Review of Electrical Leak Location and Electrical Resistivity Tomography Pilot Study of the Secondary Containment System at the Valdez Marine Terminal West Tank Farm Conducted July 2024

By

Joseph Scalia IV, PhD

Craig H. Benson, PhD, PE, NAE

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"The opinions expressed in this PWSRCAC commissioned report are not necessarily those of PWSRCAC."

EXECUTIVE SUMMARY

This review provides an assessment of the report from a pilot study undertaken by Alyeska Pipeline Service Company in July 2024, to evaluate if electrical leak location (ELL) and/or electrical resistivity tomography (ERT) are feasible methods to evaluate the integrity of catalytically blown asphalt (CBA) liner of the secondary containment system (SCS) at the Valdez Marine Terminal (VMT) tank farm. The pilot study was conducted at the West Tank Farm.

Standard methods and equipment were used for the ELL and ERT testing. Results of the pilot study demonstrate that ELL was successful in detecting manufactured leaks (holes) in the CBA liner, whereas the ERT method was unsuccessful at detecting manufactured leaks during the pilot study. Both methods required excavation of a perimeter trench around the test area down to the CBA, and installation of a geomembrane rain flap to the CBA to achieve necessary electrical isolation.

Our recommended path forward is implementation of ELL over at least 20% of the buried CBA-lined area of the East Tank Farm, prioritizing areas that may have suffered damage from past oil spills. This recommendation differs from WSP's (Alyeska's contractor, formerly known as Golder Associates) recommendation to test 5% of the buried CBA-lined area combined with a visual inspection of 15% of the unburied area. Testing 20% of the buried CBA-lined area is necessary to (i) establish the frequency and size-range of defects in the CBA liner, (ii) establish a quantitative definition (minimum performance threshold) for the required condition that the secondary containment be "sufficiently impermeable," (iii) establish a methodology for calculating leakage (or equivalent permeability) of oil through the SCS, and (iv) ultimately determine if the current SCS meets the "sufficiently impermeable" requirement.

Additional laboratory testing is also needed to demonstrate that the liner will maintain effectiveness in containing oil over the necessary duration of performance for a liner thickness of 3/16 inches (0.1875 in).

ACRONYMS

APSC	Alyeska Pipeline Service Company
CBA	Catalytically Blown Asphalt
ELL	Electrical Leak Location
ERT	Electrical Resistivity Tomography
SCS	Secondary Containment System
VMT	Valdez Marine Terminal
WTF	West Tank Farm
WSP	Alyeska's contractor, formerly known as Golder Associates

TABLE OF CONTENTS

1. INTRODUCTION

Secondary containment systems (SCS) are used at the Valdez Marine Terminal (VMT) to prevent the release of oil to the environment should a leak or other spill occur from oil storage tanks at the terminal. Each SCS consists of an area surrounding a pair of tanks with a containment berm and/or wall around the perimeter and a catalytically blown asphalt (CBA) liner placed across the surface. As shown in Figure 1 the liner is underlain by a layer of gravel prepared from crushed rock and is overlain by a thin gravel bedding layer and a thick layer of cover soil comprised of gravel fill. The SCSs also contain XR-5 Geomembrane patch areas and have exposed XR-5 on sidewall slopes. The CBA layer was specified to be at least 5/16 inches according to the construction documentation for the VMT (Golder 2018). The SCSs at VMT were constructed in the 1970s, when lining technology was in its infancy.

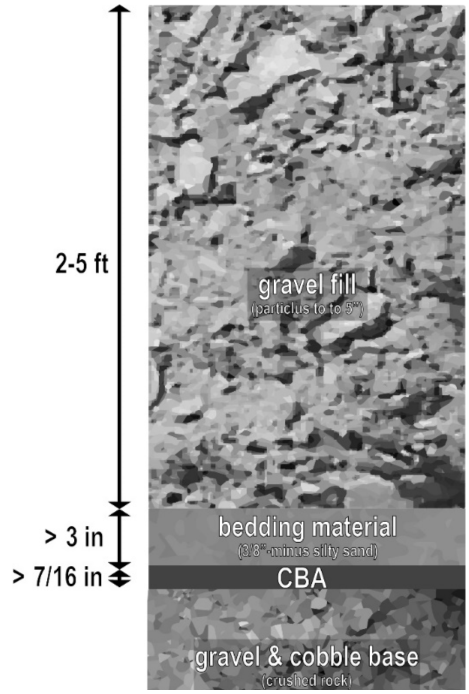

Figure 1. Schematic of the catalytically blown asphalt (CBA) portion of the secondary containment system (SCS) at the Valdez Marine Terminal (VMT).

