Single-Shell Tanks Leak Integrity Elements/ SX Farm Leak Causes and Locations - 12127

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ABSTRACT

Washington River Protection Solutions, LLC (WRPS) developed an enhanced single-shell tank (SST) integrity project in 2009. An expert panel on SST integrity was created to provide recommendations supporting the development of the project. One primary recommendation was to expand the leak assessment reports (substitute report or LD-1) to include leak causes and locations. The recommendation has been included in the M-045-91F Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) as one of four targets relating to SST leak integrity.

The 241-SX Farm (SX Farm) tanks with leak losses were addressed on an individual tank basis as part of LD-1. Currently, 8 out of 23 SSTs that have been reported to having a liner leak are located in SX Farm. This percentage was the highest compared to other tank farms which is why SX Farm was analyzed first. The SX Farm is comprised of fifteen SSTs built 1953-1954. The tanks are arranged in rows of three tanks each, forming a cascade. Each of the SX Farm tanks has a nominal 1-million-gal storage capacity. Of the fifteen tanks in SX Farm, an assessment reported leak losses for the following tanks: 241-SX-107, 241-SX-108, 241-SX-109, 241-SX-111, 241-SX-112, 241-SX-113, 241-SX-114 and 241-SX-115.

The method used to identify leak location consisted of reviewing in-tank and ex-tank leak detection information. This provided the basic data identifying where and when the first leaks were detected. In-tank leak detection consisted of liquid level measurement that can be augmented with photographs which can provide an indication of the vertical leak location on the sidewall. Ex-tank leak detection for the leaking tanks consisted of soil radiation data from laterals and drywells near the tank. The in-tank and ex-tank leak detection can provide an indication of the possible leak location radially around and under the tank.

Potential leak causes were determined using in-tank and ex-tank information that is not directly related to leak detection. In-tank parameters can include temperature of the supernatant and

sludge, types of waste, and chemical determination by either transfer or sample analysis. Ex-tank information can be assembled from many sources including design media, construction conditions, technical specifications, and other sources.

Five conditions may have contributed to SX Farm tank liner failure including: tank design, thermal shock, chemistry-corrosion, liner behavior (bulging), and construction temperature. Tank design did not apparently change from tank to tank for the SX Farm tanks; however, there could be many unknown variables present in the quality of materials and quality of construction. Several significant SX Farm tank design changes occurred from previous successful tank farm designs. Tank construction occurred in winter under cold conditions which could have affected the ductile to brittle transition temperature of the tanks. The SX Farm tanks received high temperature boiling waste from REDOX which challenged the tank design with rapid heat up and high temperatures. All eight of the leaking SX Farm tanks had relatively high rate of temperature rise. Supernatant removal with subsequent nitrate leaching was conducted in all but three of the eight leaking tanks prior to leaks being detected.

It is possible that no one characteristic of the SX Farm tanks could in isolation from the others have resulted in failure. However, the application of so many stressors – heat up rate, high temperature, loss of corrosion protection, and tank design – working jointly or serially resulted in their failure. Thermal shock coupled with the tank design, construction conditions, and nitrate leaching seem to be the overriding factors that can lead to tank liner failure. The distinction between leaking and sound SX Farm tanks seems to center on the waste types, thermal conditions, and nitrate leaching.

INTRODUCTION

The 241-SX Farm (SX Farm) tanks with leak losses are addressed on an individual tank basis. An assessment reported leak losses for the following tanks [1]: 241-SX-107, 241-SX-108, 241-SX-109, 241-SX-111, 241-SX-112, 241-SX-113, 241-SX-114 and 241-SX-115. Two tanks, 241-SX-104 and 241-SX-110, were documented as tanks with unlikely leaks and were recommended to be further assessed [2]. The individual assessments of tanks 241-SX-104 and 241-SX-110 resulted in the recommendation that the tank integrity status be changed from "Assumed Leaker" to "Sound" [3, 4].

The identification of SX Farm tank leak locations relied on the first indication of radiation detected in laterals and drywells as well as liquid level decreases as appropriate. Laterals are horizontal leak detectors located underneath the tank and three laterals were installed under each leaking SX Farm tank except for tank SX-113 which had five laterals installed. Drywells are vertical leak monitoring wells located around each tank. For tanks SX-108 and SX-115 soil sample test wells were used to collaborate the data from laterals built into the caissons and drywells. Caissons are vertical boreholes, approximately 12-ft in diameter, located between up to four tanks to allow the installation of horizontal laterals underneath the tanks. The soil sample test wells were drilled primarily to identify the volume of the leaks for the two tanks.

Data sources have included data sheets, plots of data, internal letters, documents, and monthly–quarterly–semi-annual–annual reports. The preferred source was the actual data sheets but they were not available for all cases which resulted in using the best data source available.

The SX Farm leak causes were identified as tank design, thermal shock, chemistry-corrosion, liner bulging, and tank construction conditions.

