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ENGINEERING CHANGE NOTICE

1. ECN (use no. from pg. 1): 660928

16. Design Verification Required	17. Cost Impact — ENGINEERING	17. Cost Impact — CONSTRUCTION	18. Schedule Impact (days)
☐ Yes	Additional ☐ $ N/A	Additional ☐ $ N/A	Improvement ☐
☒ No	Savings ☐ $ N/A	Savings ☐ $ N/A	Delay ☐ N/A

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*	☐		☐
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
N/A		

21. Approvals

	Signature	Date		Signature	Date
Design Authority			Design Agent	Thomas G Goetz	9/14/00
Cog. Eng.	JC Williams [signature]	9/11/00	PE		
Cog. Mgr.	BE Hey [signature]	9/13/00	QA		
QA			Safety		
Safety			Design		
Environ.			Environ.		
Other	JC Van Keuren [signature]	9/11/00	Other		

DEPARTMENT OF ENERGY

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ADDITIONAL

DISTRIBUTION SHEET

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Distribution	Safety Analysis & Nuclear Engin'g	Date August 30, 2000
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Analysis of Waste Leak and Toxic Chemical Release Accidents from Waste Feed Delivery (WFD) Diluent System

J. C. Williams
Fluor Federal Services
Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-99RL14047

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Key Words: Tank Farms, Waste Feed Delivery, Diluent System, Waste Leak, Toxic Chemical, Accident Analysis.

Abstract: Radiological and toxicological consequences are calculated for 4 postulated accidents involving the Waste Feed Delivery (WFD) diluent addition systems. Consequences for the onsite and offsite receptor are calculated. This analysis contains technical information used to determine the accident consequences for the River Protection Project (RPP) Final Safety Analysis Report (FSAR).

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Rev. 1

ANALYSIS OF WASTE LEAK AND TOXIC CHEMICAL RELEASE ACCIDENTS FROM WASTE FEED DELIVERY (WFD) DILUENT SYSTEM

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List of Terms

AB	Authorization Basis
AC	administrative control
AED	aerodynamic equivalent diameter
ARF	airborne release fraction
DR	damage ratio
DST	double-shell tank
ERPG	emergency response planning guidelines
gpm	gallons per minute
HazOp	hazards and operability sessions
LPF	leak path factor
MAR	material-at-risk
psi	pounds per square inch
NRC	Nuclear Regulatory Commission
PEL-TWA	permissible exposure limit - time weighted average
RF	release fraction
RPP	River Protection Project
SAR	Safety Analysis Report
SOF	sum-of-fractions
SSC	system, structure, or component
SST	single-shell tank
SY	SY tank farms
TSR	Technical Safety Requirement
ULD	unit liter dose
WFD	Waste Feed Delivery
χ/Q	Atmospheric dispersion coefficient

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1.0 INTRODUCTION AND PURPOSE

The Waste Feed Delivery (WFD) program will retrieve waste from double-shell tanks (DSTs) and transfer the waste to the private vitrification contractor for conversion into glass. Sludge and saltcake waste will be diluted with a sodium hydroxide (NaOH) solution as required to facilitate transfer pumping and solids dissolution. This caustic diluent solution will be provided by a diluent addition system in the tank farm. The diluent systems are still in the design process, and this analysis attempts to provide as much flexibility as possible for final design.

This analysis will examine the diluent system accidents that were identified in the facility hazards analysis, Ryan (2000). Two accidents evaluate the flow, or potential flow, of waste back into the diluent system. Consequences range from direct radiation exposure to an operator to the release of airborne aerosols from radioactive waste overflowing a diluent/flush tank. A third accident evaluates a spray leak of caustic. Finally, a fourth accident evaluates the inadvertent addition of incompatible chemicals to the diluent system. Each accident is discussed separately in Section 3.

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2.0 FACILITY DESCRIPTION

2.1 AN DILUENT SYSTEM

The AN diluent system can provide in-line dilution, (diluent injected into the transfer pump suction line), in-tank dilution (diluent injected into the tank), line flush (diluent valved into the transfer line), or transfer pump throttle bushing/column flush (diluent valved into transfer pump seal). The diluent system can also supply filtered raw water (without caustic) to the mixer pump seals. The system is being constructed as part of the W-211 project and will consist of an enclosed raw water filtration skid, an enclosed service water equipment skid, a diesel-fired package boiler, an enclosed caustic metering pump skid, a 5000-gallon vented flush tank, and a diluent pump capable of providing 70 - 140 gpm of solution at 164 psi. An enclosed safety shower will also be provided for worker safety. The AN diluent system is shown on P&ID H-14-102451 Shts. 5 and 6. A simplified block diagram of the diluent system is shown on Fig. 1.

Concentrated NaOH will be supplied to the diluent system by tank truck. A 30-foot flexible hose is used to transfer NaOH from the truck to a 2-inch coupling valve on the metering pump skid. The delivered caustic solution will have a maximum concentration of 19M (50 wt.%). The metering skid can dilute the caustic to any desired concentration.

The diluted caustic is distributed to the 241-AN-A and 241-AN-B valve pits via underground piping. This diluent is then distributed to the individual tank pump pits. At the pump, diluent is supplied to a 2-inch diluent addition nozzle on the transfer pump baseplate. The nozzle is connected to a diluent line extending down the side of the pump column to the pump intake just below the first impeller stage. See P&ID H-14-102451 Sht. 3 for piping in the 241-AN-105 pump pit, and Sh.4 for piping in the 241-AN-A and 241-AN-B valve pits. See Fig. 2 for a sketch of the transfer pump layout. Fig. 3 provides a simplified diagram of the diluent system routing. A schematic diagram of pump pit and transfer pit piping is shown in Fig. 4.

Two pressure switches are installed in the 241-AN-A valve pit between the diluent line inlet nozzle and the transfer line connection. The switches are designed to shut down the transfer pump if the flush jumper is pressurized during pump operation, which would indicate valve failure or misalignment.

The AN diluent system will also serve the aging waste Tanks 241-AZ-101 and 241-AZ-102 via the 241-AZ-02A pump pit, and the 241-AY-02A pump pit directly. Design for these tanks' retrieval systems is not complete, but pump pit and valve pit piping is assumed to be similar to 241-AN farm.

During retrieval, tank waste in 241-AN farm is transferred to the 241-AN-A and 241-AN-B valve pits. From 241-AN-B, waste is transferred to the 241-AN-104 central pump pit, and then out of the tank farm to the new 241-AP valve pit installed by Project W-521. An exception is Tank 241-AN-101, which transfers waste directly to the new 241-AZ valve pit. 241-AY tank farm waste is routed from the 241-AY-02A pump pit to the new 241-AZ valve pit.

Waste from 241-AZ farm tanks is routed directly to the new 241-AZ valve pit. Waste is transferred from the new 241-AZ valve pit to the new 241-AP valve pit, and from there to the vitrification plant.

2.2 AP DILUENT SYSTEM

The AP diluent system is identical to the AN system. The AP system supplies diluted caustic directly to the new 241-AP valve pit via underground piping. The AP diluent system is shown on P&ID H-14-102304. See P&ID H-14-102086 Sht. 3 for piping in the 241-AP-02D pump pit, Sht. 5 and 6 for piping in the 241-AP-04D pump pit, and P&ID H-2-90526 for piping in the old 241-AP valve pit.

Waste from Tanks 241-AP-102 and 241-AP-104 is routed to the vitrification plant via the old 241-AP valve pit and the new 241-AP valve pit.

2.3 AW DILUENT SYSTEM

Diluent will be supplied to 241-AW-101 via the 241-AW-A valve pit. Currently, a separate system similar to the AN and AP system is being planned for 241-AW-101 and 241-AW-105. Alternatively, the AP diluent addition system may be extended to 241-AW farm via the 241-AW-B valve pit.

Waste is routed from 241-AW-101 to the old 241-AP valve pit via the 241-AW-A valve pit and the 241-AW-02A pump pit. Design for 241-AW-101 retrieval is not complete, but pump pit and valve pit piping arrangements are assumed to be similar to 241-AN farm.

2.4 REPLACEMENT CROSS-SITE TRANSFER (RCSTS) DILUENT SYSTEM

Retrieval from Tank 241-SY-102 will use the dilution system installed for Project W-058. This system consists of a 178-kL (47,000-gallon) diluent storage tank, a diluent pump, and a skid-mounted chemical injection package for drawing 25% NaOH from drums. The system will deliver diluted caustic to the 241-SY-A valve pit, and from there to 241-SY-102.

The system will be modified for retrieval from 241-SY-101 and 241-SY-103. The package boiler, metering skid, and other components from the AW diluent system will tie in to the W-058 system upstream of the storage tank. The modified system will deliver diluted caustic to 241-SY-101 and 241-SY-103 via the 241-SY-B valve pit.

Waste is routed from the 241-SY farm tanks to the 241-SY-A valve pit. From there, waste is routed to the 241-SY-B valve pit, the 6241-A valve pit, and to 200E via the Replacement Cross-Site Transfer System. The waste line routing will bypass the 244-A lift station and connect to the 241-AN tank farm at the 241-AN-104 pump pit. From there, it can be routed to the new 241-AP valve pit.

See P&ID H-14-100597 Sht. 7 for the SY diluent system. See P&ID H-14-100597 Sht. 3 for piping in the 241-SY-102 pump pit, Sht. 4 for piping in the 241-SY-A valve pit, and Sht. 5 for piping in the 241-SY-B valve pit.

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3.0 ACCIDENT ANALYSIS

To the extent possible, this analysis will apply the accident analysis methods used in HNF-SD-WM-SAR-067, *Tank Waste Remediation System Final Safety Analysis Report,* (FDH 1999a) that is the current authorization basis (AB) for the River Protection Project (RPP). Accident scenarios were based on the hazards identified during the hazards and operability sessions (HazOp) facilitated and documented by Ryan (2000). Consequences reported here are intended to conservatively bound any actual hazard.

3.1 METHODOLOGY

3.1.1 Consequence Analysis

There are several aspects of consequence analysis methodology. The methodology presented here is used for all calculations contained in this report unless specified otherwise.

3.1.1.1 Radiological Dose Consequence Analysis

The total onsite dose can include inhalation, direct shine, and skyshine. The total offsite dose is the sum of inhalation and ingestion pathways. Usually the dominant exposure pathway is via inhalation. For the inhalation and ingestion pathways WHC-SD-WM-SARR-016, *Tank Waste Compositions and Atmospheric Dispersion Coefficients for Use in Safety Analysis Consequence Assessments,* (WHC 1996b) describes the individual dose as:

Inhalation: $D_{inh} = Q \times \chi/Q \times R \times OF \times ULD_{inh}$ (Eq. 1)

Ingestion: $D_{ing} = Q \times \chi/Q \times ULD_{ing}$ (Eq. 2)

Where:

Q = source term (L),
χ/Q = atmospheric diffusion coefficient (s/m^3),
R = breathing rate (m^3/s),
OF = onsite occupancy factor,
ULD_{inh} = inhalation unit liter dose (Sv/L),
ULD_{ing} = ingestion ($Sv\text{-}m^3/s\text{-}L$).

Direct shine and skyshine exposure is calculated by the Microshield™ and Microskyshine™ computer programs. These programs calculate the dose from gamma emitting contributors. Bremsstrahlung radiation dose from beta emitting contributors is calculated by using the Bremcalc program to provide input to Microshield™ and Microskyshine™.

The source term, Q, is the amount of radioactive material released to the environment. The initial source term is the amount of radioactive material driven airborne at the accident source. The initial respirable source term, a subset of the initial source term, is the amount of radioactive material driven airborne at the accident source that can be inhaled. Lesser source terms are determined by applying filtration or deposition factors to the initial source term.

The airborne pathway is of primary interest for tank farm facilities. DOE-STD-1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports,* (DOE 1992) quotes observations of the Nuclear Regulatory Commission (NRC) to the effect that "for all materials of greatest interest for fuel cycle and other radioactive material licenses, the dose from the inhalation pathway will dominate the (overall) dose" (NUREG 1988). The airborne source term is typically estimated by the following five-component linear equation:

$$Q = MAR \times DR \times ARF \times RF \times LPF \qquad \text{(Eq. 3)}$$

Where:

MAR = Material-at-Risk,
DR = Damage Ratio,
ARF = Airborne Release Fraction,
RF = Respirable Fraction, and
LPF = Leak Path Factor.

The initial source term and initial respirable source term are products of the first three factors and first four factors, respectively. A depleted source term after a subsequent stage of deposition or filtration is a product of the initial source term multiplied by the leak path factor of the specific stage.

3.1.1.1.1 Material-at-Risk (MAR)

The material-at-risk is the amount of radionuclides available to be acted on by a given physical stress. For tank farm facilities, the MAR is taken to be the maximum quantity of radionuclide present or reasonably anticipated in each location.

3.1.1.1.2 Damage Ratio (DR)

The damage ratio is the fraction of the MAR actually impacted by the accident-generated conditions. The DR is estimated based upon engineering analysis of the response of structural materials and materials-of-construction for containment to the type and level of stress/force generated by the event. Standard engineering approximations are typically used. These approximations often include a degree of conservatism due to simplification of phenomena to obtain a useable model, but the purpose of the approximation is to obtain, to the degree possible, a realistic understanding of potential effects.

3.1.1.1.3 Airborne Release Fraction (ARF)

The ARF is the coefficient used to estimate the amount of a radioactive material suspended in air as an aerosol and available for transport due to a physical stress from a specific accident. For discrete events, the ARF is a fraction of the material affected.

The ARFs used in the following analyses are taken from DOE-HDBK-3010-94, *DOE Handbook Airborne Release Fractions/Rates and Restorable Fraction for Tank Farm Releases,* (DOE 1994) which are based primarily upon experimentally measured values for the specific material (e.g., plutonium, uranium, mixed fission products) or surrogates subjected to the particular type of stress under controlled conditions. Attention is given to the parameters, if known, that may have a significant influence upon suspension by the specific mechanism and the uncertainty in the measurement as indicated by the variability of the results.

It is important to note that the experiments discussed in DOE-HDBK-3010-94 (DOE 1994) evaluate release phenomena holistically. No attempt is made to precisely characterize total airborne material in terms of individual mechanisms acting within an overall given release.

3.1.1.1.4 Respirable Fraction (RF)

The RF is the fraction of airborne radionuclides as particles that can be transported through air and inhaled into the human respiratory system and is commonly assumed to include particles 10-μm Aerodynamic Equivalent Diameter (AED) and less. The principal emphasis in this document is directed toward the potential downwind hazard to the populations at some distance from the point of source term generation.

3.1.1.1.5 Leak Path Factor (LPF)

The LPF is the fraction of the radionuclides in the aerosol transported through some confinement deposition or filtration mechanism. The LPF is a calculated or standard value based upon (1) established relationships between size of the particulate material, airborne transport mechanisms, and losses by depositions mechanisms, or (2) specified filtration efficiencies.

3.1.1.1.6 Exposure Durations

Radiological doses are a function of exposure duration, whereas toxicological exposure criteria are usually based on a maximum concentration or an average concentration over a specified interval.

