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Detection and Mitigation of Hanford Site Radioactive Waste Tank Surface Water Intrusion – 16396

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ABSTRACT

The last single-shell underground radioactive waste storage tanks at the U.S. Department of Energy's Hanford Site, near Richland, WA, were removed from service in November, 1980. At that time the single-shell tanks contained 153,300 m^3 (40.5 million gallons) of waste, including 34,400 m^3 (9.1 million gallons) of liquids. Subsequently the Interim Stabilization Program and Waste Retrieval/Closure Project have removed 24,600 m^3 (6.5 million gallons) of liquid from the tanks to reduce the potential for leakage to the environment. After interim stabilization, each tank was isolated by cutting and capping waste transfer lines, filling drains with grout, and covering likely surface water entry points. The minimum expected lifetime for the isolation features was 20 years, consistent with planned retrieval of all single-shell tank wastes by 2018. Since then the retrieval completion date has been extended.

In 2011 the Tank Operating Contractor began a systematic review of the aging isolation barriers to determine if surface water was entering the single-shell tanks. This paper summarizes the results of the 2011 – 2015 activities including single-shell tank inspection results, methodologies used to identify intrusions and waste leaks masked by intrusion, and eventual deployment of a prototype forced ventilation exhauster in 2015 to evaporate water intrusion pools on the waste surface. Further efforts to limit water intrusion, including deployment of surface barriers, are discussed.

INTRODUCTION

The U.S. Department of Energy's Hanford Site includes 149 single-shell underground radioactive waste tanks (SSTs) ranging in size from 208 m^3 to 3,785 m^3 (55,000 to 1,000,000 gallons [gal]) capacity[1]. The last of the SSTs were removed from service in November, 1980. At that time they contained 153,300 m^3 (40.5 million gal) of waste, including 34,400 m^3 (9.1 million gal) of liquids. The liquid inventory included remaining surface pools and liquids trapped in the interstitial spaces of the solids stored in the tanks.

Beginning *ca.* 1977, a long-term effort to remove the remaining drainable tank liquids was initiated. Dubbed the Interim Stabilization Program, a low flow jet pump and saltwell screen

[1] Throughout the paper measurements and dimensions are expressed as SI metric values, followed by equivalent English values in parentheses. All measurements, capacities, and analyses discussed in the paper were originally completed in English units. The metric values are approximations that include small conversion and rounding errors.

were inserted into SSTs having a solids layer deeper than 0.6 m (24 in.). Interstitial liquid weeping into the screen was slowly removed by the jet pump until a production lower cutoff rate of about 0.004 m^3/min (0.05 gal/min) was reached. At that rate, operating experience showed that liquid waste removal was roughly counterbalanced by the additions of dilution water and flush water needed to keep the equipment operating. At completion of the Interim Stabilization Program in 2004, 24,600 m^3 (6.5 million gal) of drainable liquid had been removed from the SSTs.

As the tanks were interim stabilized, interim isolation activities sealed off overhead pump and valve pit drains, waste transfer pipelines and ventilation ductwork surface water entry points into the underground tanks. Drains were filled with grout, waste transfer lines cut and capped or blanked, ventilation ductwork foamed closed, and pits weather sealed with polyurethane foam and a protective elastomeric top coat. The isolation work continued throughout the 1979 – 2006 period, and included nine isolation construction projects.

Isolation criteria included requirements to seal tank accesses not required for long-term surveillance with barriers capable of withstanding water intrusion pressures of at least 3,000 Pa (12 in. water column), for a period of 20 years [1]. In practice complex infrastructure systems could not be completely isolated. These included, for example, the concrete, multi-pipe encasements interconnecting the 24 SSTs s in the 241-BX/241-BY tank farms, and similarly in the 24 SSTs in the 241-TX/241-TY tank farms. The encasements lay about 0.9 m (3 ft) below grade, closed along their length with small, individual concrete ceiling blocks.

After the SSTs were interim isolated waste surface level monitoring and interstitial liquid monitoring activities continued. Other surveillance activities including remote photographic inspection of the waste surfaces were eventually discontinued. In 1993 the term “interim isolation” was replaced with the term “intrusion prevention”, an administrative designation reflecting completion of all physical effort required to minimize the addition of liquids to an inactive storage tank [2].

