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Analysis of Vehicle Fuel Release Resulting in Waste Tank Fire

L. S. Stephens, ENERCON Services, Inc., for
CH2M HILL Hanford Group, Inc.
Richland, WA 99352
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Abstract:
The purpose of the calculation documented here is to support bounding in-tank vehicle fuel fire accidents with organic solvent fire and flammable gas accidents in the DSA.

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Revision 0

Analysis of Vehicle Fuel Release Resulting In Waste Tank Fire

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

CH2MHILL
Hanford Group, Inc.

Richland, Washington

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC27-99RL14047

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L.S. Stephens
Enercon Services, Inc.

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March 2003

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LIST OF TERMS

ADF	aerosol depletion factor
ARF	aerosol release fraction
ARR	airborne release rate
DCRT	double-contained receiver tank
DSA	documented safety analysis
DST	double-shell tank
ERPG	emergency response planning guideline
HEPA	high-efficiency particulate air (filter)
LFL	lower flammability limit
LPF	leak path factor
ORPS	Occurrence Reporting & Processing System
RF	respirable fraction
SOF	sum of fractions
SST	single-shell tank
TEEL	Temporary Emergency Exposure Limit
UFL	upper flammability limit
ULD	unit-liter dose

LIST OF EQUATIONS

The following equation is obtained from referenced documents and is utilized to derive specific final spreadsheet results. The equation listed is only referenced in spreadsheet descriptions and is not included in spreadsheet formula descriptions.

EQ-1: RPP-13482, ***Atmospheric Dispersion Coefficients and Radiological/Toxicological Exposure Methodology for Use in Tank Farms***

Calculation of concentrations [C(mg/m3)] of toxin at the offsite location, where:

$$C = S \bullet V' \bullet \left[\frac{\left(\frac{\chi}{Q'}\right)}{1 + V'\left(\frac{\chi}{Q'}\right)} \right]$$

where:

S = toxic material concentration at source (mg/m^3)

V' = volumetric rate at source (m^3/s)

$\frac{\chi}{Q'}$ = continious release atmospheric dispersion factor (s/m^3).

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1.0 PURPOSE

This document reevaluates several aspects of the in-tank vehicle fuel fire/deflagration accident formally documented as an independent accident (representative accident [rep acc] 2). This reevaluation includes frequencies for the accidents and incorporates the behavior of gasoline and diesel fuel in more detail than previous analysis. This reevaluation uses data from RPP-13121, *Historical Summary of Occurrences from the Tank Farm Safety Analysis Report*, Table B-1, "Tank Farm Events, Off-Normal and Critiques," and B-2, "Summary of Occurrences," and from the River Protection Project – Occurrence Reporting & Processing System (ORPS) reports as a basis for changing some of the conclusions formally reported in HNF-SD-WM-CN-037, *Frequency Analysis of Vehicle Fuel Releases Resulting in Waste Tank Fire*. This calculation note will demonstrate that the in-tank vehicle fuel fire/deflagration accident event may be relocated to other, more bounding accidents.

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2.0 BACKGROUND AND ASSUMPTIONS

An event-tree analysis was performed to develop and evaluate all possible accident scenarios resulting from a vehicle striking a riser on top of an underground waste tank. The determination of frequencies for those accident scenarios are based on historical information and engineering analysis. Issues to be addressed include traffic flow, the expected quantity of fuel in vehicles that is available to be released, waste tank riser status, frequency of vehicle/riser interactions, and the probability of resulting fires or deflagrations.

2.1 TRAFFIC FLOW PATTERNS

Tanks are grouped into farms, and the boundaries of the farms are fenced. Determining the number of times that a vehicle passes each tank is not feasible. The ORPS reports pertinent to the accident of concern encompass all Hanford Site vehicle traffic, including all vehicle traffic in and near Hanford tank farms. Since their inception, tank farms have periodically undergone some degree of maintenance, modification, and upgrade. New tank farms and tank farm support facilities have been constructed over the same period. As an example, a new road and gate have recently been installed to support the vitrification plant. This new road and gate avoid the tank farms. Temporary traffic increases in and adjacent to tank farms above current levels would be anticipated during periods of construction and/or waste feed delivery projects and operations. Such temporary increases would not be expected to be appreciably higher than historical traffic patterns and would not be expected to significantly alter overall long-term traffic pattern expectations and observations.

2.2 EXPECTED VEHICLE FUEL VOLUME

Fifty gallons is the maximum anticipated fuel volume to be transported into any given tank farm. However, larger volumes (up to 300 gal diesel) could be expected in larger over the road vehicles that navigate roads near tank farm perimeters. Although initially the potential for an accidental spillage of as much as 300 gal of diesel fuel into an open waste tank riser could be considered remote, it may not be discounted completely. This is because all tank farms are bordered by paved roads, which vehicles carrying large quantities of fuel would traverse.

2.3 WASTE TANK RISER STATUS

This section contains explanatory text describing the physical characteristics of tank farms. Waste tank risers may be open for a variety of reasons other than breakages due to vehicle strikes. Ongoing approved work tasks such as surveillance measurements, equipment replacement, testing, and waste treatment are examples where a riser may be open at any given time. Qualitative judgment of the probability of an external accident introducing fuel into an open riser was influenced by the following physical realities:

1. The majority of riser and pit edges are at least marginally situated abovegrade. Fuel spill run on from an external accident would be diverted accordingly.

2. In a substantial portion of tank farms, a sizeable distance exists between the security fence adjacent to a paved or hard-packed gravel road and the closest riser. Fences are of chain link construction. This construction may provide some measure of vehicle diversion during an external vehicle accident. Such diversion, coupled with the riser/fence separation may limit riser strikes by vehicles involved in external vehicle accidents adjacent to the tank farm.

3. A permeable topsoil composition surrounds tanks and tank farms, allowing large quantities of fuel spilled external to a tank to be absorbed before a significant quantity would reach a tank.

4. Typically, open risers evolve from approved work packages and are administratively controlled and not subject to being left unattended.

5. Risers are sealed to the elements of weather. Fuel (or moisture) entry into a tank through a sealed riser is not anticipated. A berm, drain, slope, or french drain are provided for some tank farms and are located around a few individual tanks. Their purpose is for the redirection of weather-related moisture run-off. These controls, where available, could also be expected to divert potential fuel run-on.

6. Top hats are sealed to the riser. Top hats accommodate test, monitoring, and operational equipment. Top hats move the point at which fluids could enter the riser well abovegrade.

7. Work practices require that risers are not left unattended when open for approved activities. Upon the advent of some accident conditions, personnel may effect resealing of an open riser prior to exiting the area.

8. Typically, if a riser is removed from a tank annulus and not replaced for an extended period, cover blanks are provided to temporarily block the opening left by the removed riser.

9. An accident external to the tank farm involving large quantities of fuel would need to occur near an unattended open riser for fuel to enter a tank.

10. Airlift–circulator risers associated with aging–waste tanks are attached at grade level. Some grade level risers exist at all farms. This is especially true of the 241-AP Tank Farm. Typically grade level risers are sealed at the bottom of their associated pits, while the 241-AP Tank Farm grade level risers are double sealed.

2.4 HISTORICAL VEHICLE/RISER INTERACTIONS

Information regarding occurrences is recorded for a 30–year period at the Hanford Site in RPP-13121 and in the ORPS reports. During this period, four documented incidents involving vehicles and waste tank risers occurred. This information is used to determine frequencies and

conditional probabilities to establish the likelihood of related fires and deflagrations (see Section 4.1.1).

2.5 EXPECTED SIZE AND SEVERITY OF RELATED FIRES AND DEFLAGRATIONS

Appendix A evaluates the flammability and physical states of 50 gal of diesel and 10, 25, and 50 gal of gasoline spilled into a waste tank. Appendix A concludes that the maximum concentration of diesel fuel hydrocarbon vapor in any unventilated tank's headspace would reach approximately 8% of its lower flammability limit (LFL). Ventilated tanks would further reduce the hydrocarbon concentration in the headspace vapor. Concentrations of gasoline in its vapor phase of waste tanks with headspaces between 300,000 L and 2,500,000 L are within the LFL and upper flammability limit (UFL) of gasoline (i.e., 1.4 to 7.4%, respectively).

The following in-tank vehicle fuel fire/deflagration accident scenarios include evaluations for both diesel fuel and gasoline. Analysis formerly documented in tank farms final safety analysis report, evaluated the burning of gasoline and diesel fuel as pools on the waste surface, and as gasoline and diesel vapors forming flammable mixtures in the headspace of tanks prior to ignition (deflagration). In this document, Appendix A presents an evaluation of the partial pressures and concentrations of these fuels and fuel vapors in the headspace of different tanks. Appendix A, Part A, concludes that the highest vaporization of the diesel fuel into the maximum temperature headspace of any waste tank is not enough to exceed the LFL of the diesel–air mixture. Therefore, a headspace deflagration scenario resulting from diesel fuel vapor is not a viable accident and is not analyzed further in this calculation note. Diesel fuel vapor conclusions are based on the low vapor pressure of diesel, and highest temperatures in the waste tanks.

2.6 BACKGROUND INFORMATION AND ASSUMPTIONS

Following is a list of background information and assumptions used in this analysis:

- Tanks are grouped into farms, and the boundaries of the farms are fenced. Determining the number of times that a vehicle passes each tank is not feasible. The ORPS reports pertinent to the accident of concern encompass all Hanford Site vehicle traffic, including all vehicle traffic on and in the area of the Hanford Site tank farms.

- The single-shell tank (SST) farms were built between the early 1940s and the mid-1960s. All were in service by 1970. Since the ORPS occurrence reports document the period from 1972 to the present, a 30–year ORPS history is used for determining frequencies and estimating probabilities. RPP-13121, Tables B-1 and B-2, and the River Protection Project ORPS summarize occurrence reports and their predecessors for the last 30 years. Tables B-1 and B-2 and the ORPS document the number of accidents involving vehicles and risers.

- The SST and double-shell tank (DST) farms are combined in this analysis. The initiators and the accidents are identical for both SSTs and DSTs. No distinction between SSTs and DSTs for estimating accident frequencies is made.

- The maximum vaporization of the diesel fuel into the highest temperature headspace of any waste tank is not enough to exceed the LFL of the fuel–air mixture. The maximum hydrocarbon concentration of diesel fuel vapors in any unventilated tank's headspace would reach approximately 8% of its LFL. Ventilated headspaces would reduce this quantity. Diesel fuel vapor conclusions are based on the low vapor pressure of diesel and highest headspace temperatures in the waste tanks. Gasoline evaporation never reaches the LFL in tanks with headspaces above 2,500,000 L (Appendix A). Gasoline exceeds the UFL for tanks with headspaces less than 300,000 L (Appendix A).

- The maximum amount of fuel available for involvement in an accident is 50 gal of diesel and 50 gal of gasoline.

3.0 ACCIDENT SCENARIOS

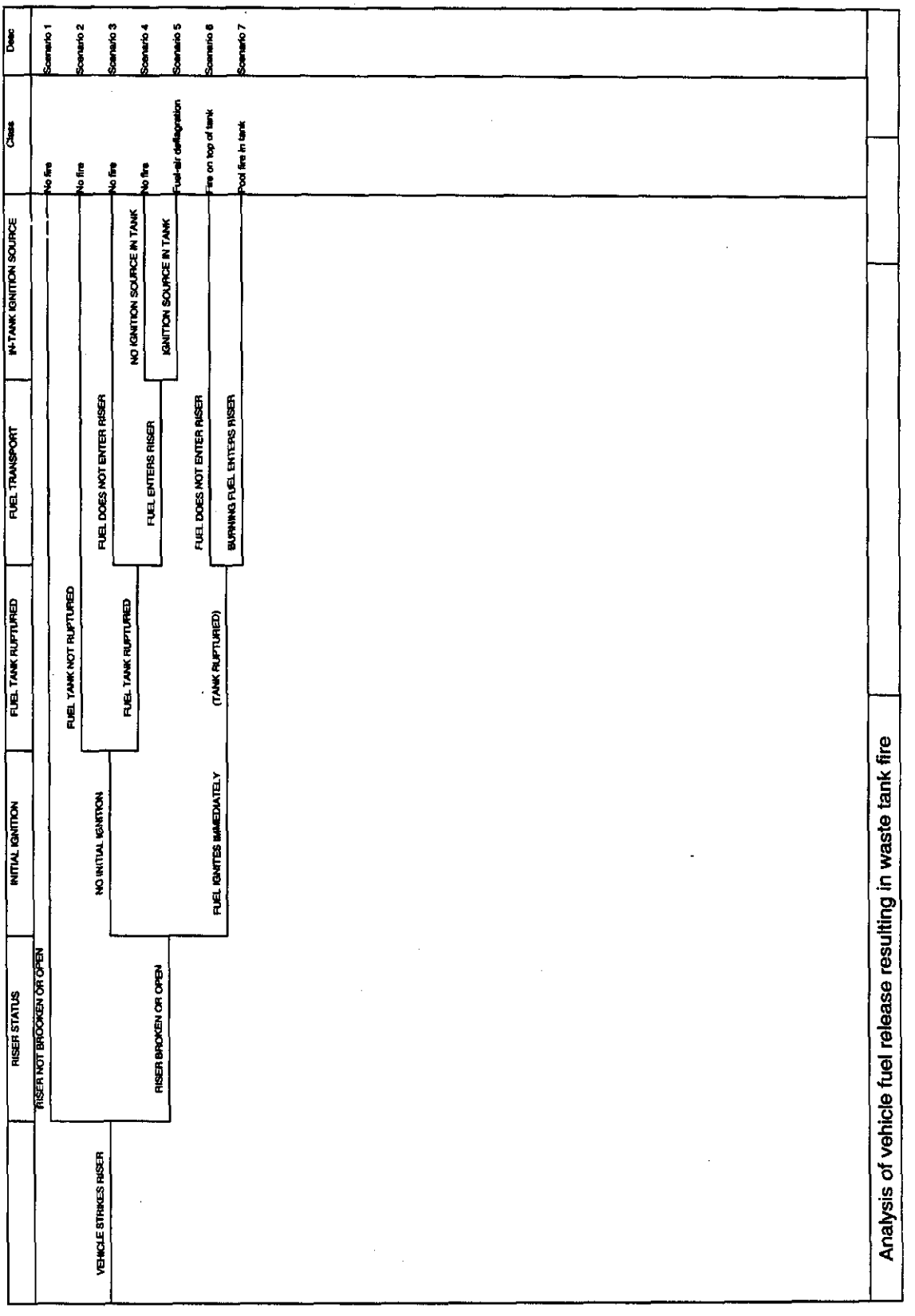
An event-tree analysis was performed to develop and evaluate all possible scenarios resulting from a vehicle striking a riser situated atop an underground waste tank. After the initial event, several possible follow-on events can occur. Examples are as follows:

- Riser may be broken when struck or may be open for another reason
- Vehicle fuel tank may be ruptured and the fuel may ignite immediately
- Fuel tank ruptures and the fuel does not ignite immediately
- Ignited or unignited fuel may flow into the broken or otherwise open riser.

Figure 3-1 shows an event tree that evaluates possible scenarios involving these questions. Seven possible scenarios are identified. Two scenarios result in pool fires, one in a fuel-air deflagration. Of the pool fires, one involves fire within the waste tank; the other is a fire on the surface above the tank.

The frequency and conditional probabilities of these events are provided in Section 4.1.1.

Figure 3-1. Accident Scenario Event Tree.



3.1 SCENARIO DESCRIPTIONS

Following is a detailed description of each scenario identified on the event tree shown in Figure 3-1.

3.1.1 Scenario 1: Vehicle Strikes Riser, Riser Does Not Break

A vehicle strikes a riser, but the riser is neither broken nor open for some other reason. This scenario does not result in a fire. This situation has occurred twice in the last 30 years.

3.1.2 Scenario 2: Vehicle Strikes Riser, Riser Broken, No Fuel Release

A vehicle strikes and breaks a riser (or the riser is open for some other reason), but the vehicle fuel tank is not ruptured. This scenario does not result in a fire.

3.1.3 Scenario 3: Vehicle Strikes Riser, Riser Broken, Fuel Released, No Fuel Entry Through Riser

A vehicle strikes and breaks a riser (or the riser is open for some other reason) and the vehicle fuel tank is ruptured. There is no initial ignition of the fuel, and the draining fuel does not enter the riser and the waste tank. This scenario does not result in a fire.

3.1.4 Scenario 4: Vehicle Strikes Riser, Riser Broken, Fuel Released, Fuel Enters Riser, No Ignition Source in Tank

A vehicle strikes and breaks a riser (or the riser is open for some other reason) and the vehicle fuel tank is ruptured. There is no initial ignition of the fuel, and the draining fuel enters the riser and the waste tank. In this scenario, there is no ignition source in the tank. Although fuel (either gasoline or diesel) enters the tank, and there is no ignition source, a fuel-air deflagration does not occur even though the fuel-air concentration may reach the LFL. Accordingly, although fuel has entered the waste tank, this scenario has no adverse consequences.

3.1.5 Scenario 5: Vehicle Strikes Riser, Riser Broken, Fuel Released, Fuel Enters Riser, Ignition Source in Tank

This scenario is similar to Scenario 4, except that an ignition source is assumed to exist in the tank. In this case, a fuel-air deflagration occurs in the tank when vapors reach the LFL of the fuel.

3.1.6 Scenario 6: Vehicle Strikes Riser, Riser Broken, Fuel Ignites Immediately, Fuel Does Not Enter Riser

A vehicle strikes a riser, the riser is either open or broken, the vehicle fuel tank ruptures and the fuel ignites immediately, but the burning fuel does not enter the waste tank through the riser. In this scenario, even though there is a fire on top of the waste tank, there is no interaction with the material in the tank. This scenario is similar to the fire in a contaminated area scenario found in the Tank Farms Documented Safety Analysis (DSA).

3.1.7 Scenario 7: Vehicle Strikes Riser, Riser Broken, Fuel Ignites Immediately, Burning Fuel Enters Riser

This scenario is similar to Scenario 6, except that the burning fuel enters the waste tank through the riser. In this case, a pool fire occurs in the tank fed by the burning fuel entering through the riser.

4.0 IN-TANK VEHICLE FUEL FIRE/DEFLAGRATION FREQUENCY DETERMINATION

4.1 SCENARIO LIKELIHOOD ANALYSIS

Of the seven scenarios, only two scenarios result in fires inside a waste tank: Scenario 5, "Vehicle Strikes Riser, Riser Broken, Fuel Released, Fuel Enters Riser, Ignition Source in Tank"; and Scenario 7, "Vehicle Strikes Riser, Riser Broken, Fuel Ignites Immediately, Burning Fuel Enters Riser." Following is a detailed analysis of the likelihood of these two scenarios. First, the frequency of the initiating event, "vehicle strikes riser," must be determined (Section 4.1.1.1). Then, given that the vehicle strike has occurred, the conditional probability of subsequent events must be calculated based on historical information or estimated using engineering judgment. These events are as follows:

- Riser status (broken or open) (Section 4.1.1.2)
- Probability of initial fuel ignition (Section 4.1.1.3)
- Probability of fuel tank rupture (Section 4.1.1.4)
- Probability of fuel entering waste tank (Section 4.1.1.5)
- Probability of an ignition source existing in a waste tank (Section 4.1.1.6).

4.1.1 Data Analysis

4.1.1.1 Vehicle Strikes Riser Initiating Event Frequency Calculation

The following analysis uses historical data to evaluate the event frequency.

Hanford Site off-normal occurrence information is chronicled for a 30–year period via the ORPS reports as documented in RPP-13121. In this period, four incidents involving vehicles and waste tank risers have been recorded. This information will be used to estimate the initiating event frequency.

1. *Occurrence Number 73–45, July 5, 1973* — A backhoe ran over a buried transfer line. The weight of the backhoe broke a flange that attached a riser to the transfer line. A subsurface leak resulted. There was no collision between the backhoe and the riser. Because Occurrence Number 73–45 was not a collision between a vehicle and a waste tank riser none of the elements necessary to act as an initiator of a vehicle fuel–fire accident was present. Therefore, this occurrence is not relevant to the accidents of concern.

2. *Occurrence Number 1991–1067, November 11, 1991* — A front–end loader was backing while spreading gravel above SST 241–T–108. The front–end loader hit a thermocouple riser. The riser broke off above a flange at grade level. The vehicle's fuel tank was not involved in the incident and remained undamaged. This is the only reported case of a waste tank riser being severed by a collision with a vehicle.

3. *Occurrence Number 1992–0029, March 24, 1992* — A drywell van was backing up and hit a riser on SST 241–SX–104. The gasoline tank at the rear of the van was punctured and about 2 gal of gasoline were spilled on the ground. The riser was not damaged, no fuel entered the tank, and no fire resulted from the accident.

4. *Occurrence Number 1993–0076, August 17, 1993* — A drywell van was backing up and hit a riser on SST 241–S–108. The gasoline tank at the rear of the van was damaged, and a small amount of gasoline leaked to the ground. The riser was not damaged, no fuel entered the tank, and no fire resulted from the accident.

As discussed in item 1, the events in that occurrence are not relevant to the vehicle/riser strike scenario addressed in this calculation note; therefore, that occurrence will not be included in determining riser strike frequency. Accordingly, the three remaining reported riser strikes in 30 years implies an expected riser strike frequency of three strikes over 30 years (3/30) or 1.0×10^{-1} strikes per year.

4.1.1.2 Riser Status (Broken or Open)

The conditional probability that the riser will be open after a vehicle strike is equal to the sum of the probability that the riser is open before the strike and the probability that the riser is broken by the strike.

The three events considered in Section 4.1.1.1 are the only known riser strike events. Of the three strikes, one resulted in a broken riser. Based on this data, the conditional probability of a broken riser, given one riser strike by a vehicle, is 1/3 or 0.33 (3.3×10^{-1}).

Related discussions in Section 2.3 indicate that the likelihood of a riser being left open is very small, much less than the value calculated above for a broken riser. Accordingly, it can be assumed that the likelihood of the riser being open after the vehicle strike is 3.3×10^{-1}. If as stated, it is assumed that the likelihood of a riser being left open is much less than the calculated value for a riser broken by a vehicle strike, then 3.3×10^{-1} conservatively bounds the likelihood of a riser being open.

4.1.1.3 Probability of Initial Fuel Ignition

There are no reported incidences at the Hanford Site tank farms of fuel being ignited while entering a broken riser or any other component of a waste tank or waste transfer system. There are two documented occurrences of a gasoline tank puncture by striking waste tank risers at the Hanford Site, but these did not result in ignition (see Section 4.1.1.1). Accordingly, other applicable data sources were examined. The following information is derived from Sandia National Laboratory's report SLA-74-001, Volume III, *Severities of Transportation Accidents*:

- Fires occur 0.4% of the time when a truck collides with a fixed object
- Fires occur 0.3% of the time when a truck collides with an auto
- Fires occur 0.8% of the time when a truck collides with a truck
- Fires occur 1.1% of the time when a truck is run off the road
- Fires occur 1.2% of the time when a truck overturns.

The data value most similar to the event of concern (i.e., initial fuel ignition) is the first item, "truck collides with a fixed object." The probability of a fire is 0.4% or 4.0×10^{-3} for this situation, and this value will be used in this analysis. This value presupposes the leakage of fuel (i.e., a ruptured fuel tank) and that an ignition source is present (i.e., fuel ignites).

4.1.1.4 Probability of Fuel Tank Rupture

The three recorded instances (Section 4.1.1.1) of vehicle/riser interactions resulted in fuel tanks being punctured twice. Using this information, the likelihood of a fuel tank rupture after a riser strike is determined to be 6.7×10^{-1}.

4.1.1.5 Probability of Fuel Entering Waste Tank

There are no reported cases in the ORPS reports of fuel draining into a broken waste tank riser. Engineering judgment will be used to determine a probability for this event.

A fuel tank is made of thinner and weaker material than the risers. It is likely that a vehicle colliding with enough force to break a riser would continue to move beyond the riser. Thus, the fuel tank puncture would not be directly in–line with the broken riser. Alternately, if the riser was broken by the frame or a cross member, the strength of the frame or cross member and the riser itself would probably bring the vehicle to a quick halt if the driver did not react first to stop the vehicle. In this scenario, the fuel tank may not be punctured, and if it were, the puncture may not be directly over the broken riser. These considerations are essentially factored into the probability of a tank being punctured and are stated here to illustrate the difficulty of establishing a perfect alignment between a broken riser and a ruptured fuel tank during an accident.

Given that the vehicle has struck the riser and punctured the fuel tank, it is instructive to consider what happens next. Either the vehicle will continue past the broken (or open) riser, in which case the punctured area of the fuel tank would not be aligned directly with the broken riser; or the vehicle will stop at the point of impact and the punctured area could be directly aligned with the broken riser. It is logical to assume that the most likely scenario is that a vehicle operator, upon hearing or feeling the vehicle strike a waste tank riser, would immediately stop and exit the vehicle in an effort to determine the cause and extent of damage. Assuming the incident resulted in a perforated vehicle fuel tank, this scenario could produce a configuration in which draining fuel could empty into the broken waste tank riser.

For the purpose of this study, it is conservatively assumed that the fuel tank in the vehicle is full, and drains completely into the tank. It is noted in HNF-SD-WM-CN-121, *Consequences of Potential Gasoline Pool Fires*, that the largest vehicle fuel tank expected to enter a tank farm will have a capacity of 50 gal of diesel fuel or 50 gal for gasoline. Per Appendix A, Part A, the vaporization of this quantity of diesel fuel inside the headspace with the highest expected temperature would not reach the LFL. This condition is also applicable to fuel spills involving diesel quantities greater than 50 gal. The maximum fuel tank capacity of vehicles entering a tank farm is expected to be limited to 50 gal for both diesel fuel and gasoline.

HNF-SD-WM-CN-121 uses bounding headspace volumes of 4,800 m^3 (169,510 ft^3) for SSTs and 5,300 m^3 (187,167 ft^3) for DSTs. These volumes maximize the quantity of oxygen available for combustion. If 50 gal of gasoline were completely vaporized in 4,800 m^3 of air, the

concentration would reach the LFL. For smaller headspace volumes, the concentration of fuel in air would increase, but the quantity of oxygen available for combustion would decrease, thus increasing the possibility that not all of the fuel would be burned.

Complete vaporization of 50 gal of gasoline could raise the headspace fuel–air concentration of a nearly empty tank (4,800 m^3 headspace) to at least the LFL. Gasoline has a lower flash point than diesel fuel and evaporates more rapidly. It is assumed that gasoline is completely evaporated and that the LFL is reached within the waste tank's headspace. As such, it is assumed that the fuel draining into the tank will reach LFL in the headspace.

Considering the factors in this event, including where the vehicle potentially stops and where the potential fuel leak location is in relation to the broken (or open) riser, a probability of 1.0×10^{-1} is assigned to the likelihood of fuel draining into a broken riser. A sensitivity analysis (Section 4.2) will be performed to evaluate the effect of this assumption.

4.1.1.6 Probability of an Ignition Source Existing in a Waste Tank

A study of in-tank ignition sources was performed in support of work in DST 241-SY-101. All sources of ignition including lightning, pumping operations, installation and removal of equipment, general operation of equipment, random sources, and seismic events for SSTs, among others, were evaluated in several control sets. With the presence of a mixer pump, lights, and television camera, DST 241–SY–101 is a reasonable choice to employ in determining the bounding number of ignition sources that could ignite a fuel–air mixture inside a waste tank headspace. HNF-SD-WM-ES-410, *Refined Safety Analysis Methodology for Flammable Gas Risk Assessment in Hanford Site Tanks*, analyzes ignition frequencies from various initiators and provides insight as to how the probability determination for ignition was attained. An available ignition source in the tank headspace for deflagration initiation is estimated to have a probability of 2.6×10^{-1} from all sources.

