

ENGINEERING CHANGE NOTICE

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Page 1 of 2

Proj.
ECN

2. ECN Category (mark one) Supplemental <input type="checkbox"/> Direct Revision <input checked="" type="checkbox"/> Change ECN <input type="checkbox"/> Temporary <input type="checkbox"/> Standby <input type="checkbox"/> Supersedeure <input type="checkbox"/> Cancel/Void <input type="checkbox"/>	3. Originator's Name, Organization, MSIN, and Telephone No. J. D. Hopkins, 74A10, R2-11, 373-5701	3a. USQ Required? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	4. Date April 12, 1996
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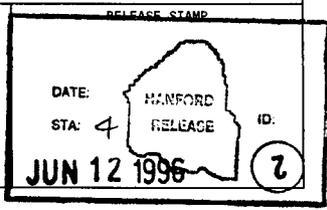
12. Description of Change
Document changed to reflect changes in methodology.

13a. Justification (mark one)

Criteria Change <input type="checkbox"/>	Design Improvement <input type="checkbox"/>	Environmental <input type="checkbox"/>	Facility Deactivation <input type="checkbox"/>
As-Found <input type="checkbox"/>	Facilitate Const <input type="checkbox"/>	Const. Error/Omission <input type="checkbox"/>	Design Error/Omission <input type="checkbox"/>

13b. Justification Details
Methodology was improved during the evaluation period. Addresses comments of review bodies.

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



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15. Design Verification Required <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	16. Cost Impact <table style="width: 100%;"> <tr> <td style="text-align: center;">ENGINEERING</td> <td style="text-align: center;">CONSTRUCTION</td> </tr> <tr> <td>Additional <input type="checkbox"/> \$</td> <td>Additional <input type="checkbox"/> \$</td> </tr> <tr> <td>Savings <input type="checkbox"/> \$</td> <td>Savings <input type="checkbox"/> \$</td> </tr> </table>	ENGINEERING	CONSTRUCTION	Additional <input type="checkbox"/> \$	Additional <input type="checkbox"/> \$	Savings <input type="checkbox"/> \$	Savings <input type="checkbox"/> \$	17. Schedule Impact (days) Improvement <input type="checkbox"/> Delay <input type="checkbox"/>
ENGINEERING	CONSTRUCTION							
Additional <input type="checkbox"/> \$	Additional <input type="checkbox"/> \$							
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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
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20. Approvals

Signature	Date	Signature	Date
OPERATIONS AND ENGINEERING			
Cog. Eng. J. D. Hopkins/ <i>J. D. Hopkins</i>	<i>6/12/96</i>	ARCHITECT-ENGINEER	
Cog. Mgr. W. B. Barton/ <i>W. B. Barton</i>	<i>4/12/96</i>	PE	_____
QA	_____	QA	_____
Safety	_____	Safety	_____
Environ.	_____	Design	_____
Other G. D. Johnson/ <i>G. D. Johnson</i>	<i>6/10/96</i>	Environ.	_____
D.M. Ogden/ <i>D.M. Ogden</i>	<i>6/12/96</i>	Other	_____
Comment from D.M. Ogden: The steady-state method as applied is non-discriminating. If tank surface level data is of poor quality, the value of the tank level and barometric slope evaluations is diminished and improved data may be required to perform an adequate flammable gas screening.			
DEPARTMENT OF ENERGY			
		Signature or a Control Number that tracks the Approval Signature	_____
ADDITIONAL			
		_____	_____
		_____	_____

Methodology For Flammable Gas Evaluations

J. D. Hopkins

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

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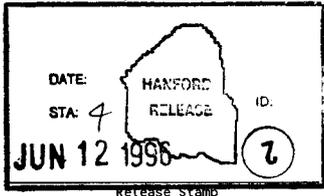
Abstract: There are 177 radioactive waste storage tanks at the Hanford Site. The waste generates flammable gases. The waste releases gas continuously, but in some tanks the waste has shown a tendency to trap these flammable gases. When enough gas is trapped in a tank's waste matrix, it may be released in a way that renders part or all of the tank atmosphere flammable for a period of time. Tanks must be evaluated against previously defined criteria to determine whether they can present a flammable gas hazard. This document presents the methodology for evaluating tanks in two areas of concern in the tank headspace: steady-state flammable-gas concentration resulting from continuous release, and concentration resulting from an episodic gas release.

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**METHODOLOGY FOR
FLAMMABLE GAS
EVALUATIONS**

J. D. Hopkins

Westinghouse Hanford Company

June 10, 1996

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LIST OF TERMS

DOE	U.S. Department of Energy
DSI	Don't Say It—Write It
DST	double-shell tank
EGR	episodic gas release
ENRAF	ENRAF-NONIUS B.V. Corporation (surface-level measurement device)
FGWL	Flammable Gas Watch List
FIC	Food Instrument Corporation (surface-level measurement device)
HEPA	high-efficiency particulate air
HMS	Hanford Meteorological Station
ILL	interstitial liquid level
LFL	lower flammability limit
LLC	liquid level, current
LLH	liquid level, historical
MT	manual tape (level measurement device)
PC-SACS	Personal Computer Surveillance Analysis Computer System
PNNL	Pacific Northwest National Laboratory
SD	standard deviation
SL	surface level
SLC	solids level, current
SLH	solids level, historical
SST	single-shell tank
TMACS	Tank Monitoring and Control System
TOC	total organic carbon
VFI	void fraction instrument
VDTT	Velocity-Density-Temperature Tree
w.g.	water gauge

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1.0 INTRODUCTION

1.1 BACKGROUND

There are 177 radioactive waste storage tanks containing over 55 million gallons of radioactive wastes at the Hanford Site. The wastes generate flammable gases, and some of the wastes have shown a tendency to trap these flammable gases. When enough gas is trapped in a tank's waste matrix, it may be released in a way that renders part or all of the tank atmosphere flammable for a period of time.

To ensure safety of workers, the public and the environment, a graded set of controls must be applied to the tanks. These controls allow the risks posed by the trapped gases to be managed during continued progress toward permanent disposal of the waste.

The controls are implemented through a series of documents. These documents contain the flammable gas criteria for applying the controls (Hopkins 1994), methodology for evaluating the tanks against the criteria (presented in this document), the evaluation results (Hodgson et al. 1996) and operating specification documents (WHC 1995a, 1995b, 1995c and 1995d).

1.2 PURPOSE

Since Revision 0 of this document was published in December 1995, the methodology used to evaluate the Hanford Site waste storage tanks against the flammable gas criteria (Hopkins 1994) has undergone continuous improvement. This revision describes the methodology in use on March 31, 1996, when the evaluation results (Hodgson et al. 1996) were published. The methodology includes excess conservatism in some areas, for example, the passive tank ventilation rate used to calculate steady-state concentration, the estimated fraction of trapped gas released, the estimated percentage of H₂ in released gas, estimated evaporation in the surface-level-rise method, and the use of the 75th-percentile barometric slope. As understanding of these and other areas improves, it is expected that the methodology will be improved and new methods developed.

1.3 ORGANIZATION OF THIS REPORT (ROAD MAP)

The main body of this document defines specific conditions which can present flammable gas hazards, identifies the two conditions currently being evaluated, and discusses the methods for evaluating tanks regarding these two conditions. The main body contains enough details for the reader to understand how the evaluation is done. Attachments contain additional information for in-depth understanding and for conducting the evaluation.

Section 2.0 defines four flammable gas conditions in which gas from the waste might exceed safe limits and be a factor in the release of waste to the environment, and it compares the magnitudes of the release events. Section 2.0 also identifies the two concerns currently being evaluated and gives the logic for applying the methodology. The section refers to Attachment I for discussion of conditions not currently evaluated.

Section 3.0 discusses the tank data required for the evaluation.

Section 4.0 describes the evaluation of the steady-state condition.

Section 5.0 describes the detailed logic for evaluating an episodic gas release (EGR) in the tanks.

Sections 6.0, 7.0 and 8.0 discuss the three methods used to evaluate the potential hazard of an EGR: the "quick screen" based on the release rate per volume of slurry for tank 241-SY-101¹, the evaluation based on surface-level rise, and the evaluation based on barometric slope.

Section 9.0 discusses the evaluation of other factors that might cause a tank to exceed the criteria, for example, being connected by a cascade line to a tank which could exceed the criteria.

Attachments (Atch) contain information primarily of interest to those evaluating tanks:

<u>Atch</u>	<u>Content/Purpose</u>
A	Includes a collection form for tank data.
B	For convenience and background, reproduces Appendix E of WHC-EP-0702, Rev. 0 (Hopkins 1994), which presents logic diagrams and discusses the assumptions behind and details of the calculation of flammable gas concentration.
C	Contains instructions for using the Microsoft Excel ² spreadsheet prepared by S. A. Barker to help standardize the methodology; a printout of a spreadsheet; and a DSI by S. A. Barker providing background for the calculation of liquid evaporation from tank waste.
D	Discusses uncertainties in surface level measurements.
E	Discusses the technical basis for assuming the location of the center of trapped gas.
F	Standardizes the distributions for inputs to Monte Carlo analysis.
G	Illustrates a distribution curve provided by Whitney for barometric slopes for a particular tank.
H	Summarizes void fraction results for 103-SY.
I	Presents information about plume burns and overpressurization, which were not evaluated by Hodgson et al. (1996), for subsequent evaluation.
J	Presents the report of the Ogdén-Piestrup committee, which on December 5 and 6, 1995 reviewed the methodology presented in this document; and includes a response to the committee's review report.
K	Presents information on estimating evaporation in waste tanks.
L	Discusses variations between barometric pressure measured at the Hanford Meteorological Station and pressure on the waste surface.

¹ Waste tanks are hereafter referred to in abbreviated form; for example, SY-101.

² Microsoft and Excel are registered trademarks of Microsoft Corporation, Redmond, WA.

2.0 FLAMMABLE GAS CONDITIONS AND LOGIC

There are four flammable gas conditions which might be factors in a release of waste to the environment: the steady-state concentration of flammable gas in the tank headspace, the concentration after an episodic release of trapped gas, the ignition of a gas plume as it escapes from the waste, and overpressurization of a tank's exhaust filter caused by the release of pressurized gas from the waste.

The overall logic for evaluating tanks is based on a three-stage approach.

- When little or no tank-specific information is available to give an indirect or direct measure of a tank's gas content or releases, perform bounding (worst-case) calculations of potential gas releases/concentration using general information (for example, total waste volume, surface level history, type waste) and information about tank SY-101 and other flammable gas tanks.
- When indirect measures of a tank's trapped gas content/releases or headspace concentration become available, use this information to improve the calculations. If direct measures are already available, this step may be skipped.
- When direct measures become available, use this information to further improve the calculations.

The current evaluation is limited to considering the steady-state concentration and the concentration after an episodic release. Neither a plume burn nor overpressurization were included in the evaluation reported by Hodgson et al. (1996). However, information on these concerns is included in Attachment I for subsequent evaluations.

In addition to the four specific areas of concern, there is a general concern regarding other potential hazards, such as flammable gas flowing into a tank through a cascade line from an adjacent tank. If a flammable gas mixture in a tank subsystem, such as exhaust ducting, can attain the threshold level of any of the four criteria and has credible potential to cause a serious release, this is a basis for the tank failing the criteria.

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3.0 TANK DATA REQUIREMENTS

Evaluations must be based on reliable data. For consistency, data for different tanks should be taken from the same source, where practical. For example, current waste surface levels should be taken from the Personal Computer Surveillance Analysis Computer System (PC-SACS) database.

To facilitate careful data collection, an evaluator collects tank data on a data collection form (see Attachment A). The evaluator signs the final form (or a final printout of the data section of the Excel™ spreadsheet) and includes it in the tank evaluation record.

When two data sets measure the same parameter and are used in the same way, the higher quality data takes precedence. For example, all other things being equal (for example, same number of replicate measurements), measures of surface level variation taken by ENRAF surface level gauges (resolution ± 0.01 in., or 0.25 mm) take precedence over measures taken by Food Instrument Corporation (FIC) gauges (resolution ± 0.1 in., or 0.25 mm); and FIC measures take precedence over measures taken by manual tape (MT) (resolution ± 0.25 in., or 0.64 mm).

In some cases, data taken from tank photographs can be of higher quality than data taken with surface level devices. For example two photographs of a tank's saltwell pool taken ten years apart can show unequivocally how large the change was in the liquid surface level between the times of the photographs. Depending on other factors, the change determined from the photographs might be more reliable than the change determined from surface level devices.

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4.0 EVALUATION OF STEADY-STATE CONCENTRATION

For more than three dozen tanks, direct measurements of the steady-state flammable gas concentration have been obtained by careful sampling and analysis. The bounding steady-state concentration was calculated as described in this section. Because the calculations are conservative, sample results take precedence over calculations.

The steady-state concentration of flammable gas in a tank's headspace is a function of how fast gas is added to and exhausted from the headspace. The evaluation methodology conservatively assumes that none of the daily gas generation is trapped, that is, as soon as it is generated, all gas is added to the gas in the headspace. Therefore, the bounding rate of gas addition to the headspace equals the bounding gas generation rate. On the other hand, the rate at which gas is exhausted from the headspace is the sum of contributing rates described in Section 4.2 below.

The calculation of generation rates, exhaust rates, and bounding steady-state concentration are explained in the following sections.

4.1 GAS GENERATION RATE

The gas generation rate is the sum of generation rates for three mechanisms: radiolytic decomposition of water and organic compounds, thermal decomposition (thermolysis) of organic compounds, and corrosion of the metal tank. The bounding generation rates for each mechanism are defined based on rates in tank SY-101 (Hopkins 1994). Appendix E of that document is reproduced in Attachment B of this document. Bounding calculations are illustrated below.

4.1.1 Radiolysis

The rate of H₂ generation by radiolysis is the product of power load and G(H₂), where G(H₂) is a measure of the rate of H₂ generation per 100 electron volts (eV), where electron volts are a measure of power. Heat loads are greater than or equal to power loads, and may be used in place of power load to calculate conservative radiolytic generation rates. Heat loads are provided by Graves (1994). Hopkins (1994) assumed the bounding G(H₂) value to be 0.100 molecules H₂/100 electronvolts (eV). However, Graves (1994) calculated somewhat lower values for the tank safety basis, and these values were used in the evaluation. A sample calculation of the bounding radiolytic generation rate for tank S-106 is given below. For further information, see Attachment B, Section 4.4.

G(H₂): 0.067 molecules H₂/100 eV (Graves 1994)
 (6.2415 x 10¹⁵ molecules H₂/J)

Heat load: 1135 watts (Graves 1994)

Rate for S-106:
 Rate = power load x G(H₂)
 Rate ≤ heat load x G(H₂)
 Rate ≤ 1135 watts x 1 J/2.7778 x 10⁻⁴ watt-h
 x 6.2415 x 10¹⁵ molecules H₂/J

$$\begin{aligned} \text{Rate} &\leq \begin{aligned} &x \text{ 1 mole}/6.022 \times 10^{23} \text{ molecules H}_2 \\ &x \text{ 0.024463 m}^3 \text{ H}_2 \text{ (25}^\circ\text{C)}/\text{mole H}_2 \times 24 \text{ h/day} \\ &\text{0.017 scm H}_2/\text{day (25}^\circ\text{C, 101.3 kPa)} \\ &\text{(0.59 scf H}_2/\text{day (standard cu. ft., 1.00 atm, 25}^\circ\text{C))} \end{aligned} \end{aligned}$$

4.1.2 Thermolysis

A sample calculation of the bounding thermolytic generation rate for tank S-106 is given below. For further explanation, see Attachment B, para. 4.3.2.

Overall Calculation:

$$\begin{aligned} \text{Rate/vol. liquid} &= 2.34 \times 10^{-4} \text{ scm gas/m}^3 \text{ liquid/day} \\ &\quad (2.34 \times 10^{-4} \text{ scf gas/ft}^3 \text{ liquid/day}) \\ \text{Rate for S-106} &= \text{SY-101 rate/vol. of liq. x S-106 vol. of liq.} \\ &\quad \times \text{total organic carbon (TOC) ratio} \\ &\quad \times \text{Aluminate ratio x Rate ratio} \\ &= \text{SY-101 rate/vol. of liq. x S-106 vol. of liq.} \\ &\quad \times \text{S-106 \% TOC/SY-101 \% TOC} \\ &\quad \times \text{S-106 \% Al/SY-101 \% Al} \\ &\quad \times \text{S-106 chemical rate/SY-101 chemical rate} \end{aligned}$$

TOC ratio:

$$\begin{aligned} \text{S-106 \% TOC:} &0.500\% \text{ (Toth et al. 1995)} \\ \text{SY-101 \% TOC:} &1.07\% \text{ (Attachment B, para. 4.3.1)} \\ \text{S-106/SY-101:} &0.500\%/1.07\% \end{aligned}$$

Aluminate ratio³:

$$\begin{aligned} \text{S-106 \% Al:} &3.07\% \text{ (Toth et al. 1995)} \\ \text{SY-101 \% Al:} &3.00\% \text{ (Attachment B, para. 4.3.1)} \\ \text{S-106/SY-101:} &3.07\%/3.00\% \end{aligned}$$

Chemical Rate ratio:

$$\begin{aligned} \text{Activation Energy, } E_a: &26,000 \text{ J (Attachment B, para. 4.3.1.8)} \\ \text{For S-106} & \\ \text{Temp:} &298^\circ\text{K} \\ e^{-E_a/RT}: &e^{-26,000/(8.3134 \times 298)} \\ \text{For SY-101} & \\ \text{Temp:} &319.3^\circ\text{K} \\ e^{-E_a/RT}: &e^{-26,000/(8.3134 \times 319.3)} \\ \text{Rate ratio:} &e^{-26,000/(8.3134 \times 298)} / e^{-26,000/(8.3134 \times 319.3)} \\ &= 0.497 \end{aligned}$$

³ Per Hopkins (1994), all aluminum in solution is assumed to be aluminate for this calculation.

Overall Rate (Hopkins 1994, p. E-13):

$$\begin{aligned}
 \text{Vol. of liq., S-106}^4: & \quad 1143 \text{ m}^3 \text{ (40,354 ft}^3\text{)} \\
 \text{Rate} & = 101\text{-SY rate/vol. of liquid x S-106 vol. of liq. x TOC} \\
 & \quad \text{ratio x Al ratio x rate ratio} \\
 & = 2.34 \times 10^{-4} \text{ scm gas/m}^3 \text{ liquid/day x 1143 m}^3 \text{ x} \\
 & \quad 0.500\%/1.07\% \times 3.07\%/3.00\% \times 0.497 \\
 & = 0.064 \text{ scm gas/day (2.25 scf gas/day)}
 \end{aligned}$$

4.1.3 Corrosion

A sample calculation of the bounding corrosion generation rate for tank S-106 is given below. For further explanation, see Hopkins 1994, p. E-13.

$$\begin{aligned}
 \text{Rate for SY-101}^5: & \quad 2.637 \times 10^{-5} \text{ scm/day/m}^2 \text{ wet steel} \\
 & \quad (8.65 \times 10^{-5} \text{ scf/day/ft}^2 \text{ wet steel)}
 \end{aligned}$$

Rate for S-106:

$$\begin{aligned}
 \text{Rate} & = 2.637 \times 10^{-5} \text{ scm/day/m}^2 \text{ wet steel} \\
 & \quad \times \text{ area exposed to waste} \\
 & = 2.637 \times 10^{-5} \text{ scm/day/m}^2 \text{ wet steel x 736.3 m}^2 \\
 & = 0.019 \text{ scm/day (0.69 scf/day)}
 \end{aligned}$$

4.1.4 Total H₂ Generation

The bounding daily generation rate is the sum of the three rates determined above:

Radiolysis	0.017
Thermolysis	0.064
Corrosion	<u>0.019</u>
TOTAL	0.100 scm/day (3.53 scf/day)

⁴ The volume of liquid in the tank is determined by adding the volume of supernate to the volume of interstitial liquid in saltcake and sludge. The volume of interstitial liquid is determined by multiplying the volume of wet solids by the solids' porosity. (This liquid volume may be reduced by gas volume if it is known.) If there is no supernate, the top of wet solids is determined from the interstitial liquid level. Additional details are included in the explanation of the Excel™ spreadsheet in Attachment C.

⁵ Anantatmula et al (1994) have shown that the conservative corrosion rate for tank steel could be about four mils/year, four times the rate on which this generation rate is based. Therefore, the rate used here may be increased when Hopkins 1994 is revised.

4.2 TANK VENTILATION RATE

The tank ventilation (exhaust) rate is the sum of the following five contributing rates:

- Mechanical exhaust. Double-shell tanks (DSTs) have mechanical exhausters, but most single-shell tanks (SSTs) do not. For mechanically exhausted tanks, none of the below-listed sources of air turnover were considered.
- Atmospheric breathing (exhalation and inhalation of headspace air with changes in barometric pressure). This breathing rate has been determined to be 0.45% per day of the headspace volume (Crippen 1993).
- FIC purge air flow. FIC gauges are equipped with purge air to prevent freeze-up. The minimum flow is about 1.70 m³/h (60 cfh). However, because the air flow is not required by an operating specification document, and many tanks do not have this supplied air flow, the evaluation takes no credit for this flow.
- Convective flow. This flow occurs because warm air above the waste is lighter than atmospheric air outside the tank. In previous modeling studies, this flow has been found to be as high as an order of magnitude above the atmospheric breathing rate, depending on headspace temperature. This flow rate was not used in calculating the steady-state % LFL reported as a result of this evaluation. If the rate can be determined, it should be used because it will reduce the calculated concentration by an order of magnitude or more.
- Bernoulli flow caused by wind blowing past the tank exhausts. This flow rate is intermittent and has not been determined, so it was not considered in the evaluation.

Analysis of existing tank data might provide a good estimate of a tank's overall exhaust rate (air turnover rate, air exchange rate, breathing rate). For example, because headspace air and air outside the tank are at different temperatures, and the headspace temperature in cooler tanks is largely determined by the tank's exhaust rate, it is possible to use the seasonal plot of headspace temperature to estimate exhaust rate. A better estimate of the rate might be made by modeling the tank's heat transfer, including transfer into/out of the waste, tank dome and surrounding soil. At this point, however, work to improve estimates of the exhaust rate is still in its early stages. Therefore, evaluation of steady-state concentration for passively ventilated tanks conservatively limited non-mechanical turnover to 0.45% per day, unless available data allowed using a higher rate. Additional discussion on determining the exhaust rate is included in the spreadsheet instructions in Attachment C.

4.3 OVERALL CALCULATION

The equation below is used to determine the bounding H₂ steady-state concentration in the headspace, based on total generation rate and total exhaust rate.

$$\text{Mole fraction of H}_2 = \frac{\text{total daily generation rate}}{\text{total daily generation rate} + \text{exhaust rate}}$$

For a daily gas evolution of g ft³ H₂/d, passively vented tanks, which have a daily breathing rate of 0.0045 times the tank's headspace volume (Crippen 1993), the equation is as follows.

$$\text{Mole fraction of H}_2 = \frac{\text{g m}^3/\text{d}}{\text{g m}^3/\text{d} + 0.0045 (\text{tank vol.} - \text{waste vol.}) \text{ m}^3/\text{d}}$$

For the generation rate calculated for tank S-106 in Section 4.1.4, the mole fraction is calculated as follows:

$$\text{Mole fraction of H}_2 = \frac{0.100 \text{ m}^3/\text{d}}{0.100 \text{ m}^3/\text{d} + 0.0045 (2,168) \text{ m}^3/\text{d}} = 0.01014 \text{ H}_2$$

As explained by Hopkins (1994), assume the NH₃ concentration is four times, and the methane concentration is 0.02 times, the H₂ concentration; and calculate the percent lower flammability limit (% LFL) as follows:

$$\begin{aligned} \% \text{ LFL} &= n_{\text{H}_2}/\text{LFL}_{\text{H}_2} + n_{\text{NH}_3}/\text{LFL}_{\text{NH}_3} + n_{\text{CH}_4}/\text{LFL}_{\text{CH}_4} \\ &= (0.01014/0.04+0.04056/0.15+0.0002/0.048) \times 100\% \\ &= 52.8\% \end{aligned}$$

4.4 SPREADSHEET

The calculations described in this section are performed by an Excel™ spreadsheet. A printout of the spreadsheet is included in Attachment C.

4.5 SAMPLING

For about 30% of the 50+ tanks sampled so far, the ratio of calculated H₂ concentration to sample H₂ concentration varies from 0.2 to 10. For almost 50% of the tanks, the ratio varies from 10 to 100. For the remaining tanks, the ratio is over 100. For one tank, the ratio is almost 700. This difference results partly because the calculation of the generation rate is conservative and partly because the exhaust rate (the breathing rate, 0.45%) used in the calculation is lower than the actual exhaust rate. Therefore, whenever calculated steady-state values exceed the criterion limit, it is desirable to determine the actual value by sampling. The maximum steady-state concentration measured by sample so far was 5.2% of the LFL, in tank SX-109.

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5.0 EVALUATION OF EGR: LOGIC

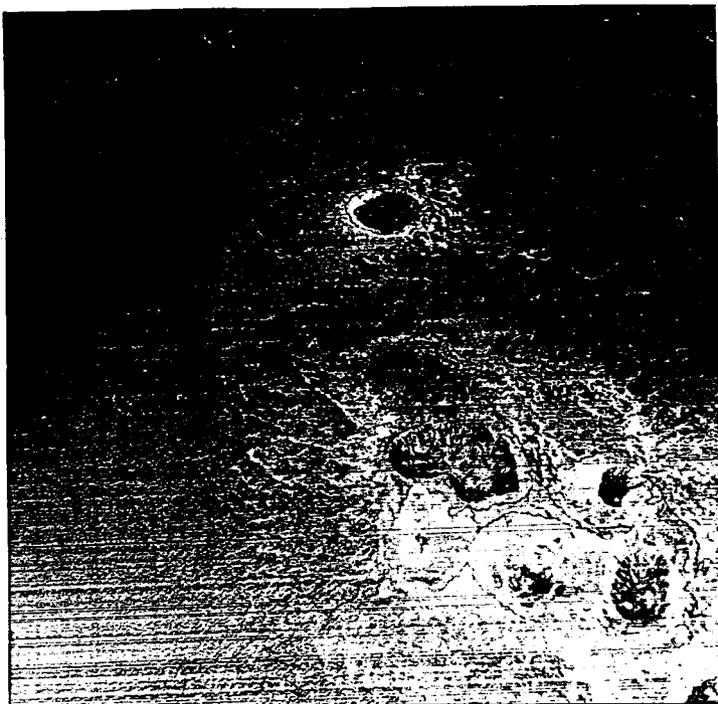
Attachment B defines the detailed logic for applying the Flammable Gas Watch List (FGWL) criterion for EGRs. The logic is taken from Figure E-2 in *Criteria for Flammable Gas Watch List Tanks*, WHC-EP-0702, Rev. 0 (Hopkins 1994), which is reproduced in Attachment B of this document. The logic diagram, which appears on page B-23, is discussed in the paragraphs below.

The first question in the logic is, "Does tank already have EGRs?" If the answer is "yes," the evaluator can proceed directly to the quick screen discussed in Section 6.0. If the answer is "no," the evaluator goes to the second question, "Is tank empty?" Because only one of 177 tank is empty, for 176 tanks the third question is, "Is the waste too rigid for EGR?" Present knowledge is insufficient to establish how rigid waste must be before it can no longer have an EGR. The EGRs in tank 101-SY have occurred in the form of rollovers, in which gas-containing waste in the nonconvecting (settled-solids) layer attains a lesser density and rises quickly through the convecting layer (fluid layer). It has been suggested that a rollover cannot occur unless settled solids are covered with a layer of supernate. However, an EGR might occur in other forms such as the release of large (for example, one-meter-diameter) bubbles or the release of gas pockets via a chimney through the waste.⁶ Whatever the mechanism, from fumaroles (craters) in photographs such as the one of tank T-107 in Figure 5-1, it appears possible that gas plumes might occasionally escape from solids in EGRs. Therefore, until shown otherwise, it is assumed that gas can be released from any waste which can accumulate quantities of trapped gas.

Because gas can only be trapped in solids, the fourth question in the logic is, "Is waste all liquid?" If the answer is "no," the fifth question "Waste contains organics, can precipitate & has high H₂ generation?" concerns whether a tank can trap flammable gas. This question applies to tanks having no indirect or direct measures of volume of trapped gas. For tanks in which surface level growth and/or a negative barometric slope are indirect measures indicating that tanks are trapping gas, skip the question, and proceed directly to the sixth question, "QUICK SCREEN: Could EGR exceed 25% of the LFL?" This question is addressed in Section 6.0. If the quick screen indicates that the tank being considered could exceed 25% of the LFL, the next step is to use indirect measures (for example, surface level growth and barometric slope) to answer the question, "FULL EVAL'N: Could EGR exceed 25% of the LFL?" This question is addressed in Sections 7.0 and 8.0.

⁶ Per personal communication on December 1, 1995 with C. W. Stewart. Stewart confirmed this view is reflected in a document he signed for R. T. Allemann (1995).

Figure 5-1. Fumaroles in Tank 241-T-107.



This photograph shows fumaroles in the waste surface of tank T-107. The fumaroles suggest that pockets of gas repeatedly escaped in specific areas.

6.0 EVALUATION OF EGR: QUICK SCREEN VS. TANK 101-SY

As prescribed by Hopkins (1994, p. E-23), a "quick screen" was done on each tank to determine whether it could have an EGR which would exceed 25% of the LFL if the tank released gas at the same ratio per volume of waste as tank SY-101 did in its bounding release. Because this case bounds all other cases discussed below, if a tank passed this screen, it was given no further evaluation to determine whether it could exceed the EGR criterion.

In its largest release, tank SY-101 released 0.0735 ft³ (*in situ* volume, or compressed volume) of gas per ft³ of the nonconvecting (solids) layer. It is assumed that each SST could release gas occupying a compressed volume equal to 7.35% of the solids volume, and the resulting % LFL is calculated, including ammonia concentration. The calculation is illustrated below for tank S-106.

Given:

Solids surface level	453.7 cm	(178.62 in.)
Atmospheric pressure	101.4 kPa	(14.7 psi ⁷)
Head on gas	51.3 kPa	(7.44 psi)
Temperature of gas	298.1 K	(536.6°R)
Dish volume	47.3 m ³	(1671 ft ³)
Headspace ⁸	2828 m ³	(82,211 ft ³)
Fraction H ₂ in trapped gas	0.97	
Fraction of NH ₃ released ⁹	0.220 m ³ NH ₃ /m ³ released gas	(0.220 ft ³ NH ₃ /ft ³ released gas)

$$\begin{aligned} \text{Solids vol.}^{10} &= 410.4 \text{ m}^3/\text{m} \text{ (surface level, m - dish, m)} + 47.3 \text{ m}^3 \text{ dish} \\ &= 410.4 \text{ m}^3/\text{m} (4.537 \text{ m} - 0.3048 \text{ m}) + 47.3 \text{ m}^3 \\ &= 1784.2 \text{ m}^3 \text{ solids (63,020 ft}^3\text{)} \end{aligned}$$

$$\begin{aligned} \text{Vol. trapped} &= 1784.2 \text{ m}^3 \text{ solids} \times 0.0735 \text{ ft}^3 \text{ trapped gas/ft}^3 \text{ solids} \\ &= 131.1 \text{ m}^3 \text{ trapped gas (4,631 ft}^3\text{)} \end{aligned}$$

⁷ The abbreviation psi is used throughout this document in lieu of lbf/in².

⁸ To shorten the calculation in the initial screen of a tank, the evaluator may use the pre-release headspace volume, as is done here. However, it is more accurate to use the post-release volume, which is larger than the pre-release volume and therefore gives a lower % LFL. In the example shown here, the increase in headspace is 198.1 m³. This results in a % LFL of 202 instead of the 219 calculated here.

⁹ In Hopkins 1994, this fraction was 0.259 for tank 101-SY. A small part of this fraction of NH₃ was emitted from the trapped slurry gas which was released; the larger part of the fraction was emitted by mass transfer of NH₃ from the waste brought to the surface by the rollover. Appendix E of Hopkins 1994 (See Section 5.3.4 of Attachment B of this methodology document) assumes a release of 0.259 m³ NH₃/m³ released gas when trapped gas is 97% H₂. However, this methodology document recognizes that trapped gas containing 97% H₂ would contain no NH₃, so it is assumed that the waste releases only 0.220 m³ NH₃/m³ released gas.

¹⁰ In most calculations in this document, more digits are shown in the calculated results than are justified by the number of significant digits in the inputs to the calculation. This is done to avoid rounding errors in successive calculations, and to show agreement with calculations done by the Excel™ spreadsheet, which carries all digits forward in successive steps of the calculation.

$$\begin{aligned} \text{Vol. released} &= 131.1 \text{ m}^3 \times (51.3 \text{ kPa head} + 101.4 \text{ kPa}) / 101.4 \text{ kPa} \\ &\quad \times 298.15^\circ\text{K} / 298.1^\circ\text{K} \\ &= 198.1 \text{ m}^3 \text{ (6997 ft}^3\text{)} \end{aligned}$$

$$\begin{aligned} \% \text{ H}_2, \text{ dome} &= 0.97 \times 198.1 \text{ m}^3 / 2328.0 \text{ m}^3 \text{ dome} \times 100\% \\ &= 8.26\% \end{aligned}$$

$$\text{Vol. NH}_3 = 0.220 \times 198.1 \text{ m}^3 = 43.6 \text{ m}^3 \text{ (1,539 ft}^3\text{)}$$

$$\begin{aligned} \% \text{ NH}_3, \text{ dome} &= 43.6 \text{ m}^3 \text{ NH}_3 / 2328.0 \text{ m}^3 \times 100\% \\ &= 1.873\% \end{aligned}$$

$$\text{Fraction LFL} = (8.26/4 + 1.873/15) = 2.19$$

$$\begin{aligned} \% \text{ LFL} &= 2.19 \times 100\% \\ &= 219\% + \text{contribution from steady-state concentration} \end{aligned}$$

The results show the tank could release enough flammable gas to exceed 25% of the LFL. The tank requires further evaluation if indirect or direct measures of trapped gas are available.

7.0 EVALUATION OF EGR BASED ON SURFACE LEVEL RISE

One of the parameters that indicated trapped gas in the 1990 FGWL screening was a surface level rise (Hopkins 1994). A surface level rise can result from other factors besides trapped gas (for example, rainwater intrusion), but the 1995-96 evaluation team assumed it resulted from trapped gas. In addition to this parameter, the team recognized a rising interstitial liquid level (ILL) as a possible indicator of trapped gas, even for a tank with a constant or falling surface level.

Figure 7-1 is a surface level plot for tank S-106, showing about 18 inches of surface level rise. Figure 7-2 is an interstitial liquid level plot for tank TX-112, showing about 20 inches of level rise. Such plots were used as the starting point for calculating the amount of trapped gas a tank's waste could contain.

Figure 7-1. Surface Level Plot for Tank 241-S-106.

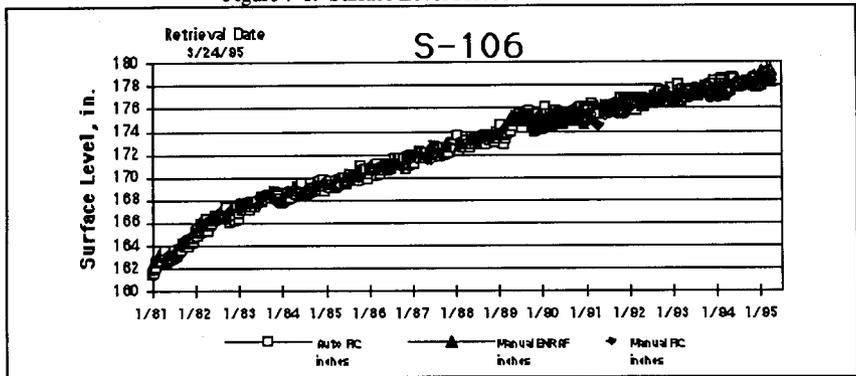
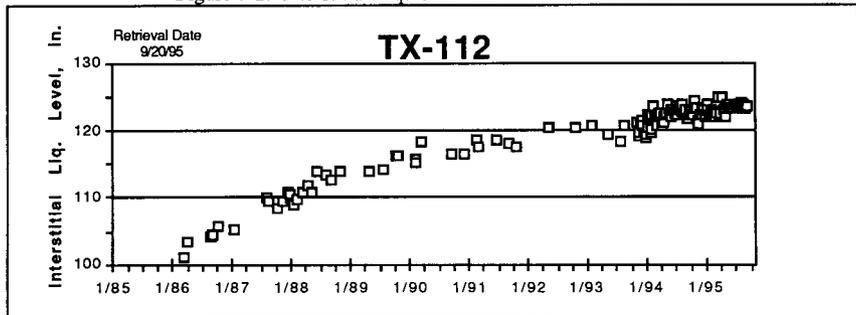


Figure 7-2. Interstitial Liquid Level Plot for Tank 241-TX-112.



The methodology for using level rise data to calculate the amount of trapped gas and the % LFL attainable in the headspace if part of that gas were released is illustrated in the following subsections.

7. 1 GENERAL

The concept underlying the methodology assumes the increase in waste volume shown by a level rise equals the increase in *in situ* volume of trapped gas. To determine the % LFL the tank could attain, determine the level rise, the location of the trapped gas and its temperature and pressure, and the fraction that can be released to the headspace, then calculate the attainable % LFL.

Applying the concept can be challenging. For example, sometimes data (especially for ILL) are only available for parts of a tank's history, so the evaluator must estimate interim or previous data. Moreover, there is a need to make adjustments to the level for potential surface level changes that have nothing to do with gas content. For example, the Tank Advisory Panel (TAP) has noted that considerable evaporation can occur from liquid on the waste surface over a 15-year period, thereby masking some level rise. Work to account for these factors has recently begun. Thurgood and Ogden (1995) began to examine the effects of evaporation, and they defined a method for evaluating the effect of evaporation on surface level rise (See Attachment K). The evaluations reported by Hodgson et al. (1996) incorporated their method for tanks with a liquid surface.