During the 1974 – 1979 period, as many as nine liquid intrusions a year were reported in the SSTs, with annual volumes as large as 102 m^3 (~ 27,000 gal) (Catlin, 1980, Figures 24, 25) [3]. In 2010, investigations of chronic, continuing surface water intrusions into tanks BX-101 and BX-103 were reported [4]. Earlier reports noted that the first evidence of tank BX-103 water intrusion occurred in 1983; the tank had been interim stabilized in 1983, and interim isolated in 1985 [5].

In early 2011, an initial review of historical waste level trends in the 40 tank 241-B/241-BX/241-BY tank farm complex identified 12 SSTs with indications of possible surface water intrusion; this group included six categorized as “assumed leakers.” Following the initial review the Tank Operations Contractor launched a global review of historical waste surface level and interstitial liquid level increase trends for all 149 SSTs. This review identified 52 SSTs with unexplained waste surface level or interstitial liquid level increases ranging from + 0.25 to + 76 mm/yr (0.01 – 3.0 in./yr) (refer to Figures 1 – 3 for tank BX-110 example). The review excluded SSTs with conflicting surface level and interstitial liquid level trends [6].

In 2012, a more detailed review of SST surface level and interstitial liquid level data was completed. After explainable anomalous waste level behavior and obvious instrumentation data spikes were removed, and SSTs with surface level and interstitial liquid level changes opposing each other now included, 20 SSTs were recommended for intrusion evaluation from a group of 66 SSTs with either increasing surface level or interstitial liquid level trends. The SSTs recommended for intrusion evaluation included 10 with both waste surface level and interstitial liquid level increases; six with a surface level increase but no interstitial liquid level increase or no interstitial liquid level measurement; and four with an interstitial liquid level increase and a waste surface level decrease or negligible surface level change. The surface level increase trends for the 20 SSTs ranged from + 0.4 to + 16 mm/yr (0.015 – 0.62 in./yr), and the interstitial liquid level increase trends ranged from + 1.9 to + 77 mm/yr (0.075 – 3.02 in./yr). These ranges are equivalent to volumes of about + 0.07 to + 7.8 m^3/yr (20 – 2,100 gal/yr) surface water accumulation in the tank, depending upon the size of the supernatant pool and the porosity of the waste [7].

Fig. 1. Tank BX-110 Surface, July, 1985

Fig. 2. Tank BX-110 Surface, July, 1994

Fig. 3. Tank BX-110 Surface, May, 2013

DISCUSSION

Changes in waste surface level or interstitial liquid level result from the net influence of the following phenomena [8]:

- Physical or chemical changes within the waste;
- Accumulation and release of retained gas within the waste;
- Interstitial liquid level disequilibrium caused by introduction of free water during water lancing to install new equipment into the solids layer, or from an interim stabilization liquid removal rate exceeding the interstitial liquid redistribution rate throughout the waste solids;
- Waste surface features affecting surface level measurement;
- Waste subsidence porosity changes;

- Water evaporation from the tank;
- Surface water intrusion into the tank;
- Waste leakage from the tank.

Physical changes are more likely to occur with saltcake waste solids than with sludge due to the greater potential for chemical changes with time and the potential for the waste to compress due to the higher saltcake porosity. However, it is unlikely that significant chemical changes have continued due to the age of the waste and the continuing waste temperature decrease as the remaining radionuclide inventory decays.

Accumulation and release of retained gas within the waste have been observed in double-shell tanks. The seesaw pattern of surface level increases and decreases as gas accumulates and releases observed in several double-shell tanks is not apparent in the interim stabilized SSTs. In gas-generating SSTs it is likely that gas generation and release rates are roughly balanced and a net accumulation does not take place [9, 10].

Interstitial liquid level disequilibrium frequently occurs following completion of interim stabilization pumping, or when water has been added to an SST during equipment installation. Interstitial liquid level re-equilibration depends on the rate of lateral and vertical movement of the liquid through the waste matrix. Re-equilibration has been observed to take longer than a decade in some cases.

Waste surface features and abandoned in-tank equipment influence the landing point of the surface level instrument plummet as it touches down for a waste height measurement in dry waste surface tanks. Repeated touch downs on the surface create a waste gully, and over time report a false downward trend. Touchdowns on the side of a sloped waste feature, or interference from abandoned in-tank equipment, create false upward or downward trends.

Waste subsidence has been observed to increase the interstitial liquid level as the interstices collapse. Interpretation is difficult because of conflicting trends that are created between surface level and interstitial liquid level, and is often complicated by accompanying changes in the rate of interstitial liquid flow as the liquid is pressed through different waste layers.

