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# **A STRUCTURAL INTEGRITY ASSESSMENT OF UNDERGROUND PIPING ASSOCIATED WITH THE TRANSFER OF RADIOACTIVE WASTE**

by

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## **A STRUCTURAL INTEGRITY ASSESSMENT OF UNDERGROUND PIPING ASSOCIATED WITH THE TRANSFER OF RADIOACTIVE WASTE**

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### **ABSTRACT**

Radioactive wastes are confined in 49 underground storage tanks at the Savannah River Site. The waste is transported between tanks via underground transfer piping. An assessment of the structural integrity of the transfer piping was performed to ensure that the present condition of the piping was sound and to provide life expectancy estimates for the piping based on anticipated service. The assessment reviewed the original design of the piping, the potential and observed degradation mechanisms, the results from past inspections of the piping, and a Fitness-For-Service evaluation for a section of piping that experienced pitting in a locally thinned area. The assessment concluded that the piping was structurally sound. Assuming that service conditions remain the same, the piping will remain functional for its intended service life.

### **INTRODUCTION**

The Savannah River Site (SRS) has been involved in the production of radioactive materials for over 50 years. A by-product of this process is over 35 million gallons of radioactive waste. The waste is currently stored on an interim basis in 49 underground carbon steel waste tanks on two tank farms. In order to transfer the waste between the tanks, the two tank farms, and other facilities (e.g., the production and vitrification facilities) an intricate system of underground and aboveground piping has been placed. The piping is heavily shielded to minimize worker exposure to radiation.

An assessment of the structural integrity of the transfer piping was performed to ensure that the present condition of the piping was sound and to provide life expectancy estimates for the piping based on anticipated service. The fact that the majority of the piping is underground and heavily shielded makes inspections, and hence condition assessments, of the piping difficult. The following steps were utilized in the assessment:

- a) The design of the piping system and expected service conditions were reviewed;
- b) Degradation mechanisms were assessed as to whether they were presently active;
- c) A Fitness-For-Service evaluation for one of the transfer line jackets was performed.

Data from visual and ultrasonic inspections of the transfer lines provided input for this assessment.

### **BACKGROUND ON THE TRANSFER LINE PIPING**

#### **Design**

A cut-away drawing of the most common pipe design for the SRS transfer system is shown in Figure 1. This type of design has been utilized since 1960. The core pipe is typically made of 304L stainless steel and has been tested to ensure that it is not susceptible to intergranular attack [1]. The sizes of the

core piping range between 1-3 inches in diameter. Core piping that was installed prior to 1988 was Schedule 40 wall thickness, while since then Schedule 10 has been allowed. The piping was designed according to ASME B31.3. The design pressure for the piping was 150 psig, although the operating pressure for the line is typically in the 100 psig range.



**Figure 1. Cut-away drawing of SRS waste transfer line system.**

The jacket pipe is constructed of carbon steel. The size of the jacket piping usually depends on the number of core pipes that are contained (between 1 and 3) within. Thus the pipe diameter may range from 4 to 10 inches. Schedule 20 or Schedule 40 piping was typically utilized.

The outside of the jacket piping is usually protected by one of several coating methods: a fusion bonded powder coating system, a coal-tar system, a polyethylene coating, a polyethylene tape, or a bitumastic coating. The first four coatings were utilized on the older pipes (circa 1950-1970); while the last coating has been utilized for the more recently constructed or repaired transfer lines. The thickness of the outer protection for the jacket depended on the type of coating utilized.

Loose granular or powdered thermal insulation was also placed around the coated carbon steel jackets. The layer of thermal insulation was 6 to 8 inches in depth. In general, the insulation materials are hydrophobic and thus prevent water penetration. Therefore, if the insulation was properly placed and the temperature near the insulation has been relatively low, minimal corrosion of the exterior of the steel jacket is expected.

## Service Conditions

### Core Pipe

Under normal service conditions the interior of the core pipe is exposed to alkaline nitrate solutions ( $\text{pH} > 13$ ). Three examples SRS waste compositions are shown in Table 1. Note that the chloride concentration in the waste is relatively low in comparison to both the nitrate and hydroxide concentrations. The temperature of the waste is generally less than  $60^\circ\text{C}$ . An exception is the line associated with an evaporator which may

on occasions be exposed to waste stream temperatures of approximately  $135^\circ\text{C}$ .

