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History Sheet

Rev	Reason for revision	Revised by
0	Issued for Permitting Use	K. Cantrell

Contents

Acronyms

AEA	Atomic Energy Act of 1954
BNI	Bechtel National, Incorporated
CCN	Correspondence Control Number
CGS	centimeter gram second units of measurement
DEP	Direct feed low activity waste effluent management facility process system
DOE	US Department of Energy
DWP	Dangerous Waste Permit
EMF	Effluent Management Facility
STD	Standard
WAC	Washington Administrative Code
WTP	River Protection Project-Waste Treatment Plant

1 Summary

The Effluent Management Facility (EMF) secondary containment system must satisfy the leak detection criteria of the Washington Administrative Code (WAC) 173-303-640(4) (Ref. 7.3) and the Waste Treatment Plant (WTP) Dangerous Waste Permit (DWP) 7890008967, Permit Condition III.10.E.9.e.ii for tank and miscellaneous treatment system secondary containment areas, Reference 7.4. This report evaluates the minimum leak rates that can be detected within 24 hours in the regulated secondary containment sumps.

The EMF facility contains nine DWP sumps. Leaks of vessels or piping within the vessels cells or rooms will flow along the floor (or in containment piping), and be collected in a sump provided with leak detection instrumentation. All sumps are considered dry type for the purpose of calculating the leak detection capability.

Since the DWP has established a minimum leak rate of 0.1 gallons per hour (gph), this report determines the time to detect the minimum leak of 0.1 gph in the sumps based on the time to fill the sump plus the time for the 0.1 gph leak to flow to the sump. The time to fill the sump is calculated by first determining the minimum detectable volume in each sump and then the time required to reach this detectable column at a leak rate of 0.1 gph. If the "time to detect" is less than 24 hours for a flow rate of 0.1 gph for all sumps, the permit condition is met.

This Permit Document will document that the time to fill the sump to the detectable level is the critical factor for establishing a leak detection rate vs. the time for the leak (rivulet) to cross the floor or for the leak to wet and travel through the pipe. This approach has been previously presented to the Department of Ecology.

2 Objective

The objective of this report is to document the capability to detect a 0.1 gph leak of dangerous waste within 24 hours in the EMF facility secondary containment area sumps. The leakages include:

- Leakage through double-wall (co-axial) piping
- Leakage on the floor

3 Description

The EMF facility regulated 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 (Reference 7.3) 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 (Reference. 7.4), Condition: III.10.E.9.e.ii requires 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 Inputs/Assumptions

4.1 The sump locations in the rooms and the maximum total floor distances are summarized in the following Table 4.1. The distances are measured conservatively from the General Arrangement drawings (Reference 7.5 & 7.6) and have been rounded up. The maximum leak travel distance is conservatively computed by summing the distance along the walls from the furthest high point of the floor. Based on the estimate of travel distances for leaks in each cell, the longest leak flow distance on the floors to any sump is 73’, see Table 4.1, for sumps SUMP-00003A/B.

Table 4.1: Sump Locations and Max Floor Distances

Room Number	Sump Name	DEP-Sump-000xx	Sump Location in Cell	Elev.	N-S Distance (rounded up)	E-W Distance (rounded up)	Max Total Distance, ft
ED-B001	Low Point Drain Vessel Area Sump	01	S Wall	-39'-0”	28’-0”	33’-0”	61
E-0103	West Process Area Sump	02A	N Wall	0’-0”	30’-0”	31’-0”	61
E-0103	West Process Area Sump	02B	S Wall	0’-0”	30’-0”	31’-0”	61
E-0102	East Process Area Sump	03A	N Wall	0’-0”	30’-0”	43’-0”	73
E-0102	East Process Area Sump	03B	S Wall	0’-0”	30’-0”	43’-0”	73
E-0105	Feed Vessel Area Sump	04A	N-W corner	0’-0”	44’-0”	20’-0”	64
E-0105	Feed Vessel Area Sump	04B	N-E corner	0’-0”	44’-0”	20’-0”	64
E-0106	Process Condensate Vessel Area Sump	05A	N Wall	0’-0”	25’-0”	43’-0”	68
E-0106	Process Condensate Vessel Area Sump	05B	S Wall	0’-0”	20’-0”	43’-0”	63

