FINAL REPORT

Review of Crude Oil Storage Tank 2 Out-of-Service Inspection Documents

Report Prepared for:

PRINCE WILLIAM SOUND RCAC REGIONAL CITIZENS' ADVISORY COUNCIL

PWSRCAC Contract # 5081.22-01

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May 2024

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ACRONYMS & ABBREVIATIONS

ADEC – Alaska Department of Environmental Conservation

API – American Petroleum Institute

APSC – Alyeska Pipeline Service Company

CP – Cathodic Protection

ETF – East Tank Farm

MIL – 1/1000th of an Inch

MMO - Mixed Metal Oxide

MP – Monitoring Procedure

MPY – Mils-Per-Year

mV - Millivolts

NACE – National Association of Corrosion Engineers

PWSRCAC - Prince William Sound Regional Citizens' Advisory Council

STD- Standard

TK - Tank

VMT – Valdez Marine Terminal

WTF – West Tank Farm

1.0 EXECUTIVE SUMMARY

1.1 GENERAL

In August of 2022, the Prince William Sound Regional Citizen's Advisory Council (PWSRCAC) tasked Taku Engineering (Taku) with reviewing documents associated with the American Petroleum Institute (API) 653 Out-of-Service inspections of Crude Oil Storage Tank 2 at the Alyeska Pipeline Service Company (APSC) Valdez Marine Terminal (VMT). The intent was to identify opportunities for reducing the risks of a future leak associated with the VMT tanks.

Background on Tank 2

Constructed in 1976, Tank 2 is a 250-foot diameter, 510,000-barrel, welded steel, crude oil storage tank located in the VMT's East Tank Farm (ETF).

In 1994, Tank 2 was removed from service for the installation of a new floor with a sub-floor cathodic protection (CP) system for corrosion mitigation. A follow-up out-of-service inspection on Tank 2 was completed in 2003. The findings from that inspection allowed for an ensuing service interval of 20 years.

The tank was returned to service in 2006 and removed from service for the next out-of-service (interna) inspection again in 2022. This report addresses a review of the inspection procedures and reports regarding the 2022 inspections on Tank 2.

This study included a review of current and historical API 653 Out-of-Service inspection reports for the tank. It also reviewed historical CP data for the period from 2006 – 2022, and the CP system as-built drawings dated 4/1995. The study has resulted in the development of several findings and recommendations. Detailed discussions are provided in Section 3 of this document. General findings and recommendations are discussed below.

After completion of the draft Tank 2 study report, APSC provided PWSRCAC with a copy of the Engineering Summary Report for the Tank 2 out-of-service inspection. Taku reviewed the engineering summary report and updated this report to reflect findings based on that report.

1.2 FINDINGS

Findings for Tank 2

Based on our review of the Crude Oil Storage Tank 2 API 653 Out-of-Service Report provided by APSC, we have derived the following conclusions:

- The techniques and equipment used to inspect the tank components align with industry standards.
- The inspectors that completed the tank inspection appear to have the proper training and credentials.
- The existing CP system design does not provide sufficient CP current to the perimeter floorplates and annular plates. Those surfaces will remain largely unprotected.

- The 2022 Tank 2 API 653 Out-of-Service report states that, "Most of the bottomside corrosion was found on the sketch plates close to the annular plate."[1] This is empirical evidence that the CP on the tank perimeter areas is insufficient.
- The existing CP monitoring tubes do not allow monitoring of CP levels beneath the outermost 10 feet of the tank floor (annular plates and perimeter plates).
- The manner in which APSC is collecting CP data on Tank 2 is not aligned with the codified National Association of Corrosion Engineers (NACE, now AMPP) standards for CP, nor is it aligned with APSC's own monitoring procedures.
- The corrosion rate calculations for the annular plate and roof plates appear to be correct.
- The tank floor coatings were fully replaced prior to returning the tank to service and if properly applied, should perform for the duration of the next service interval.
- The lack of an annular plate to ring wall seal will exacerbate the inadequacy of CP afforded to the annular plate and perimeter floorplates, due to the penetration of rainwater and lack of an effective water drainage systems under the tank floor. This is likely contributing to the relatively accelerated corrosion evidenced in the perimeter floorplates.
- There are discrepancies between the 2022 Tank 2 API 653 report and the associated APSC Engineering Summary.