**Table 1. Molar Anion Concentrations for Simulated Waste Solutions**

Waste Stream	Fresh Waste	Evaporator Concentrate	Dilute Waste
$\text{OH}^-$ (M)	1.5	11.8	0.34
$\text{CO}_3^{2-}$ (M)	0.01	0.2	-
$\text{NO}_2^-$ (M)	1.1	1.5	0.24
$\text{NO}_3^-$ (M)	2.9	1.1	0.07
$\text{Cl}^-$ (M)	0.01	0.024	0.0007
$\text{F}^-$ (M)	0.01	0.013	-
$\text{SO}_4^{2-}$ (M)	0.06	0.004	0.0004
$\text{Al}(\text{OH})_4^-$ (M)	0.34	0.38	-

### Jacket Pipe

Although the jacket pipe is coated and surrounded by thermal insulation, there is a potential that the jacket may be exposed to the soil. The soil characteristics at SRS are summarized below:

- Soil moisture content ranges from approximately 9% to 38%.
- Soil texture over a large part of the site is described as loamy and composed of particles that are clay, silt, and sand. The texture contributes to the well drained and excessively drained soil characteristics in most areas at SRS.
- pH ranges from acidic to slightly alkaline (pH of 3.6 to a high of 8), but typical values are almost neutral pH.
- Specific conductance measurements indicate very low soluble salt levels in the soils at SRS, which is probably the result of continued leaching by percolating rain water (chloride and sulfate leachate levels are relatively low).
- Soil resistivity measurements taken at depths of 5 feet to 20 feet range from 2300 ohm-cm to 149,000 ohm-cm.

These soil characteristics at SRS, which include well drained soils, low total dissolved solids and neutral pH, indicate that the potential for underground corrosion is relatively low. However, underground corrosion of piping at the Savannah River Site is well documented. Soil surveys in

the two tank farms have indicated a generally high resistivity with pockets of lower resistance. The possibility of corrosion is low in high resistivity soils, but the soil may be locally corrosive at the lower resistivities. Numerous lateral and vertical changes between sands and clays occur over short distances typical of the coastal plain environment. Large variations in soil resistivity provide for a possibility of galvanic corrosion. Galvanic corrosion usually appears when the pipe traverses soils of different composition, and as a result one section of the pipe becomes anodic with respect to another.

## Monitoring

The leak tightness of the piping is monitored with an air pressure test. Figure 2 shows an example of a leak detection system (LDS). In the example, a portable air compressor delivers air through a portable air delivery system into the LDS via a dip tube. The air pressurizes the LDS, jacket and jacket drain line, and the jacket vent line. If the pressure in the line drops 1 psig within 20 minutes, the line is recorded as having failed. This test is sensitive enough to detect hole diameters of 0.01". This test is performed at least every two years for frequently used piping and is required for inactive piping (i.e., piping not used within the last two years) before it can be utilized.

If a loss of pressure is detected, there are two tests utilized to locate the site of the through-wall penetration: a) soap bubble and b) helium leak test. For the first method the ground above the transfer line is wetted with soapy water. The ground is then examined for excessive foaming. If the through-wall penetration is not located by this method, a helium (He) leak test is utilized. For the He-leak test, the gas is introduced into the jacket through the LDS dip tube. Air samples are then extracted from soil boreholes (spaced approximately 10 feet apart along the line), tank heating and ventilation exhausts and above the ground. The air samples are then analyzed with a modified mass spectrometer for He.

