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Change Justification	Analysis of accident consequences was revised as the result of comments received during the submittal and approval of the Documented Safety Analysis (RPP-13033, Rev. 0).		

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Author (Print/Sign) K. R. Sandgren K R Sandgren	*Date:* 7/29/03
Responsible Manager (Print/Sign) Ronald J. Stevens	*Date:* 7/30/03
Reviewer (Optional, Print/Sign) Brian D. Oberg B. D. Oberg	Date: 7-29-03

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Mixing of Incompatible Materials in Waste Tanks Technical Basis Document

K. R. Sandgren
CH2M HILL Hanford Group, Inc.
Richland, WA 99352
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Abstract: This document presents onsite radiological, onsite toxicological and offsite toxicological consequences, risk binning, and control decision results for the mixing of incompatible materials in waste tanks representative accident. Revision 1 incorporates comments received from the Office of River Protection.

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Mixing of Incompatible Materials in Waste Tanks Technical Basis Document

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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Revision 1

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Prepared By
K. R. Sandgren
CH2M HILL Hanford Group, Inc.

Date Published
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CH2MHILL
Hanford Group, Inc.

P. O. Box 1500
Richland, Washington

Contractor for the U.S. Department of Energy
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LIST OF TERMS

AC	administrative control
ARF	airborne release fraction
DCRT	double-contained receiver tank
DSA	documented safety analysis
DST	double-shell tank
HEPA	high-efficiency particulate air (filter)
PFP	Plutonium Finishing Plant
SMP	safety management program
SOF	sum of fractions
SSC	structures, systems, and components
SST	single-shell tank
TEEL	Temporary Emergency Exposure Limit
TSR	technical safety requirement
TWG	Technical Working Group
ULD	unit-liter dose

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1.0 INTRODUCTION

1.1 PURPOSE

This technical basis document was developed to support the Tank Farms Documented Safety Analysis (DSA) and describes the risk binning process, the technical basis for assigning risk bins, and the controls selected for the mixing of incompatible materials representative accident and associated represented hazardous conditions. The purpose of the risk binning process is to determine the need for safety-significant structures, systems, and components (SSC) and/or technical safety requirement (TSR)-level controls for a given representative accident or represented hazardous conditions based on an evaluation of the frequency and consequence. Note that the risk binning process is not applied to facility workers, because all facility worker hazardous conditions are considered for safety-significant SSCs and/or TSR level controls. (See RPP-14286, *Facility Worker Technical Basis Document).* Determination of the need for safety-class SSCs was performed in accordance with DOE-STD-3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, as described below.

1.2 BACKGROUND INFORMATION

1.2.1 Representative Accident

Routine tank farm operations include a number of material transfer activities such as waste transfers between tanks, incoming waste transfers from non-tank farm facilities (e.g., Plutonium Finishing Plant [PFP], 222-S Laboratory, T Plant), and bulk chemical additions to double-shell tanks (DST) for corrosion control. When considering the related hazards within tank farms, it was postulated that the mixing of incompatible material in a waste tank could result in a chemical reaction that produces aerosols and enough internal pressure to expel headspace gases, vapors, and aerosolized waste. Incompatible materials that could potentially be transferred to tank farm facilities were studied to determine a bounding case. The scenarios that were considered were:

Scenario 1. Addition of an incompatible material due to a waste transfer from an internal or external source
- Case A. Misrouting or transfer of incompatible tank waste
- Case B. Incompatible waste addition from external source.

Scenario 2. Inadvertent addition of an incompatible chemical due to a vendor or paperwork error when making a chemical addition to a tank
- Case A. Addition of excess base to a waste tank
- Case B. Addition of acid to a waste tank waste.

As the tank wastes are similar, reactions due to a transfer from one tank to another will not result in a significant release according to Reynolds (2001), "Potential for Tank Farm Systems to Give Off Toxic Chemicals or Pressurizing Due to Chemical Incompatibility." Reynolds (2001) was

included as an appendix to RPP-9689, *Offsite Radiological Consequence Calculation for the Bounding Mixing of Incompatible Materials Accident.* Therefore, Case A of Scenario 1 was discarded as a potential bounding case.

The majority of waste that is generated externally to tank farms would come from the PFP, the 222-S Laboratory, and T Plant. Each of these facilities utilizes practices that ensure the final facility waste solution is not transferred to incompatible tank waste. In addition, the transfer lines are not compatible with strong acids (the most common incompatible material) and would fail before large volumes could be transferred. Therefore, Case B of Scenario 1 was discarded as the bounding case.

Inadvertent addition of chemicals was then examined. The addition of excess base to tank waste was examined for the potential to react and produce ammonia. Substantial amounts of ammonia are dissolved or trapped in some tank wastes. Ammonia is produced by the decomposition of nitrogen-containing compounds that were added to process solutions that eventually ended up as waste. Amine chelating agents such as ethylenediaminetetraacetic acid are among the chief sources. There is some potential for the ammonia in these wastes to be released into the vapor space of tanks and vented to the atmosphere.

The solubility of ammonia increases with decreasing pH due to an increasing fraction of the dissolved ammonia existing as the ammonium ion. As pH is raised, the ammonium ion is converted to the neutral, molecular ammonia solute (aqueous NH_3). The neutral aqueous ammonia desorbs to become gaseous or vapor phase ammonia. The main reactions are as follows:

$$NH_4^+ + OH^- \rightleftharpoons NH_{3(aqueous)} + H_2O$$
$$NH_{3(aqueous)} \rightleftharpoons NH_{3(vapor)}.$$

The potential exists for strong bases to be accidentally added to waste tanks in amounts that may reduce the solubility of ammonia. A series of calculations were performed to predict the solubility of ammonia in a simulated waste and the effect of adding various amounts of 100% sodium hydroxide to the worst-case tank waste. It was found that a large amount of sodium hydroxide (slightly over 4 moles/L of waste) must be added to reach the ammonia saturation point before any ammonia is released by the reaction. An estimate of the bounding ammonia release was calculated in WHC-SD-WM-CN-074, *Chemical Reaction in a DCRT Leading to a Toxic Release.* It was shown that the consequences of an ammonia release are well within conservative guidelines. Therefore, Scenario 2, Case A, was not selected as the representative case.

Since direct chemical additions can be made to the waste tanks, an accident was postulated in which bulk delivery of an unexpected chemical is made to a waste tank (e.g., instead of the caustic addition expected, the delivery truck contains an acid). Since the delivery was assumed to be from a large tanker truck, only common chemicals that are routinely shipped in bulk quantities were considered. Common industrial acids were evaluated for their potential to react with tank waste resulting in gas or vapor generation. Sulfuric acid has the potential to generate significant quantities of nitrogen dioxide. The addition of concentrated sulfuric acid to the tank waste was identified as the bounding case and is presented here.

1.2.2 Bounding Offsite Accident

The mixing of incompatible materials accident is the bounding, low-energy atmospheric vapor/gas/aerosol release event, and has been quantitatively analyzed for comparison to the DOE-STD-3009-94, Appendix A, "Evaluation Guideline," of 25 rem. The bounding quantitative analysis for the mixing of incompatible materials accident is documented in RPP-9689, and shows that offsite radiological consequences are less than 1 rem. Therefore, no safety-class equipment or TSR-level controls need to be considered for offsite radiological exposures for any of the low-energy atmospheric vapor/gas/aerosol release events. It is important to note that DOE-STD-3009-94 does not provide any other evaluation guidelines (i.e., evaluation guidelines are not provided for offsite toxicological, onsite radiological, and onsite toxicological exposures). These exposures were evaluated for the representative accident and associated hazardous conditions in accordance with the risk binning process described in Section 1.3.

1.2.3 Associated Hazardous Conditions

In addition to the hazardous condition that defines the representative accident, the current hazard evaluation database lists a number of hazardous conditions that are represented by the mixing of incompatible materials accident. The hazardous conditions typically involve chemical reactions caused by mixing incompatible materials and are postulated to occur in the various tanks (DSTs, single-shell tanks [SST], and double-contained receiver tanks [DCRT]). Also grouped under the mixing of incompatible materials representative accident are various types of conditions that result in the release of ammonia vapors. The ammonia release conditions were assigned to the mixing of incompatible materials accident because they most closely resembled the ammonia releases that were due to the inadvertent addition of excess base. Some type of waste disturbing activity is generally the cause of these ammonia release events.

1.3 RISK BINNING METHODOLOGY

Direction on risk binning was provided by the U.S. Department of Energy, Office of River Protection (Klein and Schepens, 2003, "Replacement of Previous Guidance Provided by RL and ORP"). Risk binning begins with a qualitative evaluation of the frequency and consequence of the representative accident. Consequences are evaluated for the following receptors and exposures: offsite toxicological, onsite radiological, and onsite toxicological. These consequences are assigned to one of three categories: high, moderate, or low. Based on the frequency and consequence, risk bins (ranging from I to IV) are assigned. The approach applied during DSA development was that safety SSCs and/or TSR-level controls are required for accidents or hazardous conditions that are assigned to risk bins I or II, and are considered for accidents or hazardous conditions that are assigned to Risk Bin III. For accidents or hazardous conditions assigned to Risk Bin IV, safety SSCs and TSR-level controls are not expected. Safety management programs (SMP) are acceptable for addressing the residual risk posed by Risk Bin IV conditions. Tables 1 and 2 show the criteria that were applied during DSA development for assigning the frequency and consequence categories, and the risk bins, which are assigned to the various combinations of frequency and consequence. After the risk binning process is completed for the representative accident, the process is then repeated for the represented hazardous conditions associated with the representative accident.

Table 1. Offsite (Toxicological Only) Risk Bins.

Consequence category (toxicological only[1])	Event frequency			
	$<10^{-6}$/yr Beyond extremely unlikely	10^{-4} to 10^{-6}/yr Extremely unlikely	10^{-2} to 10^{-4}/yr Unlikely	$>10^{-2}$/yr Anticipated
>ERPG-2 / TEEL-2 (High)	III	II	I	I
>ERPG-1 / TEEL-1 <ERPG-2 / TEEL-2 (Moderate)	IV	III	II	I
< ERPG-1 / TEEL-1 (Low)	IV	IV	III	III

	safety SSCs and/or TSR-level controls required.
	safety SSCs and/or TSR-level controls considered.

[1] Radiological consequences for the offsite receptor are evaluated in accordance with DOE-STD-3009-94, 2002, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, Change Notice No. 2, Appendix A, U.S. Department of Energy, Washington D.C.

ERPG = emergency response planning guideline. TEEL = Temporary Emergency Exposure Limit.
SSC = structures, systems, and components. TSR = technical safety requirement.

Table 2. Onsite (100 m) Risk Bins.

Consequence category (radiological/ toxicological)	Event frequency			
	$<10^{-6}$/yr Beyond extremely unlikely	10^{-4} to 10^{-6}/yr Extremely unlikely	10^{-2} to 10^{-4}/yr Unlikely	$>10^{-2}$/yr Anticipated
>100 rem >ERPG-3 / TEEL-3 (High)	III	II	I	I
25 to 100 rem >ERPG-2 / TEEL-2 <ERPG-3 / TEEL-3 (Moderate)	IV	III	II	I
<25 rem <ERPG-2 / TEEL-2 (Low)	IV	IV	III	III

	safety SSCs and/or TSR-level controls required.
	safety SSCs and/or TSR-level controls considered.