4.2 The sumps are 24 inch diameter cylindrical with a flat bottom (Reference 7.1, Section 8.3).

4.3 Secondary containment area floors with stainless steel liners or special protective coating are sloped at a minimum of 1% (1:100) to direct potential leakage to the sumps or sumps in each room (Reference 7.5, Note 2).

4.4 Waste are assumed to the physical properties of water at 100°F (Reference 7.8, p. 30.37), see Assumption 4.6.a. These properties are summarized Table 4.2 below:

Table 4.2: Physical Properties of Water

Constant	English Units	CGS Units
ρ, density	61.99 lbm/ft^3	0.993 gm/cm^3
μ, dynamic viscosity	1.648 lbm/ft hr	0.00681 gm/cm sec
γ, surface tension	0.0048 lbf/ft	69.96 dyn/cm or 69.96 gm/sec^2

4.5 The minimum detectable level within the EMF Secondary Containment System is assumed to be 0.5” above the bottom of each sump based on preliminary vendor information provided by C&I and a project specification for level measurement (Reference 7.11, Section 3.2.1).

4.6 The following items (a through f) were derived from agreements between BNI, DOE, and Department of Ecology (Reference 7.7):

a. The liquid leaking is water at a temperature of 100°F.
b. The leak is at a constant rate over the 24-hour period.
c. No evaporation will occur.
d. The liquid does not foam in the sumps.
e. Hold-up is defined as wetting of the surface.
f. 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.

4.7 Double-wall (co-axial) pipes run from room E-0103 to ED-0102 through a tunnel, which are the subject of pipe leakage in this report. The double-wall (co-axial) piping has a minimum slope of 1/100 (1%).

4.8 The wetting factor from experimental data was found to be 0.32 fl. oz/ft (Reference 7.9) for an NPS 6 pipe. The wetting factor will be increased by 50% to 0.48 fl. oz/ft to provide additional margin to the calculated holdup time.

4.9 The rivulet flow in this calculation will be based on the simplified model for a wide flat rivulet. Figure 5 of Ref. 7.10 shows dashed lines which are asymptotic solutions for wide-flat rivulets at high Ω values and for narrow rivulets at low Ω values. For a contact angle of 5°, Figure 5 shows that the wide flat rivulet model, represented by equations 26 and 27 of Ref. 7.10, is applicable when Ω is larger than 0.001 and P is larger than 5. This assumption will be verified by the evaluation of Ω and P using data from this calculation.

4.10 Reference 7.10, Table 2 shows for a rivulet flow rate of 6.2 ml/min (~0.1 gph), the corresponding contact angle, θ, is experimentally measured as 9 to 12 degrees. A conservative rivulet contact angle of 6 degrees is assumed for this calculation. The smaller contact angle results in a longer time to sump for a given flow path length from the following logic: a smaller contact angle yields a larger rivulet width, which yields a larger rivulet cross sectional area, which leads to a lower velocity (since the flow rate is fixed). This assumption is conservative.

4.11 The floor is uniformly sloped and the flow path is in straight lines (no meandering flow).

4.12 Double-wall (co-axial) pipes run from room E-0103 to ED-0102 through a tunnel. This horizontal distance is conservatively measured at 30 ft (Reference 7.5). Any potential leakage will travel in the outer pipe to the end and is routed verticality down through tubing to the Low Point Drain Vessel Area Sump (DEP-SUMP-00001). This vertical drop is conservatively measured and rounded up to 50 ft (Reference. 7.6).

