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ABSTRACT

In 1970, the National Institute of Standards and Technology (NIST) implemented the most ambitious and comprehensive long-term corrosion behavior test to date for stainless steels in soil environments. Over thirty years later, one of the six test sites was targeted to research subsurface contamination and transport processes in the vadose and saturated zones. This research directly applies to environmental management operational corrosion issues and long-term stewardship scientific needs for understanding the behavior of waste forms and their near-field contaminant transport of chemical and radiological contaminants at nuclear disposal sites. This paper briefly describes the ongoing research and the corrosion analysis results of the stainless steel plate specimens recovered from the partial recovery of the first test site.

Keywords: stainless steel, underground corrosion.

INTRODUCTION

The Department of Energy (DOE) Environmental Management (EM) program is responsible for cleaning up 114 sites (over 2 million acres) contaminated during the production and testing of nuclear weapons and energy research activities. Hundreds of containers containing highly activated wastes, including non-fuel activated reactor components and other metal alloys, have been disposed since the early 1950s. The primary materials are stainless steels (UNS S304000 and UNS S316000) from core barrels and core rod assemblies, aluminum fuel end boxes, beryllium reflectors and shims, and zirconium alloys and nickel alloys primarily from end boxes and assemblies. Overall, activated stainless steel and aluminum alloys are the largest contributors and will be the source of the major radiological activity in the subsurface environment.[1]

A growing environmental concern is the contamination of soil and groundwater by radionuclides and hazardous chemicals released from corroding metal waste forms and containers. Corrosion causes release of contamination in two ways: (1) via leaks from aging tanks or waste containers, where contaminants become readily available for transport; and (2) via the corrosion process itself, where the contamination becomes available for transport as the surface of the buried contaminated bulk metal waste is reduced by chemical and physical attacks. The natural processes that release these contaminants to the environment and the rates at which the releases occur are poorly understood and inadequately defined.[2] Understanding the corrosion, release, and transport processes is critical to predicting soil and groundwater contamination,

The National Institute of Standards and Technology (NIST) (formerly the National Bureau of Standards – NBS) has been actively involved in underground corrosion studies since 1910, when it was authorized by Congress to study the deterioration of underground pipelines. In 1970, an extensive program, sponsored by the American Iron & Steel Institute, was undertaken to study the underground corrosion of martensitic, ferritic, and austenitic stainless steels.[3,4] Thousands of stainless steel specimens were buried at six test sites in the United States. During the first eight years of the study, only four of five planned removals were completed, leaving one set of stainless steel specimens at each of the six test sites. These specimens are 200, 300, and 400-series stainless steels and special high-alloy stainless steels in U-bend, sheet, and tube forms in annealed, cold worked, and sensitized conditions, with and without welds and crevices.

As part of the Environmental Science Management Program (ESMP) sponsored basic research grant, the Idaho National Laboratory has implemented recovery and analysis of some of the corrosion samples from one of the NIST sites. This research directly applies to environmental management operational corrosion issues and long-term stewardship scientific needs for understanding the behavior of waste forms and their near-field contaminant transport of chemical and radiological contaminants at nuclear disposal sites. As such, the research offers the closest comparative study available for DOE waste metals and containers that have been disposed of and have been in the ground for more than 30 years. This paper briefly describes the corrosion analysis results of the stainless steel plate specimens recovered from the partial recovery of the first test site.

EXPERIMENTAL PROCEDURE

For this research the scope is limited to one test site and only the stainless steel plates, sensitized and unsensitized. The description of the experimental procedure used for this research is twofold:

The first is the experimental procedure established by NIST in 1970 followed by the recovery and analysis during the succeeding test intervals of 1, 2, 4, and 8 years.[4] The procedure NIST established is the basis for direct corrosion testing using buried coupons and is the most widely used and simplest method of underground corrosion testing.[5] The elements for testing of the stainless steel coupons are to determine the properties of the soil, materials, treatment and preparation, exposure, and examination following exposure. The procedures used by NIST helped establish the ASTM procedures now in use.

The second is the experimental procedure used by the INL to recover one of the test trenches established in 1970 by NIST and to analyze the stainless steel coupons after exposure for 33 ½ years. The elements for the testing is to examine and compare the properties of the soil and then to examine the coupons following exposure. The INL follows ASTM procedure G 1[6] for examination of coupons.