1.3 RECOMMENDATIONS

Based on the study findings, we offer the following recommendations pertaining to Crude Oil Storage Tank 2:

- The Tank 2 annular plate to ring wall seal should be replaced and maintained, or drip rings should be installed on the annular plate extension to prevent the ingress of water between the tank floor and secondary containment liner in order to mitigate corrosion and reduce corrosion rates.
- CP on the tank should be monitored in accordance with NACE SP-0193 and APSC's internal procedure, MP-166-3.23 (which is based upon SP-0193).
- APSC should perforate the first 10 feet of the CP monitoring tubes for Tank 2 to facilitate CP monitoring of the tank annular plates and sketch plates.
- APSC should ensure that the 2022 Tank API 653 report and the 2022 Tank 2 Engineering Summary report provide consistent data and calculations

2.0 INTRODUCTION

Crude Oil Storage Tank 2 at the VMT is one of the 14 crude oil storage tanks that make up the VMT's ETF. Four additional tanks are located in the West Tank Farm (WTF). However, the WTF was removed

[1] SPI 653 "Inspection Report 54-TK-2 Out-of-Service Inspection," TEAM, Issued 6/28/23. Page 6 of 77.

from service in the early 2010s. The general VMT layout is shown below in Figure 1, highlighting the location of Tank 2.

Figure 1 - VMT Aerial Photo (photo courtesy of NOAA)

All 14 ETF tanks are 250 feet in diameter, 62 feet high, welded steel, crude storage tanks built to API Standard 650. They were designed and erected by Chicago Bridge and Iron in 1976. The ETF tanks were constructed on concrete ring walls with subsurface secondary containment liners and oiled sand bedding. The sketch in Figure 2 shows the general layout and typical components of a VMT crude storage tank.