4.1.2 Scenario Frequencies

When the probabilities determined above and their complements are inserted into the event tree in Figure 3-1, the sequence frequencies can be calculated as shown in Figure 4-1. Table 4-1 displays the results. As described in Sections 3.1.5 (deflagration) and 3.1.7 (pool fire), Scenarios 5 and 7 are the scenarios of concern, and their frequencies per year are 5.7×10^{-4} and 1.3×10^{-5}, respectively. Table 4-2 shows the related categories of these scenarios, using likelihood categories from the DSA.

A sensitivity study is performed below (Section 4.2) to evaluate the effect of assumptions made in developing the probabilities used in this study.

Figure 4-1. Quantified Accident Scenario Event Tree.

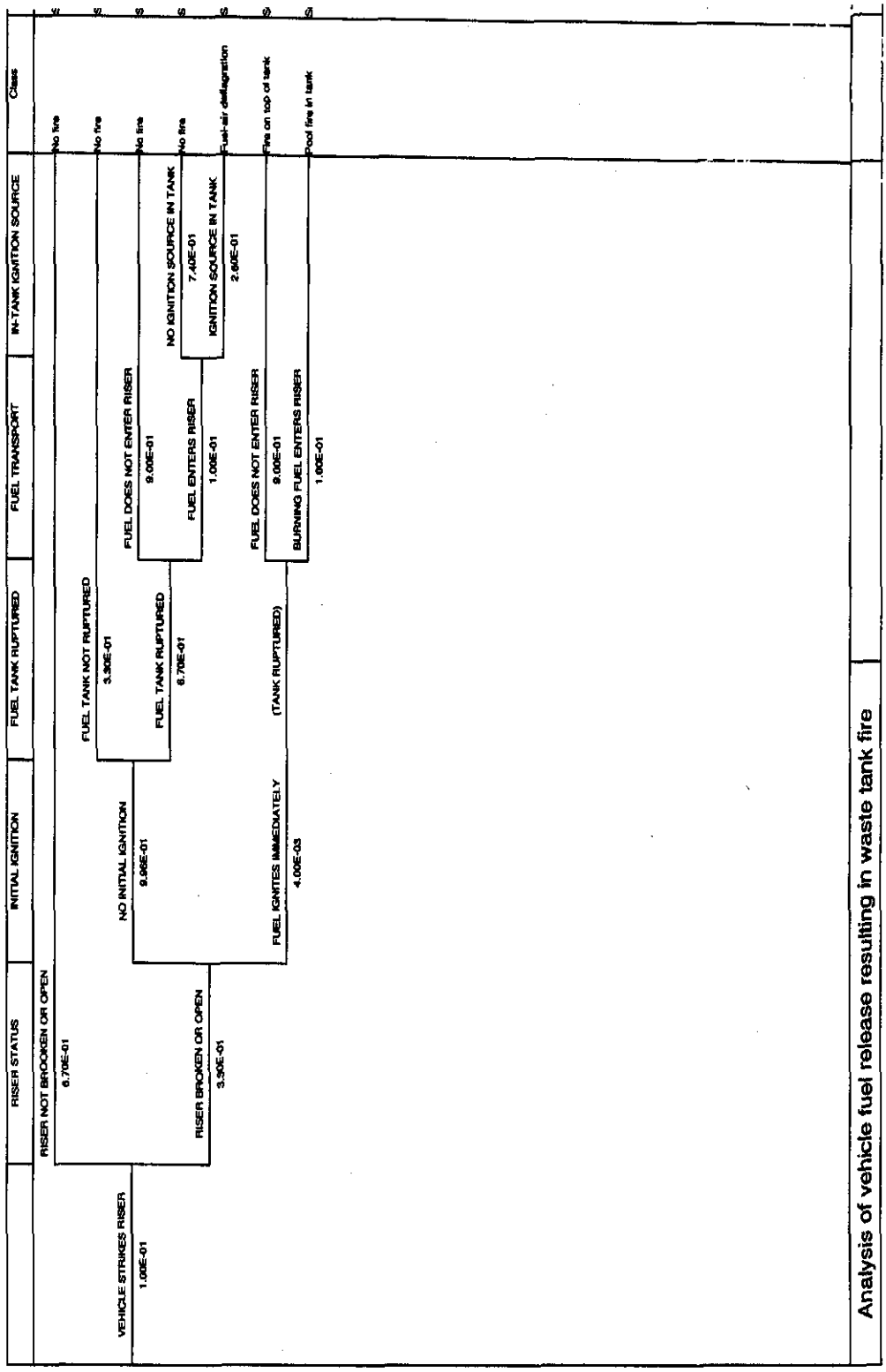


Table 4-1. Scenario Frequencies.

Scenario number	Scenario class	Scenario frequency
1	no fire	6.70 E-02
2	no fire	1.00 E-02
3	no fire	2.00 E-02
4	no fire	1.60 E-03
5	**fuel-air deflagration**	**5.70 E-04**
6	pool fire on top of tank	1.20 E-04
7	**pool fire in tank**	**1.30 E-05**

Table 4-2. Sequence Likelihood Category.

Scenario number	Frequency	Likelihood category
5	**5.70 E-04**	***Unlikely*** **10^{-4} to $\leq 10^{-2}$**
7	**1.30 E-05**	**Extremely Unlikely** **10^{-6} to 10^{-4}**

4.2 ACCIDENT SCENARIO SENSITIVITY ANALYSIS

Using data and information from applicable occurrence reports, references relevant to similar accidents, pertinent studies, operator experience, and engineering judgment, this calculation note revision has developed accident scenario likelihood for the in–tank vehicle fuel fire frequency analyses. Since assumptions were made in developing the values used in this analysis, a sensitivity analysis will be performed to evaluate the consequences of variations in these values.

The basis for the variations in values and the sensitivity of the accident frequency to these variations will be discussed below. Table 4-3 summarizes the values used in this analysis and their bases.

Table 4-3. Summary of Values Used.

	Frequency of tank riser strikes	**Probability a riser is broken**	**Probability fuel tank is ruptured**	**Probability fuel drains into broken riser**	**Probability fuel is ignited as it enters riser**	**Probability ignition source exists in tank with vaporized fuel**
Basis	3 strikes 30 years	1 broken riser in 3 strikes	2 tank punctures in three riser strikes	Engineering judgment	Historical analysis	Engineering analysis
Source	ORPS report & engineering judgment	ORPS report	ORPS report	Engineering experience	SLA-74-001 on transport accidents - fire when vehicle collides with a solid object	Supporting work for DST 241-SY-101 & engineering experience
Value	1.0 E-01 strikes per year	3.3 E-01	6.7 E-01	1.0 E-01	4.0 E-03	2.6 E-01
Sensitivity adjustment	1.0 strikes per year	1.0	1.0	1.0	4.0 E-02	1.0

Notes:
SLA-74-001, 1976, Volume III, *Severities of Transportation Accidents*, Change 1, Sandia Laboratories, Albuquerque, New Mexico.
DST = double-shell tank.
ORPS = Occurrences Reporting & Processing System.

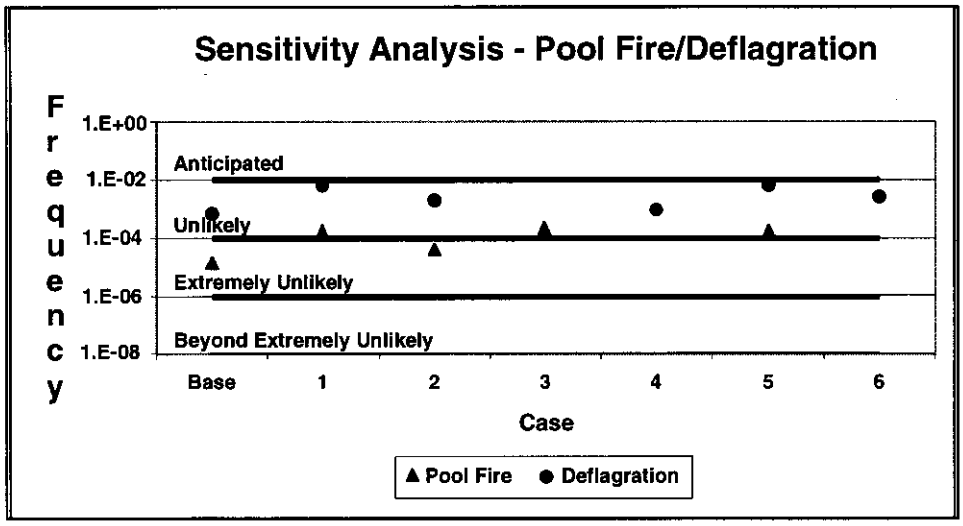
The sensitivity of the results will be evaluated on a case-by-case basis by varying the probabilities of each element. The following discussion describes each case and the basis for the variation. The results of the sensitivity analysis are summarized in Table 4-4 and displayed in Figure 4-2.

Table 4-4. Sensitivity Analysis Results.

	Pool fire frequency	**Deflagration frequency**
Base	**1.3 E-05**	**5.7 E-04**
Case 1	1.3 E-04	5.7 E-03
Case 2	4.0 E-05	1.7 E-03
Case 3	1.3 E-04	N/A
Case 4	N/A	8.6 E-04
Case 5	1.3 E-04	5.7 E-03
Case 6	N/A	2.2 E-03

Note:
N/A = not applicable.

Figure 4-2. Sensitivity Analyses.



4.2.1 Sensitivity Analysis Case 1: Number of Risers Struck

Three risers have been struck by vehicles over a 30–year period, according to review of applicable occurrence and incident reports. In Section 4.1.1.1, the resulting frequency of 1.0×10^{-1} strikes per year was determined. If the likelihood of riser strikes were increased by a factor of 10, the change in the riser strike frequency would be from 1.0×10^{-1} strikes/year to 1.0 strike/year.

Using one riser strike per year as the initiating event frequency in the accident scenario analysis changes the frequency of pool fires to 1.3×10^{-4} per year. The pool fire frequency moves to the "unlikely" category. Similarly, the frequency of a deflagration becomes 5.7×10^{-3} events per year. The deflagration frequency remains in the "unlikely" category.

4.2.2 Sensitivity Analysis Case 2: Conditional Probability of Broken Riser

The occurrence and incident reports contain only one case in which a riser is broken because of a collision with a vehicle. In Section 4.1.1.2, the conditional probability of broken risers is calculated to be 3.3×10^{1} per year.

In the most severe case, the riser would be broken on every strike. Accordingly, a value of 1.0 will be used for the likelihood of a broken riser given a vehicle strike. This changes the frequency of pool fires to 4.0×10^{-5} per year. The pool fire frequency remains in the "extremely unlikely" category. Similarly, the frequency of a deflagration becomes 1.7×10^{-3} events per year. The deflagration frequency remains in the "unlikely" category.

4.2.3 Sensitivity Analysis Case 3: Initial Fuel Ignition

The analysis in Section 4.1.1.3 is derived from SLA–74–001, and uses the likelihood of fuel ignition as 4.3×10^{-3} based on historical data. This data presupposes that the fuel vessel is punctured and an available ignition source has ignited the spilled or spilling fuel. For the sensitivity analysis, the probability of initial ignition will be increased by a factor of 10, or 4.3×10^{-2}. The frequency of a pool fire moves to the "unlikely" category at 1.3×10^{-4}.

4.2.4 Sensitivity Analysis Case 4: Fuel Tank Punctured

In Section 4.1.1.4, the likelihood of a fuel tank being punctured because of a vehicle striking a riser is calculated as 6.7×10^{-1} (two punctures resulting from three riser strikes). Again, it can be seen that a 100% error resulting in fewer punctures would make the probability of a punctured tank even smaller. If the number of punctures were increased to three punctures in three strikes (i.e., every strike results in a fuel tank puncture) the probability of a puncture would become 1. Using this value, the frequency of a headspace deflagration becomes 8.6×10^{-4} per year and remains "unlikely."

4.2.5 Sensitivity Analysis Case 5: Fuel Flows into Riser

In Section 4.1.1.5, the likelihood of fuel flowing into a broken riser from a punctured fuel tank is estimated to be 1.0×10^{-1}. For the sensitivity analysis, it will be assumed that the full amount the fuel tank contains will also flow into the riser and hence into the tank. This means that the probability of unignited fuel flowing into a riser will be assumed to be 1.0. With this assumption, the frequency of a deflagration increases from 5.7×10^{-4} per year to 5.7×10^{-3} per year, remaining in the "unlikely" category. The frequency of a pool fire increases to 1.3×10^{-4} per year and moves to the "unlikely" category.

4.2.6 Sensitivity Analysis Case 6: Fuel Evaporation and Ignition Source in Tank

It is assumed that unignited fuel spilled into the tank will evaporate and that the LFL in the headspace of the tank will be reached. The probability of an ignition source in the tank is given as 2.6×10^{-1} in Section 4.1.1.6. If it were assumed that a suitable ignition source exists in every tank, the probability would be increased to 1.0 and the frequency of a deflagration would increase to 2.2×10^{-3} per year, remaining in the "unlikely" category.

4.2.7 Summary of Sensitivity Analyses

Table 4-4 summarizes the results of the sensitivity analysis, and Figure 4-2 compares the results with the likelihood categories in the DSA.

The likelihood of these two events (a pool fire and a deflagration) is directly related to the probability of vehicle strike to a tank riser, and to the likelihood of fuel (ignited or unignited) entering the associated tank. Increasing these values by an order of magnitude has the expected result of increasing the likelihood of the two events of concern by a similar amount. In all six deflagration cases, an order of magnitude increase in frequency results in all cases remaining in the "unlikely" category, and Case 2 for a pool fire remains in the "extremely unlikely" category. A pool fire in Case 1 and Case 5 moves to the "unlikely" category with an order of magnitude increase in frequency. In Case 3, when the likelihood of fuel tank rupture or the ignition at the point of collision is increased by an order of magnitude, the resulting frequency of pool fire enters the "unlikely" category.

5.0 IN-TANK VEHICLE FUEL FIRE/DEFLAGRATION CONSEQUENCES DISCUSSION

5.1 EVALUATION OF CONSEQUENCES OF SCENARIO 5: IN-TANK FUEL DEFLAGRATION SCENARIO

Comparison of relative flammability limits, reaction rates, reaction pressure increases, relative release rates, and expected source terms for gasoline and hydrogen in-tank deflagrations will qualitatively demonstrate that the flammable gas deflagration scenario consequences in the DSA will bound the in-tank vehicle fire scenarios.

5.1.1 Expected Source Terms

The DSA assumes that the source term is identical for all deflagration accident scenarios where the headspace gases reach the LFL. This is true whether the flammable mixture results from an introduced flammable gas (e.g., diesel, gasoline), through a steady-state gas release (e.g., hydrogen, ammonia), or as a result of a gas release event.

5.1.2 Flammability Limits

It is the vapors from flammable liquids that burn. Because burning actually occurs in the vapor phases, the most hazardous combustible liquids are those with high vapor pressures, or volatility. The most common form of chemical reaction that produces high-pressure gases from other gases or vapors is the combustion of gaseous fuels in air. Examination of the heat of combustion tables in Appendix A of *The SFPE Handbook of Fire Protection Engineering* (NFPA 1998) shows that, while the heat of combustion is quite different for different organic materials, the heat produced per equivalent oxygen consumed is the same, to within 10% throughout.

For the general case of combustion involving a fuel gas and an oxidizing gas (such as air), mixtures are flammable only within a certain range of compositions. A minimum fuel proportion (LFL) is required to sustain combustion; there is also a maximum fuel proportion (UFL) above which combustion cannot be self-sustaining. Near these limiting fuel proportions, flames propagate through the mixture rather slowly, but in the middle of the flame range, combustion velocities can reach speeds faster than the speed of sound. In general, increasing the temperature and/or pressure of the mixture widens the flammability range and increases the combustion velocity throughout that range.

The great majority of combustible gas mixtures are stable at ordinary temperatures and pressures. Therefore, the combustion reaction process must be initiated by some external means. Once ignited however the combustion reaction is self-sustaining and the reaction propagates from the ignition point to the physical limits of the combustion mixture. Gas mixtures are more difficult to ignite near the flammability limits and most easily ignited somewhat above the precisely

balanced (stoichiometric) mixture. However, in general gas mixtures are very easily ignited anywhere in their flammable range.

5.1.3 Relative Reaction Rates

Pressures generated by the combustion of gas mixtures results primarily from the heat liberated and the consequent high temperatures of the product gases. Generally, the highest pressures are attained when combustion occurs rapidly. For most confined subsonic combustions (deflagrations), the maximum pressure produced is approximately 10 times the initial pressure, since the flame temperature is limited by disassociation reactions. Deflagration of gases, mists, or dusts in air produces less pressure than the deflagration of condensed phases because there is less energy released per unit of volume. The propagation of a deflagration proceeds by mass transfer (i.e., the movement of heat and activated agents into the un-reacted materials) at velocities ranging from millimeters per hour to hundreds of meters per second.

As it is the vapors from flammable liquids that burn, the ease of ignition as well as the rate of burning can be related to such properties as the vapor pressure, flash point, boiling point, and evaporation rate. Liquids that form vapors above the liquid surface at stored temperatures will have a rapid rate of flame propagation. Flammable and combustible liquids with flash points above the temperature at which they are stored have a slower rate of propagation. This is because it is necessary for the liquid surface to sufficiently heat and form a flammable vapor/air mixture before the flame will spread through the vapor.

Gasoline (a compound of light and heavy fractions of C4 to C12) will combust most rapidly when first ignited. This is because the lighter fractions burn at a higher rate and are consumed quicker, while the heavier fractions burn at a rate approaching kerosene. Per NFPA (1998), the burning rate for gasoline is 6 to 12 in. (150 to 300 mm) of depth per hour, and for kerosene, the burning rate is 5 to 8 in. (130 to 200 mm) of depth per hour. The flammability range of gasoline is 1.3 to 7.4 vol% (Appendix A).

Hydrogen has an extremely wide flammability range and the highest burning velocity of any gas. Hydrogen's ignition temperature is reasonably high, but its ignition energy is very low. Hydrogen equilibrates into a gas at its boiling point, -252 °C (-422 °F) (NFPA 1998). When hydrogen is released at low pressure, self-ignition is unlikely. Rather, hydrogen combustion explosions occur that are characterized by very rapid pressure rises. When released at high pressure, hydrogen can self ignite because of friction and/or heat release. The flammability range of hydrogen is 4.1 to 74 vol% ("Hydrogen as a Fuel for Spark Ignition Engines," *Alternative Energy Sources VIII*, Vol. 2, Research and Development [Borusbay and Veziroglu 1989]).

5.1.4 Reaction Pressure Increases

The peak pressure from a gasoline burn is equivalent to a hydrogen burn. The following discussion supporting this statement is condensed from WHC-SD-WM-CN-059, *Calculation Notes That Support Accident Scenarios and Consequence Determination of the In-Tank Fuel*

Fire/Deflagration, and supported by the closed vessel deflagration discussion of the reference NFPA 1998.

Conservative estimates of the associated pressure rise in a closed vessel can be made from flame temperature calculations. The ratio of peak pressure to initial pressure can be calculated from the ideal gas equations at the end of the combustion and prior to ignition by the formula:

$$\frac{P_M}{P_O} = \frac{M_O}{M_B} \bullet \frac{T_B}{T_O} \tag{5-1}$$

where:

P_M = maximum pressure at completion of burn

P_O = initial pressure

M_O = molecular weight of gas - air mixture

M_B = molecular weight of combustion products

T_B = temperature of burned gas

T_O = initial temperature.

Assuming a deflagration occurs sufficiently fast as to neglect heat dissipation, the value of T_B would correspond to the adiabatic flame temperature of the gas-air mixture. Adiabatic constant pressure temperatures are in the range of 2100°K to 2400°K for most hydrocarbon gas-air mixtures (NFPA 1998). The adiabatic constant-volume temperatures are generally about 10% higher than the corresponding constant-pressure temperatures. The molecular weights needed for equation 5-1are approximately the same before and following the combustion for many of the gas mixtures. An exception is hydrogen, where the molecular weight of the combustion products is less than the initial gas-air mixture by about 15% for a stoichiometric mix. For nonstoichiometric mixes, the difference becomes less.

WHC-SD-WM-CN-059 indicates that the burning velocity for hydrogen is about eight times the burning velocity of the heavier hydrocarbons. The burning velocity is the flame propagation velocity relative to the unburned gases (WHC-SD-WM-CN-059). With its extremely wide flammability range, and high burning velocity, a hydrogen deflagration would produce a greater pressure rate of rise than an equivalent gasoline deflagration.

5.1.5 Relative Release Rates

Waste material may be released from the effects of a deflagration (e.g., turbulent winds in a dome space and/or pressurization) as well as from the impact of tank debris and soil overburden into the waste in the event of a tank structural failure (i.e., dome cracking or collapse). The amount of waste material released because of a deflagration accident is intuitively related to the severity of the deflagration.

Unfiltered release pathways vary with tank internal pressures. Unfiltered release pathways occur through tank openings such as open or unsealed risers and pit drains at low pressures. When pressures exceed several kPa gauge, unfiltered pathways could include failed high-efficiency particulate air (HEPA) filters. Cracks in the tank dome of SST tanks may be expected when pressures in the headspace exceed approximately 75 kPa gauge (10.88 lb/in^2 gauge) and large tank openings (e.g., from a dome collapse) can occur at pressures greater than 410 kPa gauge (60 lb/in^2 gauge) (WHC-SD-WM-CN-074, *DELPHI Expert Panel Evaluation of Hanford High Level Waste Tank Failure Modes and Release Quantities*).

Some airborne activity is present in the headspace at all times and additional material may be released to the headspace during a gas release event. The mechanisms that can release aerosol during a deflagration event include:

- Aerodynamic entrainment of settled waste with waste deposited on tank walls and equipment and subsequent breakup into fine particles. This entrainment results from transient gas flow and pressure waves at various angles to these waste surfaces.
- Deposited wall and crust material released by pressure-induced flexure of the surface to which it is attached.
- Material suspended by the impact of falling debris into the waste caused by structural damage to the tank dome.

5.1.6 In-Tank Gas Deflagration Consequence Comparison Conclusion

The above arguments demonstrate that the flammable gas deflagration scenario in the DSA bounds the consequences of an in-tank vehicle fuel fire/deflagration accident scenario. The bases for this are recapped here:

- Pressures generated by the combustion of gas mixtures results primarily from the heat liberated and the consequent high temperatures of the product gases. Generally, the highest pressures are attained when combustion occurs rapidly.
- While the heat of combustion is quite different for different organic materials, the heat produced per equivalent oxygen consumed is the same, to within 10% throughout. The vapor phases are where actual burning occurs. Therefore, hazardous liquids with high vapor pressures or volatility are the most combustible.
- Gasoline (a compound of light and heavy fractions of C4 to C12), will combust more rapidly at first while the lighter fractions burn off. The heavier fractions burn at a rate approaching kerosene, and as the lighter compounds are consumed combustion slows down. This equates to a slower pressure rate of rise.
- Hydrogen has an extremely wide flammability range and the highest burning velocity of any gas. Hydrogen has an extremely low ignition energy requirement. Hydrogen combustion explosions occur that are characterized by very rapid pressure rises.

- The molecular weights of combustion products are approximately the same before and following the combustion for many gas mixtures. An exception is hydrogen, where the molecular weight of the combustion products is less than the initial gas-air mixture by about 15% for a stoichiometric mix. This leads to the production of higher pressures from equivalent molecular weights.

- The burning velocity for hydrogen is about eight times the burning velocity of the heavier hydrocarbons. The burning velocity is the flame propagation velocity relative to the unburned gases. With its extremely wide flammability range and high burning velocity, a hydrogen deflagration would produce a greater pressure rate of rise than an equivalent gasoline deflagration.

- The amount of waste material released because of a deflagration accident is intuitively related to the severity of the deflagration. The source term is identical for all deflagration accident scenarios where the headspace gases reach the LFL.

- Accordingly, a deflagration caused by hydrogen combustion would result in a greater pressure rise than a deflagration caused by gasoline, with a correspondingly greater severity. The amount of waste material released would be the same for both events. Therefore, the flammable gas deflagration scenario bounds the consequences of an in-tank vehicle fuel fire deflagration accident scenario.

5.2 EVALUATION OF CONSEQUENCES OF SCENARIO 7: IN-TANK VEHICLE FUEL POOL FIRE SCENARIO

In comparing the radiological and toxicological consequence calculations of in-tank gasoline pool fires and organic solvent fires, four models were calculated.

1. A gasoline puddle fire. The model was selected to maximize radiological consequences in an SST.

2. A large gasoline pool fire in an SST. This model was chosen to maximize the pressure created in the headspace of an SST.

3. A large gasoline pool fire in an SST. This model was chosen to maximize the toxicological consequences in an SST.

4. A large gasoline pool fire in a DST. This model was chosen to maximize both radiological and toxicological consequences in a DST.

RPP-8369, *Chemical Source Terms for Tank Farms Safety Analyses*, contains spreadsheets that evaluate the frequency and consequences of three types of organic solvent fires occurring in tanks resulting from combustion with headspace air. Evaluated were pool fires, puddle fires, and wick–stabilized fires. A pool fire is where solvent, larger than 1 m^2 (10.8 ft^2), is floating on top of a liquid waste layer or trapped in a depression on top of solid waste. Puddle fires result from puddles of solvent less than 1 m^2 (10.8 ft^2) existing in a depression in a solid waste surface. Wick–stabilized fires involve sludge or saltcake permeated with solvent. The important

distinction between the three fire scenarios is the rate of flame spread and the ease of ignition. Ignited fuel flowing into a tank headspace would pool or puddle on top of the tank contents, depending on the amount, resulting in a pool/puddle fire. RPP-8369 uses a spreadsheet to quantify the unmitigated bounding consequences of 24 postulated solvent pool fires in SSTs, DSTs, and double-contained receiver tanks (DCRT). Key input parameters for all cases are identified. Five postulated gasoline fuel fires have been added to the spreadsheet. Gasoline fires were inserted just below solvent fires that use similar case parameters. HNF-SD-WM-CN-121, *Consequences of Potential Gasoline Pool Fires,* defined those inserted gasoline cases. For expedience, some solvent cases were deleted to accommodate the inclusion of the gasoline fire cases. A total of 20 fire scenarios are provided in the spreadsheet. Changes made to HNF-8369 spreadsheets that differentiate gasoline from solvent consist of:

- The deletion of P_2O_5 as a toxin because it is not applicable to a gasoline fire. It should be noted that Column M of the toxicological spreadsheet contains nonzero values for P_2O_5. This is required to compute CO and NO_2 releases. At later stages in the calculation, a zero multiplier for Column M is inserted to remove P_2O_5. This is done in columns that compute combustion gas contributions to a toxicological release (columns AA, AS, AU, and AW).
- Combustion energy was calculated as 80% of 44.1 Mj/kg.
- Fire spread rate was assigned a value of 200 cm/s. Solvent was 10 cm/s.
- Aerosol depletion due to in-tank sedimentation was quantified.
- Aerosol load was equated to 20% of gasoline burned.
- Stoichiometry was altered to be consistent with the combustion of octane. Octane has a carbon/hydrogen ratio consistent with that of gasoline.

Portions of the RPP-8369 worksheets are reproduced in appendices to this document for informational and reference purposes. Each worksheet is described separately, as are the key inputs used to quantify the consequences of the postulated fires. The toxicological worksheet is truncated to include only the gasoline fires.

5.2.1 Radiological Input Data

Table 5-1 lists key data used to compute radiological doses. Note that the unit-liter dose (ULD) for offsite exposures include both inhalation and ingestion dose pathways.

Table 5-1. Radiological Input Data.

