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Author(s): P. Martinelli

Principal author signature: Pietro Martinelli

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Approved by: C. M. Keller

Approver's position: LAB Mechanical Systems Supervisor

Approver signature: Craig Keller

CRAIG MARTIN KELLER
STATE OF WASHINGTON
0032343
REGISTERED
PROFESSIONAL ENGINEER
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EXPIRES: 11-11-06

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River Protection Project
Waste Treatment Plant
2435 Stevens Center Place
Richland, WA 99354
United States of America
Tel: 509 371 2000

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History Sheet

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Contents

Acronyms

AEA	Atomic Energy Act of 1954
C3	Originally an identification of radiological contamination level potential (in the context of this report it identifies or describes subsystems or components associated with the RLD-VSL-00164 tank system)
C5	Originally an identification of radiological contamination level potential (in the context of this report it identifies or describes subsystems or components associated with the RLD-VSL-00165 tank system)
CCN	Correspondence Control Number
DOE	US Department of Energy
LAB	Analytical Laboratory Facility
LDB	Leak Detection Box
NPS	Nominal Pipe Size
PDC	WTP Project Archives & Document Control
PIN	Plant Item Number
WAC	Washington Administrative Code
WTP	River Protection Project - Waste Treatment Plant

1 Summary

The Analytical Laboratory (LAB) ancillary equipment piping and associated leak detection boxes (LDBs), effluent vessel cell sumps (cell sumps), and the pump and piping pit sumps (pit sumps) must satisfy the leak detection criteria of Dangerous Waste Permit Number WA7890008967, Permit Condition III.10.E.9.e.ii for secondary containment systems. This report evaluates the minimum leak rates that the LDBs, cell sumps, and pit sumps can detect within 24 hours. The LDBs and their associated instrumentation monitor regulated double-wall piping for signs of primary containment leakage. This piping has a minimum slope requirement of 1:192 (>0.5%) to ensure that leakage is properly directed towards the LDBs. Similarly, the cell sumps and pit sumps and their associated instrumentation monitors the effluent vessel cells, and pump and piping pits for indications of primary containment leakage. The floors in these areas have a minimum slope requirement of 1:100 to ensure that leakage is properly directed towards the sumps.

The minimum leak rates that can be detected within a 24-hour period are 0.05 gal/h for the LDBs (worst-case), 0.02 gal/h for the cell sumps, and 0.07 gal/h for the pit sumps. These values demonstrate compliance with the criterion established in Permit Condition III.10.E.9.e.ii for a leak detection capability of 0.1 gallons per hour within 24 hours. The minimum detectible leak rates are all based on the assumption that a leak occurs at the most remote location from the leak detection receptacle and its associated leak detection instrumentation.

The leak detection calculations identified three components that influence leak detection within 24 hours. These components are: 1) the volume associated with wetting of pipe and floor surfaces, 2) the volume associated with boundary layer flow, and 3) the minimum detectable fluid volume within an LDB or sump. The holdup volume required to wet the surface of the containment piping is dominant (75% of the total detection time) for the typical LDB case. This means that leak detection times for these events are dependent largely on the line length. For the cell sump and pit sump cases, the sump volume is dominant (67 and 93% of the total detection time, respectively). Considering the assumptions and inputs, the calculated minimum leak detection times are judged approximate and reasonable. In all cases within the LAB, the minimum detectable leak rate is well within the leak detection criterion identified in the Dangerous Waste Permit.

2 Objective

There are two dangerous waste vessels in the LAB. The first vessel, RLD-VSL-00164, the Laboratory Area Sink Drain Collection Vessel, will hereafter be referred to as the C3 Vessel (RLD-VSL-00164). The second vessel, RLD-VSL-00165, the Hotcell Drain Collection Vessel, will hereafter be referred to as the C5 Vessel (RLD-VSL-00165). The purpose of this report is to examine the minimum leak rate detection capabilities of the secondary containment features associated with these two tank systems.

The LAB LDBs, effluent vessel cell sumps (cell sumps), and the pump and piping pit sumps (pit sumps) and their associated instrumentation must satisfy the leak detection criteria of Dangerous Waste Permit Number WA7890008967, Permit Condition III.10.E.9.e.ii for secondary containment systems. This report evaluates the minimum leak rates that the LDBs, cell sumps, and pit sumps; and their associated instrumentation can detect within 24 hours.

The secondary containment design includes a number of features that influence leak detection:

- Instrumentation in the LDBs, cell sumps, and pit sumps that monitor for signs of primary containment leakage
- Sloping of piping, cell floors, and pit floors to direct leakage flow to central points for detection
- The geometry of the piping, cells, and pits.

This report examines these features to determine the minimum detectable leakage rate that can be detected by the LDBs, cell sumps, and pit sumps.

3 Description

The regulatory requirements for leak detection are contained in WAC 173-303-640, Tank Systems, Section 4, Containment and Detection of Releases (Ref. 1). The regulatory requirements 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. 2), Permit 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 Assumptions

Assumptions used in this evaluation of the LAB secondary containment piping and associated LDBs, cell sumps, and pit sumps, secondary containment system features, leak detection capabilities are enumerated in the succeeding subsections.

