MAY 31 2000 (21) Station 15

ENGINEERING DATA TRANSMITTAL

1. EDT 618560

HMLM0161 109310/BB20

2. To: (Receiving Organization) R. J. Cash CH2M Hill Hanford Group	3. From: (Originating Organization) FFS, Safety Analysis & Nuclear Engineering	4. Related EDT No.: N/A
5. Proj./Prog./Dept./Div.: River Protection Project	6. Design Authority/ Design Agent/Cog. Engr.: B. E. Hey	7. Purchase Order No.: N/A
8. Originator Remarks: Calculation notes are used to document the originator's analysis but are not to be used as the final or sole document to authorize activities or justify facility modifications		9. Equip./Component No.: N/A
		10. System/Bldg./Facility: N/A
11. Receiver Remarks: 11A. Design Baseline Document? [] Yes [X] No This analysis evaluates the radiological consequences of potential Hanford tank farm waste transfer leaks. These include ex-tank leaks into structures, underneath the soil, and exposed to the atmosphere. It also includes potential misroutes, tank overflows, and in-tank spray events. The controls evaluated are verification of correct valve line-up, leak detection, pump shutoff, evacuation of onsite personnel, cover blocks/supplemental covers, and double isolation valves. Results indicate that uncontrolled consequences remain far below offsite guidelines and that the application of various control options is sufficient to protect the onsite worker. A stochastic analysis methodology was applied, making use of several input probability density functions.		12. Major Assm. Dwg. No.: N/A
		13. Permit/Permit Application No.: N/A
		14. Required Response Date: N/A

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Approval Designator	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	RPP-5667	N/A	0	Stochastic Consequence Analysis for Waste Transfer Leaks	N/A	1/2	1	1

16. KEY

Approval Designator (F)	Reason for Transmittal (G)	Disposition (H) & (I)
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)	1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION
(See Approval Designator for required signatures)

(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN
1/2	1	Author #1 B.E.Hey	[signature]	5/22/00							
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18.	19.	20.	21. DOE APPROVAL (if required)
[signature] 5/22/00 B. E. Hey Signature of EDT Date Originator	[signature] 5/23/00 G. Jones Authorized Representative Date for Receiving Organization	[signature] 5/31/00 R. J. Cash Design Authority/ Date Cognizant Manager	Ctrl. No. [] Approved [] Approved w/comments [] Disapproved w/comments

BD-7400-172-2 (05/96) GEF097

DISTRIBUTION SHEET		
To Distribution	From B. E. Hey, Fluor Federal Services	Page 1 of 1 Date May 23, 2000
Project Title/Work Order RPP-5667, Rev. 0 Stochastic Consequence Analysis for Waste Transfer Leaks		EDT No. 618560 ECN No. N/A

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
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STOCHASTIC CONSEQUENCE ANALYSIS FOR WASTE LEAKS

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U.S. Department of Energy Contract DE-AC06-99RL14047

EDT/ECN: 618560 UC: 510
Cost Center: 109310 Charge Code: BB20
B&R Code: Total Pages: 207 KN

Key Words: Tank Farms, waste transfer, accident analysis, radiological dose calculations, calculation notes, stochastic analysis.

Abstract: This analysis evaluates the radiological consequences of potential Hanford Tank Farm waste transfer leaks. These include ex-tank leaks into structures, underneath the soil, and exposed to the atmosphere. It also includes potential misroutes, tank overflows, and in facility spray events. Results indicate that uncontrolled consequences remain far below offsite guidelines and that the application of various control options is sufficient to protect the onsite worker.

MAY 31 2000
DATE:
STA: 15
HANFORD RELEASE
ID:
21

Karen G. Noland 5/31/2000
Release Approval Date

Release Stamp

Approved For Public Release

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List of Terms

Acronyms

AB	Authorization Basis
AED	aerodynamic equivalent diameter
ARF	airborne release fraction
ARR	airborne release rate
AWF	Aging Waste Facility
COB	clean out box
DST	double-shell tank
FSAR	final safety analysis report
MEI	maximum exposed individual
PDF	probability density function
RF	release fraction
RPP	River Protection Project
SMD	Sauter mean diameter
SST	single-shell tank
TWRS	Tank Waste Remediation System
ULD	unit liter dose

Greek Letters

π	=	3.1415926
ρ	=	fluid density (kg/m^3)
μ	=	fluid dynamic viscosity (cp)
ν	=	kinematic viscosity (m^2/s)
ε	=	surface Roughness (m)
χ/Q	=	atmospheric dispersion coefficient (s/m^3)
μ_{sn}	=	supernatant dynamic viscosity (cp)
ρ_{sd}	=	density of solids in waste (kg/m^3)
ρ_{sn}	=	density of supernate (kg/m^3)

Nomenclature

A_{leak}	=	cross-sectional area of leak (m^2)
A_p	=	contaminated surface area (m^2)
BR	=	receptor breathing rate (m^3/s)
C_c	=	contraction coefficient
C_p	=	concentration of respirable aerosol in waste pit air (L/m^3)
CR	=	ratio of the Cs-137 concentration in the pool to the concentration
Cs_0	=	Cs-137 concentration assumed in MCNP modeling
Cs_p	=	Cs-137 concentration in waste slurry (Bq/L)
Cs_{sd}	=	Cs-137 concentration in waste solids (Bq/L)
Cs_{sn}	=	Cs-137 concentration in Supernate (Bq/L)
C_v	=	velocity coefficient
D_c	=	diameter of largest drop of concern (m)
D_{de}	=	direct exposure dose (Sv)
D_e	=	equivalent diameter of leak opening

$D_{entrain}$	=	inhalation dose resulting from wind induced entrainment (Sv)
D_p	=	diameter of pipe (m)
D_r	=	maximum respirable diameter (10 μm AED)
D_{splash}	=	inhalation dose resulting from a splash/splatter event (Sv)
D_{spray}	=	inhalation dose resulting from a spray event (Sv)
D_{vent}	=	inhalation dose resulting from the venting of the pit
EM_{10}	=	respirable mass release rate by entrainment ($kg/m^2/s$)
f	=	darcy friction factor
F	=	fraction of waste (by volume) composed of solids
F_d	=	function relating dose rate to pool radius (Sv/hr)
F_p	=	fetch, taken to be the diameter of the pool (m)
g	=	acceleration due to gravity (9.8 m/s^2)
H_o	=	depth of crack (m)
h_p	=	height of pool (m)
H_{leak}	=	fluid head at the leak location (m)
H_{pl}	=	head loss between pump and leak (m)
H_p	=	pump head from characteristic curve (m)
K_f	=	leak resistance coefficient (friction component)
K_v	=	leak resistance coefficient (velocity component)
L_{ld}	=	effective length of pipe between leak and discharge (m)
L_o	=	length of crack (m)
L_{pl}	=	effective length of pipe between pump and leak (m)
M	=	aggregate size distribution mode (mm).
N	=	number of isolation valves
N_{ex}	=	number of exchanges of pit air during the exposure time.
P_{leak}	=	pressure at leak location (Pa)
P_r	=	isolation valve rated pressure (Pa)
P_{system}	=	system pressure upstream of the isolation valve(s) (Pa)
Q	=	fraction of total leak flow that is respirable
q	=	particle size distribution fitting parameter
R_m	=	radius of the pool corresponding to the median pool size (m)
R_e	=	Reynold's number
RF	=	respirable fraction
S	=	fraction of sprays oriented in a releasable direction
T_{ex}	=	exposure time (s)
u	=	wind speed (m/s)
u_{*t}	=	threshold friction velocity (m/s)
u_t	=	threshold wind speed at 7 m above surface (m/s)
$u_t(z)$	=	threshold wind speed at height z (m/s)
V	=	fraction of the contaminated surface vegetative cover
V_{ld}	=	fluid velocity in pipe between leak and discharge (m/s)
V_{leak}	=	leak jet velocity (m/s)
V_p	=	volume of air in a pit (m^3)
V_{pl}	=	fluid velocity in pipe between pump and leak (m/s)
V_s	=	volume of waste subjected to spray (m^3)
V_{ss}	=	volume of waste subjected to splash/splatter (m^3)

W_{disch}	=	rate of discharge (m^3/s)
W_{leak}	=	leak rate (m^3/s)
W_o	=	width of leak opening (m)
W_p	=	pump flow rate (m^3/s)
W_r	=	leakage allowed for a closed isolation valve at P_r (m^3/s)
W_{system}	=	leakage through isolation valve at differential pressure Psystem
X	=	particle distribution characteristic diameter (m)
z	=	height above surface (m)
z_0	=	roughness height (m)

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1.0 INTRODUCTION

Currently the Tank Waste Remediation System Final Safety Analysis Report (HNF, 1999) Sections 3.4.2.7 *Surface Leak Resulting in Pool* and 3.4.2.9 *Spray Leak in Structure or From Waste Transfer Lines* drive above ground pit structures and covers to safety class requirements. These two analyses represent deterministic worst case scenarios on opposite sides of a continuum of transfer line leak events, one resulting in a pool only, and the other resulting in a spray only. Implicitly assumed is that intermediate cases are less severe than either of the two evaluated. A concern exists that these analyses are overly conservative, resulting in unnecessary controls such as safety class above ground pit structures and covers. This analysis uses a stochastic approach to evaluate a broad range of potential consequences from a waste transfer leak. Selected parameters of the leak scenario, such as leak size, location, viscosity, and pit size, etc. are allowed to vary over a realistic range via the use of probability density functions (pdfs) while other parameters, such as exposure time, receptor distance, and breathing rate, etc. are fixed. In addition, the transfer system is modeled in a more realistic manner so that a truer representation of system pressure and flow characteristics is obtained.

Unlike a deterministic analysis, this stochastic analysis does not yield a single answer. Instead, a spectrum of answers are provided in the form of statistical measures. The user is then given the opportunity to make decisions based upon the values of such statistical measures as the mean, median or 95 percentile. The bounding value (or outlier) has no meaning because it is a function of the number of samples taken. Hence, when a decision is made based, for example, on the 95% consequences, it must be accepted that 5% of the time the consequences are estimated to be worse.

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2.0 SCOPE OF ANALYSIS

Several instances of waste leaks have occurred at Hanford (see Appendix L). The intended purpose of this analysis is two-fold. The first is to provide information to judge the severity of the uncontrolled waste transfer leak hazard. By uncontrolled it is meant that no credit is taken for engineered barriers or administrative controls which would become safety related. The second is to provide information to judge the adequacy of the credited engineered barrier or administrative control. In the past, deterministic analyses have referred to these categories as unmitigated and mitigated. However, that terminology is misleading in a stochastic analysis of this type because it implies that no mitigation occurs in the unmitigated analysis, which is not the case. For example, in the analysis of the uncontrolled waste transfer leak hazard, mitigation of the leak rate is factored into the pdf assumed for the leak size distribution. This pdf is derived from industry data and event occurrences which typically have design and procedural requirements to limit the extent of a leak. However, that mitigation occurs through good engineering and operational practices and it is not the purpose here to evaluate the effectiveness of those controls or make them safety related. Hence the terminology of uncontrolled and controlled is used hereafter in order to distinguish between mitigation in general, and controls specifically intended to be safety related.

Currently this analysis does not consider the following phenomena or consequence aspects:

1. *Leak frequency:* Estimating the annual frequency of a leak is not currently within the scope of this analysis.
2. *Toxicological doses:* Estimating toxicological dose from a leak is not currently within the scope of this analysis.
3. *Cross site slurry transfers:* The higher pump pressures used for cross site slurry transfers are outside the scope of this analysis. However the cross site slurry transfer structures are included.
4. *Interfacing facilities:* The dose conversion factors applied here do not account for non-Hanford tank farm waste. Hence waste material from PFP, PUREX, etc., may or may not be represented.

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3.0 REPRESENTATIVE ACCIDENT SCENARIO DEVELOPMENT

The hazardous conditions related to waste transfer leaks and documented in the FSAR data base, were re-binned into five waste leak categories. They are:

- **33A** - Ex-tank waste transfer leak into structure or encasement that results in release to environment from structure.
- **33B** - Ex-tank waste transfer leak directly into soil. Leak may remain subsurface or may result in pool on soil surface.
- **33C** - Ex-tank waste transfer leak directly to the soil surface or atmosphere.
- **33D** - Misroute of waste into tanks, uncontrolled waste systems, clean systems, or 204-AR waste unloading facility.
- **33E** - Leaks inside actively vented structures.

These five categories conveniently group scenarios similar in either cause, consequence or control. In most cases even these sub-categories are further divided to account for special situations which were better handled separately. For example, leaks under normal operating pressures are evaluated separately from leaks occurring when the intended discharge is isolated or plugged. Most readers would agree that the former was more likely but the latter would be worse in consequence. Since the latter is preventable, it is necessary to separately evaluate its range of consequences in order to determine the importance of preventing this special situation.

In order to evaluate the effectiveness of mitigative controls, each of the five representative accident categories is evaluated both as an uncontrolled and controlled scenario. The paragraphs below discuss the differences between the evaluations of uncontrolled and controlled waste leak scenarios.

3.1 UNCONTROLLED SCENARIOS

In the uncontrolled scenario no credit is taken for engineered safety features or administrative controls which would be safety related (i.e., safety SSCs or TSRs). This does not mean that there is no mitigation. Mitigation can still occur from passive physical features which can not practically be eliminated. For example, a pit has the capability to contain a volume of waste spilled into it at least equal to its free air volume. Although an open drain routed to a tank could result in even more waste contained, no credit would be taken for an open drain because the drain could be inadvertently closed or plugged.

Depending upon the particular leak configuration, onsite and offsite exposure may start at either leak inception or when a surface pool starts. In no case does the exposure period exceed 12 and 24 hours for the onsite and offsite maximum exposed individual (MEI) respectively.

Each of the following source terms and radiological pathways are evaluated for their potential contribution to dose:

- aerosol generated from direct pressurized spray into the atmosphere

- aerosol generated from splash and splatter from liquid hitting surfaces
- aerosol entrainment from wind blowing across wet pool surface
- aerosol entrainment from wind blowing across dry contaminated surface
- gamma-ray shine from exposed waste pool

The offsite MEI could be subject to the first four pathways but the gamma-ray shine would be insignificant.

The efficiency of a pressurized spray to generate respirable sized aerosols can dominate the consequences for small sampled crack sizes. The SPRAY code contains formulas which can be used to calculate respirable aerosol release rates given liquid pressure, crack width, length, depth, and fluid viscosity.

The aerosol generated from splash and splatter will also contribute to the consequences and is a dominant contributor for large leak rates under lower pressures. If the source of the leak is within a pit structure, then both the spray and splash/splatter releases are assumed to stop once the pit volume is filled. However, due to their physical arrangement (i.e., fixed lids), clean out boxes (COBs) are assumed to continue a release from splash/splatter.

Aerosol entrainment from wind across the pool is a function of wind speed and fetch, both of which are consistent with the sampled atmospheric conditions and pool size. Aerosol entrainment from wind across a dry contaminated surface is also calculated but evaluated separately since this source term would occur much later when the pool is dry.

Gamma-ray shine is estimated from pre-analyzed transport runs as a function of circular pool radius. The size of the pit plays a role in determining consequences. The larger the pit the smaller the amount of waste on the ground surface. Only the waste on the ground surface contributes to wind entrainment and gamma-ray shine in the analysis.

3.2 CONTROLLED SCENARIO

In the controlled scenario various engineered safety features and administrative controls are credited in order to assess their mitigation effectiveness. These controls may take the form of leak confinement, detection, termination, or limitation and onsite evacuation. Depending upon the particular leak configuration, onsite and offsite exposure may start at either leak inception or when a surface pool starts. In no case does the exposure period exceed 12 and 24 hours for the onsite and offsite MEI respectively.

In addition to the source terms listed in the uncontrolled scenario, the following source term is used to evaluate the dose due to an aerosol escaping from a covered pit:

- aerosol released as air inside the confinement cover is displaced

This source term is simplistically calculated as the acute release of 100% of the pit free air volume with the escaping aerosol having a concentration of 100 mg/m^3. The forces which could cause air and aerosol to escape from a covered pit are displacement from the leakage, thermodynamic changes of the pit atmosphere caused by the leak, barometric pressure changes, convective currents, and wind. These mechanisms could cause the release to occur rapidly or over several hours duration. However, it is judged to be conservative to assume that the release occurs rapidly (i.e., within one hour) but that no more than one pit volume is released during the exposure period. This source term is the least significant of all of the source terms evaluated. Therefore further refinements are not considered warranted.

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4.0 ANALYSIS METHODOLOGY

The forecasting and risk analysis package called Crystal Ball® is used with the EXCEL™ spreadsheet to perform a Monte Carlo simulation in which several thousand leak scenarios are evaluated. For each leak scenario the radiological dose is calculated for both the onsite and offsite MEIs. Scenario parameters are allowed to vary according to probability density functions (pdf) defined by the analyst. These parameters are predominantly discussed in the appendices; but, basically leak size, location, viscosity, solids content, radioactivity, density, respirable release fraction, pit volume, wind speed, and atmospheric diffusion are parameters sampled from a pdf.

The sampled leak location (i.e., distance between the pump and the leak) together with the pump characteristic curve and transfer route frictional losses define the leak pressure. Leak pressure and leak size define the leak rate exit velocity which influence the rate of respirable aerosol generated in a spray. The leak rate and pit size determines how large a pool is formed, if one forms at all. The pit size also determines the amount of leakage before detection occurs, the amount of spillage contained, the amount of aerosol contained within the pit and possibly released, and the length of time the spray and splash/splatter continue. This last effect occurs because it is assumed that when the pit is 100% full, any spray or splash/splatter release stops. Finally, the leak volume not contained by the pit is assumed to form a pool on the ground, the size of which influences a subsequent gamma-ray shine dose and wind entrainment release.

The following sections describe specifically the various mathematical models incorporated into this stochastic analysis of waste transfer leaks. In many cases additional information is provided in an appendix which is also cited.

4.1 LEAK SIZE

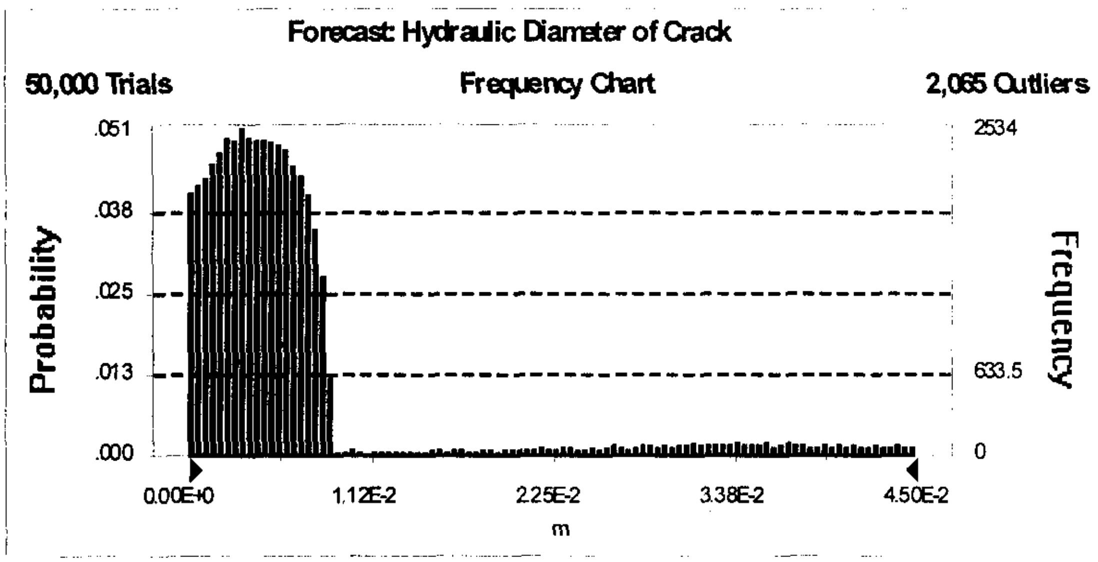
Perhaps the most important yet uncertain input parameter is the size of the leak opening. All leaks considered in this analysis are defined using the dimensions of length, width and depth. A leak having a length and width which are about the same can be used to simulate a circular orifice of equivalent diameter. The width of the leak can be important when considering the generation of aerosols such as a sheet of spray from a leaking flange. A small width will tend to generate a finer mist, while a large width will allow a higher flow rate and larger pool to form. The length of the opening is used to simulate a cracked pipe, failed flange gasket, misaligned jumper, or annular valve stem opening. The depth of the leak helps account for pressure drop such as would occur along a valve stem or a very thin crack in a pipe. Each of the parameters of length, width and depth are independently sampled according to the scheme presented in Appendix B. The combination of the largest leak width and length equate to an opening whose size is equal to the cross sectional area of a 3 in Sch. 40 pipe.

The equivalent or hydraulic diameter of the leak opening (assuming a rectangular orifice) is given by,

$$D_e = 2L_oW_o/(L_o+W_o)$$

L_0 = Length of Crack (m)
W_0 = Width of Crack (m)

Note that when $W_0 << L_0$, the equation reduces to $D_e = 2W_0$ which is the correct expression for long narrow openings. The Appendix B leak size distribution in terms of hydraulic diameter is shown below.



4.2 LEAK PRESSURE AND LINE LOSSES

The pressure in the pipe at the leak location is calculated through a process of iteration. Initially the system flow rate is a constant as determined by the pump characteristics and system line losses. When a leak occurs, the pump flow rate will increase, depending upon the location and size of the leak. The increase in the flow rate will cause both a pump head decrease and a increase in frictional line losses until a new equilibrium is reached. Pump run out could occur if the leak were very large and close to the pump. Once the location and size of the leak are determined through sampling, iteration is used to obtain a balance between pump head, flow rate and line losses.

The maximum equivalent length of the transfer route, including valves, elbows, etc., is set at 20,000 ft. Note that the actual transfer line length would be shorter because the equivalent lengths of elbows, valves, etc. are also included. Although the actual transfer length will vary depending upon the particular transfer, this value was chosen because for the pump head curve modeled, a system flow rate of about 155 gpm is achieved which is nominal. The sensitivity of analysis results to this value is the subject of further sensitivity studies. The pipe diameter assumed in this analysis is 3 in Sch. 40.

The algorithm begins by sampling a leak location at some distance from the pump to the end of the transfer line. From this value the pressure at the leak is calculated. The leak rate and intended discharge flow rate are then calculated and summed. The pump flow rate must equal the combined leak rate and discharge flow rate. The pump flow rate is adjusted and the process is repeated 20 times, which (for this application) produces errors of less than 1%. The procedure is as follows:

The head loss from the pump to the leak is given by,

$$H_{pl} = (f\, L_{pl} / D_p)\, V_{pl}^2 /(2g)$$

f = Darcy friction factor, 0.018 for fully turbulent flow in a 3 in sch. 40 commercial steel pipe
L_{pl} = Effective length of pipe between pump and leak (m), a sampled value
D_p = Diameter of pipe (m)
V_{pl} = Fluid velocity in pipe between pump and leak (m/s)
g = Acceleration due to gravity (m/s^2)

The fluid head at the leak location is given by,

$$H_{leak} = H_p - H_{pl}$$

H_p = Pump head from characteristic curve (m) (see Appendix E)

The fluid pressure at the leak is given by,

$$P_{leak} = H_{leak}\, \rho\, g$$

ρ = waste density

The velocity of waste through the leak opening is given by,

$$V_{leak} = ((2\, P_{leak})/(\rho\, (K_f + K_v + 1.0)))^{1/2}$$

K_f = Leak resistance coefficient (friction component)
K_v = Leak resistance coefficient (velocity component)

The frictional loss coefficient for flow through a thin crack in a thick walled pipe or flange can be important and is given by,

$$K_f = f\, H_o / D_e$$

f = Darcy Friction Factor
H_o = Depth of orifice (m)
D_e = Equivalent diameter of the leak (m)

The equation for f is calculated from the following equation with the assumption that the $R_e f^{1/2}$ term is insignificant (typical for fully turbulent flow).

$$f^{1/2} = -2\ log_{10}((\varepsilon/D_e/3.7) + 2.51/R_e f^{1/2})$$

R_e = Reynold's Number
ε = Surface Roughness (m)

The velocity loss coefficient is related to the velocity coefficient via the following equation,

$$K_v = C_v^{-2} - 1$$

C_v = Velocity coefficient

The leak flow rate is given by,

$$W_{leak} = C_c\ A_{leak}\ V_{leak}$$

A_{leak}= Cross-sectional area of leak (m^2)
Cc = Contraction coefficient

The cross sectional area of the leak opening is given by,

$$A_{leak} = L_o\ W_o$$

The fluid velocity downstream of the leak is given by,

$$V_{ld}^2 = 2g\ H_{leak} / (f\ L_{ld} / D_p)$$

L_{ld} = Effective length of pipe between leak and discharge (m)

The discharge flow rate is given by,

$$W_{disch} = (\pi\ D_p^2\ /4\ )\ V_{ld}$$

A new pump flow rate and fluid velocity is calculated such that,

$$W_p = W_{leak} + W_{disch}$$
$$V_{pl} = W_p / (\pi\ D_p^2\ /4\ )$$

The above procedure is repeated 20 times which effectively calculates a steady state system flow rate and pressure with less than 1% error.

In order to evaluate the condition when the transfer system may be dead headed (i.e., closed block valve or plugged line) the head loss for the piping downstream of the leak location is set to a high value, preserving the system response to various sampled leak sizes.

4.3 PUMP CHARACTERISTICS

The pump characteristic curve used in this analysis is provided in Appendix E. This idealistic curve is intended to bound the pressure and flow characteristics of all waste transfer pumps for farm to farm transfers as well as waste feed delivery to the vitrification facility. The pump shut off head is 1440 ft. Runout occurs at about 285 gpm. The transfer line equivalent length was established at 20,000 ft to simulate a nominal head of 1040 ft at 155 gpm. Using this model, simulated leaks randomly located along the length of this transfer route will be exposed to a range of pressures.

Two conditions are simulated. A normal operation condition assumes that the intended discharge of the pump system is open. Thus for a small leak the pressure at the randomly sampled leak location would range from 0 (close to the discharge) to 1040 ft (close to the pump). A discharge blocked condition assumes that the intended discharge is either plugged or isolated. Thus the only flow is through the leak (or misroute). Thus the leak pressure would range from 0 to 1440 ft. A cubic equation representing the pump characteristic curve is provided below in English units where W_p is in gpm and H_p is in feet.

$$H_p = 1440 - 0.29729\ W_p - 0.01465\ W_p^2 - 5.61E\text{-}6\ W_p^3$$

The pump will have a variable speed motor and flow controller. The above equation represents the pump characteristic at maximum speed. In the event of a leak the flow controller would normally lower pump speed to maintain an acceptable transfer flow rate. However, in this analysis the response of the flow controller is not modeled because that would decrease the leakage and hence be credited as a safety related feature.

Pump shutdown on leak detection is also modeled. To simulate pump shutoff the pump characteristic curve is replaced by a constant pressure representing the hydrostatic head between the highest vented point and the leak. This reduced flow rate is referred to as drainback and is discussed in more detail below.

4.4 DRAINBACK

In order to evaluate the benefit of a leak detection and pump shut off control, a simplified model is used to calculate the expected flow rate and inventory of waste slurry which could drain out of the leak once the pump has been turned off. This model uses the pump as a reference point with half the leaks occurring at an elevation below the pump and half occurring above the pump. The hydrostatic pressure difference is determined by uniformly sampling the distance between the leak and the pump between a range of 0 - 20,000 feet. The sampled leak location also limits the waste inventory available for drainback through the leak. The assumed hydrostatic pressure difference is 1 ft of head for 100 feet of pipe up to a maximum of 75 ft head. The drainback inventory is 0.385 gal per foot of 3 in sch. 40 pipe. For example, the drainback through a leak from an upward sloping pipe 15,000 ft from the pump would be under 50 ft of head and be limited to 1,925 gal. The flow rate would be a function of the line and discharge losses as well as the leak size and calculated according to the procedure outlined in Section 4.2. However, for an open ended leak it would not exceed 66 gpm in this case.

The maximum elevation difference between any vented transfer point and source or destination is 72 ft between the 6241-V Vent Station and 200 West. Therefore the maximum hydrostatic head is limited to 75 ft.

It is interesting to note that a leak on an open discharge path of constant pressure drop would experience zero flow. This is because the velocity head equals the hydrostatic head at all locations. However, it is assumed that drainage of waste back to the source or destination is prevented. This is entirely true where a check valve close to the pump prevents drainage back to the source or where a valve misalignment has occurred, blocking the intended discharge point, but conservative for leaks in lines sloping down to their discharge point. The model is also conservative (but much simpler) in that the decreasing head over time as the pipe drains is not accounted for.

4.5 WASTE DENSITY AND VISCOSITY

The density of the waste slurry is assumed to be the volume average of the solids and supernate density according to the equation,

$$\rho = \rho_{sd} F + \rho_{sn}(1 - F)$$

F = Fraction of waste (by volume) composed of solids
ρ_{sd} = Density of solids in waste
ρ_{sn} = Density of supernate

The assumed values for ρ_{sd} and ρ_{sn} are provided in Section 5. The value for the waste solids fraction, F, is sampled according to the algorithm which is also included in Section 5.

The dynamic viscosity of the waste slurry in cp is based on the sampled supernatant viscosity, which is then modified by the volume fraction of solids according to the following formula. See Appendix G for the origin of this equation.

$$\mu = \mu_{sn}(1 + \frac{5}{2}F + 6.2F^2)$$

F is the fraction of waste (by volume) composed of solids. The supernatant viscosity, μ_{sn}, is sampled according to the algorithm identified in Section 5. Dynamic viscosity, μ, is converted into kinematic viscosity, ν, via the following definition,

$$\nu = \mu / \rho$$

where, ρ, is waste density. Note that 1 centipoise (cp) = 0.001 kg/(m s).

4.6 LEAKAGE THROUGH ISOLATION VALVES

A model is also included (see Appendix I) to evaluate limited leakage through isolation valves. Isolation valves are a control option that could be used to isolate a portion of the transfer system undergoing maintenance, a clean raw water supply, or a diluent addition system. Since all valves leak to some degree, a model is provided below to estimate the amount of leakage into the environment when the isolation valves could leak at a rate equal to their maximum allowable leakage criteria.

Since the volume flow rate through an orifice is approximately proportional to the square root of the differential pressure (all other things being constant) an isolation valve which leaks W_r at reference pressure P_r, will leak at system pressure P_{system} as given by:

$$W_{system} = W_r \left[\frac{P_{system}}{P_r} \right]^{\frac{1}{2}}$$

With leakage past an isolation valve, it is possible to pressurize the connected system. Should this connected system have a leak, then an equilibrium pressure will be established such that the isolation valve leak rate equals the leak rate out of the connected system and into the environment. Given an equivalent leak diameter D_e, the equilibrium pressure ratio $[(P_{system} - P_{leak})/P_{system}]^{1/2}$ can be found by,

$$\left(\frac{D_e^2 \rho W_{system}^2}{C_v^2 N A_{leak}^2} + 2 D_e^2 P_{system} \right) \left[\frac{P_{system} - P_{leak}}{P_{system}} \right] + \frac{64 H_o \mu W_{system}}{\sqrt{N} A_{leak}} \left[\frac{P_{system} - P_{leak}}{P_{system}} \right]^{\frac{1}{2}} - 2 P_{system} D_e^2 = 0$$

W_{system} = leakage through isolation valve at differential pressure Psystem
D_e = equivalent diameter of leak opening
C_v = velocity coefficient
A_{leak} = leak area
H_o = leak depth
μ = fluid viscosity
ρ = fluid density
N = number of isolation valves

This quadratic equation is easily solved by standard methods and will, in general, produce two solutions. The physical solution must be a positive number less than or equal to 1. The flow rate through N closed isolation valves and the leak is given by,

$$W_{leak} = \frac{W_{system}}{\sqrt{N}} \left[\frac{P_{system} - P_{leak}}{P_{system}} \right]^{\frac{1}{2}}$$

P_{system} = system pressure upstream of the isolation valve(s) (Pa)
P_{leak} = pressure downstream of the isolation valves at the leak location (Pa).

4.7 WIND SPEED AND X/Q DISTRIBUTIONS

Wind speed and X/Q values were sampled from tables of wind speed frequencies (and associated X/Q values). Different tables were used for onsite and offsite values so, for any given single sample, the atmospheric conditions for the offsite and onsite MEI are not the same. However, the statistical measures of several thousand histories are comparable. Since the exposure duration's are long, plume meander is credited for both the offsite and onsite MEI. Additionally, plume depletion is credited. Details of the X/Q calculations are provided in Appendix D.

4.8 CESIUM CONCENTRATIONS AND ULD'S

The cesium concentration (and the corresponding ULD) are sampled from tables that provide values for different tanks based on average homogenized conditions. Different tables are used for solids and supernate. An effective cesium concentration and ULD is calculated based on the sampled fraction of solids for a particular calculation. The result is a hypothetical waste representing solids from one tank and supernate from a different tank. This does not accurately represent actual waste in any given tank but is considered to be a reasonable approximation and of no consequence to the statistical results. Tank waste sampling is weighted by the waste volume fraction (liquid or solid) of waste in that tank versus all tank waste. This means for example, that the probability of a waste transfer leak involving Tank 241-SY-101 waste is proportional to the fraction of 241-SY-101 waste on the Hanford site. The tables used in this analysis are included in Appendix F.

4.9 TOTAL DOSE TO THE MEI

For purposes of this analysis, the total dose to the MEI can be expressed as a sum of doses from several source terms. Source terms resulting in an airborne inhalation pathway are categorized as spray, splash/splatter, venting, and wind entrainment. A direct gamma-ray dose pathway is also included for the onsite MEI. The total dose could then be expressed by the following equation.

$$D_{total} = D_{spray} + D_{splash} + D_{vent} + D_{entrain} + D_{de}$$

D_{spray} = Inhalation dose resulting from a spray event (Sv)
D_{splash} = Inhalation dose resulting from a splash/splatter event (Sv)

D_{vent} = Inhalation dose resulting from the venting of the pit containing a leak event (Sv)
$D_{entrain}$ = Inhalation dose resulting from wind induced entrainment (Sv)
D_{de} = Direct Exposure Dose (Sv)

Depending upon the leak scenario, some source terms may or may not be relevant. For example, the inhalation dose resulting from venting aerosol from a pit is not relevant for an underground leak directly into the soil and would therefore not be included. A second example would be the ignoring of the spray and splash/splatter source term for a controlled accident where pit covers are credited as a safety barrier against direct introduction of aerosol into the environment. A third example would be the ignoring of a direct gamma exposure to the offsite MEI because he is too far away for it to be significant. The relevant source terms applied to each representative accident category is discussed further in Section 6. The mathematical model for each of the above source terms is described more fully below.

4.10 SPRAY INHALATION DOSE

Leaks under high pressure can be an efficient means of aerosol production. If the leak source is exposed to the atmosphere, or a space which is actively vented, then a significant respirable release can occur. Such situations could arise in the event of a misroute of waste into a valve pit when coverblocks are not installed, or a corrosion induced leak in a singly encased and bermed line after washout occurs, or inside an actively vented waste tank when a pre-existing hole in the discharge pipe of submersible pump becomes uncovered as the waste level drops. In order to assess the dose contribution of this source term, the potential inhalation dose downwind of a spray release is calculated using the following expression.

$$D_{spray} = (1000\ L/m^3) * Q * V_s * (X/Q') * BR * ULD$$

Q = Fraction of total leak flow that is respirable
V_s = Volume of waste subjected to spray (m^3)
(X/Q') = Atmospheric Dispersion Coefficient (s/m^3)
BR = Receptor Breathing Rate (m^3/s)
ULD = Unit Liter Dose for inhalation of Waste (Sv/L)

The unit liter dose for the liquid/solid mixture was calculated as follows.

$$ULD = F * ULD_{sol} + (1-F) * ULD_{liq}$$

F = Fraction of waste (by volume) composed of solids
ULD_{sol} = Unit Liter Dose for inhalation of solids (Sv/L)
ULD_{liq} = Unit Liter Dose for inhalation of liquids (Sv/L)

4.10.1 Assumptions Regarding Spray Flow Rate

When a pressurized leak source is uncovered (e.g., cover blocks removed) a spray directly into the atmosphere is assumed to be possible. Due to the dominant role that gamma-ray shine has on onsite doses, pit drain lines are assumed to be plugged, maximizing the amount of waste reaching the surface. When the liquid level rises to the top of the pit, it is assumed that the further generation of aerosol through spray or splash/splatter is prevented. This would maximize the amount of waste that could end up on the surface and create a gamma-ray exposure as well as a wind entrainment hazard.

When pit cover blocks are installed, no direct spray into the environment is possible. Valve and pump pits are concrete with interlocking concrete cover blocks and shield plugs held in place by gravity. The externals walls of the pits are straight walled and do not exceed a height of more than a couple of feet. Since the cover blocks and shield plugs are free to float upwards, the internal pressure within the valve pit cannot exceed 2-3 psig because this is the pressure due to the weight of the cover block (e.g., 2 feet high x140 lb./144 in^2 = 2 lb/in^2). The efficiency of a liquid jet at that pressure to generate aerosol is very low and negligible in comparison to the wet entrainment rates assumed in the analysis. Since no special means are available to seal the cover blocks against any significant pressure differential (i.e., > 3 psi), the cracks around the perimeter of the cover blocks are more than sufficient to accommodate the leak without resulting in a high pressure spray.

Typically, COB covers are constructed of plywood or sheet metal and are held in place by duct tape or pins. Some COBs are also flanged with covers bolted to them. For the first two configurations it is unlikely that sufficient pressure could be achieved to generate a spray release directly into the atmosphere because the plywood and sheet metal covers cannot be restrained tightly enough and would simply bulge to accommodate the flow. In these cases the releases are judged to be better represented by the splash/splatter mechanism discussed in Section 4.11.

In the case of flanged COBs with a bolted cover it may be possible to generate a spray if a leak were to occur inside and the COB filled up and pressurized. If the COB is vented then it cannot pressurize and cause a spray release, although waste exiting the vent may cause a release of aerosols due to a splash/splatter mechanism. Although the spray release is not a dominant hazard for the two leak size distributions evaluated in this study, slight alterations to the leak size distribution can cause onsite inhalation doses from spray aerosol to exceed guidelines. Since the uncertainties inherent in these leak size distributions are large with respect to their sensitivity to producing high spray aerosol releases, potential spray sources such as flanged COBs should be controlled (e.g., ensuring vent lines are open).

4.10.2 Aerosol Respirable Fraction from Spray

Only a fraction of the spray aerosol is small enough to be respirable. Hey (1994) provides a means for calculating the respirable flow rate of a liquid jet exiting either a circular or rectangular orifice. These equations are taken from Hey (1994) and are reproduced for the reader below. The waste release rate through the leak opening was calculated as follows.

$$W = C_c * A_{leak} * V_{leak}$$

C_c = Contraction coefficient
A_{leak} = Area of leak opening (m2)
= Length * Width = L_o * W_o
V_{leak} = Velocity of waste through orifice (m/s)

The fraction of flow that is respirable is given by,

$$Q = S\left(1 - \exp(-D_c / X)^q\right)$$

D_c = Diameter of largest drop of concern (m)
X = Characteristic diameter (m)
q = Fitting constant
S = Fraction of spray oriented in releasable direction

The factor S accounts for the fraction of time the spray stream is oriented in a releasable direction. At other times it is assumed to be oriented down or into an impaction area which would effectively negate the release. A reasonable value is judged to be 1/2. To account for larger aerosols evaporating to respirable sizes, the diameter of a potentially respirable sized aerosol is calculated such that the remaining solids are of respirable size when the aerosol droplet is fully evaporated. To account for about 210 g/L dissolved solids in single and double shell tank liquids (Van Keuren 1996a), mostly in the form of sodium hydroxide which has a specific gravity of 2.13, the volume fraction of total solids is increased by 0.1. The maximum diameter of concern is then,

$$D_c = \frac{D_r}{\sqrt[3]{F + 0.1}}$$

D_r = Maximum Respirable Diameter (10 µm AED)
F = Fraction of waste (by volume) characterized as solids

Thus the largest respirable drop of concern would be 21.5 um. Assuming a waste solids fraction of 7%, this drops to 18.1 um.

The characteristic diameter, X, is calculated from the Sauter Mean Diameter (SMD),

$$X = SMD / (SMD/X)$$

SMD = Sauter Mean Diameter (m)
(SMD/X) = Relationship of SMD to X as given in Table 2.2 of Hey (1994)

$$SMD = 500.0 * D_e^{1.2} * \nu^{0.2} / V_{leak}$$

D_e = Equivalent diameter of leak (m)
ν = Kinematic viscosity of the waste (m^2/s)
V_{leak} = Leak jet velocity (m/s)

4.11 SPLASH/SPLATTER INHALATION DOSE

A radioactive liquid waste stream impacting an obstruction or a pool forming below can create aerosols which are transported through the atmosphere. This could occur when pit coverblocks are not installed. In order to assess the importance of this mitigative action, the potential inhalation dose downwind of a splash/splatter release is calculated using the following expression.

$$D_{splash} = V_{ss} * ARF * RF * (X/Q') * BR * ULD$$

V_{ss} = Volume of waste subjected to splash/splatter (m^3).
ARF = Airborne Release Fraction (sampled along with RF)
RF = Respirable Fraction.

4.11.1 Assumptions Regarding Splash/Splatter

When the pit is uncovered the aerosols generated from splashing and splattering are assumed to enter the atmosphere until the pit fills. At that point it is assumed that the leak opening is sufficiently covered as to prevent further splash/splatter.

When pit cover blocks are installed, direct release of aerosols into the environment from splash/splatter is not possible. The exterior walls of a concrete valve pit are typically perpendicular to the ground, do not have a lip or flange, and are usually one to two feet above grade. Should the pit overflow, the waste would exit the cracks in the perimeter of the cover blocks or shield plug, run across to the edge of the valve pit, and down its side onto the ground.

On the other hand, when COB covers are installed there is still the possibility of a splash/splatter type of release even after the COB is filled. This could occur as a result of the COB overflowing with enough pressure to project a stream of waste horizontally or down at the ground. For this reason, the splash/splatter release is assumed to continue even after the COB fills.

4.11.2 Splash/splatter Releases

The respirable aerosol release rate is assumed to be proportional to the total leak rate. The airborne release fraction and respirable release fraction are sampled from a lognormal distribution which is discussed further in Appendix C.

4.12 VENT INHALATION DOSE

The venting pit aerosol release doses are calculated according to the following equation.

$$D_{vent} = C_p * V_p * N_{ex} * (X/Q') * BR * ULD$$

C_p = Concentration of respirable aerosol in waste pit air (L/m^3)
V_p = Volume of air in a pit (m^3)
N_{ex} = Number of exchanges of pit air during the exposure time.

The volume of air in a pit is sampled from the data provided in Appendix H.

4.13 ENTRAINMENT INHALATION DOSE

Entrainment of waste can occur as the wind sweeps the surface. The inhalation dose from the aerosol release due to wind entrainment is calculated according to the following equation.

$$D_{entrain} = (EM_{10} * A_p * T_{ex} / (\rho * 0.001\ m^3/L)) * (X/Q') * BR * ULD$$

EM_{10} = Respirable mass release rate by entrainment ($kg/m^2/s$)
A_p = Contaminated surface area (m^2)[1]
T_{ex} = Exposure Time (s)
ρ = Waste Density (kg/m^3)

4.13.1 Wet Pool

The respirable mass release rate from wind blowing across the surface of a pool is based on an empirical fit first used in Finfrock, et al., (1999) and reproduced below.

$$EM_{10} = 2.14x10^{-15} * F_p * u^{3.762}$$

EM_{10} = Respirable mass release rate by entrainment ($kg/m^2/s$)
F_p = Fetch, taken to be the diameter of the pool (m)[2]
u = Wind velocity (m/s)

4.13.2 Dry Contaminated Soil

The respirable mass release rate from wind blowing across the surface of contaminated soil of unlimited erosion potential is calculated using the following equation (Cowherd, 1985),

[1] To account for changing pool size in the wet pool case the mean area is used where the mean area is defined in Section 4.14. For the dry pool case the maximum pool size is used.
[2] To account for changing pool size the mean diameter is used, where the mean diameter is as defined in Section 4.14.

$$EM_{10} = 10^{-8}(1 - V)\left(\frac{u}{u_t}\right)^3 F(x)$$

EM_{10}	=	Respirable mass release rate by entrainment ($kg/m^2/s$),
V	=	fraction of the contaminated surface vegetative cover (assume zero),
u	=	wind speed at 7 m above surface, use sampled 10 m wind speed for conservatism (m/s),
u_t	=	threshold wind speed at 7 m above surface (m/s).

The function F(x) can be calculated from Figure 4-3 provided in Cowherd (1985) which was fitted by the equation,

$$F(x) = 1.91e^{-0.216x^3}$$

x	=	0.886 u_t/u.

The threshold wind speed/friction velocity ratio at an elevation of 7 meters can be calculated from the equation,

$$\frac{u_t(z)}{u_{*t}} = \frac{1}{0.4}\ln\left(\frac{z}{z_0}\right)$$

$u_t(z)$	=	threshold wind speed at height z (m/s),
z	=	height above surface (m), assume 7 m,
u_{*t}	=	threshold friction velocity (m/s),
z_0	=	roughness height (m), assume 0.01 m which means that surface roughness is characterized by objects about 10 cm high on average.

The threshold friction velocity can be calculated from the graph provided in Cowherd (1985) which was fitted by the equation,

$$u_{*t} = 0.66M^{0.4216}$$

u_{*t}	=	threshold friction velocity (m/s),
M	=	aggregate size distribution mode (mm).

The aggregate size distribution mode, M, is uniformly sampled between the values of 0.1 and 1 mm which is representative of fine to course sand.

Therefore for a roughness height of 0.01 m and a height above surface of 7 m, the wind speed to friction velocity ratio is about 16.4.

Example: The threshold friction velocity for a 1 mm aggregate size distribution mode is 0.66 m/s. Threshold wind speed is then calculated by multiplying the wind speed/friction velocity ratio by the threshold friction velocity, which gives 10.8 m/s. Note that wind speeds below this threshold would not cause entrainment, however the equation for EM_{10} is based on the use of an annual average wind speed. Stochastically this is achieved by calculating entrainment for all sampled wind speeds. The threshold wind speed and wind speed are then used to calculate x. For a wind speed of 19 m/s, x = 0.5. F(x) is evaluated to be approximately 1.9. Inserting all values into the equation for EM_{10} yields 1.0E-7 kg/m^2 s. This value represents the vertical flux of particles smaller than 10 μm from a dry surface of unlimited erosion potential when wind speed is 19 m/s at a height above the surface of 7 m.

4.14 DIRECT EXPOSURE DOSE

The direct exposure dose was calculated from a function relating dose rate to pool radius. Direct exposure dose is limited to the contribution from Cs-137 (and its Ba-137m daughter) only. Other components can be ignored without introducing substantial error. While D_{de} is ignored for offsite doses, the onsite dose is given by,

$$D_{de} = F_d(R_m * CR * T_{ex})$$

F_d = function relating dose rate to pool radius (Sv/hr)
R_m = Radius of the pool corresponding to the median pool size
CR = Ratio of the Cs-137 concentration in the pool to the concentration assumed by F_d = Cs_p/Cs_0
  $Cs_p = Cs_{sd} * F + Cs_{sn} * (1-F)$
  Cs_{sd} = Cs-137 concentration in waste solids (Bq/L)
  Cs_{sn} = Cs-137 concentration in supernate (Bq/L)
  Cs_0 = Cs-137 concentration assumed in MCNP modeling
  F = Fraction of waste (by volume) composed of solids
T_{ex} = Exposure Time (hr)

The pool radius is calculated from the pool volume, by assuming a circular pool of fixed depth and ignoring the surface area of the pit. For a constant leak rate the median pool size occurs at 1/2 the exposure time. The radius at one half the exposure time is equal to $(1/2)^{1/2}$ times the radius at the end of the exposure time.

$$R_m = 0.707*((W*T_{ex} - Vp)/h_p/\pi)^{1/2}$$

W = Leak Rate (m^3/s)
V_p = Volume of pit (m^3)
h_p = Depth of pool (m)
T_{ex} = Exposure Time (s)

A series of MCNP (Lan, 1999) calculations were performed to determine the expected direct dose, at 100 m from the leak, for different pool sizes. The results of those calculations are shown in Table 1 below. A curve fit was applied to the data to produce a function (of radius) that could be used in the spreadsheet analysis.

$$D_{de} = 2E\text{-}8*R^3 + 1.2E\text{-}6*R^2 + 2E\text{-}6*R$$

This function produces results that typically have an error of less than 10% for pool sizes between 5 - 60 m in radius.

Table 1. Dose Rate Function of Radius

r (m)	tally	err	v (m^3)	D (Sv/hr)	fit
0.1	4.00E-03	0.0031	0.001037	4.146E-08	2.12E-07
1	2.09E-03	0.0044	0.103673	2.170E-06	3.22E-06
2	1.97E-03	0.0053	0.41469	8.159E-06	8.96E-06
5	1.89E-03	0.0042	2.591814	4.889E-05	4.25E-05
10	1.87E-03	0.0045	10.36726	1.938E-04	1.60E-04
20	1.89E-03	0.0056	41.46902	7.849E-04	6.80E-04
30	1.94E-03	0.0042	93.3053	1.807E-03	1.68E-03
40	2.02E-03	0.0047	165.8761	3.348E-03	3.28E-03
50	2.16E-03	0.0054	259.1814	5.602E-03	5.60E-03
60	2.32E-03	0.004	373.2212	8.649E-03	8.76E-03
70	2.62E-03	0.0044	507.9955	1.333E-02	1.29E-02
80	3.13E-03	0.0034	663.5044	2.076E-02	1.81E-02
90	4.59E-03	0.0029	839.7477	3.851E-02	2.45E-02
100	2.05E-02	0.003	1036.726	2.123E-01	3.22E-02

The shine from waste contained in the open pit is ignored in this analysis as it is a minor contributor to onsite dose in comparison to the pool. The small increase in onsite uncontrolled dose by including this contribution would not change the conclusion that uncontrolled waste leaks potentially have safety significant consequences.

The dose rate is proportional to the area of the pool such that the average dose rate and the average pool area will occur at the same point in time. This means that the total gamma dose can be calculated by multiplying the total exposure time by the dose rate corresponding to the average pool area.

