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Progress Report on the Corrosion Behavior of Selected Stainless Steels in Soil Environments

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Progress Report
1970-1974

Prepared for
American Iron and Steel Institute
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A. INTRODUCTION

Stainless steels* have been successfully used in limited applications (such as for pipe clamps on cast-iron sewer lines) in soil environments for many years. In recent years, other applications in use or under test include ground rods, transformer cases, submerged switches, underground residential distribution equipment, gas lines [1, 2], water lines, caskets, culverts, residential sewage disposal systems, etc.

Corrosion data for selected annealed, unstressed austenitic and ferritic stainless steels, buried in various soils, have been reported in NBS Circular 579 [3]. Tests conducted for 14 years in various soils in the United States by NBS showed that austenitic Type 304 (containing Ni) and Type 316 (containing Ni and Mo) stainless steels were highly resistant to both pitting corrosion and general attack. Type 304 was susceptible to pitting corrosion in certain highly aggressive soils, while Type 316 was relatively unaffected by corrosion. The martensitic, Type 410 (12% Cr) and the ferritic Type 430 (17% Cr) stainless steels were found to be fully resistant in only one-third of those soils where they were exposed. Branch [1] and Steinmetz and Hoxie [2] have reported on the suitability of stainless steels for some underground uses. Stress corrosion cracking has not been reported to be a problem with Types 304 or 316 in actual underground applications [1]. In a 2 year exposure to various soils in and around Baltimore, Maryland, Type 304 gas service lines [50 for a total length of 1 mile (1.61 km)] were reported to have suffered no corrosion effects [2].

In order to evaluate more fully the corrosion and stress corrosion behavior of some of the different types of stainless steels considered for use in soil environments, NBS in cooperation with the Committee of Stainless Steel Producers, American Iron and Steel Institute, initiated in 1970 a soil burial program in representative corrosive soils utilizing 9 stainless steels in both the annealed and cold worked conditions with various treatments. Test specimens incorporated welds, crevices, galvanic couples and specimens which had been sensitized to induce carbide precipitation. In 1971 and in 1972, this program was expanded to include additional stainless steels. The results obtained for specimens buried in the soils for up to 2 years were reported in 1974 [4, 5]. This report contains the results obtained for specimens buried

*The term "stainless steel" is broadly used in industry to describe any of a number of different alloys of widely varying composition, corrosion resistance, mechanical properties and microstructures. The essential alloying element added to iron to form stainless steels is chromium, which is present from 10.5 - 30 percent. In some cases, additional alloying elements are used such as nickel or molybdenum to enhance corrosion resistance.

at the NBS soil test sites for up to 4 years.

B. EXPERIMENTAL PROCEDURE

1. Soils at NBS Test Sites

Some of the properties of the soils at the NBS test sites are given in Table 1. The relative corrosivity of these soils on plain carbon steel is shown in Fig. 1. However, the corrosivity of these soils towards stainless steels may not necessarily be the same as with carbon steel. Following are detailed descriptions of the soils at the test sites which have been selected by NBS from 128 test sites previously evaluated to represent the range of soil properties having a bearing on the corrosivity of metals in soils.

Sagemoor Sandy Loam (Site A) is a well-drained alkaline soil with a resistivity of 400 ohm-cm and a pH of 8.8 and is typical of that found in vast areas of eastern Washington and Oregon. The site is located on the Yakima Indian Reservation near Toppenish, Washington. The soil is consistent in composition to a depth of at least 7 feet (2.13 m) and supports an abundant growth of sage-brush.

Hagerstown Loam (Site B) is a well-drained soil representative of the majority of well-developed soils found in the eastern part of the United States. The site is located at the Loch Raven Reservoir of the Baltimore Water Department. The soil consists of a brown loam about 1 foot (0.30 m) deep, underlain by reddish-brown clay that extends about 5 feet (1.52 m) or more to underlying rock. The soil has a resistivity in the range of 12,600 to 37,300 ohm-cm and a pH of 5.3. Practically all of the materials that have been investigated in the extensive NBS soil corrosion tests have been exposed at this site which, therefore, can serve as a reference site for the correlation of data obtained for specimens in the present program with data obtained from the earlier tests.

Clay (Site C) is located in a large clay pit on level land at the U. S. Coast Guard Receiving Center, Cape May, New Jersey, and is subject to flooding during heavy rains. The soil consists of a plastic gray clay to a depth of 6 inches (15.24 cm) underlain by gray clay mixed with patches of brown clay to a depth of 12 inches (30.48 cm). This is underlain by a poorly drained very heavy plastic clay in which the specimens are exposed. The soil has a resistivity which ranges from 400 to 1150 ohm-cm and a pH of 4.3.

Lakewood Sand (Site D) is a white, loose sand with some black streaks occurring in places and supports an abundant growth of beach grasses. The site is located in a well-drained rolling area on the property of the U. S. Coast Guard Electronic Engineering Station, Wildwood, New Jersey. This site is not subject to overflow from the ocean except under unusual flood conditions. The sand has a pH of 5.7 and the resistivity ranges from 13,800 to 57,500 ohm-cm.

Coastal Sand (Site E)is a typical white, coastal beach sand with a high content of black sand; at this site, however, the sand is constantly damp and is occasionally flooded with sea-water. The site is located on the

Two-Mile Beach on the property of the U. S. Coast Guard Electronic Engineering Station, Wildwood, New Jersey. The sand has a pH of 7.1, and the resistivity ranges from 1,320 to 49,500 ohm-cm.

Tidal Marsh (Site G) is a soil typical of the poorly-drained marsh soils that are found along the Atlantic and Gulf coasts. The site is located along a creek (Pine Hill Run) that empties into the Chesapeake Bay at the Patuxent Naval Air Station, Lexington Park, Maryland. The soil is naturally charged with hydrogen sulfide and has a resistivity in the range from 400 to 15,500 ohm-cm and a pH of 6.0.

2. Materials, Treatment and Preparation

In order to simulate some of the conditions that may be encountered with components fabricated from stainless steels, materials for these 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.

Descriptions of the various stainless steel systems buried at each test site including treatments and preparation are given in Table 2. The chemical analyses and mechanical properties of each alloy are given in Tables 3 and 4.

Upon receipt of the specimens from the stainless steel producers, the specimens were first stamped with identification numbers using chromium plated steel dies. All of the flat sheet materials [approximately 0.06 inch (0.15 cm) thick] were supplied with sheared edges which had been deburred. In some instances further deburring was necessary. All of the materials to be exposed unstressed were then degreased in trichlorethylene vapor, passivated (using procedures described in Table 2), scrubbed with a fiber brush, thoroughly rinsed with water and then air dried.

Half of the coated [coal-tar epoxy, 16 mils (0.04 cm) per side] specimens (System No. 61) were scored diagonally from the corners, twice on one surface, by cutting through the coating to the base material with a sharp pointed instrument. The other half of the specimens were exposed in the "as coated" condition.