Parameter	Units	Numerical value	Reference
Atmospheric dispersion factor, onsite	s/m^3	3.28 E-02	RPP-5924
Atmospheric dispersion factor, offsite	s/m^3	2.22 E-05	RPP-5924
Breathing rate, onsite	m^3/s	3.3 E-04	RPP-5924
Breathing rate, offsite	m^3/s	3.3 E-04	RPP-5924
ULD, SST solids, onsite	Sv/L	1.40 E+05	RPP-5924
ULD, SST liquids, onsite	Sv/L	4.40 E+02	RPP-5924
ULD, DST liquid, onsite	Sv/L	1.00 E+03	RPP-5924
ULD, SST solids offsite	Sv/L	1.90 E+05	RPP-5924
ULD, SST liquids offsite	Sv/L	6.00 E+02	RPP-5924
ULD, DST liquids offsite	Sv/L	1.50 E+03	RPP-5924
SST solids inventory on ventilation system, passive SST	L	1.27 E-02	WHC-SD-WM-CN-054
SST solids inventory on ventilation system, active SST	L	2.0 (rounded)	HNF-SD-WM-CN-099
DST liquids inventory on ventilation system, active DST	L	3.7 (rounded)	HNF-SD-WM-CN-099
SST liquids inventory on ventilation system, DCRT	L	2.27 E-01	WHC-SD-WM-CN-054
Airborne release fraction for ventilation system releases	None	1.00 E-04	DOE-HDBK-3010-94
Respirable fraction, pool and puddle fires	None	1.0	DOE-HDBK-3010-94
Respirable fraction, entrained fires	None	0.5	DOE-HDBK-3010-94

Notes:
The ULD for DCRT liquids was assumed to be the same as the ULD for SST liquids (RPP-5924).

DOE-HDBK-3010-94, 2000, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, Change Notice No. 1, U.S. Department of Energy, Washington, D.C.
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WHC-SD-WM-CN-054, 1996, *Waste Tank Ventilation System Waste Material Accumulations*, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

DCRT = double-contained receiver tank.
DST = double-shell tank.
SST = single-shell tank.
ULD = unit-liter dose.

5.2.2 Toxicological Input Data

Toxicological consequences are quantified in terms of a sum of fractions (SOF), where the fraction is the downwind concentration of each toxic constituent divided by the limit for that constituent. Table 5-2 summarizes SOFs for SST and DST categories of Hanford Site waste tanks. The columns, from left to right, describe the waste categories for the tank type, while the remaining columns list the value for Temporary Emergency Exposure Limit (TEEL) for TEEL-0 SOF through TEEL-3 SOF, respectively. The SOF data listed in Table 5-2 are retrieved from

RPP-8369. These are the current SOFs utilized for tank farm accident toxicological consequence analyses. Release and dispersion calculations use these data points to calculate toxicological exposures at 100 m and at the site boundary.

Table 5-2. Toxicological Sum of Fraction Data for Tank Waste (RPP-8369).

Waste category	TEEL-0 SOF	TEEL-1 SOF	TEEL-2 SOF	TEEL-3 SOF
Solid wastes				
DSTs	1.9 E+10	6.4 E+09	1.1 E+09	8.4 E+07
SSTs	1.9 E+10	3.0 E+09	1.5 E+09	1.0 E+08
Liquid wastes				
DSTs	7.0 E+09	2.4 E+09	3.1 E+08	1.0 E+07
SSTs	8.9 E+09	3.1 E+09	4.8 E+08	1.2 E+07

Notes:

RPP-8369, 2003, *Chemical Source Terms for Tank Farms Safety Analyses*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

DST = double-shell tank.
SOF = sum of fractions.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.

Taken from Table 4, "ERPGs and TEELs by Chemical Name (mg/m^3)," in WSMS-SAE-02-0001, *ERPGs and TEELs of Chemical Concern*, Table 5-3 summarizes TEEL guideline limits for reaction products of concern defined by RPP-8369.

Table 5-3. Reaction Product Toxic Constituent Limits (RPP-8369 and WSMS-SAE-02-0001).

Analytic	Toxic category	TEEL-3 mg/m^3	TEEL-2 mg/m^3	TEEL-1 mg/m^3	TEEL-0 mg/m^3
Phosphorus pentoxide (P_2O_5)	corrosive and irritant	50	10	1	1
Nitrogen dioxide (NO_2)	corrosive and irritant	4	4	2.5	0.75
Carbon monoxide (CO)	systemic poison	600	400	200	60

Notes:

RPP-8369, 2003, *Chemical Source Terms for Tank Farms Safety Analyses*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

WSMS-SAE-02-0001, 2002, *ERPGs and TEELs of Chemical Concern*, Rev. 18, Westinghouse Safety Management Systems, Aiken, South Carolina.

TEEL = Temporary Emergency Exposure Limit.

The toxicological consequences of HEPA filters rupturing are computed based on waste release volumes, an aerosol release fraction (ARF) of 1.0 x 10^{-4} (see Table 5-1), release duration of 60 sec, and the applicable atmospheric dilution factors. Table 5-4 summarizes the SOFs for HEPA rupture cases applicable to solvent fires.

Table 5-4. Sums of Fractions for High-Efficiency Particulate Air Filter Rupture.

Filter type	Contaminant	Sum of fractions for stated category			
		TEEL-0	TEEL-1	TEEL-2	TEEL-3
SST passive	SST solids	1.90 E+10	3.00 E+09	1.50 E+09	1.00 E+08
SST active	SST solids	1.90 E+10	3.00 E+09	1.50 E+09	1.00 E+08
DST passive	DST liquids	7.00 E+09	2.40 E+09	3.10 E+08	1.00 E+07
DST active	DST liquids	7.00 E+09	2.40 E+09	3.10 E+08	1.00 E+07
DCRT passive	SST liquids	8.90 E+09	3.10 E+09	4.80 E+08	1.20 E+07
55 kgal passive	SST solids	1.90 E+10	3.00 E+09	1.50 E+09	1.00 E+08

Notes:
DCRT = double-contained receiver tank.
DST = double-shell tank.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.

5.3 SPREADSHEET CALCULATION SUMMARY

Twenty-four solvent pool fire cases were evaluated in an effort to quantify unmitigated bounding consequences for SSTs, DSTs, and DCRTs. The analysis was performed with the aid of the Microsoft Excel[1] program. Calculations were carried out in three work sheets, "Solvent Pool Fire Cases" (Appendix B, Table B-1), "Dose Summary" (Appendix B, Table B-2), and "Toxicological Dose" (Appendix B, Table B-3).

Five-postulated gasoline fire cases were inserted into the spreadsheets just below a solvent fire case that used similar case parameters. Note that for convenience, some solvent fires were deleted to make room for the gasoline fires. Changes made to differentiate gasoline cases from solvent cases were:

- P_2O_5 was deleted as a toxin. P_2O_5 is not an applicable toxin for a gasoline fire. It should be noted that Column M of the Toxicological spreadsheet (Appendix B, Table B-3) contains nonzero values for P_2O_5. These values are required to compute the CO and NO_2 releases. At later stages in the calculation, a zero multiplier for Column M was added to columns AA, AS, AU, and AW to remove P_2O_5 as a toxin for gasoline fires.
- Combustion energy was calculated as 80% of 44.1 Mj/kg.
- Fire spread rate was assigned a value of 200 cm/s. Solvent was 10 cm/s.
- Aerosol depletion due to in-tank sedimentation was quantified.
- Aerosol load was equated to 20% of gasoline mass burned.

[1] Excel is a trademark of Microsoft Corporation, Redmond, Washington.

- Stoichiometry was altered to be consistent with combustion of octane. Octane possesses a carbon/hydrogen ratio characteristic of gasoline.
- Columns CS and beyond were removed for expediency in Appendix B, Table B-3. Used for comparison regarding phosphorous pentoxide and phosphoric acid as toxins, they are superfluous to the discussions here.

Table 5-5 depicts the results for onsite and offsite radiological and toxicological consequences of the five gasoline fires.

Table 5-5. Radiological and Toxicological Consequences of In-Tank Vehicle Fuel Fires.

	SST small gasoline puddle fire d(m)	**SST large gasoline pool fire e(n)**	**SST large gasoline pool fire f(o)**	**SST large gasoline pool fire g(p)**	**DST large gasoline pool fire l(q)**
Total onsite dose (Sv)	5.78 E-04	1.78 E-04	2.86 E-04	3.14 E-04	7.66 E-04
Total offsite dose (Sv)	3.48 E-07	1.07 E-07	1.72 E-07	1.89 E-07	5.49 E-07
Onsite total SOF	1.96 E-01	5.18 E-01	2.36 E-01	5.23 E-01	1.02 E-00
Offsite total SOF	2.01 E-03	4.22 E-03	2.94 E+01	6.28 E-03	3.36 E-01

Notes:
DST = double-shell tank.
SOF = sum of fractions.
SST = single-shell tank.

6.0 SUMMARY AND CONCLUSIONS

6.1 SUMMARY OF LIKELIHOOD ANALYSIS

This analysis demonstrates that the frequency of the pool fire and deflagration scenarios of the in-tank vehicle fuel fire/deflagration accident are "extremely unlikely" to "unlikely." The chains of events that result in each scenario are presented in this document and are the same as used in previous analyses of this accident. Probabilities and frequencies are developed for each event, using wherever possible, information from RPP-13121, Tables B-1 and B-2, and from the River Protection Project ORPS. The estimated probabilities are considered reasonably conservative, but do not necessarily assume the worst possible outcomes or the most conservative possible cases. A sensitivity analysis performed in Section 4.2 shows that if the probability of either the ignition of fuel event or the fuel flows into riser event were underestimated by an order of magnitude, the accident frequency for a pool fire could increase and shift into the "unlikely" category. If the probability of an increase in riser strikes, or an increase in broken risers, unignited fuel entering a riser, or a fuel ignition source being present in a tank were underestimated by an order of magnitude, the accident frequency for a deflagration would remain in the "unlikely" category. When the likelihood of a broken riser is increased by an order of magnitude, a pool fire remains in the "extremely unlikely" category.

Results documented in Appendix A establish that concentrations of diesel fuel in the vapor of an unventilated tank at the highest headspace temperature are about 4 g/1,000 L or about 8% of the LFL. As such, deflagrations resulting from diesel fuel evaporation are considered "beyond extremely unlikely." The DSA accident analysis indicates that an unmitigated flammable gas deflagration or an organic solvent fire occurring in either an SST or a DST is an anticipated event ($> 10^{-2}$). Deflagration in a DST annulus is considered unlikely ($> 10^{-4}$ to $\geq 10^{-2}$). These frequencies clearly bound those of the in–tank vehicle fuel fire family of accidents.

6.2 SUMMARY OF CONSEQUENCE ANALYSIS

From data presented in Chapter 5.0, it can be argued that:

- The consequences of the DSA flammable gas deflagration bound the in–tank vehicle fuel–fire deflagration.
- The consequences of the DSA organic solvent fire bound both fuel burning scenarios in the in–tank fuel fire.

For safety analyses purposes, tank parameters have been chosen to maximize the potential consequences of solvent pool fires. Selecting headspace air volume to maximize the mass of solvent burned, and extreme vent path flow capacity for bounding pressure and vacuums are examples. It was concluded (RPP-8369) that the bounding pressure and vacuum transients would not result in dome collapse. The DSA assumes that when a deflagration occurs in the headspace of any tank, the material at risk is identical no matter what the initiating medium (e.g., hydrogen, gasoline). Based on these assumptions, the consequences of the flammable gas

deflagration, and both of the vapor phase scenarios of the in-tank vehicle fuel fire/deflagration, are equivalent.

Radiological consequences for solvent pool fires are attributed to contaminants released from the fire itself. Radiological consequences vary mainly with the quantity of solvent that is burned. Radiological releases, without controls, when reviewed against U.S. Department of Energy risk guidelines, do not exceed the maximum value for either the onsite or the offsite receptors. The consequences of the flammable gas deflagration, and both of the vapor phase scenarios of the in-tank vehicle fuel fire/deflagration, are equivalent.

Toxicological consequences are driven by the vent rate of toxic materials. Large, bounding vent paths result in bounding toxicological consequences. For toxicological releases, without controls, no offsite or onsite evaluation guidelines are exceeded. The consequence of the organic solvent fire is either equal to or greater than the consequence of both fuel-burning scenarios of the in-tank vehicle fuel fire/deflagration accident.

6.3 CONCLUSION

Both the flammable gas deflagration and the organic solvent fire are more frequent than the hypothetical in–tank vehicle fuel–fire scenarios in the DSA. Therefore, those accident event scenarios in the DSA that are characterized by the in–tank vehicle fuel fire sequence of accidents are not utilized as representative accidents and are relocated under the organic solvent fire and flammable gas deflagration scenarios.

Unmitigated, the in–tank vehicle fuel fire/deflagration pool fire consequences remain bounded by the organic solvent fire, while an unmitigated deflagration is bounded by the flammable gas deflagration event. With its extremely wide flammability range, and high burning velocity, a hydrogen deflagration would produce a greater pressure rate of rise than an equivalent gasoline deflagration. The amount of waste material released because of a deflagration accident is intuitively related to the severity of the deflagration. The source term is identical for all deflagration accident scenarios where the headspace gases reach the LFL. Therefore, the in–tank vehicle fuel fire deflagration consequence does not provide a bounding accident scenario in the DSA.

The findings of this calculation note (supported by Appendix A, Appendix B, and the listed references) provide justification for the repositioning of the in–tank vehicle fuel fire scenario. Scenarios, analyses, and discussions described by the in–tank vehicle fuel fire dialogue in the DSA may be relocated to other, more bounding accidents, since frequencies and consequences are qualitatively bounded by other representative accidents (i.e., the organic solvent fire and the flammable gas deflagration).

7.0 REFERENCES

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APPENDIX A

SPILLED FUELS

FLAMMABILITY DETERMINATION

FEBRUARY 15, 2002

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APPENDIX A

SPILLED FUELS FLAMMABILITY DETERMINATION

A.0 INTRODUCTION

The flammability and physical state of diesel and gasoline that have been accidentally spilled into the waste tanks are considered in this report.

HNF-SD-WM-CN-032, *Solvent Topical Report*, investigated the flammability of mixtures of normal paraffinic hydrocarbon and tributyl phosphate. They used Raoult's Law, the ideal gas law, and mass transfer analysis to assess the vapor phase concentrations of pools of organic liquids in ventilated and unventilated tanks. They showed that the highest vapor phase concentrations of the organic compounds were achieved when the tank was unventilated. The same approach has been used to investigate the flammability of spilled diesel motor fuel and gasoline.

Specifically, Raoult's Law was used to determine the partial pressures of the constituents in the mixture and the ideal gas law was used to determine the concentrations of the constituents in the vapor. The concentrations in the vapor were compared with the upper and lower flammability limits (LFL) to evaluate the flammability of the mixture.

It was found that the concentration of diesel fuel in the headspaces was much smaller than the LFL at the highest headspace temperature of 40 °C. The information is discussed in Part A.

Preliminary work showed that gasoline spills could lead to concentrations of gasoline vapor in the headspaces that were within the upper and LFLs under some circumstances. This finding prompted additional work. First, the headspace concentrations of gasoline were evaluated for spills of 10, 25, and 50 gal of gasoline at 20 and 40 °C to assess the influence of tank size, temperature, and other factors on volatility. Second, the stoichiometric relationship between the fuel and oxygen in the headspace were assessed. Third, the rate at which gasoline was vented from the tanks was evaluated. Fourth, the gasoline concentrations in the headspaces and the times required for the reduction of these concentrations to values below the LFL were evaluated for 177 waste tanks. The results of these assessments are discussed in Part B.

PART A: DIESEL FUEL

Diesel fuels that are used in cars and trucks and other engines are complex mixtures of organic hydrocarbons that contain low concentrations of additives. Diesel engine fuels typically have an initial distillation temperature of above 160 °C and the temperatures at which 90% of the fuel has distilled range from 290 to 360 °C. The hydrocarbons in these fuels have between 10 and 20 carbon atoms.

Assessment 1: The Weight and Number of Moles of Hydrocarbons in 50 Gallons of Diesel Fuel

The density and molecular weight of dodecane were used to determine the weight and the number of moles of hydrocarbons in 50 gal of diesel fuel.

Weight: 50 gal • 3.79 liter (L)/gal • 750 gal/L = 142,000 g
Number of moles: 142,000 grams (g) • 1 mole/170g = 840 moles.

Assessment 2: The Surface Distribution of the Liquid Fuel

Diesel fuel is insoluble in the liquid waste. HNF-SD-WM-CN-121, *Consequences of Potential Gasoline Pool Fires*, discussed the distribution of a spilled burning organic liquid. They postulated that the burning material would occupy an area of about 100 m^2. Subsequently, HNF-SD-WM-CN-032 concluded that spilled insoluble organic liquids would accumulate in the accessible depressed areas of the irregular waste surfaces in localized liquid pools.* The same concept is adopted in this letter report.

Assessment 3: Concentrations of Diesel Fuel in the Vapor

HNF-SD-WM-CN-032 used Raoult's Law, the ideal gas law, and mass transfer analysis to assess the vapor phase concentrations of organic compounds above a pool of normal paraffin hydrocarbons and tributyl phosphate. They showed that the highest vapor phase concentrations of organic material were achieved when a tank was unventilated. Accordingly, the conservative assumption that the headspaces were unventilated was used in this assessment of the concentrations of diesel fuel in the headspaces.

The same procedures were used to evaluate the flammability of spilled diesel fuel. Freshly spilled diesel fuel was modeled as a mixture consisting of:

- 0.05–mole fractions of compounds with 10–carbon atoms and the vapor pressure of decane.
- 0.1–mole fraction of compounds with 11–carbon atoms and the vapor pressure of undecane.
- 0.1–mole fraction of compounds with 12-carbon atoms and a vapor pressure of dodecane.
- 0.1–mole fraction of compounds with 13 –carbon atoms and the vapor pressure of tridecane
- 0.65 –mole fraction of less volatile constituents.

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* If the aqueous supernatant layer in a tank was 22.8 m (175 ft) in diameter and had a plane surface, then 227 L (50 gal) of spilled fuel would form a liquid layer about 0.05 cm (0.02 in) thick.

These concentrations and the vapor pressures of decane, undecane, dodecane, and tridecane at 40 °C were used to calculate the concentrations of these compounds in the vapor above the spilled liquid by using Raoult's Law and the ideal gas law. The results are shown in Table A-1.

Table A-1. The Composition and Volatility of Diesel Fuel at 40 °C.

Constituent group	Mole fraction	Molecular weight	Boiling point (°C)	Pressure at 40 °C (atm)	Pressure in fuel at 40 °C (atm)	Moles in 1000 L of vapor at 40 °C (moles)	Weight in 1000 L of vapor at 40 °C (g)
C10	0.05	142	174	0.0065	0.00032	0.013	1.8
C11	0.10	156	196	0.0027	0.00027	0.010	1.6
C12	0.10	170	216	0.0007	0.00007	0.003	0.5
C14	0.10	184	234	0.0002	0.00002	0.001	0.1
Other	0.65	--	--	--	--	--	--

This analysis indicates that the vapor pressure of the mixture in an unventilated tank at about 40 °C is about 0.0006 atm and that approximately 0.027 moles and 4.0 g of hydrocarbons are present in 1000 L of air. The LFL was determined by using Lechatelier's principle as described in HNF-SD-WM-CN-032 and the LFLs tabulated in *Flammability Characteristics of Combustible Gases and Vapors* (Zabetakis 1965) to be 48 g/1000 L. Consequently, the concentration of the diesel fuel in the vapor is approximately 8% of the LFL in an unventilated tank. Mass transfer analysis HNF-SD-WM-CN-032 showed that the concentrations of the hydrocarbons decreased in the vapors of ventilated tanks.

Assessment 4: Retention of Diesel Fuel in the Liquid Phase

The information presented in the Table A-6 spreadsheets provides the volumes and temperatures of the headspace for the Hanford Site tanks. The headspace volumes range from about 10,000 L to about 5,150,000 L and the temperature range from 20 °C to about 40 °C. The amount of hydrocarbons that could be present in the headspace of the largest unventilated tank was estimated by using the ideal gas law.

$$PV = nRT$$

where:

P = the pressure of hydrocarbons in the vapor in atmospheres
V = the volume headspace in liters (L)
n = the number of moles of the hydrocarbons in the vapor
R = the gas constant equal to 0.082 1-atm/degree Kelvin (K)
T = the temperature in the headspace on the Kelvin (K) scale.

The calculation for a tank with a headspace volume of 5,3000,000 L (185,000 ft^3) and a headspace temperature of 40 °C is shown as:

$$V = 185{,}000\ ft^3 \bullet L/ft^3 = 5,\ 300{,}000\ L$$

$$n = \text{number of moles} = (0.0011\ atm \bullet 5{,}300{,}000\ L)/(313\ K \bullet 0.082\ L\ atm/mole\ K) = 206\ moles$$

The results indicate that no more than 206 moles of hydrocarbons from diesel fuel could be present in the headspace of the tank with the largest headspace volume and highest temperature. Consequently, most of the 840 moles of spilled diesel fuel would be present in the waste pools and puddles of liquid.

A.1 DISCUSSION AND CONCLUSIONS FOR DIESEL FUEL

Diesel fuel is represented as a mixture with 5–mole percent hydrocarbons with properties similar to decane and 10–mole percent undecane, dodecane, and tridecane together with 65–mole percent of other higher molecular weight hydrocarbons. This formulation is conservative because it overestimates the volatility of the fuel. Raoult's Law and the ideal gas law are often used successfully in engineering analyses of this kind. The procedure overestimates the concentrations of the hydrocarbons in the vapor because attractive interactions between the hydrocarbons and the vapor are neglected.

The results indicate the concentrations of diesel fuel in the vapor of an unventilated tank at the highest headspace temperature is about 4 g per 1,000 L or about 8% of the LFL of these hydrocarbons. The amount of diesel fuel (206 moles) that could be present in the headspace of the tank with the largest headspace at 40 °C is approximately 25% of the amount of spilled fuel (840 moles). Consequently, pools of liquid diesel fuel would remain on the top of the waste even in the largest waste tanks.

HNF-SD-WM-CN-032 showed that the concentrations of hydrocarbons in the headspace decreased when the tanks were passively and actively ventilated. It is pertinent to note that the mole fractions of the more volatile compounds in the vapor are higher than the mole fractions for these compounds in the residual liquid. Ventilation therefore has several effects. First, it reduces the concentrations of the hydrocarbons in the headspace. Second, it leads to the selective removal of the most volatile constituents. Third, the vapor pressure of the residual liquid decreases as the concentrations of the hydrocarbons in the headspace continuously decreases.

PART B: GASOLINE

Gasoline fuels that are used in automobiles and trucks are mixtures of organic hydrocarbons, some of which contain 10% ethanol. Gasoline fuels are blended seasonally and the winter blends are much more volatile than the blends designed for use in the summer or the blends that contain ethanol. Specifically, the winter bends contain hydrocarbons with 4 to 12–carbon atoms and 10% of the material distills below 50 °C, 50% distills between 75 and 110 °C, and 90% distills

below 185 °C (*Kirk and Othmer Encyclopedia of Chemical Technology* [Howe-Grant 1994]). The flammability of this blend of gasoline is considered in this report inasmuch as it is presumably more hazardous than other less volatile blends.

Many different parameters including the amount of gasoline spilled, temperature in the headspace of the tank, volume of the headspace, ventilation rate for the tank, and amount of oxygen in the headspace will determine whether the mixture is flammable. This report considers accidents in which 10, 25, or 50 gal of gasoline are spilled into a waste tank with waste and headspace temperatures of 20 and 40 °C.

Assessment 1: The Weight and Number of Moles of Organic Hydrocarbons in Gasoline

The weight and the number of moles of gasoline in 10, 25, and 50 gal of the fuel were evaluated based on the density and molecular weight of octane.

Weight: 10 gal • 3.79 L/gal • 750g/L = 28,400 g
Number of Moles: 28,400 g • 1–mole/114 g = 250 moles

The three spills under consideration introduce 2.84×10^4 kg (250 moles), 7.11×10^4 kg (625 moles), or 1.42×10^5 kg (1,250 moles) of gasoline into the tank.

Assessment 2: The Distribution of the Liquid Fuel on the Surface

Gasoline, like diesel fuel, is insoluble in liquid waste. If the gasoline has not been ignited, then it, like diesel fuel, would spread over the waste surface as already described in Part A. However, gasoline is much more volatile than diesel fuel and a much greater fraction of the liquid can evaporate into the headspace. An accident in the winter would contact the volatile fuel with the warm waste and lead to the rapid evaporation of the more volatile hydrocarbons. The calculated headspace concentrations of gasoline are based on the idea that pressure changes and the turbulence cause by its rapid evaporation, coupled with ventilation would distribute the volatile material throughout the headspaces of the large and small tanks. To illustrate, the prompt evaporation of the most volatile 10% of the gasoline would produce about 3,000 L of gaseous hydrocarbons with attendant changes in the pressure.

Assessment 3: Concentrations of Gasoline in the Headspace

The procedures described in Part A of this report were used to evaluate the flammability of gasoline in the headspace. The winter blend of gasoline was modeled as a seven-component mixture with:

- 17 mole percent compounds with the vapor pressure of pentane
- 17 mole percent compounds with the vapor pressure of hexane
- 25 mole percent compounds with the vapor pressure of heptane
- 25 mole percent compounds with the vapor pressure of octane

and the remainder of the material distributed among compounds with the volatility of nonane, decane, and undecane.

The vapor pressures of the pure compounds at 20 and 40 °C were obtained from the technical literature. The vapor pressure of each constituent in the mixture was calculated by using

Raoult's Law, and the mole fraction of each constituent in the vapor was assessed by using these partial pressures and the ideal gas law. The number of moles and volumes of each constituent group in 1,000 L are shown in the right hand columns of Tables A-2A and A-2B.

Table A-2. The Vapor Composition in 1,000 L over a Liquid Pool of a Volatile Gasoline Blend at 20 °C and 40 °C.

Compound group	Moles	Mole fraction in liquid	Vapor pressure		Mole fraction in vapor	Moles in 1000 L of vapor at 20 °C	Volume in 1000 L of vapor at 20 °C (L)
			Pure at 20 °C (atm)	In mixture at 20 °C (atm)			
Table A-2A: 20 °C							
C5	210	0.17	0.970	0.1649	0.782	6.86	154
C6	210	0.17	0.170	0.0289	0.137	1.20	27
C7	315	0.25	0.051	0.0128	0.060	0.53	12
C8	315	0.25	0.014	0.0035	0.017	0.15	3
C9	100	0.08	0.006	0.0004	0.002	0.02	0
C10	75	0.06	0.002	0.0001	0.001	0.01	0
C11	25	0.02	0.001	0.0000	0.0000	0.00	0
Total	1,250	1.00	1.21	0.2106	0.998	8.77	196

Compound group	Moles	Mole fraction in liquid	Vapor pressure		Mole fraction in vapor	Moles in 1000 L of vapor at 40 °C	Volume in 1000 L of vapor at 40 °C (L)
			Pure at 40 °C (atm)	In mixture at 40 °C (atm)			
Table A-2B: 40° C							
C5	210	0.17	1.180	0.2006	0.647	7.82	175
C6	210	0.17	0.370	0.0629	0.203	2.45	55
C7	315	0.25	0.130	0.0325	0.105	1.27	28
C8	315	0.25	0.048	0.0120	0.039	0.47	10
C9	100	0.08	0.015	0.0012	0.004	0.05	1
C10	75	0.06	0.007	0.0004	0.001	0.02	0
C11	25	0.02	0.003	0.0001	0.000	0.00	0
Total	1,250	1.00	1.75	0.3096	0.999	12.06	270

The results indicate that the initial contact of the cool liquid gasoline with the waste at 20 and 40 °C produces a mixture of hydrocarbons in the headspace that is especially rich in compounds with 5–carbon atoms. These concentrations of hydrocarbons in the vapor are substantially greater than the upper flammability limit of 7.4 vol% when the volume of the headspace is small.

