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History Sheet

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1	03/09/05	Completely Revised according to the WTP Style Manual. Revisions bars are not shown.	Y. Nurdogan
2	03/14/05	Re-issued with PE certification.	Y. Nurdogan
3	01/07/08	Revised to incorporate comment from Washington State Department of Ecology.	Y. Nurdogan

Contents

Acronyms

AEA	Atomic Energy Act of 1954
BNI	Bechtel National, Incorporated
CGS	centimeter gram second units of measurement
DOE	US Department of Energy
DWP	Dangerous Waste Permit
HCP	HLW concentrate receipt process system
HDH	HLW canister decontamination handling system
HFP	HLW melter feed process system
HLW	high-level waste
HOP	melter offgas treatment process system
HPH	HLW canister pour handling system
HSH	HLW melter cave support handling system
RLD	radioactive liquid waste disposal system
WAC	Washington Administrative Code
WTP	Hanford Tank Waste Treatment and Immobilization Plant

1 Summary

The High Level Waste (HLW) facility secondary containment sumps must satisfy the leak detection criteria of the Washington Administrative Code (WAC) and the Hanford Tank Waste Treatment and Immobilization Plant (WTP) Dangerous Waste Permit (DWP), Permit Conditions III.10.E.9.e.ii and III.10.J.5.e.ii for secondary containment systems. This report evaluates the minimum leak rates that the cell and cave sumps can detect within 24 hours.

The HLW facility contains 15 secondary containment sumps. Six of them are rectangular and the remaining nine are round sumps. These sumps are evaluated in this report. Leaks from vessels or piping within the cells and caves will flow along the floor and collect in a sump and be 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 round sumps are the same size (30 in. outside diameter by 18 in. depth). All the rectangular sumps are the same size (31.5 in. length by 25.5 in. width by 16 in. depth). All sumps, except the Melter Cave 1 and 2 central sumps (HSH-SUMP-00003 and HSH-SUMP-00007), are provided with radar type leak detection. The Melter Cave 1 and 2 central sumps use conventional pneumatic bubblers and a level transmitter to detect leaks.

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 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 detectable leak rates are evaluated for each sump in the HLW 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 smaller 30-inch diameter sumps (HCP-SUMP-00001) indicates a maximum leak travel distance of 82 ft. The calculated minimum 24-hour leak detection rate for this sump is 0.021 gal/hr. Leak detection rates for the remaining 30-inch diameter sumps range from 0.018 to 0.020 gal/hr.

For the larger rectangular sumps (HSH-SUMP-00003 and HSH-SUMP-00007) located in the melter cave, the maximum leak travel distance is 88 ft. The minimum 24-hour leak detection rate for these sumps is 0.207 gal/hr. Leak detection rate for the remaining rectangular sumps ranges from 0.060 to 0.061 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 collected in the HLW facility secondary containment area sumps. The scope of this report includes:

- Leaks from inaccessible vessels, equipment, and piping containing DWP regulated waste that flows 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.

The scope does not include leaks collected in drain systems that flow to vessels or tanks and leaks detected by routine visual inspection.

3 Description

The HLW facility secondary containment area sumps must satisfy the leak detection criteria of the WAC and the DWP conditions for tank and miscellaneous units' secondary containment systems.

The regulatory requirements for leak detection are contained in WAC-173-303-640 (4), Tank Systems, Containment and Detection of Releases and are stated 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 WTP DWP (WA 7890008967), Conditions III.10.E.9.e.ii and III.10.J.5.e.ii 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 "Sump Data for HLW Facility" (24590-HLW-PER-M-02-001, Table 1).
2. The stainless steel liners in the vessel cells and caves are sloped at a minimum slope of 1:100 (1%) to direct potential leakage in these areas to their respective sump.
3. The selection of rectangular sumps and their design is largely governed by the physical layout and associated constraints. The Melter Cave Central rectangular sumps (HSH-SUMP-00003 and HSH-SUMP-00007) are located at the center of drainage trenches; sumps have same width as trenches to achieve better flow into sump and to minimize dead spots for flow. The physical design of these sumps is largely dictated by minimum volume requirements, containment of equipment, instrument lines and pipes, constructability, common design and configuration of melter rails in the Melter Cave. Radar level detection is not feasible for Melter Cave Central sumps, as the radar guide tube path would require several turns and bends to avoid physical constraints.

