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Technical Basis Document for Ventilation System Filtration Failures Leading to Unfiltered Release

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Richland, WA 99352
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Abstract:
Three accident scenarios were analyzed involving failures of HEPA filtration systems leading to releases from liquid waste tanks. The scenarios are failure due to high temperature (fire), overpressure (filter blowout), and unfiltered release due to filter failure, improper installation, etc.

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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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Technical Basis Document for Ventilation System Filtration Failures Leading to an Unfiltered Release

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Fluor Federal Services
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LIST OF TERMS

ALC	airlift circulators
CGM	combustible gas meter
DST	double-shell tank
HEGA	high-efficiency gas absorber
HEME	high-efficiency mist eliminator
HEPA	high-efficiency particulate air (filter)
NDA	non-destructive assay
RMCS	rotary mode core sampler
SOF	sum of fractions
SSC	structures, systems, and components
TEEL	Temporary Emergency Exposure Limit
TSR	technical safety requirement
TWG	Technical Working Group
ULD	unit-liter dose
USOF	unit sum of fractions

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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 and the technical basis for assigning risk bins for the filtration failures leading to unfiltered release 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 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 Safety Analysis Reports*, as described below.

1.2 BACKGROUND INFORMATION

1.2.1 Representative Accidents

Three representative accident scenarios were selected for analysis to comprehensively address the failure mechanisms associated with ventilation system filtration components that could result in an unfiltered release of waste aerosols to the environment.

The first scenario corresponds to high-efficiency particulate air (HEPA) filter damage due to high or over temperature. For example, a fire external to the ventilation duct or a ventilation system heater malfunction might cause this. In this scenario, radiological and toxicological consequences may result from a release to the atmosphere of a portion of the waste material that has collected on the HEPA filters and associated equipment.

The second scenario corresponds to HEPA filter damage due to a high-pressure event. This might be caused, for example, by either a short duration pressure pulse or a longer duration pressure transient occurring within a waste tank. Such a pressure pulse could have several causes, and no specific cause is postulated in this accident scenario. It is assumed, however, that the pressure pulse is not severe enough to be considered an explosion. In this scenario, as for the over temperature scenario, radiological and toxicological consequences may result from a release to the atmosphere of a portion of the waste material that has collected on the HEPA filters and associated equipment.

The third scenario corresponds to the unfiltered release from the ventilation system to the atmosphere of waste aerosol from the tank headspace. Such a release would occur, for example, if a HEPA filter has been substantially damaged as a result of an over temperature or over

pressure event. Such a release could also occur for other reasons, such as failure to reinstall a HEPA filter during maintenance or installation of a filter in a misaligned condition such that a portion of the ventilation flow bypasses the filtration component.

1.2.2 Bounding Offsite Accident

Ventilation system filtration failures leading to unfiltered releases are potentially high energy atmospheric vapor/gas/aerosol release events that are bounded by the flammable gas deflagration accident, which 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 Flammable Gas Deflagrations accident is documented in RPP-13470, *Offsite Radiological Consequence Analysis for the Bounding Flammable Gas Accident*, 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 toxicological, or facility worker exposures). These exposures were evaluated for the ventilation system filtration failures leading to unfiltered releases accident and associated hazardous conditions in accordance with the risk binning process described in Section 1.3.

1.2.3 Associated Hazardous Conditions

The hazardous conditions associated with the three accident scenarios described in Section 1.2.1 are organized under two representative accidents in the hazard evaluation database. The 24 hazardous conditions for the first (over temperature) and second (over pressure) are organized under representative accidents 106C-10J. The 21 hazardous conditions for the third accident scenario (unfiltered release) are organized under representative accident 114SX-04.c.2.a. The exact number of hazardous conditions may change in the future.

1.3 RISK BINNING METHODOLOGY

Direction on risk binning was provided by the U.S. Department of Energy (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-significant SSCs and/or TSR-level controls are required for accidents or hazardous conditions that are assigned to Risk Bins II or I, 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-significant SSCs and TSR-level controls are not expected. Safety management programs 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

Notes:

	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.
SSC = structures, systems, and components.
TEEL = Temporary Emergency Exposure Limit.
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

Notes:

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

ERPG = emergency response planning guideline.
SSC = structures, systems, and components.
TEEL = Temporary Emergency Exposure Limit.
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 August 8, 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 TWG concurred with the final risk bin results, which are shown in Table 4.

Table 4. Summary of Results for Representative Scenarios.

Postulated Accident/ Hazardous Condition	Frequency	Consequences				Risk Bin		
		Onsite radiological	Offsite toxicological	Onsite toxicological	Environmental	Onsite radiological	Offsite toxicological	Onsite toxicological
Release of radioactive and hazardous material from tank ventilation system filters due to over pressure event. The bounding system is AZ-702 (with HEME and HEGA) with ALCs operating. Includes unfiltered release from tank headspaces.	A	L	L	L	E1	III	III	III
Release of radioactive and hazardous material from tank ventilation system filters due to over temperature event. The bounding system is AZ-702 (with HEME and HEGA) with ALCs operating. Includes unfiltered release from tank headspaces.	A	L	L	L	E1	III	III	III
Unfiltered release of radioactive and hazardous material from tank headspace due to failure of filters or seals. The bounding system is a DST with ALCs operating. The onsite and offsite receptors are assumed to be exposed for 8 hr.	A	L	L	L	E1	III	III	III

Notes:
A = anticipated.
ALC = airlift circulator
DST = double-shell tank.
HEGA = high-efficiency gas adsorber
HEME = high-efficiency mist eliminator.
L = low.

2.1 VENTILATION SYSTEM FILTRATION FAILURES LEADING TO UNFILTERED RELEASES - REPRESENTATIVE ACCIDENTS WITHOUT CONTROLS

2.1.1 Scenarios

Three representative accident scenarios were selected for analysis to comprehensively address the failure mechanisms associated with ventilation system filtration components that could result in an unfiltered release of aerosols to the environment.

The first scenario corresponds to HEPA filter damage due to high temperature. This might be caused, for example, by a fire external to the ventilation duct or a ventilation system heater malfunction. In this scenario, radiological and toxicological consequences result from a release to the atmosphere of a portion of the waste material that has collected on the HEPA filters, as well as from the subsequent unfiltered release that occurs from the tank headspace.

The second scenario corresponds to HEPA filter damage due to a high-pressure event. This might be caused, for example, by either a short duration pressure pulse or a longer duration pressure transient occurring within a waste tank or within the ventilation system itself. Such a pressure pulse could have several causes, and no specific cause is postulated in this accident scenario. It is assumed, however, that the pressure pulse is not severe enough to be considered an explosion. In this scenario, as for the over temperature scenario, radiological and toxicological consequences result from a release to the atmosphere of a portion of the waste material that has collected on the HEPA filter, as well as from the subsequent unfiltered release that occurs from the tank headspace.

The third scenario corresponds to the unfiltered release from the ventilation system of waste aerosol from the tank headspace to the atmosphere. Such a release would occur, for example, if a HEPA filter were to be substantially damaged as a result of an over temperature or over pressure event. However, such a release could also occur for other reasons, such as failure to reinstall a HEPA filter during maintenance or installation of a filter in a misaligned condition such that a portion of the ventilation flow bypasses the filtration component. This condition could also be caused by damage to the ductwork from, for example, a seismic event or a crane drop onto the ventilation system. This release is included as part of the releases in the first two scenarios; however, in this third scenario, there are no releases from the filters.

In all three scenarios, the receptors were assumed to be exposed for 8 hr following the start of the release.

2.1.2 Frequency Determination

The three accident scenarios described in Section 2.1.1 were all considered to have a qualitatively derived frequency of "anticipated." The HEPA over temperature accident may occur as a result of a ventilation system heater failure or an external fire. The HEPA over pressure accident is believed to have occurred in the past when a filter became saturated with

moisture and was subsequently damaged when the ventilation fans were turned on. The unfiltered release path could occur from several causes, including human error during filter maintenance. These potential accident initiators were considered consistent with an "anticipated" frequency.

2.1.3 Consequence Determination

The releases that determine the consequences for these accident scenarios are directly dependent on the waste material inventory on the filters, and the concentration of waste suspended as an aerosol in the tank headspace air at the time of the event. The consequences due to the continuous unfiltered release following filtration failure are also determined by the ventilation rate through the tank headspace. Considering these parameters, five cases were selected to obtain a good cross-section of the limiting consequences for these scenarios. These five cases are analyzed in detail in Appendix B.

1. An actively ventilated single-shell tank (SST) system (SX farm) under stagnant conditions
2. A double-shell tank (DST) exhauster system during a waste transfer, but without airlift circulators operating
3. A DST exhauster system during a waste transfer and with airlift circulators operating in one of the tanks
4. An SST with the rotary mode core sampler (RMCS) operating
5. An aging waste facility exhauster system (AZ-702) during a waste transfer and with airlift circulators operating in one of the tanks.

The methodology used for the estimation of radiological and toxicological consequences to the onsite and offsite receptors is detailed in RPP-13482, *Atmospheric Dispersion Coefficients and Radiological/Toxicological Exposure Methodology for Use in Tank Farms*. The analysis assumptions and sensitivities are described in Table 5.

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

Analysis assumptions (AA) with references/basis	Assumption type	Sensitivity (frequency/consequence)	Need to Protect AA	Protection/~~evaluation~~ basis
Filter loadings are based on a radiation level of 200 mrem/h at the survey point for HEPA filters. Prefilters are assumed to be loaded with 10% of the maximum waste on the first-stage HEPA filter. The HEME load (AZ-702 system only) is based on a reading of 800 mrem/h contact reading at the top of the filter tank. The HEGA load (AZ-702 system only) is based on a reading of 2 mrem/h contact reading at the side of the filter enclosure.	Filter loadings are reasonably conservative assumptions based on the current design and operation of the filters. Filters are typically replaced when survey readings approach 100 mrem/h because of ALARA considerations.	The doses due to filter releases are, in most cases, a small fraction of the doses due to subsequent releases from the tank headspace through the failed filters. The conclusions of the analysis are, therefore, insensitive to the assumed filter loadings.	No	NA
All the filters in all filter trains in a system (including both first and second stage HEPA filters) are assumed to have a high waste loading, and are assumed to be involved in a filter failure accident. No credit is taken for the firewall separating the filter trains in the AZ-702 system.	This is a bounding assumption based on the current design and operation of the filters. Second stage HEPA filters are not normally subject to a significant amount of loading. In addition, only one filter train is normally operated at a time with the other filter train valved off.	The doses due to filter releases are, in most cases, a small fraction of the doses due to subsequent releases from the tank headspace through the failed filters. The conclusions of the analysis are, therefore, insensitive to the assumed filter loadings and the number of filter trains involved.	No	NA

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

Analysis assumptions (AA) with references/basis	Assumption type	Sensitivity (frequency/consequence)	Need to Protect AA	Protection/~~evaluation~~ basis
Release fractions from HEPA filters failed by over pressure or over temperature events are 2E-6 and 1E-4, respectively, as recommended in DOE-HDBK-3010-94. The same release fractions are assumed for the HEME and for the HEGA for the over pressure event. The HEGAs are assumed to burn in the over temperature event with a release fraction of 1.0.	The HEPA filter release fractions are recommended bounding values based on the data analyzed in DOE-HDBK-3010-94.	The doses due to filter releases are, in most cases, a small fraction of the doses due to subsequent releases from the tank headspace through the failed filters. The conclusions of the analysis are, therefore, insensitive to the assumed release fractions from the filters.	No	NA
The ULDs and USOFs are the maximum reported values for each tank type and waste type (solid or liquid) as tabulated in RPP-5924 and RPP-8369, respectively.	These are bounding values based on the maximum values found for each tank and waste type.	Radiological and toxicological consequences are directly proportional to the ULDs and USOFs, respectively.	No	NA
The waste on the filters and suspended in the tank headspace for DSTs with ALCs operating is assumed to be 5% solids.	Reasonably conservative based on engineering judgment.	Since solid waste ULDs are much greater than liquid ULDs, the rad doses are approximately proportional to the assumed solids fraction. The toxicological consequences are much less sensitive to changes in solids fraction.	No	NA
The headspace partition fraction for DSTs with ALCs in operation is assumed to be 2E-8.	This is a bounding assumption based on actual operating data from DSTs with ALCs operating (RHO-RE-SA-216P).	Both the radiological and toxicological consequences are approximately proportional to the assumed partition fraction. The assumed value of 2E-8 is a factor of 10 higher than that for DSTs without ALCs.	No	

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

Analysis assumptions (AA) with references/basis	Assumption type	Sensitivity (frequency/consequence)	Need to Protect AA	Protection/~~evaluation~~ basis
The DST systems are assumed to have a nominal ventilation flow rate of 1000 ft^3/min. At least four tanks are serviced by each system where ALCs could be operating. One tank in the system is assumed to have ALCs operating with a flow rate of 500 ft^3/min as a conservative maximum to allow for flow imbalances.	Reasonably conservative based on system operating experience.	Both the radiological and toxicological consequences are approximately proportional to the assumed ventilation rate. Sensitivity studies (Appendix E) indicate that ventilation rates could be increased by nearly a factor of 10 and still be within the low consequence bin.	No	NA
The atmospheric dispersion coefficients (χ/Q's) for the releases from the high pressure and high temperature filter failures are standard acute release 1-hour values from RPP-13482. 8-hour χ/Q's are assumed for the unfiltered releases from the tank headspace. These are also from RPP-13482.	These are bounding χ/Q's based on 95th percentile results over all sectors. Ground-level point releases are assumed with no credit for exhaust flow rates.	Both the radiological and toxicological consequences are directly proportional to the assumed χ/Q's.	No	NA
For purposes of estimating toxicological release rates, the filter releases from the over pressure event are assumed to be complete in less than 1 min.	Bounding assumption based on a 1-min minimum release time.	Toxicological consequences of the filter releases are inversely proportional to the assumed release time.	No	NA
For purposes of estimating toxicological release rates, the filter releases from the over temperature event are assumed to occur over a period of 15 min.	Reasonably conservative assumption based on expected time for filters to burn inside enclosure.	Toxicological consequences of the filter releases are inversely proportional to the assumed release time.	No	NA

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

Analysis assumptions (AA) with references/basis	Assumption type	Sensitivity (frequency/consequence)	Need to Protect AA	Protection/~~evaluation~~ basis

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.

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.

RHO-RE-SA-216P, 1987, Characterization of Airborne Radionuclide Particulates in Ventilated Liquid Waste Tanks, Rockwell Hanford Operations, Richland, Washington.

AA = analysis assumptions.
ALARA = as low as reasonably achievable.
ALC = airlift circulator
DST = double-shell tank.
HEGA =
HEME = high efficiency mist eliminator.
HEPA = high-efficiency particulate air (filter).
NA = not applicable.
ULD = unit-liter dose.
USOF = unit sum of fractions.

The maximum consequences for any of the five limiting systems shown in each of the three scenarios are summarized in Table 6. Each of the first two scenarios (high temperature and high pressure filter failure) includes the third scenario (unfiltered release). It should be noted that, for any given system, the radiological consequences associated with the continuous unfiltered release component of the high temperature and high pressure failure scenarios were found to dominate the total consequences such that the results are relatively insensitive to the assumptions related to the filter releases.

Table 6. Maximum Consequences of Ventilation System Failure Accidents.

Scenario	Exposure type	Onsite receptor	Offsite receptor
High Temperature Filter Failure (including unfiltered release)	Radiological Dose (rem)	5.0E-1	*
	Toxicological SOF	3.0E-1	1.5E-3
High Pressure Filter Failure (including unfiltered release)	Radiological Dose (rem)	2.9E-1	*
	Toxicological SOF	8.9E-2	3.6E-4
Continuous Unfiltered Release (no filter failure)	Radiological Dose (rem)	2.9E-1	*
	Toxicological SOF	6.2E-2	3.1E-4

Notes:

* Offsite radiological consequences are bounded by the flammable gas detonation in a single-shell tank as documented in RPP-13470, *Offsite Radiological Consequence Analysis for the Bounding Flammable Gas Accident.*

SOF = sum of fractions.

A series of sensitivity cases were also performed to test the effects of changes in assumptions related to the accident parameters. These sensitivity cases are described in detail in Appendix E and are summarized here. In the first sensitivity case, all ventilation rates were doubled. This would have the effect of doubling the continuous unfiltered release rate in all three scenarios. All consequences remained well below the upper limit for the low consequence bin. In the second sensitivity case, the injection rate of material into the headspace by the airlift circulators was greatly increased so as to increase the partition fraction by a factor of 5 and to double the solids fraction in the headspace aerosol.

All consequences remained within the "low" consequence bin. In the third sensitivity case, the waste loadings on all the filters were increased by a factor of 10. In many cases, this would exceed the physical capacity of the filter without plugging. Even in this extreme case, all the radiological consequences remained well within the low consequence bin. The active SST and AZ-702 systems exceeded the Temporary Emergency Exposure Limit (TEEL)-2 toxicological guideline at the onsite receptor. The results indicate that the filter loadings could be increased by at least a factor of 2.5 without exceeding the toxicological guidelines for the low consequence bin. Finally, in the fourth sensitivity case, the duration of the continuous unfiltered release (Scenario 3) was extended to 1 yr. This assumes that the airlift circulators are running for the entire time and that the release is not detected. All consequences remained within the low consequence bin.

2.1.3.1 Assignment of Consequence Bins for the Onsite and Offsite Receptors

The offsite toxicological and onsite radiological and toxicological consequence bins previously assigned by the risk binning team meeting were confirmed using the foregoing analysis, which applied a combination of conservative assumptions to calculate radiological and toxicological consequences. The calculated consequences shown in Table 6 are low when compared to the guidelines for anticipated accidents shown in Tables 1 and 2. Therefore, a consequence bin of "low" was assigned to the onsite radiological and the onsite and offsite toxicological exposures.

2.1.3.2 Assignment of Environmental Consequences

Based on the conservative calculations reported here, it was concluded that there is limited potential for material release to either the atmosphere or ground. Therefore, an environmental consequence of E1 was assigned to the ventilation system filtration failure representative accidents.

2.1.3.3 Assignment of Risk Bins

As discussed previously, the frequency of the ventilation system filtration failure was considered to be in the "anticipated" range and the offsite toxicological and onsite radiological and toxicological consequences were all assigned a consequence bin of "low." Therefore, each exposure category for all three of the ventilation system filtration failure representative accident scenarios was assigned to Risk Bin III.

2.2 VENTILATION SYSTEM FILTRATION FAILURES LEADING TO UNFILTERED RELEASES - ASSOCIATED HAZARDOUS CONDITIONS

There are about six additional hazardous conditions represented by the HEPA filter failure representative accident. (Note that the specific number of hazardous conditions may change based on changes in field configurations or operations.) Rather than being caused by high temperature or high pressure conditions within the ventilation system, these additional hazards involve crushing of the filters within the duct work due to some external force such as a seismic event or crane drop. Consensus was reached that all these represented hazardous conditions were bounded by the HEPA Filter Failure representative accidents. The results of the risk binning process for these hazardous conditions are shown in the hazard evaluation database under representative accident 6, HEPA Filter Failure – Exposure to High Temperature or Pressure. Included in these hazard evaluation data base entries is a basis for each consequence and frequency.

There are about 61 additional hazardous conditions represented by the unfiltered release representative accident. (Note that the specific number of hazardous conditions may change based on changes in field configurations or operations.) Rather than being caused by a failure of filtration function within the ventilation system, these additional hazards involve failure of an inlet filter, or other opening in the containment boundary, coupled with a flow reversal caused by high winds, tank pressurization, or loss of flow through the exhaust system. Several of the

additional hazards involve evaporation from material leaked from a tank or dry releases of contamination associated with access activities. Consensus was reached that all these represented hazardous conditions were bounded by the Unfiltered Release representative accident. The results of the risk binning process for these hazardous conditions are shown in the hazard evaluation database under representative accident 18B, Unfiltered Release. Included in these hazard evaluation data base entries is a basis for each consequence and frequency.

3.0 CONTROL SELECTION

The representative accidents and associated hazardous conditions are assigned to Risk Bin III for all receptors. Therefore, safety SSCs and/or TSR-level controls are not required for the ventilation system filtration failure accidents and associated hazardous conditions. However, defense-in-depth features were identified for the ventilation system filtration failure accidents and associated represented hazardous conditions as described in RPP-14821, *Technical Basis Document for Defense-In-Depth Features*. No safety SSCs or TSR-level controls were selected within the defense-in-depth features identified for the ventilation system filtration failure accidents and associated represented hazardous conditions. Facility worker hazardous conditions, including those associated with the ventilation system filtration failure representative accidents, were evaluated for controls as documented in RPP-14286, *Facility Worker Technical Basis Document*.