The amount of gasoline that can evaporate into the headspace depends on the headspace volume and temperature. The amount of gasoline evaporated into the headspaces was estimated by successive iterations of the same analysis. The results for the winter blend of gasoline are shown in Table A-3.

Table A-3. The Concentration of Gasoline in the Vapor in Waste Tanks.

Headspace volume (L)	**Gasoline spill – 10 gallons**		**Gasoline spill – 25 gallons**		**Gasoline spill – 50 gallons**	
	at 20 °C (moles)	**at 20 °C (vol%)**	**at 20 °C (moles)**	**at 20 °C (vol%)**	**at 20 °C (moles)**	**at 20 °C (vol%)**
Table A-3A: Gasoline in Vapor in the Waste Tank (20 °C)						
5,000	80	3.6	200	**9.0**	290	**13.0**
10,000	110	2.5	280	6.3	400	**9.0**
300,000	125	***0.9***	440	3.3	670	5.0
500,000	125	***0.6***	520	2.3	820	3.7
1,000,000	125	***0.3***	600	1.3	1050	2.4
1,250,000	125	***0.2***	625	***1.1***	1,120	2.0
1,500,000	125	***0.2***	625	***0.9***	1,170	1.7
2,000,000	125	***0.1***	625	***0.7***	1,250	1.4
3,000,000	125	***0.1***	625	***0.5***	1,250	***0.9***
4,000,000	125	***0.1***	625	***0.4***	1,250	***0.7***
5,000,000	125	***0.1***	625	***0.3***	1,250	***0.6***

Headspace volume (L)	**Gasoline spill – 10 gallons**		**Gasoline spill – 25 gallons**		**Gasoline spill – 50 gallons**	
	at 40 °C (moles)	**at 40 °C (vol%)**	**at 40 °C (moles)**	**at 40 °C (vol%)**	**at 40 °C (moles)**	**at 40 °C (vol%)**
Table A-3B: Gasoline in Vapor in the Waste Tank (40° C)						
5,000	110	4.9	210	**9.4**	410	**18.4**
10,000	125	2.8	310	6.9	600	**13.4**
300,000	125	***0.9***	510	3.8	990	**7.4**
500,000	125	***0.6***	590	2.6	1,150	5.2
1,000,000	125	***0.3***	625	1.4	1,250	2.8
1,250,000	125	***0.2***	625	***1.1***	1,250	2.2
1,500,000	125	***0.2***	625	***0.9***	1,250	1.9
2,000,000	125	***0.1***	625	***0.7***	1,250	1.4
3,000,000	125	***0.1***	625	***0.5***	1,250	***0.9***
4,000,000	125	***0.1***	625	***0.4***	1,250	***0.7***
5,000,000	125	***0.1***	625	***0.3***	1,250	***0.6***

The information shows that the gasoline is distributed between the liquid and vapor phases in the waste tank with smaller headspaces. Specifically, 10 gal of gasoline evaporates into the headspaces that are larger than 100,000 L at 40 °C and larger than 300,000 L at 20 °C, 25 gal

evaporates into the headspaces that are larger than 1,000,000 L at 40 °C and larger than 2,500,000 L at 20 °C. Finally, 50 gal evaporates into the headspaces that are larger than 1,000,000 L at 40 °C and larger than 2,000,000 L at 20 °C. In Table A-3 the headspace gasoline concentrations that are greater than the upper flammability limit of 7.4 vol% appear bolded. Conversely, the headspace gasoline concentrations that are less than the LFL of 1.3 vol% appear bolded and italicized. The remaining gasoline concentrations in Table A-3 are between the upper and LFLs of gasoline in air.

Assessment 4: The Amount of Oxygen Necessary for the Combustion of Gasoline

The balanced equation for the oxidation of octane was used to evaluate the amount of oxygen required to completely combust 50 gal of gasoline:

$$C_8H_{18} + 12.5O_2 \rightarrow 8CO_2 + 9H_2O$$

The reaction stoichiometry indicates that one mole of octane require 12.5 moles of oxygen for complete combustion. The volume of air at standard temperature and pressure that contains 12.5 moles of oxygen is given by the following equation:

$$12.5 \text{ mole } O_2 \bullet 22.4 \text{ L/mole} = 280 \text{ L } O_2$$
$$280 \text{ L } O_2 \bullet (1 \text{ L air}/0.209 \text{ L } O_2) = 1340 \text{ L air}$$

However, it has been pointed out by *Combustion, Flames, and Explosions of Gases* (Lewis and Von Elbe 1987) that the combustion in air will cease because the oxygen becomes insufficient to sustain the necessary high reaction rates. If nitrogen is the diluent, the combustion reaction ceases when the oxygen content decreases from 20.9 to 11.9%. If carbon dioxide is the principle diluent, then the combustion reaction ceases when the oxygen content decreases from 20.9 to 14.5%. These two limiting conditions were explored. The results are shown in Table A-4.

The headspaces of the tanks, which ranged from 50,000 to 5,000,000 L, are shown on the left column in Table A-4. The moles of oxygen available for reaction are presented in the next two columns. The moles of gasoline in a 10-gal spill and the oxygen requirements are presented in the next three columns. The same information is presented for 25– and 50–gal spills in the next six columns. The oxygen sufficiency was calculated at the 9% limit at 20 and 40 °C in the A and B segments of the table and at the 6.4% limit at 20 and 40 °C in segments C and D. The gasoline concentrations that are higher than the LFL are identified in boldface type. Finally, the situations for which the oxygen concentration is insufficient for the combustion of the hydrocarbons are in bold and italic type. The computations show that the oxygen concentrations in the headspace are insufficient to sustain the combustion reactions.

Table A-4. The Concentration of Gasoline in Waste Tanks and the Oxygen Requirements for Combustion. (4 sheets)

Note: The amount of oxygen available was taken to be 9% in Tables A-4A, A-4B, and 6.4% in Tables A-4C and A-4D.

Table A-4A

Headspace volume (L)	Oxygen available at 20.9% (moles)	Oxygen available at 9% (moles)	Gasoline 10 gallons at 20° C (moles)	Oxygen required for combustion (moles)	Oxygen deficiency for combustion (moles)	Gasoline 25 gallons at 20 °C (moles)	Oxygen required for combustion (moles)	Oxygen deficiency for combustion (moles)	Gasoline 50 gallons at 20 °C (moles)	Oxygen required for combustion (moles)	Oxygen deficiency for combustion (moles)
50,000	467	201	**80**	**1,000**	***-799***	**200**	**2,500**	***-2,299***	290	3,625	-3,424
100,000	933	402	**110**	**1,375**	***-973***	**280**	**3,500**	***-3,098***	400	5,000	-4,598
300,000	2,799	1,205	125	**1,563**	***-357***	**440**	**5,500**	***-4,295***	***670***	***8,375***	***-7,170***
500,000	4,665	2,009	125	1,563	446	**520**	**6,500**	***-4,491***	***820***	***10,250***	***-8,241***
1,000,000	9,330	4,018	125	1,563	2,455	**600**	**7,500**	***-3,482***	***1,050***	***13,125***	***-9,107***
1,250,000	11,663	5,022	125	1,563	3,460	625	7,813	*-2,790*	***1,120***	***14,000***	***-8,978***
1,500,000	13,996	6,027	125	1,563	4,464	625	7,813	-1,786	***1,170***	***14,625***	***-8,598***
2,000,000	18,661	8,036	125	1,563	6,473	625	7,813	223	***1,250***	***15,625***	***-7,589***
3,000,000	27,991	12,054	125	1,563	10,491	625	7,813	4,241	1,250	15,625	-3,571
4,000,000	37,361	16,071	125	1,563	14,509	625	7,813	8,259	1,250	15,625	446
5,000,000	46,652	20,089	125	1,563	18,527	625	7,813	12,277	1,250	15,625	4,464

Table A-4. The Concentration of Gasoline in Waste Tanks and the Oxygen Requirements for Combustion. (4 sheets)

Note: The amount of oxygen available was taken to be 9% in Tables A-4A, A-4B, and 6.4% in Tables A-4C and A-4D.

Table A-4B

Headspace volume (L)	Oxygen available at 20.9% (moles)	Oxygen available at 9% (moles)	Gasoline 10 gallons at 40 °C (moles)	Oxygen required for combustion (moles)	Oxygen deficiency for combustion (moles)	Gasoline 25 gallons at 40 °C (moles)	Oxygen required for combustion (moles)	Oxygen deficiency for combustion (moles)	Gasoline 50 gallons at 40 °C (moles)	Oxygen required for combustion (moles)	Oxygen Deficiency for combustion (moles)
50,000	467	201	***80***	***1,375***	***-1,174***	210	2,625	-2,424	410	5,125	-4,924
100,000	933	402	***110***	***1,563***	***-1,161***	***310***	***3,875***	***-3,473***	600	7,500	-7,098
300,000	2,799	1,205	125	1,563	-357	***510***	***6,375***	***-5,170***	***990***	***12,375***	***-11,170***
500,000	4,665	2,009	125	1,563	446	***590***	***7,375***	***-5,366***	***1,150***	***14,375***	***-12,366***
1,000,000	9,330	4,018	125	1,563	2,455	***625***	***7,813***	***-3,795***	***1,250***	***15,625***	***-11,607***
1,250,000	11,663	5,022	125	1,563	3,460	625	7,813	-2,790	***1,250***	***15,625***	***-10,603***
1,500,000	13,996	6,027	125	1,563	4,464	625	7,813	-1,788	***1,250***	***15,625***	***-9,598***
2,000,000	18,661	8,036	125	1,563	6,473	625	7,813	223	1,250	15,625	-7,589
3,000,000	27,991	12,054	125	1,563	10,491	625	7,813	4,241	1,250	15,625	-3,571
4,000,000	37,361	16,071	125	1,563	14,509	625	7,813	8,259	1,250	15,625	446
5,000,000	46,652	20,089	125	1,563	18,527	625	7,813	12,277	1,250	15,625	4,464

Table A-4. The Concentration of Gasoline in Waste Tanks and the Oxygen Requirements for Combustion. (4 sheets)

Note: The amount of oxygen available was taken to be 9% in Tables A-4A, A-4B, and 6.4% in Tables A-4C and A-4D.

Table A-4C

Headspace volume (L)	Oxygen available at 20.9% (moles)	Oxygen available at 9% (moles)	Gasoline 10 gallons at 20 °C (moles)	Oxygen required for combustion (moles)	Oxygen deficiency for combustion (moles)	Gasoline 25 gallons at 20 °C (moles)	Oxygen required for combustion (moles)	Oxygen deficiency for combustion (moles)	Gasoline 50 gallons at 20 °C (moles)	Oxygen required for combustion (moles)	Oxygen deficiency for combustion (moles)
50,000	467	143	***80***	***1,000***	***-847***	***200***	***2,500***	***-2,367***	290	3.625	-3,462
100,000	933	286	***110***	***1,375***	***-1,069***	***280***	***3,500***	***-3,214***	400	5,000	-4,714
300,000	2,799	857	125	1,563	-705	***440***	***5,500***	***-5,643***	***670***	***8,375***	***-7,518***
500,000	4,665	1,429	125	1,563	-134	***520***	***6,500***	***-5,071***	***820***	***10,250***	***-8,821***
1,000,000	9,330	2,857	125	1,563	1,295	***600***	***7,500***	***-4,643***	***1,050***	***13,125***	***-10,268***
1,250,000	11,663	3,571	125	1,563	2,009	625	7,813	***-4,241***	***1,120***	***14,000***	***-10,429***
1,500,000	13,996	4,286	125	1,563	2,723	625	7,813	-3,527	***1,170***	***14,625***	***-10,339***
2,000,000	18,661	5,714	125	1,563	4,152	625	7,813	-2,098	***1,250***	***15,625***	***-9,911***
3,000,000	27,991	12,429	125	1,563	9,866	625	7,813	3,616	1,250	15,625	-4,196
4,000,000	37,361	11,429	125	1,563	9,866	625	7,813	3,616	1,250	15,625	-4,196
5,000,000	46,652	14,286	125	1,563	12,723	625	7,813	6,473	1,250	15,625	-1,339

Table A-4. The Concentration of Gasoline in Waste Tanks and the Oxygen Requirements for Combustion. (4 sheets)

Note: The amount of oxygen available was taken to be 9% in Tables A-4A, A-4B, and 6.4% in Tables A-4C and A-4D.

Table A-4D

Headspace volume (L)	Oxygen available at 20.9% (moles)	Oxygen available at 6.4% (moles)	Gasoline 10 gallons at 40 °C (moles)	Oxygen required for combustion (moles)	Oxygen deficiency for combustion (moles)	Gasoline 25 gallons at 40 °C (moles)	Oxygen required for combustion (moles)	Oxygen deficiency for combustion (moles)	Gasoline 50 gallons at 40 °C (moles)	Oxygen required for combustion (moles)	Oxygen deficiency for combustion (moles)
50,000	467	143	***110***	***1375***	***-1,232***	210	2,625	-2,482	410	5,125	-4,962
100,000	933	286	***125***	***1563***	***-1,277***	***310***	***3,875***	***-3,589***	600	7,500	-7,214
300,000	2,799	857	125	1563	-705	***510***	***6,375***	***-5,518***	***990***	***12,375***	***-11,518***
500,000	4,665	1,429	125	1563	-134	***590***	***7,375***	***-5,946***	***1,150***	***14,375***	***-12,946***
1,000,000	9,330	2,857	125	1563	1,295	***625***	***7,813***	***-4,955***	***1,250***	***15,625***	***-12,768***
1,250,000	11,663	3,571	125	1563	2,009	625	7,813	-4,241	***1,250***	***15,625***	***-12,054***
1,500,000	13,996	4,286	125	1563	2,723	625	7,813	-3,527	***1,250***	***15,625***	***-11,339***
2,000,000	18,661	5,714	125	1563	4,152	625	7,813	-2,098	1,250	15,625	-9,911
3,000,000	27,991	8,571	125	1563	7,009	625	7,813	759	1,250	15,625	-7,054
4,000,000	37,361	11,429	125	1563	9,866	625	7,813	3,616	1,250	15,625	-4,196
5,000,000	46,652	14,286	125	1563	12,723	625	7,813	6,473	1,250	15,625	-1,339

Assessment 5: The Removal of Gasoline by Ventilation

The rate at which gasoline would be exhausted from these tanks is dependent upon the time required for a defined change in the concentration of a headspace gas and can be treated as a first–order process.

where:

Time = (Volume Headspace)/(Ventilation Rate) x ln(Concentration Before/Concentration After)

The time required to decrease the gasoline concentration from concentrations above the LFL to a concentration below the LFL were calculated for several representative situations. The results are shown in Table A-5.

The calculations show that gasoline can be rapidly exhausted from the headspaces of double–shell tanks (DST) with high ventilation rates. Specifically, the headspace gasoline concentrations would fall below the LFL about 8 hours after 50 gal of gasoline were spilled into a DST with a 1,000,000 L headspace at 20 °C and a ventilation rate of 2,000 L/min (70 ft^3/min). The calculations also show that the lowest ventilation rate decreases the gasoline concentrations in the headspaces of the DSTs by 50% in about 6 hours.

The ventilation rates of the 100 series of single–shell tanks (SST) are usually much smaller than the ventilation rates of the DSTs. Consequently, more time would be needed to exhaust the gasoline from the headspaces of these tanks. The information in Table A-5 indicates that the gasoline concentrations in the 1,250,000 L headspace, the volume of the headspace of the smallest 100 Series tank, would be 2.2% for a spill of 50 gal of gasoline. About 20 days are required to reduce the gasoline concentration to the LFL at the lowest ventilation rate (28 L/min [1 ft^3/min]) and about 2 days are required at the ventilation rate of 280 L/min (10 ft^3/min).

The headspace volumes of the 200 Series SSTs are smaller than the headspaces of the other series of tanks and the ventilation rates are sometimes very low. The time required for the ventilation of gasoline is also about 20 days for a spill of 50 gal into a tank with a headspace of 50,000 L at the slow flow rate of 10 L/min (0.3 ft^3/min) and 2 days for the higher flow rate of 28 L/min (1 ft^3/min).

Assessment 6: Projected Gasoline Concentrations and Ventilation Times for 177 Tanks

The tank volumes, waste volumes, headspace volumes, headspace temperature, and ventilation rates for the waste tanks are assembled on the left-hand side of Table A-6. The consequences of spills of 10, 25, and 50 gal of gasoline were examined. The gasoline concentrations in the headspaces of the DSTs and the 100 Series SSTs are shown in the center of the table together with the time required for the reduction of the gasoline concentration to below the LFL.

The equivalent information for the 200 Series SSTs is given separately on the right-hand side of the table. This information is separated because a portion of the spilled gasoline would remain in the liquid phase in these tanks.

Table A-5. General Features of Ventilation. (2 sheets)

Table A-5A: Double-Shell Tanks

Headspace volume (L)	Situation spill temperature (°C)	Gasoline liquid (moles)	Gasoline vapor (moles)	Ventilation rate (L/min)	Concentration before (%)	Concentration after (%)	Ln	Time for liquid (days)	Time for vapor (days)	Time total (days)
1,000,000	50 Gallons @ 20 °C	250	1,000	2,000	2.4	1.2	0.7	0.08	0.24	0.32
1,000,000	50 Gallons @ 20 °C	250	1,000	5,500	2.4	1.2	0.7	0.03	0.09	0.12
1,000,000	50 Gallons @ 40 °C	0	1,250	2,000	2.2	1.2	0.6	—	0.21	0.21
1,000,000	50 Gallons @ 40 °C	0	1,250	5,500	2.2	1.2	0.6	—	0.08	0.08

Table A-5B: 100 Series Single-Shell Tanks

Headspace volume (L)	Situation spill temperature (°C)	Gasoline liquid (moles)	Gasoline vapor (moles)	Ventilation rate (L/min)	Concentration before (%)	Concentration after (%)	Ln	Time for liquid (days)	Time for vapor (days)	Time total (days)
1,250,000	50 Gallons @ 20 °C	130	1,250	28	2.0	1.2	0.5	3.61	16	19
1,250,000	50 Gallons @ 20°C	130	1,250	280	2.0	1.2	0.5	0.36	2	2
1,250,000	50 Gallons @ 40 °C	0	1,250	28	2.2	1.2	0.6	—	19	19
1,250,000	50 Gallons @ 40 °C	0	1,250	280	2.2	1.2	0.6	—	2	2

Table A-5. General Features of Ventilation. (2 sheets)

Table A-5C. 200 Series Single-Shell Tanks.

Headspace volume (L)	Situation spill temperature (°C)	Gasoline liquid (moles)	Gasoline vapor (moles)	Ventilation rate (L/min)	Concentration before (%)	Concentration after (%)	Ln	Time for liquid (days)	Time for vapor (days)	Time total (days)
50,000	50 Gallons @ 20 °C	960	290	10	13	1.2	11.49	11.49	8	20
50,000	50 Gallons @ 20°C	960	290	28	13	1.2	4.10	4.10	3	7
50,000	50 Gallons @ 40 °C	840	410	10	18.4	1.2	7.10	7.10	9	17
50,000	50 Gallons @ 40 °C	840	410	28	18.4	1.2	2.54	2.54	3	6

The information presented in the table shows that the concentration of gasoline in the headspace of a DST or a 100 Series SST would not achieve the LFL when 10 gal of gasoline is spilled into the tank. The headspace gasoline concentrations that would result from a 25-gal spill exceed the LFL in fewer than 10 of these tanks. However, the headspace gasoline concentrations that result from a 50-gal spill exceed the LFL in more than 55 tanks.

The ventilation rates are sufficient to decrease the gasoline concentrations resulting from a 25-gal spill to below the LFL in less than a day. The same time is required for the decrease of the gasoline concentrations that result from 50-gal gasoline spills to below the LFL in about 20 of these tanks. About 20 tanks require 1, 2, or 3 days to reduce the concentrations to the LFL. The other 8 tanks require 3 to 8 days to exhaust sufficient concentrations to the LFL.

The headspaces of the 200 Series SSTs are small and they contain liquid gasoline. The concentrations of gasoline in the vapor are above the LFLs for small and large gasoline spills. The gasoline concentrations in the headspace frequently exceed the upper flammability limit. The ventilation rates for these tanks are also small. Consequently, many of these tanks require from one to three weeks to evaporate the liquid gasoline and to reduce the gasoline concentration below the LFL.

Assessment 7: The Consequences of Incomplete Mixing

Gasoline has a higher vapor density than air and its behavior can be capricious. Monographs concerning fire safety and fire hazards (*Fire Investigation Handbook* [Brannigan 1980]; *The Chemistry of Fire and Explosion Gases* [Turner and McCreery 1981]; *Kirks Fire Investigation* [DeHaan 1983]; *An Introduction to Fire Dynamics* [Turner and Drysdale 1985]; *Fire Fundamentals and Control* [Haessler 1989]) point out that gasoline is often distributed inhomogeneously in poorly ventilated spaces with relative high concentrations near the lower surface of the space.

One aspect of this additional hazard is illustrated by the following example. There would be sufficient oxygen for complete combustion of the gasoline in an inhomogeneous mixture in a 1,000,000 L headspace that had an average concentration of 1.4% gasoline in 500,000 L directly above the surface of the waste and low gasoline concentrations in the remainder of the headspace.

- Moles of Gasoline = 500,000 L • 0.014 L Gasoline/L • 1 mole/22.4 L of gasoline = 312 moles
- Moles of Oxygen Required for Combustion = 312 moles • 12.5 moles oxygen/mole gasoline = 3,900 moles
- Volume of Oxygen Required = 3,900 moles • 22.4 L oxygen/mole oxygen = 87,400 L
- Volume of Oxygen Available = 1,000,000 L • 0.209 L Oxygen/L = 209,000 L
- Final Concentration of Oxygen = 100 • (209,000 – 87,400)/1,000,000 = 12%.

The concentration of oxygen remains above the minimum concentration required for sustained combustion. A second aspect is provided by commentary in the literature that calls attention to the hazard associated with combustion reactions that are initiated and then are extinguished because of an oxygen deficiency. When the vapors in the confined space cool, external air and additional oxygen is drawn into the confined space and the incompletely combusted fuel may ignite.

A.2 DISCUSSION AND CONCLUSIONS FOR GASOLINE

Elementary considerations indicate that the accidental introduction of 10, 25, or 50 gal of a winter blend of gasoline into a waste tank in which the temperature of the waste surface and the headspace was between 20 and 40 °C would lead to a prompt evaporation of the volatile hydrocarbons from the liquid fuel. When headspace in the tank is small or the temperature is low, some liquid gasoline may remain on the waste surface. Although equilibrium would not be achieved immediately, it is reasonable to assume that the turbulence resulting from the rapid evolution of these volatile components of the gasoline would mix the vapors in the headspace and distribute the volatile gasoline vapors throughout the headspace. The observations that are presented in Table A-4 are based on this viewpoint.

The evaporation of the most volatile components of the gasoline into the smaller headspaces would immediately increase the pressure in the headspace. For example, the evaporation of gasoline in smaller and warmer headspaces would increase the pressure sufficiently to exhaust air and gasoline from the headspace. Specifically, the evaporation of 600 moles of gasoline in a 100,000–L headspace at 40 °C would increase the pressure in the headspace from 1–atmosphere to about 1.1 atmospheres. Presumably, air and some gasoline vapor would be expelled from the tank under these circumstances. However, these rather modest changes were not considered in the assessment and the concentrations of gasoline in the headspace, the determination of the oxygen deficiency, or the time required for the ventilation of gasoline.

The observations in tables show that the concentrations of gasoline in the headspaces from 25- or 50-gal spills can be greater than the upper flammability limit of the small headspaces of the 200 Series SSTs. The amount of oxygen available for the combustion reaction in these headspaces is also too small to support the combustion reaction as shown in Table A-4. Consequently, the combustion reactions could not be initiated under these circumstances.

Similarly, the vapor phase concentrations of gasoline that result from the 10–, 25–, and 50–gal spills are below the LFL for tanks with headspace volumes greater than about 300,000 L, 1,250,000 L, and 3,000,000 L. The embolden observations in Table B-3 and the more detailed observations in Table A-6 indicate that 10–, 25–, and 50-gal spills can lead to headspace gasoline concentrations in the flammability range of 1.4 to 7.4 vol%. Elementary considerations indicate that the combustion reactions could be initiated under these circumstances. However, there is insufficient oxygen for the completion of these reactions. Headspace volumes that have insufficient oxygen for the combustion reactions are italicized in Table A-4. Inspection of the table also shows those headspace volumes that have gasoline concentrations within the flammability limits. The combustion reactions of gasoline can be initiated under these conditions, but they would be extinguished as the concentration of oxygen falls and the concentration of carbon dioxide increases in the headspace. No attempt has been made to model

the influence of the changing temperature on the outcome of these reactions. However, it is pertinent that any remaining liquid gasoline would evaporate into the headspace to increase the oxygen demand and that the gasoline, incompletely oxidized molecules, the other combustion products, and air would be expelled from the waste tank.

Although the results show unambiguously that the combustion reactions would be extinguished under these circumstances, it is notable that the succession of the reactions would enable the headspace gases to cool. The cooling waste tank and the reduction in pressure would lead to the introduction of additional air and oxygen into the incompletely combusted mixture of gasoline and air. The combustion reactions may be reinitiated under these circumstances.

The rates of ventilation vary considerably in the Hanford Site tank farms as shown in Table A-6.

The findings shown in Table A-6 indicate that gasoline would be promptly exhausted from the DSTs quickly to reduce the headspace concentration below the LFL even at the slowest ventilation rates.

Gasoline concentrations greater than the LFL result from spills of 50 gal of gasoline into more than 55 of the 100 Series tanks. When these tanks are ventilated at rates exceeding 283 L/min (10 ft^3/min), the gasoline concentrations decrease to below the LFL in a few days as shown in Table A-6. Lower ventilation rates extend the time required to a maximum of 8 days.

Longer times are required for the ventilation of gasoline in the small headspaces of the 200 Series SSTs because of the very low ventilation rates. Between 7 and 24 days are required for 50-gal gasoline spills in these 12 tanks.

The calculated gasoline concentrations and ventilation times depend on the assumption that the headspaces of the waste tanks are well mixed and that the liquid fuel evaporates into the headspace and equilibrates with the other gases. If gasoline does not evaporate then the concentrations would be lower than the concentrations shown in the tables and the time required for its evacuation from the waste tanks would be longer. Similarly, insufficient turbulence in poorly ventilated waste tanks may cause concentration gradients with higher gasoline.

In summary:

- When the contents of the headspace are well mixed, the accidental spillage of 10 or 25 gal of gasoline into a waste tank would not produce flammable gasoline mixtures in the headspaces of most DSTs or 100 Series SSTs.

- When 50 gal of gasoline is spilled, the headspace gasoline concentrations in about 55 DSTs and 100 Series SSTs are within the LFLs. There is insufficient oxygen for the complete combustion of the gasoline and the combustion reaction would be quenched.

- When headspaces are well ventilated, as they are for the DSTs and 100 Series SSTs, no more than 8 days are required for the reduction of the gasoline concentrations to below the LFL.

- When the headspaces are poorly ventilated, as they are for the 200 Series SSTs the times required to decrease the gasoline concentration below the LFL range from 7 to 24 days.

A.3 IDENTIFIED HAZARDS

Three hazards have been identified:

1. When the combustion reaction has been initiated and quenched, the tank cools, and fresh air is introduced to the headspace, the reinitiated reactions between the partially oxidized gasoline and the oxygen can be vigorous.

2. When gasoline is not uniformly distributed in the headspace, a local concentration may exceed the LFL and there may be sufficient oxygen in the headspace to complete combustions.

3. When a concentration of gasoline in the exhausted air is above the LFL, the combustion reaction may be initiated externally.