So long as the pool is increasing at a constant rate (constant leak flow rate) then the average pool area will occur at the midpoint in time between the beginning of pool formation and the end time of interest (evacuation time or maximum exposure time). If the flow rate is not constant then these relationships no longer hold and the average area must be determined by calculating a weighted average over time using the equation,

$$A_{avg} = \frac{\sum_i w_i \Delta t_i^{\,2}}{2h \sum_i \Delta t_i}$$

Where w_i is the leak rate in interval i, Δt_i is the duration of interval i, and h is the depth of the pool. The effective mean radius is then calculated using the equation,

$$R_m = \sqrt{\frac{A_{avg}}{\pi}}$$

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5.0 INPUT ASSUMPTIONS AND BASES

This section identifies the source and bases for the input assumptions used in the equations described in Section 4. Table 2 lists parameters which are constant (i.e., not sampled) and Table 3 lists parameters defined by pdf's.

Table 2. Base Case Constants

Parameter	Value	Basis
BR = Breathing rate	3.3E-4 m^3/s onsite 2.7E-4 m^3/s offsite	These values represent reference man breathing rates for acute and 24 hour average exposures as recommended by ICRP 23.
T_{ex} = Exposure time	12 h (43,200 s) onsite uncontrolled (varies for controlled) 24 h (86,000 s) offsite	These exposure times for the maximum onsite and offsite receptors are consistent with the requirements of Hanford Procedure RPP-PRO-704 *Hazards and Accident Analysis Process.*
C_c = Contraction coefficient	1.0	This contraction coefficient applies to a square or rounded orifice and is used in estimating the pressure drop in spray aerosol calculations. The estimated doses are not sensitive to this parameter.
C_p = Aerosol concentration from escaping pit air	100 mg/m^3	This aerosol concentration represents a maximum quasi-equilibrium value a few minutes after an explosive event (Sutter, 1982). The estimated doses are not sensitive to this assumption.
C_v = Velocity coefficient	0.82	This velocity coefficient applies to a square edge orifice and is used in estimating the pressure drop in spray aerosol calculations. The estimated doses are not sensitive to this parameter.
Cs_0 = Base line Cs-137 concentration	1.0E+10 Bq/L	Reference value used in MCNP (Lan, 1999) analysis of dose rate from pools (see Appendix M).
D_p = Waste transfer line inner pipe diameter	3.068 in (7.79E-2 m)	A 3 in Sch 40 pipe was chosen as it was the most common transfer line size used. Its selection must be consistent with transfer line length and pump characteristics as discussed in Section 7.9.
D_r = AED considered to be respirable	10 μm	This value is commonly used to represent the upper bound of respirable sized aerosols. The analysis contained in this report indicates that inhalation hazards are minor contributors to onsite doses. Altering this value would not significantly change dose estimates.

Table 2. Base Case Constants

Parameter	**Value**	**Basis**
f = Darcy friction factor	0.018	Fully turbulent flow is assumed in order to simplify the analysis and to conservatively represent the pressure drop occurring from fluid flow in 3 in commercial steel pipe. Allowing for less than fully turbulent flows would increase the pressure drop and reduce the estimated leak rates to a small degree.
g = gravitational constant	9.80665 m/s^2	Physical constant.
h_p = pool depth	0.033 m	The actual depth would vary according to local topography, soil infiltration, and time. This value was chosen for consistency with past analysis practices, conservatism, and lack of information. A sensitivity discussion is provided in Section 7.6.
Maximum static head for drainback	75 ft	The maximum elevation difference between any 200 Area vented transfer point and source or destination is 72 ft between the 6241-V Vent Station and 200 West. Therefore the maximum hydrostatic head is limited to 75 ft.
N_{ex} = fraction of pit air exchanged during exposure period	1	Several estimates of pit air volume released have been made in past analyses. The effects considered were displacement, thermodynamic heating, barometric pressure changes, and wind. All appeared to predict a release volume approaching 100% over various exposure intervals. This assumption has essentially no effect on the estimated total dose.
q = particle size distribution fitting parameter	2.4	This is a fitting parameter recommended for spray aerosol calculations (page 2.7 of Hey 1994). This assumption has essentially no effect on the estimated total dose.
P_a = atmospheric pressure	1.0135E+5 Pa	Physical constant.
SMD/X = ratio of Sauter Mean Diameter to characteristic diameter	0.65415	This ratio is recommended for spray aerosol calculations (Table 2.2 of Hey 1994). This assumption has essentially no effect on the estimated total dose.
ε = absolute surface roughness	4.572E-5 m	This value represents commercial steel pipe (Crane Tech. Paper 410) and is only used for estimating spray aerosol releases. This assumption has essentially no effect on the estimated total dose.

Table 2. Base Case Constants

Parameter	Value	Basis
ρ_{sd} = waste solids density	1.6 kg/L	This value is a reasonable estimate of Hanford tank waste solids density (Van Keuren 1996a).
ρ_{sn} = waste supernate density	1.1 kg/L	This value is a reasonable estimate of Hanford tank waste supernatant density (Van Keuren 1996a).
L_{max} = maximum equivalent waste transfer length	6100 m (20,000 ft)	This transfer line length achieves nominal flow conditions (155 gpm) for given pump characteristics and pipe diameter. See Section 7.9 for further discussion.

Table 3. Base Case Probability Density Functions

Parameter	Value	Basis
U_w = Wind speed	Look up table. Hanford meteorological data	Wind speed is sampled from Hanford meteorological joint frequency data representing ground level wind speeds in the 200 Area (Schreckhise, et. al, 1993). It is correlated to the atmospheric diffusion coefficient. See Appendix D for more details.
(X/Q') = atmospheric diffusion coefficient	Look up table. Hanford meteorological data	The atmospheric diffusion coefficient. is sampled from Hanford meteorological joint frequency data representing ground level plumes in the 200 Area (Schreckhise, et. al, 1993). It is correlated to wind speed. See Appendix D for more details.
ARF*RF = Aerosol release fraction * respirable fraction	Lognormal 5%=1E-5, 95%=1E-4.	These values are based on data taken from experimental spills of slurries and aqueous solutions from a height of 3 m (Section 3.1 of DOE,1994). See Appendix C for more details.
Cs_{sd} = Cesium concentration in solids	Volume weighted look up table. Hanford tank waste data	This data was obtained from the Tank Characterization Database as documented in Jensen (2000). It is correlated to ULD. See Appendix F for more details.
Cs_{sn} = Cesium concentration in supernate	Volume weighted look up table. Hanford tank waste data	This data was obtained from the Tank Characterization Database as documented in Jensen (2000). See Appendix F for more details.
F = Solids fraction	Triangular from 0.01 to 0.33 with peak at 0.07	This represents a reasonable solids fraction range for waste transfers. The most likely value of 0.07 is based on engineering judgment. Analysis results are only slightly sensitive to this assumption.

Table 3. Base Case Probability Density Functions

Parameter	Value	Basis
h_p = Crack depth	Uniform from 0 - .00508 m	This parameter is only used to estimate pressure drop for spray aerosol releases. The upper end of 0.00508 m (0.2 in) represents the thickness of 3 in Sch. 40 pipe wall. Analysis results are not sensitive to this assumption. See Appendix B for more details.
L_o = Crack length	Uniform from .00158 - .0762 m	This range of crack lengths was selected as representative of the failure data documented in Appendix B. Since it directly affects the calculated leak rate, analysis results are sensitive to this distribution. A sensitivity discussion is included in Section 7.2.
W_o = Crack width	Bimodal uniform, 0 - .0047625 m (0 - 3/16 in) with a magnitude of 6 and 0.01905 - .063 m (3/4 - 1 1/2 in) with a magnitude of 1	This range of crack widths was selected as representative of the failure data documented in Appendix B. Since it directly affects the calculated leak rate, analysis results are sensitive to this distribution. A highly sensitive region for spray aerosol exists between 0 - 0.0002 m (0.008 in). A sensitivity discussion is included in Section 7.2.
L_p = Distance between pump and leak	Uniform from 0 – L_{max} m	It is reasonable to expect that leak location would be equally likely anywhere along the transfer route.
Uphill vs. downhill slope for drainback	Uniform binary distribution	The elevation differences in the 200 Area are slight in general. It is reasonable to expect that waste would be pumped downhill as well as uphill. This only affects the estimate of drainback.
V_p = Pit air volume	Look up table. Hanford data	Pit volumes were based on engineering drawings as documented in Appendix H.
ULD_{inh-sd} = Unit liter dose from inhalation of solids	Volume weighted look up table.	This data was obtained from an evaluation of the Tank Characterization Database as documented in Jensen (2000). Each data point represents the average for the given tank. Volume weighted means that the probability of leaking that waste type is proportional to the Hanford waste volume fraction it represents. See Appendix F for more details.
ULD_{inh-sn} = Unit liter dose from inhalation of supernate	Volume weighted look up table.	This data was obtained from an evaluation of the Tank Characterization Database as documented in Jensen (2000). Each data point represents the average for the given tank. It is correlated to cesium concentration. Volume weighted means that the probability of leaking that waste type is proportional to the Hanford waste volume fraction it represents. See Appendix F for more details.

Table 3. Base Case Probability Density Functions

Parameter	Value	Basis
μ_{sn} = Viscosity of supernate	1, 10, 20 cp triangular	Supernate viscosity's usually lie in the range of 10 to 12 cp. However, very dilute waste could approach that of water (1 cp) while viscosity's as high as 20 cp have been reported. This assumption only affects spray aerosol releases and does not greatly impact dose estimates. See Appendix G for more details.
M = Particle size distribution mode for dry entrainment	0.1 - 1 mm uniform	The particle size mode distribution of fine to course sand was used to represent Hanford soil for the purpose of estimating aerosol entrainment from dry soil. Dose estimates were found to be relatively insensitive to changes in this distribution.

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6.0 RESULTS

A discussion of the results for each representative accident category is provided below. The five categories are:

- **33A** - Ex-tank waste transfer leak into structure or encasement that results in release to environment from structure.
- **33B** - Ex-tank waste transfer leak directly into soil. Leak may remain subsurface or may result in pool on soil surface.
- **33C** - Ex-tank waste transfer leak directly to the soil surface or atmosphere.
- **33D** - Misroute of waste into tanks, uncontrolled waste systems, clean systems, or 204-AR waste unloading facility.
- **33E** - Leaks inside actively vented structures

Two statistical measures of consequences are presented. These are the 50 and 95 percentiles. The 50 percentile or median is defined as the consequence value such that it is equally probable that consequences could be smaller or greater. This value is typically considered a best estimate and useful for evaluating the risk of beyond design basis accident consequences (i.e., without controls) and the degree of reliability needed in the controls. The 95 percentile is defined as the consequence value which bounds 95 percent of all analyzed consequences. This value is typically considered a reasonable bounding value and useful for safety classification and judging the suitability of mitigative controls. Unless specified otherwise, all references to onsite and offsite dose consequences are made to the 95 percentiles.

6.1 33A - EX-TANK WASTE TRANSFER LEAK INTO STRUCTURE

Waste transfer leaks into structures may have characteristics of spray, splash/splatter or direct radiation exposure, or combinations of these characteristics. The important aspect of this accident category is that leaks either occur in or are routed to a structure equipped with a leak detection device. The structure also provides a contained volume into which a leak can accumulate. The design feature of movable coverblocks also introduces the possibility that aerosols generated from spray or splash/splatter could be exposed to the atmosphere if the covering was not in place at the time of the leak. The presence of leak detecting devices coupled with the structure volume allows actions to occur that can prevent or significantly reduce the size of the release of waste to the environment. Waste leaks have occurred in waste transfer structures during transfers and should be treated as an anticipated event.

6.1.1 33A - Leak Causes

The characteristics of the causes of waste transfer leaks into structures allow grouping into the following general categories:

- Corrosion – Corrosion is a major contributor to leaks in transfer lines. The leak can take place either in piping in the waste transfer structure or can occur at any point along the transfer piping and be routed to a structure via the transfer pipe encasement.

- Erosion – Erosion is a process that occurs where fluid suddenly changes direction as would occur in elbows, angle fittings, etc. Jumpers and other connecting piping in waste transfer related structures are made up of fittings and pipe segments that are vulnerable to erosion caused leaks. Erosion can also result in leaks in encased transfer lines with the pipe encasement routing the leakage to the structure.
- Gasket failure – Gaskets are used in flanged connections, valve bonnets, and pump casings. Valve and pump packing are also considered to be gaskets. Gaskets are not normally used in transfer piping outside of structures. Gaskets have been found to leak due to age related degradation, dry-out/shrinkage, or wear in the case of packing and seals.
- Jumper leaks (seal failure or misalignment) – It has been shown that minor off-axis forces on a jumper can cause leaks to occur. Other jumper leaks have occurred due to sealing surface imperfections or damage.
- Water hammer - Water hammer is postulated to occur when pumping is started in an uncontrolled fashion allowing an empty transfer pipe to rapidly fill with fluid. The moving slug of fluid can exert large stresses when its direction is changed by elbows or its velocity is changed in valves. If the leak occurs in a line segment away from a structure the encasement is assumed to conduct the waste to a structure.
- High temperature waste - Very hot waste being transferred into a cold transfer line can cause stresses by the expansion of the piping. If the leak occurs in a line segment away from a structure the encasement is assumed to route the waste to a structure.
- In-pipe flammable gas deflagration – In-pipe flammable gas deflagrations are postulated to occur when radioactive waste materials are left in a transfer pipe in the presence of water. Radiolytic decomposition of the water liberates hydrogen which can be ignited by very low energy sparks. The pressure pulse that is generated can cause leaks at jumper connections or weak points in the piping. Leaks occurring in line segments will be routed to a structure via the encasement. Current analysis (Van Keuren, 1999) of the ignition of flammable gas in a transfer line shows that new transfer lines (including OGT lines) will withstand pressures from the event. However, existing lines may not remain leak tight due to wall thickness reduction from corrosion. If the leak occurs in a line segment away from a structure the encasement is assumed to route the waste to a structure. The initiator for this type of leak can occur at any time that flammable gas is present.
- Seismic events – Seismic events are an initiator of leaks in transfer system structures. None of the transfer system components or structures are seismically qualified. No credit is taken for the seismic integrity of SSCs other than the gross integrity of SSTs, DSTs, and AWF tanks.

6.1.2 33A - Dose Consequences - No Controls

Results are estimated for the no controls case where onsite and offsite exposure start at leak inception and continues for 12/24 hours. No credit for coverblocks, supplemental covers, independent verification of the transfer route to prevent a pump dead head condition, leak detection, pump shutdown, or emergency response and onsite evacuation are taken. These results represent the condition where the intended discharge path beyond the leak location is blocked. This could occur as a result of valve misalignment or line plugging. The effect of this condition is to increase the system pressure and leak rate. The doses from the individual pathways of gamma-ray shine, spray, splash/splatter, and wet entrainment are presented as well as the total dose from all pathways. Note that "all pathways" represents the quantile of the sum, not the sum of the quantiles. In addition to the four acute pathways and total dose, an estimate of the subsequent dry entrainment dose is also presented. This latter pathway represents the downwind dose from airborne particulates entrained from the action of wind blowing across a dry contaminated surface. This dose can only occur after the pool has dried out. No estimate of pool dry out time is made within this study. Since dry entrainment would occur later and can be controlled separately, its consequence is presented separately.

Table 4. 33A - Important Intermediate Results - No Controls

Intermediate Result	Mean	5 %	50%	95 %	Outlier
Waste Density in kg/L	1.17	1.12	1.16	1.23	1.26
Eff. slurry viscosity in cp	15	5.4	15	28	47
Pump flow rate in m^3/s (gpm)	6.1E-3 (97)	3.6E-4 (5.7)	5.9E-3 (94)	1.3E-2 (206)	1.8E-2 (285)
Pump pressure in N/m^2 (psig)	4.2E+6 (610)	2.4E+6 (350)	4.5E+6 (650)	5.1E+6 (740)	5.4E+6 (780)
Leak pressure in N/m^2 (psig)	3.3E+6 (480)	3.8E+4 (550)	3.9E+6 (570)	5.1E+6 (740)	5.4E+6 (780)
Leak flow rate in m^3/s (gpm)	6.1E-3 (97)	3.6E-4 (5.7)	5.9E-3 (94)	1.3E-2 (206)	1.8E-2 (285)
Leak area m^2 (in^2)	3.1E-4 (0.47)	5.4E-6 (0.008)	8.9E-5 (0.14)	1.9E-3 (2.9)	4.7E-3 (7.3)
Total leak volume (12 hrs) in m^3 (gal)	2.6E+2 (69,000)	1.6E+1 (4,200)	2.5E+2 (66,000)	5.7E+2 (150,000)	7.9E+2 (210,000)
Pit air volume in m^3	1.4E+1	1.5E-1	1.3E+1	3.9E+1	1.5E+2
Eff. pool volume (12 hrs) in m^3	2.5E+2	1.7	2.4E+2	5.6E+2	7.8E+2
Effective pool radius (12 hrs) in m	44	4.0	48	73	87
Pit fill time in hrs	4.2E+2	4.3E-3	5.0E-1	1.0E+1	1.3E+7
ULD supernate inh. in Sv/L	2.1E+2	5.5E+0	7.0E+1	1.6E+3	1.7E+3
ULD solids inh. in Sv/L	4.1E+3	1.2E+2	6.7E+2	1.8E+4	2.3E+5
ULD composite inh. in Sv/L	7.3E+2	3.2E+1	2.1E+2	2.1E+3	7.3E+4
Cs-137 in supernate (Bq/L)	1.5E+10	4.9E+8	1.3E+10	5.9E+10	5.9E+10
Cs-137 in solids (Bq/L)	7.8E+9	1.2E+7	6.9E+9	2.1E+10	4.9E+10
Cs-137 composite (Bq/L)	1.4E+10	9.7E+8	1.1E+10	4.5E+10	5.8E+10
ARF * RF (for splash/splatter)	4.0E-5	1.0E-5	3.2E-5	1.0E-4	5.1E-4
Resp. spray rate in m^3/s	3.4E-7	5.0E-13	2.2E-8	1.5E-6	6.8E-5
Onsite X/Q in s/m^3	2.8E-3	2.0E-4	2.2E-03	8.0E-03	1.3E-02
Offsite X/Q in s/m^3	2.7E-6	3.8E-08	1.2E-06	1.2E-05	3.0E-05

Table 5. 33A - Dose Consequences - No Controls

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	**1.7E-2**	**1.6E-1**	-	-
Spray release	4.0E-6	3.3E-3	1.7E-9	2.3E-6
Splash/splatter	7.9E-5	4.7E-3	4.1E-8	5.1E-6
Wet entrainment	1.1E-7	1.4E-5	3.0E-10	3.7E-8
All pathways	**2.1E-2**	**1.7E-1**	8.9E-8	1.1E-5
Dry entrainment	1.9E-6	1.3E-3	3.4E-9	2.4E-6

6.1.3 33A - Dose Consequences - Independently Verify Route

This case is similar to the no controls case described above except that independent verification of the route is assumed and the correct discharge path is assured. This has the effect of lowering the pressure at the leak location and reducing the leak rate.

Table 6. 33A - Important Intermediate Results - Independently Verify Route

Intermediate Result	Mean	5 %	50%	95 %	Outlier
Pump flow rate in m^3/s (gpm)	1.1E-02 (174)	9.9E-03 (157)	1.1E-02 (174)	1.4E-02 (222)	1.8E-02 (285)
Pump pressure in N/m^2 (psig)	3.1E+6 (450)	2.0E+6 (290)	3.3E+6 (479)	3.6E+06 (522)	3.8E+6 (551)
Leak pressure in N/m^2 (psig)	1.1E+6 (160)	2.4E+04 (3.5)	8.8E+05 (128)	2.8E+6 (406)	3.7E+6 (537)
Leak flow rate m^3/s (gpm)	3.8E-03 (60)	1.6E-4 (2.5)	2.8E-03 (44)	1.1E-2 (174)	1.7E-02 (269)
Total leak volume (12 hrs) in m^3 (gal)	1.6E+02 (42,000)	6.7E+00 (1,800)	1.2E+2 (32,000)	4.9E+2 (130,000)	7.6E+2 (200,000)
Effective pool volume (12 hrs) in m^3	1.5E+2	0	1.1E+2	4.8E+2	7.4E+2
Effective pool radius (12 hrs) in m	33	0	32	68	85
Pit fill time in hrs	1.8E+3	6.9E-3	9.1E-1	2.5E+1	7.2E+7

Table 7. 33A - Dose Consequences - Independently Verify Route

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	**7.1E-3**	**1.0E-1**	-	-
Spray release	7.0E-7	6.5E-4	3.1E-10	4.4E-7
Splash/splatter	6.9E-5	3.2E-3	3.6E-8	3.4E-6
Wet entrainment	3.1E-8	6.4E-6	9.7E-11	1.8E-8
All pathways	**8.2E-3**	**1.1E-1**	5.7E-8	5.3E-6
Dry entrainment	6.2E-7	7.4E-4	1.4E-9	1.4E-6

6.1.4 33A - Dose Consequences - Leak Detection at 5% - Evacuation at +1.7 hrs

The above results indicate that offsite doses are far below guidelines but that onsite doses exceed guidelines and are dominated by gamma-ray shine. In order to reduce onsite doses to below guidelines, leak detection and onsite evacuation are necessary. The results below are for the case where automatic leak detection occurs when the leak volume exceeds 5% of the pit volume which would be sufficient level to actuate moisture or level detectors. If the onsite MEI is evacuated within 1.7 hours then his 95% dose can be limited to less than the guideline. No credit is taken for cover blocks, supplemental covers, independent verification of the transfer route to prevent a pump dead head condition, or pump shutdown.

Onsite/offsite exposure starts at leak inception. Evacuation of onsite personnel occurs 1.7 hours after leak detection, but in no case is the onsite worker exposed longer than 12 hours.

Table 8. 33A - Dose Consequences - Leak Detection at 5% - Evacuation at +1.7 hrs

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	1.3E-4	1.8E-3	-	-
Spray release	3.7E-6	1.7E-3	-	-
Splash/splatter	4.9E-5	1.4E-3	-	-
Wet entrainment	2.2E-10	6.0E-8	-	-
All pathways	4.3E-4	4.8E-3	-	-

6.1.5 33A - Dose Consequences - Leak Detection at 5% - Pump Shutoff at +30 min - Evacuation at +3.2 hrs

The above results indicate that the controls of automatic leak detection and evacuation of the onsite MEI are adequate to reduce the 95% onsite dose to below guidelines. This case evaluates the benefit of automatic pump shutoff 30 minutes after leak detection. No credit is taken for cover blocks, supplemental covers, or independent verification of the transfer route to prevent a pump dead head condition.

Onsite/offsite exposure starts at leak inception. Leak detection occurs when the pit is 5% full which would be sufficient level to actuate moisture or level detectors. Pump shutdown occurs 30 minutes after leak detection after which the flow rate out the leak is reduced to drainback values using the model discussed in Section 3.4. Evacuation of onsite personnel occurs 3.2 hours after leak detection, but in no case is the onsite worker exposed longer than 12 hours. Controlled offsite doses are not reported because they are well below guidelines even when uncontrolled.

Table 9. 33A - Important Intermediate Results - Drainback

Intermediate Result	Mean	5 %	50%	95 %	Outlier
Drainback flow rate in m^3/s (gpm)	1.4E-3 (22)	6.3E-5 (1.0)	1.2E-3 (19)	3.8E-3 (60)	4.4E-3 (70)

Table 10. 33A - Dose Consequences - Leak Detection at 5% - Pump Shutoff at +30 min - Evacuation at +3.2 hrs

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	2.5E-5	2.4E-3	-	-
Spray release	3.4E-6	1.3E-3	-	-
Splash/splatter	3.9E-5	1.1E-3	-	-
Wet entrainment	5.8E-12	5.6E-8	-	-
All pathways	3.5E-4	4.7E-3	-	-

6.1.6 33A - Dose Consequences - Pit Covers On - Leak Detection at 5% - Pump Shutoff at +30 min - Evacuation at +3.2 hrs

In addition to automatic leak detection at 5% pit fill, pump shutoff at +30 min, and evacuation of the onsite MEI at +3.2 hours, this case evaluates the benefit of cover blocks and supplemental covers for knock down of aerosol generated from spray or splash/splatter. A new dose pathway labeled pit air release is presented and is an estimate of displaced aerosol escaping from the covered pit. Ninety percent of the pit volume is assumed to be displaced as air containing a respirable aerosol concentration of 100 mg/m^3 is released. No credit is taken for independent verification of the transfer route to prevent a pump dead head condition.

Onsite/offsite exposure starts at leak inception. Leak detection occurs when the pit is 5% full which would be sufficient level to actuate moisture or level detectors. Pump shutoff occurs 30 minutes after leak detection after which the flow rate out the leak is reduced to drainback values using the model discussed in Section 3.4. Evacuation of onsite personnel occurs 3.2 hours after leak detection, but in no case is the onsite worker exposed longer than 12 hours. Controlled offsite doses are not reported because they are well below guidelines even when uncontrolled.

Table 11. 33A - Dose Consequences - Pit Covers On - Leak Detection at 5% - Pump Shutoff at +30 min - Evacuation at +3.2 hrs

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	2.5E-5	2.4E-3	-	-
Pit Air Release	7.9E-8	2.4E-6	-	-
Wet entrainment	5.8E-12	5.6E-8	-	-
All pathways	2.8E-5	2.4E-3	-	-

6.1.7 33A - Dose Consequences - Independently Verify Route - Leak Detection at 5% - Pump Shutoff at +30 min - Evacuation at +3.2 hrs

Instead of crediting pit cover blocks and supplemental covers as in the case above, this case assumes independent verification of the transfer route to prevent a pump dead head condition, automatic leak detection at 5% pit fill, pump shutoff at +30 min, and evacuation of the onsite MEI at +3.2 hours.

Onsite/offsite exposure starts at leak inception. Leak detection occurs when the pit is 5% full which would be sufficient level to actuate moisture or level detectors. Pump shutdown occurs 30 minutes after leak detection after which the flow rate out the leak is reduced to drainback values using the model discussed in Section 3.4. Evacuation of onsite personnel occurs 3.2 hours after leak detection, but in no case is the onsite worker exposed longer than 12 hours. Controlled offsite doses are not reported because they are well below guidelines even when uncontrolled.

Table 12. 33A - Dose Consequences - Independently Verify Route - Leak Detection at 5% - Pump Shutoff at +30 min - Evacuation at +3.2 hrs

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	2.9E-5	1.6E-3	-	-
Spray release	4.8E-7	2.2E-4	-	-
Splash/splatter	2.9E-5	8.2E-4	-	-
Wet entrainment	8.2E-12	2.4E-8	-	-
All pathways	1.9E-4	2.8E-3	-	-

6.1.8 33A - Dose Consequences - Pit Covers On - Independently Verify Route - Leak Detection at 5% - Pump Shutoff at +30 min - Evacuation at +3.2 hrs

This case evaluates the benefit of pit cover blocks and supplemental covers, independently verifying the transfer route to avoid a pump dead head condition, automatic leak detection at 5% pit fill, pump shutoff at +30 min, and evacuation of the onsite MEI at +3.2 hours.

Onsite/offsite exposure starts at leak inception. Leak detection occurs when the pit is 5% full which would be sufficient level to actuate moisture or level detectors. Pump shutdown occurs 30 minutes after leak detection after which the flow rate out the leak is reduced to drainback values using the model discussed in Section 3.4. Evacuation of onsite personnel occurs 3.2 hours after leak detection, but in no case is the onsite worker exposed longer than 12 hours. Controlled offsite doses are not reported because they are well below guidelines even when uncontrolled.

Table 13. 33A - Dose Consequences - Pit Covers On - Independently Verify Route - Leak Detection at 5% - Pump Shutoff at +30 min - Evacuation at +3.2 hrs

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	2.9E-5	1.6E-3	-	-
Pit Air Release	7.9E-8	2.4E-6	-	-
Wet entrainment	8.2E-12	2.4E-8	-	-
All pathways	3.1E-5	1.6E-3	-	-

6.1.9 33A - Results Summary

A no controls and several variations of controlled cases of waste leaks into structures were evaluated. In no case are offsite guidelines challenged. Uncontrolled consequences from dry entrainment releases are also far below guidelines for both offsite (24 hrs) and onsite (12 hrs) receptors. Uncontrolled consequences exceed onsite guidelines so safety significant controls are warranted. Uncontrolled onsite doses are dominated by gamma-ray shine from the radioactive pool that forms once the pit overflows. In this case pit coverblocks alone provide insufficient mitigation, but do reduce doses by a factor of two to the onsite MEI in the case where automatic leak detection at 5% pit fill, a pump shutdown 30 minutes after leak detection, and onsite evacuation 3.2 hrs after leak detection are credited. The protection cover blocks afford to workers immediately adjacent to the pit are not evaluated here. Pump shutdown within 30 minutes of leak detection extends the allowable evacuation period from 1.7 to 3.2 hours due to the decreased growth rate of the waste spill. Note that the 50% dose for the no controls case exceeds the anticipated guideline but is below the unlikely guideline, suggesting a needed control reliability of 99%. A summary of the 95% doses for each of the cases is provided below.

Table 14. 33A - Results Summary

Control	Function	Onsite Dose (Sv)	Offsite Dose (Sv)
No controls		**0.17**	1.1E-5
Independently verify route	Prevents blocked line (pump deadhead)	**0.11**	5.3E-6
Leak detection at 5%, evac at +1.7 hrs	Auto leak detection at 5% pit fill, removes MEI from pool shine	4.8E-3	1.1E-5
Leak detection at 5%, pump shutoff at +30 min, evac at +3.2 hrs	Auto leak detection at 5% pit fill, reduces leak rate, removes MEI from pool shine	4.7E-3	-
Pit covers on, leak detection at 5%, pump shutoff at +30 min, evac at +3.2 hrs	Knocks down aerosol, auto leak detection at 5% pit fill, reduces leak rate, removes MEI from pool shine	2.4E-3	-
Indep. verification, leak detection at 5%, pump shutoff at +30 min, evac at +3.2 hrs	Prevents blocked line, auto leak detection at 5% pit fill, reduces leak rate, removes MEI from pool shine	2.8E-3	-
Pit covers on, indep. verification, leak detection at 5%, pump shutoff at +30 min, evac at +3.2 hrs	Knocks down aerosol, prevents blocked line, auto leak detection at 5% pit fill, reduces leak rate, removes MEI from pool shine	1.6E-3	-

6.1.10 33A - Sensitivity Study - No Controls - Alternate Leak Size Distribution

An alternate leak size distribution was created from an independent assessment of industry failure data and Hanford occurrence reports (Ziada, 2000). The distribution is discussed in more detail in Section 7.2. The results for 33A - No Controls is shown in the table below.

Table 15. 33A - Sensitivity Study - No Controls - Alternate Leak Size Distribution

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	**95 %**	**50 %**	**95 %**
Gamma shine	1.2E-3	**1.0E-1**	-	-
Spray release	2.5E-5	2.2E-3	1.0E-8	2.1E-6
Splash/splatter	5.2E-5	2.3E-3	3.1E-8	2.5E-6
Wet entrainment	2.7E-9	4.4E-6	1.5E-11	1.3E-8
All pathways	2.1E-3	**1.1E-1**	9.2E-8	5.7E-6

6.2 33B - EX-TANK WASTE TRANSFER LEAK DIRECTLY INTO SOIL

An important aspect of waste transfer leaks directly into the soil is that leak detection is limited to radiation surveys and material balance monitoring because there are no automatic leak detection devices. Soil cover is credited to prevent the release of aerosols generated from a spray or splash/splatter mechanism. Since the soil void volume can accommodate only a limited volume of waste in comparison to the spill quantity, no soil hold up is assumed. This does not affect the results at the 50 and 95 percentiles. The spilled quantity ends up on the ground surface in a circular pool centered around the leak location. Evaluations are made for both DST transfers as well as salt well pump (SWP) transfers.

6.2.1 33B - Leak Causes

The characteristics of the causes of waste transfer leaks directly into the soil allow grouping into the following general categories:

- Corrosion – Corrosion is postulated to be a major contributor to leaks in transfer lines. The leak can take place in waste transfer piping at any point along the transfer piping route. If the encasement is not leak tight the leakage will escape to the soil. It is known currently that concrete encasements are not leak tight. Instances of pipe-in-pipe encasements pulling away from transfer pit/box structures have also been observed.
- Erosion – Erosion is a process that occurs where fluid suddenly changes direction or localized increases in fluid velocity occur as in elbows, angle fittings, etc. Transfer piping often has many locations where direction changes occur required by either routing requirements or to accommodate pipe expansion (so called expansion loops). The leakage will escape to the soil if the encasement is not leak tight. It is known currently that concrete encasements are not leak tight. Instances of pipe-in-pipe encasements pulling away from transfer pit/box structures creating potential leak locations have also been observed.
- Mechanical stress (heavy equipment and seismic) – It is postulated that mechanical stresses imposed by outside agents such as heavy equipment being moved over buried waste transfer lines could cause compression of the soil with resultant transfer line and encasement damage. The depth of transfer line burial (~3 feet) limits the potential for this type of event. Seismic events also can create mechanical stresses that have been shown to be initiators of leaks in piping systems. None of the transfer system components or structures are seismically qualified. No credit is taken for the seismic integrity of SSCs other than the gross integrity of SSTs, DSTs, and AWF tanks.
- In-pipe flammable gas deflagration – In-pipe flammable gas deflagrations are postulated to occur when radioactive waste materials are left in a transfer pipe in the presence of water. Radiolytic decomposition of the water liberates hydrogen which can be ignited by very low energy sparks. The pressure pulse that is generated from an ignition of the flammable gas can cause leaks at weak points in the piping. Current analysis (Van Keuren, 1999) of the ignition of flammable gas in a transfer line shows that new transfer lines (including OGT lines) will withstand pressures from such an event. However, existing lines may not remain leak tight due to wall thickness reduction from corrosion/erosion. If the encasement is not leak tight the leakage will escape to the soil. It is known currently that concrete encasements

are not leak tight. Instances of pipe-in-pipe encasements pulling away from transfer pit/box structures creating leakage paths have also been observed. The initiator for this type of leak can occur at any time that flammable gas is present.

- Bermed line failure – There are a number of bermed lines (surface laid lines with mounded soil covering) used for salt well pump transfers in the tank farms. Leaks from these low head/low flow rate lines are expected to have different release characteristics to the ground and are evaluated separately below.

6.2.2 33B - Dose Consequences - DST Transfers - No Controls

This case evaluates the hazard of an underground waste transfer leak representative of high head transfers such as from DSTs. Results are estimated for the no controls case where onsite and offsite exposure start at leak inception and continues for 12/24 hours. No credit for independent verification of the transfer route to avoid a pump dead head condition, leak detection, pump shutoff, or emergency response/onsite evacuation are taken. The doses from the individual pathways of gamma-ray shine and wet entrainment are presented as well as the total dose. Spray and splash/splatter are prevented by the soil overburden. In addition to the acute release pathways an estimate of the subsequent dry entrainment dose is also presented. This latter pathway represents the downwind dose from airborne particulates entrained from the action of wind blowing across a dry contaminated surface. This dose can only occur after the pool has dried out. No estimate of pool dry out times is made within this study. Since dry entrainment is a separately controlled release pathway, its consequence is presented separately.

Table 16. 33B - Dose Consequences - DST Transfers - No Controls

Pathway	**Onsite Dose (Sv)**		**Offsite Dose (Sv)**	
	50 %	**95 %**	**50 %**	**95 %**
Gamma shine	**0.021**	**0.18**	-	-
Wet entrainment	1.4E-7	1.5E-5	3.4E-10	3.9E-8
All pathways	**0.021**	**0.18**	3.4E-10	3.9E-8
Dry entrainment	2.8E-6	1.4E-3	4.0E-9	2.5E-6

6.2.3 33B - Dose Consequences - DST Transfers - Independently Verify Route

This case is similar to the no controls case evaluated above with the exception that the route has been independently verified and the correct discharge path assured. This has the effect of lowering the pressure at the leak location and reducing the leak rate.

Table 17. 33B - Dose Consequences - DST Transfers - Independently Verify Route

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	**9.6E-3**	**0.11**	-	-
Wet entrainment	5.1E-8	7.5E-6	1.3E-10	2.0E-8
All pathways	**9.6E-3**	**0.11**	1.3E-10	2.0E-8

6.2.4 33B - Dose Consequences - DST Transfers - Leak Detection in 1.3 hrs - Evacuation at +1 hr

The above results indicate that offsite doses are far below guidelines but that onsite doses exceed guidelines and are dominated by gamma-ray shine. In order to reduce onsite doses to below guidelines, leak detection and onsite evacuation are necessary. The results show that if leak detection can be accomplished within 1.3 hours then onsite evacuation within 1 hour will limit the onsite MEI 95% dose to less than the guideline. No credit is taken for independent verification of the transfer route to prevent a pump dead head condition or pump shutdown.

Onsite/offsite exposure starts at leak inception. Evacuation of onsite personnel occurs 1.3 hours after leak detection, but in no case is the onsite worker exposed longer than 12 hours. Controlled offsite doses are not reported because they are well below guidelines even when uncontrolled.

Table 18. 33B - Dose Consequences - DST Transfers - Leak Detection in 1.3 hrs - Evacuation at +1 hr

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	6.2E-4	4.9E-3	-	-
Wet entrainment	2.1E-9	2.3E-7	-	-
All pathways	6.2E-4	4.9E-3	-	-

6.2.5 33B - Dose Consequences - DST Transfers - Leak Detection in 1.3 hrs - Pump Shutoff at + 30 min - Evacuation at +1 hr

This case is similar to the above with the exception that pump shutoff occurs 30 minutes after leak detection. Pump shutoff reduces the average leak rate from 62 gpm to 16 gpm but provides little benefit here since it affects only the last 1/2 hour of exposure.

Table 19. 33B - Dose Consequences - DST Transfers - Leak Detection in 1.3 hrs - Pump Shutoff at + 30 min - Evacuation at +1 hr

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	6.2E-4	4.9E-3	-	-
Wet entrainment	2.1E-9	2.3E-7	-	-
All pathways	6.2E-4	4.9E-3	-	-

6.2.6 33B - Dose Consequences - DST Transfers - Independently Verify Route - Leak Detection in 1.3 hrs - Pump Shutoff at + 30 min - Evacuation at +1 hr

In addition to leak detection, pump shutoff, and onsite evacuation, this case evaluates the benefit of also having the transfer route independently verified so that the correct discharge path is assured. This has the effect of lowering the pressure at the leak location and reducing the leak rate.

Table 20. 33B - Dose Consequences - Independently Verify Route - Leak Detection at 1.3 hrs - Pump Shutoff at +30 min - Evacuation at +1 hr

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	3.1E-4	3.1E-3	-	-
Wet entrainment	7.7E-10	1.1E-7	-	-
All pathways	3.1E-4	3.1E-3	-	-

6.2.7 33B - Results Summary - DST Transfers

A no controls and several variations of controlled cases of waste leaks from high head DST transfers directly into the soil were evaluated. In no case are offsite guidelines challenged. Uncontrolled consequences from dry entrainment releases are also far below guidelines for both offsite (24 hrs) and onsite (12 hrs) receptors. Uncontrolled consequences exceed onsite guidelines so safety significant controls are warranted. Uncontrolled onsite doses are dominated by gamma-ray shine from the radioactive pool that forms. Leak detection within 1.3 hours and subsequent onsite evacuation in 1 hour is sufficient to limit the dose to the onsite MEI to below guidelines. Although pump shutdown within 30 minutes of leak detection does not lower the doses significantly to the onsite MEI, it would serve to minimize the waste spill and subsequent cleanup. Note that the 50% dose for the no controls case exceeds the anticipated guideline but is below the unlikely guideline, suggesting a needed control reliability of 99%. A summary of the 95% doses for each of the cases is provided below.

Table 21. 33B - Results Summary - DST Transfers

Control	Function	Onsite Dose (Sv)	Offsite Dose (Sv)
No controls		**0.18**	3.9 E-8
Independent verification of route	Prevents blocked line (pump deadhead)	**0.11**	1.9 E-8
Leak detection at 1.25 hrs, evac at +1 hr.	Removes the MEI from the pool shine	4.9E-3	-
Leak detection at 1.3 hrs, stop pump at +30 min, evac at +1 hr.	Reduces leak flow and removes the MEI from the pool shine (leakage at detection is 17,300 gal)	4.9E-3	-
Independent verification, leak detection at 1.3 hrs, stop pump at +30 min, evac at +1 hr	Prevents blocked line (pump deadhead), reduces leak flow, removes the MEI from the pool shine (leakage at detection is 14,600 gal)	3.1E-3	-

6.2.8 33B - Results Summary - SWP Transfers

Saltwell pump transfers occur through encased transfer lines (both buried and above ground), and unencased transfer lines which lay on the ground surface and are bermed for radiation shielding. The flow rates applicable to salt well pump transfers are typically on the order of 0.5 to 4 gpm. With these flow rates frictional head losses are small in comparison to elevation head. For example the frictional head loss for 4 gpm of supernatant having a viscosity of 12 cp (sg=1.1) is only 0.8 ft for 2,500 ft of clean 3 in sch. 40 commercial steel pipe. The maximum elevation difference between current source and destination points do not exceed 12 ft. The model used to represent a salt well pump system is a uniformly sampled fluid head between 0 and 12 ft with a max flow rate limit of 4.3, 8, 12 and 20 gpm. The same leak size distribution analyzed for representative accident category 33A is used here. The waste composition is 99% supernate and 1% solids. Supernate is worst case due to its higher Cs-137 concentration.

In the event of a leak in an unencased bermed line, it is of interest to know the time available for leak detection before onsite guidelines are challenged. For manual leak detection this would provide a basis for a surveillance interval. The onsite dose is calculated assuming that onsite personnel are evacuated 1 hr after leak detection. The following table lists the calculated results for four maximum transfer rates.

Table 22. 33B - Results Summary - SWP Transfers

Control	Function	Onsite Dose (Sv)	Offsite Dose (Sv)
Transfer rate limited to 4.3 gpm, leak detection in 11 hours, evac at +1 hr	Removes the MEI from the pool shine	< 5E-3	-
Transfer rate limited to 8 gpm, leak detection in 7.8 hours, evac at +1 hr	Removes the MEI from the pool shine	< 5E-3	-
Transfer rate limited to 12 gpm, leak detection in 6.2 hours, evac at +1 hr	Removes the MEI from the pool shine	< 5E-3	-
Transfer rate limited to 20 gpm, leak detection in 4.6 hours, evac at +1 hr	Removes the MEI from the pool shine	< 5E-3	-

6.2.9 33B - Material Balance Insights

The sensitivity and interval at which a material balance control might be used to detect a waste transfer leak is discussed here. Under the conditions of a blocked discharge path, a realistic conservative leak rate of 206 gpm could cause the 100 m onsite worker to exceed a 0.005 Sv dose in 2.3 hours. Thus if onsite evacuation can be accomplished in 1 hour, leak detection must occur within 1.3 hours. This establishes the maximum material balance interval. The material balance control must also be sensitive enough to detect a material discrepancy of 2,800 gal such that exposure over a 12 hour period does not exceed 0.005 Sv.[3] For a transfer flow rate discrepancy greater than 4.3 gpm, the remaining hours to initiate onsite evacuation and still ensure the onsite MEI dose is limited to less than the guideline can be obtained from the table below.

Table 23. 33B - Material Balance Insights

Leak Rate (gpm)	Detection Time (hrs)	Leaked Amt. (gal)	Remarks
4.3	11	2,800	Determines required material balance sensitivity
8	7.8	3,700	Used to determine remaining time to evacuate
12	6.2	4,500	ditto
20	4.6	5,500	ditto
206 (95% leak rate w/ blocked discharge)	1.3	-	Determines maximum material balance frequency

In the subsurface leak scenario of 33B, not only is it possible to expose an onsite worker during the leak, but given that the leak rate is small enough it is also possible to expose an onsite worker

[3] This value was obtained by multiplying a leak rate that would expose the onsite MEI to 0.005 Sv (95% assumed) over a 12 hour period by 11 hours (12 hours minus 1 to allow for onsite evacuation). This leak rate was determined to be 4.3 gpm.

to a contaminated plume due to an earlier undetected waste leak. With a material balance control based on above table, the maximum waste leak rate that could go undetected and still expose the 100 m onsite worker to 0.005 Sv over a 12 hour period is 4.3 gpm. A past concern with waste transfers is the possibility of a waste leak into the soil adjacent to a pit structure where the encasement is joined to the concrete. A 4.3 gpm subsurface leak (i.e., 1 m deep) adjacent to a pit structure is small enough that even though it could reach the surface in about 1 hour, the soil infiltration rate would prevent a large surface pool from forming. Instead the ground plume would be expected to grow at a slow rate to accommodate the 4.3 gpm leak. In 11 hours or after 2,800 gal of waste had leaked the plume radius would be about 8 feet[4]. Previous gamma-shine calculations (Finfrock 1999, Figure 3.4) estimate a dose rate of about 4E-4 Sv/hr from this pool (95% supernate activity concentration of 5.9E+10 Bq/L assumed - see Table 4 of this report). Over a 12 hour period the dose would be 12 hr x 4E-4 Sv/hr = 4.8E-3 Sv or slightly less than 0.5 rem. Therefore, a material balance procedure sensitive enough to detect a 2,800 gal leak over a 11 hour period (i.e., 4.3 gpm) would be sufficient to limit the onsite 100m worker 12 hour dose (95 percentile) to less than the 5E-3 Sv guideline.

In the event that a waste transfer ends prematurely such that a material balance is not possible, a radiation survey of the transfer route could be made to confirm that a waste leak had not surfaced.

6.3 33C - EX-TANK WASTE TRANSFER LEAK DIRECTLY TO THE SOIL SURFACE OR ATMOSPHERE.

An important aspect of this accident category is that the waste transfer leak is immediately detectable due to the obvious nature of the initiator. However, the initiator of the leak can also in most cases cause a failure the confinement barrier. As such the leak has the potential to release unmitigated aerosols generated from a spray or splash/splatter mechanism. Failure of the confinement also means that the entire spill could wind up on the ground surface. It is also acknowledged that the leak size distribution used for categories 33A and 33B which represent leak initiators of corrosion, erosion, gasket failure, etc., may not be appropriate to the leak size distribution caused by the initiators discussed below. The impact of other leak size distributions on analysis results is the subject of a sensitivity study discussed below.

6.3.1 33C - Leak Causes

The causes of waste transfer leaks directly to the soil surface or atmosphere have characteristics that allow grouping into the following general categories:

- Excavation – Excavation related leaks are one of the potential major causes of leaks directly to the soil surface or atmosphere. It is postulated that power digging equipment is used to perform an excavation, the excavation occurs in the wrong location, and the waste transfer line and encasement are breached when it is inadvertently excavated.

[4] This estimate is based on a leak depth of 1 m, a soil void fraction of 0.4, a conservative soil infiltration rate of 5.64E-3 m/min and a plume shape that is cylindrical above the leak and spherical below the leak.

- Drilling – Drilling is performed on the Hanford site for a variety of purposes. It is possible that drilling would inadvertently occur above a waste transfer line. Penetration of the transfer line would result in waste being released directly to the soil surface up the drill hole.
- Cone Penetrameter – The Cone Penetrameter, as far as leak creation is concerned, has characteristics similar to drilling. The major difference is that the Cone Penetrameter would tend to cause more crushing of the transfer line and encasement as compared to drilling which may make the leak size distribution different from drilling. It is included as a separate item to ensure that appropriate controls will be established.
- OGT Failures (vehicle impact or seismic) – Over Ground Transfer lines consist of a bolted flange metal encasement enclosing an elastomeric primary transfer line. As the name implies the line is not buried and can be subject to damage from vehicle impacts. These impacts could result in pool or spray leaks. A concrete "U" shaped cover system provides protection from vehicle impacts when access controls to the farm are not in force. The concrete OGT covers are also used to provide radiation shielding but are not required for this purpose if access controls are implemented.
- Test Riser leaks – Some transfer lines have risers connected to their encasements for the purposes of leak testing or leak detection. It is postulated that a transfer line leak could escape directly to the environment from these risers if the encasements are prevented from draining and the risers are not properly capped. The characteristic of this type of leak would be very similar to an excavation accident with the exception of the "hold up" of the encasement.
- Unsupported lines due to undermining – Undermining events due to uncontrolled flow of service water have occurred in the past in the tank farms. It is postulated that such an event occurs that undermines a large area under a transfer line resulting in a failure of the line and encasement from sagging in the undermined area. This event is considered to have a low frequency of occurrence.
- Seismic events - Seismic events are an initiator of leaks in transfer system structures. None of the transfer system components or structures are seismically qualified. No credit is taken for the seismic integrity of SSCs other than the gross integrity of SSTs, DSTs, and AWF tanks.
- External events - External events can be of low or high frequency nature. Aircraft impact is considered beyond extremely unlikely. Vehicle impact, floods, etc. are relative high frequency events. These types of events are included for completeness of treatment of initiators of leaks.
- Concurrent leak and coverblock failure - In-pit deflagrations are postulated to cause cover block displacement and resulting piping damage resulting in leaks. The pit covers are not present as a result of the accident. In-pit deflagrations would appear to be very infrequent events given that pits do not have very good flammable gas retaining capabilities. However, since many pits do not have positive ventilation, the potential for this type of accident is not dismissed.

6.3.2 33C - Dose Consequences - No Controls

Results are estimated for the no controls case where onsite and offsite exposure start at leak inception and continues for 12/24 hours. No credit for independent verification of the transfer route to prevent a pump dead head condition, leak detection, pump shutdown, or emergency response and onsite evacuation are taken. These results represent the condition where the intended discharge path beyond the leak location is blocked. The could occur as a result of valve misalignment or line plugging. The effect of this condition is to increase the system pressure and leak rate. The doses from the individual pathways of gamma-ray shine, spray, splash/splatter, and wet entrainment are presented as well as the total dose from each of these four. Note that "all pathways" represents the quantile of the sum, not the sum of the quantiles.