4.1 Design Input Assumptions

4.1.1 The vessel cell dimensions are summarized as follows:

C3 Effluent Vessel Cell (Rm No. A-B003): 13'-0" (east-west) x 27'-3" (north-south)
C5 Effluent Vessel Cell (Rm No. A-B004): 21'-0" (east-west) x 29'-0"(north-south).

4.1.2 The pump and piping pit dimensions are summarized as follows:

C3 Pump Pit (Rm No. A-B002): 13'-0" (east-west) x 14'-5 1/2" (north-south)
C5 Pump Pit (south)/(Rm No. A-B007): 6'-9" (east-west) x 6'-5" (north-south)
C5 Piping Pit (Rm No. A-B006): 6'-9" (east-west) x 14'-0" (north-south)
C5 Pump Pit (north)/Rm No. A-B005: 6'-9" (east-west) x 6'-5" (north-south).

4.1.3 All eight of the LAB LDBs are NPS 8, horizontal, Schedule 40 pipe, with an NPS 8 cap on either end. A detectable leakage volume is built up in an 11-inch segment of pipe, plus the cap, by a 2-in. high baffle located in the middle of the device.

4.1.4 The stainless steel liners in the vessel cells and the pump and piping pits are sloped at a minimum grade of 1:100 to direct potential leakage in these areas to the respective sump (Ref. 3 and 4).

4.1.5 The length of the longest run of regulated, double-wall pipe is defined by detailed isometric drawings. The longest length is approximately 220 ft, which is conservatively rounded to a length of 250 ft.

4.1.6 There is one sump in each vessel cell. The sump is 30 inches nominal diameter and approximately 13 inches deep. The sump is made from a piece of nominal pipe size (NPS 30) standard-wall pipe (or an equivalent rolled plate) and a 30-in diameter, standard-wall, pipe cap (or equivalent ellipsoidal-head section) – (Ref. 5).

4.1.7 There is one sump in each pump and piping pit. The sump is formed by a shallow rectangular depression in the liner around the drain for the pit. A removable weir around the drain hole allows formation of a detectable volume before excess leakage is directed back to its associated vessel. The sump dimensions are summarized below (Ref. 5):

C3 Pump Pit (RLD-SUMP-00042): [2'-0" x 2'-6" x 1/2"]
C5 Pump Pit, south (RLD-SUMP-00043A): [1'-6" x 3'-0" x 1/2"]
C5 Piping Pit (RLD-SUMP-000044): [2'-0" x 2'-6" x 1/2"]
C5 Pump Pit, north (RLD-SUMP-00043B: [1'-6" x 3'-0" x 1/2"].

4.1.8 Based on inspection of Ref. 3, 4, 6, 7, and 8, double-wall pipe sizes range from NPS 1 1/2 x 4 to NPS 8 x 10. Only the containment pipe for the drain collection header from the C3 Maintenance Shop Area is greater than NPS 6. This header corresponds to the NPS 8 x 10 case.

4.2 Evaluation Assumptions

4.2.1 The outer containment pipe of the double-wall piping system is either 316L stainless steel or carbon steel. Moreover, the vessel cell and pit walls are lined with 304L stainless steel liners. In either case, the dominant flow phenomena are the transient condition that is commonly referred to as "wetting" and laminar, steady-state flow. Wetting is assumed to be insensitive to surface roughness and laminar flow is not dependent on surface roughness.

4.2.2 The maximum discharge flow rate from a permit condition leak is assumed to be a constant 0.1 gal/h over the twenty-four hour period. Moreover, the minimum detectable leak rate determined in this evaluation is also assumed to be constant over the same period.

4.2.3 There are no obstructions to the liquid flow. However, holdup along the flow path (flow channel) will be considered. Holdup is defined as wetting of the surface.

Refer to Assumption 4.2.8 and Assumption 4.2.9 for discussion of wetting and transport flow.

4.2.4 The vessel cell and pit sumps have "radar-type" level detection instrumentation that can conservatively detect a minimum fluid level rise of 10 mm (0.39 in.) in the sumps when the liquid level is at the bottom of the wave-guide. The liquid level does not have to be inside the wave guide to achieve this accuracy.

4.2.5 The LDBs have "thermal dispersion" level detection instrumentation that can conservatively detect a minimum fluid level rise of 1/2 inch (12.7 mm) in the reservoir.

4.2.6 The leaking liquid has characteristics similar to water at a temperature of 100 °F. Moreover, the liquid does not contain solids and it does not foam in the sumps.

4.2.7 The leaking fluid does not evaporate while it is flowing towards the LDBs or sumps.

4.2.8 Steady-state flows in the annular-region of double-wall pipe and over liner surfaces can be modeled using equations derived from boundary layer theory for uniform flow down an inclined plane.