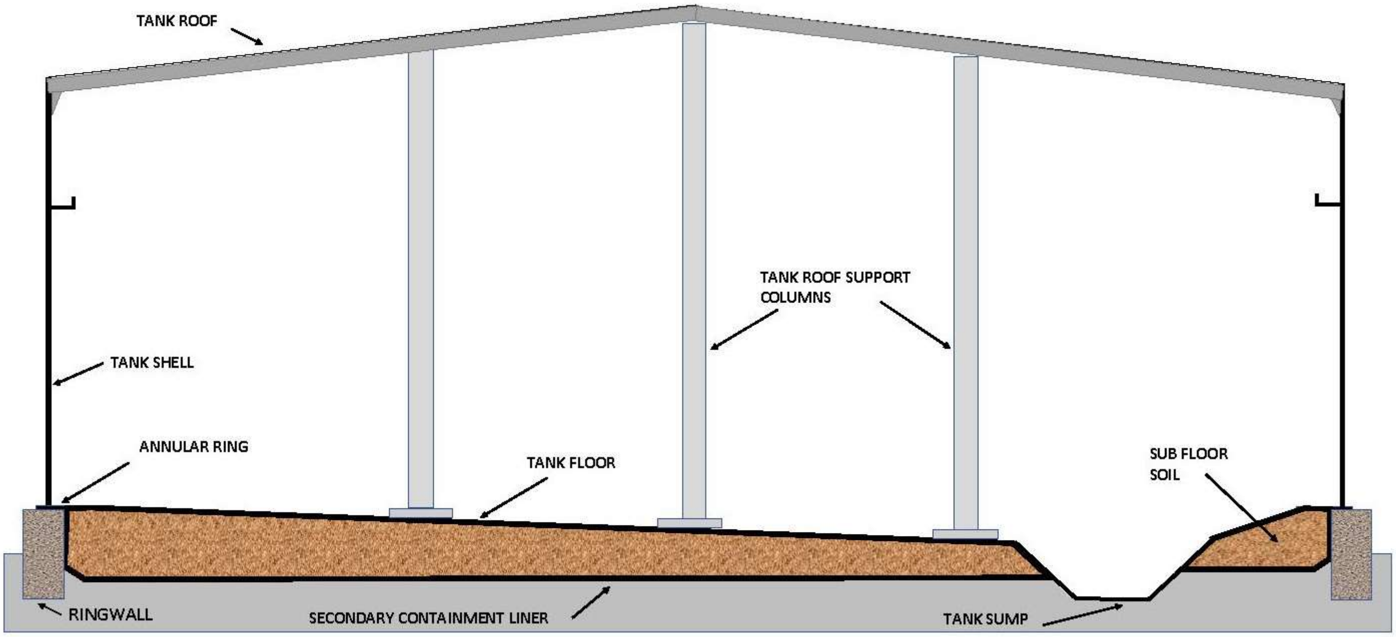

Figure 2 - Typical VMT Crude Tank Configuration

The 1991 discovery of soil-side corrosion in the crude tank floors prompted APSC to systematically replace the tank floors and install sub-floor CP systems on all ETF tanks between the years 1991 and 1998. Due to this discovery, the initial CP system was installed on Tank 5 in 1991 and consisted of mixed metal oxide (MMO) rod anodes. The anodes in the MMO rod system installed beneath Tank 5 in 1991, were spaced too far apart to distribute CP current uniformly and sufficiently to the floor. The Tank 5 CP system did not provide adequate current distribution to the tank floor, resulting in the discovery of continuing corrosion during the 2001 tank out-of-service inspection. The tank floor and CP system were replaced again in 2002. The MMO rod system was replaced with an MMO grid CP system at that time.

The MMO rod anode CP system consisted of isolated rod anodes connected to a header cable. The MMO rod placement and spacing was insufficient to distribute current to all areas of the tank bottom. The MMO grid system consists of a tightly spaced anode grid. The tight grid is designed to provide uniform CP current distribution to most of the areas of the tank floor. After the Tank 5 floor replacement, all other cure oil storage tanks were fitted with MMO grid CP systems which included monitoring tubes and/or permanent reference cells for collection of tank-to-soil potential measurements.

The floorplates on Tank 2 were removed and replaced in 1994. The original oiled sand bedding was excavated and replaced with clean bedding. An MMO grid CP system, and new floorplates were installed in the tank. The existing annular plates remained in place around the tank perimeter and beneath the shell.

Tank 2 was removed from service for internal inspection in 2003 and 2022. After the 2022 out-of-service inspection, the tank floor coatings were reported to have been fully removed and the floor was fully recoated with a thin-film liner consisting of Bar-Rust 236 epoxy.

3.0 FINDINGS AND DISCUSSION

3.1 GENERAL

This assessment was based upon a review of 2022 and past API STD 653 out-of-service inspection reports for Tank 2, CP system drawings for the tanks, tank CP monitoring data, and historical knowledge of the VMT. The author worked as a contract corrosion and project engineer with APSC from 1990 to 2015. This included oversite of the tank and repair program at the VMT.

3.2 SPECIFIC FINDINGS

PERIMETER CATHODIC PROTECTION

The ground bed for the Tank 2 CP system consists of an MMO grid distributed throughout the area beneath the tank floorplate. The CP design includes a separate MMO loop intended to protect the tank's annular plates. However, in that design, the annular ring MMO loop is located beneath the floorplate and does not extend to the annular plate (red circle in Figure 3). It is located more than 10 feet from the tank shell and more than 3 feet from the innermost edge of the annular plate (see Figure 3, excerpted from drawing D-54-E806). Figure 3 also indicates that the CP monitoring tubes beneath the annular ring are not slotted for the first 10 feet (blue circle in Figure 3), negating the ability to monitor CP below the annular plate and outermost 3 feet of floorplate (also referred to as sketch plates).