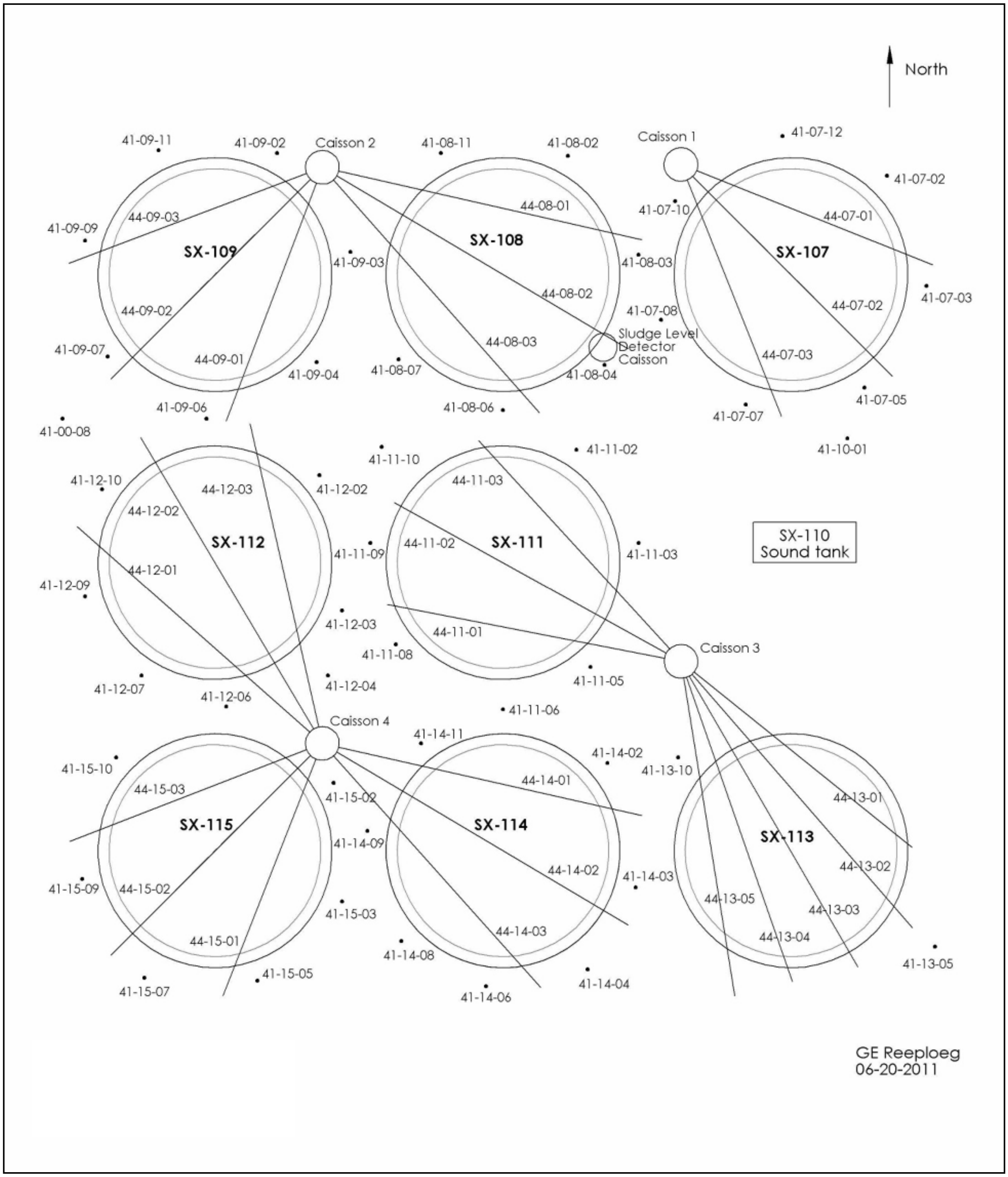
BACKGROUND

The SX Farm is comprised of fifteen Single-Shell Tanks (SSTs) built 1953 – 1954. The tanks are arranged in rows of three tanks each, forming a cascade. Each of the SX Farm tanks has a nominal 1-million-gal storage capacity. The SX Farm tank consists of a carbon steel liner inside a reinforced concrete shell. The concrete shell is a domed structure approximately ~46.5-ft in height at the apex and ~83-ft in diameter at the footings. The steel tank liner covers the 75-ft inner diameter tank bottom and sidewalls to a height of ~32-ft as measured from the tank center. The tank bottom is dish shaped and slopes approximately 3.3% from the sidewall to the tank center (i.e., 14.875-in. elevation drop over 37.5-ft radius). The tank bottom connects orthogonally to the sidewall.

The method used to identify leak location consisted of reviewing in-tank and ex-tank leak detection information. This provided the basic data identifying where and when the first leaks were detected. In-tank leak detection consists of liquid level measurement that can be augmented with photographs which can provide an indication of the vertical leak location on the sidewall. Ex-tank leak detection for the leaking tanks consists of laterals and drywells (see Figure 1). The in-tank and ex-tank leak detection can provide an indication of the possible leak location radially around and under the tank. The ex-tank leak detection can be further defined with specifically located test wells and tank concrete core samples.

Similarly, potential leak causes can be determined with in-tank and ex-tank information that is not directly related to leak detection. The other in-tank parameters can include temperature of the supernatant and sludge, types of waste, and chemical determination by either transfer or samples analysis. Ex-tank information can be assembled from many sources including design media, construction conditions, technical specifications, and other sources.

Figure 1. SX Farm Leaking Tanks with Laterals and Drywells
Tank inner ring is steel liner, outer ring is outer edge of tank footing [5-8]



Note: Sound tanks SX-101 to SX-106 lie to the north of tanks SX-107, SX-108, and SX-109. Solid straight lines extending from the caissons represent laterals and solid black dots represent drywells.

TANK DESIGN/CONSTRUCTION

The SX Farm tanks had multiple design features that could contribute to stresses or possible leak paths when the tank was being operated including:

- Orthogonal intersection between the steel bottom and the sidewall
- Fillet weld used between the bottom and sidewall intersection
- Less rigorous weld inspection testing
- Partial asphaltic membrane waterproofing
- Keyed construction joints in the sidewall

These features are common to all SX Farm tanks and differed from earlier, accepted and built tank designs.

The steel bottom of the SX Farm tanks intersects the sidewalls orthogonally rather than the knuckle transitions in earlier designed tank farms [9]. The SX Farm tank footing to the first keyed wall construction joint is shown on Figure 2 [10]. This figure shows the orthogonal intersection between the dished bottom and the sidewall, water stop at the base footing to wall construction joint and other details. The 7-in wide water stop at the footing construction joint is 2 ¼-in above the joint and 4 ¾-in below the joint. The earlier 241-BCTU tanks notched footing construction joint does not incorporate a water stop.

Figure 3 shows the detail of the orthogonal intersection between the bottom and the sidewall with a fillet weld between the bottom and sidewall orthogonal intersection [6]. Full penetration butt welds for BCTU Farm tanks are shown in Figure 4 for the rounded knuckle configuration [9].

The three ply asphaltic membrane waterproofing between the liner and the concrete shell was eliminated from the design of the SX Farm tanks (see Figure 3). An asphaltic membrane was incorporated between the concrete footing and the grout below the liner. The design for BCTU Farm tanks for comparison is shown in Figure 4 which shows the rounded knuckle configuration with the bottom, knuckle, and sidewall three ply water proofing.

Other design specification changes for the SX Farm tanks included weld testing with the Vacuum Soap Test at 10-in of mercury or other Atomic Energy Commission approved method [11]. An example of an alternate method may have been full penetration X-Ray weld testing. Spot X-Ray testing of the welds was specified for SX Farm tanks [6]. Specifications required X-Ray of welds for BCTU Farm tanks [9].

Figure 2. SX Farm Base Footing and Wall Reinforcing [10]