For unmitigated events, onsite individuals are assumed to be exposed to accidental releases for 12 hours. Offsite individuals are assumed to be exposed to accidental releases for 24 hours. Offsite consequences consider ingestion for 24 hours after the release as well as inhalation. Mitigated exposure durations depend upon the timing of the control used (e.g., accident detection, evacuation).

3.1.1.1.7 Atmospheric Diffusion Coefficients

Atmospheric diffusion coefficients, χ/Q's, are taken from WHC-SD-WM-SARR-016 (WHC 1996b) and represent point source ground level releases which are appropriate for the accidents analyzed here. The onsite 12 hr and offsite 24 hr χ/Q's were computed using logarithmic interpolation between the acute and chronic annual average values. See Table 3-1 for the values used in this analysis.

Table 3-1. Atmospheric Dispersion Coefficients.

Receptor (duration)	Integrated χ/Q' (s/m^3)
Onsite (1 hr)	3.41 E-02
Onsite (2 hr)[a]	1.13 E-02
Onsite (12 hr)	5.54 E-03
Onsite (8760 hr, chronic annual)	4.03 E-04
Offsite (1 hr)	2.83 E-05
Offsite (2 hr)[a]	2.12 E-05
Offsite (24 hr)	4.62 E-06
Offsite (8760 hr, chronic annual)	1.24 E-07

[a]Value used to interpolate 12 hr and 24 hr dispersion coefficients.

3.1.1.1.8 Breathing Rates for Radiological Exposure Calculations

A breathing rate of 2.7 E-04 m^3/s is used for a 24-hr release offsite and 1 yr release onsite and offsite, and 3.3 E-04 m^3/s is used for a 12-hr release onsite (WHC 1996b, page 4-4).

3.1.1.1.9 Waste Composition

The unit liter dose, sum of fraction multipliers, and activities for the "all tank waste" composite were taken from WHC-SD-WM-SARR-016 (WHC 1996b) and WHC-SD-WM-SARR-011, *Toxicological Chemical Considerations for Tank Farm Releases,* (WHC 1996a) and are shown below. These values conservatively represent the radiological and toxicological hazard of all SST and DST waste.

Table 3-2. All Radiological Unit Liter Doses

Waste Type	Inhalation (Sv/L)	Ingestion (Sv-m^3/s-L)
All Liquids	1.2E+04	1.1E-01
All Solids	1.9E+06	8.2E+00
67/33 Composite	6.4E+05	2.8E+00

Table 3-3. All Continuous Release SOF Multipliers (s/L)

	Anticipated Frequency		Unlikely Frequency		Extremely Unlikely Frequency	
Waste Type	Onsite	Offsite	Onsite	Offsite	Onsite	Offsite
All Liquids	1.0E+04	8.4E+00	7.5E+02	8.4E+00	2.1E+02	6.2E-01
All Solids	5.1E+04	2.5E+02	2.3E+04	4.2E+01	1.2E+03	1.9E+01
67/33 Composite	2.4E+04	8.8E+01	8.1E+03	1.9E+01	5.4E+02	6.7E+00

Table 3-4. All Gamma Producing Isotopes (Bq/L)

Waste Type	Co-60	Sr-90	Cs-137	Eu-154	Eu-155
All Liq.	9.50E+06	1.10E+10	8.80E+10	2.40E+09	5.90E+07
All Sol.	4.90E+08	2.90E+12	1.00E+11	1.10E+10	5.00E+06
67/33 Composite	1.68E+08	9.64E+11	9.20E+10	5.24E+09	4.12E+07

3.1.1.2 Toxicological Consequence Analysis

The methodology that is used to calculate the toxicological exposure consequences is documented in WHC-SD-WM-SARR-011 (WHC 1996a). In this method, the released quantity (or release rate) is multiplied by the appropriate sum-of-fraction multiplier, M_{SOF}, from Table 3-8 of WHC-SD-WM-SARR-011 (WHC 1996a). M_{SOF} values are dependent on the type of release (puff-type or continuous), the waste material released, and the event frequency.

$$SOF = Q' \times M_{SOF} \qquad \text{(Eq. 4)}$$

Where:

SOF = denotes the sum of toxicological exposure fractions for each toxic chemical as compared to its exposure criteria,
Q' = quantity released in units of L/s,
M_{SOF} = sum-of-fraction multiplier in units of L^{-1} or s/L.

An alternative method of calculating toxicological consequences, which calculates toxic chemical concentration at the receptor, is given in WHC-SD-WM-SARR-016 (WHC 1996b):

$$C = Q * \chi/Q \qquad \text{(Eq. 5)}$$

Where:

C = peak concentration (mg/m^3)
Q = release rate (mg/s)
χ/Q = atmospheric dispersion coefficient (s/m^3)

3.2 Design Basis Accidents

Two un-analyzed accidents were identified in the hazards analysis (Ryan 2000) as needing further attention. The first was "*A leak of tank waste from a failed diluent addition system, caused by pumped or siphoned backflow of Tank Waste through failed valves with failed pressure switches which would normally have functioned to shut down the transfer pump when pressure was detected in diluent addition lines.*" Two scenarios resulting in a leak of tank waste from the diluent system were evaluated in this analysis report. These scenarios were evaluated separately in order to identify their potentially unique consequences and control suite. These scenarios are:

- Drainback while in transfer line flush mode,

- Isolation valve failure or misalignment between the transfer and diluent systems.

The second un-analyzed accident identified in the hazards analysis (Ryan 2000) was an "*Unexpected chemical reactions causing damage to the diluent system, resulting in release of toxic vapors.*" Two scenarios resulting in a toxic vapor release were evaluated in this analysis report. Again, these scenarios were separately evaluated in order to identify their potentially unique consequences and control suite. These scenarios are:

- Addition of incompatible chemical to the diluent system, and
- Spray leak of caustic from the diluent system.

In addition to the accident analysis results provided, information is provided on the associated representative accident, whether unmitigated or mitigated consequences exceed those reported, whether the frequency of the unmitigated event increased from that reported, and whether new or more restrictive controls are needed.

Each accident scenario is evaluated separately and in detail in the sub-sections below.

3.2.1 Drainback While in Transfer Line Flush Mode

The hazards evaluation documented in Ryan (2000) identified several hazardous condition entries whose deviation was identified as *"Waste is routed back into the diluent addition system via the flush line while the transfer* (sic) *pump is operating. Siphon caused by elevation differences when providing transfer flush from AN, AY, or AZ Farms to AW Farm. Assume siphon can only happen if transfer flush flow from AN, AY, or AZ Farm routed back through pump in AW Farm, and diluent pump fails or is shut down and system not valved out."*

Although this statement implies the transfer pump is operating (see Section 3.2.3), this analysis evaluates the hazard as if the transfer pump is shut down and the diluent system is operating in the in-line flush mode and is intentionally valved into the transfer line. While flushing a transfer line from a lower elevation tank farm to a higher elevation farm, the diluent system is assumed to suffer a pressure drop. Hydrostatic head in the transfer line forces waste back into the diluent system.

Drainback from discharge points or vacuum breaks higher than the aboveground diluent system piping could result in contamination of normally clean systems and increased radiation exposure to operations personnel. Diluent system pressures generated under drainback conditions would be lower than normal operating pressures and would not challenge system integrity. Therefore, no waste leak would be expected in this scenario. Drainback may also initiate siphoning from the receiver tank into the diluent system, which would have worse consequences than drainback alone.

3.2.1.1 Frequency Analysis

As shown below, the hazard of this event is predominantly to operators or technicians in the immediate vicinity of above ground diluent system piping. No representative accident currently exists in Chapter 3 of HNF-SD-WM-SAR-067 (FDH 1999a). For this reason, neither the consequences nor frequency of this event are bounded in the Safety Analysis Report (SAR).

The accident is conservatively assumed to be "anticipated."

3.2.1.2 Scenario Development

Unmitigated Scenario

Table 3-5 summarizes information about component elevations that is relevant to hydrostatic head calculations. It is assumed that the new 241-AZ valve pit will be at elevation 669 feet. It is also assumed that the new 241-AP valve pit will be at the same elevation as the old 241-AP valve pit.

Table 3-5. Tank Farm Elevations (Feet)

Tank Farm	Grade	Valve pit piping	Bottom of tank	Waste (full)
241-AN	668	667	613	643
241-AP	679	677	624	654
241-AW	687	684	632	662
241-AY	675	669	615	645
241-AZ	672	669	617	647

The unmitigated accident scenarios for each of the diluent systems are as follows:

For the AN diluent system, waste would backflow through valves MOV-316, MOV-318, and MOV-802 in the 241-AN-A valve pit to the diluent system. The worst case would be drainback from 241-AW farm, which is at the highest elevation (see Table 3-5). The 3-inch Sch. 40 waste transfer line between the 241-AN-04A central pump pit and the 241-AW-A valve pit is approximately 2700 feet long and contains approximately 1000 gallons according to the *Waste Feed Delivery Technical Basis,* (Rasmussen 1998, p. A-3). This volume of waste could potentially flow back into the diluent system and the 5000-gallon flush tank. This drainback would result in contaminated equipment and personnel exposure, but not in a waste release. This would bound drainback from 241-AP farm. Design is not complete for 241-AN-104 and 241-AN-107 retrieval systems, which also connect to 241-AN-A, but pump pit arrangements are assumed to be similar. This conclusion will apply to the 241-AN-B valve pit, since its final design jumper arrangement is assumed similar to 241-AN-A. This will affect Tanks 241-AN-102 and 241-AN-103, which connect to 241-AN-B.

The AN diluent system connects directly with the pump pits for Tanks AZ-101, AZ-102, and AY-102. Design is not complete for these tanks' retrieval systems, but pump pit arrangement is assumed to be similar to 241-AN farm. Since the new 241-AZ valve pit is a transfer piping high point (Dwg. H-2-70762 [Vitro 1977]), drainback would be limited to the volume of waste in the pump pit piping and underground lines extending to the valve pit. Waste cannot backflow to a point in the diluent system that is higher than this. Consequences would be contamination of underground lines, but no release or personnel exposure.

Design for the 241-AW-101 pump pit, 241-AW-A valve pit, and 241-AW-B valve pit is not complete, but is assumed to be similar to 241-AN farm. Since 241-AW farm is at a higher elevation than other tank farms, drainback from other farms is not possible. Since the 241-AW-A valve pit is a transfer piping high point (Dwg. H-2-70427 [Vitro 1976]), drainback would be limited to the volume of waste in the pump pit piping and underground lines extending to the valve pit. Waste cannot backflow to a point in the diluent system that is higher than this. Consequences would be contamination of underground lines, but no release or personnel exposure. This conclusion would apply regardless of which diluent system is used for 241-AW-101.

Design for 241-AP farm pump pits and the new 241-AP valve pit is not complete, but is assumed to be similar to 241-AN farm. The only tank farm higher than 241-AP is 241-AW. The 3-inch waste transfer line from 241-AW-A valve pit to 241-AP valve pit is 717 feet long and contains 263 gallons. From Table 3-5, the AW-A valve pit piping is at elevation 684 feet, and the bottom of the AP diluent system flush tank is at elevation 679 feet. If the 9'6"-high tank is filled to a minimum elevation of 684 feet (approximately half full), hydrostatic head will prevent drainback into the AP diluent system. If the tank is less than half full, waste could potentially flow back into the AP diluent system and enter the 5000-gallon flush tank. This could result in contaminated equipment and personnel exposure, but not in a waste release. Hydrostatic head will prevent overflowing of the tank.

For the Replacement Cross-Site Transfer Diluent System, waste would backflow through MOV-3126B in the 241-SY-B valve pit and MOV-3111 in the 241-SY-A valve pit to the diluent system. The volume of drainback would be limited to waste in the RCSTS up to the 6241-V vent station. This 3-inch line is approximately 12,000 feet long and contains 4485 gallons (Dwgs. H-2-822210 [Kaiser 1995a] and H-6-13978 [Kaiser 1995b]). This volume of waste could potentially flow back into the diluent system and some could possibly enter the 47,000-gallon flush tank. This could result in contaminated equipment and personnel exposure, but not in a waste release.

For waste drainback to initiate siphoning from a DST into a diluent system, the elevation of the diluent system must be below the tank waste surface. The highest tank farm is 241-AW, with the tank waste surface at elevation 662 feet (when full). The lowest tank farm is 241-AN, with the diluent system at elevation 668 feet (grade). Since the lowest diluent system elevation is above the highest tank waste surface elevation, siphoning of any tank waste into any diluent system is not credible.

Mitigated Scenario

As shown below, potentially high exposure rates can result from contaminated diluent system piping located above ground. Therefore, the recommended control strategy is to prevent this event. The necessary preventive features are safety-significant interlocks on each diluent system, which close isolation valves on the diluent discharge line upon detection of reverse flow. Valves must close before backflow waste can reach aboveground piping. The 241-AN-A valve pit pressure switches will not prevent drainback, since their only function is to shut down the transfer pump.

3.2.1.3 Source Term Analysis

The accident is modeled as a worker standing 1 meter away from a 5-meter length of contaminated piping (3-inch Sch. 40) filled with "All Waste" with a 33% solids content. The source is modeled as water having a 1.4 g/mL density in a circular cylinder having a 7.8 cm (3.068 in) diameter surrounded by a 0.55-cm (0.216-inch) steel shield. Isotopic composition is given in Section 3.1. Since this event does not involve an airborne release, the only contributor is direct shine.

3.2.1.4 Consequence Analysis

With the above source term, Microshield™ yields 8.49 R/hr dose rate to the worker. The Microshield™ output files are attached as Appendix A.

3.2.1.5 Comparison to Guidelines

This dose rate will result in the worker receiving a dose exceeding the 0.5-rem onsite radiological guideline for anticipated events in 3.5 minutes. A worker standing closer to the pipe than one meter will receive a dose exceeding guidelines in even less time. This short response time makes accident mitigation unfeasible. For this reason, safety significant SSCs to prevent this occurrence are required.

3.2.1.6 Summary of Safety-Class SSCs and TSR Controls

Credited SSCs

Backflow prevention in the form of isolation valves which close on detection of reverse flow, installed on the aboveground diluent system piping, are relied upon to prevent the accident. Due to the potential impact to onsite workers from a drainback event, the diluent system interlock should be classified safety significant. The addition of this control will be new to the SAR.

Credited TSR Controls

Verify operability of the reverse flow interlock. The radiological protection program provides a secondary means to prevent overexposure to onsite personnel. This program should be considered defense-in-depth when applied to systems connected to waste transfer lines.

3.2.1.7 Key Assumptions

- For those diluent/flush tanks that can potentially be contaminated by drainback waste, it is assumed that the tank is at least 10% full of diluent solution prior to the accident. This will act as a water seal above the waste and prevent aerosol formation, which could escape from the tank vent.

- For those diluent/flush tanks that can potentially be contaminated by drainback waste, it is assumed that the tank has adequate headspace to accommodate diluent displaced by the drainback event without overflowing the tank.