Except for the data from tank SY-101, the available psychrometric and vent flow data for tanks are of poor quality; therefore, the error band around the amount of evaporation calculated from the data is wide. Moreover, the bounding evaporation calculated in the absence of such data is based on conservative assumptions for both flow and relative humidity, and this contributes to conservatism in the bounding calculation. These assumptions were necessary when using the tool for general screening purposes. These results can be improved and conservatism removed by a careful application of the method supplemented with additional thermal hydraulic analyses to better define controlling parameters such as flow and humidity. This area of the methodology should be improved in the future to remove excess conservatism from the calculation of trapped gas volume based on surface level rise.

Other adjustments besides evaporation have not yet been defined. In any case, the following methodology allows making such adjustments.

7. 2 DETERMINE THE LEVEL INCREASE

Determine the cumulative surface level rise. If there is no cumulative rise, this method cannot be used. The lack of a surface level rise may indicate that there is not a significant amount of trapped gas in the waste, or it may mean that other factors (for example, leakage from the tank) mask the level rise. If there is a cumulative rise, calculate the volume of trapped gas as follows:

$$\begin{aligned} \text{Level Rise} &= (\text{current level}) - (\text{level at start of measurement period}) \\ &+ (\text{accumulated level rise before measurement period}) \\ &+ (\text{potential losses during period}) \\ &- (\text{known additions during period}) \end{aligned}$$

Potential losses and additions before or during the measurement period include the following:

- Losses: evaporation, compaction, leakage, supernate volume pumped from tank, measuring error (icicle on FIC at initial reading or kink in tape at current reading), and gas already trapped

in the solids at initial reading. Three methods of estimating evaporation, and how to decide which method to use, are discussed in Attachment C.

- Additions: intrusions (in-leakage), condensate from ambient air dripping into waste, hygroscopic absorption of moisture from the air by hydroxide in the waste, crust expansion by gas since start date (subtract it because it is assumed gas in the crust can't be released during an EGR of gas from down in the waste), crystal expansion since the initial reading, slumping-induced displacement, measuring error (icicle on FIC plummet on current reading, for example, 1980), and kink in tape at initial reading.

In addition to the losses and additions mentioned above, there are uncertainties arising from the position of the surface level gauge, as discussed in Attachment D.

This method was initially used only for supernate surfaces or exposed solid surfaces. However, the evaluation team also used it for interstitial liquid levels and, in a few cases, submerged solids levels. For these uses, many of the additions and subtractions are not applicable.

The following conservative practice is defined: add inches for any contributing factor that reasonably could have happened, unless the evidence is *conclusive that it did not happen*; and do not subtract for any contributing factor unless the evidence is *conclusive that it actually did happen*. The current evaluation has not been able to quantify the contributing factors. Effort may be dedicated to this part of the evaluation as refinements are made to the methodology. For the present, it should be recognized that there is a great deal of uncertainty in the analysis of surface level rise, and that the actual amount of trapped gas can be significantly different than the analysis indicates. This uncertainty is not included in any Monte Carlo analysis (See Section 7.7) done on the surface level analysis.

7. 3 CALCULATE TRAPPED (IN SITU, COMPRESSED) GAS VOLUME.

If the level change is for the waste surface level, use the following formula:

$$\begin{aligned} \text{Trapped vol.} &= 410.4 \text{ m}^3/\text{m of rise} \times \text{m of rise} \\ &= (\text{or, } 368.2 \text{ ft}^3/\text{in. of rise} \times \text{in. of rise}) \end{aligned}$$

If the level change is for the interstitial level, use the following formula:

$$\begin{aligned} \text{Trapped vol.} &= 410.4 \text{ m}^3/\text{m of rise} \times \text{m of rise} \times \text{porosity} \\ &= (\text{or, } 368.2 \text{ ft}^3/\text{in. of rise} \times \text{in. of rise}) \times \text{porosity} \end{aligned}$$

Check the calculated trapped volume to insure it does not correspond to a void fraction greater than 0.300 (See Attachment F).

$$\text{Void Fraction} = \text{trapped gas volume/wet-solids volume}$$

If the void fraction exceeds 0.300, truncate it to a volume corresponding to 0.300 when calculating the amount of trapped gas released.

7. 4 CALCULATE VOLUME OF HYDROGEN RELEASED TO HEADSPACE

To calculate the volume of H₂ released to headspace, do the following:

1. Assume the average distance of the gas above tank bottom is 0.225 x the height of wet solids measured at tank center (See Attachment E). Gas is assumed to be trapped in wet solids below the liquid level but not in the supernate or in the dry solids above the liquid level. Attachment E shows plots of tentative void fraction measurements of tank SY-103. The mid-point of the gas is deduced to be 0.61 to 0.914 m (24 to 36 in.) from the tank bottom in a solids layer 3.35 m (132 in.) deep. Thus, the center of the trapped gas is assumed to be no higher than 22.5% of the wet-solids height above the bottom of all tanks measured at tank center.
2. For SSTs, assume 25% of trapped gas is released to the headspace. Because most SSTs are passively ventilated, gas released from the waste accumulates in the headspace. Thus, a prolonged release that occurs in an SST results in the same flammable gas concentration in the headspace as a near-instantaneous release in a DST.

For DSTs, also assume 25% of trapped gas is released to the headspace. Note however that in mid-November 1995, Los Alamos National Laboratory performed a Raleigh-Taylor evaluation on DST 101-AY and predicted a bounding overall release of 47%. An overall release of 54% (over a several-day period) has been credited to tank 101-SY, with a prompt release (within several minutes or an hour) of 39%. Because the tank 101-AY 47% overall release is less than the tank 101-SY 54%, the tank 101-AY prompt release is likely to be less than the tank 101-SY 39% but may be larger than 25%.

The assumed 25% release is believed to be conservative. Examination of data about the most active DSTs on the Flammable Gas Watch List (except for tank SY-101, which has been mitigated) shows that none of these DSTs has had a release fraction of more than 0.21 (Shepard, et al. 1995). SSTs are expected to have lower release fractions than DSTs. Under catastrophic conditions, such as an earthquake, a larger percent of the trapped gas is likely to be released, especially if the quake propels the trapped gas upward by exerting a substantial upward force on the waste. Scientists at Pacific Northwest National Laboratory (PNNL) are investigating the issue of release fraction under normal and earthquake conditions. Until PNNL determines the bounding release fraction, results of evaluations against the FGWL episodic-release criterion should be considered tentative.

3. Calculate the volume of released gas.
4. Calculate the volume of H₂ released, assuming 97% of gas is hydrogen. This conservative percentage is based on an estimate that a release in tank AW-101 might have been as high as 74% hydrogen and a release in tank 105-AN may have exceeded 90% H₂. (Note however that retained-gas sampling in tank AW-101 in the last few months indicates its trapped gas contains less than 20% H₂.)

7. 5 CALCULATE VOLUME OF THE HEADSPACE

To calculate the volume of the tank headspace, do the following:

1. Determine the total tank volume from tank drawings.
2. Using the appropriate formula from Joncus (1982), determine the volume of the waste before the release.
3. From total tank volume, subtract waste volume after the gas release.

7. 6 CALCULATE % LFL IN THE HEADSPACE

To calculate the % LFL in the tank headspace, do the following:

1. Calculate % H₂ in the headspace.
2. Calculate % NH₃ in the headspace.
3. Add the % H₂ and % NH₃ to get combined % LFL.
4. Add the combined % LFL to the gas concentration already present from steady state (See section 4.0).

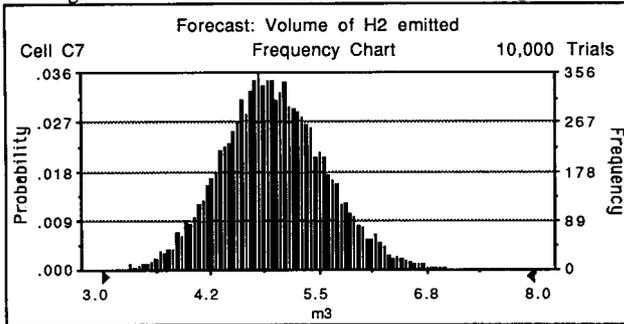
7. 7 ERROR BAND AROUND CALCULATED RESULT - MONTE CARLO ANALYSIS

For calculations which predict a resulting condition such as those discussed above, each input parameter to the calculation has an error band, or range of possible values. The calculated result also has an error band; therefore, the question arises, "Where does the calculated result fall within the range of possible results?" or, "How conservative is this result?" One way to answer these questions is to perform a Monte Carlo analysis, which uses the range for each input parameter to determine the range for the calculated result. The analysis performs hundreds or thousands of calculations using a random-number generator to generate values throughout the range for each input parameter, and it compiles a distribution range for the predicted result.

The benefit of a Monte Carlo analysis is illustrated through the following hypothetical case. It is known that a source emitted gas for two hours with a standard deviation (SD) of 0.1 hours, and that the emission rate was 5 m³/h (SD = 0.5 m³/h). It is also known that the gas emitted was 50% hydrogen (SD = 2.0%). How much H₂ gas was emitted? A single calculation using mean values of input parameters yields a result of 5 m³ of H₂ released (5 m³ gas/h x 2 h x 0.5 m³ H₂/m³ gas = 5 m³ H₂). A single calculation using values of input parameters two standard deviations above the mean (that is, at a level bounding 97.7% of the values for each parameter) yields a result of 7.1 m³ of H₂ released (6.0 m³ gas/h x 2.2 h x 0.54 m³ H₂/m³ gas = 7.1 m³ H₂). A Monte Carlo analysis shows that the hydrogen emissions could vary from 3.0 to 7.0 m³ at 99.9% certainty, with a range as shown in Figure 7-3. Therefore, the value 7.1 bounds about 99.9% of the possible values for H₂ gas emitted.

For this simple illustration, it is not difficult to hand calculate the range of the result. However, for calculations with many input parameters, it becomes more difficult. On the other hand, the analysis is easily done with Monte Carlo software.

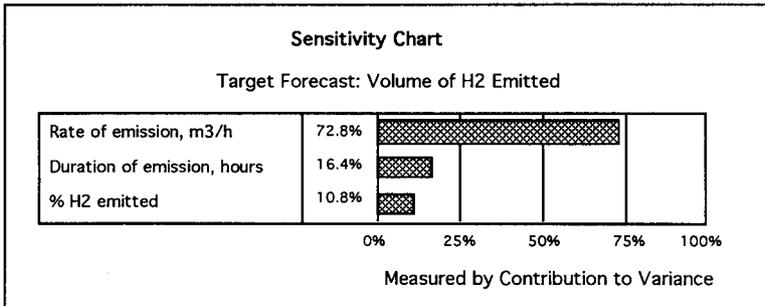
Figure 7-3. Monte Carlo Distribution for Volume of H₂ Emitted.



Monte Carlo analysis shows how individual parameters interact with each other and how much the parameters affect the calculated result. For the above case, Figure 7-4 shows the contribution the individual parameters make to the variance of the calculated result.

Attachment F includes further information about Monte Carlo analysis, including a printout of a Monte Carlo report for a tank evaluation. The analysis is used to show where a calculated value falls in the range of possible values and to determine the upper limit of the value range. The evaluator must check the upper limit, as well as the calculated value, to determine how the evaluated tank compares to the FGWL criteria. For example, if the calculated (deterministic) value is less than 25% of the LFL, but the Monte Carlo distribution shows the concentration can exceed 100% of the LFL at the upper limit of the range of values, this suggests to the evaluator that the deterministic calculation is not conservative enough, and the tank may need additional evaluation.

Figure 7-4. Sensitivity Chart: Contribution to Variance by Individual Parameters.



For a given set of values for input parameters, multiple runs of a 5,000-trial Monte Carlo analysis give a slightly different upper-limit (100-percentile) value, if the seed value (initial random number) is not the same for all runs. This reflects the effect the statistical variation of the input parameters has on the concentration. However, for runs of 5,000 trials, the 99-percentile value remains essentially the same with successive runs.

As the number of runs is increased, the 100-percentile value increases because a larger number of trials allows the software to make more random selections near the upper limits of the ranges of the input parameter. Time and software/hardware restrictions make it impractical to perform very large (for example, 100,000-trial) runs. Such large runs are not justified anyway because they would assume we have precisely defined the input parameters. In fact, for most input parameters, the variation is based partly on engineering judgment and partly on knowledge of how measures of parameters vary statistically. To limit time spent on Monte Carlo analysis and to keep from extending the analysis beyond the quality of the input parameters, Monte Carlo runs are limited to 5,000 trials.

7. 8 SPREADSHEET

The calculations in this section are performed by an Excel™ spreadsheet. A printout of the spreadsheet is included in Attachment C.

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8.0 ESTIMATE OF EGR BASED ON BAROMETRIC SLOPE

A recent report by Whitney (1995) indicates the amount of gas trapped within a tank's waste, which can be used to estimate the amount of gas which could be vented into the headspace in an EGR. Whitney examined surface level data for all 177 waste tanks taken since about 1980 and found a significant correlation between surface level and the reciprocal of barometric pressure in 58 tanks, including 21 FGWL tanks. The correlation suggests the tanks contain trapped gas. These tanks have been further evaluated to determine the % LFL attainable in the headspace if an EGR occurs.

For each tank, Whitney divided the years of data into intervals of about 60 days (15 days if level readings were taken daily), then calculated a slope (dL/dP , where L is surface level and P is barometric pressure) for each interval, where the slope has a standard error (similar to standard deviation) which defines the range of the slope for each interval. The more negative the slope, the greater the volume of gas. This slope can be used to estimate the amount of gas trapped in the 58 tanks and the concentration of flammable gas that can be attained in the tank headspace from an EGR.

Whitney determined the distribution curve of slopes for recent history of the flagged tanks being evaluated, usually from January 1, 1990 to April 1995, but sometimes for a shorter, more recent period (see Attachment G). In the attachment, the 0.25 quantile slope at -1.44 in./in. Hg¹¹ bounds 75% of the slopes, those less negative than or equal to -1.44 in./in. Hg. Using this 75th-percentile slope to calculate trapped volume is assumed to be conservative because slopes at this quantile predict a void fraction of over 30% in some tanks. Although the methodology predicts slopes this high, it is assumed that void fraction cannot exceed 30%, as explained in Section 8.1, item 8.

To illustrate the methodology for using the slope to estimate the amount of trapped gas and the % LFL attainable in the headspace after an EGR, this section shows the calculations for tank S-106. Although some data may differ from current data, the data are adequate to illustrate the calculations. The assumptions and the calculations are given below.

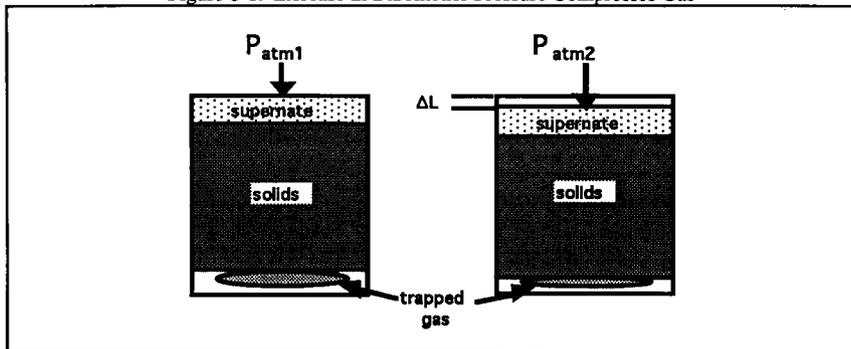
8.1 ASSUMPTIONS

The assumptions underlying the calculation of attainable % LFL based on barometric slope are as follows.

1. All surface level movement which is associated with barometric pressure variations is attributable to expansion or contraction of trapped gas. As shown in Figure 8-1, it is assumed that as barometric pressure increases, the increase in pressure is transmitted to the trapped gas, and the gas is compressed, causing a decrease (ΔL) in the surface level of the waste. This assumption is conservative because it maximizes the amount of trapped gas and, therefore, the estimated % LFL.

¹¹ English units are used in calculations involving barometric slope because tank instruments measure in inches, and barometric pressure is measured in inches of mercury (in. Hg). Results of calculations are shown in metric and English units.

Figure 8-1. Increase in Barometric Pressure Compresses Gas



2. Boyle's Law applies. For a given mass of trapped gas at a fixed temperature, the volume of the trapped gas is inversely proportional to the pressure exerted by the gas, or $PV = k$.
3. Changes in barometric pressure are sensed immediately by the trapped gas, and trapped gas responds immediately, causing an immediate surface level change. This is not a conservative assumption, since it is known not to be universally valid. In some cases, the tank acts as a damped system, that is, there is a lag of a few hours from the time when the barometric pressure changes to the time when the surface level changes. For auto-FIC readings (taken by the Food Instrument Corporation surface level gauge and transmitted electronically to the PC-SACS database), the lag is negligible or just a few hours long. The lag can be several hours long where surface level data are manually entered into the database several hours after being taken. Not taking the lag into account can result in underestimating the slope and therefore the % LFL by an amount ranging from a few percent for auto-FIC data to 30 to 40% for manual ENRAF data. The latter data are entered into the PC-SACS database and therefore time-stamped several hours after being taken in the field. Recognizing the consequences of using manual data, in most of his calculations of the 75%-percentile slope (explained in the third paragraph of Section 8.0) Whitney used auto-FIC data to minimize the error. Where auto-FIC data are not used, the slope may not account for the lag and may not be conservative.
4. Surface tension effects are negligible and do not contribute to the head pressure of the gas; that is, gas bubbles are larger than 500 microns. Surface tension is calculated using the formula for surface tension (P): $P = 4 \sigma/D$, where surface tension is measured in pressure units, σ is assumed to be the value for water, 0.09 pascal-meter (13.05 psi-micron), and D is bubble diameter in microns (Norton and Pederson 1994). Table 8-1 shows, using trial data for tank S-106 for gas under 101.325 kPa (1 atm) of head, the % LFL that would be predicted for trapped bubbles of various diameters, assuming a headspace of 931.6 m³ (32,900 ft³). As bubble diameter, D , increases from 5 to 1000 microns, the bubble surface tension decreases from 71.7 to 0.4 kPa (10.4 to 0.05 psi), and the volume of trapped gas decreases from about 127 m³ to 93 m³ (4,500-3,300 ft³), while the % LFL predicted decreases from 171% to 128%. At diameters over 100 microns there is negligible effect on the volume of trapped gas and the % LFL predicted.

Table 8-1. Effect of Surface Tension on Gas Volume and % LFL.

D, μ	Surface Tension		Total Press on Trapped Gas		Trapped Gas, ft ³		Released H ₂ , scf		% LFL
	kPa	psi	kPa	psi	m ³	ft ³	m ³	ft ³	
5	71.7	10.4	274.3	39.78	127.5	4503	62.3	2199	171
10	35.9	5.2	238.4	34.58	110.8	3914	54.1	1912	150
50	7.17	1.04	209.7	30.42	97.5	3443	47.6	1682	132
100	3.59	0.52	206.2	29.90	95.8	3384	46.8	1653	130
500	0.72	0.10	203.3	29.48	94.5	3337	47.6	1680	128.1
1000	0.36	0.05	202.9	29.43	94.3	3331	46.1	1627	127.9
-	0.0	0.0	202.6	29.38	94.2	3325	46.0	1624	127.7

Mathematical analysis of release profiles during mixer-pump runs in tank SY-101 indicate the bubble size is about 500 microns in waste that had been degassed only a few weeks earlier. Waste that remains undisturbed for much longer periods of time, as in SSTs, would be expected to have bubbles of at least this order of magnitude, so surface tension should not be a significant factor in estimating trapped gas volume. Therefore, this assumption appears to be appropriate.

5. The vertical position of the gas remains unchanged as the barometer rises and falls. This assumption is not necessarily true. For example, in tanks like SY-101, in which gas bubbles are thought to be attached to slurry particles, when the barometric pressure decreases, the bubbles expand and can migrate upwards, causing further bubble expansion. This further expansion amplifies the surface level rise, causing the slope (dL/dP) to increase. Using the increased slope in the calculation results in a larger calculated mass of trapped gas than the actual mass. Therefore, this assumption is conservative.
6. Gas is centered 22.5% of the wet-solids height above tank bottom, as assumed in Section 7.4.
7. Whitney's slopes represent gas expansion/contraction but not gas releases, intrusions, etc. It is anticipated that Whitney's algorithm (Whitney 1995) excludes significant surface level shifts (from transfers, instrument calibrations, etc.) but not all small single-point shifts caused by pumping or small gas releases. A more thorough evaluation of one tank decreased the magnitude of the 95-percentile slope but did not have a significant effect on the 75-percentile slope.
8. The maximum void fraction in settled solids is 0.30. Although a higher void fraction (above 0.40) has been seen in laboratory experiment, this was in a graduated cylinder, which has a depth-width ratio much higher than in waste tanks. It is believed that the lower ratio in actual waste will prevent attaining such high void fractions. Moreover, in actual waste, a void fraction greater than 0.300 corresponds to gas entrapment of 3 meters for waste 10 meters deep. Slurry growth of this magnitude has not been seen in tanks.
9. The trapped gas is 97% hydrogen, as assumed in Section 7.4.
10. In an SST, 25% of the trapped gas can be released to the headspace in an EGR over a period of several hours, days or weeks, as assumed in Section 7.4.
11. In a DST, 25% of the trapped gas can be released in an EGR, as assumed in Section 7.4.
12. The amount of ammonia released into the headspace as the result of an EGR can be as much as 22% of the volume of hydrogen. In an EGR, ammonia is released by mass transfer from

ammonia-containing waste brought to the waste surface by the release of trapped gas. The criteria document (Hopkins 1994) specifies that the ammonia amount in the headspace is 25.9% of the gas volume released (Hopkins 1994). Based on tank SY-101, this includes some NH₃ included in the trapped gas plus NH₃ released by mass transfer from the waste brought to the surface in a rollover. Because the trapped gas is assumed to be 97% H₂ and 3% water vapor, the trapped gas can contain no NH₃, so the fraction of NH₃ released is reduced to 0.220. Although this is not specified by Hopkins (1994), it is technically appropriate.

8. 2 CALCULATE VOLUME OF TRAPPED GAS

Beginning with Boyle's Law ($P_t V = \text{constant}$) for a given mass of gas in an isothermal processes, where P_t is the total pressure on the trapped gas and V is the volume of the trapped gas, differentiate as follows.

$$d(P_t V) = 0 = P_t dV + V dP_t$$

$$\text{or, } V dP_t = - P_t dV$$

Rearranging and substituting $A \times dL$ for dV yields the equation below.

$$V = -AP_t dL/dP_t$$

where $A = \text{area of the waste surface } (\pi \times 37.5^2 \text{ ft}^2)^{12}$
 $dL/dP_t = \text{slope determined by Whitney (1995)}$

Because the change in total pressure on the gas equals the change in barometric pressure, P_b ,

$$V = -AP_t dL/dP_b$$

Thus, besides the slope, the only other inputs to the calculation are the area of the trapped gas (the same as the cross sectional area of the tank, $\pi \times 37.5^2 \text{ ft}^2$) and the total pressure exerted on and by the gas. The total pressure on the trapped gas is the sum of barometric pressure, the head of the supernate and the head of the solids above the gas (plus any pressure exerted by surface tension). The head of waste is calculated as illustrated for a hypothetical column of water 407 in. high.

$$1 \text{ g/mL} \times 407 \text{ in.} \times 2.54^3 \text{ mL/in.}^3 \times 1 \text{ lb./453.6 g} \times 1 \text{ lb.-f/1 lb.-m} = 14.69 \text{ psi}$$

or (101.3 kPa)

The calculation of the total pressure on the trapped gas is illustrated below for tank S-106.

Mean barometric pressure	29.5 in. Hg (14.69 psi)
Liquid density ¹³	1.45 g/mL
Liquid depth (calculated)	1.45 in.
Solids density ¹⁴	1.50 g/mL
Solids depth (assumed) ¹⁵	147.17 in.

¹² English units are used in calculations involving barometric slope because tank instruments measure in inches, and barometric pressure is measured in inches of mercury (in. Hg). Results of calculations are shown in metric and English units.

¹³ If not known for a tank, assume to be 1.40 g/mL.

¹⁴ If not known for a tank, assume to be 1.80 g/mL.

¹⁵ Assumes gas is centered 30 in. above tank bottom.

$$\begin{aligned}
 P_t &= P_{\text{baro}} + P_{\text{liq}} + P_{\text{solids}} \\
 &= 14.69 \text{ psi} + (1.45 \text{ g/mL} \times 1.45 \text{ in.} \times 2.54^3 \text{ mL/in}^3 / \\
 &\quad 453.6 \text{ g/lb.}) + (1.50 \text{ g/mL} \times 147.17'' \times 2.54^3 / 453.6 \text{ g/lb.}) \\
 &= 14.49 + 0.076 + 7.98 = 22.54 \text{ psi} \quad (155.4 \text{ kPa})
 \end{aligned}$$

The trapped gas volume is calculated using the formula $V = -AP_t dL/dP_b$, derived on the previous page. The barometric slope for tank S-106 is -1.44 in./in. Hg, which bounds 75% of the range of slopes for the tank.

$$\begin{aligned}
 V &= -A P_t dL/dP_b \\
 &= -(\pi \ 37.5^2 \text{ ft}^2) \times 22.54 \text{ psi} \times 1 \text{ in Hg} / 0.491154 \text{ psi} \\
 &\quad \times (-1.44 \text{ in/in Hg}) \times 1 \text{ ft} / 12 \text{ in} \\
 &= 24,329 \text{ ft}^3 \text{ of trapped gas} \quad (688.9 \text{ m}^3)
 \end{aligned}$$

Check void fraction (VF):

$$VF = 24,329 \text{ ft}^3 \text{ gas} / 63,020 \text{ ft}^3 \text{ waste} \times 100 = 39\%$$

Truncate to void fraction of 0.300:

$$V = 0.300 \times 63,020 \text{ ft}^3 = 18,906 \text{ ft}^3 \text{ gas} \quad (1784.5 \text{ m}^3)$$

Regarding the use of the 75%-percentile slope, see the third paragraph in Section 8.0.

8. 3 BENCHMARK: TANK SY-103

Fortunately, this methodology can be verified on a tank for which data recently have been obtained on gas content, that is, tank SY-103. Assuming the gas is centered at 0.762 m (30 in.) (22.5% of the wet-solids depth) above the tank bottom, and using an estimated 50-percentile barometric slope of -0.20 in./in. Hg, the amount of gas trapped is calculated to be 118.6 m³ (4,188 ft³) (*in situ*, compressed) or 219.2 m³ (7,742 scf). This corresponds to a void space of 5.5%. If the 75 percentile slope (-0.40 inches/in. Hg) is used, the amount of gas and void space are doubled. The results from the 50-percentile slope are within the upper bound of estimates derived from recent void fraction measurements in the tank (See Attachment H).

8. 4 CALCULATE % LFL

Although it is not known whether a release in an SST can occur as a rollover, a release could occur by other means. A penetration of the waste might release a "lens" of gas contained within the waste, allowing a significant percent of the trapped gas to be released in a period of several days. Because a significant fraction of the trapped gas, beyond the fraction consisting of the lens, is expected to be dispersed throughout the waste, it seems highly unlikely that much of this dispersed gas will be released in addition to the lens. Therefore, it is assumed that 25% of the trapped gas is released. This is a preliminary estimate which needs substantiation by laboratory experimentation and modeling. The following, extracted from an Excel™ spreadsheet, illustrates the calculation of % LFL for tank S-106.

Given for tank S-106:

Compressed volume of trapped gas (ft ³)	18,906	(535.4 m ³)
Supernatate density (g/mL)	1.45	
Supernatate depth (in.)	1.45	
Solids density (g/mL)	1.50	
Solids thickness to center of trapped gas (in.) (m)	147.17	(3.738 m)
Waste temp at gas depth (°F)	76.9	
Waste temp at gas depth (°K)	298.1	
% H ₂ in solids gas (assumed)	97%	
Fraction of trapped solids gas releasable from solids (%)	25%	

Calculations for tank S-106:

Supernatate head = supernatate density x supernatate depth (psi)	0.076	(0.52 kPa)
Slurry head = solids density x solids depth (psi)	7.98	(55 kPa)
Pressure in headspace, in psia (If calculating H ₂ in scf, use 14.69)	14.69	
Total press. (psi) = press. in headspace +supernatate head+solids head	22.74	(156.8 kPa)
Pressure adjustment to scf = total head/tank pressure in psia	1.55	
Temperature adjust to scf = 298.15°K/waste temp at gas depth (K)	1.00	
Volume of slurry gas released to headspace (scf) = Compressed vol x pressure adjustment x Temperature adjustment x fraction of gas released	7,318	
Volume of H ₂ released to headspace (scf) =	7,099	(201.0 m ³)

% H₂ in headspace for tank S-106

Volume of headspace before burp (ft ³)	72,892	(2064.1 m ³)
Compressed vol. x fraction of trapped gas released = sfc level drop = headspace vol. increase caused by sfc level drop	4,727	(133.9 m ³)
Vol of headspace after burp (ft ³)	77,618	(2197.9 m ³)
% H ₂ in headspace =	9.15	

NH₃ % in headspace for tank S-106

Assume NH ₃ vol = this fraction of slurry gas released	0.22
NH ₃ vol in headspace = NH ₃ fraction X vol of slurry gas released	1,610
% NH ₃ in headspace =	2.07

% LFL = X_{H₂}/0.04 + X_{NH₃}/0.15 x 100% = 243%

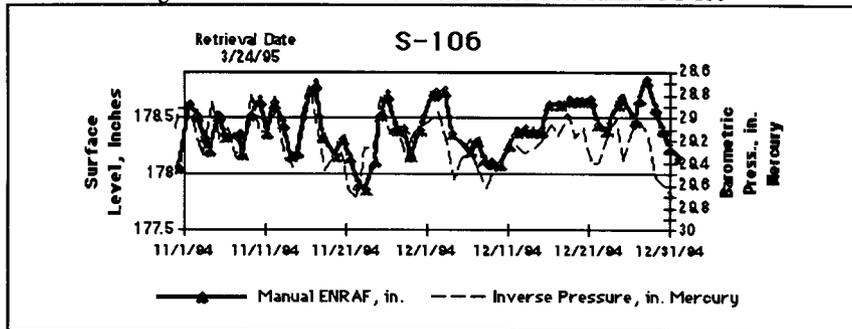
8.5 MONTE CARLO ANALYSIS

Each variable used in the calculation has an error band. When all the individual error bands are taken into account, they produce uncertainty in the calculated % LFL. A Monte Carlo analysis (See Attachment F) shows the range of the calculated % LFL.

8.6 SURFACE LEVEL VS. 1/P

The plot for tank S-106 in Figure 8-2 shows the surface level following inverse pressure quite closely, although surface level lags somewhat behind inverse pressure. The surface level plot lags behind pressure because the PC-SACS database records the time the manual ENRAF readings are entered into the database, instead of the time they are taken in the field; the readings are often

Figure 8-2. Surface Level and Inverse Pressure for Tank 241-S-106



entered many hours after being taken. Not all tanks will show a correlation as good as that shown in Figure 8-2 for tank S-106. The quality of the correlation may indicate how worthwhile it is to get better surface level data for the tank.

8.7 EFFECT OF PRESSURE DIFFERENCES

For the analysis of barometric slope to be valid, the pressure in the tanks must closely track the barometric pressure recorded at the Hanford Meteorological Station (HMS), with regard to time and pressure. For the tracks to be close, it is required that (1) the ground-level pressure at the tank closely follow the barometric pressure recorded at the Hanford Meteorological Station, which is as much as 8 km (5 mi.) from the tank farthest from the station, and (2) the pressure inside the tank closely track that at ground level.

8.7.1 Hanford Meteorological Station Pressure vs. Pressure at a Tank

Regarding the first requirement, there is a slight difference between the pressure at the HMS and at a tank. As a front passes over the HMS in West Area, the HMS pressure changes. It can take as much as 10-12 minutes for the front and its pressure change to reach tanks in East Area (see mail message in Attachment L). Thus, depending on the location of a tank, there could be a delay of a few minutes between a pressure change occurring at the HMS and at the tank. One of the highest rates of pressure change in recent decades was recorded in 1958. An estimate of the worst-case pressure difference between the HMS and the tank can be made from this rate, 0.091 in. Hg/h (0.31 kPa), and the fact that it takes 10-12 minutes for a pressure change to move from the HMS to the tank farthest away (see Attachment L).

$$0.091 \text{ in. Hg/h} \times 1 \text{ h/60 min.} \times 12 \text{ min} = 0.018 \text{ in. Hg (0.31 kPa)}$$

This is an extreme case; seldom is a front this severe. Normally the difference in pressure between the HMS and the farthest tank is from 0.0 to 0.01 in.Hg (0.03 kPa). In general, this pressure difference can make a difference of 0 to 5% in the volume of gas predicted based on barometric slope. This difference is minor compared to the uncertainty that can result from the time lags discussed in Section 8.6.

An additional but minor pressure difference is caused by the elevation difference between the HMS and a given tank. At a tank 100 ft. (30.5 m) below the HMS, the pressure is about 0.10 in. Hg

(0.31 kPa) higher. If the waste surface level is 40 ft. (12.2 m) below ground level, the pressure is 0.04 in. Hg (0.0014 kPa) higher than at ground level. Thus, the pressure difference between the HMS barometer and the waste surface is 0.14 in. Hg (0.47 kPa). Attachment L contains a comparison of the plots of HMS pressure and the pressure recorded in 200 East and 200 West tank farm areas. It shows that the pressure at the tanks is higher than that at HMS. At least part of this pressure difference exists because the barometers in the farms are lower in elevation than the HMS barometer. Such a difference has no effect on the barometric slope, since the slope depends not on pressure magnitude but on pressure variations. On the other hand, the difference does have a minor effect on the total pressure on the gas, P_t , and the predicted gas volume; the effect is only about 0.5%. This can be determined from the equations below for a hypothetical volume of trapped gas calculated to be under a total pressure of 25.00 psi, based on HMS pressure. The pressure would be 0.14 in. Hg (0.47 kPa) higher at the waste surface. The volume V_H is the gas volume calculated based on pressure at the HMS, and V_C is the volume calculated based on pressure at the waste surface, that is, the pressure corrected for the difference in elevation.

$$V = -A P_t dL/dP_b$$

$$V_H = -A \times 25.00 \text{ psi} \times dL/dP_b$$

$$V_C = -A \times 25.14 \text{ psi} \times dL/dP_b$$

The volume V_C calculated with the corrected pressure is greater than V_H by the fraction 0.14/25.00, or 0.006.

8.7.2 Ground-Level vs. Waste-Level Pressure

The second requirement for the pressure in the tanks to closely track the barometric pressure recorded at the HMS is that the pressure inside the tank closely track the pressure at tank ground level. For passively vented SSTs, the pressure in the tank *does* closely track the pressure outside the tank. That is, the rate of air flow required to pass through the breather filter is so low that the changes in barometric pressure are, for all practical purposes, transmitted instantly to the inside of the tank. This can be seen even in the case of the very steep 6-hour pressure rise on November 4, 1958. On that date, the rate of rise was 0.307 kPa/h. (0.0907 in. Hg/h.). This was an increase of about 0.3% of the absolute pressure per hour. For a tank with a large headspace, for example 2,500 m³ (88,287 ft³), in an hour the increase would cause the tank to inhale 0.3% of its headspace volume, 78 m³ (274 ft³). Over a 6-hour period, the flow rate into the tank would be 0.22 m³/min (7.4 cfm). This is an insignificant flow rate compared to the flow capacity of the HEPA filter, so that, even for this extreme rate of pressure change, barometric pressure changes are transmitted immediately to the inside of a passively tank.

For actively vented SSTs and DSTs, consider DST SY-101 as an example. Attachment L includes a plot of the barometric pressure and headspace (dome) vacuum for the tank during December 1995. The barometric pressure, the units of which are on the left-hand Y axis, varies from about 13.82 to 14.63 psia (95.29 to 100.9). The in-tank pressure (dome pressure) is shown for two locations, riser 11B and riser 17B. These pressures, the units of which are on the right-hand Y axis, average about -2 in. water gauge (w.g.) (-0.5 kPa).¹⁶

How closely does the pressure exerted on the waste surface, $P_{\text{headspace}}$, track the barometric pressure? That is, how close is $\Delta P_{\text{headspace}}$ to $\Delta P_{\text{barometric}}$? This is easily determined by

¹⁶ Note that the scale on the right-hand margin is expanded to four times that of the left-hand margin. That is, the range of the right-hand axis is 5 in. w.g., 0.18 psi (1.2 kPa), and 0.2 psi is ~1/4 the 0.8 psi (5.5 kPa) range shown on the left margin.

examining the plot of these pressures for SY-101 (again, see Attachment L). The pressure exerted on the waste surface, $P_{\text{headspace}}$, is the barometric pressure plus the vacuum resulting from the exhaust. For the barometric pressure peak on December 7, $P_{\text{headspace}}$ is calculated as follows:

$$P_{\text{headspace}} = P_{\text{barometric}} + P_{\text{vacuum}}$$

$$P_{\text{vacuum}} = -2 \text{ in. w.g.} = -0.072 \text{ psi (0.50 kPa)}$$

$$P_{\text{headspace}} = 14.63 \text{ psi} - 0.07 \text{ psi} = 14.56 \text{ psi (100.4 kPa)}$$

For the pressure low on December 12, the headspace pressure is calculated as follows:

$$P_{\text{headspace}} = P_{\text{barometric}} + P_{\text{vacuum}}$$

$$\begin{aligned} P_{\text{vacuum}} &= -1.8 \text{ to } -3.0 \text{ in. w.g.} \\ &= -0.07 \text{ to } -0.11 \text{ psi (0.50 to 0.76 kPa)} \end{aligned}$$

$$\begin{aligned} P_{\text{headspace}} &= 13.82 \text{ psi} - (0.07 \text{ to } 0.11 \text{ psi}) \\ &= 13.71 \text{ to } 13.75 \text{ psi (94.5 to 94.8 kPa)} \end{aligned}$$

Between the above high and low, $\Delta P_{\text{barometric}}$ is 0.81 psi, as calculated below.

$$\begin{aligned} \Delta P_{\text{barometric}} &= 14.63 - 13.82 \\ &= 0.81 \text{ psi} = 1.65 \text{ in. Hg} = 22.4 \text{ in. w.g.} = 5.6 \text{ kPa} \end{aligned}$$

For the same interval, $\Delta P_{\text{headspace}}$ is about 0.81 to 0.85 psi (5.6 to 5.9 kPa).

$$\begin{aligned} \Delta P_{\text{headspace}} &= 14.56 \text{ psi} - (13.71 \text{ to } 13.75 \text{ psi}) \\ &= 0.81 \text{ to } 0.85 \text{ psi (5.6 to 5.9 kPa)} \end{aligned}$$

Thus, $P_{\text{headspace}}$ tracks $P_{\text{barometric}}$ within about 5%. In tanks with lower exhaust rates, tracking is expected to be better. For the few tanks with higher exhaust rates, tracking may be somewhat worse.

