COMPLETES

ENGINEERING CHANGE NOTICE

Page 1 of 2

1. ECN 634489

Proj. ECN ——

2. ECN Category (mark one)	3. Originator's Name, Organization, MSIN, and Telephone No.	4. USQ Required?	5. Date
Supplemental [] Direct Revision [X] Change ECN [] Temporary [] Standby [] Supersedure [] Cancel/Void []	B. W. Hall, 8M400, A3-34, 376-3093	[] Yes [X] No	9/19/96
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13a. Description of Change

13b. Design Baseline Document? [] Yes [X] No

Full replacement of Revision document with Revision 1. Significant changes are identified by strikeout and redline.

NOTE: According to Section WP-6.7, Rev. 0 of WHC-CM-6-32, Calculation notes are used to document the originator's analysis but are not to be used to authorize activities or justify facility modifications, or changes to an authorization basis, safety basis, or design basis.

14a. Justification (mark one)

Criteria Change	[]	Design Improvement	[]	Environmental	[]	Facility Deactivation	[]
As-Found	[X]	Facilitate Const	[]	Const. Error/Omission	[]	Design Error/Omission	[]

14b. Justification Details

Minor math errors have been corrected in the revision 1 document. References missing from Rev 0 were also added.

15. Distribution (include name, MSIN, and no. of copies)

See attached distribution list.

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ENGINEERING CHANGE NOTICE

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16. Design Verification Required	17. Cost Impact — ENGINEERING		17. Cost Impact — CONSTRUCTION		18. Schedule Impact (days)	
[] Yes	Additional	[] $	Additional	[] $	Improvement	[]
[X] No	Savings	[] $	Savings	[] $	Delay	[]

19. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 13. Enter the affected document number in Block 20.

SDD/DD	[]	Seismic/Stress Analysis	[]	Tank Calibration Manual	[]
Functional Design Criteria	[]	Stress/Design Report	[]	Health Physics Procedure	[]
Operating Specification	[]	Interface Control Drawing	[]	Spares Multiple Unit Listing	[]
Criticality Specification	[]	Calibration Procedure	[]	Test Procedures/Specification	[]
Conceptual Design Report	[]	Installation Procedure	[]	Component Index	[]
Equipment Spec.	[]	Maintenance Procedure	[]	ASME Coded Item	[]
Const. Spec.	[]	Engineering Procedure	[]	Human Factor Consideration	[]
Procurement Spec.	[]	Operating Instruction	[]	Computer Software	[]
Vendor Information	[]	Operating Procedure	[]	Electric Circuit Schedule	[]
OM Manual	[]	Operational Safety Requirement	[]	ICRS Procedure	[]
FSAR/SAR	[]	IEFD Drawing	[]	Process Control Manual/Plan	[]
Safety Equipment List	[]	Cell Arrangement Drawing	[]	Process Flow Chart	[]
Radiation Work Permit	[]	Essential Material Specification	[]	Purchase Requisition	[]
Environmental Impact Statement	[]	Fac. Proc. Samp. Schedule	[]	Tickler File	[]
Environmental Report	[]	Inspection Plan	[]	None	[X]
Environmental Permit	[]	Inventory Adjustment Request	[]		[]

20. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number Revision
NA		

21. Approvals

	Signature	Date		Signature	Date
Design Authority			Design Agent		
Cog. Eng. B. W. Hall	Britt Hall	9/19/96	PE		
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DEPARTMENT OF ENERGY

Signature or a Control Number that tracks the Approval Signature

ADDITIONAL

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Calculation Notes in Support of TWRS FSAR Spray Leak Accident Analysis

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Westinghouse Hanford Company, Richland, WA 99352
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Abstract: This document includes the calculations needed to quantify the risk associated with unmitigated and mitigated pressurized spray releases from tank farm transfer equipment inside transfer enclosures. The calculations within this document support the spray leak accident analysis reported in the TWRS FSAR.

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(2) Title
Calculation Notes In Support of TWRS FSAR Spray Leak Accident Analysis

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CALCULATION NOTES IN SUPPORT OF TWRS FSAR SPRAY LEAK ACCIDENT ANALYSIS

WHC-SD-WM-CN-048

Rev. 1

Safety Analysis and Nuclear Engineering

1.0 INTRODUCTION

This document contains the detailed calculations that support the spray leak accident analysis in the Tank Waste Remediation System (TWRS) Final Safety Analysis Report (FSAR). The consequence analyses in this document form the basis for the selection of controls to mitigate or prevent spray leaks throughout TWRS.

Pressurized spray leaks can occur due to a breach in containment barriers along transfer routes, during waste transfers. Spray leaks are of particular safety concern because, depending on leak dimensions, and waste pressure, they can be relatively efficient generators of dispersible sized aerosols that can transport downwind to onsite and offsite receptors.

Waste is transferred between storage tanks and between processing facilities and storage tanks in TWRS through a system of buried transfer lines. Pumps for transferring waste and jumpers and valves for rerouting waste are located inside below grade pits and structures that are normally covered. Pressurized spray leaks can emanate to the atmosphere due to breaches in waste transfer associated equipment inside these structures should the structures be uncovered at the time of the leak. Pressurized spray leaks can develop through holes or cracks in transfer piping, valve bodies or pump casings caused by such mechanisms as corrosion, erosion, thermal stress, or water hammer. Leaks through degraded valve packing, jumper gaskets, or pump seals can also result in pressurized spray releases. Mechanisms that can degrade seals, packing and gaskets include aging, radiation hardening, thermal stress, etc. Another common cause for spray leaks inside transfer enclosures are misaligned jumpers caused by human error.

A spray leak inside a DST valve pit during a transfer of aging waste was selected as the bounding, representative accident for detailed analysis. Sections 2 through 5 below develop this representative accident using the DOE-STD-3009 format. Sections 2 describes the unmitigated and mitigated accident scenarios evaluated to determine the need for safety class SSCs or TSR controls. Section 3 develops the source terms associated with the unmitigated and mitigated accident scenarios. Section 4 estimates the radiological and toxicological consequences for the unmitigated and mitigated scenarios. Section 5 compares the radiological and toxicological consequences against the TWRS evaluation guidelines.

Section 6 extrapolates from the representative accident case to other represented spray leak sites to assess the conservatism in using the representative case to define controls for other postulated spray leak sites throughout TWRS. Section 7 discusses the sensitivities of the consequence analyses to the key parameters and assumptions used in the analyses. Conclusions are drawn in Section 8.

The analyses herein pertain to spray leaks initiated due to internal mechanisms (e.g., corrosion, erosion, thermal stress, etc). External initiators of spray leaks (e.g., excavation accidents), and natural phenomena initiators (e.g., seismic events) are to be covered in separate accident analyses.

2.0 SCENARIO DEVELOPMENT

This section describes the unmitigated and mitigated accident scenarios for the valve pit spray leak, and estimates the frequency range associated with the unmitigated and mitigated scenarios to allow for comparison against evaluation guidelines.

2.1 UNMITIGATED ACCIDENT SCENARIO

2.1.1 Scenario Description

Spray leaks inside valve pits can develop due to breaches in the pressure boundary of piping, jumpers, or valves. Leaks in piping, jumpers, or valve bodies can develop due to such mechanisms as erosion, corrosion, thermal stress, fatigue, weld flaws, manufacturing flaws, etc. Leaks at jumper connections to transfer pipes can occur due to human error (misalignment of the jumper), or gasket failure. Valves can leak through valve stem packing or seals. Gaskets, packing and seals degrade due to radiation hardening, aging, and thermal stress. Valve seals can also leak due to torque generated in jumper connections.

For the unmitigated scenario, it is postulated that a spray leak develops in a valve pit due to one of the mechanisms discussed above. (The initiating mechanism is not important to the analysis as mitigation rather than prevention of the initiator was found to be the best solution to the spray leak problem.) The spray is postulated to occur during a transfer of aging waste through the pit. Aging waste is selected for the bounding analysis as it produces the highest dose, on a per liter basis, of all tank waste types.

The unmitigated analysis assumes away all preventative and mitigative barriers for the purpose of determining the need for safety class or safety significant SSCs and TSR controls. It is therefore assumed that the pit cover blocks (which are the primary barrier to release) are off at the time of the leak. Such an unmitigated release could occur if the cover blocks are not replaced following a jumper change or maintenance activity in the pit and a subsequent transfer is made through that pit, or if cover blocks are inadvertently removed during a transfer, or if waste is misrouted through a pit where jumper change or maintenance activities are ongoing. The spray is postulated, due to its momentum, to emit up and out of the pit directly into the atmosphere.

The uncovered spray leak is assumed to continue unabated for 24 hours. The onsite receptor is assumed to be exposed to the plume of aerosols generated in the accident for 12 hours (this duration accounts for a work shift with possible overtime). The offsite receptor is assumed to be exposed to the entire passage of the plume, or 24 hours. It is arbitrarily assumed that the pump is shutoff at 24 hours. Although it is possible the leak could continue longer than this, this duration is sufficient to determine the safety class ramifications of the accident. The sensitivity of the analysis to assumed accident duration is discussed in Section 8.

2.1.2 Unmitigated Accident Frequency

The unmitigated accident frequency is assigned based on the frequency of the initiating event only. In this case, the initiating event is a spray leak from equipment inside the pit. The conditional probability that the cover blocks are off at the time of the spray leak is not factored into the frequency assignment.

The initiating event is considered to be in the Anticipated frequency category (1E-2 events/yr to 1 event/yr), when applied to the many valve pits across the tank farm. This frequency category is assigned based on Hanford Site experience. The table in Appendix A summarizes occurrence reports relating to leaks from transfer equipment inside process pits or diversion boxes. This table covers events back to 1972. Fourteen events are included in the table where waste or contaminated water was found to have leaked during transfers or during flushing from failed equipment in pump pits, valve pits, sluice pits, or flush pits. In four of the occurrence reports involving leaks into pits, the leaks are specifically described as sprays. The remaining ten leaks were found after the fact and may have been been sprays or low pressure liquid releases where aerosol generation would be greatly reduced.

Note that in occurrence report 77-205, the spray leak occurred during a leak test while the cover blocks were removed from the pit. Contaminated water was sprayed onto two workers standing outside the pit.

2.2 MITIGATED ACCIDENT SCENARIO

2.2.1 Scenario Description

The primary mitigative barriers to a valve pit spray leak are the valve pit cover blocks. These blocks, when in place, knock down the spray and impede the release of aerosols to the atmosphere. For the mitigated scenario, it is thus postulated that the spray leak occurs with the pit covers in place.

The cover blocks are the only potentially effective existing barrier to limit the consequences of the spray release. Efficient aerosol generating spray leaks occur through small orifices or narrow cracks. Pit leak detectors are not sensitive enough to detect low flowrate spray leaks. The liquid fraction of release may dribble down the sides of the drain pipe from the pit without contacting the conductivity probes. The consequence analysis below shows that the doses from an unmitigated spray leak are very large in a short period of time for the onsite receptor. For pits with leak detectors in sumps, the time required to buildup enough liquid to set of the leak detector would be too long to prevent unacceptable consequences to the onsite receptor.

Mass balances performed every two hours during transfers are also not sensitive enough to detect the small amount of material lost in a spray leak.

A half inch discrepancy in the receipt tank generally warrants a shutdown of transfer pumps. For double shell storage tanks, the half inch discrepancy corresponds to a material loss of 1375 gallons. Leak quantities much smaller than this are shown below to produce onsite and offsite consequences in excess of evaluation guidelines.

Since no effective controls exist to limit the duration of the spray leak, the mitigated spray leak is assumed to continue for the same duration as the unmitigated scenario, or 24 hours. As in the unmitigated scenario, the onsite receptor is assumed to be exposed for 12 hours, the offsite receptor for 24 hours.

The mitigated scenario allows for the examination of the effectiveness of the cover blocks as the only mitigative barrier to the release.

2.2.2 Mitigated Accident Frequency

The mitigated accident frequency category is Anticipated. The frequency category is the same as for the unmitigated accident scenario because no safety SSCs or TSR controls are credited with reducing the likelihood of the initiating event.

3.0 SOURCE TERM ANALYSIS

The waste postulated to be sprayed in both the unmitigated and mitigated scenarios is aging waste, containing 33 vol % entrained solids. Aging waste slurry is selected for bounding analyses because aging waste solids produce the highest dose of all waste types, based on the unit liter dose (ULD) factors reported in WHC-CM-SARR-037 (1996). The ULDs for aging waste, DST waste, and SST waste from SARR-037 are reproduced in Table 4-1.

33 vol % entrained solids is the maximum expected solids loading during transfers. This solids loading value is considered to be bounding. The upper operating limit of the 242-A evaporator, which produces the most concentrated slurry currently transferred in the tank farms, is 30 vol % solids. Level readings in receipt tanks indicate that the entrained solids content in most supernate transfers is very small (e.g., the feed tank to the 242-A evaporator is not full of solids, despite the fact that millions of gallons of waste have been run through the evaporator). Grab samples taken from supernate layers in waste storage tanks typically measure trace amounts to 5 vol % solids. There is some concern however that submersible and saltwell pumps lowered near sludge layers could entrain much more than 5 vol % solids during individual transfers. The solids are assumed to spray through the leakage path in proportion to the solids content in the waste being pumped through the transfer line. The sensitivity of the consequence analysis results to assumed solids content is discussed in Section 8, including the potential for plugging of the leakage path with waste solids.

The following subsections quantify the aerosol releases of aging waste to the atmosphere for the unmitigated and mitigated scenarios, respectively.

3.1 UNMITIGATED ACCIDENT SOURCE TERM

The SPRAY model was used to determine the flowrate and particle size distribution of the aerosols generated in the unmitigated spray release. For a detailed description of the spray model, see WHC-SD-GN-SWD-20007 (1994). In summary, SPRAY determines the total leak rate and aerosol particle size distribution based on the dimensions of the orifice or crack that is postulated to have caused the leak, the fluid pressure, the fluid viscosity, and the fluid density. SPRAY first determines the leakage flowrate and jet velocity exiting the orifice or crack using Bernoulli's equation. Cracks or orifices that are efficient generators of aerosols are very small, so the depth of the orifice or crack can be large in comparison to the diameter or width of the orifice or crack. Hence, frictional losses across the depth of the leakage path can be significant. The Darcy frictional losses across the depth of the crack are calculated by SPRAY by entering the depth of the leakage path, and the surface roughness of the leakage path as inputs. The liquid stream exiting the orifice or crack disintegrates due to turbulence and aerodynamic drag forces exerted by the surrounding air. SPRAY estimates the Sauter Mean Diameter (SMD) of the droplets formed based on the hydraulic radius of the orifice or slit, the kinematic viscosity of the liquid, and the liquid jet velocity, using an empirical correlation. From the SMD, the particle size distribution of the aerosol is calculated using an empirical particle size distribution. The SPRAY code has a subroutine to iteratively solve for the orifice diameter or crack width that produces the maximum flowrate of aerosols below a requested size.

3.1.1 SPRAY Input

For the purposes of modelling this accident, the spray leak was assumed to occur at a misaligned jumper connection to a 2 in., schedule 40 slurry transfer line. The leak was assumed to be 5.1 cm (2 in.) long. This leak length was selected because it represents, roughly, the fraction of the jumper connection circumference that could orient a spray up and out of an uncovered pit. This length is judged to be conservative for longitudinal cracks that might develop in pipes. To factor in the Darcy frictional losses across the depth of the leakage path, an equivalent crack depth of 0.391 cm (the thickness of a 2 in., Schedule 40 pipe) was entered into the code. The walls of the leakage path were assumed to have a surface roughness equivalent to that of steel, or 0.0046 cm.

The leak was assumed to occur at a maximum waste gauge pressure of 2.1 MPa (300 psi). This maximum waste pressure was selected based on a review of DST and AWF transfer pump performance curves. Appendix B contains the pump curves obtained for various transfer pumps throughout TWRS. The 300 psi limit was set based on the pump curve for the cross site transfer pump in Tank 102-SY. From Appendix B, the shutoff head for this pump is 410 ft for a fluid with an SpG of 1.7. This coverts to pressure as follows:

102-SY Deadhead Pump Pressure = (410 ft)(1.7 ft water/ft of slurry)(14.7 psi/33.9 ft water)
= 300 psig.

The 300 psi assumption is bounding for all pumps considered except the PB-2 pump in the 242-A evaporator. The variable speed drive PB-2 pump can produce pressures higher than 300 psi at its highest RPM setting. However, a rupture disk and a PRV are provided in the evaporator to limit pressure in transfer lines to less than 250 psi.

Because of the high shear rate induced in the spray leak, the thixotropic waste slurry was assumed to have a viscosity approaching that of water, or 1 cPs.

At 33 vol% solids, aerosols up to 14.5 μm in diameter can evaporate down to their solids constituents in the respirable (10 μm) size range after being emitted into the atmosphere. This can be determined using the following equation, which assumes spherically shaped particles:

$$D_i = (D_f^3/E)^{1/3}$$

Where,

D_i = diameter of initial aerosol
D_f = diameter of final aerosol
E = volume fraction of solids in initial aerosol.

The SPRAY code was used to iteratively solve for the crack width that produced the maximum flow rate particles 15 μm in diameter and less. The sub-15 μm particles are treated as respirable in the consequence calculations in Section 4.

3.1.2 SPRAY Results

The input and output files from the SPRAY run are included in Appendix C (see Case 1). The optimum crack width was found to be 1.1E-2 cm. The velocity of the jet issuing from the crack was found to be 26.5 m/s. The total flow rate through the optimum-sized leak was found to be 9.20 L/min. The respirable aerosol release rate from the spray was found to be 0.21 L/min, giving a respirable release fraction of 2.3%. Over a 12-hour period (i.e., exposure duration for the onsite receptor), this release rate corresponds to a total volumetric release of waste material in the respirable size range of 150 L. Over a 24-hour period, the total volume of waste released in the respirable size range is 300 L.

3.2 MITIGATED ACCIDENT SOURCE TERM

In the mitigated accident, the pit covers provide an impaction surface that prevents the jetting of aerosols directly into the atmosphere. The covers also create a relatively stagnant air volume that fosters agglomeration and rainout of aerosols within the pit. Aerosol removal also occurs due to condensation on the pit walls and the underside of the cover blocks. Aerosol is further removed from any air expelled from the pit through the cover block gaps because the leakage paths are tortuous and provide additional surfaces for impingement and condensation.

For the mitigated analysis it is assumed that any air expelled from the pit would be limited in aerosol concentration to the quasi-stable aerosol loading limit of 100 mg/m^3 (PNL-4154, Section 2.4.14 and BNWL-1732, Appendix C). Use of this value is considered to be conservative. For comparison purposes typical fog measures 10 mg/m^3 (PNL-2844, Appendix A). The aerosols expelled from the pit are all conservatively assumed to be in the respirable size range (less than 10 μm in diameter).

The cover blocks are not sealed and thus do not ensure confinement of aerosols. Gaps around cover blocks, gaps around plugs in the drain ports, access gaps around camera hatches, and valve handle penetrations provide leakage paths for some of the aerosol generated in the spray to be expelled from the pit.

The valve pit drain is connected to a ventilated DST. Normally, this vent system ensures a slightly negative pressure in the pit. Under spray leak conditions, however, a resulting temperature and humidity increase in the pit air could cause a volume expansion of the air that overcomes the draw of the DST ventilation system. There is also the possibility that the pit drain could be plugged (some drains are plugged by design to allow buildup for leak detectors to work), in which case the liquid spilling to the pit floor would also displace aerosol-laden air from the pit.

3.2.1 Air Expulsion due to Temperature and Humidity Increase

This effect can be estimated using psychrometric charts. The largest volume expansion occurs with the greatest temperature and humidity difference across the course of the accident. Assume the air in the pit is initially at 30 F and 15 % relative humidity (R.H). These are judged to be a conservatively low values as the pit air temperature and humidity would be moderated somewhat by heat transfer from the soil and the waste tank connected via the valve pit drain line. Conservative final values to assume for the pit air temperature and humidity are 120 F and 100 % R.H. 120 F is the maximum expected waste temperature during transfers. Heat transfer through the walls and covers of the pit, and evaporative cooling could be expected to keep the final, steady-state pit air temperature below the assumed 120 F limit.

A psychrometric chart is included in Appendix E. From this chart, the specific volume of air at 30 F and 15 % R.H. is about 12.35 ft^3/lb of dry air. The specific volume at 120 F and 100 % R.H. is about 16.7 ft^3/lb of dry air. The volume of air displaced by liquid aerosols is small in comparison to the total volume of the pit. This effect was therefore ignored. Dividing the final pit air specific volume by the initial pit air specific volume gives an estimated volume expansion of 0.35 pit volumes [(16.7/12.35) - 1].