Passive evaporation occurs in SSTs with a liquid surface or with the interstitial liquid level near the waste surface. The volume of liquid lost is dependent upon the tank breathing rate, the incoming ambient air humidity and temperature, the tank headspace air temperature and humidity, and the size of the surface pool. Breathing rates of selected SSTs have been measured and documented [11, 12]. Most SST passive breathing rates are in the range of 0.06 – 0.14 m^3/min. (2 – 5 ft^3/min.). Conversion from a breathing rate to an evaporation rate requires knowledge of the predicted relative humidity of the tank headspace above the liquid waste surface, and ambient temperature, pressure, and relative humidity data. An evaluation

performed for tank T-111 using 85% relative humidity in the tank headspace and a 0.07 m^3/min. (2.4 ft^3/min.) breathing rate predicted a 0.24 m^3/yr (63 gal/yr) evaporation rate; when the relative humidity was increased to 95% and the breathing rate was increased to 0.17 m^3/min. (6 ft^3/min.), the evaporation rate increased to 0.73 m^3/yr (193 gal/yr) [13].

Surface level and interstitial liquid level data plots show the net contribution of all the phenomena, including surface water intrusion and waste leakage. An increasing surface level or interstitial liquid level trend demonstrates that the surface water intrusion rate, together with any interstitial liquid disequilibrium or waste subsidence contributing to an interstitial liquid increase, exceed the decreases due to evaporation or potential leakage.

The change can be summarized as follows:

$$Net\ Change\ Rate = Intrusion\ Rate - Evaporation\ Rate - Leak\ Rate - \Sigma\ Minor\ Variables \quad \text{(Eq. 1)}$$

where the intrusion rate, leak rate and evaporation rate are stated as positive values, and the minor waste phenomena affecting waste surface level or interstitial liquid level are grouped as *Minor Variables*. For an SST to have an increasing surface level or interstitial liquid level trend, the intrusion rate must exceed the sum of the (*Evaporation Rate, Leak Rate, and Σ Minor Variables*) terms.

Rearranging Equation 1 yields:

$$Intrusion\ Rate = Net\ Change\ Rate + Evaporation\ Rate + Leak\ Rate + \Sigma\ Minor\ Variables \quad \text{(Eq. 2)}$$

To determine the surface water intrusion rate for an SST the ($Leak\ Rate + \Sigma\ Minor\ Variables$) terms are set to zero for sound tanks with well-aged, undisturbed waste. The net change rate is determined from the long term surface level or interstitial liquid level trend, the waste porosity, the size of the surface pool, and the evaporation rate estimated in a manner similar to the earlier tank T-111 discussion.

Single-shell tanks with suspected intrusions are subjected to confirmatory in-tank visual inspections. In-tank inspections were completed for the 20 SSTs identified as intrusion candidates between November, 2012, and February, 2014. Active intrusions were observed in 10 of the 20 tanks. For these SSTs an absolute surface water intrusion rate was determined by counting the drip rate. Seven other SSTs had evidence of historical intrusions including increases in surface pool size, and efflorescence on the tank dome and dome penetrations; the remaining three SSTs showed no evidence of intrusion [14].

During this same period an example of surface water intrusion masking a waste leak was identified in tank T-111. A leak in tank T-111 was first identified in 1974, and the tank's liquid periodically pumped out to the extent practical until 1978. An intrusion was evident in the tank

beginning at that time and continued until at least 1993 when the tank began leaking again. An attempt to interim stabilize the tank occurred during January - February, 1994, but was unsuccessful. After 1994 the surface level increase rate was constant for several years, before decreasing and eventually stabilizing in 2006. After 2006 the surface level began to decrease at an accelerating rate indicating that the tank was again leaking, when the sum of the leak and passive evaporation rates was exceeding the water intrusion rate. A surface level change history developed from Equation 2 suggested that the tank may have begun leaking again as early as 2002 [15, 16].

RESULTS

For tanks with active intrusions observed during the in-tank inspections, the standard laboratory maxim of 20 drops equaling one mL was used to estimate the intrusion rate. A constant 365 day period was assumed when calculating the annual intrusion rate. This assumption ignores the possibility that seasonal variations may exist in the rates. Seasonal variations probably account for waste surface pool increases in tanks with no observed active intrusion during an in-tank inspection. Annual intrusion rates shown in Table I have been adjusted for water evaporation due to tank passive breathing (refer to Equation 2 and the earlier discussion). The method for estimating passive evaporation losses is described in RPP-RPT-54981, 2013, *Initial Evaluation of Fourteen Tanks with Decreasing Baselines Selected for Review in RPP-PLAN-55113, Revision 1*, Rev. 0 [17].