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9.0 OTHER POTENTIAL FLAMMABILITY HAZARDS

Section 6.0 of Attachment B requires evaluation for other potential hazards, such as flammable gas flowing into a tank through a cascade line from an adjacent tank. If there is a potential hazard that could cause a tank to contain a mixture exceeding any of the criteria, the tank should be considered to have failed that criterion. Thus, if a flammable gas mixture in a subsystem (such as a vent header) can attain a criterion limit and has credible potential to cause a serious release, this is a basis for considering the tank to have failed the criterion. As of the publication date of this document, none of the flammable gas evaluations done according to this document have addressed the requirement of Section 6.0 of Attachment B. Moreover, the evaluations have not addressed the possibility that gas might flow through cascade lines from a flammable gas tank to an adjoining tank.

Any nuclear waste tank containing moisture generates flammable gas. Therefore, any operation which disturbs the waste has the potential to release some amount of flammable gas. Operations such as mixing or retrieval must be evaluated to determine whether they present a credible hazard of a serious release.

This methodology is focused on conservatively evaluating the possibility of flammable gas exceeding flammability criteria in a tank's headspace. The fact that a tank does not exceed the criteria does not mean the tank does not contain trapped gas. It is anticipated that every tank containing solids generates and traps some amount of gas.

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10.0 IMPROVEMENTS NEEDED

Reviewers have identified various improvements needed on this methodology to eliminate excess conservatism and reduce data scatter. Others have suggested that the methodology be changed to a probabilistic evaluation. Finally, there is a need to verify the methodology's conservatism in two areas. This section discusses several improvements, as well as approaches for achieving them.

10.1 EXCESS CONSERVATISMS

For some of the parameters used to calculate % LFL, the values used in the deterministic calculations contain excess conservatism, as do some of the probabilistic distributions used in the Monte Carlo analysis. Excess conservatism was included in initial assumption to compensate for the lack of knowledge about the parameters. As knowledge improves, the excess can be reduced. Several of these parameters are listed below, with possible or in-progress efforts to improve knowledge.

10.1.1 Barometric Slope Method

1. **Tank Area:** The trapped gas volume is calculated by the formula $V = \text{-Area} \times \text{porosity} \times \text{slope}$. It is assumed that the cross-sectional area is that of the entire tank. However, for gas trapped in solids, this might not be the case, since cooling around the tank perimeter would tend to increase precipitation and prohibit gas from being trapped near the perimeter, reducing the effective tank area. An effort could be made to estimate the reduction.
2. **Hydraulic effect.** In tanks in which the FIC gauge is in a salt well or the ILL is measured in a liquid observation well surrounded by supernate, there might be a hydraulic effect which greatly magnifies the supernate's response to barometer changes. That is, when barometric pressure falls, expanding trapped gas may quickly raise the supernate in the well where the FIC or neutron probe is, but only slowly raise the liquid in the surrounding solids. This would cause the tank to appear to contain more trapped gas than it actually does. If this were the case, the level reading should respond more quickly to rapid than slow pressure changes. Tank surface level plots could be examined to detect this behavior. In such cases, it seems that the slope during slower pressure changes would be a better predictor of trapped gas volume.

10.1.2 Surface Level Rise Method

1. **Evaporation.** The greater the amount of evaporation calculated, the greater the surface level rise calculated. The evaporation calculated is a function of the aqueous vapor pressure of the waste and the air flow through the headspace, among other factors. The calculation assumes the air leaving the tank is at 100% relative humidity. This is based on the conservative assumptions that 1) the waste has the aqueous vapor pressure of 100% water, and 2) water vapor in the headspace is at that pressure, that is, is at equilibrium with the water in the waste. However, in reality the waste's aqueous vapor pressure is greatly reduced by its high salt content, and the system is not at equilibrium. As an initial effort to reduce excess conservatism in this area, calculated evaporation can be reduced by conservatively estimating the effect these factors have on the relative humidity of the exhausted air. Historical psychrometric records might allow some reduction in calculated evaporation; however, data in these records tend to be of poor quality.

The air flow through a tank is estimated based on the convective flow through tank A-101. If the flow could be accurately measured (for example, with flow instruments, or with analytical instruments which measure the rate of escape of a tracer gas), the calculated evaporation might be reduced for some tanks.

Reduction can also be achieved by thermal hydraulic modeling. However, modeling often assumes that cascade lines between tanks allow air flow between tanks. In reality, these lines may be partly or completely plugged. Models could be benchmarked against current tank conditions by careful measurements of the current flow rate and absolute humidity of air entering and leaving individual tanks.

2. Condensation. The surface level can rise slightly when outside air enters a tank in summer and humidity condenses on a cold riser or salt well screen, etc., then drains down into the tank. Conservative calculation of the amount of condensation might reduce the amount of surface level rise attributed to gas in some tanks. Similarly, condensation can occur from moist air leaving a tank, making the evaporation less than calculated. If the amount of such condensation could be established, it could reduce the amount of evaporation calculated.
3. Adjustments to Surface Level Rise. Section 7.2 identifies adjustments to the surface level. An effort could be made to identify factors which legitimately minimize losses which must be added to surface level, such as factors which overestimate supernate volume pumped from a tank. For example, water added to prime saltwell pumps is not shown as having been *added* to the tank, although the water is included in waste *pumped from* the tank. In a few tanks, this might result in a significant increase in the waste's surface level rise. Also, records should be searched for provable additions to tanks, such as draining a condenser pit into a tank.

10.1.3 Barometric Slope and Surface Level Rise Methods

1. Fraction of trapped gas released. PNNL is working to determine the fraction of trapped gas that can be released from various types of waste under normal and earthquake conditions. If the release is predicted to occur over a period of several hours, days or weeks, the calculation of the % LFL should compensate for the gas exhausted from the headspace before the release is complete.
2. Fraction of trapped gas which is flammable. Use of the retained-gas sampler has begun to determine the composition of trapped gases in tank waste. Efforts are also underway to use the Toxic Vapor Program's analysis of headspace gases (referred to in the first paragraph of Section 4.0) to partly determine the composition of trapped gas.
3. Fraction of NH₃ released by mass transport. The amount of NH₃ released in an EGR is assumed to be 0.22 times the amount of trapped gas released. In reality, the possible concentration of NH₃ in the headspace may be limited by other factors. D. A. Reynolds has begun to work on this.
4. Center of trapped gas. The center of trapped gas is assumed to be deep in the waste. The methodology makes no adjustment for gas trapped higher in the tank, such as in a floating crust. In tanks in which gas is known to be centered higher in the waste, the location should be adjusted upward. The assumed location is based on tank SY-103, which periodically releases gas from the top of the wet solids. A release lowers the center of the remaining trapped gas. Thus the center of trapped gas in a tank which undergoes periodic releases should be lower than in tanks which do not have significant periodic releases. In the latter tanks, the center of gas might be significantly higher. The effect of this on the amount of calculated trapped gas should be considered.

10.2 EXCESSIVE DATA SCATTER

For some of the parameters used, the data scatter is very wide. Improving the instrumentation used to measure surface level would greatly reduce data scatter in several parameters. Several of these parameters are listed below, with possible or in-progress efforts to improve data quality.

10.2.1 Barometric Slope Method

1. **Barometric slope.** Very negative slope or a wide range on the slope is a result of poor surface level/ILL data or too wide a "shift criterion" in the algorithm defining the intervals for which a slope is calculated. Data can be poor because of an imprecise gauge; infrequent readings; or manual readings being entered into the SACS database with a time stamp several hours after they were actually taken. These problems can be solved by installing ENRAF gauges on tanks which have none and connecting them to the Tank Monitoring and Control System (TMACS) for automatic data capture. Once auto-ENRAF readings are available, the best slope data can be obtained from readings taken during a continuous pressure increase (or decrease) occurring over a period of several days. For ILL readings, data will be improved by taking IL readings with the improved equipment recently procured. Data can also be poor because the level change either lags behind or advances ahead of the barometric change (depending on the direction of the barometric change). This might be caused by waste shear strength or other physical factors, such as the hydraulic effect discussed in Section 10.1.1. This could be investigated by physical experiments or modeling.

As described in Attachment L, minor data scatter results from differences between pressure in the tank and the pressure in actively exhausted tanks. A decrease of perhaps 5 to 15% in data range might be obtained for actively exhausted tanks by using in-tank pressure instead of ambient barometric pressure to determine slope.

Whitney (1995) used an algorithm to divide surface level data into intervals. One of the algorithm's determiners of interval length was the presence of a sudden surface level shift of a few tenths of an inch. If the "shift criterion" in the algorithm was too wide, an interval might include a minor level variation from a minor gas release, causing data scatter. This problem could be reduced by manual examination of the tank's level plot to detect such intervals, then breaking each such interval into two or more intervals.

2. **ENRAF "stickiness."** Some ENRAFs show "stickiness." For example, at least one ENRAF makes a daily "step change" at about 9 AM. This limits the usefulness of the data. For tanks for which better data are needed, this problem should be addressed.
3. **Location of surface level measurement.** In tanks with an irregular waste surface it is important to know where the surface level plummet contacts the surface. In the absence of information to the contrary, it is assumed that the level at which the plummet contacts the waste is the average waste height. However, this is not true if the plummet is in a hole. In tanks for which there are no recent photographs or videos, there may be considerable uncertainty about where the plummet contacts the waste. Tanks for which this information is critical should be identified and new photographs or videos made.

10.2.2 Barometric Slope and Surface Level Rise Method

1. **Void fraction.** The calculated void fraction is used to calculate volume of gas released. The methodology assumes that the void fraction in wet solids could reach 30%. However, the void fraction instrument has not found void fractions above about 15%. The difference between

observed and calculated void fraction is probably the result of a wide error band in the slope, where the error band results from poor data quality. Reducing the scatter as described in Section 10.2.1 would reduce the calculated void fraction and the resulting % LFL. In addition, the calculated void fraction can be reduced in two ways.

First, use instrumentation to determine the void fraction of the waste. One such instrument is the void fraction instrument, which is already used in double-shell tanks. Another possibility is a pressure gauge. A 5-m (9.84-ft.) depth of solids with a density of 1.8 g/mL would exert a pressure of 53.0 kPa (7.68 psi) on trapped gas. A 30% void fraction would reduce the effective density by 30%, to 1.26 g/mL, so a 5-m depth of waste would exert a pressure of 37.1 kPa (5.38 psi). Thus, if the density of degassed solids in a particular tank were known from sample analysis, one could calculate the pressure which would be exerted at a particular depth by waste with 0% void. By inserting a pressure gauge into the tank, it would be possible to determine the actual pressure and thus the actual % void of the waste above the pressure gage. If pressure is the same at a particular depth within the waste, the % void should be an average for the solids across the entire tank. It may be possible to determine whether this approach is valid by examining data obtained from the Velocity-Density-Temperature Tree (VDTT) inserted earlier into tank SY-101.

Second, consider whether it is physically possible for a tank to contain 30% void fraction. For example, in solids 10 m deep, 3 m would be gas. That is, the solids would have experienced 3 m of gas growth. Is that possibility consistent with the waste's behavior and history? If not, how much growth is consistent? Or, if the methodology calculates that the tank already had a 30% void fraction when it was salt-well pumped in the 1980s, wouldn't sluicing the salt well into place have caused a significant volume of gas to be released (with a corresponding level drop) even before pumping began? If no decrease occurred, what is the maximum credible void fraction?

In any case, once the void fraction is calculated, it may be appropriate to iterate the calculation to determine whether and how much the void reduces the pressure on the trapped gas, then to recalculate the volume of trapped gas.

2. **Headspace volume.** The irregular surface of the waste causes uncertainty in estimating surface level and headspace volume. Because the headspace volume directly affects the calculated % LFL, it may be worthwhile in a few tanks with very irregular surfaces, to use photogrammetry to map the surface level and accurately determine the headspace volume.

10.3 SWITCH TO PROBABILISTIC CRITERIA

In the evaluations published by Hodgson et al. (1996), calculations used to evaluate a tank were deterministic. The deterministic values calculated were generally at the 97-99% confidence level, as calculated using the evaluation team's conservative Monte Carlo methods. Table 10-1 shows

Table 10-1. Confidence Level vs. Standard Deviation Above Mean

Confidence Level	Standard Deviations Above Mean
95.0	1.6
97.0	1.9
98.0	2.0
99.0	2.3
99.5	2.6
99.9	3.0
99.95	3.3

for individual confidence levels the corresponding number of standard deviations above the mean. This indicates that there is some probability that the post-EGR flammable gas concentration might be higher than the deterministic value calculated by the evaluation team. For this reason, future evaluations might better be done on a probabilistic basis.

It has been suggested that the criteria for FGWL tanks be redefined so that a tank would fail the criteria if there were a probability higher than 10^{-4} /yr. that the tank could attain 100% of the LFL. If this change were made, it would be necessary to increase the number of Monte Carlo trials to define the upper range of the % LFL distribution.

10.4 VERIFICATION OF CONSERVATISM

There are two nonconservative assumptions which should be further examined to determine whether they were appropriate.

First, the "quick screen" (described in Section 6.0), which evaluates a tank's post-EGR flammable gas concentration, assumes that if a tank passes the quick screen, it also contains too little waste to generate enough flammable gas to fail the steady-state criterion. Although this assumption appears well founded, it should be verified by examining headspace gas sampling of tanks which passed the quick screen.

Second, in some tanks the ILL was used to estimate surface level rise. In general, the period for these evaluations began in the mid 1980s. A handful of these evaluations may not estimate the amount of gas already trapped in the waste when the evaluation period began. The accuracy of the surface level rise could be verified by using the improved neutron probe (discussed in Section 10.2.1) to determine the tank's gas content using the barometric slope.

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12.0 ACKNOWLEDGEMENTS

This description of the method for evaluating tanks for potential flammable gas entrapment has been improved by the input of many individuals. Their contributions are gratefully acknowledged. Those with whom the evaluation team has most frequently interacted in recent weeks are named below. There are others who have indirectly contributed to this document, but time prevents listing them all. Their contributions are nonetheless greatly appreciated.

Barker, S. A. - contributed greatly to standardizing the evaluation process: started with a rudimentary spreadsheet incorporating basic calculations and significantly upgraded it to include evaluation logic, look-up tables, greatly improved formatting and handling of Monte Carlo inputs. For Revision 1, wrote the DSI in Attachment C providing background for the calculation of liquid evaporation from tank waste, and greatly improved the spreadsheet calculations of evaporation.

Evaluation team members: R. P. Anantatmula, S. A. Barker, K. D. Fowler, K. M. Hodgson, D. C. Hedengren, E. I. Husa, J. A. Lechelt, D. A. Reynolds, F. M. Simmons, R. E. Stout, R. T. Winward, and G. W. Reddick - As a group, significantly improved the quality of this document by challenging details of the evaluation methodology and/or by commenting on the document draft.

Hodgson, K. M. - Team leader of the evaluation team; provided considerable help in clarifying relationships between factors in the evaluation.

Reynolds, D. A. - provided frequent sanity tests between the conceptual model of tanks and the real world in waste tanks; identified significant inconsistencies between the draft of this document and how the evaluation was actually performed.

Review team members: D. Ogden, T. R. Beaver, P. U. Peistrup, F. A. Schmittroth, M. J. Thurgood (John Marvin Inc.), A. Nuels (Los Alamos National Laboratory) - Provided a thorough review of the methodology and recommended changes to improve it. Special thanks to Marv Thurgood and Don Ogden, who provided material in Attachment K regarding the adjustment for evaporation in the surface-level rise method.

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Whitney, P. D., Pacific Northwest National Laboratory - Interacted continually with the evaluation team to provide histograms of barometric slopes and advice on improving the logic of applying the slopes to tanks.

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ATTACHMENT A

TANK DATA REQUIREMENTS

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This attachment defines the data requirements for evaluating tanks against the Flammable Gas Watch List (FGWL) criteria, and it provides a form for recording data about a tank and its waste.

The following information about the tank's construction should be reported for each tank evaluated. Items, dates and references are given for tank S-106.

Tank S-106

<u>Description</u>	<u>Data</u>	<u>Reference</u>
Constructed	1950 to 51	Brevick et al. 1994
Placed in service	1953	Brevick et al. 1994
Inactivated	1976	Brevick et al. 1994
Leak Status	Sound	Hanlon 1995

Table A-1 lists the data needed to evaluate tanks against the FGWL criteria. The evaluator must record data on this form and sign the final file copy to certify the data and their sources. Alternately, the evaluator may sign the final file copy of the data section of the spreadsheet. The references listed below contain much of the data needed.

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Table A.1. Tank Data Collection Form (2 sheets).

Line	Item Description	Units	Data	Data Source/Comments
1	Tank No.			
2	Calculation date (Spreadsheet will automatically enter.)			Hanlon 1995
3	Total waste volume	gal		Hanlon 1995
4	Total solids volume (sludge + saltcake), including gas	gal		Hanlon 1995
5	Supernatate volume	gal		Hanlon 1995
6	Volume of interstitial liquid	gal		
7	Volume of sludge	gal		Hanlon 1995
8	Current solid surface level height (Reading SLC)	in.		
9	Original solid surface level height (Reading SLH)	in.		
10	as of this date:	date		
11	Current liquid level height (Reading LLC)	in.		
12	Original liquid level height (Reading LLH)	in.		
13	as of this date:	date		
14	Engineer selects source of solids volume (Hanlon, SLC or LLC)			
15	Engineer selects source of interstitial liquid volume (Hanlon, SLC or LLC)			
16	Engineer selects source of supernatate volume (Hanlon, SLC or LLC)			
17	Supernatate density. If unknown, enter 1.40.	g/mL		
18	Solids density. If unknown, enter 1.80.	g/mL		
19	Porosity (liquid fraction) in solids, by assay. If unknown, enter 0.501.			
20	Porosity (sludge). If unknown, enter 0.16.			
21	Average gas location: fraction of wet solids from bottom center. If unknown, enter = 0.225.			
22	Estimated maximum evaporation	in.		
23	g TOC/L waste (wet)	g(TOC/L (wet)		
24	g Al/L waste (wet)	g/L (wet)		
25	Average trapped gas temperature	°F		
26	Average solids temperature	°F		
27	Power load from published source. If not available, leave blank.	kW		
28	Heat load from published source. If not available, leave blank. (Don't leave both blank.)	kW		
29	Tank Farm (A, AN, AP, AW, AX, AY, AZ, B, BX, BY, C, S, SX, SY, T, TX, TY, U)			
30	H2 generation rate, G(H2). If unknown, enter 0.1.	molecules H2/ 100 eV		
33	If sampled, actual H2 value from sampling	ppm		
34	If sampled, actual NH3 value from sampling	ppm		
37	% H2 in trapped gas, ft3 H2/ft3 trapped gas x 100%. If unknown, enter 97%.	%		
38	% of trapped gas releasable. If unknown, enter 25%.	%		
39	Mean air pressure on waste surface. If unknown, enter 14.50.	psia		
40	Add to Current Surf Lvl: compaction	in.		
41	Add to Current Surf Lvl: out leakage	in.		
42	Add to Current Surf Lvl: pumped out	in.		

Form Revised 4/22/96

Table A.1. Tank Data Collection Form (2 sheets).

Line	Item Description	Units	Data	Data Source/Comments
43	Add to Current Surf Lvl: measuring error (known or possible icicle at start, kink in tape now, etc.)	in.		
44	Add to Current Surf Lvl: any gas contained in original surface level	in.		
45	Subt from Current Surf Lvl: measuring error (known or possible icicle now, kink in tape at start, etc.)	in.		
46	Subt from Current Surf Lvl: intrusion or addition	in.		
47	Subt from Current Surf Lvl: condensation from ambient air, which has dripped into tank	in.		
48	Subt from Current Surf Lvl: hygroscopic absorption	in.		
49	Subt from Current Surf Lvl: crust expansion by gas	in.		
50	Subt from Current Surf Lvl: crystal expansion	in.		
51	Tank atmospheric breathing rate - SSTw/oFIC (Crippen: 0.45% natl breathing)			
52	Tank FIC purge rate (nominally 50-200 cfh)	cfh		
53	Tank Vent Rate	cfm		
54	Tank breathing rate: SSTxFIC, SSTwFIC, or DST			
55	Ratio of NH3 % to H2 % (normally 4)			
56	Ratio of CH4 vol to fraction of H2 conc. (normally 0.020)			
57	Assume NH3 vol = this fraction of trapped gas released (normally 0.220)			
58	Assume CH4 vol = this fraction of trapped gas released (normally 0.00)			
59	Select Confidence Level for Barometric Pressure/Surface Level Correlation			
60	Slope at 95% confidence	in./in. Hg		
61	Slope at 75% confidence	in./in. Hg		
62	Slope at 50% confidence	in./in. Hg		
63	QFit Mean			
64	QFit Standard Deviation			
65	Engineer Selects Surface Rise Method: L (Liquid) or S (Solid)			
66	Engineer Identifies Level Measurement Condition: SUP, SOL, LIH			
67	Temperature of Entering Air. If unknown, enter 56.3 F (Year Avg).	deg F		
68	Relative Humidity of Entering Air. If unknown, enter 50%.	%		
69	Temperature of Vapor in Dome Space (Year Avg)	deg F		
70	Relative Humidity of Exiting Air. If unknown, enter 100%.	%		
71	Surface Temperature of Waste (Year Ave)	deg F		
72	Enter Period of Time over which evaporation occurs	years		
73	Enter Fraction of Heat Load used in calculating Vent Rate. If unknown, enter 50%.	%		
74	Enter Calculation Result to Report on lines 123 and 124			
	Date and Engineer's Name/Signature (Optional if not record copy)			

Form Revised 4/22/96

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ATTACHMENT B

LOGIC AND TECHNICAL DETAILS

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The detailed logic and technical details for evaluating tank flammable gas conditions was given in Appendix E of *Criteria for Flammable Gas Watch List Tanks*, WHC-EP-0702 Rev. 0, (Hopkins 1994). That appendix is reproduced on the following pages without change, except that page numbers have been changed to correspond to numbers for this attachment, Attachment B. Figures numbers are those assigned in the original appendix in WHC-EP-0702 Rev. 0.

REFERENCE

Hopkins, J. D., 1994, *Criteria for Flammable Gas Watch List Tanks*, WHC-EP-0702 Rev 0, Westinghouse Hanford Company, Richland, Washington.

APPENDIX E [OF WHC-EP-0702, Rev 0]

LOGIC & TECHNICAL DETAILS

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1.0 LOGIC DIAGRAMS

Figure E-1 is a diagram of the overall logic for the application of the flammable gas criteria. (Later in this appendix, Figure E-2 shows more-detailed logic for the dispersed-episodic gas release (dispersed-EGR) case.) On the left of the overall logic diagram are identified the four tank conditions below, which are defined in Section 2.5 of the text.

- In-progress EGR
- Overpressurization
- Dispersed-EGR condition
- Steady-state condition

For each condition, the diagram shows a three-stage approach for applying the corresponding criterion. The approach begins with conservative worst-case calculations. Next, when indirect measurement of flammable gas concentration/volume are available, additional evaluation is conducted. Finally, when direct concentration measurement is available, still further evaluation is done. At each stage all relevant available data on indirect and direct measurements must be considered.

At the *first stage*, worst-case calculations are done, using generally available tank data, such as waste volume, temperature and drainable liquid. If any additional second- or third-stage data are available, they must also be considered. If the calculations and data show that the tank does not exceed the Watch List criteria, it will not be placed on the Watch List.

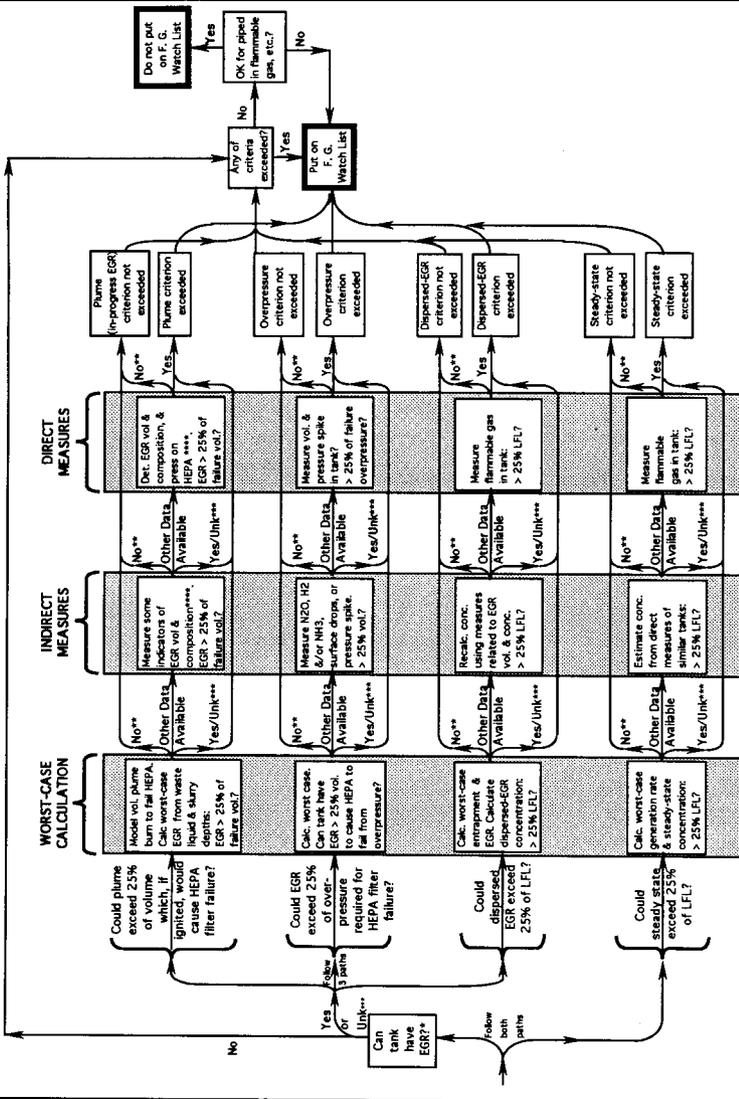
In the absence of other data, the first-stage, worst-case calculation may not be sufficient to determine whether a tank exceeds the Watch List criteria. If it cannot be determined that a tank does not exceed the Watch List criteria, it must be placed on the Watch List. Because of the lack of data, the conservative estimate of a hazard may be much higher than the actual hazard, causing a tank to be incorrectly added to the flammable gas Watch List. Nonetheless, additional data will be required about the tank before it may be removed from the Watch List.

At the *second stage*, indirect measures of flammable gas concentration are considered. These include surface level fluctuations, slurry growth, indication in tank temperature records of slurry roll-over, data from similar tanks, etc. If indirect measures cannot show a tank should be excluded from the Watch List, direct measures of flammable gas concentration are required before the tank can be excluded.

At the *third stage*, direct measures—such as obtained through on-line gas monitors and grab samples—are considered. If they do not show a tank can be excluded from the Watch List, mitigation or remediation is required before the tank can be excluded.

The technical details for applying the criteria are described in this appendix. The methodologies herein are established in accordance with current knowledge. However, this is a living document, and the methodologies will be revised as new information becomes known or changes become necessary. Revisions will be approved by the Manager of the Flammable Gas Safety Program.

Figure E-1. Overall Logic



* Can tank have an EGR? Guidelines: Heel, mud flat, "dry" salt cake; no. Liquid only; not now, maybe later. Salt cake & water, slurry; evaluate.
 ** "No" and no other data available to evaluate.
 *** Unk = too little data available to determine.
 **** Assumes all slurry gas is vented from same point in waste surface.

2.0 PLUME (IN-PROGRESS EGR)

2. 1 Criterion

The criterion for the in-progress-EGR condition is stated below.

The tank waste could release a gas plume with a volume greater than 25% of that plume volume which, if ignited, could explode and cause a serious release to the environment.

2. 2 Background

For the ignition of a plume (in-progress EGR), the volume of the gas release required for HEPA filter failure is assumed to be small—about 0.25% of the dome space volume. (The plume volume which, if ignited, could cause a serious release varies from tank to tank and is determined by dome space volume, exhaust configuration, and connections to other tanks.) Because this volume is much less than the volume of the tank dome space, it was questioned whether ignition of this volume was credible.

Therefore, Powers conducted an analysis of the ignition of the in-progress release and determined the probability of ignition for all non-Watch List tanks to be 6×10^{-6} /year. (Events with an annual frequency greater than 10^{-6} /year are considered credible.) For tanks with conditions varying from his assumptions, the probability may be higher or lower (Powers 1993).

2. 3 Worst-Case Calculation

Modeling analysis is being conducted to determine the volume of in-progress EGR which, when ignited, would generate enough pressure to cause HEPA filter failure. The volume of slurry gas predicted will vary from tank to tank according to the dome space volume above the tank waste, number and configuration of entry/exit ports (such as exhaust manifolds and cascade pipes to other tanks), and, if known, the composition of the slurry gas. The inputs to the model must be conservative. This may require determining the pressure produced by mixtures containing NH_3 and CH_4 , in addition to H_2 and N_2O .

Once the model predicts the EGR volume which would cause HEPA filter failure, tanks can be evaluated. If a tank could have an EGR of more than 25% of the volume, it must be placed on the Watch List. Whether a tank could have a release of the predicted volume can be calculated by the method, described in Section 5.0 of this appendix, to calculate the size of possible EGR for the dispersed-EGR condition.

2. 4 Indirect Measures of EGR Size

As data become available about the composition of a tank's slurry gas and the size and frequency of EGRs, the estimate of a tank's maximum tolerable EGR can be improved. Assessments of the size of small EGRs occurring in the tank might be

made based on short-term increases in steady-state flammable gas concentration, pressure spikes, and perhaps level fluctuations.

2. 5 Direct Measures of EGR Size

The best measure of an in-process EGR would be a continuous gas monitor, pressure sensor, or surface-level measuring device, each with enough precision to detect significant changes in the measured parameter. Whether such devices could provide enough precision depends on the size of the maximum tolerable EGR for a given tank.

3.0 OVERPRESSURIZATION

3. 1 Criterion

The criterion for overpressurization is stated below.

The tank could have an overpressure of more than 25% of the overpressure which could cause a serious release. (An overpressure of about 10 in. w.g. could cause a serious release; the amount varies from tank to tank.)

3. 2 Background

As discussed in Section 2.0 of the document, overpressurization can cause HEPA filter failure (or release through another system opening). HEPA filters used on double-shell and single-shell tanks are rated at 10^1 in. w.g. (Mil-F-51068F 1988). This overpressure corresponds to a pressure increase of 2.46% of atmospheric pressure (10.00 in. w.g./ $[406.78$ in. w.g./ 1 atm] = 0.0246 atm, or 2.49 kPa). This corresponds to an EGR of 2.46% of the dome space volume. With a 300% safety factor, the criterion establishes an EGR of one fourth this volume, or 0.615 % of the dome space volume. If a tank could have an episodic release of this volume, the tank meets the criteria for placement on the Flammable Gas Watch List.

3. 3 Worst-Case Calculation

Whether the tank could have a release of the predicted size can be calculated by the method, described in Section 5.0 of this appendix, to calculate the size of possible EGR for the dispersed-EGR condition.

¹ Because this is a defined value, it is taken as exact, with unlimited significant figures.

4.0 STEADY-STATE CONDITION

4.1 Criterion

The criterion for the steady-state condition is stated below.

The tank could have a "uniform"² flammable gas concentration greater than 25% of the lower flammability limit (LFL) in the dome space or ventilation headers.

4.2 Background

Although H₂ is the primary contributor to the flammable gas problem in tank waste, considerable NH₃ and some CH₄ are also generated. In a study cited in Section 2.2 of this document, the U.S. Bureau of Mines (USBM) tested mixtures of H₂ and other gases under various conditions. From these and other tests, the following LFLs were determined in air at 27°C (80.6°F): H₂, 4.0%; NH₃, 15%; and CH₄, 4.8% (i.e., 5.0% - 0.2%) (Cashdollar et al. 1992).

Slurry gas in tank 241-SY-101 contains nitrous oxide (N₂O), in which H₂ has a lower LFL. The N₂O concentration in the steady-state mixture is about the same as that of H₂. USBM tests of 4% H₂/4% N₂O in air did not increase the test's peak pressure, relative to 4% H₂ in air, except for a small increase when a high-energy ignitor was used (Cashdollar et al. 1992). It is therefore inferred that N₂O in this range does not significantly lower the LFL. (Refer to Appendix C for more information on the USBM report.)

As discussed in Appendix C, when more than one of these flammable gases is present, Le Chatelier's Linear Mixing Law is used to determine whether the mixture of flammable gases exceed their combined LFL (Cashdollar et al. 1992):

$$[H_2]/LFL_{H_2} + [NH_3]/LFL_{NH_3} + [CH_4]/LFL_{CH_4} > \text{or} = 1$$

where "[H₂]" means "concentration of H₂," and all terms are mole fractions in the diluted mixture in the dome space.

Whether the concentrations of flammable gases exceed 25% of their combined LFL can be determined by calculating whether the sum of the above terms is greater than 0.25. Values for the gas concentration terms can be determined by 1) worst-case calculation, 2) a combination of calculation and indirect measures of the H₂ concentration, or 3) direct concentration measurement, as explained below.

In flammable gas tanks, H₂ is generated by thermolysis of organics, radiolysis of water, radiolysis of organics, and corrosion of the steel tank liner. All three of these mechanisms contribute to the steady-state flammable gas concentration.

² In this document, the phrase "flammable gas at uniform concentration" refers to "a flammable gas mixture in a particular tank at a point in time, where the mixture's concentration and composition at any location in the tank do not vary from the average concentration and composition (at that point in time and in that tank) by more than a few percent (e.g., five to ten percent of the concentration and/or composition) in any significant volume throughout the dome space."

The following sections explain how to calculate the contribution of these processes to the steady-state flammable gas concentration

4. 3 Worst-Case Calculation - Thermolysis of Organics

Thermolysis may contribute a large portion of the flammable gases generated in a high-level waste tank. This section explains how to do a worst-case calculation of the amount of flammable gas generated in such tanks. In this explanation, the generic term "tank 241-XX-*nnn*" refers to any of the 177 tanks except tank 241-SY-101.

In tank 241-SY-101, there are three layers: 1) the floating crust several inches thick, 2) the convecting layer (about 13.5 feet deep) consisting of a liquid which has within it convecting currents caused by the warmer slurry layer below, and 3) the non-convecting layer, consisting of slurry, which entraps gas generated within that layer. H_2 is generated within the convecting and nonconvecting layers. Most of the H_2 for continuous release comes from the convecting layer.

The worst-case calculation determines the rate of continuous release from thermolysis per unit volume of convecting layer in tank 241-SY-101, then uses that volumetric rate doubled as a bounding rate to determine the bounding continuous release rate in individual tanks. For tank 241-XX-*nnn*, this bounding rate is multiplied by liquid volume and three ratios of that tank's characteristics compared to tank 241-SY-101: TOC ratio, aluminate ratio, and thermolytic reaction rate ratio (rate is a function of temperature).

4. 3. 1 Assumptions

4. 3. 1. 1 For tank 241-XX-*nnn*, flammable gas is continuously released into the dome space at the same rate at which it is generated. (This is conservative if the tank is still experiencing slurry growth. Furthermore, as the tank cools, further precipitation can occur, causing increased entrapment rates and, therefore, decreased steady-state release rates.)
4. 3. 1. 2 In tank 241-SY-101, since insertion of the mixer pump, which discharges entrapped gas on a regular basis, the surface level remains relatively constant. Therefore, it is assumed that the generation rate in the tank equals the release rate.
4. 3. 1. 3 In tank 241-XX-*nnn*, the thermolytic reaction is assumed to take place in the liquid phase, and the rate of thermolytic generation of H_2 for the steady state is proportional to the volume of liquid waste. The volume of liquid waste includes the interstitial liquid in the slurry layer.
4. 3. 1. 4 In tank 241-XX-*nnn* the H_2 for continuous release is generated in both the convecting and the nonconvecting layers. (The part of the H_2 that can be calculated to be retained in the slurry layer is excluded from steady-state release.)
4. 3. 1. 5 In tank 241-SY-101, the wt. % total organic carbon (TOC) in the liquid phase is 1.07, as reported by Herting, p. 7-11 (Herting et al. 1992).

For tanks in which the wt. % TOC in liquid is unknown, it is assumed that the % TOC is 2.9% (that is, 0.1% below the criteria for organic tanks), and the TOC is in the liquid phase, unless data indicate otherwise. As calculated below, the maximum wt. % TOC in liquid is 5.8%:

$$\frac{0.029 \text{ g TOC}}{1.00 \text{ g waste}} \times \frac{1.00 \text{ g waste}}{0.50 \text{ g water}} = \frac{0.058 \text{ g TOC}}{1.00 \text{ g water}}, \text{ or } 5.8 \% \text{ TOC}$$

Here it is assumed that the minimum amount of water in a tank is 50%, even in tanks which have been pumped.

4. 3. 1. 6 Based on work by Ashby (1992b), the rate equation for the production of H₂ from thermolysis of organics is assumed to be first order with respect to wt. % TOC in solution. (Reaction is assumed to take place in the liquid phase.)
4. 3. 1. 7 Hydrogen production increases as aluminate concentration increases (Pederson and Strachan 1993). It is assumed that all aluminum (Al) reported in characterization assays exists in waste as aluminate ion. Tank 241-SY-101 "Window E" sample assays indicate that the average Al content of the waste in tank 241-SY-101 is assumed to be about 3.0 wt. %. Based on work by Ashby (1992b), it is assumed that in tank 241-XX-*nnn*, the rate equation for the production of H₂ from organics is first order with respect to wt. % Al dissolved in solution. (Reaction is assumed to take place in the liquid phase.)
4. 3. 1. 8 In any high-level waste tank, the rate of H₂ generation by thermolysis is a function of waste temperature. Rate = k x e^{-E_a/(RT)}, where k is a constant, E_a is activation energy in joules, R = 8.3134 J/K-mole, and T is temperature in Kelvin.

