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INTERIM SURFACE BARRIER EVALUATION REPORT

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EXECUTIVE SUMMARY

This report was developed in partial completion of proposed Milestone M-045-90 (Ecology et al. 2009, *Proposed Consent Decree and Tri-Party Agreement Modifications for Hanford Tank Waste Treatment*). It provides monitoring and performance results for the 241-T Tank Farm Interim Surface Barrier (TISB) and an evaluation of the barrier performance to reduce water infiltration as the driver for subsurface contamination to groundwater.

The TISB demonstration is being performed as an interim measure per agreement in the 2007 annual interim measures meeting between the U.S. Department of Energy and Washington State Department of Ecology as specified by the *Hanford Federal Facility Agreement and Consent Order* Milestone M-45-56 (Ecology et al. 1989).

The barrier is monitored at four locations for water content and soil pressure; two under the barrier, one on the edge of the barrier and one outside the barrier. Each location is monitored using capacitance probes in the top 2 m, heat dissipation units to 10 m and neutron probes to 15 m (50 ft). Since April 2008, when barrier construction was completed, the capacitance probes and neutron probes have shown an insignificant reduction in moisture under the barrier. This is partly because soil-water content was low when monitoring started and partly because of the short time that monitoring has occurred. The heat dissipation units show a reduction in soil pressure under the barrier and at the edge of the barrier, and provide a more definitive measure than soil-water content measurements. Measurements from the heat dissipation units show that the soils are gradually draining and the TISB is performing as planned. There was no indication of increased moisture except in monitoring outside the barrier.

Numerical models indicate that soils beneath the barrier will continue to drain. The numerical models also show that as soils drain, the rate mobile contaminants move toward the groundwater beneath 241-T Tank Farm is expected to decrease, delaying the peak concentration arrival time by about 5 years (2030 to 2035) and reducing the peak concentration of contaminants by 40 to 50% as compared to the peak concentration with no interim barrier. Results indicate that at a depth of 40 m (131 ft) below ground surface the peak concentration of ^{99}Tc at the groundwater was reduced by about half. The maximum estimated depth for any impact for the 241-T Tank Farm barrier was about 50 m (164 ft) below ground surface.

In addition to monitoring the barrier was inspected quarterly, initially for cracks, durability and maintenance needs. The key maintenance need for the TISB was removing wind-blown sand from the runoff trench. The wind-blown sand did not result in the spill of any water from the barrier or the trench, but did require cleaning out the trench several times until a cover was placed over the trench. After installing the cover, no other maintenance needs were observed.

Based on the monitoring and modeling results to date additional interim surface barriers are recommended as interim measures to slow water flux in other locations and reduce the rate contaminants move toward the groundwater prior to a final remedy. Drying effects in the Vadose Zone due to interim barriers will also reduce the groundwater impacts from potential retrieval leaks. Lessons learned from the TISB demonstration were identified and have been incorporated as appropriate. Current plans are to construct an interim surface barrier in 241-TY Tank Farm in 2010. Based largely on potential risk reduction for an interim surface

barrier, characterization and design for a barrier in the 241-SX Tank Farm are scheduled to be completed in fiscal year 2011.

Where information regarding treatment, management and disposal of radioactive source, byproduct material, and/or special nuclear components of mixed waste (as defined by the *Atomic Energy Act of 1954*) is incorporated into this document, it is not incorporated for the purpose of regulating the radiation hazards of such components under the authority of the Revised Code of Washington 70.105, "Hazardous Waste Management Act," and its implementing regulations, but is provided for information purposes only.

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LIST OF TERMS

Abbreviations and Acronyms

bgs	below ground surface
CP	capacitance probe
DOE	U.S. Department of Energy
Ecology	State of Washington Department of Ecology
FIR	field investigation report
FM	fast-moving (water)
FY	fiscal year
H	hydrogen (atom)
HDU	heat dissipation unit
HFFACO	Hanford Federal Facility Agreement and Consent Order
HMS	Hanford Meteorological Station
NP	neutron probe
SM	slow-moving (water)
SST	single-shell tank
TISB	T Farm interim surface barrier
UPR	unplanned release

Piston-Flow Model definitions

θ_i	initial soil-water content
θ_r	residual water content
θ_{std}	standard deviation of soil-water content
θ^{sm}	moisture content of slow-moving water
ψ_{avg}	average soil-water pressure
ψ	soil-water pressure
K_d	sorption coefficient
L	thickness of vadose zone or depth to groundwater
L_s	depth of contaminants from ground surface
L_s^*	relative depth of contaminant (L_s/L) to groundwater
L_s^{*max}	maximum relative depth of contaminants at which a barrier will be effective
L^{max}	barrier effective depth
q_i	initial recharge rate
q^{sm}	estimated recharge rate for slow-moving water
t_{df}	time needed for draining front to reach water table
t_s	time needed for center of contaminant mass to travel to groundwater
v^{fm}	velocity of fast-moving water
v_s	velocity of center of contaminant mass

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1.0 INTRODUCTION

The Hanford tank 241-T Tank Farm interim surface barrier (TISB) was installed in April 2008 to demonstrate the ability of a barrier to inhibit the infiltration of rain and melting snow into the soil and thus reduce the downward migration of a plume of contamination in the soil in T Farm caused by a past leak from tank 241-T-106 (T-106).

The TISB demonstration is being conducted as an interim measure per agreement in the 2007 annual interim measures meeting between the U.S. Department of Energy (DOE) and State of Washington Department of Ecology (Ecology) as specified by the *Hanford Federal Facility Agreement and Consent Order* (HFFACO) Milestone M-45-56 (Ecology et al. 1989). The results of this demonstration will be used to evaluate building interim surface barriers at other locations. The TISB is expected to remain in place as an interim measure and the TISB will continue to be monitored for several years to come. Original plans were to monitor the barrier for two years after construction, but this has been extended as valuable data is being collected. Although the data obtained provides insight as to long term performance, as expected, moisture changes over only a two year period are small and a larger data set is needed to evaluate the future impacts of the barrier on contaminant migration.

The demonstration barrier will help DOE answer a number of questions:

- How well will this technique work?
- What is the practicality of installing the barrier over a tank farm?
- What do barriers like this really cost?
- How effective will the barrier be?
- What are the long-term costs for operations and maintenance?
- Does the barrier reduce risk in localized areas and if so, how much?

This TISB demonstration report was developed in partial completion of proposed Milestone M-045-90 (Ecology et al. 2009, *Proposed Consent Decree and Tri-Party Agreement Modifications for Hanford Tank Waste Treatment*). The work scope/completion criteria for the report are: "The report shall include a recommendation and commitment on whether to proceed with additional interim barriers, and an evaluation of the barrier's ability to reduce water infiltration that drives migration of subsurface contamination to groundwater."

Section 2.0 provides background information for the TISB project. Section 3.0 summarizes TISB monitoring results to date. Section 4.0 includes recommendations and conclusions regarding TISB performance based on results to date. This section includes an evaluation of the affect of the TISB in reducing the rate of water infiltration and expected future impacts on migration of contaminants to the groundwater. Section 5.0 describes lessons learned from the TISB and Section 6.0 discusses alternatives, considerations and information needs for future interim barriers. Finally, Section 7.0 provides recommendations for whether to proceed with additional interim barriers.

2.0 BACKGROUND

The T-106 leak, the largest known leak in tank farms, was discovered in June 1973 after an estimated 115,000 gal of waste leaked over a 6- to 7-week period. Background information on T Farm, the T-106 leak event, and a description of the current understanding of the nature and extent of past major releases in T Farm is provided in RPP-23752, *Field Investigation Report for Waste Management Areas T and TX-TY*. The leak from tank T-106 consisted of Reduction-Oxidation waste with high concentrations of the mobile radionuclide ^{99}Tc. The ^{99}Tc isotope is a major contributor to human health impacts through the groundwater exposure pathway. The ^{99}Tc is already present in the groundwater and continues to migrate from the vadose zone downward. The infiltration of rain and snow melt is the primary driver in moving the contaminant plume. The T Farm Interim Surface Barrier Demonstration Project was implemented as an interim measure to reduce impacts to groundwater from the single-shell tank (SST) T-106 leak.

2.1 TANK 241-T-106 INTERIM SURFACE BARRIER DESCRIPTION AND FUNCTION

The TISB was installed in 2007/2008. It covers an area of approximately 5,600 m^2 (60,000 ft^2), has a 1% slope to a drain ditch, and 2% slope of the ditch to an infiltration area. Figures 1 and 2 are design drawings of the TISB. Design details are described in RPP-SPEC-33429, *Construction Specifications for T-Farm Interim Surface Barrier (TISB)*. The TISB components include the following:

- soil embankment and stabilization rock
- precast concrete block retaining walls
- vehicle access ramps
- polyurea liner
- tank element and drywell liner penetrations
- lined drainage ditch and infiltration area designed for a 25-yr, 24-hr storm event.

2.1.1 Soil Embankment and Stabilization Rock

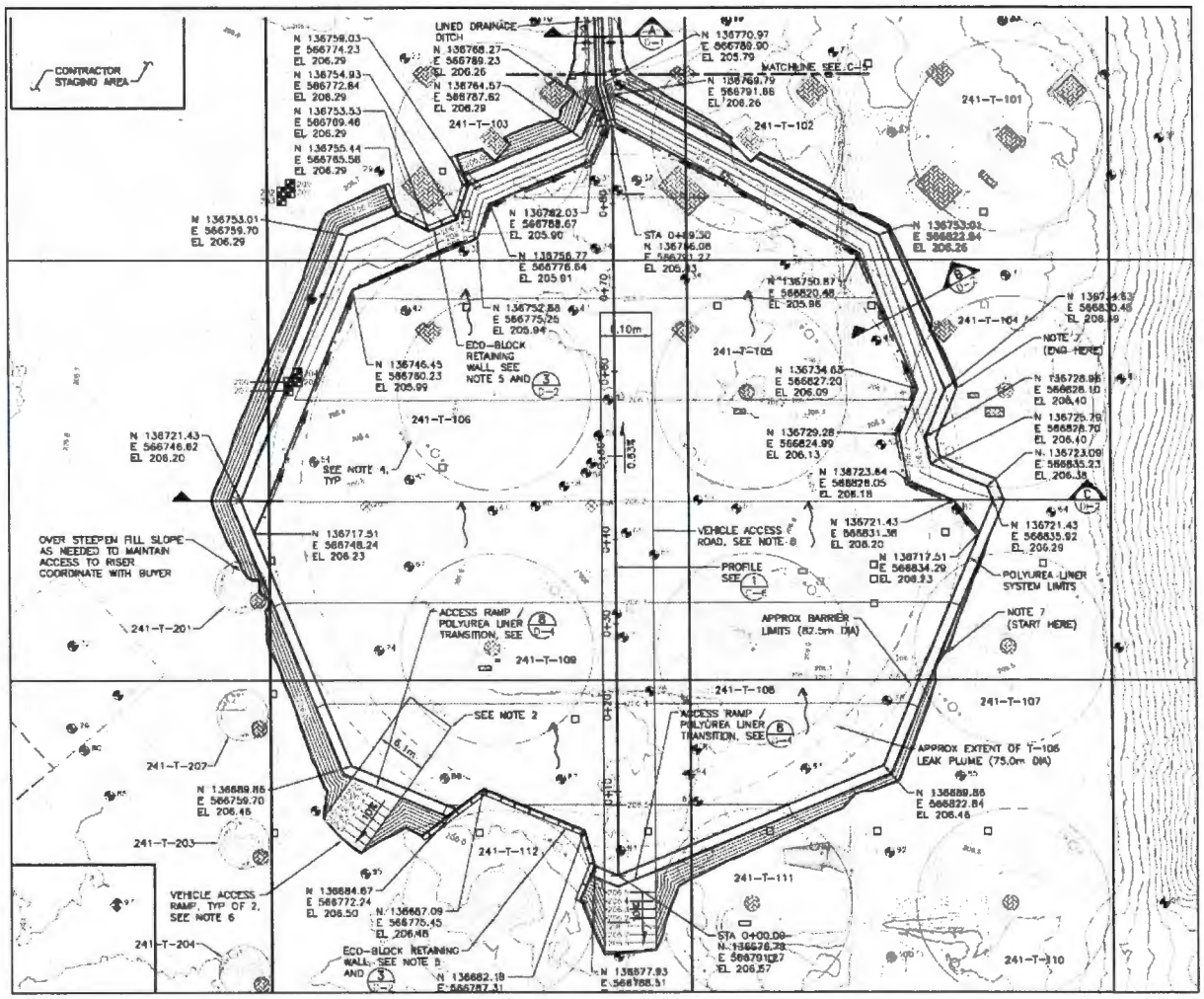
The grading plan for the TISB is shown in Drawing C-4 of the Construction Specifications (RPP-SPEC-33429). Soil fill was used to build up the area and form an engineered sloped surface to prevent surface water run-on and facilitate removal of surface water run-off from the barrier. The fill soil is sloped to the north to allow controlled surface water run-off to the lined drainage ditch. The 4 horizontal to 1 vertical (4H:1V) sloped sides of the engineered fill were covered with a minimum 0.076-m (3-in.) thick layer of 32 mm (1-¼ in.) minus crushed rock to prevent erosion of the side slopes.

2.1.2 Precast Concrete Block Retaining Walls

In perimeter areas precast concrete blocks were placed forming a retaining wall to hold the soil fill back. Two precast concrete block retaining walls were constructed: one on the south side of the interim surface barrier to avoid placement of fill soil over tank 241-T-112, and one on the

north side to avoid placement of fill soil over the weather covered riser pit for tank 241-T-103. The precast concrete blocks are placed tightly against one another and stacked to the required height. There is a guard rail attached to the top of the precast concrete block retaining walls.