4.2.9 The wetting (or hold-up) factor is assumed to equal 0.32 fl. oz./ft (Ref. 9) and to be largely independent of slope, surface roughness, or other pipe or liner parameters. However, because this factor is an empirical value that was explicitly developed for NPS 6 pipe, the factor will be doubled for flow in pipes larger than NPS 6 and for flow over flat surfaces. This approach is deemed to be conservative.

4.2.10 The maximum distance from the leak to the vessel cell or pit sump is assumed equal to the diagonal formed by the width and length of the cell or pit. Raised equipment embeds allow leakage flows to travel with minimal obstruction of the direct flow path to the sump.

4.2.11 The curved head portion of the pipe cap section that is used for the cell sumps can be approximated by a 2:1 semi-ellipsoidal head.

4.2.12 The containment pipe for all double-wall pipe runs is assumed to be Schedule 40.

4.2.13 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.

4.2.14 Based on a review of the 3-D Model and Ref. 10, the two longest runs of pipe are anticipated to be the C5 collection header from the C3 Maintenance Shop, Maintenance Decon Booth (60-MHAN-00003) and a C3 collection header from a lab sink or fumehood in the southeast corner of the Rad Lab Area. Both of these runs are estimated to be a little over 200 ft. For the purposes of this analysis, the latter case was assumed to be the longest run and determined to be approximately 220 ft. This length was conservatively rounded to 250 ft to ensure that both cases (both pipe runs) are conservatively bounded.

4.2.15 The level instrument response time (i.e., the time between the process reaching a specified level setpoint and the instrument responding to the process condition) is negligible for the purposes of this analysis.

4.2.16 The double-wall (co-axial) piping is assumed to have a minimum slope of 1/16 in. per foot (1:192 slope).

4.2.17 The diameter of the removal weir in the pit sumps is 7.00 in. (Ref. 11, Figure 8).

4.2.18 For spills in the vessel cells and pits, flows across the floors are assumed to be similar to flow in an open channel. The width of the channel is assumed to equal 10 times the depth of the channel. This assumption is not significant to the analysis because the travel distance is comparatively short (i.e., <36 ft).

5 Analysis

5.1 In-Slab Dangerous Waste Piping

In the LAB, there are a total of eight dangerous waste lines. These lines are all embedded in the building foundation slab. The lines are of a coaxial, double-wall construction. Pipe sizes range from NPS 1 1/2 x 4 to NPS 8 x 10. In general, the primary containment core pipe is two pipe sizes smaller than the containment pipe, and pipes are typically constructed of a C-22 hastalloy core pipe with a carbon steel containment pipe. For purposes of this evaluation, the containment pipe is assumed to be Schedule 40 in all cases. The length of the longest run of in-slab dangerous waste piping is 250 ft.

The in-slab dangerous waste lines have a minimum slope of 1/16 in. per foot (1:192 slope). These lines all slope towards a vessel cell. These cells are either the C3 Effluent Vessel Cell or the C5 Effluent Vessel Cell. LDBs are connected to the low point of the double-wall (coaxial) piping where it terminates in the vessel cells. The LDBs allow for the accumulation of a detectible volume of leakage while directing excess leakage to the associated vessel cell.

The in-slab dangerous waste piping is routed so that the containment pipe drains into its respective LDB in the event of a primary-containment, core-pipe leak. In each of the LDBs, there is a thermal-conductivity-type level instrument to detect potential leakage.

5.2 Effluent Vessel Cells

There are two effluent vessel cells in the LAB corresponding to the C3 Vessel and C5 Vessel, respectively. The C5 Vessel Cell is the larger of the two cells.

The floors and portions of the walls of the two effluent vessel cells have stainless liners for secondary containment. The liners are contoured to direct primary containment leakage to the respective cell sump. The minimum slope of the cell floors is 1:100. The maximum distance leakage must travel to reach a sump is approximately 36 ft.

The cell sumps allow for the accumulation of detectible volumes of leakage. In each of the sumps, there is a radar-type level instrument to detect potential leakage.

5.3 Pit Cells

There are four pump and piping pits in the LAB. One of these pits is associated with the C3 Vessel and the other three are associated with the C5 Vessel. The C3 Pump Pit is the largest of the four pits.

The floors and walls of the four pump and piping pits have stainless liners for secondary containment. The liners are contoured to direct primary containment leakage to the respective pit sump. The minimum slope of the pit floors is 1:100. The maximum distance leakage must travel to reach a sump is approximately 20 ft.

The pit sumps allow for the accumulation of detectible volumes of leakage while a removal weir within the sump allows excess leakage to be directed to the corresponding effluent vessel. In each of the sumps, there is a radar-type level instrument to detect potential leakage.

6 Detectable Leak Rates

The results of this evaluation are compiled in the table below based on the four limiting cases that are evaluated in Section 7, Bounding Calculations. This table demonstrates that the LAB secondary containment leak detection systems for the vessel cells, and pump and piping pits are capable of detecting leaks of 0.1 gal/h within 24 hours. The 0.1 gal/h value corresponds to the stipulated leakage identified in Permit Condition III.10.E.9.e.ii. Moreover, note that the leak rates are reported to only one-significant figure. This practice is consistent with the required accuracy.