4.13 The average velocity equation assigned to the leakage being conveyed within the sloped pipe is developed from boundary layer theory for flow down an inclined plane. This is simplifying assumption but is reasonable to make because the average velocity is applied to the entire length of the pipe route (e.g., from the double-wall pipe to the sump), even when it contains large vertical drops (where the velocity would increase, thereby reducing the travel time to leak detection equipment). This is a reasonable and simplifying assumption.

4.14 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 the outside of pipes or other equipment and the rivulet does not split into multiple streams as it travels across the floor. While actual leaks may not conform to this scenario, it is beyond the objectives of this calculation to assess every possible leak scenario. The intent is to provide a calculated leak detection volume that is not overly complex but still maintains sufficient accuracy to demonstrate leak detection capability within a reasonable level of uncertainty.

4.15 The double-wall pipelines have pipe classes of W11A and W31A with sizes range from 1 ½” to 10” (Ref. 7.12 – 7.14, 7.2.1). The specifications for the encasement pipe of double-wall (co-axial) pipe class W31A and W11A are summarized in Table 4.3 below. The inside diameters (I.D.) are from Ref. 7.15, p. B-13 through B-16.

Table 4.3: Double-Wall (co-axial) Pipe Specification

Pipe Class	Carrier Size (inch)	Encasement Size (inch)	Material	Sch.	I.D. (inch)
W31A	2	4	CS A106 Gr. B	STD	4.026
W31A	3	6	CS A106 Gr. B	STD	6.065
W31A	10	12	CS A106 Gr. B	STD	12.000
W11A	1 1/2	4	316L SS	40S	4.026
W11A	3	6	316L SS	40S	6.065
W11A	4	6	316L SS	40S	6.065

4.16 The level instrument response time (i.e., the time between the process reaching a specified level set point and the instrument responding to the process condition) is considered negligible with regards to the leak detection time requirement. The level instrumentation is anticipated to have response times on the order of seconds therefore the response time is insignificant based on the 24 hr detection limit.

4.17 All sumps within the EMF Facility are conservatively assumed to be dry. This maximizes the time required to fill the sumps to a detectable level.

5 Analysis

In order to establish if the EMF leak detection system is capable of detecting a permit condition leakage rate of 0.1 gph within a 24-hour time period, the time to sump (t_1), the time to fill (t_2), and the time to wet (t_3) (if applicable) are determined. Because postulated leaks for the low point drain vessel sump convey along a short segment of double-wall (co-axial) pipes as well as the liner floor, two methods are used to determine the elapsed time to detect a leak in the low point drain sump. Leakage flowing inside double-wall (co-axial) pipes makes use of boundary layer theory (Section 6.1) and leakage flowing along the liner floor makes use of rivulet flow (Section 6.2).

6 Detectable Leak Rates

6.1 Leakage through pipes

The elapsed time to detect a leak that is flowing through a pipe is composed of three time components: (i.) liquid holdup time or elapsed time for leak to wet surface, t_3, (Section 6.1.1), (ii.) elapsed time for the leak to arrive at the detection equipment, t_1, (Section 6.1.2), and (iii.) the time to fill the leak detection equipment to a level that can be detected by the associated leak detection instrumentation, t_2, (Section

6.1.3). Therefore, the total time for leakage detection through pipes is $t_{total} = t_1 + t_2 + t_3$. If the total time is less than 24 hours for a flow rate of 0.1 gph for all leak detection equipment, the permit condition is met.

6.1.1 Holdup Time within Double-Wall (Co-Axial) Pipe, t_3

The elapsed time for the leak to wet the flow path (flow channel) from the most-remote location to its corresponding leak detection feature (i.e., a sump) is estimated based on an experimentally determined value of wetting holdup (Ref. 7.9) and results in the following equation for determining the time to account for the holdup of water flowing through a pipe :

$$t_3 = \frac{cL}{Q} \qquad \text{Equation 6.1}$$

Where:
t_3 = holdup time, hr
c = wetting factor, gal/ft or fluid ounces/ft (abbreviated as: fl. oz/ft) with use of conversion factor: 128 fl. oz/gal
L = travel distance, ft
Q = leakage volumetric flow rate, ga1/hr