Figure 1. Interim Surface Barrier Drawing (from RPP-SPEC-33429)

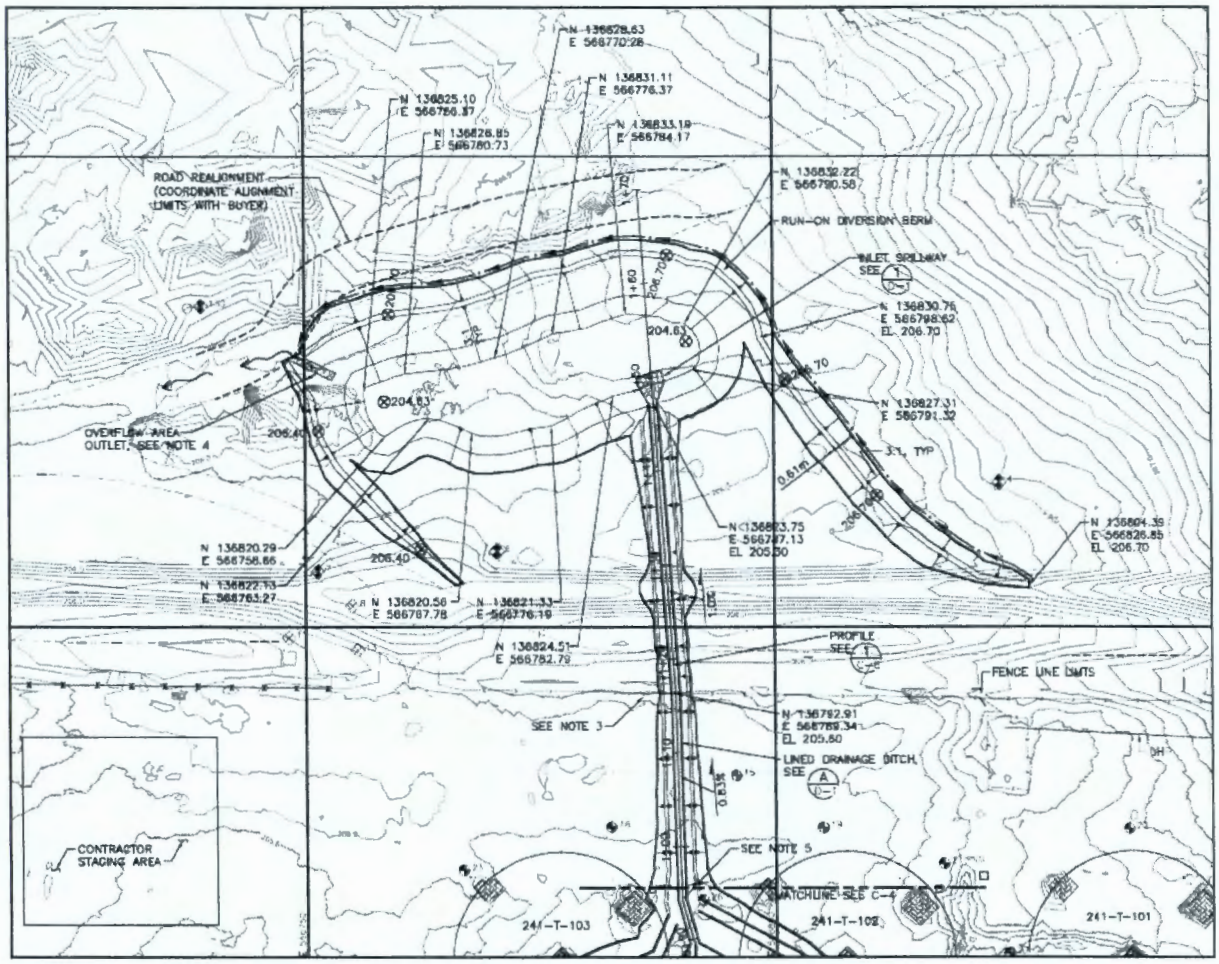


Reference: RPP-SPEC-33429, *Construction Specifications for T-Farm Interim Surface Barrier (TISB).*

2.1.3 Vehicle Access Ramps

Two ramps are provided on the south side of the interim surface barrier to provide vehicle access for operation, maintenance, and monitoring of the tank elements, drywells, and monitoring wells. The polyurea liner is designed and constructed to accommodate vehicle loads of up to 7,940 kg (17,500 lbs) per axle without material failure or permanent deformation (RPP-SPEC-32483, *T Farm Interim Surface Barrier Subsystem Specification*).

Figure 2. Tank 241-T-106 Interim Surface Barrier Infiltration Area (from RPP-SPEC-33429)



Reference: RPP-SPEC-33429, *Construction Specifications for T-Farm Interim Surface Barrier (TISB).*

2.1.4 Polyurea Liner

The liner consists of a geotextile fabric placed on and anchored to the sloped soil subgrade and covered with a spray-applied polyurea coating. The polyurea thickness is a minimum of 0.6 cm (0.25 in.). The polyurea coating is the Polyshield HT™ manufactured by Specialty Products, Inc., Lakewood, Washington. The geotextile is anchored with internal and perimeter anchor trenches filled with crushed rock. The surface of the liner is sloped to direct surface water run-off toward the lined surface water ditch that transfers the run-off to the infiltration area. The polyurea liner is constructed over a compacted soil berm on the north perimeter to prevent surface water at the north edge of the liner from running off over the exterior side slope. At the south perimeter a 15-cm (6-in.) half section of PVC pipe prevents surface water from running off the liner over the exterior side slope. A 30-cm (1-ft) high berm of 32-mm (1-¼ in.) minus crushed rock is constructed on top of the north perimeter anchor trench where needed to prevent storm water from running onto the liner.

2.1.5 Tank Element and Drywell Liner Penetrations

The TISB physically interfaces with the surface of the tank farm and all SST systems, structures, and components that are located on or penetrate the surface of the tank farm within the interim surface barrier coverage area. Various liner penetrations are constructed at these interfaces, including the following:

- tank element utility vault liner penetrations
- tank element utility vault with cover liner penetrations
- tank element pipe sleeve liner penetrations
- tank element liner boot penetrations
- drywell pipe sleeve liner penetrations
- monitoring nest pipe sleeve liner penetrations.

2.1.6 Lined Drainage Ditch and Infiltration Area

Surface water run-off is transferred away from the surface barrier through a drainage ditch to an infiltration barrier. The drainage ditch is 148.4 m (487 ft) long and 0.91 m (3 ft) wide at the bottom. Side slopes of the ditch are 2:1. The TISB infiltration area is a graded depression 2.1 m (6.8 ft) deep located north of the T Farm fence line. The bottom of the area measures 35 × 8.8 m (115 × 29 ft) and is flat to allow maximum surface area for infiltration. There is an inlet spillway where the ditch enters the infiltration area. The infiltration area is surrounded by a run-on diversion berm on the east, north, and west sides. There are 0.3-m (1-ft) thick riprap aprons at the ditch inlet spillway and the overflow area outlet spillway to minimize erosion. The entire infiltration area is located outside of the T Farm fence line. The location of the infiltration area was selected to minimize barrier cut and fill; in a clean area (sampled to ensure no contaminants below the area), and in an area far enough away from the barrier and in a location such that discharge to the infiltration area was expected to flow through the vadose zone away from the barrier.

2.1.7 Barrier Function

The function of the surface barrier is to reduce the infiltration of precipitation and snow melt into the soil resulting in gradual drying of the soils under the barrier and reducing the rate of contaminant migration towards the groundwater. Functional requirements for the surface barrier, run-off conveyance system, and infiltration/run-off areas are specified in RPP-SPEC-32483 and include the following:

- cover the ground surface of the T-106 leak vadose zone plume to minimize the infiltration of precipitation

- prevent surface water run-on

- control surface water run-off by collecting the barrier run-off in a lined ditch and routing run-off to an infiltration area outside the tank farm

- function under environmental conditions present at the Hanford Site for a period of 25 years
- function with minimal maintenance
- accommodate tank farm operational needs, including foot and vehicle access.

2.2 TANK 241-T-106 INTERIM SURFACE BARRIER MONITORING AND INSPECTION

The TISB is monitored and inspected as specified in the PNNL-16538, *T Tank Farm Interim Surface Barrier Demonstration – Vadose Zone Monitoring Plan* and the RPP-37248, *Inspection and Maintenance Guidance Manual for the T Farm Interim Surface Barrier Demonstration Project*. Monitoring, inspection and maintenance are intended to ensure that the TISB meets functional and performance objectives.

2.2.1 Moisture Monitoring

Vadose zone moisture is monitored to assess the effectiveness of the barrier at reducing soil moisture. In accordance with a monitoring plan (PNNL-16538) a solar-powered system was installed to continuously monitor soil-water conditions at four locations (i.e., instrument Nests A, B, C, and D) beneath the barrier and outside the barrier footprint as well as site meteorological conditions (see Figure 3). Nest A is placed in the area outside the barrier footprint and serves as a control, providing subsurface conditions beyond the influence of the surface barrier. Nest B provides subsurface measurements to assess surface-barrier edge effects. Nests C and D are used to assess changes in soil-moisture conditions beneath the interim surface barrier.

As shown in Table 1, each instrument nest is composed of a capacitance probe (CP) with multiple sensors, multiple heat dissipation units (HDUs), and an access tube for neutron probe (NP) measurements. The principal variables monitored for this purpose are soil-water content and soil-water pressure. Soil temperature, precipitation, and air temperature are also measured. Table 1 summarizes the monitoring system. The monitoring instruments and functions are described in detail in the monitoring plan (PNNL-16538).

2.2.1.1 Neutron Moisture Probe. The neutron moisture probe uses a radioactive source of fast neutrons (mean energy of 5 MeV) and a detector of slow neutrons (~0.025 eV) to measure soil-water content. If the neutron hits a hydrogen (H) atom, its energy is reduced. Changes in H content occur mainly because of changes in soil-water content; therefore, the concentration of thermal neutrons surrounding a neutron source placed in the soil can be related to the soil volumetric water content. Neutron-probe monitoring of the TISB uses a 503DR hydroprobe manufactured by CPN International, Inc., Martinez, California. The NP access tubes are 6.35-cm (2.5-in.)-outside diameter, 0.95-cm (0.375-in.)-thick 4140 carbon steel casings.

Figure 3. Tank 241-T-106 Interim Surface Barrier Moisture Monitoring Nests

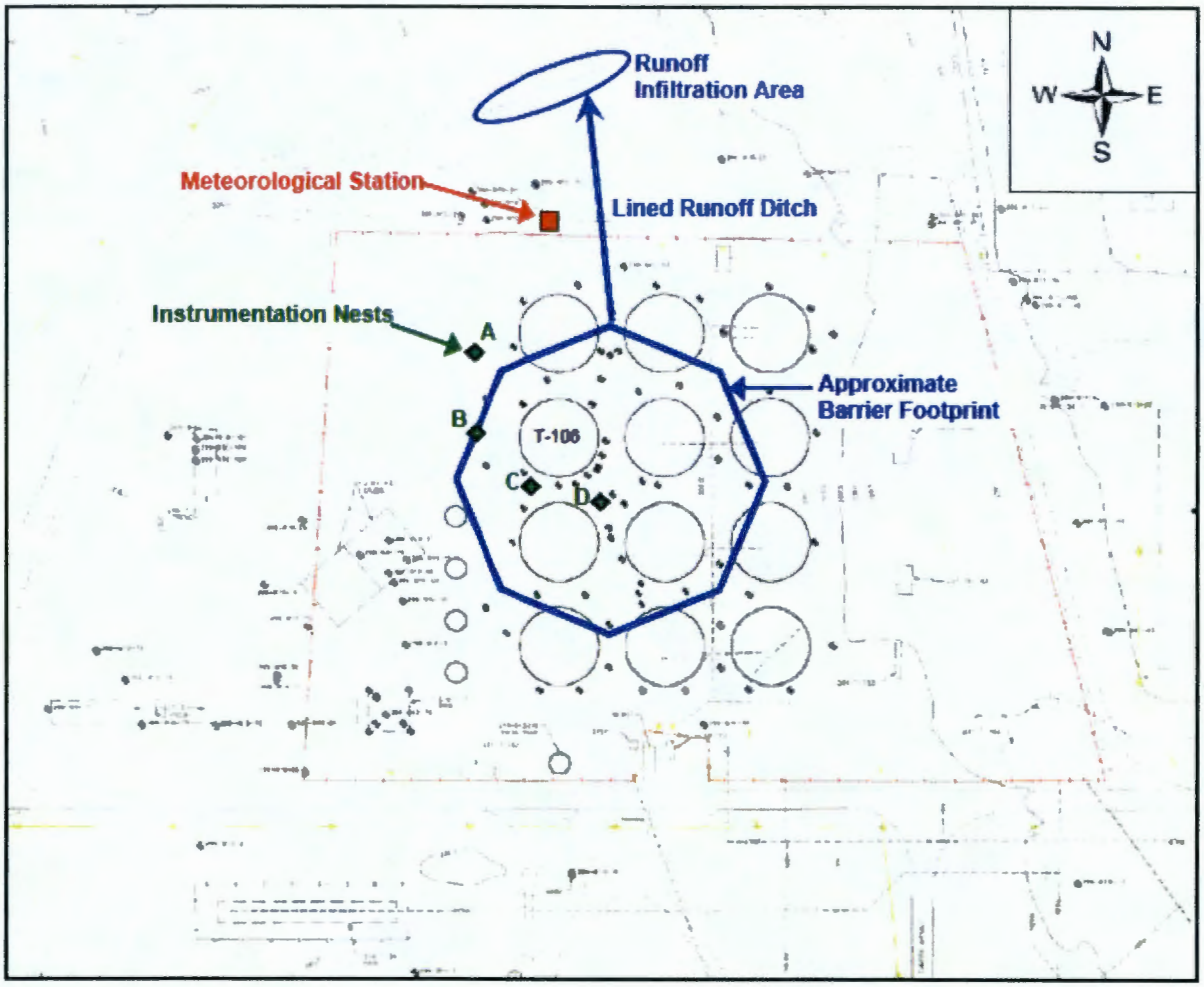


Table 1. Tank 241-T-106 Interim Surface Barrier Moisture Monitoring System

Monitoring Instrument	Monitoring Variable	Instrument Placement (Nest)	Depth of Sensors/ Measurement Points	Actual Monitoring Frequency
Neutron Moisture Probe	Soil-Water content	A, B, C, D	From 0.3 to 15.2 m below ground surface at 0.3-m interval	Quarterly
Capacitance Probe	Soil-Water content	A, B, C, D	0.6, 0.9, 1.3, 1.8, and 2.3 m	Hourly
Heat Dissipation Unit	Soil-Water Pressure	A, B, C, D	1, 2, 5, and 9 or 10 m	Every 6 hours
Heat Dissipation Unit	Soil Temperature	A, B, C, D	1, 2, 5, and 9 or 10 m	Every 6 hours
Thermistor	Air Temperature	Met Station	–	Every 15 minutes

2.2.1.2 Capacitance Probe. The CP is an electromagnetic method used to measure the volumetric soil-water content of the surrounding soil. The capacitance method uses the soil surrounding the electrodes as part of a capacitor in which the dipoles of water in the soil become polarized in response to the frequency of an imposed electric field. Hence, oscillation frequency is a function of soil-water content. The CP used for the TISB monitoring is the EnviroSMART probe manufactured by Sentek Pty Ltd, Stepney, Australia.