The "24-hour Leak Rate Detected" value is the minimum continuous leak rate that can be detected within 24 hours. As discussed in Section 7, this rate is driven by three primary components: 1) the volume associated with wetting of pipe or floor surfaces, 2) the volume associated with boundary layer flow, and 3) the minimum detectable fluid volume within an LDB or sump. The first two components (the transit volumes) are combined in the table as "Max. Volume to Reach LDB or Sump." Note that the minimum detectable leak rate is dominated by the transit volume (i.e., the length of pipe) for the piping cases, while the sump detection volume is dominant for the cell sump and pit sump cases.

LAB Facility Leak Detection Capability

Description of Leak Detection Area	*LDB or Sump PIN*	*Max. Length of Travel to LDB or Sump, ft*	*Max. Volume to Reach LDB or Sump, US gal(1)*	*Leak Detection Device Description*	*Leak Detection Device Sensitivity*	*Max. Volume in LDB or Sump for Detection, US gal*	*Max. Total Volume for Detection, US gal*	*24-Hour Leak Rate Detected, gal/h*
Rad Lab Sink Collection Header	**RLD-LDB-00005**	**250**	**0.7607**	**Thermal Dispersion**	**0.5 in. max. liquid level**	**0.0767**	**0.8374**	**0.03**
Hotcell Collection Header	RLD-LDB-00002	- - -	- - -	Thermal Dispersion	0.5 in. max. liquid level	- - -	- - -	Use 0.03
C3 Transfer Line	RLD-LDB-00004	- - -	- - -	Thermal Dispersion	0.5 in. max. liquid level	- - -	- - -	Use 0.03
PVA Drain Header	RLD-LDB-00006	- - -	- - -	Thermal Dispersion	0.5 in. max. liquid level	- - -	- - -	Use 0.03
Sample Receiving/ Shipping Drain Header	RLD-LDB-00008	- - -	- - -	Thermal Dispersion	0.5 in. max. liquid level	- - -	- - -	Use 0.03
Glovebox Header	RLD-LDB-00009	- - -	- - -	Thermal Dispersion	0.5 in. max. liquid level	- - -	- - -	Use 0.03
ASX Equipment Drain Collection Header	RLD-LDB-00011	- - -	- - -	Thermal Dispersion	0.5 in. max. liquid level	- - -	- - -	Use 0.03
C3 Maintenance Drain Header	**RLD-LDB-00007**	**189**	**1.0638**	**Thermal Dispersion**	**0.5 in. max. liquid level**	**0.0767**	**1.1405**	**0.05**
C5 Vessel Cell, A-B004	**RLD-SUMP-00042**	**35.8**	**0.1862**	**Radar**	**± 10 mm liquid level**	**0.3797**	**0.5659**	**0.02**
C3 Vessel Cell, A-B003	RLD-SUMP-00041	- - -	- - -	Radar	± 10 mm liquid level	- - -	- - -	Use 0.02
C3 Pump Pit A-B003	**RLD-SUMP-00045**	**19.4**	**0.1038**	**Radar**	**± 10 mm liquid level**	**1.4752**	**1.5790**	**0.07**
C5 Pump Pit, A-B007	RLD-SUMP-00043A	- - -	- - -	Radar	± 10 mm liquid level	- - -	- - -	Use 0.07
C5 Pump Pit, A-B005	RLD-SUMP-00043B	- - -	- - -	Radar	± 10 mm liquid level	- - -	- - -	Use 0.07
C5 Piping Pit, A-B006	RLD-SUMP-00044	- - -	- - -	Radar	± 10 mm liquid level	- - -	- - -	Use 0.07

Note 1: This quantity is the sum of the volumes associated with "wetting" and boundary layer flow.

7 Bounding Calculations

7.1 Methodology

The analysis of minimum leak rate detection capabilities for the LDBs, cell sumps, and pits sumps; and their associated instrumentation involved the following steps:

1. An initial leakage rate was judiciously selected based on engineering judgment. This leakage rate was evaluated and refined through a series of iterations.

2. The amount of time required for the leakage to wet the flow path (flow channel) from the most-remote leakage location to its corresponding leak detection feature (e.g., a cell sump) was calculated. This is done using an experimentally determined value of wetting holdup of 0.32 fl. oz./ft (Ref. 9) and the following equation:

   $$t = \frac{c\,L}{Q}$$

   Where:

   t = time, h
   c = wetting factor, gal/ft
   L = travel distance, ft
   Q = leakage rate, gal/h.

3. The time delay required for the leakage to reach the leak detection volume was calculated using equations derived from boundary layer theory for uniform flow down an inclined plane.