Valve pits range in size. A typical sized DST valve pit is 241-AW-A. The dimensions of this pit are 14' x 12' by 6'7" deep, for a total volume of 1110 ft^3. The largest active valve pit (241-AP) has dimensions of 61' x 16' x 8' deep, for a total volume of 7810 ft^3 (220 m^3). Although the temperature, humidity and aerosol concentrations assumed in this analysis are judged to be more representative of what might happen in the nominal sized valve pit, the spray leak is assumed to occur in the larger valve pit and produce the same final conditions as in the nominal case. This is done to maximize the total air volume expelled. Using the largest pit volume gives a volumetric release (air expelled) of 77 m^3 [(0.35)(220 m^3)]. This release occurs during the initial stages of the accident.

3.2.2 Air Expulsion due to Liquid Displacement

The air expulsion rate due to liquid displacement is a function of the total leak rate through the crack, which is variable. Larger leaks are less efficient generators of aerosols but displace air from the pit at a higher rate. For the mitigated analysis, it is assumed that liquid spilling into the pit displaces air from the pit at a rate of 4.6 m^3/hr. This corresponds to a liquid flowrate of 76 L/min (20 gpm). At this flowrate, the pit will be filled half full during the 24 hour duration of the accident. The piping in the pit will be submerged and aerosol production suppressed when the liquid reaches this level, so this flowrate maximizes the total volume of air expelled. Liquid flowrates larger than 20 gpm will not be efficient generators of aerosols and do not have to be considered.

3.2.3 Aerosol Release Quantities

Multiplying the air expulsion volume by the aerosol loading limit of 100 mg/m^3 gives the equivalent mass of tank waste released in the accident. This is converted to equivalent volume using an estimated density for the waste of 1.4 g/cc. This density corresponds to the upper operating limit of the evaporator and is judged to be representative of waste containing 33 vol % entrained solids.

The release of aerosols from the pit varies as a function of time. The release rate in the first hour is much higher than the release during the remainder of the accident, due to the volume expansion due to the initial temperature and humidity increase. The release of aerosols over the first hour of the accident is combination of both effects.

The equivalent volume of waste released over the first hour of the accident is estimated as follows:

$$Q(1st\ h) = [77\ m^3 + (4.6\ m^3/h)(1\ h)](100\ mg/m^3)(1\ L/1.4E6\ mg) = 5.8E{-}3\ L$$

The equivalent volume of waste released between 1 and 12 hours (used to estimate onsite dose) is estimated as follows:

$$Q(1\ to\ 12\ h) = (4.6\ m^3/h)(11\ h)(100\ mg/m^3)(1\ L/1.4E6\ mg) = 3.6\ E{-}3\ L$$

The equivalent volume of waste released over the time frame between 1 hour and 24 hours (used to estimate portion of offsite dose) can be linearly scaled from the 1- to 12-h result:

$$Q(1\ to\ 24\ h) = (3.6E{-}3\ L)(23/11) = 7.5E{-}3\ L$$

4.0 CONSEQUENCE ANALYSIS

The aerosol release results in both radiological and toxicological exposures. The radiological and toxicological consequences are calculated for the unmitigated accident in Section 4.1. The radiological and toxicological consequences for the mitigated accident are calculated in Sections 4.2.

4.1 UNMITIGATED ACCIDENT CONSEQUENCES

The unmitigated accident consequence analysis is divided into two subsections. Radiological consequences are quantified in subsection 4.1.1 below. Toxicological consequences are calculated in subsection 4.1.2.

4.1.1 Unmitigated Radiological Consequences

The onsite and offsite doses are calculated in accordance with the methodology outlined in WHC-SD-WM-SARR-016 (1996) and WHC-SD-WM-SARR-037 (1996). An inhalation dose is calculated for the onsite receptor. The offsite receptor receives an inhalation dose and is also assumed to receive a 24 hour uptake ingestion dose.

The inhalation doses to the onsite and offsite receptors are calculated as follows:

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

The ingestion dose to the offsite receptor is calculated with the following equation:

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

Where,

D_{inh} = dose, in Sv (50-yr CEDE)
D_{ing} = dose, in Sv (50-yr CEDE)
Q = respirable release volume over time period of concern, in equivalent L of waste material
X/Q' = atmospheric dispersion coefficient, in s/m^3, from SARR-016
BR = receptor breathing rate, in m^3/s
ULD_{inh} = inhalation unit liter dose, in Sv/L, from SARR-037
ULD_{ing} = ingestion unit liter dose, in Sv-m^3/s-L, from SARR-037

The release volumes (Q) over 12 and 24 hours are reported in Section 3.1.2. The acute and annual X/Q's for the onsite and offsite receptor locations are summarized in SARR-016 and reproduced in Tables D-1 and D-2. X/Q's interpolated from the acute and chronic X/Q's for various time periods of interest in the TWRS accident analyses are calculated in Appendix D and summarized in Table D-3. The active man's breathing rate (BR) is 3.3E-4 m^3/s (see SARR-016). This breathing rate applies to the onsite receptor during the entire duration of exposure. The inactive breathing rate is 1.5E-4 m^3/s.

This breathing rate applies to the offsite receptor during an assumed 8 hours out of every 24 hours when the receptor is at rest. The 24-h average BR for the offsite receptor is 2.7E-4 m^3/s [(16/24)(3.3E-4) + (8/24)(1.5E-4)].

The ULDs from SARR-037 for both the inhalation and ingestion pathways, by waste type, are reproduced in Table 4-1. For this accident, the waste being sprayed is assumed to be composed of a composite slurry of aging waste containing 33 vol % solids, 77 vol % liquids. From Table 4-1, the ULD_{inh} for aging waste solids is 1.7E+06 Sv/L. The ULD_{inh} for aging waste liquids is 1.4E03 Sv/L. The ULD_{inh} for the composite slurry is thus 5.6E+05 Sv/L [(0.33)(1.7E+06) + (0.67)(1.4E+03 Sv/L)]. Calculating in the same manner, the aging waste composite slurry ULD_{ing} is 2.7 Sv-m^3/L-s [(0.33)(8.1) + (0.67)(0.092)].

4.1.1.1 Onsite Receptor Dose. From Section 3.1.2, the 12 hour respirable release volume is 150 L. From Table D-3 (in Appendix D), the 12 hour onsite X/Q' is 5.54E-3 s/m^3. The inhalation ULD from above is 5.6E+5 Sv/L. Using the active breathing rate, the onsite dose is:

$$\text{Dose(inh, on)} = (150\ \text{L})(5.54\text{E-3}\ \text{s/m}^3)(3.3\text{E-4}\ \text{m}^3\text{/s})(5.6\text{E5}\ \text{Sv/L}) = 150\ \text{Sv}\ (1.50\text{E+4 rem}).$$

4.1.1.2 Offsite Receptor Dose. From Section 3.1.2, the 24 hour respirable release volume is 300 L. From Table D-3 (Appendix D), the 24 hour offsite X/Q' is 4.62E-6 s/m^3. The inhalation ULD from above is 5.6E+5 Sv/L. Using the 24 hour average receptor rate, the offsite inhalation dose is:

$$\text{Dose(inh, off)} = (300\ \text{L})(4.62\text{E-6}\ \text{s/m}^3)(2.7\text{E-4}\ \text{m}^3\text{/s})(5.6\text{E5}\ \text{Sv/L}) = 0.21\ \text{Sv}.$$

Using the ingestion ULD from above, the offsite ingestion dose is:

$$\text{Dose(ing, off)} = (300\ \text{L})(4.62\text{E-6}\ \text{s/m}^3)(2.7\ \text{Sv-m}^3\text{/L-s}) = 3.7\text{E-3}\ \text{Sv}$$

The total offsite dose from both pathways is:

$$\text{Dose(total, off)} = 0.21\ \text{Sv}\ (21\ \text{rem})$$

The ingestion pathway added insignificantly to the inhalation dose (within the significant digits of the calculation).

4.1.2 Unmitigated Toxicological Exposures

Onsite and offsite toxicological exposures are assessed using the sum-of-fractions methodology outlined in WHC-CM-SARR-011 (1996). Table 4-2 gives the unit liter sum-of-fractions multipliers for the various waste types, broken into liquids values and solids values. Note that the sum-of-fraction multipliers are dependent on accident frequency.

For the waste type postulated to be released in this accident, a composite sum-of-fractions multiplier must be determined. The frequency category of the unmitigated accident is Anticipated (>1E-2 events/yr). For DST solids (for toxicological assessments the DST values are used for aging waste), the onsite sum-of-fractions multiplier from Table 4-2 is 1.8E+04 s/L; the offsite value is 1.9E+02 s/L. The onsite and offsite sum-of-fractions multiplier for DST liquids are 1.0E+04 s/L and 8.4 s/L, respectively. Based on a solids content of 33 vol %, the composite sum of fractions multiplier for the onsite and offsite receptors are:

Composite sum-of-fractions multiplier, onsite = (0.33)(1.8E+04) + (0.67)(1.0E+04)
= 1.3E+04 s/L

Composite sum-of-fractions multiplier, offsite = (0.33)(1.9E+02) + (0.67)(8.4)
= 68 s/L

Toxicological exposure is assessed by multiplying the release rate by the sum-of-fractions multiplier. Products less than one are considered to indicate acceptable risk (i.e., indicate exposures below evaluation guidelines).

From Section 3.1.2, the respirable aerosol release rate in the unmitigated accident was found to be 0.21 L/min, or 3.5E-3 L/s. Multiplying by the onsite sum-of-fractions multiplier gives a product of 46 [(3.5E-3 L/s)(1.3E4 s/L)]. The offsite product is 0.24 [(3.5E-3 L/s)(68)].

4.2 MITIGATED ACCIDENT CONSEQUENCES

4.2.1 Mitigated Radiological Consequences

The mitigated dose consequences are calculated using the same dose model discussed for the unmitigated accident in Section 4.1.1. However, since the release varies with time, a dose is calculated for the first hour of the release and added to the dose from the next 11 hours to estimate the onsite receptor dose. To estimate the offsite receptor dose, the 1-h dose is added to the 1- to 24-h dose. The acute, 1-h, X/Q' is used to estimate the dose during the first hour of the release. The appropriate extended duration X/Q's from Table D-1 are used to estimate the doses following the first hour of the accident.

4.2.1.1 Onsite Receptor Dose. The acute X/Q' for the onsite receptor from Appendix D is 3.41E-2 s/m^3. From Section 3.2.3, Q(1st hr) = ~~5.7E-03~~ 5.8E-3 L. The waste composite inhalation ULD from 4.1.1 is 5.6E+5 Sv/L. The dose to the onsite receptor during the first hour is

D(inh,on,1h) =(~~5.7E-03~~ 5.8E-3 L)(3.41E-2 s/m^3)(3.3E-4 m^3/s)(5.6E+5 Sv/L)
= ~~3.6E-02~~ 3.7E-02 Sv.

The release during the 1- to 12- h time frame, from Section 3.2.3, is 3.6E-3 L. From Table D-3, the 11 hour onsite X/Q' is 5.74E-3 s/m^3. The dose during this timeframe is therefore

$$D(inh,on,1\text{-}12\ h) = (3.6E\text{-}3\ L)(5.74E\text{-}3\ s/m^3)(3.3E\text{-}4\ m^3/s)(5.6E5\ Sv/L) = 3.8E\text{-}3\ Sv.$$

The total onsite dose is

D(inh,on,tot) = ~~4.0E-02~~ 4.1E-02 Sv (~~4.0~~ 4.1 rem)

4.2.1.2 Offsite Receptor Dose. The acute X/Q' for the offsite receptor from Appendix D is 2.83E-5 s/m^3. From Section 3.2.3, Q(1st hr) = 5.7E-3 L. The waste composite inhalation ULD from Section 4.1.1 is 5.6E+5 Sv/L. The ingestion ULD is 2.7 Sv-m^3/L-s. The inhalation and ingestion doses to the offsite receptor during the first hour are therefore:

$$D(inh,off,1h) = (5.8E\text{-}3\ L)(2.83E\text{-}5\ s/m^3)(3.3E\text{-}4\ m^3/s)(5.6E{+}5\ Sv/L) = 3.0E\text{-}5\ Sv.$$

$$D(ing,off,1h) = (5.8E\text{-}3\ L)(2.83E\text{-}5\ s/m^3)(2.7\ Sv\text{-}m^3/L\text{-}s) = 4.4E\text{-}7\ Sv$$

The release during the 1- to 24- h time frame, from Section 3.2.3, is 7.5E-3 L. From Table D-3, the 23 hour offsite X/Q' is 4.74E-06 s/m^3. The doses during this timeframe are therefore

$$D(inh,off,1\text{-}24\ h) = (7.5E\text{-}3\ L)(4.74E\text{-}6\ s/m^3)(3.3E\text{-}4\ m^3/s)(5.6E5\ Sv/L) = 6.6E\text{-}6\ Sv.$$

Note: to simplify calculation, the above equation conservatively ignores the fall off in breathing rate during the period of time the receptor is at rest.

$$D(ing,off,1\text{-}24\ h) = (7.5E\text{-}3\ L)(4.74E\text{-}6\ s/m^3)(2.7\ Sv\text{-}m^3/L\text{-}s) = 9.6E\text{-}8\ Sv$$

The total offsite dose from both pathways, over both time increments, is:

Dose(total,off) = 3.7E-5 Sv (3.7E-3 rem)

4.2.2 Mitigated Toxicological Exposures

Toxicological exposures are assessed by looking at the peak concentration at the receptor location, as opposed to determining a time integrated exposure as in radiological dose calculations. The toxicological sum-of-fractions values are based on one hour exposures limits (e.g., ERPGs). It is generally interpreted that the peak concentration values to compare against the guidelines should be based on peak, 15 minute average concentrations.

The maximum aerosol release rate from the pit occurs during the initial temperature and humidity induced expansion. From Section 3.2.3, the volume of air expelled during this expansion is 77 m^3. Assume this entire volume comes out during the first 15 minutes of the accident. Also add in the volume of air displaced due to liquid spilling to the floor at a rate of 76 L/min (20 gpm). The aerosol release during the first 15 minutes of the accident can be calculated in the same manner to the one hour release rate calculated in Section 3.2.3:

$$Q(1st\ 15\ min) = [77\ m^3 + (0.076\ m^3/min)(15\ min)](100\ mg/m^3)(1\ L/1.4E6\ mg) = 5.6E-3\ L$$

Dividing by 15 gives the 15 minute average release rate, or 3.7E-4 L/min, or 6.2E-6 L/s. Using the composite sum-of-fractions multipliers from Section 4.1.2, the onsite and offsite receptor exposures, for the mitigated accident, are:

Onsite sum-of-fractions = (6.2E-6 L/s)(1.3E4 s/L) = 8.1E-2

Offsite sum-of-fractions = (6.2E-6 L/s)(68 s/L) = 4.2E-4

5.0 COMPARISON TO EVALUATION GUIDELINES

The radiological doses and toxicological exposures for the unmitigated and mitigated accidents are summarized and compared against the TWRS evaluation guidelines (EGs) in Table 5-1.

The unmitigated accident radiological doses are well above both the offsite and onsite evaluation guidelines corresponding to the frequency category of the accident (Anticipated). The unmitigated offsite dose exceeds the EG for the Unlikely category as well. The unmitigated onsite dose is well above the EG for the Extremely Unlikely category. The offsite dose from the mitigated spray leak is shown to be acceptable. The onsite dose for the mitigated accident, however, is ~~slightly~~ above the EG for the anticipated category.

The toxicological sum-of-fractions is well over one for the unmitigated accident at the onsite receptor location. The toxicological consequences therefore exceed the onsite evaluation guidelines. The offsite toxicological consequences for the unmitigated accident are below evaluation guidelines. With the cover blocks on the toxicological sum-of-fractions is shown be well below one and hence well below the evaluation guidelines for both the onsite and offsite receptors.

6.0 EXTRAPOLATION TO OTHER RELEVANT CASES

The valve pit spray leak involving aging waste was selected as the bounding, representative accident of its type. Spray leaks, however, can occur at a variety of locations throughout the tank farm transfer systems. Other process pits can experience leaks at different pressures, and with different types of waste than the representative case analyzed above. Three cases are discussed specifically in this section, to examine the conservatisms in using the aging waste spray leak as the representative case: 1) a spray leak from a valve pit involving DST waste, and 2) a spray leak inside an SST pump pit (during saltwell pumping), and 3) a spray leak inside a DCRT pump pit. All three cases examined occur inside process pits. The process pit cases are adequate to represent the other potential leakage sites (e.g., sprays inside cleanout boxes, sprays from encasement risers, sprays inside diversion boxes) because the unmitigated consequences in all cases would be expected to be similar. In all the unmitigated cases the spray emits directly to the atmosphere.

The radiological doses are shown in Section 5 to be limiting (i.e., the onsite radiation EGs are exceeded quicker than the onsite toxicological EGs). A comparison of radiation doses is therefore sufficient to draw conclusions about spray leaks at the additional spray leak sites. The following three sections develop the source terms and doses associated with the three additional spray leak sites. The doses are compared against the representative case and EGs in Section 6.4.

6.1 SPRAY LEAK OF DST WASTE INSIDE VALVE PIT

The potential leak dimensions in the DST case are the same as in the aging waste case. The gross waste properties (e.g., viscosity, density, solids content) can be assumed to be similar in both cases. Assuming a 2 inch long crack in a 2 inch schedule 40 pipe and a 300 psig maximum pressure, the optimum respirable aerosol release rate is the same in the DST case as in the aging waste case. The doses in the DST case can therefore be estimated simply by multiplying the aging waste results by the ratio of the DST waste composite ULD to the aging waste composite ULD.

For a DST waste stream containing 33 vol % solids, the composite inhalation and ingestion ULDs, using the values from Table 4-1 are:

$$\text{DST composite ULD}_{inh} = (0.33)(5.3\text{E5 Sv/L}) + (0.67)(6.1\text{E3 Sv/L}) = 1.8\text{E5 Sv/L}$$

$$\text{DST composite ULD}_{ing} = (0.33)(0.48\text{ Sv-m/L-s}) + (0.67)(0.068\text{ Sv-m/L-s}) = 0.20\text{ Sv-m}^3\text{/L-s}$$

These ULDs compare to 5.6E5 Sv/L and 2.7 Sv-m^3/L-s, respectively for the aging waste case.

6.1.1 Unmitigated Accident Doses

Ratioing the doses reported in Section 4.1.1 for the unmitigated scenario gives the following results:

Onsite Dose

D(inh,on) = (150 Sv)(1.8E5 Sv/L)/(5.6E5 Sv/L)
= 48 Sv (4800 rem)

Offsite Dose

D(inh,off) = (0.21)(1.8E5 Sv/L)/(5.6E5 Sv/L)
= 6.8E-2 Sv (6.8 rem)

D(ing,off) = (3.7E-3 Sv)(0.20 Sv-m^3/L-s)/(2.7 Sv-m^3/L-s)
= 2.7E-4 Sv (2.7E-2 rem)

D(tot,off) = 6.8E-2 Sv (6.8 rem)

6.1.2 Mitigated Accident Doses

Ratioing the doses reported in Section 4.1.2 gives the following results:

Onsite Dose

D(inh,on,1h) = (3.6E-2 Sv)(1.8E5 Sv/L)/(5.6E5 Sv/L)
= 1.2E-2 Sv

D(inh,on,1-12h) = (3.8E-3 Sv)(1.8E5 Sv/L)/(5.6E5 Sv/L)
= 1.2E-3 Sv

The total onsite dose is:

D(tot,on) = 1.3E-2 Sv (1.3 rem)

Offsite Dose

D(inh,off,1h) = (3E-5 Sv)(1.8E5 Sv/L)/(5.6E5 Sv/L)
= 9.6E-6 Sv (9.6E-4 rem)

D(ing,off,1h) = (4.4E-7 Sv)(0.20 Sv-m^3/L-s)/(2.7 Sv-m^3/L-s)
= 3.3E-8 Sv (3.3E-6 rem)

D(inh,off,1-24h) = (6.7E-6 Sv)(1.8E5 Sv/L)/(5.6E5 Sv/L)
= 2.1E-6 Sv (2.1E-4 rem)

D(ing,off,1-24h) = (9.7E-8 Sv)(0.20 Sv-m^3/L-s)/(2.7 Sv-m^3/L-s)
= 7.2E-9 Sv (7.2E-7 rem)

The total offsite dose is

D(off,tot) = 1.2E-5 Sv (1.2E-3 rem)

The ingestion doses are insignificant in comparison to the inhalation doses for this case.