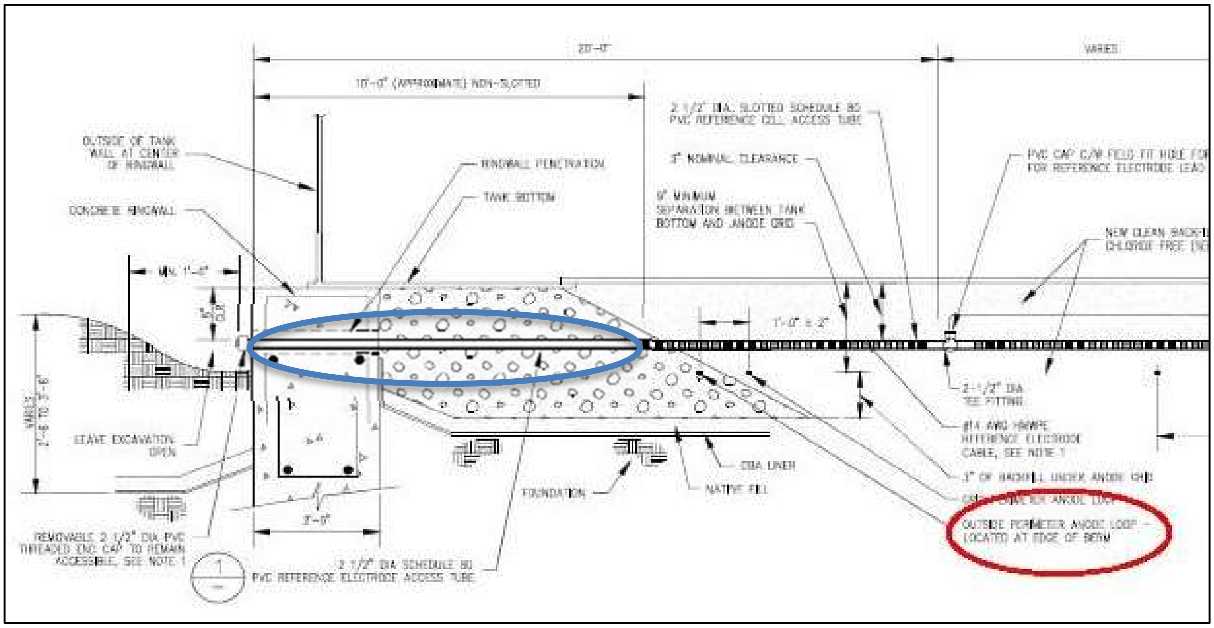

Figure 3 – Tank 2 Annular Ring CP Ground bed Design

This anode configuration does not protect the annular plates and perimeter floor plates for the following reasons.

1) The MMO loop intended to protect the annular plates will distribute current primarily via the lowest resistance pathways. However, the annular plate and floorplate are welded together, and are therefore electrically continuous. As such, assuming similar backfill resistivity and the flow of current on the lowest resistance pathways, the CP current intended for the annular plate will go to the closest steel, which is the regular floorplate steel. This means that insufficient CP is being provided to the annular plate and sketch plates. Most of the current intended for the annular plate is going instead to the floorplate immediately above the outermost anode loop.

2) The ratio of floorplate surface area to anode length is also significantly larger at the tank perimeter. This higher ratio means that without the ability to drive the perimeter anode separately from the remainder to the floorplate, the CP current density provided to the perimeter floorplate and annular plate will be significantly lower than the rest of the floor.

3) Finally, an industry rule of thumb used for designing ensuring uniform distribution of CP current for close coupled anodes, is to assume that the anode will distribute current to the steel surface in a (roughly) 120-degree arc of influence.[2] This rule of thumb is based on the resistance of the path length between the anode and structure. This is depicted below in Figure 4. However, as shown in the figure, the MMO loop intended to protect the annular plate will not provide protective current to the annular plate (also depicted in Figure 4) because the annular plate is beyond the 120-degree arc of influence from the CP system.