ERPG = emergency response planning gideline. TEEL = Temporary Emergency Exposure Limit.
SSC = structures, systems, and components. TSR = technical safety requirement.

Environmental consequences are also assigned during the risk binning process. There are four categories of environmental consequences (E0, E1, E2, and E3, in order of increasing severity); these categories are defined in Table 3.

Table 3. Environmental Consequence Categories.

Category	Definition
E3	Offsite discharge or discharge to groundwater
E2	Significant discharge onsite
E1	Localized discharge of hazardous material
E0	No significant environmental consequence

2.0 RISK BINNING RESULTS

A risk binning team meeting was conducted on July 17, 2002, to obtain consensus on the assignment of frequencies, consequences, and risk bins. The attendees represented a wide range of expertise in the areas of engineering, licensing, and operations, and included representatives from the U.S. Department of Energy, Office of River Protection. Appendix A lists the attendees and the organization each attendee represents. After the meeting, the risk binning results were distributed to the Technical Working Group (TWG) for review and concurrence. The final risk bin results, after comment resolution, are summarized in Tables 4 and 8. See RPP-15116, *Proceedings of the Nuclear Working Group and the Technical Working Group.*

2.1 MIXING OF INCOMPATIBLE MATERIALS REPRESENTATIVE ACCIDENT WITHOUT CONTROLS

2.1.1 Accident Scenario

Large quantities of sodium hydroxide or sodium nitrite are added to DSTs, as necessary, to maintain the waste chemistry within the limits specified in the corrosion control program. These chemicals are delivered in tanker trucks and typically are added directly to the DST that requires chemical adjustment.

In the accident scenario without controls, the wrong chemical is delivered and 5,000 gal of concentrated sulfuric acid is added to a waste tank. The reaction of acid with sodium nitrite in waste solutions produces nitric oxide by disproportionation of the nitrite ion to nitric oxide. Thus, large amounts of nitric oxide gas potentially can be produced from the accidental addition of acid to tank wastes that contain large amounts of nitrite. It is also well known that the nitric oxide will react with oxygen in air to produce nitrogen dioxide. Thus, the addition has the potential to generate significant quantities of nitrogen dioxide and an associated fraction of aerosol. It is conservatively assumed that the high-efficiency particulate air (HEPA) filters are not present. When the filters are present and operational there will not be any release of aerosol since the gas generation rate (~75 ft^3/min) is insufficient to cause failure of the filter bank.

2.1.2 Frequency Determination

A frequency of "unlikely" was qualitatively assigned to the mixing of incompatible materials representative accident. The scenario requires that the chemical vendor also produce bulk quantities of sulfuric acid, mistakenly fills the delivery truck with the wrong chemical, places incorrect placarding on the vehicle, and includes incorrect delivery paperwork. The highly corrosive substance would have to be shipped to the receiving facility without being noticed by delivery personnel or shipping and receiving personnel. The vehicle would have to be connected and the corrosive material delivered without notice by participating personnel. In addition the receiving tank would have to contain high concentrations of nitrite. (Most additions are due to

the corrosion mitigation program, which would not generally require an addition to a high nitrite tank.)

2.1.3 Consequence Determination

This scenario of a bulk addition of acid to a DST or DCRT has not been previously analyzed. To provide an estimate of the radiological and toxicological consequences, calculations were performed and are documented in Appendix B. The accident scenario, without controls, assumes that a cargo tanker filled with 5,000 gal of 98% sulfuric acid (18.7 M) is emptied into a waste tank instead of the chemical expected (e.g., caustic or sodium nitrite). The 5,000 gal assumption is conservative because the sulfuric acid would significantly exceed the weight that tanker trucks can transport. (While tanker trucks contain a nominal volume as large as 7,000 gal, they are limited by total weight of the filled tanker. Generally, the maximum weight that can be transported is 45,000 lb, which is the equivalent weight of 3,000 gal of sulfuric acid. The analysis conservatively assumes the tanker contains significantly more than the full weight capacity of sulfuric acid.) The rate of addition is conservatively assumed to be 175 gal/min (typical addition rates seen in the field range from 75 to 100 gal/min). The reaction of acid with sodium nitrite in waste solutions produces nitric oxide by disproportionation of the nitrite ion to nitric oxide and nitrate ion according to the following equation:

$$2H^+ + 3NO_2^- \rightarrow 2NO\uparrow + NO_3^- + H_2O\,.$$

Thus, large amounts of nitric oxide gas potentially can be produced from the accidental addition of acid to tank wastes that contain large amounts of nitrite. It is also well known that the nitric oxide will react with oxygen in air to produce nitrogen dioxide. Thus, the addition of concentrated sulfuric acid to the tank waste was examined for consequences due to the aerosol released and the venting gases. The contributors to the consequences are the venting gases and the aerosol released as a result of the venting gases when there are no HEPA filters present. When the filters are present and operational there will not be any release of aerosol since the gas generation rate (~75 ft^3/min) is insufficient to cause failure of the filter bank. The analysis conservatively assumes the HEPA filters are not in place.

The source term used for the aerosol is 10% DST solids and 90% DST liquids. DST waste is assumed since the bounding radiological unit-liter dose (ULD) is found in DST waste. While the reaction will occur in the liquid phase, agitation will occur in the vicinity of the incoming acid stream. The agitation will cause some fine solids to be suspended in liquid. Solids that are dense or have large particle sizes will not be suspended by the bubbles. As the bubbles rise/collide/consolidate and collapse much of the solids will be released. The inclusion of 10% solids in the aerosol is considered a conservative assumption. The radiological ULDs were taken from RPP-5924, *Radiological Source Terms for Tank Farms Safety Analysis*, and the toxicological sums of fractions (SOF) were taken from RPP-8369, *Chemical Source Terms for Tank Farms Safety Analyses.*

Analysis assumptions and inputs are described below:

- 5,000 gal addition (conservative as this volume would exceed the weight that tanker trucks can transport)

- 175 gal/min rate of addition
- The acid is 98% sulfuric acid
- The airborne release fraction (ARF) of 2.0×10^{-3} and the respirable fraction of 1.0 are based on those associated with boiling of aqueous solutions in flowing air from DOE-HDBK-3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*
- The source term used for the aerosol in the analysis is 10% DST sludge and 90% DST liquids
- The HEPA filters are assumed to not be in place
- The pressurization resulting from the accident is insufficient to result in dome collapse since the gas generation rate is only ~ 75 ft^3/min.

It is important to note that the key assumptions listed above were selected to maximize the calculated consequences of the inadvertent acid addition, and that it is the combination of conservative assumptions that drive the accident consequences. Each of the assumptions, the potential effect of changes in the assumption on the frequency or consequence bin (qualitatively judged), and the need to evaluate or protect the assumptions are detailed in Table 5.

2.1.3.1 Assignment of Consequence Bins for the Onsite Radiological Receptor.

Although the evaluation of consequences was intended to be qualitative, there were no previous analyses of an inadvertent large acid addition that could provide an additional frame of reference for the qualitative judgment. Therefore, the radiological consequences were estimated as shown in Appendix B. Also while determining the offsite toxicological, onsite radiological, and onsite toxicological consequence bins, the meeting participants considered an actual operational experience where a transfer of unneutralized PUREX waste occurred. While the line between the valve pit and the distributor was damaged, there was no noticeable reaction with the tank waste (Occurrence #85-34 [RPP-13121, *Historical Summary of Occurrences from the Tank Farms Final Safety Analysis Report*]). Table 6 compares the onsite radiological consequences of the bounding representative accident to the radiological risk evaluation guidelines. Since the bounding condition resulted in low consequences to the onsite radiological receptor, the hazardous condition was assigned a consequence bin of "low" for the onsite radiological receptor.

2.1.3.2 Assignment of Consequence Bins for the Onsite and Offsite Toxicological Receptor

As noted in the previous section, there were no previous analyses of an inadvertent large acid addition to influence the qualitative assignment of consequences. Thus, the toxicological consequences were also estimated as shown in Appendix B. Consequence bins were assigned based on the analysis presented in Appendix B and the occurrence discussed above. Table 7 compares the toxicological consequences of the bounding representative accident to the risk evaluation guidelines. Reviewing the consequences shows that the offsite toxicological consequences are low, while the high onsite toxicological consequences are exceeded for the

bounding condition. Since the bounding condition resulted in low consequences to the offsite toxicological receptor, the represented hazardous condition was assigned a consequence bin of "low" for the offsite toxicological receptor. A consequence bin of "high" was assigned to the onsite toxicological receptor based on the results of the analysis. A consequence bin of "high" was also assigned to the inadvertent chemical addition to a DCRT or catch tank.

Table 4. Summary of Final Risk Binning Results for Represented Conditions.

Postulated accident/hazardous condition	Frequency	Consequences				Risk bin		
		Onsite radiological	Offsite toxicological	Onsite toxicological	Environmental	Onsite radiological	Offsite toxicological	Onsite toxicological
Inadvertent chemical addition to a DST	U	L	L	H	E2	III	III	I
Inadvertent chemical addition to a DCRT or catch tank	U	L	L	H	E2	III	III	I

Notes:

DCRT = double-contained receiver tank.
DST = double-shell tank.
L = low.
M = moderate.
U = unlikely.