6.2 SPRAY LEAK INSIDE SST PUMP PIT

Surface liquids and saltwell liquor are pumped out of SSTs usually using saltwell jet pumps. In some cases, submersible pumps are used. The pump curves for each type are included in Appendix B. The SST liquids (which will include some entrained solids) are usually transferred to a DCRT, where eventually the waste is batch transferred to DST. The pump curves in Appendix B show that the pressure potential in the SST transfer lines between SST and DST pump pits is much smaller than for aging waste or DST transfers.

In the saltwell jet pump system, waste is recirculated in a loop of piping running between the tank and the SST pump pit. A diaphragm operated valve (DOV) opens and shuts as required to pump the tank without letting the saltwell run dry, which would cavitate the pump. Pressures downstream of the DOV valve are lower than pressures in the recirculation loop due to frictional losses across the DOV.

The saltwell pump recirculation loop has waste under higher pressure than the submersible pump system (although the submersible pump pumps at much higher flowrates). The saltwell system therefore poses the greatest risk for a spray leak inside an SST pump pit. A spray leak involving a saltwell system piping is analyzed as the bounding case.

6.2.1 Source Term Analysis

6.2.1.1 Unmitigated Accident Source Term. From Appendices B, the maximum head in the saltwell recirculation system is 160 ft. The pressure falls off to 100 ft for a flowrate through the DOV of 4 gpm. The flowrate through the leak in this case is likely to have a significant effect on the pressure in the line so an iterative approach is required to determine the optimum respirable aerosol release rate. The process is as follows: 1) guess waste pressure, 2) use SPRAY to determine the optimum crack size that produces the maximum flowrate of respirable sized aerosols, 3) from total flowrate predicted by SPRAY, check the pump curve and compare pressure corresponding to the total flowrate predicted by SPRAY to initial guess, 4) iterate until the guess pressure and pump curve pressure are comparable.

Step 1. Assuming an SpG of 1.4 (corresponding to slurry containing 33 vol % solids) as in the aging waste and DST cases, the maximum pressure in the saltwell recirculation loop ranges from (160 ft)(atm/33.9 ft of H_2O)(1.4)(14.7 psi/atm) = 97 psi at 0 gpm to 60 psi [(97 psi)(100)/(160)] at 4 gpm. Assume an initial pressure of 85 psi.

Step 2. The saltwell piping is 1 in., schedule 40 piping. Use the same SPRAY input parameter assumptions as in the aging waste spray leak. This gives a pipe thickness of 0.133 in, an assumed waste SpG of 1.4, a respirable aerosol size of 15 um, and a waste viscosity of 1 cps. The maximum crack length was assumed, as in the aging waste case, to be 2 inches.

The SPRAY leak input deck and results are included in Appendix C as Case 2. The optimum crack width was found to be 4.16E-3 in (1.06E-3 cm). The total flowrate through the optimum sized leak was found to be 1.21 gpm, and the respirable flowrate was found to be 7.65E-3 gpm, or 4.83E-4 L/s. The respirable fraction is 6.3E-3. Over a 12-h period this respirable aerosol release rate gives a volumetric release of 21 L. Over 24 hours, the volumetric release is 42 L.

Step 3. The total flowrate predicted by SPRAY of 1.21 gpm gives an estimated head from the saltwell pump curve in Appendix B of about 140 ft. Converting to pressure, using an SpG of 1.4, gives 85 psi. The guess pressure and predicted pressure match and hence no further iteration is required.

6.2.1.2 Mitigated Accident Source Term. With the cover blocks on, the aerosol release from the pit would be limited. Assume a maximum aerosol loading limit for the air expelled from the pit of 100 mg/m^3, as was done in the aging waste case. The potential mechanisms driving air from the SST pump pit vary a little bit from those in the aging waste valve pit leak. There is still in this case an initial expansion of air caused potentially by a temperature and humidity increase in the pit air. Unlike in the representative valve pit case analyzed above, most SSTs are not actively ventilated. Hence, there is no draw on the pit through the drain line (assuming it's open) to limit the release of aerosols after the initial volume expansion. With an open drain, there is the potential for the SST to breathe out through the pump pit drain, expelling contaminated air to the atmosphere through the cover block gaps and penetrations. This breathing out or natural ventilation mechanism can be caused by heat load in the tank and pit (i.e., chimney effect), wind effects, and barometric pressure changes.

The volumetric air exchanges from the pump pit due to both mechanisms are quantified in the following subsections.

Air Expulsion Due to Temperature and Humidity Increase. The initial temperature and humidity increase could be expected to produce a similar volumetric exchange as in the representative case. In Section 3.2.1, this exchange is predicted to be 0.35 pit volumes.

SST pump pits vary in size and shape. Some are round caissons; some are rectangular concrete pits. BY farm has several tanks scheduled to be saltwell pumped. Pump pits 241-BYR-01A, 04A, 11A, and 12A in this farm are all 17.5' long by 15.5' wide. All of these are expected to be between 5 and 6 ft deep, based on soil cover shown in the drawings for the SSTs. Assuming a depth of 6 ft gives a total volume for the typical BY farm pump pits of 1630 ft^3.

The total volume of air expelled from the pit due to this mechanism is 570 ft^3 [(1630)(0.35)], or 16.1 m^3.

Air Expulsion Due to Natural Breathing. The natural ventilation rate is difficult to quantify for the pump pit and the connected SST. No tracer studies have been performed to measure the natural ventilation rates in passively ventilated tanks or the potential leakage rate from a pit in postulated accidents such as a spray leak.

A conservative estimate for the pit breathing rate is 5 cfm, or 8.5 m^3/h. This conservative estimate comes from computer modelling results for the cascade SSTs C-101, C-102 and C-103, reported in WHC-CM-WM-ER-127 (1991). The 5 cfm value is conservative because it corresponds to the estimated total outleakage (both filtered and not filtered) predicted for the three tank series. Tanks C-101 and C-102 were predicted in the reference to have only inleakage. Tank C-103 was predicted to breathe out through both the HEPA filtered, passive ventilation path and to have fugitive emissions out other unfiltered paths in the tank. The outleakage through an individual pit would not be expected to be as high as predicted for all paths for the entire tank. The pump pit in this study has an estimated volume of 1630 ft^3 (see discussion below). The 5 cfm flowrate therefore corresponds to a volumetric exchange rate for the pit of 0.2 V/h [(5 cfm/1630 ft^3)(60 min/h)]. Compare this to rule of thumb values for interior rooms in buildings and closed basements in one story homes reported in the literature to range from 0.1 V/h to 0.4 V/h (see ASHRAE 1977 and Socolow 1994).

The natural ventilation rate leads to a greater release than would occur if it was assumed the pit drain was plugged, as was done in the representative accident case. The assumed natural ventilation rate leads to 4.8 pit volume exchanges over the 24-h duration of the accident, compared with one-half a volume exchange (assuming pipes become submerged when pit is half full) that could occur with a closed drain.

Aerosol Release Quantities. Over the first hour of the accident, the pit breathes 16.1 m^3 of air due to the initial air expansion and 8.5 m^3 of air due to natural ventilation. Assuming an airborne aerosol limit of 100 mg/m^3, and converting using an assumed waste SpG of 1.4, as was done in the aging waste spray leak analysis, gives a 1-h aerosol release of

$$Q(\text{1st hour}) = (16.1\ m^3 + 8.5\ m^3)(100\ mg/m^3)(1\ L/1.4E6\ mg) = 1.8E-3\ L$$

The aerosol released over the 1 to 12 hour time frame is

$$Q(1\text{-}12h) = (8.5\ m^3/h)(11h)(100\ mg/m^3)(1\ L/1.4E6\ mg) = 6.7E-3\ L$$

The aerosol released over the 1 to 24 hour time period is

$$Q(1\text{-}24h) = (8.5\ m^3/h)(23\ h)(100\ mg/m^3)(1\ L/1.4E6\ mg)$$

$= 1.4E-2$ L

6.2.2 Consequence Analysis

6.2.2.1 Unmitigated Accident Doses. For this case, the waste inventory is assumed to be composed of 33 vol % SST solids, 67 vol % SST liquids. The composite inhalation and ingestion ULDs for this waste mixture, using the values from Table 4-1, are as follows:

$$ULD_{inh} = (0.33)(2.2E5\ Sv/L) + (0.67)(1.1E4\ Sv/L) = 8.0E4\ Sv/L$$

$$ULD_{ing} = (0.33)(4.1\ Sv\text{-}m^3/L\text{-}s) + (0.67)(0.052\ Sv\text{-}m^3/L\text{-}s) = 1.4\ Sv\text{-}m^3/L\text{-}s$$

Onsite Dose. From Section 6.2.1.1, the respirable aerosol release rate is 6.5E-4 L/s. Over a 12 hour period, the volumetric release is 28 L. The onsite 12 h X/Q' is 5.54E-3 s/m^3 (Table D-3). Using the active breathing rate, the onsite receptor dose is

$$Dose(inh,\ on) = (21\ L)(5.54E-3\ s/m^3)(3.3E-4\ m^3/s)(8.0E4\ Sv/L) = 3.1\ Sv\ (31\ rem).$$

Offsite Dose. From Section 6.2.1.1, the 24 hour respirable release volume is 56 L. From Table D-3 (Appendix D), the 24 hour offsite X/Q' is 4.62E-6 s/m^3. Using the 24 hour average receptor rate, the offsite inhalation dose is:

$$Dose(inh,\ off) = (42\ L)(4.62E-6\ s/m^3)(2.7E-4\ m^3/s)(8.0E4\ Sv/L) = 4.2E-3\ Sv.$$

Using the ingestion ULD from above, the offsite ingestion dose is:

$$Dose(ing,\ off) = (42\ L)(4.62E-6\ s/m^3)(1.4\ Sv\text{-}m^3/L\text{-}s) = 2.7E-4\ Sv$$

The total offsite dose from both pathways is:

$$Dose(total,\ off) = 4.5E-3\ Sv\ (0.45\ rem)$$

6.2.2.2 Mitigated Accident Doses

Onsite Dose. The acute X/Q' for the onsite receptor from Appendix D is 3.41E-2 s/m^3. From Section 6.2.1.2, Q(1st hr) = 1.8E-3 L. The dose to the onsite receptor during the first hour is

$$D(inh,on,1h) = (1.8E-3\ L)(3.41E-2\ s/m^3)(3.3E-4\ m^3/s)(8.0E4\ Sv/L) = 1.6E-3\ Sv.$$

The release during the 1- to 12- h time frame, from Section 6.2.1.2, is 6.7E-3 L. From Table D-1, the 11 hour onsite X/Q' is 5.74E-3 s/m^3. The dose during this timeframe is therefore

$$D(inh,on,1\text{-}12\ h) = (6.7E\text{-}3\ L)(5.74E\text{-}3\ s/m^3)(3.3E\text{-}4\ m^3/s)(8.0E4\ Sv/L) = 1.0E\text{-}3\ Sv.$$

The total onsite dose is

$$D(inh,on,tot) = 2.6E\text{-}3\ Sv\ (0.26\ rem)$$

Offsite Receptor Dose. The acute X/Q' for the offsite receptor from Appendix D is 2.83E-5 s/m^3. From Section 6.2.1.2, Q(1st hr) = 1.8E-3 L. The inhalation and ingestion doses to the offsite receptor during the first hour are therefore:

$$D(inh,off,1h) = (1.8E\text{-}3\ L)(2.83E\text{-}5\ s/m^3)(3.3E\text{-}4\ m^3/s)(8.0E{+}4\ Sv/L) = 1.3E\text{-}6\ Sv.$$

$$D(ing,off,1h) = (1.8E\text{-}3\ L)(2.83E\text{-}5\ s/m^3)(1.4\ Sv\text{-}m^3/L\text{-}s) = 7.1E\text{-}8\ Sv$$

The release during the 1- to 24- h time frame, from Section 6.2.1.2, is 1.4E-2 L. From Table D-1, the 23 hour offsite X/Q' is 4.74E-06 s/m^3. The doses during this timeframe are therefore

$$D(inh,off,1\text{-}24\ h) = (1.4E\text{-}2\ L)(4.74E\text{-}6\ s/m^3)(3.3E\text{-}4\ m^3/s)(8.0E4\ Sv/L) = 1.8E\text{-}6\ Sv.$$

Note: to simplify calculation, the above equation conservatively ignores the fall off in breathing rate during the period of time the receptor is at rest.

$$D(ing,off,1\text{-}24\ h) = (1.4E\text{-}2\ L)(4.74E\text{-}6\ s/m^3)(1.4\ Sv\text{-}m^3/L\text{-}s) = 9.3E\text{-}8\ Sv$$

The total offsite dose from both pathways, over both time increments, is:

$$Dose(total,off) = 3.3E\text{-}6\ Sv\ (3.3E\text{-}4\ rem)$$

6.3 SPRAY LEAK INSIDE DCRT PUMP PIT

A review of the pump curves in Appendix B shows that the potential pressures in the DCRT pump pits are as high as in the representative accident. The respirable release rate in the unmitigated accident can therefore be expected to be similar to the representative case. DCRT pump pit volumes are bounded by the representative case. Therefore mitigated aerosol releases from the pump pits can be expected to be bounded by the mitigated source term estimated for the representative accident. The consequences differ between the DCRT pump pit case and the representative case primarily because of differences in waste inventory. DCRTs receive waste from SSTs and act as lag storage until that waste can be batch transferred to DSTs. The waste inventory inside the DCRTs should therefore be represented by the SST source term.

As in the representative case, it is assumed the DCRT transfer pumps can entrain a maximum of 33 vol % solids. The unmitigated and mitigated doses can be simply estimated by multiplying the doses determined in the representative case by the ratio of the SST waste composite ULD over the aging waste composite ULD.

For an SST waste stream containing 33 vol % solids, the composite inhalation and ingestion ULDs, from Section 6.2.2.1 are:

~~DST~~ SST composite ULD_{inh} = 8.0E4 Sv/L

~~DST~~ SST composite ULD_{ing} = 1.4 Sv-m^3/L-s

These ULDs compare to 5.6E5 Sv/L and 2.7 Sv-m^3/L-s, respectively for the aging waste case.

6.3.1 Unmitigated Accident Doses

Ratioing the doses reported in Section 4.1.1 for the unmitigated scenario gives the following results:

Onsite Dose

D(inh,on) = (150 Sv)(8.0E4 Sv/L)/(5.6E5 Sv/L)
= 21 Sv (2100 rem)

Offsite Dose

D(inh,off) = (0.21 Sv)(8.0E4 Sv/L)/(5.6E5 Sv/L)
= 3.0E-2 Sv (3.0 rem)

D(ing,off) = (3.7E-3 Sv)(1.4 Sv-m^3/L-s)/(2.7 Sv-m^3/L-s)
= 1.9E-3 Sv (0.19 rem)

D(tot,off) = 3.2E-2 Sv (3.2 rem)

6.3.2 Mitigated Accident Doses

Ratioing the doses reported in Section 4.2.1.1 gives the following results:

Onsite Dose

D(inh,on,1h) = (3.6E-2 Sv)(8.0E4 Sv/L)/(5.6E5 Sv/L)
= 5.1E-3 Sv

D(inh,on,1-12h) = (3.8E-3 Sv)(8.0E4 Sv/L)/(5.6E5 Sv/L)
= 5.4E-4 Sv

The total onsite dose is:

D(tot,on) = 5.6E-3 Sv (0.56 rem)

Offsite Dose

D(off,inh,1h) = (3E-5 Sv)(8.0E4 Sv/L)/(5.6E5 Sv/L)
= 4.3E-6 Sv (4.3E-4 rem)

D(off,ing,1h) = (4.4E-7 Sv)(1.4 Sv-m^3/L-s)/(2.7 Sv-m^3/L-s)
= 2.3E-7 Sv (2.3E-5 rem)

D(off,inh,1-24h) = (6.6E-6 Sv)(8.0E4 Sv/L)/(5.6E5 Sv/L)
= 9.4E-7 Sv (9.4E-5 rem)

D(off,ing,1-24h) = (9.6E-8 Sv)(1.4 Sv-m^3/L-s)/(2.7 Sv-m^3/L-s)
= 5.0E-8 Sv (5.0E-6 rem)

The total offsite dose is

D(off,tot) = 5.5E-6 Sv (5.5E-4 rem)

6.4 COMPARISON WITH REPRESENTATIVE CASE AND WITH EVALUATION GUIDELINES

Table 6-1 summarizes the results for the three additional spray leak sites and compares them with the TWRS evaluation guidelines. The table shows that the three additional spray leak sites are bounded by the representative case. Although the doses for the DST valve pit, SST pump pit, and DCRT pump pit cases are lower than for the representative case, the unmitigated offsite doses are still well above the EG for the Anticipated category. The unmitigated onsite doses are orders of magnitude above the onsite EG for the Anticipated frequency category. The represented cases, like the representative case all warrant safety class mitigation.

The mitigated doses for all cases demonstrate that the pit cover blocks are adequate to mitigate doses to below the offsite EGs. The mitigated onsite doses for the DST valve pit and DCRT pump pit cases are marginally above the onsite EG for the Anticipated frequency category. The mitigated SST pump pit case gives an onsite dose marginally below the EG for the Anticipated frequency category. The pit cover blocks are shown to be sufficient to prevent safety class consequence (significant consequences to the offsite receptor). Further controls should, however, be considered to prevent significant consequences to the onsite receptor.

7.0 SENSITIVITY ANALYSIS

Within the TWRS transfer systems, spray leaks can occur at a variety of pressures, involving waste with differing characteristics. Leak dimensions are also highly variable. The source term and consequence analyses above were performed in a conservative manner. This section examines the sensitivity of the spray leak results to key parameters and assumptions.

Since the mitigated consequences were shown in all cases analyzed above to be below guidelines, the sensitivity analysis is performed only for the unmitigated accident model. The representative accident analyzed in Sections 2 through 4 was a spray leak inside a DST valve pit. For the unmitigated model the parameters and assumptions that have a substantial impact on dose consequences are: waste type, waste solids content, leak dimensions (assumed crack width, and crack depth), and assumed accident duration. The bounding spray leak analyzed in Sections 2 through 4 was a leak of aging waste, containing 33 vol % entrained solids, through an optimally sized hole at the maximum pressure possible in the DST transfer systems.

The effects of variations in each of the above listed parameters on the source term and dose consequence analyses are addressed in Sections 7.1 through 7.4 below. Section 7.5 combines "nominal" values for each parameter in a consequence analysis to give some idea for the range of risk associated with pressurized spray releases.

7.1 WASTE TYPE AND SOLIDS LOADING

Spray leaks within the TWRS transfer systems can consist of three waste types: aging waste, DST waste, and SST waste. Any of these waste types can be transferred through a DST valve pit. The solids content of the waste being transferred is also variable. The effect on the doses for each waste type at various assumed solids loadings can be evaluated by comparing the unit liter dose (ULD) values from Table 4-1.

The consequence analyses in the previous sections show that the 24-h ingestion dose comprises a small percentage of the total offsite dose. The sensitivity of the analysis can therefore be adequately assessed by comparing inhalation ULDs.

Table 4-1 shows that waste tank solids have a higher dose potential than waste tank liquids, with aging waste solids producing significantly higher doses than the other waste types. The waste sprayed in the unmitigated analysis for the representative accident was assumed to be aging waste containing 33 vol % entrained solids. This assumption is judged to be bounding, as discussed previously. Grab samples taken from supernate layers in DSTs and measured sludge level changes in receiving tanks following transfers, however, indicate that typical transfers contain only trace amounts to 5 vol % solids.

Table 7-1 gives the composite inhalation ULDs for each waste type (aging waste, DST waste, SST waste), at three different solids loadings--33 vol % solids, 5 vol % solids, and 1 vol % solids. These values were determined by combining the solids and liquids ULDs from Table 4-1, using the appropriate solids and liquids volume weighting factors. The last column of the table gives a ratio of the computed ULD for each case relative to the base (representative accident) case. The 33 vol % solids cases are bounding for each waste type. The 5 vol % solids cases are judged to represent the nominal waste composition in a transfer line. The 1 vol % solids cases were determined to represent the "low end" and to take into account the possibility that the leakage path could filter out entrained solids.

Table 7-1 shows that DST waste at a 33 vol % solids loading will produce doses 3.2 % of those produced in the base case. SST waste at 33 vol % produces doses about 14% of those produced in the aging waste base case. At the low end (i.e., at 1 vol % solids loading), DST and SST are shown to produce doses of 3.8 % and 2.3 %, respectively, of the base case.