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4.0 REFERENCES

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RPP-13470, 2003, *Offsite Radiological Consequence Analysis for the Bounding Flammable Gas Accident*, Rev. 0, CH2M HILL Hanford Company Group, Inc., Richland, Washington.

RPP-13482, 2003, *Atmospheric Dispersion Coefficients and Radiological/Toxicological Exposure Methodology for Use in Tank Farms*, 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.

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APPENDIX A

RISK BINNING MEETING ATTENDEES

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APPENDIX A

RISK BINNING MEETING ATTENDEES

DSA Accident Rebin Team Meeting Attendance

Accident Title: HEPA

Date 8 AUG 2002

Name	Organization	Phone	Mail Stop
Ed Ford	CHG NS&L	373-1296	R1-44
Joseph Benelacqua	ORP	376-8443	H6-60
Bruce Zimmerman	CHG NS&L	376-7440	R1-39
Geoffrey Gellhaus	ORP-Support	539-1922	—
Cliff Hampton	CHG OPS	372-0566	R2-?
Laurance T. Krupa	CHG NSC	376-1061	
Bob Gustavson	CHG-Engineering	373-5090	R3-83
Bob Carrell	ORP Support	521-6421	R6-60
Milton V. Shultz	CHG-NS&L	372-3740	R1-44
Mark D. Hasty	CHG-NucOps	373-9378	S7-83

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APPENDIX B

CONSEQUENCE CALCULATIONS

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APPENDIX B

CONSEQUENCE CALCULATIONS

The methodology for estimating of radiological and toxicological consequences to the onsite and offsite receptors is developed in detail in RPP-13482, *Atmospheric Dispersion Coefficients and Radiological/Toxicological Exposure Methodology for Use in Tank Farms* (2003). Portions of RPP-13482 that are directly applicable to the accidents analyzed here are summarized here. Only toxicological consequences are calculated for the offsite receptor because the offsite radiological consequences for the filtration failure scenarios are bounded by a flammable gas detonation in a single-shell tank (SST) as documented in RPP-13470, *Offsite Radiological Consequence Analysis for the Bounding Flammable Gas Accident.*

Input Parameters. The releases that determine the consequences for these accident scenarios are directly dependent on the waste material inventory on the filters and the concentration of waste suspended as an aerosol in the tank headspace air at the time of the event. The consequences due to the continuous unfiltered release following filtration failure are also determined by the ventilation rate through the tank headspace. Considering these parameters, five cases were selected to obtain a good cross-section of the limiting consequences for these scenarios. These five cases were analyzed in detail:

1. An actively ventilated SST (SX farm) under stagnant conditions
2. A double-shell tank (DST) exhauster system during a waste transfer, but without airlift circulators operating
3. A DST exhauster system during a waste transfer and with airlift circulators operating in one of the tanks
4. A n SST with the rotary mode core sampler (RMCS) operating
5. An aging waste facility exhauster system (AZ-702) during a waste transfer and with airlift circulators operating in one of the tanks

Conservative filter loadings were determined from the results of a series of shielding calculations that estimated the dose rate at the filter survey point per liter of waste on the filter. These calculations are shown in detail in Appendix C. The SST with RMCS operating is treated as a special case and parameters for this system are developed in Appendix D. The development of the corresponding filter loadings is shown in Table B-1.

Table B-1. Development of HEPA Filter Loadings for Limiting Tank Farms Facilities.

System	HEPA Filter Geometry	Loading per Unit Dose Rate (L per mrem/h)	Filter Loading at 200 mrem/h (L)
Active SST (SX farm)	3 x 3 array of 2 ft x 2 ft x 1 ft	SST Solids 1.25E-2	2.5E+0 100% solids
DST without ALCs	2 ft x 2 ft x 1 ft	DST Solids 9.41E-4 Liquids 1.29E-3	2.6E-1 0% solids
DST with ALCs Operating			2.6E-1 5% solids
SST with RMCS operating	1 ft x 1 ft x 4 in.	SST Solids 1.16E-3	2.3E-1 100% solids
AWF (AZ-702) with ALCs operating	2 ft x 2 ft x 1 ft	DST Solids 9.41E-4 Liquids 1.29E-3	2.6E-1 5% solids

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
HEPA = high-efficiency particulate air (filter).
RMCS = rotary mode core sampler
SST = single-shell tank.

In addition to the HEPA filters, the AZ-702 system contains additional filtration components high-efficiency mist eliminators [HEME] and high-efficiency gas adsorber [HEGA]) which are also assumed to be subject to releases during the high temperature and high pressure accidents. The HEME load is assumed to be 12.7 L based on a conversion of 1.59E-2 L/(mrem/h) calculated in Appendix C and a contact dose rate of 800 mrem/h at the top of the HEME tank. The HEGA load is assumed to be 7.80E-3 L based on a contact dose rate of 2 mrem/h on the duct at the filter location (HNF-SD-WM-CN-099, *Radiological and Toxicological Analyses of Tank 241-AY-102 and Tank 241-C-106 Ventilation Systems*).

The continuous unfiltered release from the tank headspace after the filtration failure is determined by the assumed ventilation flow rate and the partition fraction of the headspace aerosols. The active SST ventilation system in the SX tank farm is assumed to operate at its design capacity of 6,100 ft^3/min. (Actual average ventilation flow is typically 3,100 to 3,200 ft^3/min.) The double-shell tank system is assumed to be operating at 1,000 ft^3/min. A DST system with airlift circulators (ALC); however, services at least four tanks. (SY Farm has three tanks on a system, but no operational ALCs.) In the case where ALCs are operating, half of the flow, or 500 ft^3/min, is conservatively assumed to be passing through the tank with the ALCs to allow for any flow imbalance. The rest of the flow is assumed to be passing through tanks with no ALCs operating. The portable ventilation system servicing the SST with the RMCS operating is assumed to be operating at 500 ft^3/min. This is equal to twice the high flow rate cutoff on the RMCS system (see Appendix D). The AZ-702 system is treated in the same way as the DST system with ALCs operating with respect to unfiltered releases.

Partition fraction estimates for all cases except the RMCS system were derived from data in RHO-RE-SA-216P, *Characterization of Airborne Radionuclide Particulates in Ventilated Liquid Waste Tanks*. The partition fraction in this analysis is the concentration of tank waste suspended as an aerosol in the air of the headspace (L of waste per L of air) per unit concentration of the

material in the waste (1 L/L in this case). Partition fractions were measured based on ^{137}Cs activities in the waste and in the tank headspace for tanks with ALCs operating, during waste transfer operations (waste being pumped into tank), and under stagnant conditions.

The average measured partition fraction with ALCs operating was 1.8E-9 with the highest value being 2.49E-9. Because of the scarcity of the available data, the average value was multiplied by 10 to produce the value of 2E-8 assumed in this analysis for tanks with ALCs operating. Similarly for tanks where no ALCs are operating, but waste is being received during a waste transfer, the average measured partition fraction was 1.6E-10 with the highest value being 5.25E-10 leading to the assumed reasonably conservative value of 2E-9 for tanks with no ALCs operating. Under stagnant conditions the average partition fraction was 1.4E-11 with highest measured value being 6.9E-11. Based on these results, a partition fraction of 1E-10 was assumed as a reasonably conservative value for stagnant conditions.

Actual measurements of solid waste aerosol concentrations in a SST headspace during RMCS operations yielded a reasonably conservative partition fraction of 3.6E-10 (see Appendix D). For conservatism in this analysis, this value was rounded up to 1E-9.

The system flow rates and partition fractions assumed for this analysis are summarized in Table B-2.

Table B-2. Summary of System Flow Rates and Partition Fractions

System	System flow rate		Partition fraction
	ft^3/min	L/s	
Active SST (SX farm)	6,100	2.9E+3	1.0E-10
DST without ALCs	1,000	4.7E+2	2.0E-9
DST with ALCs Operating	1,000	4.7E+2	2.0E-8*
SST with RMCS operating	500	2.4E+2	1.0E-9
AWF (AZ-702) with ALCs operating	1,000	4.7E+2	2.0E-8*

Notes:

* This partition fraction is applied to the assumed flow of 500 ft^3/min through one of the tanks on the system. The balance of the system flow is assumed to be through tanks with no ALCs operating.

ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler
SST = single-shell tank.

Radiological Doses. The form of the inhalation radiological dose formula applicable to tank farms is given by Equation B-1:

$$D = Q\left(\frac{\chi}{Q'}\right)(BR)(ULD) \qquad \text{(B-1)}$$

where:

D = inhalation dose to receptor (Sv)
Q = volume of tank waste released as respirable aerosol (L)
χ/Q' = atmospheric dispersion coefficient (s/m^3)
BR = Breathing rate (m^3/s)
ULD = unit-liter dose defined as the dose per liter of waste inhaled as aerosol (Sv/L).

The total consequences in these scenarios are composed of two components, which must be treated separately: (1) any releases from the inventory on the filters themselves and (2) the subsequent continuous unfiltered release from the tank headspace (or other volume serviced by the system). The maximum receptor exposure time is specified to be 8 hr in DOE-STD-3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses,* Appendix A, so Q is the release during the first 8 hr following start of the release event. The 1-hr χ/Q' is used to calculate the filter release component of the dose since such releases are expected to be complete in less than 1 hr. The continuous unfiltered release component is the release rate from the tank headspace integrated over 8 hr. The 8-hr χ/Q' is therefore used to calculate the dose due to the continuous unfiltered release. Both the 1-hr and 8-hr χ/Q's applicable to this analysis are given in RPP-13482, Tables 2-4 and 2-5 in RPP-13482 and are repeated in here Table B-3. Note that no credit was taken for any plume elevation due to a stack or upward momentum effects or for any initial dilution due to source volume rate effects. These χ/Q's are for ground-level, point-source releases.

Table B-3. 95th Percentile Dispersion Coefficients for 200 Area Tank Farms Facilities.

Receptor	1-hr χ/Q' (s/m^3)	8-hr χ/Q' (s/m^3)
Onsite (100 m)	3.28E-2	5.58E-3
Offsite (MOI)	2.22E-5	not used

Note:
MOI = maximum offsite individual.

The breathing rate assumed here for all receptors is the light activity rate of 3.33E-4 m^3/s from ICRP-66, *Human Respiratory Tract Model for Radiological Protection.*

The unit-liter dose (ULD) includes the effects of all the radionuclides in a particular mix and so must be specific to each type of waste. The ULDs for tank wastes are developed in RPP-5924, *Radiological Source Terms for Tank Farms Safety Analysis.* The numbers used here are shown in Table B-4 and are the maximums for each waste type.

Table B-4. Unit-Liter Doses for Tank Farms Waste (Sv/L).

Receptor	Waste type	Single-shell tank	Double-shell tank
Onsite	Solids	1.4E+5	1.9E+5
	Liquids	4.5E+2	1.0E+3

The total system filter loadings that determine the filter releases in the first two scenarios are determined from the individual filter loads developed in Table B-1 (plus the HEME and HEGA loads in the AZ-702 system). Except for the SST with RMCS, each system is assumed to have at risk 4 HEPA filters (two trains with two filters per train) and two prefilters (one for each train). In addition to these, the AZ-702 system is assumed to have at risk two HEMEs and two HEGAs (with no credit for the firewall between the filter trains). The special exhauster for the SST with RMCS has only one train and so contains only two HEPA filters and one prefilter. The prefilters are each assumed to be loaded to 10% of the load on one HEPA filter. In addition each system is assumed to have an amount of waste accumulated inside the ductwork equal to the load on one HEPA filter. The total system loads in each system are shown in Table B-5. Note that the composition of the waste in the systems with ALCs operating is conservatively assumed to have the solids fraction associated with ALC operation, even though only part of the air flow would be coming from that tank.

Table B-5. Total Material at Risk on System Filters and Ductwork.

System	Waste type	Solids fraction	Total system load (L)	
Active SST (SX farm)	SST	1	4 HEPA filters, 2 prefilters, and Duct	1.3E+1
DST without ALCs	DST	0		1.3E+0
DST with ALCs Operating	DST	0.05		1.3E+0
SST with RMCS operating	SST	1	2 HEPA filters, 1 prefilter, and Duct	7.2E-1
AWF (AZ-702) with ALCs operating	DST	0.05	4 HEPA filters, 2 prefilters, and Duct	1.3E+0
			2 HEMEs	2.5E+1
			2 HEGAs	1.6E-2

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
HEGA = high-efficiency gas adsorber.
HEME = high-efficiency mist eliminator.
HEPA = high-efficiency particulate air (filter).
RMCS = rotary mode core sampler
SST = single-shell tank.

For the high temperature failure the release fraction from the HEPA filters was assumed to be 1.0E-4 as recommended in DOE-HDBK-3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, Section 5.4.1. Although the HEMEs in the AZ-702 system are not constructed of flammable material and are probably not subject to high temperature releases in this kind of situation, for conservatism these components are assumed to exhibit the same release fraction as the HEPA filters, as is the material deposited within the duct work. The HEGAs, however, are composed of activated charcoal, which could burn up completely releasing 100% of their contents. A release fraction of 1.0 is therefore assumed for the HEGAs in the high temperature accident.

For the high pressure filtration failure scenario, a release fraction of 2.0E-6 was assumed for the HEPA filters as recommended in DOE-HDBK-3010-94, Section 5.4.2.1. This same release fraction was also assumed to apply to the material deposited in the duct work and the HEMEs and the HEGAs in the AZ-702 system. The resulting filtration system releases from the total system loads shown in Table B-5 for the high temperature and high pressure filtration failure accidents are shown in Table B-6. The highest releases are for the active SST (due to the large filters on this system) and the AZ-702 system in the high temperature scenario (due to the 100% release from the HEGAs).

Table B-6. Filtration System Releases in the High Temperature and High Pressure Scenarios.

System	Releases From Filtration Components and Duct (L)	
	High temperature scenario	**High pressure scenario**
Active SST (SX farm)	1.3E-3	2.6E-5
DST without ALCs	1.3E-4	2.7E-6
DST with ALCs Operating	1.3E-4	2.7E-6
SST with RMCS operating	7.2E-5	1.4E-6
AWF (AZ-702) with ALCs operating	1.8E-2	5.4E-5

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler
SST = single-shell tank.

The unfiltered releases from the tank headspace following the filtration failure are the same for all three scenarios. Since the concentration of the waste in the tank is 1 L/L, the partition fraction in this case is just equal to the headspace aerosol concentration in L of waste per L of air. The release rate is then equal to the system exhaust rate (L/s) times the partition fraction (L/L). Both parameters are shown in Table B-2. Note that in the cases where ALCs are operating, the flow must be divided between the tank with ALCs and the tanks without ALCs and the appropriate partition fraction applied to each as noted in Table B-2. The resulting system

unfiltered release rates along with the integrated releases over the 8-hr receptor exposure time are shown in Table B-7.

Table B-7. Unfiltered Release Rates and 8-Hr Releases After Filtration Failure.

System	Release rate (L/s)	8-Hr release (L)
Active SST (SX farm)	2.9E-7	8.3E-3
DST without ALCs	9.4E-7	2.7E-2
DST with ALCs Operating	5.2E-6	1.5E-1
SST with RMCS operating	2.4E-7	6.8E-3
AWF (AZ-702) with ALCs operating	5.2E-6	1.5E-1

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler
SST = single-shell tank.

The total releases during the 8-hr exposure period, i.e., the sum of the filtration system releases shown in Table B-6 and the 8-hr continuous releases shown in Table B-7 are shown in Table B-8. Note that in every case the unfiltered continuous release from the tank headspace is by far the dominant contributor to the total release.

Table B-8. Total Radiological Releases for the Three Accident Scenarios.

System	Total Release, Q (L)		
	High temperature Scenario	High pressure Scenario	Unfiltered release scenario
Active SST (SX farm)	9.6E-3	8.3E-3	8.3E-3
DST without ALCs	2.7E-2	2.7E-2	2.7E-2
DST with ALCs Operating	1.5E-1	1.5E-1	1.5E-1
SST with RMCS operating	6.9E-3	6.8E-3	6.8E-3
AWF (AZ-702) with ALCs operating	1.7E-1	1.5E-1	1.5E-1

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler
SST = single-shell tank.

Radiological doses were calculated using Equation B-1. The filtration system releases and the continuous unfiltered releases are shown in Tables B-6 and B-7, respectively. These two components must be treated separately because they require 1-hr and 8-hr χ/Q's, respectively, from Table B-3. The resulting doses due to the filtration system releases and continuous unfiltered releases, along with the totals are shown for the onsite receptor in Table B-9 for the high temperature scenario. The results for the high pressure and continuous unfiltered release scenarios are shown in Tables B-10 and B-11, respectively.

Table B-9. Onsite Receptor Doses for High Temperature Scenario.

System	Dose from filtration system (Sv)	Dose from unfiltered release (Sv)	Total dose	
			(Sv)	(rem)
Active SST (SX farm)	2.0E-3	2.2E-3	4.2E-3	4.2E-1
DST without ALCs	1.5E-6	5.1E-5	5.2E-5	5.2E-3
DST with ALCs Operating	1.5E-5	2.9E-3	2.9E-3	2.9E-1
SST with RMCS operating	1.1E-4	1.8E-3	1.9E-3	1.9E-1
AWF (AZ-702) with ALCs operating	2.1E-3	2.9E-3	5.0E-3	5.0E-1

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SST = single-shell tank.

Table B-10. Onsite Receptor Doses for High Pressure Scenario.

System	Dose from filtration system (Sv)	Dose from unfiltered release (Sv)	Total dose	
			(Sv)	(rem)
Active SST (SX farm)	4.0E-5	2.2E-3	2.2E-3	2.2E-1
DST without ALCs	2.9E-8	5.1E-5	5.1E-5	5.1E-3
DST with ALCs Operating	3.0E-7	2.9E-3	2.9E-3	2.9E-1
SST with RMCS operating	2.2E-6	1.8E-3	1.8E-3	1.8E-1
AWF (AZ-702) with ALCs operating	6.1E-6	2.9E-3	2.9E-3	2.9E-1

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SST = single-shell tank.

Table B-11. Onsite Receptor Doses for Continuous Unfiltered Release Scenario.

System	Dose from filtration system (Sv)	Dose from unfiltered release (Sv)	Total dose	
			(Sv)	(rem)
Active SST (SX farm)	0.0E+0	2.2E-3	2.2E-3	2.2E-1
DST without ALCs	0.0E+0	5.1E-5	5.1E-5	5.1E-3
DST with ALCs Operating	0.0E+0	2.9E-3	2.9E-3	2.9E-1
SST with RMCS operating	0.0E+0	1.8E-3	1.8E-3	1.8E-1
AWF (AZ-702) with ALCs operating	0.0E+0	2.9E-3	2.9E-3	2.9E-1

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SST = single-shell tank.

Toxicological Exposures. As discussed in RPP-13482, Section 5.3, the sum of fractions (SOF) for a given aerosol release rate V' (L/s) of tank waste is given by Equation B-2:

$$SOF = V'\left(\frac{\chi}{Q'}\right)USOF \tag{B-2}$$

where *USOF* is the unit sum of fractions for the particular tank waste in question as defined in RPP-8369, *Chemical Source Terms for Tank Farms Safety Analyses*.. For a given release rate, consequences are below guidelines if the SOF is less than 1. In the case of toxicological exposures, the maximum concentration at the receptor is the operative parameter so that the 1-hr χ/Q' (i.e., without plume meander) is always used in Equation B-2. The release rates from the various systems for the continuous unfiltered release component of all three scenarios are shown in Table B-7. The rationale for determining averaging times for short toxicological releases is discussed in RPP-13482, Chapter 5.0. In the high temperature scenario, the release from the filters is assumed to require at least 15 min so that the release rate is averaged over 900 sec (15 min). In the case of the high pressure event, the release from the filters is assumed to be complete in less than 1 min so that the release is averaged over 60 sec. The resulting release rates from the filters in the high temperature and high pressure events are shown in Table B-12. The combined release rates (that occur early in the event scenarios when the filters are failing, and the unfiltered headspace air is passing through the system) are the sums of the continuous unfiltered release rates shown in Table B-7 and the release rates from filters. The maximum release rates for the continuous unfiltered release scenario (which do not include any releases from filters) are just the unfiltered release rates shown in Table B-7.

Table B-12. Release Rates from Filtration Systems in the High Temperature and High Pressure Event Scenarios.