2.2.1.3 Heat Dissipation Unit. Heat dissipation units consist of a heater and a temperature sensor in a porous ceramic. An HDU indirectly measures the soil matric potential by measuring thermal conductivity. Heat dissipation unit measurements are independent of soil texture because the heat pulse is restricted to the ceramic. It is also independent of salinity because the method is independent of electrical conductivity. Heat dissipation units have the added benefit of also measuring soil temperature. The HDU used for TISB monitoring is the model 229-L HDU manufactured by Campbell Scientific, Inc., Logan, Utah.

In addition to the moisture monitoring instruments, a rain gage and thermistor are used to measure precipitation and air temperature at T Farm.

2.2.2 Inspection and Maintenance

In addition to moisture monitoring, the barrier is physically inspected for damage and maintenance needs as specified in RPP-37248. Inspections involve checking the barrier for the following most likely types of damage:

- water erosion of the embankment side slopes and ditches
- animal burrowing
- cracking of the polyurea liner from environmental stresses (e.g., thermal, wind uplift)
- punctures of the polyurea liner from vehicle traffic running over debris or off-limit access on the liner
- solar radiation degrading the polyurea liner
- temperature-caused stresses and associated cracking at the liner penetrations
- settlement and associated ponding of surface water around the liner penetrations or other hard spots beneath the liner.

Inspections and maintenance are performed for the soil embankment and stabilization rock, precast concrete block retaining walls, vehicle access ramps, polyurea liner, tank element and drywell liner penetrations, and lined drainage ditch, infiltration area, and appurtenances (inlet spillway, run-on diversion berm, and overflow area outlet). Inspection activities also cover general housekeeping (e.g., blown sand accumulation). Descriptions of these barrier components and specific inspection and maintenance are discussed in the following sections.

2.2.2.1 Soil Embankment and Stabilization Rock. The side slopes are inspected for conditions that could compromise the polyurea liner or its ability to drain surface water as intended, including erosion, settlement, or slippage of the crushed rock to the extent that the underlying fill soil is exposed.

Repairs generally will consist of regrading the crushed rock and/or placing additional crushed rock on the slopes to repair any damage. Wind-blown sand that builds up over the stabilization rock will be removed periodically so that it does not result in substantial contribution to sand covering the polyurea liner.

2.2.2.2 Precast Concrete Block Retaining Walls. The walls are visually inspected for structural integrity, including but not limited to: horizontal and vertical displacement, closeness of the concrete blocks to one another, cracking of the concrete, and other conditions that could have the potential to compromise the integrity of the retaining walls or the liner adjacent to the barrier.

Precast concrete blocks are repaired and/or replaced as needed to maintain the structural integrity of the retaining wall. Cracking or strain in the liner at the wall interface are carefully watched and repaired if visual damage or separation is evident.

2.2.2.3 Vehicle Access. Inspections include observing and documenting the condition of the access ramps. Maintenance of the ramps will consist of re-grading the crushed rock and/or placing additional crushed rock to repair any damage to the ramps.

2.2.2.4 Polyurea Liner. The liner is visually inspected for the following:

- liner is free of rocks, sticks, combustible material (tumbleweeds), and other debris
- minimal wrinkles or waves in the liner
- no areas of excessive wear, gouges, cracks, tears or evidence of animal intrusion, or other physical damage that have the potential to compromise the integrity of the interim surface barrier
- no evidence of wind uplift at the perimeters
- liner is securely anchored in the anchor trenches
- polyurea behind retaining walls drains surface water away from the liner
- liner adherence to the precast concrete retaining walls
- liner penetrations, depressions or other structural deficiencies
- rocks, sticks, and other debris are removed from the liner
- noted defects and damages in the liner potentially allowing surface water infiltration to the subsurface beneath the liner are repaired as soon as practical.

2.2.2.5 Tank Element and Drywell Liner Penetrations. The general condition of each liner penetration is inspected for liner adherence and condition. Noted defects and damages in liner penetrations are repaired.

2.2.2.6 Lined Drainage Ditch and Infiltration Area. The drainage and infiltration area are inspected to for wind-blown sand or other debris that may impede flow or impact the required infiltration area capacity. The drainage liner is inspected for defects or damages. If sediment appears to be impeding flow or infiltration, or if excessive sediment and/or debris have accumulated in the ditch or the infiltration area, maintenance is requested. Noted defects and damages in the polyurea ditch liner are repaired.

2.2.2.7 Radiological Surveys. In addition to barrier inspections, routine radiation surveys of the T Farm are conducted as directed in HNF-5183, *Tank Farms Radiological Control Manual (TFCRM)*. The drainage ditch and infiltration area outside the T Farm fence line are also inspected as part of routine surveys of the T Farm.

3.0 TANK 241-T-106 INTERIM SURFACE BARRIER MONITORING AND INSPECTION RESULTS TO DATE

3.1 MONITORING RESULTS

This section summarizes the functionality of the vadose zone monitoring system in T Farm and the affects of the TISB on soil-water content. In general, the TISB performed as expected. The primary variables monitored included:

- soil-water content measurements by the CPs
- normalized soil-water content by an NP
- soil-water pressure measurements by the HDUs.

The secondary variables monitored included:

- soil temperature measured by HDUs
- air temperature and precipitation from the T Farm Meteorological Station
- temperature within the datalogger enclosures
- battery voltages.

To check the system's functionality, measured air temperature, temperature within the data logger enclosures, and precipitation were compared with those from the Hanford Meteorological Station (HMS). Per the recommendation of the FY 2007 report (PNNL-17306, *T Tank Farm Interim Surface Barrier Demonstration—Vadose Zone Monitoring FY07 Report*), drain gauges, originally installed as part of the monitoring system, have not been used since FY 2008 because neither of the two drain gauges detected any drainage. It was determined that the drain gauges did not function correctly because soils contained more silt with higher moisture retention properties than expected.

3.1.1 Functionality of the Monitoring System

The battery voltage is examined because most instruments require a minimum voltage to remain in normal operation. The functionality of the instrument nests and meteorological station was assessed by comparing the measured air temperature and precipitation at T Farm with those measured at the HMS, which is 1.7 km (1 mile) from T Farm. Soil-temperature behavior was examined to assess the functionality of the HDUs.

3.1.1.1 Battery Voltage. Rechargeable batteries were used for the instrument nests and the meteorological station. Each battery was recharged by a connected solar panel. The system was designed to require a minimum of 12 V to function, but to date 11 V has proved to be adequate. Generally, the lowest battery voltage often occurred in December or January of the year when solar energy was least available. However, for all five batteries, the minimum voltage was 12.6, 12.6 and 12.0 V for FY 2007, FY 2008 and FY 2009, respectively, which indicates sufficient power to the instruments. In FY 2010, for the batteries in Nests A, B and the meteorological station, the minimum voltage was no less than 12 V. However, the batteries in Nests C and D showed the minimum battery voltage of 9.8 and 9.3 V, respectively, in December and January due to the extended cloudy days. Nests C and D stopped working for a period from a few hours to a day on one occasion for Nest C and two occasions for Nest D when the battery voltages were very low. These two batteries were replaced on January 13, 2010.

3.1.1.2 Air Temperature. The daily average air temperature measured at the meteorological station located outside of the fence of T Farm, the reference temperatures of the data loggers in the instrument nests, and the air temperature from the HMS are compared. The temperature measurements from the different locations were very consistent. Between all locations, the difference in daily average temperature was within about ±3°C. The measurements at T Farm were about 0.3 to 0.7°C higher than those at HMS from FY 2007 to FY 2010. The air temperatures from the sensors in Nests C and D were consistent with those of A and B. These indicate that the data loggers for each of the instrument Nests were functioning properly.

3.1.2 Barrier Effects on Soil-Water Content

A timeline showing major events of monitoring system installation, data logging, and the surface barrier construction is given below.

- September 2006: Completed the installation of instruments in Nests A and B and the T Farm meteorological station; started data logging from instruments in Nests A and B and the T Farm meteorological station.
- June 2007: Completed the installation of instruments in Nests C and D.
- April 2008: Completed the construction of the interim surface barrier.
- May 2008: Instruments in Nests C and D were connected for data logging.

Construction of the interim surface barrier was completed in April 2008. The barrier is impermeable to any liquid or gas and it is expected that there is no exchange of water between

the atmosphere and the soil beneath the barrier. As a result, the water content of the soil beneath the surface barrier (Nests C and D) should not be affected by temperature and precipitation and should have little seasonal variation compared to soils exposed to the natural condition (Nest A). The variation of θ in FY 2009 is quantified by the standard deviation of soil-water content (θ_{std}) and is summarized in Table 2. Generally, the variation of θ in Nest A was the largest with θ_{std} ranging from 0.004 m^3 m^{-3} at 2.3 m (7.5 ft) depth to 0.034 m^3 m^{-3} at 0.6-m (2-ft) depth. For Nest B, the maximum θ_{std} was 0.019 m^3 m^{-3} at the 0.9-m (3-ft) depth and was no more than 0.004 m^3 m^{-3} at other depths. For Nests C and D, the θ_{std} was no more than 0.002 m^3 m^{-3} at all depths, indicating a very stable soil-water condition.

Table 2. Standard Deviation of Soil-Water Content (m^3 m^{-3}) Measured by Capacitance Probe

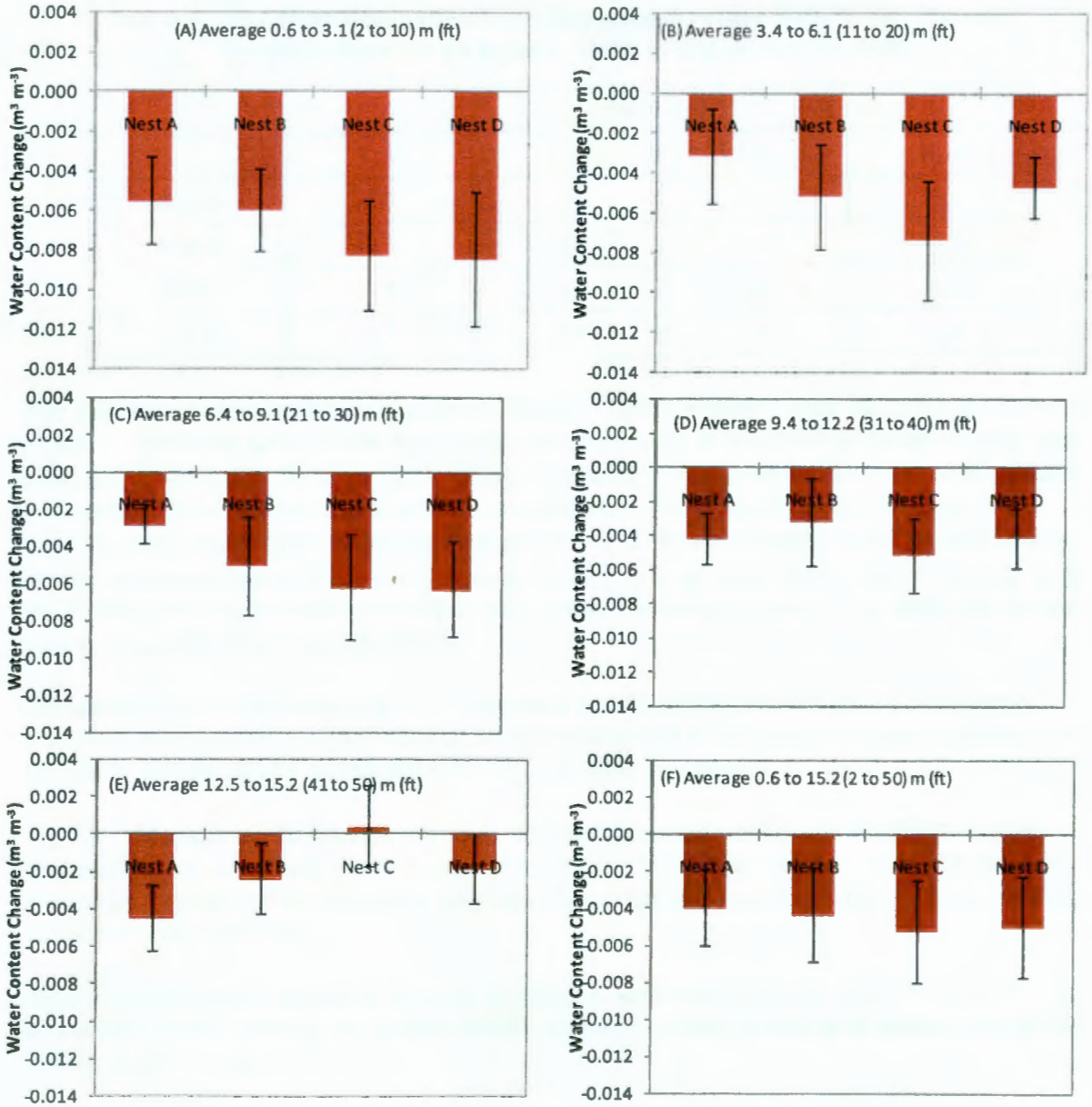
Nest	Depth (m)				
	0.6 m	0.9 m	1.3 m	1.8 m	2.3 m
Nest A	0.034	0.014	0.013	0.005	0.004
Nest B	0.004	0.019	0.001	0.001	0.001
Nest C	0.001	0.001	0.001	0.001	0.001
Nest D	0.002	0.000	0.001	0.000	0.001

Nest A data collected from October 1, 2008 to September 30, 2009.
Nest B data collected from October 1, 2008 to July 14, 2009 (data became noisy and unreliable after July 14, 2009).
Nest C data collected from October 1, 2008 to September 19, 2009.
Nest D data collected from June 12, 2009 to September 30, 2009 (data earlier than June 12, 2009 were noisy and considered unreliable).