7.2 WASTE PRESSURE

Waste pressure effects the respirable aerosol release rate and hence the doses, because it determines the velocity of the jet exiting through a given size orifice (based on Bernoulli's equation). The dimensions of the jet, the kinematic viscosity of the liquid, and the jet velocity determine the particle size distribution and respirable aerosol generation rate. A parametric study of all variables involved in determining the respirable aerosol release rate is beyond the scope of this calculation. An idea of the sensitivity of this analysis to waste pressure can be gained by varying pressure and using the SPRAY code to solve for the maximum respirable aerosol release at each selected pressure.

Depending on the location of the leak with respect to the transfer pump, transfer line length and resistance, static assist, apparent waste viscosity at pipe shear rates, etc., the pressure of the waste at the leak location under flowing conditions could vary anywhere from just above atmospheric to the bounding 300 psig pressure used in the representative analysis. Two cases were looked at to assess sensitivity: a 150 psig case and a 50 psig case. The crack length, crack depth, and waste viscosity used were the same as in the representative case. The input and output files for the SPRAY runs are included in Appendix C as Cases 3 and 4, respectively.

The optimum spray in the 150 psig case was found to produce a respirable aerosol flowrate of 6.47E-2 L/min. The optimally sized crack in the 50 psig case was found to produce a respirable aerosol flowrate of 9.96E-3 L/min. The representative accident at 300 psig produced a respirable flow of 0.21 L/min. The ratios of the doses expected in the 150 psig and 50 psig cases to the 300 psig case are therefore 0.31 and 4.7E-2, respectively. The 150 psig case produces doses about one third as high as in the representative case. The 50 psig case produces maximum doses about 5 % of the representative case.

7.3 LEAK DIMENSIONS

7.3.1 Slit Length

The spray code determines the total flowrate through the leak path based on Bernoulli's equation, using the hydraulic radius of the slit. The total flowrate and respirable aerosol flowrate are therefore approximately proportional to the length of the slit assumed, at any given pressure. Doses for other slit lengths can be scaled from the doses for the specific case analyzed.

7.3.2 Slit Width

In the representative accident, the spray code was used to iteratively solve for the slit width that produced the maximum flowrate of respirable sized aerosols. The optimum slit width was found to be 4.5E-3 in. To examine the sensitivity of the source term analysis to this parameter, two other slit widths were looked at: 0.01 inches and 0.1 inches. Nozzles in the spray drying industry tend to be 0.01 inches in diameter or larger. Problems with plugging are experienced with nozzle diameters below this size. The second slit width was selected to look at the effect of an order of magnitude change in this parameter.

The results for both cases are included in Appendix C as Cases 5 and 6. The same waste pressure, slit length, slit depth, and viscosity were assumed as in the representative accident. For the 0.01 in wide slit, the respirable aerosol release rate was found to be 0.14 L/min. For the 0.1 in wide slit, the respirable aerosol release rate was found to be 4.0E-3 L/min. These compare to a respirable aerosol release rate for the optimally sized slit of 0.28 L/min. The 0.01 in crack produces a dose half as large as the representative case. The 0.1 in crack produces doses about 1.4 % as high as the representative case.

The combined effects of varying this parameter with other variables, such as waste pressure are beyond the scope of this analysis.

7.3.3 Slit Depth

The slit depth and the surface roughness of the base material the leak develops in effect the Darcy frictional losses across the depth of the leak. For very narrow cracks, the ratio of the depth of the crack (L) to the width of the crack (D) can be very high. Higher L/D ratios give higher pressure drops across the depth of the crack and lower respirable aerosol production.

The representative accident credited Darcy frictional losses across a schedule 40 pipe thickness. Postulated spray leaks within valve pits occur in schedule 40 piping, or through other equipment (jumpers, seals, gaskets) that can be expected to produce similar frictional losses to those credited in the representative case. No sensitivity study was therefore performed on this parameter.

7.4 ACCIDENT DURATION

The unmitigated spray leak in the representative accident is assumed to continue unabated for 24 hours. The total respirable aerosol release (e.g. source term) is directly proportional to the assumed accident duration, because the release rate is constant. However, changing wind direction, wind speed, and atmospheric stability result in a logarithmically decreasing X/Q' as a function of time. This effect is demonstrated in Table D-3.

The effect of assumed accident duration on the unmitigated dose analysis can be determined by selecting a release duration, multiplying that duration by the appropriate X/Q' and comparing to the similarly derived product at a different release duration. Using the X/Q's from Table D-3, the offsite dose for a 2 hour, unmitigated spray release can be shown to be 38 % as high as the dose for a 24 hour spray release. Conversely, increasing the accident duration to 3 days can be shown to produce a dose only about a factor of 1.5 times higher than the 24 hour case.

7.6 METEOROLOGY

Deleted.

7.7 NOMINAL CASE

A detailed parametric study or Monte Carlo analysis is beyond the scope of this calculation note. However, an idea for the sensitivity of the analysis to the key parameters can be gained by examining a scenario where some of the conservatism is removed from each key parameter. This section evaluates a "nominal" unmitigated (i.e., uncovered) spray leak.

For this "nominal" case, it is assumed that the waste being sprayed consists of DST waste with a solids loading of 5 vol %. DST waste is pumped more often than aging waste and is appropriate to use for the nominal case. The 5 vol % entrained solids assumption is judged to be representative of typical supernate waste transfers, based on grab sample results and sludge level readings taken in supernate receiving tanks. A nominal waste pressure of 150 psig is assumed. The 300 psig pressure assumed in the bounding representative accident is only expected if the pump deadheads or if the transfer path is very long (providing a lot of line resistance) and the spray leak develops in a pit very close to the transfer pump). The 150 psig pressure is judged to be more representative of pressures at potential leak sites during typical transfers and for cases where leaks develop in pits a considerable distance away from the transfer pump (i.e., near the receipt tank, or beyond the half way point).

For the nominal case, it is also assumed that the crack length is 1 in. and that the crack width is 0.01 in. Since transfers are accomplished through 3 in supernate lines more often than 2 in slurry lines, the crack depth in the nominal case is assumed to be 0.216 in. (the depth of a 3 in, schedule 40 pipe). Since the waste in the nominal case is assumed to contain 5 vol % solids, an SpG of 1.2 is assumed. This value is between the 1.1 SpG typically measured on supernate samples and the 1.4 SpG assumed for the 33 vol % case. Because of evaporation, particles greater than 10 um in diameter can shrink down to respirable size. The diameter of the maximum sized particle that can shrink to 10 um is calculated with the following equation.

$$D_2 = (D_1^3/E)^{(1/3)}$$

where,

D_1 = 10 um
D_2 = radius of starting particle
E = volume fraction solids

For a solution containing 5 vol % solids, the above equation gives a starting particle size of 27 um.

The input and output files for the SPRAY run using the above "nominal" values are included as Case 7 in Appendix C. The respirable aerosol release rate was found to be 8.52E-2 L/min. The total flowrate was found to be 10.1 L/min, giving a respirable release fraction of 8.5E-3.

For this nominal case, it is assumed that the spray leak is detected and the transfer pump shutdown in 2 hours. Tank farm workers monitoring the transfer are likely to discover that the cover block has been left off the valve pit and will radio operators to shutoff the transfer within this time frame. Depending on wind direction a spray leak severe enough to lead to large onsite doses may also be detected by another facility's radiation monitors, which will spur an investigation that will discover the source of the leak within the assumed two hour time frame. Radiation protection technicians doing surveys for other purposes may also detect the leak and investigate. As discussed in the representative accident scenario discussion, valve pit leak detectors are not sensitive enough to detect low volume spray leaks. Mass balances are not sensitive enough to detect low volume spray leaks in a reasonable amount of time.

From Table 7-1, the inhalation ULD for DST waste containing 5 vol % solids is 3.2E4 Sv/L. The 2-h onsite X/Q' from Table D-3 is 1.13E-2 s/m^3. Using the respirable aerosol generation rate from above and the active receptor breathing rate, the onsite receptor dose is:

$$\begin{aligned} D(inh,on) &= (8.52E\text{-}2\ L/min)(1.13E\text{-}2\ s/m^3)(3.3E\text{-}4\ m^3/s)(3.2E4\ Sv/L) \\ &\quad \times (60\ min/h)(2h) \\ &= 1.2\ Sv\ (120\ rem) \end{aligned}$$

The 2-h offsite X/Q' from Table D-3 is 2.12E-5 Sv/L. The offsite inhalation dose therefore is

$$D(inh,off) = (8.52E\text{-}2\ L/min)(2.12E\text{-}5\ Sv/L)(3.3E\text{-}4\ m^3/s)(3.2E4\ Sv/L)$$

x (60 min/h)(2h)
= 2.3E-3 Sv (0.23 rem)

For the Anticipated frequency category, the onsite and offsite EGs are 5 mSv and 1 mSv, respectively. The nominal unmitigated spray leak well exceeds the onsite EG and produces offsite doses that are marginally higher than the offsite EG. The nominal case shows that spray leaks under a variety of conditions pose major safety concerns, and that it is prudent to apply Safety Class level controls to mitigate or prevent spray leaks throughout the tank farm transfer systems.

8.0 OVERALL SUMMARY AND CONCLUSIONS

Spray leaks within the tank farm transfer systems are Anticipated events. The unmitigated spray leak for the bounding, representative case produces doses that well exceed both the onsite and offsite evaluation guidelines for the Anticipated frequency category. In addition, the toxicological consequences of the representative accident exceed the onsite EG. The mitigated accident analysis for the representative case demonstrates that the pit cover blocks can sufficiently mitigate the consequences of the accident (both radiological and toxicological) to well below the offsite evaluation guideline. The mitigated radiological dose estimate, however, is still above ~~of the same order of magnitude as~~ the onsite EG for the Anticipated frequency category.

The consequence analyses in Sections 6 and 7 demonstrate that unmitigated (uncovered) spray leaks at potential sites throughout the tank farm transfer systems warrant Safety Class mitigation. The covers for all pits and enclosures (e.g., valve pits, pump pits, sluice pits, diversion boxes, vault pits, etc.) along transfer routes and connected to transfer routes where waste could be misrouted should be designated Safety Class. The enclosure covers are the only existing barriers that provide reliable mitigation for spray leaks inside these enclosures. Pit leak detectors and mass balances performed during transfers are not sensitive enough to preclude unacceptable consequences to the onsite receptor and may not be sensitive enough to preclude significant consequences offsite.

TSR controls (i.e., LCOs, or ACs) are necessary to ensure covers are on all pits along transfer routes or where waste could be misrouted during transfers. The unmitigated accident dose to the onsite worker is very high and additional measures must be taken to protect this receptor if the accident can not be made incredible with TSR controls.

The mitigated accident analyses demonstrate that the cover blocks alone may not be sufficient to prevent significant consequences to the onsite receptor. Additional controls (e.g., safety significant CAMs inside pits, safety significant radiation monitors throughout the tank farms, TSR AC to maintain exclusion areas around pits) should be considered to protect onsite individuals from spray leaks inside covered pits. Alternatively, more sophisticated analyses could be performed to remove some of the conservatisms from the mitigated accident model.

9.0 PEER REVIEW

See Appendix F for peer review checklist.

10.0 REFERENCES

ASHRAE, 1977, *ASHRAE Handbook and Product Directory*, American Society of Heating, Refrigerating, and Air Conditioning Engineers, New York, New York.

BNWL-1732, 1973, *Some Experimental Measurements of Airborne Uranium (Representing Plutonium) in Transportation Accidents*, Battelle, Pacific Northwest Laboratories, Richland, Washington.

PNL-2844, 1979, *Source Term and Radiation Dose Estimates for Postulated Damage to the 102 Building at the General Electric Vallecitos Nuclear Center*, Pacific Northwest Laboratories, Richland, Washington.

PNL-4154, 1982, *Accident Generated Particulate Materials and Their Characteristics--A Review of Background Information*, Pacific Northwest Laboratories, Richland, Washington.

Socolow, R.H., 1994, *Exposure to Radon and Radon Progeny in the Indoor Environment*, DOE/ER/61030--TI, Princeton University Center for Energy and Environmental Studies, Princeton, New Jersey.

WHC-CM-4-46, 1995, *Nonreactor Facility Safety Analysis Manual*, Rev. 4, Westinghouse Hanford Company, Richland, Washington.

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

WHC-SD-WM-ER-127, 1991, *Evaporation Modeling for Tank C-103*, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

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

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

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

Table 4-1. Unit Liter Doses for Inhalation and Ingestion.

Composite	Inhalation ULD (Sv/L)	Ingestion ULD ($Sv-m^3/s-L$)
Single-shell tank liquids	1.1 E+04	0.052
Single-shell tank solids	2.2 E+05	4.1
Double-shell tank liquids	6.1 E+03	0.068
Double-shell tank solids	5.3 E+05	0.48
Aging waste facility liquids	1.4 E+03	0.092
Aging waste facility solids	1.7 E+06	8.1

NOTE: The information in this table is from WHC-SD-WM-SARR-037, 1996, Development of Radiological Concentrations and Unit Liter Doses for TWRS FSAR Radiological Consequence Calculations, Westinghouse Hanford Company, Richland, Washington.
ULD = unit liter dose.

Table 4-2. Sum-of-Fractions for Unit Releases of Solids and Liquids.

*The sum of fractions are multiplied by the release rate for continuous release and release amount for a puff releases. Release rates for continuous releases are in units of liters per second for liquids and solids, and m^3/s for gases. Puff release quantities are in units of liters for solids and liquids and m^3 for gases.

Tank waste type (Units of sum of fractions follow tank waste type)	Maximum individual	Accident frequency, 1/yr		
		$1 - 10^{-2}$	$10^{-2} - 10^{-4}$	$10^{-4} - 10^{-6}$
DST or SST solid or liquid continuous release				
Single-shell liquids(s/L)	Onsite	9.6 E+03	7.5 E+02	2.0 E+02
Single-shell liquids(s/L)	Offsite	8.0 E+00	8.0 E+00	6.2 E-01
Single-shell solids(s/L)	Onsite	4.0 E+04	2.1 E+04	1.0 E+03
Single-shell solids(s/L)	Offsite	9.4 E+01	3.3 E+01	1.7 E+01
Double-shell liquids(s/L)	Onsite	1.0 E+04	7.5 E+02	2.1 E+02
Double-shell liquids(s/L)	Offsite	8.4 E+00	8.4 E+00	6.2 E-01
Double-shell solids (s/L)	Onsite	1.8 E+04	3.3 E+03	6.3 E+02
Double-shell solids(s/L)	Offsite	1.9 E+02	1.5 E+01	2.8 E+00
DST or SST liquid or solid puff release				
Single-shell liquids (L^{-1})	Onsite	2.8 E+03	2.2 E+02	5.7 E+01
Single-shell liquids (L^{-1})	Offsite	3.2 E-02	3.2 E-02	2.5 E-03
Single-shell solids (L^{-1})	Onsite	1.2 E+04	6.0 E+03	2.9 E+02
Single-shell solids (L^{-1})	Offsite	3.8 E-01	1.3 E-01	6.9 E-02
Double-shell liquids (L^{-1})	Onsite	2.9 E+03	2.2 E+02	6.0 E+01
Double-shell liquids (L^{-1})	Offsite	3.4 E-02	3.4 E-02	2.5 E-03
Double-shell solids (L^{-1})	Onsite	5.2 E+03	9.7 E+02	1.8 E+02
Double-shell solids (L^{-1})	Onsite	7.7 E-01	5.9 E-02	1.1 E-02

Table 5-1. Consequences of Valve Pit Spray Leak.

Receptor/Hazard	Calculated Dose/Exposure		Evaluation guideline		
	Unmitigated	Mitigated	Anticipated	Unlikely	Extremely Unlikely
Offsite/radiological	210 mSv	3.7E-02 mSv	1 mSv	5 mSv	40 mSv
Onsite/radiological	150 Sv	~~40~~ 41 mSv	5 mSv	50 mSv	100 mSv
Offsite/toxicological sum-of-fractions	0.24	4.2E-04	1	1	1
Onsite/toxicological sum-of-fractions	46	~~0.11~~ 8.1E-02	1	1	1

Table 6-1. Dose Consequences of Represented Cases

Receptor	Calculated Dose		Evaluation guideline		
	Unmitigated	Mitigated	Anticipated	Unlikely	Extremely Unlikely
Spray Leak of DST Waste Inside Valve Pit					
Offsite	68 mSv	1.2E-02 mSv	1 mSv	5 mSv	40 mSv
Onsite	48 Sv	13 mSv	5 mSv	50 mSv	100 mSv
Spray Leak Inside SST Pump Pit					
Offsite	4.5 mSv	3.3E-3 mSv	1 mSv	5 mSv	40 mSv
Onsite	3.1 Sv	2.6 mSv	5 mSv	50 mSv	100 mSv
Spray Leak Inside DCRT Pump Pit					
Offsite	32 mSv	5.5E-3 mSv	1 mSv	5 mSv	40 mSv
Onsite	21 Sv	5.6 mSv	5 mSv	50 mSv	100 mSv

Table 7-1. Waste Type ULDs as a Function of Solids Loading

Waste Type	Solids Loading (vol %)	Composite Inhalation ULD (Sv/L)	Ratio to ULD for aging waste at 33 vol % solids
Aging Waste	33	5.6E5	1.0
Aging Waste	5	8.6E4	0.15
Aging Waste	1	1.8E4	0.032
DST Waste	33	1.8E5	0.32
DST Waste	5	3.2E4	0.057
DST Waste	1	1.1E4	0.020
SST Waste	33	8.0E4	0.14
SST Waste	5	2.1E4	0.038
SST Waste	1	1.3E4	0.023

Appendix A

Summary of Occurrence Reports Relating to Leaks from Tank Farm Transfer Equipment inside Transfer Enclosures

Appendix A

The following table provides a summary of the occurrence reports (both unusual and offnormal) relating to leaks of waste, flush water, or hydrostatic testing water involving tank farm transfer system components. Included are process pits and other enclosures along transfer routes. The detailed occurrence reports can be found in the DOE reading room.

Table A-1. Historical Spray/Liquid Leaks Inside Transfer Enclosures

Occurrence Number	Date	Leak Type	Description
72-72	11/20/72	spray inside pit	Leak from transfer line during flushing caused spray up through valve operator holes in valve pit cover. Leak was caused by gasket failure.
75-78	7/16/75	Liquid/spray leak inside diversion box	Jumper connector failure during waste transfer from 107-TX to 103-U causes leak. Jumper located in 153-TXR diversion box. Cause for leak: threads were stripped on flex jumper.
76-131	9/27/76	leak inside pit	Radioactive waste spill during jumper disconnection in 105-U pump pit. Cause: waste transfer ongoing in adjacent tank pressurized jumper due to partial failure of a closed valve.
76-136	10/05/76	spray leak in pit	Radioactive liquid sprayed from a check valve under repair onto three personnel in BX Tank Farm. Cause: preparations for the repair were inadequate.
77-23	2/07/77	leak inside enclosure	Water leakage inside 108-BX flush pit (drained to tank 108-BX). Cause: water valve bonnet blew off during flush of line between 110-BY and 105-BX.
77-189	10/19/77	leak into pit	Failure of blank between pump pit and leak detection pit results in contamination spread to 102-SY annulus.

77-205	12/06/77	spray leak inside pit	Spray leak from 111-S pump pit during leak check of salt well pump and jumpers. The leak check was not done with cover blocks installed. Cause: failed gasket at pump inlet flange.
80-81	8/26/80	spray inside pit	Spray leak in 241-AW-05A central pump pit during slurry transfer to Tank 105-AW. Cause: worker unable to tighten connection between jumper and distributor sufficiently.
83-34	12/12/83	spray/liquid release inside cleanout box (many cases)	Smearable contamination in 200-East area cleanout boxes. Cause: assumed deterioration of plug seals on the center riser of the COBs.
WHC-TANKFARM-1993-08	1/15/93	leak to pit	Transfer from 204-AR to 101-AY failed due to frozen jumpers in path.
WHC-TANKFARM-1994-62	11/2/94	spray and/or liquid leak inside pit	During saltwell pumping of 109-BY a high radiation dose was measured over the pump pit. The saltwell pump discharge developed a leak.
WHC-TANKFARM-1995-23	3/7/95	leak inside pit	Transfer from 204-AR to 102-AY leaked into 241-A-A valve pit through nozzle. Leak drained into catch tank A-350.
WHC-TANKFARM-1995-41	4/13/95	spray and/or liquid release inside pit	Leak found by 244-A camera crew during B Plant transfer.
WHC-TANKFARM-1995-81	10/4/95	leak inside pit	Transfer line SN-274 leaked during transfer between AX-B valve pit and 101-AN. Leak at flexible jumper connection. 2 gallons leaked.