System	Waste type	Solids fraction	Release rate from filters (L/s)		Combined release rate (L/s)	
			High Temp.	High Press.	High Temp.	High Press.
Active SST (SX farm)	SST	1	1.4E-6	4.3E-7	1.7E-6	7.2E-7
DST without ALCs	DST	0	1.5E-7	4.5E-8	1.1E-6	9.9E-7
DST with ALCs Operating	DST	0.05	1.5E-7	4.4E-8	5.3E-6	5.2E-6
SST with RMCS operating	SST	1	8.0E-8	2.4E-8	3.2E-7	2.6E-7
AWF (AZ-702) with ALCs operating	DST	0.05	2.0E-5	8.9E-7	2.6E-5	6.1E-6

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SST = single-shell tank.

The USOFs to be used in Equation B-2 were derived from RPP-8369. Since the filtration system failure accidents are classified as anticipated, the USOFs for the onsite receptor and offsite receptor correspond to Temporary Emergency Exposure Limit (TEEL)-2 and TEEL-1 values, respectively. The USOFs used in this analysis are shown in Table B-13 for actively ventilated tanks. The values shown are the maximums for all tanks in each category.

Table B-13. Unit (Release Rate) Sums of Fractions.

Receptor	Waste type	USOF (dimensionless)	
		SST	DST
Onsite (TEEL-2)	Solids	7.3E+9	7.3E+8
	Liquids	5.8E+8	3.5E+8
Offsite (TEEL-1)	Solids	2.2E+9	1.4E+9
	Liquids	3.8E+9	2.7E+9

Notes:
DST = double-shell tank.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.
USOF = unit sum of fractions.

The release rates shown in Tables B-7, B-12, and B-13 were then coupled with the 1-hr χ/Q's shown in Table B-3 to calculate SOFs for the three accident scenarios. The results for the onsite and offsite receptor are shown for the three scenarios in Tables B-14 through B-19. The SOFs due to the filtration system releases and the continuous unfiltered releases are shown separately to indicate their relative contributions.

Table B-14. Onsite Receptor Toxicological Exposures (SOFs for TEEL-2) for High Temperature Failure Scenario

System	Sum of Fractions		
	Release from filters	**Continuous unfiltered release**	**Total**
Active SST (SX farm)	3.4E-1	6.9E-2	4.1E-1
DST without ALCs	1.7E-3	1.1E-2	1.2E-2
DST with ALCs Operating	1.8E-3	6.2E-2	6.4E-2
SST with RMCS operating	1.0E-2	3.0E-2	4.1E-2
AWF (AZ-702) with ALCs operating	2.4E-1	6.2E-2	3.0E-1

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SOF = sum of fractions.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.

Table B-15. Offsite Receptor Toxicological Exposures (SOFs for TEEL-1) for High Temperature Failure Scenario.

System	Sum of Fractions		
	Release From Filters	**Continuous Unfiltered Release**	**Total**
Active SST (SX farm)	7.1E-5	1.4E-5	8.5E-5
DST without ALCs	9.1E-6	5.7E-5	6.7E-5
DST with ALCs Operating	8.7E-6	3.1E-4	3.2E-4
SST with RMCS operating	1.4E-5	4.1E-5	5.5E-5
AWF (AZ-702) with ALCs operating	1.2E-3	3.1E-4	1.5E-3

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SOF = sum of fractions.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.

Table B-16. Onsite Receptor Toxicological Exposures (SOFs for TEEL-2) for High Pressure Failure Scenario.

System	Sum of Fractions		
	Release From Filters	Continuous Unfiltered Release	Total
Active SST (SX farm)	1.0E-1	6.9E-2	1.7E-1
DST without ALCs	5.1E-4	1.1E-2	1.1E-2
DST with ALCs Operating	5.3E-4	6.2E-2	6.3E-2
SST with RMCS operating	3.1E-3	3.0E-2	3.4E-2
AWF (AZ-702) with ALCs operating	1.1E-2	6.2E-2	7.3E-2

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SOF = sum of fractions.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.

Table B-17. Offsite Receptor Toxicological Exposures (SOFs for TEEL-1) for High Pressure Failure Scenario.

System	Sum of Fractions		
	Release From Filters	Continuous Unfiltered Release	Total
Active SST (SX farm)	2.1E-5	1.4E-5	3.6E-5
DST without ALCs	2.7E-6	5.7E-5	6.0E-5
DST with ALCs Operating	2.6E-6	3.1E-4	3.1E-4
SST with RMCS operating	4.2E-6	4.1E-5	4.6E-5
AWF (AZ-702) with ALCs operating	5.3E-5	3.1E-4	3.6E-4

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SOF = sum of fractions.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.

Table B-18. Onsite Receptor Toxicological Exposures (SOFs for TEEL-2) for Continuous Unfiltered Release Scenario.

System	Sum of Fractions		
	Release From Filters	Continuous Unfiltered Release	Total
Active SST (SX farm)	0.0E+0	6.9E-2	6.9E-2
DST without ALCs	0.0E+0	1.1E-2	1.1E-2
DST with ALCs Operating	0.E+0	6.2E-2	6.2E-2
SST with RMCS operating	0.0E+0	3.0E-2	3.0E-2
AWF (AZ-702) with ALCs operating	0.0E+0	6.2E-2	6.2E-2

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SOF = sum of fractions.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.

Table B-19. Offsite Receptor Toxicological Exposures (SOFs for TEEL-1) for Continuous Unfiltered Release Scenario.

System	Sum of Fractions		
	Release From Filters	Continuous Unfiltered Release	Total
Active SST (SX farm)	0.0E+0	1.4E-5	1.4E-5
DST without ALCs	0.0E+0	5.7E-5	5.7E-5
DST with ALCs Operating	0.0E+0	3.1E-4	3.1E-4
SST with RMCS operating	0.0E+0	4.1E-5	4.1E-5
AWF (AZ-702) with ALCs operating	0.0E+0	3.1E-4	3.1E-4

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SOF = sum of fractions.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.

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APPENDIX C

FILTER LOADING CALCULATIONS

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Appendix C

Exposure Rate Estimates for HEPA Filters and Prefilters

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In these calculations, 1 L of the waste material is placed on a filter. Dose rates near the filter are computed using the MICROSHIELD™ software Version 5.05. The software applications are verified using hand calculations. Input assumptions that tend to give lower dose rates are preferred because this will lead to overestimates of the amount of activity present on the filter.

RADIOACTIVE SOURCE COMPOSITIONS

The four principal waste types are single shell tank (SST) solids and liquids, and double shell tank (DST) solids and liquids. The mean concentrations of Sr-90 and Cs-137 shown in the table below are of interest in these calculations. Other nuclides are expected to contribute less than 1% to the final dose rates because their concentrations are more than four orders of magnitude smaller than these two (RPP-4534). The mean concentrations are used in the calculations rather than the 95 or 99 percentile concentrations because this gives lower dose rates for a given filter loading. In the reference six values for concentration are given. The M1 values used for the determination of ULD are used in this analysis and shown in Table C-1.

Table C-1. Composition of the Various Waste Mixtures

Nuclide	SST Solids µCi/g	SST Liquids µCi/L	DST Solids µCi/g	DST Liquids µCi /L
Sr-90	701	2,100	6,820	7,710
Cs-137	110	304,000	288	336,000
Nuclide	**SST Solids Ci/L**	**SST Liquids Ci/L**	**DST Solids Ci/L**	**DST Liquids Ci /L**
Sr-90	1.12	0.0021	10.9	0.00771
Y-90	1.12	0.0021	10.9	0.00771
Cs-137	0.176	0.304	0.461	0.336
Ba-137m	0.166	0.287	0.435	0.317

The upper two rows of numbers are the "M1" values from RPP-4534 Revision 2, Appendix C. The conversion to activity per unit volume uses the density 1,600 g/L.

The upper half of the table shows the mean concentrations listed in RPP-4534 Revision 2, Appendix C. The lower half of the table shows the values converted to a common set of units, Ci/L. The density of both the SST and DST solids is 1,600 g/L. The lower half also shows the

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activities of the short half life progeny nuclides. The equilibrium factor for Sr-90 is 1.000 while the equilibrium factor for Cs-137 is 0.944 (ENDF/B-VI).

Although the Sr-90 is the majority of the activity in both SST and DST solids, it will be ignored in these calculations. The exposure rates from Sr-90 are expected to be small compared to the exposure rates from Cs-137. In addition, ignoring the Sr-90 leads to an underestimate of the exposure rate, which is conservative in this analysis.

1 ft by 1 ft by 1 ft HEPA Filters

The nearly cubic HEPA filter is used in breather filters for many SSTs. It is also used in the 244-A DCRT ventilation system. Exposure rates near the passively ventilated SSTs are calculated at a location 4 inches from the side of the filter. This represents typical conditions and takes into account the dimensions of the ion chamber used for field measurements. Exposure rates for the 244-A DCRT are measured between the two stages of HEPA filters.

Input to the MICROSHIELD software includes the average density and composition of the HEPA filter media. This density is assumed to be the same as used for the 2 ft by 2 ft by 1 ft HEPA filter. The filter frame is not included with the media in the calculation of the average density. The total volume of the media in the 2 ft by 2 ft by 1 ft filter is 112 L. From WHC-SD-WM-CN-033 the filter media is 5 lb (2.27 kg) and the aluminum separators have a mass of 3.48 kg. The average density of the filter media is therefore 0.0202 g/cm^3, and the average density of the aluminum separators is 0.0310 g/cm^3.

For the calculation of dose rate near the side of the filter, a layer of iron 1/8 in thick was added to represent the filter housing and the duct. Calculations near the face of the filter have no shield, but are at 5 inches rather than 4 inches. The computed exposure rates are shown in Table C-2. The MICROSHIELD output for the 1ft by 1ft by 1ft cases is shown in the first attachment. It includes sketches of the filter, prefilter, and dose points.

Table C-2. Exposure Rates (mrem/h) for 1 ft by 1 ft by 1 ft HEPA Filter Systems

Location	SST Solid	SST Liquid	DST Solid	DST Liquid
HEPA -- Side	863	1,491	2,260	1,648
HEPA -- Face	765	1,321	2,002	1,460
Prefilter -- Face	248	429	651	474

Notes:

- Each of the above filters contains 1 L of the indicated waste. MICROSHIELD was used to calculate the exposure rates for the DST liquid. The other dose rates are calculated from the DST liquid using the ratios of Cs-137 concentration shown in Table C-1.
- The "Side" exposure rates are in the middle of the side, 4 in from the filter. They include 1/8 in steel shielding to account for the filter housing and the duct.
- The "Face" exposure rates are located along the airflow centerline of the HEPA filter. The detector is 5 in from the face of the HEPA.
- The prefilter is in contact with the upstream side of the upstream HEPA filter. It is 17 in from the dose point. The exposure rate shown is for the prefilter only.

The prefilter is assumed to have the same density and composition as the HEPA filter. The prefilter is 2 in thick. The prefilter is located on the upstream of and in contact with one HEPA filter. Dose rates from the prefilter are taken in front of the HEPA filter, which acts as a shield. The dose point is 17 inches from the prefilter. The prefilter exposure rates shown in Table C-1 do not include contributions from the HEPA. They are for the prefilter only.

The exposure rates shown for DST liquid were the only ones computed in MICROSHIELD. The output for these cases is shown in the first attachment. The other exposure rates were obtained using ratios of Cs-137 activity from Table C-1. An example calculation for SST Solids is shown below.

$$863\ \text{mR/h} = (1{,}648\ \text{mR/h})\left(\frac{0.176\ \text{Ci/L}}{0.336\ \text{Ci/L}}\right)$$

The exposure rates from the HEPA and prefilter may be combined according to the fraction of the activity expected on each. For example, if 10% of the total is embedded in the prefilter, then 90% is present in the HEPA filters. Thus the total dose rate for 1 L of SST solids is computed as shown below.

$$(0.1)(248\ \text{mrem/h}) + (0.9)(765\ \text{mrem/h}) = 713\ \text{mrem/h}$$

Additional exposure rates were computed at locations 2 in nearer the source, 2 in farther away, and 2 in to the side. These were computed to determine the importance of an accurate source-to-detector distance. Results are shown in Table C-3. The increase in distance is of concern, as lower readings imply larger filter loadings and greater downwind consequences should the filter inventory somehow become airborne.

Table C-3. Sensitivity Cases for the 1 ft by 1 ft by 1 ft Systems

	2 in Nearer	2 in Farther	2 in to Side
Exposure Rates (mrem/h) for DST Liquids from MICROSHIELD			
HEPA -- Side	2,559	1,141	1,600
HEPA -- Face	2,192	1,038	1,423
Prefilter -- Face	590	389	470
Percent Differences with the DST Liquids Result			
HEPA -- Side	55%	-31%	-2.9%
HEPA -- Face	50%	-29%	-2.5%
Prefilter -- Face	24%	-18%	-1.0%

Exposure rates are from MICROSHIELD using the DST liquids waste composition.
Percent differences are with the DST liquids column on the previous table.

2 ft by 2 ft by 1 ft HEPA Filters

These HEPA filters are used in most locations in a two-stage arrangement with one HEPA followed by another, sometimes with a prefilter. Exposure rates are calculated at a point 4 inches away from the side of the filter to represent typical conditions and take into account the dimensions of the ion chamber used for field measurements. A layer of steel 1/8 inch thick has been included in the calculation of exposure rates to the side of the filter to represent both the filter housing and the duct.

Input to the MICROSHIELD software includes the densities computed above for the filter media (0.0202 g/cm^3) and aluminum separators (0.0310 g/cm^3). The computed exposure rates are shown in Table C-4. The MICROSHIELD output for the DST liquid cases is shown in the second attachment. It includes sketches of the filter, prefilter, and dose points. The other exposure rates were calculated from DST liquid using the ratios of Cs-137 concentrations shown in Table C-1.

Exposure rates on the face of the HEPA were calculated at a distance of 1.75 in. This is intended to represent two HEPA filters that are 3.5 in. apart. The prefilter is assumed to have the same density and composition as the HEPA filter. The prefilter is 2 in. thick and separated 3.5 from the upstream HEPA filter. The dose point is 3.5+12+1.75=17.25 in. from the prefilter.

Table C-4. Exposure Rates (mrem/h) for 2 ft by 2 ft by 1 ft HEPA Filter Systems

Location	SST Solid	SST Liquid	DST Solid	DST Liquid
HEPA -- Side	406	701	1,063	775
Prefilter -- Side	458	792	1,200	875
HEPA -- Face	794	1,372	2,079	1,516
Prefilter -- Face	204	353	535	390

Notes:

- Each of the above filters contains 1 L of the indicated waste. MICROSHIELD was used to calculate the exposure rates for the DST liquid. The other dose rates are calculated from the DST liquid using the ratios of Cs-137 concentration shown in Table C-1.
- The "Side" exposure rates are in the middle of the side, 4 in from the filter. They include 1/8 in steel shielding to account for the filter housing and the duct.
- The "Face" exposure rates are located along the centerline between two HEPA filters. The detector is 1.75 in from the face of either HEPA.
- The prefilter is 3.5 in upstream of the HEPA filters. The exposure rate shown is for the prefilter only.

The exposure rates between two HEPA filters (Face cases) from the HEPA and prefilter may be combined according to the fraction of the activity expected on each. For example, if 10% of the total is embedded in the prefilter, then 90% is present in the HEPA filters. Thus the total dose rate for 1 L of SST solids is computed as shown below.

$$(0.1)(204 \text{ mrem/h}) + (0.9)(794 \text{ mrem/h}) = 735 \text{ mrem/h}$$

Additional exposure rates were computed at locations 2 in nearer the source, 2 in farther away, and 2 in to the side. These were computed to determine the importance of an accurate source-to-detector distance. Results are shown in Table C-5. The increase in distance is of concern, as lower readings imply larger filter loadings and greater downwind consequences should the filter inventory somehow become airborne.

Table C-5. Sensitivity Cases for the 2 ft by 2 ft by 1 ft Systems

	2 in Nearer	2 in Farther	2 in to Side
Exposure Rates (mrem/h) for DST Liquids from MICROSHIELD			
HEPA -- Side	1,072	588	758
Prefilter -- Side	1,336	636	836
HEPA -- Face	na	na	1,504
Prefilter -- Face	na	na	388
Percent Differences with the DST Liquids Result			
HEPA -- Side	38%	-24%	-2.2%
Prefilter -- Side	53%	-27%	-4.4%
HEPA -- Face	na	na	-0.8%
Prefilter -- Face	na	na	-0.6%

Exposure rates are from MICROSHIELD using the DST liquids waste composition.
Percent differences are with the DST liquids column on the previous table.

6 ft by 6 ft by 1 ft HEPA Filter Arrays

These HEPA filters are an array of 9 HEPA filters with dimensions 2 ft by 2 ft by 1 ft. Exposure rates are calculated at a point 4 inches away from the side of the filter to represent typical conditions and take into account the dimensions of the ion chamber used for field measurements. For the actively ventilated SSTs, the dose rates are measured 1 ft from the bottom. For the array at 241-SX tank farm, the dose rate is measured 39 in from the bottom. A layer of steel 1/8 inch thick has been included in the calculation of exposure rates to the side of the filter to represent both the filter housing and the duct.

Input to the MICROSHIELD software uses revised densities. The inner portion of the filter frames is included with the media in the calculation of the average density. The total volume of the array is 1,016 L. The 9*5=45 lb of filter media (WHC-SD-WM-CN-033) averaged over this volume has a density of 0.0201 g/cm^3, and the aluminum separators have an average density of 0.0308 g/cm^3. In addition, a portion of the filter housings must be included. The steel is 12 in wide, 1/16 in thick and the total length is 48 ft. (On all 9 filters the total length of steel is 72 ft. The steel around the outside is 24 ft. The steel inside the averaging volume is therefore 72 ft - 24 ft = 48 ft.) The average density of this steel over the volume of the filters is 0.0550 g/cm^3.

The prefilter is assumed to have the same density and composition as the HEPA filter. The prefilter is 2 in thick and located in contact with the upstream side of the HEPA filters. Because MICROSHIELD cannot model the effect of both the duct and the HEPA as shields, the prefilter and HEPA were combined. An external adjustment to the calculated exposure rates retrieves the dose rate from the 2-in. prefilter only.

For the prefilter cases, the MICROSHIELD source region is 14 in thick. To calculate the dose rate from the prefilter alone, the 12 in results were subtracted from the 14 in results. Both were scaled up so the result is still on a per liter basis. (The scale factors provide for 1 L of waste in every 2 in thickness of the filter.) This is shown in the formula below for DST liquids. The MICROSHIELD result (39 in from bottom) for the 12 in thick case is 153.1 mrem/h per L and the result for the 14 in thick case is 149.4 mrem/h per L of DST liquid. The calculation below shows that a prefilter loaded with 1 L of DST liquid would read 127 mrem/h.

$$127 \text{ mrem/h} = (7)(149.4 \text{ mrem/h}) - (6)(153.1 \text{ mrem/h})$$

The computed exposure rates are shown in Table C-6. The MICROSHIELD output for the 6 ft by 6 ft by 1 ft cases is shown in the third attachment. It includes sketches of the filter, prefilter, and dose points.

Table C-6. Exposure Rates (mrem/h) for 6 ft by 6 ft by 1 ft HEPA Filter Arrays

Location	SST Solid	SST Liquid	DST Solid	DST Liquid
HEPA -- Side 1 ft	70	121	183	134
Prefilter -- Side 1 ft	57	99	149	109
HEPA -- Side 39 in	80	139	210	153
Prefilter -- Side 39 in	67	115	174	127

Notes:

- Each of the above filters contains 1 L of the indicated waste. MICROSHIELD was used to calculate the exposure rates for the DST liquid. The other dose rates are calculated from the DST liquid using the ratios of Cs-137 concentration shown in Table C-1.
- The "Side" exposure rates are in the middle of the side of the HEPA filter, 4 in from the filter. They are either 1 ft or 39 in from the bottom of the filter. They include 1/8 in steel shielding to account for the filter housing and the duct.

Additional exposure rates were computed at locations 2 in nearer the source, 2 in farther away, and 2 in to the side. These indicate the importance of an accurate source-to-detector distance for the 6 ft by 6 ft by 1 ft filter. Results are shown in Table C-7. Due to the large dimensions of the filter array, it was less sensitive than smaller filter arrangements to changes in detector location.

