R10852863

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RPP-WTP PDC

Document title: **Leak Detection Capability in the Low Activity Waste Facility**

Contract number: DE-AC27-01RV14136

Department: Process and Mechanical Systems

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Document number: 24590-LAW-PER-M-05-002, Rev 2

Checked by: Lisa Han

Checker signature:

Date of issue: 11-12-07

Issue status: Issued for Permitting Use

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11/19/07

EXPIRES: 3/16/08

This bound document contains a total of 17 sheets

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24590-PADC-F00041 Rev 5 (6/28/2004)

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History Sheet

Rev	Date	Reason for revision	Revised by
0	6-May-06	Issued for Permitting Use	R. Hanson
1	17-July-07	Modified sump depth from 15 inch to 12 inch.	R. Hanson
2	12-Nov-07	Changed diameter description from 24 inch to 30 inch in section 7.2.1.1	R. Hanson

Contents

Acronyms

AEA	Atomic Energy Act of 1954
BNI	Bechtel National, Incorporated
CCN	Correspondence Control Number
CGS	centimeter gram second units of measurement
DOE	US Department of Energy
DWP	Dangerous Waste Permit
LAW	Low Activity Waste
PIN	Plant Item Number
RLD	Radioactive Liquid Waste Disposal System
STD	Standard
WAC	Washington Administrative Code
WTP	River Protection Project-Waste Treatment Plant

1 Summary

The Low Activity Waste (LAW) Vitrification facility secondary containment (includes C3/C5 cell sump, process cell sumps, effluent cell sumps) must satisfy the leak detection criteria of the Washington Administrative Code (WAC) 173-303-640(4) and the Waste Treatment Plant Dangerous Waste Permit (DWP) number 7890008967, Condition No: III.10.E.9.e.ii and III.10.H.5.e.ii for tank and miscellaneous treatment system secondary containment areas. This report evaluates the minimum leak rates that can be detected within 24 hours in the regulated secondary containment sumps.

The LAW facility contains seven regulated sumps within the process/effluent cells. Leaks of vessels or piping within the cells will flow along the floor and are collected in a sump and detected with level instrumentation. All sumps are dry type, that is, the sumps are dry unless there is a leak that reaches the sump. All sumps except one are the same size, nominally 30 inches O.D. x about 12 inches deep. The exception is the sump (RLD-SUMP-00028) in the minus 21 ft elevation C3/C5 cell which is nominally 24 inches O.D. x 30 inches deep. All sumps are provided with radar type leak detection.

The minimum leak flow rate that can be detected in 24 hours is calculated by estimating the volume of two components of the leak, 1) the minimum detectable quantity of liquid in the sump and 2) the volume associated with the leak "rivulet" formed as the leak flows along the floor to the sump. Water is used as the standard fluid for estimating leak rates. The detectable volume of the leak in the sump is related to size and geometry of the sump and the location and sensitivity of the leak detection instrumentation. The volume associated with the leak rivulet is related to the slope of the floor and the flow rate of the leak.

Minimum 24 hour leak detection rates are evaluated for each regulated sump in the LAW facility. The leak detection rate varies with the travel distance of the leak, the longer the travel distance the greater is the 24 hour leak detection rate. The bounding case for the 30-inch diameter round sumps indicates a maximum leak travel distance of 87 ft for the process cell sumps RLD-SUMP-00029/30/31/32. The calculated minimum 24 hour leak detection rate for these sumps is 0.1 gal/hr. Leak detection rates for the remaining two 30-inch diameter sumps (RLD-SUMP-00035/36) is 0.09 gal/hr.

For the C3/C5 cell sump RLD-SUMP-00028 located in the minus 21 ft elevation, the maximum leak travel distance is 80 ft. The minimum 24 hour leak detection rate for this 24-inch diameter round sump is 0.06 gal/hr.

2 Objective

The objective of this report is to document the minimum flow rate that can be detected within a 24 hour period for potential leaks that are collected in sumps in the LAW facility process /effluent cells. The scope of this report includes:

- leaks from vessels, equipment and/or piping that flow by gravity directly to sumps containing leak detection instrumentation
- leaks that flow by gravity to floor drains that are routed to another cell that contains a sump with leak detection instrumentation. This includes process bulges in LAW.