Pederson and Strachan estimate that the activation energy for H₂ generation in tank 241-SY-101 may be as low as 7 kJ/mol (Pederson and Strachan 1993). This number is derived from data such as the long-term rate of slurry growth, temperature variations, volume of gas accumulated, coupled with assumptions such as the fraction of hydrogen generated by thermolysis.

Delegard experimentally determined the activation energy to be 24.5 kcal/mol (102 kJ/mol) for the thermolysis of synthetic waste containing EDTA and HEDTA (Delegard 1980). HEDTA contributed to H₂ gas production; EDTA did not. The activation energy, E_a, was determined by Siemer to be 96 kJ/mol H₂. Meisel used only formaldehyde as the organic component of synthetic waste and determined E_a to be 84.8 kJ/mole (20.3 kcal/mol H₂) (Strachan 1992).

By measuring the gas generated from genuine tank 241-SY-101 waste heated to 65 and 100°C, Person determined values for E_a ranging from 19 to 24 kcal/mol gas (79-100 kJ/mol) (Goheen et al. 1993). Because the data were not analyzed statistically, an error band of 50% is assumed around a median of 21.5 kcal/mole (90.0 kJ/mol). This defines a range from 45.0 to 135.0 kJ/mol.

If E_a for the production of H_2 in tank 241-SY-101 waste were at the upper end of this range, dramatic differences would have been seen in gas generation rates (indicated by dramatic swings in entrapment rate) when tank temperatures were at 145°F (335.9K), compared to current temperatures around 115°F (319.3K), as indicated below. With E_a equal to 135 kJ, the rate at 145°F would be over 12 times the rate at 115°F.

$$\text{Rate} = k \times e^{-E_a/(RT)}$$

$$\text{Rate at 145°F} = k \times e^{-135,000/(8.3134 \times 335.9)} = k \times 1.016 \times 10^{-21}$$

$$\text{Rate at 115°F} = k \times e^{-135,000/(8.3134 \times 319.9)} = k \times 8.143 \times 10^{-23}$$

$$\text{Rate at 145°F} = 12.5 \times \text{Rate at 115°F}$$

Assuming thermolysis accounts for more than half the gas generated, the rate of entrapment should have decreased dramatically when the temperature dropped from 145° to 115°F. However, tank 241-SY-101's rate of surface level change has not reflected these dramatic changes.

It is therefore assumed that the activation energy, E_a , for tank 241-SY-101 waste is 26.0 kJ/mol midway between the assumed lower end of Person's range (45.0 kJ/mol) and the Pederson/Strachan value of 7 kJ/mol. With this E_a , the rate at 145°F is only about twice the rate at 115°F. This is more consistent with the observed behavior of tank 241-SY-101. It is further assumed that E_a for tank 241-XX-nnn is the same as for tank 241-SY-101.

$$\text{Rate at 145°F} = k \times e^{-26,000/(8.3134 \times 335.9)} = k \times 9.054 \times 10^{-05}$$

$$\text{Rate at 115°F} = k \times e^{-26,000/(8.3134 \times 319.9)} = k \times 5.569 \times 10^{-05}$$

$$\text{Rate at 145°F} = 1.63 \times \text{Rate at 115°F}$$

For tanks with average temperatures below that of tank 241-SY-101 (115°F) this approach appears to give conservative results.

For tanks at temperatures above that of tank 241-SY-101, E_a is assumed to be 90 kJ/mol for tanks 241-SY-101 and 241-XX-nnn. Above the temperature of tank 241-SY-101 this gives results more conservative than an E_a of 26 kJ/mol and is assumed in light of Person's value of 79-100 kJ/mol.

4. 3. 1. 9 The volumetric rate of H_2 generation by thermolysis in tank 241-SY-101 is assumed to be the base rate for calculating the rate in the convecting layer in tank 241-XX-nnn. This volumetric rate in tank 241-SY-101 is calculated as described below.

- Based on Wilkins' calculation that 15.84 ft³ (0.4485 m³) H_2 /day were generated in tank 241-SY-101 between releases, and her assumption that this is half the amount of gas generated (1993), 31.7

ft³ (0.4485 m³) H₂/day were generated in tank 241-SY-101. Per Section 4.5 of this appendix, 1.1 ft³ (0.031 m³) of this is generated by corrosion. Of the remaining 30.6 ft³ (0.866 m³), 70 percent (21.4 ft³, or 0.606 m³ H₂/day) is estimated to be from thermolysis and 30 percent from radiolysis (Meisel et al. 1993). It is assumed this applies to the convecting and nonconvecting layers.

- Determine the base volumetric rate of thermal H₂ generation by dividing 21.4 ft³ (0.606 m³) H₂/day by the volume of liquid in tank 241-SY-101. The depth of the convecting layer is assumed to be 162 in. (400 in. surface - 30 in. crust -208 in. nonconvecting layer; or 4.37 m), derived from Reynolds (1993). The nonconvecting layer is assumed to contain 40 percent liquid waste (Herting et al. 1992).

$$21.4 \text{ ft}^3 \text{ H}_2/\text{d} + \{367.7 \text{ ft}^3 \text{ waste/in ht. } [(400 \text{ in.} - 30 \text{ in. crust} - 208 \text{ in. NC layer}) + (208 \times 0.40 \text{ liquid fraction})]\}$$

$$= \frac{21.4 \text{ ft}^3 \text{ H}_2/\text{d}}{90,160 \text{ ft}^3 \text{ liquid waste}}$$

$$= 2.37 \times 10^{-4} \text{ ft}^3 \text{ H}_2/\text{ft}^3 \text{ liquid/d (or } 2.37 \times 10^{-4} \text{ m}^3 \text{ H}_2/\text{m}^3 \text{ liquid/d)}$$

$$\text{or } 5.76 \times 10^{-9} \text{ mole/L liq waste/min}$$

Note that, based on experimentation, Meisel estimated thermal generation to be 8.7×10^{-9} mole/L liq waste/min (Meisel et al. 1993). However, this rate is too high, since it would account for 32.3 ft³ of H₂ generation—0.6 ft³ more than the total H₂ generated by tank 241-SY-101.

4. 3. 1. 10 Based on the foregoing assumptions, tank 241-XX-*nnn*'s overall rate of H₂ generation by thermolysis is calculated as shown below:

$$\begin{aligned} \text{Rate} &= 2.37 \times 10^{-4} \text{ ft}^3 \text{ H}_2/\text{ft}^3 \text{ liquid/d} \times (\text{ft}^3 \text{ liquid in XX-}i{nnn}) \\ &\quad \times \% \text{ TOC in XX-}i{nnn}/\% \text{ TOC in SY-101} \\ &\quad \times \% \text{ Al in XX-}i{nnn}/\% \text{ Al in SY-101} \\ &\quad \times \text{rate XX-}i{nnn}/\text{rate SY-101} \end{aligned}$$

Where "rate XX-*nnn*/rate SY-101" is calculated using the average tank temperature for XX-*nnn* (average of all in-waste thermocouples).

4. 3. 2. Example Calculations:

Given the following data for tank 241-XX-*nnn*:

Volume of expanded slurry:	46,943 ft ³ (1329.3 m ³)
Height of slurry growth:	5.75 in (0.146 m)
Water content of slurry:	60%
Wt. % TOC:	2.3
Aluminum wt. % (liquid phase):	2.5
Average tank temperature:	26°C (79°F, 299 K)

Use the equation, repeated below, from Section 2.3.1.10 to determine the overall thermolysis rate for tank 241-XX-*nnn*.

$$\text{Rate} = 2.37 \times 10^{-4} \text{ ft}^3 \text{ H}_2/\text{ft}^3 \text{ liquid/d} \times (\text{volume of liquid, ft}^3, \text{ in XX-}i{nnn}) \times \text{TOC ratio} \times \text{aluminate ratio} \times \text{rate ratio}$$

$$\begin{aligned} \text{Rate} &= 2.37 \times 10^{-4} \text{ ft}^3 \text{ H}_2/\text{ft}^3 \text{ liquid/d} \times (\text{ft}^3 \text{ liquid in XX-}i{nnn}) \\ &\times \% \text{ TOC in XX-}i{nnn}/\% \text{ TOC in SY-101} \\ &\times \% \text{ Al in XX-}i{nnn}/\% \text{ Al in SY-101} \\ &\times \text{rate XX-}i{nnn}/\text{rate SY-101} \end{aligned}$$

Where "rate XX-*nnn*/rate SY-101" is calculated using the average tank temperature for XX-*nnn* (average of all in-waste thermocouples).

4. 3. 2. 1 Volume. Calculate the volume of liquid in tank 241-XX-*nnn*, using the volumes before slurry growth began; e.g., for single-shell tank XX-*nnn*, use the volumes in November 1980.

$$\begin{aligned} \text{Vol. XX-}i{nnn} &= \text{Convecting layer (supernate volume) + liquid fraction} \\ &\quad \text{of unexpanded slurry} \\ &= \text{supernate volume} + [\text{liquid fraction} \times (\text{volume of expanded slurry} - \\ &\quad \text{expansion volume})] \\ &= (137.55 \text{ in.} - 131.8 \text{ in.})(367.74 \text{ ft}^3/\text{in.}) + 0.60 [46,943 \text{ ft}^3 - \\ &\quad (5.75 \text{ in.})(367.74 \text{ ft}^3/\text{in.})] \\ &= 29,012 \text{ ft}^3 = 821.6 \text{ m}^3 \end{aligned}$$

4. 3. 2. 2 TOC Ratio.

The TOC ratio for the tank is calculated as follows.

$$\% \text{ TOC in XX-}i{nnn}/\% \text{ TOC in SY-101} = 2.30/1.07 = 2.15$$

4. 3. 2. 3 Aluminate Ratio.

The aluminate ratio for the tank is calculated as follows.

$$\% \text{ Al in XX-}i{nnn}/\% \text{ Al in SY-101} = 2.5/3.0 = 0.833$$

4. 3. 2. 4 Rate Ratio.

Given an E_a of 26 kJ, calculate the ratio of tank 241-XX-*nnn*'s rate to tank 241-SY-101's rate.

$$\frac{\text{XX-}i{nnn} \text{ Rate}}{\text{SY-101 Rate}} = \frac{k \times e^{-E_a/(RT)}}{k \times e^{-E_a/(RT)}}$$

Assume E_a is 26 kJ/mol. Temperature for XX-nnn is 79°F (299.3 K) and for tank 241-SY-101 is 115°F (316.5 K).

$$\text{XX-nnn Rate} = k \times e^{-26,000/(8.3134 \times 299.3)} = k \times 2.894 \times 10^{-5}$$

$$\text{SY-101 Rate} = k \times e^{-26,000/(8.3134 \times 316.5)} = k \times 5.569 \times 10^{-5}$$

$$\frac{\text{XX-nnn Rate}}{\text{SY-101 Rate}} = 0.521$$

$$\text{SY-101 Rate}$$

4. 3. 2. 5 Thermolysis Rate for tank 241-XX-nnn.

Use the equation, from Section 4.3.2 to determine the overall thermolysis rate for tank 241-XX-nnn.

$$\text{Rate} = 2.37 \times 10^{-4} \text{ ft}^3 \text{ H}_2/\text{ft}^3 \text{ liquid/d} \times (\text{ft}^3 \text{ liquid in XX-nnn}) \times \text{TOC ratio} \times \text{aluminate ratio} \times \text{rate ratio}$$

$$\text{Rate} = 2.37 \times 10^{-4} \text{ ft}^3 \text{ H}_2/\text{ft}^3 \text{ liquid/d} \times (29,013 \text{ ft}^3 \text{ liquid in XX-nnn}) \times 2.15 \times 0.833 \times 0.521$$

$$= 6.4 \text{ ft}^3 \text{ H}_2/\text{d} = 0.15 \text{ m}^3 \text{ H}_2/\text{d}$$

4. 4 Worst-Case Calculation - Radiolysis

4. 4. 1 Discussion

Tanks are expected to fall into one of three categories regarding predictors of radiolytic generation of hydrogen:

- Radionuclide content is known within acceptable bounds.
- Heat load can be estimated from temperature and waste volume.
- Neither radionuclide content nor heat load can be accurately determined, but volume of waste supernate is known.

When a tank's radionuclide content is known, its power load can be calculated; and, assuming a particular value for $G(\text{H}_2)$, the power load can be used to calculate a rate of H_2 generation. Here, $G(\text{H}_2)$ is the number of molecules of H_2 produced per 100 electron volts (eV) of energy emitted by radioactive decay.

If the estimate of a tank's radionuclide content were inadequate for some reason, but enough were known about its temperature, waste depth, evaporation rate, and other waste parameters, then its worst-case heat load could be determined. Furthermore, a worst-case power load could be estimated and a rate of H_2 generation calculated.

If neither the radionuclide content nor the heat load could be adequately estimated, a bounding rate of H₂ generation per volume could be assumed from tank 241-SY-101, and this rate could be applied to the tank.

4. 4. 2. Assumptions

4. 4. 2. 1 It is assumed that a G(H₂) value of 0.100 molecule H₂/100 eV is bounding for tanks at temperatures at or below 30°C, provided their nitrate/nitrite concentration is 2 M or greater. Further discussion is included in Appendix F. The G(H₂) value can be used in conjunction with tank heat load to calculate the amount of hydrogen generated by radiolysis.
4. 4. 2. 2 In the absence of heat-load data, a bounding value for a tank's radiolytic H₂ generation can be calculated based on a bounding volumetric rate for tank 241-SY-101. This volumetric rate in tank 241-SY-101 is calculated as described below.

- Based on Wilkins' calculation that 15.84 ft³ (0.4485 m³) H₂/day were generated in tank 241-SY-101 between releases, and her assumption that this is half the amount of gas generated (1993), 31.7 ft³ (0.4485 m³) H₂/day were generated in tank 241-SY-101. Per Section 4.5 of this appendix, 1.1 ft³ (0.031 m³) of this is generated by corrosion. Of the remaining 30.6 ft³ (0.866 m³), 70 percent (21.4 ft³, or 0.606 m³ H₂/day) is estimated to be from thermolysis and 30 percent from radiolysis (Meisel et al. 1993). It is assumed this applies to the convecting and nonconvecting layers.
- Determine the volumetric rate of radiolytic H₂ generation by dividing 9.2 ft³ (0.261 m³) H₂/day by the volume of liquid in tank 241-SY-101. The depth of the convecting layer is assumed to be 162 in. (400 in. surface - 30 in. crust -208 in. nonconvecting layer; or 4.37 m), as stated by Reynolds (1993). The nonconvecting layer is assumed to contain 40 percent liquid waste (Herting et al. 1992)

$$9.2 \text{ ft}^3 \text{ H}_2/\text{d} \div \{367.7 \text{ ft}^3 \text{ waste/in ht. } [(400 \text{ in.} - 30 \text{ in. crust} \\ - 208 \text{ in. NC layer}) + (208 \times 0.40 \text{ liquid fraction})]\}$$

$$= \frac{9.2 \text{ ft}^3 \text{ H}_2/\text{d}}{90,160 \text{ ft}^3 \text{ liquid waste}}$$

$$= 1.02 \times 10^{-4} \text{ ft}^3 \text{ H}_2/\text{ft}^3 \text{ liquid/d (or } 1.02 \times 10^{-4} \text{ m}^3 \text{ H}_2/\text{m}^3 \text{ liquid/d)}$$

$$\text{or } 2.5 \times 10^{-9} \text{ mole/L liq waste/min}$$

For tank 241-XX-*nnn*, the overall radiolytic rate of H₂ generation for the steady state is proportional to the volume of liquid waste, since the thermolytic reaction is presumed to take place in the liquid phase. The volume of liquid waste includes the interstitial liquid in the slurry layer.

4. 4. 2. 3 A tank's heat load is generated by radiolysis and thermolysis (temperature-induced degradation) of tank waste. The rate of H₂ generation from

the radiolysis of water is proportional to tank heat load, less the heat generated by thermolysis.

4. 4. 2. 4 A tank's radiolytic power load decreases as its radioactivity decreases, according to the half-life equation.

4. 4. 3 Example Calculations

4. 4. 3. 1 A tank's waste contains 2540 g ¹³⁷Cs and 3400 g ⁹⁰Sr; ¹³⁷Cs generates 0.427 watts/g and ⁹⁰Sr generates 0.916 watts/g. G(H₂) = 0.100 molecule/100 eV. Calculate the amount of H₂ generated by radiolysis.

Calculate power load:

$$0.427 \text{ watts/g } ^{137}\text{Cs} \times 2550 \text{ g } ^{137}\text{Cs} = 1088 \text{ watts}$$

$$0.916 \text{ watts/g } ^{90}\text{Sr} \times 3400 \text{ g } ^{90}\text{Sr} = 3114 \text{ watts}$$

Calculate H₂ generation:

$$\begin{aligned} & (1088+3114) \text{ watt} \times \text{J}/2.7778 \times 10^{-4} \text{ watt-h} \times \text{eV}/1.60219 \times 10^{-19} \text{ J} \\ & \times 0.100 \text{ molecule H}_2/100 \text{ eV} \times \text{mole}/6.023 \times 10^{23} \text{ molecules H}_2 \\ & \times 0.8639 \text{ ft}^3 \text{ H}_2 (50^\circ\text{C})/\text{mole H}_2 \times 24 \text{ h/d} \\ & = 3.3 \text{ ft}^3 \text{ H}_2/\text{d} = 0.92 \text{ m}^3 \text{ H}_2/\text{d} \end{aligned}$$

4. 4. 3. 2 Tank 241-XX-nnn has a total heat load of 5,000 Btu/h. Assume an enthalpy decrease (exothermic reaction) of 500 kJ/mol H₂ for thermolysis. Thermolytic H₂ generation is 3.0 ft³ H₂/d. The waste temperature is 50°C. Calculate the amount of H₂ generated by radiolysis.

Calculate the heat load generated in tank 241-XX-nnn by thermolytic H₂ generation of 3.0 ft³ H₂/d.

$$\begin{aligned} & \frac{3.0 \text{ ft}^3}{\text{d}} \times \frac{\text{d}}{24 \text{ h}} \times \frac{1 \text{ L}}{0.0353 \text{ ft}^3} \times \frac{\text{mol}}{24.5 \text{ L}} \times \frac{500 \text{ kJ}}{\text{mol}} \times \frac{0.9478 \text{ Btu}}{\text{kJ}} \\ & = 68 \text{ Btu/h} = 19.9 \text{ watts} \end{aligned}$$

Calculate tank 241-XX-nnn's remaining heat load, which is generated by radiolysis. This is conservatively assumed to be the tank's radiolytic heat load.

$$5,000 \text{ Btu/h} - 68 \text{ Btu/h} = 4,932 \text{ Btu/h} = 1445 \text{ watts}$$

Calculate H₂ generation, assuming G(H₂) is 0.100 molecule H₂/100 eV:

$$\begin{aligned} & 1445 \text{ watts/h} \times \text{J}/2.7778 \times 10^{-4} \text{ watt-h} \times \text{eV}/1.60219 \times 10^{-19} \text{ J} \\ & \times 0.100 \text{ molecule H}_2/100 \text{ eV} \times \text{mole}/6.022 \times 10^{23} \text{ molecules H}_2 \\ & \times 0.86391 \text{ ft}^3 \text{ H}_2 (\text{at } 25^\circ\text{C})/\text{mole H}_2 \times 24 \text{ h/d} \\ & = 1.1 \text{ ft}^3 \text{ H}_2/\text{d} = 0.032 \text{ m}^3 \text{ H}_2/\text{d} \end{aligned}$$

4. 4. 3. 3 A tank contains 100,000 gallons of liquid waste. Neither its heat load nor its radionuclide content can be reliably estimated. Calculate H₂ generation per section 4.4.2.2.

$$1.02 \times 10^{-4} \text{ ft}^3 \text{ H}_2/\text{d}/\text{ft}^3 \text{ liquid waste} \times 1 \text{ ft}^3/7.481 \text{ gal.}$$

$$\times 100,000 \text{ gal.} = 1.4 \text{ ft}^3 \text{ H}_2/\text{d} = 0.028 \text{ m}^3 \text{ H}_2/\text{d}$$

4. 5. Worst-Case Calculation - Corrosion

4. 5. 1., Assumptions

4. 5. 1. 1 None of the H₂ currently generated by corrosion in tank 241-XX-nnn is entrapped. It is continuously released into the dome space to contribute to steady-state H₂ concentration.

4. 5. 1. 2 The H₂-generation rate by corrosion in a tank with a 75-ft (22.9 m) diameter and waste 35 ft (10.7 m) deep has been calculated; 1 mil (2.54 x 10⁻⁵ m) of corrosion per year will produce approximately 4000 ft³ (113.3 m³) of H₂ (Ashby et al. 1992a). Coupons of A516 steel coupons, which was widely used in the construction of double shell tanks, were tested for corrosion in simulated wastes, with and without gamma radiation. The resulting corrosion rates ranged from 0.02 to 0.03 mil per year (Strachan 1994). To account for milder steels used in single shell tanks and for lower pH, which allow higher corrosion rates in some tanks, a corrosion rate of 0.10 mil per year is assumed. This estimate is believed to be conservative. This corrosion rate corresponds to the H₂ generation rate calculated below.

$$4,000 \text{ cu ft}/\text{mil} \times 0.10 \text{ mil}/\text{yr} \times 1 \text{ yr}/365 \text{ days} = 1.096 \text{ ft}^3 \text{ H}_2/\text{day}$$

$$= 0.0310 \text{ m}^3/\text{day}$$

The amount of hydrogen produced by corrosion is directly proportional to the area of steel surface exposed to moisture-containing waste. Thus, the daily production rate per square foot of exposed steel is determined as follows:

$$1.096 \text{ ft}^3 \text{ H}_2/\text{day}/\text{area of steel exposed to waste} =$$

$$1.096 \text{ ft}^3 \text{ H}_2/\text{day}/(\pi \times (37.5^2 + 75 \times 35)) = 8.65 \times 10^{-5} \text{ ft}^3 \text{ H}_2/\text{day}/\text{ft}^2$$

$$= 8.65 \times 10^{-5} \text{ ft}^3 \text{ H}_2/\text{day}/\text{ft}^2$$

$$= 2.64 \times 10^{-5} \text{ m}^3/\text{day}/\text{m}^2$$

This rate can be used to determine the amount of corrosion-generated hydrogen for any tank.

4. 5. 2. Example Calculations

The surface area of tank 241-XX-nnn in contact with waste is 9.25 x 10³ ft². Calculate the rate of H₂ production:

$$8.65 \times 10^{-5} \text{ ft}^3 \text{ H}_2/\text{d} / \text{ft}^2 \text{ of wall} \times 9,250 \text{ ft}^2 \text{ wall} = 0.80 \text{ ft}^3 \text{ H}_2/\text{d} = 0.023 \text{ m}^3 \text{ H}_2/\text{d}$$

4. 6 Worst-Case Calculation - NH₃ and Other Gases

In calculating the flammable gas concentration, contributions of NH₃, CH₄ and other flammable gases must be considered. As noted in Section 2.3.1 of the main body of this document, high NH₃ concentrations have been observed in tank 241-SY-101. Assumptions regarding NH₃ concentrations are given in Appendix D. The rate of CH₄ release is assumed to be only 2% of the H₂ release rate. Any tank containing a floating organic layer is a special case and will be dealt with under the Tank Vapor Program.

4. 7 Worst-Case Calculation - Total Flammable Gas Generation

The total rate of H₂ release into the tank 241-XX-*nnn* dome space is the sum of the foregoing quantities.

4. 8 Worst-Case Calculation - Steady-State Concentration

For calculations of steady-state concentration, it is assumed that H₂ is released from the waste at the same rate at which it is generated. Once the generation rate is determined, the equation below is used to determine the H₂ steady-state concentration (Garfield 1975).

$$\text{Mole fraction of H}_2 = \frac{\text{total daily generation rate}}{\text{total daily generation rate} + \text{breathing rate}}$$

For a daily evolution of $g \text{ ft}^3 \text{ H}_2/\text{d}$, passively vented tanks, which have a daily breathing rate of 0.0045 times the tank's dome space volume (Crippen 1993), a more-defined equation is as follows.

$$\text{Mole fraction of H}_2 = \frac{g \text{ ft}^3/\text{d}}{g \text{ ft}^3/\text{d} + 0.0045 (\text{tank vol.} - \text{waste vol.})\text{ft}^3/\text{d}}$$

For a tank with an exhauster running at $E \text{ cu ft}/\text{min}$, the corresponding equation is:

$$\text{Mole fraction of H}_2 = \frac{g \text{ ft}^3/\text{d}}{g \text{ ft}^3/\text{d} + (E \text{ ft}^3/\text{min} \times 1440 \text{ min}/\text{d})}$$

As shown below, for a tank emitting a constant $16 \text{ ft}^3 \text{ H}_2/\text{d}$ (as tank 241-SY-101 does in intervals between EGRs), an exhauster operating at $550 \text{ ft}^3/\text{min}$ establishes a steady-state mole fraction of H₂ at 2.0×10^{-5} . Even at an exhaust rate of $50 \text{ ft}^3/\text{min}$, the calculated mole fraction is 4.4×10^{-4} ; and at $5 \text{ ft}^3/\text{min}$, the calculated mole fraction is 4.4×10^{-3} .

$$\text{Mole fraction of H}_2 = \frac{16 \text{ ft}^3/\text{d}}{16 \text{ ft}^3/\text{d} + (550 \text{ cfm} \times 1440 \text{ min}/\text{d})} = 2.0 \times 10^{-5}$$

4. 9 Worst-Case Calculations vs. Actual Sampling Values

The foregoing calculations, when applied to some single-shell tanks, yield results more than 10 times higher than values obtained through dome space sampling. The daily breathing rate used in the calculations (0.45% of the dome space volume) may be much too low. The following may increase the turnover of dome space gas to several times the percentage: diffusion; convection currents (stack effect), where appropriate; buoyancy effects of lighter-than-air flammable gases; and the effect of wind. A modeling study is underway to more accurately estimate tank breathing rates.

Another calculation input which causes high steady-state concentrations is the fact that the H₂ generation rates used, which are derived from tank 241-SY-101, are substantially higher than the actual rates in other tanks. A valid method is needed to better estimate the generation rates for these other tanks.

4. 10 Indirect and Direct Measures of Flammable Gas Concentration

As shown in Section 1.0 of this appendix, the logic for applying the criteria requires refining worst-case calculations as indirect and direct measures of flammable gas concentration become available.

Indirect measures of a tank's flammable gas concentration may be known before the concentration is measured directly. Examples are as follows.

- If the range of proportions of H₂, NH₃, and N₂O generated by a tank's waste are known, and the concentration of one of them is determined, the concentrations of the remaining two can be determined within a range.
- If tanks A and B are connected via cascade piping or an exhaust system and the H₂ concentration is measured in A, that may allow estimating the concentration in B.
- Since H₂ radiolysis is proportional to the amount of decay energy, it is also proportional to the tank power load. Assuming radiolysis is responsible for 40% or more of the H₂ generated by a tank, it is possible to use power loads to estimate the amount of H₂ generated by tanks. If a tank with a particular power load generates 10 ft³ (0.28 m³) of H₂ per day, another tank with the same power load should generate a similar amount of H₂.

The best way to determine a tank's steady-state H₂ concentration is to measure it directly. The data quality must be appropriate for the level of hazard. The amount, precision and accuracy of the data required vary with the concentration of gas in the tank.

As a related matter, it is necessary to consider whether H₂ can stratify in the tank's dome space because of its low molecular weight, compared to air. R. M. Wallace of Savannah River calculated that from top to bottom of a 33-ft dome space, neglecting the difference in gravity between the top and bottom, the maximum theoretical concentration gradient is only 0.001, even without

considering decreases in the gradient caused by convection (Wallace 1991). Providing that this is not contradicted by results of multi-level vapor sampling under the Tank Vapor Issue Resolution Program, stratification is not a source of variability in sampling, and monitoring at a single level is adequate to determine steady-state H_2 concentration. Sufficient sampling must be done to provide adequate confidence that the steady-state concentration does not exceed the criterion level. The extent of sampling required will vary with the error of the technology and how far the concentration is from the criterion level.

For example, consider a tank which contains only a small amount of waste, has a low radionuclide content, and is expected to give a flammable gas concentration two orders of magnitude below the criterion level. For this tank, merely taking three gas samples within a half hour at a single point in the dome space may be adequate. However, increased rigor is required for tanks with a more variable steady-state concentration or with a concentration closer to the criterion limit.

4. 11 The Future

To be excluded from the Watch List, a tank must have no credible scenario by which its unaugmented contents can increase their flammable-gas generation and cause the steady-state concentration to exceed 25% of the LFL.

5.0 DISPERSED EGR

5. 1 Criterion

The criterion for the dispersed-EGR condition is stated below.

The tank, after an EGR has dispersed within it, could have a flammable gas concentration greater than 25% of the lower flammability limit (LFL) in the dome space or ventilation headers.

5. 2 Background

This section applies to tanks which have, or could have, episodic releases of gas entrapped in the waste, and it addresses the condition in the tank just after the gas has dispersed throughout the dome space, and before the gas is exhausted from the tank. In actuality, in tanks which are actively exhausted, some of the gas may have been exhausted before complete dispersion occurs, but this section conservatively assumes none of the gas has been exhausted.

For a tank to have an EGR requires that the waste entrap slurry gas and that the amount of gas entrapped reach and exceed the slurry's entrapment capacity. For entrapment to occur requires: 1) the presence of sufficient organics (Pederson and Strachan 1993), 2) concentration of anions and cations high enough and waste temperature cool enough for the precipitation of solids to form a slurry layer which can entrap gas generated within the layer, and 3) the generation of slurry gas at a rate exceeding the rate at which the waste continually releases gas.

If entrapment occurs, the waste slurry expands, which results in a rise in the waste surface level. The amount of rise depends on the amount of gas entrapped and the pressure head on the gas. Therefore, the amount of surface level rise is a measure of the amount of gas entrapped in a tank.

Unless the composition of the gas is known, it will be assumed to be 97% H₂ and 3% water vapor and other inert gases. Dividing the volume of flammable gas by the dome space volume gives the flammable gas concentration resulting from slurry gas. Whether the flammable-gas concentration can exceed 25% of the combined LFL can be determined by 1) worst-case calculation, 2) indirect measures combined with calculations of the flammable gas concentration, or 3) direct measurement of the concentration.

Regardless of which method is used to assess the dispersed-EGR condition, the logic requires determining whether the tank releases or could release gas, now or in the future, and whether the resulting dispersed flammable gas concentration would exceed the Watch List criteria. (A more-detailed logic for this assessment of the dispersed-EGR condition is shown in Figure 2.)

5. 3 Worst-Case Calculation

5. 3. 1 Discussion

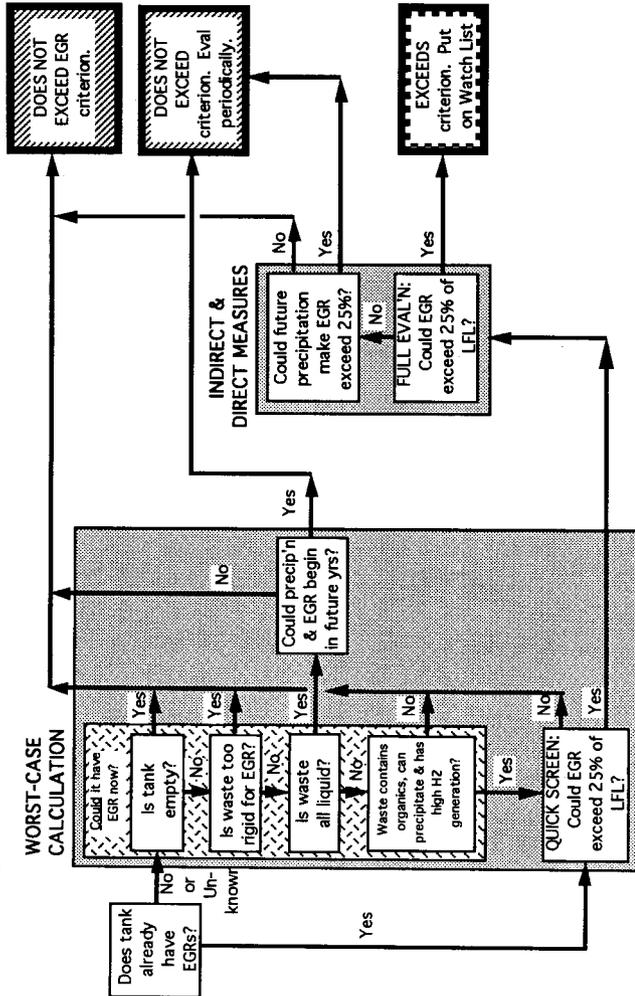
The starting point in the logic is to determine whether the tank is known to have had one or more episodic gas releases. The following are evidence of such releases: 1) an abrupt surface level drop; 2) a transient increase in a tank's dome space pressure; 3) a concentration spike detected via gas monitors; and/or 4) inversion of a tank's temperature profile, indicating entrapped slurry gas has expanded and raised the warmer waste from the tank bottom to the cooler surface of the waste.

Surface level fluctuations must be evaluated in light of the long-term behavior of the surface level. In some cases, minor fluctuations may indicate the waste's entrapment capacity is too small for a significant release, or that the ongoing release rate approximates the entrapment rate, so the waste can not exhibit (further) slurry growth. On the other hand, the larger the fluctuations, the greater the entrapment and release, and the more likely a tank will be considered to have had an EGR³.

³ Surface-level rise and fall are affected by waste evaporation, absorption of humidity, tank leakage, in-seepage by rain water, measuring errors (such as caused by "icicles" on surface level probes), and other factors which can mask or exaggerate slurry growth. Without an improved ability to predict the effect of these factors, the error band for some tanks could be so great that the uncertainty in the surface level alone will require placing the tanks on the Watch List. Nonetheless, other tank data, such as type and/or characteristics of waste content, will exclude some tanks.

Figure E-2. Detailed Logic for Dispersed EGR

Whether the tank is being assessed by worst-case calculation, indirect measurements, or direct measurements, the purpose is to determine whether the gas can exceed 25% of its combined LFL during an EGR. The diagram below illustrates the detailed logic to be applied in the assessment.



If the tank is known to have had EGRs, a worst-case calculation will be done to determine whether an EGR could cause the dome space gas to exceed the dispersed-EGR criterion. A "quick screen" will be done to determine whether the waste could hold enough gas to exceed the dispersed-EGR criterion, assuming the waste has the same volumetric entrapment capacity as tank 241-SY-101.

If the waste in tank 241-XX-*nnn* *could not* hold enough gas to exceed the dispersed-EGR criterion, the tank need not be evaluated further for the dispersed-EGR condition. If it *could* exceed the quick-screen criteria, it must be evaluated more carefully to determine whether it must be added to the Watch List. This evaluation will be done using all available data, including any indirect and direct measures of dome space gases. This method provides for characterizing each input statistically and may be used with a Monte Carlo simulation program to estimate the flammable gas concentration, within an error band; this allows determining whether the concentration is within the criterion limit, to the required confidence level. If the tank is not already known to have had EGRs, it must be evaluated to determine its potential to have an EGR in the near or distant future.

- If the tank is empty, or if the waste is too rigid to have an EGR, it will not be placed on the Flammable Gas Watch List. Determining the rigidity of the surface level requires exercising engineering judgment after examining tank photos, sample analyses, fill histories, and other available records.
- If the waste is all liquid, it will not be placed on the Flammable Gas Watch List. Nonetheless, the tank must be evaluated to determine whether, as the waste cools in the future, the waste's dissolved contents could begin to precipitate and entrap and release flammable gas. This will require engineering judgment. Entrapment is promoted by organics (Pederson and Strachan 1993) and waste of high density (Brager 1994), although these are not necessary conditions). If the tank contains negligible organics, has a low density (generally below 1.20) and shows no evidence of slurry growth, no further evaluation need be done on the tank. On the other hand, if it does have credible potential to begin entrapment in the future, it must be reevaluated periodically to determine whether entrapment has begun.
- If the waste is not all liquid (i.e., it contains solids), the tank must be evaluated to determine whether it contains sufficient organic, as described above, to cause entrapment. There is some indication that entrapment may occur in tanks which have a salt cake with a dried surface and a liquid level just below the dried surface (Kirch 1994).

5. 3. 2 Assumptions

5. 3. 2. 1 The nonconvecting layer in tank 241-SY-101 is of relatively constant volume, but at any point in time the elevation of the nonconvecting layer's surface level varies across the tank. The average depth of the nonconvecting layer is assumed to be 210 inches, or 5.33 m (conservatively estimated from Antoniak 1993, pp. 113-117).

5. 3. 2. 2 The worst-case entrapment of tank 241-SY-101 is bounding for all 177 tanks. That is, for its largest EGR (December 1991), the volume of entrapped compressed slurry gas divided by the volume of non-convecting layer is the bounding compressed entrapment volume per inch of slurry height, as shown below.

Maximum EGR:	11,820 ft ³ slurry gas (scf) (Simpson et al. 1993)
	334.7 m ³
Average nonconvecting depth:	210 in (5.33 m)
Average slurry temperature:	319 K
Average pressure on slurry gas:	32.93 psia (227.0 kPa)

COMPRESSED VOL OF SLURRY GAS / INCH SLURRY:

$$11,820 \text{ ft}^3 (\text{scf}) \times 14.7 \text{ psi} / 32.93 \text{ psi} \times 319\text{K}/298.15\text{K} = 5,649 \text{ cu ft slurry gas} = 160 \text{ m}^3$$

$$\frac{\text{volume of slurry gas (scf)}}{\text{depth of nonconv. layer}} = \frac{5,649 \text{ ft}^3 \text{ slurry gas}}{210 \text{ in}} = 26.90 \text{ ft}^3 \text{ slurry gas/in.} = 0.762 \text{ m}^3$$

5. 3. 2. 3 The slurry gas of tank 241-XX-nnn is 97% H₂, and the remaining 3% is water vapor and other inert gases. The percentage of H₂ in slurry gas is expected to vary considerably from tank to tank, as noted by Pederson and Strachan:

These data indicate that the variance in the gas composition and the generation rates are quite large—varying over about 2 orders of magnitude. It appears, however, that the ratio of hydrogen to nitrous oxide, while variable, is a sensitive function of the waste composition (Pederson and Strachan 1993).

5. 3. 2. 4 The release of NH₃ occurs as described in Appendix D.
5. 3. 2. 5 Only the part of a saltcake below the water table is capable of entrapping slurry gas, and the drainable liquid occupies 60% of the volume of the saltcake.