The VMT SCS must be "sufficiently impermeable[1]" to protect groundwater from contamination and to contain a discharge or release until it can be detected and cleaned up. The impermeability of the SCS depends on the integrity of the CBA liner. As noted in Golder (2018) "*Based on laboratory permeability test results, the CBA lined SCS will meet the 'sufficiently impermeable' criteria as defined in the State of Alaska Administrative Code 18 AAC 75.990 (124)* ***as long as there are no open perforations in the SCS [emphasis added]***." The effectiveness of any lining system is influenced by the number of leaks present in the liner. The term leak used in this report follows the definition adopted by the standardization body ASTM International, which defines "leak" as "*any unintended opening, perforation, breach, slit, tear, puncture, crack, or seam breach*" (ASTM 2021). Leak assessments are often made to determine the number, size, and location of defects. Data collected from the leak assessment are then compared to specifications for an acceptable liner, and repairs are made as needed. Most leak assessments are conducted immediately after construction of the lining system, although they can be conducted at any time.

Liners can be assessed by direct or indirect assessment methods. A direct assessment is made through visual inspection of a liner. For the SCS at the VMT, direct assessments of the CBA liner can only be conducted when the overlying material is removed (e.g., as reported in Golder 2015, 2016, 2017, 2018). Removal of existing material imposes risk, as equipment used to remove overlying soils

[1] 18 AAC 75.990 (124) "sufficiently impermeable" means, for a secondary containment system, that its design and construction has the impermeability necessary to protect groundwater from contamination and to contain a discharge or release until it can be detected and cleaned up; for design purposes for tanks constructed after May 1992, "sufficiently impermeable" means using a layer of natural or manufactured material of sufficient thickness, density, and composition to produce a maximum permeability for the substance being contained of 1 x 10^{-6} cm per second at a maximum anticipated hydrostatic pressure, unless the department determines that an alternate design standard protects groundwater from contamination and contains a discharge or release until detection and cleanup.

can damage the liner, necessitating repairs and potentially creating ambiguity regarding whether a defect existed before or was caused by excavation. Direct assessment is also labor intensive. The East Tank Farm (ETF) is ~ 2,373,000 ft^2, but only ~ 23,000 ft^2 have been directly inspected visually (~ 1%). To provide a statistically significant assessment of CBA liner integrity, more than 20% of the CBA liner should be inspected (Benson 2022). Direct assessment of the exposed SCS liner is significantly easier because removal of overlying material is not required but does not reflect the condition of the buried CBA liner.

Indirect assessment consists of imposing a known condition above the liner and measuring response that is influenced by the presence of leaks in the liner. A key difference between indirect and direct methods is that the presence and characteristics of defects are inferred from an indirect method, rather than being observed directly. Thus, outcomes of indirect assessments inherently have ambiguity that is absent from direct assessments. This ambiguity is often addressed by coupling indirect and direct methods, using the indirect method to identify or locate defects followed by excavation, visual inspection, and repair.

Geophysical methods are the preferred method for assessing the integrity of the CBA liner in the SCS at the VMT (Benson 2022). These methods consist of applying an electrical or mechanical signal to the surface of the material overlying the liner and measuring the response to the signal. Benson (2022) identified Electrical Leak Location (ELL) surveys and Electrical Resistivity Tomography (ERT) as potential methods for use in assessing the integrity of the CBA liner in the East Tank Farm SCS at the VMT.