The cross-bead welded flat sheet materials (System Nos. 3, 9, 11 and 54) were prepared in accordance with Welding Research Council recommendations.

Type 304 tube (System No. 57) was prepared in accordance with ASTM Specification A249. Type 409 tube (System Nos. 62 and 63) was tested in the "as-welded" condition. Except for cleaning and passivating, the proprietary alloys were tested as supplied by the producers. The ends of the tube specimens were plugged with rubber stoppers and then plastic or rubber caps were placed on each end to create a crevice.

All of the sheet materials to be stressed as either single or double U-bends had oblong holes, 1/4 inch x 1/2 inch (0.64 cm x 1.27 cm), punched near each end so as to be self aligning after bending. Specimens to be connected to a dissimilar metal (galvanic couples) had an additional hole 0.093 inch (0.236 cm) drilled 1/4 inch (0.64 cm) from the end and side for wire connections.

The specimens to be stressed were initially bent using a die (shown in Fig. 2) to about 20° (internal angle). The only portions of the die in contact with the specimens during the forming operation were fabricated from Type 304 stainless steel. The specimens were then cleaned and passivated using the same procedures noted above for unstressed specimens.

Single U-bend specimens were then formed by bending the two ends in a wooden jig so that they were parallel [the inside diameter at the bend was approximately 1 inch (2.54 cm)] and clamping them in this position with a Type 316 stainless steel nut and bolt. Double U-bend specimens for crevice and stress corrosion studies were formed in the same manner except that some were spot welded together (see Fig. 3) prior to the bending operation. They were then bent at the same time to form the U and clamped at the ends with Type 316 stainless steel fasteners.

For the galvanic couple studies, specimens were connected to steel (iron), zinc or magnesium anodes or to copper strips. Connection was made by soldering 14 gauge stranded copper wire to the specimen at the drilled hole using 50-50 acid core solder.

The iron anode consisted of a 1 foot (0.3 m) length of a cold finished steel (AISI 1017-1018) 3/4 inch (1.90 cm) hexagonal shaped rod with a hole [0.093 inch (0.236 cm)] drilled in the rod mid-way between each end for the electrical connection. The copper wire from the specimen was inserted in this hole and then soldered to the iron anode using 50-50 acid core solder.

The magnesium anode [4 feet (1.2 m) long and bent in the form of a horseshoe] was of the commercial flexible extruded type with an oval shaped cross-section 3/4 inch x 3/8 inch (1.90 cm x 0.95 cm) and a continuous centrally located 1/8 inch (0.32 cm) diameter iron wire core. The copper wire from the specimen was soldered to a 1 inch (2.54 cm) extension of the iron wire core using 50-50 acid core solder. In addition a bituminous (coal-tar epoxy) coating was applied to both 3/4 inch (1.90 cm) faces of the anode to extend its effective life.

The zinc anode [1 foot (0.30 m) long] was also of the commercial flexible extruded type with a diamond shaped cross section [5/8 inch x 7/8 inch (1.59 cm x 2.22 cm)] and a continuous centrally located 0.1 inch (0.25 cm) diameter zinc-coated (galvanized) iron wire core. The stranded copper wire from the specimen was soldered to an extension of the galvanized wire core.

Copper strips which were electrically coupled to the unstressed stainless steel specimens were cut from cold-rolled copper sheet, 0.065 inch (1.651 cm) thick and of the same dimensions as the stainless steel specimen [1 inch x 12 inches (2.54 cm x 30.48 cm)].

The areas at all soldered joints, including any exposed portions of the copper wire, were covered with a bituminous (coal-tar epoxy) coating.

3. Exposure

At each test site, the specimens were buried in trenches approximately 2-1/2 feet (0.76 m) deep and 2 feet (0.61 m) wide. The specimens were placed about 1 foot (0.30 m) apart. The 8 inch x 12 inch (20.32 cm x 30.48 cm) sheets were placed in the trench in a vertical position (with the long dimension horizontal). The specimens electrically connected to the steel and zinc anodes and to the copper strips were placed in the trench with the dissimilar metal parallel to the specimen and separated by approximately 1 foot (0.30 m). Specimens electrically connected to the horseshoe shaped magnesium anodes were placed at the center of the horseshoe. Upon backfilling the trenches, the insulated wires soldered to those specimens to be used in potential and corrosion current (couple corrosion) determinations were connected above ground to terminal strips mounted on 4 inch x 4 inch x 6 foot (10.16 cm x 10.16 cm x 1.83 m) wooden posts. Leads from the anodes and copper strips were connected to leads from the specimens at the terminal strips (potential and current measurements).

Sufficient specimens were buried at each of the 6 test sites to permit recovery of a complete set at specified intervals (1, 2, 4 and 8 years) and a final set to be removed at a later date to be determined. Each set of the 8 inch x 12 inch (20.32 cm x 30.48 cm) flat sheet systems and welded tube systems consisted of 4 specimens, while for the stressed and unstressed 1 inch x 12 inch (0.254 cm x 30.48 cm) sheet systems, each set consisted of 2 specimens.

The burial order for each test site is shown in Figs. 4a, b and c. One thousand fifty four (1054) specimens were buried at each test site for a total of 6324 specimens at the six test sites.

4. Electrochemical Measurements

All electrochemical measurements (potential, couple current, and corrosion current) were made at time of burial and subsequently 3 times a year when possible with the exception of Site A where measurements were usually made once a year.

Electrochemical potentials of the specimens and couples *vs.* a Cu-CuSO4 half cell were measured using a high precision portable pH meter as a millivoltmeter. The half cell was placed in a remote area (usually at the edge of the test area) and shielded from light to prevent photochemical effects.

The couple currents of the anode systems and the stainless steel-copper systems were measured using a zero impedance circuit employing an operational amplifier (Fig. 5) for small currents and a commercially available zero resistance ammeter for larger currents.

Corrosion currents were measured using a modification of the linear polarization technique based on the following relationship derived by Stern and Geary [5]:

$$\frac{\Delta E}{\Delta I} = \frac{1}{2.31 \qquad I\ corr} \quad \frac{B_a B_c}{B_a + B_c}$$

where ΔE is the overvoltage of the corroding specimen produced by a polarizing current, ΔI. B_a and B_c are the slopes of the anodic and cathodic polarization curves, respectively, in the Tafel region and I_{corr} is the corrosion current. Assuming B_a and B_c equal to 0.1 V in this investigation (the error will usually be about 20% or less, as established by Stern and Weisert [6],) the following equation was derived:

$$I_{corr}\ (mA) = \frac{2.7\Delta I \quad (mA)}{\Delta E \quad (mV)}$$

The electrical circuit described previously, [7] but minus the bridge circuit was employed. A soil auger was utilized as the auxiliary electrode. The change in potential was measured directly using the pH meter or an electrometer (0-10 mV scale) plus a battery and variable resistor (to null the initial potential) and a $Cu\text{-}CuSO_4$ reference electrode. Electrodes (auxiliary and reference) were placed so that the specimen was between them or at approximately right angles to them. In making these measurements, an increment of current was applied to the specimen unitl a stable overpotential of usually 2 to 10 mV occurred. The potential and current readings were then recorded.