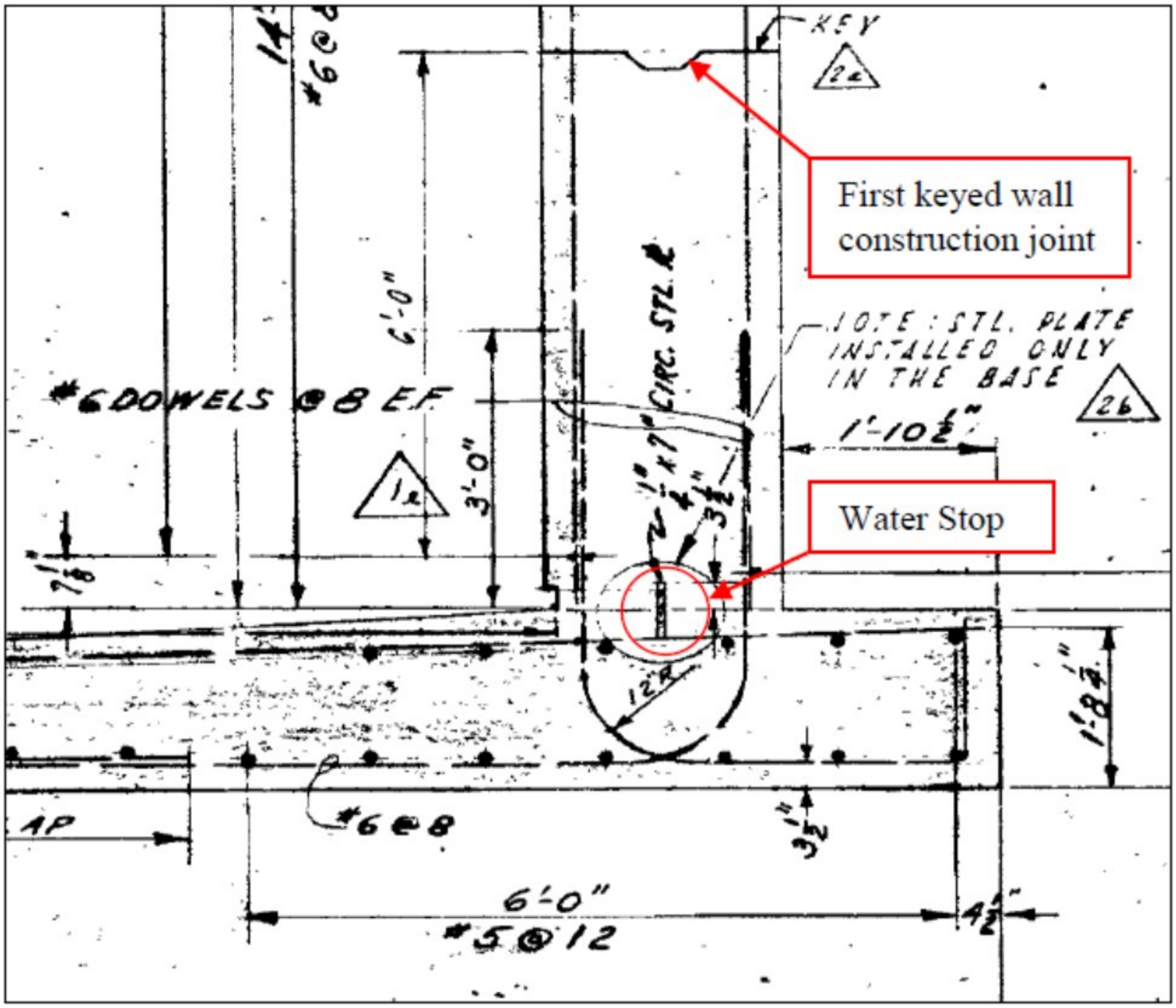
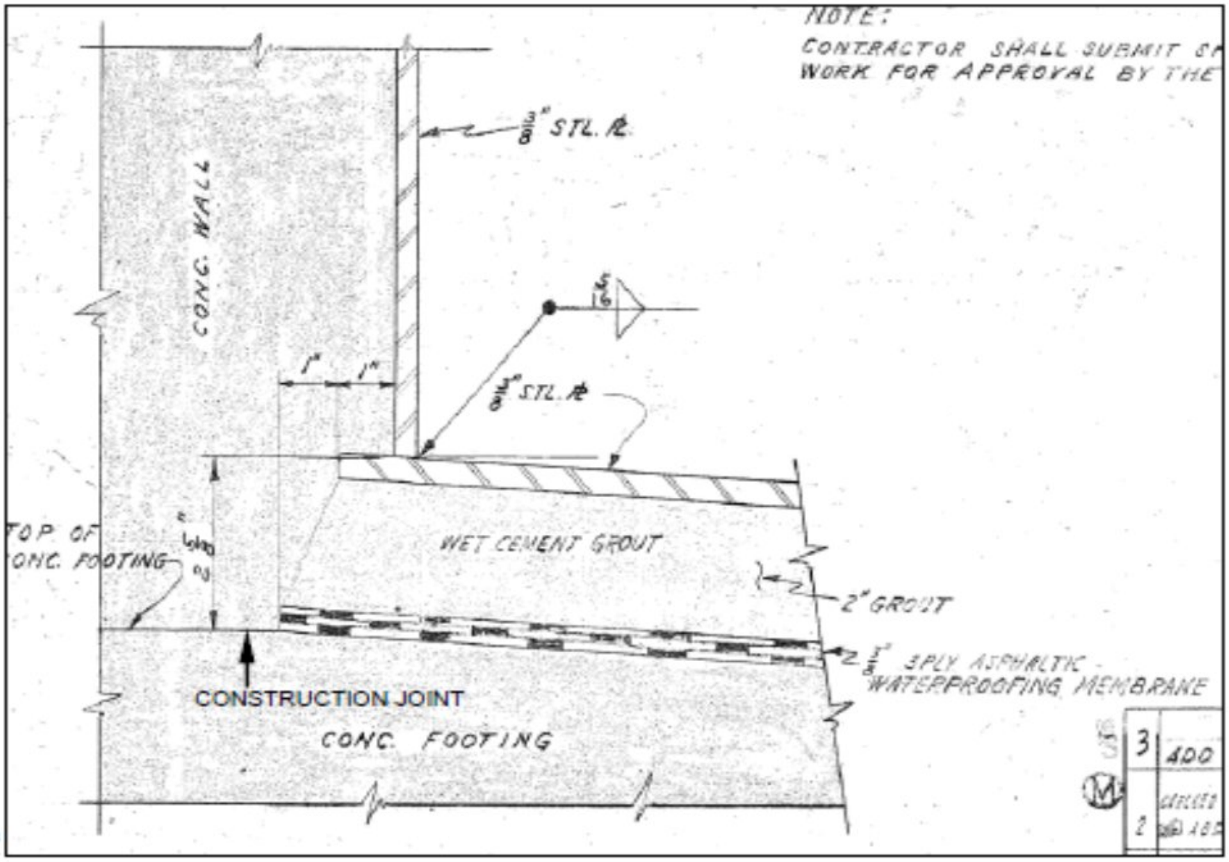
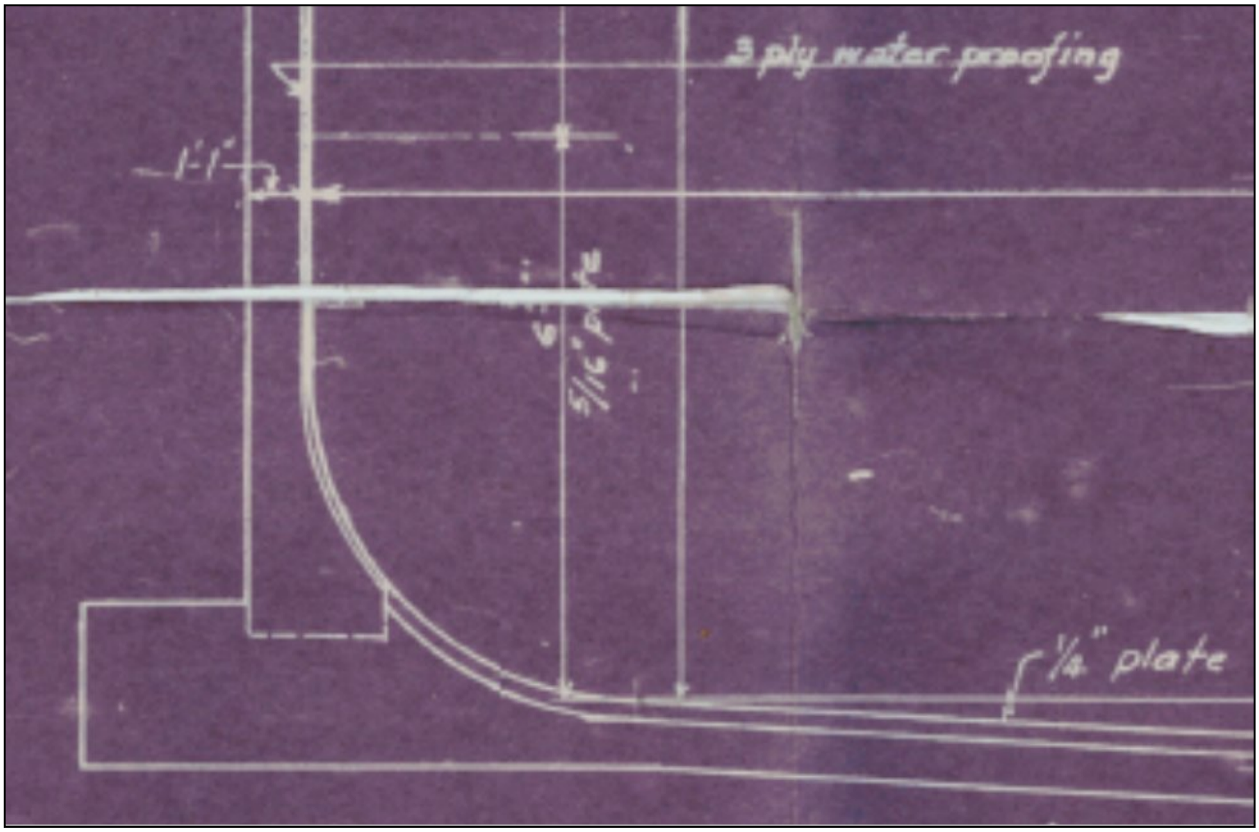