NIST Experimental Procedure

NIST identified the test location as "Site D, Lakewood Sand." The description simply was white, loose sand with some black streaks that supports an abundant growth of beach grass. The site is near the coast but is not subject to overflow from the ocean except under unusual flood conditions. The sand, in 1970, had a pH of 5.7 and the resistivity ranged from 13,800 to 57,500 ohm-cm.

The whole sample set was devised to simulate some of the conditions that may be encountered with components fabricated from stainless steels, materials for the soil corrosion studies included stressed and unstressed flat sheet specimens with and without welds, welded tube specimens, coated specimens, sensitized specimens, and stressed and unstressed galvanically coupled specimens. The subset used for this paper is the sensitized and unsensitized flat sheet specimens buried in 1970. The stainless steel systems buried at the test site with the treatments and preparation are given in Table 1. The chemical analyses of each alloy are in Table 2.

Each specimen (approximately 0.15 cm (0.06 in.) thick), were received from the stainless steel producers as flat sheets with sheared deburred edges. The plates were stamped with identification numbers using chromium plated steel dies, were degreased, passivated, scrubbed with a fiber brush, rinsed thoroughly with water, and air dried.

At the test site, the specimens were buried in trenches approximately 2-½ ft (0.76 m) deep and 2 ft (0.61 m) wide. The specimens were placed about 1 ft (0.30 m) apart. The 8 inch by 12 inch (20.32 cm by 30.48 cm) sheets buried in 1970 were placed in the trench in a vertical position with the short dimension horizontal. Sufficient specimens were buried at the test site to permit recovery of a complete set at specific intervals (after 1, 2, 4, and 8 years) and a final set to be removed at a later date. Each set consisted of four specimens (two in each trench).

Upon removal from the trench after burial for 1, 2, 4 and 8 years, the specimens were returned to the laboratory. In the laboratory, the specimens were rinsed in tap water to remove adhering soil particles. They were examined visually prior to further cleaning. All specimens were then further cleaned ultrasonically using a 10% nitric acid solution heated to 120° – 130 °F (49°– 54 °C) for 20 to 30 minutes. After cleaning, the specimens were rinsed in hot tap water and air dried. The unstressed sheets were then weighed and twice and their weight loss was determined. The average loss in weight of similar unexposed (control) specimens given the identical cleaning process was subtracted from the weight loss of the exposed specimens. Pit depth determinations were obtained for all of the sheet specimens.

INL Experimental Procedure

The INL arrived at NIST's "Site D, Lakewood Sand" in April of 2004 to do environmental sampling and recover specimens that were buried in 1970. The soil fit the NIST description; however the abundant growth of beach grass had been replaced with thirty years of trees, shrubs and undergrowth typical of coastal progression. The site may not be subject to ocean flooding but the specimens were in saturated soil conditions. The sand, in 2004, had a pH of 6.19 with a resistivity of 59,000 ohm-cm and the groundwater had a pH of 4.76.

The target for this research was to recover the specimens from one of the two trenches emplace in 1970. NIST had provided a map of Site D and the marker posts were, for the most part, in place so trenches were identifiable. The recovery occurred after 33 ½ years of exposure. From the one trench, two specimens of each type were recovered. (TABLE of Specimens)

Upon removal from the trench, the specimens were air dried, any loosely adhering sand removed, and the specimens were appropriate packaged for the trip to the laboratory. In the laboratory, the specimens were visually examined before any cleaning was done and then again after the specimens were rinsed in demineralized, deionized water to remove adhering soil particles. After the visual examination, all specimens were then further cleaned using the ASTM G1-03 standard practice for cleaning stainless steel.[6] Original unexposed control specimens from NIST were no longer available so alternate cleaning control specimens were used, see Table 3. After cleaning pit depth analysis on each of the specimens was conducted using a vertical scanning interferometer.

RESULTS

In April 2004 stainless steel specimens were recovered from NIST underground corrosion research test Site D. Among the specimens, 24 plate specimens were exhumed and the results of the corrosion evaluations are presented here. For each of the AISI series types-200, 300, and 400-The specimens were examined visually for results of the underground exposure. Tables 4, 5, and 6 are a summary of each of the AISI series types – 200, 300, and 400 – respectively. The visual examination summary includes the summary for the NIST results along with the results of the specimens exposed over 30 years.

As is expected of stainless steels, corrosion effects are localized and are generally confined to a small area. As was reported for the earlier observations by Gerhold et. al, “one specimen may have only one corrosion pit which caused perforation of the specimen, while there was little or no corrosion observed on companion specimens exposed for the same period of time in the same environment.”[4] This observation holds true with the results of the same companion specimens over time. Localized attack of the stainless steel has the same basic influences as was observed in the Gerhold et. al. report as summarized as follows.[4]

1. Inhomogeneities of the metal surface,
2. Concentration cell effects due to adhering soil particles or crevices where stagnant conditions may exist.
3. Presences of chlorides in the soil.
4. Microbiological organisms.
5. Abrasion of the metal surface by soil particles or foreign debris.