Occasionally the open circuit potential of the stainless steel alloy was found to fluctuate and the corrosion current measurements could not be made. At other times, extremely humid or rainy conditions prevented these measurements.

5. Examination of Specimens After Exposure

Upon removal from the trench after burial for 1, 2 or 4 years, each of the stressed specimens was examined for indications of failure by cracking. All specimens were then returned to the laboratory for cleaning and a more thorough examination.

In the laboratory, the specimens were rinsed in tap water to remove adhering soil particles. They were then examined visually prior to further cleaning. The stressed U-bend specimens were disassembled by removing the Type 316 stainless steel fasteners. The copper wires were unsoldered from those specimens that had been coupled to dissimilar metals.

All specimens, except the coated ones (System No. 61) and the composites (System Nos. 14, 15 and 16), were then further cleaned ultrasonically using a 10% nitric acid solution heated to 120° - 130°F (49° - 54°C) for 20 to 30 minutes. Specimens from System Nos. 14 and 16 were ultrasonically cleaned using an aqueous 10% ammonium citrate solution heated to 175° to 185°F (73° - 85°C). The time for cleaning these specimens varied and was dependent upon the tenacity of the corrosion scale. The specimens from System No. 15 were ultrasonically cleaned for approximately 30 minutes using an aqueous ammonium chloride solution at 175° to 185°F (79° - 85°C). After cleaning, the specimens were rinsed in hot tap water and then air dried.

The unstressed sheet [8 inches x 12 inches (20.32 cm x 30.48 cm)] and tube specimens were then weighed 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 unstressed tube and 8 inch x 12 inch (20.32 cm x 30.48 cm) sheet specimens.

C. RESULTS AND DISCUSSION

Table 5 summarizes the results obtained from visual examination of the unstressed non-welded sheet materials. The results obtained for welded sheet and tube materials are summarized in Table 6. The results obtained from average weight loss and pit depth determinations are given in Tables 7 through 12 and are shown graphically in Figs. 6 through 10.

Data given for each alloy system are a compilation of results obtained from either 2 or 4 specimens depending upon the number of specimens of each system that was exposed. The weight loss for a given alloy system exposed in a particular soil may appear to be extremely small in comparison to the observed corrosion. This occurs because the corrosion of stainless steels in some environments can often be localized and confined to a very small area. Similarly, 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.

Corrosion of stainless steels is generally attributed to a breakdown of the passive film at the surface of the material at localized or selective areas. If corrosion occurs it may often be influenced by one or more of the following:

1. Inhomogeneities of the metal surface.

2. Concentration cell effects due to adhering soil particles or crevices where stagnant conditions may exist.

3. Presence of chlorides in the soil.

4. Microbiological organisms.

5. Abrasion of the metal surface by soil particles or foreign debris.

A break in the passive film at the localized area results in a small anodic site. The larger surrounding area is the cathode. The electrolytic cell formed could result in localized pitting corrosion, which can rapidly penetrate the thickness of the metal. However, a stainless steel with adequate alloying content for the environment would repassivate without degradation. Concentration cells formed at stagnant areas beneath soil deposits or at crevice areas can also result in localized corrosion. An unusual form of pitting corrosion, tunneling, is normally associated with edges and can be increased by gravity flow of corrosion products. As noted above, all flat specimens were buried vertically, thus increasing the propensity for tunneling.

1. General Corrosion Behavior

AISI 200 Series

Annealed Type 201 and 202 austenitic stainless steels (System Nos. 50 and 51) buried up to 4 years in alkaline soil (Site A), Hagerstown loam (Site B) and dry sand (Site D) were in general unaffected by corrosion. However, pitting corrosion was noted at the edge of one Type 201 specimen buried for 2 years at Site D. Specimens of both systems buried in the acid clay (Site C) and wet sand (Site E) exhibited pitting and tunneling corrosion and were perforated due to corrosion after exposure for 1 year. Of the specimens buried in the tidal marsh (Site G), both systems were susceptible to pitting corrosion. Tunneling corrosion was also observed at the edge of one Type 201 specimen which had been buried for 4 years. A companion specimen buried at this site for 2 years was perforated due to corrosion. Tunneling corrosion was not observed on the Type 202 specimens. However, one specimen was perforated at the edge due to pitting corrosion.

AISI 300 Series

Annealed Materials - In general, corrosion was nil or superficial for the annealed austenitic 300 series materials buried for up to 4 years at Sites A, B and D. Annealed Type 316 buried at Sites C and G was with a few exceptions unaffected by corrosion. However, a few corrosion pits were observed at edge areas on two specimens that were buried for 4 years at Site C. At Sites C and G annealed Types 301 and 304 specimens were susceptible to pitting and tunneling corrosion. All of the annealed 300 Series alloys buried at Site E exhibited both tunneling and pitting corrosion and many specimens were perforated at corroded areas.

Sensitized Materials - Degradation of the sensitized 300 series alloys buried at Sites A and B for up to 4 years was nil or negligible.** However, some slight etching and pitting corrosion was noted at areas on some specimens buried at these sites. Of the sensitized materials buried at Site C, all were susceptible to pitting corrosion with Type 316 being the least susceptible. Sensitized Type 304 and Type 316 buried at this site were also susceptible to tunneling corrosion. Some of the sensitized Type 301 and Type 304 specimens buried at Sites D and E exhibited "blister-like eruptions" at surface areas. These appeared to be very small corrosion pits.

Degradation of sensitized Type 301 and 304 specimens buried at Site G was generally due to severe etching and non-uniform attack (Fig. 11). Some specimens were perforated at scattered localized areas after burial of 1 or 2 years, but none had perforated after burial for 4 years. Corrosion of Type 316 (sensitized) buried at this site was in general negligible.

**Many of the specimens examined exhibited incipient pitting and various forms of discoloration, e.g., iridescence, rust and dark to black stains. However, no other degradation was observed on these specimens nor was there any loss in weight due to exposure in the soil environment. Corrosion of these specimens was considered to be nil or superficial.

Welded Materials - Corrosion of the cross-bead welded Type 301 sheet and heliarc-welded Type 304 tube specimens buried at Sites A, B and D was in general nil or superficial. Pitting corrosion was noted at and adjacent to the weld bead on the cross-bead welded Type 301 sheet specimens buried at Sites C, E and G. Pitting corrosion was also observed at and adjacent to the weld seam of Type 304 tube specimens buried at Site C and at areas adjacent to the caps and at crevice areas (under the end caps) on tube specimens buried at Sites C and E. However, pitting was also noted at areas remote from the weld. It was not determined whether the welding operation resulted in sensitization at the weld or whether the pitting corrosion was or was not due to sensitization.

Figs. 12 through 15 are examples of some of the degradation noted on the 300 series specimens.