The maximum distance from any postulated leak to the Low Point Drain Vessel Sump is obtained from Assumption 4.12. The linear length from the beginning of the double-wall pipes to the sump is used, this length conservatively includes any straight-vertical drops (Assumption 4.12), which is:

L = 30 ft + 50 ft = 80 ft

The wetting factor is equal to 0.32 fl. oz/ft for 6 inch pipes, however, a factor of 0.48 fl. oz/ft is used (Assumption 4.8) to add margin to the calculated holdup time. Hence, the time required to wet the flow channel using Equation 6.1 is:

L = 80 ft
Q = 0.1 gph

$$t_3 = \left(\frac{0.48\,fl.oz}{ft}\right)\left(\frac{gal}{128\,fl.oz.}\right)\left(\frac{80\,ft}{1}\right)\left(\frac{hr}{0.1gal}\right) = 3.0hr$$

6.1.2 Leak Travel Time to the Sump via Double-Wall (Co-Axial) Pipe, t_1

The time delay for the leak to reach or activate the detection equipment is calculated using equations derived from boundary layer theory for uniform flow down an inclined plane (Assumption 4.13). The average velocity distribution from boundary layer theory (Ref. 7.16, p. 249 thru 251, Equation 9.4b) is:

$$v = \frac{g \quad S_p \quad d_p^2}{3 \quad n} \qquad \text{Equation 6.2}$$

where:
v = average leak velocity, ft/s
g = gravitation constant, 32.17 ft/s^2
S_p = Slope of the pipe, dimensionless
d_p = flow depth, ft
n = kinematic viscosity, ft^2/s

The general equation for volumetric flow rate is given by:

$$Q = Av \qquad \text{Equation 6.3}$$

where:
Q = volumetric flow rate, ft^3/s
A = cross-sectional flow area, ft^2

Therefore, combining Equation 6.2 and Equation 6.3, the flow depth, d_p, can be found by solving the following relationship:

$$d_p = \sqrt{\frac{3 \;\; n \;\; Q}{g \;\; S_p \;\; A}} \qquad \text{Equation 6.4}$$

The geometry based cross-sectional area for gravity flow in a circular pipe is found from (Ref. 7.17, p. 5)

$$A = \frac{(\theta_{fs} - \sin\theta_{fs})D_p^2}{8} \qquad \text{Equation 6.5}$$

where:
D_p = pipe diameter, ft
θ_{fs}= free surface angle (see Figure 1), radians

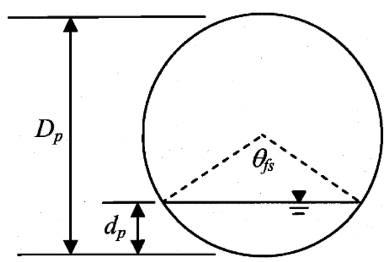

Figure 1. Partially Full Pipe Sketch

The depth of flow can be found by the following equation (Attachment A of Ref. 7.18)

$$d_p = D_p \;\; \sin^2\left(\frac{\theta_{fs}}{4}\right) \qquad \text{Equation 6.6}$$

There are four unknowns (θ_{fs}, A, v, and d_p) to the set of four equations represented by Equation 6.3 through Equation 6.6. Though it is difficult to split theta in these equations in order to use a solve-and-substitute method, iterations are used instead.