Table C-7. Sensitivity Cases for the 6 ft by 6 ft by 1 ft Systems

	2 in Nearer	2 in Farther	2 in to Side
Exposure Rates (mrem/h) for DST Liquids from MICROSHIELD			
HEPA -- Side 1 ft	168	111	125
Prefilter -- Side 1 ft	122	97	134
HEPA -- Side 39 in	na	129	na
Prefilter -- Side 39 in	na	113	na
Percent Differences with the DST Liquids Result			
HEPA -- Side 1 ft	25%	-17%	-6.2%
Prefilter -- Side 1 ft	12%	-11%	23%
HEPA -- Side 39 in	na	-16%	na
Prefilter -- Side 39 in	na	-11%	na

Exposure rates are from MICROSHIELD using the DST liquids waste composition.
Percent differences are with the DST liquids column on the previous table.

HEME FILTER

The High Efficiency Mist Eliminator (HEME) filter has the shape of a cylinder with the center removed. The cylinder is 3 ft diameter and the central channel is 26 in diameter. The overall length of the HEME is 107.75 in, or just under 9 ft. Moisture-laden air appears to enter the inner cylindrical region, make a right angle turn, and pass through the fiberglass media.

The detector locations are near the top of the HEME, 6 in from the media and 13 in from the media. An additional detector location is 3 ft from one end of the HEME and 13 in from the media (WHC-SD-WM-CN-099). A layer of iron 0.312 in thick shields the two detector locations that are 13 in from the outside of the HEME (WHC-SD-WM-CN-099).

The fiberglass filter media was modeled as concrete with a density of 0.272 g/cm^3. This is the same as used in WHC-SD-WM-CN-099 Rev 1 for the HEME. The outer jacket was represented as iron with a thickness of 1/4 in. The wire cage that supports the HEME was not modeled because the amount of iron is small.

The computed exposure rates are shown in Table C-8. The area radiation monitor (ARM) location at 3 ft from one end is an alternate location for the area radiation monitor. The MICROSHIELD output for the DST liquid cases is shown in the fourth attachment. It includes sketches of the arrangements and dose points. Under "Shields" the inner core is shown as having a dimension of 33.02 in^3 rather than 33.02 cm (13 in). This is a bug in the MICROSHIELD output that does not affect the computed results. The exposure rates for the other tank materials are calculated from ratios of the Cs-137 concentrations shown in Table C-1.

Table C-8. Exposure Rates (mrem/h) for the HEME in AZ-702

Location	SST Solid	SST Liquid	DST Solid	DST Liquid
Contact (end)	33	57	86	63
ARM (end)	16	28	43	31
ARM (3 ft)	29	50	76	55

The HEME contains 1 L of the indicated waste.
The "Contact" exposure rates are at the top of the HEME, 6 in from the filter.
The two ARM (area radiation monitor) cases are located 31 in from the central axis of the HEME behind 0.312 in iron.

CASE SUMMARY

The above exposure rates for 1 L on the filter were rearranged to represent specific filter systems shown in Table C-9. For cases with prefilters, the prefilter was assumed to hold 10% of the activity.

Table C-9. Conversion Factors (mrem/h per L) for Specific Filter Systems. Where the Prefilter Contains 10% of the Total Activity (2 sheets)

Case	Description	mrem/h per L on the filter		Weighted Total
		HEPA	Prefilter	
Actively Ventilated SSTs -- 9 HEPA Filters -- Side, 1 ft from bottom				
1	SST Solids	70	57	69
2	SST Liquids	121	99	119
3	DST Solids	183	149	180
4	DST Liquids	134	109	131
AN, AP, and AW -- 2 ft by 2ft by 1 ft HEPA -- Side				
5	DST Solids	1,063	1,200	na
6	DST Liquids	775	875	na
Passively Ventilated SSTs -- 1 ft by 1 ft HEPA -- Side				
7	SST Solids	863	na	na
244-A DCRT -- 1 ft by 1 ft HEPA -- Between Two				
8	SST Solids	765	248	713
9	SST Liquids	1,321	429	1,232

Table C-9. Conversion Factors (mrem/h per L) for Specific Filter Systems. Where the Prefilter Contains 10% of the Total Activity (2 sheets)

Case	Description	mrem/h per L on the filter		Weighted Total
		HEPA	Prefilter	
244-CR Vault -- 2 ft by 2 ft HEPA -- Between Two				
10	SST Solids	794	204	735
Actively Ventilated SSTs (SX) -- 9 HEPA Filters -- Side, 39 in from bottom				
11	SST Solids	80	67	79
12	SST Liquids	139	115	136
HEME in AZ-702 -- Contact (6 in) Near the Top				
13	DST Liquids	63	na	na
HEME in AZ-702 -- ARM Located Near the Top				
14	DST Liquids	31	na	na
The prefilters are assumed to contain 10% of the total activity on the filter.				

HAND CALCULATIONS TO VERIFY MICROSHIELD RESULTS FOR THE HEPA FILTERS

MICROSHIELD calculates exposure rates by dividing the source region into smaller regions and summing the exposure rates from each of the smaller regions. This is also known as the "point-kernel" method. In the discussion that follows, the specific method used to verify MICROSHIELD, along with the equations and parameter values is presented. The calculated results are compared with MICROSHIELD and found to agree. It is concluded that the MICROSHIELD calculations are correct.

Input Data for the Hand Calculations

The data being presented here is used to verify the use of the MICROSHIELD software in this report. This data might have been generated by software that was not QA certified. In fact, one of the references (ANSI/ANS-6.4.3) has been withdrawn and is no longer available from the publisher.

The photon source strength is for one liter of DST liquid, containing 0.336 Ci Cs-137. Each curie is 3.7×10^{10} decays per second. Each decay of Cs-137 produces 0.9443 atoms of Ba-137m. Each decay of Ba-137m produces 0.901 photons with energy 0.6616 MeV. The branching ratio and transition probability are from ENDF/B-VI. Thus the photon source strength is calculated as shown below.

$$(1\ L)(0.366\ Ci/L)(3.7x10^{10}\ dps/Ci)(0.9443)(0.901)=1.058x10^{10}\ photons/sec$$

The fluence-to-dose rate conversion factor (F_D) was obtained from the mass absorption coefficients for photons in air listed in Table 2 of ANSI/ANS-6.4.3 (1991). The mass absorption coefficients for the Cs-137 gammas are converted using the calculation shown below. The 33.97 eV per ion pair (or J/C) is from ICRU Report Number 47 (1992) Section A.2.2. This value is within the range that is recommended in ICRU Report 31 (1979) Section 5.4.1.1, namely, 33.85±0.15 eV.

$$F_D = \left(\frac{\sigma_A\ E}{W_{AIR}}\right)\left(\frac{1.6022\ x\ 10^{-13}\ J/MeV}{2.58\ x\ 10^{-4}\ C/kg-R}\right)\left(\frac{3{,}600\ s/h}{10^{-6}\ k/m}\right)$$

where

E	=	photon energy, 0.6616 MeV
F_D	=	fluence-to-exposure rate conversion factor for 0.6616 MeV photons, $1.275x10^{-3}$ mrem/h per photon/cm^2/s
W_{AIR}	=	average energy required to produce an ion pair in dry air, 33.97 J/C
σ_A	=	mass energy absorption coefficient for 0.6616 MeV photons in dry air, 0.02929 cm^2/g

The fluence-to-exposure rate conversions are also given in Table 3a of ICRP 51 (1987) and Table A.1 of ICRU Report 47. Values are listed in Table C-10 and compared with the values computed from ANSI/ANS-6.4.3. All of the numbers for the Cs-137 photons (0.6616 MeV) shown in Table C-10 are interpolated using a log-log method. The log-log interpolation method is based on the absorption/attenuation coefficients being fairly linear when plotted on log-log graphs. The formula used for this interpolation is shown below.

$$Ln\ V = \left(\frac{Ln\ V_2/V_1}{Ln\ E_2/E_1}\right)\left(Ln\ E/E_1\right) + Ln\ V_1$$

where

V	=	interpolated value at photon energy E
V_1, V_2	=	data values at photon energies E_1 and E_2

The references give fluence-to-exposure rate conversion factors that are nearly the same. The numbers from ANSI/ANS-6.4.3 are used in subsequent exposure rate calculations.

The linear attenuation coefficients (μ) were derived from ANSI/ANS-6.4.3 (1991). Values for the mass attenuation coefficients for concrete, aluminum, air, and iron are shown in Table C-11. All of the numbers for 0.6616 MeV photons were obtained by log-log interpolation of the table values at 0.6 MeV and 0.8 MeV.

Also shown in Table C-11 are the weighted sums for the HEPA filters. These weighted sums are computed as the product of the density of a material and the mass attenuation coefficient summed over all materials and divided by the total density. An example calculation for the

smaller filters is shown below. The densities used for the 6' by 6' array is 0.0201 g/cm^3 concrete, 0.0308 g/cm^3 aluminum, and 0.055 g/cm^3 iron.

$$\text{Small HEPA} = \frac{(0.0202\ \text{g/cm}^3)(0.0807\ \text{cm}^2/\text{g}) + (0.0310\ \text{g/cm}^3)(0.07769\ \text{cm}^2/\text{g})}{(0.0202\ \text{g/cm}^3) + (0.0310\ \text{g/cm}^3)}$$

$$= 0.07888\ \text{cm}^2/\text{g}$$

The linear attenuation coefficients are the products of the mass attenuation coefficients and the density of the material. The densities and linear attenuation coefficients are shown in Table C-12. These are the values used in the exposure rate formulas.

Table C-10. Exposure Rate per Unit Photon Fluence Rate

from ANSI/ANS-6.4.3 (1991)	0.6 MeV	0.6616 MeV	0.8 MeV
Energy Absorption Coefficient (cm^2/g)	0.02953	0.02929	0.02882
Exposure rate per unit photon fluence rate (mrem/h per photon/cm²-sec)	***1.166E-03***	***1.275E-03***	***1.517E-03***
from ICRP 51 (1987)	0.6 MeV	0.6616 MeV	0.8 MeV
Dose equivalent per unit photon fluence (Sv-cm²)	2.99E-12	3.252E-12	3.83E-12
Effective dose equivalent per unit exposure (rem/R)	0.919	0.9139	0.904
Exposure rate per unit photon fluence rate (mrem/h per photon/cm²-sec)	1.171E-03	1.281E-03	1.525E-03
Percent difference with ANSI/ANS-6.4.3	0.45%	0.47%	0.52%
from ICRU 47 (1992)	0.6 MeV	0.6616 MeV	0.8 MeV
Exposure per unit photon fluence (nR-cm²)	0.324	0.3544	0.422
Exposure rate per unit photon fluence rate (mrem/h per photon/cm²-sec)	1.166E-03	1.276E-03	1.519E-03
Percent difference with ANSI/ANS-6.4.3	0.03%	0.06%	0.12%

Notes:

- The first exposure rate per unit fluence rate factors are calculated using the mass energy absorption coefficients in Table 2 of ANSI/ANS-6.4.3 (1991), and the factors 1.60218×10^{-6} erg/MeV and 33.97 J/C for air. These were used in subsequent calculations.
- The second exposure rate per unit fluence factors are calculated using the dose equivalent per unit fluence values from Table 2 of ICRP 51 and EDE per unit exposure numbers from Table 3a. Both are for the anterior-posterior (AP) penetration.
- The third exposure rate per unit fluence factors are calculated using the exposure per unit fluence values from Table A.1 of ICRU 47.
- Values shown in the 0.6 MeV and 0.8 MeV columns are from the reference. Values in the 0.6616 MeV column are calculated from the 0.6 and 0.8 MeV columns using log-log interpolation.

Table C-11. Mass Attenuation Coefficients (cm^2/g)

Material	0.6 MeV	0.6616 MeV	0.8 MeV
Air	0.08041	0.07695	0.07065
Concrete	0.08070	0.07721	0.07085
Aluminum	0.07769	0.07433	0.06821
Iron	0.07611	0.07268	0.06644
HEPA (1' x 1' and 2' x 2')	0.07888	0.07547	0.06925
HEPA (6' x 6')	0.07744	0.07402	0.06779

Notes:

- Mass attenuation coefficients for air, concrete, aluminum, and iron are from ANSI/ANS-6.4.3 (1991). Values listed in this reference are given for energies of 0.6 and 0.8 MeV. The values shown for 0.6616 MeV are computed using log-log interpolation.
- The HEPA filter mass attenuation coefficients are computed from the values for concrete, aluminum, and iron weighted by the densities of the components.

Table C-12. Linear Attenuation Coefficients for 0.6616 MeV Photons

Material	Density (g/cm^3)	Linear Attenuation (per cm)
Air	0.00122	9.388E-05
Iron	7.9	5.741E-01
HEPA (1' x 1' and 2' x 2')	0.0512	3.864E-03
HEPA (6' x 6')	0.1059	7.838E-03
HEME (concrete)	0.272	2.100E-02
Linear attenuation coefficients are the product of the mass attenuation coefficients and the density.		

The exposure buildup factors for iron and concrete were used in these calculations. The iron buildup covers all the cases with readings taken through the ductwork. While most of this ductwork is some type of stainless steel, representing it as iron is adequate because the duct is relatively thin for shielding gammas from Cs-137. This is an approximation that was also used in the MICROSHIELD runs. The concrete buildup covers all the cases with readings taken near the face of the filter. The concrete represents the HEPA filter medium. Exposure buildup in aluminum is nearly the same as in concrete at this photon energy.

To simplify the buildup factor calculation, the buildup factor data was represented with a quadratic fit using the spreadsheet function LINEST in the EXCEL software. The function LINEST returns an array of results, some of which are known to be in error. The erroneous results were not used in the hand calculations.

Note that in this data set, the interpolation between 0.6 MeV and 0.8 MeV uses a linear function rather than a log-log function. The reason is that graphs of the buildup factors with energy are adequately represented on a linear scale. The least squares fit to a quadratic equation uses the interpolated buildup factors for each material for 0 to 3 MFP. The fit was forced to go through the point B=1 when the attenuation length is zero. Table C-13 shows the data, the interpolated buildup factors, and the buildup factors computed from the quadratic fit. As shown in the last column of numbers, the differences between the interpolated and fitted buildup factors are less than 1%.

Table C-13. Exposure Buildup Factors for Concrete and Iron

Buildup Factors for Concrete

MFP	0.6 MeV	0.6616 MeV	0.8 MeV	Quadratic	Percent Difference
0	1	1.0000	1	1.0000	0.00%
0.5	1.53	1.5146	1.48	1.5239	0.62%
1	2.18	2.1430	2.06	2.1467	0.17%
2	3.8	3.6984	3.47	3.6889	-0.26%
3	5.82	5.6229	5.18	5.6264	0.06%
4	8.25	7.9204	7.18	7.9594	0.49%

Buildup Factors for Iron

MFP	0.6 MeV	0.6616 MeV	0.8 MeV	Quadratic	Percent Difference
0	1	1.0000	1	1.0000	0.00%
0.5	1.46	1.4508	1.43	1.4461	-0.32%
1	1.96	1.9415	1.9	1.9356	-0.31%
2	3.07	3.0361	2.96	3.0450	0.29%
3	4.39	4.3315	4.2	4.3283	-0.07%
4	5.9	5.8138	5.62	5.7855	-0.49%

Notes:

- The column "MFP" stands for Mean Free Paths, i.e., the total shielding length.
- The exposure buildup factors shown for 0.6 and 0.8 MeV photons are from ANSI/ANS-6.4.3 (1991). The buildup factors shown for 0.6616 MeV were obtained by linear interpolation between the reference values.
- The quadratic fits were calculated using the LINEST function on the 0 to 3 MFP interpolated buildup factors with the fit forced to go through B=1 at zero MFP.
- The quadratic fit for the concrete buildup factors is $B=1+0.94900m+0.19772m^2$, where m is number of mean free paths (MFP).
- The quadratic fit for the iron buildup factors is $B=1+0.84864m+0.08693m^2$.
- The percent differences are between the 0.6616 MeV column and the "Quadratic" column.

Hand Calculated Exposure Rates for the HEPA Filters

The rectangular HEPA filters were represented as sums of smaller rectangles. The exposure rates were calculated for each of the smaller boxes and summed using Simpson's Rule. This sum was compared with the MICROSHIELD result to verify the numbers. The formulas used for the rectangular HEPA filters are shown below. In this model, the X direction is perpendicular to the side of the HEPA and the ductwork. The Y direction is in the direction of the air flow through the HEPA. The Z direction is the vertical dimension.

$$DR_{HEPA} = \frac{Q\,F_D}{27\,Nx\,Ny\,Nz}\sum_{I=0}^{Nx} S_I \left[\sum_{J=0}^{Ny} S_J \left(\sum_{K=0}^{Nz} \frac{S_K\,B\,e^{-M}}{4\,\pi\,\rho^2}\right)\right]$$

$$\rho^2 = (X_D - X_I)^2 + (Y_D - Y_J)^2 + (Z_D - Z_K)^2$$

$$X_I = \frac{X_H}{Nx} I \quad \text{and} \quad Y_J = \frac{Y_H}{Ny} J \quad \text{and} \quad Z_K = \frac{Z_H}{Nz} K$$

$$M = \left(\frac{\rho}{X_D - X_I}\right)\left[\mu_H (X_H - X_I) + \mu_S X_{SHLD} + \mu_A X_{AIR}\right]$$

$$B = 1 + a\,M + b\,M^2$$

where

a,b	=	constants derived from a fit to the buildup factor for iron or concrete, see Table C-13 for values
B	=	buildup factor for photons traveling from the location (X_I,Y_J,Z_K) inside the HEPA filter to the detector point (X_D,Y_D,Z_D)
DR_{HEPA}	=	exposure rate at the detector location (X_D,Y_D,Z_D) due to activity uniformly distributed over the HEPA filter, in mrem/h
F_D	=	fluence-to-exposure rate conversion factor for 0.6616 MeV photons, 1.275×10^{-3} mrem/h per photon/cm^2/s
I, J, K	=	indices for the locations within the HEPA filter: I ranges from 0 to Nx, J ranges from 0 to Ny, and K ranges from 0 to Nz
M	=	total attenuation length for materials between the point (X_I,Y_J,Z_K) and the detector point
Nx,Ny,Nz	=	number of segments in the x, y, and z directions inside the HEPA filter: Nx=40, Ny=24, Nz=30
Q	=	photon production rate for Cs-137 gammas in a filter containing 1 L of DST liquid, 1.058×10^{10} photons/sec
S_I, S_J, S_K	=	Simpson's Rule weighting factors for the summation. These are the numbers 1, 4, 2, 4, 2, 4, . . . 4, 2, 4, 2, 4, 1. The division by $27=3^3$ is part of the Simpson's Rule integration method in this case.
X_{AIR}	=	thickness of the air, in cm
X_{SHLD}	=	thickness of the shield, in cm
X_D,Y_D,Z_D	=	position of the detector point, in cm
X_H,Y_H,Z_H	=	position of the near corner of the rectangular HEPA filter, in cm. The far corner is at (0,0,0). The HEPA is X_H cm by Y_H cm by Z_H cm.
X_I,Y_J,Z_K	=	position of a point within the HEPA filter, in cm
μ_A	=	linear attenuation coefficient for air for 0.6616 MeV photons (from Cs-137), 9.388×10^{-5} per cm
μ_H	=	linear attenuation coefficient for the HEPA filter for 0.6616 MeV photons (from Cs-137), 0.003864 per cm for the individual HEPA filters and 0.007838 per cm for the 6' by 6' HEPA array
μ_S	=	linear attenuation coefficient for the shield material for 0.6616 MeV photons (see Table C-12)
ρ	=	distance between the point (X_I,Y_J,Z_K) inside the HEPA filter and the detector location (X_D,Y_D,Z_D), in cm

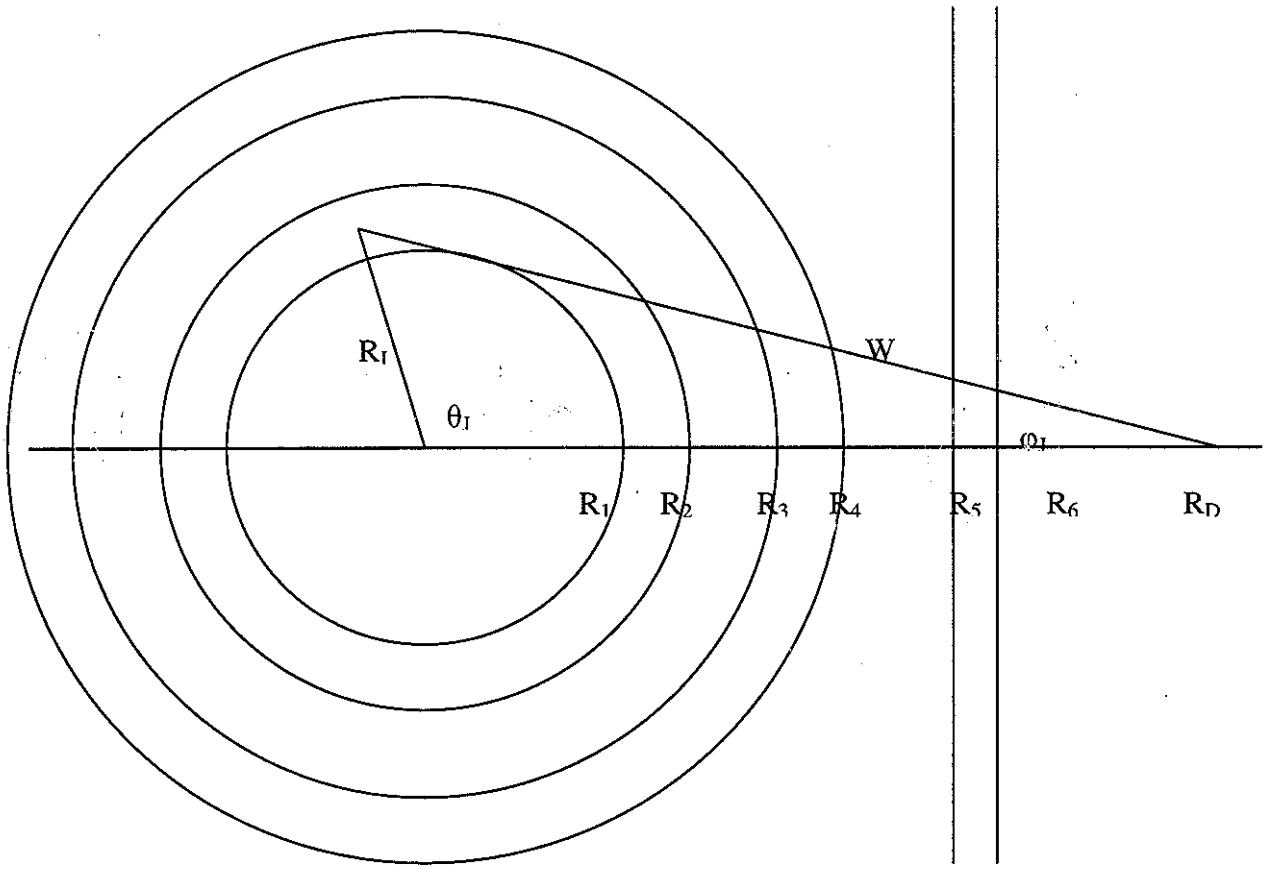
The hand calculated results for the various HEPA filter systems are shown in Table C-14. Similar differences between the hand calculations and MICROSHIELD are obtained for the detector location sensitivity cases. The hand calculations differ from MICROSHIELD by about 1 %, which is very good for this calculation. The integration method as well as some of the input parameters in the hand calculations differs from MICROSHIELD.