To assess the barrier impact on the soil-water condition based on the NP measurements, the measured soil-water content was averaged over 3.1-m (10-ft) intervals and also over the whole profile. Figure 4 shows the the average change in moisture content at different depths and the measured standard deviations from April 9, 2008, the time the barrier construction was nearly completed, to August 6, 2009 (PNNL-19123, *T Tank Farm Interim Surface Barrier Demonstration – Vadose Zone Monitoring FY09 Report*). Generally, the average changes were negative, meaning the soil became drier during this period. At the depths from ground surface to 9.1 m (30 ft) below ground surface (bgs), the decreases of θ were between 0.003 and 0.006 m^3 m^{-3} in Nests A and B, and between 0.003 and 0.009 m^3 m^{-3} in Nests C and D [Figure 4(A), (B) and (C)]. At the depth below 9.1 m [Figure 4(D) and (E)], there was no difference in θ between the Nests. On average over the whole profile (from ground surface to depth 15.2 m [50 ft]), the change was about 0.006 m^3 m^{-3} in Nests A, and about 0.008 m^3 m^{-3} in C and D. However, the difference between Nest A outside of the barrier and Nests C and D inside the barrier was less than the measuring resolution (i.e., uncertainty) of an NP, i.e., about 0.016 m^3m^{-3}. In most cases, the measured change was smaller than the standard deviation within the corresponding soil layer. Consequently, the NP soil-water content results at most can be used qualitatively but not quantitatively to indicate changes in soil moisture content. The small changes in soil moisture

content are attributed to the relatively coarse texture of the soil with low water content under natural conditions and the short evaluation period.

Figure 4. Depth-Averaged Soil-Water-Content Changes from April 9, 2008 to August 6, 2009*



*Measured using neutron probes at different depths. The vertical lines indicate the range of $2\sigma_\theta$ with σ_θ being the standard deviation of water-content change within the layer the average was taken. The depth below ground surface was relative to the ground surface before barrier construction.

However, the HDU measurements show more significant changes (Table 3). The average annual pressure (ψ_{avg}) measured in FY 2009 ranged between -1.4 and -1.8 m for Nest A, -1.1 to -2.8 m

for Nest B, -1.9 to -4.9 m for Nest C, and -1.0 to -3.2 m for Nest D. Hence, Nest A outside of the barrier footprint has the largest (least negative) ψ_{avg} values, indicating the wettest condition and fastest soil-water flux; Nests C and D below the barrier had the smallest ψ_{avg} values, indicating the driest conditions and slowest soil-water flux; Nest B at the edge of the barrier had the intermediate ψ_{avg} values.

Table 3. The Heat Dissipation Unit-Measured Average Soil-Water Pressure Head (m) Between October 1, 2008, to September 30, 2009

Nest	Depth (m)			
	1 m	2 m	5 m	10 m
Nest A	-1.8	-1.4	-1.6	-1.5
Nest B	-2.1	-2.8	-1.9	-1.1
Nest C	-4.9	-2.3	-1.9	-3.2
Nest D	-3.2	-2.5	-3.0	-1.0

The soil-water pressure (ψ) changes from October 1, 2008, to September 30, 2009, are shown in Figure 5. Different colors in the figure represent the depths at which HDU measurements were obtained. For Nest A, there was little change in ψ after a year at all depths because the ground surface condition was exposed to normal precipitation. For Nests B, C and D, there were significant decreases (more negative) in ψ at the 1-m, 2-m, and 5-m (3.3-ft, 6.6-ft, and 16.4-ft) depths, indicating the soil beneath the barrier became drier at these depths; the changes in ψ at the 10-m (33-ft) depth were relatively small because the drainage water from shallower depths kept moving into the soil at this depth.

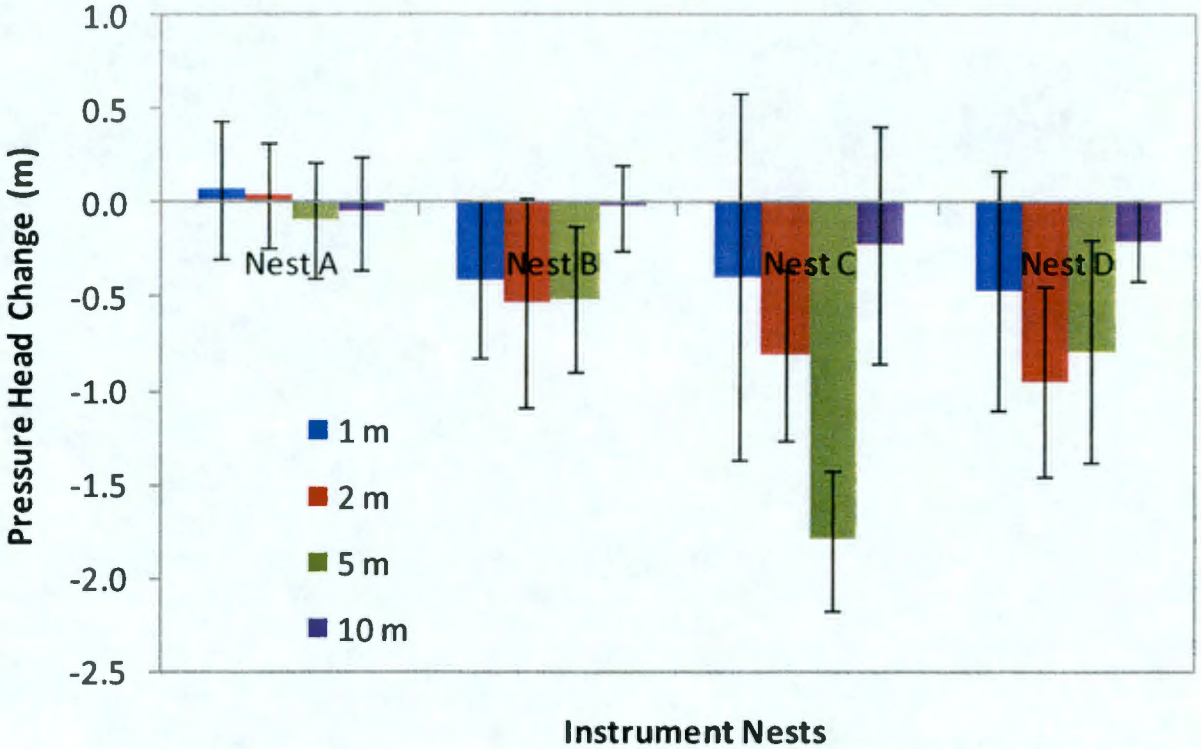
Barrier monitoring is continuing and preliminary results to date for the first two quarters of FY 2010 show similar results with HDU values continuing to gradually decrease in Nest C and D. These results will be included the FY 2010 monitoring report.

3.1.2.1 Monitoring Recommendations. Capacitance probes tended to malfunction more frequently than other sensors due to corrosion on the CPs. Water-proof sealant such as epoxy should be applied to CPs around the unsealed electronics and connectors before deployment to circumvent the corrosion.

Heat dissipation units appear to be more sensitive to soil-water changes than CPs and NP at low soil-water content beneath the surface barrier; therefore, it may be useful to install more HDUs deeper in the soil profile.

A larger solar panel, dual solar panels or batteries connected in parallel for each instrument nest are recommended to provide additional charging capabilities during the winter season and cloudy days.

Figure 5. Soil-Water Pressure Head Changes from October 1, 2008, to September 30, 2009*



*The vertical lines indicate the range of two times measurement error of pressure head.

3.2 INSPECTION RESULTS

The first quarterly inspection of the TISB was performed on May 28, 2008. The inspection team included members from Tank Farm Engineering, Tank Farm Operations, Environmental Engineering, and Construction Management (RPP-RPT-38568, *Initial Inspection of T Farm Interim Surface Barrier*).

The inspection identified three areas of concern documented in PER-2008-1207. The findings were as follows.

1) Sand has eroded away from around the base of concrete/ecology block walls on the south and north ends of the barrier.

2) Wind-blown sand remains on the barrier at the mouth of the drainage trench.

3) Small cracks or pits in the liner were observed on or near liner seams at five locations.

4) A minor amount of wind-blown sand had been deposited in front of the concrete/ecology block wall by tank 241-T-103 on the north end of the barrier.

Work plans were put in place and corrective actions were taken to repair small cracks in the liner, fill in eroded areas with gravel and remove wind-blown sand. In several surveillances the wind caused the drainage trench leading to the infiltration area to fill in with wind-blown sand. The sand did not build up on the barrier itself and to date there has not been a need to remove sand from the infiltration area. These corrections are documented in the closed PER.

As noted in RPP-RPT-38568, future inspections were scheduled through the Tank Farms work control process and performed by Operations personnel. Results were documented in work plans TFC-WO-08-0341, *241-T, Surface Barrier Check / Qtrly*, TFC-WO-08-2251, *241-T, Qtrly Surface Barrier Check*, TFC-WO-09-1792, *241-T, Qtrly Surface Barrier Check*, TFC-WO-09-2930, *241-T, Qtrly Surface Barrier Check* and TFC-WO-09-4255, *241-T, Qtrly Surface Barrier Check.*

Wind-blown sand accumulated in the discharge trench and had to be removed several times; eventually the trench was covered with metal plate and a sand fence was constructed to the west of T Farm before the September 2009 inspection. Another item noted was the liner pulling away from some of the risers. A tight seal is not required, only that the barrier integrity be sound to 15 cm (6 in.) above the riser. Since covering the trench, no additional maintenance issues have been identified for the TISB and inspections are now on a semi-annual schedule.

3.3 BASE-LINE SPECTRAL GAMMA LOGGING

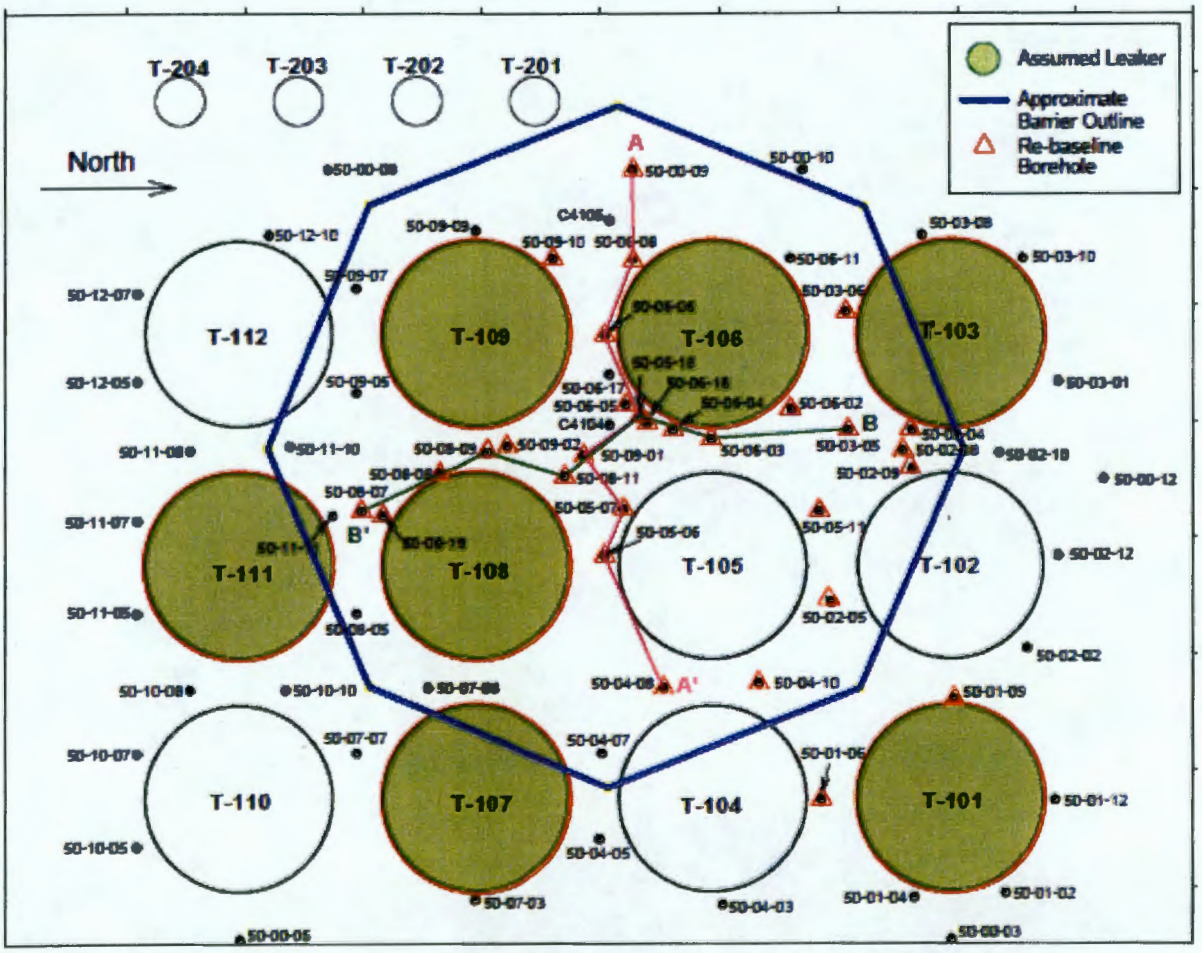
Spectral gamma logging was performed in 2008 to provide a measure of change in gamma emitting contaminant movement between the time the spectral gamma baseline was established in 1997 to 1999 and re-baselining in August and September of 2008. Re-logging the drywells allows a comparison of contaminant movement before and after barrier installation by re-establishing baseline conditions near the beginning of barrier operations. Due to the construction of the drywells, moisture measurements by logging could not be obtained. Figure 6 shows the T Farm wells that were logged. The logging results are reported in RPP-RPT-44202, *Hanford Geophysical Logging Project Spectral Gamma Re-Baseline Logging for the T-Farm Interim Surface Barrier.*

The spectral gamma logging system profiles indicate that several gamma-emitting contaminants have migrated since the 1997 to 1999 baseline as indicated by a change in contaminant activities over time that is not consistent with radioactive decay. Cobalt-60 migration was indicated in 17 of the 30 drywells logged (Figure 7). This was not a surprise; RPP-RPT-44202 states that ^{60}Co is known to be relatively mobile and indicates ^{60}Co movement was suspected based on drywell total gamma Radionuclide Assessment System monitoring between 2001 and 2003. Tracking the movement of ^{60}Co was one of the reasons for monitoring drywell activity.