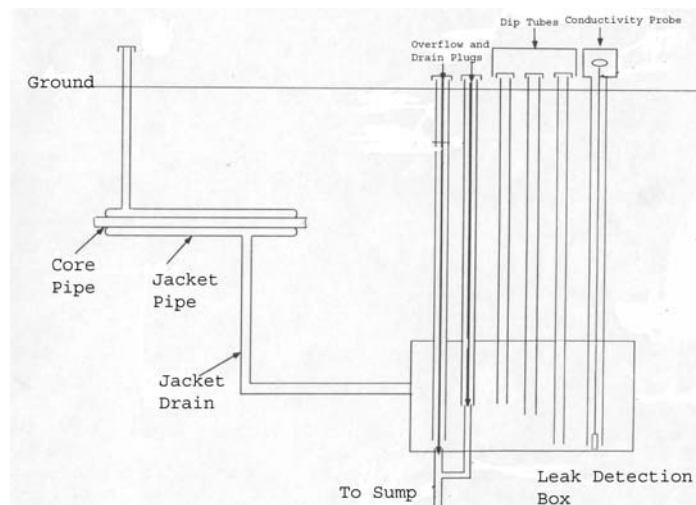
## DEGRADATION MECHANISMS

### Stainless Steel Core Pipe

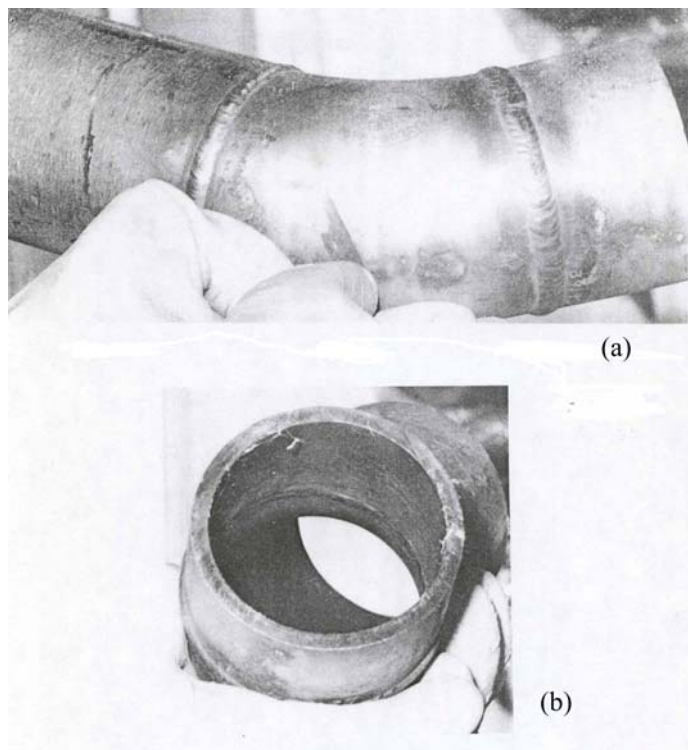
#### *General Corrosion and Pitting*

The waste solutions that are normally transferred through the core pipe are compatible with the stainless steel core pipe. The high concentrations of nitrate and hydroxide present in the waste combined with the relatively low concentrations of chloride would maintain the passive oxide film. Laboratory tests performed with 304L stainless steel in simulated high level waste solutions predicted a general corrosion rate of less than 0.1 mils per year (mpy), and no pitting susceptibility [2]. These results are confirmed by field observations. Figure 3

shows a stainless steel core pipe that was removed after 15 years of service. No evidence of pitting or general corrosion was observed.



**Figure 2.** Sketch of underground piping leak detection system.



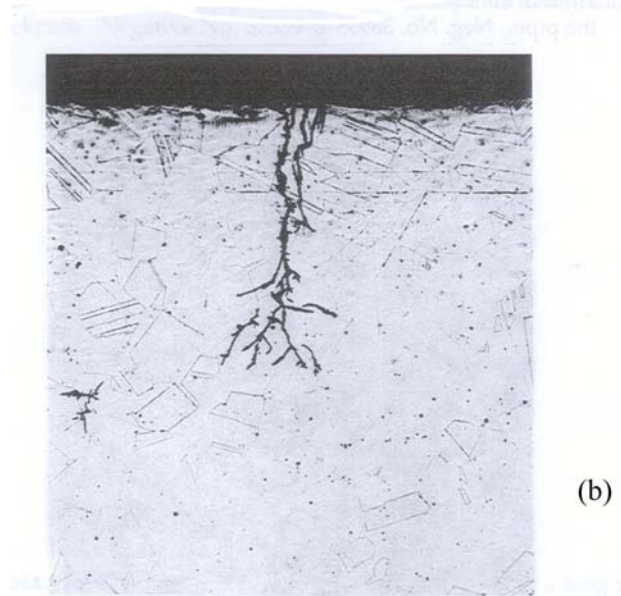
**Figure 3.** Stainless steel elbow from core pipe: (a) exterior and (b) interior.