Figure 3. SX Farm Tank Bottom Liner to Sidewall Design Detail [6]



Note: The water stop at the construction joint between footing and middle of the concrete wall is to the left of the above detail.

Figure 4. B C T U Farm Tank Knuckle Configuration w/3 Ply Waterproofing [9]



The design of the SX Farm tanks was the first that diverged from the round bottom knuckle design used in the earlier waste tanks. A fillet weld was used to close the seam where the sidewall and tank bottom liners meet versus the butt welding of the knuckle transition of earlier tank designs. A review of the basic differences between fillet and butt welds indicates that the superior butt welds would be preferred for the tank farm waste tanks.

A review of literature to compare historical failure rates for fillet welds and butt welds did not identify any relevant information that could be related to the tank farm waste tanks. There was recognition that the base of the SX Farm tanks was considered fixed and excessive steel stresses could be expected during pressure surges and elevated temperatures [12]. Tank farm experience indicates that several SSTs with fillet welds failed during service.

The problem that the orthogonal joint design introduces including changes in asphaltic waterproofing is described in the following excerpt [13].

> "A steel liner which fits tightly inside a concrete shell provides no means for differential thermal expansion. Such expansion can result in high compressive stresses in the steel which may produce elastic instability. Instability is particularly likely to occur in the flat bottom of the liner resulting in rippling of the bottom. This is more apt to occur in designs in which the junction at the lower corner is 90 degrees as in the SX Tanks than in designs in

> which a radius is used as in the BX and TX Tanks of earlier design. Empty tanks in the SX farm have been observed to have rippled bottom liners before filling.
>
> "A hydraulic head would tend to flatten the ripples but filling with hot waste would tend to increase the degree of rippling because of the restraint of the concrete shell. Under certain conditions this might cause rupture of a joint. The severity of the rippling is believed to have been demonstrated by the instability of the bottom of tank 113-SX after it was emptied. It is suggested that the restraint offered by the concrete shell be reduced by a return to the use of an asphalt expansion joint between the steel shell and the concrete shell."

The ripples identified in the preceding paragraphs probably refer the visual effects of either the support structure for the bottom liner during construction or the overall stress inherent in the welding of multiple steel plates making up the bottom liner. The small discontinuous ripples of probably less than a few inches in height observed during construction differ from bulging indicated in this report. Bulging is typically indicated by the degree of bottom liner uplift of more than several inches over a relatively larger area after the tank is being or has been filled.

Filling with hot waste could heat any water in the grout at the bottom of the tank or organics from the asphalt existing below the grout potentially trapping pressurized vapor [13]. This could result in forces that cause the liner to deform (bulge). The design of the orthogonal sidewall to bottom joint was postulated to trap the pressurized vapor under the liner because the liner edge was embedded in the structural concrete, preventing pressure release up the sidewalls. This in turn increased the temperature due to the lower vapor space heat transfer coefficient and decreased the heat transfer from the bottom of the tank which compounded the situation.

TANK CONSTRUCTION CONDITIONS

The outside temperature between January 16, 1954 and January 30, 1954 ranged from an average high of 24°F to an average low of 9°F. A photograph of the SX Farm under construction (see Figure 5), taken January 20, 1954 (high 11°F low -6°F), shows several of the tanks full of water either undergoing leak testing or for concrete wall pouring. During this cold period snow covered ice is seen in the water filled tanks. Some question exists on the ductile-brittle transition temperature during construction of the SX Farm at these low temperatures. There was also a delay on tank work pending installation of a high capacity vent system for tanks SX-107 through SX-115 based on S-104 steam eruptions [14, 15]. These tanks could have been exposed to the elements for a significant period of time.

Figure 5. SX Farm Construction Photograph
January 20, 1954 (N1D00585052)

The fracture toughness (ductility) drops sharply with temperatures below a critical value. The ductile-to-brittle transition temperature is reported (sans reference) as approximately 50°F [16].

Below the transition temperature, the metal loses its ability to absorb forces such as induced loads, or the impact of falling objects without fracturing. In this circumstance it is possible for micro-fissures or hairline cracks to be created. Later, when the metal is subjected to high stress, it might be possible for the cracks to propagate through the metal, or possibly subject the weakened areas to increased corrosion.

Winter temperatures as low as -6°F occurred during the period when the SX Farm tank liners were being constructed and leak tested (see Figure 5). The limitations of carbon steels to resist impact at low temperature was perhaps not well understood when SX Farm was constructed. Issued only recently, the ASME B31T-2010 Code indicates that a ≤10-mm thick Type A 283 steel plate had an unrestricted low temperature service limit of 20°F [17]. The SX Farm tank liners are 9.53-mm (3/8-in) thick A 283 carbon steel. The SX Farm tank construction specification stated that the storage tank liner shall conform to ASTM A-283-52T, grade A or B, with additional specific requirements on carbon composition are stated as “0.26 % maximum”

[11, 18]. Later revisions to ASTM A-283 specifications lowered the allowable carbon content to 0.14 from 0.17%.

The SX Farm Blue Print File (BPF) No. 4961 Chemical and Physical Test Reports for steel plate were reviewed and found to meet the carbon and magnesium limits [11]; carbon 0.26% maximum and manganese 0.60% maximum. Carbon ranged from 0.07 to 0.15% with an average ~0.11%. Manganese ranged from 0.04% to 0.48% with an average ~0.43%. The one manganese at 0.04% appeared to be low as the lowest above that was 0.39%. All of the 25 sheets with a total of 40 determinations were notarized and approved by the prime contractor.