Leaks collected in drain systems that flow to vessels or tanks are not in scope. Leaks that are detected by routine visual inspection are not in scope. Areas within the LAW that employ open floor drains for containment are routinely accessible and leak detection will be provided by daily visual inspection in all cases, and for that reason are not addressed in this report. Leaks from ancillary equipment/piping that are detected by routine visual inspection are not in scope.

3 Description

The LAW facility process/effluent cell sumps must satisfy the leak detection criteria of the WAC and DWP conditions for secondary containment systems. The regulatory requirements for leak detection are contained in WAC-173-303-640 (4), Tank Systems, Section 4, Containment and Detection of Releases (Ref. 8.2.1) and are restated as follows:

> (b) Secondary Containment systems must be:
>> (ii) Capable of detecting and collecting releases and accumulated liquids until the collected material is removed.
>
> (c) To meet the requirements of (b) of this subsection, secondary containment systems must be at a minimum:
>> (iii) Provided with a leak detection system that is designed and operated so that it will detect the failure of either the primary or secondary containment structure or the presence of any release of dangerous waste or accumulated liquid in the secondary containment system within twenty-four hours, or at the earliest practicable time if the owner or operator can demonstrate to the department that the existing detection technologies or site conditions will not allow detection of a release within twenty-four hours.

In addition, the Waste Treatment Plant Dangerous Waste Permit (Ref. 8.2.2), Conditions: III.10.E.9.e.ii and III.10.H.5.e.i require submittal of:

> Detailed plans and descriptions, demonstrating the leak detection system is operated so that it will detect the failure of either the primary or secondary containment structure or the presence of any release of dangerous and/or mixed waste, or accumulated liquid in the secondary containment system within twenty-four (24) hours. Detection of a leak of at least 0.1 gallons per hour within twenty-four (24) hours is defined as being able to detect a leak within twenty-four (24) hours. Any exceptions to this criteria must be approved by Ecology [WAC 173-303-640(4)(c)(iii), WAC 173-303-806(4)(c)(vii)];

4 Assumptions

4.1 Inputs

1. Sump type, leak detection type, and nominal sump dimensions are derived from "LAW Facility Sump Data" (Ref. 8.1.1).
2. The stainless steel liners in the vessel cells are sloped at a minimum slope of 1:100 to direct potential leakage in these areas to their respective sump.

4.2 Evaluation Assumptions

1. The following group of assumptions was derived from agreements between BNI, DOE, and the Department of Ecology (Ref. 8.1.2).
   a. The liquid leaking is water at a temperature of 100 °F.
   b. The leak is at a constant rate over the twenty-four hour period.
   c. The leak is assumed to occur at the farthest point from the sump.
   d. No evaporation will occur.
   e. The liquid does not foam in the sumps.
   f. Hold-up will be considered. Hold-up is defined as wetting of the surface.
   g. Level detection instruments will be properly installed and calibrated upon installation. Periodic, normal maintenance and calibration will be performed on level instruments during operation of the facility and the instruments will be maintained in an operable condition.
2. The furthest point from the sump is assumed to be bounded by the furthest corner of the cell which contains the sump. The flow path for each cell is conservatively considered to be along the straight walls rather than diagonally across the cell.
3. There are no obstructions in the flow path. Leaks from any equipment or piping fall directly to the floor at the point of leakage and do not travel along pipes or other equipment.
4. The floor is uniformly sloped and the flow path is in straight lines (no meandering flow).
5. Radar leak detection is stated by the radar instrument supplier to be accurate within ±10 mm, i.e., the minimum level of water in the sump must rise to at least 10 mm before it is detected by the radar instrument. It is not necessary for the liquid level to be within the guide tube before the radar will detect it. LAW sumps are flat bottom, therefore for conservatism, it is assumed that the detectable level in the sump is 15 mm from the bottom of the sump.

5 Analysis

The LAW facility contains seven DWP-regulated sumps within the process/effluent cells (Ref. 8.1.1). All sumps are dry type, that is, the sumps are dry unless there is a leak that reaches the sump. All sumps except one are the same size, nominally 30 inches O.D. x about 12 inches deep. The exception is the sump at the minus 21 ft elevation deep which is nominally 24 inches O.D. x about 30 in deep. All sumps are provided with radar type leak detection.

Leaks of vessels or ancillary equipment/piping within the cells will flow along the floor and will be collected in a sump and detected with level instrumentation.