Table 24. 33C - Dose Consequences - No Controls

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	**2.1E-2**	**1.8E-1**	-	-
Spray release	1.3E-4	**1.6E-2**	1.2E-7	2.1E-5
Splash/splatter	7.7E-4	**2.1E-2**	6.7E-7	3.2E-5
Wet entrainment	1.4E-7	1.5E-5	3.4E-10	3.9E-8
All pathways	**2.9E-2**	**2.1E-1**	1.5E-6	6.4E-5
Dry entrainment	2.8E-6	1.4E-3	4.0E-9	2.5E-6

6.3.3 33C - Dose Consequences - Independently Verify Route

This case is similar to the no controls case described above except that independent verification of the route is assumed and the correct discharge path is assured. This has the effect of lowering the pressure at the leak location and reducing the leak rate.

Table 25. 33C - Dose Consequences - Independently Verify Route

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	**9.6E-3**	**1.1E-1**	-	-
Spray release	1.2E-5	2.3E-3	1.1E-8	2.9E-6
Splash/splatter	4.0E-4	**1.3E-2**	3.5E-7	1.9E-5
Wet entrainment	5.1E-8	7.5E-6	1.3E-10	2.0E-8
All pathways	**1.2E-2**	**1.3E-1**	5.5E-7	2.6E-5

6.3.4 33C - Dose Consequences - Leak Detection Immediate - Evacuation at +1.2 hrs

The above results indicate that offsite doses are far below guidelines but that onsite doses exceed guidelines and are dominated by gamma-ray shine. In order to reduce onsite doses to below guidelines, leak detection and onsite evacuation are necessary. The results below are for the case where immediate leak detection occurs such as when the leak is visually observed during an excavation. If the onsite MEI is evacuated within 1.2 hours then his 95% dose can be limited to less than the guideline. No credit is taken for independent verification of the transfer route to prevent a pump dead head condition, or pump shutdown.

Onsite/offsite exposure starts at leak inception. Evacuation of onsite personnel occurs 1.2 hours later. Controlled offsite doses are not reported because they are well below guidelines even when uncontrolled.

Table 26. 33C - Dose Consequences - Leak Detection Immediate - Evacuation at +1.2 hrs

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	1.7E-4	1.3E-3	-	-
Spray release	1.3E-5	1.6E-3	-	-
Splash/splatter	7.7E-5	2.1E-3	-	-
Wet entrainment	4.3E-10	4.8E-8	-	-
All pathways	4.8E-4	4.9E-3	-	-

6.3.5 33C - Dose Consequences - Leak Detection Immediate - Pump Shutoff at +30 min - Evacuation at +2.4 hrs

The above results indicate that the controls of automatic leak detection and evacuation of the onsite MEI are adequate to reduce the 95% onsite dose to below guidelines. This case evaluates the benefit of automatic pump shutoff 30 minutes after leak detection. This has the effect of extending the available evacuation period to 2.4 hours. No credit is taken for independent verification of the transfer route to prevent a pump dead head condition.

Onsite/offsite exposure starts at leak inception. Pump shutdown occurs 30 minutes later after which the flow rate out the leak is reduced to drainback values using the model discussed in Section 3.4. Evacuation of onsite personnel occurs 2.4 hours after leak inception. Controlled offsite doses are not reported because they are well below guidelines even when uncontrolled.

Table 27. 33C - Dose Consequences - Leak Detection Immediate - Pump Shutoff at +30 min - Evacuation at +2.4 hrs

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	3.4E-4	2.6E-3	-	-
Spray release	9.1E-6	1.2E-3	-	-
Splash/splatter	5.3E-5	1.4E-3	-	-
Wet entrainment	8.6E-10	9.4E-8	-	-
All pathways	6.6E-4	4.9E-3	-	-

6.3.6 33C - Dose Consequences - Independently Verify Route - Leak Detection Immediate - Pump Shutoff at +30 min - Evacuation at +2.4 hrs

This case assumes independent verification of the transfer route to prevent a pump dead head condition, immediate leak detection, pump shutoff at +30 min, and evacuation of the onsite MEI at +2.4 hours. Onsite/offsite exposure starts at leak inception. Controlled offsite doses are not reported because they are well below guidelines even when uncontrolled.

Table 28. 33C - Dose Consequences - Independently Verify Route - Leak Detection Immediate - Pump Shutoff at +30 min - Evacuation at +2.4 hrs

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	1.9E-4	1.8E-3	-	-
Spray release	9.8E-7	1.8E-4	-	-
Splash/splatter	3.1E-5	9.3E-4	-	-
Wet entrainment	3.5E-10	4.9E-8	-	-
All pathways	3.2E-4	3.0E-3	-	-

6.3.7 33C - Material Balance Insights

This case evaluates a potential material balance control. The case assumes independent verification of the transfer route to prevent a pump dead head condition, leak detection within 30 minutes after 2,200 gal has leaked, pump shutoff at +30 min, and evacuation of the onsite MEI at +1 hours. Onsite/offsite exposure starts at leak inception

Table 29. 33C - Material Balance Insights

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	5.0E-4	2.3E-3	-	-
Spray release	2.4E-6	8.9E-4	-	-
Splash/splatter	7.8E-5	1.9E-3	-	-
Wet entrainment	1.3E-9	9.4E-8	-	-
All pathways	7.6E-4	4.9E-3	-	-

6.3.8 33C - Results Summary

A no controls and several variations of controlled cases of exposed waste leaks were evaluated. In no case are offsite guidelines challenged. Uncontrolled consequences exceed onsite guidelines so safety significant controls are warranted. Uncontrolled onsite doses are dominated by gamma-ray shine from the radioactive pool that forms. Pump shutdown within 30 minutes of leak detection extends the allowable evacuation period from 1.2 to 2.4 hours due to the decreased growth rate of the waste spill.

For cases where immediate leak detection is not possible, a potential material balance control is evaluated. Detection within 30 minutes of a 2,200 material discrepancy, and evacuation of onsite personnel within 1 hour would also be sufficient to ensure that the 95% dose to the onsite MEI remained below guidelines.

Note that the 50% dose for the no controls case exceeds the anticipated guideline but is below the unlikely guideline, suggesting a needed control reliability of 99%. A summary of the 95% doses for each of the cases is provided below.

Table 30. 33C - Results Summary

Control	Function	Onsite Dose (Sv)	Offsite Dose (Sv)
No controls		**0.21**	6.4E-5
Independent verification of route	Prevents blocked line (pump deadhead)	**0.13**	2.6E-5
Leak detection immediate, evac at +1.2 hrs.	Removes the MEI from the pool shine	4.9E-3	-
Leak detection immediate, stop pump at +30 min, evac at +2.4 hrs.	Reduces leak flow and removes the MEI from the pool shine	4.9E-3	-
Independent verification of route, leak detection immediate, stop pump at +30 min' evac at +2.4 hrs	Prevents blocked line (pump deadhead), reduces leak flow and removes the MEI from the pool shine	3.0E-3	-
Independent verification of route, 30 min leak detection on 2,200 gal material imbalance, stop pump at +30 min, evac at +1 hr	Prevents blocked line (pump deadhead), reduces leak flow and removes the MEI from the pool shine	4.9E-3	-

6.3.9 33C - Sensitivity Study - No Controls - Alternate Leak Size Distribution

An alternate leak size distribution was created from an independent assessment of industry failure data and Hanford occurrence reports (Ziada, 2000). The distribution is discussed in more detail in Section 7.2. The results for 33C - No Controls is shown in the table below.

Table 31. 33C - Sensitivity Study - No Controls - Alternate Leak Size Distribution

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	3.1E-3	**1.1E-1**	-	-
Spray release	1.4E-4	**7.0E-3**	1.3E-7	9.4E-6
Splash/splatter	1.6E-4	**1.0E-2**	1.5E-7	1.5E-5
Wet entrainment	1.3E-8	5.1E-6	3.3E-11	1.4E-8
All pathways	4.6E-3	**1.3E-1**	5.3E-7	2.9E-5

6.4 33D - MISROUTE OF WASTE

Misroute of waste during transfers have occurred and should be considered an anticipated event. Misrouted waste into a closed system (i.e., system that can become pressurized) can cause a spray leak in an uncontrolled location. Misrouted waste into an open system can result in a pool with resultant gamma-ray shine splash/splatter, and wind entrained aerosols. Because the intended receiving tank could be isolated as a result of the misroute error (e.g., mispositioned three-way valve), these scenarios will be analyzed as if the intended discharge route is blocked. One important aspect of these types of leaks is that they can occur in areas where personnel may be performing activities unassociated with the waste transfer. This may be a cause of significant worker exposure. Isolation via backflow prevention/detection devices or block valves is an analyzed control option.

Another scenario evaluated here is the misrouting of waste into another DST or DCRT. Detection of these types of leaks will depend on the situation at the misroute location. A material discrepancy control such as might be accomplished through service water flow totalizers is an analyzed control option.

6.4.1 33D - Leak Causes

Leaks due to misroutes can be grouped according to the following general categories:

- Tank overflows (misroutes, material balance errors, service or fire water intrusion) – Waste can be released onto the soil surface from tank overflow events due to a variety of causes. If a misroute into a tank occurs, the tank will fill until it overflows out of the connected pits on the top of the tank. The same condition will also occur if significant errors in material balance calculations or monitoring occur. Intrusion of large quantities of service or fire suppression water will also result in tank overflow. While the maximum flow rate of waste into a tank due to misroute or material balance error is a characteristic of the waste transfer pump(s), the rate of flow into (and therefore out of) a tank due to clean water intrusion will be related to the size opening available to let the water into the tank. Failure of service and fire suppression water lines has occurred in the past.
- Back-flow into clean systems – It has been postulated that a misroute could result in flow of waste into clean systems such as flush systems or diluent addition systems. Out of necessity, these systems are often connected to active transfer routes and only isolated from them by

valves or backflow preventers. A leak could go to the environment with no mitigation by intervening structures. Such a leak could also create large quantities of aerosols in structures that are occupied by operating personnel.

- Full pipe diameter flows into pits due to misroutes – If a misroute occurs into a pit that is open for maintenance or reconfiguration the leak flow rate will only be limited by the transfer pump capacity or hydraulic resistance of the line segment.
- 204-AR leak situations – The 204-AR building is a unique waste transfer related facility because it is used to make transfers of waste into the tank farms from rail cars and tank trucks. Since the facility can be potentially connected to active waste transfer systems at all times, misroute caused waste leaks are possible. The facility can also be occupied during operations involving waste transfers.
- Pressurization of isolated systems – Another leak situation can occur when waste is unintentionally directed into an isolated system. The concern is that the pressure of a leak will be the highest available from the transfer pumping system creating the worst case spray.

6.4.2 33D - Dose Consequences - No Controls - Misroute into Closed System with Leak

Results are estimated for an unintentional misroute into a closed system where onsite and offsite exposure start at leak inception and continues for 12/24 hours. No credit for coverblocks or leak detection is taken. It is assumed that the intended discharge path is isolated and that the closed system has a leak size distribution identical to that evaluated in representative accident categories 33A, B and C. Since this is the exact configuration represented in Section 6.3.2 for waste leak directly onto the soil surface or atmosphere with a blocked discharge, results are identical but repeated below.

Table 32. 33D - Dose Consequences - No Controls - Misroute into Closed System with Leak

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	**2.1E-2**	**1.8E-1**	-	-
Spray release	1.3E-4	**1.6E-2**	1.2E-7	2.1E-5
Splash/splatter	7.7E-4	**2.1E-2**	6.7E-7	3.2E-5
Wet entrainment	1.4E-7	1.5E-5	3.4E-10	3.9E-8
All pathways	**2.9E-2**	**2.1E-1**	1.5E-6	6.4E-5
Dry entrainment	2.8E-6	1.4E-3	4.0E-9	2.5E-6

6.4.3 33D - Dose Consequences - No Controls - Misroute into Open System

Results are estimated for an unintentional misroute into an open system where onsite and offsite exposure start at leak inception and continues for 12/24 hours. No credit for coverblocks or leak detection is taken. It is assumed that the intended discharge path is isolated so that the entire transfer is misrouted into a system with a full open discharge path.

Table 33. 33D - Important Intermediate Results - Misroute into Open System

Intermediate Result	Mean	5 %	50%	95 %	Outlier
Leak flow rate in m^3/s (gpm)	1.3E-2 (206)	9.9E-3 (157)	1.2E-2 (190)	1.7E-2 (270)	1.8E-2 (285)

Table 34. 33D - Dose Consequences - No Controls - Misroute into Open System with Leak

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	**7.3E-2**	**3.2E-1**	-	-
Spray release	5.1E-11	1.0E-9	4.8E-14	1.6E-12
Splash/splatter	2.2E-3	**4.6E-2**	2.1E-6	7.0E-5
Wet entrainment	6.9E-7	4.4E-5	1.8E-9	1.1E-7
All pathways	**8.1E-2**	**3.5E-1**	2.1E-6	7.0E-5
Dry entrainment	5.5E-6	1.6E-3	7.6E-9	2.8E-6

6.4.4 33D - Dose Consequences - Leakage Through Double Isolation Valves

The control option evaluated here is the use of isolation valves to isolate parts of the transfer system for which leak detection controls are not operationally required. In this evaluation it is assumed that the intended discharge is blocked and that in the absence of any other flow restriction the isolation valves are rated to leak no more than 4 gpm at the pump dead head of 1,440 ft. The leak rate into the connected system and into the environment is then calculated according to the methodology described in Section 4.6. The connected system is assumed to have a leak size distribution identical to that used in accident category 33A. Depending upon the size of this leak, the piping downstream of the isolation valves can become pressurized and experience a limited spray type release. Consequences from this event would be considered controlled because the spray is limited by the flow through the isolation valves.

Table 35. 33D - Important Intermediate Results - Leakage Through Double Isolation Valves

Intermediate Result	Mean	5 %	50%	95 %	Outlier
Leak flow rate in m^3/s (gpm)	1.7E-4	1.6E-4	1.8E-4 (2.8)	1.8E-4 (2.8)	1.8E-4 (2.8)
Total leak volume (12 hrs) in m^3 (gal)	7.5	7.0	7.7 (2000)	7.7 (2000)	7.7 (2000)

Table 36. 33D - Dose Consequences - Leakage Through Double Isolation Valves

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	8.5E-4	4.1E-3	-	-
Spray release	1.3E-9	1.6E-4	1.2E-12	1.7E-7
Splash/splatter	1.3E-5	3.0E-4	1.2E-8	4.6E-7
Wet entrainment	5.1E-10	3.4E-8	1.3E-12	9.2E-11
All pathways	9.8E-4	4.3E-3	1.5E-8	1.0E-6

6.4.5 33D - Material Balance Insights - Double Isolation Valves

The peak leak rate achieved through two isolation valves in series, each satisfying the 4 gpm maximum leakage criteria, is 2.8 gpm. This leak rate produces an estimated 95 % dose to the 100 m onsite worker of 4.3E-3 Sv over a 12 hour period. Therefore, if onsite evacuation can be accomplished in 1 hour, leak detection must occur within 11 hours. This establishes the maximum material balance interval and could be used as an alternate control to independent verification of correct valve position. The material balance control must also be sensitive enough to detect a material discrepancy of 2,016 gal.

6.4.6 33D - Dose Consequences - No Controls - Tank Overflow

A tank overflow could also result from a misroute. This analysis assumes that waste is either misrouted to a DST (actual fill volumes used) or a DCRT which is 80% full. Since the ground pool would form from an upwelling of waste in the tank below, no spray or splash/splatter is generated. It is also possible to have clean water intrusion into tanks. The infiltration rate of clean water intrusion is considered to be adequately represented by the analyzed flow rates simulated by the transfer system (see intermediate results below). Appendix K documents the DST headspace and DCRT capacities used in this analysis.

Table 37. 33D - Important Intermediate Results - Tank Overflow

Intermediate Result	Mean	5 %	50%	95 %	Outlier
Misroute flow rate in m^3/s (gpm)	1.3E-2 (210)	1.0E-2 (160)	1.2E-2 (190)	1.7E-2 (270)	1.8E-2 (290)
Total misroute volume (12 hrs) in m^3 (gal)	550 (150,000)	430 (110,000)	530 (140,000)	740 (200,000)	800 (210,000)
Tank fill time in hrs	16	0.74	18	27	35

Table 38. 33D - Dose Consequences - No Controls - Tank Overflow

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	0	**9.7E-2**	-	-
Wet entrainment	0	2.4E-6	5.0E-11	1.5E-8
All pathways	0	**9.7E-2**	-	-

6.4.7 33D - Results Summary

Several conditions of an uncontrolled misrouted waste transfer were evaluated. These were misroute into a closed system with a pre-existing leak, misroute into an open system, and tank overflow. In all three cases it was assumed that the intended discharge path was isolated (e.g., misalignment of valves), thus diverting full system capacity or pressure to the misrouted location. Uncontrolled, all three cases exceed onsite guidelines but are well below offsite guidelines suggesting the need for safety significant controls.

One control evaluated was the use of double isolation valves. The valves are assumed to leak no more than 4 gpm at a differential pressure of 680 psi. This pressure is equivalent to the 1440 ft shutoff head of the modeled pump at a fluid specific gravity of 1.1 which is nominal. Given that this leak criteria is satisfied, onsite consequences over a 12 hour period are shown to remain below guidelines. Because the two valves are in series, the maximum leak rate through both is 2.8 gpm. Over a 11 hour period the total leak quantity (95 percentile) is about 2,000 gal. Note that the 50% dose for the uncontrolled misroute into an open system exceeds both the anticipated and unlikely onsite guideline, suggesting a needed control reliability of 99.99%.

No mitigated tank overflow was evaluated because prevention is considered to be the more reasonable approach for controlling a tank overflow. A summary of the 95% doses for each of the cases is provided below.

Table 39. 33D - Results Summary - Misroute into System

Control	Function	Onsite Dose (Sv)	Offsite Dose (Sv)
No controls		**9.7E-2**	1.5E-8
Double valve isolation	Limits leakage to 4 gpm per valve or 2.8 gpm into the uncontrolled facility (2016 gal over 12 hrs)	4.3 E-3	-

Table 40. 33D - Results Summary - Misroute into DST or DCRT

Control	Function	Onsite Dose (Sv)	Offsite Dose (Sv)
No controls		**0.35**	7.0 E-5

6.5 33E - LEAKS INSIDE ACTIVELY VENTED STRUCTURES

This section evaluates the consequence of leaks inside actively vented double shell tanks (DSTs), double contained receiver tanks (DCRTs), and the 204-AR Waste Unloading Facility.
The depletion of aerosol before exiting the ventilation exhaust system is analyzed through the use of a leak path factor (LPF). LPFs were calculated using the FLUENT® code for various thermal and exhaust rate conditions to account for the fraction of respirable aerosol escaping the structure. FLUENT®, a commercially available computational fluid dynamics code, was used to calculate a separate leak path factor for each of the three facilities. No credit was taken for further losses in the exhaust system since many of these features are non-safety related and crediting their effectiveness would result in a safety control.

The main removal mechanism of the respirable spray droplets is the falling (gravitational effects) or swirling (downward gas flows) of the droplets to the bottom boundary which is wet and will trap the droplets upon contact. The wall boundaries were modeled as reflective surfaces, which would bounce the droplets off the surface, but the bottom boundary was modeled as a trap, which would hold onto the droplets and keep them from escaping. Even though the unloading facility did not have a liquid volume on its bottom, the spray leak would wet most of the surface with its large amounts of drops and droplets much larger than 10 microns. Hence, even the unloading facility was modeled with its bottom boundary (floor) as a trap. Also, the suspended droplets were modeled with thermophoretic forces (temperature gradients driving particles to cooler surface) and Brownian motion (random movements). Also, when the gas flow is turbulent, which happens in all cases with thermal phenomena, the stochastic particle tracking method is used. The stochastic particle tracking method varies the velocity field around the mean velocity for each cell location when tracking the particles. In effect, the stochastic particle tracking enhances the Brownian motion effects. However, if the gas flow is not turbulent, such as in the isothermal cases, then the deterministic particle tracking method has to be used. With the deterministic particle tracking under isothermal conditions, each particle follows one velocity field with only the effects of drag and Brownian motion included. In other words, the gas velocity has just one value for each spatial location. Further details are included in Appendix J.

6.5.1 33E - Leak Causes

- Spray leaks inside ventilated tanks can occur when waste is being transferred from the tank. Pump discharge piping leaks can be pre-existing and can become uncovered as the waste level decreases during transfer.

- Leaks occuring inside the 204-AR Waste Unloading Facility can result from misroutes of tank waste into the facility, or during the rail car unloading process.

6.5.2 33E - Dose Consequences - No Controls - DSTs

A two-dimensional finite element model of a DST head space under various thermal and active ventilation cases was evaluated to determine the fraction of respirable aerosols entering the ventilation exhaust. In the event the ventilation system filters were not functioning, the spray aerosol in the tank head space could be released to the environment. While waste flow causing splash/splatter conditions are considered a normal operating condition, in-tank spray leaks are abnormal. The confinement of respirable spray aerosols by the tank dome is credited through calculation of LPFs. These LPFs were largely independent of ventilation flow rate due to the dominant influence of thermal effects. A pdf describing a triangular distribution was chosen with the minimum, most likely, and maximum values being 0.015, 0.024 and 0.036 respectively. Additional details are provided in Appendix J.

Results are estimated for the no controls case where onsite and offsite exposure start with leak inception and continues for 12/24 hours. No credit for independent verification of the transfer route to prevent a pump dead head condition, leak detection, or emergency response and onsite evacuation are taken. These results represent a blocked discharge condition which maximizes pump pressure at the leak. The leak location is assumed to be at the pump discharge and to continue spraying for the duration of the leak because tank level is not increasing.

Table 41. 33E - Dose Consequences - No Controls - DSTs

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Spray	8.4E-6	8.8E-4	7.6E-9	1.2E-6

6.5.3 33E - Dose Consequences - No Controls - DCRTs

A three-dimensional finite element model of a DCRT head space (80% full) under various thermal conditions was evaluated to determine the fraction of respirable aerosols entering the ventilation exhaust in the event of a hypothetical spray leak inside a DCRT during pumping operations. Simulations were performed only for the vertical S-244 receiver tank as this tank had the highest air leakage into the tank and would bound all other DCRTs. The exhaust rate used in the model was 23 cfm. The cases analyzed would also bound spray leaks in the vault or pump pit resulting from DCRT pumping operations. The calculated LPFs were sensitive to thermal influence, with the LPF associated with the 44 °C waste being the most bounding at 0.04. Several air leakage configurations were also evaluated and it was found that in the event of an actual pumping operation, allowing air to enter through the center tank riser would lower the LPFs due to downward moving air at the spray source location. A pdf describing a uniform distribution between 0.025 and 0.028 with a uniformly decreasing probability down to 0.040 was chosen to best represent this case. Additional details are provided in Appendix J.

Results are estimated for the no controls case where onsite and offsite exposure start with leak inception and continues for 12/24 hours. No credit for independent verification of the transfer route to prevent a pump dead head condition, leak detection, or emergency response and onsite evacuation are taken. These results represent a blocked discharge condition which maximizes pump pressure at the leak. The leak location is assumed to be at the pump discharge. The spray continues for the duration of the leak because tank level is not increasing.

Table 42. 33E - Dose Consequences - No Controls - DCRT

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Spray	1.0E-5	1.1E-3	9.2E-9	1.4E-6

6.5.4 33E - Dose Consequences - No Controls - 204-AR

Consequences of a waste leak inside the 204-AR Waste Unloading Facility without any controls (i.e., receiving door open, floor drain plugged, no leak detection) would be similar to the results reported in Table 32 for a misroute into a closed system (i.e., a system with a spray potential). Consequences in this case exceed onsite guidelines but do not challenge offsite guidelines. If the receiving doors were closed so that the release of aerosols was mitigated (ventilation still running), inhalation doses would be reduced but still above onsite guidelines. In order for doses to be mitigated sufficiently below onsite guidelines, leak detection, pump shutoff, and emergency evacuation of onsite personnel must also occur.

6.5.5 33E - Dose Consequences - Leak Detection in 1.4 Hours - Pump Shutoff at +30 min - Evacuation at +1 hr - 204-AR

A three-dimensional finite element model of the 204-AR Waste Unloading Facility was evaluated to determine the fraction of respirable aerosols entering the ventilation exhaust in the event of a hypothetical spray leak inside the facility from a misroute or waste unloading operation. Simulations were performed for inlet air temperatures of 2 °C and 40 °C. The two exhaust vents are located on the north side about 6 feet apart and only about 1 foot above the floor. The bounding flow rate of the exhaust fan is 2000 cfm, which was conservatively used in the model (1000 cfm for each vent). The only air leakage into the facility is expected to occur along the bottom of the receiving door where the railroad tracks are located. In the model, an open strip is placed on the bottom of the door with a length of 12 feet. No other exterior or internal doors and structures are modeled as it is slightly conservative to have all of the incoming air enter at the bottom of door, since this air will potentially move laterally under the spray release and tend to keep the spray droplets suspended.

Based on this evaluation a pdf describing a uniform distribution between 0.124 and 0.155 was chosen to best represent the 204-AR Waste Unloading Facility when actively ventilated. Since no credit is taken for filtration this would also bound the unventilated configuration as long as the exterior receiving doors are closed. Additional details are provided in Appendix J.

Catch tank TK-1 (1,500 gal) is located below the floor of the unloading area in a stainless steel-lined pit (4,000 gal) for the purpose of temporarily storing process solutions flowing through all drains in the system. The catch tank is equipped with liquid-level instrumentation and an overflow line that drains to the sump in the pit. A leak in the waste unloading area of the 204-AR facility would first drain into the catch tank and pit and then out the receiving door. Results are estimated assuming the pit is dry but that the catch tank is 80% full. It is also assumed that a blocked discharge condition exists, such as might occur during a misroute into the facility. Also, in order for leak detection to occur there must be at least a 5% change in catch tank level (i.e., 75 gal). Once leak detection occurs, pump shutoff occurs within 30 minutes and emergency evacuation of onsite personnel within 1 hour. Any spray release occuring in the waste unloading area is assumed to continue for the duration of the leak. Once the pump is turned off, drainback is accounted for as discussed in Section 4.4. Both spray and splash/splatter aerosols are reduced by the leak path factor as discussed above. As shown below, leak detection must occur within about 1.4 hours in order for estimated onsite doses to remain below guidelines.

Table 43. 33E - Dose Consequences - Leak Detection in 1.4 Hours - Pump Shutoff at +30 min - Evacuation at + 1 hr - 204-AR

Pathway	Onsite Dose (Sv)		Offsite Dose (Sv)	
	50 %	95 %	50 %	95 %
Gamma shine	3.0E-4	3.8E-3	-	-
Spray release	3.1E-6	4.2E-4	-	-
Splash/splatter	1.8E-5	5.0E-4	-	-
Wet entrainment	6.9E-10	1.4E-7	-	-
All pathways	4.9E-4	4.7E-3	-	-

6.5.6 33E - Results Summary

In this evaluation of waste leaks in actively ventilated facilities uncontrolled consequences never approach offsite guidelines. For waste leaks in DSTs and DCRTs, uncontrolled consequences also remain below onsite even for a 12 hour exposure. This is primarely due to the low ventilation flow rate in these vessels which allow most of the respirable aerosols to stay confined. However for the 204-AR Waste Unloading Facility the additional controls of leak detection, pump shutoff, and onsite evacuation are required. This is primarely due to the high ventilation flow rate in the waste unloading area, the location of the vents, and the relative low capacity of the catch tank and pit with respect to potential leak rates. Once the catch tank and pit fill then an outdoor waste pool can develop which would cause a significant gamma-ray dose.

A summary of the 95% doses for each of the cases is provided below.

Table 44. 33E - Results Summary - Leaks Inside Actively Vented Structures

Control	Function	Onsite Dose (Sv)	Offsite Dose (Sv)
No Controls - DSTs		8.8E-4	-
No Controls - DCRTs		1.1E-3	-
No Controls - 204-AR		**2.1E-1**	6.4E-5
Leak detection at 1.4 hr, pump shutoff at +30 min, evac at +1 hr - 204-AR	Reduces leak flow and reduces MEI exposure to pool shine and aerosol releases.	4.7E-3	-

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7.0 KEY ASSUMPTIONS, CONSERVATISM'S AND SENSITIVITIES

This section discusses the sensitivities and conservatism's of model results to input assumptions and model simplifications. Based on the premise that all mathematical models only approximate reality, numerous compromises are made to obtain reasonable results without undue cost. Normally this is accomplished by selecting parameters which conservatively envelope the cases represented. However, in some instances this may result in undue conservatism. The approach used in this analysis is to represent key parameters by a pdf (e.g., leak size). Selection of the proper shape of a pdf requires much more knowledge, and in some cases that level of knowledge is not practically achievable. This report addresses the uncertainty in the results due to the uncertainty in the input through various sensitivity studies. For example, if it can be shown that reasonable alternate pdfs would result in lower consequences, or not alter the conclusions of the analysis, then an appropriate level of confidence can be obtained. The sections below describe in more detail the sensitivities of analysis results to input parameters which have been important in this or past waste leak accident analyses.

7.1 INGESTION DOSE PATHWAY

Typically the 24 hour uptake ingestion dose (50 year commitment period) is 2 to 5% of the corresponding inhalation dose from Hanford tank waste. Therefore it is neglected in this analysis as it in no way would affect the conclusions that offsite doses remain well below guidelines.

7.2 SENSITIVITY OF DOSE ESTIMATES TO LEAK SIZE

One of the surprising results of this analysis is the relatively minor contribution that spray aerosols had to either onsite or offsite dose consequences. In the case of onsite receptors, gamma-ray shine was the dominant health effect, even for exposed waste leaks (i.e., 33C). In the case of the offsite receptor, the aerosols generated from splash/splatter mechanisms dominated over spray, but consequences, even without controls, remained far below the guideline. For both shine and splash/splatter, the dose is directly proportional to the waste volume leaked. Therefore the larger the leak size, the larger the dose.

This is an important result because it suggests that coverblocks and supplemental covers are not the primary barrier for protection of the onsite worker or offsite public from radiological exposure.[5] To further explore the sensitivity of dose results to the choice of leak size pdfs which are admittedly uncertain, an alternate leak size distribution was constructed from an independent assessment of industry failure data and Hanford occurrence reports (Ziada, 2000). A pdf defining a trimodal leak size distribution was derived from this information having the following characteristics:

Small:

Probability - 58%

Length - uniform from 1.78E-3 m (0.07 in) to 5.08E-3 m (0.2 in)

[5] This analysis does not explore the hazard to the worker in the immediate vicinity of the pit which may be significant. Quantification of this hazard is beyond the scope of this analysis.

Area -	uniform from 8.06E-7 m^2 (0.00125 in^2) to 9.68E-6 m^2 (0.015 in^2)
Width -	area/length
Depth -	0.00554 m (0.218 in)

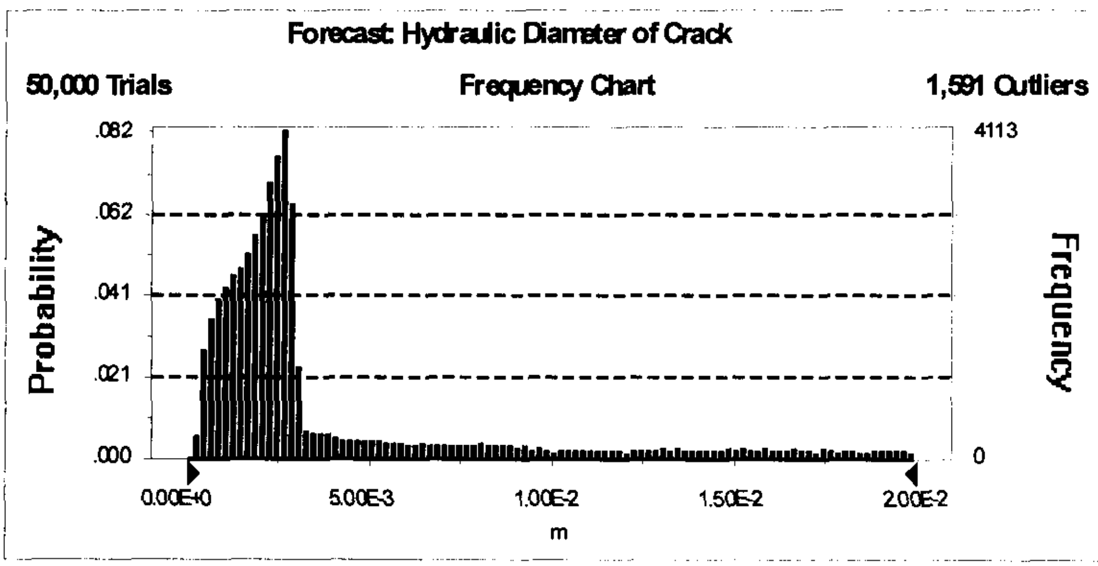
Medium:

Probability -	21%
Length -	uniform from 5.08E-3 m (0.2 in) to 7.62E-2 m (3 in)
Area -	uniform from 9.68E-6 m^2 (0.015 in^2) to 9.68E-5 m^2 (0.15 in^2)
Width -	area/length
Depth -	0.00554 m (0.218 in)

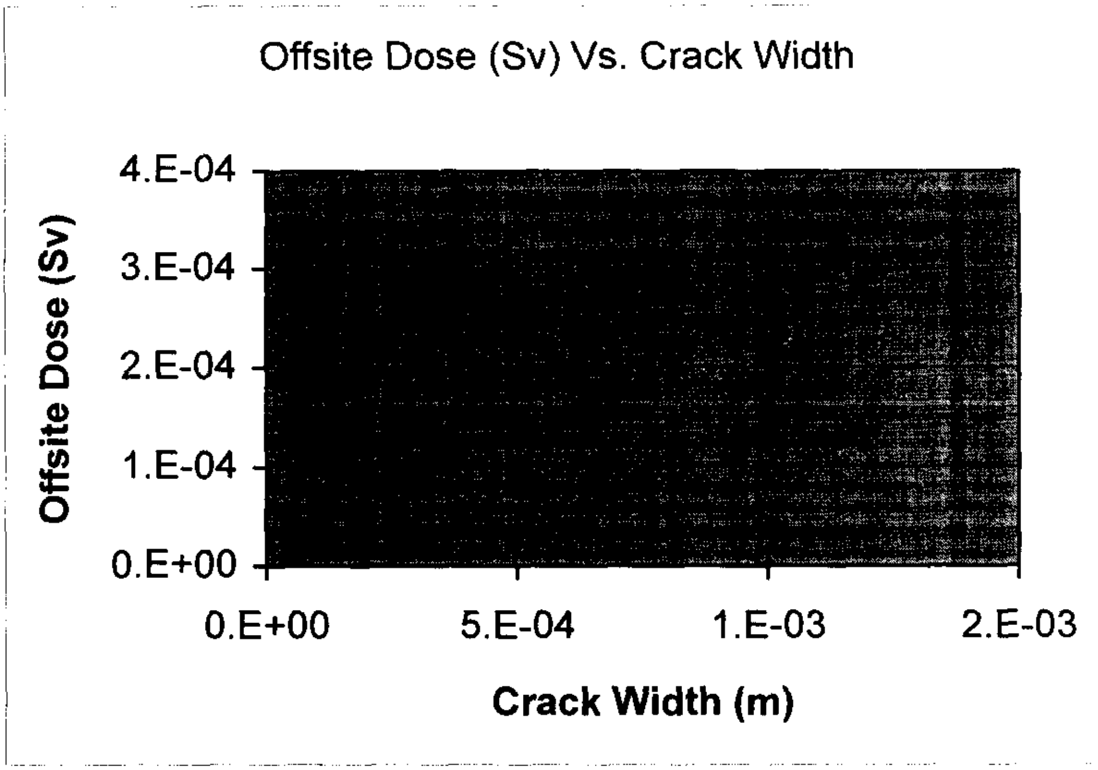
Large:

Probability -	21%
Length -	uniform from 1.27E-2 m (0.5 in) to 7.62E-2 m (3 in)
Area -	uniform from 9.68E-5 m^2 (0.15 in^2) to 6.45E-4 m^2 (1.0 in^2)
Width -	area/length
Depth -	0.00554 m (0.218 in)

Sensitivity studies using the above leak size distribution were performed for representative accident 33A - *Ex-Tank Waste Transfer Leak Into Structure* and 33C - *Ex-Tank Waste Transfer Leak Directly to the Soil Surface or Atmosphere*. The detailed results of these analyses are summarized in Sections 6.1.10 and 6.3.9. Because this latter leak size distribution predicts a narrower range of leak areas, consequences go down by about 30% for 33A and by about 50% for 33C. The leak size distribution derived from the data contained in Ziada (2000) is shown below.



However, neither this nor the original leak size distribution sample significantly from the leak flow rate regimes where spray aerosol generation is important. The graph below illustrates the dose prediction model sensitivity to crack width assumed for Case 33A - No Controls.



Note that for crack widths less than 2E-4 m (0.008 in) the dose predictions rise dramatically. If we use this knowledge to alter the smaller width of the bimodal leak size distribution of Case 33A to a uniform distribution between 0 and 2E-4 m, then onsite doses due to spray aerosol are one to two orders of magnitude higher as seen below:

Table 45. 33A - Sensitivity Study - Altered Leak Size Distribution

Control	Function	Onsite Dose (Sv)	Offsite Dose (Sv)
No controls		**2.7E-1**	2.3-4
Leak Detection at 5% - pump shutoff at +30 min - evac at +3.2 hrs	Auto leak detection at 5% pit fill, reduces leak rate, removes MEI from pool shine.	**5.8E-2**	-

Mitigated spray doses remain above onsite guidelines until the smaller width of the bimodal leak size distribution is broadened to the range of 0 to 0.002 m, causing fewer samplings in the spray sensitive region. The original range of this distribution (i.e., 0 to 0.0047625 m from Appendix B data) is not too different and could possibly have been chosen to be narrower as the data requires much interpretation. Although the possibility of spray aerosol doses exceeding onsite guidelines should not be ignored, there are several factors not accounted for which would reduce the hazard of spray aerosol from a waste transfer. One factor is plugging. The crack widths necessary to efficiently generate respirable sized aerosol are necessarily small. Since waste slurries contain large amounts of suspended solids it is likely that small cracks will be plugged. If this were accounted for, the dose predicted from spray aerosol would decrease dramatically. If the waste being transferred were 99.9% supernate, then one might argue that efficient sprays were possible. But even at 0.1%, one liter of waste contains one cc of solids. Unfortunately, the information necessary to model this effect was not practical to obtain in the time frame of this analysis.

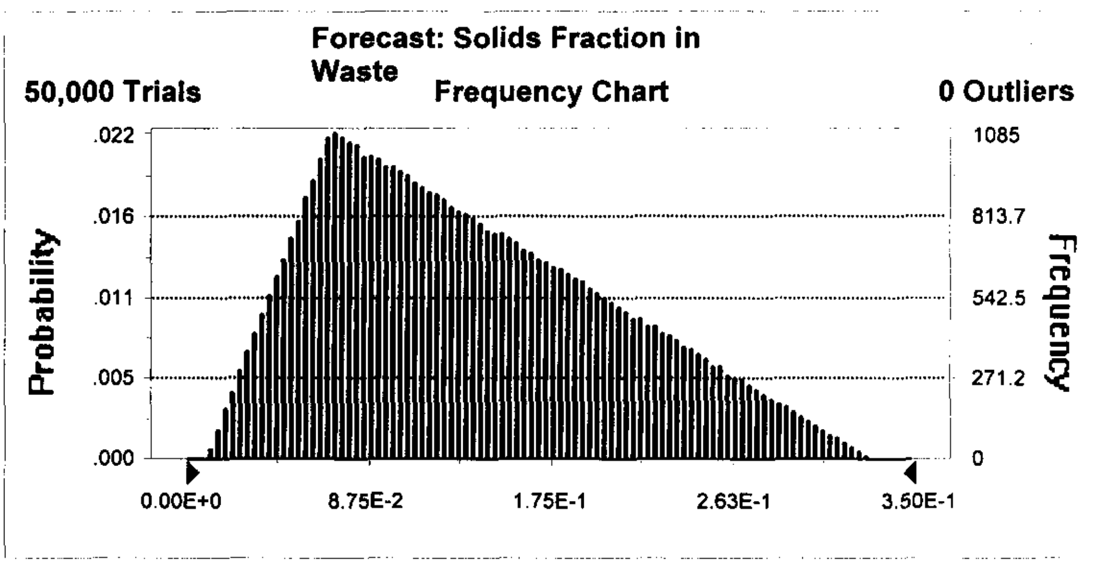
There are also other causes of leaks which are not reflected in the failure data reported in Appendix B or Ziada (2000) and if included could skew the distributions used in this analysis. Such causes that were identified in the hazards analysis were water hammer, deflagration, freezing, seismic stress, and high temperature (i.e., failure of gasket material). Insufficient information has been gathered in this analysis to know what leak size distribution should represent these causes. With the possible exception of spray aerosol, the results reported here would envelope a smaller leak size distribution while a larger leak size distribution would decrease the detection and/or evacuation time necessary to protect the onsite worker, but not challenge offsite guidelines.

With regards to the sensitivity of dose results to leak size, the following can be said in descending order of certainty:

- Offsite guidelines are not at risk of being challenged,
- Gamma-ray shine is the primary means by which onsite guidelines are challenged,
- Detection and evacuation times are sensitive to leak size assumptions and should be used with caution,
- Spray aerosol generation is extremely sensitive to small leak size assumptions, and although not likely to be a primary dose pathway, should not be ignored.

7.3 SENSITIVITY OF DOSE ESTIMATES TO WASTE SOLIDS FRACTION

It is intended that this analysis be representative of all types of waste transfers, including slurry transfers. The Hanford tank waste data analyzed in Jensen (2000) categorizes wastes as liquid or solid with the liquid being overlying or interstitial supernatant and the solid being either insoluble precipitates or crystallized solutes. In order for the solids to be pumped they must be mixed with either the supernatant or water and made into a slurry. Since the former would contain a more hazardous slurry and it is not known how much water would be added, the addition of water is not assumed in any of these analysis results. The pdf used to represent solids fraction (except in the case of salt well transfers) is shown below.



Altering the solids fraction pdf to favor higher solids fractions would have the following effects on the analysis:

- It would increase the inhalation hazard of waste aerosols,
- It would increase the viscosity of the waste slurry and decrease the generation of spray aerosol,
- It would decrease the Cs-137 concentration and reduce gamma-ray exposure,
- It would have no effect on the pump system because fully turbulent conditions were assumed for the purpose of calculating frictional losses.

Although no sensitivity calculations were performed, by inspection it can be seen that for the cases analyzed, increasing the solids fraction would lower the gamma-ray dose which is dominant. However, since the liquid Cs-137 concentration is only a factor of two higher than the solid Cs-137 concentration, the sensitivity is not high. Since dilution of the waste with water was not assumed, the cases analyzed should conservatively represent Hanford waste transfer operations.

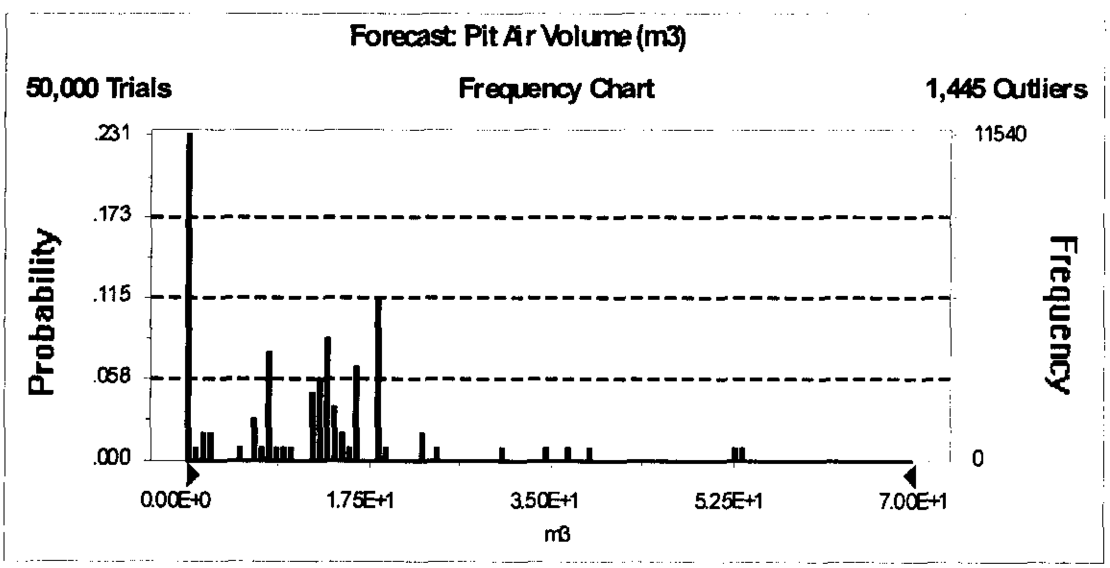
7.4 SENSITIVITY OF DOSE ESTIMATES TO AEROSOL CONCENTRATION EXITING PIT

The aerosol density in the air vented or displaced from covered pits or clean out boxes was assumed to be 100 mg/m^3. The amount of air displaced was assumed to equal 90% of the pit volume. The release duration was assumed to be acute (i.e., both onsite and offsite receptors were totally exposed to this source term). Plume meander and depletion were credited, but these dose reduction factors were small. Although all the large pits were included in this analysis, the onsite dose from inhaling vented aerosols was negligible in comparison to both gamma-ray shine and entrainment. The probability of a leak occurring in a pit was assumed to be equal to one over the total number of pits listed in Appendix H (i.e., most 200 East and West area pits and clean out boxes). It is possible that the probability of a leak in a larger pit is greater because it is more likely to contain more jumpers and potential leak sources. However, a larger pit would also be expected to have enhanced aerosol removal mechanisms over a small pit (i.e., greater distance for aerosols to travel before escaping). It should be noted that the contamination surrounding a covered pit which contained a leak is one of the means by which radiation protection personnel can detect a leak in a pit.

Since there are no inherent sensitivities of any of these assumptions which would cause a dramatic increase in dose consequences, there is little reason to believe that alternate but reasonable models of this release pathway could challenge onsite guidelines.

7.5 SENSITIVITY OF GAMMA-RAY SHINE TO PIT SIZE

Pit sizes were chosen to represent both east and west tank farms (see Appendix H). Only the cases analyzed for leaks into structures (i.e., 33A) use this data. The probability histogram created from this data is shown below.



The assumption is that the probability of a leak in any given pit is one over the total number of pits on the Hanford site as represented by Appendix H. The median pit fill time for the leak distribution derived from Appendix J is 0.5 and 0.92 hrs for the blocked discharge and open discharge case respectively (see Tables 4 and 6). The primary effect of pit size on analysis results is to confine some of the leaked waste and reduce gamma-ray shine to the onsite worker. The simple assumption used in this analysis is that gamma-ray shine from waste contained in the pit can be ignored. An indication of the validity of this assumption can be seen from the difference in gamma-ray dose from Table 5. 33A - Dose Consequences - No Controls and Table 16. 33B - Dose Consequences - DST Transfers - No Controls. Even though the latter represents no pit holdup the gamma-ray dose is only 12.5% larger.

The error in neglecting pit shine was also quantified by modeling a pit as a vertical cylinder with an aspect ratio (diameter/depth) ranging from 1.0 to 2.0. Pit diameters were assumed to range from 0.6 m to 6 m. For these ranges it was found that the ratio of (normalized) dose to surface area was consistently in the range of 1.7E-6 to 2.1E-6 Sv/hr/m^2. This is approximately 2-3 times the value for the 1" deep pools. Using the results for an aspect ratio of 2.0 the gamma dose contribution from the waste in the pit was calculated (conservatively ignoring fill times) and added to the pool contribution. This was then compared to the gamma dose without the pit contribution. The ratio of the pit dose contribution to the total varied with mitigation time but for 12 hrs and 3.2 hrs (i.e., uncontrolled and controlled) the ratio ranged from 0.01 to 0.1 (at 95%). The largest contribution from the pit (~10%) came in the mitigated case where the gamma dose is about 2/3 of the total, implying that the maximum increase from the pit gamma would be about 7%. The pit gamma dose is proportional to the aspect ratio, so if the aspect ratio were 4 then the contribution would be approximately double. Likewise, if the ratio were only 1.0 then the contribution would be halved. Taking into account the fill times would reduce the contribution as much of the gamma would be shielded by the pit walls when the pit is only partly filled.

Based on these sensitivity studies, gamma-ray shine from the pit can be ignored with relatively little error, an error that is easily overshadowed by other conservative modeling simplifications as discussed below.

7.6 SENSITIVITY OF DOSE ESTIMATES TO WASTE POOL DEPTH, SHAPE, AND SOIL SOAKING

The model of the leak using a circular pool and fixed pool depth is idealized. The actual configuration would vary significantly with the topography and soil characteristics in the vicinity of the leak, environmental conditions, and waste characteristics. In order to determine the degree of uncertainty associated with the assumed pool shape, parametric calculations were performed in Finfrock (1999). The gamma-ray shine from both a circular pool (5 m radius) and a rectangular pool 1 m wide and 80 m long were compared. Two rectangular configurations were considered, one with the pool oriented parallel to the line from the receptor to the center of the pool, and one perpendicular to it. In both cases the center point coincided with the center of the circular pool. Both of these scenarios resulted in doses that were essentially equivalent to the dose from the circular pool. Only in extreme cases where the pool stretched out nearly to the point of encompassing the receptor would the shine deviate significantly. Hence, for all realistic scenarios where the onsite receptor is10's of meters distant from the edge of the pool, the pool shape should not substantially change the dose. Based on these results, a circular pool was selected as an adequate base case geometry.

Soil soaking was also evaluated in order to determine the amount of conservatism inherent in the analysis assumption of a uniform pool depth of 1.3 in. If one were to assume that this waste material soaked into the soil filling the void space (i.e., about 4 in deep), then the dose rate was estimated to be reduced by a factor of two. A soil soaking model was not included in this analysis due to uncertainties in waste behavior (e.g., waste solidification upon contacting a cold surface), climactic conditions (e.g., freezing), and surface porosity (e.g., asphalt). However it is believed that the model assumptions used are reasonably conservative and if enhanced, would not alter the conclusions of this analysis.

7.7 SENSITIVITY OF LEAK DETECTION AND EVACUATION RESPONSE TIME TO TRANSFER PUMP SHUT OFF

Upon detection of a leak the prudent action is to stop the transfer pump as soon as possible. The sooner the pump is stopped, the longer it will take for the integrated dose to exceed onsite guidelines. This analysis assumed that 30 minutes elapses between leak detection and pump shut off.