AISI 400 Series

Materials in this series include the martensitic Type 410 and ferritic Types 409, 430 and 434 stainless steels.

Specimens of Type 409 (annealed or welded) and Type 410 (annealed) were perforated by corrosion after burial for 4 years in 5 of the 6 soils. The time to first perforation (generally 1 or 2 years) for the Type 409 materials was less for specimens buried at Sites C, E and G. Corrosion of these alloys was nil or superficial at Site B. The coal-tar epoxy coated Type 409 sheet specimens were in general relatively unaffected by corrosion.

Types 430 and 434 were relatively unaffected by corrosion after burial for 4 years at Sites A and B. Companion specimens buried at Sites C, E and G were perforated by corrosion generally in less than 1 year. At Site D first perforation for these materials was not observed until specimens had been buried for 4 years.

Figs. 16 through 23 are examples of some of the degradation noted on 400 series specimens.

Specialty and Developmental Alloys

Stainless steels in this classification include proprietary and composite materials. The proprietary stainless steels may be grouped as follows according to major alloying constituents:

1. Cr Stainless Steel

   26 Cr - 1 Mo
   18 Cr - 2 Mo
   18 Cr - 2 Mo (Nb)
   18 Cr (Ti)

2. Cr-Ni Stainless Steels

   26 Cr - 6.5 Ni
   20 Cr - 24 Ni - 6.5 Mo
   18 Cr - 8 Ni (N) (Now designated as AISI Type 304 N)

The results obtained from visual examination of specimens of these materials after burial in the various soils for up to 3 years are summarized in Tables 5 and 6.

Cr Stainless Steels - Alloy 26 Cr-1 Mo [in the annealed condition (System No. 1)] was relatively unaffected by corrosion in any of the soils after burial for up to approximately 3 years. Pitting corrosion was noted particularly at or adjacent to crevice and weld areas of some of the heliarc welded Alloy 26 Cr-1 Mo specimens (System No. 17) buried at Sites A, C, E and G.

Corrosion of annealed Alloy 18 Cr-2 Mo (System No. 6) was nil or superficial for specimens buried for up to 3 years at Sites A, B, C and D. Scattered pitting corrosion with subsequent perforation of the material was observed on specimens buried at Sites E and G. Corrosion of annealed Alloy 18 Cr-2 Mo (Nb) (System No. 7) specimens was in general nil or superficial after burial for up to 2 years. Pitting corrosion was noted at weld areas of cross-bead welded sheet specimens (System No. 11) buried at Sites C, E and G and tube specimens (System 12) buried at Sites A and E. Pitting corrosion was also observed at crevice areas of tube specimens buried at Sites E and G. Specimens of System 11 were perforated due to corrosion at Sites C and E.

Of the Alloy 18 Cr (Ti) (System Nos. 2, 3 and 18) specimens buried for up to 3 years, corrosion of those buried at Sites A, B and D was in general nil or superficial. Some specimens buried at Sites C, E and G were perforated due to corrosion.

Cr-Ni Stainless Steel - The annealed Alloy 18 Cr-8 Ni (N) (System No. 8) specimens were in general relatively unaffected by corrosion after burial for approximately 3 years at Sites A, B, C and D. Some specimens buried at Sites E and G were perforated due to corrosion. Sheet specimens of this alloy having a cross-bead weld (System No. 9) and buried at Sites C, E and G were perforated due to pitting corrosion at weld areas. There was little or no corrosion of companion specimens buried at Sites A, B and D.

There was little or no appreciable attack on the annealed (System No. 4), sensitized (System No. 5) or heliarc welded (System No. 19) Alloy 20 Cr-24 Ni-6.5 Mo specimens buried in the 6 soils. Corrosion where observed was in general superficial.

Corrosion of annealed Alloy 26 Cr-6.5 Ni (System 10) specimens buried at Sites A, B and D was in general negligible. Companion specimens of this alloy buried at Sites C, E and G were perforated by corrosion in less than 1 year.

Composite Materials - The composite systems are sandwich materials where outer layers of carbon steel are metallurgically bonded to a thin core of stainless steel (total thickness approximately 0.120 in (0.305 cm). Composites A and B (System Nos. 14 and 15) were fabricated with Type 430 stainless steel as a core material while Composite C (System No. 16) utilizes Type 304 stainless steel. In addition Composite B specimens were individually hot-dip zinc coated [galvanized, 4.5 to 5 oz/ft^2 (1377 to 1528 gms/m^2) zinc]. This was a thicker coating than would normally be used on carbon steel products.

In general, there was little difference in the corrosion behavior of System Nos. 14 and 16 buried in the same soil environment for approximately 4 years. Pitting corrosion of the carbon steel outer layers was observed on all specimens buried at the six sites. The carbon steel was perforated by corrosion on specimens buried at Sites A, B and G which thus exposed the stainless steel core of both composite materials. While there was no apparent significant corrosion of the stainless steel core of these specimens, degradation of the carbon steel was more severe for specimens buried at Site G.

The hot-dip zinc coating on specimens of System No. 16 provided protection to the underlying carbon steel and stainless steel core in all of the soils. There was some dissipation of the zinc in all of the soils. However, there was some zinc remaining on all of the specimens after burial for up to 4 years in the 6 soil environments.

2. Stress Corrosion Behavior

The results of visual and micro examinations made to determine failure of the various systems due to stress corrosion cracking are given in Table 13 for non-galvanically coupled specimens.

AISI 300 Series

Type 301 stainless steel in the half-hard condition was relatively immune to stress corrosion cracking in all of the soils after exposure for approximately 4 years. Micro-cracking was observed on one specimen buried for 2 years at Site C. Sensitization of the half-hard alloy increased the susceptibility to stress corrosion cracking in all of the soil environments. Of the specimens buried for 4 years, all exposed at Sites A, C, D, E and G had failed, while at Site B, only 1 of the 2 specimens retrieved was cracked. The same alloy in the full-hard condition was in general also immune to stress corrosion cracking after exposure for up to 4 years. However, micro-cracking was noted on one of the spot welded specimens buried for 2 years at Site G. No failures were observed on stressed Type 304 in the annealed or half-hard condition. Cracking of the sensitized Type 304 stressed specimens in the half hard condition, buried at Site C for 2 years and Site E for 1 year, was observed while companion specimens buried for 4 years at these sites were unaffected by cracking.

AISI 400 Series

Type 434 stainless steel was the only alloy in this series exposed in the soils. There were no failures after burial for 4 years in any of the soils.

Specialty and Developmental Alloys

Steels in this category included Alloys 26 Cr-1 Mo, 18 Cr-2 Mo, 20 Cr-24 Ni -6.5 Mo, 18 Cr-8 Ni (N) and 26 Cr-6.5 Ni. There were no failures of these steels after exposure for up to 3 years.

3. Stressed Dissimilar Metal Couples

The results for the stressed galvanically coupled specimens have been reported elsewhere [6]. Table 14 in this report summarizes the results obtained for specimens buried for approximately 4 years.