## Stress Corrosion Cracking

Stress corrosion cracking is also not anticipated under normal service conditions. Laboratory tests indicated that 304L stainless steel is not susceptible to stress corrosion cracking (SCC) in high level waste environments [3]. However, a case of transgranular chloride stress corrosion cracking (CSCC) of a core pipe has been observed (see Figure 4). A leak was detected from the pipe some time between hydro-testing of the system and placing the pipe in radioactive service. Neutral well water was utilized for the hydro-test and was a likely source of the chloride ions. Concurrent with the hydro-test, a leak in an underground steam line in close proximity to the pipe was discovered. The steam leakage provided a heat source which produced the elevated temperatures that resulted in evaporation of the water. Although the SRS well water is typically low in chlorides (less than 5 ppm), evaporation likely increased the chloride concentration beyond a critical level. A time/temperature combination is also required for cracks to initiate and propagate. It was observed that both the extended period of steam leakage and the extended period before the line was placed in service were likely contributors to the failure. It was therefore recommended that the repair time for leaks in buried steam lines be minimized and that new pipe lines should not be held out of service for extended periods of time. Administrative controls are currently utilized to minimize the potential for well water to be left in the lines for extended periods of time.

## Microbiologically Induced Corrosion

There are no documented cases of microbiologically induced corrosion (MIC) in the piping at the SRS waste tank farms. The high pH of the waste likely prevents the colonization of the microbes and subsequent attack. However, samples of SRS well water indicate the presence of iron or manganese oxidizing bacteria that could result in MIC. There have been three documented cases of MIC in stainless steel piping at other SRS facilities. In each situation, untreated neutral water (i.e., no biocide was added) was allowed to remain stagnant for a long period of time. Occasionally the stainless steel transfer piping is exposed to neutral water, either for flushing of the piping after a transfer or hydro-testing of recently installed piping. In order to prevent conditions that would be favorable to MIC, the lines are drained and vented after each flush. The administrative corrosion control program at SRS also requires that known "low points" in the transfer line system must be flushed with inhibited water ( $\text{pH} > 12$ ) unless another waste transfer is planned within the next five days. Requirements for pipe installation also limit contact with untreated neutral water.



**Figure 4. Section of core pipe from clean-out-port #3: (a) Dye penetrant test showing cracks on the interior of the pipe, Magnification 1X (b) Micrograph showing transgranular SCC, Magnification 50X.**

## Erosion or Erosion-Corrosion

There have been no known failures of core piping due to erosion or erosion-corrosion at the SRS waste tank farm. This observation was expected for several reasons:

- a) The frequency of transfers that contain sludge or glass frit is low. The maximum usage time on an annual basis an individual pipe is exposed to flowing waste is



estimated to be 4%. Most pipes are much less than 1%.

- b) The fluid velocities are low (i.e., less than 5 ft/s)
- c) The sludge particles and glass frit are typically at low concentrations (< 15 wt. % for sludge and less than 0.5 wt. % for glass frit)
- d) Results from erosion tests in pilot facilities at SRS indicate that erosion is not expected to be significant.
- e) Piping systems in other facilities at SRS, constructed of similar materials to the waste transfer piping, and that have handled waste streams with sludge and glass frit have been inspected visually and with ultrasonic measurements and show no evidence of erosion.