6 Detectable Leak Rates

Minimum 24 hour leak detection rates are evaluated for each sump in the LAW facility. The leak detection rate varies with the travel distance of the leak, the longer the travel distance, the greater is the 24 hour leak detection rate. The bounding case for the 30-inch diameter round sump indicates a maximum leak travel distance of 87 ft for the process cell sumps RLD-SUMP-00029/30/31/32. The minimum 24 hour leak detection rate for this sump is 0.1 gal/hr. Leak detection rates for the remaining two 30-inch diameter sumps (RLD-SUMP-00035/36) is 0.09 gal/hr.

For the C3/C5 cell sump RLD-SUMP-00028 located in the minus 21 ft elevation, the maximum leak travel distance is 80 ft. The minimum 24 hour leak detection rate for this 24 inch diameter round sump is 0.06 gal/hr.

Results of the evaluation for all LAW facility sumps are provided in Table 6.1 below.

Table 6.1 Minimum Leak Detection Rates for LAW Facility Sumps

Sump Number	Room Number	Diameter	Max. Leak Travel Distance	Volume of Leak to Reach Sump	Volume of Leak for Detection in Sump	Total Volume of Leak Detectable in 24 hours	24-Hour Leak Rate Detected (rounded)
		inches	ft	gal	gal	gal	gal/hr
RLD-SUMP-00028	L-B001B	24	80	0.388	1.08	1.47	0.06
RLD-SUMP-00029	L-0123	30	87	0.690	1.72	2.41	0.10
RLD-SUMP-00030	L-0123	30	87	0.690	1.72	2.41	0.10
RLD-SUMP-00031	L-0124	30	87	0.690	1.72	2.41	0.10
RLD-SUMP-00032	L-0124	30	87	0.690	1.72	2.41	0.10
RLD-SUMP-00035	L-0126	30	70	0.515	1.72	2.23	0.09
RLD-SUMP-00036	L-0126	30	70	0.515	1.72	2.23	0.09

7 Bounding Calculations

7.1 Methodology

The minimum leak flow rate that can be detected in 24 hours is calculated by estimating the volumes of two components of the leak:

1. The minimum detectable quantity of liquid in the sump, V_s (in gallons)
2. The volume associated with the leak "rivulet" as the leak flows along the floor to the sump, V_r (in gallons)

The total volume of the leak is then $V_t = V_r + V_s$

The minimum detectable flow rate is then:

$Q = V_t/24$ hours, in units of gal/hr

7.1.1 Minimum Detectable Volume in the Sump

7.1.1.1 Process/Effluent Sumps

The sumps are nominal 30 inches in diameter and about 12 inches in depth. The sumps are formed from 30-inch STD pipe (3/8" thick, I.D. = 29.25 in). The bottom consists of a flat plate head.

The minimum detectable volume in the sump is determined from the formula for a cylinder

$$V_s = (\pi / 4) D^2 h$$

Where V_s = volume based on the liquid level h, cubic inches

h = height of liquid in the sump, inches
D = sump inside diameter, inches

V_s in cubic inches is then converted to gallons with a conversion factor

7.1.1.2 C3/C5 Sump

The sump is a nominal 24 inches in diameter and about 30 inches in depth. The sumps are formed from 24-inch STD pipe (3/8" thick, I.D. = 23.25 in). The bottom consists of a flat plate head.

The minimum detectable volume in the sump is determined from the formula for a cylinder

$$V_s = (\pi / 4) D^2 h$$

Where V_s = volume based on the liquid level h, cubic inches

h = height of liquid in the sump, inches
D = sump inside diameter, inches

V_s in cubic inches is then converted to gallons with a conversion factor

7.1.2 Wetted Volume For Flow of Liquid Across the Floor of the Cell

When a liquid flows down an inclined surface at a low rate, separate rivulets form instead of a continuous film (Ref. 8.3.1). The hydrodynamics of rivulet flow have been empirically measured and mathematically modeled (Ref. 8.3.1). The relationships provided in this reference are used to estimate the wetted volume for flow across the cell floor. In this reference, steady state theoretical solutions are developed for the laminar flow based on the reduced form of the Navier-Stokes equations using special boundary conditions that include contact angle (angle formed by the edge of the rivulet and the surface) and relations between the pressure inside and outside the curved interface. The shape of the interface and the velocity profile in the rivulet are obtained and an integration of this velocity profile gives a relation between the rivulet width and the flow rate. This relation contains the surface inclination (slope), contact angle of the liquid on the surface, and the fluid properties: viscosity, density and interfacial surface tension. In simpler terms, this analysis considers that the flow rate is a balance of gravitational forces which drive the flow and viscous forces which resist the flow.