Appendix B

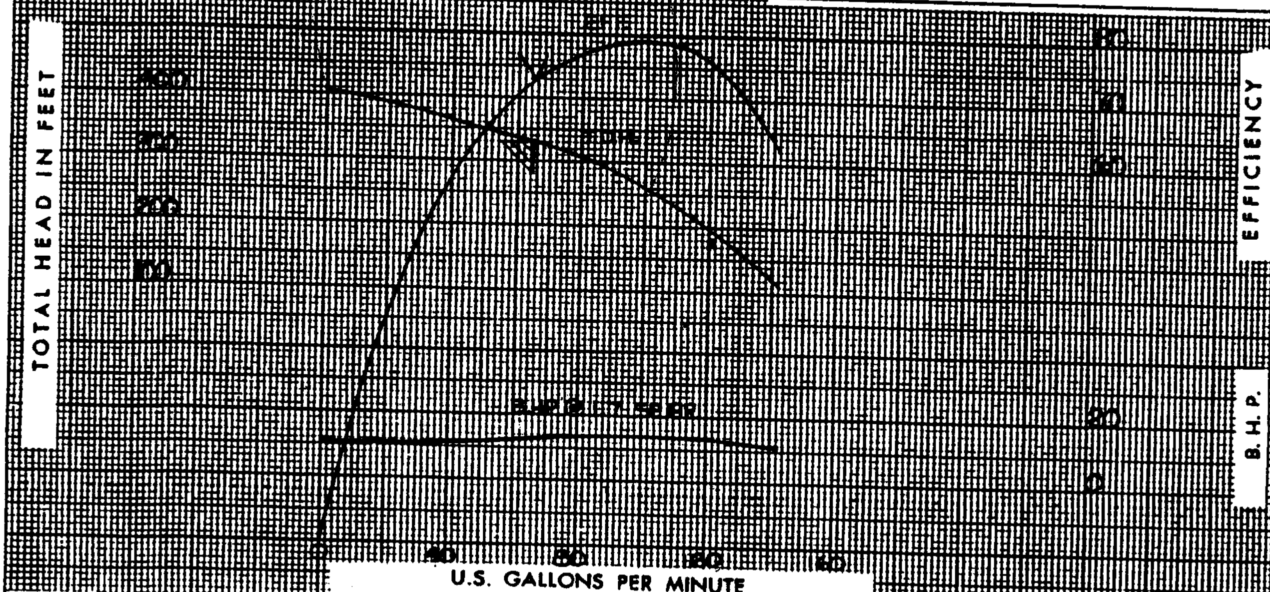
TWRS Pump Curves

DCRT Transfer Pump Curves and Data

48 of 10+2

DST/AW Transfer Pump Curves

ROCKWELL INTERNATIONAL CORP.
TAG: P-102-SY-02A-1 THRU-3
102 SY
3-20 HP CROSS COUNTRY TRANSFER PUMPS



PICATTI BROS., INC.
P.O. BOX 9576
YAKIMA, WASHINGTON 98901

Peabody Floway

TYPE 6 JOL
NO. OF STAGES 22
R.P.M. 1760
PUMP SERIAL NO. 80-2289-2291

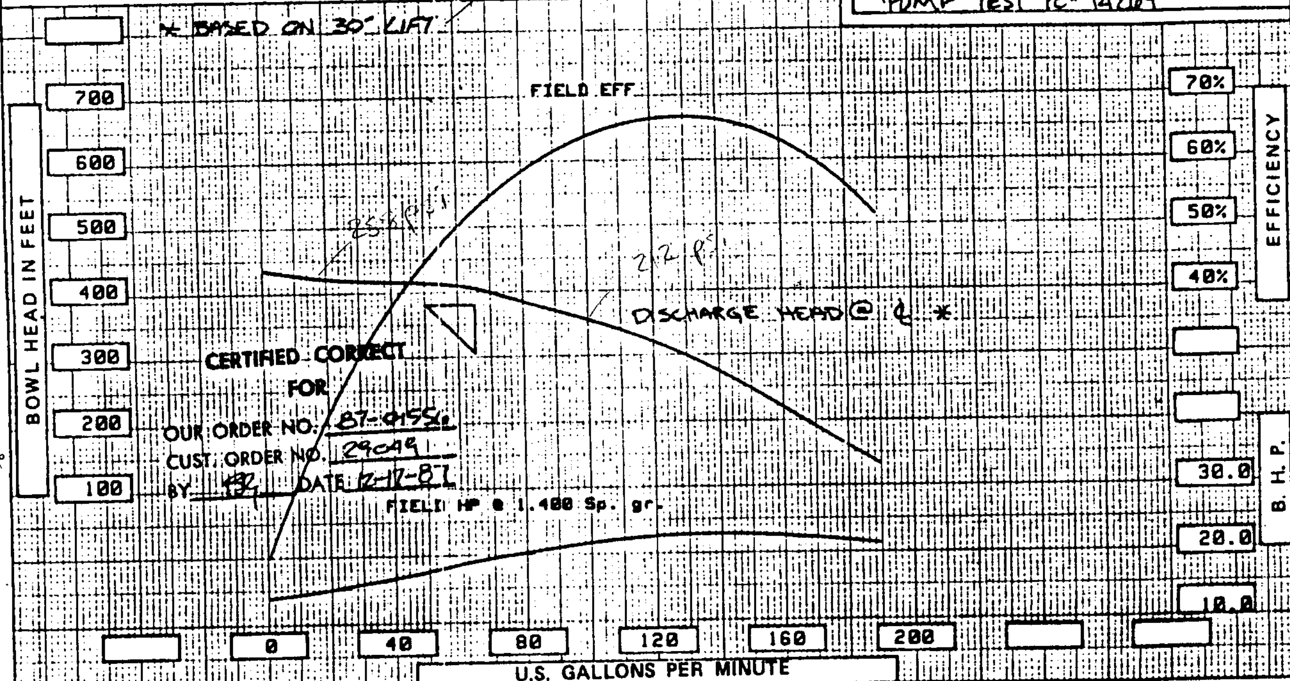
DWG. NO. 80-2268-9
FPI-213

DWN. BY L.S.H. DATE 4-16-80

102 SY, SPARE

Performance shown is the result of a test conducted in accordance with latest Hydraulic Institute Standards. Other Standards applicable when mutually agreed upon.

WESTINGHOUSE - HANFORD FACILITY
25HP CLOSE COUPLE PUMP
DASH # 615Y1
PUMP TEST PC# 14269



PICATTI BROS INC
YAKIMA, WASH 98909

Peabody Floway

TYPE 6JOLL
NO. OF STAGES 8
R.P.M.
PUMP SERIAL NO. 87-01556

DWG. NO. 87-01556

"There's a Difference..."

DWN. BY B.M.G. DATE 12/17/87

PF-5624

DCRT Transfer Pump Curves and Data

244A spare

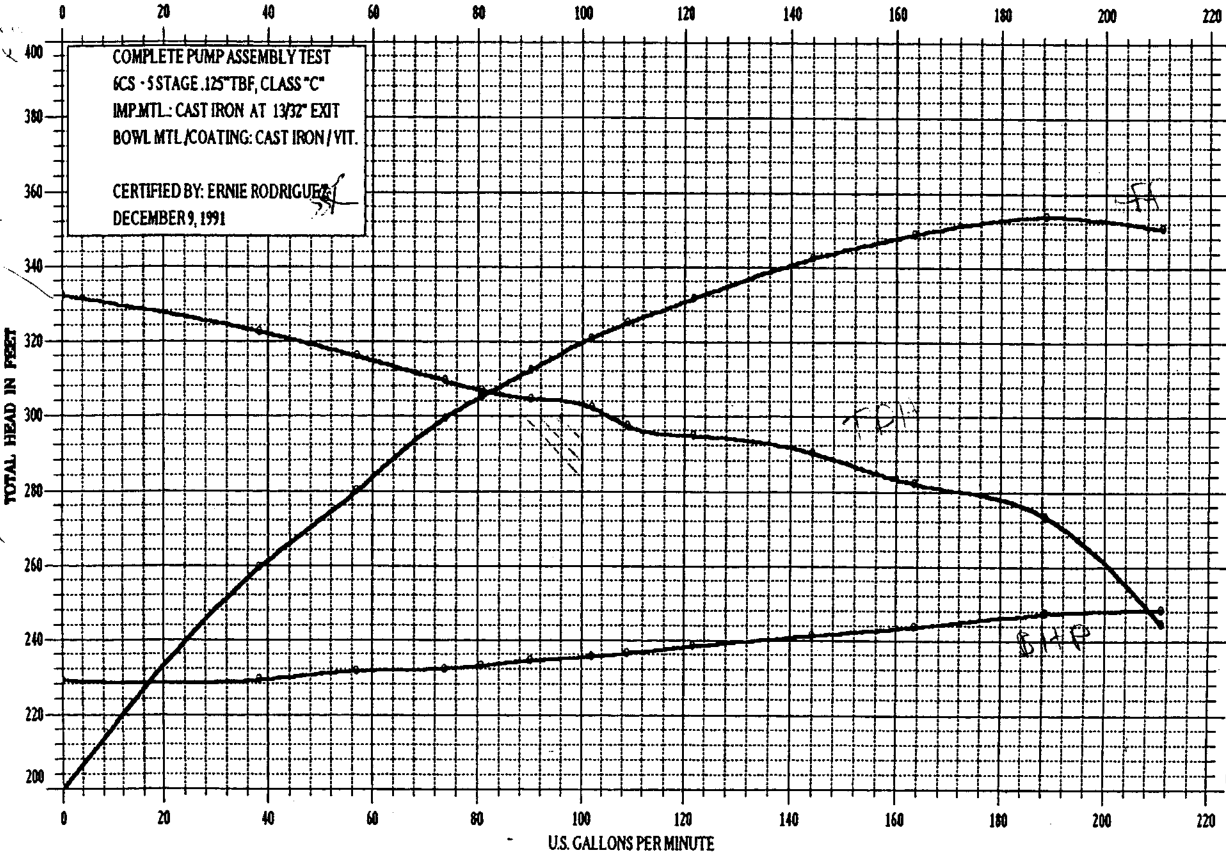
JOHNSTON PUMP COMPANY
BROOKSHIRE, TEXAS
CUSTOMER: WESTINGHOUSE HANFORD

PURCHASE ORDER # WAP-XVV-209726

JOB #: TC-6702 S/N:TC-6702 POF#:66190 TC #:06558

ITEM # 1

3565 RPM



WHC-SD-WM-CN-048
Rev. 1

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PUMP RUN-IN DATA SHEET

WORK ORDER NO. E-04865 TEST RUN-IN # 3 DATE 1-7-88
PUMP IDENTIFICATION # 2225-213P-TX-1 TEST SPECIFICATION # FS-F-10
SHAFT ROTATION CCW PUMP LENGTH 18' 4 3/8" DISCHARGE PIPE SIZE 2"

PERFORMANCE DATA

	WIDE OPEN FLOW	3/4 FLOW	RATED FLOW FROM CRITERIA	1/4 FLOW	SHUT OFF HEAD
1 GPM	186	143	100	50	0
2 DISCHARGE PRESSURE, PSIG.	9.2	88.5	152.7	199+	199+
3 DISCHARGE PRESSURE, FEET (PSIG X 2.31) water	21.3	204.4	352.7	461.8+	461.8+
4 GAGE CORRECTION (CENTER LINE OF GAGE TO WATER LEVEL IN FT)	7	7	7	7	7
5 VELOCITY HEAD DISCH PIPE	5	3	1.4	.4	—
6 PIPE DISCHARGE CORRECTION (ELBOW COUPLINGS)	26	19	14.3	10.4	9
7 TOTAL DISCHARGE HEAD FT. (ADD LINES 3+4+5+6)	59.3	233.4	375.4	479.6+	477.8+
8 AMPS	25.22	25.50	23.94	18.85	12.77
9 VIBRATION (MILS)	.3 mils	.3 mils	.3 mils	.3 mils	.3 mils
10					

RUN-IN-DATA

TIME	DISCHARGE PRESSURE PSIG	FLOW RATE GPM	AMPS	MOTOR BEARING TEMP. (150 DEGREES MAX.)	PUMP BRNG. TEMP.	VIBRATION (MILS)	COMMENTS
8:15	154.4	100	23.94	142°	86°	.3 mils	
9:15	158.7	100	24.22	146°	95°	.3 mils	
10:15	164.1	100	24.17	145°	100°	.3 mils	
11:15	164.6	100	24.14	140°	101°	.3 mils	
12:15	165.0	100	24.05	137°	103°	.3 mils	
1:15	165.2	100	24.05	141°	102°	.3 mils	
2:15	165.3	100	24.04	141°	103°	.3 mils	
3:15	165.4	100	24.00	140°	102°	.3 mils	

QC BY Q. Zimmerman DATE 1-8-88 STAMP QC RHO QCRN

50 of 10x2

1-7-88

WHC-SD-WM-CN-0048 Rev. 1

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PUMP RUN-IN DATA SHEET

WORK ORDER NO. E04865 TEST RUN-IN # 1 ONE DATE 12/21/87

PUMP IDENTIFICATION # 2225-213P-TX-1 TEST SPECIFICATION # FS-F-10

SHAFT ROTATION CCW PUMP LENGTH 18'4 3/8 DISCHARGE PIPE SIZE 2"

PERFORMANCE DATA

	WIDE OPEN FLOW	3/4 FLOW	RATED FLOW FROM CRITERIA	1/4 FLOW	SHUT OFF HEAD
1 GPM	180	140	100	50	0
2 DISCHARGE PRESSURE, PSIG.	9.2	86	148.4	195.6	199.2
3 DISCHARGE PRESSURE, FEET (PSIG X 2.31)	21.3	198.7	342.8	451.8	460.2
4 GAGE CORRECTION (CENTER LINE OF GAGE TO WATER LEVEL IN FT)	7	7	7	7	7
5 VELOCITY HEAD DISCH PIPE	4.6	2.8	1.4	—	—
6 PIPE DISCHARGE CORRECTION (ELBOW COUPLINGS)	25.3	19	14.3	10.4	9
7 TOTAL DISCHARGE HEAD FT. (ADD LINES 3+4+5+6)	58.2	227.5	365.5	469.2	476.2
8 AMPS	16.200	16.17	16.12	13.53	10.10
9 VIBRATION (MILS)	.3	.3	.3	.2	.2
10					

RUN-IN-DATA

TIME	DISCHARGE PRESSURE PSIG	FLOW RATE GPM	AMPS	MOTOR BEARING TEMP. (150 DEGREES MAX.)	PUMP BRNG. TEMP.	VIBRATION (MILS)	COMMENTS
8:30	149.4	100	15.87	129°	92°	.2	
9:30	154	100	15.90	137°	112°	.3	
10:30	158.8	100	15.85	133°	129°	.3	
11:30	158.3	100	15.90	134°	126°	.3	
12:30	157.6	100	15.96	132°	125°	.3	
1:30	158.5	100	15.93	117°	123°	.3	
2:30	156.8	100	15.30	155°	131°	.3	
3:30	157.8	100	15.42	149°	139°	.3	

QC REP. DATE STAMP QC 1-8-88 QCRN

SEE PAGE 9

51 of 102

QC INSPECTION RECORD 34828

ACCEPTANCE CRITERIA FOR PUMPING EQUIPMENT

Date of Test ______

MFR. Pump Wilkins Associates, Inc, WA.

Pump Serial No. 213 PTX-1

Purchase Order No. E 24667

Work Order No. E-04865

No. Stages A48'7

Motor MFR. US

Motor Type AU

Motor Full Load Rated Amps 36.65

Motor Service Factor 1.15

Motor Rated Horsepower 30 25

Length of Pump 18-4 3/8

Depth to Water Level 3'

Service Sp. G. ~~1.4~~ 1.7

TEST CHARACTERISTICS

1. Test Fluid = Water Sp. G. 1 or Other ______
2. S. O. Head = ______ PSIG ______ Feet (Min.)
3. Total Disch. Head (Rated) = ______ PSIG ~~150~~ 300 Feet (Min.)
4. Capacity (At Rated Head) = 100 GPM (Min)
5. Test Amps = ______ Amps (Max.)
6. Test Amps x Sp. G (Service) = ______ Amps (Compare with Motor F. L. Amps)
7. Test Voltage = 460 Volts
8. Vibration = 2 Mils Max @ ______ RPM
9. Impeller Clearance = .028 Inches Min. .032 Inches Max.

Set at .032 1-6-88

RUN-IN CHARACTERISTICS

1. Flow 100 Total Discharge Head ~~150~~ 300 Time 1 Hrs.
2. Flow ______ Total Discharge Head ______ Time ______ Hrs.

SPECIAL TEST REQUIREMENTS

Coordinate testing with Process Engineering, Jim L. Foster on 3-4189.

Remarks (Noise Level, Unusual Characteristic, etc.)

① 2nd Run-in requested because of unstable mtr. brg. temperature during 1st run-in.
① 3rd Run-in requested when it was noted the pump to motor adapter flange was cocked.
① (3rd run-in performed after flange was properly installed) Craig Shaw 1/7/88

QC INSPECTION RECORD

Approvals:

Plant Design E.E. Bordue Date 10/27/87

Deviation Approval ______ Date ______

Fabrication Control ______ Date ______

NOTE: Deviations from this Acceptance Criteria can only be approved by Plant Design.

① KH0 73 1-8-88

Quality Control Representative

Stamp

Date 1-8-88

QCRN 34828

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WHC-SD-WM-CN-048
Rev.1

PUMP RUN IN DATA SHEET PAGE 8 OF 8

WORK ORDER NO. E-04865 TEST RUN IN # 2 DATE 12/29/87
PUMP IDENTIFICATION # 2225-2139-TX-1 TEST SPECIFICATION # FS-P-10
SHAFT ROTATION CCW PUMP LENGTH ~~CCW~~ 18'4 3/8" DISCHARGE PIPE SIZE 2

PERFORMANCE DATA

		WIDE OPEN FLOW	3/4 FLOW	RATED FLOW FROM CRITERIA	1/4 FLOW	SHUT OFF HEAD
1	GPM	180	140	100	50	0
2	DISCHARGE PRESSURE, PSIG.	9	82	144.5	192.4	199+
3	DISCHARGE PRESSURE, FEET (PSIG X 2.31)	20.8	189.4	333.8	444.4	459.7+
4	GAGE CORRECTION (CENTER LINE OF GAGE TO WATER LEVEL IN FT)	7	7	7	7	7
5	VELOCITY HEAD DISCH PIPE	4.6	2.8	1.4	.4	—
6	PIPE DISCHARGE CORRECTION (ELBOW COUPLINGS)	25.3	19.0	14.3	10.4	9
7	TOTAL DISCHARGE HEAD FT. (ADD LINES 3+4+5+6)	57.7	218.2	356.5	462.2	475.7+
8	AMPS	24.32	24.11	22.89	19.49	13.99
9	VIBRATION (MILS)	< 1 mil	< 1 mil	< 1 mil	< 1 mil	< 1 mil
10						

RUN-IN-DATA

TIME	DISCHARGE PRESSURE PSIG	FLOW RATE GPM	AMPS	MOTOR BEARING TEMP. (150 DEGREES MAX.)	PUMP BRNG. TEMP.	VIBRATION (MILS)	COMMENTS
8:15	144.7	100	23.25	140°	98°	< 1 mil	
9:15	152.5	100	23.30	149°	128°	< 1 mil	
10:15	155.5	100	23.74	154°	137°	< 1 mil	
11:15	156.3	100	23.72	155°	142°	< 1 mil	
12:15	156.6	100	23.73	152°	138°	< 1 mil	
1:15	159.8	100	23.69	151°	142°	< 1 mil	
2:15	159	100	23.65	151°	142°	< 1 mil	
3:15	159.6	100	23.47	149°	144°	< 1 mil	

QC REP.	DATE	STAMP	QCRN

Added Page
53 of 142 ~~SEE PAGE 9~~

12-2

PB-2 Transfer Pump Curve (pump inside 242-A Evaporator)

WHC-SD-WM-CN-048 Rev. 1

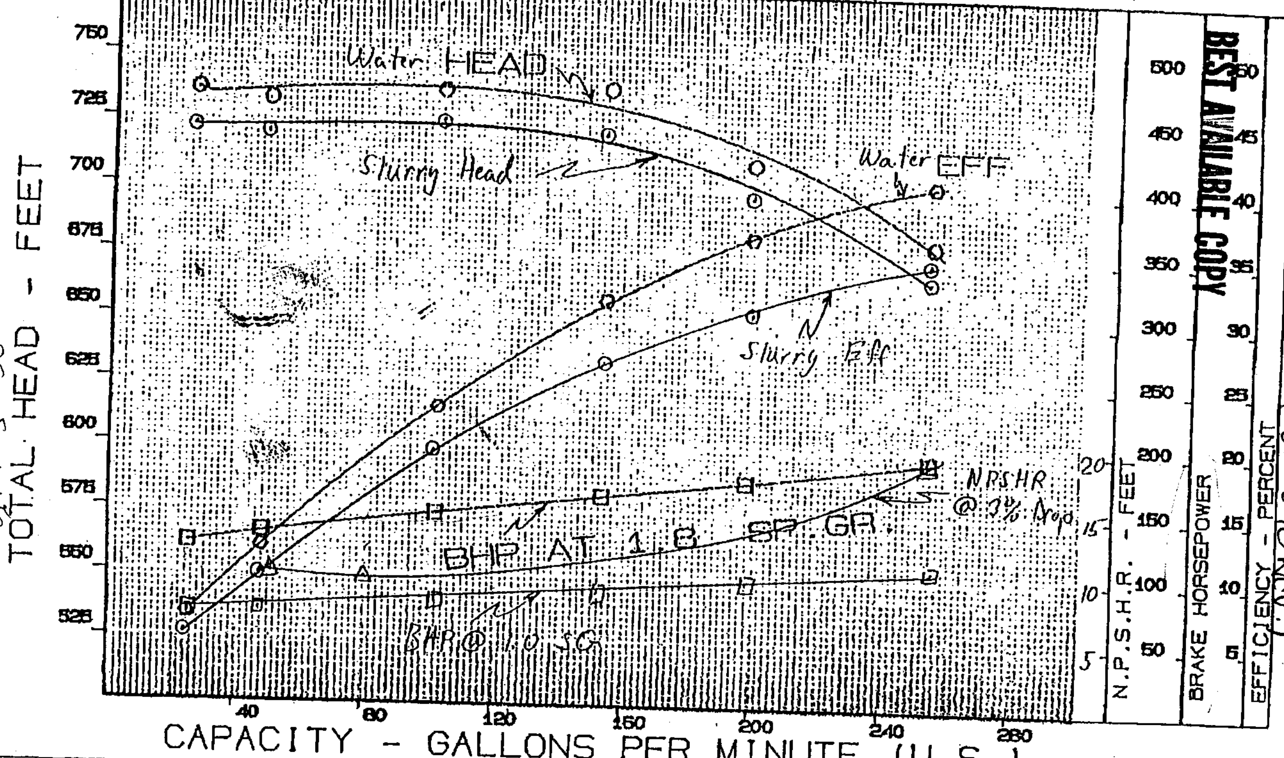
T2240H

LAWRENCE PUMPS INC.