   The average velocity distribution from boundary layer theory is given in Ref. 12 (pp. 249 thru 251) as Equation 9.4b:

   $$V = \frac{g\,S_o\,d^2}{3\,\upsilon}$$

   Where:

   V = average velocity, ft/s
   g = gravitation constant, 32.17 ft/s^2
   S_o = Slope of the incline, dimensionless
   d = flow depth, ft
   υ = kinematic viscosity, ft^2/s

   Moreover, from continuity, flow rate is given by: $Q = A\,V$

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

Therefore, combining the latter two equations, the flow depth, d, can be found by solving the following relationship:

$$d = \sqrt{\frac{3\,\upsilon\,Q}{g\,S_o\,A}}$$

The cross-sectional flow area, A, is solved for based on the assumed flow rate and the physical constrains of the flow channel.

Returning to the original boundary layer equation:

$$V = \frac{g\,S_o\,d^2}{3\,\upsilon}$$

The time delay for the leakage to reach the LDBs is simply:

t = (h/3600 s)*(L/V)

Where:

t = time, h
V = average velocity, ft/s
L = travel distance, ft.

4. The amount of leakage required to obtain a detectible volume in a cell sump, pit sump, or LDB is determined using the physical dimensions and other characteristics of the LDBs or sumps.

5. The time required to obtain a detectible volume in a LDB, cell sump, or pit sump is calculated. The time required to obtain a detectable accumulation of leakage is simply the volume of the fluid at the minimum detectible level divided by the assumed leakage rate ($t = W/Q$).

   Where:

   t = time, h
   W = Volume (at minimum detectable level), gal
   Q = leakage rate, gal/h.

6. The time required to wet the flow channel (Step 2), the time required by the fluid to reach a LDB or sump based on boundary layer flow conditions (Step 5), and the time required to obtain a detectible volume (Step 5) were summed together. If the calculated time was significantly more or less than 24 hours, the iteration process was repeated with alternate assumptions of leakage rates until the calculations converge on a solution.

7.2 Bounding Calculation for LDBs on In-Slab Dangerous Waste Piping

The succeeding analysis determines the minimum leak rate that can be detected by the LDBs in a 24-hour period. The analysis evaluates a leak in the longest run of in-slab dangerous waste pipe.

7.2.1 Initial Minimum Detectible Leak Rate Assumption

Try an initial minimum detectible leakage rate that is equal to 1/3 of the 0.1 gal/h permit condition leak rate or 0.0333 gal/h.

7.2.2 Time Required to Wet the Outer Jacket of the Coaxial Pipe Flow Path

The maximum distance from any postulated leak to its respective LDB is obtained from Assumptions 4.1.5 and 4.2.14. Tallying the line lengths from the pipe cleanout upstream of the furthest drain to the LDB and conservatively treating straight-vertical drops as sloped segments, a travel distance of 217.32 ft is obtained. This value is consistent with the estimate of slightly more than 200 ft. Moreover, conservatively round the total to 250 ft.

The wetting factor is equal 0.32 fl. oz./ft (Assumption 4.2.9). Hence, the time required to wet the flow channel is given by:

$$t = \frac{c\,L}{Q}$$

Where the variables are defined in Section 7.1(2).

$$t_1 = \left(\frac{0.32\ fl.\,oz.}{ft}\right)\left(\frac{gal}{128\ fl.\,oz.}\right)\left(\frac{250\ ft}{1}\right)\left(\frac{h}{0.0333\ gal}\right) = 18.8\ h$$

7.2.3 Calculation of Leakage Travel Time to LDB

The time required for the leakage to travel from its point of origin to the LDB under boundary layer flow conditions is calculated by simultaneously solving the following sets of equations:

$$Q = VA$$ Section 7.1.3

$$d = \sqrt{\frac{3\,\upsilon\,V}{g\,S_o}}$$ Section 7.1.3

$$A = \frac{(\theta - \sin\theta)D^2}{8}$$ Ref. 13, pg. 168

$$d = D\sin^2\left(\frac{\theta}{4}\right)$$ Ref. 13, pg. 168

Where:

D = inside diameter of the encasement pipe. Based on Assumptions 4.1.8 and 4.2.12, the inside diameters of the containment pipe will vary as follows:

D = 4.026 in. (0.3355 ft) to 10.020 in. (0.8350 ft). Use the latter end of the range. The larger cross-sectional area will yield the lower velocities.

θ = the angle formed by the intersection of the fluid free surface and the wall of the pipe, and the centerline of the pipe, radians.

Q = 0.0333 gal/h (1.237 x 10^{-6} ft^3/s)

υ = kinematic viscosity of water @ 100 °F (Assumption 4.2.6), 7.37 x 10^{-6} ft^2/s (Ref. 12, pg. 513)
g = gravitation constant, 32.17 ft/s^2
S_o = Slope of the incline, 0.00521 (Assumption 4.2.16)

Using an equation processor as a tool to solve for these equations simultaneously, the equations converged on the following solution:

θ = 9.751 deg
d = 1.511 x 10^{-3} ft
V = 1.7302 x 10^{-2} ft/s
A = 7.150 x 10^{-5} ft^2

Thus, the travel delay for the leakage to reach the LDB is:

t_2= (h/3600 s)*(L/V)
= (h/3600 s)*(250 ft)*(s/1.7302 x 10^{-2} ft) = 4.0 h

7.2.4 Calculation of Leakage Volume Required for a Detectable LDB Level Change

Each of the eight LAB LDBs consists of a NPS 8, horizontal, Schedule 40 pipe, with a NPS 8 cap on either end. A detectable leakage volume is built up in an 11-inch segment of pipe, plus the cap, by a 2-in. high baffle located in the middle of the LDB (Input 4.1.3).