The time required for the leakage flow to travel from its point of origin to the sump is calculated from the Equations 6.3 through 6.6. The following constants are used:

D_p = ranges from 4.026 inch (0.3355 ft) to 12.000 inch (1.0 ft) (Table 4.3). The larger diameter of 1.0 ft is used in this calculation, since it yields a lower velocity, which is more conservative.
Q = 0.1 gph = 3.714 E-6 ft^3/s
g = 32.17 ft/s^2
S_p = Slope of the pipe = 1/100 = 0.01 (Assumption 4.7)

μ = 1.648 lbm/ft.hr (Table 4.2)
ρ = 61.99 lbm/ft^3 (Table 4.2)

Since kinematic viscosity (n) is equal to dynamic viscosity (μ) / density (ρ), kinematic viscosity is calculated as:

n = (1.648 lbm/ft.hr) / (61.99 lbm/ft^3) x (1 hr / 3600 sec) = 7.39E-6 ft^2/sec

A Mathcad equation solve block is used to determine the unknowns. The results are:

d_p = 1.674E-3 ft
A = 9.13E-5 ft^2
θ_{fs} = 0.164 Radians
v = 0.041 ft/s

The time delay for the leak to reach the sump is simply:

$$t_1 = L / v \times \left(hr / 3600 \sec \right) \qquad \text{Equation 6.7}$$

where:
t_1 = time to reach detection equipment, hr
v = average velocity of leak, ft/sec
L = travel distance, ft

Equation 6.7 applies to rivulet flow as well.

Substituting the values in Equation 6.7, we have:

t_1 = (L/v) x (hr/3600s) = (80 ft / 0.041 ft/s) / 3600s = 0.6 hr

6.1.3 Time to Obtain a Detectable Sump Volume, t_2

The sumps are all round with flat bottoms (Assumption 4.2) and the detectable volume is calculated with:

$$\forall = \frac{\pi}{4} D_s^2 \times h \times \frac{gal}{231 \ in^3} \qquad \text{Equation 6.8}$$

where:
D_s = sump diameter, in
h = detectable liquid height, in
$\forall$ = volume to detection, gal

Based on Assumption 4.2, the sumps have a 24" diameter. The sump detectable volume is determined from Equation 6.8 with the following values:

h = 0.5 in (Assumption 4.5)
D_s = 24 in (Assumption 4.2)

$\forall = \pi/4$ x (24 in)^2 x 0.5 in / 231 gal/in^3 = 0.98 gal

The time to fill the leak detection equipment, t_2, is calculated from the following equation:

$t_2 = \forall / Q$ Equation 6.9

where:
t_2 = time to fill the leak detection equipment, hr
$\forall$ = volume to detection, gallons
Q = leak rate, 0.1 gph

Substituting $\forall = 0.98$ gal and Q = 0.1 gph in Equation 6.9 we have:

t_2 = 0.98 gal/ 0.1 gal/hr= 9.8 hr

6.1.4 Total Detection Time, t_{total}

The total detection time is the sum of the previously enumerated pipe wetting, transport, and sump filling delays, which can be expressed in equation form as:

$t_{total} = t_1 + t_2 + t_3$

t_{total} = 0.6 hr + 9.8 hr + 3.0 hr = 13.4 hr

The resultant value is less than 24 hours for a minimum leak rate of 0.1 gph, thus satisfying the permit requirement for leakage detection.

6.2 Leakage Along Floor-Rivulet Flow

The time to detect a leak traveling across a floor liner is composed of two time components: t_1 and t_2. The first time component, t_1, is the time for the leak to reach the leak detection equipment (Equation 6.7). The secondary time component, t_2, is the time to fill the leak detection equipment based on the minimum leak rate.

For each leak detection equipment, " t_2 " is calculated by dividing the minimum detectable volume by the volumetric flow rate of the leak. The time component " t_1 " is calculated using the methodology from Reference 7.10 (rivulet flow). The elapsed time to detect a leak, t_{total} is the sum of these two time components: $t_{total} = t_1 + t_2$. If the total time is less than 24 hours for a flow rate of 0.1 gph for all leak detection equipment, the permit condition is met.

Calculation of " t_1" for each leak detection equipment is not necessary; using the longest path length bounds the "time to detection." As indicated in Assumption 4.1, the rivulet leak travel distance is computed by summing the distance along the walls: adding the north-south wall distance to the east-west wall distance.