3.2.2 Isolation Valve Failure or Misalignment

The hazards evaluation documented in Ryan (2000) identified several hazardous condition entries whose deviation was identified as *"Waste is routed back into the diluent addition system via the flush line while the transfer pump is operating. Human error; failure of flush line valves AND pressure switches."*

This scenario assumes valve misalignment or failure during operation of the diluent system in the in-line dilution mode. During transfers, the diluent system is normally valved in to the transfer pump suction line to provide in-line dilution, but is isolated from the transfer pump discharge line by two or more motor-operated three-way valves (see Figure 4). Failed valves provide a cross-connection between the waste transfer and diluent systems. Since the transfer pump discharge pressure is higher than the diluent system pressure, such a cross-connection could potentially allow waste into the diluent system.

The pressure switches referred to in the HazOp are two redundant, safety class pressure switches installed on the flush line jumper in a valve pit. These switches are interlocked to the master pump shutdown system and prevent backflow of waste by stopping the transfer pump. Failure of a safety class SSC would be a beyond-design-basis accident and is not considered in this analysis.

3.2.2.1 Frequency Analysis

As shown below, this accident has the potential to result in a surface pool of waste. The representative accident contained in HNF-SD-WM-SAR-067 (FDH 1999a) is found in Section 3.4.2.7, *Surface Leak Resulting in Pool,* which is considered to be an anticipated event. Although the unmitigated spill quantity remains the same, the radiological and toxicological consequences of this event exceed those reported in the SAR.

3.2.2.2 Scenario Development

Unmitigated Scenario

In the unmitigated accident, waste will be pumped back through the diluent system to the flush tank. Waste could fill the 5000-gallon flush tank and flow out the 4-inch diameter tank overflow line, creating a pool leak of waste. The scenarios by which this could occur are described for each diluent system below.

AN Diluent System:

Since Tank 241-AN-105 has no communication between the diluent and transfer lines in pump pit 241-AN-05A, this cross-connection can only happen in the 241-AN-A valve pit. Failure or misalignment of MOV-316 and MOV-318 can let waste backflow to MOV-802. Failure or misalignment of MOV-802 can then let waste backflow to the AN diluent system. Design is not complete for the retrieval systems for 241-AN-104 and 241-AN-107, which will also connect with 241-AN-A, but pump pit arrangements are assumed to be similar to the 241-AN-105 pump pit.

Design is not complete for 241-AN-102 and 241-AN-103 retrieval systems, which connect to the 241-AN-B valve pit, but pump pit and valve pit arrangements are assumed to be similar to the 241-AN-105 pump pit and 241-AN-A valve pit.

The AN diluent system connects directly with the pump pits for Tanks 241-AZ-101, 241-AZ-102, and 241-AY-102. Design is not complete for these tanks' retrieval systems. This analysis assumes a cross-connection between the diluent and transfer lines in the pit, with two three-way valves separating the lines.

AW Diluent System:

Design is not complete for the retrieval system in 241-AW farm, but it is assumed to be similar to the 241-AN farm. The above conclusion will apply regardless of which diluent system is used for 241-AW-101.

AP Diluent System:

Design is not complete for the retrieval system in 241-AP farm, but it is assumed to be similar to the 241-AN farm.

Replacement Cross-Site Transfer Diluent System:

Design is not complete for the retrieval system in 241-SY farm, but it is assumed to be similar to the 241-AN farm.

Mitigated Condition

Mitigative controls consist of safety class pressure switches installed on the flush jumper and interlocked to the master pump shutdown system. Failure of the isolation valves would pressurize the flush jumper. Redundant safety class pressure switches would detect the failure and shut down the transfer pump. These switches are located on piping in the 241-AN-A and 241-AW-B valve pits, the new 241-AP valve pit, the 241-AW-A and 241-AW-B valve pits, and the 241-SY-A valve pit. They are also located in the pump pits for tanks in the 241-AY and 241-AZ tank farms.

In the mitigated case, the valve failure or misalignment is detected immediately upon transfer pump startup, when pressure is detected in the flush jumper. The redundant pressure switches interlocked to the master pump shutdown system shut down the pump and stop the accident.

3.2.2.3 Source Term Analysis

Unmitigated Condition

The existing SAR Section 3.4.2.8 Surface Leak Resulting in a Pool is based on the *Calculation Notes for Surface Leak Resulting in Pool, TWRS FSAR Accident Analysis* (Hall 1996). The radiological source term for this analysis will be calculated in a manner consistent with this, evaluating the combined effects of splatter and splashing of the waste, air entrainment from the pool or from contaminated soil, from direct shine, and from skyshine. Consistent with Hall (1996), the leak is assumed to occur for 12 hours before detection and transfer pump shutdown. For consistency with other analyses, the maximum transfer pump flow rate is assumed to be 300 gpm. The total amount of waste leaked is therefore 300 gpm x 12 hr = 216,000 gal (811,650 L).

Due to the many differing piping configurations, and the preliminary state of design, piping friction flow losses are neglected for simplicity. This simplification is a departure from Hall (1996) but is conservative.

Although the waste overflowing from the flush tank will mostly run down the sides of the 3-m tall tank, a 3-m free fall as described in DOE (1994) is conservatively assumed. The bounding Airborne Release Fraction (ARF) and Respirable Fraction (RF) from Table 3-8 of that document are 5.0E-05 and 0.78, respectively. The splatter source term is therefore 8.1E05 x 5.0E-05 x 0.78 = 31.6 L.

The flush tank sits on a concrete basin 20'10" by 25'3", with a 6-in. high berm that is 8 in. thick. The amount of waste the basin can contain is therefore 233 ft^3 or 1744 gallons. 216,000 gallons of waste will quickly overflow the basin. Using the 8.7-ft^{-1} "spreading factor" in Hall (1996), the 216,000-gal (28,877-ft^3) spill will create a 251,230-ft^2 (23,339-m^2) pool. Resuspension from the pool will add to the radiological dose to downwind operating personnel.

Aerosols will be resuspended from the pool surface due to wave action. The resuspension rate is estimated from DOE (1994) Fig. 3-8 to be 2E-10 kg/m^2-s, based on a wind speed of 5 m/s and a 200-m fetch. This is consistent with Hall (1996).

Since the resuspension rate from the growing liquid pool is proportional to surface area, it will vary with time. The time integrated dose over the 12-hour leak period can be estimate by using an average resuspension rate. The average pool surface area will be assumed to be 11,970 m^2, half the final pool surface area. The estimated density of waste slurry containing 1/3 solids is 1.4-kg/L, which would result in resuspension rate of 2E-10 x 11970 x 1.4^{-1} = 1.7E-06 L/s.

Resuspension is assumed to occur throughout the entire 12-hour leak (the 17 minutes required for the waste to fill the 5000-gal [19,000-L] tank is neglected). The pool resuspension source term is therefore 1.7E-06 x 12 x 3600 = 0.07 L.

After the transfer pump is shut off at 12 hours, the waste will soak into the soil. As the soil dries out, this surface contamination can be resuspended by wind. The fraction estimated by DOE (1994), Section 3.2.4.4, is 8.4E-05, based on a 24-hour time frame. The soil resuspension term is 8.1E05 x 8.4E-05 = 68 L.

After the waste has soaked into the ground, waste remaining in the basin will continue to be resuspended. The curbed area is 50.1 m^2. The amount resuspended in 24 hours is 2E-10 x 50.1 x 1.4^{-1} x 24 x 3600 = 6.2E-04 L.

The pool will create a significant direct shine and reflected skyshine dose to operating personnel. Source terms are not derived for these dose contributors. They are calculated directly by Microshield™ and Microskyshine™ computer programs, based on pool size and waste composition. To facilitate the Microshield™ and Microskyshine™ calculations, the pool is assumed to be circular, with a 283-ft (86-m) radius.

The toxicological source terms are 31.6 L from splatter for 12 hours (31.6L/12 hr), and 31.6 L from splatter plus 68 L from soil resuspension for 24 hours (99.6L/24 hr).

Mitigated Condition

No release is postulated for the mitigated condition.

3.2.2.4 Consequence Analysis

Radiological dose is calculated for onsite and offsite receptors. Total onsite dose is the sum of inhalation, direct shine, and skyshine. Onsite dose is calculated for 12 hours. Total offsite dose is the sum of inhalation and ingestion. Offsite dose is calculated for 24 hours.

The direct shine dose rate as calculated by Microshield™ is 7.432E02 mR/hr (see Appendix A). Over a 12-hour period, the dose would be 8.92 R (0.089 Sv). The skyshine dose rate as calculated by Microshield™ is 7.363E03 mR/hr (see Appendix A). Over a 12-hour period, the dose would be 88.36 R (0.884 Sv)

Toxicological consequences are calculated for onsite and offsite receptors. Consequences are the toxicological source term multiplied by the appropriate M_{SOF} multiplier from Table 3-3.

Unmitigated Consequences

Onsite radiological, 12 hours:

Q (splatter) = 31.6L.
Q (pool resuspension) = 0.07 L.
χ/Q = 5.54E-03 s/m^3
R = 3.34E-04 m^3/sec
OF = 1
ULD (inhalation) = 6.4E05 Sv/L

D (splatter + resuspension) = 37 Sv (3700 rem)
D (direct shine) = 0.089 Sv (8.92 rem)
D (skyshine) = 0.884 Sv (88.4 rem)
D (total) = 38 Sv (3800 rem)

Onsite toxicological: 31.6L/12 hr x hr/3600 s x 2.4E04 s/L = 17.6

Offsite radiological, 24 hours:

Q (splatter) = 31.6 L
Q (pool resuspension) = 0.07 L
Q (soil resuspension) = 68 L
Q (basin resuspension) = 6.2E-04 L
χ/Q = 4.62E-06 s/m^3
R = 2.7E-4 m^3/sec
OF = 1
ULD (inhalation) = 6.4E05 Sv/L
ULD (ingestion) = 2.8E00 Sv/L

D (splatter + resuspension, inhalation) = 97.5 mSv (9.75 rem)
D (splatter + resuspension, ingestion) = 3.49E-04 mSv (3.49E-05 rem)
D (total) = 97.5 mSv (9.75 mrem)

Offsite toxicological: 99.6L/24 hr x hr/3600s x 8.8E1 s/L = 0.101

Mitigated Consequences

The mitigated accident would result in contamination of the flush jumper, but not in a waste release or in personnel exposure.

3.2.2.5 Comparison to Guidelines

Unmitigated consequences from the accident are summarized below:

Receptor/hazard	Calculated dose exposure	Risk guidelines (anticipated)
Onsite radiological	38 Sv (3800 rem)	5 mSv (0.5 rem)
Offsite radiological	97.5 mSv (9.75 rem)	1 mSv (0.1 rem)
Onsite toxicological sum-of-fractions	17.6	1 (<= ERPG-1)
Offsite toxicological sum-of-fractions	0.1	1 (<= PEL-TWA)

The radiological and toxicological consequences from the unmitigated accident exceed guidelines. Therefore, controls and/or SSCs are required to prevent this accident.

3.2.2.6 Summary of Safety-Class SSCs and TSR Controls

Credited SSCs

Backflow prevention, in the form of the safety class pressure switches interlocked to the master pump shutdown system, is relied upon to mitigate the accident. Upon detection of fluid pressure in the flush jumper during waste transfer operations, the interlock will shut down the transfer pump. Similar controls are identified in SAR section 4.3.6 for the service water system, and are classified as safety class. The application of these controls to the diluent system will be new to the SAR.

Credited TSR Controls

Administrative Control (AC) 5.12.2 requires two closed valves between the diluent system and the waste transfer system prior to a transfer. AC 5.12.2 also requires verification of proper valve alignment prior to a waste transfer. Position sensors on the isolation valves are interlocked to the master pump shutdown system to prevent transfer pump startup in the event of valve misalignment, and provide defense in depth.

Verify operability of the pressure switch interlock. AC 5.12 provides a secondary means to prevent overexposure to onsite personnel by verifying correct valve alignment and isolation of connected systems prior to a waste transfer. This control should be considered defense-in-depth when applied to systems connected to waste transfer lines.

3.2.2.7 Key Assumptions

Maximum transfer pump capacity is 300 gpm. Unmitigated consequences could be higher than those reported here if pump rates exceed this value. However, mitigated consequences would still be prevented.

3.2.3 Spray Leak Of Caustic

The hazards evaluation documented in Ryan (2000) identified several hazardous conditions, which could result in a caustic spray leak.

This analysis evaluates the consequences and potential controls for caustic spray releases from the diluent systems.

There are many potential causes of a breach in a pressurized portion of the diluent system. Such a breach could result in a spray of concentrated NaOH, which would then be carried downwind and expose onsite individuals to toxic concentrations. Although not all leaks result in a spray release, the hazard of the event is bounded by that assumption.

The storage tank is vented to the atmosphere, so piping upstream of the flush pump is essentially unpressurized. A pipe break caused by boiler controller failure could cause a spray leak of caustic from the broken pipe, due to metering pump design. Failure of diluent line heat tracing could also allow a spray leak of caustic from a frozen and broken pipe.

3.2.3.1 Frequency Analysis

The representative accident contained in HNF-SD-WM-SAR-067 (FDH 1999a) is found in Section 3.3.2.4.9, *Caustic Spray Leak*, which is considered to be an anticipated event. The unmitigated spray leak of caustic was found to have unacceptable onsite consequences. As shown below, the spray leak of caustic in this analysis also has unacceptable onsite consequences. Caustic transfer controls are currently included in HNF-SD-WM-TSR-006 (FDH 1999b) AC 5.23, but these controls do not acknowledge the safety significant function provided by the spray shields installed on the diluent system. Such new safety classifications and associated controls would be new to the SAR.

3.2.3.2 Scenario Development

Unmitigated Scenario

Caustic for the 241-SY-102 diluent system will be delivered to a storage drum. Caustic will be delivered by tank truck to the other diluent systems. From the truck (or drum), it is unloaded to the enclosed metering pump skid, mixed with hot water, and delivered to the storage tank. Storage tank contents are delivered via the flush pump to DSTs at the transfer pump pit or valve pit (see Figure 1).

Most metering skid piping is 3-inch stainless steel. The initiating event is assumed to be a crack in a circumferential weld at a flange or fitting in the diluent system piping. The leak may be in underground piping (pump or valve pit), or overground piping. The leak may also be in the reinforced polyethylene hose connecting the metering skid to the tank truck. The release continues until an operator stops the caustic addition and depressurizes the system.