The detectable volume consists of the partial volume of the pipe, partial volume of the straight portion of the cap, plus the partial volume of the curved portion of the cap.

Solving the equations for the geometric properties of these sections for the volume needed to produce a minimum detectable level change of 0.5 in (0.0417 ft) [Assumption 4.2.5] yields a total required volume of 7.665 x 10^{-2} gal.

7.2.5 Time to Obtain a Detectible Volume in the LDB

The time required to obtain a detectible volume in a LDB is given by:

$$t_3 = \frac{W}{Q}$$

t_3 = (7.665 x 10^{-2} gal)*(h/0.0333 gal) = 2.3 h

7.2.6 Total LDB Detection Time and Minimum Detectible Flow Rates

The total detection time is the sum of the previously enumerated pipe wetting, boundary layer flow transport, and LDB filling delays:

$t = t_1 + t_2 + t_3$
t = 18.8 h + 4.0 h + 2.3 h = 25.1 h.

The resultant value is greater than 24 h. Therefore, the iterative process is repeated for successively larger leakage rates. The iteration process converged on a solution for a leakage rate of 0.0348 gal/h (say 0.03 gal/h) and a θ = 9.813 deg, when the following detection times are obtained:

t = 17.9 h + 3.9 h + 2.2 h = 24.0 h.

The corresponding partial volumes required for detection are summarized as follows:

$W = W_1 + W_2 + W_3$

W = (0.32 fl. oz./ft)*(250 ft)*(gal/128 fl. oz.) + (0.0348 gal)*(3.9 h) + 0.0767 gal
= 0.6250 gal + 0.1357 gal + 0.0767 gal = 0.8374 gal

7.2.7 Additional Study of the Drain Collection Line from the C3 Maintenance Shop

Because of concerns regarding the ability of the wetting factor to pipe that is larger than NPS 6, the case of the Drain Collection Line from the C3 Maintenance Shop is re-evaluated further in greater detail to confirm that the previous calculations are in fact bounding. When these calculations are re-run for an actual travel length, L = 189 ft and a wetting factor c = 0.64 fl. oz./ft (twice the empirically-determined value), the 24-hour minimum detectible leakage rate is 0.0475 gal/h (round to 0.05 gal/h) and following results are obtained:

$t = t_1 + t_2 + t_3$
t = 19.9 h + 2.5 h + 1.6 h = 24.0 h.

The corresponding partial volumes required for detection are summarized as follows:

$W = W_1 + W_2 + W_3$

W = (0.64 fl. oz./ft)*(189 ft)*(gal/128 fl. oz.) + (0.0475 gal)*(2.5 h) + 0.0767 gal
= 0.9450 gal + 0.1188 gal + 0.0767 gal = 1.1405 gal

7.3 Vessel Cell Sumps

The succeeding analysis determines the minimum leakage rate that can be detected by the C3 and C5 vessel cell sumps in a 24-hour period.

7.3.1 Initial Minimum Detectible Leak Rate Assumption

Try an initial minimum detectible leakage rate that is equal to 1/5th of the 0.1 gal/h permit condition leak rate or 0.020 gal/h.

7.3.2 Time Required to Wet the Cell Liner Flow Path

The longest distance from a leak to the associated cell sump is conservatively equal to the diagonal formed by the width and the length of the cell (Assumption 4.2.10). Based on Assumption 4.1.1, the bounding case occurs in the C5 Vessel Cell. This distance is equal to the following:

$$L = \sqrt{(21.00\text{ ft})^2 + (29.00\text{ ft})^2}$$

$$L = 35.81\text{ ft}$$

The wetting factor is equal 0.32 fl. oz./ft (Assumption 4.2.9). Double this value to account for uncertainty in the validity of this parameter to flow over a flat surface. Hence, the time required to wet the flow channel is given by:

$$t = \frac{c\,L}{Q}$$

Where the variables are defined in Section 7.1(2).

$$t_1 = \left(\frac{0.64\ fl.\,oz.}{ft}\right)\left(\frac{gal}{128\ fl.\,oz.}\right)\left(\frac{35.81\ ft}{1}\right)\left(\frac{h}{0.020\ gal}\right) = 9.0\ h$$

7.3.3 Calculation of Leakage Travel Time to Cell Sump

The time required for the leakage to travel from its point of origin to the cell sump under boundary layer flow conditions is calculated by simultaneously solving the following sets of equations:

$$d = \sqrt{\frac{3\,\upsilon\,Q}{g\,S_o\,A}}$$ Assumption 4.2.8

and

$A = d^*z$, where d = flow depth, ft; and z = the flow width = 10^*d, ft Assumption 4.2.18