The recovered specimens were examined for pit depth using a vertical scanning interferometer. The examination is summarized and combines the results from Gerhold et. al.[4] in Table 7. Full penetrations were excluded from the average pit depth calculations.

CONCLUSIONS

For AISI 200 Series stainless steels, one of the two specimens exposed over 30 years was perforated, similar to what was reported by Gerhold after 8 years of exposure, Figure 1. The specimens had some surficial staining with localized metal attach in the form of pitting, tunneling undercut, and one minor area of blistering.

For the AISI 300 Series stainless steels, comparisons can be drawn when examining annealed specimens and sensitized specimens. See Figures 2 and 3. The sensitized specimens had their passivation layer removed prior to exposure to enhance the potential corrosion effects. In general, the corrosion was superficial for the annealed austenitic stainless steels buried over 30 years at the site. Some minor pitting and tunneling was notable. Of the sensitized set, only two specimens had perforation – UNS S301000 and UNS S304000. These specimens had more propensity of adhering soil and staining.

For AISI 400 Series stainless steels, results are similar to those observed after the 8-year exposure. The 400 Series all had metal attack that lead to pitting, tunneling, and perforation. Figure 4. Staining was evident to some extent on each of the specimen recovered. Gerhold et. al. noted the first perforation of the 400 Series at the test site was only after 4 years of exposure.[4]

The results of stainless steels exposed to an underground environment for over 30 years are of particular value in nuclear waste applications as many internal non-fuel activated reactor components as well as waste containers are made from stainless steel. The affirmation of low or no evidence of corrosion of particular types of stainless steels such as the AISI 300 Series indicates the long-lived radionuclides contained in those metals or metal matrixes have a low potential for release. In turn, the potential release of specific long-lived radionuclides from buried waste directly influences the management of the radioactive burial site and the subsequent closure and remediation actions required.

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TABLE 1

TREATMENT AND PASSIVATION PROCEDURES FOR NIST STAINLESS STEELS[4]

Stainless Steel Type	Treatment	Passivation Procedure
201	Annealed	I
202	Annealed	I
301	Annealed	I
301	Sensitized	I a
304	Annealed	I
304	Sensitized	I a
316	Annealed	I
316	Sensitized	I
409	Annealed	III
410	Annealed	III
430	Annealed	II
434	Annealed	I
Sensitized: by heating at 1200 ˚F for 2 hrs, followed by air cooling and descaling in sodium hydroxide.		
I – Passivation: 20 to 40% by volume of 67% nitric acid at 120-160 ˚F for 20-30 minutes.		
II – Passivation: 20% by volume of 67% nitric acid plus 2-6% sodium dichromate at 110-140 ˚F for 20-30 minutes.		
III – Passivation: 20 to 40% by volume of 67% nitric acid at 110-140 ˚F for 20-30 minutes.		
a. Minimum specified concentration of acid, temperature at the time for sensitized material.		

TABLE 2

CHEMICAL ANALYSIS FOR EACH NIST ALLOY[4]

	C	Mn	Si	S	P	Cr	Ni	Mo	N	Cu	Ti	Others
Type 201	0.066	6.9	0.47	0.009	0.034	16.76	5.1	0	0.078	0	0	0
Type 202	0.1	8.05	0.41	0.004	0.003	17.5	5.13	0.15	0.15	0.12	0	0
Type 301	0.092	1.1	0.49	0.006	0.015	16.1	7.1	0	0	0	0	0
Type 304	0.048	1.46	0.5	0.012	0.03	18.2	9.8	0.17	0.042	0.19	0	0
Type 316	0.049	1.62	0.53	0.09	0.02	17.48	13.53	2.28	0	0.11	0	0
Type 409	0.58	0.47	0.57	0.005	0.014	10.75	0.61	0.12	0	0.37	0.6	Al 0.13
Type 410	0.14	0.55	0.14	0.014	0.016	12.53	0	0	0	0	0	0
Type 430	0.06	0.46	0.5	0.01	0.017	16.67	0	0	0	0	0	0
Type 434	0.076	0.42	0.43	0.011	0.017	18.2	0.32	0.76	0.046	0.05	0	Al 0.046 V 0.025