Mitigated Scenario

AC 5.23.2.a calls for the use of plastic sleeving around the reinforced polyethylene hose connecting the metering skid to the tank truck, to mitigate a spray leak from the hose. This control currently only applies to caustic transfers less than 125 psi. However, higher pressures could be accommodated. For example, the reaction force imparted by the spray leak analyzed below is given by the product of jet velocity and flow rate or F = (31.5 m/s)(0.995 kg/s) = 31.3 N (7.2 lbf). The value could be twice that (F = 14.4 lbf) if the impact area is deformed such that it reflects the stream back almost 180 degrees. A flow rate of 0.995 kg/s is equivalent to 12 gpm (sg = 1.4) or about 1/10 the nominal pump flow rate. Consider the jet impacting a circular area of 4 mil polyethylene film about 3 inches in diameter. The cross-sectional area of sheeting under stress is given by, $A = \pi$ (3 in) (0.004 in) = 0.0377 in^2. The tensile stress on the plastic is given by $\sigma = F/A$ = (14.4 lbf)/(0.0377 in^2) = 382 psi. Low density polyethylene film has a tensile strength of between 1,000-2,300 psi and high density polyethylene film has a tensile strength of between 3,100-5,500 psi (Marks' 1978). In this example the strength of the polyethylene sleeving is sufficient to withstand the impact of the jet without tearing. The same calculation can be performed for other leak rates, but the decreased pump head with increased flow must be considered. For a nominal pump flow rate of 140 gpm and 6 ft/s velocity, the force calculation would yield approximately the same result. The polyethylene hose may fail due to the weight of its contents, but the conditions of the leak are not conducive to a spray release.

The sleeving is not expected to be pressure tight, and the solution would still leak out. This would result in a minor local cleanup problem, but there would be no significant aerosol release.

Diluted caustic can leak from aboveground piping, or from below ground piping in a pump pit or valve pit. Spray shields installed at pipe flanges and valve bonnets to knock down the spray provide mitigation for aboveground piping. The pit cover blocks will mitigate a caustic spray leak inside a pump pit or valve pit.

3.2.3.3 Source Term Analysis

Unmitigated Scenario

Caustic solution viscosity varies widely with NaOH concentration. A parametric study was conducted (see Appendix B) to determine the NaOH concentration associated with the maximum solution release rate and with the maximum NaOH release rate. The highest NaOH release rate occurs at the maximum concentration of 50%. The crack was modeled as a square edge orifice with a length of one pipe diameter. The crack width that produced the highest NaOH aerosol release rate was determined by iteration. Since NaOH poses a hazard to personnel by absorption through the skin as well as inhalation, a 50-μm maximum diameter for transportable particles was used instead of 10 μm, which is normally used in radionuclide inhalation calculations. A diameter of 50-μm is judged to be the upper end of particle sizes that would tend to evaporate and remain suspended rather than deposit on the ground. This size range (0-50 μm) is referred to as the transportable fraction. Minimum roughness was assumed for conservatism. The pipe was assumed to be 3" Sch. 40. Although the diluent pump operates at 164 psi, a 200-psi pump dead head pressure was assumed in the event of valve misalignment.

The maximum transportable NaOH release rate was estimated to be 46.8 g/s (see Appendix B). The associated pump flow rate (i.e., total leak rate) was 995 g/s (11.3 gpm).

Mitigated Scenario

The spray hazards from the flexible hose leak are mitigated by plastic sleeving around the hose. This effectively eliminates the spray source term, but does not prevent leakage of caustic onto the ground. The dominant hazard in this case would be aerosol formation through splatter. The maximum flow of caustic can be modeled as a discharge from a tank through an orifice (this conservatively neglects friction in the hose). The caustic tank trailer is assumed to be 2 meters tall, and the hose leak is assumed to be a square-edged orifice the same size as 2-inch Schedule 40 pipe (2.067 inches internal diameter). Caustic escapes by gravity flow, without the use of a trailer-mounted pump. The fluid is assumed to be NaOH solution with density and viscosity as described in Appendix B, Table 1.

A parametric study was performed to evaluate the effects of concentrations, from 10% to 50%. Since the ARF depends highly on the viscosity, lower concentrations of NaOH result in higher consequences. The highest onsite consequences, 0.9 mg/m^3, resulted from a concentration of 20% NaOH, using the method described below. This is sufficiently below guidelines that further refinement of this model is not warranted.

The ideal flow velocity through the orifice is $V = (2gH)^{1/2}$, where g is the gravitational constant and H is the pressure head. For a fluid with a density of 1.5 g/mL, the head would be 3 meters and the velocity would be 7.67 m/s. The Reynolds number is $N_{Re} = DV\rho/\mu$, where D is the orifice diameter, V is the velocity, ρ is the fluid density, and μ is the fluid viscosity. For a fluid with a viscosity of 1.9 centipoise, the Reynolds number would be 2.55E+05.

For these conditions, Crane (1981) gives the discharge coefficient as 0.6. The flow rate is therefore the coefficient times the velocity times the cross-sectional area, or 10 L/s.

The fluid is conservatively assumed to undergo a 1-meter free fall as it flows from the sleeving. Due to the high viscosity of the fluid, the ARF is calculated by Equation 3-13 of DOE (1994) rather than Table 3-8 as was done in Section 3.2.2.3. Since NaOH poses a hazard to personnel by absorption through the skin as well as inhalation, the RF is assumed to be 1. The Archimedes number of the fluid is $(\text{density}_{air})^2 *(\text{spill height})^3 *g/(\text{solution viscosity})^2$, where the density of air is 1.23E-03 g/mL (Marks 1978), spill height is in cm, viscosity is in poise, and g is 981 cm/s^2. The Archimedes number is 3.91E+06. The ARF is 8.9E-10(Archimedes number)$^{0.55}$ times a factor of 3 for low-density fluids, or 1.13E-05. The source term for the fluid leak is therefore 10 x 1.13E-05, or 1.13E-04 L/s of solution (2.70E-03 g/s of NaOH).

The spray leak from aboveground piping is mitigated by the spray shields. The spray leak inside a valve or pump pit is mitigated by the cover blocks. The maximum NaOH release rate occurs at a solution concentration of 40% (see the SPRAY code results summary table above). The maximum air loading of an aerosol mist is assumed to be 100 mg/m^3 (ANSI N46.1-1980). It is assumed that liquid spilling into either enclosure displaces air from the enclosure at a rate of one volume per hour. Valve pits vary in size, but a typical valve pit is 1110 ft^3. The largest active pit is the old 241-AP, which is 2650 ft^3 or 74.9 m^3 (Himes, 1997). Although the new 241-AZ and new 241-AP valve pits are not yet built, they are assumed to be smaller than the old 241-AP. DST pump pits typically are smaller than valve pits, and all pump pits are assumed to be smaller than the old 241-AP valve pit. The bounding mitigated release rate is therefore 74.9 m^3/hr or 0.021 m^3/s. The aerosol release rate is 2.1 mg/s of solution or 0.84 mg/s of NaOH.

3.2.3.4 Consequence Analysis

Unmitigated Scenario

The atmospheric dispersion coefficient (χ/Q) is taken from RPP-5924 (Cowley et. al. 2000) and is 3.28E-02 s/m^3 for onsite receptors and 2.22E-05 s/m^3 for offsite receptors (see Eq. 5). With an unmitigated NaOH release rate of 46.8 g/s, the onsite concentration is 1535 mg/m^3 and the offsite concentration is 1.04 mg/m^3.

In the event of a spray release of caustic, some of the NaOH would react with CO_2 in the air to form sodium carbonate (Na_2CO_3), which is less toxic than NaOH. Cherdron et. al (1984) states that essentially all airborne sodium particles are converted to sodium carbonate in less than three minutes at relative humidity greater than 20%. The lowest average monthly relative humidity at Hanford is 33% (TWRS FSAR Section 1.4.1.1.7). The closest offsite receptor is over 8000 meters away (TWRS FSAR Table 3.4.1-3). It is therefore reasonable to assume that the closest offsite receptor is exposed to sodium carbonate rather than sodium hydroxide. The TEEL-0 guideline for sodium carbonate is 10 mg/m^3.

Mitigated Scenario

Using the same transport assumptions as before, the resulting receptor concentrations for the hose leak are 0.9 mg/m^3 and 6E-04 mg/m^3 for the onsite and site boundary receptors, respectively. For the enclosure leak, the onsite concentration is 0.03 mg/m^3 and the offsite concentration is 2E-05 mg/m^3.

3.2.3.5 Comparison to Guidelines

For the unmitigated scenario, the onsite consequences are above the EPRG-1 guideline of 2 mg/m^3. The offsite consequences are below the permissible exposure limit - time weighted average (PEL-TWA) guideline of 2 mg/m^3.

For the mitigated scenario, the onsite concentrations are below and the offsite concentrations are negligible compared to the risk guidelines of 2 mg/m^3 for both receptors. Conservatively estimated onsite consequences do not challenge the guidelines, therefore further refinement of the model is not warranted.

3.2.3.6 Summary of Safety-Class SSCs and TSR Controls

Credited SSCs

Since the unmitigated offsite dose is below guidelines, no safety-class SSCs are required to prevent or mitigate this event. The unmitigated onsite dose is above guidelines, and safety-significant SSCs are required to mitigate the event. Spray shields around pipe flanges and valve bonnets perform this function by knocking down a spray leak from aboveground piping. Pit cover blocks are credited with knocking down a spray leak inside a pit and also perform a safety significant function.

It is recommended that the metering skid enclosure be identified as providing a defense-in-depth control.

Credited TSR Controls

- AC 5.23 controls pump and valve pit cover blocks.
- Current AC 5.23 controls include the installation of polyethylene sleeving around caustic delivery piping.

- AC 5.23 could be made to apply to the cargo truck and delivery system, but current controls do not fully apply to the diluent metering skid, storage tank, pump or pump discharge piping.

3.2.3.7 Key Assumptions

The estimated consequences of the unmitigated event, which are below offsite guidelines, are dependent upon the assumption of a maximum pump pressure output of 200 psi. Alternate pumps with significantly higher pressures could cause calculated toxic concentrations to exceed offsite guidelines, which require safety class controls. Higher pump pressures could also create reaction forces exceeding the tensile strength of the polyethylene sheeting, reducing the effectiveness of this mitigative barrier.

3.2.4 Inadvertent Addition of Incompatible Chemical

The hazards evaluation documented in Ryan (2000) identified several hazardous condition entries whose deviation was identified as *"Mislabeled chemical used for supply of diluent; human error. Unexpected chemical reactions causing damage to the diluent system, resulting in release of toxic vapors."* This accident postulates a chemical other than NaOH is inadvertently added to the diluent system, which reacts with the NaOH already in the system. The reaction is conservatively assumed to produce a pressure buildup sufficient to breach the system and release toxic vapors.

3.2.4.1 Frequency Analysis

The representative accident contained in HNF-SD-WM-SAR-067 (FDH 1999a) is found in Section 3.3.2.4.11, *Mixing of Incompatible Material – Toxic Vapor Generation* and is considered to be an anticipated event. However, this mixture does not result from an inadvertent addition of a chemical other than NaOH, does not involve SSCs resembling the diluent system, and does not describe the potential accident. An unmitigated spray leak of caustic has been analyzed in Section 3.3.2.4.9, *Caustic Spray Leak*, and found to have unacceptable onsite consequences, but there is no assurance that a caustic spray release conservatively bounds the hazards of this event. Although waste compatibility controls currently exist in HNF-SD-WM-TSR-006 (FDH 1999b) AC 5.12, these do not currently apply to the diluent system. As shown below, similar preventative controls are needed for the diluent system and would be an addition to the SAR.

3.2.4.2 Scenario Development

Unmitigated Scenario

Chemicals will be delivered by tank truck to the diluent system. From the truck, it is unloaded to the enclosed metering pump skid (see Figure 1). Since most metering skid piping is

3-inch stainless steel, the breach will most likely occur in the reinforced polyethylene hose connecting the metering skid to the tank truck. Check valves on the tank truck are assumed to prevent an unexpected chemical reaction from propagating to the truck. Chemicals for the 241-SY-102 diluent system only will be delivered to a storage drum, and the reaction is assumed to occur there.

Mitigated Scenario

There is no cost-effective way to ensure that consequences of introducing an incompatible chemical to a diluent system could be mitigated to acceptable levels. Therefore the primary strategy that should be employed is prevention. However, there are various engineering features on the caustic supply truck and on the diluent system that could be classified as defense-in-depth controls. These controls would tend to prevent a release of toxic chemicals, but should not be relied upon as the primary barrier. These defense-in-depth controls are discussed below.

Check valves on the caustic delivery tank truck will prevent backflow of chemical reaction products to the truck and will prevent an unexpected reaction from propagating to the truck.

Use of a rupture disk on the caustic addition piping inside the metering skid enclosure can also convert the spray leak to a pool leak. The disk setpoint would be less than the reinforced hose burst pressure. The rupture disk flow could be piped to a vented container to contain the spray. Again, the metering skid enclosure is not expected to be pressure tight. There would still be a cleanup problem in and around the enclosure, but no significant aerosol release.

3.2.4.3 Source Term Analysis

An unexpected chemical reaction occurring within the diluent system could result in a leak of caustic. An unmitigated spray leak of caustic has been analyzed in WHC-SD-WM-CN-065 (Lansing 1997), and found to have unacceptable onsite consequences. This leak is not postulated to occur from a chemical reaction, and does not describe the postulated accident. However, if a spray leak of caustic alone has unacceptable onsite consequences, any chemical addition capable of causing the postulated accident would also have unacceptable onsite consequences.

Since the accident control strategy relies on preventive rather than mitigative controls, the mitigated consequences are not analyzed.

3.2.4.4 Consequence Analysis

The caustic spray release evaluated in Section 3.2.3 may be a potential consequence of the diluent system breach, but is not necessarily bounding. Preventive controls for this accident are needed.

3.2.4.5 Comparison to Guidelines

Both WHC-SD-WM-CN-065 and Section 3.2.3 predict consequences, which exceed onsite guidelines in the event of a spray.