A review of toughness and the ductile to brittle transition temperature for carbon steels (designated as "impact transition temperature) indicates that carbon content can have a significant effect [19]. A decreased carbon content not only raises the propagation energy for crack growth but also lowers the temperature for transition from ductile to brittle behavior [19]. The modern ASME B31T-2010 Code low temperature service limit may be lower than what could be expected for 1950's higher carbon steel used in SX Farm construction [17].

The possible variability of liner steel from either different runs from the same supplier, or because of multiple suppliers could affect the resistance to low temperatures.

The low temperatures experienced during construction were less than the 20°F allowable temperature where impact loading had the potential for creating micro-fissures. The load of the steel liner wall on itself and the bottom liner along with filling the tank with water or other impact occurrences may have triggered the fissures in the steel liner that were not detected during liner leak testing.

TEMPERATURE

A report issued October 22, 1959 indicated that the self boiling waste operating temperature should be maintained between 50°F and 220°F [20]. The maximum sludge temperature should not exceed 300°F. This report contained the first boiling waste limitations on temperature [20]. Thermal shock creates stress both from rapid temperature rise as well as high temperatures.

The same document states that tank contents should also be heated slowly to not exceed the recommended rate of 2°F per day. An attempt was apparently made in one tank (SX-115) to control the rate of rise basically by dilution. Water and/or condensate was added to the tank prior to receiving waste; however, the tank exceeded the 2°F per day rate of rise in spite of the thermal dilution effect.

Temperature data used for the SX Farm evaluations were taken from RHO-CD-1172 [21] and temperature data sheets and are designated as Bulb temperatures. However, the bulb temperature design and the degree of data uncertainty are unclear as no documentation for this information has been located.

Waste storage tanks have observed a phenomenon called bumping, which is a series of abrupt pressure surges and more severe cases referred to as steam eruptions [22]. Bumping is believed to be the result of rapid evaporation of water by stored heat with the sudden release of steam due to temperature gradients in the waste. Prior to May 1955, bumping was only observed in tanks S-101, S-104, SX-101 and later observed in tank SX-104. All of these pressurizations occurred when either the tank contents were not being agitated or when an agitator was initially started. No pressurizations have originated in tanks with an air lift circulator (ALC) being operated. Tests were conducted in tanks SX-107, SX-108, and SX-109 prior to February 1957 to develop operating conditions to minimize bumping. Once one of the short ALC in tank SX-107 was placed into service on February 18, 1957, no pressure surges or signs of a temperature gradient formation in the SX-107 supernatant occurred [23]. However, a steam eruption leading to ground contamination occurred in August 1958 in tank SX-114. This event was believed to be the result of turning off the air supply to the ALC and replacing with water [24].

There doesn't seem to be a direct relationship with leaking tanks. In the most severe bumping incident with tank SX-114, the pressurization could have affected the piping seals into or out of the tank; however, it remains inconclusive. Therefore, bumping which is an effect of thermal conditions has not been considered in the overall factors that cause tank liner failure.

LINER OBSERVATIONS

A bulge in a tank liner may result in the direct failure of the liner or cause enough stress or thinning on the steel liner plates and welds that they become more susceptible to the effects of corrosion. SST bulging tends to be a dynamic phenomenon, and it is possible that a tank with no measured bulge at one point in time may actually have had a displaced liner that was not detected at another time.

A possible indicator of a bulge may be broken ALC turnbuckle guy rods and/or bent piping which can be seen in some photographs (see Photographs section).

CHEMISTRY-CORROSION

The process of nitrate waste leaching involved first, pumping the supernatant from the tank down to the apparent sludge depth. The tank would then be filled with condensate to a liquid level of about 10-ft and the sludge would be dissolved using ALCs for mixing. The dissolution process would take between one and three months, at which time the nitrate solution would be pumped to the feed tank for the REDOX plant and the leached tank would be returned to service to receive REDOX waste for self-concentration.

Nitrite (NO_2^-) and hydroxide (OH^-) are known as nitrate induced stress corrosion cracking inhibitors. One key characteristic for inhibiting stress corrosion cracking is to maintain a high nitrite concentration to nitrate concentration ratio. Prior to nitrate leaching the NO_2^- and OH^- would have been removed from the tank when the supernatant was pumped out. Leaching the sludge with condensate after the supernatant had been pumped out would result in a nitrate ion rich waste with a low nitrite to nitrate ratio which, at the temperature of the tank, would be conducive to stress corrosion cracking.

Table 1 shows examples of waste sample chemical composition results for the important factors in stress corrosion cracking. The supernatant samples taken in April 1961 represent the supernatant waste compositions shortly before the nitrate leaching process began. While the nitrite concentration to nitrate concentration ratio is very low in the supernatant layers, the nitrate leachate samples show that the concentration ratio is even smaller in the leachate samples from tanks SX-105 and SX-113. The nitrate leaching process to retrieve nitrate would have produced a nitrate ion rich solution that contained insufficient nitrite and hydroxide concentrations to inhibit stress corrosion cracking at the tank temperatures. Also, increasing temperatures accelerates stress corrosion cracking [25].

Table 1. Waste Sample Chemical Composition Results for SX Farm Tanks during the 1960s

Source	Layer	Date	$[OH^-]$ M	$[NO_2^-]$ M	$[NO_3^-]$ M	$[NO_2^-]/[NO_3^-]$
SX-101[1]	Supernatant	April 1961	4.58	2.48	6.03	0.41
SX-107[1]	Supernatant	April 1961	1.27	0.65	8.65	0.08
SX-108[1]	Supernatant	April 1961	1.32	0.61	8.35	0.07
SX-114[1]	Supernatant	April 1961	1.53	0.45	8.15	0.06
SX-114[2]	Sludge	November 1961	0.16	0.05	1.64	0.03
SX-114[2]	Sludge	November 1961	0.22	0.07	3.47	0.02
SX-113[3]	Leachate	October 1962	0.4	0.1	4.2	0.02
SX-105[4]	Leachate	February 1967	0.52	0.18	4.23	0.04

[1] Results were obtained from [26].
[2] Results were obtained from [27].
[3] Results were obtained from [28].
[4] Results were obtained from [29].

PHOTOGRAPHS

Missing or disconnected ALC turnbuckle guy rods could indicate that there was bulging of the bottom liner sufficient to cause the upper connection to fail with the guy rod sinking below the liquid surface (missing). Some ALC turnbuckle guy rods were also hanging free from the upper connection as it had apparently become disconnected from the bottom connection either at the attachment plate or the plate itself pulled away from the bottom of the tank.

Some SX Farm tank photos show equipment damage that may be linked to liner bulges. Each ALC was anchored to the tank floor by three 0.5-in diameter guy rods. In several tanks, broken ALC turnbuckle guy rods and/or bent piping are visible.

All of the leaking tanks as well as some of the sound SX Farm tanks contained ALCs that had one or more disconnected turnbuckle guy rods with the possible exception of tank SX-109 which could not be determined because of solids encrusted ALCs.