4.2 Assumptions

1. The following (a through g) were derived from agreements between BNI, DOE, and the Department of Ecology:
   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 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 will be no hold-up of the leakage on its way to the floor due to obstructions. The floors of the facility are properly sloped so that the leakage will flow into the low-point sumps and cause a level increase in sump. Obstructions in the flow path that may cause deviation from an idealized flow path, but do not cause temporary accumulation of liquid, may be neglected.
4. The floor is uniform (no undulations or low spots) 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 (0.4 inch), i.e., the minimum level of water in the sump must rise to at least 10 mm (0.4 inch) before it is detected by the radar instrument. The radar guide tube is located 1/2 inch from the bottom of the sump. It is not necessary for the liquid level to be within the guide tube before the radar will detect it. Because the bottom of the round sump is dished (it is formed from an

ellipsoidal head), and the radar guide tube is offset from the center of the sump by about 4 inches, the level as measured from the center of the sump must rise slightly higher in the sump to be within the radar's 10 mm (0.4 inch) detection specification. Therefore, for conservatism, it is assumed that the detectable level in the round sump is one inch from the bottom of the sump measured in the center. However, for rectangular sumps, it is assumed that the detectable level in the sump is 10 mm (0.4 inch) from the bottom of the sump.

6. The pneumatic bubbler leak detection instrument in the melter cave rectangular sump uses a 1/2-inch Schedule 40 pipe dip pipe with a straight end (not slanted). The bottom of the dip pipe is located 1/4 inch from the bottom of the sump. The leak detection instrumentation includes a pneumatic level transmitter that can detect a level that is 1 inch above the bottom of the dip tube. Therefore, added to the 1/4-inch dip tube clearance, the liquid must rise to a total depth in the sump of at least 1.25 inches before it can be detected.

5 Analysis

The HLW facility contains 15 secondary containment sumps. All round sumps are the same size (30 in. outside diameter by 18 in. depth). All the rectangular sumps are the same size, 31.5 in. length by 25.5 in. width by 16 in. depth. All sumps except the Melter Cave 1 and 2 central sumps (HSH-SUMP-00003 and HSH-SUMP-00007) are provided with radar type leak detection. The Melter Cave 1 and 2 central sumps use conventional pneumatic bubblers and level transmitter to detect leaks.

Leaks of vessels or 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 HLW facility. The leak detection rate varies with the travel distance of the leak, the sump size and leak detection instrument type. Longer the travel distance, the greater is the 24-hour leak detection rate. The bounding case for the smaller 30-inch diameter sumps (HCP-SUMP-00001) indicates a maximum leak travel distance of 82 ft. The minimum 24-hour leak detection rate for this sump is 0.021 gal/hr. Leak detection rates for the remaining eight 30-inch diameter sumps range from 0.018 to 0.020 gal/hr.

For the larger rectangular sumps (HSH-SUMP-00003 and HSH-SUMP-00007) located in the melter cave, the maximum leak travel distance is 88 ft. The minimum 24-hour leak detection rate for this sump is 0.207 gal/hr (0.21 gal/hr). Leak detection rate for the remaining four rectangular sumps range from 0.060 to 0.061 gal/hr.