Table C-14. Hand Calculated Exposure Rates (mrem/h) for Rectangular HEPA Filter Systems

Location	MicroShield	Hand Calculation	Percent Difference
1' by 1' HEPA -- Side	1,648	1,660	0.71%
1' by 1' HEPA -- Face	1,460	1,444	-1.13%
1' by 1' Prefilter -- Face	474	475	0.09%
2' by 2' HEPA -- Side	775	780	0.57%
2' by 2' Prefilter -- Side	875	880	0.62%
2' by 2' HEPA -- Face	1,516	1,503	-0.83%
2' by 2' Prefilter -- Face	390	391	0.18%
6' by 6' HEPA -- Side 1 ft	133.5	133.5	0.02%
6' by 6' Prefilter -- Side 1 ft	109.0	108.9	-0.12%
6' by 6' HEPA -- Side 39 in	153.1	153.0	-0.06%
6' by 6' Prefilter -- Side 39 in	127.2	126.9	-0.23%

Hand Calculations for the HEME

A schematic of a cross-section through the HEME filter is shown below. The inner two circles define the fiberglass source region. This is modeled as concrete with a density of 0.272 g/cm^3. The outer two circles represent the cylindrical wall of the HEME, made of iron with a density of 7.9 g/cm^3. The vertical lines represent the additional iron shield. The other regions are air gaps.



A cylindrical coordinate system is used, centered on the HEME centerline. A location in the source region has coordinates (R_I,θ_J,Z_K). The detector is located at θ=0. The volume of the small region at (R_I,θ_J,Z_K) varies with position, hence the $\Delta V/V$ term is included in the summation shown below.

The length in each region is calculated in the R-θ plane. The distances W are measured from the detector location rather than the source point location. Extension to the Z-direction is accomplished using the ratio ρ/W.

$$DR_{HEME} = \frac{Q F_D}{27 V} \sum_{I=0}^{N_R} S_I \left[\sum_{J=0}^{N_\theta} S_J \left(\sum_{K=0}^{N_Z} \frac{S_K B e^{-M}(\Delta V)}{4 \pi \rho^2} \right) \right]$$

$$\frac{\Delta V}{V} = \frac{\left(\frac{R_2 - R_1}{N_R}\right)\left(\frac{2 \pi R_I}{N_\theta}\right)\left(\frac{Z_H}{N_Z}\right)}{\pi (R_2^2 - R_1^2) Z_H} = \frac{2 R_I}{N_R N_\theta N_Z (R_1 + R_2)}$$

$$W^2 = R_D^2 + R_I^2 - R_D R_I \operatorname{Cos} \theta_J$$

$$\rho^2 = W^2 + (Z_D - Z_K)^2$$

$$R_I = \left(\frac{R_2 - R_1}{N_R}\right) I \quad \text{and} \quad \theta_J = \left(\frac{2 \pi}{N_\theta}\right) J \quad \text{and} \quad Z_K = \frac{Z_H}{N_Z} K$$

$$M = \left(\frac{\rho}{W}\right)(\mu_H W_{HEME} + \mu_S W_{IRON} + \mu_A W_{AIR})$$

$$B = 1 + a M + b M^2$$

where

a,b	=	constants derived from a fit to the buildup factor for iron or concrete, see Table C-13 for values
B	=	buildup factor for photons traveling from the location (R_I,θ_J,Z_K) inside the HEME filter to the detector point (R_D,0,Z_D)
DR_{HEME}	=	exposure rate at the detector location (R_D,0,Z_D) due to activity uniformly distributed over the HEME filter, in mrem/h
F_D	=	fluence-to-exposure rate conversion factor for 0.6616 MeV photons, 1.275×10^{-3} mrem/h per photon/cm^2/s
I, J, K	=	indices for the locations within the HEPA filter: I ranges from 0 to N_R, J ranges from 0 to N_θ, and K ranges from 0 to N_Z
M	=	total attenuation length for materials between the point (R_I,θ_J,Z_K) and the detector point
N_R,N_θ,N_Z	=	number of segments in the R, θ, and Z directions inside the HEME filter: N_R=10, N_θ=40, N_Z=30
Q	=	photon production rate for Cs-137 gammas in a filter containing 1 L of DST liquid, 1.058×10^{10} photons/sec
R_1	=	inner radius of the HEME filter media, 33.02 cm (13 in)
R_2	=	outer radius of the HEME filter media, 45.72 cm (18 in)
R_3	=	inner radius of the iron container, 50.80 cm (20 in)
R_4	=	outer radius of the iron container, 51.435 cm (20.25 in)
R_6-R_5	=	thickness of the extra iron shield, 0.7925 cm (0.312 in). The actual position of this shield has no effect on the calculated exposure rates.
S_I, S_J, S_K	=	Simpson's Rule weighting factors for the summation. These are the numbers 1, 4, 2, 4, 2, 4, . . . 4, 2, 4, 2, 4, 1. The division by 27=3^3 is part of the Simpson's Rule integration method in this case.
V	=	volume of the HEME filter media, 859,800 cm^3
W_{AIR}	=	thickness of the air along the line joining the source point with the detector location, in cm

W_{HEME} = thickness of the HEME along the line joining the source point with the detector location, in cm

W_{IRON} = thickness of the iron along the line joining the source point with the detector location, in cm

$R_D,0,Z_D$ = position of the center of the detector, in cm

Z_H = height of the cylindrical HEME filter, in cm

R_I,θ_J,Z_K = position of a point within the HEME filter, in cm

ΔV = volume of a segment from which the exposure rate is calculated. $\Delta V/V$ is the fraction of the total source strength that is present at the source location.

μ_A = linear attenuation coefficient for air for 0.6616 MeV photons (from Cs-137), 9.388×10^{-5} per cm

μ_H = linear attenuation coefficient for the HEPA filter for 0.6616 MeV photons, 0.02100 per cm

μ_S = linear attenuation coefficient for the iron for 0.6616 MeV photons, 0.5741 per cm

ρ = distance between the point (R_I,θ_J,Z_K) inside the HEPA filter and the detector location $(R_D,0,Z_D)$, in cm

Additional equations to define the shielding thickness of each region are shown below. There is a transition angle (φ_T) corresponding to a line from the detector that is tangent to the inner boundary of the HEME filter media (R_I). Note that the air thickness (W_{AIR}) has a term in braces that only applies when $\varphi_J < \varphi_T$.

$$\operatorname{Sin}\varphi_T = \frac{R_I}{R_D}$$

$$\operatorname{Sin}\varphi_J = \frac{R_I \operatorname{Sin}\theta_J}{W} \quad \text{and} \quad \operatorname{Cos}^2\varphi_J = 1 - \left(\frac{R_I \operatorname{Sin}\theta_J}{W}\right)^2$$

$$W_6 = \frac{R_D - R_6}{\operatorname{Cos}\varphi_J} \quad \text{and} \quad W_5 = \frac{R_D - R_5}{\operatorname{Cos}\varphi_J}$$

$$W_4 = R_D \operatorname{Cos}\varphi_J - \sqrt{R_4^2 - R_D^2 \operatorname{Sin}^2\varphi_J}$$

$$W_3 = R_D \operatorname{Cos}\varphi_J - \sqrt{R_3^2 - R_D^2 \operatorname{Sin}^2\varphi_J}$$

$$W_2 = R_D \operatorname{Cos}\varphi_J - \sqrt{R_2^2 - R_D^2 \operatorname{Sin}^2\varphi_J}$$

$$W_1^{\pm} = R_D \operatorname{Cos}\varphi_J \pm \sqrt{R_1^2 - R_D^2 \operatorname{Sin}^2\varphi_J} \quad \text{when } \varphi_J < \varphi_T$$

$$W_{AIR} = W_6 + (W_4 - W_5) + (W_2 - W_3) + \left\{2\sqrt{R_1^2 - R_D^2 \operatorname{Sin}^2\varphi_J}\right\}$$

$$W_{IRON} = (W_5 - W_6) + (W_3 - W_4)$$

$$W_{HEME} = W - W_2 \quad \text{when } \varphi_J > \varphi_T$$

$$= (W - W_1^+) + (W_1^- - W_2) \quad \text{when } \varphi_J < \varphi_T$$

Because the source region is symmetric about the plane through the cylinder centerline and the detector point, the summation in the θ direction went from 0 to π radians (20 intervals). This half sum was then doubled to obtain the final exposure rate.

Using the above formulas to calculate the exposure rate at locations near the HEME gives the results shown in Table C-15. These results are also compared with the MICROSHIELD results in Table C-15. The hand calculations agree with MICROSHIELD to within about 1%, which is very good for this calculation. The integration method as well as some of the input parameters in the hand calculation differs from MICROSHIELD.

Table C-15. Hand Calculated Exposure Rates (mrem/h) for the HEME Filter System

Location	MicroShield	Hand Calculation	Percent Difference
Contact (end)	63.0	63.4	0.64%
ARM (end)	31.3	31.2	-0.27%
ARM (3 ft)	55.5	55.3	-0.25%

References

ENDF/B-VI, Evaluated Nuclear Data File, Release VI. This nuclear data library is maintained by the Cross Section Evaluation Working Group. Data and documentation is available from the National Nuclear Data Center, Brookhaven National Laboratory, Upton, New York. www.nndc.bnl.gov.

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Desk Instruction 2.0, Rev. 1

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed -

Title: Appendix C of RPP-13437, *Technical Basis Document for Ventilation System Filtration Failures Leading to an Unfiltered Release*
Author: Paul D. Rittmann
Date: February 25, 2003

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

M. G. Piepho Mel G. Piepho — 2/25/03

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.

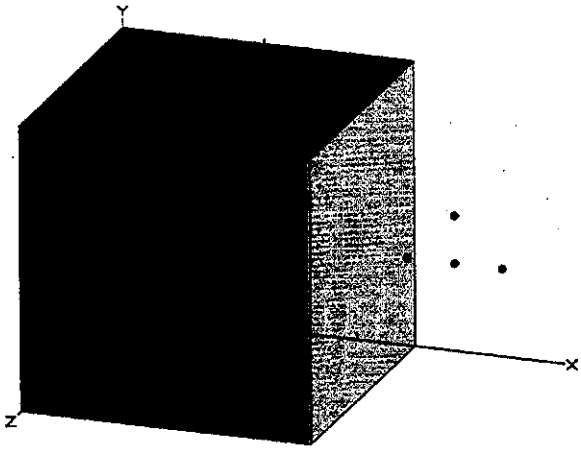
Attachment C-1. MICROSHIELD Output for the 1 ft by 1 ft by 1 ft Cases

MicroShield v5.05 (5.05-00321)
Fluor Daniel Northwest

Page : 1
DOS File: HEPA1S.MS5
Run Date: June 21, 2001
Run Time: 10:43:12 AM
Duration: 00:00:28

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: 1 by 1 HEPA Side
Description: 1 L DST Liquid on 1 ft by 1 ft HEPA -- Side
Geometry: 13 - Rectangular Volume



Source Dimensions

Length	30.48 cm	1 ft
Width	30.48 cm	1 ft
Height	30.48 cm	1 ft

Dose Points

	X	Y	Z
# 1	40.64 cm	15.24 cm	15.24 cm
	1 ft 4.0 in	6.0 in	6.0 in
# 2	35.56 cm	15.24 cm	15.24 cm
	1 ft 2.0 in	6.0 in	6.0 in
# 3	45.72 cm	15.24 cm	15.24 cm
	1 ft 6.0 in	6.0 in	6.0 in
# 4	40.64 cm	20.32 cm	15.24 cm
	1 ft 4.0 in	8.0 in	6.0 in

Shields

Shield Name	Dimension	Material	Density
Source	1728.0 in³	Mixed ->	0.0511
		Aluminum	0.031
		Concrete	0.0201
Shield 1	.125 in	Iron	7.9
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Ba-137m	3.1700e-001	1.1729e+010	1.1195e+001	4.1421e+005
Cs-137	3.3600e-001	1.2432e+010	1.1866e+001	4.3903e+005

Buildup
The material reference is : Shield 1

Integration Parameters

X Direction	30
Y Direction	30
Z Direction	30

Results - Dose Point # 1 - (16,6,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	5.842e-06	6.357e-06	4.867e-08	5.295e-08
0.0322	4.480e+08	1.995e-05	2.173e-05	1.605e-07	1.749e-07
0.0364	1.630e+08	1.561e-03	1.747e-03	8.871e-06	9.924e-06

Page : 2
DOS File: HEPA1S.MS5
Run Date: June 21, 2001
Run Time: 10:43:12 AM
Duration: 00:00:28

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.6616	1.055e+10	6.991e+05	8.498e+05	1.355e+03	1.648e+03
TOTALS:	1.141e+10	6.991e+05	8.498e+05	1.355e+03	1.648e+03

Results - Dose Point # 2 - (14,6,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	5.965e-06	6.490e-06	4.969e-08	5.406e-08
0.0322	4.480e+08	2.040e-05	2.222e-05	1.641e-07	1.788e-07
0.0364	1.630e+08	1.629e-03	1.822e-03	9.254e-06	1.035e-05
0.6616	1.055e+10	1.059e+06	1.320e+06	2.054e+03	2.559e+03
TOTALS:	1.141e+10	1.059e+06	1.320e+06	2.054e+03	2.559e+03

Results - Dose Point # 3 - (18,6,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	5.648e-06	6.145e-06	4.705e-08	5.118e-08
0.0322	4.480e+08	1.924e-05	2.096e-05	1.549e-07	1.687e-07
0.0364	1.630e+08	1.465e-03	1.639e-03	8.326e-06	9.314e-06
0.6616	1.055e+10	4.887e+05	5.885e+05	9.474e+02	1.141e+03
TOTALS:	1.141e+10	4.887e+05	5.885e+05	9.474e+02	1.141e+03

Results - Dose Point # 4 - (16,8,6) in

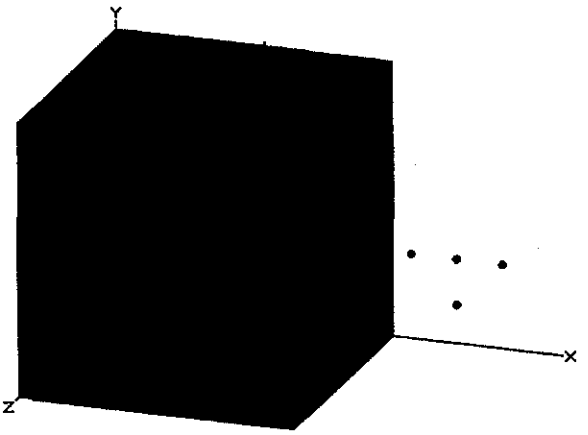
Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	5.721e-06	6.224e-06	4.765e-08	5.184e-08
0.0322	4.480e+08	1.951e-05	2.126e-05	1.570e-07	1.711e-07
0.0364	1.630e+08	1.515e-03	1.694e-03	8.605e-06	9.627e-06
0.6616	1.055e+10	6.775e+05	8.253e+05	1.313e+03	1.600e+03
TOTALS:	1.141e+10	6.775e+05	8.253e+05	1.313e+03	1.600e+03

MicroShield v5.05 (5.05-00321)
Fluor Daniel Northwest

Page : 1
DOS File: HEPA1F.MS5
Run Date: June 21, 2001
Run Time: 10:47:12 AM
Duration: 00:00:27

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: 1 by 1 HEPA Face
Description: 1 L DST Liquid on 1 ft by 1 ft HEPA -- Face
Geometry: 13 - Rectangular Volume



Source Dimensions

Length	30.48 cm	1 ft
Width	30.48 cm	1 ft
Height	30.48 cm	1 ft

Dose Points

	X	Y	Z
# 1	43.18 cm	15.24 cm	15.24 cm
	1 ft 5.0 in	6.0 in	6.0 in
# 2	38.1 cm	15.24 cm	15.24 cm
	1 ft 3.0 in	6.0 in	6.0 in
# 3	48.26 cm	15.24 cm	15.24 cm
	1 ft 7.0 in	6.0 in	6.0 in
# 4	43.18 cm	10.16 cm	15.24 cm
	1 ft 5.0 in	4.0 in	6.0 in

Shields

Shield Name	Dimension	Material	Density
Source	1728.0 in³	Mixed ->	0.0511
		Aluminum	0.031
		Concrete	0.0201
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	μCi/cm³	Bq/cm³
Ba-137m	3.1700e-001	1.1729e+010	1.1195e+001	4.1421e+005
Cs-137	3.3600e-001	1.2432e+010	1.1866e+001	4.3903e+005

Buildup
The material reference is : Source

Integration Parameters

X Direction	30
Y Direction	30
Z Direction	30

Results - Dose Point # 1 - (17,6,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	5.167e+02	6.066e+02	4.304e+00	5.052e+00
0.0322	4.480e+08	9.763e+02	1.147e+03	7.857e+00	9.231e+00
0.0364	1.630e+08	4.470e+02	5.289e+02	2.540e+00	3.005e+00
0.6616	1.055e+10	7.167e+05	7.442e+05	1.389e+03	1.443e+03

Page : 2
DOS File: HEPA1F.MS5
Run Date: June 21, 2001
Run Time: 10:47:12 AM
Duration: 00:00:27

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
TOTALS:	1.141e+10	7.187e+05	7.465e+05	1.404e+03	1.460e+03

Results - Dose Point # 2 - (15,6,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	7.840e+02	9.184e+02	6.530e+00	7.650e+00
0.0322	4.480e+08	1.481e+03	1.736e+03	1.192e+01	1.397e+01
0.0364	1.630e+08	6.767e+02	7.981e+02	3.845e+00	4.534e+00
0.6616	1.055e+10	1.077e+06	1.117e+06	2.088e+03	2.166e+03
TOTALS:	1.141e+10	1.080e+06	1.121e+06	2.111e+03	2.192e+03