Solving for d:

$$d = \left[\frac{3\,\upsilon\,Q}{10\,g\,S_o}\right]^{0.25}$$ Assumption 4.2.8

Where:

d = flow depth, ft
υ = kinematic viscosity of water @ 100 °F (Assumption 4.2.6), 7.37 x 10^{-6} ft^2/s (Ref. 12, pg. 513)
g = gravitation constant, 32.17 ft/s^2
S_o = Slope of the incline, 0.01 (Input 4.1.4)
Q = leakage flow rate, 0.020 gal/h (7.427 x 10^{-7} ft^3/s)

d = [(3/10)*(7.37 x 10^{-6} ft^2/s)*(7.427 x 10^{-7} ft^3/s)*(s^2/32.17 ft)*(1/0.010)]^0.25

d = 0.00150 ft

The average flow velocity is given by:

$$V = \frac{g\ S_o\ d^2}{3\ \upsilon}$$

V = (32.17 ft/s^2)*(0.010)*(0.00150 ft)^2*(1/3)*(1/7.37 x 10^{-6} ft^2/s)
= 0.0327 ft/s

Thus, the travel delay for the leakage to reach the vessel cell sump is:

t_l = (h/3600 s)*(L/V)
= (h/3600 s)*(35.81 ft)*(s/0.0327 ft) = 0.3 h

7.3.4 Calculation of Leakage Volume Required for a Detectable Cell Sump Level Change

The curved head portion of the pipe cap that is used for the cell sump can be approximated by a 2:1 semi-ellipsoidal head (Assumption 4.2.11). The cap is NPS 30 (Assumption 4.1.6).

The partial volume of the cap at various levels is thus given by the following equation (Ref. 14, Appendix D):

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

Where:

W_p = Partial volume (from the bottom of the cap to a height H_b)

and where:

D = Diameter of the cap, 29.250 in. (Assumption 4.1.6)

H_b = Height of the fluid in the curved portion of the head and $H_{b\,max}$ = 0.25D or 7.3 in.

Radar-type level detection instrumentation is capable of detecting a level rise of 10 mm (0.39 in.) (Assumption 4.2.4). To account for any uncertainties associated with wave guide positioning and rangeability of the curved bottom of the sump, conservatively use a detectible level change of 1 in. (25.4 mm). Solving the previous equation to obtain a volume change corresponding to a 1 in. rise in level:

$$W_p = \pi \cdot (29.250\text{ in.}) \cdot (1.0\text{ in.})^2 \left[1 - \frac{4\,(1.0\text{ in.})}{3\,(29.250\text{ in.})}\right]$$

$W_p = 87.70\text{ in.}^3$ (0.3797 gal)

7.3.5 Time to Obtain a Detectible Volume in a Vessel Cell Sump

The time required to obtain a detectible volume in a cell sump is given by:

$$t_3 = \frac{W}{Q}$$

t_3 = (0.3797 gal)*(h/0.020 gal) = 19.0 h

7.3.6 Total Vessel Cell Detection Time and Minimum Detectible Flow Rates

The total detection time is the sum of the previously enumerated floor wetting, boundary layer flow transport, and cell sump filling delays:

$t = t_1 + t_2 + t_3$
t = 9.0 h + 0.3 h + 19.0 h = 28.3 h.

The resultant value is greater than 24 h. Therefore, the iterative process is repeated for successively larger leakage rates. The iteration process converged on a solution for a leakage rate of 0.0236 gal/h (say 0.02 gal/h) when the following detection times are obtained:

t = 7.6 h + 0.3 h + 16.1 h = 24.0 h.

The corresponding partial volumes required for detection are summarized as follows:

$W = W_1 + W_2 + W_3$

W = (0.64 fl. oz./ft)*(35.81 ft)*(gal/128 fl. oz.) + (0.0236 gal)*(0.3 h) + 0.3797 gal
= 0.1791 gal + 0.0071 gal + 0.3797 gal = 0.5659 gal

7.4 Pit Sumps

The succeeding analysis determines the minimum leak rate that can be detected in the C3 Pump Pit, the C5 pump pits, or C5 Piping Pit in a 24-hour period.

7.4.1 Initial Minimum Detectible Leak Rate Assumption

Try an initial minimum detectible leakage rate that is equal to two-thirds of the 0.1 gal/h permit condition leak rate or 0.067 gal/h.