AISI 300 Series

There were no failures noted for Type 304 in the annealed condition when coupled to zinc, magnesium or iron. Type 301 full-hard and Type 301 half-hard have a tendency to stress crack. As shown in Table 14 all of the stressed Type 301 full-hard stainless steel specimens and all but 1 of the Type 301 half-hard specimens coupled to magnesium failed in the four years of exposure. When coupled to iron, these materials were resistant to cracking at 4 of the 6 sites (Sites A, B, D and E). One Type 301 full-hard specimen buried at Site G had failed while Type 301 half hard specimens buried at this site had not failed. Both materials when coupled to zinc had failed at all of the sites except for those buried at Site A. The largest currents were generated by magnesium followed by zinc and iron. It was noted that below 1 $\mu A/cm^2$ no failures occurred for the Type 301 materials. As the current density increased to above 8 $\mu A/cm^2$ all Type 301 full-hard specimens failed and above 20 $\mu A/cm^2$ all Type 301 half-hard specimens failed. The fact that the number of failures increased with increasing cathodic current indicates that hydrogen embrittlement was the mode of failure.

Specialty and Developmental Alloys

There were no failures of the 26 Cr-1 Mo or 26 Cr-6.5 Ni galvanically coupled to zinc, magnesium or iron after exposure for approximately 3 years in the soils.

4. Unstressed Dissimilar Metal Couples

The results obtained for unstressed stainless steels coupled to a dissimilar metal (copper) have been reported elsewhere [7]. Table 15 in this report summarizes the results obtained for these stainless steels, each coupled to copper, after burial for up to 4 years in the various soil environments. The data shows that where the galvanic current was negative, little or no corrosion occurred. The only exception was on Alloy 26 Cr-6.5 Ni material exposed at Site E where pitting corrosion was noted on specimens at areas under the solder. This corrosion suggests that the solder connection was poor resulting in an inaccurate current determination for the specimens. The Type 409 stainless steel was the most severely corroded. However, there was no clear indication that the copper adversely affected the stainless steel. The results obtained from visual examination of the copper electrodes are given in Table 16. Since the copper was coupled to stainless steel, the electrochemical tabulations given in Table 15 also apply to the copper. It was noted that as the potential of the galvanic couple became more noble (more positive), the corrosion of the copper increased. The galvanic potentials at Site B were around zero (vs. Cu-Cu SO_4 reference electrode) and caused the most corrosion observed on the copper. The corrosion of the copper was least at Site G.

D. SUMMARY

1. AISI 200 and 300 Series

In general all of the austenitic (200 and 300 series) stainless steels included in this program exhibited good resistance to corrosion after burial for up to approximately 4 years in alkaline soil (Site A), Hagerstown loam (Site B) and Lakewood sand (Site D). These stainless steels were susceptible to corrosion in the acid clay (Site C), coastal sand (Site E) and tidal marsh (Site G). Type 316 (annealed) was the least susceptible to corrosion in the 6 soils investigated. Degradation of the 200 and 300 series stainless steels was generally due to pitting or tunneling corrosion or a combination of both with subsequent perforation of the specimens at localized areas. For some specimens buried in the tidal marsh, corrosion was observed at large areas on the specimens and was attributed to severe etching or general corrosion of the metal surfaces. Sensitization by heat treatment of Types 301, 304 and 316 generally resulted in increased susceptibility to corrosion in all of the soils.

Pitting corrosion was observed at or adjacent to the weld beads on cross-bead welded Type 301 sheet specimens buried at Sites C, E and G and at or adjacent to the weld seams on Type 304 tube specimens buried at Sites A, C and G. It must be stressed that pitting also occurred at other areas on the specimens remote from the welds. It was not determined at this time whether the welding operation resulted in sensitization at the weld areas or whether the pitting corrosion observed was or was not due to sensitization. Future studies will examine these questions. Type 304 tube specimens buried at Sites C and G were also susceptible to crevice corrosion.

With some exceptions the non-galvanic couples stressed 300 series alloys exhibited good resistance to stress corrosion cracking in all of the soils. Type 316 in the annealed or sensitized condition was immune to stress corrosion cracking in all of the soils after exposure for 4 years. Type 301 in the half-hard condition was susceptible to cracking at Site C, while spot-welded Type 301 in the full-hard condition was susceptible to cracking at Site G. Sensitization of Type 301 half-hard increased the susceptibility to stress corrosion cracking in all of the soils. Type 304 (annealed) was immune to stress corrosion, but sensitization of this material made the alloy susceptible to stress corrosion at Sites C and E.

Galvanic coupling of Type 301 half-hard or full-hard stainless steel to magnesium or zinc increased the susceptibility to stress-cracking. When coupled to zinc, failures were observed in five of the six soils (exception was Site A) while, when coupled to magnesium, failures were observed in all of the soils. This alloy in the half-hard condition and coupled to iron failed at Site C only, while similar specimens in the full-hard condition failed at Sites C and G.

2. AISI 400 Series

The martensitic Type 410 and the ferritic Types 409, 430 and 434 stainless steels were in general susceptible to pitting or tunneling corrosion or a combination of both at Sites A, C, D and E and to severe etching or general corrosion attack at Site G. Except for the Type 430 and Type 434 buried at Site A, all were perforated due to corrosion. Of these materials buried for 4 years at Site B, the corrosion observed was nil or superficial. Areas at and adjacent to the weld seam on the heliarc welded Type 409 specimens buried at Sites C and G and the high-frequency welded Type 409 specimens buried at Sites A, C, D, E and G were susceptible to pitting corrosion. Pitting corrosion was also observed at crevice areas on these two materials buried at all sites except Site B. The coal-tar epoxy coating applied to the Type 409 stainless steel appeared to be effective in providing protection from corrosion at all sites. However, some superficial corrosion was noted at areas where the coating had been scored to bare metal prior to burial.

Type 434 was the only stainless steel in the 400 series included in the stress corrosion study. No failures were observed for non-galvanically coupled stressed specimens of this material in any of the soil environments.

3. Specialty and Developmental Stainless Steels

Annealed and heliarc-welded Alloy 20 Cr-24 Ni-6.5 Mo was resistant to corrosion in all of the soils after burial for 3 years. Sensitized specimens of this material were resistant to corrosion in all of the soils except at Sites C and G.

Annealed 26 Cr-1 Mo stainless steel was slightly pitted (< 5 mils deep) due to corrosion at Site C only after burial for 3 years. However, heliarc-welded tube was susceptible to crevice corrosion and/or pitting at Sites A, C, E and G. This alloy was not exposed in the sensitized condition.

Alloy 18 Cr-2 Mo (Nb) in the annealed condition and buried for 3 years was resistant to corrosion at Sites B and D. Also after exposure for 3 years, cross-bead welded sheet specimens of this alloy were unaffected by corrosion at Sites A, B and D. Heliarc welded tube specimens, exposed for 2 years, were resistant to corrosion at Sites B, D and G.