Results - Dose Point # 3 - (19,6,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	3.620e+02	4.266e+02	3.016e+00	3.554e+00
0.0322	4.480e+08	6.843e+02	8.071e+02	5.507e+00	6.495e+00
0.0364	1.630e+08	3.143e+02	3.736e+02	1.786e+00	2.123e+00
0.6616	1.055e+10	5.088e+05	5.290e+05	9.863e+02	1.026e+03
TOTALS:	1.141e+10	5.101e+05	5.306e+05	9.966e+02	1.038e+03

Results - Dose Point # 4 - (17,4,6) in

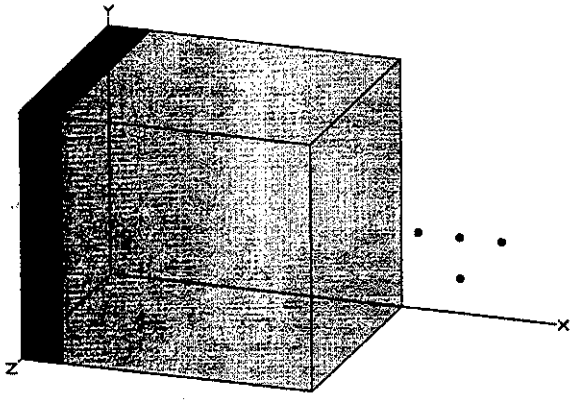
Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	5.002e+02	5.881e+02	4.167e+00	4.899e+00
0.0322	4.480e+08	9.453e+02	1.112e+03	7.607e+00	8.952e+00
0.0364	1.630e+08	4.334e+02	5.138e+02	2.462e+00	2.919e+00
0.6616	1.055e+10	6.980e+05	7.251e+05	1.353e+03	1.406e+03
TOTALS:	1.141e+10	6.999e+05	7.274e+05	1.367e+03	1.423e+03

MicroShield v5.05 (5.05-00321)
Fluor Daniel Northwest

Page : 1
DOS File: PRE1FACE.MS5
Run Date: June 21, 2001
Run Time: 10:51:18 AM
Duration: 00:00:19

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: 1 by 1 Prefilter
Description: 1 L DST Liquid on a 1 ft by 1 ft Prefilter -- Face
Geometry: 13 - Rectangular Volume



Source Dimensions

Length	5.08 cm	2.0 in
Width	30.48 cm	1 ft
Height	30.48 cm	1 ft

Dose Points

	X	Y	Z
# 1	48.26 cm	15.24 cm	15.24 cm
	1 ft 7.0 in	6.0 in	6.0 in
# 2	43.18 cm	15.24 cm	15.24 cm
	1 ft 5.0 in	6.0 in	6.0 in
# 3	53.34 cm	15.24 cm	15.24 cm
	1 ft 9.0 in	6.0 in	6.0 in
# 4	48.26 cm	10.16 cm	15.24 cm
	1 ft 7.0 in	4.0 in	6.0 in

Shields

Shield Name	Dimension	Material	Density
Source	288.0 in³	Mixed ->	0.0512
		Aluminum	0.031
		Concrete	0.0202
Shield 1	12.0 in	Mixed ->	0.0512
		Aluminum	0.031
		Concrete	0.0202
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Ba-137m	3.1700e-001	1.1729e+010	6.7168e+001	2.4852e+006
Cs-137	3.3600e-001	1.2432e+010	7.1194e+001	2.6342e+006

Buildup
The material reference is : Shield 1

Integration Parameters

X Direction	20
Y Direction	30
Z Direction	30

Results - Dose Point # 1 - (19,6,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	5.416e+01	8.230e+01	4.512e-01	6.855e-01

Page : 2
DOS File: PRE1FACE.MS5
Run Date: June 21, 2001
Run Time: 10:51:18 AM
Duration: 00:00:19

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0322	4.480e+08	1.061e+02	1.621e+02	8.537e-01	1.304e+00
0.0364	1.630e+08	6.575e+01	1.052e+02	3.736e-01	5.980e-01
0.6616	1.055e+10	2.176e+05	2.434e+05	4.219e+02	4.718e+02
TOTALS:	1.141e+10	2.179e+05	2.437e+05	4.236e+02	4.744e+02

Results - Dose Point # 2 - (17,6,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	6.667e+01	1.014e+02	5.553e-01	8.449e-01
0.0322	4.480e+08	1.306e+02	1.999e+02	1.051e+00	1.609e+00
0.0364	1.630e+08	8.121e+01	1.302e+02	4.614e-01	7.399e-01
0.6616	1.055e+10	2.708e+05	3.029e+05	5.249e+02	5.873e+02
TOTALS:	1.141e+10	2.710e+05	3.034e+05	5.270e+02	5.904e+02

Results - Dose Point # 3 - (21,6,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	4.475e+01	6.793e+01	3.728e-01	5.659e-01
0.0322	4.480e+08	8.763e+01	1.338e+02	7.052e-01	1.076e+00
0.0364	1.630e+08	5.420e+01	8.664e+01	3.079e-01	4.922e-01
0.6616	1.055e+10	1.785e+05	1.995e+05	3.460e+02	3.868e+02
TOTALS:	1.141e+10	1.787e+05	1.998e+05	3.474e+02	3.890e+02

Results - Dose Point # 4 - (19,4,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	5.322e+01	8.093e+01	4.433e-01	6.741e-01
0.0322	4.480e+08	1.043e+02	1.594e+02	8.390e-01	1.283e+00
0.0364	1.630e+08	6.473e+01	1.038e+02	3.678e-01	5.895e-01
0.6616	1.055e+10	2.153e+05	2.409e+05	4.174e+02	4.670e+02
TOTALS:	1.141e+10	2.155e+05	2.412e+05	4.191e+02	4.696e+02

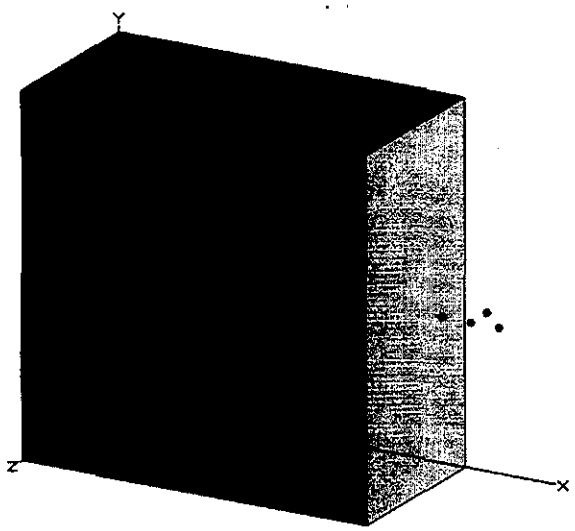
Attachment C-2. MICROSHIELD Output for the 2 ft by 2 ft by 1 ft Cases

MicroShield v5.05 (5.05-00321)
Fluor Daniel Northwest

Page : 1
DOS File: HEPA-2S.MS5
Run Date: June 27, 2001
Run Time: 12:41:31 PM
Duration: 00:00:19

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: 2 by 2 Side
Description: 1 L DST Liquids in a 2 ft by 2 ft HEPA Filter -- Side
Geometry: 13 - Rectangular Volume



Source Dimensions

Length	60.96 cm	2 ft
Width	30.48 cm	1 ft
Height	60.96 cm	2 ft

Dose Points

	X	Y	Z
# 1	71.12 cm	30.48 cm	15.24 cm
	2 ft 4.0 in	1 ft	6.0 in
# 2	66.04 cm	30.48 cm	15.24 cm
	2 ft 2.0 in	1 ft	6.0 in
# 3	76.2 cm	30.48 cm	15.24 cm
	2 ft 6.0 in	1 ft	6.0 in
# 4	71.12 cm	30.48 cm	10.16 cm
	2 ft 4.0 in	1 ft	4.0 in

Shields

Shield Name	Dimension	Material	Density
Source	6912.0 in³	Mixed ->	0.0512
		Aluminum	0.031
		Concrete	0.0202
Shield 1	.125 in	Iron	7.9
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	μCi/cm³	Bq/cm³
Ba-137m	3.1700e-001	1.1729e+010	2.7987e+000	1.0355e+005
Cs-137	3.3600e-001	1.2432e+010	2.9664e+000	1.0976e+005

Buildup
The material reference is : Shield 1

Integration Parameters

X Direction	30
Y Direction	30
Z Direction	20

Results - Dose Point # 1 - (28,12,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	1.741e-06	1.895e-06	1.450e-08	1.579e-08
0.0322	4.480e+08	5.983e-06	6.521e-06	4.815e-08	5.248e-08
0.0364	1.630e+08	4.995e-04	5.590e-04	2.838e-06	3.176e-06

Page : 2
DOS File: HEPA-2S.MS5
Run Date: June 27, 2001
Run Time: 12:41:31 PM
Duration: 00:00:19

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.6616	1.055e+10	3.179e+05	3.999e+05	6.162e+02	7.753e+02
TOTALS:	1.141e+10	3.179e+05	3.999e+05	6.162e+02	7.753e+02

Results - Dose Point # 2 - (26,12,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	1.774e-06	1.931e-06	1.478e-08	1.609e-08
0.0322	4.480e+08	6.105e-06	6.654e-06	4.913e-08	5.355e-08
0.0364	1.630e+08	5.171e-04	5.786e-04	2.938e-06	3.288e-06
0.6616	1.055e+10	4.292e+05	5.530e+05	8.320e+02	1.072e+03
TOTALS:	1.141e+10	4.292e+05	5.530e+05	8.320e+02	1.072e+03

Results - Dose Point # 3 - (30,12,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	1.697e-06	1.848e-06	1.414e-08	1.539e-08
0.0322	4.480e+08	5.825e-06	6.348e-06	4.688e-08	5.109e-08
0.0364	1.630e+08	4.778e-04	5.346e-04	2.715e-06	3.038e-06
0.6616	1.055e+10	2.436e+05	3.032e+05	4.722e+02	5.878e+02
TOTALS:	1.141e+10	2.436e+05	3.032e+05	4.722e+02	5.878e+02

Results - Dose Point # 4 - (28,12,4) in

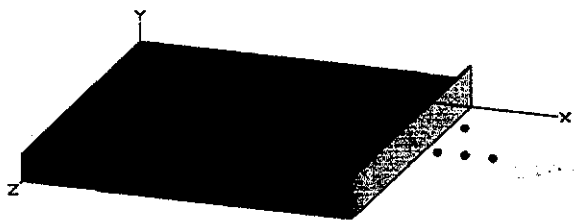
Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	1.697e-06	1.847e-06	1.413e-08	1.538e-08
0.0322	4.480e+08	5.825e-06	6.349e-06	4.688e-08	5.109e-08
0.0364	1.630e+08	4.830e-04	5.405e-04	2.744e-06	3.071e-06
0.6616	1.055e+10	3.101e+05	3.910e+05	6.012e+02	7.580e+02
TOTALS:	1.141e+10	3.101e+05	3.910e+05	6.012e+02	7.580e+02

MicroShield v5.05 (5.05-00321)
Fluor Daniel Northwest

Page : 1
DOS File: PRE2SIDE.MS5
Run Date: June 21, 2001
Run Time: 12:49:13 PM
Duration: 00:00:19

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: 2 by 2 Side
Description: 1 L DST Liquids in a 2 ft by 2 ft PreFilter -- Side
Geometry: 13 - Rectangular Volume



Source Dimensions

Length	60.96 cm	2 ft
Width	60.96 cm	2 ft
Height	5.08 cm	2.0 in

Dose Points

	X	Y	Z
# 1	71.12 cm	2.54 cm	30.48 cm
	2 ft 4.0 in	1.0 in	1 ft
# 2	66.04 cm	2.54 cm	30.48 cm
	2 ft 2.0 in	1.0 in	1 ft
# 3	76.2 cm	2.54 cm	30.48 cm
	2 ft 6.0 in	1.0 in	1 ft
# 4	71.12 cm	7.62 cm	30.48 cm
	2 ft 4.0 in	3.0 in	1 ft

Shields

Shield Name	Dimension	Material	Density
Source	1152.0 in³	Mixed ->	0.0512
		Aluminum	0.031
		Concrete	0.0202
Shield 1	.125 in	Iron	7.9
Air Gap		Air	0.00122
Immersion		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Ba-137m	3.1700e-001	1.1729e+010	1.6792e+001	6.2131e+005
Cs-137	3.3600e-001	1.2432e+010	1.7799e+001	6.5855e+005

Buildup
The material reference is : Shield 1

Integration Parameters

X Direction	30
Y Direction	20
Z Direction	30

Results - Dose Point # 1 - (28,1,12) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	4.181e-06	4.546e-06	3.483e-08	3.787e-08
0.0322	4.480e+08	1.412e-05	1.537e-05	1.136e-07	1.237e-07

Page : 2
DOS File: PRE2SIDE.MS5
Run Date: June 21, 2001
Run Time: 12:49:13 PM
Duration: 00:00:19

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0364	1.630e+08	9.986e-04	1.117e-03	5.673e-06	6.345e-06
0.6616	1.055e+10	3.639e+05	4.513e+05	7.055e+02	8.750e+02
TOTALS:	1.141e+10	3.639e+05	4.513e+05	7.055e+02	8.750e+02

Results - Dose Point # 2 - (26,1,12) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	5.434e-06	5.908e-06	4.526e-08	4.921e-08
0.0322	4.480e+08	1.838e-05	2.001e-05	1.479e-07	1.610e-07
0.0364	1.630e+08	1.317e-03	1.472e-03	7.481e-06	8.366e-06
0.6616	1.055e+10	5.492e+05	6.890e+05	1.065e+03	1.336e+03
TOTALS:	1.141e+10	5.492e+05	6.890e+05	1.065e+03	1.336e+03

Results - Dose Point # 3 - (30,1,12) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	3.358e-06	3.651e-06	2.797e-08	3.041e-08
0.0322	4.480e+08	1.134e-05	1.234e-05	9.126e-08	9.935e-08
0.0364	1.630e+08	8.017e-04	8.965e-04	4.555e-06	5.094e-06
0.6616	1.055e+10	2.658e+05	3.278e+05	5.152e+02	6.356e+02
TOTALS:	1.141e+10	2.658e+05	3.278e+05	5.152e+02	6.356e+02

Results - Dose Point # 4 - (28,3,12) in

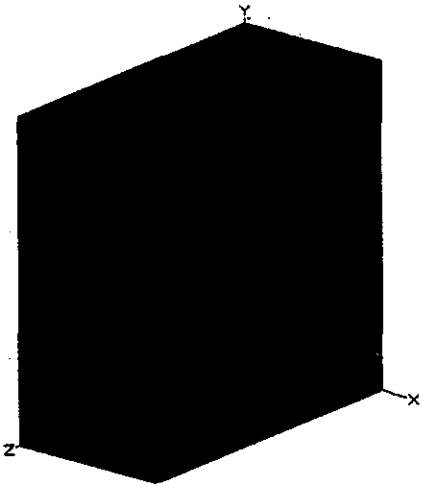
Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	3.274e-06	3.562e-06	2.727e-08	2.967e-08
0.0322	4.480e+08	1.115e-05	1.214e-05	8.971e-08	9.771e-08
0.0364	1.630e+08	8.451e-04	9.453e-04	4.802e-06	5.371e-06
0.6616	1.055e+10	3.518e+05	4.314e+05	6.820e+02	8.363e+02
TOTALS:	1.141e+10	3.518e+05	4.314e+05	6.820e+02	8.363e+02

MicroShield v5.05 (5.05-00321)
Fluor Daniel Northwest

Page : 1
DOS File: HEPA-2F.MS5
Run Date: June 21, 2001
Run Time: 12:44:11 PM
Duration: 00:00:55

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: 2 by 2 Face
Description: 1 L DST Liquids in a 2 ft by 2 ft HEPA Filter -- Face
Geometry: 13 - Rectangular Volume



Source Dimensions

Length	30.48 cm	1 ft
Width	60.96 cm	2 ft
Height	60.96 cm	2 ft

Dose Points

	X	Y	Z
# 1	34.925 cm	30.48 cm	30.48 cm
	1 ft 1.7 in	1 ft	1 ft
# 2	34.925 cm	25.4 cm	30.48 cm
	1 ft 1.7 in	10.0 in	1 ft
# 3	34.925 cm	30.48 cm	25.4 cm
	1 ft 1.7 in	1 ft	10.0 in

Shields

Shield Name	Dimension	Material	Density
Source	6912.0 in³	Mixed ->	0.0512
		Aluminum	0.031
		Concrete	0.0202
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Ba-137m	3.1700e-001	1.1729e+010	2.7987e+000	1.0355e+005
Cs-137	3.3600e-001	1.2432e+010	2.9664e+000	1.0976e+005

Buildup
The material reference is : Source

Integration Parameters

X Direction	30
Y Direction	50
Z Direction	50

Results - Dose Point # 1 - (13.75,12,12) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	4.451e+02	5.462e+02	3.707e+00	4.550e+00
0.0322	4.480e+08	8.448e+02	1.039e+03	6.799e+00	8.360e+00
0.0364	1.630e+08	4.034e+02	5.045e+02	2.292e+00	2.866e+00
0.6616	1.055e+10	7.342e+05	7.740e+05	1.423e+03	1.501e+03
TOTALS:	1.141e+10	7.359e+05	7.761e+05	1.436e+03	1.516e+03

Results - Dose Point # 2 - (13.75,10,12) in

Page : 2
DOS File: HEPA-2F.MS5
Run Date: June 21, 2001
Run Time: 12:44:11 PM
Duration: 00:00:55

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	4.416e+02	5.417e+02	3.678e+00	4.512e+00
0.0322	4.480e+08	8.382e+02	1.030e+03	6.745e+00	8.291e+00
0.0364	1.630e+08	4.002e+02	5.003e+02	2.274e+00	2.842e+00
0.6616	1.055e+10	7.284e+05	7.679e+05	1.412e+03	1.489e+03
TOTALS:	1.141e+10	7.300e+05	7.700e+05	1.425e+03	1.504e+03

Results - Dose Point # 3 - (13.75,12,10) in

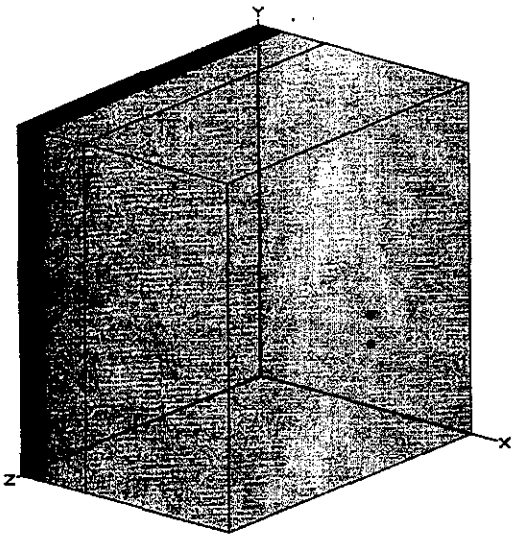
Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	4.416e+02	5.417e+02	3.678e+00	4.512e+00
0.0322	4.480e+08	8.382e+02	1.030e+03	6.745e+00	8.291e+00
0.0364	1.630e+08	4.002e+02	5.003e+02	2.274e+00	2.842e+00
0.6616	1.055e+10	7.284e+05	7.679e+05	1.412e+03	1.489e+03
TOTALS:	1.141e+10	7.300e+05	7.700e+05	1.425e+03	1.504e+03

MicroShield v5.05 (5.05-00321)
Fluor Daniel Northwest

Page : 1
DOS File: PRE2FACE.MS5
Run Date: June 21, 2001
Run Time: 12:52:25 PM
Duration: 00:00:17

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: 2 by 2 Face
Description: 1 L DST Liquids in a 2 ft by 2 ft HEPA PreFilter -- Face
Geometry: 13 - Rectangular Volume



Source Dimensions

Length	5.08 cm	2.0 in
Width	60.96 cm	2 ft
Height	60.96 cm	2 ft

Dose Points

	X	Y	Z
# 1	48.895 cm	30.48 cm	30.48 cm
	1 ft 7.3 in	1 ft	1 ft
# 2	48.895 cm	25.4 cm	30.48 cm
	1 ft 7.3 in	10.0 in	1 ft