7.4.2 Time Required to Wet the Pit Liner Flow Path

The longest distance from a leak to the associated pit sump is conservatively equal to the diagonal formed by the width and the length of the pit (Assumption 4.2.10). Based on Assumption 4.1.3, the bounding case occurs in the C3 Pump Pit. This distance is equal to the following:

$$L = \sqrt{(13.00\text{ ft})^2 + (14.46\text{ ft})^2}$$

$$L = 19.44\text{ ft}$$

The wetting factor is equal 0.32 fl. oz./ft (Assumption 4.2.9). Double this value to account for uncertainty in the validity of this parameter to flow over a flat surface. Hence, the time required to wet the flow channel is given by:

$$t = \frac{c\,L}{Q}$$

Where the variables are defined in Section 7.1(2).

$$t_1 = \left(\frac{0.64\ fl.\,oz.}{ft}\right)\left(\frac{gal}{128\ fl.\,oz.}\right)\left(\frac{19.44\ ft}{1}\right)\left(\frac{h}{0.067\ gal}\right) = 1.5\ h$$

7.4.3 Calculation of Leakage Travel Time to Pit Sump

The time required for the leakage to travel from its point of origin to its respective pit sump under boundary layer flow conditions is calculated by simultaneously solving the following sets of equations:

$$d = \sqrt{\frac{3\,\upsilon\,Q}{g\,S_o\,A}}$$ Assumption 4.2.8

and

$A = d^*z$, where d = flow depth, ft; and z = the flow width = 10^*d, ft Assumption 4.2.18

Solving for d:

$$d = \left[\frac{3\,\upsilon\,Q}{10\,g\,S_o}\right]^{0.25}$$ Assumption 4.2.8

Where:

d = flow depth, ft
υ = kinematic viscosity of water @ 100 °F (Assumption 4.2.6), 7.37 x 10^{-6} ft^2/s (Ref. 12, pg.513)
g = gravitation constant, 32.17 ft/s^2
S_o = Slope of the incline, 0.01 (Assumption 4.1.4)
Q = leakage flow rate, 0.067 gal/h (2.488 x 10^{-6} ft^3/s)

d = [(3/10)*(7.37 x 10^{-6} ft^2/s)*(2.488 x 10^{-6} ft^3/s)*(s^2/32.17 ft)*(1/0.010)]^0.25

d = 0.00203 ft

The average flow velocity is given by:

$$V = \frac{g\, S_o\, d^2}{3\, \upsilon}$$

V = (32.17 ft/s^2)*(0.010)*(0.00203 ft)^2*(1/3)*(1/7.37 x 10^{-6} ft^2/s)
= 0.05996 ft/s

Thus, the travel delay for the leakage to reach the vessel cell sump is:

t_2= (h/3600 s)*(L/V)
= (h/3600 s)*(19.44 ft)*(s/0.05996 ft) = 0.1 h

7.4.4 Calculation of Leakage Volume Required for a Detectable Pit Sump Level Change

Based on inspection of Assumption 4.2.8, the two largest pit sumps are in the C3 Pump Pit or the C5 Piping Pit. These sumps are identical in size. The partial volume of the sump at various levels is thus given by the following:

W_g = 2.00 ft x 2.5 ft x (144 $in.^2/ft^2$) x (gal/231 $in.^3$) x H = (3.1169 gal/in.) x H

Where, H = height of the liquid in the sump in inches.

Similarly, based on Assumption 4.2.17, the partial volume displaced by the removal weir inside the sumps is equal to a straight cylinder with a diameter of 7.00 in. Therefore, the partial volume displaced by the weir at various levels is given by the following:

W_w = (1/4) x (π) x $(7.00\ in.)^2$ x (gal/231 $in.^3$) x H = (0.1666 gal/in.) x H

Radar-type level detection instrumentation is capable of detecting a level rise of 10 mm (0.39 in.) (Assumption 4.2.4). To account for any potential uncertainties associated with rangeability, conservatively use a detectible level change of 1/2 in. (12.7 mm). Solving the previous equation to obtain a volume change corresponding to a 1/2 in. rise in level:

$W_h = W_g - W_w$ = (3.1169 gal/in. - 0.1666 gal/in.) * (0.50 in) = 1.4752 gal

7.4.5 Time to Obtain a Detectible Volume in a Pit Sump

The time required to obtain a detectible volume in a cell sump is given by:

$$t_3 = \frac{W}{Q}$$

t_3 = (1.4752 gal)*(h/0.067 gal) = 22.0 h

7.4.6 Total Pit Sump Detection Time and Minimum Detectible Flow Rates

The total detection time is the sum of the previously enumerated floor wetting, boundary layer flow transport, and pit sump filling delays:

$t = t_1 + t_2 + t_3$
t = 1.5 h + 0.1 h + 22.0 h = 23.6 h.

The resultant value is slightly less than 24 h. Therefore, the iterative process is repeated for successively smaller leakage rates. The iteration process converged on a solution for a leakage rate of 0.0658 gal/h (say 0.07 gal/h) when the following detection times are obtained:

t = 1.5 h + 0.1 h + 22.4 h = 24.0 h.

The corresponding partial volumes required for detection are summarized as follows:

$W = W_1 + W_2 + W_3$

W = (0.64 fl. oz./ft)*(19.44 ft)*(gal/128 fl. oz.) + (0.0658 gal)*(0.1 h) + 1.4752 gal
= 0.0972 gal + 0.0066 gal + 1.4752 gal = 1.5790 gal

8 References

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