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4.0 REFERENCES

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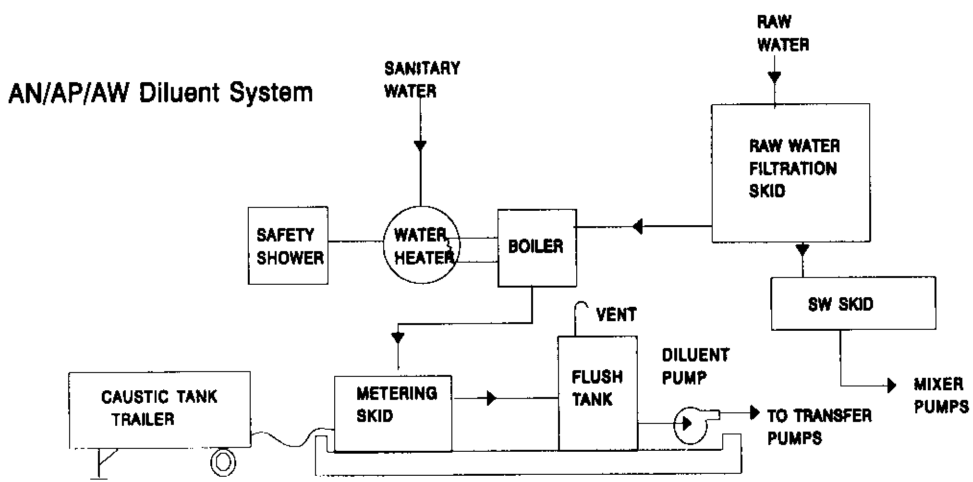
Figure 1. Diluent System Block Diagram



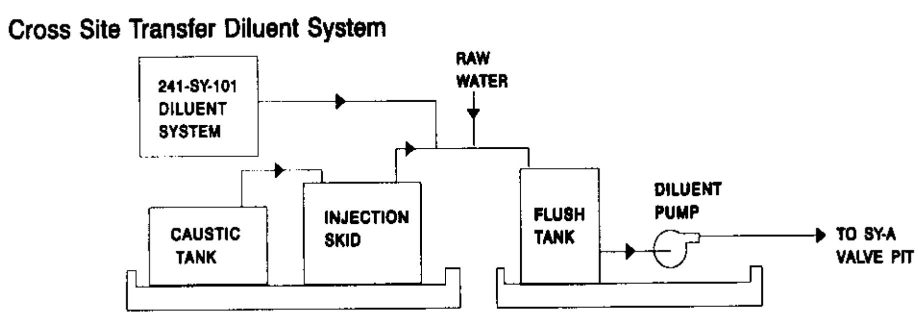


Figure 2. Transfer Pump

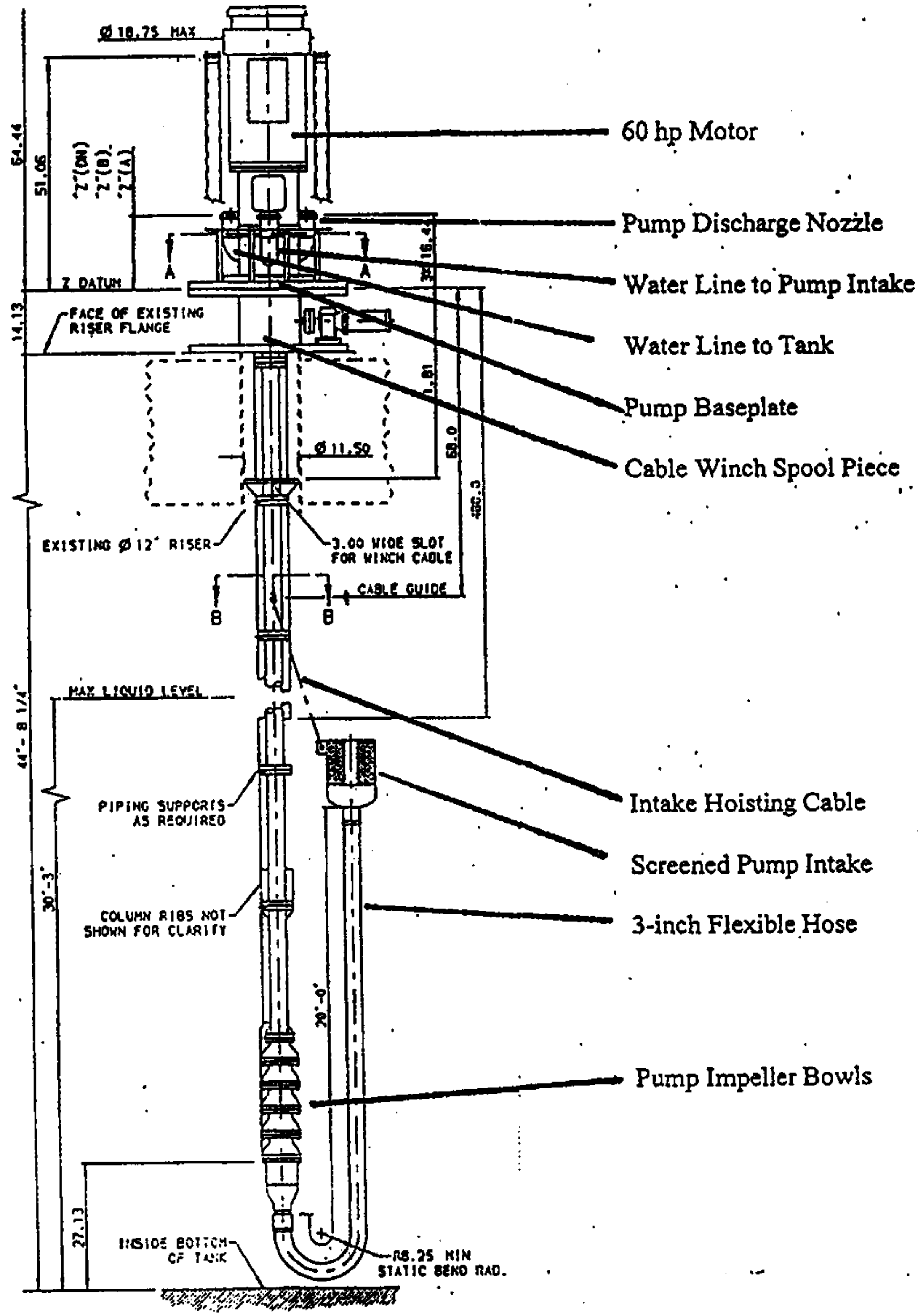
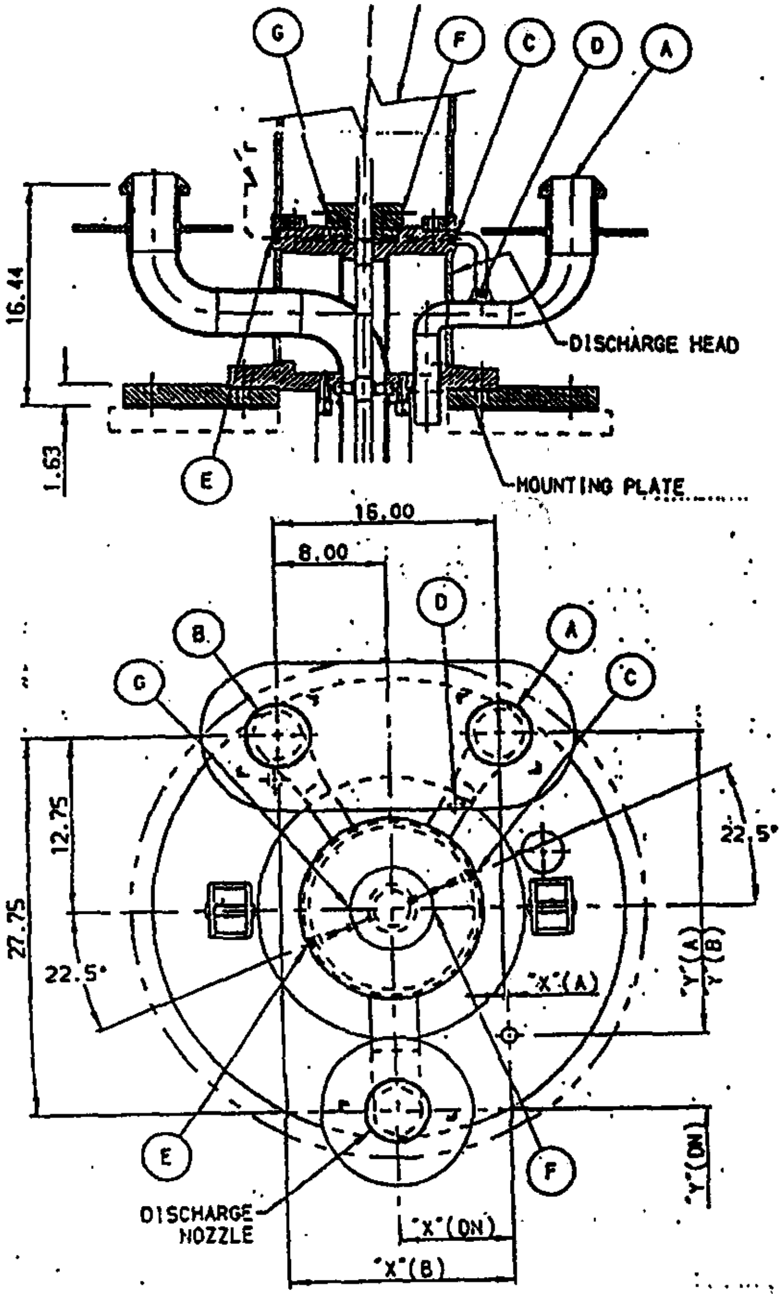
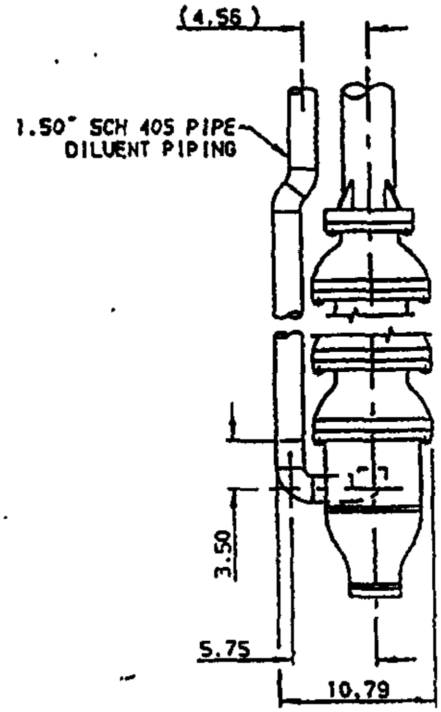


Figure 2. Transfer Pump (Cont.)

Pump Baseplate and Seal Details (left)



Water Injection Pipe Arrangement (below)



ITEM	DESCRIPTION		NPT UNLESS NOTED
A	IN-TANK DILUTION - INLET (PUREX NOZZLE)	■	3.00
B	IN-LINE DILUTION - INLET (PUREX NOZZLE)	■	3.00
C	RETURN TO TANK - SOURCE	●	0.50
D	RETURN TO TANK - INLET	●	0.50
E	THROTTLE BUSHING FLUSH (SEE NOTE 1)	▲	0.50
F	SEAL BUFFER GAS SUPPLY (SEE NOTE 2)	▲	0.25
G	SEAL DRAIN	▲	0.25

Figure 3. Waste Routing Lines

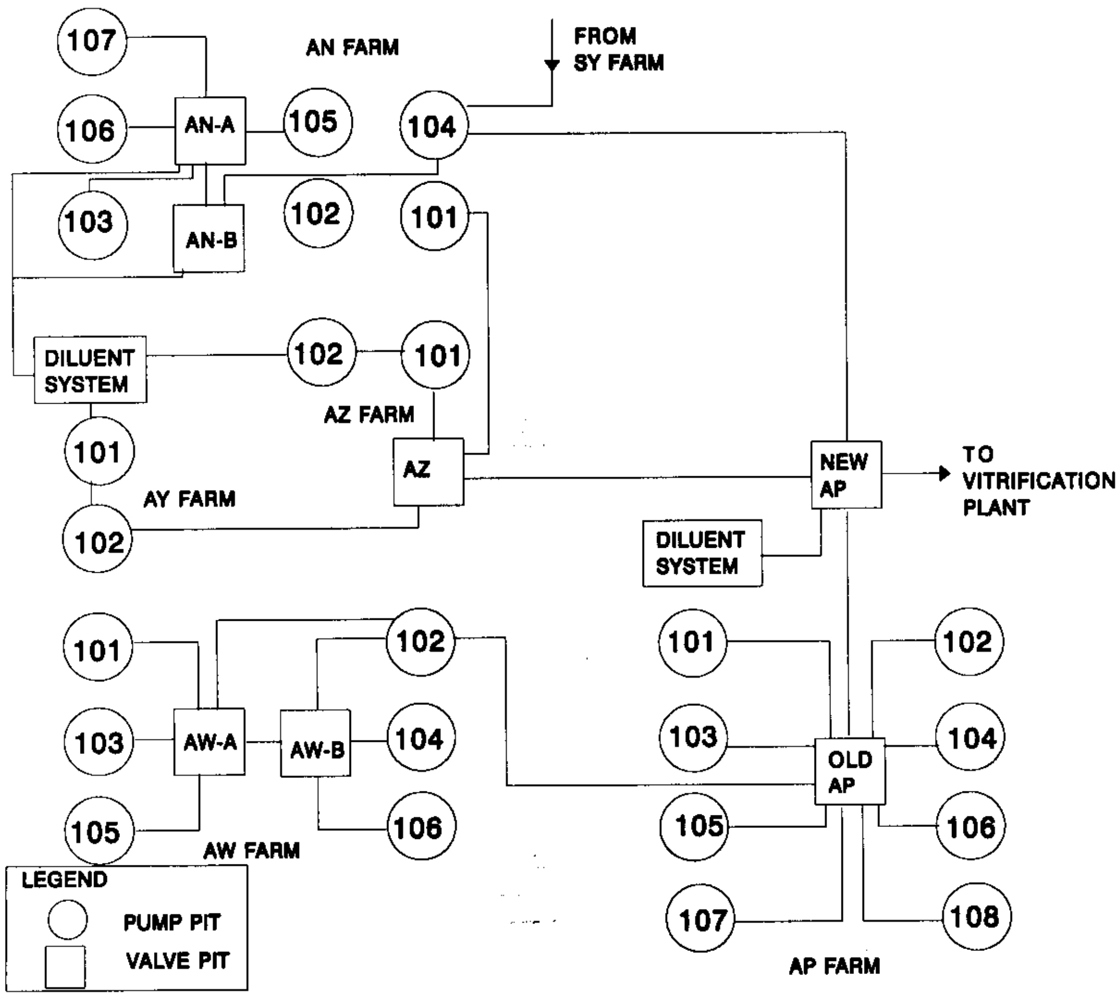
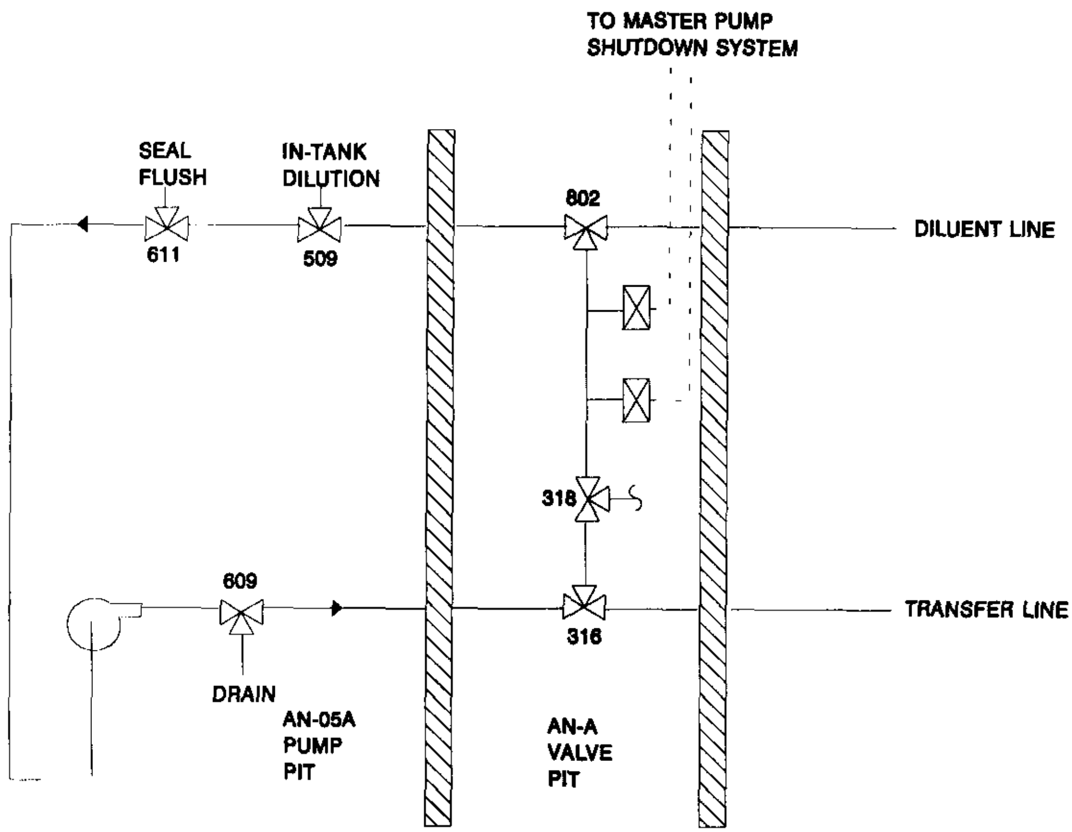