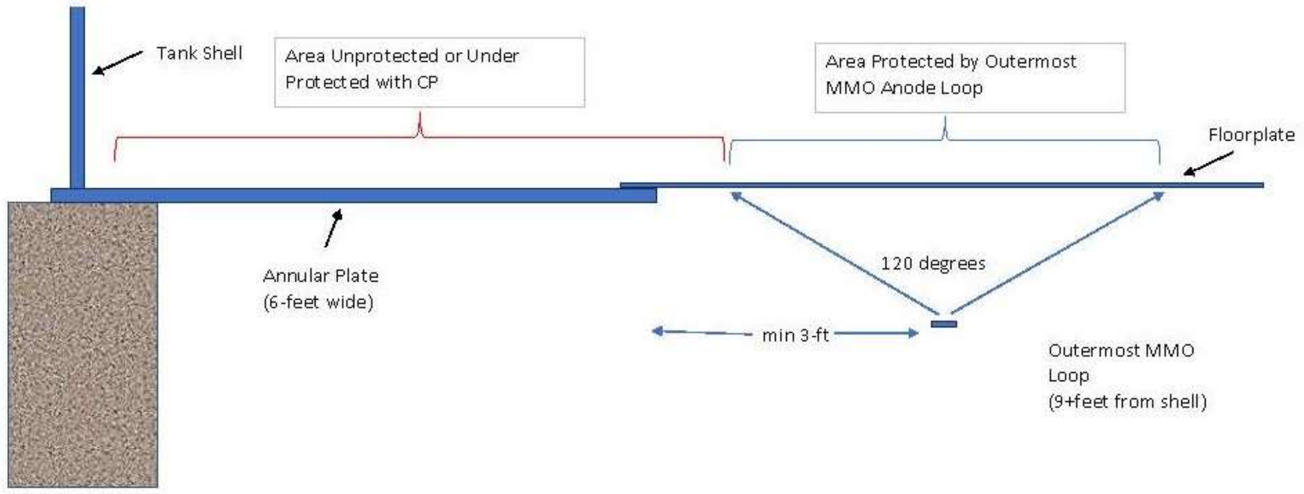

Figure 4 – Tank 2 CP System Perimeter Current Distribution

4) The MMO loop that is dedicated for the annular plate and perimeter floorplates (circled in red in Figure 3) is tied to a single circuit that cannot be adjusted independently of the

[2] NACE CP-3 Cathodic Protection Technologist Manual, Section 4.1.1.4, “Effects of Anode-to-Structure Spacing on Current Distribution,” January 2010.

floorplate system. Even if the system had the ability to independently power the MMO loop nearest to the annular plate, the resulting CP current will go predominantly to the perimeter floorplate and will not measurably impact the annular plate.

5) As further evidence of the lack of CP coverage and the impact on corrosion rates, during the 2022 tank outage, 39 patch plates were installed due to bottom-side corrosion. Nearly all repairs were on perimeter floorplates, validating that the corrosion protection being provided to the perimeter areas is insufficient.

CATHODIC PROTECTION MONITORING

The CP monitoring data collected on Tank 2 between 2006 and 2022 does not appear to be valid for the following reasons:

1) IR is the voltage drop that forms in the electrolyte (in this case the soil) due to the passage of CP current through that electrolyte. It represents an error in any CP potential reading and must be accounted for accurate CP potential readings. IR-free (Instant off) data cannot be more negative than -1.1 – 1.2 V.[3] Data more negative than that suggests that there are outside current sources still acting on the structure. CP monitoring readings reported by APSC for Tank 2 between 2006 and 2022 include "IR-free" data as negative as -2.865 volts. As these results are significantly more negative than -1.2V, it suggests that there are outside current sources still acting on Tank 2 which need to be identified and removed for the accurate collection of CP data and monitoring.

2) The outermost 10 feet of the CP monitoring tubes are not slotted (circled in blue on Figure 3), which prevents the CP tester from monitoring the level of CP in that area. Slots in the monitoring tubes, allow the CP monitoring reference cell to make electrolytic contact to the soil beneath the tank floor. That enables the CP tester to measure the electrical potential of the floor above the monitoring tube. Based on the insufficient CP current to the perimeter area (as discussion in point 1 above) and the lack of a perimeter seal, the perimeter areas are least likely to be sufficiently protected from corrosion. The high concentration of corrosion damage in the perimeter areas that required repair in 2022, confirms that the CP levels are insufficient in those areas.

3) APSC is using historical depolarized potential data to measure 100 millivolts (mV) of polarization, which is not aligned with the codified NACE (now AMPP) standards for CP, which require that the formation or decay of polarization be measured to utilize the 100 mV criteria. This is because the depolarized voltage of a structure changes over time due to soil chemistry, temperature, moisture content, and even the application of CP.[4] Measurement of the formation or decay of polarization must be done during the same relative timeframe as collection of the IR-free or Instant off data. The use of 1-, 2- or 3-year-old depolarized data, to determine the amount of polarization on a structure, does not meet the requirements of NACE SP-0193 and does not provide accurate measurement of the true level of polarization.

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[3] Barlo & Fessler, "Interpretation of True Pipe-to-Soil Potentials on Coated Pipelines with Holidays." CORROSION 1983.

[4] Dr. T. J. Barlo, "Cathodic Protection Parameters Measured on Corrosion Coupons and Pipes Buried in the Field." CORROSION 1988.

As such, there are resulting concerns that the CP monitoring data, and thus the projected level of corrosion mitigation to be expected from the CP system, may have significant errors.