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Table A-6. Individual Tank Headspace Gasoline Concentration and Ventilation Times. (3 sheets)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1	Table 6. Gasoline Concentrations and Times for Its Ventilation to Values Below the Lower Flammability Limit												Table 6. Worksheet for Computation of Headspace Gasoline Concentrations and the Time Required for Ventilation.														
2													Double-Shell and Series 100 Single-Shell Tanks with Gasoline in Vapor						The Series 200 Single Shell Tanks with Gasoline in the form of Liquid and Vapor States								
3													Gasoline Concentration in Vapor			Time to Decrease to 1.2% in Vapor			Amount of Gasoline in Liquid			Gasoline Concentration in Vapor			Time to Decrease to 1.2% in Vapor		
4 5 6 7	Tank	Waste Volume (kgal) Hu Ref 1	Waste Volume (kL) Hu Ref 1	Headspace (cu ft) Hu Ref 1	Headspace (kgal) Hu Ref 1	Headspace (kL) Hu Ref 1	Tank Volume (kL) Calculated	Waste Volume (kL) Hu Rev 2	Headspace Volume (kL) Hu Ref 2	Dome Temperature (C) Hu Ref 2	Ventilation Rate (cu ft/min) Hu Ref 1	Ventilation Rate (L /min) Hu Ref 1	10 Gallon Spill (%)	25 Gallon Spill (%)	50 Gallon Spill (%)	10 Gallon Spill (days)	25 Gallon Spill (days)	50 Gallon Spill (days)	10 Gallon Spill (moles)	25 Gallon Spill (moles)	50 Gallon Spill (moles)	10 Gallon Spill (%)	25 Gallon Spill (%)	50 Gallon Spill (%)	10 Gallon Spill (days)	25 Gallon Spill (days)	50 Gallon Spill (days)
8	241-AN-101	160.0E+0	606.4E+0	166.7E+3	1.2E+3	4.7E+3	5.3E+3	956.0E+0	4.4E+3	25.0	113.0	3.2E+3	7%	35%	70%												
9	241-AN-102	1.1E+3	4.0E+3	46.4E+3	347.0E+0	1.3E+3	5.3E+3	4.0E+3	1.3E+3	31.0	119.0	3.4E+3	23%	116%	233%			0.18									
10	241-AN-103	958.0E+0	3.6E+3	60.0E+3	449.0E+0	1.7E+3	5.3E+3	3.4E+3	1.9E+3	31.0	100.0	2.8E+3	16%	81%	163%			0.14									
11	241-AN-104	1.1E+3	4.0E+3	47.3E+3	354.0E+0	1.3E+3	5.3E+3	3.8E+3	1.5E+3	33.0	100.0	2.8E+3	21%	104%	208%			0.20									
12	241-AN-105	1.1E+3	4.3E+3	37.6E+3	281.0E+0	1.1E+3	5.3E+3	4.2E+3	1.2E+3	32.0	100.0	2.8E+3	27%	136%	272%		0.03	0.23									
13	241-AN-106	39.0E+0	147.8E+0	182.9E+3	1.4E+3	5.2E+3	5.3E+3	143.0E+0	5.2E+3	23.0	117.0	3.3E+3	6%	29%	59%												
14	241-AN-107	1.0E+3	4.0E+3	48.5E+3	363.0E+0	1.4E+3	5.3E+3	3.9E+3	1.4E+3	29.0	129.0	3.7E+3	22%	111%	223%			0.16									
15	241-AP-101	1.1E+3	4.2E+3	39.0E+3	292.0E+0	1.1E+3	5.3E+3	4.2E+3	1.1E+3	23.0	108.0	3.1E+3	27%	136%	272%		0.03	0.21									
16	241-AP-102	1.1E+3	4.1E+3	42.1E+3	315.0E+0	1.2E+3	5.3E+3	4.1E+3	1.2E+3	24.0	135.0	3.8E+3	25%	126%	252%		0.01	0.16									
17	241-AP-103	285.0E+0	1.1E+3	150.0E+3	1.1E+3	4.2E+3	5.3E+3	1.1E+3	4.3E+3	24.0	200.0	5.7E+3	7%	36%	72%												
18	241-AP-104	24.0E+0	91.0E+0	184.9E+3	1.4E+3	5.2E+3	5.3E+3	4.2E+3	1.1E+3	24.0	71.0	2.0E+3	27%	135%	271%		0.05	0.32									
19	241-AP-105	765.0E+0	2.9E+3	85.8E+3	642.0E+0	2.4E+3	5.3E+3	4.3E+3	1.0E+3	19.0	176.0	5.0E+3	29%	145%	290%		0.03	0.13									
20	241-AP-106	93.0E+0	352.5E+0	175.7E+3	1.3E+3	5.0E+3	5.3E+3	2.4E+3	3.0E+3	24.0	111.0	3.1E+3	10%	51%	103%												
21	241-AP-107	976.0E+0	3.7E+3	57.6E+3	431.0E+0	1.6E+3	5.3E+3	3.7E+3	1.6E+3	26.0	342.0	9.7E+3	19%	95%	189%			0.05									
22	241-AP108	369.0E+0	1.4E+3	138.8E+3	1.0E+3	3.9E+3	5.3E+3	121.0E+0	5.2E+3	23.0	129.0	3.7E+3	6%	29%	58%												
23	241-AW-101	1.1E+3	4.3E+3	37.6E+3	281.0E+0	1.1E+3	5.3E+3	4.2E+3	1.2E+3	30.0	100.0	2.8E+3	27%	134%	268%		0.03	0.23									
24	241-AW-102	80.0E+0	303.2E+0	177.4E+3	1.3E+3	5.0E+3	5.3E+3	322.0E+0	5.0E+3	23.0	292.0	8.3E+3	6%	30%	61%												
25	241-AW-103	510.0E+0	1.9E+3	119.9E+3	896.9E+0	3.4E+3	5.3E+3	4.2E+3	1.2E+3	26.0	134.0	3.8E+3	27%	133%	265%		0.02	0.17									
26	241-AW-104	1.1E+3	4.2E+3	38.5E+3	288.0E+0	1.1E+3	5.3E+3	1.2E+3	4.1E+3	22.0	141.0	4.0E+3	7%	37%	73%												
27	241-AW-105	429.0E+0	1.6E+3	130.7E+3	977.9E+0	3.7E+3	5.3E+3	1.6E+3	3.7E+3	21.0	194.0	5.5E+3	8%	41%	81%												
28	241-AW-106	473.0E+0	1.8E+3	124.9E+3	933.9E+0	3.5E+3	5.3E+3	1.1E+3	4.2E+3	33.0	158.0	4.5E+3	7%	37%	75%												
29	241-AY-101	154.0E+0	583.7E+0	167.5E+3	1.3E+3	4.7E+3	5.3E+3	694.0E+0	4.6E+3	41.0	250.0	7.1E+3	7%	35%	70%												
30	241-AY-102	622.0E+0	2.4E+3	104.9E+3	784.9E+0	3.0E+3	5.3E+3	2.4E+3	2.9E+3	44.0	250.0	7.1E+3	11%	56%	111%												
31	241-AZ-101	845.0E+0	3.2E+3	75.1E+3	562.0E+0	2.1E+3	5.3E+3	3.6E+3	1.8E+3	64.0	150.0	4.2E+3	20%	98%	197%			0.14									
32	241-AZ-102	931.0E+0	3.5E+3	63.6E+3	476.0E+0	1.8E+3	5.3E+3	3.8E+3	1.6E+3	46.0	112.0	3.2E+3	21%	105%	210%			0.19									
33	241-SY-101	1.2E+3	4.5E+3	29.1E+3	218.0E+0	824.7E+0	5.3E+3	3.6E+3	1.7E+3	31.0	461.0	13.0E+3	18%	91%	181%			0.04									
34	241-SY-102	612.0E+0	2.3E+3	106.3E+3	794.9E+0	3.0E+3	5.3E+3	3.9E+3	1.4E+3	41.0	363.0	10.3E+3	23%	114%	228%			0.06									
35	241-SY-103	744.0E+0	2.8E+3	88.6E+3	663.0E+0	2.5E+3	5.3E+3	2.8E+3	2.6E+3	31.0	116.0	3.3E+3	12%	61%	121%			0.01									
36	241-A-101	953.0E+0	3.6E+3	48.8E+3	365.0E+0	1.4E+3	5.0E+3	3.4E+3	1.6E+3	40.0	10.0	283.0E+0	20%	99%	199%			2.00									
37	241-A-102	41.0E+0	155.4E+0	170.7E+3	1.3E+3	4.8E+3	5.0E+3	146.0E+0	4.8E+3	32.0	7.6	215.1E+0	6%	32%	65%												
38	241-A-103	371.0E+0	1.4E+3	126.6E+3	946.9E+0	3.6E+3	5.0E+3	1.4E+3	3.6E+3	35.0	10.0	283.0E+0	9%	44%	88%												
39	241-A-104	28.0E+0	106.1E+0	172.4E+3	1.3E+3	4.9E+3	5.0E+3	106.0E+0	4.9E+3	34.0	10.0	283.0E+0	6%	32%	65%												
40	241-A-105							139.0E+0																			
41	241-A-106	125.0E+0	473.8E+0	159.5E+3	1.2E+3	4.5E+3	5.0E+3	299.0E+0	4.7E+3	45.0	10.0	283.0E+0	7%	35%	70%												
42	241-AX-101	748.0E+0	2.8E+3	80.2E+3	600.0E+0	2.3E+3	5.1E+3	2.5E+3	2.6E+3	37.0	28.3	800.9E+0	12%	62%	124%			0.07									
43	241-AX-102	30.0E+0	113.7E+0	176.2E+3	1.3E+3	5.0E+3	5.1E+3	114.0E+0	5.0E+3	26.0	16.5	467.0E+0	6%	31%	62%												
44	241-AX-103	112.0E+0	424.5E+0	165.2E+3	1.2E+3	4.7E+3	5.1E+3	410.0E+0	4.7E+3	34.0	24.7	699.0E+0	7%	34%	67%												
45	241-AX-104	8.0E+0	30.3E+0	179.1E+3	1.3E+3	5.1E+3	5.1E+3	28.0E+0	5.1E+3	32.0	7.0	198.1E+0	6%	31%	62%												
46	241-B-101	113.0E+0	428.3E+0	98.4E+3	735.9E+0	2.8E+3	3.2E+3	411.0E+0	2.8E+3	31.0	7.8	220.7E+0	11%	56%	111%												
47	241-B-102	32.0E+0	121.3E+0	109.2E+3	816.9E+0	3.1E+3	3.2E+3	121.0E+0	3.1E+3	21.0	7.0	198.1E+0	10%	49%	98%												
48	241-B-103	59.0E+0	223.6E+0	105.6E+3	789.9E+0	3.0E+3	3.2E+3	211.0E+0	3.0E+3	20.0	7.0	198.1E+0	10%	50%	100%												
49	241-B-104	371.0E+0	1.4E+3	63.9E+3	478.0E+0	1.8E+3	3.2E+3	1.4E+3	1.8E+3	19.0	7.0	198.1E+0	17%	83%	167%			2.07									
50	241-B-105	158.0E+0	598.8E+0	92.4E+3	691.0E+0	2.6E+3	3.2E+3	1.1E+3	2.1E+3	19.0	7.0	198.1E+0	14%	71%	142%			1.23									
51	241-B-106	117.0E+0	443.4E+0	97.9E+3	731.9E+0	2.8E+3	3.2E+3	464.0E+0	2.7E+3	19.0	7.0	198.1E+0	11%	54%	109%												
52	241-B-107	165.0E+0	625.4E+0	91.4E+3	684.0E+0	2.6E+3	3.2E+3	611.0E+0	2.6E+3	15.0	7.0	198.1E+0	11%	57%	114%												
53	241-B-108	94.0E+0	356.3E+0	100.9E+3	754.9E+0	2.9E+3	3.2E+3	349.0E+0	2.9E+3	19.0	7.0	198.1E+0	10%	52%	105%												
54	241-B-109	127.0E+0	481.3E+0	96.5E+3	722.0E+0	2.7E+3	3.2E+3	473.0E+0	2.7E+3	19.0	7.0	198.1E+0	11%	55%	109%												
55	241-B-110	246.0E+0	932.3E+0	80.6E+3	603.0E+0	2.3E+3	3.2E+3	929.0E+0	2.3E+3	21.0	7.0	198.1E+0	13%	66%	132%			0.76									
56	241-B-111	237.0E+0	898.2E+0	81.8E+3	612.0E+0	2.3E+3	3.2E+3	914.0E+0	2.3E+3	24.0	3.5	99.1E+0	13%	66%	132%			1.59									
57	241-B-112	33.0E+0	125.1E+0	109.1E+3	815.9E+0	3.1E+3	3.2E+3	132.0E+0	3.1E+3	19.0	7.0	198.1E+0	10%	49%	97%												
58	241-B-201	29.0E+0	109.9E+0	4.0E+3	30.0E+0	113.5E+0	223.4E+0	115.0E+0	108.4E+0	18.0	7.0	198.1E+0							21.0E+0	345.0E+0	847.0E+0	229%	617%	888%	0.08	0.47	0.80
59	241-B-202	27.0E+0	102.3E+0	4.3E+3	32.0E+0	121.1E+0	223.4E+0	111.0E+0	112.4E+0	21.0	7.2	203.8E+0							20.0E+0	345.0E+0	847.0E+0	225%	601%	865%	0.07	0.47	0.81
60	241-B-203	51.0E+0	193.3E+0	1.1E+3	8.0E+0	30.3E+0	223.5E+0	195.0E+0	28.5E+0	12.0	0.3	8.5E+0							60.0E+0	462.0E+0	1.0E+3	533%	1335%	1712%	2.16	6.62	11.63
61	241-B-204	50.0E+0	189.5E+0	1.2E+3	9.0E+0	34.0E+0	223.5E+0	192.0E+0	31.5E+0	18.0	0.3	8.5E+0							58.0E+0	462.0E+0	1.0E+3	507%	1234%	1582%	2.23	7.31	12.85
62	241-BX-101	43.0E+0	163.0E+0	107.9E+3	806.9E+0	3.1E+3	3.2E+3	180.0E+0	3.0E+3	23.0	7.0	198.1E+0	10%	50%	100%												
63	241-BX-102	96.0E+0	363.8E+0	100.8E+3	753.9E+0	2.9E+3	3.2E+3	424.0E+0	2.8E+3	21.0	7.0	198.1E+0	11%	54%	108%												
64	241-BX-103	71.0E+0	269.1E+0	104.1E+3	778.9E+0	2.9E+3	3.2E+3	277.0E+0	2.9E+3	22.0	7.0	198.1E+0	10%	51%	103%												
65	241-BX-104	99.0E+0	375.2E+0	100.4E+3	750.9E+0	2.8E+3	3.2E+3	379.0E+0	2.8E+3	25.0	8.7	246.2E+0	11%	54%	108%												
66	241-BX-105	51.0E+0	193.3E+0	106.8E+3	798.9E+0	3.0E+3	3.2E+3	271.0E+0	2.9E+3	21.0	8.5	240.6E+0	10%	51%	102%												

Table A-6. Individual Tank Headspace Gasoline Concentration and Ventilation Times. (3 sheets)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1	Table 6. Gasoline Concentrations and Times for Its Ventilation to Values Below the Lower Flammability Limit												Table 6. Worksheet for Computation of Headspace Gasoline Concentrations and the Time Required for Ventilation.														
2													Double-Shell and Series 100 Single-Shell Tanks with Gasoline in Vapor						The Series 200 Single Shell Tanks with Gasoline in the form of Liquid and Vapor States								
3													Gasoline Concentration in Vapor			Time to Decrease to 1.2% in Vapor			Amount of Gasoline in Liquid			Gasoline Concentration in Vapor			Time to Decrease to 1.2% in Vapor		
4	Tank	Waste Volume (kgal) Hu Ref 1	Waste Volume (kL) Hu Ref 1	Headspace (cu ft) Hu Ref 1	Headspace (kgal) Hu Ref 1	Headspace (kL) Hu Ref 1	Tank Volume (kL) Calculated	Waste Volume (kL) Hu Rev 2	Headspace Volume (kL) Hu Ref 2	Dome Temperature (C) Hu Ref 2	Ventilation Rate (cu ft/min) Hu Ref 1	Ventilation Rate (L /min) Hu Ref 1	10 Gallon Spill (%)	25 Gallon Spill (%)	50 Gallon Spill (%)	10 Gallon Spill (days)	25 Gallon Spill (days)	50 Gallon Spill (days)	10 Gallon Spill (moles)	25 Gallon Spill (moles)	50 Gallon Spill (moles)	10 Gallon Spill (%)	25 Gallon Spill (%)	50 Gallon Spill (%)	10 Gallon Spill (days)	25 Gallon Spill (days)	50 Gallon Spill (days)
67	241-BX-106	38.0E+0	144.0E+0	108.5E+3	811.9E+0	3.1E+3	3.2E+3	142.0E+0	3.1E+3	21.0	7.0	198.1E+0	10%	49%	98%												
68	241-BX-107	345.0E+0	1.3E+3	67.5E+3	505.0E+0	1.9E+3	3.2E+3	1.3E+3	1.9E+3	21.0	7.0	198.1E+0	16%	79%	158%			1.85									
69	241-BX-108	26.0E+0	98.5E+0	110.2E+3	823.9E+0	3.1E+3	3.2E+3	119.0E+0	3.1E+3	20.0	7.0	198.1E+0	10%	49%	97%												
70	241-BX-109	193.0E+0	731.5E+0	87.8E+3	657.0E+0	2.5E+3	3.2E+3	731.0E+0	2.5E+3	22.0	7.0	198.1E+0	12%	61%	122%												
71	241-BX-110	207.0E+0	784.5E+0	86.0E+3	643.0E+0	2.4E+3	3.2E+3	776.0E+0	2.4E+3	21.0	7.0	198.1E+0	12%	62%	124%												
72	241-BX-111	162.0E+0	614.0E+0	92.0E+3	688.0E+0	2.6E+3	3.2E+3	714.0E+0	2.5E+3	20.0	7.0	198.1E+0	12%	60%	120%												
73	241-BX-112	165.0E+0	625.4E+0	91.6E+3	685.0E+0	2.6E+3	3.2E+3	622.0E+0	2.6E+3	20.0	7.0	198.1E+0	12%	58%	116%												
74	241-BY-101	387.0E+0	1.5E+3	88.4E+3	661.0E+0	2.5E+3	4.0E+3	1.4E+3	2.6E+3	25.0	7.0	198.1E+0	12%	60%	119%												
75	241-BY-102	277.0E+0	1.0E+3	103.1E+3	770.9E+0	2.9E+3	4.0E+3	1.0E+3	2.9E+3	22.0	7.0	198.1E+0	10%	52%	104%												
76	241-BY-103	400.0E+0	1.5E+3	86.6E+3	648.0E+0	2.5E+3	4.0E+3	1.6E+3	2.4E+3	26.0	14.4	407.5E+0	13%	64%	128%			0.27									
77	241-BY-104	326.0E+0	1.2E+3	96.5E+3	722.0E+0	2.7E+3	4.0E+3	1.4E+3	2.6E+3	28.0	7.6	215.1E+0	12%	59%	118%												
78	241-BY-105	503.0E+0	1.9E+3	72.9E+3	545.0E+0	2.1E+3	4.0E+3	1.9E+3	2.1E+3	39.0	15.9	450.0E+0	15%	77%	155%			0.81									
79	241-BY-106	562.0E+0	2.1E+3	65.0E+3	486.0E+0	1.8E+3	4.0E+3	2.1E+3	1.8E+3	25.0	5.9	167.0E+0	17%	83%	166%			2.48									
80	241-BY-107	266.0E+0	1.0E+3	104.5E+3	781.9E+0	3.0E+3	4.0E+3	1.0E+3	2.9E+3	28.0	5.2	147.2E+0	11%	53%	105%												
81	241-BY-108	228.0E+0	864.1E+0	109.6E+3	819.9E+0	3.1E+3	4.0E+3	841.0E+0	3.1E+3	29.0	6.8	192.4E+0	10%	50%	99%												
82	241-BY-109	290.0E+0	1.1E+3	101.3E+3	757.9E+0	2.9E+3	4.0E+3	1.0E+3	2.9E+3	17.0	14.7	416.0E+0	10%	51%	102%												
83	241-BY-110	398.0E+0	1.5E+3	86.9E+3	650.0E+0	2.5E+3	4.0E+3	1.4E+3	2.6E+3	26.0	13.3	376.4E+0	12%	59%	119%												
84	241-BY-111	459.0E+0	1.7E+3	78.7E+3	589.0E+0	2.2E+3	4.0E+3	1.1E+3	2.8E+3	24.0	6.0	169.8E+0	11%	54%	108%												
85	241-BY-112	291.0E+0	1.1E+3	101.2E+3	756.9E+0	2.9E+3	4.0E+3	1.1E+3	2.9E+3	25.0	13.6	384.9E+0	11%	53%	106%												
86	241-C-101	88.0E+0	333.5E+0	101.7E+3	760.9E+0	2.9E+3	3.2E+3	333.0E+0	2.9E+3	33.0	3.6	101.9E+0	11%	54%	109%												
87	241-C-102	316.0E+0	1.2E+3	71.3E+3	533.0E+0	2.0E+3	3.2E+3	1.2E+3	2.0E+3	27.0	11.8	333.9E+0	15%	76%	152%			1.00									
88	241-C-103	198.0E+0	750.4E+0	87.0E+3	651.0E+0	2.5E+3	3.2E+3	750.0E+0	2.5E+3	39.0	10.0	283.0E+0	13%	65%	130%			0.48									
89	241-C-104	295.0E+0	1.1E+3	74.1E+3	554.0E+0	2.1E+3	3.2E+3	980.0E+0	2.2E+3	33.0	67.1	1.9E+3	14%	70%	140%			0.20									
90	241-C-105	91.0E+0	344.9E+0	95.4E+3	714.0E+0	2.7E+3	3.0E+3	500.0E+0	2.5E+3	40.0	535.0	15.1E+3	13%	63%	126%			0.01									
91	241-C-106	107.0E+0	405.5E+0	99.2E+3	741.9E+0	2.8E+3	3.2E+3	138.0E+0	3.1E+3	29.0	176.0	5.0E+3	10%	50%	101%												
92	241-C-107	257.0E+0	974.0E+0	79.1E+3	592.0E+0	2.2E+3	3.2E+3	940.0E+0	2.3E+3	43.0	1.1	31.1E+0	14%	71%	143%			8.73									
93	241-C-108	66.0E+0	250.1E+0	104.7E+3	782.9E+0	3.0E+3	3.2E+3	250.0E+0	3.0E+3	26.0	7.0	198.1E+0	10%	52%	104%												
94	241-C-109	66.0E+0	250.1E+0	104.7E+3	782.9E+0	3.0E+3	3.2E+3	240.0E+0	3.0E+3	26.0	13.0	367.9E+0	10%	52%	103%												
95	241-C-110	178.0E+0	674.6E+0	89.7E+3	671.0E+0	2.5E+3	3.2E+3	674.0E+0	2.5E+3	23.0	7.9	223.6E+0	12%	60%	120%												
96	241-C-111	57.0E+0	216.0E+0	105.9E+3	791.9E+0	3.0E+3	3.2E+3	217.0E+0	3.0E+3	26.0	7.0	198.1E+0	10%	51%	102%												
97	241-C-112	104.0E+0	394.2E+0	99.6E+3	744.9E+0	2.8E+3	3.2E+3	393.0E+0	3.2E+3	28.0	11.2	317.0E+0	10%	48%	96%												
98	241-C-201	2.0E+0	7.6E+0	7.6E+3	57.0E+0	215.6E+0	223.2E+0	4.0E+0	219.2E+0	19.0	3.9	110.4E+0							000.0E+0	388.0E+0	576.0E+0	137%	259%	737%	0.00	2.26	1.18
99	241-C-202	1.0E+0	3.8E+0	7.8E+3	58.0E+0	219.4E+0	223.2E+0	4.0E+0	219.2E+0	18.0	3.6	101.9E+0							000.0E+0	388.0E+0	576.0E+0	136%	258%	734%	0.00	2.45	1.28
100	241-C-203	5.0E+0	19.0E+0	7.2E+3	54.0E+0	204.3E+0	223.2E+0	10.0E+0	213.2E+0	18.0	7.0	198.1E+0							000.0E+0	380.0E+0	569.0E+0	140%	274%	763%	0.00	1.16	0.62
101	241-C-204	3.0E+0	11.4E+0	7.5E+3	56.0E+0	211.9E+0	223.2E+0	10.0E+0	213.2E+0	16.0	3.0	84.9E+0							000.0E+0	380.0E+0	569.0E+0	139%	272%	757%	0.00	2.71	1.46
102	241-S-101	427.0E+0	1.6E+3	83.3E+3	623.0E+0	2.4E+3	4.0E+3	1.6E+3	2.4E+3	13.0	6.2	175.5E+0	12%	62%	124%												
103	241-S-102	514.0E+0	1.9E+3	71.7E+3	536.0E+0	2.0E+3	4.0E+3	1.2E+3	2.7E+3	29.0	2.2	62.3E+0	11%	57%	114%												
104	241-S-103	248.0E+0	939.9E+0	107.2E+3	801.9E+0	3.0E+3	4.0E+3	897.0E+0	3.1E+3	26.0	15.3	433.0E+0	10%	50%	100%												
105	241-S-104	294.0E+0	1.1E+3	101.1E+3	756.0E+0	2.9E+3	4.0E+3	1.1E+3	2.9E+3	32.0	5.6	158.5E+0	11%	54%	108%												
106	241-S-105	456.0E+0	1.7E+3	79.4E+3	594.0E+0	2.2E+3	4.0E+3	1.5E+3	2.4E+3	25.0	16.7	472.6E+0	13%	63%	125%			0.15									
107	241-S-106	426.0E+0	1.6E+3	83.4E+3	624.0E+0	2.4E+3	4.0E+3	1.7E+3	2.3E+3	23.0	9.2	260.4E+0	13%	67%	135%			0.70									
108	241-S-107	376.0E+0	1.4E+3	90.1E+3	674.0E+0	2.5E+3	4.0E+3	1.4E+3	2.6E+3	29.0	4.4	124.5E+0	12%	61%	121%												
109	241-S-108	450.0E+0	1.7E+3	80.2E+3	600.0E+0	2.3E+3	4.0E+3	2.1E+3	1.9E+3	26.0	7.0	198.1E+0	16%	81%	162%			1.99									
110	241-S-109	507.0E+0	1.9E+3	72.6E+3	543.0E+0	2.1E+3	4.0E+3	2.0E+3	2.0E+3	25.0	7.0	198.1E+0	16%	78%	156%			1.80									
111	241-S-110	390.0E+0	1.5E+3	88.2E+3	660.0E+0	2.5E+3	4.0E+3	1.5E+3	2.5E+3	29.0	10.4	294.3E+0	12%	62%	124%												
112	241-S-111	540.0E+0	2.0E+3	68.2E+3	510.0E+0	1.9E+3	4.0E+3	1.8E+3	2.2E+3	26.0	5.4	152.8E+0	14%	69%	139%			1.46									
113	241-S-112	523.0E+0	2.0E+3	70.5E+3	527.0E+0	2.0E+3	4.0E+3	2.0E+3	2.0E+3	25.0	4.0	113.2E+0	15%	75%	151%			2.84									
114	241-SX-101	448.0E+0	1.7E+3	113.2E+3	846.9E+0	3.2E+3	4.9E+3	1.6E+3	3.3E+3	37.0	40.0	1.1E+3	10%	48%	97%												
115	241-SX-102	514.0E+0	1.9E+3	104.4E+3	780.9E+0	3.0E+3	4.9E+3	1.9E+3	3.0E+3	35.0	40.0	1.1E+3	11%	53%	106%												
116	241-SX-103	634.0E+0	2.4E+3	88.4E+3	661.0E+0	2.5E+3	4.9E+3	1.9E+3	3.0E+3	34.0	52.5	1.5E+3	11%	53%	106%												
117	241-SX-104	467.0E+0	1.8E+3	110.7E+3	827.9E+0	3.1E+3	4.9E+3	1.7E+3	3.2E+3	33.0	30.0	849.0E+0	10%	49%	98%												
118	241-SX-105	637.0E+0	2.4E+3	88.0E+3	658.0E+0	2.5E+3	4.9E+3	1.3E+3	3.6E+3	37.0	40.5	1.1E+3	9%	44%	87%												
119	241-SX-106	423.0E+0	1.6E+3	116.6E+3	871.9E+0	3.3E+3	4.9E+3	1.5E+3	3.4E+3	32.0	38.8	1.1E+3	9%	46%	92%												
120	241-SX-107	104.0E+0	394.2E+0	159.2E+3	1.2E+3	4.5E+3	4.9E+3	357.0E+0	4.5E+3	50.0	387.0	11.0E+3	7%	36%	73%												
121	241-SX-108	87.0E+0	329.7E+0	161.5E+3	1.2E+3	4.6E+3	4.9E+3	276.0E+0	4.6E+3	58.0	455.0	12.9E+3	7%	37%	73%												
122	241-SX-109	250.0E+0	947.5E+0	139.7E+3	1.0E+3	4.0E+3	4.9E+3	913.0E+0	4.0E+3	48.0	30.0	849.0E+0	8%	41%	83%												
123	241-SX-110	62.0E+0	235.0E+0	164.8E+3	1.2E+3	4.7E+3	4.9E+3	212.0E+0	4.7E+3	64.0	293.0	8.3E+3	7%	37%	74%												
124	241-SX-111	122.0E+0	462.4E+0	156.8E+3	1.2E+3	4.4E+3	4.9E+3	436.0E+0	4.5E+3	56.0	264.0	7.5E+3	8%	38%	76%												
125	241-SX-112	108.0E+0	409.3E+0	158.7E+3	1.2E+3	4.5E+3	4.9E+3	283.0E+0	4.6E+3	51.0	225.0	6.4E+3	7%	36%	72%												
126	241-SX-113	31.0E+0	117.5E+0	169.0E+3	1.3E+3	4.8E+3	4.9E+3	71.0E+0	4.8E+3	28.0	7.0	198.1E+0	6%	32%	64%												