5. 3. 3 Example Calculation - Quick Screen

The maximum release of slurry gas to date was 11,820 scf, or 334.7 m³ (Simpson et al. 1993). For the sake of calculation, assume the gas is 100% H₂. Using van der Waals equation below, determine that the 11,820 scf, or (334.7 m³) would occupy 5680 ft³ (160.8 m³) when compressed within the slurry in tank 241-SY-101.

$$(P + n^2a/V^2) (V-nb) = n RT$$

Here, P is pressure in psia, V is volume in ft³, a = 925.12 psia (ft³/lb-mole)² and b = 0.4256 ft³/lb-mole, R = 19.31 psia ft³/lb-mol, and T is temperature in Kelvin.

This provides the basis for calculating the per-volume content of compressed gas in tank 241-SY-101's slurry, given 210 inches (5.33 m) of slurry (Alleman et al. 1993).

$$5680 \text{ ft}^3/210 \text{ in.} = 27.0 \text{ ft}^3 \text{ H}_2/\text{in. slurry.} = 30.1 \text{ m}^3/\text{m}$$

To determine the volume of compressed slurry gas entrapped in 100 inches (2.54 m), for example, of slurry in tank 241-XX-*nnn*, multiply the volumetric capacity in tank 241-SY-101 by the depth of slurry in tank 241-XX-*nnn*. Use van der Waals equation to determine the standard volume and the concentration in the tank dome space.

5. 3. 4 Example Calculations - Volume Based on Slurry Growth

The potential volume of a gas release depends on the amount of slurry gas entrapped in the waste, which can be conservatively estimated from the waste's height of slurry growth. Any known intrusions or waste additions must be subtracted from the growth and conservative adjustments made for decreases caused by evaporation. Once the adjusted height of slurry growth has been determined, the amount of gas that can be released must be conservatively determined.

For example, for a single-shell tank, which has had slurry growth of 1.5 inches (0.038 m) calculated to yield 700 scf (19.8 m³) of released slurry gas, and a 60,000 ft³ (1699 m³) of dome space, it will be assumed that all the gas is released instantly into the dome space and that the gas is 97% H₂ (679 scf, or 19.2 m³), with 3% water vapor and other inert gases. Based on Appendix D, it is assumed that 0.259 scf (or m³) of NH₃ is released per scf (or m³) of H₂, or 181 scf NH₃ (5.12 m³).

These volumes can be used to calculate the mole fraction of each gas. The

$$679 \text{ scf H}_2/60,000 \text{ scf dome space} = 0.01132 \text{ mole fraction H}_2$$

$$181 \text{ scf NH}_3/60,000 \text{ scf dome space} = 0.00302 \text{ mole fraction NH}_3$$

The formula from section 4.2 of this appendix is used to determine the fraction of the LFL for the gas mixture.

$$[\text{H}_2]/\text{LFL}_{\text{H}_2} + [\text{NH}_3]/\text{LFL}_{\text{NH}_3} = \text{fraction of LFL}$$

where "[H₂]" means "concentration of H₂," and all terms are mole fractions.

$$\frac{0.01132}{0.04} + \frac{0.00302}{0.15} = 0.303 \text{ LFL, or } 30.3\% \text{ of the combined LFL}$$

5. 4 Indirect and Direct Measures of Flammable Gas Concentration

As noted in Section 1.0 of this appendix, the logic for applying the criteria calls for refining worst-case calculations as indirect and direct measures of flammable gas concentration become available.

For example, data about the average size of a tank's releases and the probable range of slurry gas composition allows determining whether the resulting concentration is likely to exceed 25% of the LFL.

As with steady-state concentrations, the best way to determine a tank's dispersed-EGR flammable gas concentration is to measure it directly. As a general rule, we should determine the statistical variability of a tank's surface level fluctuations, then evaluate five EGRs to establish the relationship between surface level drop and flammable gas concentration. The length of the interval between EGRs will determine how long the tanks must be monitored. If, from the data produced, it can be established that the flammable gas concentration at the extreme case (at the 99th percentile, 2.5 SD's above the mean) is below 25% of the LFL, there is no need to monitor the tank further. Increased sampling may be required for tanks with a more variable concentration or with a concentration closer to 25% of the LFL.

5. 5 Future entrapment

If the tank's current condition is found to not exceed the Watch List criteria, its future condition must still be evaluated to determine whether it has credible potential to increase its EGR size enough to exceed the dispersed-EGR criterion in the foreseeable future, before the tank contents are treated/removed. Engineering judgment is required to assess factors such as whether tank cooling entrapment so much that the potential resulting gas release would exceed the criterion level. This judgment involves assessing the waste volume and density, concentration of chelating organics and aluminate (for crystal formation) in the waste, dome space volume, etc. In practice, because of the sparsity of data about waste contents, this requirement may be met by reevaluating the status of tanks periodically to determine whether slurry growth is increasing.

6.0 OTHER

Regarding the foregoing conditions, if it has been found that a tank does not belong on the Watch List, the tank must be evaluated for other potential hazards. For example, if tank A is connected to tank B by cascade lines or common exhaust system, and evaluation determines that gas inflow from tank B can cause tank A to contain a mixture which exceeds the criteria, tank A will be placed on the Watch List.

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ATTACHMENT C

SPREADSHEET AND INSTRUCTIONS

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Pages C-5 through C-13 of this attachment are instructions for using the Excel™ spreadsheet used to evaluate the tanks. The spreadsheet performs the calculations described in Sections 4.0 through 8.0. Pages C-14 through C-27 are a printout of the most recent version of the spreadsheet, which includes data for tank 241-S-106. Following the spreadsheet is a Don't Say It—Write It! (DSI) by S. A. Barker providing background on the evaporation calculations performed by the spreadsheet. Conventions for using the spreadsheet are as follows:

SOLIDS SURFACE LEVEL VS. LIQUID LEVEL

To use the spreadsheet, determine where the liquid level is relative to the solids level. When the liquid is above the solids level, the rise and fall of the liquid should closely match the expansion and contraction of the trapped gas. When the liquid is below the solids level, and the solids surface does not rise and fall but the interstitial liquid level (ILL) does, the ILL movement is magnified by the fact that the liquid is moving in pores. The apparent ILL rise or slope from such ILL movement must be scaled down by multiplying Whitney's barometric slope by the solid's porosity to get the actual slope.

VOLUME OF WET SOLIDS

Examine the surface level plots from the PC-SACS database and tank photographs. For a tank with no supernate layer per Hanlon (1995), determine whether the liquid level is at or just below the top of the solids surface.

- If yes, then the FIC measures liquid and solids at the same time. Calculate the wet solids volume from the FIC.
- If not, the FIC measures solids only, and the neutron probe measures the ILL, which is below the solids level. Calculate the wet solids volume from the ILL.
- If it cannot be determined, there is ILL data on PC-SACS, and the neutron probe reading is below the FIC level, assume that the ILL measures liquid and the FIC measures solids. Calculate the wet solids volume from the ILL.
- If it cannot be determined, and there is no ILL data on PC-SACS, calculate the wet solids volume from Hanlon's interstitial liquid (IL) volume.

SELECTING DATA

When two devices measure the same variable, use the data from the higher-quality instrument. For example, if there are data from an ENRAF gauge (resolution ± 0.01 in.), FIC gauge (resolution ± 0.1 in.), and a manual tape (resolution ± 0.25 in.) use the data in the following order: ENRAF, FIC, and manual tape. There is a caution: a few ENRAFs "stick" and make a stair-step change at 9 a.m. each morning; in such cases, ENRAF data are not of higher quality than FIC data.

SURFACE LEVEL RISE

If the surface level is falling, but the ILL is rising, there is a rise in IL. It is assumed that if the waste surface is dry solids and there is no significant exposed liquid pool, then the evaporation rate is essentially zero, and the ILL is not affected by evaporation. If the exposed solids surface level is falling, and the ILL is falling or stationary, there is no rise.

BAROMETRIC ANALYSIS

- If a tank is not on Whitney's list of 58 tanks, his analysis did not show significant statistical evidence of gas. Do not perform a barometric analysis on the tank.
- If the tank has a supernate layer, Whitney's analysis of *good* surface level data *did not* show statistical evidence of gas, and the ILL data *did* show statistical evidence of gas, then there is no basis for a barometric analysis because ILL data are considered the most unreliable.
- If the tank has no supernate layer, Whitney analysis based on contact with solids predicts no gas, but analysis of the ILL slope predicts gas, use the ILL slope to calculate trapped gas volume.
- If the tank has *no supernate* layer and Whitney analysis based on contact with solids *predicts* gas, but analysis of the *ILL slope predicts no* gas, use the SL slope to calculate trapped gas volume.
- If Whitney's analysis of the FIC data predicts no gas, but analysis of the manual tape data predicts gas, accept the FIC data and conclude there is no gas in the waste.
- If Whitney's analysis of the FIC data predicts gas, but analysis of the manual tape data predicts no gas, use the FIC data.

Table C-1. Decision Summary

SL is for supernate	Whitney predicts gas based on SL	Whitney predicts gas based on ILL	Should tank be given barometric evaluation for trapped gas?
Yes	No	No	No
Yes	No	Yes	No
Yes	Yes	No	Yes. Use SL data
No	No	No	No
No	No	Yes (ILL below SL)	Yes. Use ILL data. LIH flag, line 66
No	Yes	No	Yes. Use SL data.

PRIORITIES

In general, if the monthly waste status report (Hanlon) says there is supernate, this is considered accurate unless pumping has begun in the tank since the report was published. If the most recent tank photographs show no supernate, assume there is none, regardless of what the report says.

INSTRUCTIONS

Table C-2 contains instructions for filling in the Excel™ spreadsheet. These instructions have evolved continually during the evaluation period; the instructions are the ones used by the evaluation team in March 1966. The line descriptions are taken directly from the spreadsheet, therefore they are not edited. Some line numbers are missing because the lines have been deleted from the spreadsheet.

Table C-2. Instructions for Filling in the Excel™ Spreadsheet (9 sheets).

Line	Description	Instruction/Comment/Explanation
3	Total waste volume	Enter vol. from Hanlon (1995).
4	Total solids volume (sludge + saltcake), includes gas	Enter vol. from Hanlon 1995.
5	Supernate volume	Enter vol. from Hanlon 1995. After entering lines 3-5, check lines 79-99 to see whether the values Excel™ calculates are reasonable.
6	Volume of interstitial liquid	<p>This is a <i>crucial</i> volume.</p> <p>For tanks with a supernate layer, this volume is used to calculate the generation rate by thermolysis and corrosion. Enter the volume calculated on line 84 of the spreadsheet.</p> <p>For tanks that have been pumped (i.e., have no supernate layer above the solids), this volume is used to calculate the head on trapped gas, wet solids volume, overall void fraction in wet solids, and the generation rate by thermolysis and corrosion. Preferentially use ILL data; otherwise, calculate the volume as illustrated in Swaney 1994, in a way which gives the most realistic, but still conservative, value.</p>
7	Volume of sludge	Enter volume from Hanlon 1995.

Table C-2. Instructions for Filling in the Excel™ Spreadsheet (9 sheets).

Line	Description	Instruction/Comment/Explanation
8	Current solid surface level height (Reading SLC)	Enter the current level from PC-SACS or volume based on information in Hanlon 1995, temperature profiles, or other sources. For a tank with supernate, the evaluator can use the spreadsheet to calculate SLC (surface level, current) as follows: on line 4 enter the volume reported in Hanlon and in line 14 enter Hanlon. This calculates current solid level (SLC) on line 97. Enter this value in line 8, then change line 14 to SLC. In column titled Data Sources/Comments, enter type gauge, such as auto FIC, or enter "calculated from Hanlon."
9	Original solid surface level height (Reading SLH)	Enter the original level from PC-SACS, if available. Otherwise, enter best level available from other source(s). In column titled Data Sources/Comments, enter type gauge, such as auto FIC. (SLH = surface level, historical)
10	as of this date	Enter date of original solids level height.
11	Current liquid level height (Reading LLC)	For a tank with a supernate layer, enter its current liquid level reading. For a tank with no supernate, enter the current ILL reading or use the spreadsheet to calculate LLC; that is, enter in line 6 the value calculated per Swaney, and in line 15 enter Hanlon. This calculates a current liquid level height on line 99. Enter this value on line 11.
12	Original liquid level height (Reading LLH)	Enter the historical liquid level. This may be the waste's liquid surface level in 1981, for example, or it could be the earliest ILL in the mid- to late-1980s.
13	as of this date	Enter date of original liquid level height.
14	Engineer selects source of solids volume (Hanlon, SLC or LLC)	In general, for a tank with supernate, enter SLC (see instructions for line 8) for tanks with known surface level. For tanks in which the liquid and solid levels are the same (e.g., tanks that have been pumped) enter LLC. For pumped tanks in which the ILL is below the solids level, enter SLC.
15	Engineer selects source of interstitial liquid volume (Hanlon, SLC or LLC)	If there is supernate, enter SLC; if not, LLC. Enter Hanlon only if there is no liquid level measurement below the solid upper surface.
16	Engineer selects source of supernate volume (Hanlon, SLC or LLC)	If there is a supernate layer, enter LLC. Enter Hanlon only as a last resort.

Table C-2. Instructions for Filling in the Excel™ Spreadsheet (9 sheets).

Line	Description	Instruction/Comment/Explanation
17	Supernate density. If unknown, enter 1.40.	Enter the value from Tank Characterization Report if available; otherwise, enter the value from other lab data. If no number is available, enter the assumed mean value, 1.40 g/mL. If the only number available is reported as specific gravity (SpG), which approximates density, assume this is density.
18	Solids density. If unknown, enter 1.80.	Enter value from Tank Characterization Report if available; otherwise, enter the value from other lab data. If no number is available, enter the assumed mean value, 1.80 g/mL. If the only number available is reported as SpG, assume this is density.
19	Porosity (liquid fraction) in solids, by assay. If unknown, enter 0.501.	If the value has been determined from waste sample, enter the value. Otherwise, enter 0.501, the average value determined by Colson and Whitney (1995).
20	Porosity (sludge). If unknown, enter 0.16.	If the value has been determined from waste sample, enter the value. Otherwise, enter 0.16, the average value determined by Colson and Whitney.
21	Average gas location: fraction of wet solids from bottom center. If unknown, enter 0.225.	Enter 0.225 (see Section 7.4 and Attachment E).
22	Estimated maximum evaporation	If psychrometric data are available and can be used to estimate evaporation, enter the estimate here. Then, if INP is entered on line 53, Excel™ will use this value to override any value calculated by the spreadsheet. If a good estimate cannot be made, leave this line blank. Additional discussion of evaporation is included in S. A. Barker's DSI, later in this attachment.
23	g TOC/L waste (wet)	Enter value from Tank Characterization Report if it is available. Otherwise, use other lab data. In the absence of data, see Toth et al. (1994).
24	g Al/L waste (wet)	Enter value for liquid assay from Tank Characterization Report if available; otherwise, use other lab data. Assume all aluminum reported in the liquid assay is present as aluminate ion, AlO_2^- (see Attachment E, paragraph 4.3.1.7 of Hopkins (1994).
25	Average trapped gas temperature	From the temperatures obtained from PC-SACS data base, estimate the temperature at the height of the center of trapped gas: $0.225 \times$ depth of wet solids, above center bottom of tank.

Table C-2. Instructions for Filling in the Excel™ Spreadsheet (9 sheets).

Line	Description	Instruction/Comment/Explanation
26	Average liquid temperature	Enter the estimated average temperature of the tank liquid (supernate + interstitial liquid). As an alternative, it's conservative to enter the average temperature of the total waste.
27	Power load from published source. If not available, leave blank.	Enter power load from published source.
28	Heat load from published source. If not available, leave blank. (Don't leave both blank.)	If there is no power load listed in a published source, enter the heat load published in Graves (1994).
29	Tank Farm (A, AN, AP, AW, AX, AY, AZ, B, BX, BY, C, S, SX, SY, T, TX, RT, U)	Self-explanatory
30	H ₂ generation rate, G(H ₂). If unknown, enter 0.1.	Enter G(H ₂) from Graves, if available. Otherwise, enter 0.10.
33	If sampled, actual H ₂ value from sampling	Self-explanatory
34	If sampled, actual NH ₃ value from sampling	Self-explanatory
37	% H ₂ in trapped gas, ft ³ H ₂ /ft ³ gas x 100%. If unknown, enter 97%.	Enter 0.97.
38	% of trapped slurry gas releasable. If unknown, enter 25%.	Use 25%. Note: For DST AY-101, a bounding release of 47% was determined by LANL's Raleigh-Taylor/Neutral Buoyancy method. For DSTs, see Section 7.4.
39	Mean air pressure on waste surface. If unknown, enter 14.50.	This pressure determines the pressure on the trapped gas and the expansion when the gas is released: expansion = (head + P)/P.
40	Add to Current Sfc Lvl: compaction	Not yet defined
41	Add to Current Sfc Lvl: out leakage	Self-explanatory
42	Add to Current Sfc Lvl: pumped out	Self-explanatory
43	Add to Current Sfc Lvl: measuring error (known or possible icicle at start, kink in tape now, etc.)	Self-explanatory

Table C-2. Instructions for Filling in the Excel™ Spreadsheet (9 sheets).

Line	Description	Instruction/Comment/Explanation
44	Add to Current Sfc Lvl: any gas contained in original surface level	Welty (1988) tracks cumulative unexplained slurry growth, as far back as the 1950s or 1960s for some tanks. Unless this growth can be attributed to some other cause, such as known intrusion, it is assumed to have come from trapped gas. The gas is assumed to have been trapped around the center of the tank waste. Removal of supernate from above solids is assumed not to remove gas trapped in the solids. Only when interstitial liquid is pumped from saltcake is gas assumed to escape—from the part of the saltcake from which the interstitial liquid is removed.
45	Subt from Current Sfc Lvl: measuring error (known or possible icicle now, kink in tape at start, etc.)	Enter the inches of known or possible icicle at start of period (for example, January 1981) or extra inches of tape added by a kink in the current tape (such as observed by in-tank video)
46	Subt from Current Sfc Lvl: intrusion or addition	Enter inches of proven intrusion or addition, not hypothetical or speculated.
47	Subt from Current Sfc Lvl: condensation from ambient air, which has dripped into tank	Enter inches of proven condensation, not hypothetical or speculated.
48	Subt from Current Sfc Lvl: hygroscopic absorption	Enter inches of proven absorption, not hypothetical or speculated.
49	Subt from Current Sfc Lvl: crust expansion by gas	Enter inches of proven expansion, not hypothetical or speculated.
50	Subt from Current Sfc Lvl: crystal expansion	Enter inches of proven expansion (such as by Ostwald ripening), not hypothetical or speculated.
51	Tank atmospheric breathing rate - SSTw/oFIC (Crippen: 0.45% natural breathing)	Enter 0.45% (Crippen 1993) unless the tank can be conclusively shown to breathe at a higher rate.
52	Tank FIC purge rate (nominally 50-200 cfh)	Enter 0. Purge is not required by a safety document, therefore no credit is taken for the purge.
53	Tank Vent rate	See explanation for line 74.
54	Tank breathing rate: SSTxFIC, SSTwFIC, or DST	Enter SSTxFIC for SSTs to take no account of purge rate. Enter DST if there is a non-zero value in line 53; entering DST causes the spreadsheet to calculate steady-state concentration based on vent flow rate.
55	Ratio of NH3 to H2 (normally 4)	Enter 4 as the bounding NH ₃ /H ₂ ratio in steady-state headspace air unless shown otherwise by sampling. If sample values were entered in lines 33 and 34, spreadsheet disregards value entered here.

Table C-2. Instructions for Filling in the Excel™ Spreadsheet (9 sheets).

Line	Description	Instruction/Comment/Explanation
56	Ratio of CH ₄ to H ₂ (normally 0.020)	Enter 0.020.
57	Assume NH ₃ vol = this fraction of slurry gas released (normally 0.220)	Per Hopkins (1994), in SY-101, in which trapped gas is ~30% H ₂ and a few percent NH ₃ , this fraction is 0.259. In the current evaluation, trapped gas is assumed to be 97% H ₂ and 0% NH ₃ ; therefore, NH ₃ is assumed to be decreased to 0.220.
58	Assume CH ₄ vol = this fraction of trapped gas released (normally 0.00 per Hopkins)	Per Hopkins, fraction is 0.02 in tanks like SY-101, in which H ₂ is about 30% of trapped gas. However, in this case, the trapped gas is 97% H ₂ and 3% water vapor, with no room for CH ₄ , so enter 0.
59	Select Confidence Level for Barometric Pressure/Surface Level Correlation	Normally, enter 75%.
60	Slope at 95% confidence	Enter value of slope from Whitney, including negative sign.
61	Slope at 75% confidence	Enter value of slope from Whitney, including negative sign
62	Slope at 50% confidence	Enter value of slope from Whitney, including negative sign
63	QFit Mean	Enter value from plots obtained from Whitney.
64	QFit Standard Deviation	Enter value from plots obtained from Whitney.

Table C-2. Instructions for Filling in the Excel™ Spreadsheet (9 sheets).

Line	Description	Instruction/Comment/Explanation																				
65	Engineer Selects Surface Rise Method: L (Liquids) or S (Solids)	<p>Line 65 tell Excel™ how to calculate SL rise. Line 66 tells Excel™ whether to take into account the porosity of the solids when calculating gas volume based on surface level rise and barometric slope. The table below tells what entries to make in these two lines and whether Excel™ adjusts for porosity based on the entry in line 66.</p> <table border="1" data-bbox="518 333 952 510"> <thead> <tr> <th data-bbox="518 333 674 399">SL Rise Is Based on ΔLevel in</th> <th data-bbox="674 333 773 399">Line 65 Enter</th> <th colspan="2" data-bbox="773 333 952 399">Line 66 Adjusts for Porosity</th> </tr> </thead> <tbody> <tr> <td data-bbox="518 399 674 427">Supernate Layer</td> <td data-bbox="674 399 773 427">L</td> <td data-bbox="773 399 827 427">SUP</td> <td data-bbox="827 399 952 427">No</td> </tr> <tr> <td data-bbox="518 427 674 454">Supernate in Hole</td> <td data-bbox="674 427 773 454">L</td> <td data-bbox="773 427 827 454">LIH</td> <td data-bbox="827 427 952 454">Yes</td> </tr> <tr> <td data-bbox="518 454 674 482">ILL</td> <td data-bbox="674 454 773 482">L</td> <td data-bbox="773 454 827 482">LIH</td> <td data-bbox="827 454 952 482">Yes</td> </tr> <tr> <td data-bbox="518 482 674 510">Solids</td> <td data-bbox="674 482 773 510">S</td> <td data-bbox="773 482 827 510">SOL</td> <td data-bbox="827 482 952 510">No</td> </tr> </tbody> </table>	SL Rise Is Based on Δ Level in	Line 65 Enter	Line 66 Adjusts for Porosity		Supernate Layer	L	SUP	No	Supernate in Hole	L	LIH	Yes	ILL	L	LIH	Yes	Solids	S	SOL	No
SL Rise Is Based on Δ Level in	Line 65 Enter	Line 66 Adjusts for Porosity																				
Supernate Layer	L	SUP	No																			
Supernate in Hole	L	LIH	Yes																			
ILL	L	LIH	Yes																			
Solids	S	SOL	No																			
66	Engineer Identifies Level Measurement Condition: SUP, SOL, LIH	<p>In general, for a tank which has (1) a liquid surface level (SL) measured below the solids surface via FIC/ENRAF/MT in a hole or small pool, and (2) an ILL reading, the supernate readings should be more reliable than the ILL. Therefore, calculate the SL rise based on ΔL in supernate in a hole: enter LIH for liquid in hole.</p> <p>Generally, ILL is measured via a neutron probe in a liquid observation well (LOW) in a hole sluiced into the waste, so LIH (liquid in hole) is the appropriate entry in line 66.</p> <p>For a tank with supernate level and submerged-solids level measurements for the beginning and end of the evaluation period, in general, calculate the SL rise based on ΔL in Solids, since solids gives a direct measure of the gas growth during the period.</p>																				
67	Temperature of Entering Air. If unknown, enter 56.3 F (Year Avg).	Unless known otherwise, enter year-round average of 56.3°F.																				
68	Relative Humidity of Entering Air. If unknown, enter 50%	If psychrometric data show actual humidity, enter that RH. Otherwise, enter 50%.																				
69	Temperature of Vapor in Dome Space (Year Ave)	For the period during which evaporation occurred, obtain from PC-SACS or best source, . If not available, estimate conservatively (higher is more conservative).																				
70	Relative Humidity of Exiting Air. If unknown, enter 100%.	If psychrometric data are available and actual relative humidity (RH) is therefore known, enter that RH. Otherwise enter 100%.																				

Table C-2. Instructions for Filling in the Excel™ Spreadsheet (9 sheets).

Line	Description	Instruction/Comment/Explanation
71	Surface Temperature of Waste (Year Ave)	Obtain from PC-SACS, or best source, for the period during which evaporation occurred. If not available, estimate conservatively (higher is more conservative).
72	Enter Period of Time over which evaporation occurs	For the time period during which surface level rise is estimated, enter the number of years (for example, 6.5) when tank had exposed liquid surface.
73	Enter Fraction of Heat Load used in calculating Vent Rate. If unknown, enter 50%.	If heat-load modeling has been done for the tank, enter fraction from that work. Otherwise, enter 50%.
74	Enter Calculation Result to Report on lines 123 and 124 (continued on next page)	<p>Excel™ always calculates evaporation three ways:</p> <ol style="list-style-type: none"> 1. <u>HL</u>: Based on line 73, fraction of <u>heat load</u> (HL) driving evaporation, determines the evaporation rate and resulting surface level drop during the evaluation period (line 74). 2. <u>INP</u>: Based on the entering air's temperature and RH (lines 67 and 68), calculates the mass of water in the air. Likewise, Excel™ uses the exiting air's temperature and RH (lines 69 and 70) to calculate the mass in exiting air. The increase is the evaporated water the exiting air removes from the tank. Excel™ uses the <u>input</u> (INP) vent rate (line 53) to determine the amount of water removed, and the surface level drop, during the evaluation period (line 74). 3. <u>SAM</u>: Calculates H₂ generation rate and the vent rate that would result in the concentration of H₂ determined by <u>sampling</u> (SAM) (line 33). Then, as described above for INP, Excel™ uses that flow rate to determine the amount of water removed, and the surface level drop, during the evaluation period. Because the calculated H₂ generation rate is sometimes very conservative, the level drop calculated using this rate can be very conservative. <p>(continued on next page)</p>

Table C-2. Instructions for Filling in the Excel™ Spreadsheet (9 sheets).

Line	Description	Instruction/Comment/Explanation
74	Enter Calculation Result to Report on lines 123 and 124 (continued from previous page)	<p>Excel™ then calculates the amount of surface level rise needed to bring the level back up to its current level. Line 74's entry determines which rise the spreadsheet displays on lines 123 and 124. Use the logic below to decide what to enter in line 74:</p> <pre> graph TD A[Is tank exhausted?] -- yes --> B[Enter INP on line 74 & vent rate in line 53] A -- no --> C[Is sample H2 conc. available?] C -- yes --> D[Enter SAM in line 74. Is calculated vent rate on line 110 > 10 cfm?] C -- no --> E[Enter HL in line 74. Is calculated vent rate on line 110 > 10 cfm?] D -- yes --> F[Enter 10 in line 53 & INP in line 74] D -- no --> G[No further action] E -- yes --> H[Enter 10 in line 53 & INP in line 74] E -- no --> I[No further action] </pre> <p>Additional discussion is provided in S. A. Barker's DSI at the end of this attachment.</p>

Results of Calculations of Entrapped Gas Volume and % LFL Based on Surface Level Rise

	A	B	C	D	E	F
1	Tank No.	enter	CHC703A	241-S-105	Data Sources/Comments	
2	Calculation date:	enter		02/28/95	@NOW	
3	Total waste volume	enter	gal	795,000	Hanson 1995	
4	Volume of solids (kicks + subsoils), including gas	enter	gal	4,000	Hanson 1995	
5	Superstrate volume	enter	gal	4,000	Hanson 1995	
6	Volume of drainable interstitial liquid	enter	gal	186,000	Hanson 1995	
7	Volume of sludge	enter	gal	20,000	Hanson 1995	
8	Current surface level height (Reading S/C)	enter	ft.	17.717	Calculated	
9	Original surface level height (Reading S/C)	enter	ft.	17.852	ENRAC	
10	Original surface level height (Reading S/C) as of this date:	enter	ft.	17.852	ENRAC	
11	Current liquid level height (Reading LLO)	enter	ft.	19.150	ENRAC	
12	Original liquid level height (Reading LLO)	enter	ft.	19.150	ENRAC	
13	Engineer selects source of interstitial liquid volume (Hanson, S/C or LLO)	enter	ft.	19.150	ENRAC	
14	Engineer selects source of interstitial liquid volume (Hanson, S/C or LLO)	enter	ft.	19.150	ENRAC	
15	Engineer selects source of supernate volume (Hanson, S/C or LLO)	enter	ft.	19.150	ENRAC	
16	Engineer selects source of supernate volume (Hanson, S/C or LLO)	enter	ft.	19.150	ENRAC	
17	Superstrate density. If unknown, enter 1.40.	enter	g/ml	1.250	WPC-SD-WM-EH-410, Rev.0, July 1995	
18	Sludge density. If unknown, enter 1.60.	enter	g/ml	1.530	WPC-SD-WM-EH-410, Rev.0, July 1995	
19	Powder density. If unknown, enter 1.10.	enter	g/ml	0.180	WPC-SD-WM-EH-410, Rev.0, July 1995	
20	Porosity (blank). If unknown, enter 0.501.	enter		0.225	Hopkins	
21	Average gas location: fraction of wet solids from bottom center. If unknown, enter = 0.225.	enter		0.225	Hopkins	
22	Estimate maximum evaporation	enter	ft.	17.40	WPC-SD-WM-EH-410, Rev.0, July 1995	
23	g TCC/L waste (wet)	enter	g/L	7.25	WPC-SD-WM-EH-410, Rev.0, July 1995	
24	Average trapped gas temperature	enter	°F	47.15	Use from EH-410, Rev.0, July 1995	
25	Average solids temperature	enter	°F	77	Temperatures from S&W, Loflin, 10/1995	
26	Power load from published source. If not available, leave blank.	enter	kw	0.31	DJ Sherwood, unpublished	
27	Heat load from published source. If not available, leave blank. (Don't leave both blank)	enter	kw	0.31	DJ Sherwood, unpublished	
28	Heat load from published source. If not available, leave blank. (Don't leave both blank)	enter	kw	0.31	DJ Sherwood, unpublished	
29	H2 generation rate, G/H2.	enter	ft	0	WPC-SD-WM-EH-410, Rev.0, July 1995	
30	H2 generation rate, G/H2.	enter	ft	0	WPC-SD-WM-EH-410, Rev.0, July 1995	
31	If sampled, actual H2 value from sampling	enter	enter	0.190	Extant Spreadsheet	
32	% H2 in trapped gas, 10 H2's trapped gas. If unknown, enter 97%.	enter	per cent	97%		
33	Mean air pressure on waste surface. If unknown, enter 14.50.	enter	per cent	14.50		
34	Add to Current Surf LVL: contraction	enter	ft.	0.00		
35	Add to Current Surf LVL: out leakage	enter	ft.	0.00		
36	Add to Current Surf LVL: measuring error (known or possible error at start, kick in tape now, etc)	enter	ft.	0.00		
37	Add to Current Surf LVL: measuring error (known or possible error at start, kick in tape now, etc)	enter	ft.	0.00		
38	Add to Current Surf LVL: any gas contained in original surface level	enter	ft.	0.00		
39	Subtract from Current Surf LVL: condensation from ambient air, which has dripped into tank	enter	ft.	0.00		
40	Subtract from Current Surf LVL: condensation from ambient air, which has dripped into tank	enter	ft.	0.00		
41	Subtract from Current Surf LVL: hygroscopic absorption	enter	ft.	0.00		
42	Subtract from Current Surf LVL: crust separation by gas	enter	ft.	0.00		
43	Subtract from Current Surf LVL: crust separation by gas	enter	ft.	0.00		
44	Subtract from Current Surf LVL: crust separation by gas	enter	ft.	0.00		
45	Subtract from Current Surf LVL: crust separation by gas	enter	ft.	0.00		
46	Subtract from Current Surf LVL: crust separation by gas	enter	ft.	0.00		
47	Subtract from Current Surf LVL: crust separation by gas	enter	ft.	0.00		
48	Subtract from Current Surf LVL: crust separation by gas	enter	ft.	0.00		
49	Subtract from Current Surf LVL: crust separation by gas	enter	ft.	0.00		
50	Subtract from Current Surf LVL: crust separation by gas	enter	ft.	0.00		
51	Tank atmospheric breathing rate: SS1+WF+FC (Chopper: 0.45% rated breathing)	enter	dm	0.15%	Crigden 1983	
52	Tank FC purge rate (nominally 50-200 cfm)	enter	dm	0		
53	Tank Vent Rate	enter	dm	0		
54	Ratio of CH4 vol to fraction of H2 conc. (normally 0.020)	enter		0.020	SS1+WF+FC, SST with H2 (SST+WF+FC), or DST (DST1)	
55	Ratio of CH4 vol to fraction of H2 conc. (normally 0.020)	enter		0.020	Hopkins 1994	
56	Ratio of CH4 vol to fraction of H2 conc. (normally 0.020)	enter		0.020	Assumed. Max = 0.2% per WPC-EF-0702	
57	Ratio of CH4 vol to fraction of H2 conc. (normally 0.020)	enter		0.020	Hopkins 1994	
58	Ratio of CH4 vol to fraction of H2 conc. (normally 0.020)	enter		0.020	Hopkins 1994	
59	Shape at 95% confidence	enter	In./In. Hg	-1.78	Whitney 1955 (FC)	
60	Shape at 75% confidence	enter	In./In. Hg	-1.44	Whitney 1955 (FC)	
61	Shape at 50% confidence	enter	In./In. Hg	-1.25	Whitney 1955 (FC)	
62	Shape at 50% confidence	enter	In./In. Hg	-1.25	Whitney 1955 (FC)	
63	Shape at 50% confidence	enter	In./In. Hg	-1.25	Whitney 1955 (FC)	
64	Shape at 50% confidence	enter	In./In. Hg	-1.25	Whitney 1955 (FC)	
65	Off-Standard Deviation	enter		0.274	Whitney 1955 (FC)	
66	Off-Standard Deviation	enter		0.274	Whitney 1955 (FC)	
67	Off-Standard Deviation	enter		0.274	Whitney 1955 (FC)	
68	Off-Standard Deviation	enter		0.274	Whitney 1955 (FC)	
69	Off-Standard Deviation	enter		0.274	Whitney 1955 (FC)	
70	Temperature of Vapor in Dome Space (Year Avg)	enter	deg F	50.7%	SS1P (Superstrate), SOX (Solid Surface), LFL (Liquid in Hole)	
71	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
72	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
73	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
74	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
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79	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
80	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
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160	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
161	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
162	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
163	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
164	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
165	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
166	Relative Humidity of Existing Air. If unknown, enter 100%	enter	deg F	71.3		
167	Relative Humidity of Existing Air. If unknown, enter					

Results of Calculations of Entrapped Gas Volume and % LFL Based on Surface Level Rise

A	B	C	D	E	F
1	Tank No.		241-S-106		
2	Calculation date:	CS6/03A	03/28/98	Data Sources/Comments	
3	enter		SRV/W		
76	Volume of Tank	Method	Value (ft ³)		
77	Total Waste Volume	S/LC	471,370		
78	Total Solids	S/LC	467,370		
79	Sludge Volume	Hendon	26,000		
80	Substrate Volume	S/LC	190,033		
81	Interstitial Liquid	LLC	4,000		
82	Supernatant Liquid	LLC	4,000		
83	Volume of Tank	Method	Value (ft ³)		
84	Total Waste Volume	S/LC	470,800		
85	Total Solids	S/LC	462,478		
86	Sludge Volume	Hendon	3,743		
87	Substrate Volume	S/LC	58,735		
88	Interstitial Liquid	LLC	2,594		
89	Supernatant Liquid	LLC	2,594		
90	Waste Depth (ft)	S/LC	178.60		
91	Soak Depth (ft)	S/LC	177.17		
92	Supernatant Depth, (ft)	LLC	1.45		
93	Effective Wet Solids Depth, (ft)	S/LC	177.17		
102	STEADY STATE - ASSUMES ENTRAPMENT RATE = 0				
103	TEST VS. CRITERIA (% of LFL)				
104	105% % LFL (Calc. Vapor Sample)				N/A
106	% LFL (Calc. Vapor Sample)	%			42.17%
107	% LFL (Calc. Net Breathing Only)	%			42.17%
108	% LFL (Calc. Net Breathing Only)	%			42.17%
109	% LFL (Calc. Based on Given Vent Rate)	dm			0.24
110	Vent Rate (CFM) (Calc. Based on Given Vent Rate)	dm			
111					
112	EPISODIC RELEASE (EGR/GRE)				
113	EGR/GRE: QUICK SCREEN				
114	TEST VS. CRITERIA (% of LFL)				
115	TEST VS. CRITERIA (% of LFL)				215.69%
116					
117	% LFL				
118					
119	EGR/GRE: EVAL BASED ON SL RISE				
120	TEST VS. CRITERIA (% of LFL)				
121	TEST VS. CRITERIA (% of LFL)				
122	% LFL (Calc. Based on Given Vent Rate)				187.56%
123	Vent Rate (CFM) (Calc. Based on Given Vent Rate)				0.24
124					
125	CALCULATION USING PAUL WHITNEY'S SLOPE				
126					
127	% LFL = (0.9/0.04) + (0.9/15.0) =				224.69%
128					
129					
130					
131					
132					

Results of Calculations of Entrapped Gas Volume and % LFL Based on Surface Level Rise