Table 5. Qualitative Evaluation of Analysis Assumptions for Representative Accident. (4 sheets)

Analysis assumptions (AA) with references/basis	Assumption type	Sensitivity (frequency/consequence)	Need to Protect AA	Protection basis
An addition rate of 175 gal of acid per minute is assumed.	Reasonably conservative assumption.	No anticipated effect on consequence bin. Field experience with actual chemical additions show that addition rates are typically 75-100 gal/min. Even if higher flowrates were postulated, the analysis is relatively insensitive to the increase. Doubling the rate of addition results in roughly a 10% increase in the radiological release that is two orders of magnitude below the moderate consequence radiological guidelines and high consequence toxicological guidelines are already exceeded.	No	N/A
Acid is 18.7 M sulfuric acid.	Bounding (physically limiting) assumption.	No anticipated effect on consequence bin. 98% sulfuric acid is 18.7 M. This is a bounding assumption.	No	N/A
A breathing rate of 3.3×10^{-4} m^3/s from RPP-5924 is used.	Reasonably conservative assumption.	No anticipated effect on consequence bin. This is a standard analysis assumption.	No	N/A
An atmospheric dispersion coefficient of 1.97×10^{-5} s/m^3 was used for offsite consequences and an atmospheric dispersion coefficient of 4.12×10^{-3} s/m^3 was used for onsite consequences.	Reasonably conservative assumption.	No anticipated effect on consequence bin. The accident specific atmospheric dispersion coefficients are from Finfrock (2002), which is reproduced as an appendix to RPP-9689. No credit is taken for either plume meander or deposition.	No	N/A
An ARF of 2.0×10^{-3} and a respirable fraction of 1.0 are based on those associated with boiling of aqueous solutions in flowing air from DOE-HDBK-3010-94.	Bounding value presented in the handbook for this type of phenomenon.	No anticipated effect on consequence bin. The ARF and respirable fraction being used are the most applicable values presented in DOE-HDBK-3010-94.	No	N/A

Table 5. Qualitative Evaluation of Analysis Assumptions for Representative Accident. (4 sheets)

Analysis assumptions (AA) with references/basis	Assumption type	Sensitivity (frequency/consequence)	Need to Protect AA	Protection basis
The source term used for the aerosol in the analysis is 10% DST solids and 90% DST liquids.	Reasonably conservative estimate of solids in the aerosol.	No anticipated effect on consequence bin. This is a modeling assumption that cannot be verified but is considered to be conservative because boiling will occur in the vicinity of the incoming acid stream. The agitation caused by the boiling will not cause the solid waste to be thoroughly mixed with the liquid. In addition, the solids will settle out as they pass through the liquid phase toward the surface. It should also be noted that the SOFs for DST liquids and solids are similar so there is little sensitivity.	No	N/A
The HEPA filters are assumed to not be in place.	Bounding assumption. If the HEPA filters are in place and operational, then they will filter out much of the release.	No anticipated effect on consequence bin. When the filters are in place and operational there will not be any release of aerosol since the gas generation rate (~75 ft^3/min) is insufficient to cause failure of the filter bank.	No	N/A
The pressurization resulting from the accident would not cause a dome collapse. The maximum gas generation rate is only ~75 ft^3/min, which is insufficient to result in significant tank pressurization.	Reasonably conservative assumption.	No anticipated effect on consequence bin. Gas generation at the rates shown cannot cause dome cracking or failure. This because the expected failure pressure for a DST is 60 lb/in^2 gauge (WHC-SD-TWR-RPT-003).	No	N/A
The radiological ULDs used were the bounding DST liquid and sludge values provided in RPP-5924.	The bounding values reported in RPP-5924 were used.	No anticipated effect on consequence bin. The ULD would have to be increased by two orders of magnitude for the moderate consequence bin to be challenged.	No	N/A
The toxicological SOFs used were the bounding DST liquid and solid values provided in RPP-8369.	The bounding values reported in RPP-8369 were used.	No anticipated effect on consequence bin. The SOF would have to be increased by an order of magnitude to challenge the offsite moderate consequence bin.	No	N/A

Table 5. Qualitative Evaluation of Analysis Assumptions for Representative Accident. (4 sheets)

Analysis assumptions (AA) with references/basis	Assumption type	Sensitivity (frequency/consequence)	Need to Protect AA	Protection basis
The assumed height of the hose above the waste surface was 15 m based on a nearly empty tank and the maximum soil elevation.	Reasonably conservative assumption	No anticipated effect on consequence bin. Even if the waste surface was assumed to be at the bottom of the tank, yet still contains enough waste to fully react, the consequences would increase less than 10%.	No	N/A
The volume of the acid addition was assumed to be 5,000 gal. Based on the density of sulfuric acid, this exceeds the allowable gross vehicle weight for tanker trucks. (While tanker trucks contain a nominal capacity of as much as 7,000 gal, they are limited by total weight of the filled tanker. Generally, the maximum weight that can be transported is 45,000 lb which is the equivalent weight of 3,000 gal of sulfuric acid. The analysis conservatively assumes the tanker contains significantly more than the full weight capacity of sulfuric acid.)	Reasonably conservative assumption due to weight limitation.	No anticipated effect on consequence bin. Could affect consequence bin if conditions change allowing tanker trucks to transport much larger quantities. If current transportation regulations were changed to make larger shipments credible, the radiological consequences would increase. The allowed quantities would have to be greater than 300,000 gal before the consequence bin would need to be reevaluated. Toxicological consequences would not require reevaluation since they are based on the peak release and not the total release.	No	N/A

Table 5. Qualitative Evaluation of Analysis Assumptions for Representative Accident. (4 sheets)

Analysis assumptions (AA) with references/basis	Assumption type	Sensitivity (frequency/consequence)	Need to Protect AA	Protection basis
Qualitative Evaluation of Analysis Assumptions for Other Represented Conditions.				
It is assumed that there will be no chemical additions to SSTs.	Reasonably conservative assumption.	Could affect consequence bin if additions to SSTs are proposed. If additions are proposed to SSTs, the hazards would have to be identified, analyzed, and appropriate controls applied before additions were permitted.	No	N/A

Notes:

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.

Finfrock, S., 2002, *Contract No. 8249, Release No. 163, Determination of Dispersion Coefficients for NO_2 Release from Tanks*, (Letter report to K. R. Sandgren, CH2M HILL Hanford Group, Inc., January 30), Fluor Federal Services, Richland, Washington.

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

WHC-SD-TWR-RPT-003, 1996, *DELPHI Expert Panel Evaluation of Hanford High Level Waste Tank Failure Modes and Release Quantities*, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

AA = analysis assumptions.
ARF = airborne release fraction.
DST = double-shell tank.
HEPA = high-efficiency particulate air (filter).
N/A = not applicable.
SOF = sum of fractions.
ULD = unit-liter dose.

Table 6. Summary of Onsite Radiological Consequences for the Mixing of Incompatible Materials Without Controls.

Accident	Onsite Radiological Consequences		
	Calculated dose (rem)	Moderate consequence guideline (rem)	High consequence guideline (rem)
Mixing of incompatible materials	4.2×10^{-1}	2.5×10^{1}	1.0×10^{2}

Table 7. Summary of Toxicological Consequences for the Mixing of Incompatible Materials Without Controls.

Case	Toxicological Consequences							
	Onsite				Offsite			
	Moderate consequence		High consequence		Moderate consequence		High consequence	
	SOF	Guideline	SOF	Guideline	SOF	Guideline	SOF	Guideline
Mixing of incompatible materials	2.4×10^{1}	1 (ERPG-1)	6.4×10^{0}	1 (ERPG-2)	1.4×10^{-1}	1 (ERPG-2)	1.1×10^{-1}	1 (ERPG-3)

Notes:
ERPG = emergency response planning guideline.
SOF = sum of fractions.

2.1.3.3 Assignment of Environmental Consequences.

Based on operational experience and the conservative calculations in Appendix B it was concluded that there is potential for material release to either the atmosphere or ground. Therefore, an environmental consequence of E2 was assigned to the mixing of incompatible materials representative accident.

2.1.3.4 Assignment of Risk Bins.

Table 4 summarizes the frequency and risk bin assignments for the mixing of incompatible materials accident scenario without controls. The assignment of risk bins is derived from the consequences and estimated frequency of the accident. The risk bin for the onsite radiological receptor and the offsite toxicological receptor is III because the consequence is "low" and the frequency is "unlikely." The risk bin for the onsite toxicological receptor is I since the consequence is "high" and the frequency is "unlikely."

2.2 MIXING OF INCOMPATIBLE MATERIALS ASSOCIATED HAZARDOUS CONDITIONS

There are more than 40 hazardous conditions represented by the mixing of incompatible materials representative accident. (Note that the specific number of hazardous conditions reported in the hazard evaluation database may increase or decrease in the future based on changes in field configurations or operations.) The results of the risk binning process for these hazardous conditions are shown in the hazard evaluation database under the representative accidents 03 and 23. Included in the hazard evaluation database entries is a basis for each consequence and frequency.

Meeting participants considered process knowledge, operational history, and the conservatisms in the analysis when assigning consequence and frequency bins to the other represented hazardous conditions. The results are summarized in Table 8, and are discussed below.

- Small inadvertent addition. Inadvertent additions from small containers, such as 55-gal drums, was assigned a frequency of "unlikely" for reasons similar to the bounding case. The consequences were judged to be low since the total volume of potentially reactive acid is small and the credible rate of addition was much lower than the bounding case.

- Tank waste mixing with tank waste conditions that result in energetic reactions. Tank waste mixing with tank waste conditions were judged to be "extremely unlikely" because process history and knowledge have shown that mixing different tank wastes does not result in an energetic reaction (Reynolds 2001). Even if a reaction were assumed to occur, it was judged that it would be significantly less than the bounding case of 5,000 gal of concentrated sulfuric acid.

- Incompatible waste transfer from external sources (B Plant, T Plant, 222-S Laboratory, and PFP). Waste transfers from B Plant were judged to be "beyond extremely unlikely" since it is physically disconnected from tank farms. Transfers from PFP, T Plant, and

222-S Laboratory were judged to be "unlikely" due to the physical configuration and inventories of acids contained in the facilities. Even if a transfer was assumed to occur, it was judged to be significantly lower than the consequences of the bounding case of 5,000 gal of concentrated sulfuric acid.

- Toxic gas (ammonia) release during intrusive activity. Toxic gas releases due to intrusive activities were assigned a frequency of anticipated based on the history of tank farms. The consequences were shown to be low in WHC-SD-WM-CN-074.

Table 8. Summary of Final Risk Binning Results for Associated Conditions.

Postulated accident/hazardous conditions	Frequency	Consequences				Risk bin		
		Onsite radiological	Offsite toxicological	Onsite toxicological	Environmental	Onsite radiological	Offsite toxicological	Onsite toxicological
Small inadvertent addition (55-gal drum)	U	L	L	L	E1	III	III	III
Tank waste mixing with tank waste conditions that result in energetic reactions	EU	L	L	L	E1	IV	IV	IV
Incompatible waste transfer from B-Plant	BEU	L	L	M	E1	IV	IV	IV
Incompatible waste transfers from 222-S Laboratory, T Plant, or the PFP	U	L	L	L	E1	III	III	III
Toxic gas release during intrusive activity	A	L	L	L	E0	III	III	III

Notes:

A = anticipated.
BEU = beyond extremely unlikely.
EU = extremely unlikely.
L = low.
M = moderate.
PFP = Plutonium Finishing Plant.
U = unlikely.

3.0 CONTROL SELECTION

After the allocation of risk bins, a group was empanelled to select controls for the represented hazardous conditions. A multidisciplinary group representing organizations both internal and external to the Tank Farm Contractor performed the selection of controls. The list of control decision makers is listed in Appendix C. Controls were considered and selected to prevent or mitigate consequences of the hazards that were identified as requiring controls.

3.1 PROPOSED CONTROLS FOR THE MIXING OF INCOMPATIBLE MATERIALS REPRESENTATIVE ACCIDENT

A summary of the representative accident, as well as a synopsis of the risk binning results, was presented to the control selection team. The group then proposed and discussed numerous potential mitigative and preventative controls for the representative accident. The possible mitigative controls proposed were:

- Waste temperature monitoring
- Headspace gas/vent gas monitoring
- Self-evacuation training
- Limit the chemical addition rate
- HEPA filter efficiency controls activated carbon filtration of ventilation exhaust
- Scrubbing of ventilation gases with water/caustic solution
- Personal protective equipment
- Limited area access.