Annealed 18 Cr-2 Mo stainless steel was resistant to corrosion during a 3 year period at Sites A, B and D but was susceptible to pitting corrosion at Sites C, E and G.

Annealed and cross-bead welded 18 Cr-8 Ni (N) (now designated AISI Type 304 N) stainless steel specimens exposed for 3 years were also resistant to corrosion at Sites A, B and D and were similarly susceptible to pitting corrosion at Sites C, E and G.

Alloy 26 Cr-6.5 Ni in the annealed condition was resistant to corrosion at Sites B and D but was susceptible to pitting corrosion at Sites A, C, E and G.

Annealed 18 Cr (Ti) sheet and heliarc welded tube stainless steel specimens were resistant to corrosion at Sites A and B. The heliarc welded tube was also resistant to corrosion at Site D, but the annealed sheet material at this site was pitted due to corrosion. Both types of specimens of this alloy were severely corroded at Sites C, E and G.

Of the proprietary steels included in the stress corrosion study, there were no failures of either galvanically coupled or non-galvanically coupled specimens after 4 years exposure in any of the soils.

ACKNOWLEDGEMENTS

The assistance of James L. Fink in various capacities during this investigation is acknowledged.

Acknowledgement is made also to the following organizations which provided test sites and assistance during the burial and removal of the specimens and during the inspections at the test sites.

Bonneville Power Administration
U. S. Department of Interior
Portland, Oregon 97208

Baltimore Bureau of Water Supply
Baltimore, Maryland 21217

U. S. Coast Guard Training Center
Cape May, New Jersey 08204

Patuxent Naval Air Station
Lexington Park, Maryland 20653

U. S. Coast Guard Electronics Engineering Station
Wildwood, New Jersey 08260

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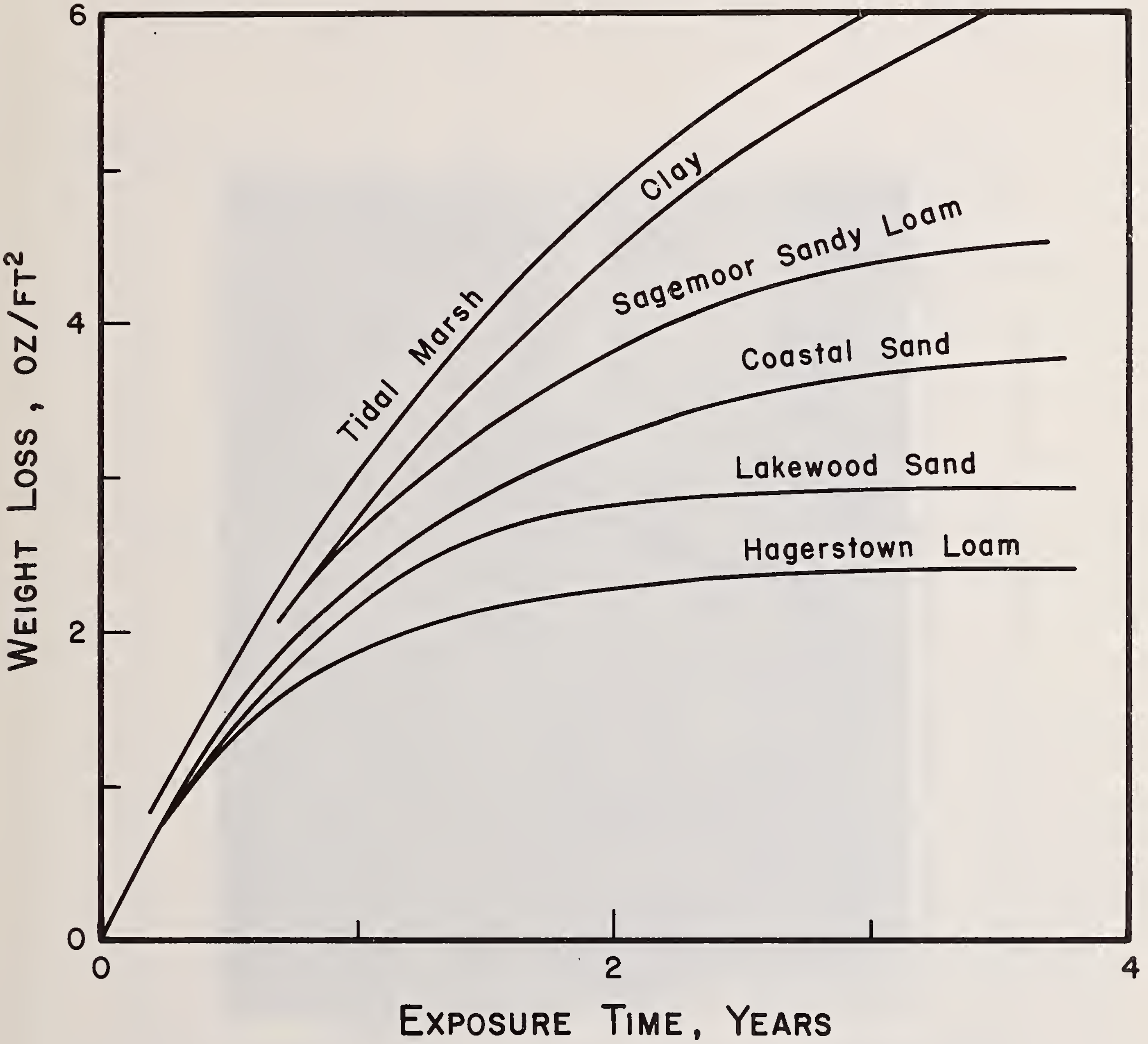


Fig. 1. Relative Corrosion Effects of the Soils at the Six NBS Test Sites on Carbon Steel.