Table A-6. Individual Tank Headspace Gasoline Concentration and Ventilation Times. (3 sheets)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1	Table 6. Gasoline Concentrations and Times for Its Ventilation to Values Below the Lower Flammability Limit												Table 6. Worksheet for Computation of Headspace Gasoline Concentrations and the Time Required for Ventilation.														
2													Double-Shell and Series 100 Single-Shell Tanks with Gasoline in Vapor						The Series 200 Single Shell Tanks with Gasoline in the form of Liquid and Vapor States								
3													Gasoline Concentration in Vapor			Time to Decrease to 1.2% in Vapor			Amount of Gasoline in Liquid			Gasoline Concentration in Vapor			Time to Decrease to 1.2% in Vapor		
4	Tank	Waste Volume (kgal) Hu Ref 1	Waste Volume (kL) Hu Ref 1	Headspace (cu ft) Hu Ref 1	Headspace (kgal) Hu Ref 1	Headspace (kL) Hu Ref 1	Tank Volume (kL) Calculated	Waste Volume (kL) Hu Rev 2	Headspace Volume (kL) Hu Ref 2	Dome Temperature (C) Hu Ref 2	Ventilation Rate (cu ft/min) Hu Ref 1	Ventilation Rate (L/min) Hu Ref 1	10 Gallon Spill (%)	25 Gallon Spill (%)	50 Gallon Spill (%)	10 Gallon Spill (days)	25 Gallon Spill (days)	50 Gallon Spill (days)	10 Gallon Spill (moles)	25 Gallon Spill (moles)	50 Gallon Spill (moles)	10 Gallon Spill (%)	25 Gallon Spill (%)	50 Gallon Spill (%)	10 Gallon Spill (days)	25 Gallon Spill (days)	50 Gallon Spill (days)
127	241-SX-114	181.0E+0	686.0E+0	148.9E+3	1.1E+3	4.2E+3	4.9E+3	594.0E+0	4.3E+3	52.0	325.0	9.2E+3	8%	39%	77%												
128	241-SX-115	12.0E+0	45.5E+0	171.5E+3	1.3E+3	4.9E+3	4.9E+3	14.0E+0	4.9E+3	25.0	7.0	198.1E+0	6%	31%	63%												
129	241-T-101	102.0E+0	386.6E+0	99.9E+3	747.0E+0	2.8E+3	3.2E+3	376.0E+0	2.8E+3	22.0	7.0	198.1E+0	11%	53%	107%												
130	241-T-102	32.0E+0	121.3E+0	109.2E+3	816.9E+0	3.1E+3	3.2E+3	121.0E+0	3.1E+3	18.0	7.0	198.1E+0	10%	48%	97%												
131	241-T-103	27.0E+0	102.3E+0	109.9E+3	821.9E+0	3.1E+3	3.2E+3	102.0E+0	3.1E+3	20.0	7.0	198.1E+0	10%	48%	97%												
132	241-T-104	326.0E+0	1.2E+3	69.9E+3	523.0E+0	2.0E+3	3.2E+3	1.2E+3	2.0E+3	21.0	7.0	198.1E+0	15%	75%	150%			1.56									
133	241-T-105	98.0E+0	371.4E+0	100.4E+3	750.9E+0	2.8E+3	3.2E+3	371.0E+0	2.8E+3	16.0	7.0	198.1E+0	10%	52%	104%												
134	241-T-106	21.0E+0	79.6E+0	110.7E+3	827.9E+0	3.1E+3	3.2E+3	82.0E+0	3.1E+3	21.0	7.0	198.1E+0	10%	48%	96%												
135	241-T-107	173.0E+0	655.7E+0	90.4E+3	676.0E+0	2.6E+3	3.2E+3	655.0E+0	2.6E+3	32.0	6.4	181.1E+0	12%	61%	122%												
136	241-T-108	44.0E+0	166.8E+0	107.6E+3	804.9E+0	3.0E+3	3.2E+3	60.0E+0	3.2E+3	22.0	7.0	198.1E+0	10%	48%	96%												
137	241-T-109	58.0E+0	219.8E+0	105.7E+3	790.9E+0	3.0E+3	3.2E+3	235.0E+0	3.0E+3	20.0	7.0	198.1E+0	10%	50%	101%												
138	241-T-110	387.0E+0	1.5E+3	61.8E+3	462.0E+0	1.7E+3	3.2E+3	1.4E+3	1.8E+3	21.0	7.0	198.1E+0	17%	83%	166%			2.07									
139	241-T-111	446.0E+0	1.7E+3	53.9E+3	403.0E+0	1.5E+3	3.2E+3	1.7E+3	1.5E+3	23.0	6.0	169.8E+0	20%	100%	199%			3.16									
140	241-T-112	67.0E+0	253.9E+0	104.5E+3	781.9E+0	3.0E+3	3.2E+3	252.0E+0	3.0E+3	21.0	7.0	198.1E+0	10%	51%	102%												
141	241-T-201	29.0E+0	109.9E+0	4.0E+3	30.0E+0	113.5E+0	223.4E+0	118.0E+0	105.4E+0	20.0	7.0	198.1E+0							21.0E+0	345.0E+0	847.0E+0	237%	639%	919%	0.07	0.46	0.78
142	241-T-202	21.0E+0	79.6E+0	5.1E+3	38.0E+0	143.8E+0	223.4E+0	81.0E+0	142.4E+0	20.0	7.0	198.1E+0							21.0E+0	291.0E+0	766.0E+0	176%	564%	817%	0.10	0.43	0.79
143	241-T-203	35.0E+0	132.7E+0	3.2E+3	24.0E+0	90.8E+0	223.4E+0	140.0E+0	83.4E+0	20.0	0.4	11.3E+0							30.0E+0	382.0E+0	898.0E+0	274%	700%	1014%	1.62	8.05	13.06
144	241-T-204	38.0E+0	144.0E+0	2.8E+3	21.0E+0	79.4E+0	223.5E+0	140.0E+0	83.5E+0	20.0	7.0	198.1E+0							30.0E+0	382.0E+0	898.0E+0	274%	700%	1014%	0.09	0.46	0.75
145	241-TX-101	87.0E+0	329.7E+0	128.5E+3	960.9E+0	3.6E+3	4.0E+3	344.0E+0	3.6E+3	23.0	7.0	198.1E+0	8%	42%	84%												
146	241-TX-102	217.0E+0	822.4E+0	111.1E+3	830.9E+0	3.1E+3	4.0E+3	821.0E+0	3.1E+3	27.0	11.5	325.5E+0	10%	49%	98%												
147	241-TX-103	157.0E+0	595.0E+0	119.1E+3	890.9E+0	3.4E+3	4.0E+3	548.0E+0	3.4E+3	22.0	7.0	198.1E+0	9%	44%	89%												
148	241-TX-104	65.0E+0	246.4E+0	131.4E+3	982.9E+0	3.7E+3	4.0E+3	262.0E+0	3.7E+3	21.0	3.5	99.1E+0	8%	41%	81%												
149	241-TX-105	609.0E+0	2.3E+3	58.7E+3	439.0E+0	1.7E+3	4.0E+3	2.2E+3	1.8E+3	36.0	14.4	407.5E+0	18%	89%	177%			1.19									
150	241-TX-106	341.0E+0	1.3E+3	94.5E+3	706.9E+0	2.7E+3	4.0E+3	1.3E+3	2.6E+3	27.0	7.0	198.1E+0	12%	58%	116%												
151	241-TX-107	36.0E+0	136.4E+0	135.3E+3	1.0E+3	3.8E+3	4.0E+3	112.0E+0	3.9E+3	22.0	7.0	198.1E+0	8%	39%	79%												
152	241-TX-108	134.0E+0	507.9E+0	122.2E+3	913.9E+0	3.5E+3	4.0E+3	489.0E+0	3.5E+3	20.0	9.0	254.7E+0	9%	43%	86%												
153	241-TX-109	384.0E+0	1.5E+3	88.8E+3	664.0E+0	2.5E+3	4.0E+3	1.4E+3	2.6E+3	22.0	7.0	198.1E+0	12%	58%	117%												
154	241-TX-110	462.0E+0	1.8E+3	78.3E+3	586.0E+0	2.2E+3	4.0E+3	1.8E+3	2.2E+3	22.0	7.0	198.1E+0	14%	69%	137%			1.05									
155	241-TX-111	370.0E+0	1.4E+3	90.6E+3	678.0E+0	2.6E+3	4.0E+3	1.4E+3	2.6E+3	23.0	9.7	274.5E+0	12%	59%	117%												
156	241-TX-112	649.0E+0	2.5E+3	53.3E+3	399.0E+0	1.5E+3	4.0E+3	2.4E+3	1.6E+3	21.0	7.0	198.1E+0	19%	96%	192%			2.59									
157	241-TX-113	607.0E+0	2.3E+3	59.0E+3	441.0E+0	1.7E+3	4.0E+3	2.4E+3	1.6E+3	22.0	9.3	263.2E+0	19%	97%	195%			1.99									
158	241-TX-114	535.0E+0	2.0E+3	68.6E+3	513.0E+0	1.9E+3	4.0E+3	2.0E+3	2.0E+3	18.0	12.0	339.6E+0	15%	76%	153%			0.96									
159	241-TX-115	568.0E+0	2.2E+3	64.2E+3	480.0E+0	1.8E+3	4.0E+3	2.1E+3	1.9E+3	21.0	10.0	283.0E+0	16%	81%	161%			1.35									
160	241-TX-116	631.0E+0	2.4E+3	55.7E+3	417.0E+0	1.6E+3	4.0E+3	2.3E+3	1.7E+3	20.0	3.1	87.7E+0	18%	88%	175%			5.15									
161	241-TX-117	626.0E+0	2.4E+3	56.4E+3	422.0E+0	1.6E+3	4.0E+3	1.8E+3	2.2E+3	20.0	6.5	184.0E+0	14%	70%	140%			1.24									
162	241-TX-118	300.0E+0	1.1E+3	100.0E+3	747.9E+0	2.8E+3	4.0E+3	968.0E+0	3.0E+3	23.0	10.0	283.0E+0	10%	51%	101%												
163	241-TY-101	118.0E+0	447.2E+0	124.6E+3	931.9E+0	3.5E+3	4.0E+3	447.0E+0	3.5E+3	21.0	3.2	90.6E+0	9%	43%	86%												
164	241-TY-102	64.0E+0	242.6E+0	131.8E+3	985.9E+0	3.7E+3	4.0E+3	261.0E+0	3.7E+3	19.0	7.0	198.1E+0	8%	40%	81%												
165	241-TY-103	162.0E+0	614.0E+0	118.7E+3	887.9E+0	3.4E+3	4.0E+3	587.0E+0	3.4E+3	21.0	8.2	232.1E+0	9%	45%	89%												
166	241-TY-104	46.0E+0	174.3E+0	134.2E+3	1.0E+3	3.8E+3	4.0E+3	167.0E+0	3.8E+3	20.0	13.4	379.2E+0	8%	39%	79%												
167	241-TY-105	231.0E+0	875.5E+0	109.5E+3	818.9E+0	3.1E+3	4.0E+3	874.0E+0	3.1E+3	23.0	7.0	198.1E+0	10%	49%	98%												
168	241-TY-106	21.0E+0	79.6E+0	137.6E+3	1.0E+3	3.9E+3	4.0E+3	62.0E+0	3.9E+3	19.0	7.0	198.1E+0	8%	38%	77%												
169	241-U-101	25.0E+0	94.8E+0	110.2E+3	823.9E+0	3.1E+3	3.2E+3	89.0E+0	3.1E+3	22.0	7.0	198.1E+0	10%	48%	97%												
170	241-U-102	375.0E+0	1.4E+3	63.4E+3	474.0E+0	1.8E+3	3.2E+3	1.1E+3	2.1E+3	28.0	2.1	59.4E+0	15%	73%	147%			4.93									
171	241-U-103	468.0E+0	1.8E+3	50.9E+3	381.0E+0	1.4E+3	3.2E+3	1.4E+3	1.8E+3	29.0	2.4	67.9E+0	17%	86%	172%			6.60									
172	241-U-104	122.0E+0	462.4E+0	97.2E+3	727.0E+0	2.8E+3	3.2E+3	462.0E+0	2.8E+3	24.0	7.0	198.1E+0	11%	55%	111%												
173	241-U-105	418.0E+0	1.6E+3	57.6E+3	431.0E+0	1.6E+3	3.2E+3	1.3E+3	1.9E+3	29.0	5.0	141.5E+0	16%	82%	165%			2.93									
174	241-U-106	226.0E+0	856.5E+0	83.3E+3	623.0E+0	2.4E+3	3.2E+3	644.0E+0	2.6E+3	27.0	1.3	36.8E+0	12%	60%	120%												
175	241-U-107	408.0E+0	1.5E+3	59.0E+3	441.0E+0	1.7E+3	3.2E+3	1.6E+3	1.7E+3	25.0	11.8	333.9E+0	18%	92%	184%			1.48									
176	241-U-108	468.0E+0	1.8E+3	50.9E+3	381.0E+0	1.4E+3	3.2E+3	1.8E+3	1.4E+3	26.0	3.6	101.9E+0	21%	106%	213%			5.62									
177	241-U-109	465.0E+0	1.8E+3	51.3E+3	384.0E+0	1.5E+3	3.2E+3	1.1E+3	2.1E+3	29.0	4.3	121.7E+0	15%	73%	145%			2.31									
178	241-U-110	186.0E+0	704.9E+0	88.6E+3	663.0E+0	2.5E+3	3.2E+3	665.0E+0	2.5E+3	26.0	1.9	53.8E+0	12%	60%	120%												
179	241-U-111	329.0E+0	1.2E+3	69.5E+3	520.0E+0	2.0E+3	3.2E+3	1.3E+3	1.9E+3	26.0	1.9	53.8E+0	16%	80%	159%			7.03									
180	241-U-112	49.0E+0	185.7E+0	106.9E+3	799.9E+0	3.0E+3	3.2E+3	172.0E+0	3.0E+3	21.0	1.3	36.8E+0	10%	50%	99%												
181	241-U-201	5.0E+0	19.0E+0	7.2E+3	54.0E+0	204.3E+0	223.2E+0	19.0E+0	204.2E+0	19.0	7.0	198.1E+0							000.0E+0	250.0E+0	696.0E+0	147%	440%	650%	0.00	0.48	0.90
182	241-U-202	5.0E+0	19.0E+0	7.2E+3	54.0E+0	204.3E+0	223.2E+0	17.0E+0	206.2E+0	19.0	7.0	198.1E+0							000.0E+0	250.0E+0	696.0E+0	145%	436%	644%	0.00	0.48	0.91
183	241-U-203	3.0E+0	11.4E+0	7.5E+3	56.0E+0	211.9E+0	223.2E+0	17.0E+0	206.2E+0	18.0	2.1	59.4E+0							000.0E+0	250.0E+0	696.0E+0	145%	434%	641%	0.00	1.61	3.03
184	241-U-204	3.0E+0	11.4E+0	7.5E+3	56.0E+0	211.9E+0	223.2E+0	15.0E+0	208.2E+0	18.0	10.2	288.7E+0							000.0E+0	250.0E+0	696.0E+0	143%	430%	635%	0.00	0.33	0.63

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APPENDIX B

SPREADSHEET CALCULATIONS

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APPENDIX B

SPREADSHEET CALCULATIONS

B.1 SPREADSHEET CALCULATIONS

Twenty-four solvent pool fire cases were previously evaluated in an effort to quantify unmitigated bounding consequences for single-shell tanks (SST), double-shell tanks (DST), and double-contained receiver tanks (DCRT). Analysis was performed with the aid of the Microsoft Excel[1] program. Calculations are provided in three worksheets, "Solvent Pool Fire Cases" (Table B-1), "Solvent Pool Fire Dose Summary" (Table B-2), and "Toxicological Dose" (Table B-3).

B.1.1 Postulated Gasoline Fires

Five postulated gasoline fire cases were inserted into the spreadsheets. Each fire was placed just below a solvent fire case that used similar case parameters. It should be noted that for convenience, some solvent fires were deleted to make room for the gasoline fires. Changes made to differentiate gasoline cases from solvent cases were:

- P_2O_5 was deleted as a toxin. P_2O_5 is not an applicable toxin for a gasoline fire. It should be noted that Column M of the Toxicological spreadsheet (Table B-3) contains nonzero values for P_2O_5. These values are required to compute the CO and NO_2 releases. At later stages in the calculation, a zero multiplier for Column M was added to columns AA, AS, AU, and AW to remove P_2O_5 as a toxin for gasoline fires.
- Combustion energy was calculated as 80% of 44.1 Mj/kg.
- Fire spread rate was assigned a value of 200 cm/s. Solvent was 10 cm/s.
- Aerosol depletion due to in-tank sedimentation was quantified.
- Aerosol load was equated to 20% of gasoline mass burned.
- Stoichiometry was altered to be consistent with combustion of octane. Octane possesses a carbon/hydrogen ratio characteristic of gasoline.
- In Table B-3, Columns CS and beyond were removed for expediency. Used for comparison regarding phosphorous pentoxide and phosphoric acid as toxins, they are superfluous to the discussions here.

Each worksheet is individually described below.

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[1]Excel is a trademark of Microsoft Corporation, Redmond, Washington.

B.1.1.1 Solvent Pool Fire Cases

Table B-1 shows Solvent Pool Fire Case worksheet. Each column entry is described as follows.

Column A Assigns case numbers on an alphabetic lettering sequence. Case letters carry over to all three worksheets as the first column on each page.

Column B Identifies the type of waste tank considered for each case.

SST	=	single-shell tank
DST	=	double-shell tank
DCRT	=	double-contained receiver tank
55 kgal SST	=	55,000-gal single-shell tank.

Column C Describes the size of pool analyzed for each case.

Column D Lists the pool surface area assumed for each case.

Column E Identifies the parameter (a consequence of a fire) that is maximized or highlighted for the stated case. For example, Cell E3 identifies "pressure" as the parameter. The highest pressure for the puddle fire (case a) results from assuming the minimal vent path (the high-efficiency particulate air [HEPA] vent) for this case. The parameter "vacuum" indicates that vent path configuration was selected to cause the highest possible tank vacuum following fire extinction and the cool down of headspace gases.

"Radiological" and "toxicological" descriptors indicate the cases were designed to yield bounding radiological and toxicological consequences, respectively.

The descriptor "C 103" in Cell E9 indicates that this case analyzes SST 241-C-03, the only known tank containing a large solvent pool.

The descriptor "passive vent" in Cell E21 indicates that this case was run to evaluate the passive ventilation case, even though it does not represent a maximum.

Column F Describes the type of ventilation assumed for each case. "Passive" applies to SSTs and DCRTs where ventilation is caused by atmospheric breathing and natural convection. The ventilation flow for actively ventilated tanks is listed as "100 ft^3/min (0.047 m^3/s)." This flow rate designator was used to remind the analyst that ventilation flow rates in actively ventilated tanks are in the order of 100 ft^3/min under normal conditions. This flow rate number is used when estimating aerosol depletion by in tank sedimentation.

Column G Lists the type of vent path assumed for each case. Footnotes 1 through 4 quantify the size of the equivalent orifice used in POOLFIRE.4 calculations (RPP-8369, *Chemical Source Terms for Tank Farms Safety Analyses*).

Cases M and I are specified to have "none." Because available information is insufficient to characterize the minimal vent opening for DSTs and DCRTs, a default value of zero was assumed for these cases. Peak pressures computed for these cases are a conservative upper bound on pressures, which could be generated by pool fires in these tanks.

Column H Lists the peak pressure computed by POOLFIRE.4 for each case. As noted in RPP-8369, POOLFIRE.4 calculates specific burning rate as a function of oxygen concentration in headspace air. All cases analyzed here use a bounding high value of 10 cm/s for fire spread velocity.

Column I Lists the peak vacuum inside the tank referenced to the outside atmosphere for each case. Headspace air pressure is computed as a function of time by POOLFIRE.4, and the numbers in Column I are minimum gauge pressures from runs with POOLFIRE.4.

Column J Lists the mass of solvent burned from fire initiation to fire extinguishment at an oxygen level of 13-mole percent for each case. These numbers come from runs with POOLFIRE.4. Note that cases with small vents result in the highest mass of solvent burned. The venting of oxygen from the tank leaves less oxygen in the tank to oxidize fuel; therefore, less fuel burns when larger vent paths are specified.

Column K Lists aerosol release fraction (ARF) for each case analyzed. Puddle fires use ARF = 0.1 and large pool fires use ARF = 0.03. RPP-8369 describes the bases for these values.

Column L Lists the leak path factor (LPF), defined as the fraction of reaction products released from the tank during the course of a pool fire, for each case. For passively ventilated tanks, the numbers in this column are values calculated by POOLFIRE.4. For actively ventilated tanks, a default value of unity is assumed. This factor is calculated based on zero depletion (i.e., on ideal gas behavior).

Column M Lists the aerosol depletion factor (ADF), defined as the ratio of aerosol mass leaked to the mass of aerosol which would leak if no deletion took place, for each case. The ADF is a transmission factor for aerosol mass. An ADF of 1.0 indicates that no depletion by aerosol deposition is predicted; a value of 0.16 indicates that in-tank sedimentation is calculated to reduce leaked aerosol mass to 16% of the mass leaked based on ideal gas behavior.

The product of LPF (see column L), the fractional leakage of contaminants based on ideal gas behavior, and ADF is the fractional leakage of particulate contaminants predicted for solvent fires. For information on the methodology used to predict ADF for each fire case, see RPP-8369.

Column N Calculates from Equation EQ-2 the solvent release from the tank to the environs (mass in kg) and assigns C a default value of unity.

$$S = M \bullet 1 \bullet ARF \bullet LPD \bullet ADF$$

The spreadsheet equation for Cell N3 is: $N3 = J3 \bullet K3 \bullet L3 \bullet M3$

This equation is reproduced in all rows by advancing the row number appropriately. The ADF has been included to account for in-tank deposition of particulate contaminants. The release of contaminants in the solvent may be quantified by multiplying their concentrations by the solvent mass releases calculated in Column N. This mass release is also the appropriate mass to be used for computing doses using unit-liter dose (ULD) values as:

$$D(Sv) = Q(L) \bullet \frac{X}{Q'}(s/m^3) \bullet R(m^3/s) \bullet ULD(Sv/L)$$

Column O Calculates the mass of water evaporated as explained in RPP-8369:

$$aqueous\,mass = fuel\,burned \bullet 1.26$$

The spreadsheet equation, for Cell O3 is: $O3 = 1.26 \bullet J3$

Column P Assigns a value of 0.002 to the ARF for water evaporation for all cases. This ARF is cited as a bounding value for boiling liquids by DOE-HDBK-3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities.*

Column Q Calculates from Equation EQ-2 the atmospheric release of aqueous waste caused by evaporation and assigns C a default value of unity:

$$S = M \bullet 1 \bullet ARF \bullet LPF \bullet ADF$$

The spreadsheet equation for Cell Q3 is: $Q3 = O3 \bullet P3 \bullet L3 \bullet M3$

This equation is reproduced in all rows by advancing the row number appropriately. The ADF (in Column M) has been included to account for in-tank sedimentation of particulate contaminants.

Column R Lists the ULDs for liquid waste, the waste subject to evaporative release for each case. The values in Column R are those given in Table 5-1 of the main document for inhalation of SST and DST liquids.