Possible preventative controls were also considered:

- Perform a pH analysis to ensure compatibility
- Verify procurement/delivery paperwork prior to additions
- Use an evaluated suppliers list including periodic reviews/audits of chemical vendor quality control and assurance programs
- Control volume of additions
- Eliminate the need for liquid chemical additions
- Monitor the tank temperature during additions
- Evaluate waste volume of tank prior to allowing addition.

3.2 SELECTED CONTROL FOR THE MIXING OF INCOMPATIBLE MATERIALS REPRESENTATIVE ACCIDENT

3.2.1 Control Selection

The proposed controls were discussed and evaluated by the group. Control decision criteria are established in:

- Title 10, *Code of Federal Regulations,* Part 830, Subpart B, "Nuclear Safety Management"
- DOE-STD-3009-94
- DOE G 421.1-2, *Implementation Guide for Use in Developing Documented Safety Analyses to Meet Subpart B of 10 CFR 830*
- DOE G 423.1-1, *Implementation Guide for Use in Developing Safety Requirements*
- Klein and Schepens (2003).

The control decision preference can be summarized as follows:

- Preventive controls over mitigative
- Passive controls over active control
- Engineering controls over administrative controls
- Controls with the highest reliability
- Controls closest to the hazard
- Controls with the lowest implementation and maintenance costs.

A consensus was reached based on the judgment of the participants to perform a pH analysis to ensure compatibility. This analysis is a reliable and effective preventive control. It is close to the hazard and can be implemented with minimal operational or budgetary impact. The other controls were eliminated because:

- Monitoring the waste temperature or controlling the volume of the addition were considered unreliable or ineffective as a selected control.
- Monitoring the headspace gas/vent gas or limiting the chemical addition rate are mitigative controls that are considered unreliable.
- HEPA filter efficiency controls are mitigative controls that are only effective for non-bounding conditions as the HEPA filter fails in the analyzed accident.
- Activated carbon filtration of ventilation exhaust or the scrubbing of ventilation gases with water/caustic solution are mitigative controls that would require major plant modifications including additional safety analyses.

- Verification of procurement/delivery paperwork prior to additions and the use of an evaluated suppliers list, including periodic reviews/audits of chemical vendor quality control and assurance programs, were not considered as effective as the selected control.

- Eliminating the need for liquid chemical additions would degrade the safe storage of waste by eliminating the current corrosion control program, and hinder the tank closure effort by eliminating many potential decontamination and decommissioning proposals.

- Evaluating the waste volume of the tank prior to allowing addition was not considered an effective control.

3.2.2 Format of the Selected Control

Once the control was selected, options for how the control would be depicted were evaluated. The possibilities were:

- The control could be documented as a new standalone TSR administrative control (AC).
- The control could be a key element under a TSR AC (i.e., transfer controls).
- The control could be included in the SMPs:
  - Reflected as a bullet point in the SMP AC, specifying the key elements
  - Reflected as a bullet point in the SMP AC, with the details listed in the DSA
  - Listed in the DSA description of the SMP.

After discussion, it was agreed to represent the preventative control as a standalone AC in the TSRs. A standalone AC most strongly links the basis and applicability of the control with the final disposition of the control.

The precise wording of the control was then considered. The key areas of discussion were on the use of "field testing," whether a specific pH should be defined, and whether SSTs, DCRTs, and catch tanks should be included in the applicability. The consensus resulted in Table 9.

Table 9. Summary of Technical Safety Requirement Controls for Mixing of Incompatible Material.

Control	Safety function	Comments
Bulk Chemical Additions • Perform field testing to verify that bulk chemicals shipped in tanker trucks have a pH ≥ 7 before addition to DSTs, DCRTs, and catch tanks.	Prevents inadvertent additions of acids.	—
Safety Management Programs • Training	To decrease the consequences of a mixing of incompatible materials accident	—
Safety Management Programs • Industrial hygiene	To decrease the consequences of a mixing of incompatible materials accident	—
Safety Management Programs • Measuring and test equipment program	Ensures program is maintained to control tank farm measuring and test equipment used to verify parameters to comply with TSRs.	—

Notes:
DST = double-shell tank.
DCRT = double-contained receiver tank.
TSR = technical safety requirement.

It was noted during the evaluation that:

- The AC bases should address the following:
  - The control does not apply to waste transfers; chemical delivery from drums (e.g., 55-gal drums) that connect to tank farm tanks or to waste transfer systems during chemical additions; or to additions of water or inhibited water. Inhibited water includes dilute concentrations of sodium hydroxide and sodium nitrite.
  - DSTs, DCRTs, and catch tanks are the only tank farm facilities where the addition of bulk chemicals from tank trucks is authorized (i.e., within the scope of the DSA). The addition of bulk chemicals to SSTs to support proposed retrieval methods would require additional safety analysis.
  - Clarification of the intent of "field testing." "Field testing" is intended to mean a test by the Tank Farm Contractor after receipt of the shipment but before addition of the chemical.
- The specific method(s) of testing for pH (e.g., litmus paper) will be identified and controlled by a TSR AC program for instrumentation and measuring and test equipment. Any special requirements for the identified testing method(s) will be developed and documented for program implementation.

3.3 CONTROL ALLOCATION

Of the conditions grouped under the mixing of incompatible materials accident scenario, a few conditions were identified as requiring controls due to onsite toxicological consequences of the inadvertent addition of acid. For these cases, the standalone AC was allocated. This new AC requires that the pH of bulk chemical additions be verified before transferring, thereby preventing the accident. Also allocated for these cases was a measuring and test equipment program that stipulates that any required instrumentation is properly calibrated or functionally tested. Defense-in-depth features were also identified for some of the represented conditions and are described in RPP-14821, *Technical Basis Document for Defense-In-Depth Features.*

4.0 REFERENCES

10 CFR 830, "Nuclear Safety Management," *Office of the Federal Register* (FR 1810, Vol. 66, No. 7), January 10, 2001.

DOE G 421.1-2, 2001, *Implementation Guide for Use in Developing Documented Safety Analyses to Meet Subpart B of 10 CFR 830*, U.S. Department of Energy, Washington, D.C.

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Klein, K. A., and R. J. Schepens, 2003, "Replacement of Previous Guidance Provided by RL and ORP" (letter 03-ABD-0047 to E. K. Thomson, Fluor Hanford Inc., and E. S. Aromi, CH2M HILL Hanford Group Inc., February 4), U.S. Department of Energy, and Office of River Protection, Richland, Washington.

Reynolds, D. A., 2001, "Potential for Tank Farm Systems to Give off Toxic Chemicals or Pressurize Due to Chemical Incompatibilities" (internal Memo 7G300-01-MAK-027, to K. R. Sandgren, October 9), CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-5924, 2003, *Radiological Source Terms for Tank Farms Safety Analysis*, Rev. 1, CH2M HILL Hanford Group, Inc., Richland, Washington.

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

RPP-9689, 2003, *Offsite Radiological Consequence Calculation for the Bounding Mixing of Incompatible Materials Accident*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-13121, 2003, *Historical Summary of Occurrences from the Tank Farms Final Safety Analysis Report*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-14286, 2003, *Facility Worker Technical Basis Document*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-14821, 2003, *Technical Basis Document for Defense-In-Depth Features*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-15116, 2003, *Proceedings of the Nuclear Working Group and the Technical Working Group*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

WHC-SD-TWR-RPT-003, 1996, *DELPHI Expert Panel Evaluation of Hanford High Level Waste Tank Failure Modes and Release Quantities*, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-WM-CN-074, 1997, *Chemical Reaction in a DCRT Leading to a Toxic Release*, Rev. 0-A, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A

RISK BINNING MEETING ATTENDEES

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APPENDIX A

RISK BINNING MEETING ATTENDEES

DSA Accident Risk Binning Attendance Sheet

Meeting Subject: Criticality (Rep Acc 01) Incompatible material (Rep Acc 2 & 23) Date 7/17/02

Name	Organization	Phone	Mail Stop
MILTON V. SHULTZ	CHG-NS&L	372-3740	R1-44
* David M. Carson	FFS Sol+VE	372-1719	E1-64
Joseph J. Bevelacqua	ORP	376-8443	H6-60
* Steve Faulk	CHG EP	376-0618	S7-86
Richard Williams	CHG Rad Con	373-2909	S7-75
Robert D Carrell	ORP support	521-6921	H6-60
Kevin Sandgren	CHG - NS&L	372-0374	R1-49
Mark Hasty	CHG-OPS	373-2378	S7-83
Steve Fischer	ORP Support (HEPMC)	373-5107	E1-60
Clifford Thompson	CHG OPS	372-0562	R2-50
Ed Ford	CHG-NS&L	373-1296	R1-44
Robert Sheppard	ORP Support (LMA)	521-2680	—
* Kenny Fowler	CHG-Proc Engr	373-5930	B2-11

* only Criticality

DSA Accident Risk Binning Attendance Sheet

Meeting Subject: Mixing of Encapsulated Material Date 7/18/02

DAY 2

Name	Organization	Phone	Mail Stop
MILTON Y. SHULTZ	CHG-NSRL	372-3240	R1-44
Ed Ford	CHG-NSRL	373-1298	R1-44
CLIFF HAMPTON	CHG OPS	372-0566	R2-50
Phil Miller	CHG ENV	373-1920	R1-57
Joseph Bonneau	ORP	376-4443	H6-60
MARK HASTY	CHG-OPS	373-9378	S7-83
Kevin Schwinkendorf	Fluor Federal Services	376-0960	
Robert Shepard	ORP-Support (CNA)	521-2680	
Steve Eischeid	ORP-Support (HPME)	528-5007	
RYK WILLIAMS	CHG	373-4909	S7-75
BRAD SMITH	CHG-NSRL	376-1907	R1-44
Kevin Sandgren	CHG-NSRL	372-0371	R1-49

APPENDIX B

CONSEQUENCE CALCULATIONS FOR THE MIXING OF INCOMPATIBLE MATERIALS

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APPENDIX B

CONSEQUENCE CALCULATIONS FOR THE MIXING OF INCOMPATIBLE MATERIALS

B1.0 ONSITE RADIOLOGICAL CONSEQUENCES

The accident scenario assumes that a cargo tanker filled with 5,000 gal of concentrated sulfuric acid is emptied into a waste tank instead of the chemical expected (e.g., caustic or nitrite). The rate of addition is conservatively assumed to be 175 gal/min (typical addition rates seen in the field range from 75 to 100 gal/min). The reaction of acid with sodium nitrite in waste solutions produces nitric oxide by disproportionation of the nitrite ion to nitric oxide and nitrate ion according to the following equation:

$$2H^+ + 3NO_2^- \rightarrow 2NO\uparrow + NO_3^- + H_2O\,.$$

Thus, large amounts of nitric oxide gas potentially can be produced from the accidental addition of acid to tank wastes that contain large amounts of nitrite. It is also well known that the nitric oxide will react with oxygen in air to produce nitrogen dioxide. The nitrogen dioxide, in turn, will dissolve in condensed water to form nitric acid and nitric oxide. These reactions proceed as shown in the following equations:

$$2NO + O_2 \rightarrow 2NO_2$$

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO\,.$$

The residual nitric oxide is oxidized with more oxygen to form nitrogen dioxide, and eventually most or all of the nitric oxide is converted to nitrogen dioxide.

$$HNO_3 + NaOH \rightarrow NaNO_3 + H_2O\,.$$

The addition of concentrated sulfuric acid to the tank waste is examined for onsite radiological consequences from the aerosol released with the venting gases below.