371 Market Street, Lawrence, MA 01843-9966

CHARACT[illegible]TIC CURVE ☐
TEST PERFORMANCE CURVE ☒
TEST NO. T2240H
NOTE:

CERT. FOR: KAISER
TESTED BY: RJM DATE: 6/28/90
ACCEPTED BY: [illegible] DATE: 7/6/90
COMMENT:



OWNER KAISER ENG
HANFORD
P.O. NO. KOA-Y25-44413
ITEM NO. P-B-2

SERVICE SALT SLURRY
GPM 78 TDH 600
SP. GR. 1.8 VISC. 80CP
P.T. 180F P.H. N/A

PUMP SIZE 1 1/2X3X12.5
PUMP TYPE HORIZ SLURRY
IMP.: DESIGN 12.5 MAX 12.5 MIN 8
RPM 3450 SER. NO. 80181

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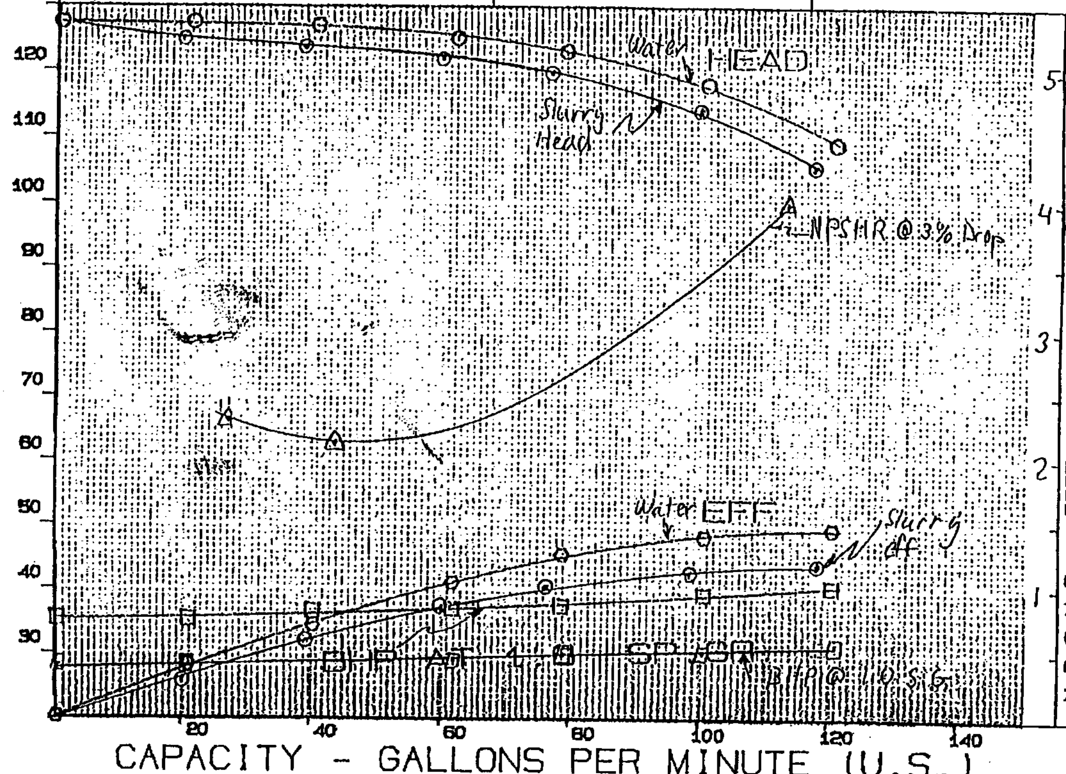
WHC-SD-WM-CN-048 Rev. 1

T2240C

LAWRENCE PUMPS INC.

371 Market Street, Lawrence, MA 01043-9966

CHARACTERISTIC CURVE ☐	CERT. FOR: KAISER
TEST PERFORMANCE CURVE ☒	TESTED BY: RJM DATE: 6/28/90
TEST NO. T2240C	ACCEPTED BY: KBB DATE: 7/6/90
NOTE:	COMMENT:



...ER KAISER ENG	SERVICE SALT SLURRY	PUMP SIZE 1 1/2X3X12.5
HANFORD	GPM 78 TDH 600	PUMP TYPE HORIZ SLURRY
NO. KGA-Y25-44413	SP.GR. 1.8 VISC. 60CP	IMP.: DESIGN 12.5 MAX 12.5 MIN 8
...O. P-B-2	P.T. 180F P.H. N/A	RPM 1450 SER. NO. 90151

SST Saltwell Pump Curve

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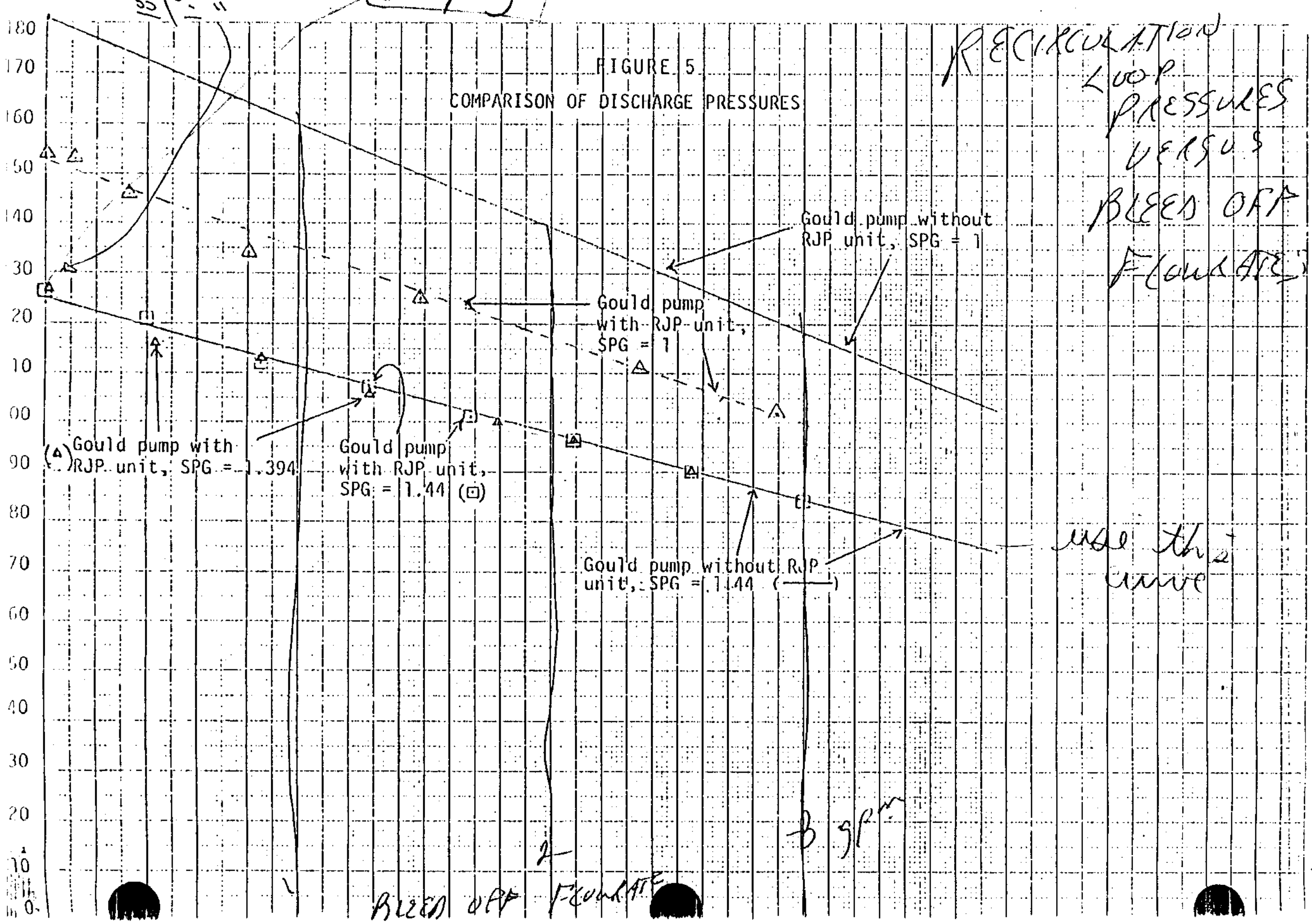
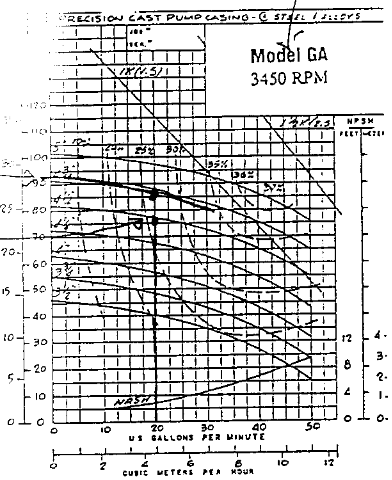
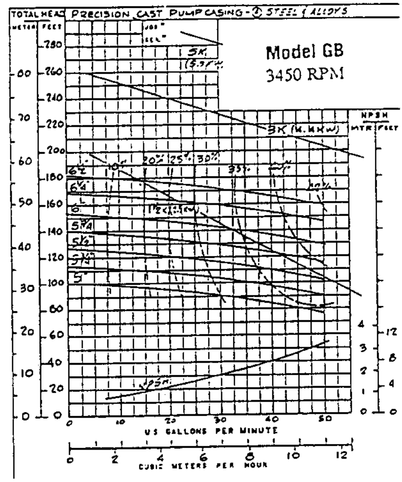
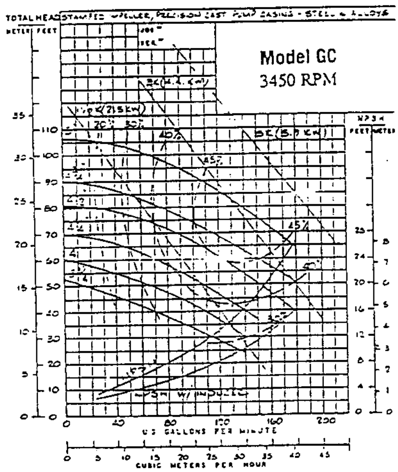


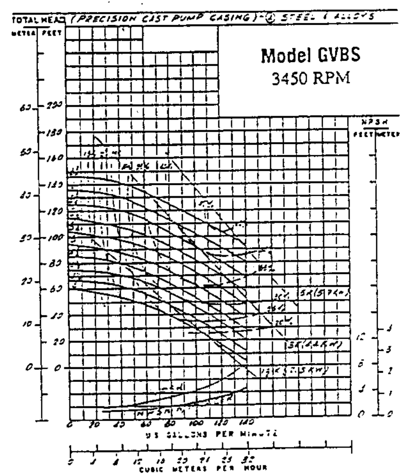
CENTRIFUGAL PUMP FOR JET PUMP

BEST AVAILABLE COPY



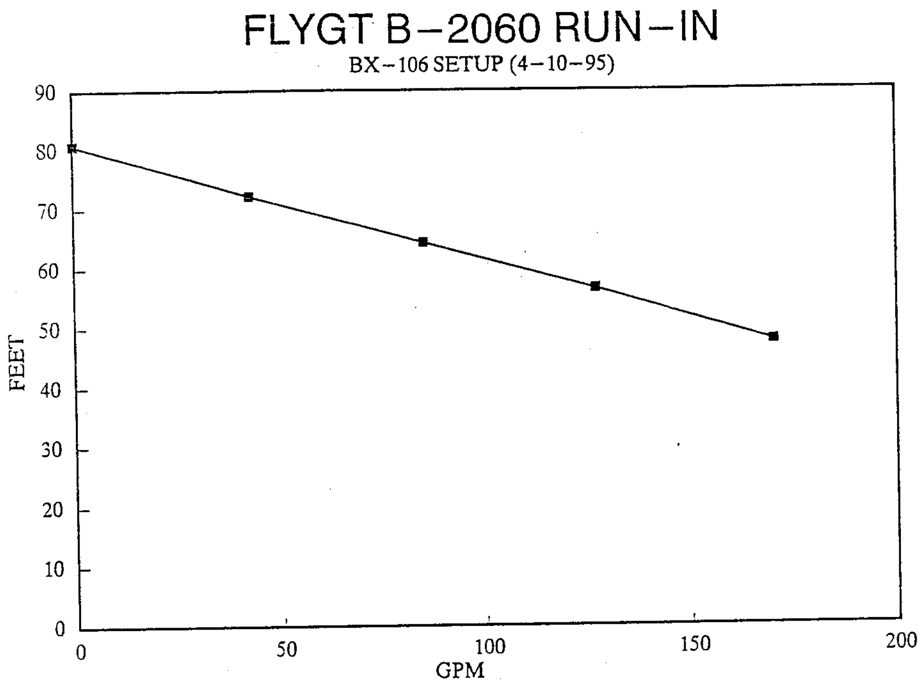






Curves are based on shop test while handling clear water at 20°C and at sea level. Performance guarantees apply at rating point only. Efficiencies shown are overall wire to water. Numbers beneath model designations indicate full load kilowatt ratings for the referenced motor load lines. When pumping fluids with specific gravities other than 1.0, select pump model (see load line) to handle load equivalent in feet of water. e.g. 40 feet of fluid of Sp. Gr. 1.5 is load equivalent of 60 feet (1.5x40) of water. Please note that this is merely a short cut method to estimate the model required. For proper model selection, especially when handling a fluid with a Sp. Gr. greater than 1.7, consult your Champump representative or the factory.

SST Submersible Pump Curve


FLYGT B-2060 RUN-IN
BX-106 SETUP (4-10-95)
FEET
GPM
0
10
20
30
40
50
60
70
80
90
0
50
100
150
200

204-AR Unloading Facility Transfer Pump Curve

DATE 4-8-74 REV. DATE

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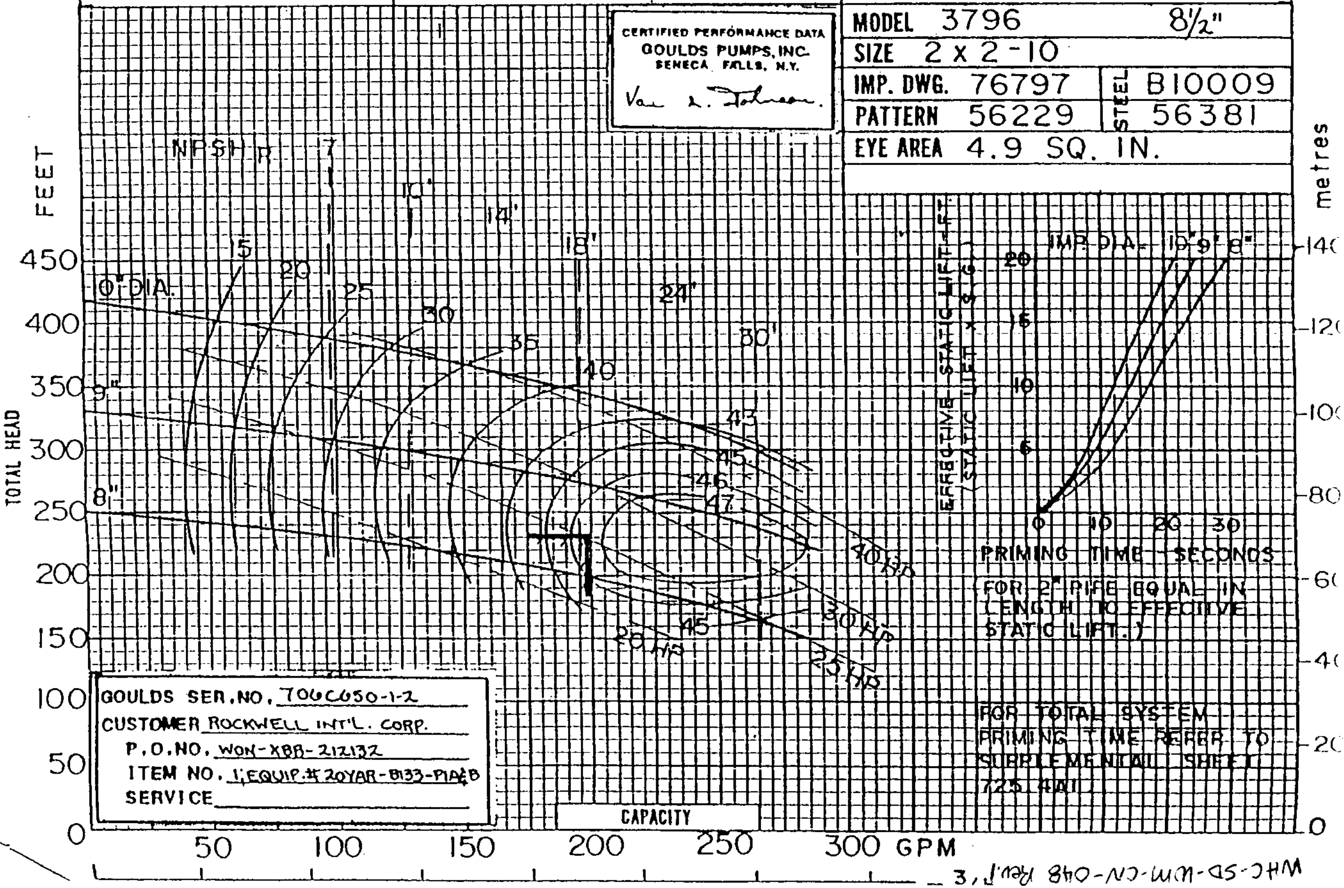
GOULDS PUMPS, INC. SENECA FALLS, NEW YORK 13148

CENTRIFUGAL PUMP CHARACTERISTICS

RPM	3550 CDS 2298
MODEL	3796 8½"
SIZE	2 x 2-10
IMP. DWG.	76797
STEEL	B10009
PATTERN	56229
STEEL	56381
EYE AREA	4.9 SQ. IN.