LATERALS

A prototype five lateral leak detection system was installed under tank SX-113 after indications of a >4-ft liner bulge in 1958. The tank SX-113 prototype laterals were installed 10-ft under the tank and varied between 6-ft and 12-ft below the bottom of the tank over the course of a lateral. The horizontal alignment was calculated to be within ~2-ft [8]. The alignment was addressed in HW-60749 and included the following: "The subcontractor was permitted to complete the five laterals to the best of his ability without official alignment checks because of the short time limit of the construction schedule." In addition, the document included future specifications to control alignment.

In 1962, a three lateral leak detection system was installed underneath tanks SX-105, and SX-107 through SX-115. The procedure for drilling the laterals was stated in HW-68661 [30]. The driller was required to check the alignment of the laterals every 20-ft during the installation according to this document and it was assumed installation of the laterals were improved as no records of vertical or horizontal variation were found.

Each lateral is a 3-in pneumatic stainless steel tubing enclosed in 4-in carbon steel pipe. The laterals are horizontal and extend radially from a large caisson (12-ft diameter) that is located between up to four tanks. A "lateral shack" was constructed over each caisson. The access to each lateral is through a separate vertical tube (also made of 3-in. pneumatic stainless steel) that extends up to the floor of the lateral shack. The lateral tube transitions from vertical to horizontal at the bottom of the caisson through a 90° elbow with a 4-ft bend radius. The laterals are numbered clockwise from 1 to 3. Probes are inserted into each lateral to monitor for gamma radiation that could indicate waste leakage from a tank. Operation of the laterals and details of the probes and data are described in RPP-RPT-27605 [31].

DRYWELLS

Fifteen of the original SX Farm drywells were drilled around the tanks between 1954 and 1958 [32]. The remainder of the SX Farm drywells was drilled starting in 1962 [32]. Some soil sampling test wells were drilled for specific leak volume determinations for tanks SX-108 and SX-115.

The "00" series drywells were installed shortly after tank construction, usually around the periphery of the farm and most extend to 150-ft below grade. Others with tank numbers embedded in the drywell number were constructed later, sometimes after tank operations had ceased and generally to 100-ft below grade (or less). The usual number of drywells surrounding a tank is 1 to 4. If there are more, then there likely was some concern regarding a release which was being investigated.

Four gamma ray probe types were used to monitor gamma in drywells to detect leaks [33]. The most widely used probe was the unshielded gross gamma sodium-iodide (NaI) probe (or probe 04 and the shielded NaI probe is referred to as probe 14). The NaI probe (04) is very sensitive and able to record gamma ray activity from 30 counts per second (cps) up to about 40,000 cps before the data becomes unreliable. The next most commonly used probe was the Red-GM (or probe 02) which is less sensitive but can reliably record gross gamma at much higher levels of activity. Operation of these and other probes are discussed in HNF-3136 [33]. A scintillation probe (SP) was also used to measure low levels of radiation in the drywells but the earliest drywell data sheets found (1969) did not list readings below 50K counts per minute (cpm). Leak location identification is primarily focused on the first indication of a leak and is therefore typically concerned with the lower levels of gross gamma detection.

LINER LEAK LOCATIONS

Liquid level decreases, if detected, are typically the first indication of a tank liner leak. Liquid level decreases are typically confirmed by drywell and/or lateral radioactivity. Drywell and lateral radioactivity when first detected can be an indication of the radial location of a liner leak. The location of a liner leak, however, is not necessarily the same as the location where radiation is detected. The leak path out of the tank structure and through the soil path determines where the leak is detected.

A bottom liner leak detected by lateral or drywell radioactivity may have penetrated the waterproof membrane at any location or pooled on the waterproof membrane and followed concrete cracks or breaks in the footing to a different location including the top of the tank footing. Therefore, the point of waste egress from the tank liner may not be the point of entry of the leaking waste to the soil. Radioactivity detected in drywells is typically dependent on the leak path through the concrete sidewall or footing. Also, if the drywell radioactivity is detected above the footing there could be a possibility of a sidewall leak or leaks associated with pipe lines or other sources. If enough information is available, liquid level and drywell radioactivity can be used to locate the approximate vertical location of a liner leak. Lateral radioactivity almost always indicates a leak at or below the footing.

POSSIBLE LINER LEAK CAUSE(S)

Analysis which centered on tank design/construction, in-tank data, and ex-tank data indicates that there were up to five SX Farm tank conditions that could contribute to a failed liner; tank design, thermal shock, chemistry-corrosion, liner bulging, and tank construction temperature. Some or all of the factors can act serially or together to contribute to tank liner failure.

Other general tank construction factors such as the quality of materials and fabrication could also contribute to tank liner failure. No evidence has been found to substantiate quality defects but they still remain a possibility as a primary or secondary liner leak cause.

CONCLUSIONS

Five conditions may have contributed to SX Farm tank liner failure which includes the following:

- Tank design
- Thermal shock
- Chemistry-corrosion
- Liner behavior (bulging)
- Construction temperature

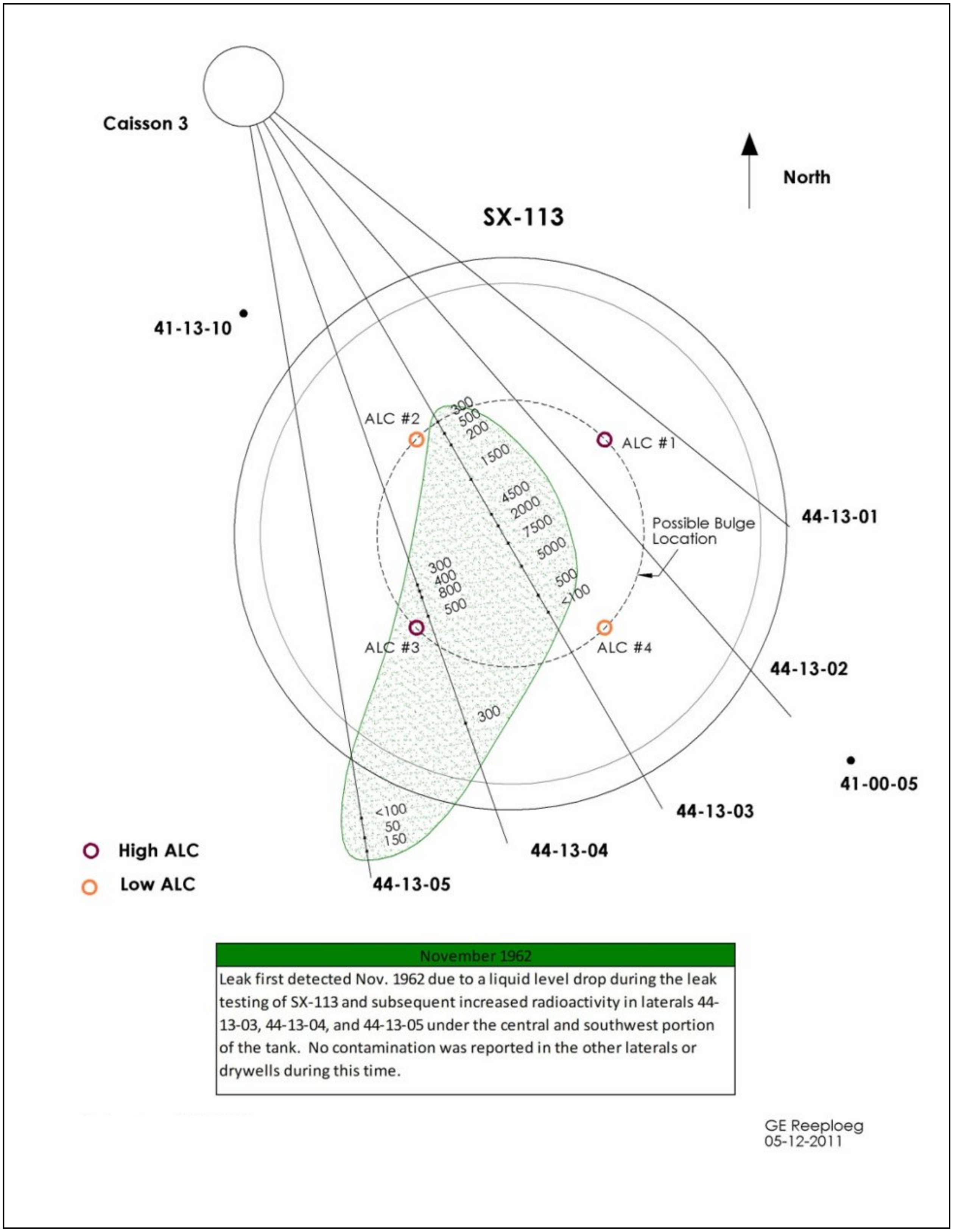
Tank design did not apparently change from tank to tank for the SX Farm tanks; however, there could be many unknown variables present in the quality of materials and quality of construction. Several significant SX Farm tank design changes occurred from previous successful tank farm designs including fillet welded orthogonal bottom-sidewall joint and waterproof membrane changes. Tank construction occurred in winter under cold conditions which could have affected the ductile to brittle transition temperature in some or all of the tanks. The remaining three conditions varied from tank to tank and are discussed below (see Table 2 and Table 3).