An effort to confirm or dismiss the constant intrusion rate assumption has proven unsuccessful. Three of the tanks (tanks B-202, BX-101, and T-201) with active intrusions have surface level measurement instrumentation touching down in surface pools and giving daily readings. For these tanks the surface level increase has been reasonably constant through the year, suggesting the intrusion is unaffected by seasonal variations in rainfall and snowmelt surface water. However, the seasonal changes in surface level due to the thermal expansion and contraction of the liquid tank waste that result from changes in ambient air temperature prevent confirmation of a constant intrusion rate. The remaining two tanks (tanks A-102 and T-101) with active intrusions and surface level measurement instrumentation touching down in surface pools have such small surface level increase rates that no conclusions can be drawn about seasonal rates.

For tanks with active water intrusions and interstitial liquid level measurement capability, the interstitial liquid level shows a constant annual increase rate. However, the once per quarter measurement frequency is insufficient to confirm year-round intrusions are taking place. Using a constant, year-round drip rate is a conservative assumption based on the limited data available [18].

TABLE I. SST In-Tank Visual Inspections for Water Intrusion

Tank	In-Tank Visual Inspection Water Intrusion Observations	Estimated Surface Water Intrusion Rate m^3/yr (gal/yr)
A-102	Active intrusion present during inspection	0.15 – 0.30 (40 – 80)
A-103	Evidence of past intrusion; no active intrusion during inspection	0
B-109	Evidence of past intrusion; no active intrusion during inspection	0
B-202	Active intrusion present during inspection	0.19 (50)
BX-101	Active intrusion present during inspection	1.5 – 1.9 (400 – 500)
BX-103	Surface pool size increase; no active intrusion during inspection	1.1 – 1.5 (300 – 400)
BX-110	Surface pool size increase; no active intrusion during inspection	0.57 – 0.76 (150 – 200)
BY-101	Evidence of past intrusion; no active intrusion during inspection	0
BY-102	Active intrusion present during inspection	0.95 – 1.3 (250 – 350)
BY-103	Active intrusion present during inspection	1.5 – 1.9 (400 – 500)
BY-106	No intrusion evidence	0
BY-111	No intrusion evidence	0
S-106	Active intrusion present during inspection	0.19 (50)
S-109	No intrusion evidence	0
S-111	Indeterminate; interstitial liquid equilibrating	0
SX-106	Active intrusion present during inspection	3.0 – 3.8 (800 – 1,000)
T-101	Active intrusion present during inspection	0.11 – 0.19 (30 – 50)
T-201	Active intrusion present during inspection	0.13 – 0.19 (35 – 50)
TY-102	Surface pool size increase; no active intrusion during inspection	0.49 – 0.57 (130 – 150)
U-111	Active intrusion present during inspection	0.23 – 0.38 (60 – 100)

Tank T-111 Leak Discovery and Mitigation

The determination that another leakage episode for tank T-111 had begun, possibly as early as 2002, and had been masked by a continuing intrusion for about four years, raised concerns for the continued viability of that tank's intrusion prevention barriers (Schofield, 2014). The tank's surface penetrations except for those required for interim stabilization jet pumping were sealed by Construction Project B-222, *Isolation of Salt Wells and Single-Shell Tanks*, *ca*. 1988. A pump pit weather cover was installed after the 1994 interim stabilization pumping effort [19].

In the event that a water intrusion into an SST is discovered, the Tank Operations Contractor is required to determine the cause of the intrusion and to stop it. Liquid created by the intrusion will be removed during waste retrieval from the tank (Miller, 2008, Section 4.1.1 A.3.) [20]. In-tank inspections of tank T-111 were performed in February, 2013, and on two consecutive days in December, 2013. Ripples created by falling water droplets were visible on the surface of the waste pool. The water droplets appeared to originate on the concave surface of the concrete tank dome and were present in several locations [21].