A		B		C		D		E	
		COS/CSA				Data Sources/Comments			
1	Trunk No.	enter				241-5-108			
2	Calculation date:					03/26/98	UNKNOWN		
3	Inventoried Liquid	S.L.C	43			25,404	+D18@D648.D648		
4	Supernatant Liquid	L.L.C	43			538	+D18@D648.D648		
Monte Carlo (Crystal Ball Tie-Ins)									
270	Method						@F(D218-0,F(D143-0,D2140156,D218D156),0)		
271	Volume of Tank	Method				Value (gal)			
272	Total Waste Volume	S.L.C	44			758,300	+D183		
273	Total Solids	S.L.C	44			471,370	@F(B3-0,D184)		
274	Sludge Volume	S.L.C	44			26,000	+D186		
275	Substrate Volume	S.L.C	44			438,370	+D197		
276	Inventoried Liquid	S.L.C	44			190,033	@F(B3-0,I,D189)		
277	Supernatant Liquid	S.L.C	44			140,800	@F(B23-0,D2,D201)		
278	Volume of Tank	S.L.C	43			63,013	+D217D648.D648		
279	Total Waste Volume	S.L.C	43			62,478	+D217D648.D648		
280	Total Solids	S.L.C	43			56,725	+D217D648.D648		
281	Substrate Volume	S.L.C	43			25,404	+D217D648.D648		
282	Inventoried Liquid	S.L.C	43			178,62	@F(D218-0,F(D143-0,D218D156,D218D156+12,D218D156+12,D218D156+12),0)		
283	Supernatant Liquid	S.L.C	43			177,17	@F(D218-0,D230,F(D191-0,F(D143-0,D218D156+12,D218D156+12),0),0)		
284	Waste Depth (ft)	S.L.C	43			38.86	@F(D143-0,D294)		
285	Soils Depth (ft)	S.L.C	43			137.20	@F(B235-SOIL,D290-D235,D232-D235)		
286	Effective Wet Soils Depth, (ft)	S.L.C	43			120.28	+D235-@M(A)(D150,0)		
287	Average gas location in _____ in above center bottom					137.28	+D237		
288	Soils depth over center of trapped gas (from top of soils)					137.28	+D237		
289	OR, conservative ht. of expanded slurry - expansion ht.					137.28	+D237		
290	Height of entrapped-capable soils					137.28	+D237		
291	TOC (Wet wt. %) - MUST be wet					137.28	+D237		
292	TOC to % TOC (wet)					137.28	+D237		
293	ENTER g TOC/waste (wet)					137.28	+D237		
294	ENTER g TOC/LQ waste (wet)					137.28	+D237		
295	ENTER g TOC/g LQ waste (wet)					137.28	+D237		
296	ENTER g TOC/g waste (wet)					137.28	+D237		
297	ENTER g TOC/g waste (wet)					137.28	+D237		
298	ENTER g TOC/g waste (wet)					137.28	+D237		
299	ENTER g TOC/g waste (wet)					137.28	+D237		
300	ENTER g TOC/g waste (wet)					137.28	+D237		
301	ENTER g TOC/g waste (wet)					137.28	+D237		
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371	ENTER g TOC/g waste (wet)					137.28	+D237		
372	ENTER g TOC/g waste (wet)					137.28	+D237		
373	ENTER g TOC/g waste (wet)					137.28	+D237		

Calculate Air Vent Rate (Flow Rate) based on Heat Load

Psychrometric Calculations
 Reference: Hatbach, J. A. and Wiggins, E. G. "A psychrometric Model for Tank Vapor Plus", Computers in Education Division of ASCE, p22-28
 Inputs (Temp)(DB), Pwet(temp), & (Temp)(WB) or RH):
 Waste Volume (to ft) with trapped gas
 Tank TH-4 Space (ft release) -total vol-waste volume
 Psychrometric Calculations
 Reference: Hatbach, J. A. and Wiggins, E. G. "A psychrometric Model for Tank Vapor Plus", Computers in Education Division of ASCE, p22-28
 Inputs (Temp)(DB), Pwet(temp), & (Temp)(WB) or RH):

Results of Calculations of Entrapped Gas Volume and % LFL Based on Surface Level Rise

A	B	C	D	E	F
1	Tank No.				
2	Calculation date:		24.5.19	Gas Sources/Comments	
274	Temp (Dry Bulb), Required	50.0%	50.0%	80K/W	
275	Temp (Wet Bulb), Required	50.0%	50.0%		
276	Temp (Wet Bulb), Actual	50.0%	50.0%		
277	Press (atm), Required	14.489	14.489		
278	Press (atm), Actual				
279	Calculations:				
280	A	N/A	N/A	N/A @F(0276)=0.7047; 2037.4167(0275+458.6779)+4.99357@L(0261)+586.671(0279)+22.5518	
281	B	0.1920	0.1920	0.4309; 2637.4167(0274+458.6779)+4.9285@L(0261)+586.671(0279)+22.5518	
282	Relative Humidity	50.00%	50.00%	100.00%; @F(0276)=0.0276; (10-D286-0.001243)/(0277-0.0277)+1+(0274-0279)/(0-D281)	
283	Temp (C)	515.37	515.37	531.57; +0274+458.67	
284	PH2O, MBS, DB	0.22386	0.22386	0.38656 @E(PI(5.11964+12066.35686)/(03271-4.69652@LN(03271)))	
285	Water Vap Press (slew point)	0.1120	0.1120	0.3866; +0282*0.28	
286	Humidity Ratio, W	0.0049	0.0049	0.0179; 18.016296; 864/(03299/(0277-0.952))	
287	Enthalpy, h	18.77	18.77	35.88; 0.24*(0274+0282)+1080.04+445*(0274)	
288	Specific Volume, V	13.26	13.26	13.94; 53.34*(0277)/(0277-0.5320)/144	
289	Outlets:				
290	Temp (Dry Bulb)	56.3	56.3	71.8; +0274	
291	Relative Humidity	50.00%	50.00%	100.00%; +0282	
292	Humidity Ratio	0.0049	0.0049	0.0170; +0359	
293	Enthalpy	18.77	18.77	18.77; +0461	
294	Specific Volume of Dry Air	13.26	13.26	13.94; +0363	
295	Water Partial Pressure @ Temp(08)	0.22386	0.22386	0.38656; +0328	
296	Water Partial Pressure @ Temp(OP)	0.11197	0.11197	0.38656; +0352	
297	Enthalpy change of vent air			17.1197; +0371-0371	
298	Temperature of Waste Surface			0.0177; +071	
299	Rate of Water Evaporated			0.0181; +0270	
300	Total Tank Head Load			0.81; @F(0285)=0.028; @F(0275)=0.0277*(N/A)1	
301	Total Tank Heat Load			2.784; @F(0365)=0.3412; 14.12856618*(0360/(N/A)1)	
302	50% of Total Tank Heat Load			1.392; @F(0361)=0.1706; 0.3412*(N/A)1	
303	Rate of Water Evaporated			0.0181; +0270; +0359; +0328; +0372	
304	Vent Rate to Remove 50% of Heat Load			18.77; @F(0380)=0.0380; 0.0380*(0372)/(0.528)	
305	Rate of Water Evaporated			0.0652; +0363*(0379)	
306	Vent Rate Based on Evaporation			1.058; +0365+24.386+256.8+333333	
307	Waste Level Change based on Evaporation			0.358; +0368*(0156)	
308	Method used above to calculate vent rate			Vent Rate Based on Heat Load	
309				@F(0380)=0; Vent Rate Based on Heat Load; Vent Rate Based on Heat Breathing	
310					
311	Temp, in. Hg		26.50	+0363+0.491154	
312	Press, in. Hg		14.489	+036	
313	PHg				
314	kg density		1.45	+0177	
315	kg/m3 density		1.45	+0177	
316	PHg		0.078	+0368*(0397+254+3+1453.59)	
317	Proble				
318	solids density		1.50	+018	
319	solids weight over center of trapped gas		13.74	+018	
320	PHg		7.441	+0400*(0401+254+3+1453.59)	
321	PHg				
322	Surface tension		19.050		
323	sigma in psi-microns		1000.000		
324	sigma in psi-microns		0.052	4*(0400+0405)	
325	mean bubble diameter		22.858	+0366+0396+0402+0408	
326	Surface tension = 4*sigma/diam				
327	PROVAL				

Combo6 4.xls for S:106

Results of Calculations of Entrapped Gas Volume and % LFL Based on Surface Level Rise

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1	Tank No.		CB603A			
2	Calculation date:		enter			
3	Enter breathing rate based on above answer (%)		enter			
476	Enter breathing rate based on above answer (cfm)		0.15%			
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Results of Calculations of Entrapped Gas Volume and % LFL Based on Surface Level Rise

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Results of Calculations of Entrapped Gas Volume and % LFL Based on Surface Level Rise

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1	Trnk No.					
2	Calculation date:			24-5-106	Data Source/Comments	
3		enter	CS6/03A	19/28/96	UNKNOWN	
4		enter				
5	Vol. of Head Space		13	77.597	+0710	
6	Vol. of Head space before burp					
7	Compressed vol X fraction of entrapped gas released = sic level drop		13	4.686	+0720/0743	
8	Vol. of head space vol. increase caused by sic level drop		13	82.273	+0736-0737	
9	Vol. of head space after burp					
10	142 % in Head Space			0.064	+0752/0758	
11	Vol. of H2 in Head Space/Vol of head space after burp					
12	NH3 % in head space =	linked		0.220	+057	
13	Assume NH3 vol = this fraction of entrapped gas released (max = 0.259)			1.570	+0764/0748	
14	NH3 vol in head space = NH3 fraction X vol of entrapped gas released			0.019	+0765/0758	
15	NH3 % in head space =					
16	TEST VS. CRITERIA (% of LFL)					
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Results of Calculations of Entrapped Gas Volume and % LFL Based on Surface Level Rise

	G	H	J	K	L	M	N	O	P
	Distributor	Calculated Description	Assumption	Mean	St Dev	Truncate	Truncate	units	
1	Normal	Value							
2	Normal	Total Waste, gal	NOT USED	=H3	=2.2750		High		
3	Normal	Supernatant Volume, gal	NOT USED	874500	=0.15*K5	851180	=K3*1.1	1000000	
4	Normal	Current Solid Surface Level, In	CELL D08	=H6	2	=K8-4*L8		=K8-4*L8	
5	Normal	Current Liquid Surface Level, In	CELL D11	=H11	2	=K11-4*L11		=K11-4*L11	
6	Normal	Supernatant Density, g/ml	CELL D17	=H17	0.05	=K17-4*L17		=K17-4*L17	
7	Normal	Solids Density, g/ml	CELL D18	=H18	0.05	=MAX(N17, K18-4*L18)		=K18-4*L18	
8	Normal	Porosity (liquid fraction) in solids, by assay--if unknown, enter 0.501	CELL D19	=D19	=0.15*H19	=K19-0.15		=K19-0.15	
9	Normal	Ave gas location above tank bottom, In	CELL D21	=H21	0.01	=K21-4*L21		=K21-4*L21	
10	Normal	Temperature, F	CELL D26	=H26	2	=K26*0.9		=K26*1.1	
11	Normal	Tank Total Volume, (ft3)		=H29	500	=K29*0.99		=K29*1.01	
12	Normal	%H2 in entrapped gas, (ft3 H2/R3 slurry gas)*100%. Default is 97%	CELL D37	0.5	0.15	0.02		0.97	
13	Normal	Fraction of entrapped slurry gas releasable from slurry (%). Default is 25%	CELL D38	0.15	0.14	0.00001		0.75	
14	Normal	Whitney Slope	CELL D61	=D63	=D64	=-5		5	

smooth	2
rough	4

DON'T SAY IT --- Write It!DATE: March 28, 1996TO: Dave HopkinsFROM: SA Barker

R2-11

Telephone: 372-0485

SUBJECT: Implications of Vent Rate and Evaporation in the Flammable Gas Evaluation, January through March 1996

1.0 Summary

In response to peer review comments in December 1995, the model for the evaluation of tanks against the Flammable Gas Watch-List Criteria was modified to include the effect of evaporation on surface level rise. In the November 1995 version of the Excel™ spreadsheet, the engineer could enter evaporation amounts expressed in inches of tank level (about 2,750 gallons per inch for 100 series tanks). The modifications allow the Excel™ spreadsheet to calculate the steady-state flammable gas concentration using a tank ventilation rate corresponding to:

- the natural breathing rate (0.45 volume % per day),
- a natural convection rate,
- the forced ventilation rate,
- a ventilation rate based on removal of 50% (user selectable) of the tank heat load, and
- a ventilation rate calculated based on the comparison between the calculated steady-state flammable gas concentration and a sample result flammable gas composition.

These ventilation rates are utilized to calculate tank evaporation rates, which are then incorporated into the calculation of surface level rise and volume of trapped gas. The effect and methodology as related to the calculation of the steady-state flammable gas concentration and the surface-level rise release event flammable gas concentration are presented.

2.0 Vent Rate Calculations

The Flammable Gas Evaluation (FGE) establishes its ventilation and evaporation calculations on several different bases. In all evaluations, the program calculates ventilation rates based on the 4 methods discussed in this section. The evaluator inputs some basic information, but generally due to lack of data, assumed values are used.

2.1 Vent rate calculation based on natural breathing

The ventilation rate based on natural breathing is always calculated by the spreadsheet and reported in the results section of the model. In most of the single-shell tanks (SST), the sole source of tank ventilation is natural breathing. In tanks with forced exhausters, the natural breathing rate would be the tank ventilation rate if power were lost to the ventilation blowers and if there is no natural convection. This ventilation reflects the movement of air into and out of the tank as the outside air temperature and barometric pressure change. Crippen (1993) reported that averaged over the temperature cycles for the full day and the full year, the natural breathing rate is 0.45 volume % of the tank vapor space per day. This ventilation rate gives a very conservative value for the tank steady-state flammable gas concentration. In addition, this ventilation rate will give a very small evaporation rate, which results in a non-conservative flammable gas concentration based on the surface level rise evaluation.

Input data: Natural Breathing Rate in percent of vapor space volume per day (assumed value of 0.45% of the tank vapor space per day).

2.2 Vent rate calculation based on input ventilation rate

This is the tank's ventilation rate based on forced ventilation or natural convection. The source of ventilation may be through Food Instrument Corporation Level Measurement Device (FIC) instrument air, or may be exhausters fans. In non-forced ventilation tanks, temperature differences between tanks and the atmosphere may cause natural convection to occur. Sadasivan (1995) reports flow rates up to 10 cfm for high temperature tanks based on his modeling efforts. Flow rates for natural convection may be input (line 53), but usually this amount is only input if vapor sample data supports the presence of significant natural convection flow rates. A flow rate is then input only if the natural convection flow rate based on vapor sample analysis or heat load analysis is greater than 10 cfm.

Input data: Ventilation rate through Food Instrument Corporation Level Measurement Device (FIC). This value is expressed in cubic feet per hour.

Ventilation rate through forced ventilation or natural convection. This value is expressed in cubic feet per minute.

2.3 Vent rate calculation based on sampled value

If a vapor sample is available, a flammable gas concentration is calculated by the Excel™ spreadsheet in terms of the lower flammability limit. This value is then compared to the calculated value for the steady-state flammable gas concentration. A tank ventilation rate is then calculated which would produce the vapor sample concentration in the head space if the waste generated hydrogen at the calculated generation rate. This calculation assumes that the tank hydrogen generation rate is correct. As a result, ventilation rates based on the vapor sample may be very large (and unrealistic). A "natural convection" flow rate limit of 10 cfm may be used to override the rate based on the vapor sample.

Input data: Results of vapor space sampling in ppm hydrogen and ppm ammonia.

2.4 Vent rate calculation based on heat load

For tanks without a vapor sample and without forced ventilation, an alternate method of calculating ventilation rate is used. A ventilation rate can be calculated using 50% of the calculated heat load for the tank. Built in psychometric relationships determine the flow rate. Once again, a "natural convection" flow rate limit of 10 cfm may be used to override the ventilation rate based on the heat load.

Input data: Tank heat load in kilowatts. An alternate value is power load in kilowatts.

Percent of heat load to be removed by evaporation and heating of ventilation air (assumed value is 50 %).

Temperature (assumed value is 56.3 °F) and relative humidity of the inlet air (assumed value is 50 %).

Temperature (tank thermocouple reading or waste surface temperature minus 5 °F) and relative humidity of the outlet air (assumed value is 100 %).

3.0 Steady-State Calculation

A steady-state flammable gas concentration value is calculated. This value is a measure of the generation rate for the flammable gas components (primarily hydrogen). This calculation assumes that the flammable

gases are not trapped within the waste solids, but are continuously released to the tank dome vapor space. When the steady-state flammable gas concentration is compared to vapor analysis results, a ventilation rate (or error in hydrogen generation rate) can be estimated. Other than being used to help calculate a ventilation rate for tanks without forced exhaust, this calculation is of little value. Sampled vapor concentrations are very low and do not approach the tank failure criteria of greater than 25% of the lower flammability limit (LFL). For the engineer's evaluation, steady-state flammable gas concentrations are always calculated based on a vapor sample (if available), a natural breathing rate (with assumed hydrogen generation rate), or a given ventilation rate (forced exhaust or natural convection).

4.0 Surface Level Rise Prediction for a Flammable Gas Release Event

This calculation uses changes in measured waste surface level over time to determine the quantity of flammable gases trapped within the waste matrix. It is assumed that periodically, this trapped gas can be released into the vapor space causing a hazardous condition. The spreadsheet's calculated surface level rise is adjusted by factors such as additions to the tank, evaporation of tank liquids, leakage from the tank, condensation into the tank, and existing gases within the waste matrix prior to the study period.

The December 5-6, 1995 peer review of the methodology for flammable gas evaluation determined that the surface level rise prediction was not conservative. The weakness was that evaporation was not consistently taken into account. For a select number of tanks, psychometric studies have been performed. Most tanks, especially SSTs without forced ventilation have not had psychometric studies performed. Since the review, a method was incorporated to estimate evaporation rates using tank ventilation rates and assumed inlet and outlet ventilation air conditions. The FGE spreadsheet always calculates the flammable gas concentration 3 ways (data permitting). These three methods differ only in the evaporation rate, which is expressed as a function of the ventilation rate. Flammable gas concentrations based on release events are calculated using evaporation rates based on 1) input maximum evaporation rate (line 22) or on input ventilation rate (if line 22 is 0.0), 2) ventilation rate determined by the heat load calculation, and 3) a ventilation rate determined by the vapor sample calculation.

5.0 References

- Crippen, M. D., 1993, "Barometric Pressure Variations," WHC-EP-0651, Westinghouse Hanford Company, Richland, WA.
- Sadasivan, P., Nichols, B., Spore, J., September 1995, "Passive Ventilation in Single-Shell Tanks," Los Alamos National Laboratories, Los Alamos, NM.

ATTACHMENT D

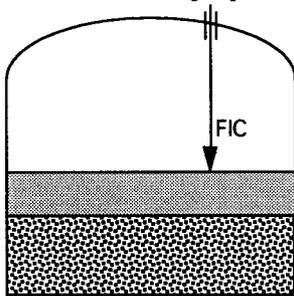
**UNCERTAINTIES INVOLVING
SURFACE LEVEL GAUGES**

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There are sources of uncertainty in surface level readings. One uncertainty involves changes to the waste volume. For example, evaporation of liquid would decrease waste volume. In addition, some uncertainty arises from where the surface level gauge contacts the waste.

For the surface-level-rise method to be accurate, any change in the surface level reading must be directly proportional to the change in waste volume. This is the case when the surface level is all liquid, as seen in Figure D-1. However, in many cases, a change in

Figure D-1. FIC Contacting Liquid Surface.

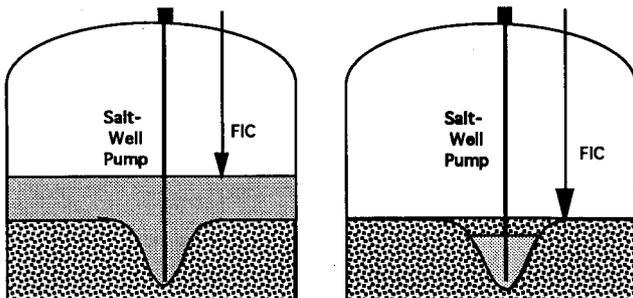


the surface level reading does not reflect a corresponding change in the volume, as illustrated by the following examples:

- The waste surface is partly covered with a floating crust of varying thickness. The crust, which varies in thickness, may move on the surface. A change in FIC reading might represent a difference in crust position, that is, no change in volume.
- The waste surface is mostly solids, and the FIC is contacting the surface of a liquid pool, near the pool's edge. If the pool evaporates, it can appear that the waste is losing more volume (that is, from a 75-foot diameter pool, instead of a small-diameter pool) than it is. As further evaporation occurs, and the FIC contacts and remains on the solids surface below where the pool was, it can appear that the waste volume is constant, even though the liquid is still evaporating.

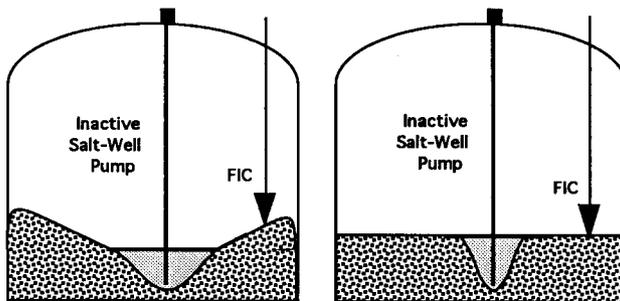
- Waste with a layer of supernate is pumped, and the FIC comes to rest on moist solids, as shown in Figure D.2. Although the pump continues to remove liquid waste, the loss will not be reflected in the solids surface, which remains stationary while the liquid is pumped from the interstitial space in the solids. The liquid in the solids is replaced with air from the tank head space.

Figure D-2. Pumped Tank With FIC on Solids.



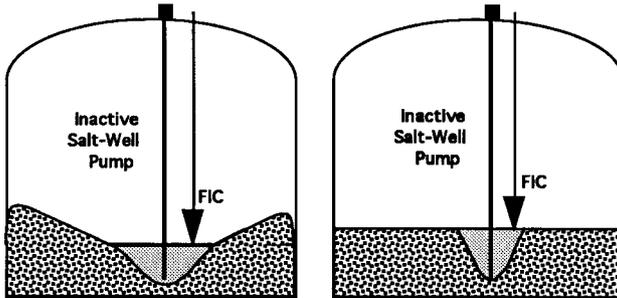
- Waste with a layer of supernate has been pumped, and the FIC has come to rest on moist solids, as shown in Figure D.3. The solids can eventually slump so that the FIC falls, making it appear that the surface level and, by inference, the waste volume are decreasing.

Figure D-3. FIC on solids falls as solids slump.



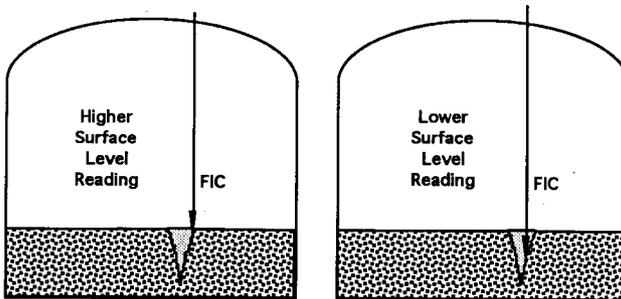
- As a variation of the foregoing case, waste with a layer of supernate has been pumped, and the FIC has come to rest in the liquid pool, as shown in Figure D.4. The solids can eventually slump so that the liquid level in the pool rises and the FIC rises, making it appear that the entire waste surface level and, by inference, the waste volume are increasing.

Figure D-4. FIC in pool rises as solids slump.



When such slumping occurs in a sludge tank, the rise in FIC level is likely to be more than for a slump of an equal volume of solids in a saltcake tank. Before sludge slumps, its volume above the water line is likely to be fairly saturated with water because of capillary action. When it slumps, it is unable to absorb any water from the pool around the pump. On the other hand, the saltcake has more pore space than sludge, and before the saltcake slumps, its pores above the water line are essentially devoid of liquid. As the salt slumps, its pores fill with water from the pool, allowing some of the pool to spread out instead of contributing to the rise.

- In a small number of tanks, repeated measurements over many years have worn a hole in the waste surface, so that current surface level readings vary, depending on where the FIC contacts the surface, as shown in Figure D.5.



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ATTACHMENT E

**TECHNICAL BASIS FOR
CENTER OF TRAPPED GAS**

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Subject: Re: Void Fraction Results from SY-103
 From: Chuck Stewart 7/20/95 4:09 PM
 To: Zenen Antoniak, et al.

Here are the preliminary void fraction results from SY-103 from Ruben's data sheets:

- A. 1st traverse with arm away from center, sample chamber 30.5 ft from center
- B. 2nd traverse, arm toward center, sample chamber at 25.5 ft. radius
- C. 3rd traverse, arm to NE, sample chamber at 28 ft.

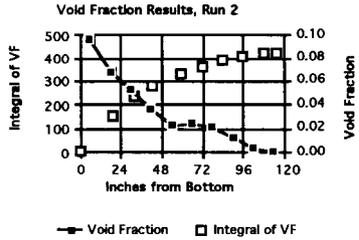
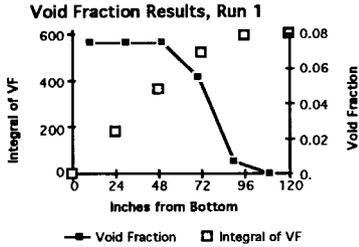
--(A)--		--(B)--		--(C)--	
Ht (in.)	Void (%)	Ht (in.)	Void (%)	Ht (in.)	Void (%)
above 120	0	above 120	0		
120	0	116	0		
		108	0.3		
96	0.7	96	1.3		
		84	2.1		
72	5.5/5.0	72	2.5	68	2.4,2.0
		60	2.3	53.4	2.9
48	7.6/7.0	43	3.6	42.4	2.9
		32	5.2		
24	2.3/2.0	19	6.7/6.0*	20.9	10.6,14.6
12	5.6/5.3*				

* Small gas release at this level observed as bubbles and surface motion (per telecon with Jim Alzheimer).

The notation 5.6/5.3 indicates a double pressurization of the same sample, while 2.4,2.0 indicates two tests at the same location with cover opened and closed between.

Chuck

Plots of data presented in Stewart's mail message are shown below. Integrals were determined by algebraically calculating cumulative sums of inches x void fraction. Void fractions at zero inches are assumed based on extrapolation of VF curve. Mid-point of integral is about 36 in. for Run 1 and about 24 inches for Run 2. Average = 30 in. Solids depth = 130-132 in. Fraction of wet-solids depth above tank bottom = 30 in./130 in. = 0.231.



ATTACHMENT F

MONTE CARLO ANALYSIS

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F-1.0 DEFINITION OF DISTRIBUTIONS

Members of the evaluation team have defined distributions for the parameters listed in Table F-1. The distributions for measures are based in part on a knowledge of statistical variation of parameters and in part on engineering judgment based on the character and behavior of tank waste.

The distributions for "% H₂ in trapped gas" (line 37) and "% of trapped gas releasable" (line 38) are predominantly based on engineering judgment, which draws on experimental reports, tank models and calculations regarding a few DSTs. The distribution for barometric slope (line 61) is based on surface level and barometric pressure data but is influenced by Whitney's judgment about how to identify statistically significant correlations among the data.

Table F-1. Terms Included in Monte Carlo Simulation. (2 sheets)

Line	Description	Mean	SD*	Limits**	Value Used in Spreadsheet
8	Current solid surface level height	Current reading	2.0 in.	± 4 SD	Mean
11	Current liquid level height	Current reading, max = 1.40	2 in.	± 4 SD	Mean
17	Supernate density	Value from literature, default = 1.40	0.05 g/mL	Min = mean - 4 SD. Max = mean + 4 SD, or min of solids density, whichever is less	Mean
18	Solids density	Value from literature, default = 1.80	0.05 g/mL	Min = mean - 4 SD or supernate mean, whichever is greater. Max = mean + 4 SD	Mean
19	Porosity (liquid fraction) in solids, by assay [Entry for saltcake]	0.501 or experimental value	0.075	± 2 SD	Mean
19	Porosity (liquid fraction) in solids, by assay [Entry for sludge]	0.16 or experimental value	0.035	± 2 SD	Mean
21	Average gas location: fraction of wet solids from bottom	0.225	0.01	± 4 SD	Mean

* SD is not a true standard deviation, but rather it represents the evaluation team's consensus of the variability of the parameter.

** Mean ± 3 SD covers 99.7% of possible values; mean ± 4 SD, 99.99% of values.

Table F-1. Terms Included in Monte Carlo Simulation. (2 sheets)

Line	Description	Mean	SD*	Limits**	Value Used in Spreadsheet
25	Average trapped gas temperature	Value from PC-SACS	2°F	± (0.1 x mean) or ± 4 SD (varies by evaluator)	Mean
37	% H ₂ in trapped gas, ft ³ H ₂ /ft ³ gas x 100%	50%	15%	2%, 97%	97% theoretical max (for conservatism) vs. 75-90% observed
38	% of trapped gas releasable	15% Log-normal	14%	Low = 0% High = 75%	25% (higher in AW- 101); assumed to give conservative results for normal operations. May not be conservative for earthquake.
61	Barometric slope	Qfit mean	Qfit SD	Low = value which gives void fraction of 0. High = value which gives void fraction of 0.300 (wet solids)	75 percentile slope; assumed to give conservative results. Spreadsheet limits slope to value which gives void fraction = 0.300.
201	Tank total volume, ft ³	From look-up table in spreadsheet	500 ft ³	± 4 SD	Mean

For the calculation of % LFL based on surface level rise, no distributions were defined for terms adjusting the surface level (for example, evaporation or gas trapped at beginning of period). Lack of time prevented defining these distributions. The sum of these distributions is probably quite wide, so the variation in the % LFL calculated by surface level rise may be greater than the variation in % LFL calculated from barometric slope.

Sensitivity analysis shows that about 90% of the variation in the calculated % LFL is from the variation in the following terms: barometric slope, % H₂ in trapped gas, and % of gas released. This is to be expected. There is a wide range of possible values for each of these parameters, and for a given tank the value of these parameters used in the spreadsheet may be significantly different from the actual value. This is especially true for the % H₂ in the gas and the percent of trapped gas released. For each of these parameters, the Monte Carlo defined distribution is generalized for all tanks (that is, the same trio of distributions is used for all tanks) and is therefore very wide. It may be possible to narrow the distribution on a tank-by-tank basis and thereby narrow the range of the calculated % LFL.

F-2.0 SPREADSHEET VALUES

For the three parameters discussed in the previous paragraph, to provide conservatism in the calculated % LFL, the evaluators used spreadsheet values at the upper end of the distribution range, as shown in the table. It is not unreasonable to use values this high, as discussed below.

- Barometric slope. The spreadsheet has a logic step which limits the slope to the value corresponding to a void fraction of 0.30 in wet solids. Informal discussions among some reviewers of this methodology indicate that although this is an arbitrary ceiling, it seems appropriate in light of tank behavior and laboratory experiments.
- % H₂ in trapped gas. The spreadsheet uses the value of 97%. Estimates of releases in DSTs since mid-1994 indicate that gas released could have contained 70-90% H₂, which is not far below 97%. If the distribution curve were modified for each individual tank based on *in situ* sampling (if that were possible), the mean of distribution curve might be well above 50% for many tanks.
- % of gas released. The spreadsheet uses 25%. Again, although this is an arbitrary ceiling, most reviewers of this methodology agree that this value appears to be reasonable for normal conditions in SSTs, although in an earthquake the release might be greater than 50%. Experimental work is needed as a technical basis for estimating the release in an earthquake.

NOTE: In 101-SY, the prompt release was calculated to have reached about 39% of the trapped slurry gas. For DSTs, the evaluation team used a 25% release except for tank AW-101, for which the Raleigh-Taylor/Neutral Buoyancy method predicted a maximum release of 47%. This was the only tank for which a release greater than 25% was assumed.

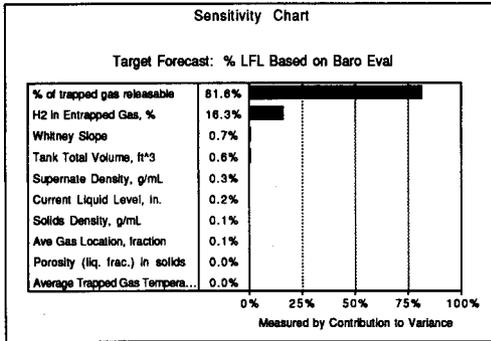
For parameters besides the three discussed above, the spreadsheet uses the mean of each Monte Carlo distribution. This tends not to give conservative results, however, the variance in these parameters accounts for only about 10-15% of the variation in the calculated % LFL, therefore the use of mean values instead of conservative values is not expected to have a major effect on the result.

F-3.0 EXAMPLE PRINTOUT

The following pages contain an example Monte Carlo report for tank S-106, including the distribution of the % LFL based on barometric evaluation; % LFL based on surface level rise; compressed volume of trapped gas, and % void. Because the report is only for illustration, only 2,500 trials were run, instead of the usual 5,000.

Crystal Ball Report

SENSITIVITY CHART



FORECASTS

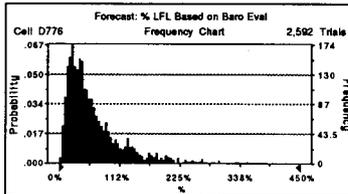
Forecast: % LFL Based on Baro Eval

Cell: D776

Summary:

Display Range is from 0% to 450%
 Entire Range is from 2% to 477%
 After 2,594 Trials, the Std. Error of the Mean is 1%

Statistics:	Value	Percentile	% LFL (approx.)
Trials	2594	0%	2%
Mean	66%	10%	16%
Median (approx.)	48%	20%	24%
Mode (approx.)	24%	30%	31%
Standard Deviation	58%	40%	40%
Variance	34%	50%	48%
Skewness	2.12	60%	60%
Kurtosis	9.30	70%	75%
Coeff. of Variability	0.87	80%	97%
Range Minimum	2%	90%	140%
Range Maximum	477%	100%	477%
Range Width	474%		
Mean Std. Error	1.14%		



End of Forecast

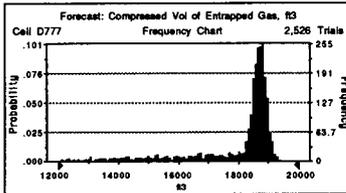
Forecast: Compressed Vol of Trapped Gas, ft3

Cell: D777 Cell: D777

Summary:

Display Range is from 12000 to 20000 ft3
 Entire Range is from 3518 to 19464 ft3
 After 2,594 Trials, the Std. Error of the Mean is 39

Statistics:	Value	Percentile	ft3 (approx.)
Trials	2594	0%	3518
Mean	17744	10%	14840
Median (approx.)	18612	20%	16859
Mode (approx.)	18746	30%	18251
Standard Deviation	2003	40%	18501
Variance	4010023	50%	18812
Skewness	-2.47	60%	18897
Kurtosis	10.17	70%	18777
Coeff. of Variability	0.11	80%	18859
Range Minimum	3518	90%	18966
Range Maximum	19464	100%	19464
Range Width	15946		
Mean Std. Error	39.32		



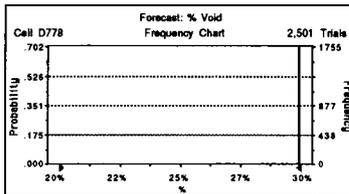
Forecast: % Void

Cell: D778

Summary:

Display Range is from 20% to 30%
 Entire Range is from 6% to 30%
 After 2,594 Trials, the Std. Error of the Mean is 0%

Statistics:	Value	Percentile	% Void (approx.)
Trials	2594	0%	6%
Mean	28%	10%	24%
Median (approx.)	30%	20%	27%
Mode (approx.)	30%	30%	29%
Standard Deviation	3%	40%	30%
Variance	0%	50%	30%
Skewness	-2.50	60%	30%
Kurtosis	10.24	70%	30%
Coeff. of Variability	0.11	80%	30%
Range Minimum	6%	90%	30%
Range Maximum	30%	100%	30%
Range Width	24%		
Mean Std. Error	0.06%		



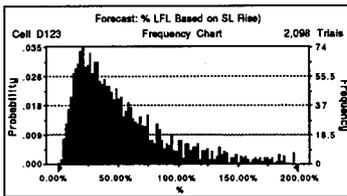
Forecast: % LFL Based on SL Rise

Cell: D123

Summary:

Display Range is from 0.00% to 200.00%
 Entire Range is from 1.83% to 447.52%
 After 2,594 Trials, the Std. Error of the Mean is 1.00%

Statistics:	Value	Percentile	% LFL (approx.)
Trials	2594	0%	2%
Mean	58.57%	10%	15%
Median (approx.)	42.64%	20%	21%
Mode (approx.)	30.80%	30%	29%
Standard Deviation	50.97%	40%	35%
Variance	25.98%	50%	43%
Skewness	2.20	60%	53%
Kurtosis	9.88	70%	66%
Coeff. of Variability	0.87	80%	86%
Range Minimum	1.83%	90%	161%
Range Maximum	447.52%	100%	448%
Range Width	445.70%		
Mean Std. Error	1.00%		



End of Forecast

ASSUMPTIONS

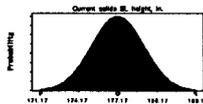
Assumption: Current solids SL height, in.

Normal distribution with parameters:

Mean 177.17 (=K8)
 Standard Dev. 2.00 (=L8)

Selected range is from 169.17(=M8) to 185.17(=N8)
 Mean value in simulation was 177.20

Cell: D8



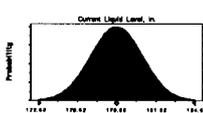
Assumption: Current Liquid Level, in.