Figure 4. Piping Schematics



241-AN-105 SHOWN, SIMILAR ARRANGEMENT FOR ALL DILUENT SYSTEMS

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APPENDIX A - MICROSHIELD™ FILES

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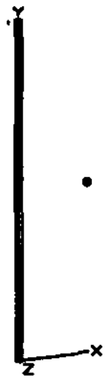
MicroShield v5.03b (5.03-00321)
Fluor Daniel Northwest

Page : 1
DOS File: 1MCYVOL2.MS5
Run Date: August 11, 1999
Run Time: 8:19:55 AM
Duration: 00:00:11

File Ref: ________
Date: ________
By: ________
Checked: ________

Case Title: Overground Pipe
Description: Person 1m away from pipe transporting all waste comp.
Geometry: 7 - Cylinder Volume - Side Shields



Source Dimensions

Height	500.0 cm	16 ft 4.9 in
Radius	4.14 cm	1.6 in

Dose Points

	X	Y	Z
# 1	100 cm	250 cm	0 cm
	3 ft 3.4 in	8 ft 2.4 in	0.0 in

Shields

Shield Name	Dimension	Material	Density
Source	2.69e+04 cm³	Water	1.4
Shield 1	.61 cm	Iron	7.86
Transition		Air	0.00122
Air Gap		Air	0.00122

Source Input
Grouping Method : Standard Indices
Number of Groups : 25
Lower Energy Cutoff : 0.015
Photons < 0.015 : Excluded
Library : Grove

Nuclide	curies	becquerels	μCi/cm³	Bq/cm³
Ba-137m	6.3747e+001	2.3587e+012	2.3676e+003	8.7600e+007
Co-60	6.9351e-003	2.5660e+008	2.5757e-001	9.5300e+003
Cs-137	6.7386e+001	2.4933e+012	2.5027e+003	9.2600e+007
Eu-154	3.8132e+000	1.4109e+011	1.4162e+002	5.2400e+006
Eu-155	2.9836e-002	1.1039e+009	1.1081e+000	4.1000e+004
Sr-90	6.9642e+002	2.5768e+013	2.5865e+004	9.5700e+008
Y-90	6.9642e+002	2.5768e+013	2.5865e+004	9.5700e+008

Buildup
The material reference is : Transition

Integration Parameters

Radial	16
Circumferential	16
Y Direction (axial)	16

Results

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.03	1.389e+11	5.166e-15	1.532e-13	5.120e-17	1.518e-15
0.04	6.170e+10	1.621e-05	1.036e-03	7.171e-08	4.583e-06

Page : 2
DOS File: 1MCYVOL2.MS5
Run Date: August 11, 1999
Run Time: 8:19:55 AM
Duration: 00:00:11

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.05	7.359e+09	1.113e-02	9.270e-01	2.965e-05	2.469e-03
0.06	1.432e+07	1.293e-03	9.370e-02	2.568e-06	1.861e-04
0.08	3.428e+08	1.143e+00	4.388e+01	1.808e-03	6.943e-02
0.1	5.732e+10	8.722e+02	1.861e+04	1.334e+00	2.847e+01
0.2	9.635e+09	1.255e+03	7.376e+03	2.215e+00	1.302e+01
0.4	1.007e+09	4.167e+02	1.293e+03	8.119e-01	2.520e+00
0.5	3.055e+08	1.766e+02	4.730e+02	3.467e-01	9.284e-01
0.6	2.134e+12	1.611e+06	3.872e+06	3.145e+03	7.558e+03
0.8	5.502e+10	6.287e+04	1.295e+05	1.196e+02	2.462e+02
1.0	4.366e+10	6.841e+04	1.278e+05	1.261e+02	2.356e+02
1.5	5.531e+10	1.516e+05	2.432e+05	2.550e+02	4.092e+02
TOTALS:	2.564e+12	1.897e+06	4.400e+06	3.651e+03	8.494e+03

MicroShield v5.03b (5.03-00321)
Fluor Daniel Northwest

Page	: 1		File Ref:	________
DOS File:	SURLKGM.MS5		Date:	________
Run Date:	August 17, 1999		By:	________
Run Time:	9:47:50 AM		Checked:	________
Duration:	00:00:19			

Case Title: Surface Leak
Description: Gamma/Bremsstrahlung, Direct Shine
Geometry: 7 - Cylinder Volume - Side Shields

Source Dimensions

Height	3.5 cm	1.4 in
Radius	8.6e+3 cm	282 ft 1.8 in

Dose Points

	X	Y	Z
# 1	18600 cm	150 cm	0 cm
	610 ft 2.8 in	4 ft 11.1 in	0.0 in

Shields

Shield Name	Dimension	Material	Density
Source	8.13e+08 cm³	Water	1.4
Transition		Air	0.00122
Air Gap		Air	0.00122
Wall Clad	1.00e+04 cm	Concrete	1.6

Source Input
Grouping Method : User Defined Energies

Group #	Energy (MeV)	Activity Photons/sec	Volume Source Photons/sec/cm³	% Energy Activity
1	0.015	1.6500e+016	2.0289e+007	.471
2	0.025	8.4800e+015	1.0428e+007	.403
3	0.035	5.5100e+015	6.7754e+006	.367
4	0.045	3.8100e+015	4.6850e+006	.326
5	0.055	2.9700e+015	3.6521e+006	.311
6	0.065	2.3300e+015	2.8651e+006	.288
7	0.075	1.8900e+015	2.3241e+006	.270
8	0.085	1.5700e+015	1.9306e+006	.254
9	0.095	1.3400e+015	1.6477e+006	.242
10	0.15	8.7200e+015	1.0723e+007	2.488
11	0.25	3.0500e+015	3.7505e+006	1.451
12	0.35	1.4600e+015	1.7953e+006	.972
13	0.475	1.4700e+015	1.8076e+006	1.328
14	0.65	6.4400e+016	7.9190e+007	79.631
15	0.825	2.0700e+015	2.5454e+006	3.249
16	1.0	1.4200e+015	1.7461e+006	2.701
17	1.225	1.9700e+015	2.4224e+006	4.591
18	1.475	4.4500e+013	5.4720e+004	.125
19	1.7	1.6100e+014	1.9798e+005	.521
20	1.9	2.9700e+012	3.6521e+003	.011
21	2.1	3.1800e+011	3.9103e+002	.001
22	2.3	1.7600e+009	2.1642e+000	.000

Buildup
The material reference is : Transition

Integration Parameters

Radial	16
Circumferential	16

Page : 2
DOS File: SURLKGM.MS5
Run Date: August 17, 1999
Run Time: 9:47:50 AM
Duration: 00:00:19

Y Direction (axial) 16

Results

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	1.650e+16	8.958e-09	1.536e-08	7.683e-10	1.317e-09
0.025	8.480e+15	1.537e-01	6.089e-01	2.651e-03	1.050e-02
0.035	5.510e+15	3.474e+00	3.200e+01	2.201e-02	2.027e-01
0.045	3.810e+15	9.117e+00	1.616e+02	3.032e-02	5.374e-01
0.055	2.970e+15	1.427e+01	3.775e+02	3.211e-02	8.496e-01
0.065	2.330e+15	1.757e+01	5.705e+02	3.190e-02	1.036e+00
0.075	1.890e+15	1.989e+01	7.008e+02	3.241e-02	1.142e+00
0.085	1.570e+15	2.163e+01	7.709e+02	3.360e-02	1.198e+00
0.095	1.340e+15	2.323e+01	8.050e+02	3.556e-02	1.232e+00
0.15	8.720e+15	3.752e+02	9.190e+03	6.178e-01	1.513e+01
0.25	3.050e+15	3.670e+02	5.235e+03	6.771e-01	9.658e+00
0.35	1.460e+15	3.498e+02	3.505e+03	6.748e-01	6.761e+00
0.475	1.470e+15	6.612e+02	4.921e+03	1.297e+00	9.655e+00
0.65	6.440e+16	5.532e+04	3.110e+05	1.074e+02	6.038e+02
0.825	2.070e+15	2.904e+03	1.348e+04	5.503e+00	2.554e+01
1.0	1.420e+15	2.959e+03	1.192e+04	5.455e+00	2.197e+01
1.225	1.970e+15	6.222e+03	2.185e+04	1.101e+01	3.867e+01
1.475	4.450e+13	2.050e+02	6.422e+02	3.464e-01	1.085e+00
1.7	1.610e+14	9.868e+02	2.858e+03	1.603e+00	4.643e+00
1.9	2.970e+12	2.272e+01	6.215e+01	3.570e-02	9.765e-02
2.1	3.180e+11	2.965e+00	7.721e+00	4.515e-03	1.176e-02
2.3	1.760e+09	1.962e-02	4.891e-02	2.901e-05	7.233e-05
TOTALS:	1.292e+17	7.048e+04	3.881e+05	1.348e+02	7.432e+02

MicroSkyshine
=============
(Nuclear & Radiological Safety Analysis - 1.16-007)

Page:	1	File Ref:	________
File:	VERCY.SKY	Date:	__/__/__
Run:	10:07 a.m.	By:	________
:	October 11, 1999	Checked:	________

CASE: Surface Pool, gamma and bremmstrahlung

GEOMETRY: Vertical cylinder area source behind a wall

DIMENSIONS (meters):

Distance between wall and detector...........	X	99.
Depth of source behind wall..................	Y	0.956
Offset of detector...........................	Z	0.
Depth of dose point..........................	H	-0.544
Distance between center of source and wall...	R1	87.
Thickness of cover slab......................	T1	0.
Thickness of second shield...................	T2	0.
Radius of source.............................	W	86.
Height of source.............................	L	0.035

INTEGRATION PARAMETERS:

Number of Radial Segments....................	M	5
Number of Circumferential Segments...........	N	5
Number of Vertical Segments..................	C	5
Quadrature Order............................		16

MATERIAL DENSITIES (g/cc):

Ambient air: .0012

Material	Cover Slab	Lower Shield	Volume Source
Air			
Water			1.4
Concrete			
Iron			
Lead			
Zirconium			
Urania			

Buildup factor based on: AIR.

Page 2

CASE: Surface Pool, gamma and bremmstrahlung

SOURCE NUCLIDES:

Source was entered by energy groups.

RESULTS:

Group #	Energy (mev)	Activity (photons/sec)	Dose point rads/photon	Dose rate (mr/hr)
1	1.70	1.610e+14	2.321e-20	1.541e+01
2	1.48	4.450e+13	2.257e-20	4.141e+00
3	1.23	1.970e+15	2.383e-20	1.935e+02
4	1.00	1.420e+15	2.346e-20	1.374e+02
5	.82	2.070e+15	2.231e-20	1.904e+02
6	.65	6.440e+16	2.212e-20	5.873e+03
7	.47	1.470e+15	2.136e-20	1.295e+02
8	.35	1.460e+15	1.954e-20	1.177e+02
9	.25	3.050e+15	1.710e-20	2.150e+02
10	.15	8.720e+15	1.354e-20	4.869e+02
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
	TOTALS:	8.477e+16		7.363e+03

APPENDIX B – APPLICATION OF D&J SPRAY MODEL TO SODIUM HYDROXIDE SPRAY THROUGH A LONG SLIT

APPENDIX B

APPLICATION OF D&J SPRAY MODEL TO SODIUM HYDROXIDE SPRAY THROUGH A LONG SLIT

By
M. G. Piepho
Fluor Federal Services, Inc.
August 9, 2000

This appendix employs the Dombrowski and Johns (D&J) spray model described in Attachment A for a sodium hydroxide (NaOH) spray through a long slit. The spray calculation was documented previously in Rev. 0 of this document, but is being updated with the more accurate D&J spray model and with a smaller diluent pump discharge pressure of 200 psig instead of 500 psig. Assuming the same slit length of 3.068 in (7.79 cm), but a square edge orifice (contraction coefficient of 1.0 and velocity coefficient of 0.82) instead of a sharp edge orifice, the width of slit was varied in order to determine the optimum width. The optimum width is defined as the width that maximizes the transportable sodium hydroxide mass leak rate. Also, two NaOH concentrations (40% and 50%) in the liquid were examined. The spray liquid with 50% NaOH resulted in the higher transportable NaOH mass leak rate, but the NaOH leak rate was not very sensitive to its concentration in the spray liquid. The maximum transportable size diameter used previously was 50 microns, which is the value used here.

The optimum slit width value was determined here to be 0.27 mm or about 0.011 in. The maximum transportable sodium hydroxide mass leak rate for a pressure of 200 psig is estimated at 46.8 g/s, which is more than half of the leak rate previously reported in Rev. 0 for the higher pressure of 500 psig. The details of the calculations are described below.

The two spray liquid properties (HNF 1997) are summarized in Table 1. Also, the liquid surface tension is required for the D& J model, and the surface tension of water (72 dynes/cm) was used in this analysis. The surface tension of NaOH solutions is higher than 72 dynes/cm and depends on both the NaOH concentration and liquid temperature. A higher surface tension results in larger spray droplets which is less conservative. Hence, the more conservative water surface tension value of 72 dynes/cm, which is well known, is used here.

Table 1. Spray Liquid Properties

NaOH mass fraction	Mass Density (g/cm^3)	Viscosity (centi-poise)
0.40	1.410	8.5
0.50	1.504	14.3

Using the D&J model (described in Attachment A) with the equation and friction factors described in WHC (1994), the slit width was varied to determine the optimum size and maximum sodium hydroxide spray release for both spray liquids. Table 2 shows several spray results for various slit widths for the 50% NaOH solution spray. The transportable NaOH mass leak rate is still increasing slightly when the Reynolds number exceeds the laminar flow criteria

(2000). When the turbulent flow friction factor is used (assuming smooth side with small surface roughness thickness of 1.52 x 10^{-4} cm), the velocity and Reynolds number get smaller (due to larger friction factor), and the mass rate is smaller.