6.2.1 Leakage Travel Time to Room Sumps, t_1

There is no need to calculate the flow rate of the leak across the floor since the permit has established a minimum leak rate of 0.1 gph. The approach illustrated here has been presented to and concurred by the Department of Ecology.

The "time to detection" is determined using the average leak velocity at the minimum leak rate of 0.1 gph. The methodology shown in Reference 7.10 for rivulet flow forms the basis for the rivulet leak velocity calculation. The method requires the calculation of the angle of inclination for the rivulet, the capillary constant, and the rivulet cross sectional area. In order to be consistent with the units in Ref. 7.10, most units within this section are presented in grams (gm) and centimeters (cm).

The angle of inclination, α, which is the slope of the floor with respect to a vertical plane, as shown in Figure 2, is determined using trigonometry as shown with the following equation:

$$\alpha = 90^{\circ} - \tan^{-1}(S_o) \qquad \text{Equation 6.10}$$

where:
α = angle of inclination, degrees
S_o = slope of floor, dimensionless

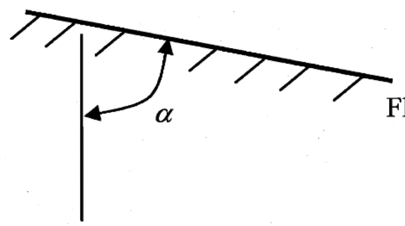

Figure 2. Inclination Angle for Rivulet Flow

From Assumption 4.3, S_o = 1/100 = 0.01. Substituting the values in the above Equation 6.10, we have:

α = 90° - tan^{-1}(0.01) = 90° - 0.5729° = 89.427°

The capillary constant, the basis for the dimensionless width, is defined below (Ref. 7.10, p. 973, equation following equation 9):

$$a = \sqrt{\gamma / \rho g \sin\alpha} \qquad \text{Equation 6.11}$$

where:
a = capillary constant, cm
γ = liquid surface tension, dyne/cm (= gm/sec^2)
ρ = liquid density, gm/cm^3
g = gravitational acceleration = 980.7 cm/sec^2

The liquid properties are based on water at 100 °F (Assumption 4.4 & 4.6), which are listed in Table 4.2 and are as follows:

γ = 69.96 g/sec^2 (Assumption 4.4)
ρ = 0.993 g/cm^3 (Assumption 4.4)
α = 89.427°

Substituting these in Equation 6.11 above, we have:

$$a = \sqrt{\frac{69.96 \;\; g/\sec^2}{0.993 \;\; g/cm^3 \times 980.7 \;\; cm/s^2 \times \sin(89.427°)}}$$

a = 0.268 cm

For the wide flat rivulet, its depth is determined based on (Ref. 7.10, 2nd equation following equation 25):

$$Y_0 = 2\sin\left(\theta/2\right)$$ Equation 6.12

where:
Y_0 = dimensionless depth and is defined in Reference 7.10, definitions following equation 17 (2nd line following equation 17), as:

$$Y_0 = \eta_0/a$$

where:
η_0 = rivulet depth, cm
θ = contact angle, degrees

Solving for η_0 yields:

$$\eta_0 = 2a\sin(\theta/2)$$ Equation 6.13

From Assumption 4.10 we have θ = 6°. Substituting this in Equation 6.13 results in:

η_0 = 2 x 0.268 cm x sin (6°/2)
η_0 = 0.02805 cm

The rivulet width, l, is determined from Ref. 7.10, equation 27:

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

Rearrange above equation to solve for l:

$$l = \frac{3\mu Q\tan\alpha}{8\gamma\sin^3(\theta/2)}\sqrt{\frac{\rho g\sin\alpha}{\gamma}}$$ Equation 6.14

where:
l = rivulet width, cm
μ = dynamic liquid viscosity, gm/cm.sec
Q = volume flow, cm^3/sec

We can now calculate the width of the rivulet using Equation 6.14 below:

α = 89.427°
γ = 69.96 gm/sec^2 (Assumption 4.4)
μ = 0.00681 gm/cm.sec (Assumption 4.4)
ρ = 0.993 gm/cm^3 (Assumption 4.4)
g = 980.7 cm/sec^2
θ = 6° (Assumption 4.10)
Q = 0.1 gph = 0.1052 cm^3/sec

$$l = \frac{3 \times 0.00681 gm/cm.\sec \times 0.1052 cm^3/\sec \times \tan(89.427°)}{8 \times 69.96 gm/\sec^2 \times \sin^3(6°/2)} \sqrt{\frac{0.993 gm/cm^3 \times 980.7 cm/\sec^2 \times \sin(89.427°)}{69.96 gm/\sec^2}}$$

l = 9.99 cm

The rivulet cross-sectional area is determined using the approximation that the wide flat rivulet has a rectangular cross-section (rectangular cross-section for the wide flat rivulet is noted in Ref. 7.10, p. 975), thus the area is defined as:

$$A = l \cdot \eta_0 \qquad \text{Equation 6.15}$$

where:
A = rivulet area, cm^2

Substituting values in Equation 6.15 we have:

A = 9.99 cm x 0.02805 cm = 0.2802 cm^2

With the volumetric flow rate known, the rivulet velocity, v, can be calculated from rearranging Equation 6.3

$$v = Q/A \qquad \text{Equation 6.16}$$

Substituting values in Equation 6.16 we have:

v = 0.1052 cm^3/s / 0.2802 cm^2= 0.3754 cm/sec

The method used in this calculation is from Reference 7.10 and is based on a dimensionless flow rate, Ω, and dimensionless stream width, P, along with other parameters. The following equations for the dimensionless parameters, P and Ω, are used to calculate these values from Ref. 7.10, p. 974, equation following equation 17 and the 3rd equation following equation 17, respectively.

$$P = l/a \qquad \text{Equation 6.17}$$

where:
P = dimensionless width
l = rivulet width, cm
a = capillary constant, cm

The dimensionless rivulet width (P) is calculated using Equation 6.17 as follows:

P = 9.99 cm / 0.268 cm = 37.3

The Equation for Ω is defined in Ref. 7.10 as:

$$\Omega = \frac{\mu \rho g Q}{\gamma^2} \cdot \tan\alpha \cdot \sin\alpha \qquad \text{Equation 6.18}$$

where:
Ω = dimensionless flow rate

Q = volumetric flow rate, cm^3/sec
γ = liquid surface tension, dyne/cm (= gm/sec^2)
ρ = liquid density, gm/cm^3
g = gravitational acceleration = 980.7 cm/sec^2
α = angle of inclination (slope), degrees

The dimensionless flow rate (Ω) is calculated using Equation 6.18:

α = 89.427°
γ = 69.96 gm/sec^2 (Assumption 4.4)
μ = 0.00681 gm/cm.sec (Assumption 4.4)
ρ = 0.993 gm/cm^3 (Assumption 4.4)
g = 980.7 cm/sec^2
Q = 0.1 gph = 0.1052 cm^3/sec

$$\Omega = \frac{0.00681\ gm/cm.\sec \times 0.993\ gm/cm^3 \times 980.7\ cm/\sec^2 \times 0.1052\ cm^3/\sec}{69.96^2\ gm/\sec^2} \cdot \tan(89.427°) \cdot \sin(89.427°)$$

Ω = 0.014

From Reference 7.10 (p. 977, Figure 5), the point at the coordinates of Ω = 0.014 and P = 37.3 falls right on the asymptotic solutions for a wide rivulet close to θ = 5 degrees. This confirms the assumption for a wide rivulet flow (Assumption 4.9).