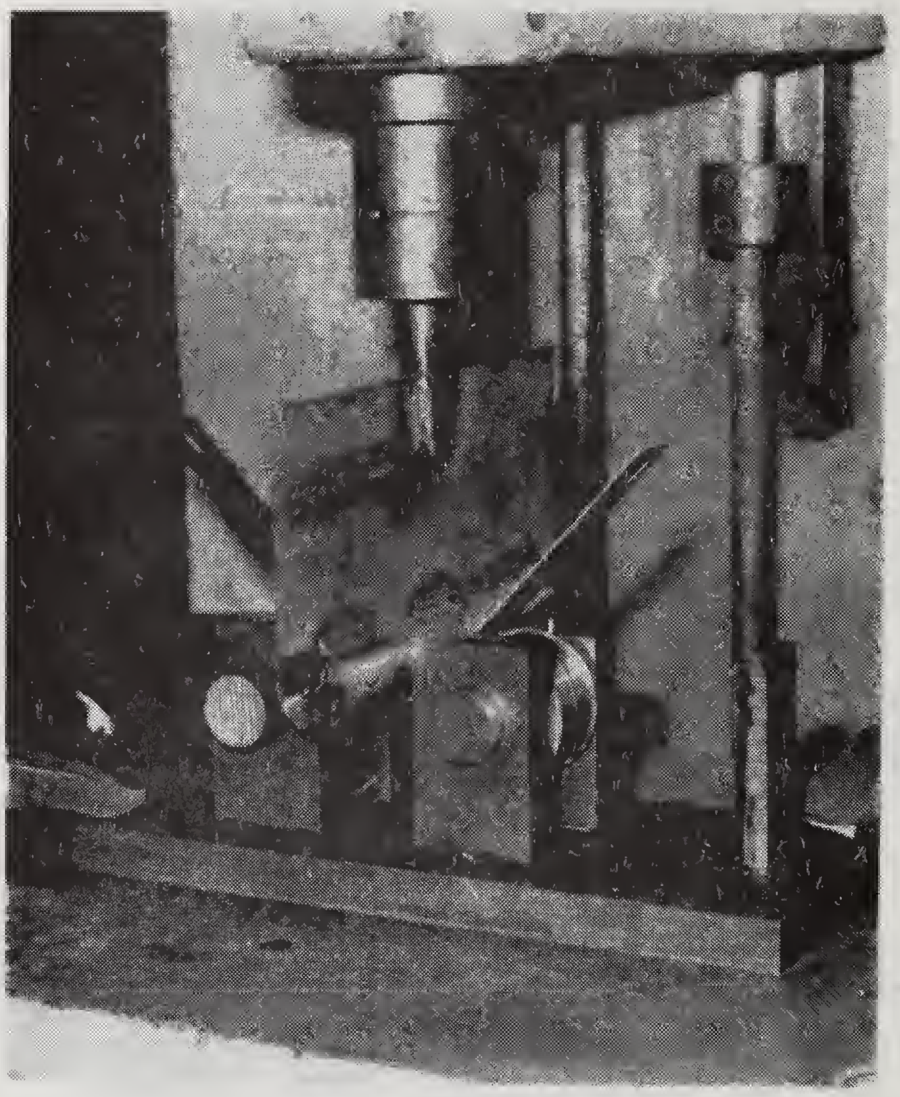


Fig. 2. Die for forming U-bend specimens.

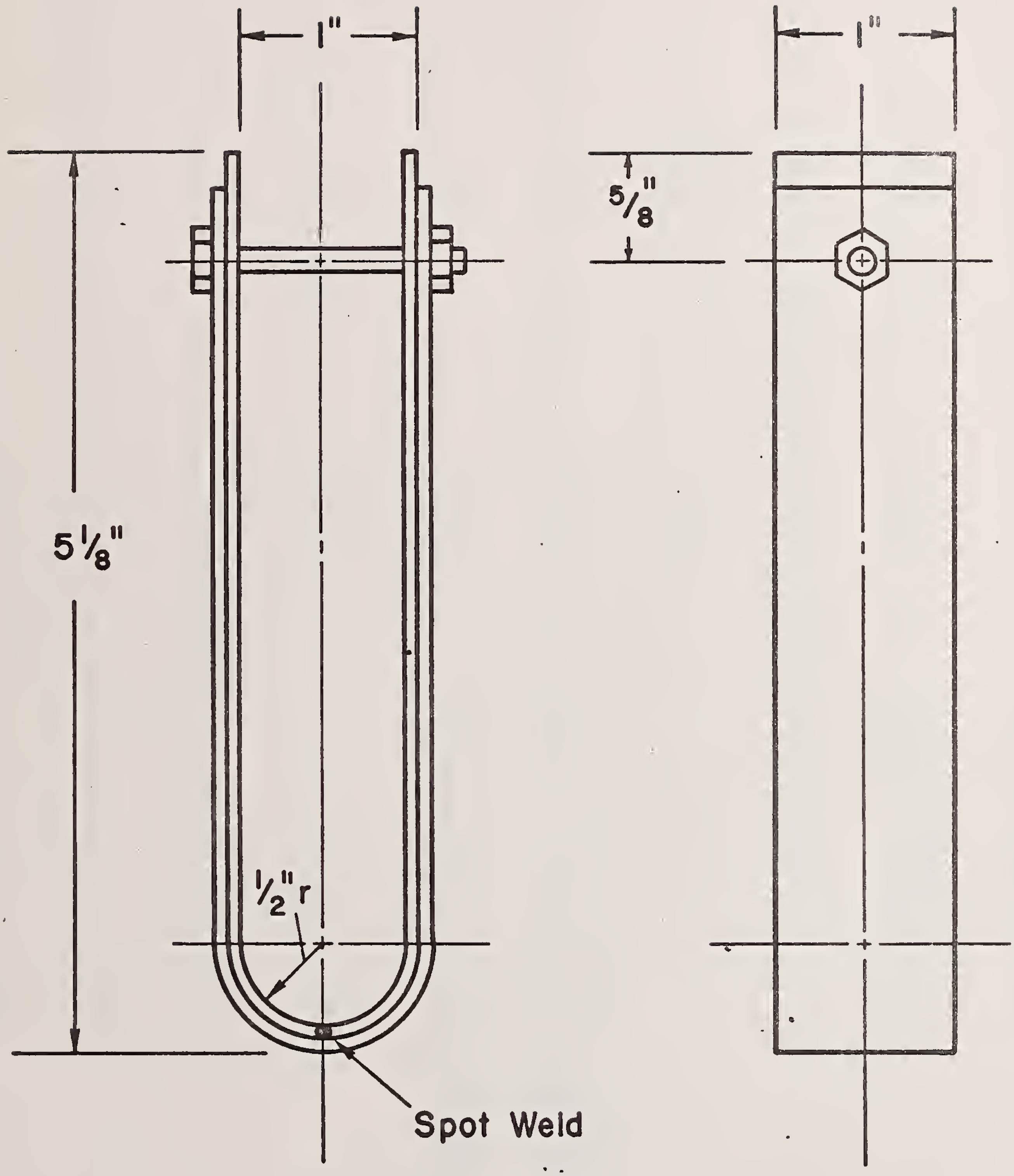


Fig. 3. Double or crevice U-bend specimen for underground exposure.

Figure 4a. Map showing burial order for specimens exposed in 1970 at the various test sites.