Shields

Shield Name	Dimension	Material	Density
Source	1152.0 in³	Mixed ->	0.0512
		Aluminum	0.031
		Concrete	0.0202
Shield 1	3.5 in	Air	0.00122
Shield 2	12.0 in	Mixed ->	0.0512
		Aluminum	0.031
		Concrete	0.0202
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Ba-137m	3.1700e-001	1.1729e+010	1.6792e+001	6.2131e+005
Cs-137	3.3600e-001	1.2432e+010	1.7799e+001	6.5855e+005

Buildup
The material reference is : Shield 2

Integration Parameters

X Direction	20
Y Direction	40
Z Direction	40

Results - Dose Point # 1 - (19.25,12,12) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	3.923e+01	6.048e+01	3.268e-01	5.037e-01
0.0322	4.480e+08	7.711e+01	1.196e+02	6.206e-01	9.627e-01
0.0364	1.630e+08	4.933e+01	8.070e+01	2.803e-01	4.585e-01
0.6616	1.055e+10	1.775e+05	2.004e+05	3.441e+02	3.884e+02

Page : 2
DOS File: PRE2FACE.MS5
Run Date: June 21, 2001
Run Time: 12:52:25 PM
Duration: 00:00:17

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
TOTALS:	1.141e+10	1.777e+05	2.006e+05	3.454e+02	3.904e+02

Results - Dose Point # 2 - (19.25,10,12) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	3.883e+01	5.989e+01	3.235e-01	4.988e-01
0.0322	4.480e+08	7.635e+01	1.185e+02	6.144e-01	9.534e-01
0.0364	1.630e+08	4.888e+01	8.000e+01	2.777e-01	4.545e-01
0.6616	1.055e+10	1.763e+05	1.991e+05	3.419e+02	3.860e+02
TOTALS:	1.141e+10	1.765e+05	1.994e+05	3.431e+02	3.879e+02

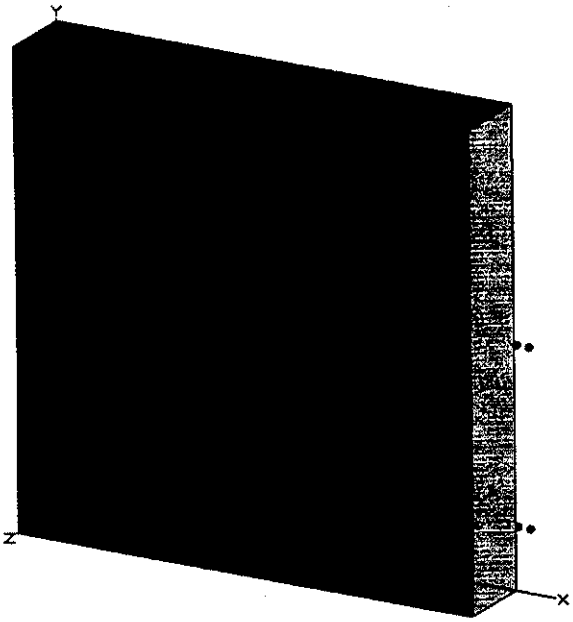
Attachment C-3. MICROSHIELD Output for the 6 ft by 6 ft by 1 ft Cases

MicroShield v5.05 (5.05-00321)
Fluor Daniel Northwest

Page : 1
DOS File: HEPA6S.MS5
Run Date: June 21, 2001
Run Time: 1:40:25 PM
Duration: 00:01:02

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: 6 by 6 HEPA Side
Description: 1 L DST Liquids in a 6 ft by 6 ft HEPA Filter -- Side
Geometry: 13 - Rectangular Volume



Source Dimensions

Length	182.88 cm	6 ft
Width	30.48 cm	1 ft
Height	182.88 cm	6 ft

Dose Points

	X	Y	Z
# 1	193.04 cm 6 ft 4.0 in	30.48 cm 1 ft	15.24 cm 6.0 in
# 2	187.96 cm 6 ft 2.0 in	30.48 cm 1 ft	15.24 cm 6.0 in
# 3	198.12 cm 6 ft 6.0 in	30.48 cm 1 ft	15.24 cm 6.0 in
# 4	193.04 cm 6 ft 4.0 in	30.48 cm 1 ft	25.4 cm 10.0 in
# 5	193.04 cm 6 ft 4.0 in	99.06 cm 3 ft 3.0 in	15.24 cm 6.0 in
# 6	198.12 cm 6 ft 6.0 in	99.06 cm 3 ft 3.0 in	15.24 cm 6.0 in

Shields

Shield Name	Dimension	Material	Density
Source	6.22e+04 in³	Mixed ->	0.1059
		Aluminum	0.0308
		Concrete	0.0201
		Iron	0.055
Shield 1	.125 in	Iron	7.9
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Ba-137m	3.1700e-001	1.1729e+010	3.1097e-001	1.1506e+004
Cs-137	3.3600e-001	1.2432e+010	3.2960e-001	1.2195e+004

Buildup
The material reference is : Shield 1

Integration Parameters

X Direction	40
Y Direction	40
Z Direction	20

Results - Dose Point # 1 - (76,12,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.454e-08	2.673e-08	2.044e-10	2.226e-10

Page : 2
DOS File: HEPA6S.MS5
Run Date: June 21, 2001
Run Time: 1:40:25 PM
Duration: 00:01:02

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0322	4.480e+08	8.538e-08	9.310e-08	6.871e-10	7.493e-10
0.0364	1.630e+08	8.395e-06	9.400e-06	4.770e-08	5.340e-08
0.6616	1.055e+10	4.629e+04	6.886e+04	8.975e+01	1.335e+02
TOTALS:	1.141e+10	4.629e+04	6.886e+04	8.975e+01	1.335e+02

Results - Dose Point # 2 - (74,12,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.439e-08	2.656e-08	2.032e-10	2.212e-10
0.0322	4.480e+08	8.487e-08	9.254e-08	6.830e-10	7.448e-10
0.0364	1.630e+08	8.387e-06	9.390e-06	4.765e-08	5.335e-08
0.6616	1.055e+10	5.782e+04	8.639e+04	1.121e+02	1.675e+02
TOTALS:	1.141e+10	5.782e+04	8.639e+04	1.121e+02	1.675e+02

Results - Dose Point # 3 - (78,12,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.446e-08	2.663e-08	2.037e-10	2.219e-10
0.0322	4.480e+08	8.508e-08	9.277e-08	6.847e-10	7.466e-10
0.0364	1.630e+08	8.328e-06	9.324e-06	4.732e-08	5.297e-08
0.6616	1.055e+10	3.827e+04	5.707e+04	7.419e+01	1.106e+02
TOTALS:	1.141e+10	3.827e+04	5.707e+04	7.419e+01	1.106e+02

Results - Dose Point # 4 - (76,12,10) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.348e-08	2.556e-08	1.956e-10	2.129e-10
0.0322	4.480e+08	8.140e-08	8.874e-08	6.551e-10	7.142e-10
0.0364	1.630e+08	7.669e-06	8.585e-06	4.357e-08	4.878e-08
0.6616	1.055e+10	4.272e+04	6.457e+04	8.282e+01	1.252e+02
TOTALS:	1.141e+10	4.272e+04	6.457e+04	8.282e+01	1.252e+02

Results - Dose Point # 5 - (76,39,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.453e-08	2.671e-08	2.043e-10	2.225e-10
0.0322	4.480e+08	8.533e-08	9.304e-08	6.867e-10	7.488e-10
0.0364	1.630e+08	8.394e-06	9.398e-06	4.769e-08	5.340e-08
0.6616	1.055e+10	5.266e+04	7.896e+04	1.021e+02	1.531e+02
TOTALS:	1.141e+10	5.266e+04	7.896e+04	1.021e+02	1.531e+02

Results - Dose Point # 6 - (78,39,6) in

Page : 3
DOS File: HEPA6S.MS5
Run Date: June 21, 2001
Run Time: 1:40:25 PM
Duration: 00:01:02

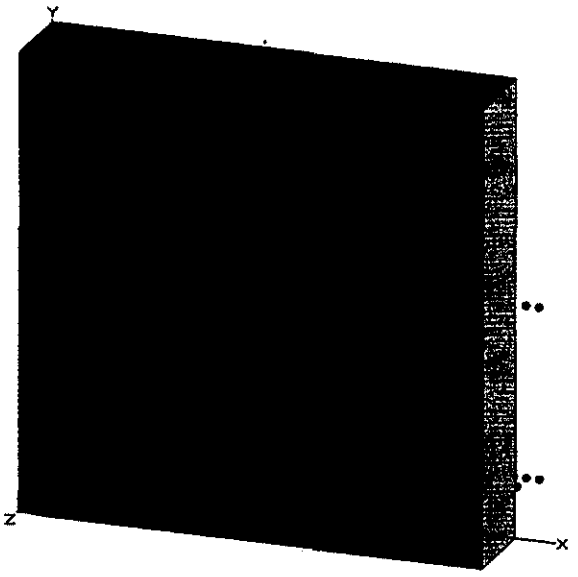
Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.446e-08	2.663e-08	2.038e-10	2.219e-10
0.0322	4.480e+08	8.508e-08	9.277e-08	6.847e-10	7.466e-10
0.0364	1.630e+08	8.328e-06	9.324e-06	4.732e-08	5.297e-08
0.6616	1.055e+10	4.433e+04	6.627e+04	8.594e+01	1.285e+02
TOTALS:	1.141e+10	4.433e+04	6.627e+04	8.594e+01	1.285e+02

MicroShield v5.05 (5.05-00321)
Fluor Daniel Northwest

Page : 1
DOS File: PRE6SIDE.MS5
Run Date: June 21, 2001
Run Time: 1:50:27 PM
Duration: 00:01:00

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: 6 by 6 Prefilter
Description: 1 L DST Liquids in a 6 ft by 6 ft Pre-Filter -- Side
Geometry: 13 - Rectangular Volume



Source Dimensions

Length	182.88 cm	6 ft
Width	35.56 cm	1 ft 2.0 in
Height	182.88 cm	6 ft

Dose Points

	X	Y	Z
# 1	193.04 cm 6 ft 4.0 in	30.48 cm 1 ft	15.24 cm 6.0 in
# 2	187.96 cm 6 ft 2.0 in	30.48 cm 1 ft	15.24 cm 6.0 in
# 3	198.12 cm 6 ft 6.0 in	30.48 cm 1 ft	15.24 cm 6.0 in
# 4	193.04 cm 6 ft 4.0 in	30.48 cm 1 ft	25.4 cm 10.0 in
# 5	193.04 cm 6 ft 4.0 in	99.06 cm 3 ft 3.0 in	15.24 cm 6.0 in
# 6	198.12 cm 6 ft 6.0 in	99.06 cm 3 ft 3.0 in	15.24 cm 6.0 in

Shields

Shield Name	Dimension	Material	Density
Source	7.26e+04 in³	Mixed ->	0.1059
		Aluminum	0.0308
		Concrete	0.0201
		Iron	0.055
Shield 1	.125 in	Iron	7.9
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	μCi/cm³	Bq/cm³
Ba-137m	3.1700e-001	1.1729e+010	2.6654e-001	9.8620e+003
Cs-137	3.3600e-001	1.2432e+010	2.8252e-001	1.0453e+004

Buildup
The material reference is : Shield 1

Integration Parameters

X Direction	40
Y Direction	40
Z Direction	20

Results - Dose Point # 1 - (76,12,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.104e-08	2.291e-08	1.752e-10	1.908e-10

Page : 2
DOS File: PRE6SIDE.MS5
Run Date: June 21, 2001
Run Time: 1:50:27 PM
Duration: 00:01:00

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0322	4.480e+08	7.319e-08	7.980e-08	5.890e-10	6.422e-10
0.0364	1.630e+08	7.200e-06	8.061e-06	4.091e-08	4.580e-08
0.6616	1.055e+10	4.477e+04	6.706e+04	8.680e+01	1.300e+02
TOTALS:	1.141e+10	4.477e+04	6.706e+04	8.680e+01	1.300e+02

Results - Dose Point # 2 - (74,12,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.091e-08	2.277e-08	1.742e-10	1.896e-10
0.0322	4.480e+08	7.275e-08	7.932e-08	5.855e-10	6.384e-10
0.0364	1.630e+08	7.189e-06	8.049e-06	4.084e-08	4.573e-08
0.6616	1.055e+10	5.506e+04	8.305e+04	1.067e+02	1.610e+02
TOTALS:	1.141e+10	5.506e+04	8.305e+04	1.067e+02	1.610e+02

Results - Dose Point # 3 - (78,12,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.097e-08	2.284e-08	1.747e-10	1.902e-10
0.0322	4.480e+08	7.296e-08	7.956e-08	5.872e-10	6.403e-10
0.0364	1.630e+08	7.162e-06	8.018e-06	4.069e-08	4.556e-08
0.6616	1.055e+10	3.737e+04	5.602e+04	7.245e+01	1.086e+02
TOTALS:	1.141e+10	3.737e+04	5.602e+04	7.245e+01	1.086e+02

Results - Dose Point # 4 - (76,12,10) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.102e-08	2.288e-08	1.751e-10	1.906e-10
0.0322	4.480e+08	7.309e-08	7.970e-08	5.882e-10	6.414e-10
0.0364	1.630e+08	7.151e-06	8.007e-06	4.063e-08	4.549e-08
0.6616	1.055e+10	4.331e+04	6.528e+04	8.396e+01	1.265e+02
TOTALS:	1.141e+10	4.331e+04	6.528e+04	8.396e+01	1.265e+02

Results - Dose Point # 5 - (76,39,6) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.102e-08	2.289e-08	1.751e-10	1.907e-10
0.0322	4.480e+08	7.314e-08	7.975e-08	5.886e-10	6.419e-10
0.0364	1.630e+08	7.199e-06	8.060e-06	4.090e-08	4.579e-08
0.6616	1.055e+10	5.106e+04	7.706e+04	9.898e+01	1.494e+02
TOTALS:	1.141e+10	5.106e+04	7.706e+04	9.898e+01	1.494e+02

Results - Dose Point # 6 - (78,39,6) in

Page : 3
DOS File: PRE6SIDE.MS5
Run Date: June 21, 2001
Run Time: 1:50:27 PM
Duration: 00:01:00

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.098e-08	2.284e-08	1.747e-10	1.902e-10
0.0322	4.480e+08	7.296e-08	7.956e-08	5.872e-10	6.403e-10
0.0364	1.630e+08	7.162e-06	8.018e-06	4.069e-08	4.556e-08
0.6616	1.055e+10	4.336e+04	6.512e+04	8.406e+01	1.263e+02
TOTALS:	1.141e+10	4.336e+04	6.512e+04	8.406e+01	1.263e+02

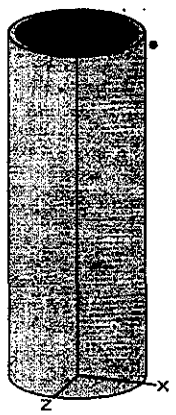
Attachment C-4. MICROSHIELD Output for the HEME Cases

MicroShield v5.05 (5.05-00321)
Fluor Daniel Northwest

Page : 1
DOS File: HEME1.MS5
Run Date: June 21, 2001
Run Time: 2:16:14 PM
Duration: 00:00:09

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: HEME Filter
Description: Dose Rates at Contact Location
Geometry: 12 - Annular Cylinder - External Dose Point



Source Dimensions

Height	273.685 cm	8 ft 11.8 in
Radius	33.02 cm	1 ft 1.0 in

Dose Points

	X	Y	Z
# 1	60.96 cm	271.78 cm	0 cm
	2 ft	8 ft 11.0 in	0.0 in

Shields

Shield Name	Dimension	Material	Density
Cyl. Core	33.02 in³	Air	0.00122
Source	5.0 in	Concrete	0.272
Shield 3	2.0 in	Air	0.00122
Shield 4	.25 in	Iron	7.86
Transition	1.0 in	Air	0.00122
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Ba-137m	3.1700e-001	1.1729e+010	3.6869e-001	1.3641e+004

Buildup
The material reference is : Shield 4

Integration Parameters

Radial	20
Circumferential	30
Y Direction (axial)	30

Results

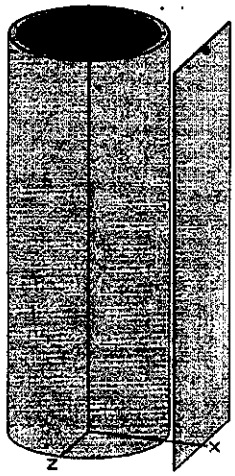
Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	8.678e-16	9.595e-16	7.229e-18	7.992e-18
0.0322	4.480e+08	5.204e-15	5.771e-15	4.188e-17	4.644e-17
0.0364	1.630e+08	5.505e-11	6.250e-11	3.128e-13	3.551e-13
0.6616	1.055e+10	1.661e+04	3.248e+04	3.220e+01	6.297e+01
TOTALS:	1.141e+10	1.661e+04	3.248e+04	3.220e+01	6.297e+01

MicroShield v5.05 (5.05-00321)
Fluor Daniel Northwest

Page : 1
DOS File: HEME2.MS5
Run Date: June 21, 2001
Run Time: 2:22:06 PM
Duration: 00:00:17

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: HEME Filter
Description: Dose Rates at ARM Locations
Geometry: 12 - Annular Cylinder - External Dose Point



Source Dimensions

Height	273.685 cm	8 ft 11.8 in
Radius	33.02 cm	1 ft 1.0 in

Dose Points

	X	Y	Z
# 1	79.53248 cm	271.78 cm	0 cm
	2 ft 7.3 in	8 ft 11.0 in	0.0 in
# 2	79.53248 cm	91.44 cm	0 cm
	2 ft 7.3 in	3 ft	0.0 in

Shields

Shield Name	Dimension	Material	Density
Cyl. Core	33.02 in³	Air	0.00122
Source	5.0 in	Concrete	0.272
Shield 3	2.0 in	Air	0.00122
Shield 4	.25 in	Iron	7.86
Transition	9.75 in	Air	0.00122
Shield 6	.312 in	Iron	7.86
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Ba-137m	3.1700e-001	1.1729e+010	3.6869e-001	1.3641e+004

Buildup
The material reference is : Shield 6

Integration Parameters

Radial	20
Circumferential	30
Y Direction (axial)	30

Results - Dose Point # 1 - (31.312,107,0) in

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	2.582e-34	3.923e-25	2.151e-36	3.268e-27
0.0322	4.480e+08	6.213e-33	7.354e-25	5.001e-35	5.918e-27
0.0364	1.630e+08	1.063e-23	1.276e-23	6.041e-26	7.251e-26
0.6616	1.055e+10	6.384e+03	1.613e+04	1.238e+01	3.127e+01
TOTALS:	1.141e+10	6.384e+03	1.613e+04	1.238e+01	3.127e+01

Results - Dose Point # 2 - (31.312,36,0) in

Page : 2
DOS File: HEME2.MS5
Run Date: June 21, 2001
Run Time: 2:22:06 PM
Duration: 00:00:17

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0318	2.428e+08	3.849e-34	6.186e-25	3.206e-36	5.153e-27
0.0322	4.480e+08	9.310e-33	1.160e-24	7.493e-35	9.333e-27
0.0364	1.630e+08	1.673e-23	2.007e-23	9.505e-26	1.140e-25
0.6616	1.055e+10	1.160e+04	2.862e+04	2.249e+01	5.548e+01
TOTALS:	1.141e+10	1.160e+04	2.862e+04	2.249e+01	5.548e+01

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APPENDIX D

ROTARY MODE CORE SAMPLING SYSTEM PARAMETERS

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APPENDIX D

ROTARY MODE CORE SAMPLING SYSTEM PARAMETERS

The rotary mode core sampling (RMCS) ventilation system is a temporary, portable exhauster system that is installed on single-shell tanks (SST) during RMCS operations. It consists of a single train of two high-efficiency particulate air (HEPA) filters in series with a prefilter upstream of the first-stage HEPA filter. The filter train is serviced by a single fan and a short stack. The overall arrangement of the system is shown in Figure D-1. The prefilter has dimensions of 56.8 cm × 56.8 cm × 5.1 cm (22.4 in. × 22.4 in. × 2 in.) and the two HEPA filters are 56.8 cm × 56.8 cm × 10.2 cm (22.4 in. × 22.4 in. × 4 in.). The exhauster system is equipped with a maximum flow-rate shutdown at 250 ft^3/min. For purposes of estimating the unfiltered release rate from the tank headspace in case of a filtration failure (Appendix B), an exhaust rate of 500 ft^3/min (236 L/s) was assumed for conservatism.