Likewise, APSC's Monitoring Procedure, MP-166-3.23 "Facilities Cathodic Protection Systems," Revision 9, requires that areas not meeting -850 mV criteria be assessed for 100 mV of polarization. MP-166-3.23 dictates that areas failing the -850 mV criteria must be depolarized and that the operator, "Periodically check the structure to soil potentials at these locations until they have stopped shifting (depolarizing) or have shifted at least 100 mV more positive than the INSTANT OFF potentials that were recorded…"[5] While MP-166-3.23 aligns with the requirements of NACE SP-0193, it appears that APSC has not been following their own internal procedure. The 2006-2022 CP data reported by APSC utilized old, depolarized data to determine if the structure met the 100 mV criteria for CP. The practice of using outdated depolarized data conflicts with recognized industry practices, Alaska Department of Environmental Conservation (ADEC) requirements, and APSC's own internal CP data collection procedures.

ANNULAR PLATE EXTENSION TO RING WALL SEAL

The annular plate extension to ring wall seal on Tank 2 has not been maintained or replaced. The seal was reported as being separated between the chine and concrete ring wall. The inspection report recommended that the seal be repaired.

The lack of a competent ring wall to annular plate seal or drip ring on the annular plate extension will exacerbate corrosion of the annular plate and perimeter floorplates plates by allowing rainwater flowing off the tank to seep beneath the annular plate. The constant influx of oxygenated water will increase the CP current required to protect the annular plates and perimeter floorplates, further exacerbating the shortfall in CP to that area of the tank bottom. The lack of sufficient CP on the perimeter plates is evidenced by the high concentration of corrosion pitting and patch repairs executed on the perimeter plates.

FLOORPLATE SOIL-SIDE CORROSION RATES

The report for the Tank 2 API 653 2022 Out-of-Service inspection indicated that the deepest corrosion pitting on the floorplates was 148 mils remaining thickness. This corrosion depth occurred between the last floorplate inspection in 2003 and the 2022 inspection (19 years). This corresponds to a long-term corrosion rate of 3.53 mil-per-year (MPY). Although API 653 allows the use of the corrosion rate in the repaired area for calculating the next service interval, empirical corrosion data from APSC's crude tanks indicate that using the corrosion rate of the deepest pit overall provides a much more accurate predictor of the corrosion rates in the next service interval.

(215 mils – 148 mils)/19 years = 3.53 MPY

The 2022 API 653 Out-of-Service Inspection Report indicated that the Tank 2 floorplate had beeb subjected to a corrosion rate of 2.2 MPY and could be returned to service for an interval of greater than 20 years. The 11/15/23 Engineering Summary Report calculated a corrosion rate of 3.64 MPY and indicated that the tank can be returned to service for 20 years. The Engineering Summary

[5] MP-166-3.23, "Facilities Cathodic Protection Systems," Revision 13. Paragraph 4.8 Depolarized Potential Measurements.

Report corrosion rate was calculated using a long-term corrosion rate (based on the corrosion from when the tank floor was installed until 2022).

This study calculated the short-term corrosion rate (from the last inspection, 2003 to 2022) based on the deepest pit of 3.53 MPY.

Using a minimum remaining floorplate thickness of 200 mils, a minimum remaining floorplate thickness of 100 mils at the end of the next service interval, and a corrosion rate of 3.53 MPY the next service interval can be calculated as:

(200 mils-100 mils)/3.53. MPY = 28 years

These calculations, using the short-term corrosion rate, confirm that it is safe to return the tank to service for up to 20 years. This complies with the minimum requirements laid out in API 653 and aligns with empirical data from APSC's tanks.

ANNULAR PLATE SOIL-SIDE CORROSION RATES

The report for the Tank 2 API 653 2022 Out-of-Service inspection indicated that the deepest corrosion pitting on the annular plates was 686 mils remaining thickness. This corrosion occurred between original construction (1976) and the 2022 inspection (46 years). This corresponds to a long-term corrosion rate of 2.65 MPY.

(808 mils – 686 mils)/46 years = 2.65 MPY

The 2022 API 653 Out-of-Service Inspection Report indicated that the Tank 2 could be returned to service for an interval of greater than 20 years. The 11/15/23 Engineering Summary Report calculated a corrosion rate of 3.64 MPY and indicated that the tank can be returned to service for 20 years. The Engineering Summary Report corrosion rate was calculated using a long-term corrosion rate (based on the corrosion from when the tank floor was installed until 2022).