TABLE 3

CHEMICAL ANALYSIS FOR INL CONTROL SPECIMENS

	C	Mn	Si	S	P	Cr	Ni	Mo	N	Cu	Ti	Others
UNS S201000	0.022	6.7	0.34	0.004	0.03	16.61	4.22	0.18	0.15	0.43	0	Al 0.004 V 0.077
UNS S301000	0.088	0.91	.5	0.012	0.025	17.41	7.29	0.22	0.053	0.46	0	0
UNS S304000	0.8	2	1	0.01	0	20	10.51	0	0	0	0	0
UNS S316000	0.29	1.652	0.298	0.001	0.028	16.92	10.332	2.174	0.044	0.373	0	0
UNS S409000	0.054	0.37	0.4	0.006	0.036	11.6	0.25	0.055	0.0087	0.373	0.47	Al 0.13
UNS S410000	0.14	0.4	0.32	0.001	0.24	11.68	0.22	0.04	0.016	0.19	0	Al 0.001 Sn 0.005
UNS S430000	0.04	0.44	0.39	0.002	0.02	16.6	0.29	0.06	0	0	0	Sn 0.005 Nb 0.05

TABLE 4

VISUAL EXAMINATION OF AISI TYPE 200 SERIES STAINLESS STEEL SHEET SPECIMENS BURIED AT NBS SOIL CORROSION TEST SITE D. (8, 4, 2, AND 1 YEAR EXPOSURE DATA[4])

				Visual Observations								
				Invasive					Surficial			
Material	Year(s) of exposure	Coupon number	NBS-ID	Perforation	Pitting	Tunneling	Undercut	Blister	Rust Stain	Black Stain	Dark Stain	Iridescent film
UNS S20100 Annealed	33.5	1	50D20	–	●a,b,g	●a,b	●a,b	●a	●	●	–	●
		18	50D19	●a,b	●b,c,g	●b,c	●b,c	–	●g	–	–	–
	8	*		●	●	●a,b,d	–	–	–	–	–	–
	4	*		–	–	–	–	–	–	–	–	–
	2	*		–	●	–	–	–	–	–	–	–
	1	*		–	●	–	–	–	–	–	–	–
UNS S20200 Annealed	33.5	2	51D20	–	●b,c,g,i	–	●c	–	–	●	–	●
		19	51D19	–	●b,c,f,g,h	–	–	–	●	●	–	●
	8	*		●	●	●a,b,d	–	–	–	–	–	–
	4	*		–	–	–	–	–	–	–	●	–
	2	*		–	–	–	–	–	–	–	●	–
	1	*		–	●d	–	–	–	–	–	–	–

Key

● present	a. adjacent to edge	d. initiation	g. slight
– not present	b. edge	e. extensive	h. moderate
* four coupon summary	c. face	f. filiform	i. sever

TABLE 5

VISUAL EXAMINATION OF AISI TYPE 300 SERIES STAINLESS STEEL SHEET SPECIMENS BURIED AT NBS SOIL CORROSION TEST SITE D. (8, 4, 2, AND 1 YEAR EXPOSURE DATA [4])