Turning off the pump lowers the leak rate but does not stop it due to hydrostatic head in the transfer piping (i.e., drainback). These models are discussed more fully in Sections 4.3 and 4.4. The immediate advantage of stopping the transfer pump is to almost double the allowable detection or evacuation time for leaks into structures (33A) or exposed to the atmosphere (33C) as summarized in the table below.

Table 46. Advantage of Transfer Pump Shutoff

Representative Accident Category	Advantage	Reference
Case 33A - Leaks into Structures	Increases allowable evacuation time from 1.7 to 3.2 hours	See Tables 8 and 9
Case 33B - Leaks Underneath the soil	Allowable evacuation time unchanged at 1.3 hours	See Tables 18 and 19
Case 33C - Leaks Exposed to the Atmosphere	Increases allowable evacuation time from 1.2 to 2.4 hours	See Tables 26 and 27

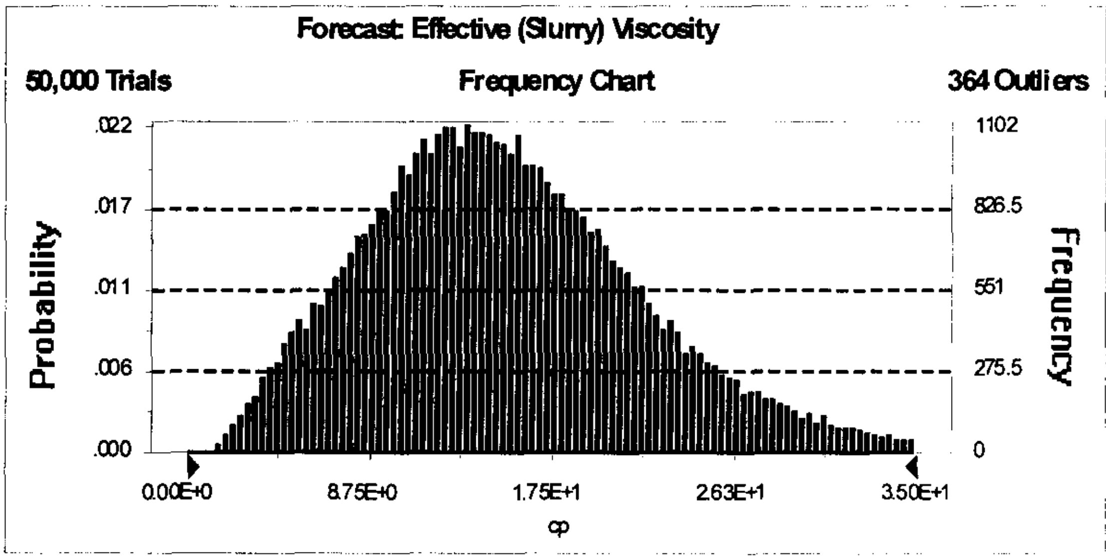
For leaks underneath the soil (33B) detection is harder to achieve. Allowing 1.3 hours for leak detection leaves only 1 hour for onsite evacuation and little dose reduction occurs as a result of the pump being shut off during the last 30 minutes of exposure.

Keep in mind that the time available for leak detection and evacuation is sensitive to input parameters such as leak size distributions. By time available it is meant the time available before onsite guidelines are exceeded. The relationship between the onsite dose and the time at which the transfer pump is shut off is complicated by having to integrate the dose rate of a growing pool over time. When the pump is shut off, the leak rate decreases and the pool grows at a slower rate. If the transfer line inventory available for drainback is exhausted, the leak rate stops, the pool growth stops, and the dose rate becomes constant.

7.8 SENSITIVITY OF DOSE ESTIMATES TO WASTE VISCOSITY

The hydraulic models used in this analysis assume fully turbulent conditions for calculating friction factors. Hence the friction factor is independent of Reynold's number and viscosity. The net effect of this assumption is to lower the friction factor, underestimate frictional line losses, and increase leak pressures. The degree of conservatism is not thought to be great because in most cases the flow would be fully turbulent. Where this might not be true would be for blocked discharge cases and small leak sizes. However, the difference between the blocked discharge and normal operation cases are not so different as to suggest the possibility of uncontrolled onsite consequences ever being below guidelines.

The fluid viscosity does play a role in determining the respirable fraction of aerosol generated in a spray (see Section 4.10). The quadratic form of the Einstein equation, discussed in Section 4.5, yields lower viscosity values that those measured and is conservative in that the respirable spray quantity for a given leak scenario is exaggerated. No better model currently exists for relating the broad spectrum of Hanford pumped waste chemistry to viscosity. The liquid/solid composite probability distribution for waste viscosity is shown in the histogram below.



The above viscosity distribution is believed to be conservative for undiluted waste mixtures. In the case of diluted waste, not only would the viscosity decrease but the unit liter dose and Cs-137 concentration would decrease as well. Since the only effect of reducing viscosity in this model is to increase the respirable aerosol spray fraction, which is already considered to be a second order health risk, further refinements are not considered warranted.

7.9 PUMP AND TRANSFER SYSTEM SIMPLIFICATIONS

For simplicity, fully turbulent flow is assumed for purposes of calculating pressure drop. This has the effect of removing any correlation between viscosity and friction factor and is a conservative assumption because it underestimates pressure drop which increases leak flow rate. This assumption is accurate for nominal and high flow conditions but underestimates frictional losses under low flow conditions. It is unlikely that the degree of conservatism caused by this simplification would alter the basic conclusions of this analysis.

The transfer line length of 20,000 ft is matched to the pump characteristic curve and pipe diameter (3 in Sch 40 assumed) discussed in Section 4.3 in order to achieve a nominal flow rate of 155 gpm. Changing the transfer line length without modifying either of these other two parameters would result in unrealistic flow rates. Choosing a pipe diameter and transfer line length is not so important as realistically modeling a typical transfer system to be representative of many possible transfer routes. Once this is done, uniformly sampling leak location along the length of the transfer route ensures that the full range of transfer system pressures will be analyzed. For the cases where the transfer system is modeled as having a blocked discharge, pipe diameter and transfer line length become even less important.

The pump characteristic curve is intended to conservatively envelope current tank farm safe storage operations and waste feed delivery. The one exception is the cross site transfer of slurry which is designed to operate at even higher pressures. A flow controller (or any other pump controlling device) is not included in the pump model because it is not desirable to credit its function for nuclear safety. Therefore large leaks close to the pump can cause the pump to approach run out conditions and small leaks under blocked discharge conditions can increase system pressure to pump dead head pressures.

The drainback head is also conservatively modeled as if it were constant even though it would be expected to go down with time. This greatly simplifies the modeling without adding excessive conservatism (i.e., it would not change the basic conclusions of the analysis).

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Appendix A - Sample Spread Sheet Calculation - 33A w/ Open Discharge

Waste Release Evaluation

33A - Ex-tank into pit; Corrosion, Erosion, Gasket; Drainback; No Deadhead
fixed drainback pool radius 5/1; added offsite mitigated 5/8; fixed dry entr. 5/9

Date:	5/22/00			
Number of Samples:	50000			
Input Properties	Assumptions	Units	PDF	
Miscellaneous Values				
Acceleration due to gravity (g)	9.80665	m/s2	constant	
Waste Properties				
Density of Supernate	1.1	kg/L	constant	
Density of Solids in Waste	1.6	kg/L	constant	
Viscosity of Supernate	15.1213	cp	triangular	
Solids Fraction in Waste	0.066451		triangular	
Pointer, Supernate ULD and Cs137	8		data	q-r
Pointer, Solids ULD and Cs137	92		data	l-m
ULD, Supernate	1562.225	Sv/L	look-up	
ULD, Solids	1587.578	Sv/L	look-up	
Cs137 Concentration in Supernate	1.34E+10	Bq/L	look-up	
Cs137 Concentration in Solids	6.33E+09	Bq/L	look-up	
Crack Properties				
Crack Shape	rectangular		constant	
Crack Edge Type	rounded		constant	
Velocity Coefficient Cv	0.82		constant	
Contraction Coefficient Cc	1		constant	
Crack Width	0.000362	m	bimodal	
Crack Length	0.067064	m	uniform	
Crack Depth	0.000264	m	uniform	

Crack Roughness	4.57E-05 m	constant	
Pipe Flow Properties			
Initial Flow Rate Guess	0.00946 m3/s	constant	
Deadhead Condition (0=false/1=true)	0	constant	
Pipe Diameter	0.077927 m3/s	constant	
Pipe Relative Roughness	0.0006	constant	
Friction Factor	0.018	constant	
Maximum Friction Factor (deadhead)	1E+10	constant	
Maximum Equivalent Pipe Length	6096 m	constant	
Pipe Length Equivalent	2320.038 m	uniform	
Drainback Slope	0.01	constant	
Maximum Drainback Head	22.86 m	constant	
Uphill Flag (0=no, 1=yes)	1	binary	
Pit Properties			
Pointer, Pit Size	35	data	v-w
Pit Air Volume	7.724554 m3	look-up	
Minimum Pit Size for Spray Cut-Off	0.0001 m3	constant	
Minimum Pit Size for Splash/Splatter Cut-Off	0.2 m3	constant	
Number of Pit Volume Releases	1	constant	
Escaping Aerosol Concentration	0.0001 kg/m3	constant	
Pool Properties			
Pool Depth	3.3 cm	constant	
Soil Properties			
Aggregate Size Distribution Mode	0.284881 mm	uniform	
Roughness Height	0.01 m	constant	
Respiration Properties			
ARF*RF (for splash/splatter)	2.65E-05	lognormal	
Drop Size Distribution Coefficient q	2.4	constant	
SMD/X	0.65415	constant	
Maximum Respirable Diameter	0.00001 m	constant	
Pointer - Onsite X/Q, Wind Speed	10	data	b-c

Pointer - Offsite X/Q, Wind Speed	184	data	g-h
Wind Speed - Onsite	2.65 m/s	look-up	
Wind Speed - Offsite	2.65 m/s	look-up	
X/Q - Onsite	0.00402 s/m3	look-up	
X/Q - Offsite	9.53E-07 s/m3	look-up	
Breathing Rate - Onsite	0.00033 m3/s	constant	
Breathing Rate - Offsite	0.00027 m3/s	constant	

Accident Scenarios

Exposure Time - Onsite	12 hr	constant
Exposure Time - Offsite	24 hr	constant
Leak Detection Delay	0 hr	constant
Evacuation Delay	3.2 hr	constant
Pump Shut-Off Delay	0.5 hr	constant

Calculations	Value	Units	Equivalen t	Units
Waste Parameters:				
Waste Density	1.133225	kg/L		
Inhalation ULD	1563.91	Sv/L		
Pipe Parameters:				
Loss Coefficient	535.8936			
Friction Factor, downstream	0.018			
Loss Coefficient, downstream	872.1898			
Pipe Cross-Sectional Area	0.004769	m2		
Leak Parameters:				
Effective Crack Width	0.000362	m		
Effective Crack Length	0.067064	m		
Hydraulic Diameter of Crack	0.00072	m		
Friction Resistance Coefficient Kf	0.029373			
Velocity Resistance Coefficient Kv	0.48721			
Total Resistance Coefficient K	0.516583			

Leak Area	2.43E-05 m2	0.037621 in2
Pressure and Flow (initial guess):		
Initial Pump Flow Rate	0.009105 m3/s	144.3227 gpm
Initial Pump Head	327.8844 m	
Initial Pump Pressure	3643827 N/m2	528.4925 psi
Initial Velocity in Pipe	1.909093 m/s	
Initial Head Loss	99.58232 m	
Initial Pressure Drop	1106673 N/m2	160.5093 psi
Initial Leak Pressure	2537154 N/m2	367.9831 psi
Initial Velocity of Leak	54.3372 m/s	
Initial Leak Flow Rate	0.001319 m3/s	20.90411 gpm
Initial Pipe Velocity Past Leak	2.264519 m/s	
Initial Pipe Flow Rate Past Leak	0.010801 m3/s	
Pressure and Flow (after iteration):		
Pump Flow Rate	0.010366 m3/s	164.3098 gpm
Pump Head	296.1109 m	971.4924 ft
Pump Pressure	3290723 N/m2	477.2791 psi
Velocity in Pipe	2.173481 m/s	
Head Loss	129.0743 m	
Pressure Drop	1434421 N/m2	208.0452 psi
Leak Pressure	1856302 N/m2	269.2338 psi
Velocity of Leak	46.47807 m/s	
Leak Flow Rate	0.001128 m3/s	17.88062 gpm
Pipe Flow Velocity Past Leak	1.936987 m/s	
Pipe Flow Rate Past Leak	0.009238 m3/s	
Convergence Factor	1.000014	
Pressure and Flow after Pump Shutoff (initial guess):		
Pump Head	22.86 m	75 ft
Pump Pressure	254046.5	
Pump Flow Rate	0.004359 m3/s	
Velocity in Pipe	0.913838 m/s	
Head Loss	22.81742 m	
Pressure Drop	253573.3 N/m2	36.7777 psi
Leak Pressure	473.1785 N/m2	0.068629 psi
Velocity of Leak	0.742055 m/s	

Leak Flow Rate	1.8E-05 m3/s	0.285477 gpm
Initial Pipe Velocity Past Leak	0.030925 m/s	
Initial Pipe Flow Rate Past Leak	0.000147 m3/s	

Pressure and Flow after Pump Shutoff (after iteration):

Pump Flow Rate	0.002881 m3/s	45.65792 gpm
Pump Head	22.86 m	75 ft
Pump Pressure	254046.5 N/m2	36.84633 psi
Velocity in Pipe	0.603961 m/s	
Head Loss	9.966559 m	
Pressure Drop	110759.8 N/m2	16.06435 psi
Leak Pressure	143286.7 N/m2	20.78198 psi
Velocity of Leak	12.91299 m/s	
Drainback Leak Flow Rate	0.000313 m3/s	4.967766 gpm
Pipe Flow Velocity Past Leak	0.538153 m/s	
Pipe Flow Rate Past Leak	159.3528 m3/s	
Convergence Factor	1.000014	

Spray Release Parameters:

Effective (Slurry) Viscosity	18.04734 cp
Kinematic Viscosity of Waste	1.59E-05 m2/s
Sauter Mean Diameter SMD	0.0002
Maximum Diameter of Concern	1.82E-05 m
Characteristic Diameter X	0.000306
Respirable Volume Fraction Q	0.000572
Respirable Release Rate	6.45E-07 m3/s

Total Leak Volume:

Total Leak Volume - Onsite	48.73341 m3	12874.01 gal
Total Leak Volume - Offsite	97.46682 m3	25748.01 gal

Mitigation Time and Volume:

Leak Detection Time (5% full)	0.095104 hr	
Pump Shut-Off Time	0.595104 hr	
Leak Volume at Pump Shut-Off	2.416786 m3	638.4475 gal
Maximum Drainback Volume	18.00925 m3	4757.541 gal

Maximum Drainback Duration	15.96142 hr	
Mitigated Exposure Time	3.295104 hr	
Actual Drainback Duration	2.7 hr	
Actual Drainback Volume	3.046407 m3	
No-Flow Duration	0 hr	
Pool Initiation Time	1.902076 hr	
Mitigated Pool Initiation Time	24 hr	
Mitigated Volume	5.463193 m3	1443.223 gal
Mitigated Volume - no shutoff	13.3818 m3	3535.099 gal

Splash/Splatter Volume:		
Splash/Splatter Volume - Onsite	7.724554 m3	2040.612 gal
Splash/Splatter Volume - Offsite	7.724554 m3	2040.612 gal
Mitigated Splash/Splatter Volume	5.463193 m3	1443.223 gal
Respirable Aerosol From Splash/Splatter - Onsite	0.000204 m3	0.054002 gal

Spray Release Volume:		
Spray Release Volume - Onsite	7.724554 m3	2040.612 gal
Spray Release Volume - Offsite	7.724554 m3	2040.612 gal
Mitigated Spray Release Volume	5.463193 m3	1443.223 gal
Respirable Aerosol Spray Release - Onsite	0.004416 m3	1.166573 gal

Pit Vent Volume:		
Pit Air Release Volume:	7.724554 m3	2040.612 gal
Respirable Aerosol From Pit Volume - Onsite	6.82E-07 m3	0.00018 gal

Pool Formation:		
Pumped Pool Formation Duration	0 hr	
Drainback Pool Formation Duration	0 hr	
Pool Volume at Max Onsite Exposure Time	41.00886 m3	10833.4 gal
Pool Volume at Max Offsite Exposure Time	89.74227 m3	23707.4 gal
Pool Volume at Mitigated Exposure Time	0 m3	0 gal
Pool Volume Effective Average - Mitigated Exposure	0 m3	
Pool Radius at Max Onsite Exposure Time	19.88872 m	
Pool Radius at Max Offsite Exposure Time	29.42162 m	
Pool Radius at Mitigated Exposure Time	0 m	

Pool Radius at 1/2 Onsite Exposure Time	14.06345 m
Pool Radius at 1/2 Offsite Exposure Time	20.80423 m
Pool Radius Effective Average - Mitigated Exposure	3.11E-05 m

Gamma Shine Dose (Onsite):	
Cs137 Concentration in Waste	1.3E+10 Bq/L
Gamma Dose at Max Onsite Exposure Time	0.004202 Sv
Gamma Dose, Mitigated Exposure Time	0 Sv

Wet Entrainment Rate:	
Wet Entrainment Rate - Onsite:	8.37E-14 kg/m3/s
Wet Entrainment Rate - Offsite:	8.37E-14 kg/m3/s
Respirable Aerosol From Wet Resuspension - Onsite	4.69E-08 m3

Dry Entrainment Rate:	
Threshold Friction Velocity	0.388714 m/s
Threshold Wind Speed	6.366238 m/s
Dry Entrainment Rate - Onsite	0.000618 g/m2/hr
Dry Entrainment Rate - Offsite	0.000618 g/m2/hr
Respirable Aerosol From Dry Entrainment - Onsite	0.004065 m3

Inhalation Dose:	
Spray Release Dose - Onsite	0.009162 Sv
Spray Release Dose - Offsite	1.78E-06 Sv
Spray Release Dose - Onsite, Mitigated	0.00648 Sv
Spray Release Dose - Offsite, Mitigated	1.26E-06 Sv
Splash/Splatter Dose - Onsite	0.000424 Sv
Splash/Splatter Dose - Offsite	8.23E-08 Sv
Splash/Splatter Dose - Onsite, Mitigated	0.0003 Sv
Splash/Splatter Dose - Offsite, Mitigated	5.82E-08 Sv
Pit Air Release Dose - Onsite	1.41E-06 Sv
Pit Air Release Dose - Offsite	2.74E-10 Sv
Pit Air Release Dose - Onsite, Mitigated	1.41E-06 Sv
Pit Air Release Dose - Offsite, Mitigated	2.74E-10 Sv
Wet Entrainment Dose - Onsite	9.73E-08 Sv
Wet Entrainment Dose - Offsite	1.34E-10 Sv
Wet Entrainment Dose - Onsite, Mitigated	0 Sv

Wet Entrainment Dose - Offsite, Mitigated	0 Sv
Dry Entrainment Dose - Onsite	1.69E-05 Sv
Dry Entrainment Dose - Offsite	1.43E-08 Sv
Dry Entrainment Dose - Onsite, Mitigated	0 Sv
Dry Entrainment Dose - Offsite, Mitigated	0 Sv

Total Dose:

OnM0, C+NoShutoff+NoEvac, Gam+Pit+Wet	0.004203 Sv
OnM1, NoC+Shutoff+Evac, Gam+Spr+Spl+Wet	0.00678 Sv
OnM2, C+Shutoff+Evac, Gam+Pit+Wet	1.41E-06 Sv
OffM0, C+NoShutoff+NoEvac, Pit+Wet	4.08E-10 Sv
OffM1, NoC+Shutoff+NoEvac, Spr+Spl+Wet	1.31E-06 Sv
OffM2, C+Shutoff+NoEvac, Pit+Wet	2.74E-10 Sv
OnU1, NoC+NoShutoff+NoEvac, Gam+Spr+Spl+Wet	0.013788 Sv
OffU1, NoC+NoShutoff+NoEvac, Spr+Spl+Wet	1.86E-06 Sv

Appendix B - Probability Density Functions for Leak Length, Width and Depth

Circular, annular and irregular leaks can be approximated by rectangular openings having a length, width and depth. This report provides the probability density function (pdf) for the leak length, width and depth for use in the Crystal Ball™ analysis of realistic consequences of sprays and leaks. The spreadsheet takes the result of the sampling performed on the leak length pdf and multiplies it by the leak width pdf to obtain the leak area. The leak depth pdf is used in the calculation of friction losses through the crack. The pdf's are developed independent of frequency of failure, transfer route, or waste being transferred.

General Causes of Leaks

A failure must occur for a leak to be present. Das (1997) provides a list of the potential failure mechanism for metals. The list is re-created in Table 1.

Table 1
Failure Mechanisms

A.	Failures due to Overload	
	1. tension loads	4. torsional loads
	2. bending loads	5. shear loads
	3. impact loads	6. tearing
B.	Failures due to Distortion	
	1. warping	2. bending
C.	Failures due to Fatigue	
	1. push-pull	5. bending
	2. flexural	6. rotary-bending
	3. torsional	7. spalling
	4. brinelling (excess pressure on a stationary piece)	8. thermal
D.	Failures due to Corrosion	
	1. general corrosion	4. intergranular corrosion
	2. pitting corrosion	5. corrosion fatigue
	3. ex foiliation	6. hydrogen enbrittlement
E.	Failures due to Creep	
F.	Failures due to Wear	
	1. erosion wear	3. abrasive wear
	2. surface fatigue	4. corrosion wear

Many of the failure mechanisms listed in Table 1 are also appropriate for the non-metallic components (e.g., gaskets and seals) of the pipeline.

Specific Causes of Leaks

In a Hanford-specific study, Schwenk (1995) provides the results of a review of the 200 E and 200 W double-shell tank to determine the remaining life. Schwenk reviewed the failure history of waste transfer piping systems from the 1940's to 1995. Failure information sources included interviews with facility personnel, reviews of past failure analyses and reports, reviews of unusual occurrence reports and review of the waste transfer design documents. The author determined that the major factors in waste transfer failures were the following:

- External corrosion due to lack of cathodic protection, improperly applied cathodic protection or lack of or degradation of the coating on carbon steel pipe.

- Internal corrosion due to accumulation and concentration of chlorides (or other materials that degrade steel) or out-of-specification waste chemistry.

The corrosion mechanisms are biological corrosion, galvanic corrosion, erosion-corrosion.

Edgemon (1996) presents the results of a similar study to that of Schwenk (1995). The results were similar in that the mechanisms of degradation included those listed in Schwenk (1995). In both Schwenk (1995) and Edgemon (1996) a leak is an opening through which enough liquid passes, that the loss is observed. Observation requires detection by leak detector systems or material balance discrepancies. In these cases hundreds of gallons of liquid must be lost to be detected. In contrast, spray releases can involve low flow rates while still generating a large quantity of aerosols. For example the spray release from the "worse-case" spray from the Tank Farms FSAR is two gallons per minute.

Neither Edgemon (1996) nor Schwenk (1995) considered failures in non-metallic components. However, since Schwenk reviewed the failure and the unusual occurrence data, it might be concluded that failures of non-metallic components do not result in noticeable leaks. As was discussed above, spray releases rarely are large enough to cause operator action in the same way leaks (i.e., streams) do.

The postulated mechanisms of the non-metallic components are as follows:

- Radiolytic, chemical or age degradation

- Human error during installation or maintenance (e. g., wrong gasket, failure to include the gasket)

- Lack of proper sealing or seating (e. g., excessive moments on the gasketed surface, or incorrect tightening).

From the references cited, it is seen that large leaks occur due to corrosion. This implies that the main failure for leaks is also corrosion, although other failure causes could also be contributors.

A different source that provides data on leaks is the Hanford Database for Unusual Operational Occurrences (ORPS). This database was reviewed to find information on pipe leaks and sprays. The following key words were used in the search:

- transfer line and failure
- pipe and failure
- jumper and failure
- transfer line an leak
- pipe and leak
- jumper and leak
- nozzle and leak
- transfer line leak
- transfer line failure
- pipe leak
- pipe spray

Tables 2 and 3 provide the results of the search relative to leak size (or quantity) and cause.

Table 2
Results of Search Using "Transfer Line" or "Pipe" and "Leak" or "Failure"

Occurrence Report	Quantity Leaked	Cause	Comments
1997 – 0074	250 gallons	line failure	---
1992 – 0040	(15 min of spray)	external corrosion	spray
1995 – 0109	at least 20 gallons	not determined	---
1992 – 0009	not determined	not determined	water heard draining in pit
1994 – 0059	not determined	corrosion - 23 ft of line needs to be replaced	leak behind kick-plate of jumper (in wall)
1992 – 0072	3575 gallons	not determined	---
1995 – 0081	not determined	not determined	---
1992 – 0046	not determined (partial volume of transfer line SN-215)	metal fatigue caused by cyclic thermal stress (hot waste, cool flush)	---
1992 – 0045	same as 1992 – 0046	same as 1992 – 0046	---
1994 – 0070	1 gallon	not determined	leak at quick connect

Table 3
Results of Search Using "Jumper" or "Nozzle" and "Leak" or "Failure"

Occurrence Report	Quantity Leaked	Cause	Comments
1997 – 0073	not determined	not determined	valve leak
1995 – 0041	not determined	jumper misaligned	-----
1993 – 0014	1100 gallons	gasket between nozzle and jumper failed in 3 places	---
1995 – 0023	11 gallons	gasket failed	leak at L11 nozzle
1995 – 0081	2 gallons	not identified	leak at connection of jumpers to test assembly

Leak Size in Pipes

Six documents were found that contain metallurgical information on failed pipes. Each document was reviewed to obtain an estimate of the size of the failure. The results from each document follow.

1. Hanson (1985) presents the results of a metallurgical analysis of a leak in the 241-A-B Valve Pit. Figure 6 of the report shows six openings in a 2 inch long by 0.5 inch wide section of pipe. Five of the openings are 0.125 to 0.375 inches in diameter. One opening is generally in the shape of an equilateral triangle with a 0.5 inch base and 0.5 inch height. The total flow area is about 0.37 in^2. The equivalent failure diameter would be 0.69 in. There was significant wall thinning.

2. Carlos (1994) presented the results of the failure of piping run SL-119. Appendix A of the reference indicated that "the pipe was completely corroded through at two places leaving two large hole" (pg A-2, Section II a). The document contains photographs of the pipe openings but the quality of the photograph is such that the leak size cannot be determined independently. Section 5 of the report states that there were two holes in the line, each 1 inch in diameter. There was thinning of the exterior wall of the pipe.

3. Edgemon (1996) presents the results of the metallurgical examination of the failure of SL-503 valve pit jumper. The failure of this line occurred within the wall of the valve pit. The failure mechanism was determined to be corrosion originating in the interior of the pipe. The failure area could not be directly viewed. The failure area was characterized as "small." There was no appreciable wall thinning.

4. Riddelle (1984) presents the SN-402 transfer line leak location and repair efforts, and the results of the V-406 transfer line corrosion information. The failure mechanism was found to be chloride-pitting corrosion. The examination of the lines showed 20 to 40 pits in each of four sections of the transfer line. Most of the pits were small. One section of the line had six

pits each 1/8 inch in diameter and two pits each 3/16 inch in diameter. Two sections of the line each had one pit 3/16 inch in diameter. One section, four pits each, 3/32 inch in diameter. There was one slot having dimensions 7/32 by 1/16 inch. No wall thinning was found.

5. Bendixsen (1983) presents the results of the analysis of the failure of SL-176. The report concluded that the line failed at the point of a small oxide inclusion in the metal at a point where the line was under significant stress. The leak came from a crack that was about half of the circumference in length or 3 inches. The crack width was very small. It was estimated from the photograph to be 0.025 inches. There was no wall thinning found.

6. Certa (1983) presented the results of the metallurgical analysis of the V-398 line failure. It was concluded that the cause of the failure was corrosion. A number of small openings were found. The estimated diameter is 1/16 inch for each opening. There was no wall thinning found.

Leak Size in Jumpers

Table 3 shows that leaks have also occurred in jumpers due to gasket failure or misalignment. The openings could be circular having a diameter of about 1/16 to 1/8 inch or take the form of a crack with a length about 1/8 to ½ of the circumference and width of 1/16 to 1/8 inch.

Conclusions Regarding Leak Size

Table 4
Results of Leak Size from Metallurgical Examinations

Reference	Leak Size
Hanson (1985)	5 somewhat circular holes, 1/8 to 3/8 inch diameter. One opening ½ by ½ inch.
Carlos (1994)	2 – 1 inch circular holes.
Edgemon (1996)	Characterized as "small," diameter is unknown. A value of ¼ inch is chosen based on Hanson (1985).
Riddelle (1984)	4 openings each 3/16 inch diameter 2 openings each 1/8 inch diameter 4 openings each 3/32 inch diameter One slot 7/32 by 1/16 inch.
Bendixsen (1983)	Crack, 3 inches long, 0.025 inches wide.
Certa (1983)	A number of pits each with a diameter of about 0.06 inches.
Jumpers (inferred from ORPS)	Crack length of up to 3 inches long, and up to 1/8 inches wide.

From the results shown in above, the leak sizes seem to cluster about three sizes.

- A number (5 to 8) of small (1/16 to 3/16 diameter) holes
- A number (2) of large (1 inch diameter) holes
- Long cracks (3 inches long, 1/16 to 1/8 inches wide).

These can be grouped into three slot openings. The grouping comes about by combining the 5 to 8 holes and the 2 – 1 inch holes into slot openings.

- slot 1/16 to 3/16 wide and ¼ to 3 inches long
- slot 1 inch wide and 1 inch long

The pdf will be developed from this data. The values chosen for use in the pdf will be a little larger and a little smaller than the results shown above to account for uncertainties and the fact that the leaks may have occurred in smaller openings than those seen in the metallurgical analysis. Based on this, the pdf for slot length will be chosen to be uniform from 1/16 to 3 inches. This will cover the jumper data and data from Certa (1983) as well as a small number of small holes.

The pdf on slot width will be bimodal with a uniform distribution from 0 to 3/16 and another one from ¾ to 1.5 inches. The heights of the mode at the small diameters is 6 times greater than the height at the large diameters. The height of the pdf between 3/16 inch and ¾ inch is zero.

The pdf on depth will be uniform from 0 inch to the wall thickness or 0.2 inches. The value of 0.2 inches is chosen as the wall thickness for 2 inch Sch 40 pipe is 0.15 inches, for 3 inch Sch 40 pipe is 0.216 inches and for 3.5 inches Sch 40 pipe is 0.226 inches.

Table 5 provides a summary of the pdf's.

Table 5 Summary of Leak Width, Length and Depth PDF's
Leak Width ▪ Bimodal distribution ▪ First peak represented by a uniform distribution between 0 inches and 3/16 inches ▪ Second peak represented by a uniform distribution between ¾ inches and 1 ½ inches ▪ First peak is 6 times larger than second peak ▪ Between 3/16 inches and ¾ inches, the distribution is uniform. The magnitude is much less than the first or second peak. Leak Length ▪ Uniform distribution between 1/16 and 3 inches. Leak Depth ▪ Uniform distribution between 0 and 0.2 inches.

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Appendix C - Probability Density Function for Splash and Splatter

Aerosol is formed, due to splash and splatter, when liquid streams fall from a height onto an unyielding surface. Liquid streams fall onto the floor of the pit if a pipe or jumper fails during transfer. DOE (1994) provides data on airborne release fraction (ARF) and respirable fraction (RF) spills of 125 to 1000 ml of solutions onto an unyielding surface from heights of 1 m and 3 m. Liquids having densities from 1 g/cm^3 to 1.4 g/cm^3, viscosity's from 1 to 46 centipoise and surface tension up to 77 dynes/cm were used in the experiments. The value of ARF*RF representing a spill of slurries and aqueous solutions from a height of 3 m is provided in Section 3.1 of DOE (1994). The data is given in Table 1.

Table 1
Values of ARF*RF for a 3 m Drop of Slurries and Aqueous Solution

	ARF*RF	
Solution	Median	Bounding
Aqueous Solution	3×10^{-5}	1×10^{-4}
Slurry	1.4×10^{-5}	4×10^{-5}

For this analysis the median value will be chosen to be 2×10^{-5}. The bounding (95%) value will be taken to be 1×10^{-4}. A lognormal fit is judged to best represent this data.

To change this pdf for other types of solutions, the correlation DOE (1994) is used. The correlation shows that ARF is proportional to the following:

$$\text{ARF} \sim (H^3/\mu^2)^{0.55}$$

where

H = spill height, m
μ = viscosity of the waste in poise

Table 2 provides a summary of the pdf.

Table 2
Probability Density Function Data for Splash and Splatter

ARF*RF for 3 m spills:	
5%	10^{-5}
median	2×10^{-5}
95%	10×10^{-5}
Scaling equation:	
ARF $\sim (H^3/\mu^2)^{0.55}$	

References

DOE, 1994, *Airborne Release Fractions/Rates and Respirable Fraction for Nonreactor Nuclear Facilities*, DOE-HDBK-3010-94, U. S. Department Of Energy, Washington D.C.

Appendix D - Probability Density Function for Atmospheric Diffusion and Wind Speed

Introduction

This analysis accounts for the possible variation in consequence from natural weather fluctuations by means of a pdf relating atmospheric diffusion to frequency of occurrence. The air concentration of particulates is represented by X and can be determined by taking the product of the atmospheric diffusion coefficient, X/Q', and the source term release rate Q'. The Gaussian straight-line continuous plume model is employed here for calculating atmospheric diffusion. For a ground level release and at the lateral centerline of the plume the X/Q' is given by

$$\frac{\chi}{Q'} = \frac{1}{\pi \sigma_y \sigma_z u}$$

where σ_y and σ_z are the Pasquill Gifford diffusion coefficients and u is the wind speed.

Plume Depletion

The source term already accounts for the respirable fraction of material made airborne, but even this material will settle out over time. This is accounted for through use of a plume depletion correction factor via the so called "source depletion model." The model does not alter the plume shape but reduces its concentration uniformly assuming dry deposition. A discussion of the model can be found in Slade (1968) in Equation 5.48. The model is implemented through use of the GXQ code (Hey 1995a, 1995b).

$$\frac{Q_{x'}}{Q_{0'}} = \exp\left[\frac{-v_d}{\sqrt{2\pi}} \int_{0.1}^{x} \frac{g(z=0)}{u_e \sigma_z} dx\right]$$

where :

$Q_{x'}$ = *depleted source term at distance x*

$Q_{0'}$ = *original source term*

v_d = *deposition velocity (m/s)*

Deposition Velocity

A deposition velocity of 0.07 cm/s was chosen to roughly correspond to particles 0.1 to 1 um in diameter (i.e., well within respirable), a roughness height of 3 cm (grass 5-60 cm tall), an aerosol density of 1 g/cm^3, and 10 meter wind speeds of 1.5 to 7.3 m/s. At higher wind speeds the deposition velocity tends to increase so ignoring this effect is slightly conservative. As an indication of its effect, plume depletion as calculated here reduces the plume respirable quantity by about 8% at 100 m and 25% at 10 km. This approximately mirrors the results shown in NRC (1977) Figure 2 for ground-level releases experiencing plume depletion.

Plume Meander

The plume meander model is based on the empirical model given by the NRC (1982). It is implemented in GXQ. The procedure is given below.

For 1 m/s $\leq$ u $\leq$ 2 m/s :

M = 6	Stability Class G
4	F
3	E
2	D

For 2 m/s < u $\leq$ 6 m/s :

M = (u/6)**(-ln(6)/ln(3))	Stability Class G
= (u/6)**(-ln(4)/ln(3))	F
= (u/6)**(-ln(3)/ln(3))	E
= (u/6)**(-ln(2)/ln(3))	D

For x < 800 m :

$$\Sigma_y = M\,\sigma_y(x)$$

For x $\geq$ 800 m :

$$\Sigma_y = (M-1)\,\sigma_y(800) + \sigma_y(x)$$

Receptor Locations

The onsite receptor is assumed to be 100 m from the location of the leak while the offsite receptor is assumed to be located at the site boundary. The site boundary distances used in this analysis is taken from Van Keuren (1996) which conservatively represents the distance from any RPP facility to the near bank of the Columbia River. To be consistent with DOE (1999), highway 240 is not considered a site boundary in this analysis. The site boundary distances used here are reproduced in Table 1.

Table 1. RPP Facility Minimum Site Boundary Distances (Van Keuren, 1996)

Transport Direction	Minimum Distance to Fence Line or Near River Bank (m)
S	15,360
SSW	15,640
SW	13,875
WSW	11,100
W	11,100
WNW	11,100
NW	11,440
NNW	8,690
N	8,760
NNE	10,610
NE	10,680
ENE	10,530
E	12,630
ESE	18,730
SE	22,440
SSE	19,960

Joint Frequency Data

Joint frequency data is tabular data relating the frequency of combinations of wind speed, direction and stability class. This data was taken from Schreckhise, et al. (1993) for the 200 Area meteorological tower at 10 m height and is reproduced in Table 2 below.

Table 2. Atmospheric Joint Frequency Data for 200 AREA (HMS) - 10 M - Pasquill A - G (1983 - 1991 Average)

Wind Speed Bin	Pasquill Stability Class	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Total	Total
0.89	A	0.36	0.2	0.23	0.26	0.4	0.24	0.17	0.1	0.1	0.06	0.06	0.06	0.1	0.1	0.14	0.22	2.8	
	B	0.15	0.13	0.1	0.11	0.16	0.09	0.07	0.03	0.05	0.02	0.01	0.03	0.04	0.05	0.07	0.1	1.21	
	C	0.14	0.1	0.09	0.12	0.14	0.1	0.06	0.04	0.04	0.02	0.02	0.02	0.04	0.04	0.1	0.1	1.17	
	D	0.87	0.58	0.59	0.59	0.77	0.5	0.43	0.32	0.27	0.19	0.21	0.17	0.4	0.44	0.54	0.55	7.42	
	E	0.39	0.26	0.28	0.25	0.46	0.34	0.31	0.3	0.34	0.21	0.25	0.29	0.49	0.44	0.45	0.39	5.45	
	F	0.23	0.13	0.12	0.14	0.31	0.23	0.28	0.26	0.35	0.23	0.22	0.27	0.48	0.36	0.32	0.23	4.16	
	G	0.1	0.04	0.08	0.08	0.13	0.13	0.13	0.14	0.17	0.09	0.1	0.09	0.22	0.14	0.14	0.09	1.87	24.08
2.65	A	0.69	0.44	0.29	0.32	0.6	0.51	0.45	0.29	0.24	0.12	0.17	0.19	0.25	0.3	0.42	0.48	5.76	
	B	0.21	0.15	0.06	0.08	0.16	0.13	0.13	0.09	0.08	0.04	0.03	0.05	0.07	0.09	0.16	0.16	1.69	
	C	0.19	0.12	0.06	0.09	0.13	0.13	0.19	0.1	0.06	0.02	0.03	0.05	0.08	0.1	0.19	0.15	1.69	
	D	0.84	0.48	0.4	0.33	0.66	0.57	0.75	0.53	0.35	0.18	0.24	0.28	0.69	1.09	1.05	0.77	9.21	
	E	0.32	0.17	0.11	0.13	0.31	0.34	0.47	0.52	0.46	0.21	0.29	0.48	1.58	1.68	1.11	0.39	8.57	
	F	0.13	0.05	0.05	0.05	0.16	0.21	0.39	0.44	0.45	0.21	0.27	0.46	1.6	1.69	0.82	0.25	7.23	
	G	0.04	0.02	0.02	0.03	0.09	0.1	0.2	0.23	0.2	0.08	0.1	0.2	0.82	0.69	0.3	0.08	3.2	37.35
4.7	A	0.26	0.24	0.1	0.03	0.08	0.1	0.1	0.13	0.12	0.07	0.14	0.34	0.35	0.35	0.4	0.17	2.98	
	B	0.09	0.06	0.03	0.01	0.03	0.03	0.04	0.05	0.03	0.02	0.05	0.07	0.1	0.14	0.12	0.06	0.93	
	C	0.08	0.05	0.03	0.01	0.02	0.02	0.04	0.04	0.05	0.02	0.03	0.06	0.09	0.13	0.12	0.03	0.82	
	D	0.32	0.2	0.09	0.04	0.12	0.11	0.25	0.27	0.24	0.13	0.23	0.39	0.83	1.46	0.84	0.21	5.73	
	E	0.19	0.09	0.04	0.01	0.06	0.06	0.15	0.25	0.22	0.12	0.18	0.39	1.98	2.5	0.75	0.13	7.12	
	F	0.04	0.06	0.01	0.01	0.01	0.02	0.05	0.17	0.14	0.03	0.07	0.2	1.19	1.6	0.32	0.06	3.98	
	G	0.01	0	0	0	0	0.01	0.01	0.09	0.07	0.01	0.02	0.09	0.56	0.84	0.13	0.01	1.85	23.41
7.15	A	0.07	0.07	0.05	0.01	0	0	0.01	0.03	0.04	0.04	0.11	0.25	0.25	0.25	0.33	0.05	1.56	
	B	0.02	0.03	0.01	0.01	0	0	0	0.01	0.02	0.01	0.04	0.08	0.06	0.07	0.09	0.01	0.46	
	C	0.02	0.03	0.01	0	0	0	0	0.01	0.02	0.01	0.02	0.07	0.06	0.07	0.06	0.01	0.39	
	D	0.1	0.1	0.03	0.01	0	0.01	0.03	0.07	0.1	0.11	0.25	0.38	0.58	1.14	0.5	0.05	3.46	
	E	0.07	0.12	0.01	0	0	0	0.01	0.05	0.07	0.08	0.17	0.3	0.65	1.75	0.41	0.02	3.71	
	F	0.03	0.02	0	0	0	0	0	0.01	0.02	0	0.01	0.02	0.07	0.08	0.03	0	0.29	
	G	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0.01	0	0	0.02	9.89

Wind Speed Bin	Pasquill Stability Class	S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	Total	Total
9.8	A	0.02	0.02	0.01	0	0	0	0	0	0.01	0.01	0.05	0.16	0.1	0.11	0.24	0	0.73	
	B	0.01	0.01	0	0	0	0	0	0	0	0	0.02	0.04	0.02	0.03	0.06	0	0.19	
	C	0.01	0.01	0	0	0	0	0	0	0.01	0	0.02	0.05	0.02	0.03	0.05	0	0.2	
	D	0.02	0.04	0.01	0	0	0	0	0	0.02	0.07	0.16	0.24	0.13	0.5	0.29	0.01	1.49	
	E	0.01	0.06	0.01	0	0	0	0	0	0.01	0.05	0.11	0.15	0.06	0.38	0.11	0	0.95	
	F	0.01	0.01	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0.03	
	G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.59
12.7	A	0	0.01	0	0	0	0	0	0	0	0	0.02	0.06	0.02	0.02	0.03	0	0.16	
	B	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0.01	0	0.01	0	0.05	
	C	0	0.01	0	0	0	0	0	0	0	0	0.02	0.01	0	0.01	0.01	0	0.06	
	D	0.02	0.03	0	0	0	0	0	0	0	0.02	0.09	0.09	0.03	0.07	0.08	0	0.43	
	E	0.01	0.01	0.01	0	0	0	0	0	0	0.01	0.04	0.02	0.01	0.05	0.03	0	0.19	
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.89
15.6	A	0.01	0.01	0	0	0	0	0	0	0	0	0	0.01	0	0	0.01	0	0.04	
	B	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	
	C	0.01	0.01	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0.03	
	D	0.01	0.02	0	0	0	0	0	0	0	0	0.03	0.03	0.02	0	0	0	0.11	
	E	0.01	0.02	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0.04	
	F	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	
	G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25
19	A	0.02	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	
	B	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	
	C	0.01	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	
	D	0.04	0.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.11	
	E	0.07	0.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.19	
	F	0.03	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	
	G	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.48
	Total	6.3	4.53	2.93	2.72	4.8	3.98	4.72	4.58	4.36	2.49	3.9	6.17	14.05	18.8	10.83	4.78	99.94	99.94

Coefficients

Using the GXQ code (Hey 1995a and 1995b) to implement the Gaussian continuous plume model, with corrections for plume depletion and plume meander, a frequency distribution table of X/Qs (and wind speeds) was created. This table is then used to randomly sample both wind speed and X/Q for use in leak simulations. The output of these code runs are included in Appendix A.

References

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Slade, D. H., July 1968, Meteorology and Atomic Energy 1968, U.S. Atomic Energy Commission, Office of Information Services, Washington, D.C.

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GXQ Input/Output Files

```
Current Input File Name: real-on.IN


                        GXQ Version 4.0D
                        February 8, 1999

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

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


Run Date = 11/23/99
Run Time = 10:08:06.67


INPUT ECHO:
Realistic Leak Onsite X/Q
c GXQ Version 4.0D Input File
c   mode
    1
c MODE SELECTION:
c   1 - X/Q based on Hanford site specific meteorology
c   2 - X/Q based on atmospheric stability class and wind speed
c   3 - X/Q plot file is created
c
c SITE WIND & POPULATION OPTIONS:
c   ifox  inorm icdf  ichk  isite ipop
    T     F     T     F     T     F
c   ifox  = t then joint frequency used to compute frequency-to-exceed X/Q
c         = f then joint frequency used to compute annual average X/Q
c   inorm = t then joint frequency data is normalized (as in GENII)
c         = f then joint frequency data is un-normalized
c   icdf  = t then cumulative distribution file created (CDF.OUT)
c         = f then no cumulative distribution file created
c   ichk  = t then X/Q parameter print option turned on
c         = f then no parameter print
c   isite = t then X/Q based on joint frequency data for all 16 sectors
c         = f then X/Q based on joint frequency data of individual sectors
c   ipop  = t then X/Q is population weighted
c         = f then no population weighting
c
c PUFF, DEPOSITION, & WIND SPEED MODELS:
c   ipuff idep  isrc  iwind
    0     1     0     0
c DIFFUSION COEFFICIENT ADJUSTMENTS:
c   iwake ipm   iflow ientr
    0     1     0     0
c EFFECTIVE RELEASE HEIGHT ADJUSTMENTS:
c  (irise igrnd)iwash igrav
    0     0     0     0
c   ipuff = 1 then X/Q calculated using puff model
c         = 0 then X/Q calculated using default continuous plume model
c   idep  = 1 then plume depletion model turned on (Chamberlain model)
c   isrc  = 1 then X/Q multiplied by scalar
```

```
c         = 2 then X/Q adjusted by wind speed function
c   iwind = 1 then wind speed corrected for plume height
c   iwake = 1 then NRC RG 1.145 building wake model turned on
c         = 2 then MACCS virtual distance building wake model turned on
c   ipm   = 1 then NRC RG 1.145 plume meander model turned on
c         = 2 then 5th Power Law plume meander model turned on
c         = 3 then sector average model turned on
c   iflow = 1 then sigmas adjusted for volume flow rate
c   ientr = 1 then method of Pasquill used to account for entrainment
c   irise = 1 then MACCS buoyant plume rise model turned on
c         = 2 then ISC2 momentum/buoyancy plume rise model turned on
c   igrnd = 1 then Mills' buoyant plume rise modification for ground effects
c   iwash = 1 then stack downwash model turned on
c   igrav = 1 then gravitational settling model turned on
c         = 0 unless specified otherwise, 0 turns model off
c
c PARAMETER INPUT:
c   release        anemometer     mixing         frequency
c   height         height         height         to
c   (m)            (m)            (m)            exceed
    0.00000E+00    1.00000E+01    1.00000E+03    5.00000E+00
c
c   initial        initial                                      gravitational
c   plume          plume          release        deposition     settling
c   width          height         duration       velocity       velocity
c   Wb(m)          Hb(m)          (hour)         (m/s)          (m/s)
    0.00000E+00    0.00000E+00    0.00000E+00    7.00000E-04    0.00000E+00
c
c                  initial        initial                       convective
c   ambient        plume          plume          release        heat release
c   temperature    temperature    flow rate      diameter       rate*
c   (øC)           (øC)           (m3/s)         (m)            (watts)
    4.30000E+01    3.20000E+01    1.22500E+04    3.50000E+01    1.52000E+08
c   *If zero then buoyant flux based on plume/ambient temperature difference.
c
c   X/Q            Wind
c   scaling        Speed
c   factor         Exponent
    1.00000E+00    0.00000E+00
c
c RECEPTOR LOCATIONS (no line limit)
c   MODE               RECEPTOR DEPENDENT DATA
c   1 (site winds)     sector, distance, receptor height
c   2 (special case)   class, windspeed, distance, offset, receptor height
c   3 (plot file)      class, windspeed, xmax, imax, ymax, jmax, xqmin, power
c
c RECEPTOR PARAMETERS
c   sector = 0, 1, 2... (all, S, SSW, etc.)
c   distance = receptor distance (m)
c   receptor height = height of receptor (m)
c   class = 1,2,3,4,5,6,7 (Pasquill stability A,B,C,D,E,F,G)
c   windspeed = anemometer wind speed (m/s)
c   offset = offset from plume centerline (m)
c   xmax  = maximum distance to plot or calculate to (m)
c   imax  = distance intervals
c   ymax  = maximum offset to plot (m)
c   jmax  = offset intervals
c   xqmin = minimum scaled X/Q to calculate
c   power = exponent in power function step size

MODE:
Site specific X/Q calculated.

LOGICAL CHOICES:
Joint frequency used to calculate X/Q based on frequency of exceedance.
No normalization of joint frequency.
Cumulative distribution contained in file CDF.OUT.
```

X/Q calculated for overall site.

MODELS SELECTED:
NRC RG 1.145 plume meander model selected.
Source depletion model selected.
Default Gaussian plume model selected.