ELL surveys are the most common geophysical method used to evaluate the integrity of liners constructed with thin non-polar materials (e.g., geomembranes and CBA liners). A high voltage and low current DC power source is used to apply an electric field across the surface of the liner (Peggs 2007, Koerner et al. 2013, Calendine et al. 2018, Gilson-Beck 2019). When intact, the non-polar liner (such as a geomembrane or the CBA liner) acts as an insulator that prevents current flow. When a leak in the liner exists, current flows through the leak and into the adjacent soils. This current flow is recorded as a change in voltage between pairs of points measured across the ground surface. Surveys are conducted by walking in parallel lines across the surface of the liner, and mapping voltage looking for anomalies that indicate potential leaks. The surveyed area must be electrically isolated from the outside of the liner for ELL to work. The specific location and size of the leak is identified by removing the soils overlying the liner in the vicinity of the location where the survey identified the presence of a leak and performing a direct assessment. The leak is then repaired, and the area re-surveyed to ensure the leak was not obscuring the signature of nearby smaller leaks.

ERT is a more elaborate application of the principles used in ELL. An array of electrodes is deployed at the ground surface and a current is applied across every combination of electrode couples in the array. The voltage drop across each electrode couple is then measured. The array of voltage drops is then used to constrain a 2D inversion of Gauss' Law to obtain a cross-section of electrical resistivity over the area of assessment (Schmia et al. 1996, Zhou 2019).

A pilot study was undertaken by Alyeska Pipeline Service Company (APSC) on July 22-29, 2024, to evaluate if ELL and/or ERT surveys are feasible methods to evaluate the integrity of CBA component of the East Tank Farm SCS at the VMT (i.e., can one or both indirect assessment methods reliably identify leaks.) If the pilot study is successful, ELL and/or ERT can be used to evaluate the presence and prevalence of leaks in the SCS over larger portions of the VMT East Tank Farm. The pilot study was completed on an approximate 15,000 ft^2 area of the cell containing Tanks 15 and 16 in the West Tank Farm (WTF). Figure 2 provides a photograph of the pilot study area, which is outlined by the electrical isolation trench. The WTF tanks have been drained and decommissioned, although cathodic/corrosion protection remains normally energized (APSC temporarily deenergized these systems during the pilot study) (ELL and ERT Survey at VMT SCS – July 2024, Pilot Study, West Tank Farm; WSP 2024a). The pilot study consisted of establishment and verification of electrical isolation, ELL testing, ERT testing, installation of three defects (a large gash, small gash, and knife slit), additional ELL testing of the defect area, and SCS repair. The results of the pilot study are reported in WSP (2024a). This report provides a review of the pilot study results, and recommendations for the path forward.