					Visual Observations										
					Invasive						Surficial				
Material		Year(s) of Exposure	Coupon Number	NBS-ID	Perforation	Pitting	Tunneling	Etched	Cracking	Blister	Rust Stain	Black Stain	Dark Stain	Iridescent Film	Adhering Product
UNS S30100	Annealed	33.5	3	52D20	–	•c,d,i	–	–	–	–	–	•	–	•	–
			20	52D19	–	•b,c,d	•b,c	–	–	•a	•	–	•	•	–
		8	*		–	–	–	–	–	–	–	–	–	–	–
		4	*		–	–	–	–	–	–	•g	–	•g	–	–
		2	*		–	•d	–	–	–	–	–	–	–	–	–
		1	*		–	•d	–	–	–	–	–	–	–	–	–
	Sensitized	33.5	4	53D20	•a	•a,b	–	–	–	•e	•e,g	–	•	•	•e
			21	53D19	–	•c	–	–	–	•c	•a,e,g,i	•	•	•	•a,g,h
		8	*		–	•	–	–	•	•	•a,c,e	–	–	–	–
		4	*		–	•d,i	–	•	–	•	–	–	–	–	–
		2	*		–	•d	–	–	–	•	–	–	–	–	–
		1	*		–	•a,d	–	–	–	–	–	–	–	–	–
UNS S30400	Annealed	33.5	6	55D20	–	•d,c,g	•c	–	–	–	–	–	•	•	–
			23	55D19	–	•c,f	•c	–	–	–	•g,h	•	–	•	•
		8	*		–	•	•a,b	–	–	–	–	–	–	–	–
		4	*		–	–	–	–	–	–	–	–	•	–	–
		2	*		–	–	–	–	–	–	–	–	–	–	–
		1	*		–	–	–	–	–	–	–	–	–	•	–
	Sensitized	33.5	7	56D20	•c	•a,b,c,g	•a,b	–	–	•c	•g	•	•	•	•
			24	56D19	–	•a,c,g	•b	–	–	–	•	•	–	•	•
		8	*		•	•a,b,c	•	–	–	–	–	–	–	–	–
		4	*		–	•a	•a,b	–	•	•	–	–	–	–	–
		2	*		–	•a,b,d	–	–	–	•	–	–	–	–	–
		1	*		–	–	–	–	–	–	–	–	–	•	–
UNS S31600	Annealed	33.5	9	58D20	–	–	–	–	–	–	•g	–	•	–	–
			26	58D19	–	–	–	–	–	–	•g	•	–	–	–
		8	*		–	–	–	–	–	–	–	–	–	–	–
		4	*		–	–	–	–	–	–	–	–	–	–	–
		2	*		–	–	–	–	–	–	–	–	–	–	–
		1	*		–	–	–	–	–	–	–	–	–	–	–
	Sensitized	33.5	10	59D20	–	–	–	–	–	–	–	–	•	–	–
			27	59D19	–	•c,d	–	–	–	–	–	•	•	–	–
		8	*		–	–	–	–	–	–	–	–	–	–	–
		4	*		–	•	–	•	–	–	–	–	•	–	–
		2	*		–	–	–	–	–	–	–	–	–	–	–
		1	*		–	–	–	–	–	–	–	–	–	•	–

Key

• present	a. adjacent to edge	d. initiation	g. slight
– not present	b. edge	e. extensive	h. moderate
* four coupon summary	c. face	f. filiform	i. sever

TABLE 6

VISUAL EXAMINATION OF AISI TYPE 400 SERIES STAINLESS STEEL SHEET SPECIMENS BURIED AT NBS SOIL CORROSION TEST SITE D. (8, 4, 2, AND 1 YEAR EXPOSURE DATA[4])

				Visual Observations										
				Invasive						Surficial				
Material	Year(s) of exposure	Coupon	NBS-ID	Perforation	Pitting	Tunneling	Undercut	Etched	Blister	Rust Stain	Black Stain	Dark Stain	Iridescent film	Adhering product
UNS S40900 Annealed	33.5	11	60D20	●a,b,c	●a,b,c,g,h,i	●a,b,c	●c	–	–	●e,g	●	●	●	–
		28	60D19	●a,b,c,i	●a,b,c,f,g,h,i	●a,b,c	●b,c	–	–	●g,h	–	–	●	–
	8		*	●	●a,b,c	●	–	–	–	–	–	–	–	–
	4		*	●	●a,b,c	●	–	●	–	–	–	–	–	–
	2		*	–	●	●	–	–	–	–	–	–	–	–
	1		*	–	–	–	–	–	–	●	–	–	●	–
UNS S41000 Annealed	33.5	15	64D20	●a,b,c,i	●b,c,h,i	●b,c	–	–	–	●g	–	●	–	●
		32	64D19	●a,b,c,i	●a,b,c,f,g,i	●c	●c	–	●a	●e,g	–	–	–	●
	8		*	●	●a,b,c	●	–	–	–	–	–	–	–	–
	4		*	●	●b,c	●a,b,c	–	–	–	–	–	–	–	–
	2		*	●	●c,b,d	●	–	●i	–	–	–	–	–	–
	1		*	●	●c,d	●	–	–	–	–	–	–	–	–
UNS S43000 Annealed	33.5	16	65D20	●a	●a,f,h,ib,c	●b,c	–	–	–	●	–	–	–	–
		33	65D19	●a	●a,b,c,f,g,h,i	●b,c	●b,c	–	–	●	–	–	–	–
	8		*	●	●	●a,b,c	–	–	–	–	–	–	–	–
	4		*	●	●	●a,b,c	–	–	–	–	–	–	–	–
	2		*	–	–	●c	–	–	–	–	–	–	–	–
	1		*	–	–	–	–	–	–	–	–	–	●	–
UNS S43400 Annealed	33.5	17	66D20	●a	●a,b,c,f,g,i	●b,c	●c	–	–	–	–	–	–	●
		34	66D19	●a	●a,b,c,f,g,i	●b,c	●c	●c	–	–	–	–	●	–
	8		*	●	●	●a,b,c	–	–	–	–	–	–	–	–
	4		*	●	●a,c	●a	–	–	–	–	–	–	–	–
	2		*	–	●a,b,c	–	–	–	–	–	–	–	–	–
	1		*	–	–	–	–	–	–	–	–	–	–	–