Table 2. Spray Results For Several Width Sizes And 50% NaOH Liquid

Orifice Width (cm)	Transportable NaOH Mass Rate (g/s)	Total Transportable Mass Rate (g/s)	Transportable Fraction (Dia. <50 microns)	Reynolds Number	Friction Factor
Laminar Flow Friction Factor					
0.025	46.60	93.2	0.0103	1620	0.0395
0.026	46.75	93.5	0.0984	1700	0.0377
0.027	46.81	93.6	0.0941	1780	0.0360
0.028	46.80	93.6	0.0900	1860	0.0344
0.030	46.60	93.2	0.0825	2020	0.0317
Turbulent Flow Friction Factor					
0.030	41.9	83.9	0.0776	1920	0.0498
0.035	40.5	81.0	0.0631	2250	0.0482

The optimum slit width is 0.027 cm (~0.011 in) with laminar flow. The exit velocity of the optimum spray release is 31.5 m/s, and the Sauter mean diameter of the spray droplets is 85.8 microns using the D&J spray model (see Attachment A). Using the Rosin-Rammler distribution with a spread parameter (q) of 2.4, a transportable mass fraction 0.0941 (see Table 2) is obtained for a maximum transportable particle size of 50 microns. In other words, 9.41% of the total spray mass consists of droplets less than or equal to 50 microns in diameter.

For square edge orifices, such as the sheet spray, the contraction coefficient is expected to be one, and the velocity coefficient is 0.82. The total mass rate exiting the slit is 995 g/s, and the transportable mass is about 93.6 g/s (0.0941 x 995) with 50% of the mass being sodium hydroxide. Hence, the transportable sodium hydroxide mass rate is about 46.8 g/s (93.6 x 0.50).

The optimum width for 40% NaOH spray liquid was also obtained. In the laminar flow regime (Re < 2000), the optimum width was found to be 0.019 cm (0.19 mm), which resulted in transportable NaOH mass leak rate of 44.2 g/s. This rate is lower than the 50% NaOH liquid with a larger slit width, even though the total transportable mass rate of 40% NaOH liquid is larger at 110.5 g/s. Basically, with the smaller fraction of NaOH (0.40), the transportable NaOH mass rate is only 44.2 g/s (110.5 x 0.40). In the turbulent flow regime, the transportable mass rates are smaller than the mass leak rates in the laminar flow regime, as was the case for the 50% NaOH liquid (see above). The transportable NaOH mass leak rate is somewhat insensitive to the NaOH concentration in the 40 to 50% range.

Since there are numerous spray output results and orifice properties, they are summarized for the optimum slit width of 0.027 cm (0.106 in)and 50% NaOH liquid below:

Optimum Spray Results (Laminar flow regime)

Sauter mean diameter	= 85.8 microns
R-R spread parameter, q	= 2.4
Transportable Fraction	= 0.0941
Total spray mass rate	= 995 g/s
Total transportable mass rate	= 93.6 g/s
Transportable NaOH mass rate	= 46.8 g/s
Exit velocity	= 31.5 m/s
Reynolds number	= 1780

Orifice Properties

Length	= 7.79 cm (3.068 in.)
Width	= 0.027 cm (0.0106 in.)
Area	= 0.21 cm^2
Velocity Coefficient	= 0.82
Contraction Coefficient	= 1.0
Surface roughness	= 0.000152 cm (6.0 x 10^{-5} in)
Depth (thickness)	= 0.5486 cm (0.216 in.)
Pressure difference	= 200 psig (1.38 x 10^{+7} dynes/cm^2)

References

HNF 1997, Lansing, L. C. and R. J. Van Vleet, *Consequence Analysis of a NaOH Solution Spray Release during Addition to Waste Tank*, HNF-SD-WM-CN-065, Rev. 2, Fluor Daniel Hanford, Inc., Richland, Washington.

WHC 1994, B. E. Hey and D. S. Leach, *A Model for Predicting Respirable Releases from Pressurized Leaks*, WHC-SD-GN-SWD-20007, Westinghouse Hanford Company, Richland, Washington.

APPENDIX C – PEER REVIEW CHECKLISTS

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Practice 134 290 1112
Publication Date 22Nov99
Attachment 02 - Sheet 1 of 1

FLUOR DANIEL NORTHWEST

TECHNICAL PEER REVIEWS

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed: RPP-5098, Rev. 1
Title: Analysis of Waste Leak and Toxic Chemical Release Accidents from Waste Feed Delivery (WFD) Diluent System
Author: J. C. Williams and B. E. Hey
Date: 8/29/00
Scope of Review: Entire document

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

John C. VanKeuren [signature] 9/11/00
Reviewer: (Printed and Signed) Date

* All "NO" responses must be explained below or on an additional page.

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

NUCLEAR ENGINEERING

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ATTACHMENT 1 - COMPARISON OF JET AND FAN SPRAYS

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FLUOR GLOBAL SERVICES

Memorandum

To:	Brit Hey	Date:	August 17, 2000
Location:	Richland	Reference:	BEH-00-030
From:	Mel Piepho and John Van Keuren MGP. JVK		
Location:	Richland	Client:	CHG
Phone:	376-2920	Subject:	Comparison of Jet and Fan Sprays
FAX:			

c: Mel Piepho
John Van Keuren
BEH File/LB

As requested, please find attached a comparison between the correlation for circular jet and sheet sprays as applied to a slit. Surprisingly, application of the Dombrowski and Johns (D & J) correlation predicts a smaller Sauter Mean Diameter (SMD) than the Merrington and Richardson (M & R) formula for a sheet spray, especially at lower velocities (<40 m/s).

MGP:JCVK:gjr

Attachment

ATTACHMENT

to

BEH-00-030

ATTACHMENT 1

RECOMMENDATION AND COMPARISON OF DROP SIZE CORRELATIONS FOR JET AND FAN SPRAYS

By
M.G. Piepho and J.C. VanKeuren
Fluor Federal Services, Inc.
August 17, 2000

The correlation for the surface-volume mean diameter (or Sauter mean diameter [SMD]) for the spray leak analysis in the RPP FSAR is based on sprays from simple circular plain-orifice nozzles (Merrington and Richardson [M&R], 1947), which was taken from Lefebvre (1989). This correlation is given in Equation (1).

$$SMD = 500\frac{\left(d^{1.2}\nu^{0.2}\right)}{U} \tag{1}$$

SMD = Sauter mean diameter or volume-surface mean diameter (m)
ν = Kinematic viscosity of liquid (1.0 x 10^{-6} m^2/s for water at 20 °C)
U = Liquid velocity (m/s), varied between 10 and 70 m/s,
d = Hole diameter (m),
= Hydraulic effective diameter for extension to fan sprays (WHC 1994) = 4A/perimeter, where A is the orifice area

Sprays from slits or cracks are referred to as fan sprays. One correlation for the Sauter mean diameter (SMD) for fan sprays is described in Dombrowski and Johns (1963). This correlation is given in Equations 2, 3 and 4.

$$d_l = 0.9614\left(\frac{K^2}{\rho\,\rho_a}\frac{\sigma^2}{U^4}\right)^{1/6}\left[1+2.6\mu\left(\frac{K\,\rho_a^4}{72\rho^2}\frac{U^7}{\sigma^5}\right)^{1/3}\right]^{1/5} \tag{2}$$

$$d_d = 1.882\ d_l\left[1+\frac{3\mu}{\left(\rho\,d_l\sigma\right)^{1/2}}\right]^{1/6} \tag{3}$$

$$d_m = 0.63\ d_d \tag{4}$$

d_d = Theoretical droplet diameter (cm)
d_L = Theoretical ligament diameter (i.e., sheet thickness at time of breakup, cm)
d_m = Surface-volume mean diameter or SMD (cm)

μ	=	Absolute (or Dynamic) viscosity of liquid (0.01 g/cm-s [0.01 poise] for water at 20 °C)
ρ	=	Density of liquid (1 g/cm^3 for water at 20°C)
ρ_a	=	Density of gas (1.21 x 10^{-3} g/cm^3 for air at 20 °C)
K	=	Sheet thickness times length (cm^2) flow parameter (spray nozzle parameter)
	=	Function(orifice size) = $0.5A/\sin(\theta/2)$, where θ = full spray angle (118° in Hasson and Mizrahi, 1961), which is extended here to a hydraulic effective diameter formulation below
	=	$0.656(D_h)^2$ for fan sprays (aspect ratio > 1)
	=	$2.26(D_h)^2$ for circular jet sprays
	=	$2.88(D_h)^2$ for square jet sprays (aspect ratio = 1)
D_h	=	Hydraulic effective diameter (cm)
	=	4A/perimeter, where A = orifice area
σ	=	Surface tension of liquid (72 dynes/cm for water at 20°C)
U	=	Fluid velocity of liquid (cm/s) varies from 1000 to 7000 cm/s for many sprays
	=	$C_D(2p/\rho)^{0.5}$, where C_D= discharge coefficient for orifice (0.6 to 0.9 for most orifices and liquids) and p is the pressure differential in $dynes/cm^2$

Another correlation for a fan spray is given in Dorman (1951). This correlation is shown in Equation (5).

$$D_0 = 4.4\left(\frac{Q}{\theta}\right)^{1/3} \gamma^{1/3} \rho^{1/6} p^{-1/2} \quad (5)$$

D_0	=	Sauter mean diameter (cm)
Q	=	Liquid throughput (cm^3/s) = UA = $C_D A(2p/\rho)^{1/2}$, varied in experiments from 7 to 75 cm^3/s
C_D	=	Discharge coefficient for orifice (0.6 to 0.9 for most orifices and liquids)
A	=	Area of slit (cm^2), 0.05 cm x 7.62 cm = 0.381 cm^2 in example
U	=	Exit velocity of spray liquid (cm/s)
ρ	=	Density of liquid (1 g/cm^3 for water at 20 °C)
p	=	Differential pressure ($dynes/cm^2$), varied in experiments from 3.1 x 10^6 to 7.2 x 10^6 $dynes/cm^2$ (45 to 105 psid)
γ	=	Surface tension (72 dynes/cm for water at 20 °C)
θ	=	Spray angle assumed to be $\pi/2$ radians

Qualitative Comparison of Correlations

All three correlations calculate a mean volume-surface diameter, which is the Sauter mean diameter. The Merrington and Richardson (M&R) equation (Equation [1]) was derived for circular plain-orifice atomizers spraying low viscosity liquids such as water into stagnant air. It is simple to use, requiring only the orifice diameter and two liquid properties (viscosity and density). It is expected to over-estimate the SMD for a slit or fan spray (mainly because the fan spreads out more than a jet, resulting in smaller droplets), if the hydraulic equivalent diameter ($4A_{orifice}$/perimeter) for the slit is used in Equation (1). However, a larger SMD is not conservative for safety purposes, since a larger SMD results in smaller fraction of respirable mass (particles less than 10 microns) existing in a spray release and a smaller dose. This is due to the Rosin-Rammler (R-R) distribution function (Lefebvre, 1989), which is used to determine the mass fractions of particle sizes in a spray release. The Rosin-Rammler distribution uses the SMD and a spread parameter (varies from 1.8 to 3.0 for most sprays) to determine the respirable mass fraction. If a larger SMD (or larger spread parameter, q) is used in the R-R distribution, a smaller respirable mass fraction is obtained (see Lefebvre, 1989, for detailed explanation).

In order to be more accurate for slit or fan sprays, the Dombrowski and Johns (D&J) equation (Equation [4]) or the Dorman equation (Equation [5]) should be used, since they were derived for fan sprays. Furthermore, even though the D&J correlation was intended for fan sprays with sheet attenuation, it can be extended to simple plain-orifice (jet) sprays and sprays from long slits, if an appropriate sheet thickness parameter (K) is used.

One disadvantage of the D&J correlation is estimating the value of K for various orifices with different sizes and aspect ratios (length/width). The proposed correlation here is to make K (see above, D&J correlation) proportional to the square of the hydraulic effective diameter. It is expected to under-estimate the SMD for plain-orifice atomizers (jets), but is expected to be more accurate (and conservative) for sprays from slits with high aspect ratios.

The disadvantages of Dorman's correlation are the following:

(1) the spray angle is difficult to estimate, except that spray angles are larger for fan sprays (about 90° to 150°) than for jet sprays (around 5° to 20°),
(2) the mass throughput, Q, does not specify the orifice aspect ratio or the hydraulic effective diameter; hence, different shaped orifices with the same area will give the same SMDs, which is not physically correct. Therefore, this correlation is difficult to extend to jet sprays and to sprays from long slits, if not impossible.

Quantitative Comparison of Correlations

The M&R and D&J correlations are used to calculate SMDs for a plain-orifice atomizer for two different hole sizes, and a fan (or slit) spray with one rectangular slit size. The correlations are then compared to two sets of mass-size data (Lee data [WHC 1994], and the Delavan data [WHC 1992]). The Dorman correlation is not evaluated further, since it cannot be extended to long slits and may not be accurate for jet sprays.

The liquid properties for water at room temperature are assumed for all sprays. The M&R equation (Equation [1]) requires a hole diameter, which is extended to the more generic hydraulic equivalent diameter (4A/perimeter) for any orifice. The D&J correlation also depends on the hydraulic equivalent diameter (in order to obtain the sheet thickness parameter, K). The slit through which liquid is assumed to spray was assumed to be 0.05 cm wide by 7.62 cm (3 in) long. This assumption is consistent with FSAR assumptions.

The D&J correlation was derived for fan sprays with attenuating sheets, but can be extended to jet sprays and fan sprays with large aspect-ratio orifices by modifying the sheet thickness parameter, K, in terms of the hydraulic effective diameter, D_h.

The value for K is estimated by the following equation (Hasson and Mizrahi, 1961):

$$K = 0.5A/\sin(\theta/2) \tag{6}$$

θ is the maximum full spray angle (90° to 150° for most fan sprays), and A is the rectangular orifice area. For the fan nozzles, with an aspect ratio of approximately 2 (actually from 1.8 to 2.2, Fraser et al., 1962), used by Hasson & Mizrahi and Fraser, et al., the spray angle was 118°, which gives a K value of about 0.583A using Equation (6). For a given nozzle, K can be determined experimentally (sheet thickness times radial distance from orifice, especially at time of break up into ligaments). Experiments have shown (Dombrowski et al., 1960) that K is somewhat independent of liquid viscosity values less than 0.10 poise (water's viscosity is about 0.01 poise) and differential pressures larger than 20 psid, which are the usual conditions encountered in spray calculations for safety purposes. Also, for liquid viscosity values greater than 0.10 poise (10 centi-poise), the D&J method will under-estimate the SMD slightly, which is conservative for safety calculations.