Migration of ^{137}Cs was also indicated by small changes in two drywells near tank T-106 and an apparent increase in drywell 50-02-05. After re-logging 50-02-05 using a High Rate Logging System in 2009, a significant increase (from 2,000 pCi/g to 50,000 pCi/g) was observed. A tank leak assessment was convened and additional logging performed at drywell 50-02-05 and surrounding drywells. These wells were selected in an effort to circle 50-02-05 and to assess the

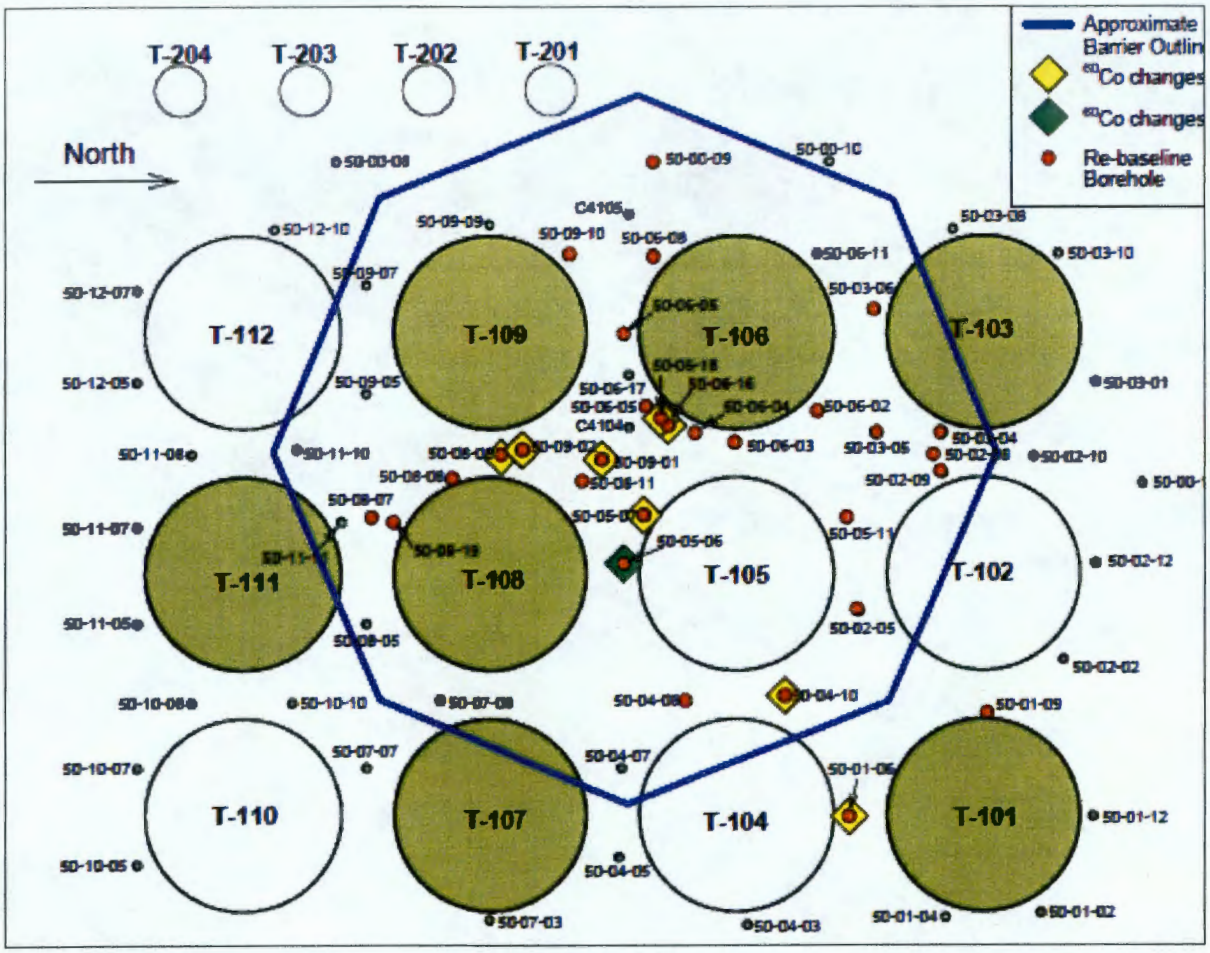
potential for movement or influence from the infiltration area. Neither increases in gamma activity in surrounding wells nor indication of influence from the infiltration area were observed. There has been no additional increase in gamma activity at drywell 50-02-05 since the 2009 High Rate Logging System logs were run. The liquid surface level in tank 241-T-102 is stable and the assessment concluded that there is no indication of a tank leak. Additional detail regarding monitoring at 50-02-05 is included in the logging report (RPP-RPT-44202) and Letter WRPS-0901156, "Drywell 50-02-05 Investigation Plan, Revision 0."

Figure 6. 241-T Tank Farm Drywells (Dry Boreholes) Logged in 2008 Using the Spectral Gamma Logging System



As the soil under the barrier dries out, the rate of contaminant movement is expected to be reduced or completely stop. Because drying under the barrier is a slow process, as discussed in Section 3.1, changes in gamma movement will not likely be evident from logging until several years in the future.

Figure 7. Cobalt Changes in 241-T Tank Farm Logging



4.0 EVALUATION OF TANK 241-T-106 INTERIM SURFACE BARRIER PERFORMANCE

After the emplacement of an interim surface barrier, water exchange conditions between soil and the atmosphere are altered. It is expected that a surface barrier will reduce or eliminate meteoric water entering into soil and as a result will reduce the rate of downward movement of flow. The effectiveness of a surface barrier may be evaluated by its impact on reducing water flow and contaminant transport.

The effectiveness of a surface barrier is dependent on (but is not limited to) the properties of the barrier, properties of the soil beneath the barrier, location and type of contaminants in the soil, and natural conditions (e.g., precipitation). For an impermeable surface barrier (e.g., the TISB), at shallow depths, there will be no water supply from above to replace the draining water, and shallow soils will drain more quickly. At greater depths, soils will continue to receive drainage from the soil above for some time and will effectively drain more slowly. Therefore, it may take years for drainage rates deep in the profile to be reduced significantly. As the soil below the

surface barrier becomes drier, the soil in the uncovered region near the vertical plane directly beneath the barrier edge will also be drier than if there was no surface barrier. PNNL-18661, *Technical Basis for Evaluating Surface Barriers to Protect Groundwater from Deep Vadose Zone Contamination* reviewed the information available to support surface barrier evaluations for the deep vadose zone, identified gaps in the information and outcomes necessary to fill the data gaps, and outlined tasks to achieve those outcomes.

As shown in Section 3.0, the T Farm surface barrier has performed as expected to date. Data collected between April 2008 and September 2009 show that the barrier prevented meteoric water from infiltrating into the soil, with the result that the soil became gradually drier. The barrier also affected the soil below the barrier edge but at a reduced magnitude. Preliminary data collected in FY 2010 also show a continued slow drying trend beneath the barrier. Based on model estimates, continued draining of the soil and reducing of water flow rates is expected in the future.

The following potential long term impacts of the TISB on soil-water flow and contaminant transport are summarized based on numerical simulations of PNNL-14838, *2004 Initial Assessments for the T and TX-TY Tank Farms Field Investigation Report (FIR): Numerical Simulations*, PNNL-15913, *T Tank Farm Interim Cover Test – Design Plan*, and RPP-33431, *Design Analysis for T-Farm Interim Surface Barrier (TISB)*, "Section 8. Performance Simulations of an Interim Surface Barrier Over the 241-T-106 Tank Release."

4.1 EVALUATION OF ABILITY TO REDUCE WATER INFILTRATION IN THE FUTURE

Three-dimensional numerical simulation modeling was conducted as reported in PNNL-15913 and PNNL-16538 to investigate the soil-water regime after the emplacement of a 76 × 66 m (249 × 217 ft) rectangular impermeable surface barrier. The simulation domain was 148 m (486 ft) horizontally and 55 m (180 ft) vertically with tank T-106 near the center of the horizontal plane. It was assumed that the recharge rate was 100 mm/yr (3.9 in./yr) under natural condition and the recharge water was evenly distributed in time. The results show that soil-water content, and pressure and flux decrease with time beneath the surface barrier. Three years after the emplacement of the barrier, the model indicated that the rate of vertical water flow in the soil would be reduced by a factor of ~50 at 0.5 m (2 ft) bgs, 7 to 8 at 5.5 m (18 ft) bgs, 3 at 15.5 m (51 ft) bgs, and 1 at 25.5 m (84 ft) bgs. The simulation was for 50 years but the original reports presented only the results for the first 3 years. Further data analysis showed that 50 years after the emplacement of the barrier the vertical water flow would be reduced by factors of as much as 1,000 at 0.5 m (2 ft) bgs, 140 at 5.5 m (18 ft) bgs, 50 at 15.5 m (51 ft) bgs, and 17 at 25.5 m (84 ft) bgs.

4.2 EVALUATION OF ABILITY TO REDUCE MIGRATION OF SUBSURFACE CONTAMINANTS IN THE FUTURE

RPP-33431, Section 8 describes a series of two-dimensional numerical analyses of vadose zone contaminant transport with and without variously sized surface barriers in place to estimate contaminant concentrations in groundwater at the WMA T fenceline over 1,000 years. The simulation domain was the vertical cross-section across tanks T-106, 241-T-105 and 241-T-104 and was 400 m (1300 ft) horizontally and 89 m (290 ft) vertically. The groundwater table is ~69 m (~226 ft) bgs. The ground surface recharge from meteoric water depends on the surface conditions, i.e., 3.5 mm/yr before the construction of the tank farm in 1945, 100 mm/yr between 1945 and the time a surface barrier is emplaced (in 2007 or 2032), 0.0 mm/yr for the TISB, 0.5 mm/yr for the enhanced RCRA Subtitle C barrier (between 2032 and 2532) and 1.0 mm/yr after 2532. The estimated ^{99}Tc plume size at 2000 was 72.5 m (238 ft) easterly and 75 m (246 ft) northerly. The same as in PNNL-14838, the transport of ^{99}Tc, Cr, NO_3, and ^{238}U was investigated by treating ^{99}Tc, Cr, and NO_3 as conservative solutes and ^{238}U as reactive solute with an adsorption coefficient of 0.6 cm^3/g. At the beginning of the simulation (year 2000), almost all of the contaminants reside above 40 m (131 ft) bgs (the starting depth of contaminants was assumed to be 30 to 35 m [98 to 115 ft]). The modeling results indicate that installing an impermeable interim surface barrier may reduce the maximum concentrations in the groundwater at the WMA T fenceline by 40 to 50% for ^{99}Tc and nitrate and 50 to 60% for Cr. Figure 8 shows simulated barrier impacts for ^{99}Tc. The peak ^{99}Tc concentration was reached about year 2035 with an interim barrier. The ^{238}U peak concentration did not reach the fenceline during the 1,000-yr simulation time period. The performance of a surface barrier improves with the barrier size, but the improvement becomes marginal once the barrier length is approximately the same as the plume length, especially with respect to ^{99}Tc and nitrate groundwater concentrations.

5.0 LESSONS LEARNED FROM 241-T TANK FARM INTERIM SURFACE BARRIER

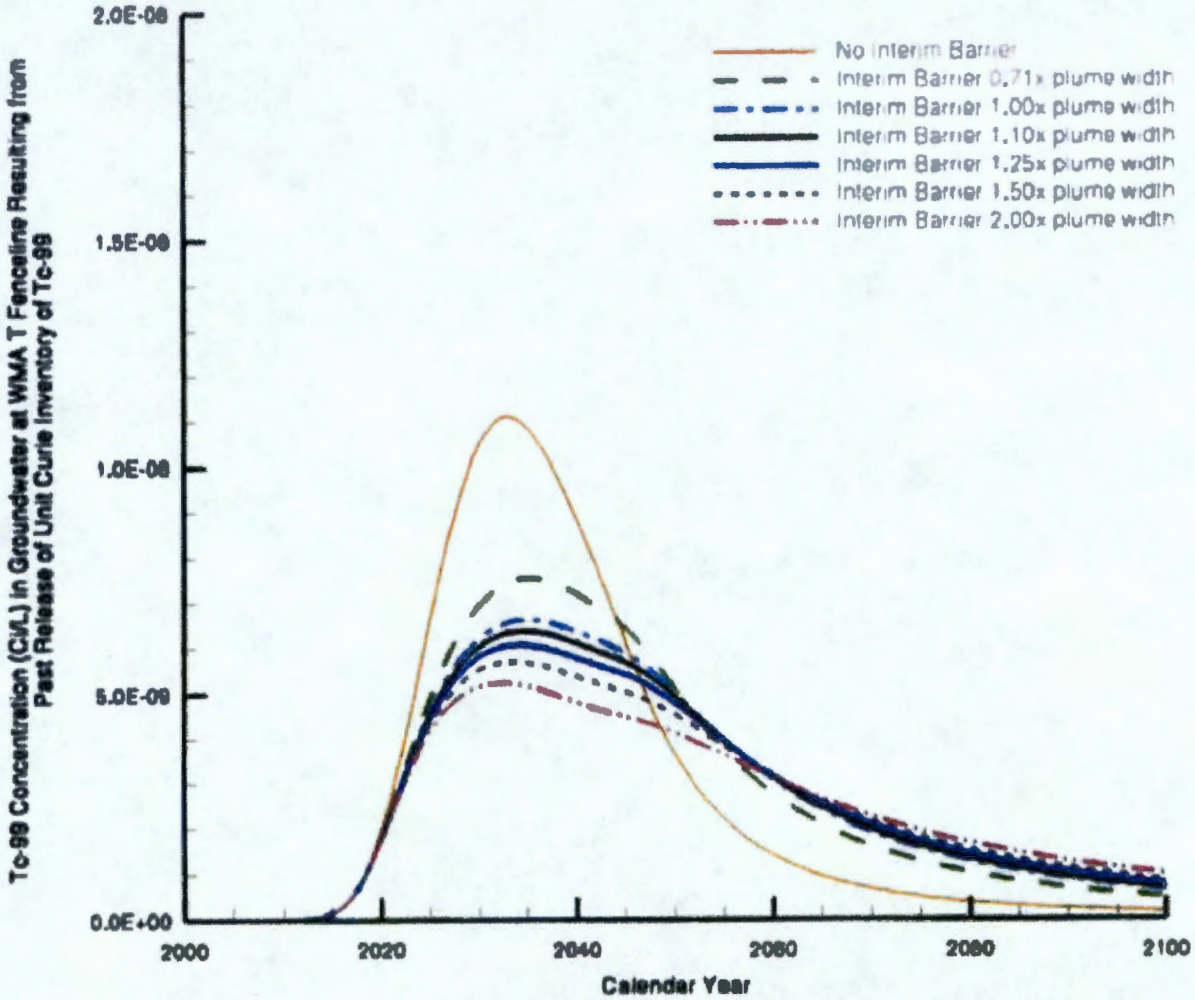
In 2008, after completing the T Farm interim surface barrier, a value engineering workshop was held to evaluate alternatives for future tank farm surface barriers. RPP-39785, *Surface Barrier Project Value Engineering Workshop* documents the results of the value engineering workshop and lessons learned. Several operational and project lessons were learned and incorporated to the TY barrier. The following general recommendations were made to reduce construction costs and enhance performance for future barriers.