The SX Farm tanks received high temperature self-boiling waste from REDOX which challenged the tank design with rapid heat up and high temperatures. The tanks should have been pre-heated to avoid rate of rise thermal shock and the possibility of releasing moisture from the grout under the bottom liner as well as the possibility of vaporizing some of the organic asphalt under the grout. The resulting buildup of trapped pressure caused by the orthogonal sidewall to bottom steel liner joint results in the possibility of a bulged bottom liner. Only tank SX-115 was reported to have been pre-heated but the resulting rate of temperature rise was more than 2.5 times the recommended rate and formed a measured 3-in bulge. There could have been larger bulges in tank SX-115 that were not measured. Bulging along with other factors such as stress corrosion cracking caused by nitrate leaching probably resulted in tank SX-115 leaking as well as well as other SX Farm tanks.

Supernatant removal with subsequent nitrate leaching was conducted in all but three of the eight leaking tanks and all of the nitrate leached tanks leaked. Nitrate leaching lowered nitrite and hydroxide concentrations which inhibit stress corrosion cracking. The effects of stress corrosion cracking increased with higher temperatures. One of the three tanks (tank SX-113) only stored nitrate leachate waste; however, the effect on nitrite and hydroxide concentrations was the same, as the supernatant had been removed. Tank SX-113 only stored nitrate leached waste one month before leaking.

A bulged tank bottom was present or possible in all of the eight leaking SX Farm tanks. A bulge of the tank bottom imparts stresses in the liner that could have predisposed it to stress corrosion cracking. A bulge of 4-ft developed when tank SX-113 was filled with a temperature rate of rise at more than 4.5 times the recommended rate. Tank SX-113 could have experienced a weakened sidewall and bottom liner to such an extent that the liner failed. In addition, the added effect of nitrate leachate stress corrosion cracking on an already stressed tank liner could have contributed to liner failure. The possible leak and bulge location for tank SX-113 is shown in Figure 6. Tank SX-113 was the first tank to fail in SX Farm in November 1962, shortly after waste was first added to the tank.

Figure 6. Tank SX-113 Possible Radial Leak Locations with Estimated Bulge [6-8, 29]



The two SX Farm leaking tanks that were not nitrate leached or contained nitrate leached waste (tank SX-109 and SX-112) were reported to have bulged and they both sustained a temperature rate of rise more than 2.5 times the recommended rate. The bulging along with the rate of temperature rise could have resulted in liner failure. Only one of the sound tanks (tank SX-105) stored nitrate leachate waste (see Table 3). The nitrate leachate waste was stored at the relatively low temperature of ~115°F, and tank SX-105 was not inspected for a bulge.

There may be a combination threshold relationship for leaking versus sound SX Farm tanks between the rate of rise in temperature and the maximum temperature. All eight of the leaking SX Farm tanks had relatively high rate of temperature rise; however, there were three of the five sound tanks that had similar rates of temperature rise but overall lower maximum temperatures.

Bumping (pressurization) was experienced in several of the leaking and one of the sound tanks. There doesn't seem to be a direct relationship with leaking tanks. In the most severe bumping incident with tank SX-114, the pressurization could have affected the piping seals into or out of the tank; however, the data remains inconclusive. Therefore, bumping which is an effect of thermal conditions has not been considered in the overall factors that cause tank liner failure.

It is possible that no one characteristic of the SX Farm tanks could in isolation from the others have resulted in failure. However, the application of so many stressors – heat up rate, high temperature, loss of corrosion protection, and tank design – working jointly or serially on these eight tanks, resulted in their failure. Thermal shock coupled with the tank design, construction conditions, and nitrate leaching seem to be the overriding factors that can lead to tank liner failure. The distinction between leaking and sound SX Farm tanks seems to center on the waste types, thermal conditions, and nitrate leaching.

CURRENT AND FUTURE WORK

Currently, SX Farm remains inactive. All of the leaking SX Farm tanks have been declared interim stabilized and are waiting to be retrieved. Liquid levels in SX Farm are monitored daily while laterals and drywells are periodically monitored as needed.

Budget shortfalls at Hanford during FY2012 have resulted in all SST integrity project (SSTIP) work being suspended which included the expanded leak assessments of leak location and causes. Thus, only a draft of the 241-BY, 241-TY, and SX Farm Leak Location and Causes has been prepared while SSTIP is on hold pending future budget and prioritization of work activities.