Key

● present	j. adjacent to edge	m. initiation	p. slight
– not present	k. edge	n. extensive	q. moderate
* four coupon summary	l. face	o. filiform	r. sever

TABLE 7

PIT DEPTHSFOR STAINLESS STEEL SHEET SPECIMENS BURIED AT NBS SOIL CORROSION TEST SITE D. (8, 4, 2, AND 1 YEAR EXPOSURE DATA [4])

		Year(s) of exposure				
Material	Pit Depths [a]	1 [b]	2 [b]	4 [b]	8 [b]	33.5 [c]
UNS S20100 Annealed	Maximum (mm)	+	1.0	–	X	X
	Ave. of 5 deepest (mm)	–	–	–	0.4	1.05
UNS S20200 Annealed	Maximum (mm)	–	–	–	X	1.35
	Ave. of 5 deepest (mm)	–	–	0.2	–	0.76
UNS S30100 Annealed	Maximum (mm)	+	+	–	–	1.5
	Ave. of 5 deepest (mm)	–	–	–	–	1.17
UNS S30100 Sensitized	Maximum (mm)	–	–	0.75	1.45	X
	Ave. of 5 deepest (mm)	–	–	0.175	0.775	0.77
UNS S30400 Annealed	Maximum (mm)	+	–	–	X	1.46
	Ave. of 5 deepest (mm)	–	–	–	X	1.20
UNS S30400 Sensitized	Maximum (mm)	–	X	1.425	X	X
	Ave. of 5 deepest (mm)	–	–	–	X	1.31
UNS S31600 Annealed	Maximum (mm)	–	–	–	–	–
	Ave. of 5 deepest (mm)	–	–	–	–	–
UNS S31600 Sensitized	Maximum (mm)	–	–	<0.125	–	0.15
	Ave. of 5 deepest (mm)	–	–	–	–	–
UNS S40900 Annealed	Maximum (mm)	–	1.35	X	X	X
	Ave. of 5 deepest (mm)	–	–	X	X	X
UNS S41000 Annealed	Maximum (mm)	X	X	X	X	X
	Ave. of 5 deepest (mm)	–	–	X	X	X
UNS S43000 Annealed	Maximum (mm)	–	0.45	X	X	X
	Ave. of 5 deepest (mm)	–	–	X	X	X
UNS S43400 Annealed	Maximum (mm)	–	1.4	X	X	X
	Ave. of 5 deepest (mm)	–	–	X	X	X

Key

a. Average from non-penetrating pits	**X** Perforated
b. Four coupon summary	**+** Pit initiation
c. two coupon summary	– Negligible or none