- Simplify surface preparation. Establishing the 0.8-percent slope in TY Farm required approximately 3,100 m^3 (4,000 cubic yards) of fill material. Utilize the existing tank farm contours and only use enough fill material to limit the size and depth of puddles that would occur following a rain storm. Water would be disposed of by local evaporation and a perimeter trench.

- Optimize liner. The polyurea material was sprayed to a minimum thickness of 0.6 cm (0.25 in.). With an improved geotextile substrate, the thickness of the polyurea could be reduced by 50%. Consider using an improved polyurea product to minimize seam preparation. Additionally, a 15-cm (6-in.) layer of gravel over the polyurea barrier

should be used to reduce thermal stresses, eliminate ultraviolet exposure, and eliminate the need for anchor trenches around the perimeter of the barrier.

Figure 8. Modeled Effect of T Farm Barrier on Peak Concentration of Technetium-99 in Groundwater



- Temporary roof. Consider constructing a temporary roofed structure to cover specific areas for future interim barrier applications.

- Water disposal. Evaluate evaporating the water inside the farm and eliminate the infiltration area and lined trench.

In 2009 a design study (RPP-RPT-38323, *Tank Farm Interim Surface Barrier Materials and Runoff Alternatives Study*) was performed for the TY Farm barrier that looked closer at the value engineering study recommendations and cost estimates and the specific TY Farm conditions, and revisited material selection and water run-off controls.

5.1 MATERIAL SELECTION ALTERNATIVES

Material Selection barrier construction alternatives included:

- Spray-on Polyurea (similar to the TISB)
- Spray-on Polyurea with Gravel layer on top
- Metal-Roofed Structure
- Fabric-Roofed Structure
- Geomembrane
- Geomembrane/Geotextile Combination with Gravel
- Geosynthetic Clay Liner
- Spray-on Polymer (soil stabilization sprays)
- Evaporative Soil Barrier
- Evaporative Geomembrane Barrier with Gravel
- Modified Asphalt
- Specialty Concrete
- Evapo-Transpiration Barrier (Soil and Vegetation).

The modified asphalt option was determined to be the best alternative for use in the TY Farm. Details of the evaluation and scoring are in RPP-RPT-38323.

The modified asphalt barrier in TY Farm would consist of creating a sloped sub-grade over the area to be capped and then installing the asphalt cap over the tank farm using commercial paving techniques. Runoff control structures would route water away from the tank farm. Standard asphalt paving is sufficiently permeable that it is not a good candidate to prevent water from infiltrating into the subsurface. Modified asphalt products have been developed with reduced permeabilities. Modified asphalt was considered, but was not used for the TISB due to concerns about the weight of asphalt and tank dome load requirements in pre-barrier planning for that farm. Also, use of a polyurea liner at the TISB resulted in radiation control issues due to increased radon on the barrier. This is not expected to be an issue for a modified asphalt barrier.

Advantages of using the modified asphalt option include:

- installation and maintenance costs are relatively low
- environmental conditions should not affect the barrier
- barrier can be expanded
- allows easy access to the farm
- easily monitored
- can be removed if necessary.

Disadvantages of using the modified asphalt option include:

- may not be applicable for other farms due to potential dome load or other design restrictions.

The 2009 study concluded that the durability of the modified asphalt option combined with the low cost make this the most feasible option. A modified asphalt interim surface barrier can be constructed safely. The costs for the modified asphalt option are relatively low compared to other options. The modified asphalt option poses the fewest operational issues and allows for future flexibility.

5.2 WATER CONTROL ALTERNATIVES

Water control alternatives assessed in RPP-RPT-38323 included:

- unlined infiltration area
- lined evaporation pond
- storage and evaporation basin – lined basin and discharge system covered by soil and vegetation to promote evaporation.
- storm water discharge system – engineered drainage and discharge field
- soil evaporation barrier west of T Farm
- retention pond and water treatment (e.g., transport to effluent treatment facility).

Of the options evaluated for water control, the storage and evaporation option was recommended for the TY Farm interim surface barrier application. This option involves constructing an evaporative barrier or an evapo-transpiration barrier at a designated location outside of the tank farm. Runoff from the interim surface barrier would be collected and conveyed to the evaporative system where it would be stored until it is evaporated. This option involves constructing an evaporative barrier or an evapo-transpiration barrier. Runoff from the interim surface barrier would be collected and routed to a lined evaporation basin where it would be distributed into a contained soil layer. The soil layer would be used to store the water until it is evaporated. With a lined basin none of the runoff would be discharged to the soil column and the precipitation that falls on the evaporative basin would be captured for subsequent evaporation. This would reduce the net recharge in the area surrounding the tank farm. With this option, the soil excavated could be replaced after the liner is installed eliminating excess spoils. Once in place, this system would be passively operated, and would involve minimal operating expense, and maintenance. Native vegetation would be established on the barrier to promote evapo-transpiration.

A lined evaporation basin configured as an evapo-transpiration system meets the objective of eliminating the water discharge to the subsurface in the area surrounding the tank farm with minimal maintenance and operating requirements.

6.0 CONSIDERATIONS FOR FUTURE INTERIM SURFACE BARRIERS

The following sections describe factors to consider in determining whether or not an interim surface barrier is needed at a site and identifying locations for future interim surface barriers.

6.1 BARRIER EFFECTIVE DEPTH

The purpose of a surface barrier is to reduce or eliminate water infiltration into soils with an expectation of reducing the flow rate of underlying waste to groundwater. In simple terms, barrier effective depth is defined as the depth at which a barrier is expected to reduce the rate of migration of contaminants in the soil sometime in the future. Depending on the depth of the waste and its distance to groundwater, a surface barrier may or may not slow down the movement of waste. In this section a simple model is presented to illustrate the concept of effective depth. This model illustrates the importance of soil-water content in assessing the effective depth for a barrier.

6.1.1 Effective Depth Concept

Four main factors that affect the effective depth of a surface barrier are:

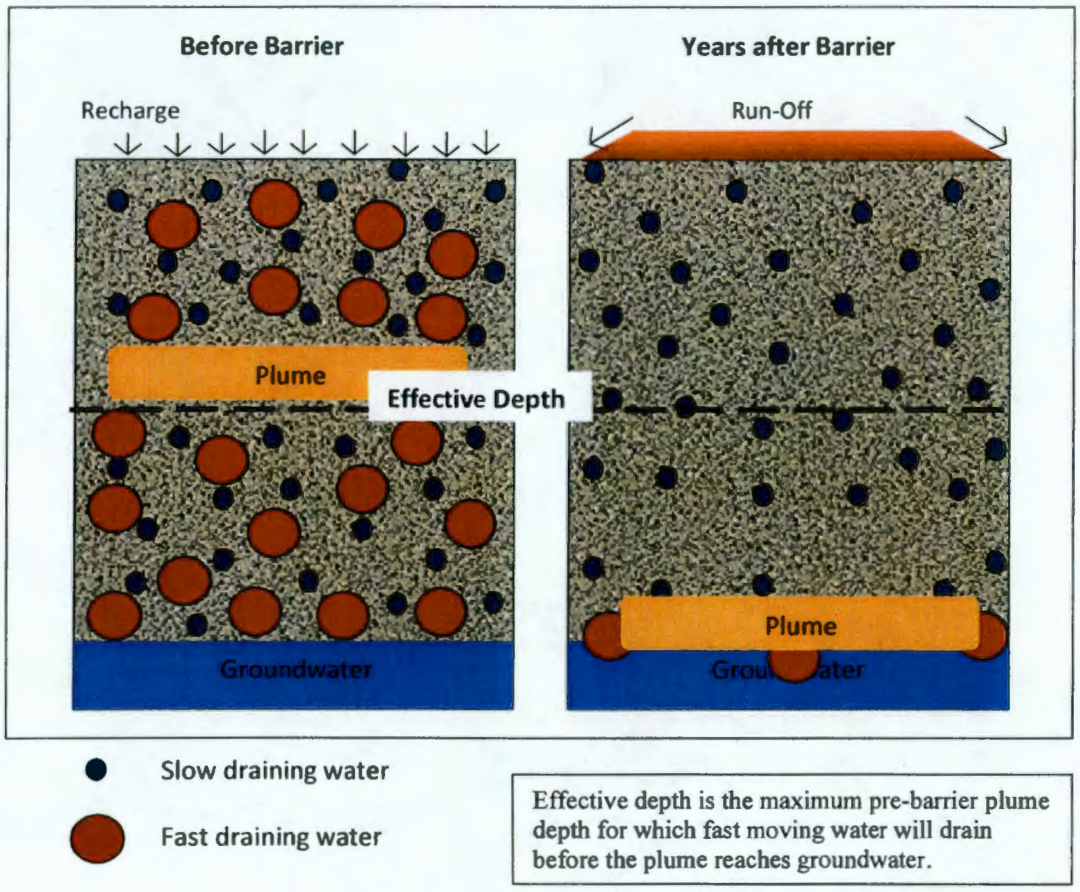
- soil properties,
- contaminant location,
- contaminant properties (i.e., mobility), and
- recharge rate.

In the vadose zone, soil water resides in voids of different sizes. According to the similar-media concept ("Physical Theory for Capillary Flow Phenomena" [Miller and Miller 1956]), soil hydraulic conductivity is proportional to the second power of the pore size. Because the size of soil pores often varies by 2 to 4 orders of magnitude, the rate of movement of water in different pores varies by 2^2 to 4^2 orders of magnitude. Water in larger pores moves relatively fast and drains between saturation and the water holding capacity of the soil (θ^{sm}) and here is termed as fast-moving (FM) water. The water remaining in the smaller pores tends to move relatively slowly. This water is referred to as slow-moving (SM) water. Some of the SM water moves so slowly that it is often considered as immobile and is referred to as the residual water. Similar concepts have been used in the two-region nonequilibrium transport model of "Dead-End Pore Volume and Dispersion in Porous Media" (Coats and Smith 1964) to describe solute transport with a tailing effect. Figures 9 and 10 illustrate this concept.

After the emplacement of a surface barrier, which reduces or eliminates the recharge or infiltration of meteoric water into the soil, the FM water in the soil drains at a relatively fast rate while the SM water moves slowly, at a rate that may be orders of magnitude smaller. Because a solute distributes in both the FM and SM water (and is also sorbed on solid particles for a reactive contaminant), the rate of solute transport is slower than that of the FM water. Before the FM water drains to the depth of the waste, solute continues to travel at a rate as if there was no barrier. To slow down the solute transport, the FM water must drain out to θ^{sm} at the depth of

the waste before the waste reaches the groundwater. If the waste is too deep, it may migrate to groundwater before the soil drains to this level. Thus, there exists a maximum depth at which the surface barrier is effective in reducing the flow of contaminants.

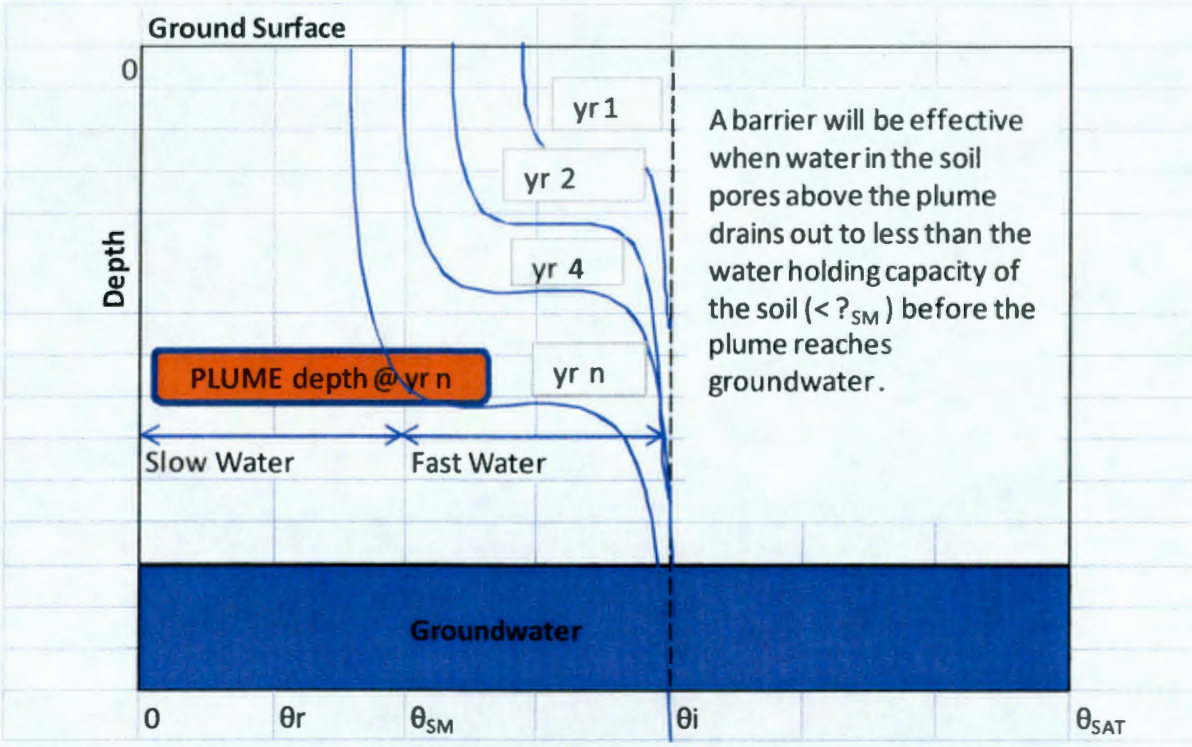
Figure 9. Schematic of Barrier Effective Depth



6.1.2 The Piston-Flow Model

"Studies on Soil Physics: I. Flow of air and water through soils" (Green and Ampt 1911) used the piston-flow concept to describe soil-water infiltration. It assumes that a sharp boundary separates the wet region and the dry region. The boundary between the two regions is termed as the wetting front. Similarly, we can apply the piston-flow concept to the drainage condition under a barrier and assume that a "draining front" separates the upper drier region and the lower wetter region. In reality, the soil wetness varies gradually over a vertical distance and a "draining front" may be more like a transition zone. However, for mathematical convenience, the location of the draining front may be considered as the midpoint of the transition zone. Solute dispersion is not considered during the transport of contaminants. This assumption does not affect the estimate of the solute velocity of the center of mass. However, the plume size will be different from that when dispersion is considered.