The Tank Operations Contractor refurbished an existing portable ventilation exhauster last used in February, 2007, and relocated it to tank T-111 in order to evaporate the water intrusion. Exhauster operation was initiated June 24, 2015, and began sustained operation July 15, 2015. As of October 21, 2015, 8.5 m^3 (2,250 gal) of water have been evaporated from the tank as water vapor at a nominal rate of 0.11 m^3/day (30 gal/day). The evaporation rate is expected to remain relatively constant until the existing surface pool is eliminated and liquid transport through the near-surface waste solids becomes the controlling phenomenon for water removal.

Fig. 4. Tank T-111 Portable Exhauster POR-106

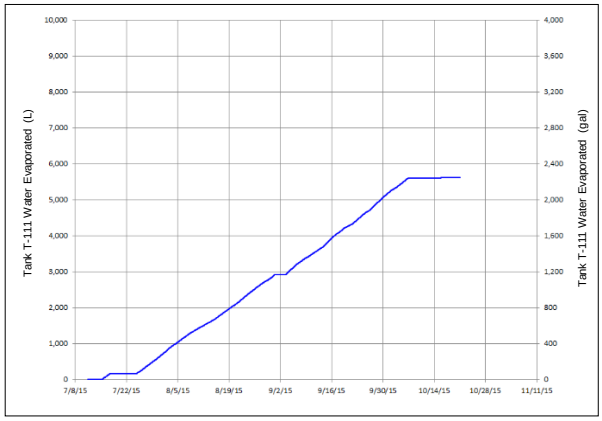

Fig. 5. Tank T-111 Water Evaporation Portable Exhauster POR-106

Tank Farm Interim Surface Barriers

The interim isolation / intrusion prevention approach of locating and sealing individual surface water entry points to the SSTs, including their pump pits and valve pits and interfacing pipeline encasement networks, has been generally successful. However the SST intrusion investigations summarized here show that the continued integrity of the barriers can be difficult to maintain over an extended time period; and that surface water may accumulate in the tanks in a variety of ways not amenable to barricading individual entry points, as in the tank T-111 concrete dome example.

The Tank Operations Contractor and the U.S. Department of Energy Office of River Protection have deployed two interim surface barriers extending over tank farms to prevent infiltration of surface water into the soil. The barriers provide the benefit of sealing potential surface water intrusion entryways into the SSTs when they extend to the tank farm boundary.

The 241-T Tank Farm interim surface barrier was installed in 2008, covering a portion of the tank farm: four SSTs, and portions of six other SSTs. In 2010 the 241-TY Tank Farm interim surface barrier was installed covering all of that tank farm. Soil moisture within the first 15 m (50 ft) below grade is monitored at select locations under the barriers and around their boundaries. Monitoring data indicate that barriers are curtailing recharge of water into the vadose zone. Near-surface moisture levels have been reduced, moisture levels deeper in the vadose zone have stabilized, and the amplitude of seasonal variations in soil moisture have been dampened [22]. Similar barriers deployed in the other SST farms would be expected to perform similarly.

Fig. 6. 241-T Tank Farm Interim Surface Barrier, 2015

Fig. 7. 241-TY Tank Farm Interim Surface Barrier, 2015

CONCLUSION

A method to predict the existence of surface water intrusion into SSTs has been developed and tested. Applying the method to the 149 Hanford single-shell tanks identified 20 SSTs likely to be experiencing surface water intrusion; active intrusions were observed in 10 of the 20, and evidence of past intrusions in another seven. The rate of intrusion was adjusted to account for evaporative water losses from passive tank breathing.

Adaptation of the method to analyze an observed surface level decrease in tank T-111 identified an active waste leak, as well as a new water intrusion mechanism not previously observed: water droplets were forming on the inner surface of the concrete tank dome and falling into the surface pool without an apparent source.

A portable ventilation exhauster was subsequently connected to tank T-111 to reduce the liquid volume susceptible to continued leakage, and mitigate the water intrusion. During the three month period, mid-July – mid-October, 2015, the exhauster removed 8.5 m^3 (2,250 gal) of water from the tank as water vapor.

An alternative to continued reliance individual tank interim isolation / intrusion prevention measures could be deployment of waterproof interim surface barriers that cover entire tank farms. Two test barriers have been installed to assess their ability to limit soil moisture recharge and the movement of existing vadose zone radionuclide plumes. Soil moisture levels beneath the barriers have been reduced, moisture levels deeper in the vadose zone have stabilized, and the amplitude of seasonal variations in soil moisture have been dampened. Test performance suggests the barriers would be an effective means of eliminating surface water intrusions into the interim stabilized single-shell tanks.

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