CERTIFIED PERFORMANCE DATA
GOULDS PUMPS, INC.
SENECA FALLS, N.Y.
Van L. Johnson

GOULDS SER. NO. 70GC650-1-2
CUSTOMER ROCKWELL INT'L. CORP.
P.O. NO. WON-XBB-212132
ITEM NO. 1, EQUIP. #20YAR-B133-P1A&B
SERVICE



Appendix C

SPRAY Model Input and Output

Case 1. Spray Leak Through 2 in. Sch. 40 pipe at 300 psi, Optimum Sized Crack Width, 2 in. Long Crack

---

SPRAY Version 3.2
August 31, 1995

```
Spray Leak Code
Produced by Radiological & Toxicological Analysis
Westinghouse Hanford Company


Run Date = 07/29/96/
Run Time = 13:33:41.29


INPUT ECHO:
c Case 1:  Spray at 300 psig through 2 inch crack, slit width optimized
c SPRAY Code Version 3.2 Input File
c
c MODEL OPTIONS:
c
c mode  - program calculation mode
c         = 1 for orifice leak
c         = 2 for slit leak
c ifric - integer flag for friction factor
c         = 0 for program selection
c         = 1 for laminar relation
c         = 2 for turbulent relation
c iopt  - integer flag for flow determination
c         = 0 for optimal diameter search given initial guess diameter and Re
c         = 1 for flow based on user specified diameter
c         = 2 for flow based on user specified Reynold's number
c
c   mode ifric iopt
    2    0    0
c
c PARTICLE SIZE DISTRIBUTION TABLE PARAMETERS:
c
c   Starting
c   Particle
c   Size           Geometric      Number of
c   (um)           Step Size      Intervals
c  ___________    ___________    ___________
    1.00000E+01    2.00000E+00    10
c
c PARAMETER INPUT:
c
c   Initial Slit                  Slit or
c   Width or       Slit           Orifice
c   Orifice Dia.   Length         Depth          Reynold's
```

```
c   (in)             (in)            (in)            Number
c   ____________     _____________   ____________    ____________
    1.00000E-02      2.00000E+00     1.54000E-01     2.00000E+03
c
c                    Absolute
c                    Surface
c                    Roughness       Contraction     Velocity
c                    (in)            Coefficient     Coefficient
c   Pressure         0.00006 tube    0.61   and      0.98  for sharp edge orifice
c   Differential     0.0018  steel   1.00   and      0.98  for rounded orifice
c   (psi)            0.0102  iron    1.00   and      0.82  for square edge orifice
c   ____________     _____________   ____________    ______________________________
    3.00000E+02      1.80000E-03     1.00000E+00     8.20000E-01
c
c   Fluid            Dynamic         Respirable      RR Fitting
c   Density          Viscosity       Diameter        Constant
c   (g/cc)           (centi-poise)   (µm)            (q)
c   ____________     _____________   ____________    ____________
    1.40000E+00      1.00000E+00     1.50000E+01     2.40000E+00
c
c   Ambient          Wind
c   Density          Speed
c   (g/cc)           (m/s)
c   ____________     _____________
    1.22000E-03      1.00000E+00


MESSAGES:
Slit Model
Code search for optimal equivalent diameter.


OUTPUT:
     Liquid Velocity =  8.70E+01 ft/s      2.65E+01 m/s
     Reynolds Number =  8.44E+03 Turbulent Flow
Sauter Mean Diameter =  4.72E+01 µm
Mass Median Diameter =  6.19E+01 µm
Characteristic Dia.  =  7.21E+01 µm
  Optimum Slit Width =  4.48E-03 in        1.14E-04 m
 Respirable Fraction =  2.28E-02
     Total Leak Rate =  2.43E+00 gpm       1.53E-04 m3/s       2.15E+02 g/s
Respirable Leak Rate =  5.55E-02 gpm       3.50E-06 m3/s       4.90E+00 g/s
            Jet Rise =  1.32E+00 ft        4.02E-01 m

Particle     Section      Cumulative
Diameter     Release      Release      Cumulative
Sections     Rate         Rate         Percent
(m)          (kg/s)       (kg/s)       (%)
__________   __________   __________   __________
1.00E-05     1.87E-03     1.87E-03        0.87
2.00E-05     7.80E-03     9.67E-03        4.50
4.00E-05     3.67E-02     4.64E-02       21.58
```

8.00E-05	1.09E-01	1.55E-01	72.28
1.60E-04	5.93E-02	2.15E-01	99.89
3.20E-04	2.46E-04	2.15E-01	100.00
6.40E-04	0.00E+00	2.15E-01	100.00
1.28E-03	0.00E+00	2.15E-01	100.00
2.56E-03	0.00E+00	2.15E-01	100.00
5.12E-03	0.00E+00	2.15E-01	100.00

Case 2. SST Pump Pit Spray Leak--Spray Leak Through 1 in. Schedule 40 Pipe at 85 Psig, Optimum Sized Crack Width, 2 in. Long Crack

SPRAY Version 3.2
August 31, 1995

Spray Leak Code
Produced by Radiological & Toxicological Analysis
Westinghouse Hanford Company

Run Date = 07/29/96/
Run Time = 13:37:59.16

```
INPUT ECHO:
c Case 2:  Spray at 85 psig through 2 inch crack, slit width optimized
c SPRAY Code Version 3.2 Input File
c
c MODEL OPTIONS:
c
c mode  - program calculation mode
c         = 1 for orifice leak
c         = 2 for slit leak
c ifric - integer flag for friction factor
c         = 0 for program selection
c         = 1 for laminar relation
c         = 2 for turbulent relation
c iopt  - integer flag for flow determination
c         = 0 for optimal diameter search given initial guess diameter and Re
c         = 1 for flow based on user specified diameter
c         = 2 for flow based on user specified Reynold's number
c
c   mode ifric iopt
    2    0    0
c
c PARTICLE SIZE DISTRIBUTION TABLE PARAMETERS:
c
c   Starting
c   Particle
c   Size            Geometric       Number of
c   (um)            Step Size       Intervals
c   ____________    ___________     ___________
    1.00000E+01     2.00000E+00     10
c
c PARAMETER INPUT:
c
c   Initial Slit                    Slit or
c   Width or        Slit            Orifice
```

```
c   Orifice Dia.   Length          Depth          Reynold's
c   (in)           (in)            (in)           Number
c
    1.00000E-02    2.00000E+00     1.33000E-01    2.00000E+03
c
c                  Absolute
c                  Surface
c                  Roughness       Contraction    Velocity
c                  (in)            Coefficient    Coefficient
c   Pressure       0.00006 tube    0.61    and    0.98  for sharp edge orifice
c   Differential   0.0018  steel   1.00    and    0.98  for rounded orifice
c   (psi)          0.0102  iron    1.00    and    0.82  for square edge orifice
c
    8.50000E+01    1.80000E-03     1.00000E+00    8.20000E-01
c
c   Fluid          Dynamic         Respirable     RR Fitting
c   Density        Viscosity       Diameter       Constant
c   (g/cc)         (centi-poise)   (µm)           (q)
c
    1.40000E+00    1.00000E+00     1.50000E+01    2.40000E+00
c
c   Ambient        Wind
c   Density        Speed
c   (g/cc)         (m/s)
c
    1.22000E-03    1.00000E+00


MESSAGES:
Slit Model
Code search for optimal equivalent diameter.


OUTPUT:
     Liquid Velocity =  4.65E+01 ft/s      1.42E+01 m/s
     Reynolds Number =  4.19E+03 Turbulent Flow
Sauter Mean Diameter =  8.08E+01 µm
Mass Median Diameter =  1.06E+02 µm
Characteristic Dia.  =  1.23E+02 µm
  Optimum Slit Width =  4.16E-03 in        1.06E-04 m
 Respirable Fraction =  6.34E-03
     Total Leak Rate =  1.21E+00 gpm       7.61E-05 m3/s      1.07E+02 g/s
Respirable Leak Rate =  7.65E-03 gpm       4.82E-07 m3/s      6.75E-01 g/s
            Jet Rise =  6.71E-01 ft        2.05E-01 m

Particle    Section     Cumulative
Diameter    Release     Release     Cumulative
Sections    Rate        Rate        Percent
(m)         (kg/s)      (kg/s)      (%)

1.00E-05    2.56E-04    2.56E-04        0.24
2.00E-05    1.09E-03    1.34E-03        1.26
```

4.00E-05	5.56E-03	6.90E-03	6.47
8.00E-05	2.48E-02	3.17E-02	29.76
1.60E-04	5.84E-02	9.01E-02	84.50
3.20E-04	1.65E-02	1.07E-01	99.99
6.40E-04	5.68E-06	1.07E-01	100.00
1.28E-03	0.00E+00	1.07E-01	100.00
2.56E-03	0.00E+00	1.07E-01	100.00
5.12E-03	0.00E+00	1.07E-01	100.00

Case 3. Spray Leak Through 2 in. Schedule 40 Pipe at 150 Psig, Optimum Sized Crack Width

SPRAY Version 3.2
August 31, 1995

```
Spray Leak Code
Produced by Radiological & Toxicological Analysis
Westinghouse Hanford Company


Run Date = 07/29/96/
Run Time = 13:44:36.06


INPUT ECHO:
c Case 3:  Spray at 150 psig through 2 inch crack, slit width optimized
c SPRAY Code Version 3.2 Input File
c
c MODEL OPTIONS:
c
c mode  - program calculation mode
c         = 1 for orifice leak
c         = 2 for slit leak
c ifric - integer flag for friction factor
c         = 0 for program selection
c         = 1 for laminar relation
c         = 2 for turbulent relation
c iopt  - integer flag for flow determination
c         = 0 for optimal diameter search given initial guess diameter and Re
c         = 1 for flow based on user specified diameter
c         = 2 for flow based on user specified Reynold's number
c
c   mode ifric iopt
    2    0    0
c
c PARTICLE SIZE DISTRIBUTION TABLE PARAMETERS:
c
c   Starting
c   Particle
c   Size           Geometric      Number of
c   (um)           Step Size      Intervals
c   ____________   ____________   ___________
    1.00000E+01    2.00000E+00    10
c
c PARAMETER INPUT:
c
c   Initial Slit                  Slit or
c   Width or       Slit           Orifice
```

```
c   Orifice Dia.   Length         Depth          Reynold's
c   (in)           (in)           (in)           Number
c
    1.00000E-02    2.00000E+00    1.54000E-01    2.00000E+03
c
c                  Absolute
c                  Surface
c                  Roughness      Contraction    Velocity
c                  (in)           Coefficient    Coefficient
c   Pressure       0.00006 tube   0.61   and     0.98  for sharp edge orifice
c   Differential   0.0018  steel  1.00   and     0.98  for rounded orifice
c   (psi)          0.0102  iron   1.00   and     0.82  for square edge orifice
c
    1.50000E+02    1.80000E-03    1.00000E+00    8.20000E-01
c
c   Fluid          Dynamic        Respirable     RR Fitting
c   Density        Viscosity      Diameter       Constant
c   (g/cc)         (centi-poise)  (µm)           (q)
c
    1.40000E+00    1.00000E+00    1.50000E+01    2.40000E+00
c
c   Ambient        Wind
c   Density        Speed
c   (g/cc)         (m/s)
c
    1.22000E-03    1.00000E+00
```

MESSAGES:
Slit Model
Code search for optimal equivalent diameter.

OUTPUT:

```
     Liquid Velocity =  6.13E+01 ft/s      1.87E+01 m/s
     Reynolds Number =  5.91E+03 Turbulent Flow
Sauter Mean Diameter =  6.66E+01 µm
Mass Median Diameter =  8.73E+01 µm
Characteristic Dia.  =  1.02E+02 µm
  Optimum Slit Width =  4.46E-03 in        1.13E-04 m
 Respirable Fraction =  1.01E-02
     Total Leak Rate =  1.70E+00 gpm       1.07E-04 m3/s      1.50E+02 g/s
Respirable Leak Rate =  1.71E-02 gpm       1.08E-06 m3/s      1.51E+00 g/s
           Jet Rise =  9.25E-01 ft        2.82E-01 m
```

Particle Diameter Sections (m)	Section Release Rate (kg/s)	Cumulative Release Rate (kg/s)	Cumulative Percent (%)
1.00E-05	5.73E-04	5.73E-04	0.38
2.00E-05	2.43E-03	3.00E-03	1.99

4.00E-05	1.22E-02	1.52E-02	10.09
8.00E-05	4.95E-02	6.46E-02	42.96
1.60E-04	7.81E-02	1.43E-01	94.83
3.20E-04	7.78E-03	1.50E-01	100.00
6.40E-04	2.98E-08	1.50E-01	100.00
1.28E-03	0.00E+00	1.50E-01	100.00
2.56E-03	0.00E+00	1.50E-01	100.00
5.12E-03	0.00E+00	1.50E-01	100.00

Case 4. Spray Leak Through 2 in. Sch. 40 Pipe at 50 Psig, Optimum Crack Width, 2 in. Crack Length

SPRAY Version 3.2
August 31, 1995

```
Spray Leak Code
Produced by Radiological & Toxicological Analysis
Westinghouse Hanford Company


Run Date = 07/29/96/
Run Time = 13:48:43.44


INPUT ECHO:
c Case 4:  Spray at 50 psig through 2 inch crack, sch. 40 pipe, optimum slit
c SPRAY Code Version 3.2 Input File
c
c MODEL OPTIONS:
c
c mode  - program calculation mode
c         = 1 for orifice leak
c         = 2 for slit leak
c ifric - integer flag for friction factor
c         = 0 for program selection
c         = 1 for laminar relation
c         = 2 for turbulent relation
c iopt  - integer flag for flow determination
c         = 0 for optimal diameter search given initial guess diameter and Re
c         = 1 for flow based on user specified diameter
c         = 2 for flow based on user specified Reynold's number
c
c   mode ifric iopt
    2    0    0
c
c PARTICLE SIZE DISTRIBUTION TABLE PARAMETERS:
c
c   Starting
c   Particle
c   Size           Geometric      Number of
c   (um)           Step Size      Intervals
c   ____________   ___________    ___________
    1.00000E+01    2.00000E+00    10
c
c PARAMETER INPUT:
c
c   Initial Slit                  Slit or
c   Width or       Slit           Orifice
```

```
c   Orifice Dia.   Length          Depth          Reynold's
c   (in)           (in)            (in)           Number
c   ____________   ____________    ____________   ____________
    1.00000E-02    2.00000E+00     1.54000E-01    2.00000E+03
c
c                  Absolute
c                  Surface
c                  Roughness       Contraction    Velocity
c                  (in)            Coefficient    Coefficient
c   Pressure       0.00006 tube    0.61   and     0.98  for sharp edge orifice
c   Differential   0.0018  steel   1.00   and     0.98  for rounded orifice
c   (psi)          0.0102  iron    1.00   and     0.82  for square edge orifice
c   ____________   ____________    ____________   ______________________________
    5.00000E+01    1.80000E-03     1.00000E+00    8.20000E-01
c
c   Fluid          Dynamic         Respirable     RR Fitting
c   Density        Viscosity       Diameter       Constant
c   (g/cc)         (centi-poise)   (µm)           (q)
c   ____________   ____________    ____________   ____________
    1.40000E+00    1.00000E+00     1.50000E+01    2.40000E+00
c
c   Ambient        Wind
c   Density        Speed
c   (g/cc)         (m/s)
c   ____________   ____________
    1.22000E-03    1.00000E+00


MESSAGES:
Slit Model
Code search for optimal equivalent diameter.


OUTPUT:
     Liquid Velocity =  3.54E+01 ft/s      1.08E+01 m/s
     Reynolds Number =  3.43E+03 Critical Flow
Sauter Mean Diameter =  1.16E+02 µm
Mass Median Diameter =  1.52E+02 µm
Characteristic Dia.  =  1.77E+02 µm
  Optimum Slit Width =  4.48E-03 in        1.14E-04 m
 Respirable Fraction =  2.66E-03
     Total Leak Rate =  9.88E-01 gpm       6.24E-05 m3/s      8.73E+01 g/s
Respirable Leak Rate =  2.63E-03 gpm       1.66E-07 m3/s      2.32E-01 g/s
            Jet Rise =  5.36E-01 ft        1.63E-01 m

Particle    Section     Cumulative
Diameter    Release     Release     Cumulative
Sections    Rate        Rate        Percent
(m)         (kg/s)      (kg/s)      (%)
________    ________    ________    ________
1.00E-05    8.78E-05    8.78E-05      0.10
2.00E-05    3.75E-04    4.62E-04      0.53
```

4.00E-05	1.95E-03	2.41E-03	2.76
8.00E-05	9.59E-03	1.20E-02	13.75
1.60E-04	3.53E-02	4.73E-02	54.19
3.20E-04	3.86E-02	8.59E-02	98.38
6.40E-04	1.42E-03	8.73E-02	100.00
1.28E-03	0.00E+00	8.73E-02	100.00
2.56E-03	0.00E+00	8.73E-02	100.00
5.12E-03	0.00E+00	8.73E-02	100.00

Case 5. Spray Leak Through 2 in. Sch. 40 Pipe at 300 psig, 0.01 in Crack Width, 2 in. Long Crack.

```
            SPRAY Version 3.2
             August 31, 1995

Spray Leak Code
Produced by Radiological & Toxicological Analysis
Westinghouse Hanford Company


Run Date = 05/30/96/
Run Time = 15:44:56.01


INPUT ECHO:
c Case 5: 300 psig, 0.01 in wide crack

c SPRAY Code Version 3.2 Input File
c
c MODEL OPTIONS:
c
c mode  - program calculation mode
c         = 1 for orifice leak
c         = 2 for slit leak
c ifric - integer flag for friction factor
c         = 0 for program selection
c         = 1 for laminar relation
c         = 2 for turbulent relation
c iopt  - integer flag for flow determination
c         = 0 for optimal diameter search given initial guess diameter and Re
c         = 1 for flow based on user specified diameter
c         = 2 for flow based on user specified Reynold's number
c
c   mode ifric iopt
    2    0    1
c
c PARTICLE SIZE DISTRIBUTION TABLE PARAMETERS:
c
c   Starting
c   Particle
c   Size            Geometric      Number of
c   (um)            Step Size      Intervals
c   ____________    __________     __________
    1.00000E+01     2.00000E+00    10
c
c PARAMETER INPUT:
c
c   Initial Slit                   Slit or
c   Width or        Slit           Orifice
```

```
c    Orifice Dia.    Length          Depth           Reynold's
c    (in)            (in)            (in)            Number
c
     1.00000E-02     2.00000E+00     1.54000E-01     2.00000E+03
c
c                    Absolute
c                    Surface
c                    Roughness       Contraction     Velocity
c                    (in)            Coefficient     Coefficient
c    Pressure        0.00006 tube    0.61    and     0.98  for sharp edge orifice
c    Differential    0.0018  steel   1.00    and     0.98  for rounded orifice
c    (psi)           0.0102  iron    1.00    and     0.82  for square edge orifice
c
     3.00000E+02     1.80000E-03     1.00000E+00     8.20000E-01
c
c    Fluid           Dynamic         Respirable      RR Fitting
c    Density         Viscosity       Diameter        Constant
c    (g/cc)          (centi-poise)   (µm)            (q)
c
     1.40000E+00     1.00000E+00     1.50000E+01     2.40000E+00
c
c    Ambient         Wind
c    Density         Speed
c    (g/cc)          (m/s)
c
     1.22000E-03     1.00000E+00
```

MESSAGES:
Slit Model
User specified orifice diameter or slit width.

```
OUTPUT:
     Liquid Velocity =  1.19E+02 ft/s      3.64E+01 m/s
     Reynolds Number =  2.57E+04 Turbulent Flow
Sauter Mean Diameter =  8.99E+01 µm
Mass Median Diameter =  1.18E+02 µm
Characteristic Dia.  =  1.37E+02 µm
 Respirable Fraction =  4.91E-03
     Total Leak Rate =  7.44E+00 gpm       4.69E-04 m3/s      6.57E+02 g/s
Respirable Leak Rate =  3.65E-02 gpm       2.30E-06 m3/s      3.23E+00 g/s
           Jet Rise  =  3.08E+00 ft        9.39E-01 m
```

Particle Diameter Sections (m)	Section Release Rate (kg/s)	Cumulative Release Rate (kg/s)	Cumulative Percent (%)
1.00E-05	1.22E-03	1.22E-03	0.19
2.00E-05	5.20E-03	6.42E-03	0.98
4.00E-05	2.68E-02	3.32E-02	5.05