WARNING/ERROR MESSAGES:

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

Realistic Leak Onsite X/Q

SECTOR	DISTANCE (m)	RECEPT HEIGHT (m)	SECT. FREQ. (%)	POPULATION	TOTAL POPULATION SCALED X/Q (s/m3)	AVERAGE INDIVIDUAL SCALED X/Q (s/m3)	ATM. STAB. CLASS	WIND SPEED (m/s)
ALL	100	0	99.98	1	8.63E-03	8.63E-03	F	0.89

GXQ Version 4.0D
February 8, 1999

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

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

Run Date = 11/23/99
Run Time = 10:08:06.73

CUMULATIVE DISTRIBUTION

SECTOR	DISTANCE (m)	ATM. STAB. CLASS	WIND SPEED (m/s)	SECT. FREQ. (%)	CUM. FREQ. (%)	SCALED X/Q (s/m3)
S	100.	G	0.89	1.53	0.77	1.27E-02
S	100.	G	4.70	1.94	2.50	1.06E-02
SSW	100.	G	7.15	0.36	3.65	1.05E-02
SSW	100.	F	0.89	3.30	5.48	7.98E-03
N	100.	G	9.80	0.04	7.15	7.68E-03
SSW	100.	G	2.65	3.03	8.69	7.29E-03
SW	100.	E	0.89	4.46	12.43	4.82E-03
SW	100.	F	4.70	4.68	17.00	4.72E-03
NNW	100.	F	7.15	0.81	19.74	4.25E-03
SW	100.	F	2.65	6.82	23.56	4.02E-03
S	100.	G	19.00	0.01	26.98	3.98E-03
WSW	100.	D	0.89	4.87	29.42	3.98E-03
WSW	100.	C	0.89	0.75	32.23	3.45E-03
SSW	100.	F	9.80	0.07	32.64	3.11E-03
SSW	100.	F	12.70	0.02	32.68	2.40E-03
S	100.	E	4.70	8.00	36.69	2.25E-03
W	100.	E	2.65	9.52	45.45	2.23E-03
SSW	100.	F	15.60	0.01	50.22	1.96E-03
WNW	100.	E	7.15	2.99	51.72	1.89E-03
W	100.	B	0.89	0.66	53.54	1.82E-03
W	100.	D	2.65	9.69	58.72	1.65E-03
S	100.	F	19.00	0.08	63.60	1.61E-03
N	100.	E	9.80	0.80	64.04	1.38E-03
S	100.	D	4.70	7.70	68.29	1.34E-03
WNW	100.	C	2.65	1.54	72.91	1.18E-03
SW	100.	E	12.70	0.24	73.80	1.07E-03
NW	100.	A	0.89	1.47	74.66	1.05E-03
NW	100.	D	7.15	3.84	77.31	1.03E-03
S	100.	E	15.60	0.11	79.29	8.71E-04
S	100.	D	9.80	1.23	79.96	7.54E-04
S	100.	E	19.00	0.18	80.66	7.15E-04
WSW	100.	C	4.70	1.18	81.34	6.71E-04
NNW	100.	B	2.65	1.59	82.73	6.22E-04
SSW	100.	D	12.70	0.48	83.76	5.82E-04
S	100.	D	15.60	0.14	84.07	4.74E-04

NNW	100.	C	7.15	0.63	84.46	4.42E-04
NE	100.	D	19.00	0.13	84.84	3.90E-04
N	100.	A	2.65	5.13	87.47	3.56E-04
N	100.	B	4.70	1.30	90.68	3.52E-04
NNE	100.	C	9.80	0.16	91.41	3.23E-04
SSW	100.	C	12.70	0.06	91.52	2.49E-04
N	100.	B	7.15	0.70	91.90	2.32E-04
NE	100.	C	15.60	0.01	92.26	2.03E-04
NW	100.	A	4.70	4.14	94.33	2.02E-04
NNE	100.	B	9.80	0.20	96.50	1.69E-04
SSW	100.	C	19.00	0.05	96.63	1.67E-04
WSW	100.	A	7.15	2.30	97.80	1.33E-04
NNE	100.	B	12.70	0.05	98.98	1.31E-04
SSW	100.	B	15.60	0.02	99.01	1.06E-04
NNE	100.	A	9.80	0.66	99.35	9.68E-05
SSW	100.	B	19.00	0.03	99.70	8.73E-05
NNE	100.	A	12.70	0.16	99.79	7.48E-05
NNE	100.	A	15.60	0.05	99.90	6.09E-05
NE	100.	A	19.00	0.06	99.95	5.00E-05
NNE	100.	F	15.60	0.00	99.98	0.00E+00
SSE	100.	G	19.00	0.00	99.98	0.00E+00

```
   Current Input File Name: real-off.IN


                          ______________________

                              GXQ Version 4.0D
                              February 8, 1999
                          ______________________

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

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


Run Date = 11/23/99
Run Time = 10:08:28.48


INPUT ECHO:
Realistic Leak Offsite X/Q
c GXQ Version 4.0D Input File
c   mode
    1
c MODE SELECTION:
c   1 - X/Q based on Hanford site specific meteorology
c   2 - X/Q based on atmospheric stability class and wind speed
c   3 - X/Q plot file is created
c
c SITE WIND & POPULATION OPTIONS:
c   ifox  inorm icdf  ichk  isite ipop
    T     F     T     F     T     F
c   ifox  = t then joint frequency used to compute frequency-to-exceed X/Q
c         = f then joint frequency used to compute annual average X/Q
c   inorm = t then joint frequency data is normalized (as in GENII)
c         = f then joint frequency data is un-normalized
c   icdf  = t then cumulative distribution file created (CDF.OUT)
c         = f then no cumulative distribution file created
c   ichk  = t then X/Q parameter print option turned on
c         = f then no parameter print
c   isite = t then X/Q based on joint frequency data for all 16 sectors
c         = f then X/Q based on joint frequency data of individual sectors
c   ipop  = t then X/Q is population weighted
c         = f then no population weighting
c
c PUFF, DEPOSITION, & WIND SPEED MODELS:
c   ipuff idep  isrc  iwind
    0     1     0     0
c DIFFUSION COEFFICIENT ADJUSTMENTS:
c   iwake ipm   iflow ientr
    0     1     0     0
c EFFECTIVE RELEASE HEIGHT ADJUSTMENTS:
c  (irise igrnd)iwash igrav
    0     0     0     0
c   ipuff = 1 then X/Q calculated using puff model
c         = 0 then X/Q calculated using default continuous plume model
c   idep  = 1 then plume depletion model turned on (Chamberlain model)
c   isrc  = 1 then X/Q multiplied by scalar
c         = 2 then X/Q adjusted by wind speed function
c   iwind = 1 then wind speed corrected for plume height
c   iwake = 1 then NRC RG 1.145 building wake model turned on
```

```
c        = 2 then MACCS virtual distance building wake model turned on
c   ipm  = 1 then NRC RG 1.145 plume meander model turned on
c        = 2 then 5th Power Law plume meander model turned on
c        = 3 then sector average model turned on
c   iflow = 1 then sigmas adjusted for volume flow rate
c   ientr = 1 then method of Pasquill used to account for entrainment
c   irise = 1 then MACCS buoyant plume rise model turned on
c         = 2 then ISC2 momentum/buoyancy plume rise model turned on
c   igrnd = 1 then Mills' buoyant plume rise modification for ground effects
c   iwash = 1 then stack downwash model turned on
c   igrav = 1 then gravitational settling model turned on
c         = 0 unless specified otherwise, 0 turns model off
c
c PARAMETER INPUT:
c   release        anemometer     mixing         frequency
c   height         height         height         to
c   (m)            (m)            (m)            exceed
    0.00000E+00    1.00000E+01    1.00000E+03    5.00000E+00
c
c   initial        initial                                      gravitational
c   plume          plume          release        deposition     settling
c   width          height         duration       velocity       velocity
c   Wb(m)          Hb(m)          (hour)         (m/s)          (m/s)
    0.00000E+00    0.00000E+00    0.00000E+00    7.00000E-04    0.00000E+00
c
c                  initial        initial                       convective
c   ambient        plume          plume          release        heat release
c   temperature    temperature    flow rate      diameter       rate*
c   (øC)           (øC)           (m3/s)         (m)            (watts)
    4.30000E+01    3.20000E+01    1.22500E+04    3.50000E+01    1.52000E+08
c   *If zero then buoyant flux based on plume/ambient temperature difference.
c
c   X/Q            Wind
c   scaling        Speed
c   factor         Exponent
    1.00000E+00    0.00000E+00
c
c RECEPTOR LOCATIONS (no line limit)
c   MODE               RECEPTOR DEPENDENT DATA
c   1 (site winds)     sector, distance, receptor height
c   2 (special case)   class, windspeed, distance, offset, receptor height
c   3 (plot file)      class, windspeed, xmax, imax, ymax, jmax, xqmin, power
c
c RECEPTOR PARAMETERS
c   sector = 0, 1, 2... (all, S, SSW, etc.)
c   distance = receptor distance (m)
c   receptor height = height of receptor (m)
c   class = 1,2,3,4,5,6,7 (Pasquill stability A,B,C,D,E,F,G)
c   windspeed = anemometer wind speed (m/s)
c   offset = offset from plume centerline (m)
c   xmax  = maximum distance to plot or calculate to (m)
c   imax  = distance intervals
c   ymax  = maximum offset to plot (m)
c   jmax  = offset intervals
c   xqmin = minimum scaled X/Q to calculate
c   power = exponent in power function step size

MODE:
Site specific X/Q calculated.

LOGICAL CHOICES:
Joint frequency used to calculate X/Q based on frequency of exceedance.
No normalization of joint frequency.
Cumulative distribution contained in file CDF.OUT.
X/Q calculated for overall site.

MODELS SELECTED:
```

NRC RG 1.145 plume meander model selected.
Source depletion model selected.
Default Gaussian plume model selected.

WARNING/ERROR MESSAGES:

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

Realistic Leak Offsite X/Q

SECTOR	DISTANCE (m)	RECEPT HEIGHT (m)	SECT. FREQ. (%)	POPULATION	TOTAL POPULATION SCALED X/Q (s/m3)	AVERAGE INDIVIDUAL SCALED X/Q (s/m3)	ATM. STAB. CLASS	WIND SPEED (m/s)
ALL	19960	0	99.98	1	1.23E-05	1.23E-05	G	2.65

GXQ Version 4.0D
February 8, 1999

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

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

Run Date = 11/23/99
Run Time = 10:08:28.53

CUMULATIVE DISTRIBUTION

SECTOR	DISTANCE (m)	ATM. STAB. CLASS	WIND SPEED (m/s)	SECT. FREQ. (%)	CUM. FREQ. (%)	SCALED X/Q (s/m3)
NNW	8690.	G	0.89	0.08	0.04	2.99E-05
N	8760.	G	0.89	0.14	0.15	2.96E-05
ENE	10530.	G	0.89	0.07	0.25	2.38E-05
NNE	10610.	G	0.89	0.12	0.35	2.36E-05
NE	10680.	G	0.89	0.09	0.45	2.34E-05
WSW	11100.	G	0.89	0.20	0.60	2.23E-05
NW	11440.	G	0.89	0.07	0.73	2.15E-05
E	12630.	G	0.89	0.14	0.84	1.90E-05
NNW	8690.	F	0.89	0.16	0.99	1.70E-05
SW	13875.	G	0.89	0.06	1.10	1.69E-05
N	8760.	F	0.89	0.34	1.30	1.68E-05
NNW	8690.	G	2.65	0.25	1.59	1.68E-05
N	8760.	G	2.65	0.47	1.95	1.66E-05
S	15360.	G	0.89	0.18	2.28	1.48E-05
SSW	15640.	G	0.89	0.09	2.41	1.44E-05
ENE	10530.	F	0.89	0.19	2.56	1.35E-05
ENE	10530.	G	2.65	0.07	2.69	1.35E-05
NNE	10610.	F	0.89	0.23	2.84	1.34E-05
NNE	10610.	G	2.65	0.22	3.06	1.34E-05
NE	10680.	F	0.89	0.25	3.30	1.33E-05
NE	10680.	G	2.65	0.14	3.49	1.33E-05
NNW	8690.	G	4.70	0.43	3.78	1.28E-05
WSW	11100.	G	2.65	0.15	4.07	1.27E-05
WSW	11100.	F	0.89	0.45	4.37	1.27E-05
N	8760.	G	4.70	0.40	4.79	1.27E-05
NW	11440.	G	2.65	0.11	5.05	1.23E-05
NW	11440.	F	0.89	0.16	5.18	1.22E-05
ESE	18730.	G	0.89	0.08	5.30	1.13E-05
E	12630.	G	2.65	0.10	5.39	1.09E-05
E	12630.	F	0.89	0.26	5.57	1.08E-05
SSE	19960.	G	0.89	0.10	5.75	1.04E-05
ENE	10530.	G	4.70	0.01	5.81	1.00E-05
NNE	10610.	G	4.70	0.18	5.90	9.92E-06
NE	10680.	G	4.70	0.05	6.01	9.83E-06
SW	13875.	G	2.65	0.13	6.11	9.76E-06
SW	13875.	F	0.89	0.15	6.24	9.62E-06

NNW	8690.	G	7.15	0.05	6.34	9.18E-06
N	8760.	G	7.15	0.09	6.41	9.09E-06
NW	11440.	G	4.70	0.06	6.49	9.01E-06
SE	22440.	G	0.89	0.11	6.57	8.79E-06
S	15360.	G	2.65	0.39	6.82	8.65E-06
NNW	8690.	E	0.89	0.23	7.13	8.55E-06
N	8760.	E	0.89	0.46	7.48	8.47E-06
S	15360.	F	0.89	0.31	7.86	8.47E-06
SSW	15640.	G	2.65	0.27	8.15	8.46E-06
SSW	15640.	F	0.89	0.20	8.39	8.27E-06
E	12630.	G	4.70	0.01	8.49	7.94E-06
NNW	8690.	F	2.65	0.64	8.82	7.84E-06
N	8760.	F	2.65	1.09	9.68	7.76E-06
ENE	10530.	G	7.15	0.01	10.23	7.15E-06
NNE	10610.	G	7.15	0.12	10.30	7.08E-06
SW	13875.	G	4.70	0.02	10.37	7.05E-06
NE	10680.	G	7.15	0.03	10.39	7.02E-06
ESE	18730.	G	2.65	0.17	10.49	6.80E-06
N	8760.	G	9.80	0.01	10.58	6.74E-06
ENE	10530.	E	0.89	0.28	10.73	6.71E-06
NNE	10610.	E	0.89	0.32	11.03	6.64E-06
NE	10680.	E	0.89	0.29	11.33	6.59E-06
ESE	18730.	F	0.89	0.20	11.58	6.56E-06
SSE	19960.	G	2.65	0.28	11.82	6.29E-06
WSW	11100.	E	0.89	0.63	12.27	6.27E-06
ENE	10530.	F	2.65	0.20	12.69	6.25E-06
NNE	10610.	F	2.65	0.61	13.09	6.20E-06
S	15360.	G	4.70	0.10	13.45	6.19E-06
NE	10680.	F	2.65	0.39	13.69	6.15E-06
SSW	15640.	G	4.70	0.07	13.92	6.05E-06
NW	11440.	E	0.89	0.20	14.06	6.03E-06
SSE	19960.	F	0.89	0.20	14.26	6.03E-06
WSW	11100.	F	2.65	0.40	14.56	5.87E-06
NW	11440.	F	2.65	0.35	14.93	5.67E-06
SE	22440.	G	2.65	0.28	15.25	5.44E-06
NNW	8690.	F	4.70	0.80	15.79	5.37E-06
N	8760.	F	4.70	0.99	16.68	5.32E-06
E	12630.	E	0.89	0.38	17.37	5.31E-06
NNE	10610.	G	9.80	0.02	17.57	5.26E-06
NE	10680.	G	9.80	0.01	17.58	5.22E-06
SE	22440.	F	0.89	0.20	17.69	5.16E-06
E	12630.	F	2.65	0.30	17.94	5.04E-06
ESE	18730.	G	4.70	0.08	18.13	4.81E-06
SW	13875.	E	0.89	0.19	18.26	4.70E-06
SW	13875.	F	2.65	0.26	18.49	4.50E-06
SSE	19960.	G	4.70	0.21	18.72	4.43E-06
SSW	15640.	G	7.15	0.01	18.83	4.29E-06
NNW	8690.	D	0.89	0.31	18.99	4.24E-06
ENE	10530.	F	4.70	0.07	19.18	4.21E-06
N	8760.	D	0.89	0.41	19.42	4.19E-06
NNE	10610.	F	4.70	0.58	19.92	4.17E-06
NE	10680.	F	4.70	0.18	20.30	4.14E-06
S	15360.	E	0.89	0.34	20.56	4.12E-06
SSW	15640.	E	0.89	0.21	20.83	4.02E-06
S	15360.	F	2.65	0.70	21.29	3.98E-06
WSW	11100.	F	4.70	0.03	21.65	3.94E-06
SSW	15640.	F	2.65	0.48	21.91	3.90E-06
SE	22440.	G	4.70	0.32	22.31	3.82E-06
NW	11440.	F	4.70	0.14	22.54	3.79E-06
NNW	8690.	F	7.15	0.06	22.64	3.75E-06
N	8760.	F	7.15	0.16	22.75	3.72E-06
NNW	8690.	E	2.65	0.84	23.25	3.54E-06
N	8760.	E	2.65	1.37	24.35	3.51E-06
E	12630.	F	4.70	0.09	25.08	3.35E-06
ENE	10530.	D	0.89	0.20	25.23	3.22E-06
NNE	10610.	D	0.89	0.31	25.48	3.19E-06
ESE	18730.	E	0.89	0.30	25.79	3.17E-06

NE	10680.	D	0.89	0.26	26.07	3.16E-06
SSE	19960.	G	7.15	0.02	26.21	3.14E-06
ESE	18730.	F	2.65	0.33	26.38	3.13E-06
WSW	11100.	D	0.89	0.87	26.98	2.99E-06
SW	13875.	F	4.70	0.06	27.45	2.97E-06
ENE	10530.	F	7.15	0.02	27.49	2.93E-06
SSE	19960.	E	0.89	0.34	27.67	2.91E-06
NNE	10610.	F	7.15	0.30	27.99	2.90E-06
SSE	19960.	F	2.65	0.50	28.39	2.90E-06
NE	10680.	F	7.15	0.09	28.68	2.88E-06
NW	11440.	D	0.89	0.29	28.87	2.86E-06
ENE	10530.	E	2.65	0.40	29.22	2.78E-06
NNE	10610.	E	2.65	0.88	29.86	2.75E-06
N	8760.	F	9.80	0.01	30.30	2.74E-06
NE	10680.	E	2.65	0.53	30.57	2.73E-06
SE	22440.	G	7.15	0.03	30.85	2.70E-06
S	15360.	F	4.70	0.22	30.98	2.62E-06
WSW	11100.	E	2.65	0.63	31.40	2.60E-06
SSW	15640.	F	4.70	0.19	31.81	2.56E-06
SE	22440.	F	2.65	0.57	32.19	2.51E-06
NW	11440.	E	2.65	0.50	32.73	2.50E-06
SE	22440.	E	0.89	0.29	33.12	2.48E-06
E	12630.	D	0.89	0.29	33.41	2.48E-06
E	12630.	F	7.15	0.02	33.57	2.32E-06
NNW	8690.	E	4.70	0.83	33.99	2.29E-06
N	8760.	E	4.70	1.29	35.05	2.26E-06
E	12630.	E	2.65	0.72	36.06	2.21E-06
SW	13875.	D	0.89	0.27	36.55	2.16E-06
NNE	10610.	F	9.80	0.02	36.70	2.14E-06
NE	10680.	F	9.80	0.03	36.72	2.12E-06
ESE	18730.	F	4.70	0.24	36.86	2.04E-06
SW	13875.	E	2.65	0.28	37.12	1.96E-06
SSE	19960.	F	4.70	0.40	37.46	1.88E-06
S	15360.	D	0.89	0.44	37.88	1.87E-06
SSW	15640.	D	0.89	0.28	38.24	1.82E-06
S	15360.	F	7.15	0.02	38.39	1.81E-06
ENE	10530.	E	4.70	0.23	38.51	1.77E-06
SSW	15640.	F	7.15	0.03	38.64	1.77E-06
NNE	10610.	E	4.70	1.02	39.17	1.75E-06
NE	10680.	E	4.70	0.44	39.90	1.74E-06
S	15360.	G	19.00	0.01	40.12	1.74E-06
S	15360.	E	2.65	0.71	40.48	1.72E-06
SSW	15640.	E	2.65	0.38	41.03	1.68E-06
WSW	11100.	E	4.70	0.10	41.27	1.65E-06
NNW	8690.	D	2.65	0.92	41.78	1.63E-06
SE	22440.	F	4.70	0.69	42.58	1.62E-06
N	8760.	D	2.65	1.21	43.53	1.61E-06
NW	11440.	E	4.70	0.21	44.24	1.59E-06
NNW	8690.	E	7.15	0.07	44.38	1.57E-06
N	8760.	E	7.15	0.29	44.56	1.56E-06
ESE	18730.	F	7.15	0.02	44.72	1.41E-06
ESE	18730.	D	0.89	0.26	44.86	1.40E-06
E	12630.	E	4.70	0.44	45.21	1.39E-06
ESE	18730.	E	2.65	0.73	45.79	1.33E-06
SSW	15640.	F	9.80	0.01	46.16	1.31E-06
SSE	19960.	F	7.15	0.04	46.19	1.30E-06
SSE	19960.	D	0.89	0.34	46.38	1.27E-06
ENE	10530.	D	2.65	0.23	46.66	1.24E-06
SW	13875.	E	4.70	0.09	46.82	1.23E-06
SSE	19960.	E	2.65	0.64	47.19	1.23E-06
NNE	10610.	D	2.65	0.71	47.86	1.22E-06
ENE	10530.	E	7.15	0.17	48.30	1.21E-06
NE	10680.	D	2.65	0.34	48.56	1.21E-06
NNE	10610.	E	7.15	0.72	49.09	1.20E-06
NE	10680.	E	7.15	0.41	49.65	1.19E-06
W	11100.	D	2.65	1.16	50.44	1.15E-06
N	8760.	E	9.80	0.02	51.03	1.14E-06

WSW	11100.	E	7.15	0.02	51.05	1.13E-06
SE	22440.	F	7.15	0.05	51.08	1.12E-06
NW	11440.	D	2.65	0.64	51.43	1.10E-06
NW	11440.	E	7.15	0.01	51.75	1.09E-06
S	15360.	E	4.70	0.27	51.89	1.07E-06
SE	22440.	D	0.89	0.34	52.20	1.07E-06
SE	22440.	E	2.65	0.91	52.82	1.05E-06
SSW	15640.	E	4.70	0.22	53.39	1.05E-06
SSW	15640.	F	12.70	0.02	53.51	1.02E-06
NNW	8690.	C	0.89	0.05	53.54	1.00E-06
NNW	8690.	D	4.70	0.55	53.84	9.91E-07
N	8760.	C	0.89	0.04	54.14	9.87E-07
N	8760.	D	4.70	1.25	54.78	9.80E-07
E	12630.	D	2.65	0.49	55.65	9.53E-07
E	12630.	E	7.15	0.15	55.97	9.50E-07
ENE	10530.	E	9.80	0.06	56.08	8.92E-07
NNE	10610.	E	9.80	0.17	56.19	8.83E-07
NE	10680.	E	9.80	0.21	56.38	8.75E-07
SW	13875.	E	7.15	0.04	56.51	8.38E-07
SW	13875.	D	2.65	0.47	56.76	8.33E-07
SSW	15640.	F	15.60	0.01	57.00	8.33E-07
ESE	18730.	E	4.70	0.93	57.47	8.27E-07
SSE	19960.	E	4.70	0.56	58.22	7.60E-07
ENE	10530.	D	4.70	0.20	58.60	7.48E-07
NNE	10610.	D	4.70	1.08	59.24	7.40E-07
NE	10680.	D	4.70	0.40	59.98	7.33E-07
S	15360.	E	7.15	0.05	60.20	7.32E-07
S	15360.	D	2.65	0.84	60.65	7.20E-07
SSW	15640.	E	7.15	0.09	61.11	7.14E-07
ENE	10530.	C	0.89	0.02	61.17	7.06E-07
S	15360.	F	19.00	0.04	61.20	7.02E-07
SSW	15640.	D	2.65	0.56	61.50	7.01E-07
E	12630.	E	9.80	0.03	61.79	6.99E-07
NNE	10610.	C	0.89	0.04	61.83	6.97E-07
WSW	11100.	D	4.70	0.25	61.97	6.93E-07
ENE	10530.	E	12.70	0.01	62.10	6.92E-07
NE	10680.	C	0.89	0.04	62.13	6.88E-07
SSW	15640.	F	19.00	0.04	62.17	6.86E-07
NNE	10610.	E	12.70	0.06	62.22	6.85E-07
NE	10680.	E	12.70	0.08	62.29	6.79E-07
NNW	8690.	D	7.15	0.05	62.35	6.70E-07
NW	11440.	D	4.70	0.22	62.49	6.63E-07
N	8760.	D	7.15	0.38	62.79	6.63E-07
SE	22440.	E	4.70	1.37	63.66	6.52E-07
WNW	11100.	C	0.89	0.17	64.43	6.42E-07
SW	13875.	E	9.80	0.02	64.53	6.17E-07
NW	11440.	C	0.89	0.07	64.57	6.08E-07
E	12630.	D	4.70	0.38	64.80	5.74E-07
ESE	18730.	E	7.15	0.34	65.16	5.62E-07
NNE	10610.	E	15.60	0.01	65.33	5.59E-07
NE	10680.	E	15.60	0.03	65.35	5.54E-07
ESE	18730.	D	2.65	0.61	65.67	5.41E-07
S	15360.	E	9.80	0.01	65.98	5.39E-07
SSW	15640.	E	9.80	0.09	66.03	5.26E-07
SSE	19960.	E	7.15	0.14	66.15	5.17E-07
E	12630.	C	0.89	0.05	66.24	5.11E-07
ENE	10530.	D	7.15	0.22	66.38	5.05E-07
SW	13875.	D	4.70	0.21	66.59	5.00E-07
NNE	10610.	D	7.15	1.02	67.21	4.99E-07
NE	10680.	D	7.15	0.48	67.96	4.95E-07
SSE	19960.	D	2.65	0.69	68.54	4.94E-07
N	8760.	D	9.80	0.03	68.90	4.86E-07
SW	13875.	E	12.70	0.01	68.92	4.78E-07
WNW	11100.	D	7.15	0.03	68.94	4.67E-07
NE	10680.	E	19.00	0.01	68.96	4.56E-07
NW	11440.	D	7.15	0.05	68.99	4.47E-07
SE	22440.	E	7.15	0.49	69.26	4.43E-07

SW	13875.	C	0.89	0.04	69.53	4.36E-07
S	15360.	D	4.70	0.46	69.78	4.31E-07
NNW	8690.	B	0.89	0.03	70.02	4.30E-07
N	8760.	B	0.89	0.06	70.07	4.26E-07
SSW	15640.	D	4.70	0.36	70.28	4.20E-07
SE	22440.	D	2.65	0.82	70.87	4.17E-07
ESE	18730.	E	9.80	0.07	71.31	4.14E-07
SSW	15640.	E	12.70	0.05	71.37	4.08E-07
SW	13875.	E	15.60	0.01	71.40	3.91E-07
E	12630.	D	7.15	0.22	71.52	3.86E-07
SSE	19960.	E	9.80	0.01	71.63	3.81E-07
S	15360.	C	0.89	0.06	71.67	3.71E-07
ENE	10530.	D	9.80	0.13	71.76	3.70E-07
NNE	10610.	D	9.80	0.21	71.93	3.66E-07
NE	10680.	D	9.80	0.28	72.18	3.63E-07
SSW	15640.	C	0.89	0.06	72.35	3.62E-07
ENE	10530.	B	0.89	0.02	72.39	3.61E-07
NNE	10610.	B	0.89	0.03	72.41	3.58E-07
NE	10680.	B	0.89	0.03	72.44	3.56E-07
NNW	8690.	C	2.65	0.14	72.53	3.54E-07
N	8760.	C	2.65	0.22	72.71	3.49E-07
WSW	11100.	B	0.89	0.17	72.90	3.44E-07
WSW	11100.	D	9.80	0.01	72.99	3.43E-07
S	15360.	E	15.60	0.01	73.00	3.41E-07
SW	13875.	D	7.15	0.04	73.03	3.37E-07
NW	11440.	B	0.89	0.04	73.07	3.34E-07
SSW	15640.	E	15.60	0.04	73.11	3.33E-07
NNW	8690.	A	0.89	0.07	73.16	3.29E-07
N	8760.	A	0.89	0.13	73.26	3.27E-07
SE	22440.	E	9.80	0.11	73.38	3.26E-07
ESE	18730.	D	4.70	0.71	73.79	3.23E-07
ESE	18730.	E	12.70	0.01	74.15	3.21E-07
E	12630.	B	0.89	0.03	74.17	3.05E-07
SSE	19960.	D	4.70	0.59	74.48	2.94E-07
S	15360.	D	7.15	0.14	74.85	2.90E-07
ENE	10530.	D	12.70	0.05	74.94	2.87E-07
NNE	10610.	D	12.70	0.07	75.00	2.84E-07
E	12630.	D	9.80	0.09	75.08	2.83E-07
SSW	15640.	D	7.15	0.12	75.19	2.82E-07
S	15360.	E	19.00	0.09	75.29	2.81E-07
NE	10680.	D	12.70	0.21	75.44	2.81E-07
SW	13875.	B	0.89	0.05	75.57	2.80E-07
ENE	10530.	A	0.89	0.06	75.63	2.77E-07
NNE	10610.	A	0.89	0.08	75.70	2.75E-07
SSW	15640.	E	19.00	0.08	75.78	2.74E-07
NE	10680.	A	0.89	0.06	75.85	2.73E-07
ESE	18730.	C	0.89	0.03	75.89	2.72E-07
WSW	11100.	A	0.89	0.40	76.11	2.64E-07
ESE	18730.	E	15.60	0.01	76.31	2.63E-07
NW	11440.	A	0.89	0.10	76.37	2.57E-07
SSE	19960.	C	0.89	0.04	76.44	2.57E-07
S	15360.	B	0.89	0.06	76.49	2.55E-07
SE	22440.	E	12.70	0.02	76.53	2.53E-07
SSW	15640.	B	0.89	0.05	76.56	2.51E-07
ENE	10530.	C	2.65	0.03	76.60	2.50E-07
SE	22440.	D	4.70	1.04	77.14	2.48E-07
SW	13875.	D	9.80	0.01	77.66	2.47E-07
NNE	10610.	C	2.65	0.10	77.72	2.47E-07
NE	10680.	C	2.65	0.05	77.79	2.44E-07
E	12630.	A	0.89	0.08	77.86	2.35E-07
ENE	10530.	D	15.60	0.01	77.90	2.34E-07
NNE	10610.	D	15.60	0.02	77.92	2.31E-07
SE	22440.	C	0.89	0.04	77.95	2.30E-07
NE	10680.	D	15.60	0.05	77.99	2.29E-07
W	11100.	C	2.65	0.23	78.13	2.28E-07
E	12630.	D	12.70	0.02	78.26	2.19E-07
ESE	18730.	D	7.15	0.37	78.45	2.17E-07

NW	11440.	C	2.65	0.12	78.70	2.16E-07
SW	13875.	A	0.89	0.08	78.80	2.16E-07
ESE	18730.	B	0.89	0.03	78.85	2.13E-07
S	15360.	D	9.80	0.02	78.88	2.13E-07
SSW	15640.	D	9.80	0.05	78.91	2.07E-07
NNW	8690.	C	4.70	0.06	78.97	2.02E-07
SSE	19960.	B	0.89	0.03	79.01	2.01E-07
N	8760.	C	4.70	0.17	79.11	1.99E-07
SSE	19960.	D	7.15	0.16	79.28	1.98E-07
S	15360.	A	0.89	0.12	79.42	1.97E-07
SSW	15640.	A	0.89	0.11	79.53	1.93E-07
SW	13875.	D	12.70	0.01	79.59	1.91E-07
NE	10680.	D	19.00	0.01	79.60	1.88E-07
E	12630.	C	2.65	0.06	79.64	1.81E-07
SE	22440.	B	0.89	0.03	79.68	1.80E-07
E	12630.	D	15.60	0.02	79.71	1.79E-07
SE	22440.	D	7.15	0.56	80.00	1.67E-07
S	15360.	D	12.70	0.01	80.28	1.65E-07
ESE	18730.	A	0.89	0.06	80.32	1.64E-07
SSW	15640.	D	12.70	0.05	80.37	1.60E-07
ESE	18730.	D	9.80	0.12	80.46	1.59E-07
SSE	19960.	A	0.89	0.07	80.55	1.55E-07
SW	13875.	C	2.65	0.10	80.64	1.55E-07
NNW	8690.	B	2.65	0.13	80.75	1.49E-07
N	8760.	B	2.65	0.19	80.91	1.48E-07
SSE	19960.	D	9.80	0.03	81.02	1.45E-07
ENE	10530.	C	4.70	0.03	81.05	1.43E-07
NNE	10610.	C	4.70	0.21	81.17	1.41E-07
SE	22440.	A	0.89	0.05	81.30	1.40E-07
NE	10680.	C	4.70	0.06	81.36	1.39E-07
S	15360.	D	15.60	0.01	81.39	1.34E-07
NNW	8690.	C	7.15	0.01	81.40	1.34E-07
S	15360.	C	2.65	0.15	81.48	1.32E-07
N	8760.	C	7.15	0.05	81.58	1.32E-07
SSW	15640.	D	15.60	0.03	81.62	1.31E-07
WSW	11100.	C	4.70	0.07	81.67	1.30E-07
SSW	15640.	C	2.65	0.11	81.76	1.29E-07
ENE	10530.	B	2.65	0.05	81.84	1.25E-07
NNE	10610.	B	2.65	0.14	81.94	1.24E-07
NE	10680.	B	2.65	0.05	82.03	1.24E-07
ESE	18730.	D	12.70	0.01	82.06	1.23E-07
NW	11440.	C	4.70	0.04	82.09	1.23E-07
SE	22440.	D	9.80	0.25	82.23	1.22E-07
WNW	11100.	B	2.65	0.29	82.50	1.19E-07
NW	11440.	B	2.65	0.11	82.70	1.16E-07
NNW	8690.	A	2.65	0.41	82.96	1.13E-07
SSE	19960.	D	12.70	0.01	83.17	1.12E-07
N	8760.	A	2.65	0.70	83.53	1.12E-07
S	15360.	D	19.00	0.07	83.91	1.11E-07
SSW	15640.	D	19.00	0.05	83.97	1.08E-07
E	12630.	B	2.65	0.06	84.03	1.06E-07
E	12630.	C	4.70	0.06	84.09	1.04E-07
SW	13875.	B	2.65	0.11	84.17	9.76E-08
ESE	18730.	C	2.65	0.06	84.26	9.69E-08
ENE	10530.	A	2.65	0.12	84.35	9.49E-08
SE	22440.	D	12.70	0.04	84.43	9.48E-08
ENE	10530.	C	7.15	0.06	84.48	9.43E-08
NNE	10610.	A	2.65	0.38	84.70	9.42E-08
NE	10680.	A	2.65	0.17	84.97	9.37E-08
NNE	10610.	C	7.15	0.19	85.15	9.31E-08
NE	10680.	C	7.15	0.09	85.29	9.20E-08
SSE	19960.	C	2.65	0.09	85.38	9.15E-08
W	11100.	A	2.65	1.10	85.98	9.05E-08
S	15360.	B	2.65	0.15	86.60	8.90E-08
SW	13875.	C	4.70	0.05	86.70	8.84E-08
NW	11440.	A	2.65	0.41	86.93	8.80E-08
SSW	15640.	B	2.65	0.11	87.19	8.76E-08

NNW	8690.	B	4.70	0.06	87.28	8.47E-08
N	8760.	B	4.70	0.24	87.43	8.41E-08
SE	22440.	C	2.65	0.08	87.59	8.22E-08
NW	11440.	C	7.15	0.01	87.63	8.13E-08
E	12630.	A	2.65	0.21	87.74	8.05E-08
S	15360.	C	4.70	0.10	87.90	7.54E-08
ESE	18730.	B	2.65	0.04	87.97	7.43E-08
SW	13875.	A	2.65	0.36	88.17	7.39E-08
SSW	15640.	C	4.70	0.11	88.40	7.34E-08
ENE	10530.	B	4.70	0.06	88.49	7.12E-08
NNE	10610.	B	4.70	0.24	88.64	7.07E-08
NE	10680.	B	4.70	0.07	88.79	7.03E-08
SSE	19960.	B	2.65	0.08	88.87	7.02E-08
ENE	10530.	C	9.80	0.02	88.92	6.90E-08
E	12630.	C	7.15	0.04	88.95	6.84E-08
NNE	10610.	C	9.80	0.03	88.98	6.81E-08
WSW	11100.	B	4.70	0.08	89.04	6.79E-08
S	15360.	A	2.65	0.40	89.28	6.75E-08
NE	10680.	C	9.80	0.05	89.50	6.73E-08
SSW	15640.	A	2.65	0.35	89.70	6.64E-08
NW	11440.	B	4.70	0.04	89.90	6.60E-08
NNW	8690.	A	4.70	0.15	89.99	6.39E-08
N	8760.	A	4.70	0.77	90.45	6.35E-08
SE	22440.	B	2.65	0.08	90.88	6.31E-08
E	12630.	B	4.70	0.04	90.94	6.04E-08
SW	13875.	C	7.15	0.01	90.96	5.84E-08
ESE	18730.	A	2.65	0.16	91.05	5.64E-08
NNW	8690.	B	7.15	0.01	91.13	5.59E-08
SW	13875.	B	4.70	0.04	91.16	5.55E-08
N	8760.	B	7.15	0.05	91.20	5.55E-08
ESE	18730.	C	4.70	0.04	91.25	5.53E-08
ENE	10530.	A	4.70	0.16	91.35	5.37E-08
NNE	10610.	A	4.70	0.68	91.77	5.34E-08
ENE	10530.	C	12.70	0.01	92.11	5.33E-08
SSE	19960.	A	2.65	0.19	92.21	5.32E-08
NE	10680.	A	4.70	0.24	92.43	5.31E-08
SSE	19960.	C	4.70	0.10	92.60	5.22E-08
NE	10680.	C	12.70	0.02	92.66	5.20E-08
WSW	11100.	A	4.70	0.27	92.80	5.12E-08
S	15360.	B	4.70	0.15	93.01	5.06E-08
E	12630.	C	9.80	0.01	93.09	5.01E-08
NW	11440.	A	4.70	0.11	93.15	4.99E-08
S	15360.	C	7.15	0.03	93.22	4.98E-08
SSW	15640.	B	4.70	0.09	93.28	4.98E-08
SSW	15640.	C	7.15	0.03	93.34	4.85E-08
SE	22440.	A	2.65	0.17	93.44	4.79E-08
SE	22440.	C	4.70	0.08	93.57	4.70E-08
ENE	10530.	B	7.15	0.07	93.64	4.70E-08
NNE	10610.	B	7.15	0.21	93.78	4.66E-08
NE	10680.	B	7.15	0.07	93.92	4.64E-08
E	12630.	A	4.70	0.23	94.07	4.56E-08
WSW	11100.	B	7.15	0.01	94.19	4.48E-08
NW	11440.	B	7.15	0.01	94.20	4.36E-08
NE	10680.	C	15.60	0.01	94.21	4.24E-08
ESE	18730.	B	4.70	0.03	94.23	4.23E-08
NNW	8690.	A	7.15	0.02	94.26	4.21E-08
SW	13875.	A	4.70	0.17	94.35	4.19E-08
N	8760.	A	7.15	0.20	94.54	4.18E-08
N	8760.	B	9.80	0.01	94.64	4.05E-08
SSE	19960.	B	4.70	0.07	94.68	3.99E-08
E	12630.	B	7.15	0.07	94.75	3.98E-08
E	12630.	C	12.70	0.01	94.79	3.87E-08
S	15360.	A	4.70	0.44	95.02	3.82E-08
SSW	15640.	A	4.70	0.33	95.40	3.76E-08
ESE	18730.	C	7.15	0.05	95.59	3.66E-08
SW	13875.	B	7.15	0.01	95.62	3.66E-08
SE	22440.	B	4.70	0.09	95.67	3.59E-08

SSW	15640.	C	9.80	0.01	95.72	3.55E-08
ENE	10530.	A	7.15	0.21	95.83	3.54E-08
NNE	10610.	A	7.15	0.62	96.25	3.52E-08
NE	10680.	A	7.15	0.34	96.73	3.49E-08
SSE	19960.	C	7.15	0.02	96.91	3.45E-08
ENE	10530.	B	9.80	0.04	96.94	3.43E-08
NNE	10610.	B	9.80	0.03	96.97	3.41E-08
NE	10680.	B	9.80	0.05	97.01	3.39E-08
WSW	11100.	A	7.15	0.01	97.04	3.38E-08
S	15360.	B	7.15	0.03	97.06	3.34E-08
NW	11440.	A	7.15	0.01	97.08	3.28E-08
SSW	15640.	B	7.15	0.04	97.11	3.28E-08
ESE	18730.	A	4.70	0.16	97.21	3.19E-08
SE	22440.	C	7.15	0.04	97.31	3.11E-08
N	8760.	A	9.80	0.02	97.34	3.05E-08
SSE	19960.	A	4.70	0.20	97.45	3.02E-08
E	12630.	A	7.15	0.22	97.66	3.00E-08
E	12630.	B	9.80	0.02	97.78	2.91E-08
ESE	18730.	B	7.15	0.04	97.81	2.79E-08
SW	13875.	A	7.15	0.05	97.85	2.76E-08
SSW	15640.	C	12.70	0.01	97.88	2.74E-08
SE	22440.	A	4.70	0.23	98.00	2.71E-08
ESE	18730.	C	9.80	0.01	98.12	2.68E-08
ENE	10530.	B	12.70	0.01	98.13	2.65E-08
SSE	19960.	B	7.15	0.03	98.15	2.63E-08
NNE	10610.	B	12.70	0.01	98.17	2.63E-08
NE	10680.	B	12.70	0.02	98.19	2.62E-08
ENE	10530.	A	9.80	0.11	98.25	2.59E-08
NNE	10610.	A	9.80	0.13	98.37	2.57E-08
NE	10680.	A	9.80	0.15	98.51	2.55E-08
SSE	19960.	C	9.80	0.01	98.59	2.53E-08
S	15360.	A	7.15	0.10	98.65	2.52E-08
SSW	15640.	A	7.15	0.09	98.74	2.48E-08
WSW	11100.	A	9.80	0.01	98.79	2.47E-08
SSW	15640.	B	9.80	0.01	98.80	2.40E-08
SE	22440.	B	7.15	0.05	98.83	2.37E-08
SE	22440.	C	9.80	0.02	98.87	2.27E-08
E	12630.	A	9.80	0.09	98.92	2.19E-08
ESE	18730.	A	7.15	0.13	99.03	2.10E-08
ESE	18730.	B	9.80	0.01	99.10	2.04E-08
SW	13875.	A	9.80	0.01	99.11	2.02E-08
ENE	10530.	A	12.70	0.03	99.13	2.00E-08
SSE	19960.	A	7.15	0.11	99.20	1.99E-08
NNE	10610.	A	12.70	0.02	99.27	1.98E-08
NE	10680.	A	12.70	0.06	99.31	1.97E-08
SSE	19960.	B	9.80	0.01	99.34	1.92E-08
S	15360.	C	19.00	0.02	99.36	1.89E-08
SSW	15640.	B	12.70	0.01	99.37	1.85E-08
S	15360.	A	9.80	0.01	99.38	1.84E-08
SSW	15640.	C	19.00	0.03	99.40	1.84E-08
SSW	15640.	A	9.80	0.03	99.43	1.81E-08
SE	22440.	A	7.15	0.19	99.54	1.79E-08
SE	22440.	C	12.70	0.01	99.64	1.76E-08
SE	22440.	B	9.80	0.02	99.66	1.73E-08
E	12630.	A	12.70	0.02	99.68	1.69E-08
NNE	10610.	A	15.60	0.01	99.69	1.61E-08
NE	10680.	A	15.60	0.02	99.71	1.61E-08
ESE	18730.	A	9.80	0.03	99.73	1.54E-08
SSW	15640.	B	15.60	0.02	99.76	1.51E-08
SSE	19960.	A	9.80	0.01	99.77	1.45E-08
SSW	15640.	A	12.70	0.01	99.78	1.40E-08
NE	10680.	A	19.00	0.01	99.79	1.32E-08
SE	22440.	A	9.80	0.06	99.83	1.31E-08
S	15360.	B	19.00	0.01	99.86	1.26E-08
SSW	15640.	B	19.00	0.02	99.88	1.24E-08
ESE	18730.	A	12.70	0.01	99.89	1.19E-08
SSW	15640.	A	15.60	0.01	99.90	1.14E-08

SE	22440.	A	12.70	0.01	99.91	1.01E-08
S	15360.	A	19.00	0.02	99.93	9.50E-09
SSW	15640.	A	19.00	0.03	99.95	9.34E-09
SE	22440.	A	15.60	0.01	99.97	8.21E-09
NNE	10610.	F	15.60	0.00	99.98	0.00E+00
SSE	19960.	G	19.00	0.00	99.98	0.00E+00

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Appendix E - Pump Characteristic Curve

The pump characteristic curve included in this appendix was provided by Mr. W. L. Willis of Numatec Engineering. Its use was intended to provide enveloping pressure and flow characteristics for Hanford tank waste transfers for both safe storage operations and waste feed delivery. It was also intended to conservatively represent cross site supernate transfers but not slurry transfers. Two cases are provided. The second and most conservative Case 2 was that chosen for use in this analysis. The equation representing Case 2 is given by:

$$H_p = 1440 - 0.29729\ W_p - 0.01465\ W_p^2 - 5.61E\text{-}6\ W_p^3$$

where W_p is in gpm and H_p is in feet.

Post-it® Fax Note 7671	Date	# of pages ▸ 3
To Brit Hey	From Bill Willis	
Co./Dept.	Co. Numatec	
Phone #	Phone # 376-7097	
Fax # 376-5396	Fax # 372-0065	

ULATIONS

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____ Date ____

____ Date ____

Assumptions

a. Same Basic curve shape as Sulzer Bingham Curve No. 57626

b. Run-Out for pumps based on NPSH, so will be same for higher head pump.

c. Specific Gravity ~ 1.47

Look at 2 cases. Case 1 is for a 650 psi dead head.

Case 2 is for a 650 psi operating pressure.

Case 1

$$650 \text{ psi} \times \frac{33.91 \text{ ft of water}}{14.7 \text{ psi}} \times \frac{\text{ft of waste}}{1.47 \text{ ft of water}}$$

= 1020 ft of waste

pump dead head is ~ 1020 ft

Case 2

operation is 1020 ft

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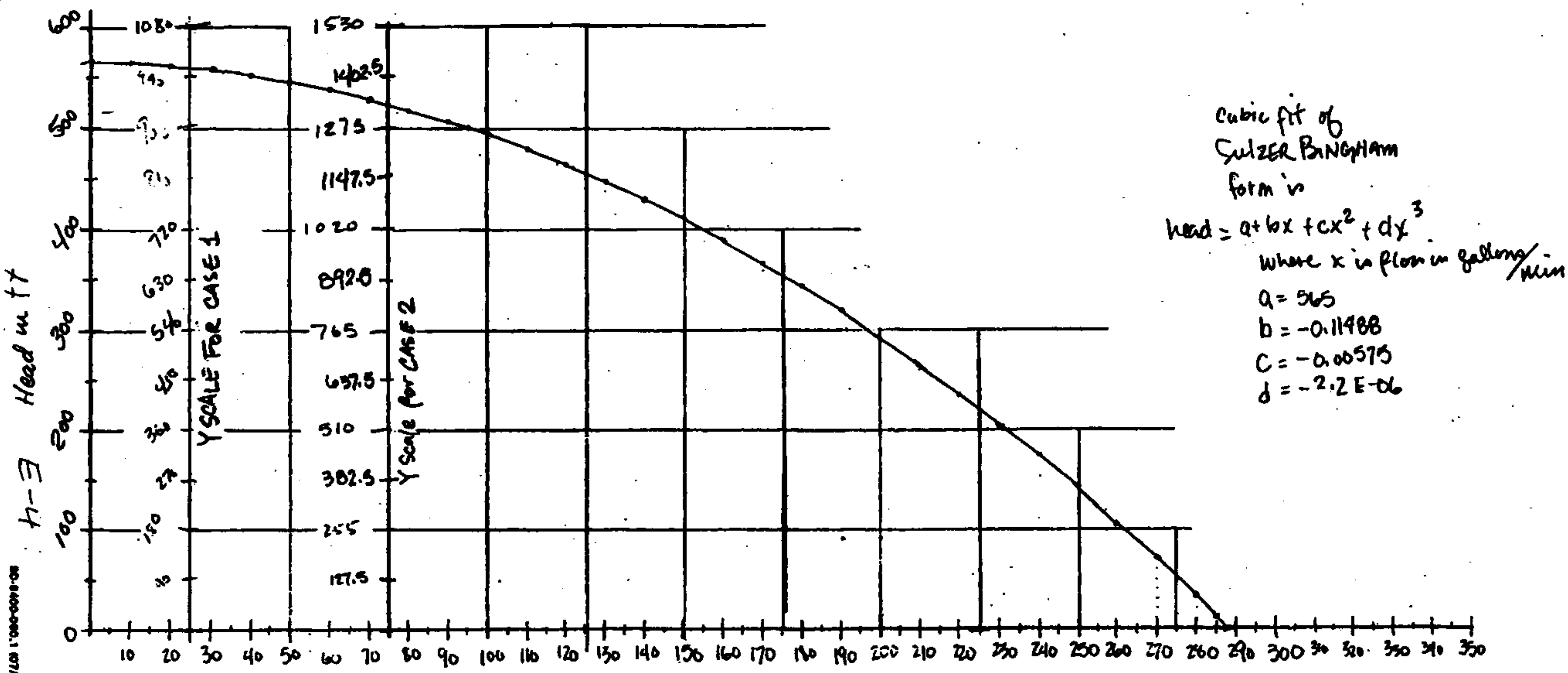
from the pump curve,

for Case 1
operating Point is ~ 720 ft
Shut off is 1020 ft

for Case 2
Operating Point is 1020 ft
Shut off is ~ 1440 ft


Head in ft
Y SCALE FOR CASE 1
Y scale for CASE 2
Cubic fit of
Sulzer Bingham
form is
head = a + bx + cx^2 + dx^3
where x is flow in gallons/min
a = 565
b = -0.11488
c = -0.00575
d = -2.2 E-06
600
500
400
300
200
100
0
1080
720
630
540
360
150
1530
1402.5
1275
1147.5
1020
892.5
765
637.5
510
382.5
255
127.5
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
350

Appendix F - Probability Density Function for Cs-137 and ULD

An essential component in calculating radiological consequences is the inhalation unit-liter dose (ULD) or the concentration of specific radionuclides in the waste released to the environment. For this model, the ULD and specific radionuclide (137Cs, alpha, and 90Sr/90Y) information was excerpted from Jensen (2000) *Sample Based Unit Liter Dose Estimates.*

Jensen (2000) assessed the impacts of new (post 1994) data from recent solid and liquid tank samples.