Table B-1. Solvent Pool Fire Cases Worksheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1																		
2	Case	Tank Type	Solvent Pool Description	Pool Area m3	Bounding Parameters	Ventilation Flow	Vent Description	Poolfire4 Peak Pressure psig (kPa)	Poolfire4 Peak Vacuum psig (kPa)	Poolfire4 Solvent Burned kg	Solvent Aerosol Release Factor ARF	Poolfire4 Leak Path Factor LPF	Aerosol Depletion Factor ADF	Solvent Atmosphere Release Basis kg	Aqueous Boiloff kg	Aerosol Release Factor for Aqueous ARF	Aqueous Atmospheric Release kg	Aqueous Unit Liter Dose Sv/L
3	a	SST	puddle	1	pressure	passive	HEPA[1]	3.1 (21.4)	0.5 (3.45)	128	0.1	0.0747	1.00 E+00	9.56 E-01	161.28	0.002	2.41 E-02	1.44 E+03
4	b	SST	puddle	1	vacuum	passive	HEPA/Flapper[2]	1.0 (6.89)	0.5 (3.45)	124	0.1	0.0399	1.00 E+00	4.95 E-01	156.24	0.002	1.25 E-02	1.44 E+03
5	c	SST	puddle	1	radiological	100 cfm (0.047 m^3/s)	HEPA	3.1 (21.4)	0.5 (3.45)	128	0.1	1.0	1.60 E-01	2.05 E+00	161.28	0.002	5.16 E-02	1.44 E+03
6	d	SST	puddle	1	toxicological	100 cfm (0.047 m^3/s)	HEPA	3.1 (21.4)	0.5 (3.45)	128	0.1	1.0	1.60 E-01	2.05 E+00	161.28	0.002	5.16 E-02	1.44 E+03
7	d(m)	SST	gasoline puddle	1	gasoline	100 cfm (0.047 m^3/s)	HEPA	3.5 (24.4)	0.5 (3.45)	138	0.1	1.0	1.73 E-01	2.39 E+00	173.88	0.002	6.02 E-02	4.40 E+02
8	e	SST	large	210	pressure	passive	HEPA	29 (200)	0.1 (0.69)	146	0.03	0.146	8.85 E-01	5.86 E-01	183.96	0.002	4.75 E-02	1.44 E+03
9	e(n)	SST	gasoline large pool	100	gasoline	passive	HEPA	28 (193)	0.1 (0.69)	154	0.03	0.156	8.58 E-01	6.18 E-01	194.04	0.002	5.19 E-02	4.40 E+02
10	f	SST	large	210	vacuum	passive	HEPA/Flapper	1.8 (12.4)	6.8 (46.9)	84	0.03	0.3	1.00 E+01	7.56 E-01	105.84	0.002	6.35 E-02	1.44 E+03
11	f(o)	SST	gasoline large pool	100	gasoline	passive	HEPA/Flapper	7.0 (48.3)	8.9 (47.4)	95.1	0.03	0.35	1.00 E+00	9.99 E-01	119.826	0.002	8.39 E-02	4.40 E+02
12	f1	SST	large	210	C-103	passive	HEPA/Flapper	1.8 (12.4)	6.8 (46.9)	84	0.03	0.3	1.00 E+00	7.56 E-01	105.84	0.002	6.35 E-02	1.44 E+03
13	g	SST	large	210	Radiological	100 cfm (0.047 m^3/s)	HEPA	29 (200)	0.1 (0.69)	146	0.03	1.0	2.31 E-01	1.01 E+00	183.96	0.002	8.50 E-02	1.44 E+03
14	g(p)	SST	gasoline large pool	100	small headspace vacuum	100 cfm (0.047 m^3/s)	HEPA	32 (223)	0.25 (1.7)	37.2	0.03	1.0	2.68 E-01	2.99 E-01	46.872	0.002	2.51 E-02	4.40 E+02
15	h	SST	large	210	toxicological	passive	HEPA/Flapper	1.8 (12.4)	6.8 (46.9)	84	0.03	0.3	1.00 E+00	7.56 E-01	105.84	0.002	6.35 E-02	1.44 E+03
16	i	DST	large	210	pressure	sealed tank	none	30.8 (212)	0 (0)	162	0.03	0.0	1.00 E+00	0.00 E+00	204.12	0.002	0.00 E+00	7.95 E+02
17	j	DST	large	210	vacuum	passive	Flapper	2.1 (14.5)	8 (55.2)	92.5	0.03	0.31	1.00 E+00	8.60 E-01	116.55	0.002	7.23 E-02	7.95 E+02
18	k	DST	puddle	1	radiological	100 cfm (0.047 m^3/s)	Vent Pipe[3]	0.9 (6.21)	0.1 (0.69)	132	0.1	1.0	1.33 E-01	1.76 E+00	1.86.32	0.002	4.42 E-02	7.95 E+02
19	l	DST	large	210	toxicological	100 cfm (0.047 m^3/s)	Flapper/Vent Pipe	2.0 (13.8)	5.2 (35.9)	92.1	0.03	1.0	3.80 E-01	1.05 E+00	116.046	0.002	8.82 E-02	7.95 E+02
20	l(q)	DST	gasoline large pool	100	toxicological (gasoline)	100 cfm (0.047 m^3/s)	Flapper/Vent Pipe	6.8 (46.9)	5.1 (35.2)	104	0.03	1.0	3.30 E-01	1.03 E+00	131.04	0.002	8.65 E-02	1.00 E+03
21	m	DCRT	pressure	34.1	pressure	sealed tank	none	30.5 (210)	0 (0)	2.47	0.03	0.0	1.00 E+00	0.00 E+00	3.1122	0.002	0.00 E+00	1.44 E+03
22	n	DCRT	vacuum	34.1	vacuum	passive	4 in. (0.1 m) Orifice	18.3 (126)	1.2 (8.27)	2.12	0.03	0.31	1.00 E+00	1.97 E-02	2.6712	0.002	1.66 E-03	1.44 E+03
23	o	DCRT	radiological	34.1	radiological	passive	4 in. (0.1 m) Orifice	18.3 (126)	1.2 (8.27)	2.12	0.03	0.31	1.00 E+00	1.97 E-02	2.6712	0.002	1.66 E-03	1.44 E+03
24	p	DCRT	toxicological	34.1	toxicological	passive	4 in. (0.1 m) Orifice	18.3 (126)	1.2 (8.27)	2.12	0.03	0.31	1.00 E+00	1.97 E-02	2.6712	0.002	1.66 E-03	1.44 E+03

25 [1] HEPA Vent Modeled as 3.75 in. (9.5 mm) Orifice
26 [2] Flapper is 50 in. (1.27 m) Orifice Opening at 1 psid (6.89 kPa)
27 [3] Vent Pipe on DST Modeled as 9.6 in. (0.24 m) Orifice
28 [4] HEPA Vent for 55 kgal Tanks is 3.42 in. (0.087 m) Orifice/Flapper is 17 in. (0.43 m) Orifice

ARF = aerosol release fraction.
DCRT = double-contained receiver tank.
DST = double-shell tank.
HEPA = high-efficiency particulate air (filter).
SST = single-shell tank.

B.1.1.2 Dose Summary

Table B-2 shows the Dose Summary worksheet. Each entry is described as follows.

Columns A Through G These columns are repeated from Table B-1 to remind the analyst of case descriptions.

Column H Calculates from $D(Sv) = Q(L) \bullet \frac{\chi}{Q'}(s/m^3) \bullet R(m^3/s) \bullet ULD(Sv/L)$ the onsite dose attributable to solvent smoke.

The product of $\frac{\chi}{Q'}$ and R is entered as a constant:

$$\frac{\chi}{Q'} \bullet R = 0.0328 \frac{s}{m^3} \bullet 3.3E-04 \frac{m^3}{s} = 1.08E-05 .$$

The dose is calculated from: $D(Sv) = Q(L) \bullet 1.08E-5 \bullet ULD(Sv/L)$.

The Excel equation for Cell H3 is: $H3 = N3\ (Table\ B\text{-}1) \bullet 1.08E-05 \bullet 2.83$

All of the cases use a respirable fraction (RF) of 1.0. The Excel equation for the entrained fire cases as typified by Row 20 is:

$$H20 = N20\ (Table\ B\text{-}1) \bullet 1.08E-05 \bullet 2.83 \bullet 0.5$$

The ULD for solvent is expressed in sieverts per kilogram units (see Table 5-1); therefore, the $Q(L)$ is also expressed in kilograms (see Column N of Table B-1).

Column I Computes onsite doses attributable to aqueous boil off from:

$$D(Sv) = Q(kg) \bullet \frac{1}{density\ (kg\ /L)} \bullet 1.08E\text{-}05 \bullet ULD(Sv/L)$$

Q (kilograms) and ULD (sieverts per liter) are data in columns Q and R in Table B-1 and aqueous density is assigned a value of 1.4 kg/L; therefore, the Excel equation for Cell I3 is:

$$I3 = Q3\ (Figure\ B\text{-}1) \bullet R3\ (Figure\ B\text{-}1) \bullet 1.08E-05/1.4 .$$

All of the cases use an RF of 1.0. The Excel equation for the entrained fire case in Row 20 is:

$$I20 = Q20\ (Table\ B\text{-}1) \bullet R20\ (Table\ B\text{-}1) \bullet 1.08E-05 \bullet \frac{0.5}{1.4}$$

Note that Q3 (Table B-1) is the mass in kilograms of aqueous waste released. The volume of waste in liters, the quantity needed to match with ULD values expressed on a per liter basis, is the mass in kilograms divided by density in kilograms per liter. A conservative default density of 1.4 kg/L has been used here.

Column J Lists the onsite radiological dose caused by HEPA filter rupture. The doses for Column J are calculated separately and entered in Column J. A spreadsheet titled "Calculate Onsite Rad Dose" calculates the dose and is included in RPP-8369. The onsite doses are calculated with the following formula:

$$D = Q \bullet ARF \bullet ULD \bullet \frac{\chi}{Q'} \bullet BR .$$

where:

BR = breathing rate = 3.3x10 4 m^3/sec.

$\frac{\chi}{Q'}$ = 3.28x10 2 sec/m^3.

ULD = unit-liter dose (different values of Sv/L for different waste).

ARF = aerosol release factor, a dimensionless factor. Taken from DOE-HDBK-3010-94. Section 5.4 of DOE-HDBK-3010-94 gives the ARF figures for HEPA filters. An ARF of 1.00×10^{-2} is for blast effects. An ARF of 2.00×10^{-6} is for shock effects. The overpressure resulting from a solvent burn is best characterized as a shock effect. A conservative interpolation between the two values is 1.00×10^{-4}.

Q = Liters of waste loaded on the filters taken from document HNF-SD-WM-CN-099, *Radiological and Toxicological Analyses of Tank 241-C-106 Ventilation Systems*. For these calculations, 1.98 L was rounded to 2.0 L, and 3.66 L was rounded to 3.7 L.

The HEPA rupture doses calculated in the spreadsheet, from RPP-8369, are entered in Column J of the Dose Summary spreadsheet. Values of BR, χ/Q', and ULD used in the above equation are given in Table 5-1.

Column K Computes total onsite dose by summing doses caused by solvent smoke, aqueous boil off, and HEPA rupture. The Excel equation for Row 3 is:

$$K3 = H3 + I3 + J3 .$$

Column L Calculates offsite doses from onsite dose and ratios of offsite to onsite factors. Offsite dose can be expressed as:

$$offsite\ dose = onsite\ dose \bullet \left[\frac{\frac{\chi}{Q'}\ offsite}{\frac{\chi}{Q'}\ onsite} \right] \bullet \left[\frac{ULD\ offsite}{ULD\ onsite} \right].$$

The ratio of atmospheric dispersion factors ($\frac{\chi}{Q'}$ in the above equation) is:

$$offsite/onsite = \frac{2.22E-05}{3.28E-02} = 6.77E-04$$

The ratios of unit-liter doses ($ULD_{offsite}/ULD_{onsite}$) are calculated from Table B-1 data. The dominant dose contributor is aqueous carryover, so data for SST and DST liquids is used to compute the ULD ratio.

For SSTs and DCRTs, cases the ULD ratio is $1.28E-03/1.44E-03 = 0.889$.

For DSTs, the ratio is $8.45E-02/7.95E-02 = 1.06$.

The Excel equation for Cell L3 is: $L3 = K3 \bullet 6.77E-04 \bullet 0.889$.

For DST cases, typified by Case J (Row 15), the Excel equation for Cell L3 is:

$$L3 = K3 \bullet 6.77E-04 \bullet (1 + 0.06)$$

Table B-2. Solvent Pool Fire Dose Summary Worksheet

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	**Case**	**Tank Type**	**Solvent Pool Description**	**Pool Area m3**	**Bounding Parameters**	**Ventilation Flow**	**Vent Description**	**Onsite Solvent Smoke Dose (Sv)**	**Onsite Aqueous Boiloff Dose (Sv)**	**HEPA Rupture Dose Onsite (Sv)**	**Total Onsite Dose (Sv)**	**Total Offsite Dose (Sv)**
3	a	SST	puddle	1.0	pressure	passive	HEPA(1)	2.92 E-05	2.68 E-04	1.46 E-06	2.98 E-04	1.80 E-07
4	b	SST	puddle	1.0	vacuum	passive	HEPA/ Flapper(2)	1.51 E-05	1.39 E-04	1.46 E-06	1.55 E-04	9.33 E-08
5	c	SST	puddle	1.0	radiological	100 cfm (0.047 m^3/s)	HEPA	6.26 E-05	5.73 E-04	2.29 E-04	8.65 E-04	5.61 E-07
6	d	SST	puddle	1.0	toxicological	100 cfm (0.047 m^3/s)	HEPA	6.26 E-05	5.73 E-04	2.29 E-04	8.65 E-04	5.21 E-07
7	d(m)	SST	gasoline puddle	1.0	gasoline	100 cfm (0.047 m^3/s)	HEPA	0.00 E+00	3.49 E-04	2.29 E-04	5.78 E-04	3.48 E-07
8	e	SST	large	210	pressure	passive	HEPA	1.73 E-05	5.28 E-04	1.46 E-04	5.47 E-04	3.29 E-07
9	e(n)	SST	gasoline large pool	100	gasoline	passive	HEPA	0.00 E+00	1.76 E-04	1.46 E-06	1.78 E-04	1.07 E-07
19	f	SST	large	210	vacuum	passive	HEPA/ Flapper(2)	2.31 E-05	7.05 E-04	1.46 E-06	7.30 E-04	4.39 E-07
11	f(o)	SST	gasoline large pool	100	gasoline	passive	HEPA/ Flapper	0.00 E+00	2.85 E-04	1.46 E-06	2.86 E-04	1.72 E-07
12	f1	SST	large	210	C-103	passive	HEPA/ Flapper	2.31 E+05	7.05 E-04	1.46 E-06	7.30 E-04	4.39 E-07
13	g	SST	large	210	radiological	100 cfm (0.047 m^3/s)	HEPA	3.09 E-05	9.44 E-04	2.29 E-04	1.20 E-03	7.25 E-07
14	g(p)	SST	gasoline large pool	100	small headspace volume	100 cfm (0.047 m^3/s)	HEPA	0.00 E+00	8.35 E-05	2.29 E-04	3.14 E-04	1.89 E-07
15	h	SST	large	210	toxicological	passive	HEPA/ Flapper	2.31 E-05	7.05 E-04	1.46 E-06	7.30 E-04	4.39 E-07
16	i	DST	large	210	pressure	sealed tank	none	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00
17	j	DST	large	210	vacuum	passive	Flapper	2.63 E-05	4.43 E-04	1.09 E-07	4.70 E-04	3.37 E-07
18	k	DST	puddle	1.0	radiological	100 cfm (0.047 m^3/s)	Vent Pipe(3)	5.37 E-05	2.71 E-04	3.18 E-05	3.57 E-04	2.56 E-07
19	l	DST	large	210	toxicological	100 cfm (0.047 m^3/s)	Flapper/ Vent Pipe	3.21 E-05	5.41 E-04	3.18 E-05	6.05 E-04	4.34 E-07
20	l(q)	DST	gasoline large pool	100	toxicological (gasoline)	100 cfm (0.047 m^3/s)	Flapper/ Vent Pipe	0.00 E+00	7.34 E-04	3.18 E-05	7.66 E-04	5.02 E-07
21	m	DCRT	large	34.1	pressure	sealed tank	none	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00
22	n	DCRT	large	34.1	vacuum	passive	4 in. (0.1 m) Orifice	6.03 E-07	1.84 E-05	3.54 E-06	2.25 E-05	1.36 E-08
23	o	DCRT	large	34.1	radiological	passive	4 in. (0.1 m) Orifice	6.03 E-07	1.84 E-05	3.54 E-06	2.25 E-05	1.36 E-08
24	p	DCRT	large	34.1	toxicological	passive	4 in. (0.1 m) Orifice	6.03 E-07	1.84 E-05	3.54 E-06	2.25 E-05	1.36 E-08

25 (1) HEPA Vent Modeled as 3.75 in. (9.5 mm) Orifice
26 (2) Flapper is 50 in. (1.27 m) Orifice Opening at 1 psid (6.89 kPa)
27 (3) Vent Pipe on DST Modeled as 9.6 in. (0.24 m) Orifice
28 (4) HEPA Vent for 55 kgal Tanks is 3.42 in. (0.087 m) Orifice/Flapper is 17 in. (0.43 m) Orifice

CDRT = double-contained receiver tank.
DST = double-shell tank.
HEPA = high-efficiency particulate air (filter).
SST = single-shell tank.

B.1.1.3 Toxicological Dose

Toxicological dose will be determined for the same 5-gal fire scenarios used in calculating the radiological dose. The methodology used to derive the toxicological exposure uses the released quantity of material multiplied by the airborne release rate (ARR) and then multiplied by the appropriate sum of fractions (SOF) value from Table 5-2 of the main document.

Table B-3, drawn from the RPP-8369, and presented in a vertical format, provides updated SOFs for the fires of concern (i.e., gasoline). Parameters and other input changes to the RPP-8369 toxicological spreadsheet are reflected in the results. Table B-3 shows quantified toxicological consequences of the five fires of interest (i.e., gasoline fires). The interrelationship of each applicable fire case has been documented in the preceding radiological spreadsheet, and by the applicable parameters established and discussed in Appendix A. Current Tank Farm Contractor SOFs originate from guidance found in RPP-8369 and are substantially larger than SOFs provided in RPP-8369. Temporary Emergency Exposure Limit (TEEL) and emergency response planning guideline (ERPG) values are updated values retrieved from WSMS-SAE-02-0001, *ERPGs and TEELs of Chemical Concern*. Each of the calculation steps are explained in the row descriptions that follow:

Rows 1 through 7

These rows are repeated from Table B-1 to remind the analyst of the particulars for each case being analyzed. These rows are also repeated on each page of the table.

Row 8 Lists the headspace air volume in cubic meters assumed for each fire case. In general, bounding high values were assumed to maximize the oxygen inventory, thereby maximizing the quantity of solvent, which could be burned.

Row 9 Lists the time period in seconds for which the pool fire is calculated to cause tank pressurization and outflow from the tank. The word "maximum" is included in the label descriptor because vent rate is a factor in quantifying the concentration of toxins in the downwind plume. The average vent rate during the fire induced outflow period was found to be larger than the active ventilation flow rate (assumed to be 100 ft^3/min) so the limiting toxicological consequences are associated with the outflow period listed in Row 9.

For puddle fires, outflow is calculated to end well before the fire extinguishes. For puddle fires with passive ventilation, outflow stops at 2,500 sec, but the fire burns for 5,018 sec before extinguishment. Gas heat up, caused by the relatively high specific burning rate computed for high oxygen concentrations, is sufficient to pressurize the atmosphere for 2,500 sec. For a longer time, the reduced burning rate is insufficient to increase gas temperature, and venting ceases for tanks not connected to a forced ventilation system.

Row 10 Lists the masses of solvent burned in kilograms during the outflow period. These numbers are smaller than the total solvent burned (Column J of Table B-1) for puddle fires. For large pools, outflow continues for the whole of the burn period, and masses burned during the vent are equal to the total mass burned for all but the puddle fire cases. Mass burned is a calculated output of POOLFIRE.4, as detailed in RPP-8369.

Row 11 Lists the fraction of the reaction gas products vented during the outflow period for each fire case. Carbon dioxide is a reaction product tracked in POOLFIRE.4, and the fractional release from the tank is computed at each time step. The CO_2 release fraction, computed from POOLFIRE.4 output, is listed in this column.

Row 12 Lists the headspace gas fraction, defined as the fraction of headspace gas vented from the tank during the outflow period for each fire case. The numbers are computed from POOLFIRE.4 output. The fraction of headspace gases vented is larger than the fraction of reaction gas products vented. The difference is that reaction gas products are formed during the burn, whereas headspace gases are present at maximum concentration at the beginning of the vent cycle.

Row 13 The source concentration of P_2O_5 in milligram per cubic meter, defined as the mass of P_2O_5 vented divided by the volume of gas vented, is calculated for each fire case. The mass of P_2O_5 formed was calculated as 4.32% of solvent mass burned (see RPP-8369). The Excel formula for Cell B13 is:

$$B13 = 0.0432 * B10 * B11 * 1E+06\ (mg/kg)/(B8 * B12).$$

This formulation yields the average P_2O_5 concentration during the release period. No attempt is made to compute the instantaneous release rate as a function of time.

It should be noted that P_2O_5 is not applicable to gasoline fires and a multiplier of zero is inserted in Row 23 of gasoline fires to remove P_2O_5 as a toxin. Nonzero values for P_2O_5 found here are required to compute the CO and NO_2 releases.

Row 14 The average source concentration of CO in milligrams per cubic meter, defined as the mass of CO vented divided by the volume of gas vented is calculated for each case. Based on an emission factor of 0.0425 kg/kg (WHC-SD-WM-SARR-001, *Risk from Organic Solvent Fires in C-103 Following Interim Stabilization*), the mass of CO formed is calculated to be 98% of the P_2O_5 mass. The Excel formula for Cell B14 is:

$$B14 = 0.98 * B13 .$$

Row 15 Calculates the average milligrams per cubic meter source concentration of NO_2 vented for each case. Based on an emission factor of 5.5 E 03 kg/kg (WHC-SD-WM-SARR-001), the mass of NO_2 formed is calculated to be 12.7 % of the mass of P_2O_5 formed. The Excel formula for Cell B15 is:

$$B15 = 0.127 * B13 .$$

Row 16 Lists atmospheric dilution factors at 100 m for each case. This factor accounts for turbulent mixing in the vicinity of the tank vent. For case e(n), the dilution factor is 2.60×10^3 indicating that the airborne concentration at 100 m downwind would be 2.60×10^3 times the concentration in vented gases. The bases for the dilution factors listed in this column are described in RPP-8369.

Row 17 The carryover rate of aqueous waste, defined as mass vented divided by the time of the vent, is calculated for each fire case. The Excel equation for Cell B17 is:

$$B17 = O3(Figure\ 5.3.1\text{-}1) * 1.0E-04 * \frac{B11}{(B9 * 1.4)}.$$

The units of Row 17 are liters per second; therefore, the above equation is based on the assumption of an aqueous density of 1.4 kg/L.

The ARF has been assigned a value of 1.0 x 10^{-4} (Table 5-1). This Excel equation can be written as:

$$\frac{S}{time} = M * ARF * \frac{RF}{(time * 1.4)}.$$

Row 18 Lists SOF multipliers for aqueous waste for onsite exposure. The SOF multiplier is computed by multiplying the applicable dimensionless SOF listed in Table 5-2 by the onsite atmospheric dispersion factor. For onsite receptor, ERPG-2/TEEL-2 data applies, and the ADF is 0.0328 (Table 5-1). A factor of 1,000 is also needed to compute a multiplier that has units of seconds per liter. As an example, the SOF multiplier for puddle fires with passive ventilation (cells in Row 18) is computed as:

$$Multiplier = 1.50E+09 * 3.28E-02\ s/m^3 * 10^{-3}\ m^3/L = 4.92E+04\ s/L.$$

Row 19 Lists SOF multipliers for aqueous waste for offsite exposure. The numbers listed in this column were computed from Table 5-2 data in the same way as was described for Row 18 data. For this category, the applicable exposure guideline is ERPG-1/TEEL-1 and the ADF is 2.22 x 10^{-5} (Table 5-1). For puddle fires with passive ventilation, the multiplier is computed as:

$$Multiplier = 3.00E+09 * 2.22E\text{-}5\ s/m^3 * 10^{-3} m^3/L = 6.66E+01\ s/L.$$

Row 20 Lists computed values of SOFs for aqueous waste for an onsite receptor. Implicit in this calculation is the minimal atmospheric dilution factor based on a χ/Q' value of 0.0328. This χ/Q' value was used in quantifying the SOF multipliers listed in rows 18 and 19. The SOFs shown in this column are baseline values that are adjusted at a later stage in the calculation to account for turbulent mixing in the vicinity of the tank vent. The Excel equation for Cell B20 is:

$$B20 = B17 * B18.$$

Row 21 Lists computed values of SOFs for aqueous waste, for an offsite receptor. The Excel equation for Cell B21 is:

$$B21 = B17 * B19.$$

Row 22 The vent rate of gas from the tank, cubic meters per second, is calculated as the volume vented divided by the time of venting. The Excel equation for Cell B21 is:

$$B21 = B8 * \frac{B12}{B9}.$$

Row 23 Computes onsite concentrations for P_2O_5 by multiplying headspace concentrations by the atmospheric dilution factor. The Excel equation is:

$$B23 = B13 * B16.$$

Row 13 lists the source concentration of P_2O_5 and Row 16 lists atmospheric dilution factors at 100 m. A multiplier of zero is inserted here for gasoline fires.

Rows 24, 25, 26, and 27

These four columns list the guideline concentration limits for P_2O_5. The respective values for TEEL-3, TEEL-2, TEEL-1, and TEEL-0 are taken from Table 5-3. P_2O_5 is not applicable to gasoline fires.

Row 28 Lists computed concentrations of CO at 100 m downwind. The onsite concentration is computed as the product of source concentration and the applicable dilution factor. The Excel equation for Cell B28 is:

$$B28 = B14 * B16.$$

Row 14 lists source concentration for CO and Row 16 lists the dilution factors predicted to result from turbulent mixing in the vicinity of the tank vent.

Rows 29, 30, 31, and 32

These columns list the guideline concentration limits for CO. The respective values for TEEL-3, TEEL-2, TEEL-1, and TEEL-0 are taken from Table 5-3.

Row 33 Lists computed onsite concentrations of NO_2 at 100 m downwind. The onsite concentration is computed as the product of source concentration and the dilution factor applicable at 100 m downwind. The Excel equation for Cell B33 is:

$$B33 = B15 * B16.$$

Row 15 lists the source concentrations for NO_2 and Row 16 lists the dilution factors predicted to result from turbulent mixing in the vicinity of the tank vent.

Rows 34, 35, 36, and 37

These four columns list the guideline concentration limits for NO_2. The respective values for TEEL-0, TEEL-1 are taken from Table 5-3.

Row 38 A normalized onsite concentration is computed on the basis of a source concentration of 1 mg/m^3. The Excel equation for Cell B38 is:

$$B38 = MIN(1 * B16, 0.0328 * 1 * B22 / (1 + B22 * 0.0328)).$$

This calculation selects the minimum value of downwind concentrations based on either the atmospheric dilution factors in row 16 or the dilution factor based on Equation EQ-1. As evident from comparing numbers in Row 16 and Row 26, ADF in Row 16 are selected as the minimum in every case.

Row 39 A normalized offsite concentration is computed on the basis of a source concentration of 1 mg/m^3. The Excel equation for Cell B39 is:

$$B39 = 2.22E\text{-}5 * 1 * B22/(1 + B22 * 2.22E\text{-}5).$$

This formulation for predicting downwind pollutant concentration is based on Equation EQ-1. The atmospheric dispersion factor, 2.22 x 10^5, is from Table 5-1.

Row 40 This row lists computed SOFs for gaseous toxic constituents formed by the assumed combustion of the gasoline. The data listed in this column apply to the onsite receptor. The combustion gas SOF is computed as the sum of individual fractions for P_2O_5, CO and NO_2. The Excel equation for Cell B40 is:

$$B40 = B23/B25 + B28/B30 + B33/B35.$$

Cells B23, B28 and B33 are calculated onsite concentrations of P_2O_5, CO and NO_2, respectively. Cells B25, B30, and B35 are ERPG-2/TEEL-2 onsite guideline concentrations for P_2O_5, CO and NO_2, respectively.

Row 41 This row lists computed SOFs for combustion gases for an offsite receptor. The calculation is the same as described for Row 40 except that airborne concentrations are those for the offsite location; and the guideline limits are ERPG-1/TEEL-1 values. A P_2O_5 multiplier of zero is inserted here for gasoline fires. The Excel equation is:

$$B41 = B39 * (B13/B26 + B14/B31 + B15/B36).$$

Note that Row 39 is a dilution factor for the offsite location. Cells B13, B14, and B15 represent source concentrations for P_2O_5, CO and NO_2, respectively.

Row 42 Computes soot concentration in vented gas as the mass of soot vented divided by the volume of gas vented. Soot formation is calculated as 20% of mass of solvent burned. The Excel equation for Cell B42 is:

$$B42 = 0.2 * B10 * B11 * 1.0E+6\ (mg/kg)/(B8 * B12).$$

Note that Row 10 contains masses of solvent or vehicle fuel burned, and Row 11 contains the fraction of reaction products that is carried out of the tank with vented gas.

Row 43 Computes onsite total particulate concentration as that due to soot alone. The Excel equation for Cell B43 is:

$$B43 = B38 * B42 \ .$$

Note that P_2O_5, which is not applicable to gasoline fires as an aerosol particle, is not included in the total particulate burden. The rationale for excluding P_2O_5 from the particulate mass is that it is already counted as a toxic constituent in the combustion gas fraction.