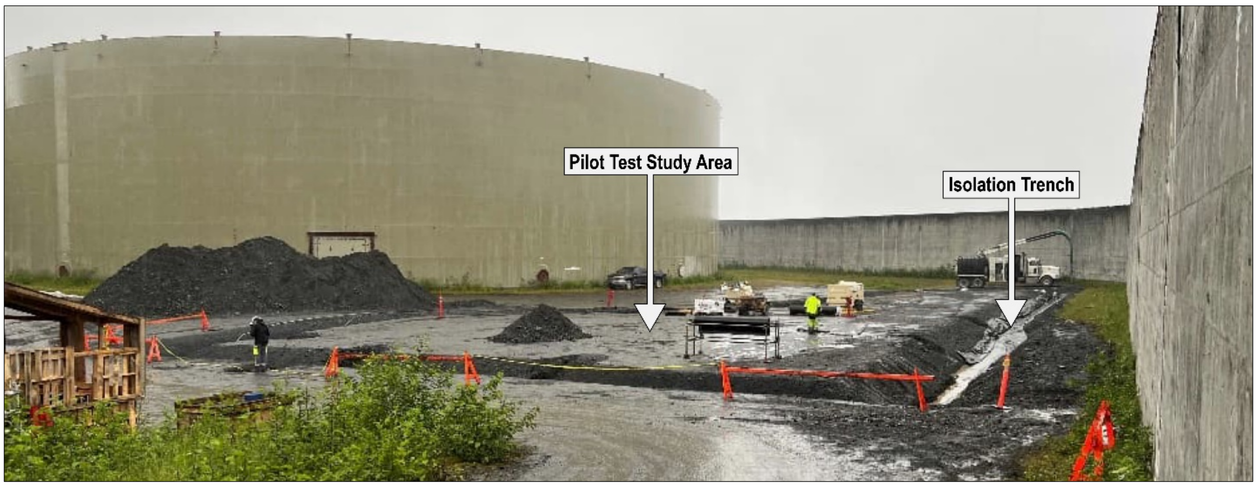

Figure 2. Photograph of pilot study test area (trimmed from WSP 2024a).

2. REVIEW OF PILOT TEST METHODS

The effectiveness of ELL and ERT depends on electrical isolation of the test area (open air and the CBA barrier layer serve as electrical insulators). Achieving electrical isolation was the most difficult aspect of the pilot study fieldwork. Prior to testing and isolation, a trench (moat) was excavated around the perimeter of the test area to the CBA (refer to Figure 2). Appreciable rainfall, which is common in the temperate rainforest climate in which Valdez is situated, necessitated the further installation of a rain flap consisting of a strip of non-conductive geomembrane (XR-5) bonded to the CBA surface (see Figure 3) using hot asphalt "*in accordance with Alyeska's CIVE-50 Catalytically Blown Asphalt (CBA), Hypalon, or XR-5 Liner Repair Procedure*" (WSP 2024a). The shape was chosen to achieve a 15,000 ft^2 test intended to "*optimize drainage and minimize other conflicts*" (WSP 2024a). The shape that was selected added complexity to trenching and the installation of the rain flap.

Figure 3. Photographs of installed rain flap (from WSP 2024a).

ELL surveying (shown in Figure 4a) was performed in general accordance with ASTM D7007-24, *Standard Practices for Electrical Locating Leaks in Geomembranes Covered with Water or Earthen Materials* (ASTM 2024) and ASTM D8265-23, *Standard Practices for Electrical Methods for Mapping Leaks in Installed Geomembranes* (ASTM 2023). These methods are appropriate for ELL testing and are widely used in practice. Equipment used for ELL surveys is described in WSP (2024a) and is typical and appropriate for the work conducted. Initial testing demonstrated the gravel cover over the CBA was electrically isolated via the isolation trench. The ELL survey was initially conducted using east-west transects, but both north-south and east-west transects were used to evaluate manufactured leaks.