Estimates of unit liter doses (ULDs) for waste in the single-shell tanks (SSTs) and double-shell tanks (DSTs) were computed based on recent sampling data from the tanks. The TCD (Tank Characterization Database) contains the waste characterization data from tank samples obtained since 1989. This database was the source of data used to estimate the ULD for each waste storage tank. There was sufficient data to estimate a ULD for 54 SSTs with solid samples, 23 SSTs with liquid samples, 14 DSTs with solid samples, and 24 DSTs with liquid samples.

Jensen's (2000) estimates of the ULD were computed based on three procedures for incorporating observations that were below detection limits. The first procedure required that all observations below detection limits be deleted. This is the estimate used in this analysis.

Also used in the model to calculate a probability density function is an estimate of the contents (supernatant, sludge, and saltcake) found in each tank for which information was developed in HNF-4534. The tank contents information is taken from Tables E-5 and E-6 of HNF-EP-0182-138, *Waste Tank Summary Report for Month Ending September 30, 1999.*

The unit liter dose (ULD) for tank farms is defined as the dose from the inhalation of 1 liter of tank waste. Different ULDs are generated for SST solids, SST liquids, DST solids and DST liquids. The ULD is calculated by multiplying the concentration of each radionuclide times the dose conversion factor for that radionuclide and summing over all the significant radionuclides. Analyses were originally based on tracking 11 radionuclides, which were shown to contribute 99% of the dose. It is desirable to reduce the number of tracked radionuclides to the minimum in order to simplify the analyses. Five of the tracked radionuclides (^{241}Am, ^{239}Pu, ^{238}Pu, ^{237}Np, and ^{244}Cm) are alpha emitters. The isotopes ^{239}Pu and ^{240}Pu are combined and treated as ^{239}Pu since the two isotopes are radiologically equivalent. Since gross alpha activity is known for many tank samples, these isotopes can be grouped together under gross alpha. A weighted average of the dose conversion factor based on the "supertank" concentrations for these isotopes is used. Data tracking only gross alpha, ^{90}Sr, ^{90}Y and ^{137}Cs will give over 98% of the values from tracking the 11 isotopes for the solids and over 92% for the liquids. Unit liter doses are calculated by multiplying the tank-by-tank concentrations for the gross alpha and the three isotopes times the appropriate dose conversion factors.

The dose conversion factors are based on updated International Commission Radiological Protection (ICRP) calculations. ICRP publications 68, 71, and 72 dose conversion factors for inhalation were used to determine the contribution of each nuclide to the total inhalation dose. ICRP 68 gives dose conversion factors for the workers. ICRP-68 gives both 5 μm and 1 μm activity median aerodynamic diameter (AMAD) data but the 5 μm data are recommended as being more typical for onsite aerosol distributions. Unit liter dose factors for the onsite worker were calculated using the 5 μm data. Age dependent dose conversion factors for the offsite receptors are given in ICRP 71 and 72. The dose conversion factors selected were for adults with the solubility class taken as recommended in ICRP-71. ICRP 72 worst case dose conversion factors were used for ^{90}Y, which does not have data given in ICRP 71. ULDs in this report are based on ICRP-71 dose conversion factors.

A weighted average of the alpha emitting isotope dose conversion factors was used to determine the effective dose conversion factor for the alpha radiation. The tank data described in Van Keuren (1996) was used to determine the weighted average. Dose calculations are made based on total alpha and concentration data for ^{90}Sr, and ^{137}Cs. The ^{90}Y is assumed to be in equilibrium with the ^{90}Sr.

Tables 1 and 2 show the data that was used in this model. A conversion factor of (1.0E-06Ci/uCi)*(3.7E10 Bq/L)*(1.6 g/ml)*(1000 ml/L) was used to convert to Bq/L. Note that this conversion factor assumes a solids density of 1.6 kg/L. The reference for the tank contents information was HNF-EP-0182-138 (Page E-7).

References

Cowley, W. L., 1996, *Development of Radiological Concentrations and Unit Liter Doses for TWRS FSAR Radiological Consequence Calculations,* WHC-SD-WM-SARR-037, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Jensen, L., April 2000, *Sample Based Unit Liter Dose Estimates,* HNF-4534, Rev. 1, CH2M Hill Hanford Group, Richland, Washington.

HNF-EP-0182-138, 1999, *Waste Tank Summary Report for Month Ending September 30, 1999*, Lockheed Martin Hanford Corporation, Richland, Washington.

Van Keuren, J. C. 1996, *Tank Waste Compositions and Atmospheric Dispersion Coefficients for Use In Safety Analysis Consequence Assessments*, WHC-SD-WM-SARR-016, Rev. 2, Westinghouse Hanford Co., Richland, Washington.

Table 1. Volume, ULD and Cs-137 Concentration for Tank Waste Liquids

Tank	Supernate (kgal)	ULD (Sv/L)	Cs-137 (Bq/L)
241-A-101	508	70	1.31E+10
241-AN-101	127	18	3.74E+09
241-AN-102	971	473	1.35E+10
241-AN-103	501	230	2.91E+10
241-AN-104	604	132	2.42E+10
241-AN-105	637	116	1.49E+10
241-AN-107	797	1562	1.34E+10
241-AP-101	1115	28	5.96E+09
241-AP-102	1092	41	8.33E+09
241-AP-103	285	39	2.31E+09
241-AP-104	24	2	1.84E+08
241-AP-105	676	53	7.77E+09
241-AP-106	93	8	1.47E+09
241-AP-107	976	7	1.12E+09
241-AP-108	369	13	2.62E+09
241-AW-101	820	93	1.71E+10
241-AW-102	44	8	1.29E+09
241-AW-103	147	0	7.62E+08
241-AW-104	888	7	4.88E+08
241-AW-105	174	6	5.22E+08
241-AW-106	248	80	6.88E+09
241-AY-101	60	128	3.26E+09
241-AY-102	592	3	1.33E+08
241-AZ-101	799	376	5.88E+10
241-AZ-102	843	327	3.96E+10
241-BY-105	0	84	7.36E+09
241-C-106	42	1720	4.63E+09
241-C-110	1	4	1.44E+08
241-S-102	0	76	1.20E+10
241-S-103	0	65	1.35E+10
241-S-106	0	49	9.88E+09
241-SX-101	0	1437	1.49E+10
241-SX-102	134	84	1.62E+10
241-SX-103	0	96	1.63E+10
241-SX-104	0	48	1.05E+10
241-SX-105	0	78	1.42E+10
241-SX-106	0	71	1.39E+10

Tank	Supernate (kgal)	ULD (Sv/L)	Cs-137 (Bq/L)
241-SY-101	604	234	3.69E+10
241-SY-102	541	29	2.03E+09
241-SY-103	378	75	1.48E+10
241-T-107	0	12	3.12E+08
241-T-110	0	0	1.27E+05
241-U-102	18	122	1.61E+10
241-U-103	1	143	1.73E+10
241-U-107	33	79	1.30E+10
241-U-108	24	86	1.54E+10
241-U-109	19	65	1.35E+10

Table 2. Volume, ULD and Cs-137 Concentration for Tank Waste Solids

Tank	Sludge (kgal)	Saltcake (kgal)	ULD (Sv/L)	Cs-137 (Bq/L)
241-A-101	3	380	254	1.20E+10
241-AN-102	0	89	1795	1.41E+10
241-AN-103	457	0	120	1.49E+10
241-AN-104	0	449	277	2.05E+10
241-AN-105	0	489	188	1.58E+10
241-AN-107	0	247	3273	1.03E+10
241-AW-101	0	306	358	1.51E+10
241-AW-102	0	36	7891	5.11E+09
241-AW-105	255	0	4810	2.26E+09
241-AW-106	0	225	673	6.81E+09
241-AX-101	3	295	232	1.18E+10
241-AX-104	8	0	78664	3.59E+10
241-AY-101	94	0	20381	5.07E+09
241-AY-102	30	0	230025	1.68E+10
241-AZ-101[1]	46	0	1.70E+6	1.00E+11
241-AZ-102	88	0	163927	4.88E+10
241-B-106	116	0	296	1.20E+09
241-B-108	53	41	32	1.02E+09
241-B-111	236	0	969	8.82E+09
241-B-201	28	0	2423	2.72E+08
241-B-202	27	0	1085	7.46E+06
241-BX-107	344	0	356	1.31E+09

[1] Values for AZ-101 solids were not contained in Jensen (2000) and were taken from Cowley (1996).

Tank	Sludge (kgal)	Saltcake (kgal)	ULD (Sv/L)	Cs-137 (Bq/L)
241-BX-109	193	0	496	7.81E+08
241-BX-112	164	0	534	3.01E+09
241-BY-104	150	176	738	6.10E+09
241-BY-105	48	455	575	3.88E+09
241-BY-106	84	478	156	5.92E+09
241-BY-107	40	226	208	7.40E+09
241-BY-110	103	295	408	5.50E+09
241-C-103	119	0	41284	7.99E+09
241-C-104	295	0	17703	3.64E+09
241-C-106	8	0	8678	3.27E+10
241-C-108	66	0	686	9.83E+09
241-C-109	62	0	2715	2.82E+10
241-C-110	177	0	349	1.10E+09
241-C-111	57	0	11545	2.56E+09
241-C-112	104	0	3812	1.21E+10
241-S-101	211	204	1524	7.64E+09
241-S-102	105	409	562	6.93E+09
241-S-104	293	0	2175	3.46E+09
241-S-106	0	337	143	5.98E+09
241-S-107	293	69	2839	4.87E+09
241-S-109	13	494	34	4.49E+08
241-S-110	131	259	1126	5.20E+09
241-S-111	117	244	393	7.04E+09
241-SX-101	0	448	1588	6.33E+09
241-SX-102	0	380	837	8.82E+09
241-SX-103	115	519	777	7.52E+09
241-SX-108	87	0	15611	1.15E+10
241-SY-101	0	585	1216	2.05E+10
241-SY-103	0	366	2462	1.34E+10
241-T-102	19	0	1144	1.24E+09
241-T-104	326	0	382	1.23E+07
241-T-105	98	0	1585	2.71E+09
241-T-107	173	0	744	1.22E+09
241-T-111	446	0	1000	7.93E+06
241-T-201	28	0	2017	2.05E+06
241-T-204	38	0	405	4.59E+05
241-TX-118	34	266	61152	1.38E+09
241-U-102	43	314	713	9.59E+09

Tank	Sludge (kgal)	Saltcake (kgal)	ULD (Sv/L)	Cs-137 (Bq/L)
241-U-105	32	349	2095	9.18E+09
241-U-106	0	211	3276	9.00E+09
241-U-107	15	360	616	5.06E+09
241-U-108	29	415	202	8.52E+09
241-U-109	35	411	150	6.87E+09
241-U-110	186	0	2345	1.43E+09

Appendix G - Viscosity of Supernate and Suspensions

The presence of a particle in a fluid will modify the velocity distribution (Mewis and Macosko, 1993). Solid particles in a liquid medium are referred to as a *suspension*. Extra energy dissipation as a result of particulates in solution will reflect a corresponding rise in viscosity. For dilute systems Einstein (1906,1911) represents this phenomenon by the equation,

$$\mu = \mu_s(1 + \frac{5}{2}F)$$

where, μ is viscosity of the suspension, μ_s is the viscosity of the supernate, and F is the volume fraction of particles.

For non-dilute systems it is necessary to consider particle interaction. The quadratic term, which is the first interaction term, was published in 1977 by Batchelor:

$$\mu = \mu_s(1 + \frac{5}{2}F + 6.2F^2)$$

This equation fits available data within measurement accuracy.

The viscosity of salt cake supernate in Hanford tanks reported by Handy (1975) and Metz (1976) are 12.5 cp (cp=centipoise) and 10 cp, respectively. If the salt cake supernate is free of particulates and the supernate in the tank waste has similar properties as the salt cake, the only difference becomes the particulate load in the tank waste. If the volume of solids in a waste slurry stream is 30%, the parameter, F becomes 0.3.

References

Batchelor, G. K., *J. Fluid Mech.* 1977, 83, 97.

Einstein, *A. Ann. Phy.* 1906, 19, 289; 1911, 34, 591.

Handy L.L., 1975, Flow Properties of Salt Cake for Interstitial Liquid Removal/Immobilization Development Program, ARH-C-6, Atlantic Richfield Hanford Company, Richland, Washington.

Metz W.P., 1976, A Topical Report on Interstitial Liquid Removal from Hanford Salt Cakes, ARH-CD-545, Atlantic Richfield Hanford Company, Richland, Washington.

Mewis J. and C. W. Macosko, 1993, Suspension Rheology, in Rheology: Principles, Measurements, and Applications, ed. C.W. Macosko,VCH Publishers, New York, New York.

-----Original Message-----
TO: Brit Hey
FROM: Gene Freeman
DATE: March 28,2000
SUBJECT: Viscosity calculations for tank waste

Brit,

After reading through the report by Stewart et al., (1996) regarding viscosity of tank wastes it appears that the quadratic form of the Einstein equation will not give a representative value of viscosity. During phone conversations with Greg Lumetta, Paul Bredt, and Chuck Stewart, each questioned whether the Einstein equation would be valid given the volume fraction of particulate material. In the report of Stewart et al. tank waste viscosity was measured in six Hanford waste storage tanks. Most of the measurements were made in undisturbed, stratified tanks. However, one set of measurements was performed for SY-101, which is mixed on a regular basis. The results stated by Stewart et al., indicate that a best fit viscosity is about 1000 cP with an uncertainty of a factor of 2. The mixed slurry is noted to behave as a non-Newtonian, shear-thinning fluid. Note that assumptions of the Einstein eqaution as stated by Mewis and Macosko (1994) are

1 – surrounding fluid is incompressible and Newtonian
2 – creeping flow
3 – neutral density (particle and solute density equal)
4 – no slip between particles and solute
5 – rigid, spherical particles
6 – dilute particles
7 – no influence of walls
8 – no particle migration
9 – velocity perturbations are local

The waste in an undisturbed tank is stratified and consists of a surface crust underlain by a convective fluid, which overlies a stratified, nonconvective fluid. The convective layer (supernate) exhibits properties of a Newtonian fluid, while the nonconvective layer is non-Newtonian.

The work of Stewart et al. is based on empirical meausrements in the tanks. They suggest that the results from SY-101 are not necessarily ported to other tanks. Factors that affect viscosity include particle size, particle shape, and chemical composition of the tank wastes. The only way to definitively quantify viscosity in the tanks is by taking measurements in different tanks to generate a database. Another set of data is potentially available from the C-106 sluicing campaign. Viscosity may be derived from sluicing data including waste flow, pressure drop, and particle loading. Another potential data set may be available from the Flammable gas DQO, which is reported to collect physical properties of tank wastes including viscosity. However, this waste is probably not mixed and therefore not representative of the slurry from a tank.

I have not found a simple equation that we can use to solve this problem. There may be a more involved equation available, but this may take some time to figure out.

REFERNCES

Stewart C.W., J.M. Alzheimer, M.E. Brewster, G. Chen, R.E. Mendoza, H.C. Reid, C.L. Shepard, and G. Terrones, 1996, In Situ Rheology and Gas Volume in Hanford Double-Shell Waste Tanks. PNNL-11296, Pacific Northwest National Laboratory, Richland, Washington.

Mewis J. and C.W. Macosko, 1994, Suspension Rheology. In Rheology: Principles, Measurements, and Applications. Ed. C.W. Macosko. VCH Publishers, New York, New York.

-----Original Message-----
From: Eugene.Freeman@fluor.com [SMTP:Eugene.Freeman@fluor.com]
Sent: Wednesday, April 05, 2000 1:07 PM
To: Brit_E_Hey@rl.gov
Subject: more on viscosity

Brit,

I spoke with Yasuo Onishi with the PNNL, fluid dynamics group about viscosity of slurry. I mentioned that we were using the quadratic Einstein equation. He indicated that he is using this equation as well, not because it is necessarily correct, but because that is the only equation he has available and by using this equation results are consistent between cases. He felt that slurry chemistry would have a greater impact on viscosity than would particle loading for the flow velocities that we will encounter. He also indicated that viscosity does not rise smoothly, but at some particulate load the viscosity "jumps" to a high value. The particulate load for the jump is not known and again chemistry may be a significant factor.

The impression I get from talking to all these people is that the viscosity issue is not well understood and that further work is needed. Until better information is available it appears the Einstein equation is the only option.

Gene Freeman

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Appendix H - 200 Area Pit and COB Sizes

MEMORANDUM **CH2MHILL**

200 EAST AREA STRUCTURE VOLUMES

TO:	G. L. Jones	R1-44	74100-00-007
COPIES:	B. E. Hey G. W. Ryan	B4-47 B4-47	
FROM:	DST Engineering	S5-05	
DATE:	February 16, 2000		

The attached list of structures with their reference drawings and calculated volumes represent a portion of the 200 East Area Transfer System. Whether or not a structure is "physically connected" is dependent on the specific routing configuration at the time of a transfer. This is not a comprehensive listing and does not reflect the currently "physically connected" system nor does it include all structures potentially "physically connected" in the 200 East Area tank farms.

If you have any questions regarding this information please contact me on 376-9886.

L.A. Domnoske-Rauch

L. A. Domnoske-Rauch
DST Engineering

bln

Attachment

ANALYTICAL CALCULATIONS

Subject: 200 EAST AREA STRUCTURE VOLUMES

Originator: Lisa Dominick - Pant Date: 2/16/2000

Checker: Todd Blood Date: 2/16/00

Sample of structures that may be physically connected to transfer route			
PIT	STRUCT. DRAWING	PIT VOL (FT^3)	
244-BX PUMP PIT	73784 73785 73786	3068.5	
244-BX FLUSH PIT	73910	80.69	
241-ER-151	43042	2,071.98	
241-ER-311* PUMP PIT	71643	108.33	
241-ER-152	37965	1,183	
241-ER-153	37966	1,450	
244-CR PUMP PIT	41889, 41496	5822.9	
244-A PUMP PIT	38225	2,088.45	
COB-AN-1*	72003	6.02	
COB-AN-2*	72003	6.02	
COB-AN-3*	72003	6.02	
COB-AN-4*	72003	6.02	
COB-AN-5*	72003	6.02	
COB-AN-6*	72003	6.02	
COB-AN-7*	72003	6.02	
COB-AN-9*	72003	6.02	
241-AN-B	71913	722.88	
241-AN-A	71913	722.88	
241-AN-01A*	71912	491.68	
241-AN-07A*	71912	491.68	
241-AN-06A*	71912	491.68	
241-AZ-02B*	68305	375.96	
COB-AZ-1*	70789	6.02	

* Denotes pit volume smaller than 530 cubic feet (241-A-A Valve Pit)

ANALYTICAL CALCULATIONS

Subject: 200 EAST AREA STRUCTURE VOLUMES

Originator: [signature] Date: 2/16/00

Checker: Todd Black [signature] Date: 2/16/00

Sample of structures that may be physically connected to transfer route

PIT	STRUCT. DRAWING	PIT VOL (FT^3)
COB-AZ-2*	70789	6.02
COB-AZ-3*	70789	6.02
COB-AZ-4*	70789	6.02
COB-AZ-5*	70789	6.02
COB-AZ-6*	70789	6.02
COB-AZ-7*	70789	6.02
COB-AZ-8*	70789	6.02
COB-AZ-9*	70789	6.02
COB-AZ-10*	70789	6.02
241-AX-A*	69150	570
COB-AY-1*	70789	6.02
241-AY-02D*	94036 64314	334
241-AY-02A*	64313	482.88
241-AY-01A*	64313	482.88
241-AX-B*	69150	570
241-A-B VP*	69150	570
241-A-A VP*	69150	570
241-AW-A VP	70313	590.4
241-AW-B	70313	590.4
241-AW-02D	70414	945.69
241-AW-06A*	70312	500.64
241-AW-02A*	70312	500.64
241-AW FLUSH PIT*	70416	108.33
COB-AW-10*	70418	6.02
241-AP VP	90448	2,870.37

* Denotes pit volume smaller than 530 cubic feet (241-A-A Valve Pit)

ANALYTICAL CALCULATIONS

Subject 200 EAST AREA STRUCTURES VOLUMES

Originator [signature] Date 2/16/2000

Checker [signature] Date 2/16/00

Sample of structures that may be physically connected to transfer route

PIT	STRUCT. DRAWING	PIT VOL (FT^3)	
241-AP FLUSH PIT*	90449 90568	68.72	
241-AP-01A*	90447	547.68	
241-AP-02A*	90447	547.68	
241-AP-03A*	90447	547.68	
241-AP-04A*	90447	547.68	
241-AP-05A*	90447	547.68	
241-AP-06A*	90447	547.68	
241-AP-07A*	90447	547.68	
241-AP-08A*	90447	547.68	
241-AP-03D*	90451 90571	264.9	

* Denotes pit volume smaller than 530 cubic feet (241-A-A Valve Pit)

ANALYTICAL CALCULATIONS

Subject: 200 EAST AREA STRUCTURE VOLUMES
Originator: [signature] Date: 2/16/2000
Checker: [signature] Date: 2/16/00

A-417 TRANSFER ROUTE PITS

PITS	STRUCTURAL DRAWINGS	PIT VOL (FT^3)	
A-417 PUMP PIT	56800,57302	1,536	
A-417 VALVE PIT*	56800,57302	511.68	
501-AX*	44607	46.25	
501-AY*	64322	537.99	
152-AX DIVERSION PIT	44580	902	
152-AX PUMP PIT*	44580	285.12	

A-350 TRANSFER PITS

PITS	STRUCTURAL DRAWINGS	PIT VOL (FT^3)	
A-350 PUMP PIT	70538,70318	755.73	
A-350 SUMP PIT	70538,70318	NA	
COB-AW-1*	70418	6.02	
241-AW-02E*	70415	404	

* Denotes pit volume smaller than 530 cubic feet (241-A-A Valve Pit)

ANALYTICAL CALCULATIONS

Subject: 200 EAST AREA STRUCTURE VOLUMES
Originator: [signature] Date: 2/16/2000
Checker: Todd Blaak Date: 2/16/00

AZ-151 TRANSFER PITS

PITS	STRUCTURAL DRAWINGS	PIT VOL (FT^3)	
AZ-151 PUMP PIT*	68316	303.1	
AZ-152	68307	1372.85	
241-AZ-02A	68304	648	

152-AX TRANSFER PITS

PITS	STRUCTURAL DRAWINGS	PIT VOL (FT^3)	
152-AX DIVERTER PIT	44580	902	
152-AX PUMP PIT*	44580	285.12	

* Denotes pit volume smaller than 530 cubic feet (241-A-A Valve Pit)

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Appendix I - Leakage Through Isolation Valves

INTRODUCTION

A spray leak is assumed to occur at some point downstream of the isolation valve(s) in a waste transfer pipe. System pressure upstream of the isolation valve(s) is assumed to be a constant 250 psig (1.7 MPa). The most likely type of spray leak downstream of the isolation valve(s) is a slit at the sealing surface of a misaligned jumper connector or blank fitting. The maximum length of the slit is assumed to be 2 inches (5.1 cm) corresponding to one pipe diameter for nominal 2-inch pipe. Although less likely, a round orifice through the pipe wall is also analyzed since it is a more efficient atomizer in a flow-limited situation.

SYSTEM DESCRIPTION

The system to be analyzed consists of a length transfer pipe with either one or two isolation valves near one end and a spray leak somewhere downstream of the isolation valve(s). If two valves are used, they are assumed to have identical characteristics. The pipe upstream of the valve(s) is assume to be at a pressure of 250 psig (1.7 MPa). Each isolation valve is specified to leak at a maximum rate of 1 gal/hr (1.05E-3 L/s) at a differential pressure equal to full system pressure (250 psig). The spray leak can be either a slit or a round orifice sized so as to maximize the respirable release rate. Since the flow velocities in the pipe downstream of the isolation valve(s) would be very low, any solids carried through the valve(s) are assumed to settle out in the pipe and not be carried through the spray leak. For conservatism, therefore, the material issuing from the spray leak is specified to be "All Liquids" as defined in *Development of Radiological Concentrations and Unit Liter Doses for TWRS FSAR Radiological Consequence Calculations* (WHC-SD-WM-SARR-037). Since the spray leak is assumed to be in an area outside the part of the system involved in the transfer, the leak is assumed to be in a structure such as a pit with no cover blocks in place, i.e., the respirable part of the spray is released directly to the environment.

ANALYSIS METHODOLOGY

Respirable Spray Release:

Since the volume flow rate through an orifice is approximately proportional to the square root of the differential pressure (all other things being constant) the flow rate through a closed isolation valve is assumed to be given by:

$$V' = V_0'\left[\frac{P_0 - P_1}{P_0}\right]^{\frac{1}{2}} \qquad (1)$$

where V_0' = the flow allowed for a closed isolation valve at P_0 (m^3/s)
P_0 = system pressure upstream of the isolation valve(s) (Pa)
P_1 = line pressure downstream of the isolation valve(s) (Pa).

N identical valves in series will have equal pressure drops since the flows will be the same. The pressure differential across each valve is then $(P_0 - P_1)/N$. Therefore Eqn. (1) becomes

$$V' = \frac{V_0'}{\sqrt{N}}\left[\frac{P_0 - P_1}{P_0}\right]^{\frac{1}{2}} \tag{2}$$

where V_0' = assumed flow rate for a closed isolation valve at P_0 (m^3/s)
N = the number of identical isolation valves in series
P_0 = system pressure upstream of the isolation valve(s) (Pa)
P_1 = line pressure downstream of the isolation valve(s) (Pa).

The analysis of the spray leak downstream of the isolation valve(s) is consistent with the spray leak analysis developed in *A Model For Predicting Respirable Releases From Pressurized Leaks* (WHC-SD-GN-SWD-20007). The flow velocity through the leak is given by

$$U = \sqrt{\frac{2\Delta P}{\rho(K+1)}} \tag{3}$$

where U = flow velocity through leak (m/s)
ΔP = differential pressure across leak (Pa)
ρ = liquid density (Kg/m^3)
K = total resistance (dimensionless).

In this case the pressure downstream of the leak is 0 psig so that $\Delta P = P_1$. The resistance is given by $K = K_f + K_v$ and accounts for friction within the leak channel (K_f) along with entrance and exit effects (K_v). The Friction resistance K_f is given by

$$K_f = f\frac{t}{d_e} \tag{4}$$

where f = Darcy friction factor (dimensionless)
t = leak path depth (m)
d_e = equivalent diameter of leak (m).

The equivalent diameter of a flow channel is 4 times the flow area divided by the wetted perimeter. For a circular orifice, d_e is just the geometric diameter. For a rectangular orifice with width w and length l, d_e is given by $2(wl)/(w + l)$. For a long narrow slit ($w << l$) d_e is closely approximated by 2w.

For the orifice sizes and liquids considered here, the flow through the leak will generally be laminar. In any case, however, laminar flow will produce higher release rates than turbulent flow. Laminar flow is therefore conservatively assumed for all cases in this analysis. For laminar flow the Darcy friction factor is given by

$$f = \frac{64}{\text{Re}} \tag{5}$$

where the Reynolds number Re is given by

$$\text{Re} = \frac{d_e U \rho}{\mu} \tag{6}$$

where μ is the dynamic (absolute) viscosity (Kg/m·s).

The velocity resistance K_v is given by

$$K_v = \frac{1}{C_v^2} - 1 \tag{7}$$

where C_v is the velocity coefficient equal to 0.98 for sharp or round-edged orifices and 0.82 for square-edge orifices.

Combining Eqn (3) through (7) yields

$$U^2 = \frac{2P_1}{\rho\left[\dfrac{64t\mu}{d_e^2 U \rho} + \dfrac{1}{C_v^2}\right]} \tag{8}$$

or, with a little manipulation,

$$\frac{d_e^2 \rho}{C_v^2} U^2 + 64t\mu U - 2P_1 d_e^2 = 0 \tag{9}$$

This is just a simple quadratic equation for the flow velocity in the orifice U, however the intermediate pressure P_1 is not yet known. The flow velocity is related to the volumetric flow rate by $U = V'/A_e$. A_e is the effective flow area of the orifice given by $A_e = C_c A$ where C_c is the contraction coefficient and A is the geometric area of the orifice. C_c is equal to 0.61 for sharp-edge orifices and 1.00 for round or square-edge orifices. Since the volumetric flow rate through the spray leak and the isolation valve(s) must be the same, Eqn (2) can be used to determine V' resulting in

$$U = \frac{V_0'}{\sqrt{N}A_e}\left[\frac{P_0 - P_1}{P_0}\right]^{1/2} \qquad (10)$$

Substituting Eqn (10) into Eqn (9) we obtain

$$\frac{d_e^2 \rho V_0'^2}{C_v^2 N A_e^2}\left[\frac{P_0 - P_1}{P_0}\right] + \frac{64 t \mu V_0'}{\sqrt{N}A_e}\left[\frac{P_0 - P_1}{P_0}\right]^{1/2} - 2P_1 d_e^2 = 0 \qquad (11)$$

The P_1 in the third term can be brought into the unknown parameter as follows

$$-2P_1 d_e^2 = 2d_e^2 (P_0 - P_1) - 2P_0 d_e^2$$

or

$$-2P_1 d_e^2 = 2d_e^2 P_0\left[\frac{P_0 - P_1}{P_0}\right] - 2P_0 d_e^2 \qquad (12)$$

Substituting Eqn 12 for the third term in Eqn 11 then produces the following equation for the parameter $[(P_0 - P_1)/P_0]^{1/2}$

$$\left(\frac{d_e^2 \rho V_0'^2}{C_v^2 N A_e^2} + 2d_e^2 P_0\right)\left[\frac{P_0 - P_1}{P_0}\right] + \frac{64 t \mu V_0'}{\sqrt{N}A_e}\left[\frac{P_0 - P_1}{P_0}\right]^{1/2} - 2P_0 d_e^2 = 0 \qquad (13)$$

This equation is easily solved for $[(P_0 - P_1)/P_0]^{1/2}$ by standard methods and will, in general, produce two solutions. The physical solution must be a positive number less than or equal to 1. The physical solution of Eqn 13 can be immediately substituted into Eqn 2 to yield the volumetric flow rate V' through the leak. The flow velocity through the orifice is then just $U = V'/A_e$.

Droplet size distributions of atomizing sprays are correlated in terms of the Sauter Mean Diameter (SMD) which is defined as the drop size with a surface-to-volume ratio equal to that of the entire droplet distribution. The correlation for SMD in meters is given as

$$SMD = \frac{500 d_e^{1.2} \nu^{0.2}}{U} \qquad (14)$$

where ν is the kinematic viscosity (m^2/s), which is equal to the dynamic (absolute) viscosity divided by the liquid density, i.e. $\nu = \mu/\rho$.

The fraction of the total flow volume contained in drops of diameter less than D (m) can be expressed as

$$Q = 1 - e^{-(D/X)^q} \tag{15}$$

where Q = fraction of the total flow volume contained in droplets with diameters less than D
X = characteristic diameter for the droplet size distribution (m)
q = fitting constant – provides a measure of the spread of the droplet sizes in the distribution.

The relationship between the characteristic size of the droplet distribution, X, and the SMD is given by

$$\frac{SMD}{X} = \left[\Gamma(1 - 1/q)\right]^{-1} \tag{16}$$

where Γ is the gamma function. Solutions of Eqn 16 for a range of values for q were developed in WHC-SD-GN-SWD-20007 and compared with data for atomization of oil sprays with a best fit obtained for q = 2.4 yielding a recommended value of 0.65415 for SMD/X. Eqn 15 is then used to obtain the volume fraction of the spray corresponding to a droplet less than D using X = SMD/(0.65415) where the SMD is calculated using Eqn 14.

For a given system pressure, P_0, and isolation valve leak rate, V_0', a range of orifice sizes (diameter of round hole or width of slit) were investigated to determine a maximum respirable aerosol release rate. For very small leaks the intermediate pressure, P_1, is high enough to cause efficient production of small droplets, but the flow rate is very low leading to a low respirable release rate. For large leaks the total flow rate approaches the maximum flow rate through the isolation valve(s) causing the intermediate pressure to drop to the point where the orifice cannot efficiently produce a fine spray, again leading to a low respirable release rate. At some intermediate size, the orifice will produce a maximum respirable release rate.

Radiological Doses:

Consequence calculations were performed as described *in Tank Waste Compositions and Atmospheric Dispersion Coefficients for Use in Safety Analysis Consequence Assessments* (WHC-SD-WM-SARR-016, Rev. 2). Doses calculated are 50-year committed effective dose equivalents (CEDE). Ingestion doses to the site boundary receptor are for a 24-hour uptake period before evacuation and/or interdiction of food supplies. Inhalation doses (onsite or offsite) are given by:

$$D_{inh} = (Q)(X/Q')(BR)(ULD_{inh}) \tag{17}$$

where

D_{inh} = inhalation dose (Sv)
Q = release in terms of liters of waste (L)
X/Q′ = atmospheric dispersion coefficient (s/m^3)

BR = receptor breathing rate (m^3/s)
ULD_{inh}= inhalation unit liter dose (Sv/L).

The offsite ingestion dose is given by:

$$D_{ing} = (Q)(X/Q')(ULD_{ing}) \quad (18)$$

where

D_{ing} = ingestion dose (Sv)
ULD_{ing}= ingestion unit liter dose (Sv-m^3/s-L).

For ground level release durations less than 1 hour, the atmospheric dispersion coefficient, X/Q', is 3.41E-2 s/m^3 (100 m E) for the onsite receptor. For releases of at least 1 hour (up to 2 hours) duration, plume meander effects can be included and the onsite receptor X/Q' is 1.13E-2 s/m^3. For purposes of this analysis, the onsite receptor is assumed to evacuate after 1 hour. The site boundary receptor is assumed to be exposed for 24 hours. Since the spray release rate would be constant, the 24-hour X/Q' (4.62E-6 s/m3 at 12.63 km E) can be used for the site boundary receptor (WHC-SD-WM-SARR-016). The breathing rate for the onsite receptor is the light activity breathing rate equal to 3.3E-4 m^3/s. For the site boundary receptor the 24-hour average breathing rate, 2.7E-4 m^3/s, is applicable. The inhalation and ingestion ULDs for "All Waste" liquid are 1.17E+4 Sv/L and 1.10E-1 m^3·Sv/s·L, respectively (WHC-SD-WM-SARR-037).

Toxicological Exposures:

The toxicological consequences are calculated in terms of a sum of fractions (SOF) of all the toxic components of the mix. Each "fraction" is the ratio of the component concentration at the receptor to the concentration limit for that component for the given accident frequency. In a manner analogous to unit liter doses, unit release (rate) SOFs have been calculated for various tank waste mixes for each accident frequency and receptor location. To obtain the SOF for a given release, the unit release rate SOF for the particular mix, receptor and accident frequency is multiplied by the source release rate. The risk guideline for a SOF for a given release is equal to 1. The unit release rate SOFs for "All Waste" liquid are 1.00E+4 s/L and 8.4E+0 s/L for the onsite and site boundary receptors, respectively (anticipated frequency class) (WHC-SD-WM-SARR-011).

ASSUMPTIONS

For purposes of this analysis the system pressure upstream of the isolation valve(s) is assumed to be 250 psig (1.72 MPa). Each isolation valve is assumed to leak 1 gph (1.05E-3 L/s) with full system pressure on one side and atmospheric pressure on the other side. The calculations can be carried out for any number of isolation valves in series, however results are given only for one and two valves. The leak is assumed to be either a slit or a round orifice. The depth of a slit is assumed to be 0.16 inches (4.1 mm) with round edges based on the width of the sealing surface in jumper or blank fittings. A round orifice is assumed to be located in a section of piping which has been thinned by corrosion and so is assumed to have a zero depth and sharp edges.

It is assumed that only liquid is sprayed from the leak based on the extremely low flow velocity in the pipe between the isolation valve(s) and the spray leak. Any solids traversing the isolation valve(s) are assumed to settle out in the pipe before reaching the leak. The liquid issuing from the spray leak is conservatively assumed to be "All Liquids" as defined in *Development of Radiological Concentrations and Unit Liter Doses for TWRS FSAR Radiological Consequence Calculations* (WHC-SD-WM-SARR-037). This liquid is assumed to have a density of 1.1 g/cm^3 and a dynamic (absolute) viscosity of 10 centipoise (kinematic viscosity = 9.1 centistokes).

The effective respirable droplet size at the orifice is assumed to be 50 μm to allow for evaporation before the droplet impacts the ground or other surface. The evaporation of the spray droplets will be slowed considerably by the dissolved components which will increase in concentration as the droplet evaporates, especially near the surface of the droplet where the evaporation is taking place. Since the leak could take place in a part of the system not under controls for the transfer, the spray leak is assumed to be unmitigated (e.g. by a pit cover), and to be able to spray upwards into the open air.

RESULTS

The most likely location of a spray leak is at a jumper connector or blank fitting. In this case the orifice is assumed to be in the form of narrow slit with some given length and a variable width (to maximize the respirable release rate). For this flow-limited situation the respirable release rate increases with decreasing slit length. The total flow rate is proportional to the length of the slit so that a shorter slit will result in less pressure drop across the isolation valve and a higher intermediate pressure (between the isolation valve and the leak). The higher pressure behind the slit then increases the respirable fraction of the spray resulting in a larger respirable release even though the total flow is less. The limiting case would be a circular orifice.

Sample calculations for the cases considered here are shown in detail in Attachment 1. The procedure is to choose a system pressure [upstream of the isolation valve(s)], the number of isolation valves in series (generally one or two), and the leak rate assumed for each valve at full system pressure. If the leak is a slit, a length and initial width are chosen. For either a slit or a circular orifice, a depth is specified and the increment for the slit width or circle diameter is chosen. Eqn 13 is then solved and the total flow rate calculated using Eqn 2 for a series of slit widths or circle diameters. Eqn 15 is then used to calculate respirable release rates for the same series of incremented orifice sizes. If the initial orifice size and the increment have been well chosen, the series of respirable release rates will contain a maximum value corresponding to optimum values of intermediate pressure and total flow rate. Radiological doses and toxicological exposures are then calculated in the usual way as described in the methodology section.

The results of a series of such calculations are shown below in Tables 1 and 2. For all the results shown in Tables 1 and 2, the system pressure is assumed to be 250 psig (1.72 MPa). Each isolation valve is assumed to leak 1 gph (1.05E-3 L/s) at a ΔP of 250 psig. The slit-type orifices are assumed to have a depth of 0.16 inches (4.1 mm) (width of connector sealing surface) and to have a round edge (Cv = 0.98 and Cc = 1). The round orifice was assumed to be in a section of pipe which has been thinned by corrosion and so is assigned zero depth and is assumed to have a sharp edge (Cv = 0.98 and Cc = 0.61). The liquid is conservatively assumed to be "All Liquids" with a density of 1.1 g/cm3 and a dynamic viscosity of 10 cp. The respirable fraction was assumed to include all droplets less than 50 µm at the orifice to allow for evaporation. Table 1 shows the results for one isolation valve while Table 2 shows results for two valves in series.

Table 1. Results for 1 Isolation Valve

Parameter	Slit Length (in)			Round Orifice
	2	1	0.5	
Optimum Width or Diameter, inches	0.0006	0.0007	0.0009	0.006
Intermediate Pressure, psig	163	182	177	187
Total Flow Rate, L/s	6.21E-4	5.50E-4	5.68E-4	5.28E-4
Respirable Fraction	8.94E-3	1.56E-2	2.35E-2	7.90E-1
Respirable Release Rate, L/s	5.55E-6	8.56E-6	1.34E-5	4.17E-4
Onsite Dose, Sv (rem)	8.72E-4 (8.72E-2)	1.34E-3 (1.34E-1)	2.10E-3 (2.10E-1)	6.55E-2 (6.55E+0)
Offsite Dose, Sv (rem)	7.24E-6 (7.24E-4)	1.12E-5 (1.12E-3)	1.74E-5 (1.74E-3)	5.44E-4 (5.44E-2)
Onsite SOF	5.55E-2	8.56E-2	1.34E-1	4.17E+0
Offsite SOF	4.66E-5	7.19E-5	1.12E-4	3.50E-3

Table 2. Results for 2 Isolation Valves in Series

Parameter	Slit Length (in)			Round Orifice
	2	1	0.5	
Optimum Width or Diameter, inches	0.0005	0.0007	0.0008	0.005
Intermediate Pressure, psig	179	153	177	188
Total Flow Rate, L/s	3.95E-4	4.63E-4	4.01E-4	3.68E-4
Respirable Fraction	7.94E-3	1.03E-2	1.90E-2	9.31E-1
Respirable Release Rate, L/s	3.14E-6	4.79E-6	7.59E-6	3.43E-4
Onsite Dose, Sv (rem)	4.93E-4 (4.93E-2)	7.52E-4 (7.52E-2)	1.19E-3 (1.19E-1)	5.38E-2 (5.38E+0)
Offsite Dose, Sv (rem)	4.10E-6 (4.10E-4)	6.25E-6 (6.25E-4)	9.91E-6 (9.91E-4)	4.47E-4 (4.47E-2)
Onsite SOF	3.14E-2	4.79E-2	7.59E-2	3.43E+0
Offsite SOF	2.64E-5	4.02E-5	6.38E-5	2.88E-3

CONCLUSION

The shorter slits produce somewhat higher consequences since the optimum width and respirable fraction increase with decreasing length in this kind of flow-limited situation. The respirable release rate and consequences for the circular orifice are much higher because a zero-depth, sharp-edged orifice produces a much higher respirable fraction at a given flow rate, and represents a much more severe situation.

REFERENCES

WHC-SD-GN-SWD-20007, Rev 0, 1994, *A Model for Predicting Respirable Releases from Pressurized Leaks*, Westinghouse Hanford Company, Richland, WA.

WHC-SD-WM-SARR-011, Rev. 2, 1996, *Toxic Chemical Considerations for Tank Farm Releases*, Westinghouse Hanford Company, Richland, WA.

WHC-SD-WM-SARR-016, Rev. 2, 1996, *Tank Waste Compositions and Atmospheric Dispersion Coefficients for Use in Accelerated Safety Analysis Consequences Assessments*, Westinghouse Hanford Company, Richland, WA.

WHC-SD-WM-SARR-037, Rev. 0, 1996, *Development of Radiological Concentrations and Unit Liter Doses for TWRS FSAR Radiological Consequence Calculations*, Westinghouse Hanford Company, Richland, WA.

ATTACHMENT 1

SAMPLE CALCULATIONS

2 Inch Slit

One Isolation Valve

System Characteristics:

System pressure = 250 psig 1.72E+06 Pa (N/m2)

Number of isolation valves = 1

Leak rate of each valve at full system pressure = 1 gph 1.67E-02 gpm
1.05E-06 m3/s

Leak Characteristics:

Slit length = 2 inches 5.08E-02 m (zero length ==> circular orifice)

Width (or diameter) increment = 0.0001 inches

Depth of orifice = 0.16 inches 4.06E-03 m

0.0001	2.54E-06	5.08E-06
0.0002	5.08E-06	1.02E-05
0.0003	7.62E-06	1.52E-05
0.0004	1.02E-05	2.03E-05
0.0005	1.27E-05	2.54E-05
0.0006	1.52E-05	3.05E-05
0.0007	1.78E-05	3.56E-05
0.0008	2.03E-05	4.06E-05
0.0009	2.29E-05	4.57E-05
0.001	2.54E-05	5.08E-05

equivalent diameter is 4 times the geometric area divided by wetted perimeter of the orifice

Velocity coefficient (Cv) = 0.98
sharp or round edge ==> Cv = 0.98
square edge ==> Cv = 0.82

Contraction coefficient (Cc) = 1
sharp edge ==> Cc = 0.61
round or square edge ==> Cc = 1.00

[illegible]	[illegible]	[illegible]
0.0001	2.54E-06	1.29E-07
0.0002	5.08E-06	2.58E-07
0.0003	7.62E-06	3.87E-07
0.0004	1.02E-05	5.16E-07
0.0005	1.27E-05	6.45E-07
0.0006	1.52E-05	7.74E-07
0.0007	1.78E-05	9.03E-07
0.0008	2.03E-05	1.03E-06
0.0009	2.29E-05	1.16E-06
0.001	2.54E-05	1.29E-06

effective flow area is the geometric area of orifice times the contraction coefficient, Cc

Liquid characteristics:

Density = 1.1 g/cm3 1.10E+03 kg/m3

Dynamic (absolute) viscosity = 10 centipoise 1.00E-02 kg/ms

Kinematic viscosity = 9.09E-02 stokes 9.09E-06 m2/s

kinematic viscosity is dynamic (absolute) viscosity divided by the density of the liquid

Effective respirable droplet size in spray = 50 um
5.00E-05 m

(accounts for evaporation)

Solution for total volumetric flow rate through orifice
From Eqn 13 in the standard form ax^2 + bx + c = 0

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0001	2.54E-06	9.09E-05	2.12E-02	-8.90E-05	4.20E-03	1.72E+06	[illegible]	4.41E-09
0.0002	5.08E-06	3.58E-04	1.06E-02	-3.56E-04	3.35E-02	1.72E+06	[illegible]	3.53E-08
0.0003	7.62E-06	8.03E-04	7.06E-03	-8.01E-04	1.12E-01	1.70E+06	[illegible]	1.18E-07
0.0004	1.02E-05	1.43E-03	5.30E-03	-1.42E-03	2.52E-01	1.61E+06	[illegible]	2.65E-07
0.0005	1.27E-05	2.23E-03	4.24E-03	-2.22E-03	4.28E-01	1.41E+06	[illegible]	4.50E-07
0.0006	1.52E-05	3.20E-03	3.53E-03	-3.20E-03	5.90E-01	1.12E+06	[illegible]	6.21E-07
0.0007	1.78E-05	4.36E-03	3.03E-03	-4.36E-03	7.11E-01	8.52E+05	[illegible]	7.48E-07
0.0008	2.03E-05	5.70E-03	2.65E-03	-5.69E-03	7.94E-01	6.37E+05	[illegible]	8.35E-07
0.0009	2.29E-05	7.21E-03	2.35E-03	-7.21E-03	8.50E-01	4.79E+05	[illegible]	8.93E-07
0.001	2.54E-05	8.90E-03	2.12E-03	-8.90E-03	8.88E-01	3.65E+05	[illegible]	9.33E-07

Corresponding respirable flow rate through orifice

[redacted]						
0.0001	2.54E-06	0.034	6.36E-04	8.06E-04	3.56E-12	[redacted]
0.0002	5.08E-06	0.137	3.66E-04	3.04E-03	1.07E-10	
0.0003	7.62E-06	0.304	2.68E-04	6.43E-03	7.56E-10	
0.0004	1.02E-05	0.513	2.24E-04	9.82E-03	2.60E-09	
0.0005	1.27E-05	0.698	2.15E-04	1.08E-02	4.88E-09	
0.0006	1.52E-05	0.802	2.33E-04	8.94E-03	5.55E-09	
0.0007	1.78E-05	0.828	2.72E-04	6.20E-03	4.64E-09	
0.0008	2.03E-05	0.809	3.26E-04	3.99E-03	3.33E-09	
0.0009	2.29E-05	0.769	3.95E-04	2.53E-03	2.26E-09	
0.001	2.54E-05	0.723	4.77E-04	1.61E-03	1.50E-09	

Maximum respirable release rate = [redacted] L/s

Calculation of radiological doses and toxic exposures

Inhalation ULD = 1.17E+04 Sv/L

Ingestion ULD = 1.10E-01 m3Sv/sL

Onsite receptor:

Exposure time = 1 hr

X/Q = 1.13E-02 s/m3

1 hour source term = 2.00E-02 L

Inhalation dose = [redacted] Sv 8.72E-02 rem REG = [redacted] Sv

Continuous unit release SOF = 1.00E+04 s/L anticipated frquency class

Sum of fractions = [redacted]

Site boundary receptor:

Exposure time = 24 hr

X/Q = 4.62E-06 s/m3 Breathing rate = 2.70E-04 m3/s

24 hour source term = 4.80E-01 L

Inhalation dose =	7.00E-06	Sv	7.00E-04	rem
Ingestion dose =	2.44E-07	Sv	2.44E-05	rem

Total dose = [redacted] Sv 7.24E-04 rem REG = [redacted] Sv

Continuous unit release SOF = 8.40E+00 s/L anticipated frquency class

Sum of fractions = [redacted]

Circular Orifice

Two Isolation Valves

System Characteristics:

System pressure = 250 psig 1.72E+06 Pa (N/m2)

Number of isolation valves = 2

Leak rate of each valve at full system pressure = 1 gph 1.67E-02 gpm
1.05E-06 m3/s

Leak Characteristics:

Slit length = 0 inches 0.00E+00 m (zero length ==> circular orifice)

Width (or diameter) increment = 0.001 inches

Depth of orifice = 0 inches 0.00E+00 m

0.001	2.54E-05	2.54E-05
0.002	5.08E-05	5.08E-05
0.003	7.62E-05	7.62E-05
0.004	1.02E-04	1.02E-04
0.005	1.27E-04	1.27E-04
0.006	1.52E-04	1.52E-04
0.007	1.78E-04	1.78E-04
0.008	2.03E-04	2.03E-04
0.009	2.29E-04	2.29E-04
0.01	2.54E-04	2.54E-04

equivalent diameter is 4 times the geometric area divided by wetted perimeter of the orifice

Velocity coefficient (Cv) = 0.98

sharp or round edge ==> Cv = 0.98
square edge ==> Cv = 0.82

Contraction coefficient (Cc) = 0.61

sharp edge ==> Cc = 0.61
round or square edge ==> Cc = 1.00

0.001	2.54E-05	3.09E-10
0.002	5.08E-05	1.24E-09
0.003	7.62E-05	2.78E-09
0.004	1.02E-04	4.95E-09
0.005	1.27E-04	7.73E-09
0.006	1.52E-04	1.11E-08
0.007	1.78E-04	1.51E-08
0.008	2.03E-04	1.98E-08
0.009	2.29E-04	2.50E-08
0.01	2.54E-04	3.09E-08

effective flow area is the geometric area of orifice times the contraction coefficient, Cc

Liquid characteristics:

Density = [illegible] g/cm3 1.10E+03 kg/m3

Dynamic (absolute) viscosity = 10 centipoise 1.00E-02 kg/ms

Kinematic viscosity = 9.09E-02 stokes 9.09E-06 m2/s

kinematic viscosity is dynamic (absolute) viscosity divided by the density of the liquid

Effective respirable droplet size in spray = 50 um
5.00E-05 m

(accounts for evaporation)

Solution for total volumetric flow rate through orifice
From Eqn 13 in the standard form ax^2 + bx + c = 0

0.001	2.54E-05	4.28E+00	0.00E+00	-2.22E-03	2.28E-02	1.72E+06		1.70E-08
0.002	5.08E-05	1.08E+00	0.00E+00	-8.90E-03	9.09E-02	1.71E+06		6.76E-08
0.003	7.62E-05	4.95E-01	0.00E+00	-2.00E-02	2.01E-01	1.65E+06		1.50E-07
0.004	1.02E-04	3.03E-01	0.00E+00	-3.56E-02	3.43E-01	1.52E+06		2.55E-07
0.005	1.27E-04	2.27E-01	0.00E+00	-5.56E-02	4.95E-01	1.30E+06		3.68E-07
0.006	1.52E-04	1.99E-01	0.00E+00	-8.01E-02	6.35E-01	1.03E+06		4.72E-07
0.007	1.78E-04	1.96E-01	0.00E+00	-1.09E-01	7.45E-01	7.66E+05		5.54E-07
0.008	2.03E-04	2.09E-01	0.00E+00	-1.42E-01	8.25E-01	5.51E+05		6.13E-07
0.009	2.29E-04	2.33E-01	0.00E+00	-1.80E-01	8.79E-01	3.91E+05		6.54E-07
0.01	2.54E-04	2.65E-01	0.00E+00	-2.22E-01	9.16E-01	2.78E+05		6.81E-07

Corresponding respirable flow rate through orifice

[redacted]						
0.001	2.54E-05	54.849	2.74E-06	1.00E+00	1.70E-08	[redacted]
0.002	5.08E-05	54.636	6.31E-06	1.00E+00	6.76E-08	[redacted]
0.003	7.62E-05	53.743	1.04E-05	1.00E+00	1.50E-07	[redacted]
0.004	1.02E-04	51.538	1.54E-05	9.98E-01	2.54E-07	[redacted]
0.005	1.27E-04	47.659	2.17E-05	9.31E-01	3.43E-07	[redacted]
0.006	1.52E-04	42.400	3.04E-05	6.96E-01	3.29E-07	[redacted]
0.007	1.78E-04	36.582	4.24E-05	4.15E-01	2.30E-07	[redacted]
0.008	2.03E-04	31.005	5.87E-05	2.18E-01	1.34E-07	[redacted]
0.009	2.29E-04	26.115	8.03E-05	1.09E-01	7.15E-08	[redacted]
0.01	2.54E-04	22.029	1.08E-04	5.53E-02	3.76E-08	[redacted]

Maximum respirable release rate = [redacted] L/s

Calculation of radiological doses and toxic exposures

Inhalation ULD = 4.17E+04 Sv/L

Ingestion ULD = 1.10E-01 m3Sv/sL

<u>Onsite receptor:</u>

Exposure time = [illegible] hr

X/Q = 1.19E-02 s/m3

1 hour source term = 1.23E+00 L

Inhalation dose = [redacted] Sv 5.38E+00 rem REG = [redacted] Sv

Continuous unit release SOF = 1.00E+04 s/L anticipated frquency class

Sum of fractions = [redacted]

Site boundary receptor:

Exposure time = 24 hr

X/Q = 4.62E-06 s/m3 Breathing rate = 2.70E-04 m3/s

24 hour source term = 2.96E+01 L

Inhalation dose =	4.32E-04	Sv	4.32E-02	rem
Ingestion dose =	1.50E-05	Sv	1.50E-03	rem

Total dose = [redacted] Sv 4.47E-02 rem REG = [redacted] Sv

Continuous unit release SOF = 8.40E+00 s/L anticipated frquency class

Sum of fractions = [redacted]

FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed:
Title: Analysis of Spray Leak in Structure with Isolation Valves
Author: D. A. Himes
Date: Mar. 9/00
Scope of Review: entire document of Appendix I

Yes	No*	NA	
[X]	[ ]	[ ] **	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[X]	[ ]	[ ]	Problem completely defined.
[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).