Row 44 Computes offsite total particulate concentration from equation EQ-1, on the basis of the computed soot load. The Excel equation for Cell B44 is:

$$B44 = 2.22E\text{-}5 * (B42) * B22 / (1 + B22 * 2.22E\text{-}5).$$

Rows 45, 46, 47, and 48

List the onsite and offsite total particulate guideline limits. The guidelines are applied to the combined mass of the particles in the plume. Guidelines for individual compounds are not superceded by the guidelines for total particulates. These guideline values are RPP-8369. The guidelines used for total particulate are: PEL, 10 mg/m^3; ERPG-1, 30 mg/m^3; ERPG-2, 50 mg/m^3; and ERPG-3, 500 mg/m^3. It should be noted that these values do not necessarily correspond to the health effects defined in the ERPG categories; they are surrogate values used because little data is available on which to base ERPGs for particulates not otherwise classified. It is unlikely that toxic concentrations in excess of the total particulate ERPG-3 value of 500 mg/m^3 could be achieved. This is because 500 mg/m^3 is considered to be the maximum concentration of inhalable particles (10 µm and under) that can be sustained in a plume.

Row 49 Calculates the ratio of onsite particle concentration to the guideline limit (ERPG-2) for each case. The Excel equation for Cell B49 is:

$$B49 = B43/B46 .$$

Row 50 Calculates the ratio of offsite particle concentration to the guideline limit (ERPG-1) for each case. The Excel equation for Cell B50 is:

$$B50 = B44/B47 .$$

Row 51 Computes offsite concentration for a source concentration of 1 mg/m^3 using Equation 1. The Excel equation for Cell B51 is:

$$B51 = 2.22E\text{-}5 * 1 * B22/(1 + B22 * 2.22E\text{-}5) \ .$$

Row 51 is a repeat of Row 39.

Row 52 Lists SOF multipliers for headspace gases for onsite receptors. These multipliers are computed by multiplying dimensionless SOFs (Table 5-1 data) by the applicable ADF. As an example, for puddle fires with passive ventilation where data for passively ventilated tanks is applicable. The multiplier is computed as follows:

$$Multiplier = 9.89E+00 * 0.0328\ s/m^3 = 3.24E+01\ s/m^3.$$

Note that the TEEL-2 SOF data are applicable.

Row 53 Lists SOF multipliers for the offsite receptor for which TEEL-1 guidelines are applicable. The multiplier is computed as follows:

$$Multiplier = 8.13E+01 * 2.22E\text{-}5\ s/m^3 = 1.80E+3\ s/m^3.$$

Row 54 This row lists the calculated SOF for headspace gases for an onsite receptor. The Excel equation for Cell B54 is:

$$B54 = B16 * B52/0.0328.$$

The SOF multiplier listed in Cell B52 is multiplied by the onsite turbulent dispersion factor, Cell B16, and the product is then divided by the ADF, 0.0328 s/m^3, which is a factor used in calculation of the SOF multipliers listed in Row 52. Division by the onsite ADF implicit in the SOF multipliers is a calculation step that applies the turbulent mixing analysis to composite source terms. The algebraic manipulations necessary for applying turbulent mixing factors to onsite SOF multipliers is presented in detail in RPP-8369.

Row 55 Lists calculated SOFs for headspace gases applicable to an offsite receptor. The Excel equation for Cell B55 is:

$$B55 = B22 * B53.$$

Cell B22 is the vent rate of headspace gas and B53 is the applicable SOF multiplier. Note that turbulent mixing in the vicinity of the tank vent is not accounted for in calculating offsite consequences so the SOF is calculated simply as the product of the vent rate and the rate multiplier. The rate multipliers for offsite calculations are based on an ADF of 2.22×10^{-5} s/m^3.

Row 56 Repeats Row 49 and lists onsite particulate fraction for each case. This row is repeated to exhibit the particulate fraction in the same area of the page where other toxic material categories are summed. This fraction is calculated using ERPG-2 limits.

Row 57 Repeats of Row 50 and lists offsite particulate fraction for each case. This column is repeated to exhibit the particulate fraction in the same area of the page where other toxic material categories are summed. This fraction was based on ERPG-1 values.

Rows 58 and 59 (below)

The SOFs for HEPA filter ruptures are listed in rows 58 and 59. TThe SOFs are calculated using the following formula:

$$SOF = SOF\ multiplier * release\ rate * jet\ mixing\ factor$$

where:

SOF = sum of fractions is a dimensionless number. Values listed are from Table 5-4 of this document.

SOF Multiplier = has different values in seconds per liter for different wastes.

Release Rate = calculated by dividing volume of waste released by release time. Units are liters per seconds. In all cases, a release time of 60 sec is used. Release volumes are taken from document HNF-SD-WM-CN-099, and are rounded to 2.0 L and 3.7 L.

Jet mixing factor = a multiplier which accounts for turbulent mixing in the vicinity of the tank vent. This factor applies to onsite calculations only. Its basis and numerical values are detailed in RPP-8369.

Row 58 Lists the onsite SOF for HEPA rupture. Jet mixing factors for each case is calculated in RPP-8369, and applied individually in this column.

Row 59 Lists the offsite SOF for HEPA rupture. Jet mixing is not calculated as a factor at the offsite location. Therefore, a default value of unity (1) is used in this column for the jet mixing factor.

Row 60 Lists the SOF for onsite aqueous boiloff. The concentration of aerosolized waste at the 100-m downwind location has been calculated to account for turbulent mixing in the atmosphere in the vicinity of the tank vent. The Excel formula for Cell B60 is:

$$B60 = B20 * B16/(B22 * 0.0328) \ .$$

The value of Cell B20 is the SOF for aqueous waste based on an χ/Q' atmospheric dispersion factor of 0.0328 s/m^3, applied to a waste release rate expressed in L/s. The quantity that multiplies B20, B16 / B22*0.0328, adjusts the SOF B20 to account for dilution based on jet mixing. The technical basis for this adjustment factor is presented in RPP-8369.

Row 61 Lists the SOF for offsite aqueous boiloff. The numbers shown are copied from Row 21 and are reproduced here to exhibit the aqueous boiloff SOF on the same page where other toxicological sums are shown. Offsite SOFs were not recalculated to reflect jet mixing in the vicinity of the tank vent.

Row 62 Sums the SOFs for toxic materials in the several classes for the onsite receptor. The Excel equation for Cell B62 is:

$$B62 = B40 + B54 + B56 + B58 + B60.$$

The several classes of toxins are:

Row 54: Headspace gases

Row 56: Total particulates

Row 58: HEPA filter released contaminants

Row 60: Aqueous Waste Boiloff

Row 40: Combustion gas toxic materials.

Each row cited above applies to the onsite receptor.

Row 63 Sums the SOFs for the offsite receptor. The Excel equation for Cell B63 is:

$$B63 = B41 + B55 + B57 + B58 + B61.$$

Each row listed in the equation above applies to the offsite receptor. The toxic material classes are the same as those identified in the text describing Row 62.

Table B-3. Toxicological Dose Worksheet. (4 sheets)

	A	B	C	D	E	F
1	CASE	d(m)	e(n)	f(o)	g(p)	l(q)
2	Tank Type	SST	SST	SST	SST	DST
3	Solvent Pool Description	gasoline puddle	gasoline large pool	gasoline large pool	gasoline large pool	gasoline large pool
4	Pool Area (m^3)	1.0	100	100	100	100
5	Bounding Parameters	gasoline	gasoline	gasoline	small headspace volume	toxicological (gasoline)
6	Ventilation Flow	100 cfm (0.047 m^3 /s)	passive	passive	100 cfm (0.047 m^3/s)	100 cfm (0.047 m^3/s)
7	Vent Description	HEPA	HEPA	HEPA/ Flapper	HEPA	Flapper/ Vent Pipe
8	Tank Headspace Gas Volume (m^3)	4.82 E+03	4.82 E+03	4.28 E+03	1.16 E+03	5.30E+03
9	Poolfire.4 Maximum Vent Duration (s)	2.50 E+03	1.60 E+03	3.79 E+01	2.93 E+02	4.10 E+01
10	Poolfire.4 Solvent Burned in Vent (kg)	9.07 E+01	1.54 E+02	9.51 E+01	3.72 E+01	1.04 E+02
11	Poolfire.4 Reaction Gas Fraction Gas Fraction	1.17 E-01	1.56 E-01	3.50 E+01	1.70 E-01	3.55 E-01
12	Poolfire.4 Headspace Gas Fraction	2.33 E-01	1.67 E-01	6.09 E+01	1.82 E-01	6.15 E-01
13	Source Concentration P_2O_5 (mg/m^3)	4.09 E+02	1.29 E+03	5.52 E+02	1.29 E+03	4.89 E+02
14	Source Concentration CO (mg/m^3)	4.00 E+02	1.26 E+03	5.41 E+02	1.27 E+03	4.80 E+02
15	Source Concentration NO_2 (mg/m^3)	5.19 E+01	1.64 E+02	7.01 E+01	1.64 E+02	6.21 E+01
16	Atmospheric Dilution Factor at 100m (Dimensionless)	2.60 E-03	2.60 E-03	2.60 E-03	2.60 E-03	1.30 E-02
17	Aqueous Vent Rate (L/s)	1.16 E-05	2.70 E-05	1.58 E-01	3.89 E-05	1.62 E-03
18	Van's Onsite Limit (s/L)	1.57 E+045	1.57 E+04	1.57 E+04	1.57 E+04	1.02 E+04
19	Van's Offsite Limit (s/L)	1.07 E+01	1.07 E+01	1.07 E+01	1.07 E+01	6.88 E+00
20	Onsite SOF Aqueous Boiloff	1.83 E-01	4.26 E-01	2.49 E+03	6.12 E-01	1.65 E+01

Table B-3. Toxicological Dose Worksheet. (4 sheets)

	A	B	C	D	E	F
1	CASE	d(m)	e(n)	f(o)	g(p)	l(q)
2	Tank Type	SST	SST	SST	SST	DST
3	Solvent Pool Description	gasoline puddle	gasoline large pool	gasoline large pool	gasoline large pool	gasoline large pool
4	Pool Area (m^3)	1.0	100	100	100	100
5	Bounding Parameters	gasoline	gasoline	gasoline	small headspace volume	toxicological (gasoline)
6	Ventilation Flow	100 cfm (0.047 m^3 /s)	passive	passive	100 cfm (0.047 m^3/s)	100 cfm (0.047 m^3/s)
7	Vent Description	HEPA	HEPA	HEPA/ Flapper	HEPA	Flapper/ Vent Pipe
21	Offsite SOF Aqueous Boiloff	1.24 E-04	2.88 E-04	1.68 E+00	4.14 E-04	1.12 E-02
22	Vent Rate of Gas (m^3/s)	4.49 E-01	5.03 E-01	6.88 E+03	7.21 E-01	7.95 E+01
23	Onsite Concentration P_2O_5 (mg/m^3)	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00	0.00 E+00
24	P_2O_5 Limit TEEL-3 (mg/m^3)	5.00 E+01	5.00 E+01	5.00 E+01	5.00 E+01	5.00 E+01
25	P_2O_5 Limit TEEL-2 (mg/m^3)	1.00 E+01	1.00 E+01	1.00 E+01	1.00 E+01	1.00 E+01
26	P_2O_5 Limit TEEL-1 (mg/m^3)	1.00 E+00	1.00 E+00	1.00 E+00	1.00 E+00	1.00 E+00
27	P_2O_5 Limit TEEL-0 (mg/m^3)	1.00 E+00	1.00 E+00	1.00 E+00	1.00 E+00	1.00 E+00
28	Onsite Concentration CO (mg/m^3)	1.04 E+00	3.29 E+00	1.41 E+00	3.30 E+00	6.23 E+00
29	CO Limit TEEL-3 (mg/m^3)	6.00 E+02	6.00 E+02	6.00 E+02	6.00 E+02	6.00 E+02
30	CO Limit TEEL-2 (mg/m^3)	4.00 E+02	4.00 E+02	4.00 E+02	4.00 E+02	4.00 E+02
31	CO Limit TEEL-1 (mg/m^3)	2.00 E+02	2.00 E+02	2.00 E+02	2.00 E+02	2.00 E+02
32	CO Limit TEEL-0 (mg/m^3)	6.00 E+01	6.00 E+01	6.00 E+01	6.00 E+01	6.00 E+01
33	Onsite Concentration NO_2 (mg/m^3)	1.35 E-01	4.26 E-01	1.82 E-01	4.27 E-01	8.08 E-01
34	NO_2 Limit TEEL-3 (mg/m^3)	4.00 E+00	4.00 E+00	4.00 E+00	4.00 E+00	4.00 E+00
35	NO_2 Limit TEEL-2 (mg/m^3)	4.00 E+00	4.00 E+01	4.00 E+01	4.00 E+01	4.00 E+01

Table B-3. Toxicological Dose Worksheet. (4 sheets)

	A	B	C	D	E	F
1	CASE	d(m)	e(n)	f(o)	g(p)	l(q)
2	Tank Type	SST	SST	SST	SST	DST
3	Solvent Pool Description	gasoline puddle	gasoline large pool	gasoline large pool	gasoline large pool	gasoline large pool
4	Pool Area (m^3)	1.0	100	100	100	100
5	Bounding Parameters	gasoline	gasoline	gasoline	small headspace volume	toxicological (gasoline)
6	Ventilation Flow	100 cfm (0.047 m^3 /s)	passive	passive	100 cfm (0.047 m^3/s)	100 cfm (0.047 m^3/s)
7	Vent Description	HEPA	HEPA	HEPA/ Flapper	HEPA	Flapper/ Vent Pipe
36	NO_2 Limit TEEL-1 (mg/m^3)	2.50 E+00	2.50 E+00	2.50 E+00	2.50 E+00	2.50 E+00
37	NO_2 Limit TEEL-0 (mg/m^3)	7.50 E-01	7.50 E-01	7.5 E-01	7.50 E-01	7.50 E-01
38	Onsite Normalized Concentration (1 mg/m^3 at source)	2.60 E-03	2.60 E-03	2.60 E-03	2.60 E-03	1.30 E-02
39	Offsite Normalized Concentration (1 mg/m^3 at source)	9.96 E-06	1.12 E-05	1.32 E-01	1.60 E-05	1.76 E-03
40	Onsite Combustion Gas SOF	3.63 E-02	1.15 E-01	4.91 E-02	1.15 E-01	2.81 E-01
41	Offsite Combustion Gas SOF	2.27 E-04	6.02 E-04	4.07 E+00	1.15 E-03	4.80 E-02
42	Source Soot Concentration (mg/m^3)	1.89 E+03	5.97 E+03	2.55 E+03	5.99 E+03	2.27 E+03
43	Onsite Total Particulates (mg/m^3)	4.92 E+00	1.55 E+01	6.64 E+00	1.56 E+01	2.94 E+01
44	Offsite Total Particulates (mg/m^3)	1.88 E-02	6.67 E-02	3.38 E+02	9.58 E-02	3.99 E+00
45	Particulate Limit ERPG-3 (mg/m^3)	5.00 E+02	5.00 E+02	5.00 E+02	5.00 E+02	5.00 E+02
46	Particulate Limit ERPG-2 (mg/m^3)	5.00 E+01	5.00 E+01	5.00 E+01	5.00 E+01	5.00 E+01
47	Particulate Limit ERPG-1 (mg/m^3)	3.00 E+01	3.00 E+01	3.00 E+01	3.00 E+01	3.00 E+01
48	Particulate Limit PEL-TWA (mg/m^3)	1.00 E+01	1.00 E+01	1.00 E+01	1.00 E+01	1.00 E+01
49	Onsite Total Particulates Fraction	9.84 E-02	3.11 E-01	1.33 E-01	3.12 E-01	5.89 E-01

Table B-3. Toxicological Dose Worksheet. (4 sheets)

	A	B	C	D	E	F
1	**CASE**	**d(m)**	**e(n)**	**f(o)**	**g(p)**	**l(q)**
2	**Tank Type**	**SST**	**SST**	**SST**	**SST**	**DST**
3	**Solvent Pool Description**	**gasoline puddle**	**gasoline large pool**	**gasoline large pool**	**gasoline large pool**	**gasoline large pool**
4	**Pool Area (m^3)**	**1.0**	**100**	**100**	**100**	**100**
5	**Bounding Parameters**	**gasoline**	**gasoline**	**gasoline**	**small headspace volume**	**toxicological (gasoline)**
6	**Ventilation Flow**	**100 cfm (0.047 m^3/s)**	**passive**	**passive**	**100 cfm (0.047 m^3/s)**	**100 cfm (0.047 m^3/s)**
7	**Vent Description**	**HEPA**	**HEPA**	**HEPA/ Flapper**	**HEPA**	**Flapper/ Vent Pipe**
50	**Offsite Total Particulate Fraction**	6.28 E-04	2.22 E-03	1.13 E+01	3.19 E-03	1.33 E-01
51	**Offsite Normalized Concentration (1 mg/m^3 at source)**	9.96 E-06	1.12 E-05	1.32 E-01	1.60 E-05	1.76 E-03
52	**Onsite Headspace (s/m^3)**	3.24 E-01	3.24 E-01	3.24 E-01	3.24 E-01	3.24 E-01
53	**Offsite Headspace (s/m^3)**	1.80 E-03	1.80 E-03	1.80 E-03	1.80 E-03	1.80 E-03
54	**Onsite Headspace SOF**	2.57 E-02	2.57 E-02	2.57 E-02	2.57 E-02	1.29 E-01
55	**Offsite Headspace SOF**	8.10 E-04	9.07 E-04	1.24 E+01	1.30 E-03	1.43 E-01
56	**Onsite Particulate Fraction**	9.84 E-02	3.11 E-01	1.33 E-01	3.12 E-01	5.89 E-01
57	**Offsite Particulate Fraction**	6.28 E-04	2.22 E-03	1.13 E+01	3.19 E-03	1.33 E-01
58	**Onsite HEPA Fraction**	3.49 E-03	1.74 E-04	1.74 E-04	3.49 E-03	1.29 E-03
59	**Offsite HEPA Fraction**	2.22 E-04	1.41 E-06	1.41 E-06	2.22 E-04	3.29 E-04
60	**Onsite SOF Aqueous Boiloff**	3.23 E-02	6.71 E-02	2.87 E-02	6.73 E-02	8.22 E-02
61	**Offsite SOF Aqueous Boiloff**	1.24 E-04	2.88 E-04	1.68 E+00	4.14 E-04	1.12 E-02
62	***Onsite Total SOF***	**1.96 E-01**	**5.18 E-01**	**2.36 E-01**	**5.23 E-01**	**1.02 E+00**
63	***Offsite Total SOF***	**2.01 E-03**	**4.22 E-03**	**2.94 E+01**	**6.28 E-03**	**3.36 E-01**

Notes:

DST = double-shell tank.
ERPG = emergency response planning guideline.
HEPA = high-efficiency particulate air (filter)
PEL = permissible exposure limit.
SOF = sum of fractions.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.
TWA = time-weighted average.

B.2 REFERENCES

DOE-HDBK-3010-94, 2000, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, Change Notice No. 1, U.S. Department of Energy, Washington, D.C.

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WSMS-SAE-02-001, 2002, *ERPGs and TEELs of Chemical Concern*, Rev. 18, Westinghouse Safety Management Systems, Aiken, South Carolina.

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APPENDIX C

TECHNICAL REVIEW CHECKLIST

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APPENDIX C

TECHNICAL REVIEW CHECKLIST

Document Reviewed: RPP-13261, Analysis of Vehicle Fuel Release Resulting in Waste Tank Fire

Scope of Review (e.g., document section or portion of calculation): All

Yes	No	NA*	
[x]	[ ]	[ ]	1. Previous reviews are complete and cover the analysis, up to the scope of this review, with no gaps.
[x]	[ ]	[ ]	2. Problem is completely defined.
[x]	[ ]	[ ]	3. Accident scenarios are developed in a clear and logical manner.
[x]	[ ]	[ ]	4. Analytical and technical approaches and results are reasonable and appropriate. *(ORP QAPP criterion 2.8)*
[x]	[ ]	[ ]	5. Necessary assumptions are reasonable, explicitly stated, and supported. *(ORP QAPP criterion 2.2)*
[x]	[ ]	[ ]	6. Computer codes and data files are documented.
[x]	[ ]	[ ]	7. Data used in calculations are explicitly stated.
[x]	[ ]	[ ]	8. Bases for calculations, including assumptions and data, are consistent with the supported safety basis document (e.g., the Tank Farms Final Safety Analysis Report).
[x]	[ ]	[ ]	9. Data were checked for consistency with original source information as applicable. *(ORP QAPP criterion 2.9)*
[x]	[ ]	[ ]	10. For both qualitative and quantitative data, uncertainties are recognized and discussed, as appropriate. *(ORP QAPP criterion 2.17)*
[ ]	[ ]	[x]	11. Mathematical derivations were checked including dimensional consistency of results. *(ORP QAPP criterion 2.16)* [No derivations]
[x]	[ ]	[ ]	12. Models are appropriate and were used within their established range of validity or adequate justification was provided for use outside their established range of validity.
[x]	[ ]	[ ]	13. Spreadsheet results and all hand calculations were verified.
[x]	[ ]	[ ]	14. Calculations are sufficiently detailed such that a technically qualified person can understand the analysis without requiring outside information. *(ORP QAPP criterion 2.5)*
[x]	[ ]	[ ]	15. Software input is correct and consistent with the document reviewed.
[x]	[ ]	[ ]	16. Software output is consistent with the input and with the results reported in the document reviewed.
[x]	[ ]	[ ]	17. Software verification and validation are addressed adequately. *(ORP QAPP criterion 2.6)*
[x]	[ ]	[ ]	18. Limits/criteria/guidelines applied to the analysis results are appropriate and referenced. Limits/criteria/guidelines were checked against references. *(ORP QAPP criterion 2.9)*
[ ]	[ ]	[ ]	19. Safety margins are consistent with good engineering practices. [No margins]
[x]	[ ]	[ ]	20. Conclusions are consistent with analytical results and applicable limits.

[x]	[ ]	[ ]	21. Results and conclusions address all points in the purpose. *(ORP QAPP criterion 2.3)*
[x]	[ ]	[ ]	22. All references cited in the text, figures, and tables are contained in the reference list.
[x]	[ ]	[ ]	23. Reference citations (e.g., title and number) are consistent between the text callout and the reference list.
[ ]	[x]	[ ]	24. Only released (i.e., not draft) references are cited. *(ORP QAPP criterion 2.1)* †
[x]	[ ]	[ ]	25. Referenced documents are retrievable or otherwise available.
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[x]	[ ]	[ ]	27. There are no duplicate citations in the reference list.
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[x]	[ ]	[ ]	30. The Table of Contents is correct.
[x]	[ ]	[ ]	31. All figure, table, and section callouts are correct.
[x]	[ ]	[ ]	32. Unit conversions are correct and consistent.
[x]	[ ]	[ ]	33. The number of significant digits is appropriate and consistent.
[x]	[ ]	[ ]	34. Chemical reactions are correct and balanced.
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[x]	[ ]	[ ]	37. The document is free of typographical errors.
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[x]	[ ]	[ ]	39. The document was prepared in accordance with HNF-2353, Section 4.3, Attachment B, "Calculation Note Format and Preparation Instructions".
[x]	**[ ]**	**[ ]**	**Concurrence**

D.M. Carson — 4 Mar 03

Reviewer (Printed Name and Signature) — Date

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† Draft documents cited will be released before this document.

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed:

Scope of Review (e.g., document section or portion of calculation):

Yes	No	NA*	
[ ]	[ ]	[X]	1. Previous reviews are complete and cover the analysis, up to the scope of this review, with no gaps.
[ ]	[ ]	[X]	2. Problem is completely defined.
[ ]	[ ]	[X]	3. Accident scenarios are developed in a clear and logical manner.
[ ]	[ ]	[X]	4. Analytical and technical approaches and results are reasonable and appropriate. *(ORP QAPP criterion 2.8)*
[ ]	[ ]	[X]	5. Necessary assumptions are reasonable, explicitly stated, and supported. *(ORP QAPP criterion 2.2)*
[ ]	[ ]	[X]	6. Computer codes and data files are documented.
[ ]	[ ]	[X]	7. Data used in calculations are explicitly stated.
[ ]	[ ]	[X]	8. Bases for calculations, including assumptions and data, are consistent with the supported safety basis document (e.g., the Tank Farms Final Safety Analysis Report).
[ ]	[ ]	[X]	9. Data were checked for consistency with original source information as applicable. *(ORP QAPP criterion 2.9)*
[ ]	[ ]	[X]	10. For both qualitative and quantitative data, uncertainties are recognized and discussed, as appropriate. *(ORP QAPP criterion 2.17)*
[ ]	[ ]	[X]	11. Mathematical derivations were checked including dimensional consistency of results. *(ORP QAPP criterion 2.16)*
[ ]	[ ]	[X]	12. Models are appropriate and were used within their established range of validity or adequate justification was provided for use outside their established range of validity.
[ ]	[ ]	[X]	13. Spreadsheet results and all hand calculations were verified.
[ ]	[ ]	[X]	14. Calculations are sufficiently detailed such that a technically qualified person can understand the analysis without requiring outside information. *(ORP QAPP criterion 2.5)*
[ ]	[ ]	[X]	15. Software input is correct and consistent with the document reviewed.
[ ]	[ ]	[X]	16. Software output is consistent with the input and with the results reported in the document reviewed.
[ ]	[ ]	[X]	17. Software verification and validation are addressed adequately. *(ORP QAPP criterion 2.6)*
[ ]	[ ]	[X]	18. Limits/criteria/guidelines applied to the analysis results are appropriate and referenced. Limits/criteria/guidelines were checked against references. *(ORP QAPP criterion 2.9)*
[ ]	[ ]	[X]	19. Safety margins are consistent with good engineering practices.
[ ]	[ ]	[X]	20. Conclusions are consistent with analytical results and applicable limits.

[ ]	[ ]	[X]	21. Results and conclusions address all points in the purpose. *(ORP QAPP criterion 2.3)*
[X]	[ ]	[ ]	22. All references cited in the text, figures, and tables are contained in the reference list.
[X]	[ ]	[ ]	23. Reference citations (e.g., title and number) are consistent between the text callout and the reference list.
[X]	[ ]	[ ]	24. Only released (i.e., not draft) references are cited. *(ORP QAPP criterion 2.1)*
[X]	[ ]	[ ]	25. Referenced documents are retrievable or otherwise available.
[X]	[ ]	[ ]	26. The most recent version of each reference is cited, as appropriate. *(ORP QAPP criterion 2.1)*
[X]	[ ]	[ ]	27. There are no duplicate citations in the reference list.
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[X]	[ ]	[ ]	30. The Table of Contents is correct.
[X]	[ ]	[ ]	31. All figure, table, and section callouts are correct.
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[ ]	[ ]	[X]	33. The number of significant digits is appropriate and consistent.
[ ]	[ ]	[X]	34. Chemical reactions are correct and balanced.
[X]	[ ]	[ ]	35. All tables are formatted consistently and are free of blank cells.
[X]	[ ]	[ ]	36. The document is complete (pages, attachments, and appendices) and in the proper order.
[X]	[ ]	[ ]	37. The document is free of typographical errors.
[ ]	[ ]	[ ]	38. The tables are internally consistent.
[ ]	[ ]	[X]	39. The document was prepared in accordance with HNF-2353, Section 4.3, Attachment B, "Calculation Note Format and Preparation Instructions".
[ ]	[ ]	[ ]	**Concurrence**

NA check for those items not responsibility of tech editor.

Laurie L Kraemer Laurie L Kraemer 3/18/02

Reviewer (Printed Name and Signature) Date

RPP-14499

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