In Reference 8.3.1, experimental measurements consisting of rivulet width measurements as a function of rivulet flow rate were conducted for a variety of liquids including water. The data were then checked against the models and found to be in good agreement.

Based on the information in Ref. 8.3.1, for the range of flow rates of interest in this calculation, the solution to the flow equations can be simplified by considering the rivulet as a relatively wide and flat rectangular shape. For this shape of rivulet, the maximum flow depth, Y_0 is given by:

$$Y_0 = 2\sin\theta/2 \qquad \text{Equation 1}$$

Where θ = contact angle (angle formed at the edge of the rivulet where it contacts the surface)

The width of the rivulet, l, is determined by Equation 27 in Ref. 8.3.1 as follows:

$$\frac{\mu Q \tan\alpha}{l\gamma}\sqrt{\frac{\rho g \sin\alpha}{\gamma}} = \frac{8}{3}\sin^3\theta/2 \qquad \text{Equation 2}$$

Where:
α = angle of inclination between the surface and vertical (90^0 - slope in degrees)
γ = interfacial surface tension, dynes/cm = g/sec^2
μ = viscosity, g/cm sec
θ = contact angle (measured from the surface), degrees
ρ = density of liquid, g/cm^3
l = rivulet width, cm
Q = flow rate, cm^3/sec
g = acceleration of gravity, cm/sec^2

Note that CGS units are used in this calculation for consistency with the reference. The volume and flow rate results then are converted to English units.

Rearranging and solving for l gives:

$$l = \frac{3\mu Q \tan\alpha}{8\gamma(\sin^3\theta/2)}\sqrt{\frac{\rho g \sin\alpha}{\gamma}} \qquad \text{Equation 3}$$

The contact angle, θ, is unknown, but according to Table 2, Ref. 8.3.1, at a flow rate of 6.3 cm^3/min (~0.1 gal/hr), the contact angle was measured experimentally at 9-12°. At lower flow rates, the measured contact angle varied from 3 to 8 degrees but did not show proportionality to flow rate possibly due to varying shape of the rivulet and/or the slope of the surface. Low contact angles applied in equations 1 and 3 yield results of disproportionately wide and shallow rivulets (l is very large compared to Y_0). In the experiments, rivulet width varied up to a maximum of about 4 cm with most of the widths in the range of 0.4 to 3 cm for the smallest incline tested. Rivulet widths below 3 cm correspond to a contact angle of about 6 degrees. Below 6 degrees, widths increase greatly and at contact angles of 4 degrees and lower, the solution does not converge. Therefore, for purposes of this calculation, for flow rates <0.05 gal/hr, contact angles between 6 degrees and 12 degrees are considered bounding, with the lower of the two angles yielding the highest flow rate. For flow rates of 0.1 gal/hr and higher, a range of 9 degrees to 12 degrees is used; 9 degrees yields the highest flow rate, so it is the most conservative.

The remainder of the calculation procedure is now iterative by performing the following steps:

Step 1 - Assume a contact angle and assume a starting flow rate, Q
Step 2 - Calculate the volume of the rivulet as follows:

Since the rivulet is approximated as rectangular, the cross-sectional area, A, of the rivulet is:

$A = Y_0 l$, where A is in the units of cm^2.

The total volume of the rivulet, in cm^3, is V_r

$V_r = A$ x flow path length (in cm)

V_r is then converted to gallons by dividing by 3785 cm^3/gal.

Step 3 - Calculate a total volume of liquid collected in 24 hours:

Add the rivulet volume, V_r, (in gallons) to the volume of liquid collected in the sump to get V_t, the total volume of liquid leaked in a 24 hour period.

i.e., $V_t = V_s + V_r$

Step 4 - Calculate an adjusted total 24 hour flow rate, i.e.,

$Q_{adj} = V_t/24$

This new adjusted Q takes the total volume of liquid into account whereas the starting Q only considered the volume of the sump. Therefore, Q_{adj}, may differ from the initial guess for Q if the volume of the rivulet is significant relative to the volume of the sump, so an iterative trial and error is performed by setting the new trial Q = Q_{adj} from the first trial. This is continued until the starting Q matches the final Q_{adj} (i.e., the iteration converges).