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

Table 6.1 Minimum Leak Detection Rates for HLW Facility Sumps

Sump Number	Max. Leak Travel Distance ft*	Volume of Leak to Reach Sump gal	Volume of Leak for Detection in Sump gal	Total Volume of Leak Detectable in 24 hours gal	24-Hour Leak Rate Detected (rounded) gal/hr
HCP-SUMP-00001	82	0.130	0.380	0.510	0.02
RLD-SUMP-00001	74	0.112	0.380	0.492	0.02
HDH-SUMP-00001	61	0.092	0.380	0.472	0.02
HDH-SUMP-00002	58	0.083	0.380	0.463	0.02
HDH-SUMP-00003	33	0.045	0.380	0.425	0.02
HOP-SUMP-00003	77**	0.122	0.380	0.502	0.02
HOP-SUMP-00008	77**	0.122	0.380	0.502	0.02
HFP-SUMP-00002	46	0.094	1.370	1.464	0.06
HFP-SUMP-00005	46	0.094	1.370	1.464	0.06
HSH-SUMP-00008	39	0.078	1.370	1.448	0.06
HSH-SUMP-00009	39	0.078	1.370	1.448	0.06
HSH-SUMP-00003	88	0.610	4.350	4.960	0.21
HSH-SUMP-00007	88	0.610	4.350	4.960	0.21
HPH-SUMP-00001	36	0.049	0.380	0.429	0.02
HPH-SUMP-00005	63	0.095	0.380	0.475	0.02

* Total distance is rounded up the nearest ft.

** Leak distance includes HEME/SBS bermed area distance to the floor drain and the leak travel distance inside SBS drain collection cell (32 + 45 = 77 ft). This distance is still less than the bounding distance 82 ft used for round sumps. Melter Cave 1 and Melter Cave 2 configuration and distances are identical.

7 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: $V_t = V_r + V_s$

The minimum detectable flow rate: $Q = V_t/24$ in gal/hr

7.1.1 Minimum Detectable Volume in the Sump

7.1.1.1 Round Sumps

The round sumps are nominally 30 inches in diameter and about 18 inches in depth. The round sumps are formed from 30-inch Schedule 10S pipe with an inside diameter of 29.376 inches. The bottom consists of a 2:1 ellipsoidal head.

The minimum detectable volume in the sump is determined using the following formula that relates depth in the ellipsoidal head to volume (24590-WTP-GPG-019, p 5).

$$V_s = \pi D h^2 \left[1 - \frac{4h}{3D}\right]$$

Where:

V_s: volume based on the liquid level h, in^3
h: height of liquid in the sump, in.
D: sump inside diameter, in.
V_s: in^3 is then converted to gallons.

7.1.1.2 Rectangular Sump

The rectangular sump size is 31.5 in. long by 25.5 in. wide by 16 in. deep (24590-HLW-PER-M-02-001, Table 1). The minimum detectable volume in the sump is

$$V_s = L \; x \; W \; x \; h$$

Where:

L: length, in
W: width, in.
h: depth of liquid in sump, in.
V_s: in^3 is then converted to gallons.

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 (Towell and Rothfeld 1966, p 972). The hydrodynamics of rivulet flow have been empirically measured and mathematically modeled (Towell and Rothfeld 1966, p 972-980). 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. First the shape of the interface and the velocity profile in the rivulet is obtained. Then, a relationship between the rivulet width and the flow rate is produced by an integration of the velocity profile. This relationship equation 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.

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 (Towell and Rothfeld 1966, p 979).

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 (Towell and Rothfeld 1966, p 972). 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:

- Y_o: Maximum flow depth, cm
- 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 (Towell and Rothfeld 1966, p 975) 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:

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

The contact angle (θ) is unknown, but according to Table 2 (Towell and Rothfeld 1966, p 978), at a flow rate of 6.2 cm^3/min (~ 0.1 gal/hr), the contact angles ranging from 9 to 12 degrees were measured experimentally. 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 needed for detection in 24 hours, 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.

Since the rivulet is approximated as rectangular, the cross-sectional area of the rivulet, A, in cm^2:

$$A = Y_0\, l$$

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

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

V_r is then converted to gallons by dividing by 3,785 cm^3/gal.

Step 3 - Calculate a total volume of liquid leaked in 24 hours.

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

$$V_t = V_s + V_r$$

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

$$Q_{adj} = V_t / 24$$

This new adjusted Q takes the total volume of liquid into account whereas the starting Q only considered the volume of liquid in 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 Calculations

7.2.1 Calculation for the Longest Leak Travel Distance for the 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 (24590-HLW-P1-P01T-

P0001 and 24590-HLW-P1-P01T-P0002). 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.