8.00E-05	1.24E-01	1.57E-01	23.93
1.60E-04	3.45E-01	5.02E-01	76.39
3.20E-04	1.55E-01	6.57E-01	99.95
6.40E-04	3.22E-04	6.57E-01	100.00
1.28E-03	0.00E+00	6.57E-01	100.00
2.56E-03	0.00E+00	6.57E-01	100.00
5.12E-03	0.00E+00	6.57E-01	100.00

Case 6: Spray Leak Through 2 in. Schedule 40 Pipe, 2 in. Long Crack, 0.1 in. Crack Width.

```
________________________

SPRAY Version 3.2
August 31, 1995
________________________

Spray Leak Code
Produced by Radiological & Toxicological Analysis
Westinghouse Hanford Company

Run Date = 05/30/96/
Run Time = 15:48:15.01

INPUT ECHO:
c Case 6. 300 psig, 0.1 in wide crack

c SPRAY Code Version 3.2 Input File
c
c MODEL OPTIONS:
c
c mode  - program calculation mode
c         = 1 for orifice leak
c         = 2 for slit leak
c ifric - integer flag for friction factor
c         = 0 for program selection
c         = 1 for laminar relation
c         = 2 for turbulent relation
c iopt  - integer flag for flow determination
c         = 0 for optimal diameter search given initial guess diameter and Re
c         = 1 for flow based on user specified diameter
c         = 2 for flow based on user specified Reynold's number
c
c   mode ifric iopt
    2    0    1
c
c PARTICLE SIZE DISTRIBUTION TABLE PARAMETERS:
c
c   Starting
c   Particle
c   Size           Geometric      Number of
c   (um)           Step Size      Intervals
c   ____________   ___________    ___________
    1.00000E+01    2.00000E+00    10
c
c PARAMETER INPUT:
c
c   Initial Slit                  Slit or
```

```
c   Width or        Slit            Orifice
c   Orifice Dia.    Length          Depth           Reynold's
c   (in)            (in)            (in)            Number
c
    1.00000E-01     2.00000E+00     1.54000E-01     2.00000E+03
c
c                   Absolute
c                   Surface
c                   Roughness       Contraction     Velocity
c                   (in)            Coefficient     Coefficient
c   Pressure        0.00006 tube    0.61    and     0.98  for sharp edge orifice
c   Differential    0.0018  steel   1.00    and     0.98  for rounded orifice
c   (psi)           0.0102  iron    1.00    and     0.82  for square edge orifice
c
    3.00000E+02     1.80000E-03     1.00000E+00     8.20000E-01
c
c   Fluid           Dynamic         Respirable      RR Fitting
c   Density         Viscosity       Diameter        Constant
c   (g/cc)          (centi-poise)   (µm)            (q)
c
    1.40000E+00     1.00000E+00     1.50000E+01     2.40000E+00
c
c   Ambient         Wind
c   Density         Speed
c   (g/cc)          (m/s)
c
    1.22000E-03     1.00000E+00


MESSAGES:
Slit Model
User specified orifice diameter or slit width.


OUTPUT:
     Liquid Velocity =  1.45E+02 ft/s      4.41E+01 m/s
     Reynolds Number =  2.99E+05 Turbulent Flow
Sauter Mean Diameter =  1.11E+03 µm
Mass Median Diameter =  1.46E+03 µm
Characteristic Dia.  =  1.70E+03 µm
 Respirable Fraction =  1.17E-05
     Total Leak Rate =  9.03E+01 gpm       5.70E-03 m3/s      7.98E+03 g/s
Respirable Leak Rate =  1.06E-03 gpm       6.68E-08 m3/s      9.35E-02 g/s
           Jet Rise =  1.69E+01 ft        5.14E+00 m
```

Particle Diameter Sections (m)	Section Release Rate (kg/s)	Cumulative Release Rate (kg/s)	Cumulative Percent (%)
1.00E-05	3.53E-05	3.53E-05	0.00
2.00E-05	1.51E-04	1.87E-04	0.00

4.00E-05	7.98E-04	9.85E-04	0.01
8.00E-05	4.21E-03	5.20E-03	0.07
1.60E-04	2.22E-02	2.74E-02	0.34
3.20E-04	1.16E-01	1.43E-01	1.80
6.40E-04	5.85E-01	7.29E-01	9.14
1.28E-03	2.44E+00	3.17E+00	39.69
2.56E-03	4.26E+00	7.42E+00	93.07
5.12E-03	5.53E-01	7.98E+00	100.00

Case 7: Nominal Spray Leak

SPRAY Version 3.2
August 31, 1995

Spray Leak Code
Produced by Radiological & Toxicological Analysis
Westinghouse Hanford Company

Run Date = 06/04/96/
Run Time = 17:43:44.30

```
INPUT ECHO:
c Case 7:  Spray leak using nominal values

c SPRAY Code Version 3.2 Input File
c
c MODEL OPTIONS:
c
c mode  - program calculation mode
c         = 1 for orifice leak
c         = 2 for slit leak
c ifric - integer flag for friction factor
c         = 0 for program selection
c         = 1 for laminar relation
c         = 2 for turbulent relation
c iopt  - integer flag for flow determination
c         = 0 for optimal diameter search given initial guess diameter and Re
c         = 1 for flow based on user specified diameter
c         = 2 for flow based on user specified Reynold's number
c
c   mode ifric iopt
    2    0    1
c
c PARTICLE SIZE DISTRIBUTION TABLE PARAMETERS:
c
c   Starting
c   Particle
c   Size           Geometric      Number of
c   (um)           Step Size      Intervals
c   ___________    ___________    ___________
    1.00000E+01    2.00000E+00    10
c
c PARAMETER INPUT:
c
c   Initial Slit                  Slit or
```

```
c   Width or         Slit             Orifice
c   Orifice Dia.     Length           Depth            Reynold's
c   (in)             (in)             (in)             Number
c
    1.00000E-02      1.00000E+00      2.16000E-01      2.00000E+03
c
c                    Absolute
c                    Surface
c                    Roughness        Contraction      Velocity
c                    (in)             Coefficient      Coefficient
c   Pressure         0.00006 tube     0.61    and      0.98  for sharp edge orifice
c   Differential     0.0018  steel    1.00    and      0.98  for rounded orifice
c   (psi)            0.0102  iron     1.00    and      0.82  for square edge orifice
c
    1.50000E+02      1.80000E-03      1.00000E+00      8.20000E-01
c
c   Fluid            Dynamic          Respirable       RR Fitting
c   Density          Viscosity        Diameter         Constant
c   (g/cc)           (centi-poise)    (μm)             (q)
c
    1.20000E+00      1.00000E+00      2.70000E+01      2.40000E+00
c
c   Ambient          Wind
c   Density          Speed
c   (g/cc)           (m/s)
c
    1.22000E-03      1.00000E+00
```

MESSAGES:
Slit Model
User specified orifice diameter or slit width.

OUTPUT:

```
     Liquid Velocity =  8.53E+01 ft/s       2.60E+01 m/s
     Reynolds Number =  1.57E+04 Turbulent Flow
Sauter Mean Diameter =  1.29E+02 μm
Mass Median Diameter =  1.69E+02 μm
Characteristic Dia.  =  1.97E+02 μm
 Respirable Fraction =  8.46E-03
     Total Leak Rate =  2.66E+00 gpm        1.68E-04 m3/s       2.01E+02 g/s
Respirable Leak Rate =  2.25E-02 gpm        1.42E-06 m3/s       1.70E+00 g/s
           Jet Rise  =  2.09E+00 ft         6.36E-01 m
```

Particle Diameter Sections (m)	Section Release Rate (kg/s)	Cumulative Release Rate (kg/s)	Cumulative Percent (%)
1.00E-05	1.58E-04	1.58E-04	0.08
2.00E-05	6.73E-04	8.31E-04	0.41

4.00E-05	3.52E-03	4.35E-03	2.16
8.00E-05	1.76E-02	2.19E-02	10.88
1.60E-04	6.98E-02	9.17E-02	45.57
3.20E-04	1.01E-01	1.93E-01	95.97
6.40E-04	8.12E-03	2.01E-01	100.00
1.28E-03	1.49E-08	2.01E-01	100.00
2.56E-03	0.00E+00	2.01E-01	100.00
5.12E-03	0.00E+00	2.01E-01	100.00

Appendix D

Time Dependent Atmospheric Dispersion Coefficients

Appendix D

This appendix determines time dependent X/Q's for the onsite and offsite receptor locations. Time dependent X/Q's are used to model releases of differing durations, and to model releases where release rates vary with time.

Table D-1 summarizes the acute (99.5%), the acute with plume meander, the annual average, and the puff X/Q's for the onsite receptor. Table D-2 summarizes these same values for the offsite receptor. Tables D-1 and D-2 were reproduced from WHC-SD-WM-SARR-016. The acute X/Q's are appropriate for releases that last less than 1 hour. (Puff release X/Q's are not applicable to this accident analysis). The acute X/Q's, with plume meander, are appropriate for releases that do not vary substantially and that last for 1 to 2 hours. For releases that last longer than 2 hours, it is necessary to determine longer term X/Q's. This is done by logorithmically interpolating between the 2-h X/Q' and the annual average X/Q' for the given receptor location, in accordance with the methodology outlined in SARR-016. A logarithmic interpolation gives the following equation, where 8760 is the number of hours in a year:

$$\frac{\log(X/Q' \text{ at 2 h}) - \log(X/Q' \text{ at x h})}{\log(X/Q' \text{ at 2 h}) - \log(X/Q' \text{ ann. avg})} = \frac{\log(2) - \log(x)}{\log(2) - \log(8760)}$$

Example calculation. Using the values in Tables D-1 and D-2, a 12-h onsite X/Q' calculation would be set up as follows:

$$\frac{\log(1.13E-02) - \log(X/Q' \text{ at 12 h})}{\log(1.13E-02) - \log(4.03E-04)} = \frac{\log(2) - \log(12)}{\log(2) - \log(8760)}$$

Rearranging and taking the antilog gives a 12-h onsite X/Q' of 5.54E-3 s/m^3.

Table D-3 summarizes the onsite and offsite X/Q's for potential time periods of interest in the accident analysis. The X/Q's for release durations longer than 2 hours were interpolated as shown in the example calculation above. X/Q' corresponding to release duration less than 2 hours were taken directly from tables D-1 and D-2. The X/Q's in Table D-3 are applied in the accident analysis in a conservative manner. For releases that vary with time, the release is broken down into logical increments (e.g., 0 to 2 h release, 2- to 12- h release, etc.), with the appropriate duration X/Q's applied to each increment. The short term (larger) X/Q's are applied to the increments of the release where the release rate is the highest.

Table D-1. Centerline Atmospheric Dispersion Coefficients for a 200 Area Tank Farm Acute, Ground-Level Release.

Maximum individual	Bounding integrated χ/Q' (s/m^3)	Bounding integrated χ/Q' (s/m^3) with plume meander
Onsite sector and distance	3.41 E-02 E 100 m	1.13 E-02 ESE 100 m
Offsite sector and distance	2.83 E-5 N 8760 m	2.12 E-05 N 8760 m

NOTE: The information in this table is from WHC-SD-WM-SARR-016, 1996, Tank Waste Compositions and Atmospheric Dispersion Coefficients for Use in Accelerated Safety Analysis Consequence Assessments, Westinghouse Hanford Company, Richland, Washington.
E = east
ESE = east, southeast.
N = north.

Table D-2. Chronic Annual Average Atmospheric Dispersion Coefficients for 200 Area Tank Farms.

Maximum individual	Integrated χ/Q' (s/m^3)
Onsite sector and distance	4.03 E-04 ESE 100 m
Offsite sector and distance	1.24 E-07 E 12,630 m

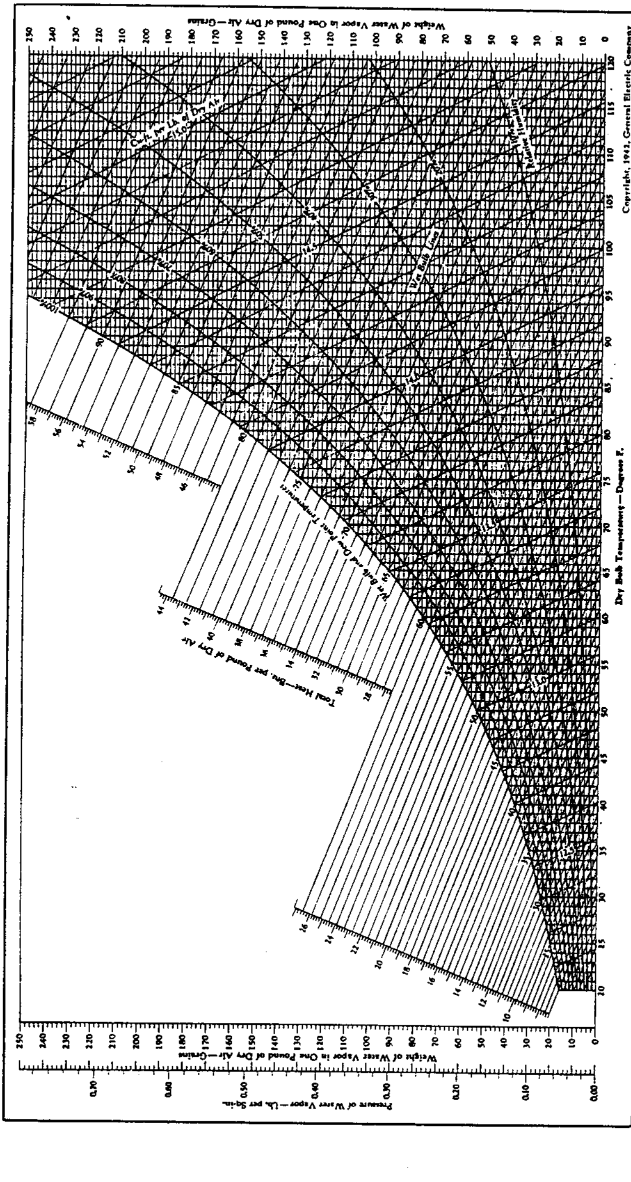
NOTE: The information in this table is from WHC-SD-WM-SARR-016, 1995, Tank Waste Compositions and Atmospheric Dispersion Coefficients for Use in Accelerated Safety Analysis Consequence Assessments, Westinghouse Hanford Company, Richland, Washington.
E = east.
ESE = east, southeast.

Table D-3. X/Q's for Various Time Periods, Onsite and Offsite

Receptor Location	Release duration (h)	X/Q' (s/m^3)
Onsite	<1	3.44E-2
	1 - 2	1.13E-02
	4	8.58E-03
	6	7.30E-03
	8	6.51E-03
	10	5.96E-03
	11	5.74E-03
	12	5.54E-03
Offsite	<1	2.83E-05
	1 - 2	2.12E-05
	4	1.39E-05
	6	1.08E-05
	8	9.06E-06
	10	7.90E-06
	12	7.07E-06
	14	6.43E-06
	16	5.92E-06
	18	5.51E-06
	20	5.17E-06
	22	4.87E-06
	23	4.74E-06
	24	4.62E-06
	72	2.36E-06

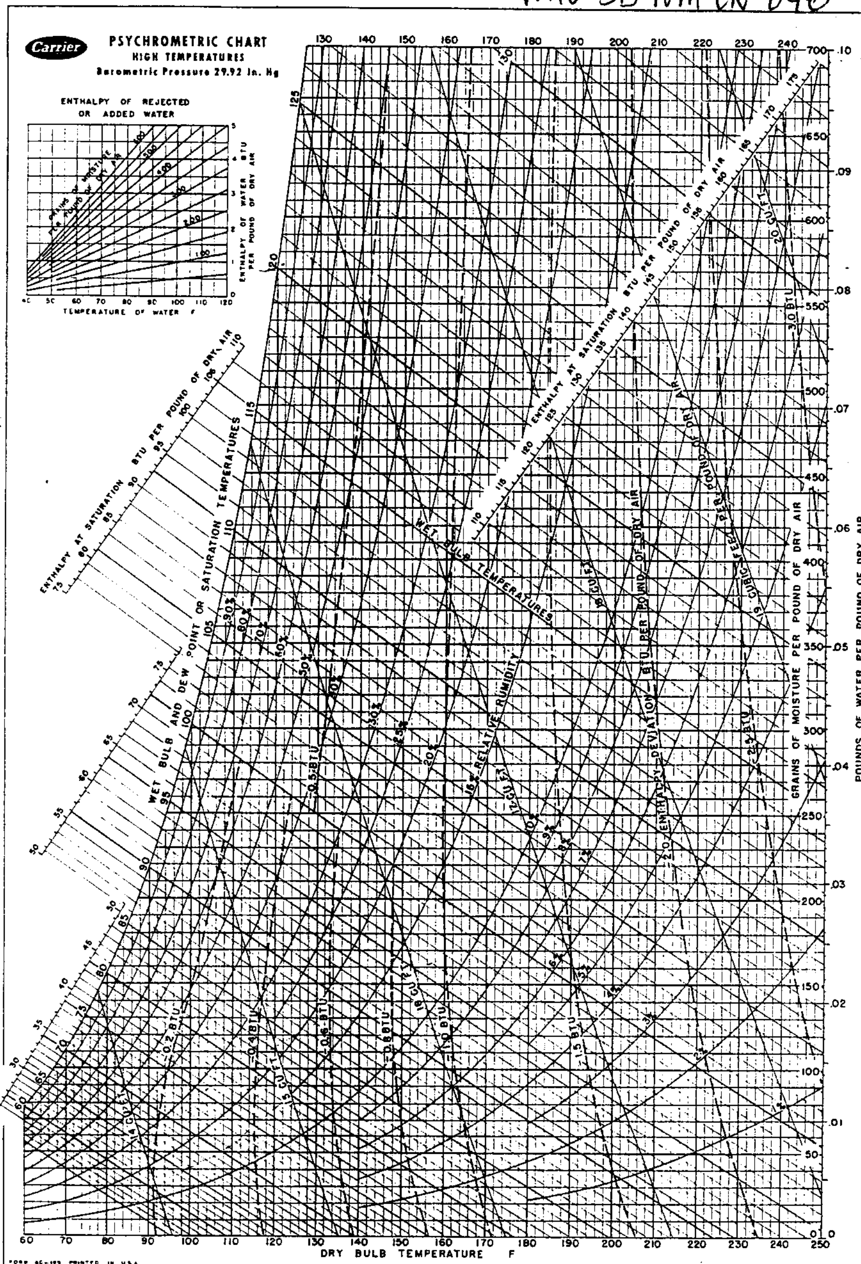
Appendix E

Psychrometric Chart



PSYCHROMETRIC CHART

Barometric Pressure 14.696 Lb. per Sq.In.


Carrier
PSYCHROMETRIC CHART
HIGH TEMPERATURES
Barometric Pressure 29.92 In. Hg
ENTHALPY OF REJECTED OR ADDED WATER
TEMPERATURE OF WATER F
ENTHALPY OF WATER BTU PER POUND OF DRY AIR
GRAINS OF MOISTURE PER POUND OF DRY AIR
ENTHALPY AT SATURATION BTU PER POUND OF DRY AIR
WET BULB AND DEW POINT OR SATURATION TEMPERATURES
WET BULB TEMPERATURES
RELATIVE HUMIDITY
ENTHALPY DEVIATION BTU PER POUND OF DRY AIR
CUBIC FEET PER POUND OF DRY AIR
GRAINS OF MOISTURE PER POUND OF DRY AIR
POUNDS OF WATER PER POUND OF DRY AIR
DRY BULB TEMPERATURE F
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Appendix F

Peer Review Checklist

PEER REVIEW CHECKLIST

Document Reviewed: Calc Note in Support of TWRS FSAR Spray Leak Accident analysis
Author: B. W. Hall
Date: 7-31-96
Scope of Review: As indicated below

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 appropriate NRC Regulatory Guide or other standards
[ ]	[X]	[ ]	Review calculations, comments, and/or notes are attached.
[X]	[ ]	[ ]	**Document approved.**

W. L. Cowley W. L. Cowley 7-31-96
Reviewer (Printed Name and Signature) Date

CHECKLIST FOR TECHNICAL PEER REVIEW

A. Calculation Notes in Support of TWRS FSAR Spray Leak Accident Analysis, WHC-SD-WM-CN-048, Rev. 1, Brett Hall, 9/19/96

B. Scope of Review: Entire document

Yes	No*	NA	
[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] **	Review calculations, comments, and/or notes are attached.
[x]	[ ]	[ ]	**Document approved (i.e., the reviewer affirms the technical accuracy of the document).**
[x]	[ ]	[ ]	Traceability

Donald R. Porten   Donald R. Porten   9/19/96

Reviewer (Printed Name and Signature)   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.

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