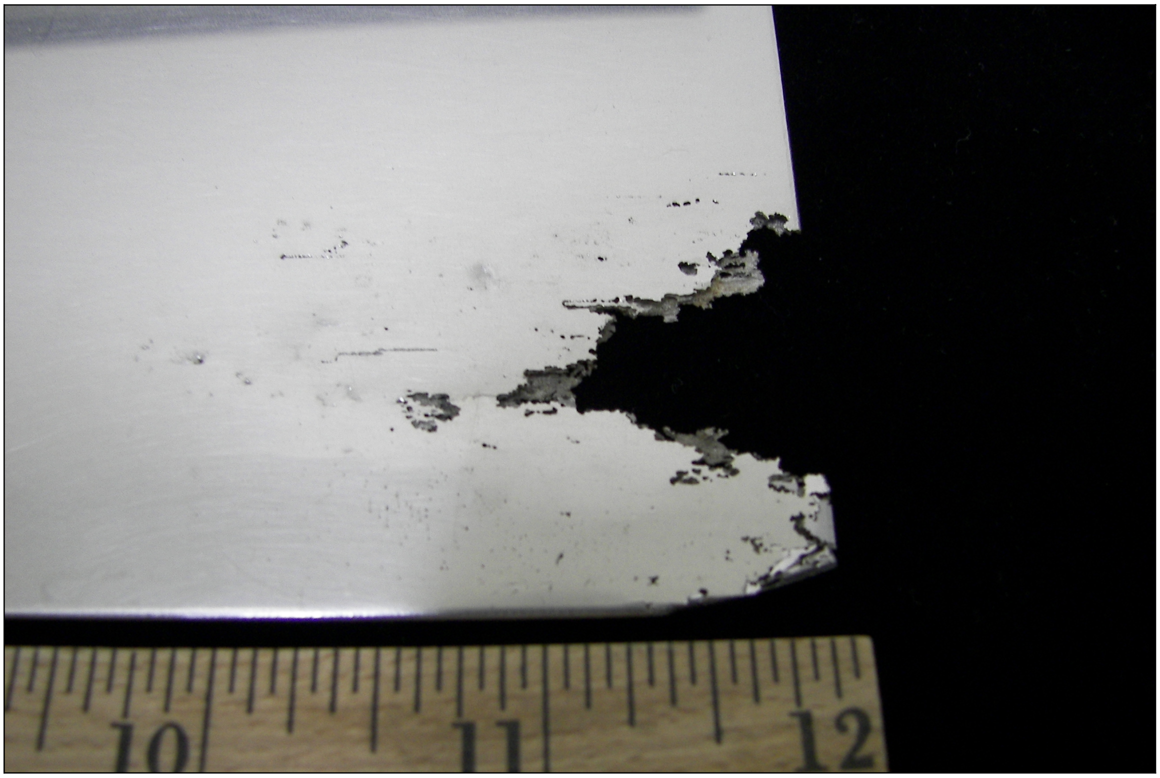

FIGURE 1. Annealed Type 201 with Evidence of Penetration, Pitting and Tunneling.

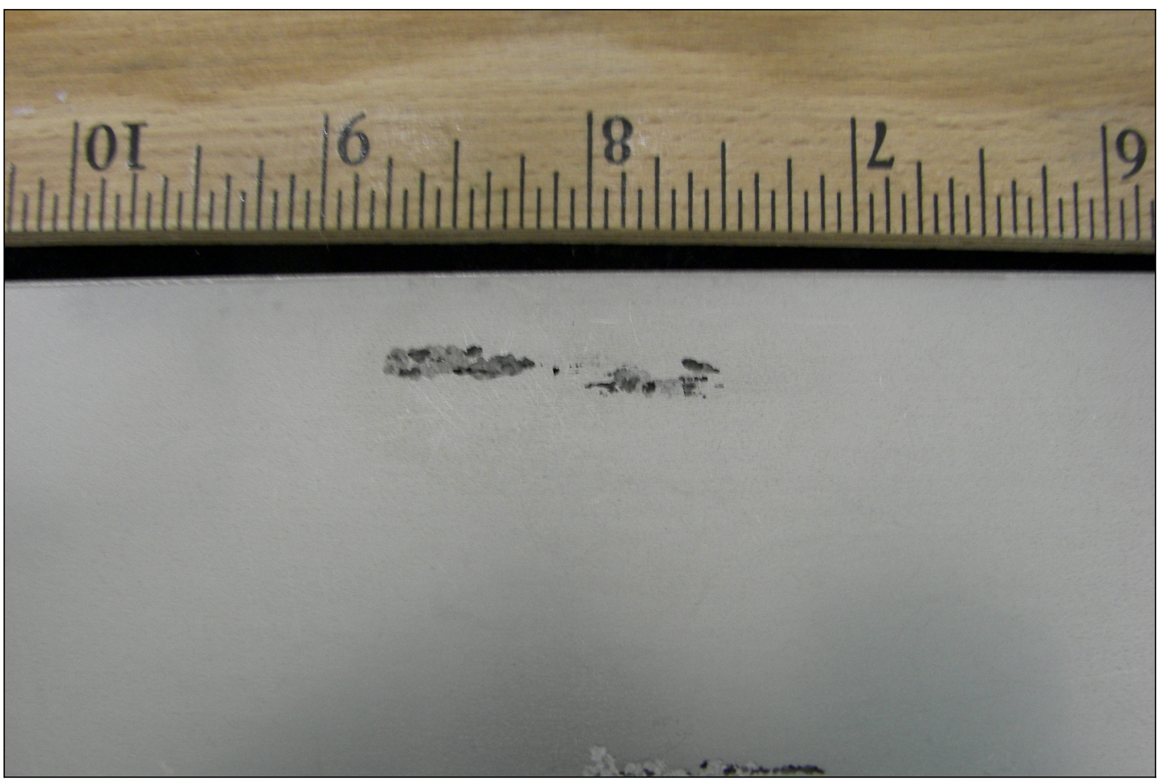

FIGURE 2. Annealed Type 304 with Evidence of Pitting.