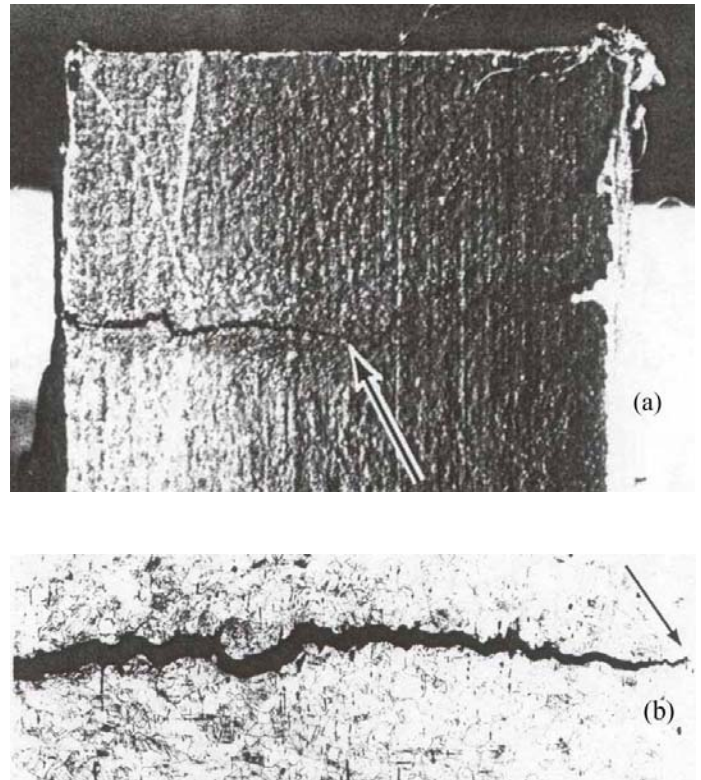
### *Thermal Fatigue*

Thermal fatigue was identified as the cause of leakage from one stainless steel core pipe (see Figure 5). The pipe failed in a straight, anchored section. The combination of anchoring the internal pipe to the carbon steel jacket, restricting the space for expansion, and having multiple lines within the same jacket intensified the stresses on the transfer line. The line had been in service for approximately 4.5 years and had experienced approximately 5500 thermal cycles. The cycles resulted from transfer of concentrated waste at a temperature of 115-135 °C alternated with desalination back flushes with water at 20-50 °C. A second pipe, adjacent to this pipe in the same carbon steel jacket, also showed indications of cracks at the anchor plate between the jacket and the core pipe. This second line had been in service for only six months and had experienced approximately 100 thermal cycles.

To reduce the likelihood of failure it was recommended that the projected total usage cycles be reduced by increasing the flush water temperature from 20 °C to 120-135 °C. Increased monitoring of these lines and remedial actions were implemented where practical (e.g., modifications to reduce thermal stresses).

### *Pitting Corrosion*

There have been several reports of through-wall penetrations of underground piping [4]. Several of these failures occurred due to improper and/or inconsistent application of the outer protective coatings. The carbon steel jackets were coated with bitumastic and wrapped with tape. The tape was usually polyethylene and approximately 10 mils thick. Pitting occurred at pinholes or holidays in the protective coating.



**Figure 5. Fatigue crack in pipe: (a) View of interior surface of pipe, (b) Micrograph showing the fatigue crack.**

### **Carbon Steel Jacket Pipe**

#### *Corrosion beneath Thermal Insulation*

There have been examples of degradation of carbon steel piping that was buried in the insulation. Poor placement of the insulation such that water is allowed to penetrate to the jacket surface is usually the cause of corrosion. This jacket pipe shown in Figure 6 had been in service for approximately 20 years. During excavation of a nearby line, broad shallow pitting with isolated areas having deeper pits was observed in a 30" segment of this jacket. The attack was determined to be pitting within a locally thinned region. The corrosion was greater (more frequent and deeper pitting) along the bottom half of the jacket. The isolated nature of this attack was also observable as a majority of the line remained un-attacked.



**Figure 6. View of jacket pipe that shows corrosion beneath the thermal insulation.**

## FITNESS-FOR-SERVICE EVALUATION

The design codes and standards for pressurized equipment provide rules that govern the design, fabrication, inspection, and testing of new piping systems. These codes however do not address in-service degradation. Fitness-For-Service assessments are quantitative engineering evaluations which are performed to demonstrate the structural integrity of an in-service component that contains a flaw. API-579 provides guidance for performing these evaluations [5]. It is significant to realize that these evaluations are primarily performed for components that have 1) experienced some degradation, and 2) degradation is part through-wall and a decision to run, repair, or replace is needed. In most of the cases cited in the previous section, corrosion was either insignificant or localized through-wall penetration had occurred. The exception was the carbon steel jacket, which showed pitting and localized thinning, but no through-wall penetration. Therefore, an assessment was performed utilizing data from this pipe.

The application of the API-579 “Fitness-for-Service” requires the following steps:

- Identification of the type of flaw and the type of damage that caused the flaw.
- Identification of the type of failure mode.
- Obtain the necessary data.
- Selection of the level of assessment.