Tomoko V. Jensen-otsu (signature) — 4/3/00
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 intelligible to a technically qualified third party.

Appendix J - Leak Path Factor for Actively Ventilated Structures

INTRODUCTION

Leak path factors are calculated for various thermal and exhaust rate conditions in the double-shell tanks (DSTs), double contained receiver tanks (DCRTs), and the 204-AR unloading facility, during an accidental spray leak from the center vertical retrieving pipe. The modeling or calculational approach is described in Section 2. The cases, which cover the range of thermal and exhaust rate conditions in a double shell tank, are presented with results in Section 3. The cases for the DCRTs and 204-AR unloading facility are presented in Sections 4 and 5, respectively. The summary and conclusions are presented in Section 6.

MODEL AND APPROACH

The FLUENT® code was used to calculate the temperature distribution and velocities in the gas space above the waste in a full double shell tank. The FLUENT® code is a commercially available computational fluid dynamics code that was developed by Fluent Incorporated (10 Cavendish Court, Centerra Resource Park, Lebanon, New Hampshire 03766, telephone 603-643-2600) under the ANSI software quality assurance standard ISO-9001. The code was used previously at Hanford for calculating leak path factors in the K-Basin facilities, which was documented in the K-Basin Safety Analysis Report's supporting calculation note (HNF-1777).

Leak Path Factor per Particle Size

The leak path factor (LPF) is defined as the mass fraction of respirable particles in a release inside a containment structure that gets out of the structure. If there is only one level of containment or confinement, then the leak path factor is the fraction of release that reaches the environment. Normally, the LPF will vary with particle size since particle terminal velocities are size dependent. However, with the simulations performed for the spray releases in tanks, the gas flow streams are very circulating. As a result of natural circulation and vent induced circulation, the LPFs are size independent. For example, both the one and ten micron diameter droplets circulate with the gas flow and escape out of the exhaust orifice at the almost the same rate. As a result, the leak path factor per particle size does not have to be combined with the mass size distribution of spray leak and does not have to be reported on a particle size basis. The small mass sizes tend to have slightly higher LPFs than the larger sizes.

Mass-Particle Size Distribution of Spray Leak

The mass-particle size distribution that was used for the spray leak was the Rosin-Rammler distribution (Lefebvre, 1989), which was originally developed for powders, but can be extended to droplets as well. Since the particle size distribution was not needed for the LPF calculation, due to LPF being independent of particle size (see Section 2.1), the details of the Rosin-Rammler distribution are not given here.

Overall Leak Path Factor

If the LPF were particle size dependent (i.e., LPF=LPF(D), where D is the particle or droplet diameter), then the overall LPF for all respirable particle sizes would need to be calculated. The overall LPF is the sum of LPFs per size times the fraction of mass with that size. The overall LPF can be calculated by the following equation:

$$LPF = \sum_i LPF(D_i) \times MF(D_i)$$

where MF is the respirable mass fraction with particle size D_i, where the resolution of the particle size bins (denoted by i subscript) can be as fine as needed, but normally ten size bins, one for each size from one micron to ten microns is sufficient. However, for the simulations in this analysis, $LPF(D_i)$ = LPF for all respirable sizes and the sum over the respirable mass fractions is one by definition.

Removal Mechanisms

The main removal mechanism of the respirable spray droplets is the falling (gravitational effects) or swirling (downward gas flows) of the droplets to the bottom boundary which is wet and will trap the droplets upon contact. The wall boundaries were modeled as reflective surfaces, which would bounce the droplets off the surface, but the bottom boundary was modeled as a trap, which would hold onto the droplets and keep them from escaping. Even though the unloading facility did not have a liquid volume on its bottom, the spray leak would wet most of the surface with it large amounts of drops and droplets much larger than 10 microns. Hence, even the unloading facility was modeled with its bottom boundary (floor) as a trap. Also, the suspended droplets were modeled with thermophoretic forces (temperature gradients driving particles to cooler surface) and Brownian motion (random movements). Also, when the gas flow is turbulent, which happens in all cases with thermal phenomena, the stochastic particle tracking method is used. The stochastic particle tracking method varies the velocity field around the mean velocity for each cell location when tracking the particles. In effect, the stochastic particle tracking enhances the Brownian motion effects. However, if the gas flow is not turbulent, such as in the isothermal cases, then the deterministic particle tracking method has to be used. With the deterministic particle tracking under isothermal conditions, each particle follows one velocity field with only the effects of drag and Brownian motion included. In other words, the gas velocity has just one value for each spatial location.

CASES AND RESULTS FOR DOUBLE SHELL TANKS

Six cases with different tank temperature and flow conditions were simulated. There are four thermal cases with two different waste temperatures and two different flow rates out of the tank. There are also two isothermal cases where all temperatures are fixed at about 27 °C (81 °F) including the incoming air. The second isothermal case has the exhaust orifice located more towards the middle of the two-dimensional model.

Case 3-1, (t50c-rng100ia), Expected Thermal and Exhaust Rate Case

This case is the base case since it is closer to the real conditions in a double shell tank than the other cases. The temperature of the waste in the tank, which is the bottom boundary in the model (see Figure 3-1 for model boundaries and grid of left side of tank and Figure 3-2 for right side of tank), is set to 50 °C (122 °F). The dome temperature was set at 27 °C (81 °F). The outside air that enters into the tank (left top part of tank, see Figure 3-1) was set at a temperature of 2 °C (36 °F). The LPFs are expected to be larger if the gas volume is smaller; hence, a half-full tank would have a lower LPF than a full tank, so the simulations assumed a full tank with headspace height of 3.8 m.

Since the real tank is three dimensional (3D), some changes to the orifice sizes were needed for the two dimensional (2D) model in order to be equivalent in terms of volume exchange rate and time. The volume exchange (or turnover) time is the time needed to replace one entire gas volume, which is calculated by dividing the gas volume by the volume exhaust rate. The volume exchange time for the real tank, that is very full (~32 feet full of waste), is 368 minutes (~6 hours) based on the exhaust rate of 100 ft^3/min and a gas headspace volume of about 36,800 ft^3. Since the model is two dimensional, the 2D exhaust velocity was lowered to 0.025 m/s (0.082 ft/s) so that the volume exchange rate of the 2D model is the same as the real 3D tank. The exhaust orifice in the 2D model has an area of 0.1276 m^2, which gives a volume flow rate of 0.00319 m^3/s (0.1276 x 0.025) or 0.19 m^3/min. The total 2D headspace volume (model has unit thickness) is 68.4 m^3, which gives a volume exchange time of 6 hours (68.4/0.19 x 60) when dividing by the 2D model's 0.19 m^3/min exhaust rate. In other words, the 2D model gas volume, which has a thickness of 1 m, a length of 22.86 m (75 ft) and a dome height of about 3.8 m (12.5 ft), is exchanged every 6 hours just like the real tank with an exhaust rate of 100 ft^3/min. Having the same volume exchange time is equivalent to having the same orifice area to volume ratio.

The flow pattern is shown in Figure 4-3, which shows the natural circulation effects that are caused by the hot bottom boundary and the cooler top boundary as well as the exhaust and inflow rates. The heat up of the upper boundary was not included in the model since that effect would involve adding the dome thickness and surrounding soil to the grid. As shown in Figure 3-3, the droplets that are released in the horizontal center of the tank get caught in a circulating flow and only a small number of droplets actually escape out of the model domain.

The particle tracking option was exercised with the FLUENT® code to calculate the LPF. Ten groups of particles were tracked with the diameters ranging from 1 to 10 microns. After the steady-state flow pattern, shown in Figure 3, was developed, the particles were then tracked. The release location of the particles or droplets from the spray release was varied from just above the waste to about two feet below the dome. This location variation was accomplished by specifying a vertical range in the horizontal center of the tank and then releasing 50 streams of particles along this range. This is done for each size of particle. The particle tracking algorithm incorporated stochastic particle velocities around a mean flow that is turbulent. There were 200 stochastic samples (of perturbed particle velocity) for each of the 50 release locations for a total of 10,000 particle tracks for each size of particle. For all ten sizes, there was total of 100,000 particle tracks with about 2293 particles escaping through the exhaust and inlet orifices. Some particles actually go out of the inlet orifice due to thermal effects. The LPF of this case is the number of escaped particles divided by the total number of particles (2293/100,000) and is equal to 0.02293 or about 0.023.

Case 3-2, (t50c-rng400ia), Expected Thermal, Bounding Exhaust Rate

This case is the same as case 3-1, the base case, except that the exhaust volume flow rate is equivalent to about 400 ft^3/min based on time of a volume exchange for the 2D model and the real tank. This exhaust volume rate represents a bounding value for the double shell tanks. The exhaust velocity in the 2D model is 0.1 m/s, which is four times larger than the first case's exhaust velocity. All of the boundary temperatures are the same. The circulating flow pattern is shown in Figure 3-4.

This case resulted in about 2392 particles out of 100,000 particles escaping the model domain. Hence, the LPF is about 0.024, which is slightly larger than the first case's LPF, even though the exhaust rate is four times higher. This is primarily because the thermal currents with large natural circulation dominate the flow regime in the model.

Case 3-3, (t88c-rng100ia), Bounding Thermal, Expected Exhaust Rate

This case is the same as case 3-1, except that the waste temperature is higher at about 88 °C (~190 °F), which is the maximum temperature allowed in a double-shell tank. In other words, this case has the bounding waste temperature. The flow patterns are shown in Figure 3-5.

Using the same method to calculate the LPF, 3517 respirable particles escape the model domain out of a total of 100,000 for an LPF of 0.0352. Due to the higher heat on the bottom boundary, the natural circulation is faster and the LPF is larger than the LPFs in the first two cases, but still fairly small.

Case 3-4, (t88c-rng400ia), Bounding Thermal, Bounding Exhaust Rate

This case is the same as case 3-3, except that the exhaust flow rate is larger (same as case 3-2) at 400 cfm instead of 100 cfm. The purpose of this case is to show the effects of higher exhaust rates on the LPF. The flow pattern is shown in Figure 3-6.

The LPF for this case is calculated to be 0.0357 (3570/100,000) or about 0.036. This value is very close to the LPF value from case 3-3. This shows that the thermal induced velocities dominate the flow regime instead of the exhaust rate. This LPF is the most bounding one calculated. To show how much the LPF is independent of particle size, the ten micron particle size in this case has an LPF of 0.0365 which is very close to the average LPF value for all sizes of 0.036.

Case 3-5 , (dome5-lam400), Isothermal and Bounding Exhaust Rate

An isothermal case was simulated with all of the temperatures, including the incoming air, set to about 27 °C (81 °F). This case is not expected to occur since all double shell tanks have some heat. Since the natural circulation is due to the exhaust rate, the bounding exhaust velocity (0.1 m/s) was used. The flow pattern is shown in Figure 3-7. Since the gas flow velocities are small, the laminar flow solver option in FLUENT® was used. In the first four cases, the natural circulation velocities are large enough to result in turbulent flow conditions. For turbulent flow, the RNG-k-epsilon solver option in FLUENT® was chosen.

Since the flow was not fast enough for the turbulent solver in FLUENT®, the stochastic particle tracking method could be used. A deterministic particle tracking method was used. For this method, 100 particles along the vertical in the horizontal center of the tank were tracked for each size. For all ten sizes, 1,000 particles were tracked. Of the 1,000 respirable particles, only 122 escape the model domain, resulting in an LPF value of 0.0122.

Case 3-6, (dome5-lam400), Isothermal and Bounding Exhaust Rate at Different Location

This case is the same as case 3-5, except that the exhaust orifice is located closer to the horizontal center of the tank. The purpose of this case is quantify the effect of an exhaust rate closer to the location of the spray release. The flow pattern is shown in Figure 3-8.

Out of the 1,000 particles tracked, 154 escape the domain for a LPF value of 0.0154. Even though the flow patterns are different from the other case flows, the gas flow is still circulating and the LPF is still small, although slightly larger than the previous case.

CASES AND RESULTS FOR DOUBLE-CONTAINED RECEIVER TANKS

The double-contained receiver tanks (DCRTs) consist of two types of tanks (RPP-6244). One type is a horizontal cylinder with a dome on each end, a radius of 6 feet and a length of about 37 feet. The horizontal DCRTs are the TX-244 and BX-244 tanks. The other type of DCRT is a vertical cylinder with a dome on top, a radius of 7.5 feet and a height of about 18 feet. The vertical DCRTs are the S-244 and A-244 tanks. All of these tanks are double shell with a vented air annulus surrounding the inner shell. Even though there is an exhaust line for the inner shell, there is no designated inlet for air entry into the inner shell. Hence, the amount of air removed from the tanks depends on the amount of air leakage into the headspace of the inner tank. Based on the headspace gas tests that were performed to determine gas concentration and ventilation rate in the headspace (HNF-2923), the S-244 tank had the highest ventilation (or flow) rate of about 14 ft^3/min (cfm). The A-244 tank had the next highest ventilation rate of 7.6 cfm, and the horizontal DCRTs, TX-244 and BX-244, had the lowest ventilation rates, which were below 1 cfm. Hence, the bounding DCRT, in regards to spray releases, is the vertical S-244 tank.

The top down view of the three dimensional grid for the S-244 tank headspace (80% full, headspace height of 1.8 m, RPP-6244) is shown in Figure 4-1. There are three potential air leak paths into the tank. The main one is located in the Q orifice (24-in diameter), which holds multiple 2-in diameter lines, and one of the 2-in lines in Q is open (HNF-2923). This is believed to be the main air inlet into tank S-244. In addition to the Q orifice, there could some leakage from the D and M spare lines, which are loosely covered in the pump and filter pits. The M spare line is located close to the Q orifice, so in the model and grid, the Q and M lines are combined with an equivalent open diameter of 3 inches. In other words, the combined Q and M orifice in the model includes the open 2-in diameter line in Q and a partial opening of the M spare line. The D spare line is included in the grid with an equivalent diameter of 2 inches. Also, during pumping through the center orifice, there could be some air leakage, which was not accounted for in the gas tests (HNF-2923). Hence, the bounding flow rate increased from 14 cfm (HNF-2923) to 23 cfm in the model. The side view of the three dimensional grid, which clearly shows the dome curvature, is shown in Figure 4-2. The drain lines from the pump and filter pits are equipped with level monitoring instruments to ensure the seal loops remain liquid filled, allowing no leakage. Since the drain lines are not expected to have any air leakage, they were not included in the model.

The spray leak is released in the model along a 1.6-m vertical line (hose) in the center of the tank from a height of about 8 cm above the bottom boundary (80% full tank) to about 12 cm below the dome peak. One hundred spray locations were simulated from this vertical source. The spray velocity was 30 m/s in the positive X direction, towards the exhaust orifice.

The exhaust rate used in the model was about 23 cfm, as the mass exit rate was 0.0132 kg/s and the air density was about 1.215 kg/m^3, which yields a volume exhaust rate of 0.0108 m^3/s or about 23 cfm. This value bounds the maximum measured value of 14 cfm (HNF-2923). The waste temperatures in the tank are expected to be considerably lower than the temperatures in the hottest single or double shell tanks. Even with no dilution effects from sluicing, the DCRTs have an air-cooled annulus and only a 15 foot diameter. Hence, the surface area to volume ratio of the DCRTs is much larger than the single or double shell tanks, which promotes a higher cooling rate and lower temperatures. Three waste temperatures were simulated and reported here: 22 °C (72 °F), 30 °C (86 °F), and 44 °C (111 °F). One simulation was performed with a waste temperature of 57 °C, but since the LPF was lower at this high temperature than the LPF from the 44 °C waste and temperatures this high are not expected, the case was not included in the results of this report.

After some early simulations with various inlets in the model closed and opened, it was determined that the maximum LPFs resulted from only one inlet, the equivalent Q and M orifice (see Figure 4-1), being open and the others closed. If the center orifice is open, allowing leakage during pumping, the incoming air drives the spray droplets, which are released from a vertical hose in the center, downward into the waste where it is trapped. If the D spare line leaks, the incoming air partially feeds the exhaust outlet and prevents some of the spray droplets from reaching the exhaust. Hence, the maximum LPFs are realized when only the equivalent Q and M orifice (see Figure 4-1) is open. Hence, only the waste temperature was varied in the following three DCRT cases. The wall temperature was set to 20 °C (68 °F).

Case 4-1, (s244m-qy-22c), 22 °C Waste and 23 ft^3/min Exhaust Rate

This case has a bottom boundary temperature of 22 °C, which is only 2 °C hotter than the walls, so the case is very much like an isothermal case. The stochastic particle tracker was used, which sampled 50 particles from each of the 100 release locations along the center vertical spray source for each particle size. Ten particle sizes were used (1 micron to 10 microns), so 50,000 particles were tracked in all. A total of 1231 particles escaped from the tank for an overall LPF of 0.0246 (1231/50,000). To check the LPF for size dependence, the largest size particles (10 microns) had an LPF of 0.0218, which is smaller than the overall LPF due to the smaller particles having a larger LPF. So in terms of mass, the overall LPF of 0.0246 is conservative.

Case 4-2, (s244m-qy-30c), 30 °C Waste and 23 ft^3/min Exhaust Rate

This case is the same as the previous case except that the bottom boundary temperature is 30 °C (86 °F). Following the same procedure as before, an overall LPF was calculated to be 0.0276 (1379/50,000). The LPF for the largest size particle (10 microns) was calculated to be 0.023, which is smaller than the overall leak path factor. Hence, the overall LPF of 0.0276 is conservative.

Case 4-3, (s244m-qy-44c), 44 °C Waste and 23 ft^3/min Exhaust

This case is the same as the previous case except that the bottom boundary temperature is 44 °C (111 °F). Following the same procedure as before, an overall LPF was calculated to be 0.0395 (1977/50,000). The LPF for the largest size particle (10 microns) was calculated to be 0.032, which is smaller than the overall leak path factor. Hence, the overall LPF of 0.0395 is conservative. Since the gas flow pattern is very similar for each case, only the gas flow pattern is shown for this case (see Figure 4-3). The flow pattern is calculated by releasing zero mass particles in a vertical plane that runs along the X axis. The exhaust orifice (Y) is located on the right side of plot and the air inlet (equivalent Q and M) is located on the left side.

CASES AND RESULTS FOR 204-AR UNLOADING FACILITY

A three dimensional grid was constructed for the 204-AR unloading facility (only the unloading part), and a side view is shown in Figure 5-1. The outer dimensions of the grid are 64 ft long, 18 ft wide, and 25 ft high. The roll up receiving door is 12 ft wide and 18 ft high and is located on the West (and slightly North) side (FDM-T-290-00001). A sketch of the unloading room (top down and side views) domain used in the model is shown in Figure 5-2. No detailed structures were included in the model, which is expected to be conservative since the structures would cause the spray particles to bounce off of the detailed structures, slow down, and potentially fall down to the floor. The floor for this model is a trap for the respirable spray droplets since most of the spray release consists of much larger drops, which will wet the floor before any respirable droplets reach it. The spray release is from a high-pressure flex hose, which starts at the center of the unloading room where the top center of waste car retrieval orifice is located with an elevation of about 13 feet (4 m). The high-pressure flex hose runs to the South wall (see Figure 5-2) and part way to the East wall. The spray release was chosen to occur from 100 locations along this flex hose. Also, the spray velocity used was 25 m/s in the downward direction since the exhaust vents are located near the floor.

The two exhaust vents are located on the North side about 6 feet apart and only about 1 foot above the floor. Since it was difficult to insert overhanging vents in the model, two orifices were placed in the North wall, even though the gas in sucked in vertically in the real facility. This modeling change is expected to affect only the gas flow near the vents, and is expected to be conservative. It is expected to be conservative since the droplets will not have to drop down below the vents and then be sucked up, but instead, in the model, the droplets can exit the domain by moving laterally through the vents, which is easier. The bounding flow rate of the exhaust fan is 2000 cfm, which was conservatively used in the model (1000 cfm for each vent), even though there are frictional losses in the ducts and HEPA filters. The only air leakage into the facility is expected to occur along the bottom of the receiving door, especially where the railroad tracks are located. In the model, an open strip is placed on the bottom of the door with a length of 12 feet. The width of the strip is not important since a smaller opening will have larger velocities, which will slow down very quickly upon entering the facility. Also, there is a second receiving door on the East side of the outer receiving door. In the model, the interior receiving doors are excluded, since air leaks around these doors as well. Also, it is slightly conservative to have all of the incoming air enter at the bottom of door, since this air will potentially move laterally under the spray release and tend to keep the spray droplets suspended.

Only two cases were simulated for spray leaks in the 204-AR unloading facility. One case has hot outside air (40 °C [104 °F]) infiltrating under the outer receiving door, and the second case has cold air (2 °C [36 °F)]) infiltrating under the receiving door. The exhaust rate for both cases is the bounding value of 2000 cfm. The floor temperature is 15 °C (59°F), and the wall and ceiling temperatures are 27 °C (81 °F). These two cases will show the effect of outside air temperature on the LPF values.

Case 5-1 , (ar204-40c), 40 °C Inlet and 2000 ft^3/min Exhaust

This case is the hot infiltrating air case with the outside air entering the unloading facility at a temperature of 40 °C (104 °F). The gas flow pattern is shown in Figure 5-3. The hot entering air comes and then goes up, pulling the gas above the floor towards the receiving door (to the left). The same stochastic particle tracking methodology in Section 4 was employed here. A total of 6203 respirable particles out of a total of 50,000 escaped out of the unloading facility domain, which yields an LPF of 0.124. The LPF for the large particles is 0.122, so the overall LPF of 0.124 is slightly conservative and the LPF is rather independent of particle sizes in the range of 1 to 10 microns.

Case 5-2 , (ar204-2c), 2 °C Inlet and 2000 ft^3/min Exhaust

This case is the same as the previous case except that the infiltrating air is only 2 °C (36 °F). The gas flow pattern is shown in Figure 5-4. This figure, which is on a plane (X-axis is horizontal, and Z-axis is vertical) that is 2 m from the South wall (front of page), shows that the cold entering air stays near the bottom and moves towards the right until it gets close to the vents. This is in sharp contrast to the previous case, where the hot air rises upon entry. The LPF for this case is 0.155 (7727/50,000). The LPF for the large particles is 0.152, indicating the LPF is independent of respirable particle sizes and the overall LPF value of 0.155 is slightly conservative.

SUMMARY AND CONCLUSIONS

Double Shell Tanks

The thermal effects of the waste in the tanks strongly influence the flow patterns in the tank and have larger effects on the flow than the exhaust rate. The leak path factors for all six cases are shown in Table 1. The most bounding LPF value of 0.036 results from a bounding temperature for the waste and a bounding exhaust rate. The expected LPF value is 0.023, which is from a waste with a moderate temperature of 50 °C (122 °F) and a normal exhaust rate of 100 ft^3/min.

Table 1. DST Leak Path Factors for the Six Cases Simulated

Case Number	Case Name	Case Description	Leak Path Factor
3-1	T50C-RNG100IA	50 °C waste, 100 ft^3/min exhaust	0.023
3-2	T50C-RNG400IA	50 °C waste, 400 ft^3/min exhaust	0.024
3-3	T88C-RNG100IA	88 °C waste, 100 ft^3/min exhaust	0.035
3-4	T88C-RNG400IA	88 °C waste, 400 ft^3/min exhaust	0.036
3-5	DOME4-LAM400	Isothermal, 400 ft^3/min exhaust	0.012
3-6	DOME5-LAM500	Isothermal, 400 ft^3/min exhaust closer to spray location	0.015

Double-Contained Receiver Tanks

The LPFs for spray releases in the DCRTs also have a thermal influence, with the LPF associated with the 44 °C waste being the most bounding at 0.04. Simulations were performed only for the vertical S-244 receiver tank as this tank has the highest air leakage into the tank (HNF-2923). If there is any additional air leakage due to the actual pumping event allowing air to enter through the center tank orifice, the LPFs would be lower due to downward moving air at the spray source location.

Table 2. DCRT Leak Path Factors for the Three Cases Simulated

Case Number	Case Name	Case Description	Leak Path Factor
4-1	S244M-QY-22CW	22 °C waste, 23 ft^3/min exhaust	0.025
4-2	S244M-QY-30CW	30 °C waste, 23 ft^3/min exhaust	0.028
4-3	S244M-QY-44CW	44 °C waste, 23 ft^3/min exhaust	0.040

204-AR Unloading Facility

The 204-AR unloading facility was modeled with no inner structures present, which should provide bounding values for the LPFs. Also, the exhaust rate was its bounding value of 2000 cfm. Only the temperature of the infiltrating air entering the outer receiving door was varied. The highest LPF value occurs when the outside air is cold, but the difference between hot and cold air infiltration does not cause a large difference in the LPFs.

Table 3. 204-AR Unloading Facility Leak Path Factors for the Two Cases Simulated

Case Number	Case Name	Case Description	Leak Path Factor
5-1	AR204-40C	40 °C Inlet, 2000 ft^3/min exhaust	0.124
5-2	AR204-2C	2 °C Inlet, 2000 ft^3/min exhaust	0.155

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Figure 3-1. Left Side of Gas Volume in 2D Model Domain

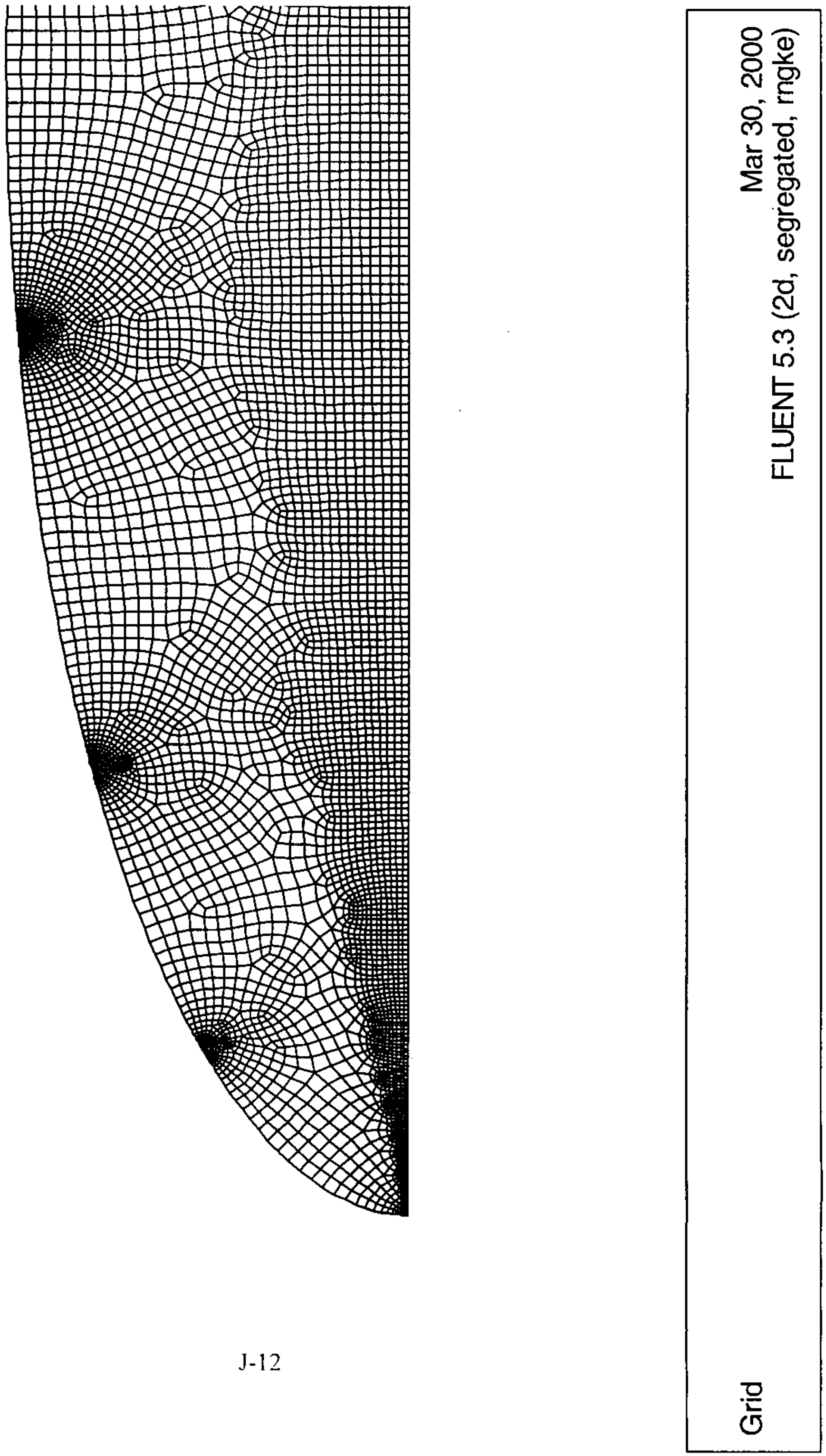


Figure 3-2. Right Side of Gas Volume in 2D Model Domain

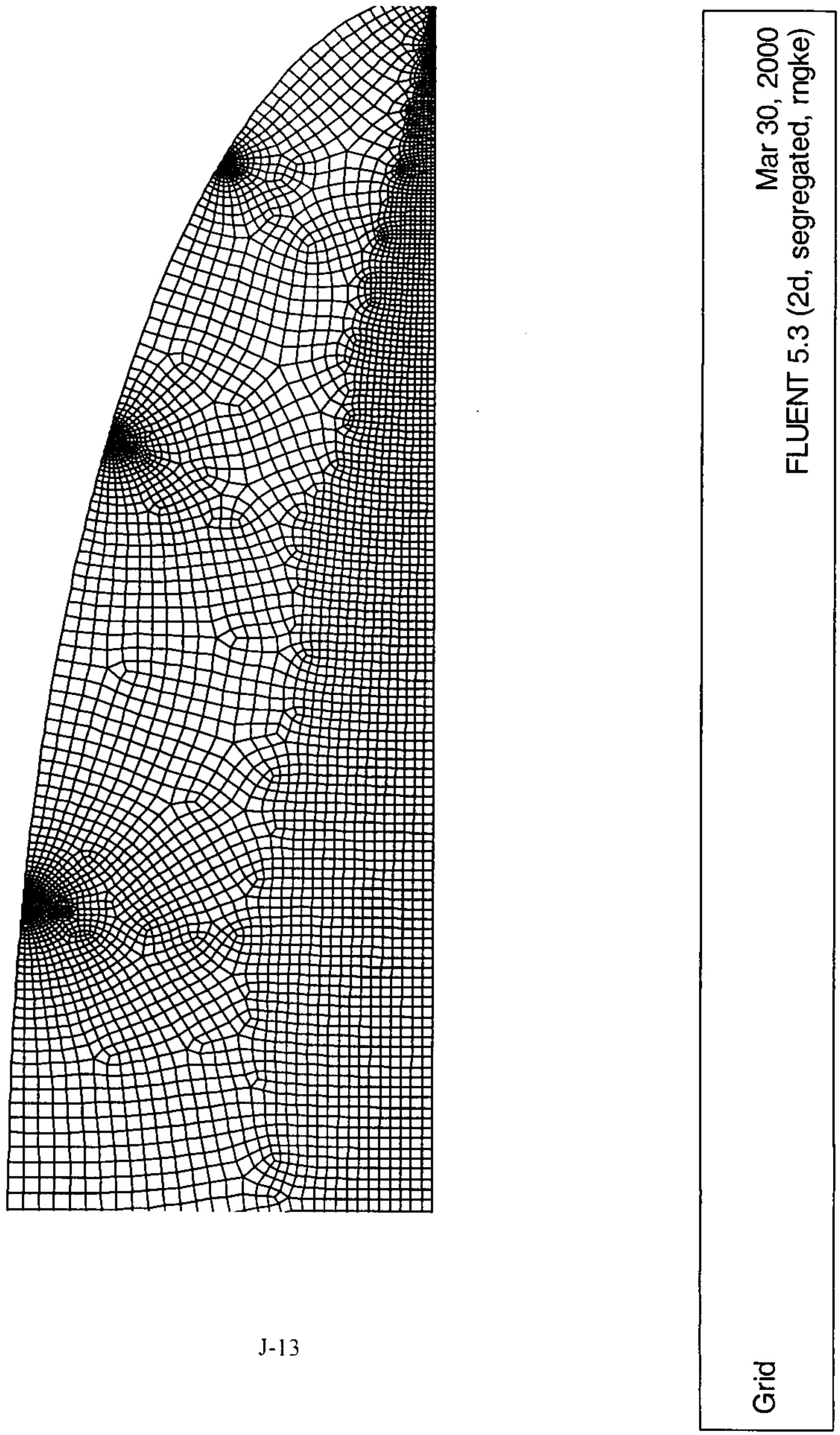


Figure 3-3. Case 3-1 (T50C-RNG100IA) with 50 °C Waste and 100 ft^3/min Exhaust Rate: Gas Flow Pattern

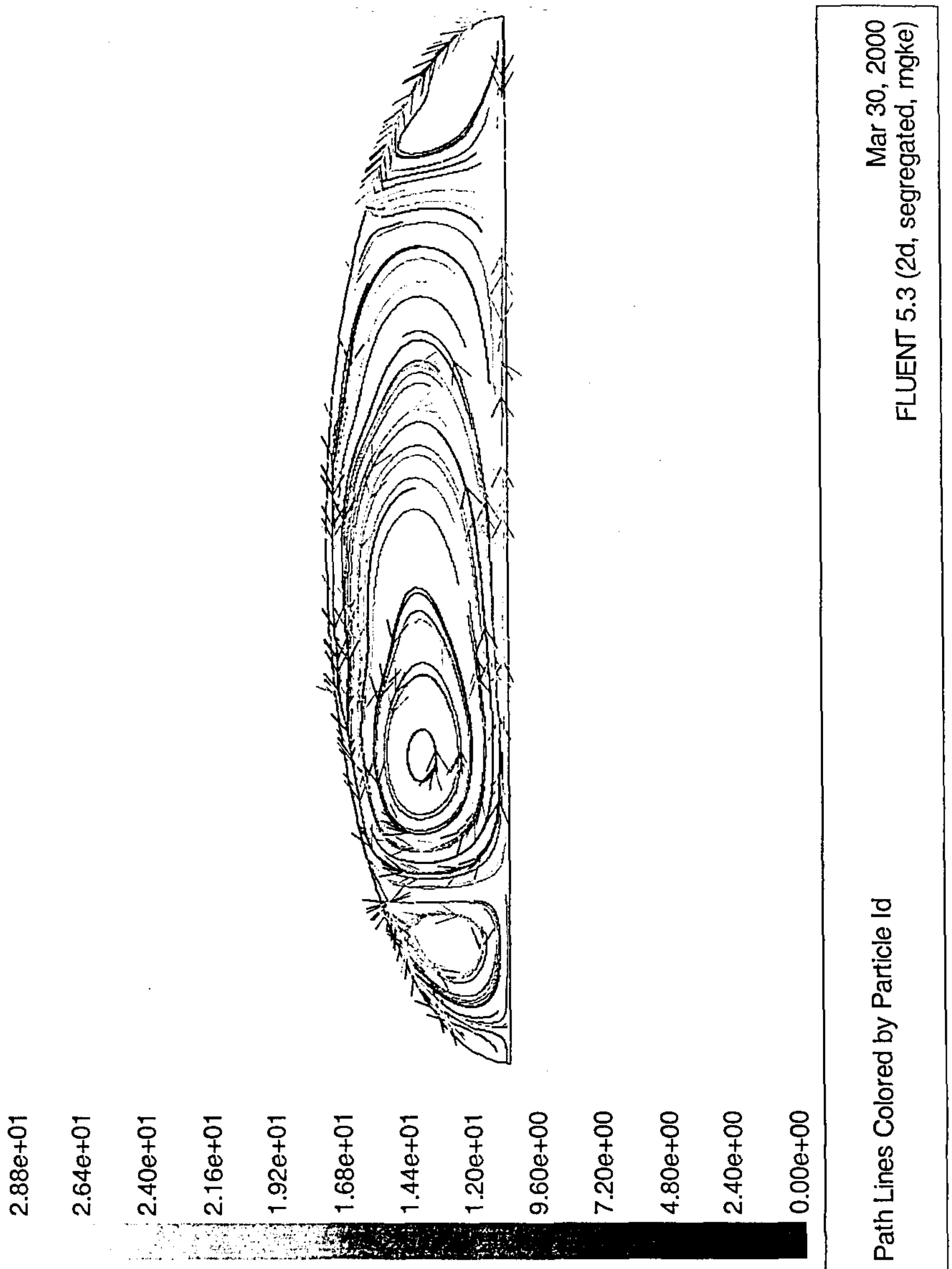


Figure 3-4. Case 3-2 (T50C-RNG400IA) with 50 °C Waste and 400 ft3/min Exhaust Rate: Gas Flow Pattern

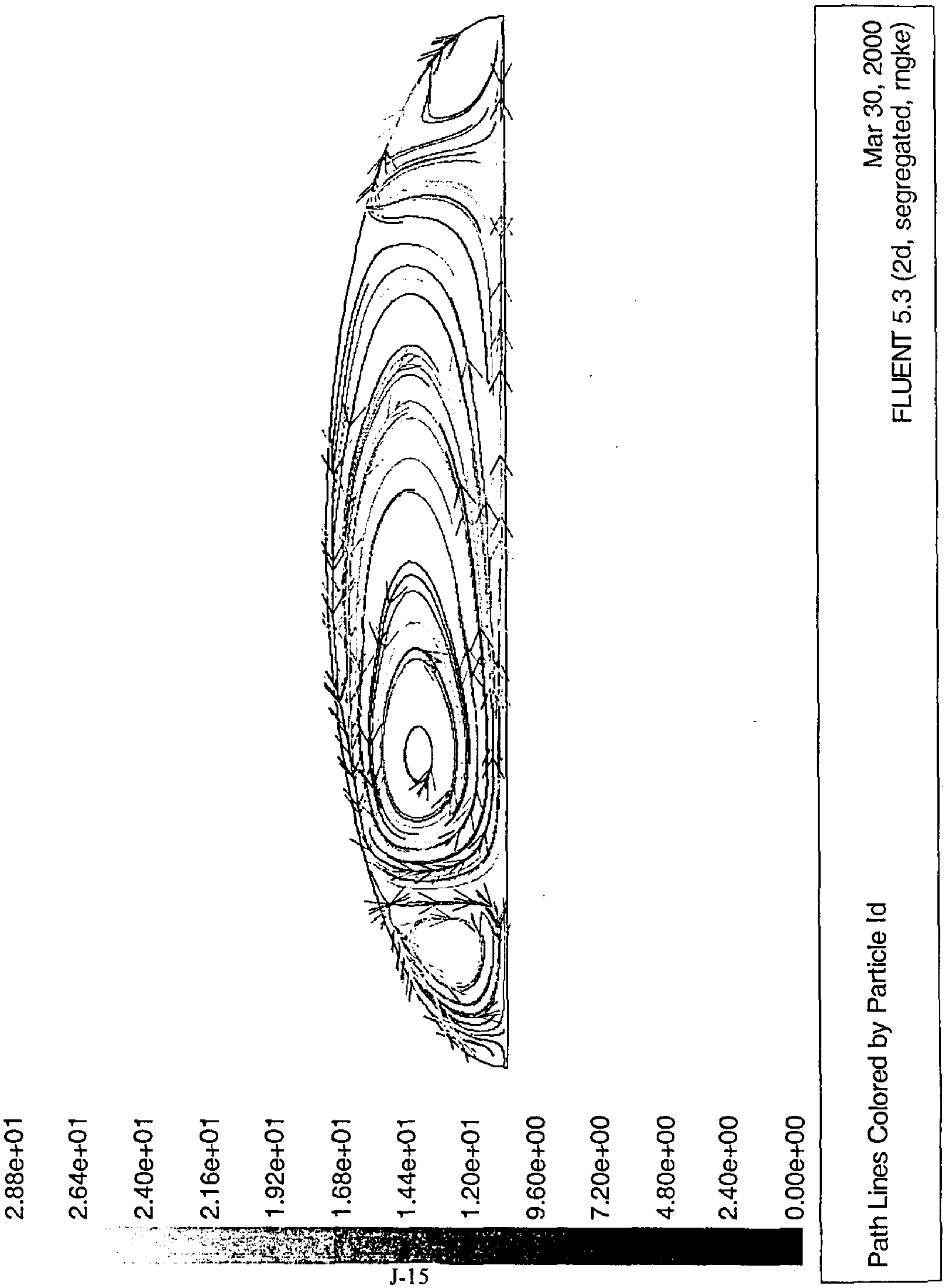


Figure 3-5. Case 3-3 (T88C-RNG100IA) with 88 °C Waste and 100 ft3/min Exhaust Rate: Gas Flow Pattern

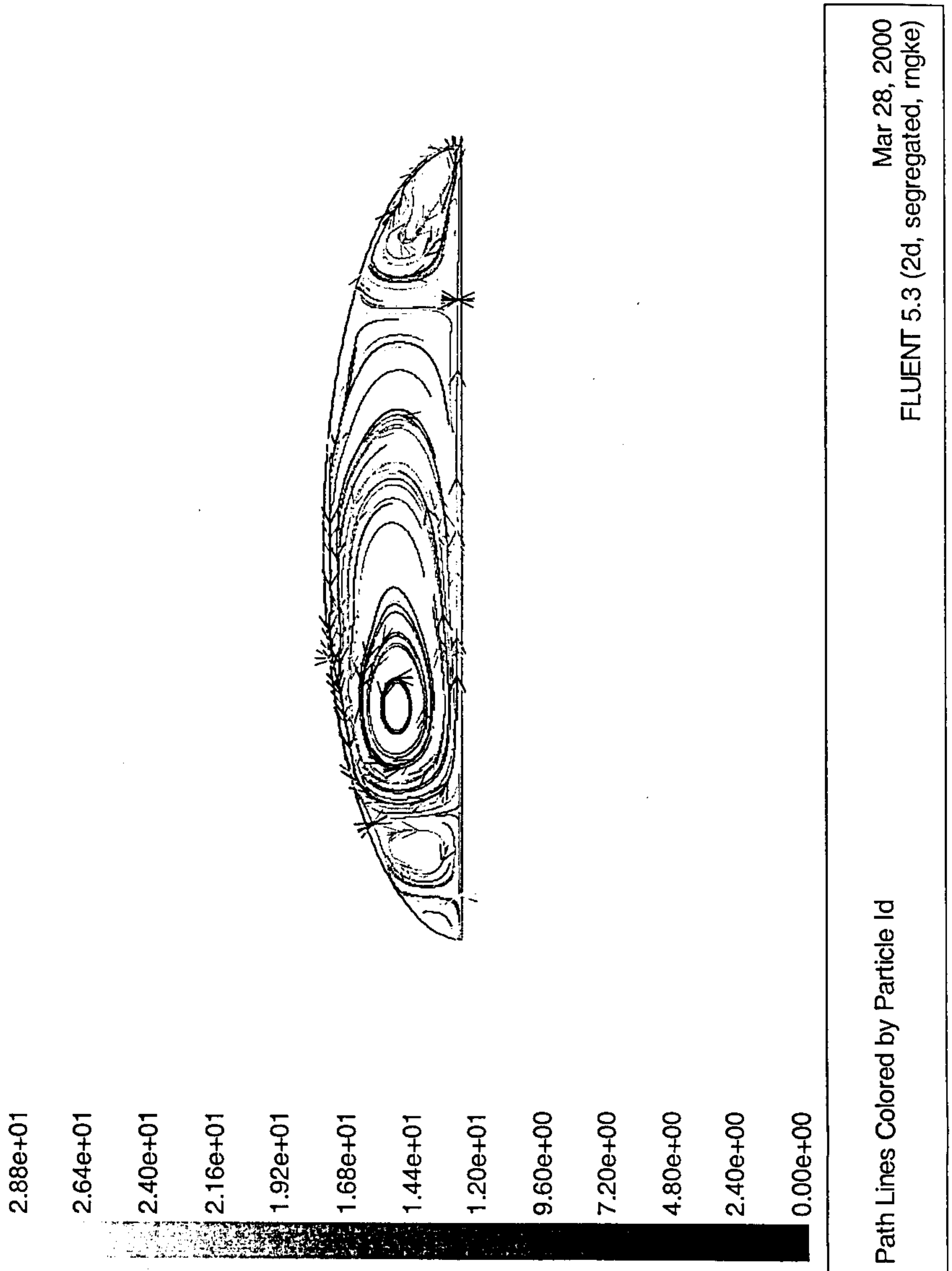


Figure 3-6. Case 3-4 (T88C-RNG400IA) with 88 °C Waste and 400 ft3/min Exhaust Rate: Gas Flow Pattern