Figure 10. Illustration of Fast and Slow Moving Water Draining Profiles for an Effective Barrier



To quantitatively describe the effective barrier depth, soils were assumed to be homogeneous with an initial water content θ_i, composed of both the SM and FM water (Figure 9), under a constant surface recharge of q_i. Assuming that both the FM water and the solute move like a piston, after the emplacement of a surface barrier, there is a draining front due to the drainage of the FM water (Figure 10). The model is referred to as the "piston-flow model".

Travel Time of FM Water to Groundwater

The content of the SM water, θ^{sm}, may be considered as the water content corresponding to a low recharge rate, q^{sm}. Because the residual water is immobile, θ^{sm} is between θ_i and the residual water content, θ_r. In this work, θ^{sm} was estimated to correspond to roughly 0.1 times a recharge or water flux rate (0.1*q). (Note: The correlation between 0.1q and θ^{sm} was derived based on the parameters and assumptions from SGW-34059, *Effect of Waste Depth on Barrier Effectiveness*, described below, and may not apply for more complex soil strata or different conditions.)

After the emplacement of an infinite surface barrier, the velocity of the draining front is the same as that of the FM water, v^{fm}:

$$v^{fm} = (q_i - q^{sm}) / (\theta_i - \theta^{sm}) \qquad (6.1)$$

The time needed for the draining front to reach the water table, t_{df}, is

$$t_{df} = L/v^{fm} = L(\theta_i - \theta^{sm})/(q_i - q^{sm}) \tag{6.2}$$

where L is the thickness of the vadose zone or depth to groundwater (Figure 9).

Travel Time of a Contaminant to Groundwater

Now suppose that a contaminant resides in the vadose zone and is dissolved in soil water, as schematically shown in Figure 9. The velocity of the center of contaminant mass, v_s, can be determined by

$$v_s = q_i/\theta_i R \tag{6.3}$$

where R is related to the sorption coefficient, K_d, by $R = 1 + K_d\rho_b/\theta_i$ with ρ_b being the soil bulk density. Hence, the time needed for the center of the contaminant mass to travel to the groundwater, t_s, is

$$t_s = (L - L_s)/v_s = (L - L_s)\theta_i R/q_i \tag{6.4}$$

For this simplified model the depth of contaminants L_s is the depth of the center of the contaminant plume.

Effective Depth of a Surface Barrier

For a surface barrier to be effective in reducing the transport of a contaminant, t_s must be larger than t_{df}, namely

$$(L - L_s)\theta_i R/q_i > L(\theta_i - \theta^{sm})/(q_i - q^{sm}) \tag{6.5}$$

After defining the relative depth of contaminant as $L_s^* = L_s/L$, the maximum relative depth of the contaminant from ground surface, L_s^{*max}, is given as

$$L_s^{*max} = 1 - (1 - \theta^{sm}/\theta_i)\frac{q_i}{R(q_i - q^{sm})} \tag{6.6}$$

If $q^{sm} \ll q_i$, Eq. (6.6) may be approximated by

$$L_s^{*max} \approx 1 - (1 - \theta^{sm}/\theta_i)/R \tag{6.7}$$

For a conservative solute, R = 1 and hence

$$L_s^{*max} \approx \theta^{sm}/\theta_i \tag{6.8}$$

Equation (6.8) shows that the effective depth for a barrier for a mobile contaminant ($K_d = 0$, R=1) is approximately equal to the ratio of the content of slow-moving water to pre-barrier water content. The effective depth increases when a contaminant is less mobile and R is larger. For a

layered soil, superposition of water or solute travel times in the layers can be used to determine the total travel time. For the draining front, the superposition of t_{df} (6.2) applied to all the layers from ground surface to water table. For the waste, the superposition of t_s (6.4) applied to only the layer the contaminant resides in and those below it.

When water moves in natural geological sediments especially during water drainage, the existence of a sharp draining front is very rare. Dispersion also occurs during the transport of contaminants. As a result the piston-flow model tends to underestimate the effective depth of a surface barrier.

A more sorptive contaminant transports more slowly under the same condition. As a result, the effective depth of a surface barrier is greater for a more sorptive contaminant.

6.1.3 Test of the Model

The numerical simulations in SGW-34059 were applied to estimate θ^{sm} and an effective depth of a surface barrier using the piston-flow model. The variables and parameters used are summarized in Table 4. The numerical simulations in SGW-34059 indicated that for an infinite surface barrier and groundwater depth at 104 m a surface barrier can reduce the peak concentration by about a factor of 2 when the contaminant resides initially at 80-m depth (Figure 11).

Table 4. Parameter Values

Variable Name	Value
Vadose Zone Thickness, L (m)	104
Initial Soil-Water Content, θ_i (under recharge rates of 25 and 5 mm/yr)	0.088, 0.071
Slow-Moving Water Content, θ^{sm} (estimates for recharge rates of 2.5 and 0.5 mm/yr)	0.065, 0.054
Sorption Coefficient, K_d (cm^3/g)	0, 0.1, 1.0
Bulk Density, ρ_b (g/cm^3)	1.77
Retardation Factor, R (under the recharge of 25 mm/yr)	1, 3, 21

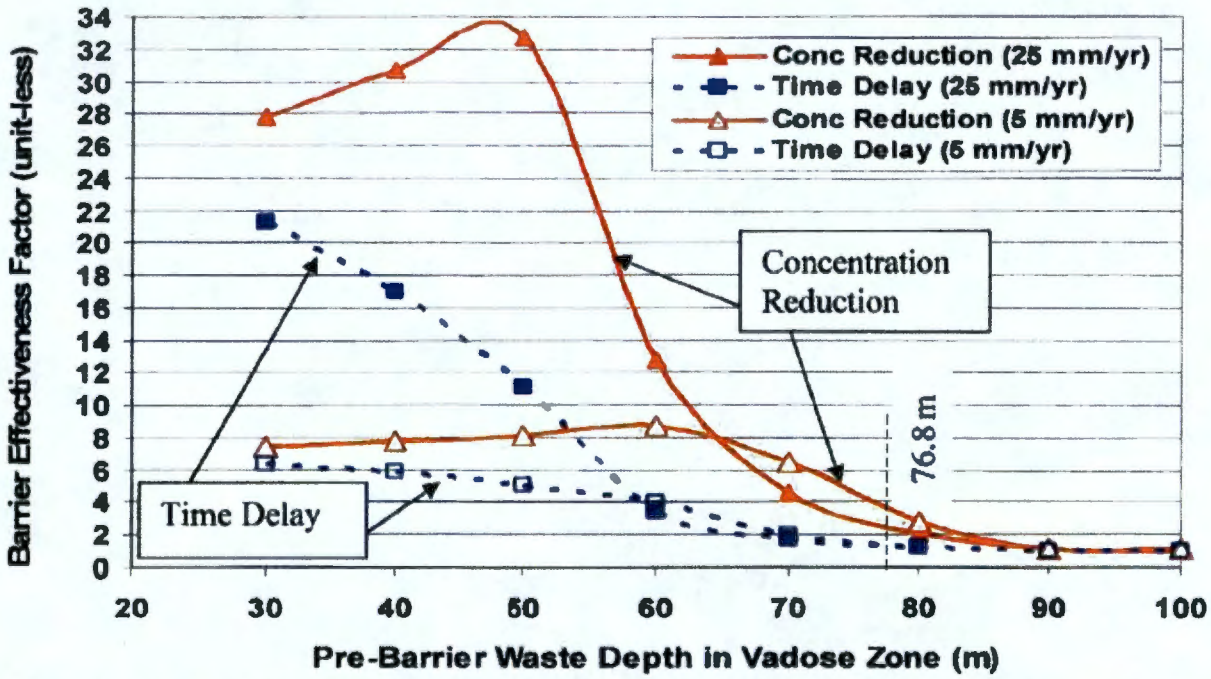
The key parameters in Table 4 for the piston-flow model are initial soil-water content (θ_i) and water holding capacity (θ^{sm}). Residual soil-water content (θ_r) is a more common and more technically defensible physical parameter that could be used in place of θ^{sm}, but it results in a more conservative effective depth.

For a non-sorptive contaminant ($K_d = 0$) for the piston-flow model, the estimated effective depth (L^{max}) of an infinite surface barrier with groundwater at 104 m (341 ft) was 76.8 m (252 ft) ($L^{*max} = 0\ 0.74$).

L^{max} increases to 93.2 m (306 ft) when $K_d = 0.1\ cm^3/g$ and to 102.9 m (338 ft) when $K_d = 1.0\ cm^3/g$. These estimates are consistent with those in SGW-34059 (Figure 12). These

results indicate that the effective depth estimates for the simple piston-flow model are reasonably close to estimates in SGW-34059. In reality the depth to groundwater is less than 80 m (262 ft) throughout the 200 Area.

Figure 11. Barrier Concentration Reduction Factor for a Conservative Contaminant*



*The points and curves are from Figure 4 of SGW-34059, *Effect of Waste Depth on Barrier Effectiveness*; the vertical dashed line marks the estimate of the maximum effective depth of a surface barrier based on the piston-flow model.

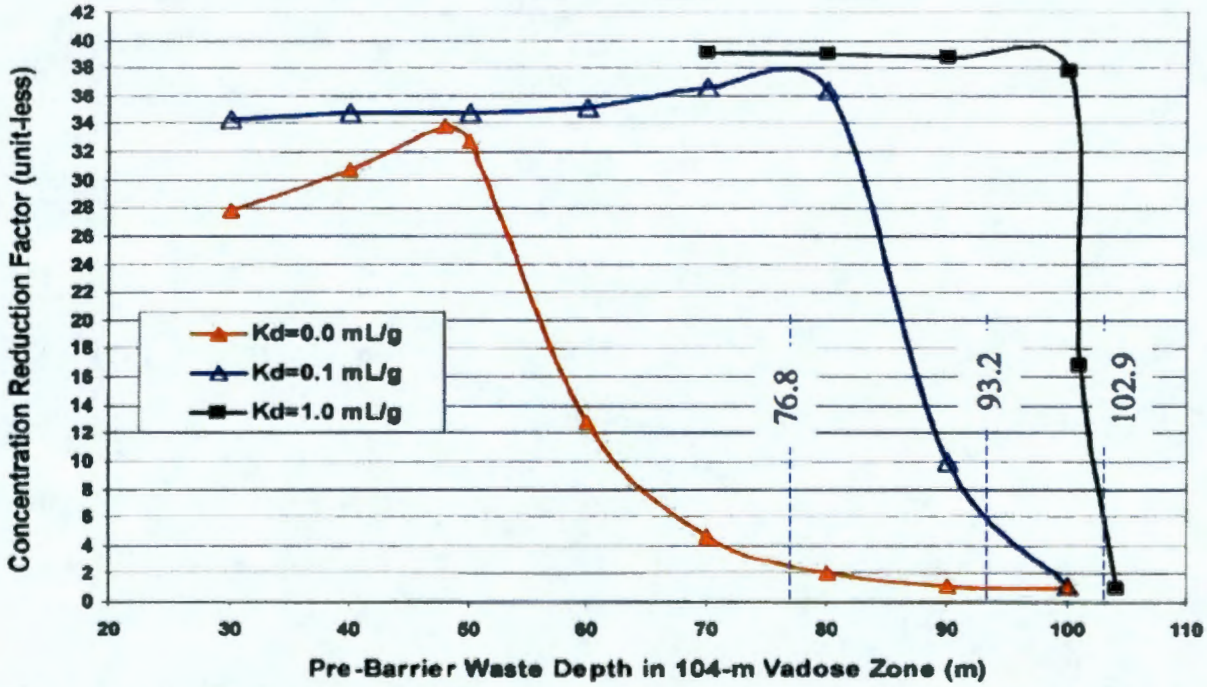
6.1.4 Application of Piston Flow Model to 241-T Tank Farm

RPP-33431 examined the depth of barrier effectiveness with numerical simulations for a T Farm surface barrier of different lengths. Table 5 shows parameters used for this model. Results indicate that the maximum depth of any impact for the T Farm barrier is about 50 m (164 ft) bgs. The maximum depth to reduce by half the peak concentration of ^{99}Tc at the groundwater is about 35 m (115 ft) bgs (Figure 13).

Applying the piston-flow model to estimate the effective depth of the TISB, it was assumed that the impact of the impermeable tanks on flow is negligible and the geology of T Farm is approximated by a layered structure with the approximate layer thickness given in Table 5. It is noted that the water velocities in the various layers differ due to different water contents, although the water flux rate is nearly the same. The bottom-most layer is the thickest and has the greatest hydraulic conductivity. This indicates that it takes less time in this layer than in a layer above it (except the backfill) for the contaminants to transport a given distance. Based on the piston-flow model for a layered soil, the estimated maximum depth of a conservative solute for a surface barrier to be effective is about 50 m (170 ft) ($L_{max}^{*} = 0.67$) bgs. For sorptive contaminants, the effective depth of a surface barrier will be greater. This estimated effective depth from the piston-flow model is in reasonable agreement with the numerical results in

RPP-33431 (Figure 13) indicating that the simple piston-flow model predicts the effective depth for the T Farm surface barrier reasonably well compared to the more complex numerical model.

Figure 12. Barrier Concentration Reduction Factor for Contaminants with Different Sorption Properties*



*The points and curves are from Figure 14of SGW-34059, *Effect of Waste Depth on Barrier Effectiveness*; the vertical dashed lines and numbers show the estimates of maximum effective depth of a surface barrier based on the piston-flow model.

The piston flow model indicates that for T Farm, a contaminant depth of 60% or less of the depth to groundwater (rounded down from 67% [$L_{max}^{*} = 0.67$]) is a reasonable indication of whether or not a barrier would be effective.