B1.1 CONTRIBUTION OF AEROSOLIZED WASTE

The gas generation rate for the reaction is physically limited. The gas generation occurs over two regimes. Gas is generated in the zone of penetration formed by the stream of acid. The stream penetrates the waste to a point where it is then dispersed by the gas generated and the generation regime changes to generation around dispersed droplets of acid. The total gas generated will consist of the gas generated from both regimes.

The maximum gas generation from the penetrating jet was modeled in *Reaction Product Gas Generation Rates Due to Nitric Acid Jets Plunging into Waste Liquid* (Epstein 2001) which is reproduced as Appendix B in RPP-9689, *Offsite Radiological Consequence Calculation for the Bounding Mixing of Incompatible Materials Accident.* Maximum gas generation from the jet can be represented as follows:

$$Q_p = \alpha_{max} Q_j (1+Fr)^{1/3}$$

where:

α_{max} = 0.4 (bounding jet void fraction for the liquid regime [Epstein 2001])
Q_j = 1.10×10^{-2} m^3/s (175 gal/min [flow rate of penetrating stream])
Fr = 4.68×10^2 (Froude Number [see below]).

Therefore

$$Q_p = 3.42 \times 10^{-2} \ m^3/s .$$

Froude Number

$$Fr = [(12) E_0 (1-\alpha_{max}) V_j^2] / [(5) \alpha_{max} g R_0]$$

where:

E_0 = 0.1 (empirical jet entrainment coefficient [Epstein 2001])
g = 9.81 m/s^2 (gravitational acceleration constant)
R_0 = 0.0254 m (jet radius in meters)
V_j = 18.0 m/s (jet velocity in meters per second from 2-in. stream falling 3 m)
$(V_0^2 + 2gL_j)^{1/2}$
V_0 = 5.44 m/s (velocity at hose outlet, flow/area)
L_j = 15 m (assumed height of hose above waste surface).

The contribution from dispersed droplets of sulfuric acid can be represented as follows (Epstein 2001):

$$Q_g = [2 \rho_f g \delta^3 v_j] / [3 \mu_g d^2]$$

where:

ρ_f = 1,840 kg/m^3 (density of 98% sulfuric acid [Weast 1981, *CRC Handbook of Chemistry and Physics*])
g = 9.81 m/s^2 (gravitational acceleration constant)
δ = 1.0×10^{-6} m (minimum film thickness [Epstein 2001])
v_j = 18.9 m^3 (5,000 gal [total volume of acid])
μ_g = 2×10^{-5} kg/ms (viscosity of nitric oxide [Epstein 2001])
d = 0.011 m (droplet diameter of falling drops
= $4 (\sigma / g [\rho_f - \rho_l])^{1/2}$ [Epstein 2001])
σ = 0.055 kg/s^2 (surface tension of sulfuric acid [Weast 1981])
ρ_l = 1,100 kg/m^3 (estimated density of liquid waste).

Therefore

$$Q_g = 9.38 \times 10^{-5} \ m^3/s .$$

Maximum total gas generation

$$Q_t = Q_g + Q_p$$
$$= 3.43 \times 10^{-2}\ m^3/s.$$

The production of gas occurs for 28.6 min (5,000-gal tanker pumping at 175 gal/min), therefore:

$$(3.43 \times 10^{-2}\ m^3/s)\ (28.6\ min)\ (60\ s/min) = 58.9\ m^3\ NO_2\ produced.$$

Since the dispersed droplets produce 1×10^{-6} as much gas as the jet penetration regime, the production of gas essentially stops when the tanker truck is emptied.

The grams of nitrogen dioxide produced at a gas temperature of 80 °C is calculated as follows:

$$[(58.9\ m^3) / (29.0\ m^3/kg\ mole)]\ (46.01\ kg/kg\ mole)\ (1{,}000\ g/kg) = 9.34 \times 10^4\ g$$

where:

29.0 m^3/kg mole = volume of ideal gas at 353 K and 1 atmosphere pressure
= (22.4 m^3/kg mole) (273 + 80)/(273)
46.01 = molecular weight of NO_2.

The source term used for the aerosol is 10% double-shell tank (DST) solids and 90% DST liquids. DST waste is assumed since the bounding unit-liter dose (ULD) is found in DST waste. While the reaction will occur in the liquid phase, agitation will occur in the vicinity of the incoming acid stream. The agitation will cause some fine solids to be suspended in liquid. Solids that are dense or have large particle sizes will not be suspended by the bubbles. As the bubbles rise/collide/consolidate and collapse much of the solids will be released. The inclusion of 10% solids in the aerosol is considered a conservative assumption. An airborne release fraction (ARF) of 2.0×10^{-3} and a respirable fraction of 1.0 are based on those associated with the boiling of aqueous solutions in flowing air from DOE-HDBK-3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*. The radiological source terms for the waste are from RPP-5924, *Radiological Source Terms for Tank Farms Safety Analysis*.

Waste aerosolized is calculated as follows:

$$(9.34 \times 10^4\ g)\ (2 \times 10^{-3}) = 187\ g\ .$$

The aerosol is assumed to consist of 10% solids and 90% liquids.

Converting to liters aerosolized yields

$$(187\ g) / (1{,}200\ g/L) = 1.56 \times 10^{-1}\ L$$

where:

1,200 g/L is the assumed density of the waste (90% liquid and 10% solid).

Given the following ULD equivalents for DST waste:

Onsite ULD for DST liquids = 1.0×10^3 Sv/L (RPP-5924)
Onsite ULD for DST sludge = 1.9×10^5 Sv/L (RPP-5924)

Onsite ULD for aerosol = $[(1.0 \times 10^3 \text{ Sv/L})(0.9)] + [(1.9 \times 10^5 \text{ Sv/L})(0.1)]$
$= 1.99 \times 10^4$ Sv/L.

Onsite aerosol dose is calculated as follows:

Onsite $D_{aerosol}$ = (aerosol released) (χ/Q) (ULD) (breathing rate) (respirable fraction)
$= (1.56 \times 10^{-1} \text{ L})(4.12 \times 10^{-3} \text{ s/m}^3)(1.99 \times 10^4 \text{ Sv/L})(3.3 \times 10^{-4} \text{ m}^3\text{/s})(0.8)$
$= 4.2 \times 10^{-3}$ Sv

where:

3.3×10^{-4} m^3/s = breathing rate (RPP-5924)
4.12×10^{-3} s/m^3 = the onsite χ/Q (Finfrock 2002, *Contract No. 8249, Release No. 163, Determination of Dispersion Coefficients for NO_2 Release from Tanks*) reproduced as Appendix D to this document.

B1.2 OVERALL ONSITE RADIOLOGICAL CONSEQUENCES

The radiological consequences for this case are from the aerosol release when no high-efficiency particulate air (HEPA) filters are present. When the filters are operational there will not be any release of aerosol since the gas generation rate (~ 75 ft^3/min) is insufficient to cause failure of the filter bank.

Total onsite radiological consequences = aerosol contribution

$$\text{Onsite } D_{Total} = (4.2 \times 10^{-3} \text{ Sv}) = 4.2 \times 10^{-1} \text{ rem}.$$

B2.0 TOXICOLOGICAL CONSEQUENCES

The accident scenario assumes that a cargo tanker filled with 5,000 gal of concentrated sulfuric acid is emptied into a waste tank instead of the chemical expected (e.g., caustic or nitrite). The rate of addition is conservatively assumed to be 175 gal/min (typical addition rates seen in the field range from 75 to 100 gal/min). The reaction of acid with sodium nitrite in waste solutions produces nitric oxide by disproportionation of the nitrite ion to nitric oxide and nitrate ion according to the following equation:

$$2H^+ + 3NO_2^- \rightarrow 2NO\uparrow + NO_3^- + H_2O.$$

Thus, large amounts of nitric oxide gas potentially can be produced from the accidental addition of acid to tank wastes that contain large amounts of nitrite. It is also well known that the nitric oxide will react with oxygen in air to produce nitrogen dioxide. The nitrogen dioxide, in turn,

will dissolve in condensed water to form nitric acid and nitric oxide. These reactions proceed as shown in the following equations:

$$2NO + O_2 \rightarrow 2NO_2$$

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO\,.$$

The residual nitric oxide is oxidized with more oxygen to form nitrogen dioxide, and eventually most or all of the nitric oxide is converted to nitrogen dioxide.

$$HNO_3 + NaOH \rightarrow NaNO_3 + H_2O\,.$$

The addition of the acid is through a riser. The acid would contact the inner surface of the riser before falling into the waste. The contact between the acid and steel in the riser could generate very limited amounts of hydrogen gas. Since hydrogen is more than 20,000 times less toxic than nitrogen dioxide gas, the contribution to the consequences from hydrogen will be insignificant. The toxicological consequences for this case consist of contributions from the nitrogen dioxide gases and the aerosolized waste.

B2.1 CONTRIBUTION FROM NITROGEN DIOXIDE

The maximum gas generation rate for the reaction is physically limited. The gas generation occurs over two regimes. Gas is generated in the zone of penetration formed by the stream of nitric acid. The stream penetrates the waste to a point where it is then dispersed by the gas generated and the generation regime changes to generation around dispersed droplets of acid. The total gas generated will consist of the gas generated from both regimes.

The maximum gas generation from the penetrating jet was calculated using methodology from Epstein 2001 (which is reproduced as Appendix B of RPP-9689). Maximum gas generation from the jet can be represented as follows:

$$Q_p = \alpha_{max}\, Q_j\, (1+ Fr)^{1/3}$$

where:

α_{max} = 0.4 (bounding jet void fraction for the liquid regime [Epstein 2001])
Q_j = 1.10×10^{-2} m^3/s (175 gal/min [flow rate of penetrating stream])
Fr = 4.68×10^2 (Froude Number [see below]).

Therefore

$$Q_p = 3.42 \times 10^{-2}\ m^3/s\,.$$

Froude Number

$$Fr = [(12)\, E_0\, (1-\alpha_{max})\, V_j^2] \,/\, [(5)\, \alpha_{max}\, g\, R_0]$$

where:

E_0	=	0.1 (empirical jet entrainment coefficient [Epstein 2001])
g	=	9.81 m/s^2 (gravitational acceleration constant)
R_0	=	0.0254 m (jet radius in meters)
V_j	=	18.0 m/s (jet velocity in meters per second from 2-in. stream falling 3 m) $(V_0^2 + 2gL_j)^{1/2}$
V_0	=	5.44 m/s (velocity at hose outlet, flow/area)
L_j	=	15 m (assumed height of hose above waste surface).