Table 2. SX Farm Leakers Leak Location and Causes

Leaking Tank	Initial Waste Details				Leak Status		Nitrate Leaching				Evidence of a Bulging Liner		Thermal Conditions				
	First Filled	**First Boiling**	**Waste Type**	**Tank Pre-heated**	**Leak Detected**	**Indication of leak**	**Nitrate Leached**	**Months Leachate stored**	**Addition of waste after nitrate leached**	**Duration from start of leaching until leak detected**	**Bulge Present**	**Failed ALCs**	**Rate of Rise**	**Max Temp**	**Temp Duration**	**Bumping**	**Maximum pressurization**
SX-107	4/13/1956	Jun-56	R	No	Mar-64	Lateral	yes- Dec. 1962	~ 1 mo at 200-245°F	~ 1 week	~ 14 mo	Yes	Yes- #2 & #3	5.8°F/ day April 13 to May 2, 1956	390°F Feb. 1958	7 months > 300°F	Yes- Jan. and Feb. 1957	0.2 to 0.6 psig
SX-108	11/8/1955	Jan-56	R	No	Dec-62	Laterals	yes- May 1962	~ 3 mo at 180-260°F	~ 1 mo	~ 7 mo	Yes- Rodding 2.5-ft	Yes- #2	4.6°F/ day Nov. 8 to Dec. 1, 1955	320°F Sept. 1958	11 months > 300°F	Yes- Jan. and Feb. 1957	0.6 psig
SX-109	9/20/1955	12/12/1955	R	No	Jan-65	Laterals/ drywells	no	NA	NA	NA	Yes	Cannot be determined	5.7°F/ day Sept. 20 to Oct. 13, 1955	290°F Sept. 1962	22 months > 280°F	No	NA
SX-111	6/9/1956	Nov-56	R, EB, RIX	No	Apr-74	Laterals	yes- Mar. 1964	~ 3 mo at 185-240°F	~ 6 mo	~ 10 yrs	Yes	Yes- #1 & #3	5.7°F/ day June 9 to June 27, 1956	320°F Jan. 1968	27 months > 300°F	No	NA
SX-112	2/13/1956	Mar-56	R	No	Jan-69	Laterals/LL decrease	no	NA	NA	NA	Yes	Yes- #3 & #4	5.8°F/ day Feb. 13 to Feb. 29, 1956	316°F Mar. 1962	1 month > 300°F	No	NA
SX-113	2/20/1958	4/20/1958	R	No	Nov-62	Lateral/LL decrease	no- but held leachate	~ 1 mo at 105-117°F	no waste added after leachate transferred	Leaked during leak test with leachate	Yes- Rodding 4-ft, applied vacuum before receiving waste	Yes - #2 & #3	9.7°F/ day Feb. 20 to Mar. 12, 1958	254°F July 1958	1 month > 250°F	No	NA
SX-114	11/5/1956	Jun-59	R, EB, RIX	No	Aug-72	drywell	yes- Sept. 1961	~ 20 mo at ~175°F	~ 11 mo	~ 11 yrs	Possible	Yes- #4	4.7°F/ day Nov. 5 to 14, 1956; 9.8°F/ day Aug. 13 to 22, 1958	357°F Aug. 1958	41 months > 300°F	Yes- Aug. 1958	2.1 psig
SX-115	9/1/1958	Oct-58	R	Yes	Feb-Mar 65	LL decrease	yes- June 1964	~ 3 mo at 170-220°F	Leaked ~ 5 mo later, no waste added	~8 mo	Yes- Rodding 3-in	Yes- #2 & #4	5.2°F/ day Aug. 31 to Sept. 17, 1958	266°F Sept. 1960	3 months > 260°F	No	NA

Construction of SX Farm: June 1953 to May 1954
* Reference [34]
B: B Plant HLW
BL: B Plant Low Level
BNW: Battelle Northwest Laboratory Waste
CPLX: Complexant Concentrate
CW: Cladding Waste
DSSF: Dilute Double-Shell Slurry Feed
DW: Decontamination Waste
EB: Evaporator Bottoms
Evap: Evaporator Feed (post 1976)
IX: Ion Exchange Waste
LW: Laboratory Waste
N: N-Reactor Waste
OWW: Organic Wash Waste from PUREX
PNF: Partial Neutralization Feed
PSS: PUREX Sludge Supernatant
R: REDOX High Level Waste
Resid: Residual Evaporator Liquor
RIX: REDOX Ion Exchange
TBP: Tri-Butyl Phosphate-waste
TL: Terminal Liquor
Water: Flush water from miscellaneous sources
224: Lanthanum Fluoride Finishing Waste

Table 3. SX Farm Sound Tank Leak Location and Causes

Sound Tanks	Initial Waste Details				Leak Status		Nitrate Leaching				Evidence of a Bulging Liner		Thermal Conditions				
	First Filled	First Boiling	Waste Type	Tank Pre-heated	Leak Detected	Indication of leak	Nitrate Leached	Months Leachate stored	Addition of waste after nitrate leached	Duration from start of leaching until leak detected	Bulge Present	Failed ALCs	Rate of Rise	Max Temp	Temp Duration	Bumping	Maximum pressurization
SX-101	5/20/1954	1/13/55	R, EB, RIX, TL, PNF, CPLX, Resid	No	-	-	-	-	-	-	Tank not inspected for a bulge*	NA	1.3°F/ day	417°F	22 months >300°F	Yes- Feb. 1955	1.5 psig March 1, 1955
SX-102	9/9/1954	-	R, EB, RIX, PNF, Resid., DSSF	No	-	-	-	-	-	-	Tank not inspected for a bulge*	NA	5.2°F/ day	212°F	0 months >250°F	No	NA
SX-103	11/21/1954	-	R, CW, OWW, PNF, EB, Resid., DSSF	No	-	-	-	-	-	-	Tank not inspected for a bulge*	NA	7.2°F/ day	225°F	0 months >250°F	No	NA
SX-104	2/28/1955	7/21/55	R, EB, RIX, PNF, Resid., DSSF	No	-	-	-	-	-	-	Tank not inspected for a bulge*	NA	4.6°F/ day	300°F	13 months >300°F	Yes	Less than 1.5 psig
SX-105	6/2/1955	-	R, EB, RIX, PNF, Resid., DSSF	No	-	-	-	~ 48 mo at ~115°F	-	-	Tank not inspected for a bulge*	NA	3°F/ day	200°F	2 months >200°F	No	NA
SX-106	10/4/1954	-	R, EB, RIX, CPLX, BL, PNF, CW, IX, Resid., Evap., PL, B, Water, OWW, N, BNW, LW, TBP, DW, PSS	No	-	-	-	-	-	-	Tank not inspected for a bulge*	NA	2.7°F/ day	195°F	0 months >250°F	No	NA
SX-110	12/9/1960	4/19/1962	R, RIX, EB, IX, BL, 224, BNW	Yes	-	-	-	-	-	-	Tank not inspected for a bulge*	Yes- #1, #3, #4	1.2°F/ day	310°F	5 months >300°F	No	NA

Construction of SX Farm: June 1953 to May 1954
* Reference [34]
B: B Plant HLW
BL: B Plant Low Level
BNW: Battelle Northwest Laboratory Waste
CPLX: Complexant Concentrate
CW: Cladding Waste
DSSF: Dilute Double-Shell Slurry Feed
DW: Decontamination Waste
EB: Evaporator Bottoms PNF: Partial Neutralization Feed
Evap: Evaporator Feed (post 1976)
IX: Ion Exchange Waste
LW: Laboratory Waste
N: N-Reactor Waste
OWW: Organic Wash Waste from PUREX
TL: Terminal Liquor
PSS: PUREX Sludge Supernatant
R: REDOX High Level Waste
Resid: Residual Evaporator Liquor
RIX: REDOX Ion Exchange
TBP: Tri-Butyl Phosphate-waste
Water: Flush water from miscellaneous sources
224: Lanthanum Fluoride Finishing Waste

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