Partition Fraction

RPP-4826, *Experience with Aerosol Generation During Rotary Mode Core Sampling in the Hanford Single Shell Waste Tanks*, provides all available waste aerosol data from all RMCS sampling events from the start of nitrogen-purged RMCS in November 1994 through the last event in June 1999. From RPP-4826, Table 2, the weighted-average tank headspace waste aerosol concentration during RMCS operation was 2.4 E-05 g/m^3 (0.024 mg/m^3).

The values in RPP-4826, Table 2, are based upon three distinct measurement methods — non-destructive assay (NDA) of the exhauster HEPA filters, dose rate measurements taken on the exhauster filter housing, and analysis of the filter papers removed from the combustible gas meter (CGM) sampling line. The CGM filter papers are located in-line with the CGM and are used to filter tank air drawn directly from the tank headspace for flammable gas monitoring purposes.

Concentrations based on NDA and dose rate were calculated by measuring material on the exhauster filters and dividing by the total off-gas flow. Concentrations based upon CGM filter papers were calculated by measuring material on the CGM filter papers and dividing by the total CGM air flow. CGM filter paper-based waste aerosol concentrations were generally higher than concentrations based on the other two methods. For conservatism the CGM filter paper data were used to estimate the tank headspace concentration for the exhauster unfiltered release calculations in Appendix B.

RPP-4826, Table 2, indicates the weighted-average tank headspace aerosol concentration based on CGM filter paper data is 4.0 E-05 g/m^3 (0.04 mg/m^3). There were 42 CGM filter paper data points (14 total beta, 14 total alpha, and 14 ^{137}Cs) from 14 RMCS CGM sampling periods in eight tanks during which 79 RMCS segments were obtained. For conservatism, eight of the total alpha data points were not used since the data were very low and had $> \pm 100\%$ analytical error. The total alpha concentrations for these eight samples were at or near background and averaged two orders of magnitude less than the average of the

remaining 34. For example, 241-SX-101, Riser 4 CGM filter papers showed 3.89 E-05 ±13.1% μCi α present; this quantity was used to calculate a tank headspace concentration. The 241-SX-103 Riser 7 CGM filter paper showed 3.36 E-07 ±113% μCi α present and this data point was not used. The data from RPP-4826 for the 34 samples used are repeated here in Table D-1.

The unweighted average of these 34 concentrations and standard deviation (σ) is 4.2 E-05 ± 7.6 E-05 g/m^3. Taking the highest data point of 3.5 E-04 g/m^3 and adding a 3σ deviation gives the following:

$$3.5\text{ E-04} + (3 \times 7.6\text{ E-05}) = 5.8\text{ E-04 g/m}^3$$

The actual density of SST saltcake at zero porosity is typically in the range of 2-2.5 g/cm^3. Conservatively assuming a density of 1.6 g/cm^3 (SST sludge), the above aerosol mass concentration corresponds to a volume concentration of 3.6E-10 L of solids per L of air. Using a value of 1.6 g/cm^3 is conservative since the smaller the density, the larger the calculated release volume. Since the saltcake concentration in the saltcake being core-drilled is 1 L/L, This corresponds to a partition fraction (concentration in headspace/concentration in waste) of 3.6E-10. For purposes of estimating unfiltered releases due to a filtration failure in Appendix B, this was rounded up to 1E-9 for additional conservatism.

Maximum Filter Loadings

In Appendix C, a calculation was made of the contact radiation reading on the outside of the filter duct per L of SST solids on a HEPA filter for passively ventilated SSTs. The value, reported in Table C-9, is 863 mrem/h per liter of SST solids on the filter. This corresponds to 1.16E-3 L per mrem/h. A maximum 200 mrem/h contact reading on the filter duct therefore implies a maximum loading of 2.32E-1 L on a HEPA filter in a passively ventilated SST exhaust system. The HEPA filters in a passively ventilated SST exhaust system nominally measure 1 ft x 1 ft x 1ft. Since these filters are larger than the filters in the RMCS exhaust system, the material in the filter is, on average, further away from the radiation survey point. A given loading on the passive SST HEPA filter will therefore produce a lower reading than the same amount of material on a RMCS HEPA filter. Conversely, a given radiation reading on the passive SST HEPA filter will correspond to a higher filter loading than the same reading on the RMCS HEPA filter. It is therefore conservative to apply the maximum filter loading on a passively ventilated SST system to the RMCS system.

Accordingly, the maximum RMCS exhaust system HEPA filter loading was assumed to be 2.32E-1 L of SST solids for purposes of estimating releases from filters in Appendix B. Consistent with the other systems analyzed, the load on the prefilter was assumed to be 10% of the maximum load on a HEPA filter and an amount of material equal to one HEPA filter load was assumed to be deposited on the inside of the duct work.

References

RPP-4826, 2001, Experience with Aerosol Generation During Rotary Mode Core Sampling in the Hanford Single Shell Waste Tanks, Rev. 2, CH2M HILL Hanford Group Inc., Richland, Washington.

Figure D-1. Sketch of RMCS Exhauster System

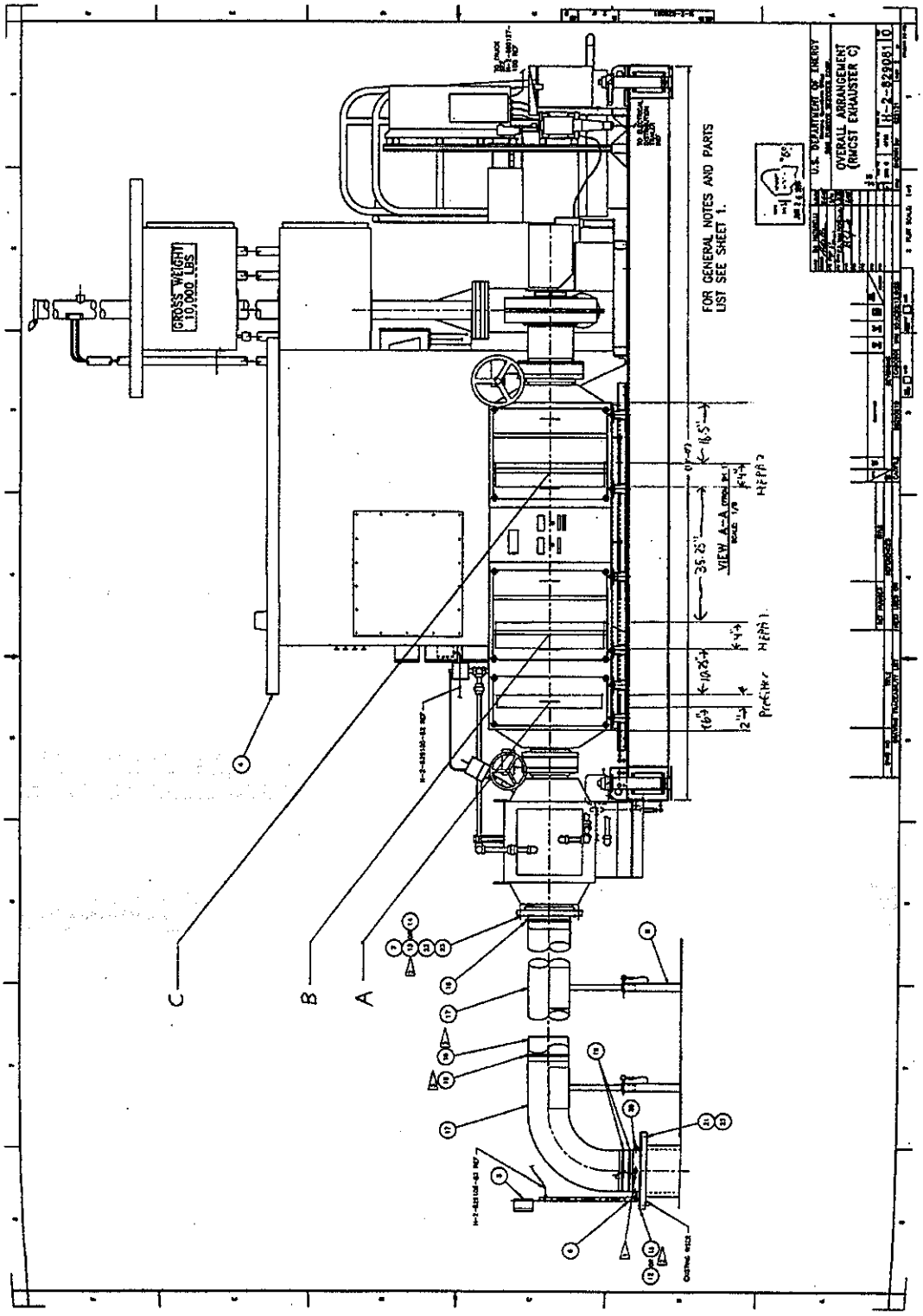

Table D-1. Tank Headspace Aerosol Mass Concentrations and Loadings During Rotary Mode Core Sampling Based on Combustible Gas Meter Filter Paper Data.

Tank and Riser Sampled		**SX-101 R19**	**SX-101 R4**	**SX-103 R7**	**SX-103 R11**	**SX-105 R6**	**SX-105 R14**	**SX-102 R8&4**	**S-110 R6**	**S-110 R14**	**U-107 R2&7**	**BY-105 R7**	**BY-105 R11B**	**TX-113 R3**	**TX-113 R5**
Values in (g/m^3)	^{137}Cs	5.3 E-6	2.7 E-6	5.3 E-5	7.4 E-5	5.8 E-7	1.1 E-4	9.9 E-6	1.2 E-6	3.2 E-5	5.2 E-5	3.1 E-5	3.5 E-4	9.3 E-7	1.6 E-6
	Total α	3.3 E-5	1.4 E-4	-	6.8 E-6	-	-	2.7 E-4	-	-	-	-	3.6 E-5	1.5 E-5	-
	Total β	1.2 E-5	5.5 E-6	1.6 E-5	2.0 E-5	2.7 E-7	3.1 E-5	2.8 E-6	3.0 E-7	1.2 E-5	1.4 E-5	6.4 E-6	8.6 E-5	5.3 E-7	1.4 E-6
Average Mass in Tank Headspace (g)		5.5 E-2	1.6 E-1	8.7 E-2	8.5 E-2	1.1 E-3	1.8 E-1	2.8 E-1	1.9 E-3	5.6 E-2	5.5 E-2	4.3 E-2	3.6 E-1	1.1 E-2	2.9 E-3

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APPENDIX E

SENSITIVITY CASES

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APPENDIX E

SENSITIVITY CASES

A series of sensitivity cases on the calculations shown in Appendix B were run to determine the effects varying several of the parameters assumed for this analysis. Of particular interest were the tank ventilation rates, the amount of material suspended in the tank headspace by airlift circulator (ALC) operation, and the filtration system loadings. In these cases, the calculations proceed in the same way as shown in Appendix B, but with the appropriate adjustments to the parameters of interest. In addition, the consequences of running the continuous unfiltered release scenario for an entire year (i.e., assuming the release is not detected) were of interest as a limiting case. Only the onsite receptor consequences are shown here since they are limiting and the offsite consequences remain insignificant in every case.

Ventilation Flow Rates

The flow rates through all the ventilation systems were doubled. This has the effect of doubling both the radiological and toxicological consequences of the continuous unfiltered release component of all three scenarios. It does not affect the releases from the failed filters in the high temperature and high pressure filtration failure accidents. These results are highly conservative because, for a constant injection rate of waste into the tank headspace, doubling the ventilation rate would decrease the headspace concentrations by a factor of 2 under steady-state conditions and there would be no net change of the rate of waste removal from the headspace. However, to allow for transient conditions, no credit was taken for this effect. The results for the onsite receptor are shown in Table E-1 for the three representative scenarios.

Table E-1. Onsite Receptor Consequences With All Ventilation Rates Doubled.

System	High Temp. Failure		High Press. Failure		Continuous Unfiltered Release	
	Dose (rem)	TEEL-2 SOF	Dose (rem)	TEEL-2 SOF	Dose (rem)	TEEL-2 SOF
Active SST (SX farm)	6.3E-1	4.8E-1	4.4E-1	2.4E-1	4.3E-1	1.4E-1
DST without ALCs	1.0E-2	2.3E-2	1.0E-2	2.2E-2	1.0E-2	2.1E-2
DST with ALCs	5.8E-1	1.3E-1	5.8E-1	1.3E-1	5.8E-1	1.2E-1
SST with RMCS	3.7E-1	1.3E-1	3.5E-1	1.2E-1	3.5E-1	1.1E-1
AWF with ALCs	7.9E-1	3.7E-1	5.8E-1	1.4E-1	5.8E-1	1.2E-1

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SOF = sum of fractions.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.

As can be seen, all the consequences remain well within the "low" consequence bin.

Air Lift Circulator Suspension Rate

A large increase in the ALC injection rate of waste aerosol into the tank headspace was modeled by increasing the partition fraction in the tanks with ALCs operating by a factor of 5 (from 2E-8 to 1E-7) and doubling the solids fraction in the headspace aerosol (from 5% to 10%). Only the systems with ALCs operating are affected. In those systems, the filter loadings decrease slightly because of the higher proportion of solids on the filters (which produces a higher dose rate on the survey meter). However, the waste solids have a much higher unit-liter dose (ULD) than the liquids, , so there is a net increase in the doses due to the filter releases. The continuous unfiltered release component of all three scenarios increases due to the increased partition fraction and the associated doses increase due to the higher ULD of the 10% solids mix. Note however that only half the corresponding system flow rate goes through the tank with ALCs operating. The results for the onsite receptor are shown in Table E-2 for the three representative scenarios.

Table E-2. Onsite Receptor Consequences With Increased ALC Suspension Rate.

System	High Temp. Failure		High Press. Failure		Continuous Unfiltered Release	
	Dose (rem)	TEEL-2 SOF	Dose (rem)	TEEL-2 SOF	Dose (rem)	TEEL-2 SOF
Active SST (SX farm)	4.2E-1	4.1E-1	2.2E-1	1.7E-1	2.2E-1	6.9E-2
DST without ALCs	5.2E-3	1.2E-2	5.1E-3	1.1E-2	5.1E-3	1.1E-2
DST with ALCs	2.6E+0	3.0E-1	2.6E+0	3.0E-1	2.6E+0	3.0E-1
SST with RMCS	1.9E-1	7.5E-2	1.8E-1	6.2E-2	1.78E-1	5.6E-2
AWF with ALCs	3.0E+0	5.6E-1	2.6E+0	3.1E-1	2.6E+0	3.0E-1

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SOF = sum of fractions.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.

As can be seen, all the consequences remain well within the "low" consequence bin.

Filter Loadings

In this case, the waste loading on all the filters and associated equipment (including deposition inside the duct work) was increased by a factor of 10. Note that this will increase the loading on the large single-shell tank (SST) high-efficiency particulate air (HEPA) filter (3 x 3 array) to 25 L and on the double-shell tank (DST) single HEPA filter to 2.55 L. The filter release components of the first two scenarios (high temperature and high pressure filter failure) will then increase by a factor of 10. The consequences of the continuous unfiltered release in all three scenarios will not change. The results for the onsite receptor are shown in Table E-3 for the three representative scenarios.

Table E-3. Onsite Receptor Consequences With All Filter Loads Increased by a Factor of 10.

System	High Temp. Failure		High Press. Failure		Continuous Unfiltered Release	
	Dose (rem)	TEEL-2 SOF	Dose (rem)	TEEL-2 SOF	Dose (rem)	TEEL-2 SOF
Active SST (SX farm)	2.2E+0	3.5E+0	2.6E-1	1.1E+0	2.2E-1	6.9E-2
DST without ALCs	6.5E-3	2.8E-2	5.1E-3	1.6E-2	5.1E-3	1.1E-2
DST with ALCs	3.1E-1	8.0E-2	2.9E-1	6.7E-2	2.9E-1	6.2E-2
SST with RMCS	2.9E-1	2.5E-1	1.8E-1	1.1E-1	1.8E-1	5.6E-2
AWF with ALCs	2.4E+0	2.5E+0	3.0E-1	1.7E-1	2.9E-1	6.2E-2

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SOF = sum of fractions.
SST = single-shell tank.
TEEL = Temporary Emergency Exposure Limit.

As can be seen, all the radiological consequences remain well within the "low" consequence bin even for this extreme filter loading. The toxicological sums of fractions (SOF) for the active SST system and the aging waste facility (AWF) with ALCs exceed the Temporary Emergency Exposure Limit (TEEL)-2 guideline for the low consequence bin. In the case of the active SST system, this happens because of the very large amount of material on the large filters (3 x 3 array) associated with this system. It is doubtful whether these filters could hold this much solid waste (25 L per filter array) without plugging. In the case of the AWF (AZ-702) system, the SOFs exceed 1 because of the very large amount of waste (127 L) assumed to be in the high-efficiency mist eliminator (HEME) and, in the high temperature scenario, the assumed 100% release from the burning high-efficiency gas adsorber (HEGA). This kind of loading in the (HEME) is not realistic since it would be washed down long before the corresponding 8,000 mrem/h contact reading was reached. The HEGA is situated between the first and second stage HEPA filters and is not normally subject to a significant loading of tank waste. Even under these extreme assumptions, the loading of all filtration components (including the HEME and the HEGA) could be increased by a factor of 2.5 without exceeding any of the "low" consequence bin criteria.

EXTENDED CONTINUOUS UNFILTERED RELEASE DURATION

As a limiting case, assuming that it is not detected, the cumulative consequences of the continuous unfiltered release scenario extended out to 1 yr are of interest. The toxicological exposures would not change since they depend only on the air concentration at the receptor, which would be constant. The 8-hr onsite receptor radiological doses can be extended to one

year by multiplying by 1,096 8-hr periods per year, correcting the χ/Q' to an annual average value and applying an occupancy factor. The maximum sector onsite annual average χ/Q' (from RPP-13482, *Atmospheric Dispersion Coefficients and Radiological/Toxicological Exposure Methodology for Use in Tank Farms*) is 4.03E-4 s/m^3. Dividing this by the 8-hr χ/Q' of 5.58E-3 s/m^3 from Table B-3 yields a correction factor of 0.0722. An occupancy factor of 0.228 is then applied to account for the fraction of time spent at work. The resulting radiological doses for a 1-yr exposure of the onsite receptor to continuous unfiltered releases from the systems analyzed are shown in Table E-4.

Table E-4. Radiological Doses to the Onsite Receptor Exposed to a 1-year Continuous Unfiltered Release.

System	Dose (rem)
Active SST (SX farm)	3.9E+0
DST without ALCs	9.1E-2
DST with ALCs Operating	5.2E+0
SST with RMCS operating	3.2E+0
AWF (AZ-702) with ALCs operating	5.2E+0

Notes:
ALC = airlift circulator.
AWF = aging waste facility.
DST = double-shell tank.
RMCS = rotary mode core sampler.
SOF = sum of fractions.
SST = single-shell tank.

As can be seen, all the consequences remain well within the "low" consequence bin. Note that for the cases where the RMCS or ALCs are operating, the rotary mode core sampler (RMCS) and ALCs are assumed to be operating continuously for the entire year.

References

RPP-13482, 2003, *Atmospheric Dispersion Coefficients and Radiological/Toxicological Exposure Methodology for Use in Tank Farms*, Rev. 0, CH2M HILL Hanford Company, Inc., Richland, Washington.

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APPENDIX F

PEER REVIEW CHECKLIST

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APPENDIX F

PEER REVIEW CHECKLIST

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: RPP-13437, *Technical Basis Document for Ventilation System Filtration Failures Leading to Unfiltered Release*

Scope of Review (e.g., document section or portion of calculation): All except for Appendix C, Filter Loading Calculations, which was peer reviewed separately.

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. [No computer codes used]
[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. [No software used in TSB]
[ ]	[ ]	[x]	16. Software output is consistent with the input and with the results reported in the document reviewed. [No software used in TSB]
[ ]	[ ]	[x]	17. Software verification and validation are addressed adequately. *(ORP QAPP criterion 2.6)* [No software used in TSB]
[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.
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[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.
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CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: RPP-13437

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

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

[ ]	[ ]	[X]	21. Results and conclusions address all points in the purpose. *(ORP QAPP criterion 2.3)*
[X]	[ ]	[ ]	22. All references cited in the text, figures, and tables are contained in the reference list.
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[ ]	[ ]	[X]	33. The number of significant digits is appropriate and consistent.
[ ]	[ ]	[X]	34. Chemical reactions are correct and balanced.
[X]	[ ]	[ ]	35. All tables are formatted consistently and are free of blank cells.
[X]	[ ]	[ ]	36. The document is complete (pages, attachments, and appendices) and in the proper order.
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RPP-13437 TE Laurie L Kraemer Laurie L Kraemer 3/21/03

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