The time to flow to sump, t_1, is calculated for the sump with the longest rivulet travel distance, which is 73' (Assumption 4.1). Equation 6.7 is used to calculate the time to flow to sump, t_1:

$$t_1 = L/v \times (hr/3600\sec)$$

L = 73' = 2225 cm
v = 0.1052 cm^3/s / 0.2802 cm^2 = 0.3754 cm/sec

t_1 = (2225 cm / 0.3754 cm/s) x (1/3600)
t_1 = 1.65 hr

6.2.2 Time to Obtain a Detectable Sump Volume, t_2

The time to obtain a detectable vessel sump volume is calculated in Section 6.1.3 and is:

t_2 = 9.8 hr

6.2.3 Total Detection Time, t_{total}

The total detection time is the sum of the previously enumerated elapsed times t_1 and t_2:

$t_{total} = t_1 + t_2$ = 1.65 hr + 9.8 hr = 11.45 hr

6.3 Results

Table 6.1 below summarizes the result for the EMF's capability to detect a leakage. This analysis demonstrates that the EMF sumps are capable of detecting a permit condition leakage rate of 0.1 gal/hr within a 24-hour period, thus the permit condition for EMF is satisfied.

Table 6.1: EMF Time to Leak Detection Capability

Type of Leak	Time to Sump t_1 (hr)	Time to Fill t_2 (hr)	Time to Wet t_3 (hr)	Total Time to Detect t_{total} (hr)
Leakage thru double-wall (co-axial) piping	0.6	9.8	3.0	13.4
Leakage on the floor	1.65	9.8	*	11.45

*For leakage on the floor, Time to Wet (t_3) is included in the Time to Sump (t_1)

Table 6.1 above shows that using the bounding distance of 73 ft (maximum total floor distance to sump DEP-SUMP-00003A/B from Table 4.1) resulted in a bounding total detection time of 11.45 hours. Therefore, the total detection time for all other DWP sumps, which have a distance less than 73 ft, are less than 11.45 hours.

7 References

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7.2 P&IDs:

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7.2.2 24590-BOF-M6-DEP-00009001, Rev. 0, Process Area Sumps, DEP-SUMP-00002A/B

7.2.3 24590-BOF-M6-DEP-00009004, Rev. 0, Process Area Sumps, DEP-SUMP-00003A/B

7.2.4 24590-BOF-M6-DEP-00009002, Rev. 0, Process Vessel Area Sumps, DEP-SUMP-00004A/B

7.2.5 24590-BOF-M6-DEP-00009005, Rev. 0, Process Vessel Area Sumps, DEP-SUMP-00005A/B

7.3 WAC 173-303-640. Tank Systems, Section 4, Containment and Detection of Releases in Dangerous Waste Regulations, Washington State Administrative Code.

7.4 WA 7890008967. Dangerous Waste Permit (DWP). 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, Rev. 05/10, p 49.

7.5 Drawing 24590-BOF-P1-25 -00001, Rev. 0, Balance of Facilities LAW Effluent Process BLDG & LAW Effluent Drain Tank BLDG General Arrangement Plan at Elev. 0'-0"

7.6 Drawing 24590-BOF-P1-25-00002, Rev. 0, Balance of Facilities LAW Effluent Process BLDG & LAW Effluent Drain Tank BLDG General Arrangement Sections A, B, & C

7.7 CCN 097799, Leak Detection Capability Scoping Statement, Revision 6, 08/19/2004

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7.13 24590-BOF-M6-DEP-00002006, Rev. 0, P&ID - BOF/EMF Direct Feel LAW EMF – Process System Evaporator Concentrate / Feed Vessels - LAW Effluent Cooler DEP-HX-00001

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7.15 Crane Co. 2011. Flow of Fluids through Valves, Fittings, and Pipe, Technical Paper No. 410, Stamford, CT

7.16 Roberson, John A. and Clayton T. Crowe, Engineering Fluid Mechanics, Houghton Mifflin Co., Boston, MA, 1975

7.17 24590-WTP-GPG-M-033, Rev. 4, Fire Water Drain System

7.18 24590-WTP-M6C-M11 T-00004, Rev. 1, Supporting Calculation for Fire Water Floor Drain System Design Guide