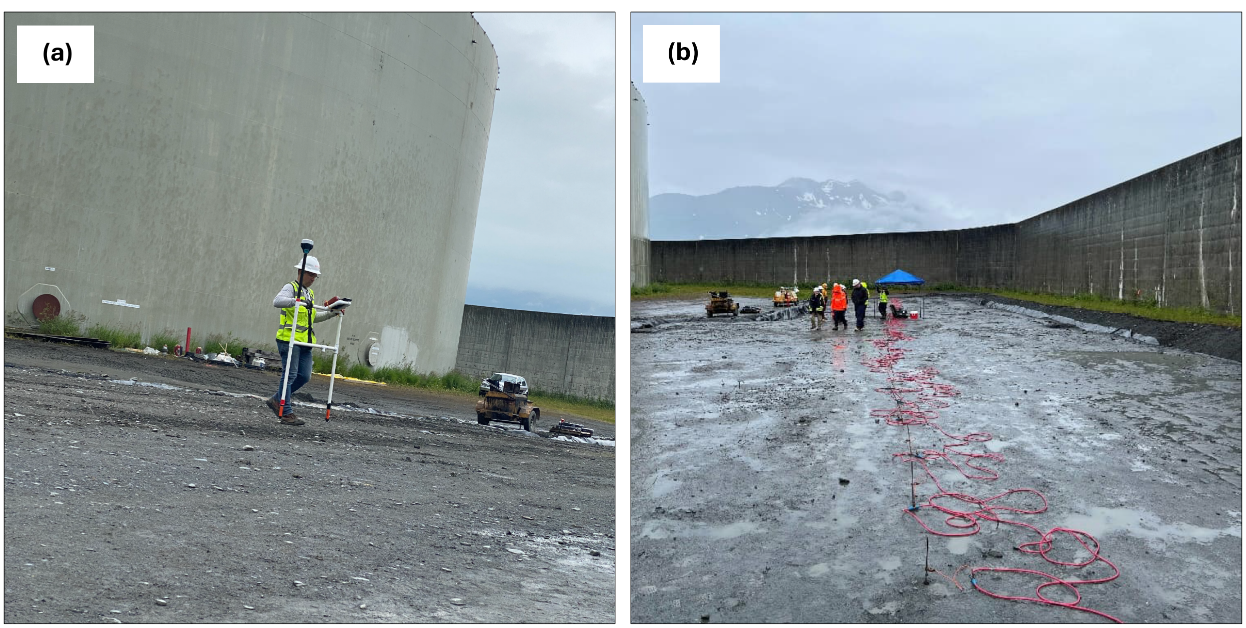

Figure 4. Photographs (a) electrical leak location survey and (b) electrical resistivity tomography (from WSP 2024a)

ERT (shown in Figure 4b) was performed along three approximately parallel transects running north-south in general accordance with ASTM D6431-18, *Standard Guide for Using Direct Current Resistivity Method for Subsurface Investigation* (ASTM 2018). Equipment used for ERT surveys is described in WSP (2024a) and is appropriate for the work conducted. Data were processed and the interpretation was conducted using industry standard commercial software.

After initial ELL and ERT surveys, four fully penetrating rips/cuts or holes were intentionally made (manufactured) in the CBA liner and re-buried. These defects are shown in Figure 5 and consisted of (1) a rip/cut 12-inch long with a ½-inch gap, (2) a rip/cut 6-in long without a gap, (3) a 1-in-diameter hole, and (4) a ½-inch-diameter hole.

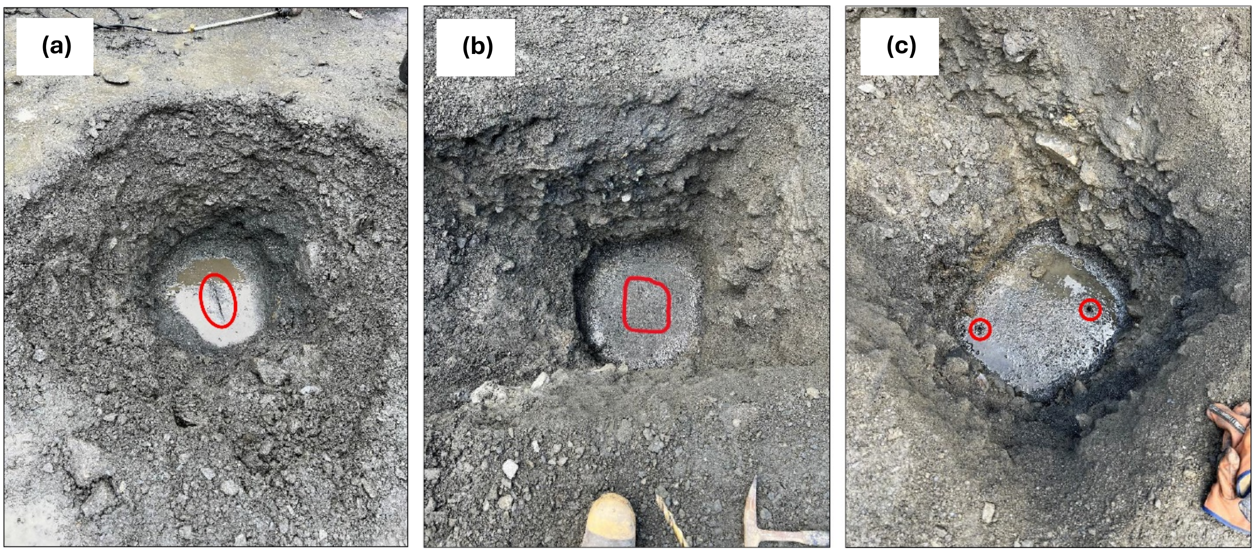

Figure 5. Photographs of manufactured defects: (a) a rip/cut 12-inch long with a ½-inch gap, (b) a rip/cut 6-in long without a gap, (c) a 1-in-diameter hole and a ½-inch-diameter hole (photos from WSP 2024a). Red oval in (a) outlines the rip/cut. Red outline in (b) outlines the rip/cut. Red circles in (c) outline the holes.