The contribution from dispersed droplets of nitric acid can be represented as follows (Epstein 2001):

$$Q_g = [2\, \rho_f\, g\, \delta^3\, v_j] / [3\, \mu_g\, d^2]$$

where:

ρ_f	=	1,840 kg/m^3 (density of 98% sulfuric acid [Weast 1981])
g	=	9.81 m/s^2 (gravitational acceleration constant)
δ	=	1.0×10^{-6} m (minimum film thickness [Epstein 2001])
v_j	=	18.9 m^3 (5,000 gal [total volume of acid])
μ_g	=	2×10^{-5} kg/ms (viscosity of nitric oxide [Epstein 2001])
d	=	0.011 m (droplet diameter of falling drops
	=	$4\,(\sigma / g\,[\rho_f - \rho_l])^{1/2}$ [Epstein 2001])
σ	=	0.055 kg/s^2 (surface tension of nitric acid [Weast 1981])
ρ_l	=	1,100 kg/m^3 (estimated density of liquid waste).

Therefore

$$Q_g = 9.38 \times 10^{-5}\ m^3/s\,.$$

Maximum total gas generation

$$Q_t = Q_g + Q_p$$
$$= 3.43 \times 10^{-2}\ m^3/s.$$

The production of gas occurs for 28.6 minutes (5,000-gal tanker pumping at 175 gal/min), therefore:

$$(3.43 \times 10^{-2}\ m^3/s)\ (28.6\ min)\ (60\ s/min) = 58.9\ m^3\ NO_2 \text{ produced.}$$

Since the dispersed droplets produce 1×10^{-6} as much gas as the jet penetration regime, the production of gas essentially stops when the tanker truck is emptied.

Converting to grams of nitrogen dioxide produced per second yields

$$[(3.43 \times 10^{-2}\ m^3/s) / (29.0\ m^3/kg\ mole)]\ (46.01\ kg/kg\ mole)\ (1{,}000\ g/kg) = 54.4\ g/s$$

where:

29.0 m^3/kg mole = volume of ideal gas at 353 K and 1 atmosphere
46.01 = molecular weight of NO_2.

It is considered conservative to assume undiluted nitrogen dioxide for the toxicological calculation since the toxicity of nitrogen dioxide is greater than that of the headspace gases.

Accident-specific values were calculated for the atmospheric dispersion (χ/Q) factors (Finfrock 2002). Details on the calculation of the dispersion factors are reproduced in Appendix D of this document. Since both the production of nitrogen dioxide and the dilution of acid with base are exothermic, the reasonably conservative dispersion factor for an 80 °C release from a 10-ft stack was selected.

All values for atmospheric dispersion coefficients in this report were generated using the GXQ computer program, which is documented in WHC-SD-GN-SWD-30002, *GXQ User's Guide.* The GXQ output files are included in Attachment B. All GXQ atmospheric dispersion coefficients are generated using the methods described in NRC Regulatory Guide 1.145, *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants.*

The GXQ program has been verified and benchmarked against the GENII computer code (PNL-6584, *GENII – The Hanford Environmental Radiation Dosimetry Software System*). The program has also been verified to produce atmospheric dispersion coefficients consistent with NRC Regulatory Guide 1.145 methodology. For more detailed information in the models used in GXQ and their applicability, please refer to the GXQ documentation in WHC-SD-GN-SWD-30002 and its references.

It is conservatively assumed that all the gas released is nitrogen dioxide since its toxicity is higher than headspace gases or sulfuric acid fumes.

B2.1.1 Onsite Nitrogen Dioxide Contribution

Onsite moderate consequence sum of fractions (SOF) of NO_2
= (grams per second of NO_2) (onsite χ/Q) / (TEEL-2 of NO_2)

Onsite moderate consequence SOF_{NO2} = (54.4 g/s) (4.12 x 10^{-3} s/m^3) / (0.0094 g/m^3)
= 2.4 x 10^1

where:

4.12 x 10^{-3} s/m^3 = onsite χ/Q (Finfrock 2002)
0.0094 g/m^3 = TEEL-2 of NO_2 (WSMS-SAE-02-0171, *ERPGs and TEELs for Chemicals of Concern*).

Onsite high consequence SOF of NO_2
= (grams per second of NO_2) (onsite χ/Q) / (TEEL-3 of NO_2)

Onsite high consequence SOF_{NO2} = (54.4 g/s) (4.12 x 10^{-3} s/m^3) / (0.035 g/m^3)
= 6.4 x 10^0

where:

4.12 x 10^{-3} s/m^3 = onsite χ/Q (Finfrock 2002)
0.035 g/m^3 = TEEL-3 of NO_2 (WSMS-SAE-02-0171).

B2.1.2 Offsite Nitrogen Dioxide Contribution

Offsite moderate consequence SOF of NO_2
= (grams per second of NO_2) (offsite χ/Q) / (TEEL-1 of NO_2)

Offsite moderate consequence SOF_{NO2} = (54.4 g/s) (1.97 x 10^{-5} s/m^3) / (0.0075 g/m^3)
= 1.4 x 10^{-1}

where:

1.97 x 10^{-5} s/m^3 = offsite χ/Q (Finfrock 2002)
0.0075 g/m^3 = TEEL-1 of NO_2 (WSMS-SAE-02-0171).

Offsite high consequence SOF of NO_2
= (grams per second of NO_2) (offsite χ/Q) / (TEEL-2 of NO_2)

Offsite high consequence SOF_{NO2} = (54.4 g/s) (1.97 x 10^{-5} s/m^3) / (0.0094 g/m^3)
= 1.1 x 10^{-1}

where:

1.97 x 10^{-5} s/m^3 = offsite χ/Q (Finfrock 2002)
0.0094 g/m^3 = TEEL-1 of NO_2 (WSMS-SAE-02-0171).

B2.2 CONTRIBUTION FROM AEROSOLIZED WASTE

The rate of gas generation was shown to be 0.034 m^3/s. The exhaust stacks include HEPA filters, which are not expected to fail at these gas generation rates (~75 ft^3/min). With the HEPA filters in place, any aerosol carried by the gas would be retained on the filter. However, it is possible that the filters might not be in place. The contribution of aerosols is calculated here assuming the filters are not in place.

The source term used for the aerosol is 10% DST solids and 90% DST liquids. DST waste is assumed since the sum of fractions (SOF) are similar to the single-shell tanks and additions are more commonly made to DSTs. While the reaction will occur in the liquid phase, agitation will occur in the vicinity of the incoming acid stream. The agitation will cause some fine solids to be suspended in liquid. Solids that are dense or have large particle sizes will not be suspended by the bubbles. As the bubbles rise/collide/consolidate and collapse much of the solids will be released. The inclusion of 10% solids in the aerosol is considered a conservative assumption. An ARF of 2.0 x 10^{-3} and a respirable fraction of 1.0 are based on those associated with the

boiling of aqueous solutions in flowing air from DOE-HDBK-3010-94. The toxicological source terms for the waste are from RPP-8369, *Chemical Source Terms for Tank Farms Safety Analyses.*

Waste aerosolized is calculated as follows:

$$(54.4\ g/s)\ (2 \times 10^{-3}) = 1.1 \times 10^{-1}\ g/s = 1.1 \times 10^{-4}\ kg/s$$
$$= 9.1 \times 10^{-8}\ m^3/s \text{ if the waste density is assumed to be } 1200\ kg/m^3.$$

The aerosol is assumed to consist of 10% solids and 90% liquids.

B2.2.1 Onsite Aerosol Contribution

Given

Onsite moderate consequence SOF multiplier for DST liquids = 3.45×10^8 (RPP-8369)
Onsite moderate consequence SOF multiplier for DST solids = 7.26×10^8 (RPP-8369)

Onsite SOF multiplier for aerosol = $[(3.45 \times 10^8)\ (0.9)] + [(7.26 \times 10^8)\ (0.1)]$
$= 3.83 \times 10^8$.

Onsite moderate consequence SOF of aerosol

= (aerosol release rate) (onsite SOF multiplier) (onsite χ/Q)

Onsite moderate consequence $SOF_{aerosol} = (9.1 \times 10^{-8}\ m^3/s)\ (3.83 \times 10^8)\ (4.12 \times 10^{-3}\ s/m^3)$
$= 1.4 \times 10^{-1}$

where:

$4.12 \times 10^{-3}\ s/m^3$ = the onsite χ/Q (Finfrock 2002).

Given

Onsite high consequence SOF multiplier for DST liquids = 1.16×10^7 (RPP-8369)
Onsite high consequence SOF multiplier for DST solids = 8.06×10^7 (RPP-8369)

Onsite SOF multiplier for aerosol = $[(1.16 \times 10^7)\ (0.9)] + [(8.06 \times 10^7)\ (0.1)]$
$= 1.85 \times 10^7$.

Onsite high consequence SOF of aerosol

= (aerosol release rate) (onsite SOF multiplier) (onsite χ/Q)

Onsite high consequence $SOF_{aerosol} = (9.1 \times 10^{-8}\ m^3/s)\ (1.85 \times 10^7)\ (4.12 \times 10^{-3}\ s/m^3)$
$= 6.9 \times 10^{-3}$

where:

4.12×10^{-3} s/m^3 = the onsite χ/Q (Finfrock 2002).

B2.2.1 Offsite Aerosol Contribution

Given

Offsite moderate consequence SOF multiplier for DST solids = 1.38×10^9 (RPP-8369)
Offsite moderate consequence SOF multiplier for DST liquids = 2.74×10^9 (RPP-8369)

Offsite SOF multiplier for aerosol = $[(2.74 \times 10^9)(0.9)] + [(1.38 \times 10^9)(0.1)]$
$= 2.60 \times 10^9$.

Offsite moderate consequence SOF of aerosol

= (aerosol release rate) (offsite SOF multiplier) (offsite χ/Q)

Offsite moderate consequence $SOF_{aerosol}$ = $(9.1 \times 10^{-8}$ m^3/s$)(2.60 \times 10^9)(1.97 \times 10^{-5}$ s/m$^3)$
$= 4.7 \times 10^{-3}$

where:

1.97×10^{-5} s/m^3 = the offsite χ/Q (Finfrock 2002).

Given

Offsite high consequence SOF multiplier for DST solids = 7.26×10^8 (RPP-8369)
Offsite high consequence SOF multiplier for DST liquids = 3.45×10^8 (RPP-8369)

Offsite SOF multiplier for aerosol = $[(3.45 \times 10^8)(0.9)] + [(7.26 \times 10^8)(0.1)]$
$= 3.83 \times 10^8$.

Offsite high consequence SOF of aerosol

= (aerosol release rate) (offsite SOF multiplier) (offsite χ/Q)

Offsite high consequence $SOF_{aerosol}$ = $(9.1 \times 10^{-8}$ m^3/s$)(3.83 \times 10^8)(1.97 \times 10^{-5}$ s/m$^3)$
$= 6.9 \times 10^{-4}$

where:

1.97×10^{-5} s/m^3 = the offsite χ/Q (Finfrock 2002).

B2.3 OVERALL TOXICOLOGICAL CONSEQUENCES

Total toxicological consequences = NO_2 contribution + aerosol contribution .