Barrier effective depth estimates based on the piston-flow model are an approximation due to the assumptions of a sharp draining front and negligible solute dispersion and should be used only for screening purposes to determine whether or not to consider an interim surface barrier in a selected location. However the piston-flow model illustrates the importance of physical properties of the soil such as soil-water content in addition to plume location and contaminant mobility in assessing the effective depth of a barrier, indicating that soil particle size and soil moisture relationships are key parameters for more detailed modeling of groundwater predictions and potential barrier impacts.

Field investigation reports (FIRs) such as RPP-23752 provide initial numerical modeling results of potential barrier effectiveness and long-term impacts of a barrier in each of the SST waste management areas. The FIRs indicate that an interim surface barrier should be placed over areas of shallow vadose zone contamination within the SST farms and recommend additional site-specific studies to evaluate potential barrier impact, design and cost for different waste

management areas (DOE/ORP-2008-01, *RCRA Facility Investigation Report for Hanford Single-Shell Tank Waste Management Areas*). The numerical modeling for the FIRs may need to be revisited if additional site data are obtained. Additional studies, similar to those performed for the TISB (RPP-33431) and configured to site-specific conditions, may be needed to evaluate and/or design interim barriers for other locations.

Table 5. Parameter Values for 241-T Tank Farm

Variable Name	Backfill	Sand	Gravelly Sand/ Sandy Gravel	Plio-Pleistocene	Sandy Gravel	Total
θ_s ($m^3\ m^{-3}$)[a]	0.1380	0.3819	0.2126	0.4349	0.1380	-
θ_r ($m^3\ m^{-3}$)[a]	0.0100	0.0443	0.0032	0.0665	0.0100	-
K_s ($m\ s^{-1}$)[a]	5.6×10^{-6}	9.88×10^{-7}	2.62×10^{-6}	2.40×10^{-6}	5.60×10^{-6}	-
α (m^{-1})[a]	2.10	1.17	1.41	0.85	2.10	-
n (-)[a]	1.374	1.616	1.373	1.851	1.374	-
θ_i ($m^3\ m^{-3}$)[b]	0.078	0.215	0.126	0.194	0.078	-
θ^{sm} ($m^3\ m^{-3}$)[c]	0.061	0.16	0.095	0.147	0.061	-
Approximate layer thickness (m)	12	10	10	7	40	79

[a] From RPP-17393, *Modeling Data Package for WMAs T and TX-TY Field Investigation Report.*

[b] θ_i are the values corresponding to recharge rate of 100 mm/yr.

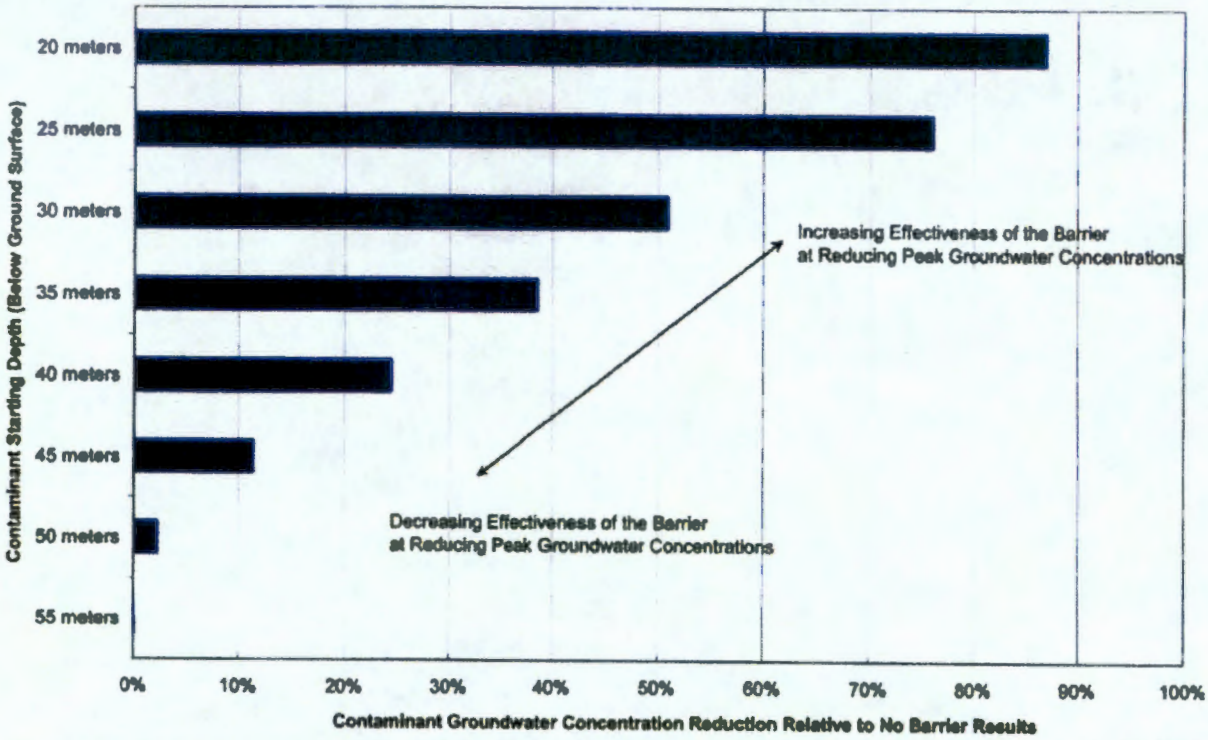
[c] θ^{sm} are the values corresponding to recharge rate of 10 mm/yr.

6.2 DRAINAGE AREA

As noted by the proposed alternatives for future barriers (Section 5.2) one of the lessons learned from the TISB and implemented for the TY Farm barrier is the need to minimize water discharges to the soil. This is especially needed in TY Farm because there was no "clean" area to which run-off could be directed. The T Farm infiltration area was sampled to ensure there were no contaminants below it and water flow was expected to be away from the barrier. However, although there is no evidence of the infiltration area at T Farm contributing to increased water movement or migration of contaminants, in retrospect, minimizing continuous discharges to the soil is desirable, even in a "clean area," because the amount and direction of horizontal spreading is highly uncertain.

The proposed drainage area for TY Farm moves the discharge further from the farm and minimizes infiltration by containing the discharge in a lined basin. The basin is lined to prevent infiltration, and the basin size, soil type, and vegetation are designed for a 25-yr/24-hr maximum precipitation event.

Figure 13. Interim Barrier Performance in Reducing the Groundwater Concentrations at the Waste Management Area T Fenceline for Technetium-99 Plumes at Different Depths in the Vadose Zone*



*The bar chart is from Figure A-4 of RPP-33431, *Design Analysis for T-Farm Interim Surface Barrier (TISB)*; the effective depth of a surface barrier based on the piston-flow model was about 50 m.

Another alternative to consider for future drainage or run-off areas is to minimize the drainage area and pump water to be used for other purposes such as pump and treat remediation.

6.2.1 Other Considerations

When planning a future barrier, the following factors should be considered to ensure the barrier will be effective in reducing the transport of contaminants below it. Characterization should be performed as needed to define these parameters.

- *Soil hydraulic properties*: For a homogeneous soil, the initial water content and soil-water properties affect the effective barrier depth.

- *Geological structure*: The textures and sequence of geological formations affect the water content and distribution and hence the flow rate of water and contaminants.

- *Location of the contaminant plume*: A surface barrier has limited effects on contaminants located below the maximum effective depth of a surface barrier.

- *Sorption coefficient of a contaminant*: The effective depth for a barrier over slow moving sorptive contaminants will be greater than the effective depth for less-sorptive, faster moving contaminants.

- *Barrier properties*: The recharge rate through the barrier and the lateral extension will impact the barrier effectiveness.

- *Runoff*: The redirected-infiltration of the barrier-intercepted precipitation into the soil may have significant impacts on the barrier effectiveness.

6.3 FUTURE BARRIER LOCATIONS

Milestone M-045-92 requires a second barrier to be constructed in TY Farm by September 2010. Barrier construction has started and a monitoring system similar to the T Farm moisture monitoring system is installed. Moisture monitoring outside the barrier footprint began in March 2010. The TY Farm applies lessons learned and design changes. It is larger (covers all tanks in the farm), will be constructed using modified-asphalt vs. polyurea and uses an evapo-transpiration basin rather than an infiltration area.

In addition to the barrier in TY Farm, four additional barriers are required (M-045-92). The locations for these barriers have not been determined. Based on a barrier prioritization study (RPP-ENV-41309, *Criteria for Prioritizing Hanford Site Tank Farm Interim Surface Barriers and for Evaluating Their Performance*), the next barrier being considered is a barrier covering releases in SX Farm.

The barrier prioritization study looked at several criteria for prioritizing barriers. The key criterion was the ability to reduce groundwater risk. Several constituents were identified as groundwater risks, a key contributor to risk is ^{99}Tc. As a means of prioritizing barrier effectiveness a measure of risk was determined as the difference in the peak ^{99}Tc concentrations in the groundwater with and without an interim barrier. Assumptions used for modeling estimates are presented in the barrier prioritization study (RPP-ENV-41309). Table 6 shows results for the 10 tanks with the largest peak ^{99}Tc concentration reductions with an interim barrier. Based on the models and assumptions the T-106 plume shows the largest potential difference followed by four SX Farm tanks. Table 7 shows composite differences for groups of tanks.

As noted in the report, these differences are based on the assumptions made regarding the location and size of ^{99}Tc plumes, the recharge rate, and mobility parameters in the STOMP model to estimate peak concentrations at the tank farm fence line. Sensitivities associated with these parameters are discussed in the prioritization report.

While the absolute values shown in preliminary modeling are highly uncertain and contaminants are known to have reached the groundwater much earlier than the models indicate, the model still provides a visual of the relative long term risk for different tanks and tank farms. Also, note that the values shown in Tables 6 and 7 are <u>differences</u> in peak concentrations, not absolute

concentrations. In general, the magnitude of differences correlates with the amount of ^{99}Tc in the plumes. For all SSTs shown, although the peak ^{99}Tc concentration will be reduced with an interim barrier, the peak value is still significantly greater than the drinking water standard or other regulatory limits.

Table 6. Ten Tanks with the Largest Peak Technetium-99 Concentration Reductions with a Barrier

Tank	GW Tc (pCi/L) Saved by Interim Barrier		Tank	GW Tc (pCi/L) Saved by Interim Barrier
241-T-106	1.98E+05		241-U-101	1.46E+04
241-SX-108	6.14E+04		241-BY-107	1.35E+04
241-SX-112	3.41E+04		241-SX-111	1.27E+04
241-SX-115	2.71E+04		241-U-104	1.12E+04
241-SX-107	2.57E+04		241-TY-103	8.72E+04

GW = groundwater pCi/L = picocuries/liter Tc = technetium

Table 7. Cumulative Reductions in Peak Technetium-99 Concentration for Selected Barriers

Tanks/UPRs	Peak Tc GW Saved (pCi/L)
241-T-106+241-T-108+241-T-109	1.994E+05
241-SX-107 through 241-SX-115	1.621E+05
241-U-101+241-U-104	2.580E+04
241-BY-107+241-BY-108+UPR-E-105	1.799E+04
241-TY-101 through 241-TY-106*	1.519E+04

* This ranking is based on data that does not include recent (2008/2009) data. Results obtained in 2008/2009 indicate that there may be another source in the 241-TY Tank Farm.

GW = groundwater pCi/L = picocuries/liter UPR = unplanned release

Also note that as discussed above, although the peak concentration decreases appreciably for some tanks, the total mass of mobile contaminants that have reached or will eventually reach the groundwater is assumed to be about the same with or without an interim barrier. The interim barrier simply slows migration of mobile contaminants, reduces the peak and stretches out migration to the groundwater over a much longer time period (see Figure 8).

As discussed above, there are several factors that influence barrier effectiveness. A key question for the high risk areas in SX Farm was whether the bulk of the mobile contaminants are already too deep or too close to the groundwater for an interim barrier to effectively reduce the risk due to ^{99}Tc. 241-SX Tank Farm modeling presented in the FIR indicate that a barrier would be

effective in reducing future peak ^{99}Tc concentrations at the groundwater at SX Farm (DOE/ORP-2008-01).

7.0 RECOMMENDATION AND COMMITMENT WHETHER OR NOT TO PROCEED WITH ADDITIONAL INTERIM SURFACE BARRIERS

Monitoring results for the TISB from September 2006, before the barrier was constructed, through 2009 show positive indications that the TISB is performing as expected. The TISB is expected to remain in place as an interim measure and the TISB will continue to be monitored for several years. Initial results based on HDU measurements indicate gradual drying of the barrier; NP and CP water content results are not yet statistically significant. Additional data after more years of continued monitoring are expected to show more pronounced changes.

Models indicate that soils below the barrier in T Farm will continue to drain resulting in reducing the peak concentration of ^{99}Tc at the groundwater by 40 to 50% compared to the peak concentration with no interim barrier (see Figure 8).

Based on initial monitoring and inspection results and modeling predictions for T Farm and other locations, interim barriers are expected to be effective in reducing moisture flux and peak concentrations of contaminants in the groundwater at T Farm and other locations before a final remedy is selected and implemented. Therefore, future interim surface barriers are recommended.

In agreement with Ecology per M-45-56 meeting minutes ("Meeting Minutes Annual Meeting Between the U.S. Department of Energy, Office of River Protection (ORP) and the State of Washington, Department of Ecology (Ecology) to Discuss Interim Measures for Fiscal Year 2009," [Memo 0084798]), a second barrier is under construction in TY Farm and will be completed in FY 2010. A barrier monitoring plan was approved (RPP-PLAN-36705, *241-TY Tank Farm Interim Surface Barrier Monitoring Plan*) and monitoring nests and instrumentation were installed and data collection has started. Lessons learned from the T barrier are being implemented as appropriate for the TY Farm barrier. As for the TISB, monitoring results for the TY barrier will be documented in annual reports. Additional data will be collected from the T and TY Farm barriers to help to validate models and further assess interim barrier performance.

In addition to the TY barrier, the TPA requires four additional barriers be constructed between June 2012 and June 2015 (M-045-92). Section 6.2 of this report identifies other barrier alternatives under consideration. Specific criteria and selection of barriers will be determined in annual interim measures meetings with Ecology per HFFACO M-45-56. Following completion of the TY barrier, construction of a barrier is planned in SX Farm (HFFACO M-045-92).

Barrier depth effectiveness site-specific modeling studies should be conducted and additional characterization performed as needed to further assess the potential effectiveness of interim barriers in other farms. Other interim measures to mitigate contaminant movement and reduce the migration of contaminants to the groundwater could also be assessed during this time.

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