7.2 Bounding Calculations

7.2.1 Calculation for the Longest Leak Travel Distance for the Round Sumps

The maximum leak travel distances for each sump in the facility is derived from the cell dimensions and sump locations as provided in the facility general arrangement drawings (Ref. 8.1.3, 8.1.4). As indicated in Assumption 2, the maximum leak travel distance is computed by summing the distance along the walls from the furthest corner of the cell, i.e., adding the north-south wall distance to the east-west wall distance. A summary of distance data for each sump is provided in Table 7.1. The sumps also have gravity drain piping from other floor drains or bulges that terminate in the sumps. Table 7.2 summarizes the longest horizontal pipe run to the sump.

Table 7.1 Maximum Leak Distances along floor for Each Sump

Elev.	Room Number	Room Name	Sump PIN RLD-SUMP-000xx	Sump Location in Cell	N-S Distance	E-W Distance	Total Distance, ft (rounded up)
(-) 21'-0"	L-B001B	C3/C5 Drain Collection Cell	28	NE corner	16'-7"	23'-4"	40
3'-0"	L-0123	Melter 1 Process Cell	29	W wall	38'-4"	48'-4"	87
3'-0"	L-0123	Melter 1 Process Cell	30	E wall	38'-4"	48'-4"	87
3'-0"	L-0124	Melter 2 Process Cell	31	W wall	38'-4"	48'-4"	87
3'-0"	L-0124	Melter 2 Process Cell	32	E wall	38'-4"	48'-4"	87
3'-0"	L-0126	Effluent Cell	35	W wall	38'-4"	31'-4"	70
3'-0"	L-0126	Effluent Cell	36	E wall	38'-4"	31'-4"	70

Table 7.2 Maximum Leak Distances for drain piping for Each Sump

Elev.	Room Number	Room Name	Sump PIN RLD-SUMP-000xx	Sump Location in Cell	Starting Location	Horizontal Travel Distance, ft (rounded up)
(-) 21'-0"	L-B001B	C3/C5 Drain Collection Cell	28	NE corner	Outer pipe drain from ASX-SMPLR-00013 return line	80
3'-0"	L-0123	Melter 1 Process Cell	29	W wall	LCP-BULGE-00002	24
3'-0"	L-0123	Melter 1 Process Cell	30	E wall	LFP-BULGE-00001	43
3'-0"	L-0124	Melter 2 Process Cell	31	W wall	LCP-BULGE-00003	18
3'-0"	L-0124	Melter 2 Process Cell	32	E wall	LFP-BULGE-00002	43
3'-0"	L-0126	Effluent Cell	35	W wall	No hard piped drains	NA
3'-0"	L-0126	Effluent Cell	36	E wall	RLD-BULGE-00004	NA (No Horizontal Piping)

Based on the estimate of travel distances for leaks in each cell, the longest leak flow distance to any round sump was determined to be 87 ft (see table 7.1) for sumps RLD-SUMP-00029, 30, 31, 32 in the melter process cells. The calculation for this bounding case is provided below.

7.2.1.1 Minimum Detectable Volume in the Process Cell Sumps

Minimum detectable volume is determined from:

$$V_s = (\pi / 4) D^2 h$$

D = 29.25 in = inside diameter of a 30 inch 3/8' thick pipe.
h = 0.59 inch (15mm = 0.59 inch -Assumption 5)

$$V_s = (\pi / 4)(29.25in)^2 (0.59in)$$

V_s = 397 cu in

Multiply by 0.00433 to convert cu in to gallons

V_s = 1.72 gal

7.2.1.2 Wetted Volume For Flow of Liquid Across the Floor of the Cell

Based on the methodology described in Section 7.1.2, the bounding contact angle, θ, is assumed to be 6°

Using Equation 1 (Section 7.1.2), the depth of the rivulet, Y_0, is calculated

$$Y_0 = 2\sin \theta/2$$

$$Y_0 = 2\sin 6\ \deg/2$$

$$Y_0 = 0.105 cm$$

Next, the width of the rivulet is calculated using Equation 3 (Section 7.1.2)

$$l = \frac{3\mu Q \tan\alpha}{8\gamma(\sin^3\theta/2)}\sqrt{\frac{\rho g \sin\alpha}{\gamma}} \qquad \text{Equation 3}$$