Total onsite moderate consequence SOF $= (2.4 \times 10^{1}) + (1.4 \times 10^{-1}) = 2.4 \times 10^{1}$.
Total onsite high consequence SOF $= (6.4 \times 10^{0}) + (6.9 \times 10^{-3}) = 6.4 \times 10^{0}$.

Total offsite moderate consequence SOF $= (1.4 \times 10^{-1}) + (4.7 \times 10^{-3}) = 1.4 \times 10^{-1}$.
Total offsite high consequence SOF $= (1.1 \times 10^{-1}) + (6.9 \times 10^{-4}) = 1.1 \times 10^{-1}$.

B3.0 RESULTS

Tables B3-1 and B3-2 compare the accident consequences with the risk evaluation guidelines. Reviewing the consequences shows that the mixing of incompatible materials accident is below the onsite radiological guidelines. Offsite toxicological consequences are also below the guidelines. However, the toxicological release exceeds the onsite toxicological guidelines.

Table B3-1. Summary of Onsite Radiological Consequences Without Controls for the Mixing of Incompatible Materials.

Case	Onsite Radiological Consequences		
	Calculated dose (rem)	Moderate consequence guideline (rem)	High consequence guideline (rem)
Mixing of incompatible materials	4.2×10^{-1}	$2.5 \times 10^{+1}$	$1.0 \times 10^{+2}$

Table B3-2. Summary of Toxicological Consequences Without Controls for the Mixing of Incompatible Materials.

Case	Toxicological Consequences							
	Onsite				Offsite			
	Moderate consequence		High consequence		Moderate consequence		High consequence	
	SOF	Guideline	SOF	Guideline	SOF	Guideline	SOF	Guideline
Mixing of incompatible materials	2.4×10^{1}	1	6.4×10^{0}	1	1.4×10^{-1}	1	1.1×10^{-1}	1

Notes:

DST = double-shell tank.
SOF = sum of fractions.

B4.0 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.

Epstein, M., 2001, *Reaction Product Gas Generation Rates Due to Nitric Acid Jets Plunging into Waste Liquid* (Letter report to K. R. Sandgren, CH2M HILL Hanford Group, Inc., December 11), Fauske and Associates, Inc., Burr Ridge, Illinois.

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APPENDIX C

MIXING OF INCOMPATIBLE MATERIALS CONTROL DECISION MEETING ATTENDEES

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APPENDIX C

MIXING OF INCOMPATIBLE MATERIALS CONTROL DECISION MEETING ATTENDEES

MIXING OF INCOMPATIBLE MATERIALS
CONTROL DECISION MEETING ATTENDANCE
SEPTEMBER 16, 2002

Name	Knowledge Area(s) Represented (see below)	Organization	Telephone Number
LAWRENCE T KRIAPS	1,2,3,6,7,9,10	NS&L - CHG	376-1061
Kevin Sandgren	1,2,3,6,9,10	NS&L - CHG	373-0379
JOSEPH BENGHALOUA	1-23	ORG	376-8743
JOHN C GEISBOSH		CHG/ADI	373-0486
CLIFF HAMPTON		CHG OAS	372-0566
Willie Louis Wilker	1234 10	NS&L DSA	373-9045
Jennifer Stewart	1,7,9		
Ed Ford	1,2,3,6,7,9,10	NS&L-CHG	373-1296
MILTON V. Shultz	1,2,3,6,7,9,10	NS&L - CHG	372-3740
Tim Trujillo	1,2,3,4,5,9,10		
Mark Sandman		DNFSB	373-0101
Curt Reichmann	5	SST	6-4796
Brad Smart		CHG NS&L	376 1907

Knowledge Areas:

1 Licensing
2 Safety Analysis
3 Hazard Analysis
4 Engineering
5 Operations
6 Accident Analysis
7 Nuclear Safety
8 Design Authority
9 Technical Safety Requirements
10 Safety Structures, Systems, and Components
11 Emergency Preparedness
12 Radiological Control
13 Regulatory Compliance
14 Environmental Protection
15 Quality Assurance
16 Other - specify
17 Industrial Safety
18 Project Management
19 Industrial Hygiene
20 Maintenance Engineering
21 Reliability Engineering
22 Process Engineering
23 Equipment Engineering

MIXING OF INCOMPATIBLE MATERIALS
CONTROL DECISION MEETING ATTENDANCE
SEPTEMBER 16, 2002

Name	Knowledge Area(s) Represented (see below)	Organization	Telephone Number
Don Quilici	19	EH&S	6-6549
Robin Fogg	19	EH&S	3-0630
BC Wyatt	5	CHG	3-3355
YA White	5	CHG	3-3355
K.D. Fowler	16-Crit Safety, 22	CHG	3-5936
R.D. Carrell	2 3 6 7 9 10	ORP support	947-6421
Tom Black	4	SYS Eng	373-3880

Knowledge Areas:

1 Licensing
2 Safety Analysis
3 Hazard Analysis
4 Engineering
5 Operations
6 Accident Analysis
7 Nuclear Safety
8 Design Authority
9 Technical Safety Requirements
10 Safety Structures, Systems, and Components
11 Emergency Preparedness
12 Radiological Control
13 Regulatory Compliance
14 Environmental Protection
15 Quality Assurance
16 Other - specify
17 Industrial Safety
18 Project Management
19 Industrial Hygiene
20 Maintenance Engineering
21 Reliability Engineering
22 Process Engineering
23 Equipment Engineering

MIXING OF INCOMPATIBLE MATERIALS
CONTROL DECISION MEETING ATTENDANCE
AUGUST 23, 2002

Name	Knowledge Area(s) Represented (see below)	Organization	Telephone Number
LAURENCE J KAMS	2,3,9,10	NS&L	376-KG1
Kevin Sandgren	1,2,3,6,9	NS&L	372-0374
Bobby McDuiel	2,3,5,9	OPS	373-1450
CHUNN MALCOM	5	OPS	373-2525
Johnston, Julie	5	CPO	3-3578
HAMPTON, CLIFFORD	2,3,5,9,13	OPS	2-0566
Bob Carrell	2,6,7,9,10	ORP-support	501-6421
Brad Evans	1-3,6,7,9,10		
MILTON SHULTS	2,3,6,7,9,10	CHG - NS&L	372-3740
Ed Ford	2,3,6,7,9,10	CHG - NS&L	373-1296
Mark Scutmen		DNFSB	373-0101
KENNY FOWLER	4,22,16-Crit Safety	CHG Proc Engr	373-5930
Greg Jones	1,2,3,5,7,9,10	OPS	373-5717

Knowledge Areas:

1 Licensing
2 Safety Analysis
3 Hazard Analysis
4 Engineering
5 Operations
6 Accident Analysis
7 Nuclear Safety
8 Design Authority
9 Technical Safety Requirements
10 Safety Structures, Systems, and Components
11 Emergency Preparedness
12 Radiological Control
13 Regulatory Compliance
14 Environmental Protection
15 Quality Assurance
16 Other - specify
17 Industrial Safety
18 Project Management
19 Industrial Hygiene
20 Maintenance Engineering
21 Reliability Engineering
22 Process Engineering
23 Equipment Engineering

MIXING OF INCOMPATIBLE MATERIALS
CONTROL DECISION MEETING ATTENDANCE
AUGUST 23, 2002

Name	Knowledge Area(s) Represented (see below)	Organization	Telephone Number
Don Quilici	17/19	EH&S	6-6549
TODD Blank	4	DST SYS Eng	3-3880
W.J. Powell	4	Design Eng	373-1072
M.A. Fish	4	Design Eng.	372-3657
J.L. Stewart	1,7,9	NS+L	376-5633
JON SPARKS		QA	372-1749
Craig Carro	1,2,3,6,7 (PARTIAL)		
Eustolio Salmasol	5	EAST TANK FARM	373-3475
Wujielen Walker	1 2 3 4 7 9 10	NS&L	373-1342
Tim Trapuzzano	1,2,3,4,5,7,9,10	NS&L	373-1342
Curt Reichmuth	5	55T OPS	6-4796

Knowledge Areas:

1 Licensing
2 Safety Analysis
3 Hazard Analysis
4 Engineering
5 Operations
6 Accident Analysis
7 Nuclear Safety
8 Design Authority
9 Technical Safety Requirements
10 Safety Structures, Systems, and Components
11 Emergency Preparedness
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APPENDIX D

DETERMINATION OF DISPERSION COEFFICIENTS FOR NO_2 RELEASE FROM TANKS

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APPENDIX D

DETERMINATION OF DISPERSION COEFFICIENTS FOR NO_2 RELEASE FROM TANKS

Fluor Federal Services
1200 Jadwin, PO Box 1050
Richland, WA 99352-1050

509.372.2000 tel
509.372.3000 fax

FLUOR

January 30, 2002

CHG-FMTOA-2001
CO-02-RPP-242

Mr. K. R. Sandgren
CH2M HILL Hanford Group, Inc.
P. O. Box 1500
Richland, Washington 99352-1505

Dear Mr. Sandgren:

CONTRACT NO. 8249, RELEASE NO. 163, DETERMINATION OF DISPERSION COEFFICIENTS FOR NO_2 RELEASE FROM TANKS

Response Requested By: N/A

Responds To: N/A

Please find attached, the peer reviewed deliverable, "Determination of Dispersion Coefficients for NO_2 Release from Tanks." This completes our deliverable for subtask C8249R163-ST-06.

If you have any questions related to this deliverable, please contact Scott Finfrock on 376-4078.

Sincerely,

Mark W. Hoffmann
Project Manager

MWH:rde

Attachment

c: J. G. Paetel, CHG, w/attachment
W. L. Cowley, CHG, w/attachment

Determination of Dispersion Coefficients for NO_2 Release from Tanks

In order to determine the dose consequences from the Incompatible Materials Accident, it is necessary to determine the applicable dispersion coefficients (χ/Q). This letter documents the calculated χ/Q values for the NO_2 release scenario.

The analysis was performed using the GXQ code (Hey, 1995). This code determines the peak values in the 200 Area of the Hanford Site based on historical average wind conditions compiled from 1983 to 1991. These weather conditions, along with the stack dimensions and release velocity make up the primary input values for the code. GXQ also allows consideration of several mitigating factors such as wind variation with height, entrainment, and buoyancy (MACCS buoyant plume model). Note that the buoyancy effect will only be a factor when the release temperature is greater than the ambient temperature. The code determines which of these effects is most significant and takes credit for it (the sum of multiple effects is not considered). The stack downdraft effect was also taken into account.

The NO_2 release scenario is applicable to three different stack sizes (heights and diameters) as listed in Table 1. The release flow rate was set at 1.44×10^{-2} m^3/s (30.5 cfm) for all cases. The temperature of the release gas may vary so three different temperatures were considered (40 °C, 80 °C, and 120 °C). A higher release temperature relative to the ambient temperature results in a greater buoyancy effect and, consequently, a lower χ/Q value. The ambient temperature was conservatively set at 45 °C (113 °F) for all of these cases.