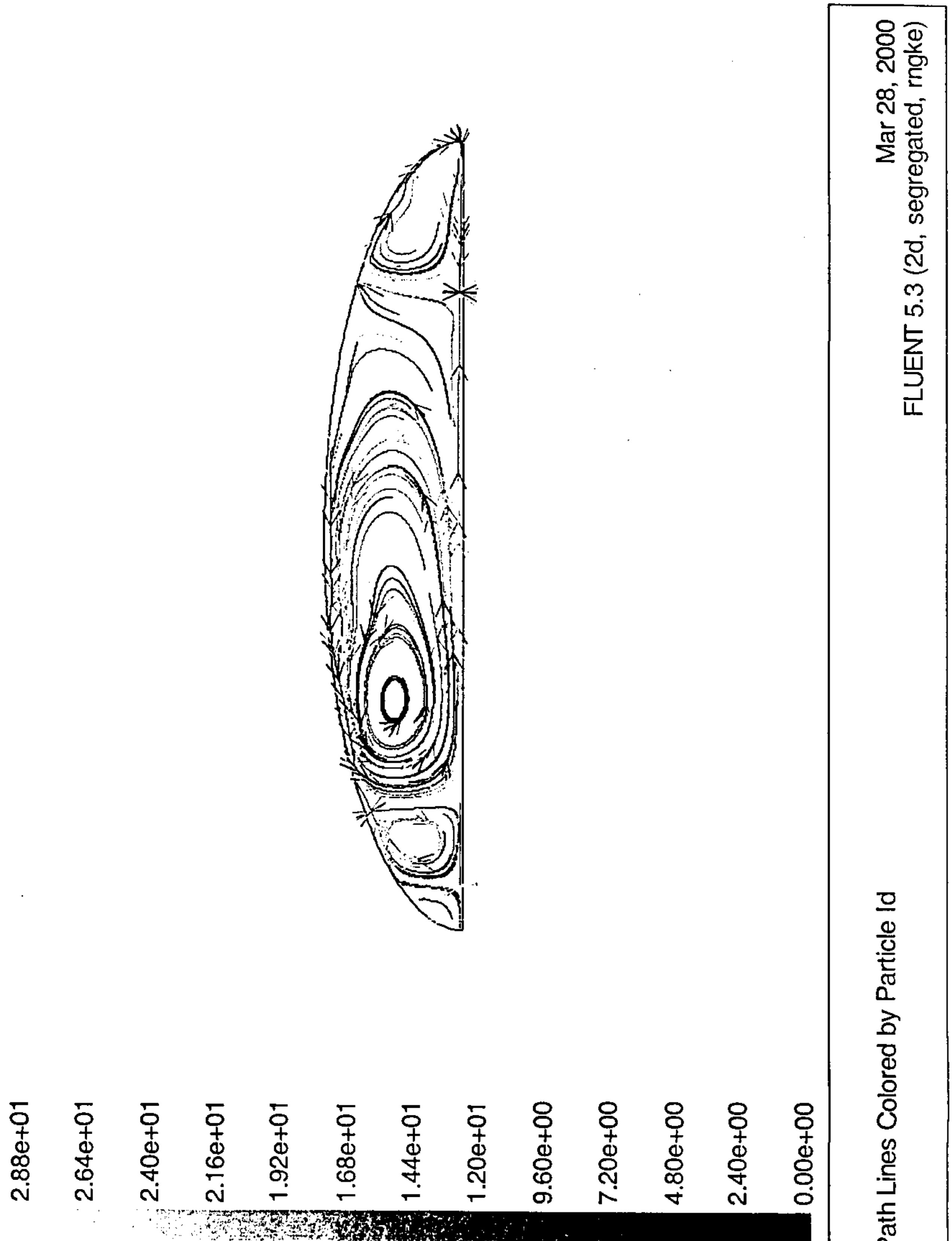


Figure 3-7. Case 3-5 (DOME4-LAM400) Isothermal and 400 ft3/min Exhaust Rate: Gas Flow Pattern

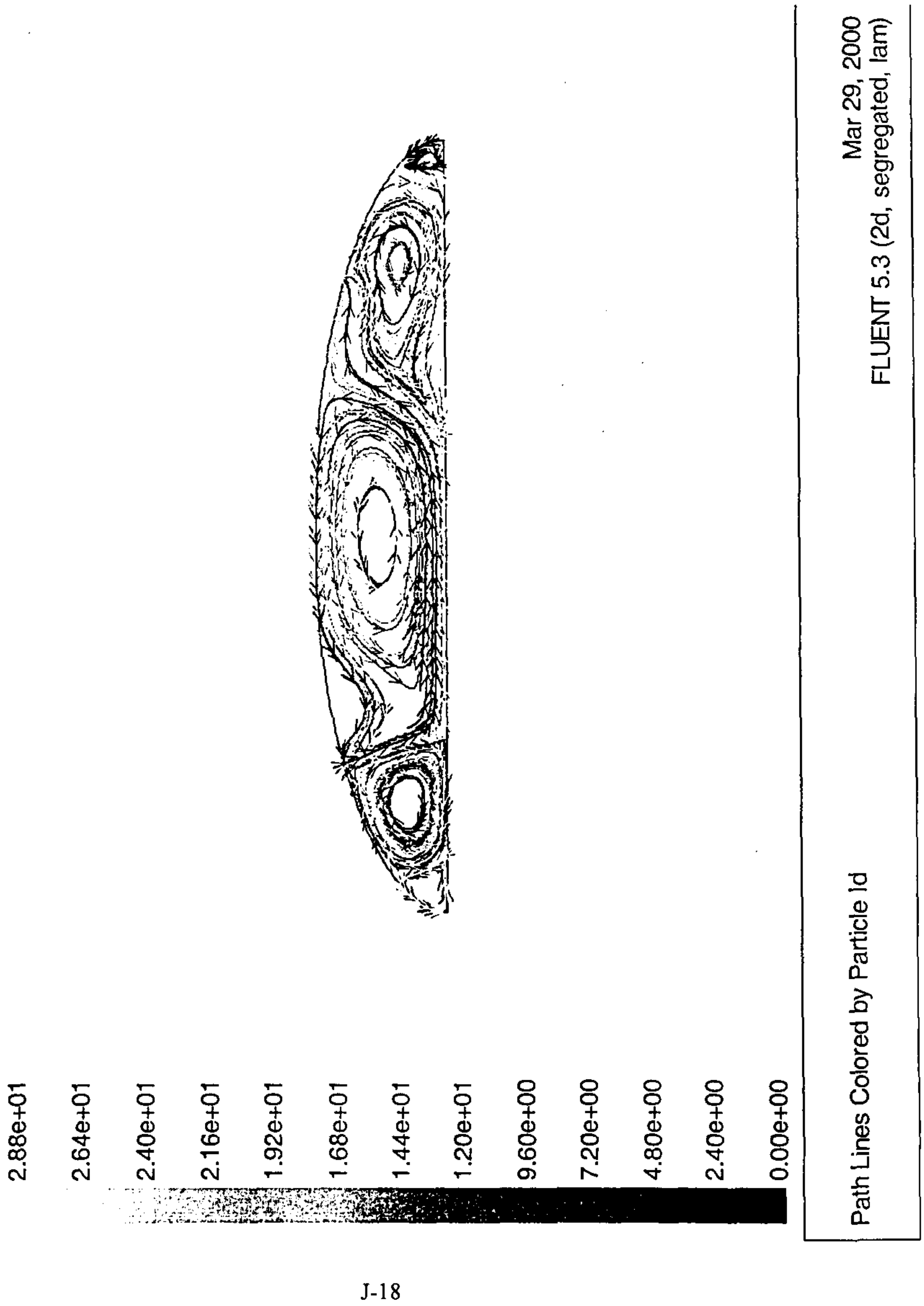


Figure 3-8. Case 3-6 (DOME5-LAM400) Isothermal and 400 ft3/min Exhaust Rate Closer to the Spray: Gas Flow Pattern

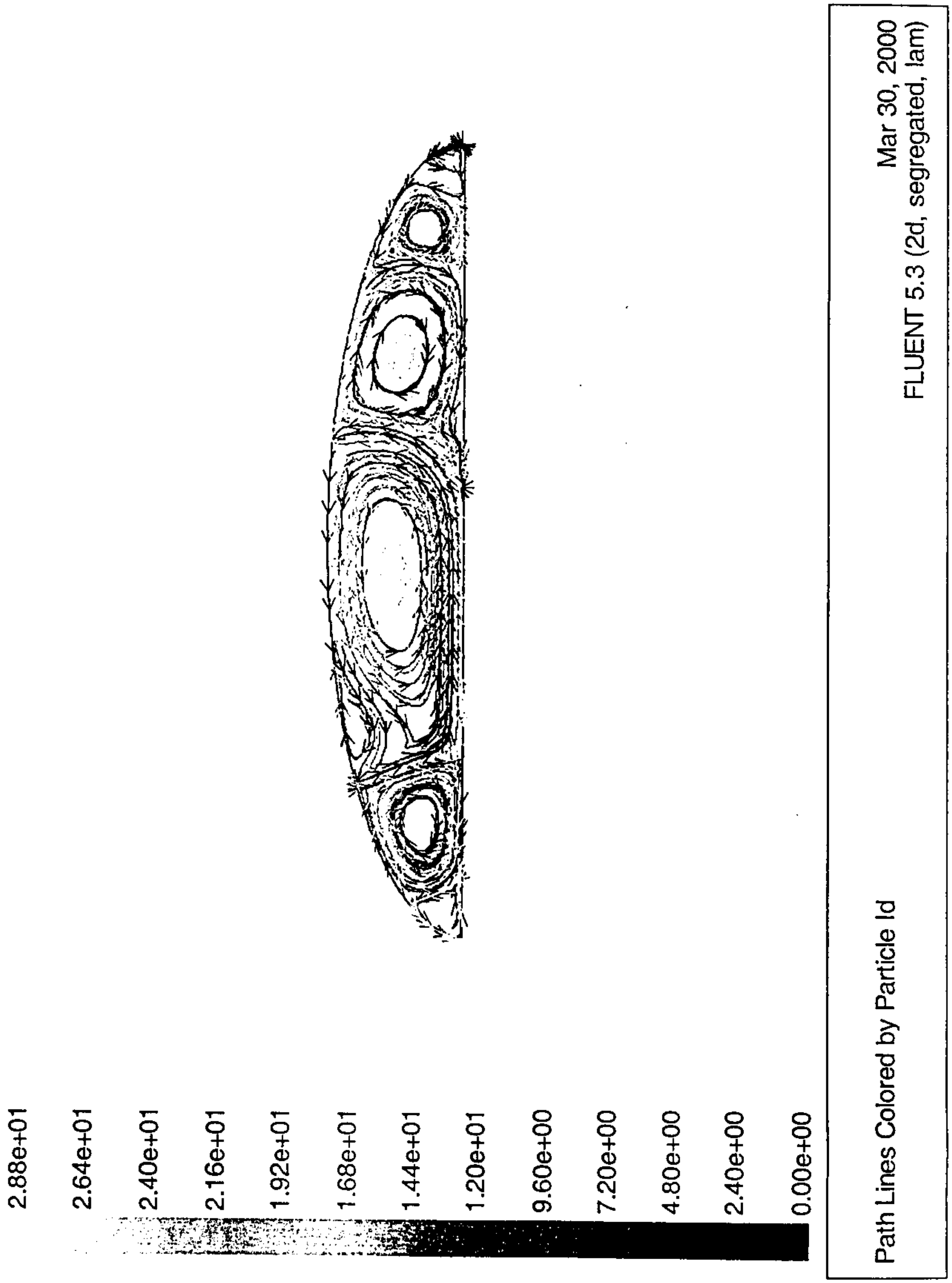


Figure 4-1. Grid for Double-Contained Receiver Tank Simulations: Top Down View

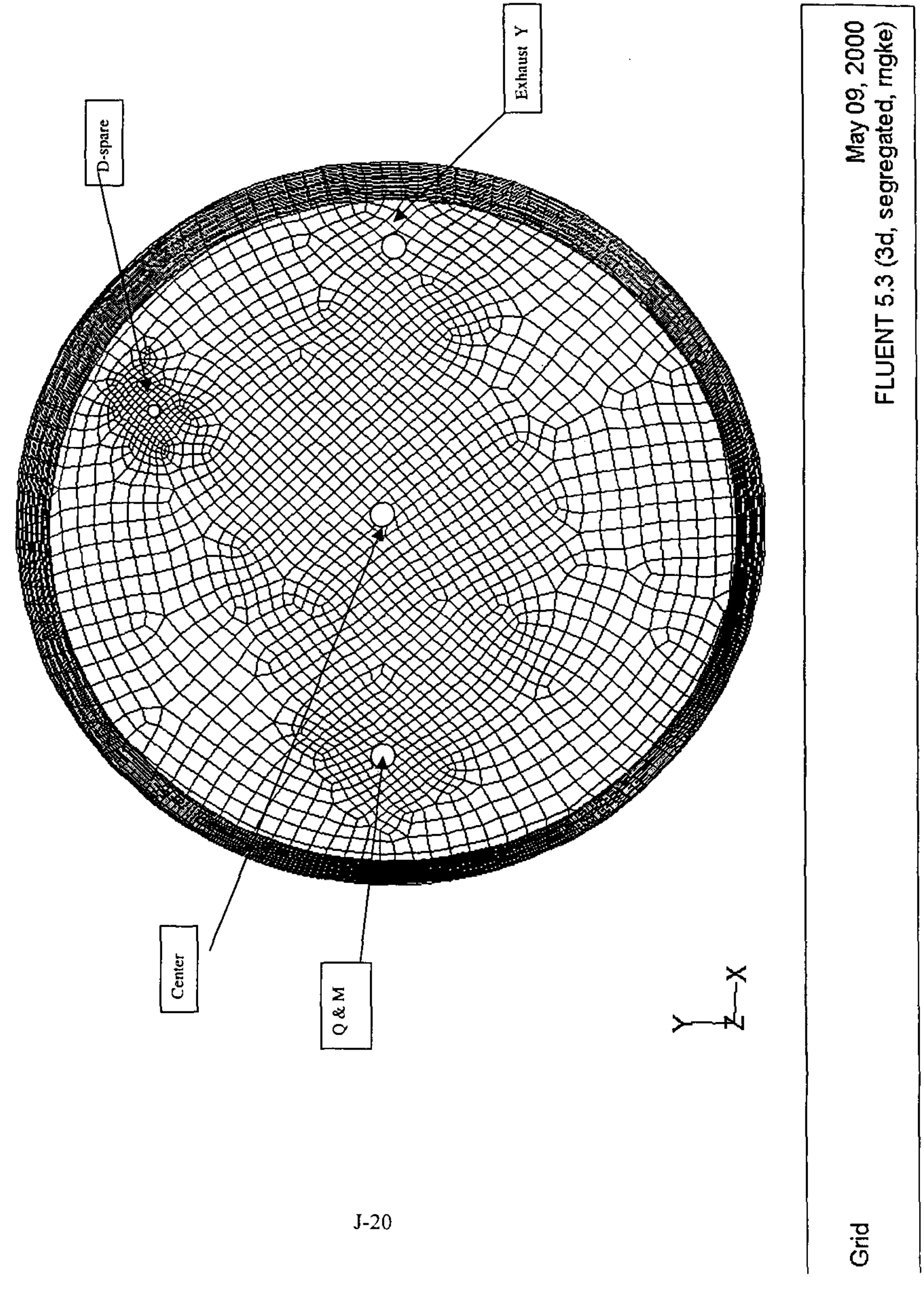


Figure 4-2. Grid for Double-Contained Receiver Tank Simulations: Side View

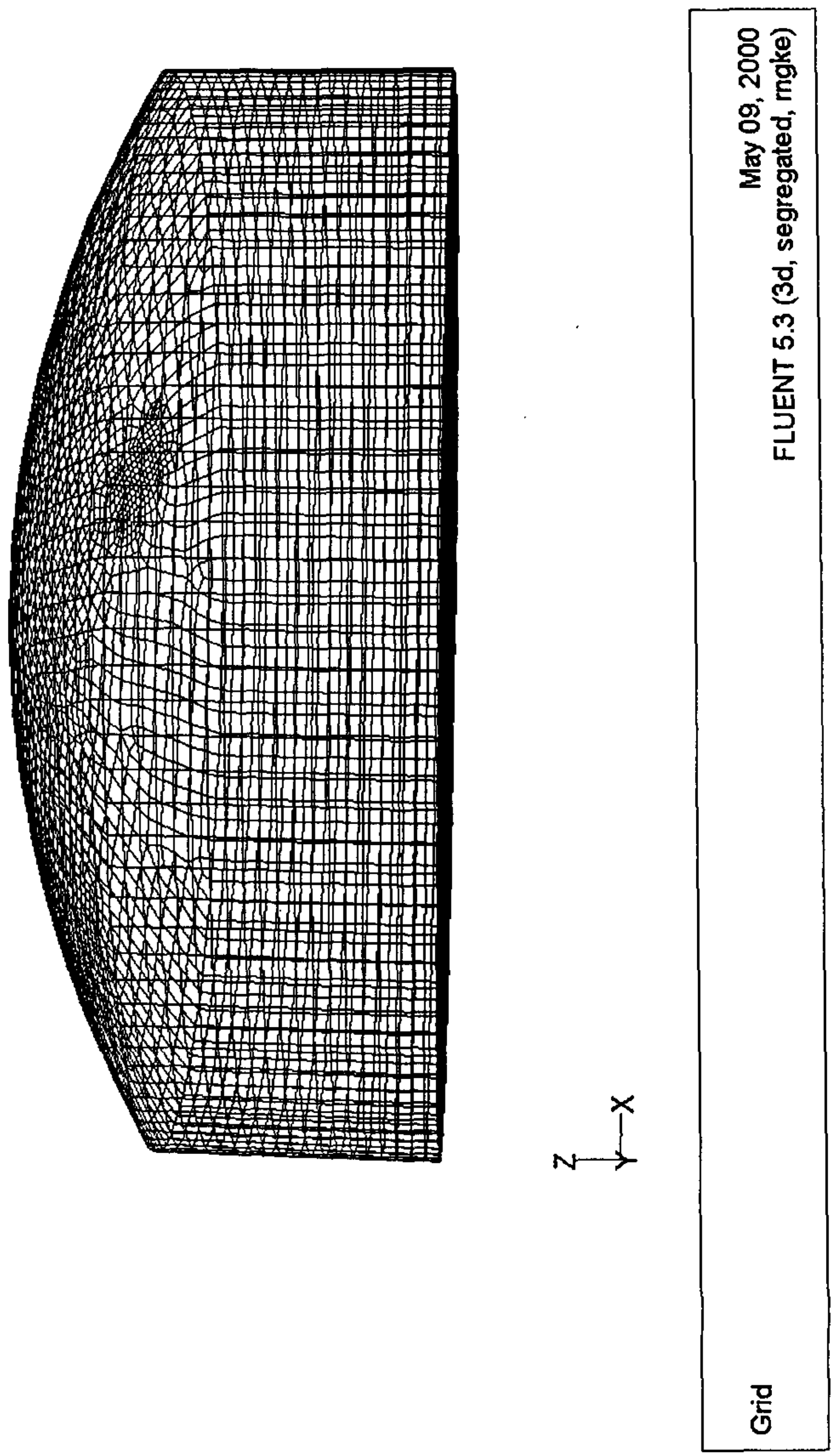


Figure 4-3. Case 4-3 (S244M-QY-44CW) 44 °C Waste and 23 ft3/min Exhaust Rate: Gas Flow Pattern

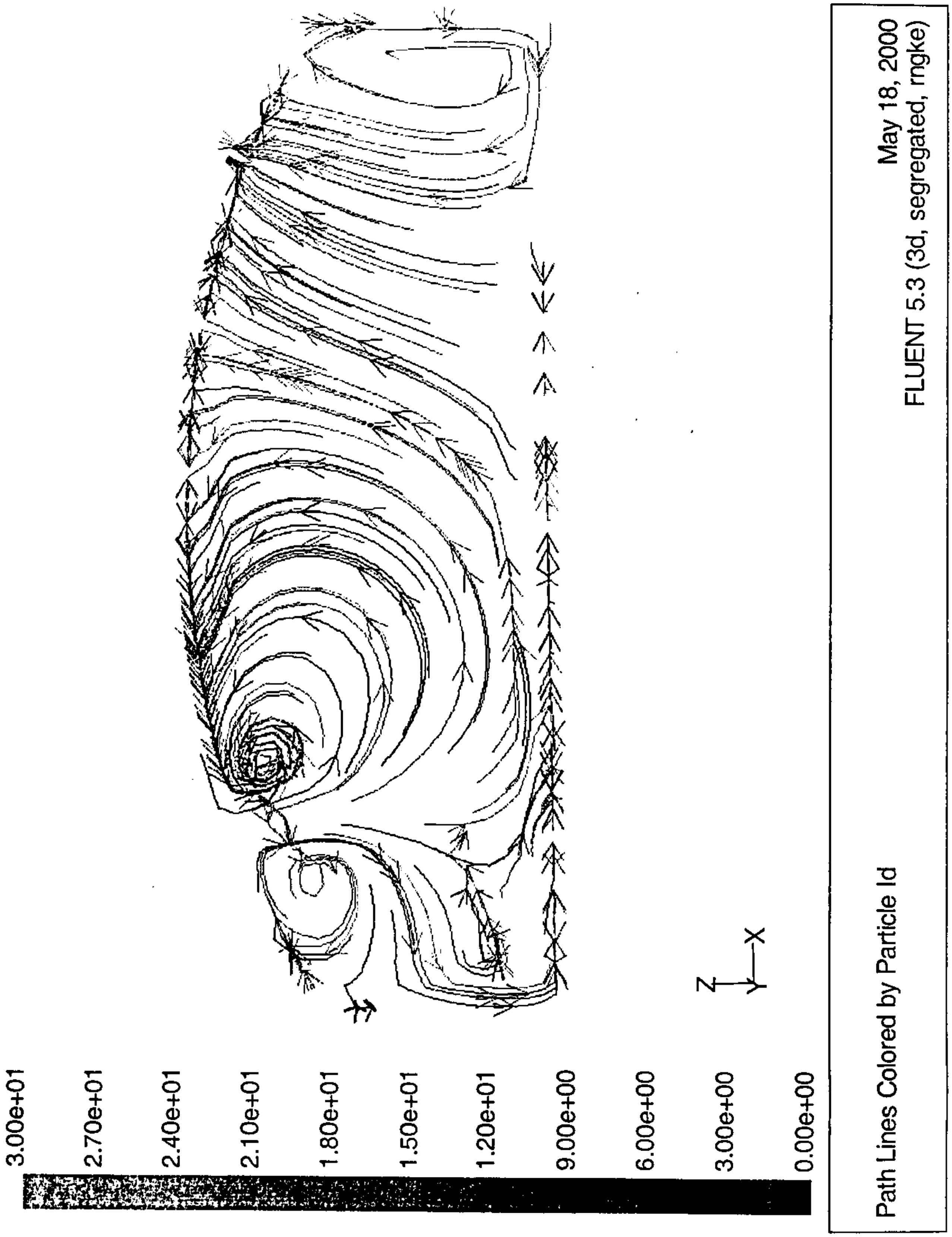


Figure 5-1. Grid for 204-AR Unloading Facility Simulations: Side View

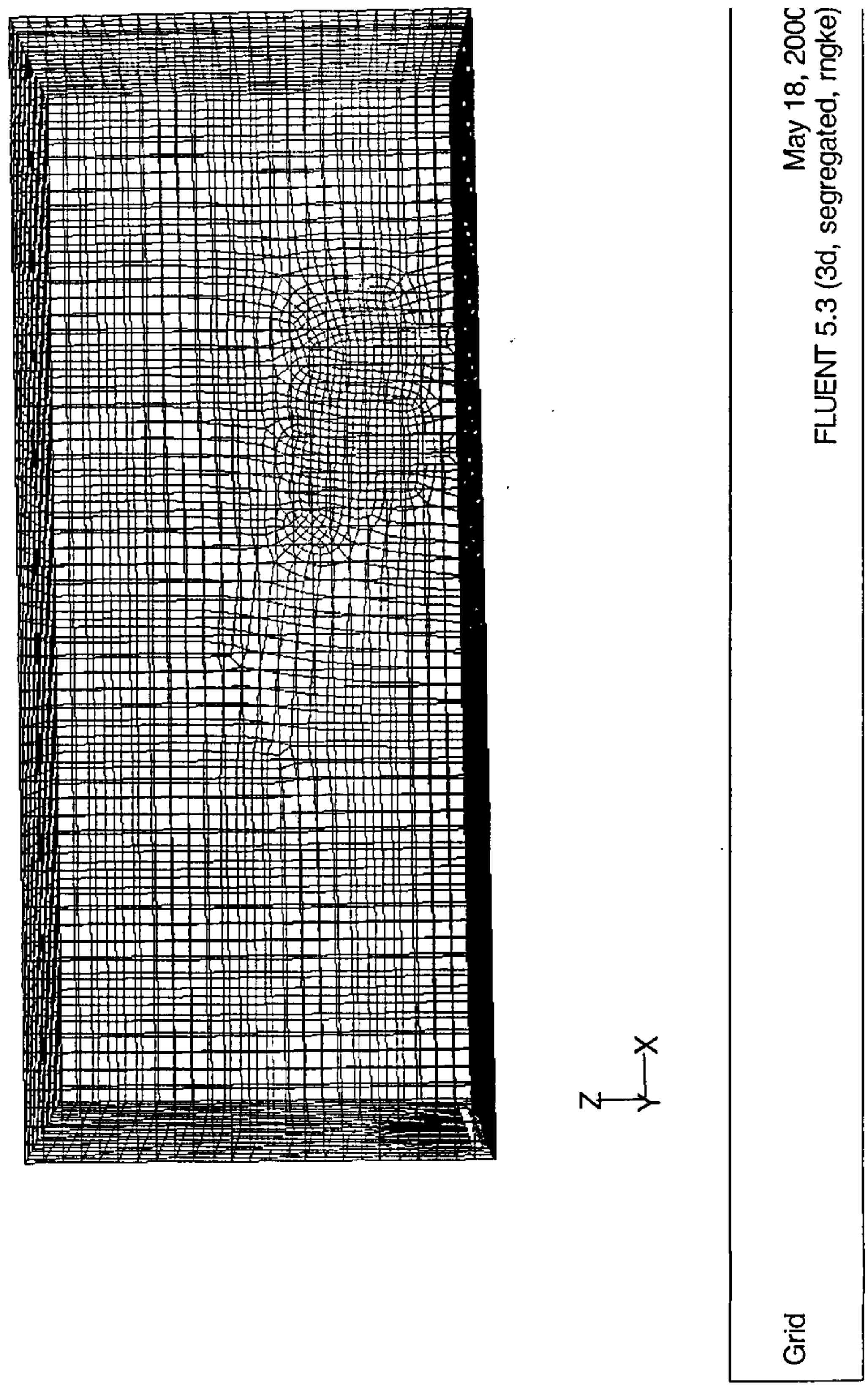
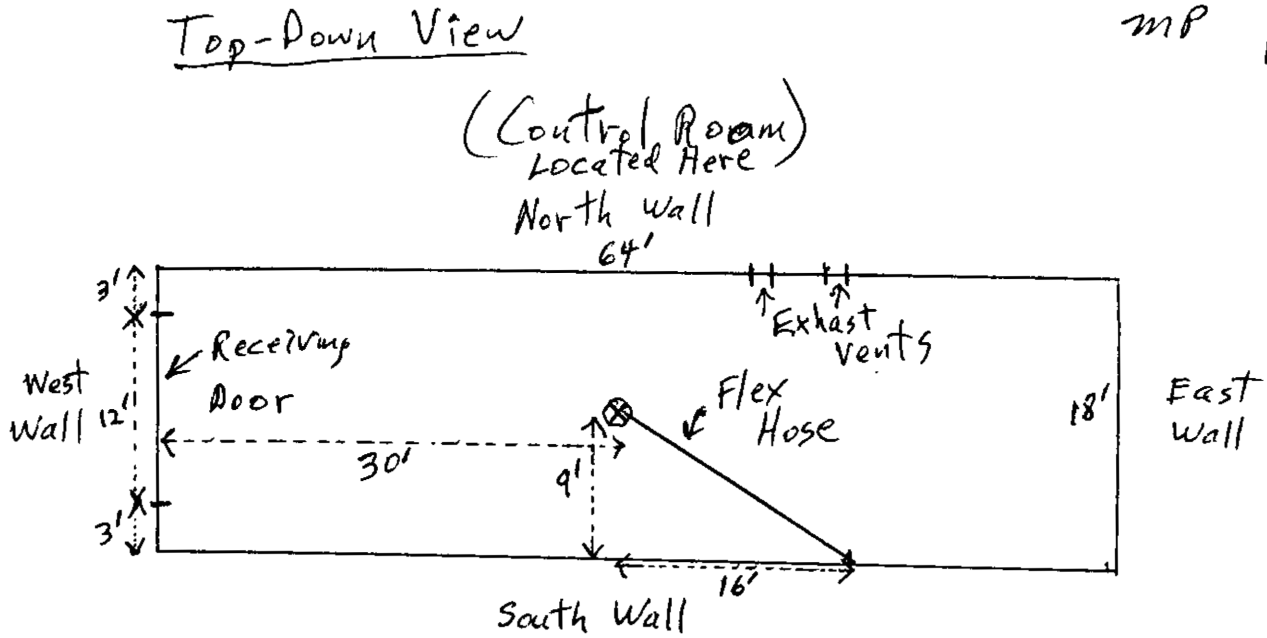


Figure 5-2. Sketch of 204-AR Unloading Facility Model Domain: Top Down and Side Views

5/18/00
M. Piepho
MP
p. 1 of 1



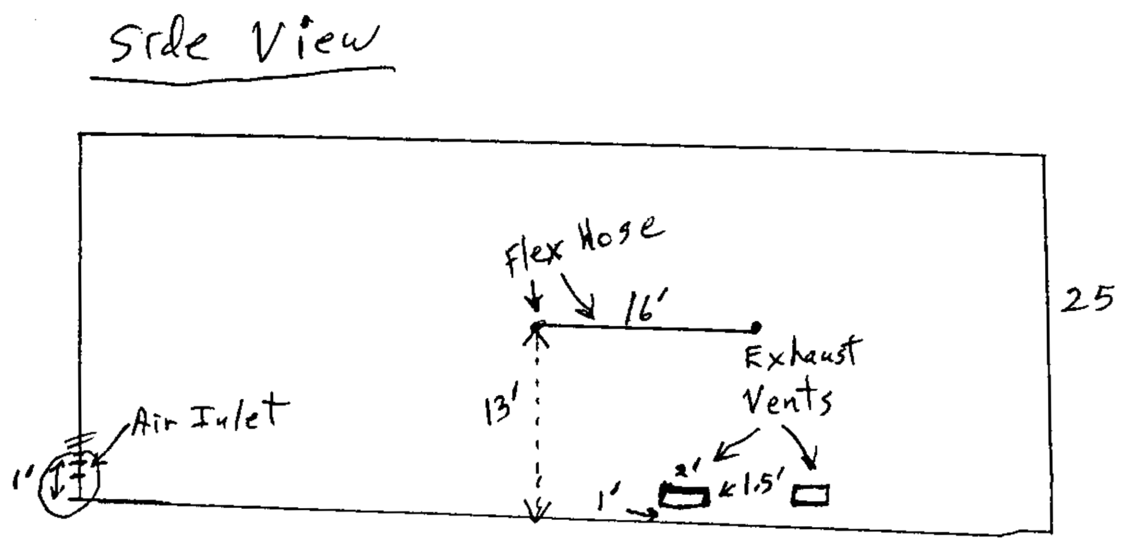


Figure 5-3. Case 5-1 (AR204-40C) 40 °C Inlet and 2000 ft3/min Exhaust Rate: Gas Flow Pattern

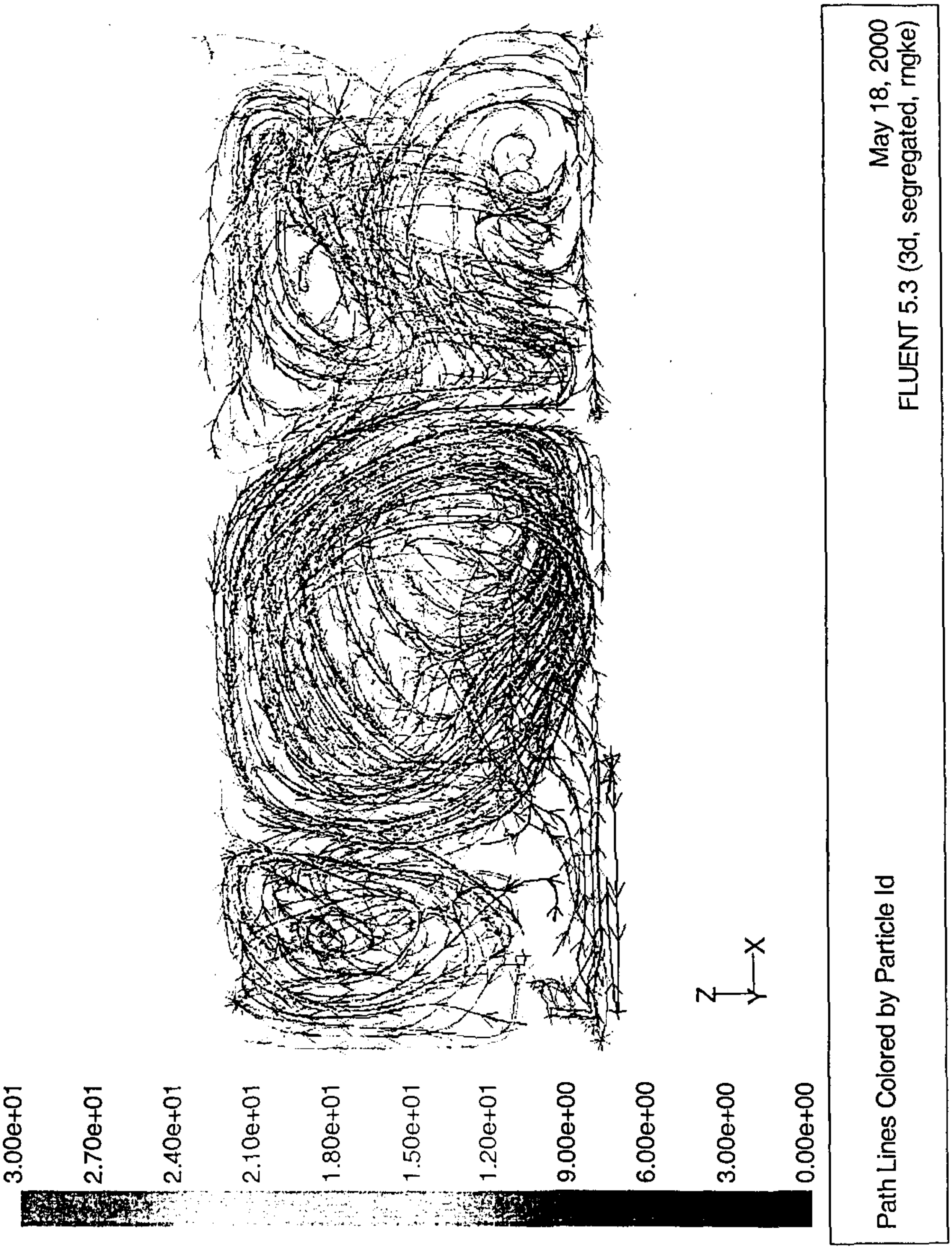
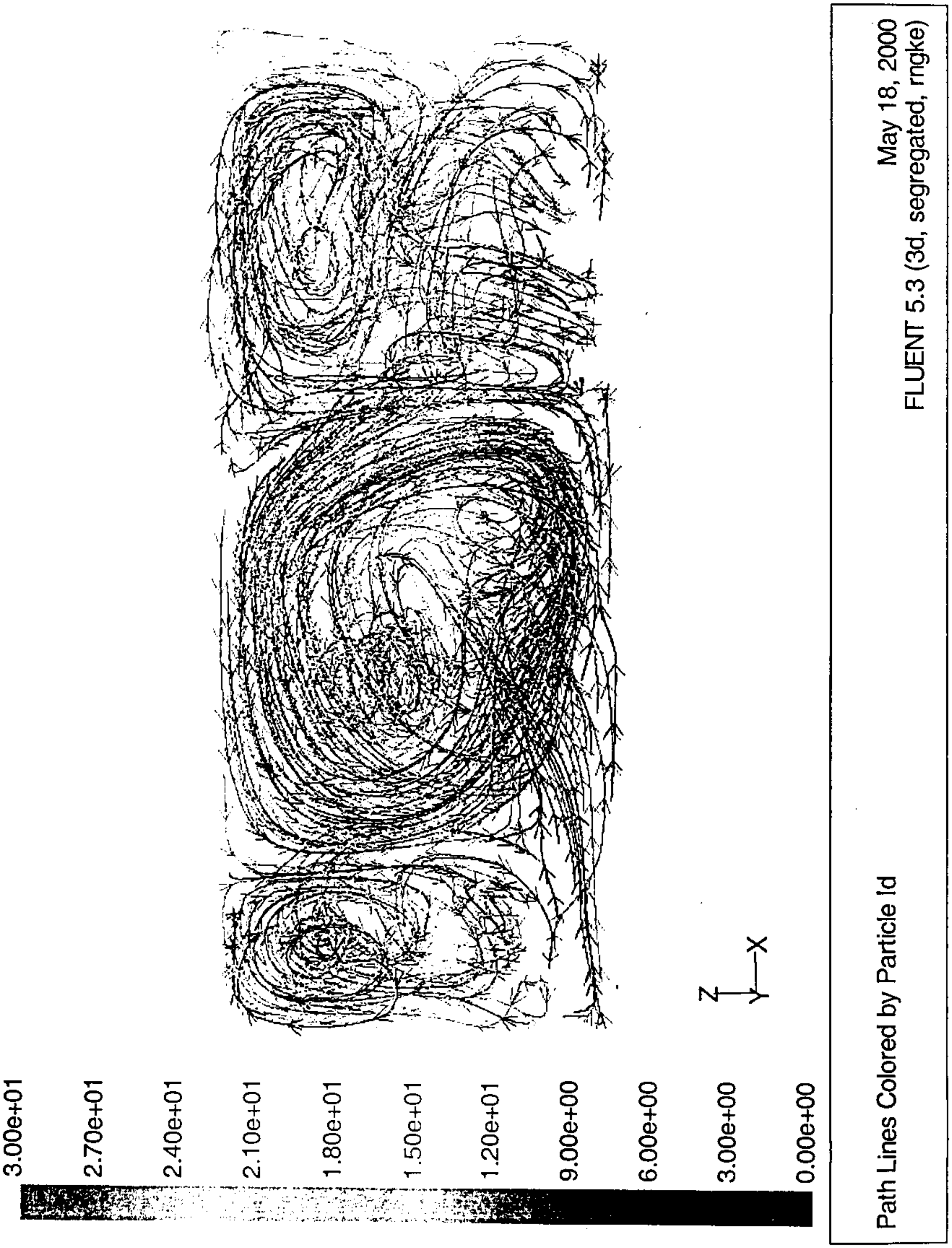


Figure 5-4. Case 5-2 (AR204-2C) 2 °C Inlet and 2000 ft^3/min Exhaust Rate: Gas Flow Pattern



FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: RPP-5667 Stochastic Waste Transfer Leak Analysis,
Title: Appendix J
Author: ~~Brian~~ Mel Piepho (App. J) Leak Path Factors for In-Tank Spray
Date: 4/17/00
Scope of Review: Appendix J only (DST only)

Yes	No*	NA	
[ ]	[ ]	[X] **	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[X]	[ ]	[ ]	Problem completely defined.
[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).

A. K. Biswas — Reviewer (printed name and signature)

4/18/00 — 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 intelligible to a technically qualified third party.

FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed:
Title: RPP-5667 Appendix J

Author: Mel Piepho
Date: 5-19-2000
Scope of Review: whole Appendix

Yes	No*	NA	
[X]	[ ]	[ ]**	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[X]	[ ]	[ ]	Problem completely defined.
[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 (i.e., the reviewer affirms the technical accuracy of the document).

Paul Rittmann — 5-19-00
Reviewer: (Printed and Signed) — Date

* All "NO" responses must be explained below or on an additional page.

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

~~NUCLEAR ENGINEERING~~

Appendix K - DST Head Space and DCRT Capacities

The table below documents the assumed DST and DCRT capacities to overflow used in this analysis. The DST waste volumes were taken HNF-EP-0182-138 (1999). DST capacities to overflow were calculated by subtracting the waste volumes from the estimated total tank volumes. The DCRT capacities were taken from DOE (1999). The DCRTs were assumed to be 80% full.

Tank	Type	Capacity to Overflow (m3)
241-AY-101 - 102	DST	1158
241-AZ-101 - 102	DST	1158
241-AW-101 - 106	DST	802
241-AN-101 - 107	DST	802
241-AP-101 - 108	DST	802
241-SY-101 - 103	DST	802
244-A	DCRT	12
244-BX	DCRT	24
244-S	DCRT	15
244-TX	DCRT	24
244-U	DCRT	24
244-CR	DCRT	11

References

HNF-EP-0182-138, 1999, *Waste Tank Summary Report for Month Ending September 30, 1999*, Lockheed Martin Hanford Corporation, Richland, Washington.

DOE, 1999, *Tank Waste Remediation System Final Safety Analysis Report*, HNF-SD-WM-SAR-067 Rev 1, U.S. Department of Energy, Richland, Washington.

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Appendix L - Historical Time Line Of Leak Events

T, TX and TY Farms

1950	Diversion box 241-TX-155 overflows; waste runs down side of hill (UPR-200-W-5).
Spring '51	Waste leak from riser at 242-T (UPR-200-W-12).
9/52	TX farm contaminated while moving sluice pump (UPR-200-W-17).
10/52	Cooling water leak between 242-T and 207-T (UPR-200-W-14).
11/52	1.33E+04 L (3.5E+03 gal) of 50% nitric acid sent to 241-TX-155 catch tank. Neutralized and pumped to 216-T-20 pit.
3/13/53	241-TX-155 catch tank almost full of nitric acid. Soda ash added to neutralize waste prior to pumpout results in foam eruption from riser (UPR-200-W-131). Tank later abandoned in place and replaced.
3/54	UPR-200-W-100, underground piping leak of 1C.
4/54	Jumper leak and cave-in at diversion box 241-TX-155 (UPR-200-W-135, -28).
11/15/54	1C leak to ground (UPR-200-W-29).
8/59	20-kgal leak from TY-106, diatomite added (UPR-200-W-153).
9/60	35-kgal leak from 241-TY-105 (UPR-200-W-152).
5/4/66	Waste leak while using previously failed line between 241-T-152 and 241-TX-153 (see UPR-200-W-29) (UPR-200-W-62, -97).
9/21/66	Jumper from diversion box 216-TX-153 being moved to T Plant drips waste onto 23rd St. (UPR-200-W-63).
9/21/66	Airborne dust from 216-TX-153 contaminates Camden Ave (UPR-200-W-99).
1/20/67	Excavation for 216-Z-16 trench discovers underground pipe leak (UPR-200-W-130).
2/13/69	Contaminated mud noted around 241-TX-153 (UPR-200-W-64).
1/7/71	Contaminated caustic spray from 241-TX-113 (UPR-200-W-129).
1973	Leak from 241-T-103 (UPR-200-W-147).
1973	Leak from 241-TY-103 (UPR-200-W-150).
4/20/73	115 kgal leak from 241-T-106 (UPR-200-W-148).
5/73	3-kgal leak from 241-TY-103 (UPR-200-W-147).
1974	Leak from 241-TY-104 (UPR-200-W-151).
5/8/75	Surface contamination of TX farm from broken gasket pieces (UPR-200-W-126).
1977	Leak from 241-TX-107 (UPR-200-W-149).
8/24/77	Surface contamination noticed at 241-TX-155 (UPR-200-W-76, -113).
1986	Surface contamination noted at TY farm (UPR-200-W-167).
1992	Surface contamination noted at T trenches (UPR-200-W-166).

B, BX and BY Farms

Mar 20 1951:	UPR-200-E-5, underground cascade piping MW leak at 241-BX-102
Mid-1951:	Continuous overflow from 241-B-112 to 216-B-8
Fall 1951:	UPR-200-E-4, diversion box MW leak at 241-B-151
Dec 1951:	Finish 2C discharge to 216-B-8; isolate crib
1951-1952:	UPR-200-E-73 (UN-216-E-1), diversion box MW leak at 241-B-151
Dec 1952:	UPR-200E-105, overground piping 1C leak at 241-BY-107

Apr 14 1953:	UPR-200-E-108, overground MW leak at 241-B-102
Jun 1953:	UPR-200-E-79 (UN-216-E-7), underground pipeline cooling water leak between 242-B and 207-B
Nov 11 1953:	UPR-200-E-109, riser TBP leak at 241-B-104
1954:	UPR-200-E-6, diversion box leak at 241-B-153
Spring 1954:	UPR-200-E-74 (UN-216-E-2), diversion box leak at 241-B-152
1954-1955:	UPR-200-E-75 (UN-216-E-3), diversion box leak at 241-B-153
Aug 7 1955:	UPR-200-E-110, valve pit MW leak at 241-BY-112
Sep 15 1955:	UPR-200-E-9, flush tank TBP overflow at 216-BY-201 (within UPR-200-E-89)
Jan 4 1968:	UPR-200-E-38, diversion box leak at 241-B-152
Jan 4 1968:	UPR-200-E-76 (UN-216-E-4), underground line leak at 241-B-153
1968:	UPR-200-E-127, tank leak at 241-B-107
1968:	UPR-200-E-129, tank leak at 241-B-201
1969:	UPR-200-E-128, tank leak at 241-B-110
1971:	UPR-200-E-131tank leak at 241-BX-102
Jan 10 1972:	UPR-200-E-43, truck spill on road near BY farm
1972:	UPR-200-E-135, tank leak at 241-BY-108
Nov 20 1972:	UPR-200-E-116, flush water spill at 241-BY-112
May 1973:	UPR-200-E-134, tank leak at 241-BY-103
1974:	UPR-200-E-132, tank leak at 241-BX-102
1974:	UPR-200-E-133, tank leak at 241-BX-108
Apr 1976:	UPR-200-E-130, tank leak at 241-B-203
1978:	UPR-200-E-89 (UN-216-E-17), surface contamination at BY cribs, spread by wind
Aug 1985:	UPR-200-E-101 (UN-216-E-30), surface contamination at 242-B

Appendix M - MCNP Input File "Typical"

The MCNP input file listed below models a waste pool on the surface and a receptor 1.5 m above the surface and 100 m from the center of the pool. The pool is 3.3 cm deep and, in this typical input file, 10 m in radius. A series of cases were run to determine the effect of differing pool radii, with values ranging from 1 cm to 100 m. In order to change the model in this file to represent a different radius, two lines must be changed. The existing radius (10 m) must be replaced with the new radius in the line describing surface card 100 and in source information card 13 (SI13).

```
surface pool (spray leak), 1.5g/cc waste, pool rad= 10
  100     1  -1.6         -500 300 -320 $ground
  200     4  -1.5         -100 320 -330 $pool
  300     3  -0.0012      -500 320 #200 $air
 9999     0   500:-300 $void

c surfaces
  100          cz        1000.
  300          pz        -100.
  320          pz           0.
  330          pz            3.30
  500          so       30000.

mode  p
m1    $  Hanford Concrete
           1001.01p   -0.00310  $  Hydrogen
           8016.01p   -0.44070  $  Oxygen
          11023.01p   -0.01820  $  Sodium
          12000.01p   -0.03760  $  Magnesium
          13027.01p   -0.06070  $  Aluminum
          14000.01p   -0.21570  $  Silicon
          15031.01p   -0.00090  $  Phosphorus
          16032.01p   -0.00090  $  Sulfur
          20000.01p   -0.13060  $  Calcium
          22000.01p   -0.00490  $  Titanium
          25055.01p   -0.00130  $  Manganese
          26000.01p   -0.07880  $  Iron
          36000.01p   -0.00660  $  Krypton
m2    $  Hanford Concrete + 37.3% 1.5g/cc h2o
           1001.01p   -0.00310  $  Hydrogen
           8016.01p   -0.44070  $  Oxygen
          11023.01p   -0.01820  $  Sodium
          12000.01p   -0.03760  $  Magnesium
          13027.01p   -0.06070  $  Aluminum
          14000.01p   -0.21570  $  Silicon
          15031.01p   -0.00090  $  Phosphorus
          16032.01p   -0.00090  $  Sulfur
          20000.01p   -0.13060  $  Calcium
          22000.01p   -0.00490  $  Titanium
          25055.01p   -0.00130  $  Manganese
          26000.01p   -0.07880  $  Iron
          36000.01p   -0.00660  $  Krypton
           1001.01p   -0.03920  $  Hydrogen
           8016.01p   -0.31080  $  Oxygen
m3    $  Air at 80øF and 20.0% Relative Humidity
           1001.01p   -0.00048  $  Hydrogen
           6012.01p   -0.00014  $  Carbon
           7014.01p   -0.75191  $  Nitrogen
           8016.01p   -0.23464  $  Oxygen
          18040.01p   -0.01282  $  Argon
m4    $ water
```

```
       1001.01p  0.66667   8016.01p  0.33333
imp:p  1  2r 0
phys:p
c      ansi/ans-6.1.1-1991 fluence-to-dose,photons(mrem/hr/(p/cm**2/s)
de0    log  .01 .015 .02 .03 .04 .05
            .06 .08 .10 .15 .20 .30
            .40 .50 .60 .80 1.0 1.5
            2.0 3.0 4.0 5.0 6.0 8.0
            10. 12.
df0    log  2.232e-5 5.652e-5 8.568e-5 1.184e-4 1.314e-4 1.382e-4
            1.440e-4 1.624e-4 1.919e-4 2.797e-4 3.708e-4 5.616e-4
            7.416e-4 9.144e-4 1.076e-3 1.379e-3 1.656e-3 2.246e-3
            2.758e-3 3.672e-3 4.500e-3 5.292e-3 6.012e-3 7.488e-3
            8.892e-3 1.040e-2
c
c source 1e10 bq of cs137
c source 1e10 bq of cs137 (@ 0.946 photons per disentigration)
sdef   erg=0.662  cel=200  pos= 0.0 0.0 0.0  rad=d13  ext=d16
       axs=0.0 0.0 1.0  wgt=0.946e10
si13      0.00  1000.         $pool radius
si16      0.00   3.30         $pool depth
c  ----------- tally specifications ----------------
f15z:p 150. 10000. 1.
prdmp  j -10 1 1
print 10 40 50 170
nps    1000000
```

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Appendix N - Peer Review Checklists

Practice 134 290 1112
Publication Date 22Nov99
Attachment 02 - Sheet 1 of 1

FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed:
Title: Stochastic Consequence Analysis for Waste Transfer Leaks
Author: B.E. Hey, S.H. Finfrock, R. M. Marusich, G. W. Ryan
Date: May 2000
Scope of Review: Sections 1-8, Appendices A, B, C, D, F + G

Yes	No*	NA	
[X]	[ ]	[ ] **	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
[X]	[ ]	[ ]	Problem completely defined.
[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).

John C Van Keuren [signature] — 5/22/00
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 intelligible to a technically qualified third party.