3. REVIEW OF PILOT STUDY FINDINGS

Key findings from the ELL and ERT pilot study reported in WSP (2024a) are summarized below in *italics*, followed by point-by-point comments.

1. ***ELL can effectively locate larger leaks in the CBA.*** *East-west ELL survey transects did not detect any potential leaks but also did not detect any of the manufactured leaks. North-south ELL survey transects were effective at locating the larger manufactured leaks. Therefore, future ELL survey transects should be run both parallel and perpendicular to one another (e.g., both north-south and east-west).*

   We agree that based on the findings of this study, ELL has been demonstrated to provide a method for indirect assessment of leaks in the SCS for the VMT East Tank Farm.

WSP notes that north-south survey transects were effective at locating the larger manufactured leaks, whereas none of the manufactured leaks were identified along the east-west survey transects. This dependence of transect orientation (north-south vs. east-west) is not common and is likely due to subsurface features that exist in the West Tank Farm, such as metal pipes, storm drains, and structural elements associated with the tank farm. These features may act as preferential flow paths for current below the liner, affecting orientation of the applied electrical field and masking electrical anomalies from defects in the CBA. Similar subsurface features are likely to exist in the East Tank Farm.

Furthermore, even though identified manufactured leaks were only detected using ELL surveys along north-south transects, the pilot study should not be interpreted to indicate that pre-existing leaks (non-manufactured) leaks do not exist along the east-west transects (or elsewhere). North-south ELL survey transects were only conducted over a limited area around the manufactured defects (less than 1/3 of the total area). Consequently, pre-existing leaks may exist but were not found detected along the north-south transects.

2. *Based on the results of the pilot study, ERT does not appear to be effective in delineating leaks in the CBA.*

   ERT surveys were only conducted in a north-south orientation and not in perpendicular orientations like the ELL surveys around the manufactured leaks. However, given the data were collected in the same orientation as ELL surveys that were successful in identifying the larger manufactured leaks, the likelihood of detecting leaks with additional perpendicular ERT transects is small. Therefore, we agree that ERT does not appear to be effective for delineating leaks in the CBA at the VMT.

3. *Effort was required to create an electrically isolating trench given the wet climate in Valdez.*

   We agree with this conclusion but also note that the isolation trench was constructed successfully for the pilot test. Additionally, Alyeska and their contractor (WSP) now have a much better sense of the level of effort and timing needed to successfully construct an isolation trench for future testing.

4. REVIEW OF PILOT STUDY RECOMMENDATIONS

Recommendations from the ELL and ERT pilot study reported in WSP (2024a) are summarized in *italics* below, followed by point-by-point comments.

1. *Based on the results of the pilot study, future efforts to evaluate the integrity of the East Tank Farm CBA liner at the VMT should include ELL surveys, temporarily de-energizing cathodic protection systems, and isolating any known potentially conductive perforations (e.g., metal pipes, storm drain catch basins) where practical.*

   We agree with this recommendation.

2. *ELL survey areas should be sized for each cell to include sufficient area to statistically calculate the estimated permeability of the SCS. WSP recommends a test area of 5% of the SCS (based on Pump*

Station 1, 3, 4, and 5 Liner Evaluation Method Recommendations; WSP 2024b; [this report was not made available for the authors' review]

We agree that the size of the ELL survey area should be selected for each cell so the evaluated area is sufficient to provide statistical confidence in the assessment. We disagree with the recommendation that 5% of the area should be tested. As described in Benson (2022), at least 20% of the CBA liner must be tested to adequately reduce uncertainty in the total number of defects determined from the survey. Additionally, assessments conducted on exposed CBA liner should not be extrapolated to represent conditions for buried CBA liner.