Normal distribution with parameters:

Mean 178.62 (=K11)
 Standard Dev. 2.00 (=L11)

Selected range is from 170.62(=M11) to 186.62(=N11)
 Mean value in simulation was 178.64

Cell: D11



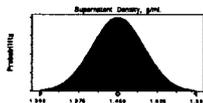
Assumption: Supernatant Density, g/mL

Normal distribution with parameters:

Mean 1.450 (=K17)
 Standard Dev. 0.050 (=L17)

Selected range is from 1.250(=M17) to 1.650(=N17)
 Mean value in simulation was 1.449

Cell: D17

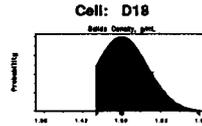


Assumption: Solids Density, g/mL

Normal distribution with parameters:

Mean 1.50 (=K18)
Standard Dev. 0.05 (=L18)

Selected range is from 1.45 to 1.70(=N18)
Mean value in simulation was 1.52

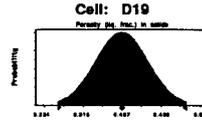


Assumption: Porosity (liq. frac.) in solids

Normal distribution with parameters:

Mean 0.407 (=K19)
Standard Dev. 0.061 (=L19)

Selected range is from 0.257(=M19) to 0.557(=N19)
Mean value in simulation was 0.406

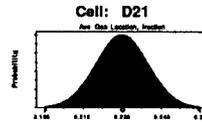


Assumption: Ave Gas Location, fraction

Normal distribution with parameters:

Mean 0.225 (=K21)
Standard Dev. 0.010 (=L21)

Selected range is from 0.185(=M21) to 0.265(=N21)
Mean value in simulation was 0.225

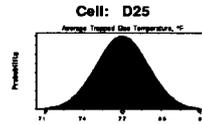


Assumption: Average Trapped Gas Temperature, °F

Normal distribution with parameters:

Mean 77 (=K25)
Standard Dev. 2 (=L25)

Selected range is from 69(=M25) to 85(=N25)
Mean value in simulation was 77

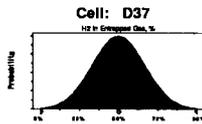


Assumption: H2 In Entrapped Gas, %

Normal distribution with parameters:

Mean 50% (=K37)
Standard Dev. 15% (=L37)

Selected range is from 2%(=M37) to 97%(=N37)
Mean value in simulation was 49%

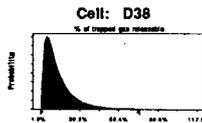


Assumption: % of trapped gas releasable

Lognormal distribution with parameters:

Mean 15.0% (=K38)
Standard Dev. 14.0% (=L38)

Selected range is from 0.0% to 75.0%
Mean value in simulation was 14.3%

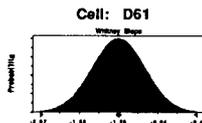


Assumption: Whitney Slope

Normal distribution with parameters:

Mean -1.25 (=K61)
Standard Dev. 0.27 (=L61)

Selected range is from -5.00(=M61) to 5.00(=N61)
Mean value in simulation was -1.25

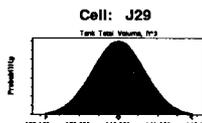


Assumption: Tank Total Volume, ft^3

Normal distribution with parameters:

Mean 140,600 (=K29)
Standard Dev. 500 (=L29)

Selected range is from 139,194(=M29) to 142,006(=N29)
Mean value in simulation was 140,603



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ATTACHMENT G

DISTRIBUTION OF SLOPES

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The ranges of slopes determined by Whitney (1995) for an individual tank for a period of time (e.g., January 1991 through summer 1995) can be summed mathematically and depicted graphically by an approximate distribution, as shown by the solid curve on Figure G.1. The distribution can be divided into quantiles, and an approximate mean and an approximate standard deviation can be determined as well. The slope of -1.44 in. of level per in. Hg at the 0.25 quantile is the 75-percentile slope, that is, 75% of the slope values are less negative than -1.44 in. of level per in. Hg.

The approximating distribution cannot be described simply in the software program Crystal Ball¹, which is used to perform Monte Carlo analyses. Therefore, Whitney has defined "Qfit," a Gaussian distribution which has the same 25-percentile and 75-percentile values as the approximating distribution. The Qfit mean and a Qfit SD can be entered into Crystal BallTM to represent the approximating distribution. See Whitney's explanation in his mail message reproduced on page G-5.

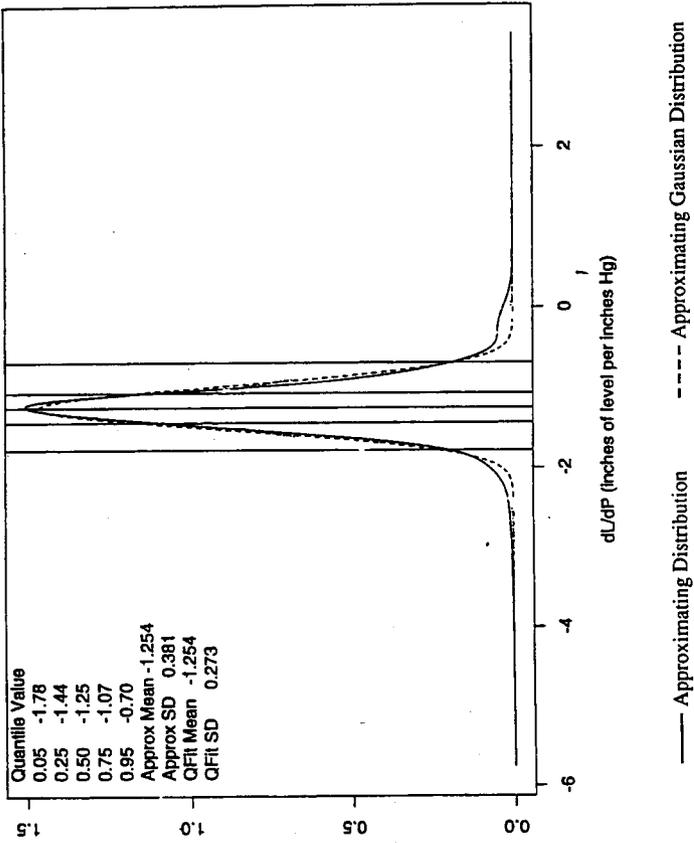
REFERENCE

Whitney, P. D., 1995, *Screening the Hanford Tanks for Trapped Gas*, PNL-10821, Pacific Northwest Laboratory, Richland, Washington.

¹ Crystal Ball is a registered trademark of Decisioneering, Inc. of Aurora, CO.

Figure G.1. Distribution of Barometric Slopes

S-106 FIC (lag = 0)



cc:Mail for: James D (Dave) Hopkins

Subject: QFIT**From: whitney@blake.pnl.gov at -SMTPlink 11/21/95 11:55 AM****To: James D (Dave) Hopkins at -WHC55****cc: Kent M Hodgson at -WHC215**

Dave,

The distribution used to summarize the slope estimate is described in section 5.2 of the report PNL-10821. Since Crystal Ball cannot take that generic a distribution as input, an approximating Gaussian distribution was made by matching the first and third quantiles of the summary distribution and a Gaussian distribution. The resulting mean and standard deviation of this approximating Gaussian distribution are reported on the "histogram" plots as QFit Mean and QFit SD, respectively. Also, on these plots the solid line shows the approximating distribution and the dashed line shows the approximating Gaussian distribution.

-Paul

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ATTACHMENT H

**VOID FRACTION RESULTS
FOR TANK 241-SY-103**

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cc: Mall for: James D (Dave) Hopkins

Subject: Latest gas volume in SY-103
From: Charles W Stewart at ~PNL106 8/23/95 4:45 PM
To: James D (Dave) Hopkins at ~WHC55
To: Gerald D (Jerry) Johnson at ~WHC130
To: Jack W Lentsch at ~WHC130
To: Paul D Whitney at ~SMPTLink
To: Joe W Brothers at ~PNL35
To: Norton G McDuffie at ~WHC130
To: Joseph E Meacham at ~WHC130
To: W B (Blaine) Barton at ~WHC12
To: Mary E Brewster
To: kop@lanl.gov at ~SMPTLink
To: bobwhite@lanl.gov at ~SMPTLink
To: wkubic@lanl.gov at ~SMPTLink

Having received the 'validate' and re-calculated void fractions from Jim Alzheimer last night, I have recalculated the gas volumes. Here is what I get:

Both risers have:

Waste surface level = 272 inches
 Max sludge depth = 130 inches

22A riser - may represent 'pre-GRE' state

Average void fraction 7.8 ± 2 %
 Effective pressure 1.8 atm
 Best estimate volume 6700 ± 1700 SCF (if entire tank had this void)

17C riser - may represent 'post-GRE' state

Average void fraction 4.8 ± 1.9%
 Effective pressure 1.85 atm
 Best estimate volume 4100 ± 1600 SCF (if entire tank had this void)

WHOLE TANK - ASSUMING HALF IS LIKE 22A AND HALF IS LIKE 17C:

Best estimate volume 5400 ± 1700 SCF
 Upper bound volume 7400 SCF

For information only, release volumes and resulting hydrogen concentrations are:

Best est. release 2000 ± 1000 SCF
 Upper bound release 3800 SCF

Best est. H2 concentration 0.7 ± 0.4%
 Upper bound H2 conc. 1.8%

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ATTACHMENT I

CONDITIONS NOT EVALUATED

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Section 2.0 of this document defines four flammable gas conditions in which gas from the waste might exceed safe limits and be a factor in the release of waste to the environment: the steady-state concentration of flammable gas in the tank headspace, the concentration after an EGR, the ignition of a gas plume as it escapes from the waste, and overpressurization of a tank's exhaust filter caused by the release of pressurized gas from the waste. Sections 4.0 through 8.0 present the method for evaluating steady-state and post-EGR conditions, except for potential future increases in entrapment. Future entrapment is discussed briefly in Section I-1.0 below.

The main body does not discuss plume burn or overpressurization. A brief discussion of the plume burn is provided in Section I-2.0 for background, and a discussion of overpressurization is provided in Section I-3.0 for possible use in future evaluations.

I-1.0 POTENTIAL FUTURE ENTRAPMENT

Attachment B, paragraph 5.5, requires that even if a tank is found not to meet the flammable gas criteria, the tank's trends must be evaluated to determine whether it has the potential to increase the size of gas release in the foreseeable future. For example, if analysis of a tank's surface level shows an EGR in the tank currently could attain 24% of the LFL (too low to meet the criteria), but the tank has a steadily increasing level rise and might exceed the 25% level in the near future, then the tank should be considered to exceed the criteria.

I-2.0 EVALUATION OF PLUME BURN POTENTIAL

Evaluating whether a plume burn can cause failure in an SST requires information not yet available. Heard (1995) has performed a modeling study to determine the pressure required to cause exhaust high-efficiency particulate air (HEPA) filter failure in DST SY-101. A plume of about 190 ft³, containing 48% H₂ and 48% N₂O could generate the 10 in. w.g. pressure differential required to cause failure of the exhaust HEPA filter in this DST. A plume of about 50 ft³ of the same mixture could generate the 10 in. water gauge (w.g.) needed to cause failure of the tank's inlet HEPA filter (Heard 1995). Because the HEPA filter on an SST is located at the top of a riser, as is the 101-SY inlet filter, it is assumed that a 50-ft³ plume also could cause failure of an SST HEPA filter in an SST filled with waste. The explosive force of this plume could be generated by a plume of about 25 ft³ of 97% H₂, assuming this plume mixed with air and underwent 100% combustion.

The criteria for plume burns requires that a tank not be able to have a burn of a plume which has 25% of the volume which could cause a serious release to the environment. Whether a plume burn of that size is credible in an SST must be determined by safety analysis.

I-3.0 EVALUATION OF OVERPRESSURIZATION

There is a concern that when pressurized gas is released from tank waste, it can overpressurize the tank's HEPA filter. New HEPA filters can withstand an overpressure of about 6.9 kPa (1 psi, or 27.7 in. w.g.) However, when a filter is placed into service, its pores begin to accumulate fine specs of dust, thereby decreasing the rate at which the filter relieves the overpressure. Moreover, the filter material and strength degrade after prolonged exposure to heat. The longer a filter is used, the lower the overpressure it can withstand. HEPA filters are rated to withstand only 2.49 kPa (10.0 in. w.g., or 0.361 psi) (DOD 1988). Including a factor-of-four safety margin in accordance with the flammable gas criteria document (Hopkins 1994), the criterion for overpressurization is a pressure differential of 0.623 kPa (2.50 in. w.g., or 0.0903 psi).

I-3.1 OVERPRESSURIZATION QUICK SCREEN

A quick screen to determine whether a release can overpressurize a tank can be made by determining how much trapped gas *would have to be instantly released* to overpressurize the filter and comparing that to how much gas *can be released*. For example, if a tank would have to instantly release 100 m³ of trapped gas, but it contains only 50 m³ and could only release 25% of that (12.5 m³), the tank could not possibly exceed the overpressurization criterion. In this example, the ratio of the required instantaneous release to the maximum possible release is 200:12.5, that is, 8:1. Here, a 100 m³ release corresponds to a release fraction of 2.0, so the ratio of the required instantaneous release fraction to the maximum possible release fraction, 0.25, is also 8:1.

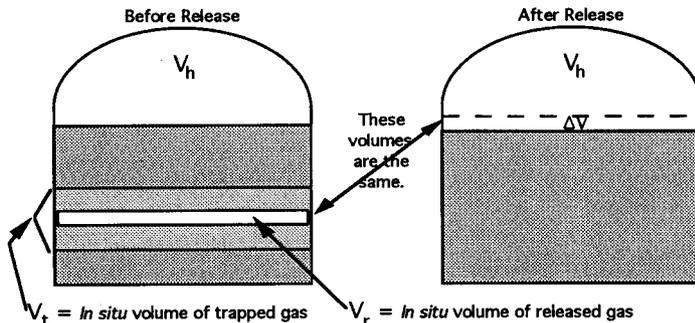
Therefore, a quick screen can be performed by calculating the required release fraction, k , and comparing that to 0.25. If the required instantaneous release is greater than 0.25, the tank can not possibly overpressurize the HEPA filter, that is, could not possibly exert an overpressure of 0.623 kPa on the HEPA filter. A formula for calculating whether this can occur in a tank is derived in Sections I-3.1.1 and I-3.1.2.

I-3.1.1 Assumptions

The following conservative assumptions are made.

- The release is adiabatic; that is, with the system defined as the headspace gas plus the gas released into the headspace, the system neither gains nor loses heat during the release.
- The release of trapped gas from the waste is instantaneous.
- The final volume, V_f , of the headspace (after the gas is released from the waste) is the volume of the headspace before the release, V_h , plus the *in situ* volume of the gas release, kV_t , where k is the release fraction and V_t is the total volume of trapped gas. That is, $V_f = V_h + kV_t$. See Figure I-1.

Figure I-1. Gas Release Increases Headspace.



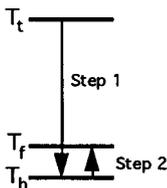
I-3.1.2 Calculations

The final pressure is determined by calculating the headspace temperature after the release, then using that temperature to calculate the final pressure. The calculation has three parts. Note that for parameters in this section, subscripted letters have the following meanings:

- a at ambient conditions
- f for/in/of the final headspace condition, immediately after release
- h for/in/of the headspace, before release
- r for/in/of the gas released
- t for/in/of the trapped gas

Part 1: Calculate the amount of heat given off when the released gas cools to T_h . As shown in Figure I-2, the temperature of the trapped gas, T_t is greater than the initial headspace gas temperature, T_h . Therefore, the final temperature of the headspace gas will be a bit higher than T_h .

Figure I-2. Calculate the Final Temperature of Headspace Gas in Two Steps



The heat released, Q, when the plume cools to T_h in Step 1 is:

$$Q = n_r \times C_p^t \times \Delta T = kn_t \times C_p^t \times (T_t - T_h) \quad [\text{Eq. I-1}]$$

Note: C_p^t = specific heat (at constant pressure) of the trapped gas
 n_r = moles of gas released
 n_t = moles of trapped gas
 k = fraction of gas released

C_p values are shown in Table I-1.

Table I-1. Specific Heats

Gas	C_p^t joules/mol-°C
Air	29.16
H ₂	28.82
H ₂ O	33.9
N ₂	29.12
N ₂ O	38.45

Part 2: Return the heat back to the mixture of plume gas and headspace air to raise the temperature of the combined gas, as shown in Step 2 in Figure I-2. Using the value of Q from Part 1, calculate the resulting temperature as follows:

$$Q = (kn_t C_p^t + n_h C_p^h) \times (T_f - T_h)$$

where C_p^h = specific heat (at constant pressure) of the headspace gas before the release

Substituting for Q from Equation I-1.

$$Q = kn_t C_p^t (T_t - T_h) = (kn_t C_p^t + n_h C_p^h) \times (T_f - T_h)$$

$$(T_f - T_h) = kn_t C_p^t (T_t - T_h) / (kn_t C_p^t + n_h C_p^h)$$

$$T_f = T_h + \frac{kn_t C_p^t (T_t - T_h)}{kn_t C_p^t + n_h C_p^h}$$

$$T_f = T_h + \frac{kn_t C_p^t T_t - kn_t C_p^t T_h}{kn_t C_p^t + n_h C_p^h}$$

$$T_f = \frac{T_h (kn_t C_p^t + n_h C_p^h)}{kn_t C_p^t + n_h C_p^h} + \frac{kn_t C_p^t T_t - kn_t C_p^t T_h}{kn_t C_p^t + n_h C_p^h}$$

$$T_f = \frac{T_h (kn_t C_p^t + n_h C_p^h) + kn_t C_p^t T_t - kn_t C_p^t T_h}{kn_t C_p^t + n_h C_p^h}$$

$$T_f = \frac{(kn_t C_p^t T_h + n_h C_p^h T_h) + kn_t C_p^t T_t - kn_t C_p^t T_h}{kn_t C_p^t + n_h C_p^h}$$

$$T_f = \frac{n_h C_p^h T_h + kn_t C_p^t T_t}{kn_t C_p^t + n_h C_p^h}$$

$$T_f = \frac{kn_t C_p^t T_t + n_h C_p^h T_h}{kn_t C_p^t + n_h C_p^h} \quad [\text{Eq. I.2}]$$

Part 3: Determine the final pressure by conservation of mass. The number of moles of gas contained in the headspace after the release is the sum of the moles of gas in the headspace before the release and moles of gas released from the waste.

where

$$n_f = n_h + n_r = n_h + kn_t \quad [\text{Eq. I.3}]$$

k = fraction of gas released
 n_f = final moles in the headspace, after release
 n_h = moles in the headspace before release
 n_r = moles released = kn_t
 n_t = moles trapped gas

From the ideal gas law,

$$n_f = P_f V_f / RT_f \quad [\text{Eq. I.4}]$$

$$n_h = P_h V_h / RT_h$$

$$kn_t = P_t k V_t / RT_t$$

Into Equation I.3, substitute Equation I.4, then solve for P_f .

$$P_f V_f / RT_f = n_h + kn_t$$

$$P_f = (n_h + kn_t) RT_f / V_f$$

$$P_f = (P_h V_h / RT_h + k P_t V_t / RT_t) \times RT_f / V_f$$

$$P_f = \frac{P_h V_h / T_h + k P_t V_t / T_t}{V_f} \times T_f \quad [\text{Eq. I.5}]$$

Into Equation I.5, substitute $V_f = V_h + \Delta V = V_h + k V_t$ from Figure I-1 to get the following:

$$P_f = \frac{P_h V_h / T_h + P_t k V_t / T_t}{V_h + k V_t} \times T_f \quad [\text{Eq. I.6}]$$

Into Equation I.6, substitute for T_f from Equation I.2:

$$P_f = \frac{P_h V_h / T_h + P_t k V_t / T_t}{V_h + k V_t} \times \frac{k n_t C_p^t T_t + n_h C_p^h T_h}{k n_t C_p^t + n_h C_p^h} \quad [\text{Eq. I.7}]$$

Once the final headspace pressure is determined from this formula, the overpressure on the HEPA filter can be determined. The overpressure, P_o , is the difference between barometric pressure outside the tank, P_b , and P_f .

$$P_o = P_f - P_b \quad [\text{Eq. I.8}]$$

According to the criterion given by Hopkins (1994), P_o may not exceed 0.623 kPa, (2.5 in. w.g., or 0.364 psi). Substituting from Equation I.8 gives the following:

$$P_o = 0.623 \text{ kPa} = P_f - P_b \quad [\text{Eq. I.9}]$$

Into Equation I.9, substitute for P_f from Equation I.7:

$$\begin{aligned} P_o &= 0.623 \text{ kPa} \\ &= \left[\frac{P_h V_h / T_h + P_t k V_t / T_t}{V_h + k V_t} \times \frac{k n_t C_p^t T_t + n_h C_p^h T_h}{k n_t C_p^t + n_h C_p^h} \right] - P_b \end{aligned} \quad [\text{Eq. I.10}]$$

This equation can be solved for k . However, the solution is too long to present here.¹ On the other hand, an approximation which gives results within about 1% of the actual value for k can be derived by assuming C_p^t is equal to C_p^h . Substituting C_p^h for C_p^t in Equation I.10 and simplifying gives Equation I.11:

$$\begin{aligned} P_o &= 0.623 \text{ kPa} \\ &= \left[\frac{P_h V_h / T_h + P_t k V_t / T_t}{V_h + k V_t} \times \frac{k n_t C_p^h T_t + n_h C_p^h T_h}{k n_t C_p^h + n_h C_p^h} \right] - P_b \end{aligned}$$

Factoring and canceling C_p^h gives:

$$P_o = \left[\frac{P_h V_h / T_h + P_t k V_t / T_t}{V_h + k V_t} \times \frac{k n_t T_t + n_h T_h}{k n_t + n_h} \right] - P_b$$

¹ A simple way to determine the value of k is to set up Equation I.10 in an Excel™ spreadsheet and use "Goal Seek" to determine the value of k .

Rearranging the first numerator gives:

$$P_o = \left(\frac{kP_t V_t / T_t + P_h V_h / T_h}{V_h + kV_t} \times \frac{kn_t T_t + n_h T_h}{kn_t + n_h} \right) - P_b$$

Substituting nR for PV/T gives:

$$P_o = \left(\frac{kn_t R + n_h R}{V_h + kV_t} \times \frac{kn_t T_t + n_h T_h}{kn_t + n_h} \right) - P_b$$

Rearranging and canceling like terms gives:

$$P_o = \left(\frac{(kn_t + n_h)R}{V_h + kV_t} \times \frac{kn_t T_t + n_h T_h}{kn_t + n_h} \right) - P_b$$

$$= \frac{R(kn_t T_t + n_h T_h)}{V_h + kV_t} - P_b$$

Substituting PV/R for nT gives:

$$P_o = \frac{R(kP_t V_t / R + P_h V_h / R)}{V_h + kV_t} - P_b$$

$$= \frac{kP_t V_t + P_h V_h}{V_h + kV_t} - P_b$$

$$= 0.623 \text{ kPa} = \frac{kP_t V_t + P_h V_h}{V_h + kV_t} - P_b \quad [\text{Eq. I.11}]$$

Solving for k gives the following:

$$k = \frac{-V_h(P_h - P_b - P_o)}{V_t(P_t - P_b - P_o)} = \frac{-V_h(P_h - P_b - 0.623)}{V_t(P_t - P_b - 0.623)} \quad [\text{Eq. I.12}]$$

When C_p^t and C_p^h are equal, there is no difference between the results calculated using Equation I.10 and I.11. However, in bounding calculations, C_p^t and C_p^h are not equal, and the value of k approximated with Equation I.11 can be as much as 3 to 4% higher.

The bounding case involves a trapped gas mixture with the highest specific heat, that is, 97% N₂O and 3% H₂O. Its specific heat is 38.3 J/mol-°C (0.97 x 38.45 + 0.03 x 33.9).

For a plume containing 97% H₂ and 3% H₂O, the specific heat is 29.0 J/mol·°C ($0.97 \times 28.82 + 0.03 \times 33.9$).

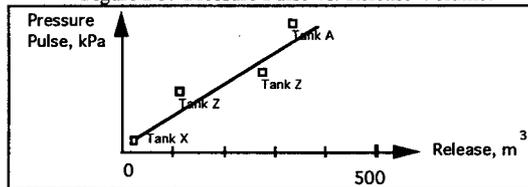
If overpressurization would require a release fraction greater than 0.25 (may be larger for DSTs), the tank's HEPA filter cannot be overpressurized, as explained at the beginning of Section I-3.1. On the other hand, if the calculation shows that the HEPA can be overpressurized by a release fraction of less than or equal to 0.25, further analysis is required.

I-3.1.3 Further Evaluation

For tanks that fail this quick screen, a more comprehensive evaluation can be done to remove the excess conservatism from the estimate. The most conservative of the three assumptions is that the release of trapped gas from the waste is instantaneous, which means the overpressurization takes place instantly. In fact, a release takes place over a time interval ranging from a few minutes to several hours. It may be possible to use release data to estimate the effect of this delay on tanks.

Moreover, for DSTs it may be possible, by plotting bounding pressure pulse vs. release volume, to determine a relationship such as that shown in Figure I-3, and to use this relationship plus a safety margin as a predictor of the maximum pressure pulse in other tanks. On the other hand, if insufficient information is available, it may not be possible to remove the excess conservatism.

Figure I-3. Pressure Pulse vs. Release Volume.



I-4.0 REFERENCES

- DOD, 1988, *Filters, Particulate (High-Efficiency Fire Resistant)*, Mil-F-51068F, U.S. Department of Defense.
- Heard, F. J., 1995, Rev 0, *Waste Tank 241-SY-101 Dome Air Space and Ventilation System Response to a Flammable Gas Plume Burn*, WHC-SD-WM-ER-515, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

ATTACHMENT J

METHODOLOGY REVIEW

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On December 5 and 6, 1995, a committee co-chaired by D. M. Ogden and P. U. Peistrup reviewed the methodology presented in this document. The report of their review is presented on pages J-4 through J-10 of this attachment. Following their report is the response of the evaluation team to the review comments.

REFERENCES

- Hopkins, J. D., 1994, *Criteria for Flammable Gas Watch List Tanks*, WHC-EP-0702, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- Shepard, C. L., C. W. Stewart, J. M. Alzheimer, G. Terrones, G. Chen, and N. E. Wilkins, 1995, *In Situ Determination of Rheological Properties and Void Fraction: Hanford Waste Tank 241-SY-103*, PNL-10865, Pacific Northwest National Laboratory, Richland, Washington.

**Westinghouse
Hanford Company**
**Internal
Memo**

From: Plant Systems Safety Basis/TWRS Safety Basis 74D10-95-DMO-009
 Phone: 376-0438 HO-34/373-3119 S7-14
 Date: December 12, 1995
 Subject: REVIEW OF THE FLAMMABLE GAS EVALUATIONS

To: A. M. Umek S7-81

cc: W. B. Barton R2-11 E. J. Lipke S7-14
 T. R. Beaver HO-34 F. A. Schmittroth HO-35
 G. R. Franz S7-81 E. R. Siciliano HO-31
 G. D. Johnson S7-15 J. P. Slaughter R2-54
 N. W. Kirch R2-11 DMO File/LB
 PEP File/LB

- References:
- (1) Whitney, P., 1995, *Screening the Hanford Tanks for Trapped Gas*, PNL-10821, Pacific Northwest Laboratory, Richland, Washington.
 - (2) Hopkins, J. D., 1994, *Criteria for Flammable Gas Watch List Tanks*, WHC-EP-0702, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
 - (3) Hopkins, J. D., 1995, *Methodology for Flammable Gas Evaluations*, WHC-SD-WM-TI-724, Rev. 0, REVIEW DRAFT, Westinghouse Hanford Company, Richland, Washington.
 - (4) WHC, *Flammable Gas Evaluation*, WHC-SD-WM-ER-526, Rev. 0, DRAFT, Westinghouse Hanford Company, Richland, Washington.

INTRODUCTION

A screening of the Hanford high level waste tanks was performed by Pacific Northwest National Laboratory (PNNL) (Reference 1) using a barometric pressure method. The 38 tanks not previously identified on the Flammable Gas Watch List were subsequently evaluated against existing flammable gas criteria (Reference 2). Per your request, an independent peer review of this flammable gas evaluation has been conducted. The scope of the review included the methodology for the evaluations (Reference 3), the application of the methods (Reference 4), and the recommendation of tanks to be placed on the Flammable Gas Watch List. The review was conducted in two phases. The first phase included a detailed evaluation of the screening methods including quality assurance reviews and independent statistical and thermal

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hydraulic analyses. A two-day formal review was then performed for all aspects of the flammable gas evaluations. The review team members included:

Phil Peistrup (Co-chairman)	Westinghouse Hanford Company
Don Ogden (Co-chairman)	Westinghouse Hanford Company
Al Neuls	Los Alamos National Laboratory
Marvin Thurgood	John Marvin, Inc.
Frank Schmittroth	Westinghouse Hanford Company
Tom Beaver	Westinghouse Hanford Company

Martin Plys, Fauske & Associates, Inc., reviewed the referenced documents and provided comments but did not participate in the formal review.

A summary of the review teams evaluation is provided below followed by a detailed discussion of the review.

SUMMARY

The review team believes that the screening methods identified in Reference 3 and applied in Reference 4, with some recommended modifications, are suitable tools for evaluating the potential for gas generation, storage and release to the tank dome space. The methods selected to quantify trapped gas are valid for this purpose. The conservatism of the screening methods and the poor quality of some of the data available for evaluation can lead to false positive results for individual screening methods. However, the review team believes that when the screening methods are properly applied, there should be consistency in the results. For these reasons, it is recommended that a waste tank not be considered for the Flammable Gas Watch List unless it fails two-out-of-three evaluation methods. Twenty tanks are recommended by the review team for the Flammable Gas Watch List based on this approach. Fifteen of the twenty waste tanks failed three-out-of-three screening methods.

A103	AW104	AY101
BX107	BY101	BY102
BY103	BY105	BY109
C104	C105	S101
S102	S103	S106
S107	S109	TX112
TX115	U102	

The review team concurs that the Quick Screen methodology as applied is sufficiently conservative for the purpose of quickly identifying waste tanks requiring no further consideration or screening. However, all tanks which

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fail the Quick Screen should be evaluated by the full suite of evaluation methods.

The team was presented with proposed revisions to the flammable gas criteria based on 100% of the Lower Flammability Limit (LFL) but did not attempt to evaluate revised criteria or review specific controls for flammable gas tanks. However, many assumptions in the methodology depend on this criteria and, if it is changed, then the review team believes certain assumptions in the methodology will need to be reevaluated.

The review team believes that there is reasonable evidence to show that all waste tanks generate and trap flammable gas to some degree and that appropriate flammable gas controls should be applied to all tanks during intrusive waste activities.

A discussion of the review teams evaluation follows.

BAROMETRIC PRESSURE METHOD

The review team concurs with the overall methodology of the barometric pressure method. This method is based on correlating measured changes in tank waste level to changes in atmospheric pressure through statistical analyses of the data (Reference 1 and 3). It is believed to be adequately conservative although individual assumptions including gas release fraction and gas location may not be conservative for all situations and some gas trapping mechanisms can result in an underestimate of the trapped gas volume (false negative). The overall conservatism of the method is demonstrated by the following. The estimated gas volumes are based on a slope estimate which bounds 75% of the calculated slopes. The Monte Carlo method presented to the review team was used to quantify the uncertainties in the analytical parameters and showed that the 75% slope estimate generally compared to the Monte Carlo method at the 99% confidence level. Schmittroth and Beaver presented statistical analyses performed by using independent statistical analyses tools. Their analyses compared well with void fraction data for three waste tanks and demonstrated that the 75th percentile slope is conservative by a factor of 50% to 100%. In principle the 75% point estimate and the Monte Carlo method at the 99% confidence levels are both acceptable approaches. However, the Monte Carlo uncertainty distribution for the gas release fraction should peak near the assumed 25% release fraction and the uncertainty in the gas overpressure should be included. The review team believes that these refinements of the model are required.

The application of the barometric pressure method to tanks which have been saltwell pumped may lead to an overly conservative estimate of trapped gas or a false positive result. In these tanks the method relies on interstitial liquid level measurements which are currently of poor quality. In addition the liquid level increase observed in some of these tanks may be due to liquid draining rather than flammable gas storage. The review team believes that the three methods should show a consistency of results and recommends that no tank be placed on the flammable Gas Watch List unless it fails two-out-of-three of the methods. For tanks with poor quality level data, an attempt should be made to collect data which can remove the large uncertainty in the estimate of trapped gas volume.

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TANK LEVEL METHOD

The review team believes that the tank level method described in Reference 2 is a reasonable and valid method. The stated methodology takes into account factors that may influence the liquid level other than gas accumulation. These include losses due to evaporation, compaction, leakage and pumping and additions due to in-leakage, moisture absorption, and crystal expansion. The review team found, however, that these contributing factors have not been adequately accounted for in the current evaluation and the results are therefore of limited value. Thurgood presented results of his independent analyses and application of the tank level method. His work used reasonable and conservative assumptions to estimate tank ventilation flows and the resulting evaporation. The Thurgood results were very consistent with the barometric pressure method and a modified steady-state method. The consistency between these methods is a result of improved ventilation flow and evaporation estimates. It should be noted that the initial gas volume has not been accounted for in the application of this method. The estimates of the ventilation flow rates are conservative and will generally compensate for small amounts of initial gas. However, future applications of this method should consider this possible non-conservatism. The review team recommends incorporation of the Thurgood enhancements to the tank level method.

The current methodology document recommends that this method be used only when the surface level measurement (or ILL level measurement) shows an increase in time. Because evaporation can mask the effect of gas accumulation even in tanks where the measured level is decreasing, it is recommended that the method be applied to all tanks where the liquid level is near or above the solids level. We believe that it is not appropriate to apply these estimates of evaporation to tanks which have liquid levels that are a significant distance below the waste level since evaporation in these tanks probably comes from damp solids above the gas trapping saturated liquid level which is lower in the waste and do not affect the liquid level that is affected by gas accumulation. However, for these situations it is appropriate to apply the tank level method without evaporation.

STEADY-STATE METHOD

The original purpose of this evaluation was to determine the potential for exceeding 25% of the LFL in the dome space from steady state release of generated gas, not episodic or accidental releases. As implemented, the evaluation used a combination of predicted and measured values for dome space gas concentration. The results were inconsistent and of little value for screening purposes. Thurgood showed that by using the ventilation flow estimates from his revised tank level method, the steady-state method resulted in consistent estimates of dome space gas concentrations. These results also compared very well with measured values where they existed and demonstrated that flammable gas concentrations would not be expected to exceed 25% of the LFL even for tanks with high generation rates and passive ventilation. Thus, the method is of little value for screening purposes. The real value in the steady-state method is the estimate of gas generation rate.

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The review team recommends that the steady-state method should use the conservative barometric breathing rate when calculating flammable gas concentrations. The results will then indicate the gas generation potential of the tank. The gas concentrations from the revised steady-state method should not be added to the other methods. The value of using the revised steady state method (which could be called the gas generation method) is seen for tanks like AP107 and AZ101. The modified steady-state method predicts a very high gas generation rate for these tanks. The other methods suggest that they have little potential for trapping the gas, and therefore are not recommended for the Flammable Gas Watch List. However, future operations which may change the level of settled solids and thus the tanks ability to trap gas, may require a flammable gas screening.

It should also be noted that when the steady-state method is applied as suggested, the results are consistent with the other methods. Thus, if one of the methods is not available because of poor data, two viable methods remain to screen the tank.

QUICK-SCREEN METHOD

The purpose of the quick screen is to eliminate tanks from further analysis. This method assumes that 7.35% of the total waste volume is compressed gas (based on SY-101 experience) which is released to the dome space (100% release fraction). If the resulting concentrations is less than 25% of the LFL, the tank passes the screen and is not considered for further evaluation. The review team concurs with this approach if the total waste volume is used for the analyses, not the less conservative wet solids volume. This method appropriately eliminates about 40 tanks with low volumes from further evaluation.

APPLICATION OF METHODS

The four methods that are used in the current methodology are: (1) the quick screen, (2) the steady-state method, (3) the tank level method and (4) the barometric pressure method. It is understood that all the methods are conservative and rely on tank data which can be of poor quality with large uncertainty. Furthermore, the methods should give consistent results if they are properly applied. The review team believes that one method by itself is insufficient evidence to place a tank on the Flammable Gas Watch List. There should be consistent evidence from at least two of the three methods that the tank meets the Flammable Gas Watch List criteria. The review team recommends that the modifications to the tank level and steady-state method discussed previously be implemented and that a tank should be considered for the Flammable Gas Watch List if it fails two-out-of-three of the methods. We note, however, that the gas generation potential should be noted for tanks in which this parameter exceeds 25% of the LFL since a change in the operating status or waste loading of tanks could result in a flammability hazard.

FLAMMABLE GAS WATCH LIST CRITERIA AND CONTROLS

The review team was presented with a revised Flammable Gas Watch List criteria which would utilize 100% of the LFL as its basis. The team did not attempt to evaluate this revised criteria or review specific controls for

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flammable gas tanks. However, the following cautions are offered. The criteria chosen for Flammable Gas Watch List determination should consider the degree of conservatism in the analytical methods being used and the uncertainty of the data available to perform the calculations. The four methods defined in Reference 2 do not consider the in situ ignition of flammable gas or the ignition of hydrogen in local plumes where the gas is escaping from the waste. The conservatism of the methodology relies on maintaining the average concentration of flammable gas in the tank dome at a safe level below the lower flammability limit. This concentration has currently been established to be 25% of the LFL. It is the opinion of the review team that many assumptions in the methodology depend on this criteria and, if the criteria is changed, then certain assumptions in the methodology need to be reevaluated.

If the entire body of work documented in References 1, 3 and 4 are considered as a whole, a reasonable person can conclude that all waste tanks produce flammable gas and are capable of trapping it to some degree. The review team recommends that all activities in waste tanks be conducted in accordance with NFPA standards recognizing that releases from unexpected mechanisms may occur, particularly for waste intrusive activities.

RECOMMENDATION FOR FLAMMABLE GAS WATCH LIST

Reference 4 evaluated 44 waste tanks. Only the 38 tanks which failed the Whitney Screen were considered by the teams review. The review team used the revisions to the tank level and steady-state methods presented by Thurgood and a two-out-of-three criteria to evaluate the tanks for the Flammable Gas Watch List. It should be noted that 75% of the tanks recommended for the Flammable Gas Watch List failed all three screening methods.

Tanks AW106 and BY106 are excluded from the list and require reevaluation because of recent pumping activities in the tank.

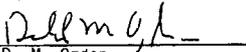
The committee recommends the following tanks for the Flammable Gas Watch List based upon a careful consideration of the evaluation methods and applications and believes the list reasonably represents the tanks which could have "serious potential for release of high level waste."

A103	AW104	AY101
BX107	BY101	BY102
BY103	BY105	BY109
C104	C105	S101
S102	S103	S106
S107	S109	TX112
TX115	U102	

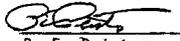
A. M. Umek
Page 7
December 12, 1995

74D10-95-DMO-009

The review team recommends that all waste tanks should be evaluated using the four screening methods with the recommended modifications.