The receptor, for all cases, was assumed to be at least 100 m from the release point and at a height of 2 m. It was also assumed that the stacks were a sufficient distance from buildings or similar structures that might cause turbulence or otherwise alter the wind data used in the model. The necessary distance is not well defined but 100 ft (~30 m) is a reasonable estimate for these cases.

The results of the analysis are shown in Table 1 (onsite) and Table 2 (offsite). These values are for the overall site with a frequency of exceedance of 5%. The onsite results are peak values over a range of distances from the release point (starting at 100 m). The distance from the release point to the peak value point varies from case to case and is not reported here. The offsite results are based on minimum distances from the tank farms to the site boundary in each of the 16 directions. An example output file (for the 10ft stack, 40 °C release temperature case) is included as an attachment.

Table 1. Peak Onsite χ/Q values for various stack sizes and release temperatures.

Stack Height (m)	Stack Diameter (m)	χ/Q for 40 °C release (s/m^3)	χ/Q for 80 °C release (s/m^3)	χ/Q for 120 °C release (s/m^3)
3.0480 (10 ft)	0.1016 (4 in)	1.54E-02	4.12E-03	2.92E-03
3.3528 (11 ft)	0.1524 (6 in)	1.48E-02	4.03E-03	2.84E-03
15.240 (50 ft)	0.4572 (18 in)	4.44E-04	4.26E-04	4.08E-04

Table 2. Overall Offsite χ/Q values for various stack sizes and release temperatures.

Stack Height (m)	Stack Diameter (m)	χ/Q for 40 °C release (s/m^3)	χ/Q for 80 °C release (s/m^3)	χ/Q for 120 °C release (s/m^3)
3.0480 (10 ft)	0.1016 (4 in)	2.00E-05	1.97E-05	1.96E-05
3.3528 (11 ft)	0.1524 (6 in)	1.99E-05	1.97E-05	1.96E-05
15.240 (50 ft)	0.4572 (18 in)	1.49E-05	1.36E-05	1.33E-05

These results are generally applicable to any 200 Area tank, provided that the stacks match the dimensions considered and fall within the range of release temperatures used in the analysis. Variations of +/- 10% in the parameters will not increase the results by more than 10%. It should be noted, however, that some site specific conditions can result in localized increases in the χ/Q values. An example would be a vortex forming behind a building or large tent that pulls higher concentration air down from the plume to the height of the receptor. GXQ does not consider these types of localized effects and so they are not reflected in the results presented here. This analysis also does not consider receptors closer than 100 m. At distances significantly closer than 100 m it might be credible for the receptor (or a building air intake) to be located directly in the plume, which could result in significantly higher χ/Q values.

References

Hey, Brit, 1995, GXQ 4.0 Program Users' Guide, WHC-SD-GN-SWD-30002, Rev 1, Westinghouse Hanford Company.

Attachment 1. Example GXQ Output File

```
Current Input File Name: no2-h10-t40.IN


                    GXQ Version 4.0D
                    February 8, 1999


General Purpose Atmospheric Dispersion Code
Produced by Fluor Daniel Northwest, Inc.

Users Guide documented in WHC-SD-GN-SWD-30002 Rev. 1.
Validation documented in WHC-SD-GN-SWD-30003 Rev. 1.
Code Custodian is: Brit E. Hey
                   Fluor Daniel Northwest, Inc.
                   P.O. Box 1050
                   Richland, WA 99352-1050
                   (509) 376-2921


Run Date = 01/29/02
Run Time = 14:14:20.04


INPUT ECHO:
NO2, 10' stack height, release temp 40 C
c   mode
    1
c
c LOGICAL CHOICES:
c   ifox  inorm icdf  ichk  isite ipop
    T     T     F     F     T     F
c
c X/Q AND WIND SPEED ADJUSTMENT MODELS:
c   ipuff idep  isrc  iwind
    0     0     0     1
c DIFFUSION COEFFICIENT ADJUSTMENT MODELS:
c   iwake ipm   iflow ientr
    0     0     0     1
c EFFECTIVE RELEASE HEIGHT ADJUSTMENT MODELS:
c  (irise igrnd iwash)igrav
    1     0     1     0
c
c PARAMETER INPUT:
c                 reference                       frequency
c   release       anemometer     mixing           to
c   height        height         height           exceed
c   (m)           (m)            (m)              (%)
c   ------------  ------------   ------------     ------------
    3.04800E+00   1.00000E+01    1.00000E+03      5.00000E+00
c
c   initial       initial                                          gravitational
c   plume         plume          release          deposition       settling
c   width         height         duration         velocity         velocity
c   (bldg width)  (bldg hght)
c   (m)           (m)            (hr)             (m/s)            (m/s)
c   ------------  ------------   ------------     ------------     ------------
    0.00000E+00   0.00000E+00    0.00000E+00      0.00000E+00      0.00000E+00
c
c                 initial        initial                           convective
c   ambient       plume          plume            release          heat release
c   temperature   temperature    flow rate        diameter         rate(1)
c   (C)           (C)            (m3/s)           (m)              (w)
c   ------------  ------------   ------------     ------------     ------------
    4.50000E+01   4.00000E+01    1.44000E-02      1.01600E-01      0.00000E+00
c
c   X/Q
```

```
c   scaling        Wind
c   factor         Speed
c   (?)            Exponent
c   ____________   ____________
    1.00000E+00    1.00000E+00
c
c RECEPTOR DEPENDENT DATA (no line limit)
```

MODE:
Site specific X/Q calculated.

LOGICAL CHOICES:
Joint frequency used to calculate X/Q based on frequency of exceedance.
Joint frequency data normalized.
X/Q calculated for overall site.

MODELS SELECTED:
Plume rise air entrainment model selected.
MACCS buoyancy plume rise model based on temperature difference.
Stack downwash model selected.
Default Gaussian plume model selected.
Wind velocity corrected for average plume height.

WARNING/ERROR MESSAGES:

JOINT FREQUENCY DATA:
200 AREA (HMS) - 10 M - Pasquill A - G (1983 - 1991 Average)
Created 8/26/92 KR

NO2, 10' stack height, release temp 40 C

SECTOR	DISTANCE (m)	RECEPT HEIGHT (m)	SECT. FREQ. (%)	POPULATION	TOTAL POPULATION SCALED X/Q (s/m3)	AVERAGE INDIVIDUAL SCALED X/Q (s/m3)	ATM. STAB. CLASS	WIND SPEED (m/s)
ALL	100	2	100.00	1	1.54E-02	1.54E-02	F	0.89
ALL	105	2	100.00	1	1.44E-02	1.44E-02	F	0.89
ALL	110	2	100.00	1	1.36E-02	1.36E-02	F	0.89
ALL	115	2	100.00	1	1.29E-02	1.29E-02	F	0.89
ALL	120	2	100.00	1	1.22E-02	1.22E-02	F	0.89
ALL	125	2	100.00	1	1.16E-02	1.16E-02	F	0.89
ALL	130	2	100.00	1	1.11E-02	1.11E-02	F	0.89
ALL	140	2	100.00	1	1.02E-02	1.02E-02	F	0.89
ALL	150	2	100.00	1	9.34E-03	9.34E-03	F	0.89
ALL	175	2	100.00	1	7.74E-03	7.74E-03	F	0.89
ALL	200	2	100.00	1	6.56E-03	6.56E-03	F	0.89
ALL	250	2	100.00	1	4.93E-03	4.93E-03	F	0.89
ALL	300	2	100.00	1	3.86E-03	3.86E-03	F	0.89
ALL	500	2	100.00	1	1.86E-03	1.86E-03	F	0.89
ALL	700	2	100.00	1	1.11E-03	1.11E-03	F	0.89
ALL	1000	2	100.00	1	6.32E-04	6.32E-04	F	0.89
ALL	19960	2	100.00	1	2.00E-05	2.00E-05	G	2.65

Desk Instruction 2.0, Rev. 1

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed - Memo by Scott Finfrock

Title: Determination of Dispersion Coefficients for NO_2 Release from Tanks

Author: Scott Finfrock

Date: January 29, 2002

Yes	No*	NA		
[ ]	[ ]	[✓]		Referenced analyses appropriate.
[✓]	[ ]	[ ]		Problem completely defined and all potential configurations considered.
[ ]	[ ]	[✓]		Accident scenarios developed in a clear and logical manner.
[✓]	[ ]	[ ]		Necessary assumptions explicitly stated and supported.
[✓]	[ ]	[ ]		Computer codes and data files documented.
[✓]	[ ]	[ ]		Data used in calculations explicitly stated in document.
[✓]	[ ]	[ ]		Data checked for consistency with original source information as applicable.
[ ]	[ ]	[✓]		Mathematical derivations checked including dimensional consistency of results
[✓]	[ ]	[ ]		Models appropriate and used within range of validity, or use outside range of established validity justified.
[✓]	[ ]	[ ]		Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
[✓]	[ ]	[ ]		Software input correct and consistent with document reviewed.
[✓]	[ ]	[ ]		Software output consistent with input and with results reported in document reviewed.
[ ]	[ ]	[✓]		Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
[✓]	[ ]	[ ]		Safety margins consistent with good engineering practices.
[✓]	[ ]	[ ]		Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]		Results and conclusions address all points required in the problem statement.
[✓]	[ ]	[ ]		Format consistent with applicable guides or other standards.
[ ]	[ ]	[✓]	**	Review calculations, comments, and/or notes are attached.
[✓]	[ ]	[ ]		Document approved (for example, the reviewer affirms the technical accuracy of the document).

Paul D. Rittmann Paul Rittmann 1-29-2002

Technical Peer Reviewer (printed name and signature) Date

* All "no" responses must be explained below or on an additional sheet.

** Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. The material should be labeled and recorded in such a manner as to be understandable to a technically qualified third party.

APPENDIX E

PEER REVIEW CHECKLIST

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APPENDIX E

PEER REVIEW CHECKLIST

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: RPP-12646, *Mixing of Incompatible Materials in Waste Tanks Technical Basis Document*, Revision 1.

Scope of Review: Changes made for Revision 1 of the document.

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.
[x]	[ ]	[ ]	28. Referenced documents are spelled out (title and number) the first time they are cited.
[x]	[ ]	[ ]	29. All acronyms are spelled out the first time they are used.
[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.
[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.
[x]	[ ]	[ ]	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".
[x]	[ ]	[ ]	**Concurrence**

Brian D. Olsen B.D. Olsen 7-30-03

Reviewer (Printed Name and Signature) Date

- If No or NA is chosen, provide an explanation on this form.

6, 15, 16, 17 No computer codes or data files have been used. Hence, no software inputs are involved.

24 Draft references will be changed to "released" status prior to issuance of the calculation note.

34 The calculation note does not involve any chemical reactions.

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: RPP-12646, Rev. 1

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.
[X][ ] [ ] 28. Referenced documents are spelled out (title and number) the first time they are cited.
[X][ ] [ ] 29. All acronyms are spelled out the first time they are used.
[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.
[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.
[X][ ] [ ] 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".

Comments: RPP-12646, Rev. 1

Tech. Edit: CJ LYNCH CJ Lynch 7-29-03
Reviewer (Printed Name and Signature) Date

* If No or NA is chosen, an explanation must be provided on this form.

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