FIGURE 3. Sensitized Type 304 with Evidence of Pitting,, Cracking, Penetration, and Tunneling.

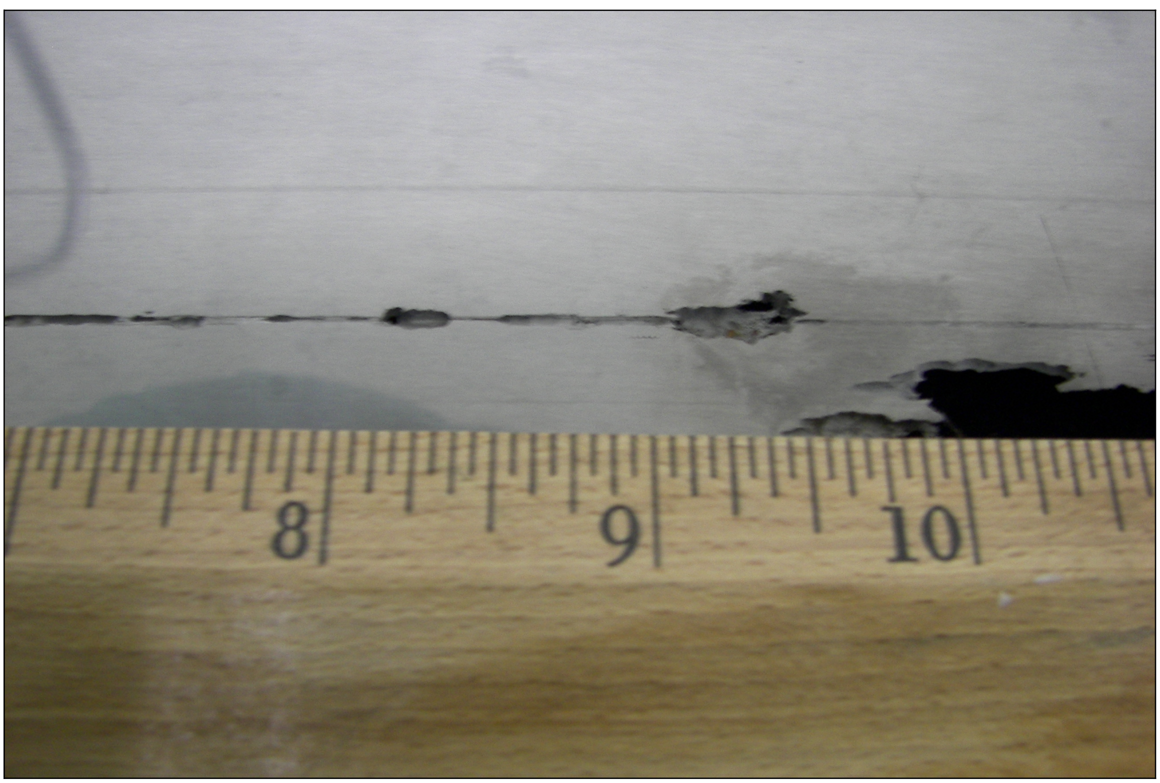

FIGURE 4. Annealed Type 410 with Evidence of Staining, Penetration, Pitting and Tunneling.

REFERENCES

1. Randolph, P. D., 1994*, Evaluation of INEL Facilities' Low-Level Waste Radiological Characterization Practices.* EGG-WM-10987.
2. U.S. Department of Energy's Environmental Management Science Program, 2000, *Research Needs in Subsurface Science,* National Research Council, National Academy Press, Washington, D.C.
3. Gerhold,W.F., E. Escalante, and B. T. Sanderson, 1976, *Progress Report on Corrosion Behavior of Selected Stainless Steels in Soil Environments,* (NBSIR 76-1081), Washington, DC: U.S. Department of Commerce.
4. Gerhold,W.F., E. Escalante, and B. T. Sanderson, 1981, *Progress Report on Corrosion Behavior of Selected Stainless Steels in Soil Environments,* (NBSIR 81-2228), Washington, DC: U.S. Department of Commerce.
5. Romanoff, M., 1957, *Underground Corrosion,* Washington, DC: U.S. Government Printing Office, National Bureau of Standards Circular 579.
6. ASTM G 1-03, "Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens," Philadelphia, Pennsylvania: American Society for Testing and Materials, 2003.