D. M. Ogden
Plant Systems Safety Basis



P. E. Peistrup
TWRS Safety Basis

Table J.1. Response to Review Comments (4 sheets)

No.	Location	Recommendation/Comment	Response
1	P. 3, Baro Press Method	... assumptions including gas release fraction and gas location may not be conservative for all situations, and some gas trapping mechanisms can result in underestimate of the trapped gas volume.	<p>a. <u>Gas release fraction</u>. This is a valid issue for the deterministic calculation. PNNL is investigating this issue. Meanwhile, preliminary indications are that the assumptions used are conservative. The evaluation methodology will be modified if PNNL's results determine the assumptions are not conservative.</p> <p>b. <u>Gas location</u>. This needs further study. A videotape of recent 1/75th-scale gas-release experiments by P. A. Gauglitz show that gas has a tendency to continually migrate upwards in solids waste. Intuitively, it seems that for tanks which have never had a major gas release (most or all SSTs), the center of gas would be higher than for a tank which has had a release recently. In any case, sensitivity analysis shows that varying the gas location has little impact on the % LFL. Because the location is already assumed to be deep in the tank, the assumed gas depth can only be increased a small amount and therefore can only raise the pressure on the gas, and the trapped-gas volume, by a few percent (e.g., 2-5%) in most cases.</p> <p>c. <u>Gas-trapping mechanisms</u>. This needs further study. If trapping occurs via certain mechanisms, the gas volume can be underestimated, but it appears that the factors that cause the gas to be underestimated would also cause the fraction released to be smaller than 0.25; e.g., a high yield strength for sludge could delay gas expansion caused by decreasing barometric pressure, but the high yield strength is likely to decrease the fraction released at any one time.</p>
2	P. 3, Baro Press Method, para 1	... Monte Carlo uncertainty distribution for the gas release fraction should peak near the 25% release fraction... (continued on next page)	Examination of data for DSTs which have periodic releases (except for tank SY-101, which has been mitigated) shows that no DST has had a release fraction of more than 0.21 (Shepard, et al. 1995). SSTs are expected to have lower release fractions than DSTs. (continued on next page)

Table J.1. Response to Review Comments (4 sheets)

No.	Location	Recommendation/Comment	Response
2	P. 3, Baro Press Method, para 1	... Monte Carlo uncertainty distribution for the gas release fraction should peak near the 25% release fraction... (continued from previous page)	<p>This proposed distribution would be <u>very</u> conservative and not realistic. For example:</p> <ul style="list-style-type: none"> • For 58% of EGRs, the release fraction would exceed 0.25. • For 50% of EGRs, the fraction would be higher than 0.29. • For 10% , the fraction would exceed 0.51. • For 1%, the fraction would exceed 0.70. <p>On the other hand, if the distribution were just for a particular scenario—say, a DST during a magnitude 8 earthquake—the distribution should be shifted to the right.</p>
3	P. 3, Baro Press Method, para 1	... the uncertainty in the gas overpressure should be included.	<p>The effect on barometric analysis appears to be minor regarding variations between pressure at the Hanford Meteorological Station and the tank, as discussed in Section 8.7 of this methodology document.</p> <p>One element of pressure on the gas is surface tension, which has been addressed in Section 8.1 and found not to be significant. Uncertainties related to variations in solids yield stress are not addressed in the document but are being investigated by PNNL.</p> <p>The effect appears to be more significant regarding the practice of not recording the exact time when a manual surface level readings is taken. This means there is some uncertainty in the pressure at the time of the surface level reading. This issue still needs to be resolved.</p> <p>Meanwhile, the review committee found that using the 75-percentile barometric slope gives conservative values for gas volumes.</p>
4	P. 3, Baro Press Method, para 2	... the three methods should show a consistency of results and recommends that no tank be placed on the FGWL unless it fails two-out-of-three of the methods.	<p>It is desirable that results be consistent. However, this is not always possible, perhaps owing to the poor quality of surface level data available. Moreover, a tank might pass the surface level evaluation simply because a leak from the tank masks a surface-level rise, while the tank fails analysis based on barometric slope.</p> <p>The evaluation team does not recommend whether a tank be placed on the Flammable Gas Watch List. It simply reports evaluation results. Note, however, that the criteria document for FGWL (Hopkins 1994) requires that if a tank fail any one of the criteria—for example, the steady-state criterion or the episodic-release criterion—that it be placed on the FGWL. This proposal will be considered in any future revision to the criteria.</p>

Table J.1. Response to Review Comments (4 sheets)

No.	Location	Recommendation/Comment	Response
5	P. 3, Baro Press Method, para 2	For tanks with poor quality level data, an attempt should be made to collect data which can remove the large uncertainty in the estimate of trapped gas volume.	Agreed. This has been done for some tanks.
6	P. 4, Tank Level Method, para 1 and para 2	... the initial gas volume has not been accounted for.... ...future applications of this method should consider this possible nonconservatism. The review team recommends incorporation of the Thurgood enhancements to the tank level method. ... It is recommended that the method be applied to all tanks where the liquid level is near or above the solids level.	<p>Most of the evaluations have accounted for the initial gas volume, However, for a few tanks evaluated in 1995, this was not done.</p> <p>The Thurgood enhancements to the tank level method were incorporated into the evaluations for tanks with a liquid surface.</p>
7	P. 5, Steady-State Method, first para on page 5	The review team recommends that the steady state method should use the conservative barometric breathing rate when calculating flammable gas concentrations [and not take into account any mechanical ventilation]. The results will then indicate the <u>gas generation potential</u> of the tank. The gas concentration from the revised steady state method should not be added to the other methods. (Emphasis added by underlining.)	<p>The recommended practice is more conservative than required by Hopkins 1994, Appendix E, para 4.8, "Worst Case Calculation - Steady-State Concentration." On the other hand, the recommendation is consistent with Appendix E, para 6.0, "OTHER," which requires evaluating the tank for "other potential hazards."</p> <p>For tanks evaluated since January 1996, the Excel™ spreadsheet calculated and reported the steady-state concentration without mechanical exhaust. However, the concentration was not considered in the decision-making process.</p> <p>The recommended calculation is appropriate for Safety Analysis work to identify tanks which need ventilation and Technical Safety Requirements-level controls on the ventilation system.</p>
8	P. 5, Application of Methods	The review team recommends that the modifications to the tank level ... discussed previously be implemented	See item 6.

Table J.1. Response to Review Comments (4 sheets)

No.	Location	Recommendation/Comment	Response
9	P. 5, Application of Methods	The review team recommends that the modifications to the ... steady state method discussed previously be implemented... the <u>gas generation potential</u> should be noted for tanks in which this parameter exceeds 25% of the LFL since a change in the operating status or waste loading to tanks could result in a flammability hazard. (Emphasis added by underlining.)	See item 7.
10	P. 5, Application of Methods	The review team recommends that ... a tank should be considered for the Flammable Gas Watch List if it fails two-out-of-three of the methods.	See item 4.
12	p 6, Flammable Gas Watch List and Controls	The following cautions are offered. ... The four methods ... do not consider <i>in situ</i> ignition of flammable gas or the ignition of hydrogen in local plumes	<p>a. <u>In situ ignition</u>. The evaluation team is not evaluating the possibility of <i>in situ</i> ignition.</p> <p>b. <u>Plume burn</u>. Further study is required on this issue. Analysis based Heard's (1995) small-burn model results is being done to see if a plume burn is credible. If so, tanks must be evaluated against the plume burn criteria. Until then, tanks passing the other screens should not be considered free of plume burn hazard.</p>

ATTACHMENT K

**REVISED TANK LEVEL METHOD FOR
FLAMMABLE GAS EVALUATION**

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REVISED TANK LEVEL METHOD FOR FLAMMABLE GAS EVALUATION

by

M.J. Thurgood
D.M. Ogden

John Marvin, Inc.
WHC

1. INTRODUCTION.

A rising liquid level is one of the parameters that has been recognized to indicate trapped gas in the 1990 Flammable Gas Watch List (FGWL) evaluation and is being used by the current evaluation team as a method for determining the volume of trapped gas in waste tanks [Ref 1]. While the current evaluation team has recognized the importance of the effect of evaporation on liquid level, hence, on the estimate of the volume of trapped gas in the waste tank, time limitations have not permitted them to incorporate this effect into their spread sheet calculation for estimating the potential flammable gas concentration in the tank dome resulting from a gas release event (GRE) in a tank.

As a part of a review that we have been asked to conduct on the Methodology for Flammable Gas Evaluations, we have developed an approximate method for estimating the level change that should occur within a tank due to evaporation. This estimate of expected level change can then be compared with the measured level change to obtain an estimate of the volume of trapped gas in the waste. The methods and assumptions developed in Reference 1 are then used to determine the fraction of this gas that can be released to the tank dome and the resulting percentage of the lower flammability limit (LFL).

2. ESTIMATION OF EVAPORATION RATE.

The method for estimating the evaporation rate is dependent on the following parameters:

1. Ventilation flow rate.
2. Inlet air temperature and relative humidity.
3. Tank dome atmosphere temperature and relative humidity.

The air inlet temperature has been assumed to be at the yearly average atmospheric temperature for Hanford, 56.3°F and the relative humidity of the inlet air is assumed to be 50%. The dome atmosphere temperature is assumed to be the yearly average dome temperature where this value is available, otherwise, the slurry temperature given in the spreadsheets of [Ref 1] is assumed to be the dome average temperature.

The ventilation flow rate is estimated using one of three methods:

1. If the tank is ventilated and/or tank ventilation rates have been estimated previously using more sophisticated thermal hydraulic analyses, the known or calculated ventilation flow rates are used to estimate the evaporation rates. Often, the values used for the forced ventilation flows are those given in the spread sheets if better references are not known. In addition, these ventilation flows are limited to be no larger than the flows estimated using method 3 below.
2. If measured values for dome hydrogen concentration are available, the passive ventilation required to

maintain the tank dome at the measured concentration given the hydrogen generation rates given in the spreadsheets of [Ref 1] can be calculated as:

$$Q = R \frac{(1 - v_{fH2})}{v_{fH2}} \quad (2.1)$$

where:

Q = passive ventilation inflow rate.

R = Hydrogen generation rate from spreadsheet.

v_{fH2} = measured volume fraction of hydrogen in the tank dome.

If flows cannot be determined from method 1 above, then the flow estimate obtained using this method is used to estimate the tank evaporation rate.

3. If no other information is available to provide natural ventilation flows, it is assumed that all of the tank heat load is removed by natural ventilation flow and the flow required to remove this energy is calculated. This is believed to provide a very conservative estimate of ventilation flow and evaporation rate since thermal analyses that have been performed to date indicate that most, if not all, of the heat generated in these passively ventilated tanks can be removed by conduction through the ground [Ref. 2].

The total heat removed from the tank by the ventilation flow is:

$$q_T = q_A + q_S + q_E \quad (2.2)$$

where:

q_T = total heat removed by ventilation flow.

q_A = heat removed by sensible heat transfer to air.

q_S = heat removed by sensible heat transfer to water vapor that is in the incoming air.

q_E = heat removed by latent heat of vaporization due to evaporation of liquid from the tank waste surface.

Each of these quantities can be calculated as follows:

By definition, the relative humidity of the inlet air is:

$$\phi_I = \frac{P_{SI}}{P_{gI}} \quad (2.3)$$

where:

P_{SI} = partial pressure of water vapor in the inlet flow.

P_{gI} = saturation pressure of water vapor at the inlet temperature.

Since the inlet air humidity and temperature are specified quantities, the partial pressure of steam in the inlet flow can be calculated:

$$P_{SI} = \phi_I P_{gI} \quad (2.4)$$

The volume fraction of steam in the inlet flow is:

$$v_{fSI} = \frac{P_{SI}}{P_{\infty}} \quad (2.5)$$

where:

P_{∞} = Atmospheric pressure

The inlet volumetric flow rate of steam is:

$$Q_{SI} = Q_I v_{fSI} \tag{2.6}$$

where:

Q_I = total inlet volumetric flow.

The inlet volumetric flow rate of dry air is:

$$Q_{AI} = Q_I (1 - v_{fSI}) \tag{2.7}$$

The outlet volumetric flow rate of dry air is proportional to the volumetric flow of air in and the ratio of the outlet to inlet air temperatures:

$$Q_{AO} = Q_{AI} \frac{T_O}{T_I} \tag{2.8}$$

where:

T_O = outlet temperature = average dome atmosphere temperature.

T_I = inlet air temperature = annual average ambient air temperature.

The outlet volume fraction of steam is:

$$v_{fSO} = \phi_0 \frac{P_{gO}}{P_{\infty}} \tag{2.9}$$

where:

ϕ_0 = outlet relative humidity = 100%.

P_{gO} = water vapor saturation pressure at the outlet temperature.

The outlet volume fraction of air in the outlet flow is:

$$v_{fAO} = (1 - v_{fSO}) \tag{2.10}$$

So, the outlet volumetric flow of water vapor is:

$$Q_{SO} = Q_{AO} \frac{v_{fSO}}{v_{fAO}} \quad (2.11)$$

and the total outlet volumetric flow is:

$$Q_O = Q_{AO} + Q_{SO} \quad (2.12)$$

The corresponding mass flow rates are:

$$m_{AI} = \frac{P_{\infty}}{R_A T_I} Q_{AI} \quad (2.13)$$

$$m_{SI} = \frac{P_{\infty}}{R_S T_I} Q_{SI} \quad (2.14)$$

$$m_{AO} = \frac{P_{\infty}}{R_A T_O} Q_{AO} \quad (2.15)$$

$$m_{SO} = \frac{P_{\infty}}{R_S T_O} Q_{SO} \quad (2.16)$$

where:

m_{AI} = air mass flow rate in.

m_{SI} = water vapor mass flow rate in.

m_{AO} = air mass flow rate out.

m_{SO} = water vapor mass flow rate out.

R_A = gas constant for air.

R_S = gas constant for water vapor.

T_I = inlet temperature.

T_O = outlet temperature.

Q_{AI} = partial volumetric flow rate of air in.

Q_{SI} = partial volumetric flow rate of water vapor in.

Q_{AO} = partial volumetric flow rate of air out.

Q_{SO} = partial volumetric flow rate of water vapor out.

The rate of evaporation is given as:

$$m_E = m_{SO} - m_{SI} \quad (2.17)$$

The rate of change in tank liquid level is:

$$\Delta \text{level} = \frac{m_E}{\rho_1(T_0) A_{\text{tank}}} \quad (2.18)$$

where:

$\rho_1(T_0)$ = density of water at the dome temperature.

A_{tank} = cross-sectional area of tank.

m_E = evaporation rate.

The heat removed by each heat removal mechanism is:

Sensible heat to air:

$$Q_A = m_{AI} C_{PAI} (T_0 - T_I) \quad (2.19)$$

where:

C_{PAI} = specific heat of inlet air.

Sensible heat to inlet water vapor:

$$Q_S = m_{SI} (h_{gout} - h_{gin}) \quad (2.20)$$

where:

h_{gout} = water vapor saturation enthalpy at T_0 .

$h_{g,in}$ = water vapor saturation enthalpy at T_I .

Heat of vaporization due to evaporation:

$$Q_E = m_E h_{fg} \quad (2.21)$$

where:

h_{fg} = latent heat of vaporization for water at T_0 .

Since the inlet temperature, inlet relative humidity and outlet relative humidity are specified and given the inlet volumetric flow and dome temperature, the above set of equations can be solved to obtain a set of curves that give the evaporation rate versus tank inlet ventilation flow for each outlet temperature or a set of curves that give the heat removal rate versus tank inlet ventilation flow for each outlet temperature. These curves are shown in the following two figures.

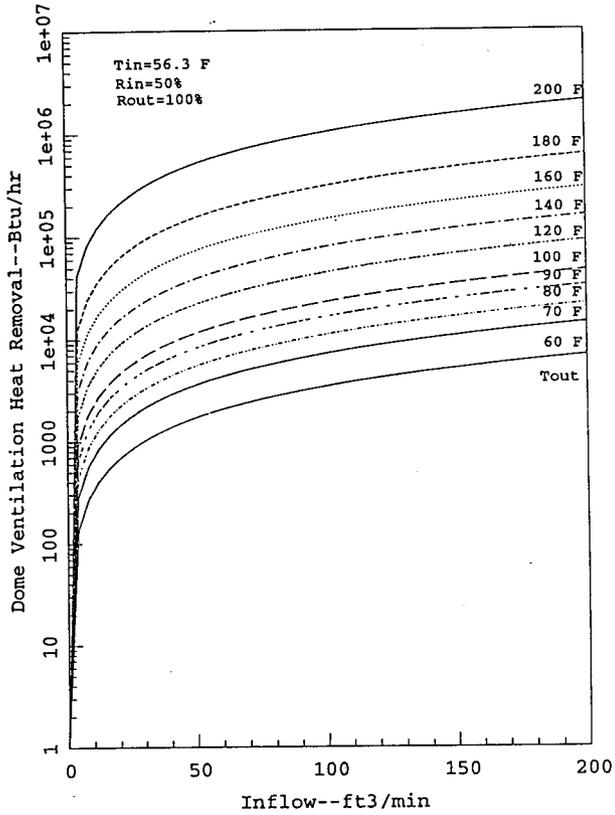


Figure 2.1 Low Heat Tanks with Natural Inflow Leakage. Dome Ventilation Heat Removal versus Inflow and Outlet Temperature.

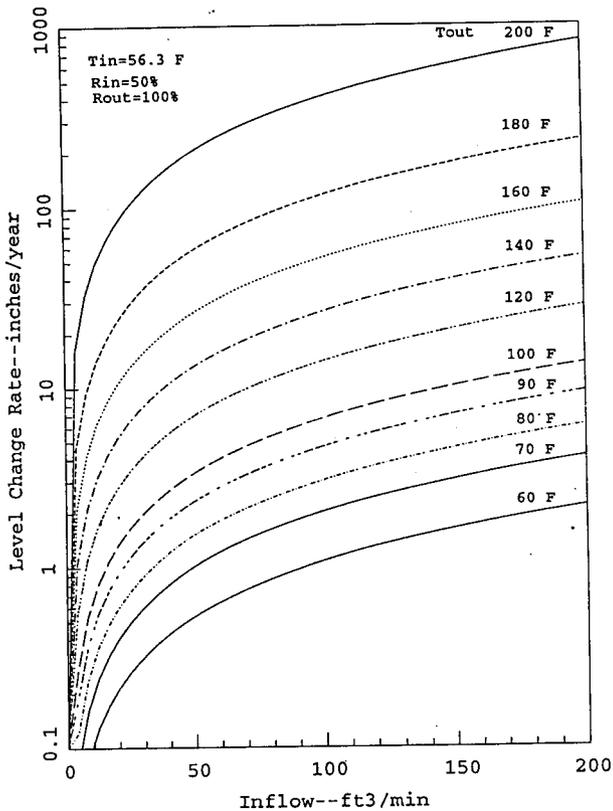


Figure 2.2 Low Heat Tanks with Natural Inflow Leakage. Tank Level Change Due to Evaporation Versus Inflow and Outlet Temperature

If the inlet ventilation flow is known, Figure 2.2 may be used to obtain the level change due to evaporation in inches per year. If the ventilation flow is not known by any of the other two methods for estimating the ventilation flow, then Figure 2.1 may be used to obtain the ventilation flow by assuming the y axis of the graph is the total tank heat load, drawing a horizontal line over to the curve corresponding to the tank dome temperature and then drawing a vertical line down to the horizontal axis of the graph to obtain an estimate for the tank's passive ventilation flow. Using this value for flow, enter Figure 2.1 using the estimate for flow on the horizontal axis and drawing a vertical line to the curve corresponding to the tank's dome temperature. Next draw a horizontal line to the vertical axis to obtain an estimate of the tank evaporation rate in inches/year.

3. ESTIMATE OF TANK LEVEL CHANGE.

The change in tank level is estimated in one of two ways.

1. When the tank exhibits a gradual change in level over several years and there is no apparent addition of water or waste nor is there any apparent extraction of waste from the tank, then the tank level early in its history is subtracted from the current tank level to obtain the net change in liquid level over that period of time.
2. When a tank's level is periodically changing (apparently due to water additions, waste subtractions or GRE's) then the most recent occurrence of a steady change in liquid level is used to obtain a rate of level change in inches per year. This rate is then multiplied by the period of time the tank is believe to have been accumulating gas to obtain an estimate of the total change of tank waste level over that period of time.

4. ESTIMATE OF TRAPPED GAS VOLUME.

The estimates for the evaporation rate and the tank level change are used to obtain an estimate for the in situ trapped gas volume. The time from when the tank is estimated to have started accumulating gas until the present time is used to calculate the total evaporation that should have occurred during this time period. If no estimate for the time period when gas generation started to occur is available, the earliest time available on the liquid level plots provided in [Ref 3] is used as the starting point for the trapping of gas. It is recognized that some gas may have been trapped in the waste prior to this time and further refinement of the gas estimate could be made if the time of the start of gas accumulation were more accurately known.

Once the total evaporation is known in inches and the total change in level is known, then the volume of trapped gas can be calculated as the difference between the two. If the measured tank level has increased in time, then the volume of trapped gas is equal to the measured change in level plus the change in level that should have occurred due to evaporation multiplied by the tank cross-sectional area. If the tank level has decreased over time, then the total volume of trapped gas is equal to the difference between the measured change in tank level and the change in tank level that should have occurred due to evaporation.

No limit is placed on the gas volume fraction that can be achieved in the waste.

5. VOLUME OF H₂ RELEASED AND %LFL IN HEAD SPACE.

The methods and assumptions for calculating the volume of gas released to the tank head space and for calculating the %LFL are exactly the same as those given in [Ref 1].

6. RESULTS.

The estimated ventilation flows, calculated amount of evaporation, estimated change in tank level, tank heat loads used to estimate ventilation flows, tank dome volumes, estimated H_2 generation rates and %LFL's resulting from gas generation rates with estimated vent flows and change in level with evaporation are presented in the following table. The %LFL calculated assuming the spreadsheet values of [Ref 1] for the gas generation rate and the estimated ventilation flows obtained from the analysis reported here result in %LFL's that are very low. This is to be anticipated since small ventilation flows can easily vent all of the gas that is being generated in the passively ventilated tanks and forced ventilation flow can easily remove the gas being generated in actively ventilated tanks without building up high H_2 concentrations. The estimated values are also consistent with values that have been measured in the tanks. Flows estimated from the tank heat load are conservative with respect to calculating the evaporation rate and volume of stored gas since they over estimate the evaporation rate. However, they are non conservative for estimating tank flammable gas venting rates since actual passive ventilation flows are likely to be lower than these estimated values.

A conservative estimate of the %LFL in the dome space can be obtained if the tank barometric breathing rate is used with the estimated gas generation rates.

The %LFL based on tank level change are the values obtained using the methodology described in this letter. The %LFL has been divided by a factor of 2 when the tank heat load estimate is the only method for estimating the tank ventilation flow. This is because, for passively ventilated tanks, previous heat transfer analyses have shown that most of the tank heat load can be removed by

conduction through the ground. The idea behind dividing by 2 is that at least one half of the tank heat load can be expected to be removed by conduction through the soil to the surface, however, dividing the %LFL by this factor is not strictly correct since the gas volume is also affected by the change in liquid level. The limited time available to perform this analysis has not permitted us to repeat the calculations using one half of the tank heat load (assume 1/2 is lost through the soil). This should be done, time permitting, in the near future. The values given in the table are still considered to be conservative and I would not expect any changes in recommendations for the tank watch list after the calculations are repeated.

Tank Number	Tank Heat Load (kW)	Measure Hydrogen Volume Fraction	Tank Ventilation Flow (cfm)	Measured Level Change (in.)	Tank Evaporation (in.)	Tank Dome Volume (ft ³)	H ₂ Gen Rate (ft ³ /day)	Steady State (B.E. flow) (%)	Tank Level Method with Evap (% LFL)
AI03	3.4		78	0.0	42	118272	6.38	0.6%	57%
AI05			150	-5	37.2	167135	0.49	0.012%	54%
AI07			150	-13.6	24	184808	16.6	0.40%	14%
AW103			100	-7.42	18.2	119511	0.075	0.027%	33%
AW104	3.11		160	-2.09	13.3	38233	2.68	0.10%	142%
AW106	2.79		48	-25.2	32.84	116258	3.38	0.11%	24%
AY101			600	-92.12	101.5	62121	24.6	0.10%	105%
AZ101			600	-1291	1320	67407	36.8	0.19%	Bad data
BX104		9.4e ⁻⁵	8.7	0.5	5.6	101022	1.18	0.39% -0.49%	17% - 31%
BX107	1.35		78	0.0	16.8	68256	1.5	0.078%	45%
BX112	0.926		61	-1.0	12.7	92812	1.26	0.15%	19%
BY101				No Corr	No Corr	111778	1.41		Bad data
BY102	1.62		73	2.0	23.8	103570	2.21	0.21%	35%
BY103		9.9e ⁻⁵	23.5	0.0	8.4	89320	3.35	0.42% - 0.52%	33% - 41%
BY105		4.79e ⁻⁵	43	7.0	13.1	82095	2.97	0.25% - 0.32%	56% - 85%
BY106	2.959	4.55e ⁻⁵	82	6.0	40.6	50586	7.29	0.32% -0.48%	141% - 365%
BY109	0.30		8	0.0	4.2	96959	4.7	4.2%	7.3%
C104		6.8e ⁻⁵	77.84	-26	44.8	81068	3.49	0.45%	66%
C105		2.2e ⁻⁵	110	-37	46.2	96353	3.5	0.12%	26%
C107		2.3e ⁻⁴	1.75	0.0	2.46	81068	0.81	1.6%	7.7%
S101	1.94		33	-14	28	84063	3.92	0.86%	28%

Tank Number	Tank Heat Load (kW)	Measure Hydrogen Volume Fraction	Tank Ventilation Flow (cfm)	Measured Level Change (in.)	Tank Evaporation (in.)	Tank Dome Volume (ft ³)	H ₂ Gen Rate (ft ³ /day)	Steady State (B.E. flow) (%)	Tank Level Method with Evap with Flow (% LFL)
S102		6.69e ⁻⁴	15.76	8.3	17.5	67949	18.4	4.2%	145% -
S103	0.80		27	5.54	11.2	104565	1.75	0.24%	52%
S105			400	No Corr.	No Corr.	85178	0.5	.004%	Bad data
S106	0.81		43	17	15.4	77587	2.85	0.48%	74%
S107	1.08		27	9	15.4	89817	2.29	0.61%	86%
S109				No Corr.	No Corr.	79656	1.78		Bad data
T107		9.4e ⁻³	6.5	1.0	1.5	90161	0.88	0.063% - 0.49%	8.6% - 18%
T111			21	1.3	3.92	52904	0.83	0.14%	13%
TX102				No Corr.	No Corr.	113342	0.83		Bad data
TX107						136794	0.59		
TX111				No Corr.	No Corr.	93646	1.52		Bad data
TX112				No Corr.	No Corr.	56278	2.07		Bad data
TX113				No Corr.	No Corr.	64046	0.67		Bad data
TX115				No Corr.	No Corr.	70084	0.72		Bad data
TY102	0.8		70	1.6	9.02	131640	0.85	0.084%	11%
TY103		9.3e ⁻⁵	8.5	-2	2.4	119159	1.14	0.11% - 0.48%	1.11% - 0.48%
U102	1.67		49	3.15	26.6	64317	13.8	2.0%	76%
U106			4.8	1.0	2.24	84087	1.45	0.22% - 1.0%	12% - 38%

7. REFERENCES

1. J.D. Hopkins, "Methodology for Flammable Gas Evaluations", WHC-SD-WM-TI-724, Rev.0, Westinghouse Hanford Company, November 1995.
2. R.D. Crowe, et. al., "Estimation of Heat Load in Waste Tanks Using Average Vapor Space Temperatures.", WHC-EP-0709, Westinghouse Hanford Company, December, 1993.
3. Paul Whitney, "Screening the Hanford Tanks for Trapped Gas", PNL-10821, Battelle Pacific Northwest Laboratories, October, 1995.

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ATTACHMENT L

PRESSURE VARIATIONS

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cc: Mail for: James D (Dave) Hopkins

Subject: Re: Pressure Variation in Tank Farms
From: Kenneth W Burk at ~PNL83 3/15/96 11:30 AM
To: James D (Dave) Hopkins

Dave,

I've answered your questions below using information we have here at HMS (Hanford Meteorological Station).

Ken,

I'm analyzing the correlation between surface level changes in tank waste and inverse barometric pressure. For the analysis to be valid, the ground-level pressure at the tanks must closely track the barometric pressure recorded by the PNNL Weather Station. I have 2 questions:

1. What are the average and bounding time intervals (to the closest 5 min.) between the recording of a pressure peak at the Station and the arrival of the peak at the tank farthest from the Station?

A typical weather front will pass through the area at about 25-30 miles per hour. I estimate that the straight line distance from HMS to the east edge of the 200 East area is about 5 miles. So the 200 East area would expect to experience a front anywhere from 10-12 minutes after HMS.

2. Using Station Pressure as a reference, what is the pressure differential per foot of elevation differential.

The "standard" is 1.00 inches Hg per 1000 feet, or 0.01 in. Hg per 10 feet.

3. What is the elevation of the Station barometer?

Our station (HMS) is at 733 feet, and the 200 East telemetry station is at 680 feet.

4. What is the steepest rate of pressure change seen in our area?

Last December (1995) we had 2 classic severe pressure change incidents.

Dec. 3, 1995: from 1200 PST to 2400 PST the pressure dropped 0.56 inches (-0.047 inches/hour), followed by a rise from 2400 PST to 1200 PST 12/4/95 of 0.76 inches (+0.063 inches/hour)

Dec. 12, 1995: from 000 PST to 1400 PST the pressure dropped 0.58 inches (-0.041 inches/hour), followed by a rise from 1400 PST to 0400 PST 12/13/95 of 0.61 inches (+0.044 inches/hour)

We also have a case documented from 1958.

Nov. 3, 1958: from 1500 to 1600 the pressure dropped 0.16 inches, and from 1500 to 2100 a total of 0.492 inches (-.082 inches/hr), followed by a rise 2300 to 0500 11/4/58 of 0.544 inches (+0.091 inches/hour)

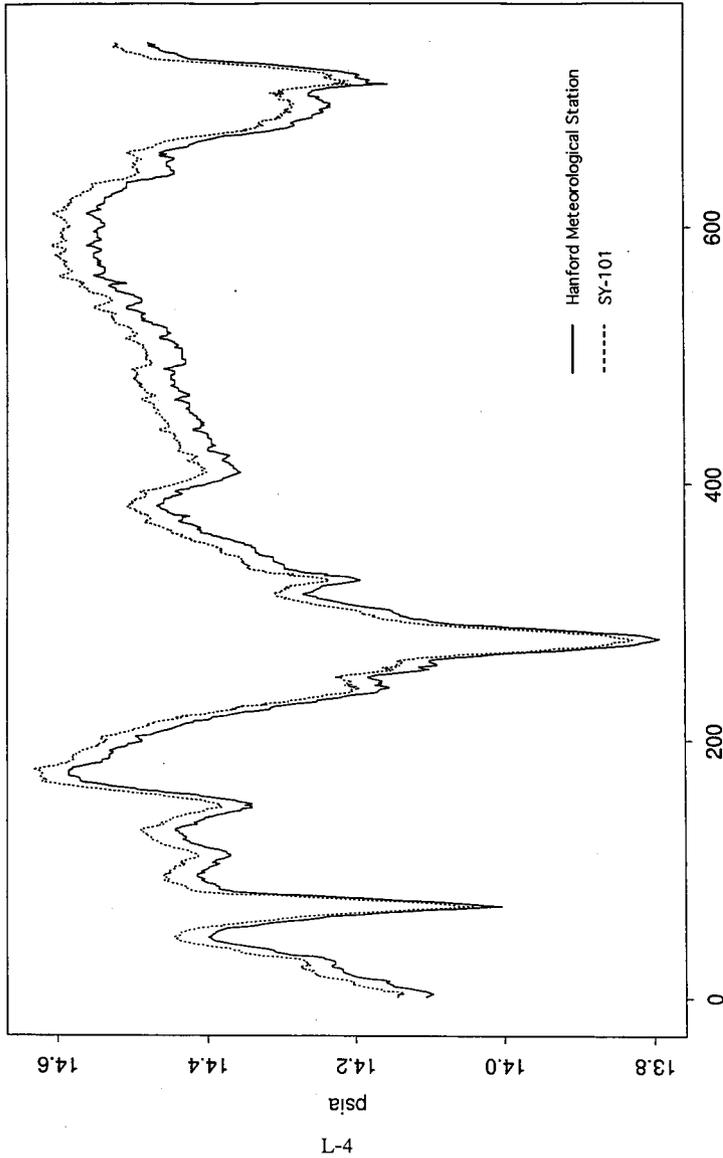
Dave - 373-5701

If you need any more information please let me know.

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Ken Burk
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(509)373-3215
Hanford Meteorological Station (HMS)
Battelle - PNNL S3-91
+++++

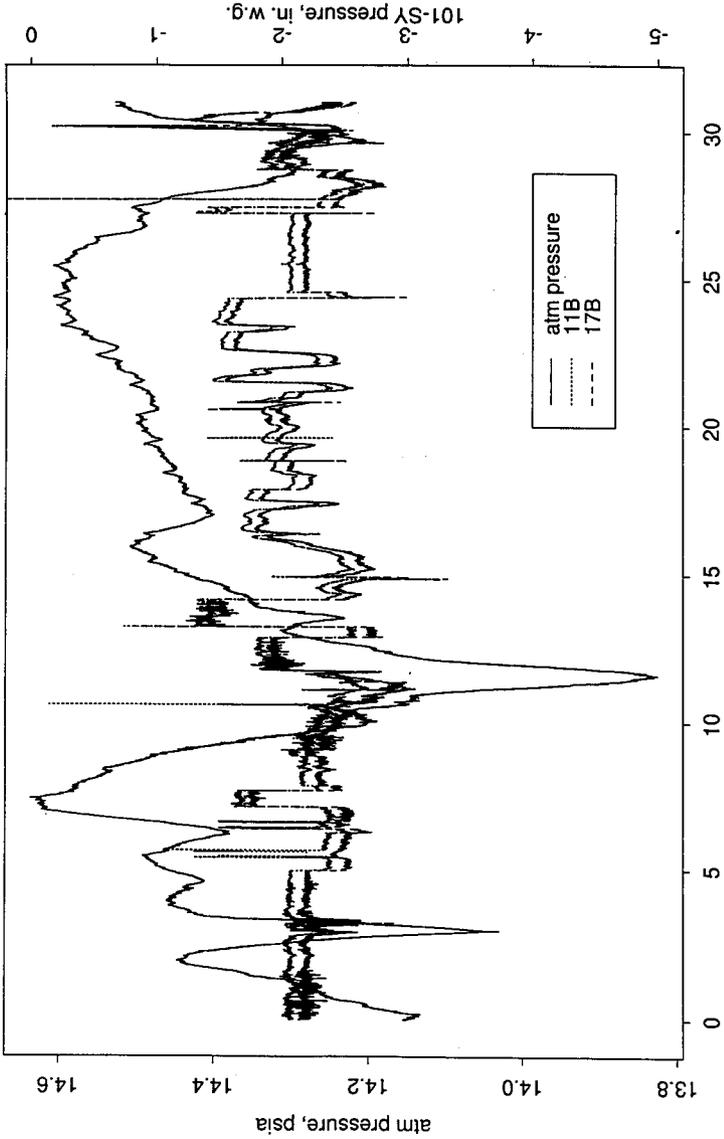
Barometric Pressure Comparison HMS Pressure vs. SY-101 Pressure



December 1 - 31, hours

PNL Wed Feb 28 11:36:25 PST 1996

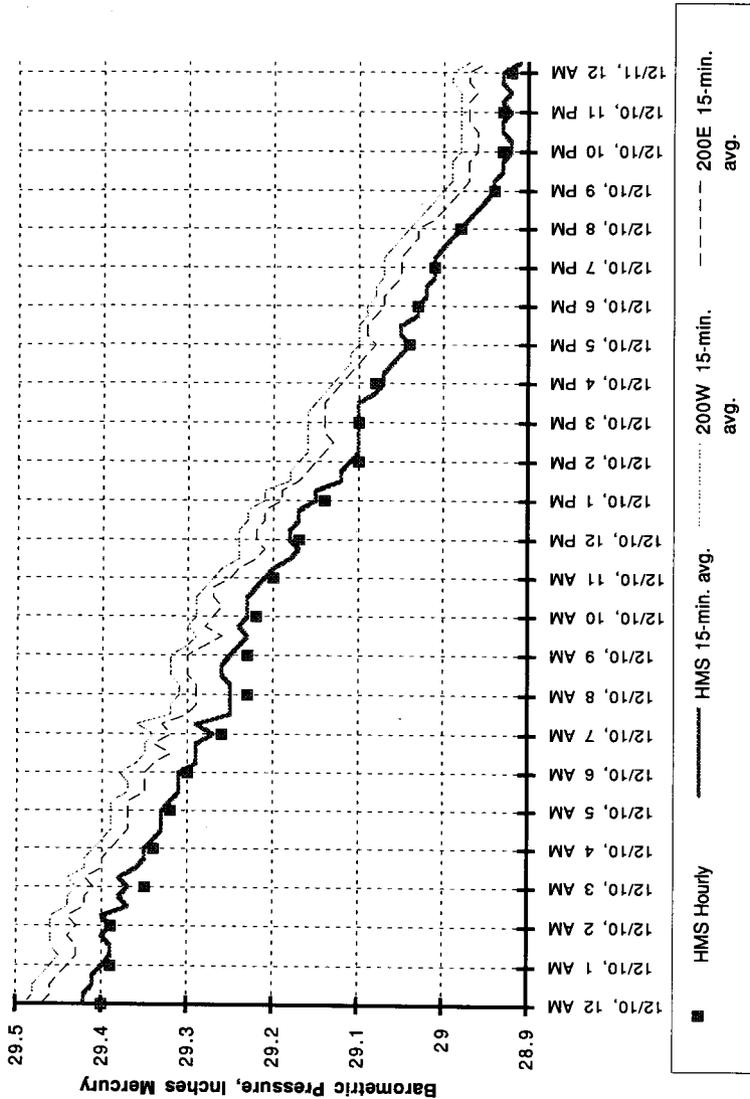
Atmospheric Pressure & 101-SY Dome Pressure



December 1 - 31, 1995

PNL Wed Mar 13 09:41:36 PST 1996

Comparison of HMS Pressure with 200 West and 200 East Pressure



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