- Selection of the appropriate acceptance criteria to assess current condition.
- Evaluation of remaining life.

The application of these steps to the current condition of the pipe are summarized below:

- The type of flaw is a through-wall penetration due to pitting in a locally thinned area.
- The failure mode of concern is leakage. In this case the jacket may not be able to contain radioactive waste should it leak from the core pipe.
- Ultrasonic measurements taken on the pipe shown in Figure 6 were used to estimate the remaining useful life of carbon steel jackets. Ultrasonic line scans were performed every 45 degrees around the jacket circumference to determine the wall thickness profile. The average wall thickness was approximately 0.24” or 10 mils less than the installed nominal thickness of the pipe. The minimum wall thickness at the deepest pit was 0.127”. Twelve pit-couples were measured in order to perform the assessment.
- A Level 1 assessment was utilized for an initial assessment. The calculations for the minimum required wall thickness considered supplemental loading due to a seismic event.
- The Level 1 acceptance criteria for API-579 were applied for this assessment (i.e., the Remaining Strength Factor is 1.0 and the adjusted average pit depth is less than zero). The assessment concluded that continued use of the pipe is acceptable.
- Remaining life estimates were performed assuming pitting corrosion would result in a through-wall penetration of the carbon steel jacket. For purposes of this calculation pit depth was assumed to increase with time in a parabolic fashion according to the following equation:

$$\text{Maximum Pit Depth} = K \tau^{1/2} \quad (1)$$

where  $\tau$  is time. The jacket had been in service for approximately 20 years and the maximum pit depth was 0.113”. Thus,

$$K = (0.113") / (20 \text{ years})^{1/2} = 0.0253"/\text{yr}^{1/2} \quad (2)$$

Total penetration (T) through the jacket wall is determined by the following equation:

$$T = [(P + 1) K \tau^{1/2}] / P \quad (3)$$



where:

$$P = \text{Maximum Pit Depth/Depth of General Corrosion} \quad (4)$$

Re-arrangement of equation (3) to solve for  $\tau$  gives:

$$\tau = [PT/((P + 1)K)]^2 \quad (5)$$

Assuming that the depth of general corrosion was 10 mils,  $P$  is determined to be 11.3. If  $T$  is the nominal thickness of 0.25", the time to through-wall penetration is estimated to be approximately 80 years. Given that the pipe had already experienced 20 years of service, 60 years of remaining life was projected. However, this estimate assumes the jacket continues to corrode at the present rate. If the thermal insulation was properly placed around the jacket when this line was returned to service, the corrosion rate may slow significantly and the jacket would remain in essentially the present condition. Therefore, this calculation may be more applicable to a similar pipe that remained buried and therefore the corrosion went undetected.

The carbon steel jackets are likely to continue to suffer further pitting attack at local thin areas beneath insulation or at holidays in a coating due to improper placement of thermal insulation or poor coating application at isolated areas along the transfer line system. The 80 year lifetime estimation is supported by the observation that relatively few failures of transfer line jackets have occurred to date. Thus, the 80 year life expectancy can be utilized to estimate approximately when the transfer line system jackets as a whole may begin to see a significant increase in failure rate. Most of the transfer lines have been in-service for approximately 20 to 50 years. Thus, the remaining life of the jackets is estimated to be 30 to 60 years (2035 to 2065). Due to the statistical nature of pitting some jackets may fail earlier, but it is expected that a significant increase in the number of jacket pressure test failures will be observed after this time. The two year frequency for testing the jacket is sufficient to monitor for these failures for the next 30 years. However, after that time, a shorter testing frequency should be considered.

## CONCLUSIONS

The performance of the waste transfer piping, both the core and jacket pipes, was evaluated. In general, the piping has performed well for over fifty years. The performance of the stainless steel core piping is expected to continue well into the future (i.e., more than 100 years). It is expected that the carbon steel jackets will continue to fail in isolated regions due to either pitting at holidays in a protective coating or corrosion beneath thermal insulation. However, a significant increase in the number of jacket failures (i.e., through-wall penetrations) is not expected to occur for another 30 to 60 years.

## ACKNOWLEDGMENTS

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