$\alpha = (90° - 0.01(90°)) = 89.1$ degrees
$\gamma = 69.9$ dynes/cm = 69.9 g/sec^2
$\mu = 1$ cP = 0.01 g/cm sec (Note: although viscosity of water at 100F is lower than 1 cP, the 1 cP value is used for conservatism)
$\rho = 1.0$ g/cm^3 (Note: although the density of water at 100F is slightly lower than 1.0 g/cm^3, this value is used for conservatism)
g = 980.7 cm/sec^2

The remainder of the calculation procedure is now iterative by performing the following steps:

Step 1 - Assume a starting flow rate, Q, and calculate the rivulet width, l

As a first guess for Q, use the sump volume $V_s/24$ = 1.72 gal/24 hr = 0.072 gal/hr = 0.0754 cm^3/sec

$$l = \frac{3(0.01\ g/cm\sec)(0.0754\,cm^3/\sec)\tan 89.1\deg}{8(69.9\,g/\sec^2)\left(\sin^3(6\deg/2)\right)}\sqrt{\frac{(1\,g/cm^3)(980.7\,cm/\sec^2)\sin 89.1\deg}{(69.9\ g/\sec^2)}}$$

$l = 6.72$ cm

Step 2 - Calculate the volume of the rivulet as follows:

Since the rivulet is approximated as rectangular, the cross-sectional area, A, of the rivulet is:

$A = Y_0\, l,$

A = 0.105 cm x 6.72 cm = 0.706 cm^2

The total volume of the rivulet, in cm^3, is V_r

$V_r = A$ x flow path length, cm

Path length = 87 ft x 30.48 cm/ft = 2652 cm

V_r = (0.706 cm^2)(2652 cm) = 1872 cm^3

V_r is then converted to gallons by dividing by 3785 cm^3/gal.

V_r = 0.495 gal

Step 3 - Calculate a total volume of liquid collected in 24 hours:

Add the rivulet volume, V_r, (in gallons) to the volume of liquid collected in the sump to get V_t, the total volume of liquid leaked in a 24 hour period.

i.e., $V_t = V_s + V_r$

$$V_t = (1.72\ gal\ + 0.495\, gal) = 2.215\, gal$$

Step 4 - Calculate an adjusted total 24 hour flow rate, i.e.,

$Q_{adj} = V_t/24$

Q_{adj} = (2.215 gal/24 hr) = 0.092 gal/hr

The initial guess for Q was 0.072 gal/hr so an iterative trial and error is performed until the starting Q matches the final Q_{adj} (i.e., the iteration converges).

When the iterations converge, the flow rate is:

Q = 0.1003 gal/hr.

This is rounded to one significant figure:

Q = 0.10 gal/hr

7.3 Minimum Flow Rates for the Remaining Sumps

Calculations for the remaining 6 sumps in the LAW facility are performed using the same methodology described in Section 7.1. The only variable is the leak travel distance to the sump. The results are summarized in Table 6.1.

8 References

8.1 Project Documents

8.1.1 24590-LAW-PER-M-02-001, Rev. 4, "LAW Facility Sump Data," 4/21/05

8.1.2 CCN 097799, Leak Detection Capability Scope Statement, Revision 6, 8/19/04

8.1.3 24590-LAW-P1-P01T-P0001, Rev. 2, LAW Vitrification Building General Arrangement Plan at El. (-) 21'-0"

8.1.4 24590-LAW-P1-P01T-P0002, Rev. 3, LAW Vitrification Building General Arrangement Plan at El. 0'-0"

8.2 Codes and Standards

8.2.1 WAC 173-303, Dangerous Waste Regulations, Washington Administrative Code.

8.2.2 WA 7890008967, *Dangerous Waste Portion of the Hanford Facility Resource Conservation and Recovery Act Permit for the Treatment, Storage, and Disposal of Dangerous Waste*, Chapter 10 and Attachment 51, "Waste Treatment and Immobilization Plant."

8.3 Other Documents

8.3.1 Towell, G.D. and Rothfeld, L.B., "Hydrodynamics of Rivulet Flow," September, 1966, *AIChE Journal,* Vol. 12, No. 5, Pages 972-980