Table 7.1 Maximum Leak Distances for Each Sump

Elev. (ft)	Room Number	Room Name	Sump Number	Sump Type	Sump Location in Cell	N-S Distance (ft)	E-W Distance (ft)	Total* Distance (ft)
-21	H-B014	Wet Process Cell - South	HCP-SUMP-00001	Round	W wall	64	18	82
-21	H-B014	Wet Process Cell - North	RLD-SUMP-00001	Round	SE corner	3.9	69.2	74
-21	H-B021	SBS Drain Collection Cell No. 1	HOP-SUMP-00003	Round	NW corner	17.1	14.8	32
-21	H-B005	SBS Drain Collection Cell No. 2	HOP-SUMP-00008	Round	NW corner	17.1	14.8	32
-16.5	H-B039B	Canister Rinse Tunnel	HDH-SUMP-00001	Round	S wall	11.3	49.3	61
-16	H-B035	Canister Decon Cave	HDH-SUMP-00003	Round	NE corner	21.5	11	33
-16	H-B039A	Bogie Maintenance Room	HDH-SUMP-00002	Round	SW corner	34	23.3	58
-3	H-0136	Canister Handling Cave	HPH-SUMP-00001	Round	NE corner	17.8	17.3	36
-3	H-0136	Canister Handling Cave	HPH-SUMP-00005	Round	SW corner	45.3	17.3	63
0	H-0310A	Melter 1 Equipment Decon Pit	HSH-SUMP-00008	Rectangular	North	9.2	29.1	39
0	H-0304A	Melter 2 Equipment Decon Pit	HSH-SUMP-00009	Rectangular	North	9.2	29.1	39
0	H-0117	Melter Cave No.1 HEME/SBS Bermed Area	HOP-SUMP-00003	Round	NW corner	31.8	12.8	45**
0	H-0106	Melter Cave No.2 HEME/SBS Bermed Area	HOP-SUMP-00008	Round	NW corner	31.8	12.8	45**
3	H-0117	Melter Cave No.1	HFP-SUMP-00002	Rectangular	N wall	14.8	30.5	46
3	H-0106	Melter Cave No. 2	HFP-SUMP-00005	Rectangular	N wall	14.8	30.5	46
3	H-0117	Melter Cave No. 1	HSH-SUMP-00003	Rectangular	Center	54.1	33	88
3	H-0106	Melter Cave No. 2	HSH-SUMP-00007	Rectangular	Center	54.1	33	88

* Total distance is rounded up the nearest ft.

** Leak distance includes HEME/SBS bermed area distance to the floor drain and the leak travel distance inside SBS drain collection cell (32 + 45 = 77 ft). This distance is still less than the bounding distance 82 ft used for round sumps. Melter Cave 1 and Melter Cave 2 configuration and distances are identical.

7.2.2 Calculation for the Round Sump

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 82 ft for sump HCP-SUMP-00001 in the Wet Process Cell-South. The calculation for this bounding case is provided below.

7.2.2.1 Minimum Detectable Volume in the Sump

Minimum detectable volume is determined using the following equation (24590-WTP-GPG-M-019, p 5):

$$V_s = \pi D h^2 \left[1 - \frac{4h}{3D}\right]$$

Where:

D: 29.376 in (I.D. of a 30-inch Schedule 10S pipe)
h: 1 inch (Assumption 5)

$$V_s = \pi(29.376\, in)(1\, in)^2 \left[1 - \frac{4(1\, in)}{3(29.376\, in)}\right]$$

$V_s = 88.1\ in^3$

Multiply by 0.00433 to convert in^3 to gallons.

$V_s = 0.38$ gal

7.2.2.2 Wetted Volume for Flow of Liquid Across the Floor of the Cell

Based on the methodology described in Section 7.1.2 (CCN 101514), the bounding contact angle (θ) is assumed to be 6°.

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

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

$$Y_0 = 2\sin(6\ \mathrm{deg}/2)$$

$Y_o = 0.105$ cm

Next, the width of the rivulet is calculated using Equation 3 in Section 7.1.2.