We disagree that the findings from the ELL surveys should be used to calculate an effective permeability of the SCS. Instead, we recommend that the findings be used to estimate a leakage rate (e.g., gallons per acre per day). Permeabilities are appropriate for porous media (e.g., soils), but are not appropriate for flow through defects in membrane-type liners such as the CBA liner.

We also agree with WSP (2024b) that the surveyed area should not include the isolation trench or a 5-ft-wide strip extending inward from the strip due to edge effects.

3. *Where future ELL indicates potential defects/leaks, the locations should be marked and excavated for visual inspection. If leaks are discovered, they should be patched, backfilled, and the ELL survey rerun over the location to verify there are no additional leaks.*

We agree with this recommendation.

5. RECOMMENDED PATH FORWARD

The pilot study demonstrated that ELL is effective at identifying larger leaks in the CBA liner in the SCS of the VMT. The following path forward is recommended to continue the evaluation of the SCS and to determine whether the SCS is "*sufficiently impermeable.*"

1. ELL surveys should be implemented over at least 20% of the CBA-lined area of the East Tank Farm. This does not include SCS area with exposed geomembrane that can be directly inspected, as this is a different liner material. Testing should consider the lessons learned from the pilot study, including:
    a. Use of similar methods and equipment as the pilot study (see WSP 2024a for specific testing details).
    b. Implementation of a series of orthogonal ELL survey transects by a skilled implementation team.
    c. The need for effective isolation of the test area.

    The ELL surveys can then be used to establish the frequency and size range of defects in the total East Tank Farm CBA liner.

2. Establish a quantitative definition of "*sufficiently impermeable*" as it applies to the SCS of the VMT. If the SCS had been built after May 1992, the definition would be "*sufficiently*

impermeable" would be "*using a layer of natural or manufactured material of sufficient thickness, density, and composition to produce a maximum permeability for the substance being contained of 1 x 10^{-6} cm per second at a maximum anticipated hydrostatic pressure, unless the department determines that an alternate design standard protects groundwater from contamination and contains a discharge or release until detection and cleanup.*"

[18 AAC 75.990 (124)] states that *"for a secondary containment system, that its design and construction has the impermeability necessary to protect groundwater from contamination and to contain a discharge or release until it can be detected and cleaned up.*"

A definition in terms of a maximum allowable leakage rate per unit area (i.e., maximum allowable oil leakage per acre of SCS per day) is preferred over a maximum permeability because the release of oil would occur predominantly through discrete defects in the liner and not by flow (permeation) of oil through the CBA liner.

3. Establish a methodology for computing the leakage rate (or equivalent permeability) of oil through the SCS. There are numerous methodologies used in practice for calculating leakage of liquids through defects in geomembranes. Modification of current state-of-practice methods to compute the leakage of oil will likely be required because the existing methods were developed for computing leakage rates for water. Additional physical characterization of the materials above and below the CBA liner will likely be required as inputs for these calculations.

4. Use the extrapolated survey results in (1) and the methodology in (3) to compute a leakage rate (or effective permeability) of the SCS and compare to this leakage rate to quantitative definition of "sufficiently impermeable" identified in (2).

Finally, WSP (2024a) indicates that the CBA liner has a "*thickness ranging from 0.1875 to 1.625 inches*." This is a change from earlier reports, which state that "*According to the construction documentation for the VMT, the specified minimum CBA liner thickness was 5/16 inch (0.31 inches)"* (Golder 2018). A portion of the CBA liner was observed to be thin (i.e., approximately 0.1875 inches) during pilot testing. Previous laboratory testing reported and summarized in Golder (2018) was conducted on liner as thin as 0.31 inches. Consequently, additional laboratory testing is needed to demonstrate that the liner will be effective in containing oil over the anticipated necessary duration of performance at a thickness of 3/16 inches (0.1875 inches).

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