In order to extend Equation (6) to slits with large aspect ratios and not over-estimate the SMD values, the orifice area is replaced with a hydraulic effective diameter squared term. For a rectangle with an aspect ratio of 2, the area is $2w^2$, where w is the smaller side (width) of rectangle. The hydraulic effective diameter, D_h, of the rectangle is $4(2w^2)/(6w)$ or $4w/3$. Hence, the area in terms of the hydraulic effective diameter is $9(D_h)^2/8$, which yields an estimate for K of $0.656(D_h)^2$ for fan spray nozzles. Equation (6) is extended to square jet sprays (square orifice) by using the maximum expected jet spray angle of 20°, which minimizes the K value and the SMD from the D&J correlation. An angle of 20° results in an estimate for K of 2.88A, and the area of a square is just the hydraulic effective diameter squared; hence, $K = 2.88(D_h)^2$ for a square orifice. For a circular orifice, the area is $\pi(D_h)^2/4$, so the 2.88A expression becomes $2.26(D_h)^2$, which is the estimate for K for a circular jet spray. The following summarizes the formulas for K above:

1) $K = 0.656(D_h)^2$ for rectangular orifices (aspect ratio > 1),

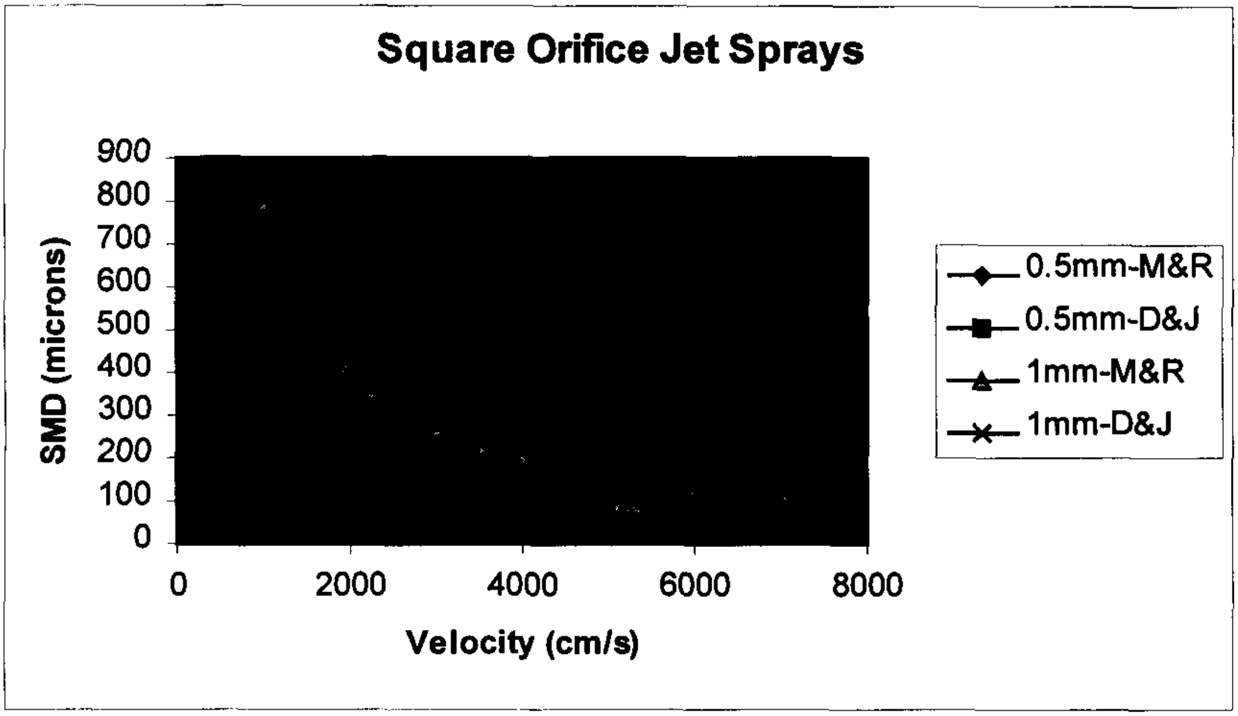
2) $K = 2.26(D_h)^2$ for circular orifices,

3) $K = 2.88(D_h)^2$ for square orifices (aspect ratio = 1).

Plain-Orifice Atomizer (Jet) Comparison

The M&R and D&J correlations are compared for two square orifices with sides of 0.5 and 1.0 mm. The SMD values for the two square orifices as a function of velocity are shown in Figure 1.

Figure 1. Comparison of Particle Size (SMD) Correlations For Square Orifices

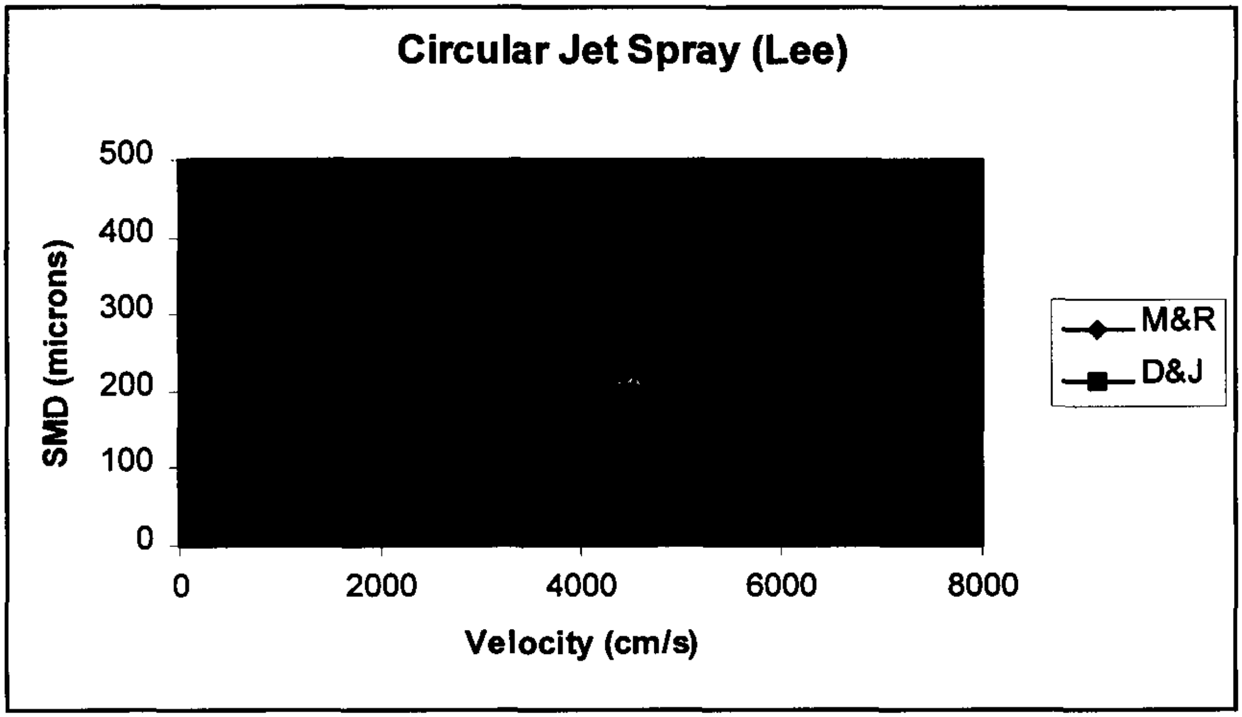


The liquid properties of plain water at 20 °C were used in these calculations. As shown in Figure 1, the D&J correlation estimates lower particle sizes for lower velocities than the M&J correlation, and larger particle sizes for larger velocities. In other words, for jet sprays with square orifices, the D&J correlation's estimates of the SMD is more conservative than the M&J correlation for lower velocities, and less conservative for higher velocities. However, as the square orifice size increases, the D&J correlation for particle sizes increases slower than the M&J correlation. In fact, for square orifices larger than 1 mm (not shown in Figure 1), the D&J correlation is more conservative than the M&J correlation for all velocities up to 70 m/s.

Circular Jet Spray (Lee Data)

Particle sizes are also compared for a circular orifice with fuel as the spray liquid. The SMD was measured in the original jet spray experiment by Lee (1932), where the orifice was circular with a diameter of 0.508 mm. The measured SMD value was 68.8 microns at a velocity of 70 m/s (WHC 1994). The mass density of the fuel was 860 g/cm^3, and kinematic viscosity was 0.0364 cm^2/s (stokes) for an absolute viscosity of 0.0313 g/cm-s (3.13 centi-poise). The surface tension of the liquid fuel was 28 dynes/cm. The SMD value estimated by the M&R correlation is 65 microns at 70 m/s, which is close the measured value of 68.8 microns (Lee), and to the value of 68.4 microns estimated by the D&J correlation. The SMD values as a function of velocity are shown for the two correlations in Figure 2. Even though the particle size estimates are close at the high velocity of 70 m/s (corresponding to a high-pressure difference of 450 psid), the particle sizes are much larger, and less conservative, for the M&R correlation at velocities below 60 m/s.

Figure 2. Particles Sizes (SMD) Versus Velocity for Circular Jet Fuel Spray (Lee)



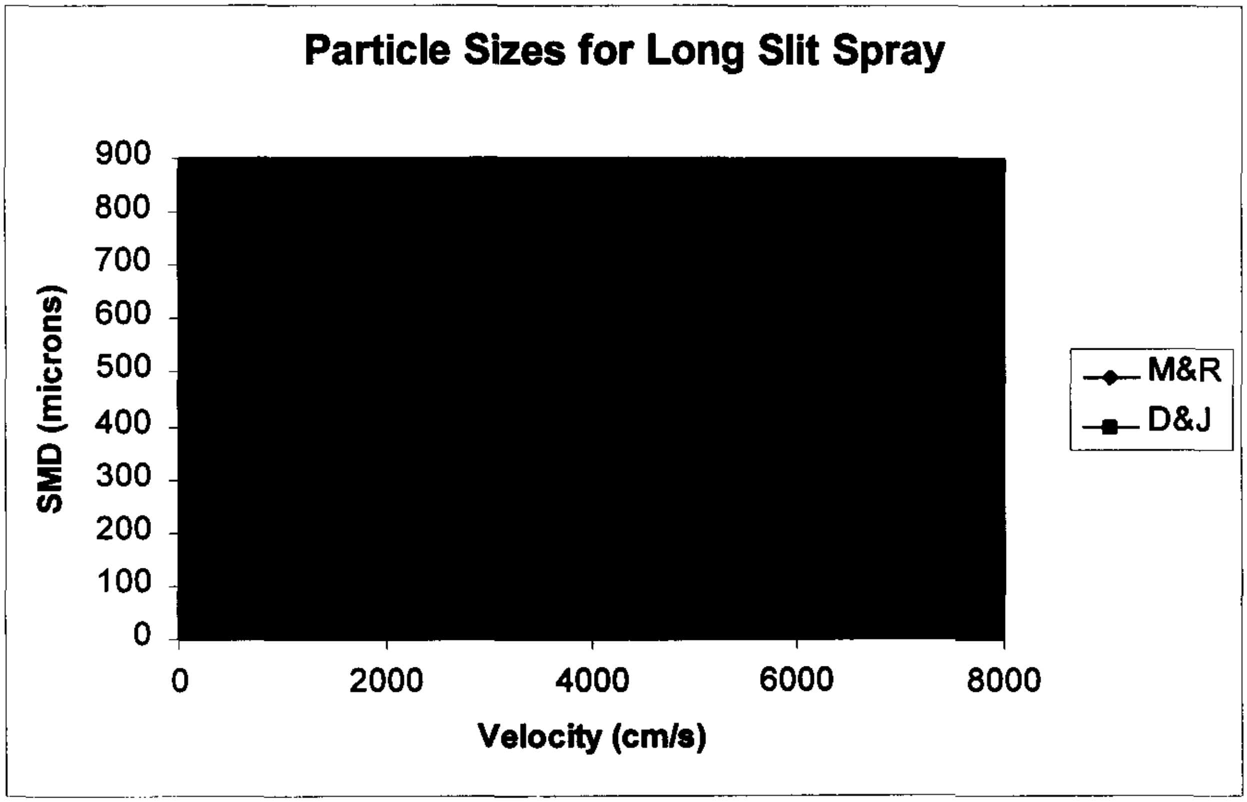
Delavan Spray Data

No graphical comparisons were made with the Delavan spray nozzle data (WHC 1992) since Delavan Manufacturing Company primarily made pressure-swirl nozzles (Lefebvre. 1989). Pressure-swirl nozzles may have more than one orifice or port, which are adjacent to a swirl chamber, where the liquid enters to form liquid sheets, which spin around the chamber before exiting the nozzle. If the Delavan nozzle consisted of only a plain-jet orifice, which is not expected to be the case, then the orifice diameter would be 1.52 mm with an exit velocity of 19.3 m/s (based on throughput of 33.6 gallons/hour and differential pressure of 40 psid). The M&R correlation estimates an SMD value of about 680 microns, whereas the D&J correlation estimates a value of 350 microns, which are both much larger than the measured value of 137 microns. The fact, that both correlations estimate much larger SMD values than the measured value, gives credence to the nozzle not being a plain-orifice nozzle, but rather a pressure-swirl nozzle.

Fan-Spray Nozzle (Slit) Comparison

The SMD values versus velocity for the long slit (0.5mm by 7.62 cm) are shown in Figure 3. This fan spray with a large aspect ratio of 150 shows that the D&J correlation estimates smaller SMD values (more conservative with regards to safety) the SMD values estimated by the M&R correlation. For fan sprays, the D&J correlation, which is based on fan spray theory and data, should be more accurate than the M&R correlation, which is based only on circular jet spray data.

Figure 3. Particle Sizes (SMD) Versus Velocity for Fan Spray With Long Slit



A sensitivity calculation of the effects of increasing the surface tension on the D&J correlation (Equations 2, 3 and 4) was made. Surface tension for solutions with dissolved solids is typically higher than pure water. Increasing the surface tension from 72 dynes/cm to 100 dynes/cm (expected to be larger than surface tension of tank waste) increased the value of the SMD by about 10%. This magnitude of change does not affect the conclusions, and it is conservative, in regards to dose, to use the lower surface tension of water in safety calculations.

Conclusions

From the many drop size correlations for sprays examined, only two were chosen for quantitative comparison. These two correlations are the 1) Merrington and Richardson equation, and 2) the Dombrowski and John's correlation. The M&R correlation is simpler and applicable to circular jet sprays, whereas the original D&J method is applicable to fan sprays for a wider variety of spray liquids, including liquids with high viscosity values. The D&J method was extended to jet sprays and to fan sprays with long slits, by deriving expressions for the thickness parameter, K, in terms of a hydraulic effective diameter. The D&J method is based on the theory of attenuating liquid sheets and modified slightly, by Equation (4), to fit experimental fan spray data. As a result, the D&J method has a better theoretical basis and also fits a wider range of experimental spray data than the M&R correlation.

The D&J correlation has been shown here to accurately estimate the SMD for the circular jet spray by Lee. The extended D&J correlation is applicable to all jet and fan sprays with differential pressures above 20 psid and any liquid viscosity value, and its SMD estimates are expected to be conservative (i.e., smaller SMDs), especially for viscosity values greater than 10 centi-poise (0.1 g/cm-s).

References

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Dombrowski, N., D. Hasson, and D. E. Ward, 1960, *Some Aspects of Liquid Flow Through Fan Spray Nozzles*, Chemical Engineering Science, Volume 12, pp. 35-50.

Dorman, R.G, 1951, *The Atomization of Liquid in a Flat Spray*, British Journal of Applied Physics, Volume 3, pp 189-192.

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