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

For water at 100 °F and a floor slope of 1%, the following values can be used in this equation (CCN 101514, Attachment 1):

α: [90°- 0.01(90°)] = 89.1 degrees

γ: 69.9 dynes/cm = 69.9 g/sec^2

μ: 1 cP = 0.01 g/cm sec (viscosity of water at 100 °F is lower than 1 cP, but this value is used to be conservative).

ρ: 1.0 g/cm^3 (density of water at 100 °F is slightly lower than 1.0 g/cm^3, but this value is used to be conservative).

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 = 0.38 gal/24 hr = 0.016 gal/hr = 0.017 cm^3/sec

$$l = \frac{3(0.01\ g/cm\sec)(0.017 cm^3/\sec)\tan 89.1\deg}{8(69.9 g/\sec^2)\left(\sin^3(6\deg/2)\right)}\sqrt{\frac{(1 g/cm^3)(980.7 cm/\sec^2)\sin 89.1\deg}{(69.9\ g/\sec^2)}}$$

l = 1.52 cm

Step 2 - Calculate the volume of the rivulet.

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 1.52 cm = 0.16 cm^2

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

V_r = A x flow path length, cm

Path length = 82 ft x 30.48 cm/ft = 2,499 cm

V_r = (0.16 cm^2) (2,499 cm) = 399.8 cm^3

V_r is then converted to gallons by dividing by 3,785 cm^3/gal.

V_r = 0.10 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.

$$V_t = V_s + V_r$$

$$V_t = (0.38\ gal\ + 0.10\, gal) = 0.48\, gal$$

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

$Q_{adj} = V_t/24$

Q_{adj} = (0.48 gal/24 hr) = 0.02 gal/hr

The initial guess for Q was 0.016 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 = 0.021 gal/hr.

This is rounded to one significant figure:

Q = 0.02 gal/hr

7.2.3 Calculation for the Rectangular Sump

7.2.3.1 Minimum Detectable Volume in the Sump

Minimum detectable volume of the rectangular sump is determined as follows:

V_s = L x W x h

Where:

L: 31.5 in.
W: 25.5 in.
H: 1.25 in. (Assumption 6)

V_s = (31.5 in) (25.5 in) (1.25 in) = 1004 in^3 = 4.35 gal

7.2.3.2 Wetted Volume for Flow of Liquid Across the Floor of the Cell

The same calculation process as performed in Section 7.2.1.2 is used to calculate the wetted volume for flow of liquid across the floor of the cell. All input parameters are the same except:

- The longest flow path length to the sump is 88 ft.
- Contact angle is 9 degrees and starting flow rate for the iterations is 4.35 gal/24 hr = 0.181 gal/hr.

Q is iterated until convergence is achieved. At convergence, the following are determined:

l: 5.46 cm
Y_0: 0.157 cm
A: 0.86 cm^2
V_r: 0.60 gal

V_t: 4.95 gal
Q: 0.206 gal/hr

Q value would be 0.21 gal/hr after rounding to two significant figures.

7.2.4 Minimum Leak Flow Rates for the Remaining Sumps

Calculations for the remaining 13 sumps in the HLW facility are performed using the same methodology described in Section 7. 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

24590-HLW-PER-M-02-001, *HLW Facility Sump Data.*

24590-HLW-P1-P01T-P0001, *HLW Vitrification Building General Arrangement Plan at El. -21 ft - 0 in.*

24590-HLW-P1-P01T-P0002, *HLW Vitrification Building General Arrangement Plan at El. 0 ft - 0 in.*

24590-WTP-GPG-M-019, *Mechanical Systems Design Guide: Vessel Sizing.*

CCN 097799, *Leak Detection Capability Scoping Statement*, Rev. 6.

CCN 101514, *24-Hour Leak Detection.*

8.2 Codes and Standards

WAC 173-303. *Dangerous Waste Regulations*. Washington Administrative Code.

WA 7890008967. Dangerous Waste Permit. *Dangerous Waste Portion of the Resource Conservation and Recovery Act Permit for the Treatment, Storage, and Disposal of Dangerous Waste at the Hanford Waste Treatment and Immobilization Plant.*

8.3 Other Documents

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