First Removal (1 Yr)		Second Removal (2 Yr)		Third Removal (4 Yr)		Fourth Removal (8 Yr)		Fifth Removal (X Yr)	
■	■	■	■	■	■	■	■	■	■
50x01*	50x03*	50x05*	50x07*	50x09*	50x11*	50x13*	50x15*	50x17*	50x19*
51	51	51	51	51	51	51	51	51	51
52	52	52	52	52	52	52	52	52	52
53	53	53	53	53	53	53	53	53	53
54	54	54	54	54	54	54	54	54	54
55	55	55	55	55	55	55	55	55	55
56	56	56	56	56	56	56	56	56	56
57	57	57	57	57	57	57	57	57	57
58	58	58	58	58	58	58	58	58	58
59	59	59	59	59	59	59	59	59	59
60	60	60	60	60	60	60	60	60	60
61	61	61	61	61	61	61	61	61	61
62	62	62	62	62	62	62	62	62	62
63	63	63	63	63	63	63	63	63	63
64	64	64	64	64	64	64	64	64	64
65	65	65	65	65	65	65	65	65	65
66x01	66x03	66x05	66x07	66x09	66x11	66x13	66x15	66x17	66x19
50x02	50x04	50x06	50x08	50x10	50x12	50x14	50x16	50x18	50x20
51	51	51	51	51	51	51	51	51	51
52	52	52	52	52	52	52	52	52	52
53	53	53	53	53	53	53	53	53	53
54	54	54	54	54	54	54	54	54	54
55	55	55	55	55	55	55	55	55	55
56	56	56	56	56	56	56	56	56	56
57	57	57	57	57	57	57	57	57	57
58	58	58	58	58	58	58	58	58	58
59	59	59	59	59	59	59	59	59	59
60	60	60	60	60	60	60	60	60	60
61	61	61	61	61	61	61	61	61	61
62	62	62	62	62	62	62	62	62	62
63	63	63	63	63	63	63	63	63	63
64	64	64	64	64	64	64	64	64	64
65	65	65	65	65	65	65	65	65	65
66x02	66x04	66x06	66x08	66x10	66x12	66x14	66x16	66x18	66x20
■	■	■	■	■	■	■	■	■	■
67x02	67x04	67x06	67x08	68x10	68x12	67x14	67x16	68x18	68x20
68	68	68	68	69	69	68	68	69	69
69	69	69	69	71	71	69	69	71	71
70	70	70	70	73	73	70	70	73	73
71	71	71	71	74	74	71	71	74	74
72	72	72	72	75	75	72	72	75	75
73	73	73	73	76	76	73	73	76	76
74	74	74	74	78	78	74	74	78	78
75	75	75	75	79	79	75	75	79	79
76	76	76	76	81x10	81x12	76	76	81x18	81x20
77	77	77	77	67x10	67x12	77	77	67x18	67x20
78	78	78	78	70x10	70x12	78	78	70x18	70x20
79	79	79	79	72x10	72x12	79	79	72x18	72x20
80	80	80	80	77x10	77x12	80	80	77x18	77x20
81	81	81	81	80x10	80x12	81	81	80x18	80x20
82	82	82	82	82x10	82x12	91	91	91x18	91x20
83	83	83	83	83x10	83x12	92x14	92x16	92x18	92x20
84	84	84	84	84x10	84x12	■	■		
85	85	85	85	85x10	85x12				
86	86	86	86	86x10	86x12				
87	87	87	87	87x10	87x12				
88	88	88	88	88x10	88x12				
89	89	89	89	89x10	89x12				
90	90	90	90	90x10	90x12				
91	91	91	91	91x10	91x12				
92x02	92x04	92x06	92x08	92x10	92x12				
■	■	■	■						

■ 4"x4" Post

——► ■ Wire terminal to post for electrical measurements

═══► ■ Wire terminals (galvanic couple) to post for electrical measurements.

*Specimen identification: Digits preceding "x" denote system number (see Table 2) "x" represents site designation. Would be A, B, C, D, E or G depending upon where specimen was exposed. Digits following "x" are specimen numbers.

Figure 4b. Map showing burial order for specimens exposed in 1971 at the various sites.

First Removal (1 yr)		Second Removal (2 yr)		Third Removal (4 yr)		Fourth Removal (8 yr)		Fifth Removal (X yr)	
1x01*	1x03*	1x05*	1x07*	1x09*	1x11*	1x13*	1x15*	1x17*	1x19*
2x	2x	2x	2x	2x	2x	2x	2x	2x	2x
3x	3x	3x	3x	3x	3x	3x	3x	3x	3x
4x	4x	4x	4x	4x	4x	4x	4x	4x	4x
5x	5x	5x	5x	5x	5x	5x	5x	5x	5x
6x	6x	6x	6x	6x	6x	6x	6x	6x	6x
8x	8x	8x	8x	8x	8x	8x	8x	8x	8x
9x	9x	9x	9x	9x	9x	9x	9x	9x	9x
10x	10x	10x	10x	10x	10x	10x	10x	10x	10x
14x	14x	14x	14x	14x	14x	14x	14x	14x	14x
15x	15x	15x	15x	15x	15x	15x	15x	15x	15x
16x	16x	16x	16x	16x	16x	16x	16x	16x	16x
17x	17x	17x	17x	17x	17x	17x	17x	17x	17x
18x	18x	18x	18x	18x	18x	18x	18x	18x	18x
19x01	19x03	19x05	19x07	19x09	19x11	19x13	19x15	19x17	19x19
1x02	1x04	1x06	1x08	1x10	1x12	1x14	1x16	1x18	1x20
2x	2x	2x	2x	2x	2x	2x	2x	2x	2x
3x	3x	3x	3x	3x	3x	3x	3x	3x	3x
4x	4x	4x	4x	4x	4x	4x	4x	4x	4x
5x	5x	5x	5x	5x	5x	5x	5x	5x	5x
6x	6x	6x	6x	6x	6x	6x	6x	6x	6x
8x	8x	8x	8x	8x	8x	8x	8x	8x	8x
9x	9x	9x	9x	9x	9x	9x	9x	9x	9x
10x	10x	10x	10x	10x	10x	10x	10x	10x	10x
14x	14x	14x	14x	14x	14x	14x	14x	14x	14x
15x	15x	15x	15x	15x	15x	15x	15x	15x	15x
16x	16x	16x	16x	16x	16x	16x	16x	16x	16x
17x	17x	17x	17x	17x	17x	17x	17x	17x	17x
18x	18x	18x	18x	18x	18x	18x	18x	18x	18x
19x02	19x04	19x06	19x08	19x10	19x12	19x14	19x16	19x18	19x20
20x02	20x04	20x06	20x08	20x10	20x12	20x14	20x16	20x18	20x20
21x	21x	21x	21x	22x	22x	21x	21x	22x	22x
22x	22x	22x	22x	24x	24x	22x	22x	24x	24x
23x	23x	23x	23x	25x	25x	23x	23x	25x	25x
24x	24x	24x	24x	27x	27x	24x	24x	27x	27x
25x	25x	25x	25x	21x	21x	25x	25x	21x	21x
26x	26x	26x	26x	23x10	23x12	26x	26x	23x18	23x20
27x	27x	27x	27x			27x	27x		
28x	28x	28x	28x			28x	28x		
30x	30x	30x	30x			30x	30x		
33x	33x	33x	33x			42x	42x		
34x	34x	24x	34x	26x10	26x12	43x	43x	26x18	26x20
35x	35x	35x	35x	28x	28x	44x	44x	28x	28x
36x	36x	36x	36x	30x	30x	45x14	45x16	30x	30x
37x	37x	37x	37x	33x10	33x12			42x18	42x20
38x	38x	38x	38x						
42x	42x	42x	42x						
				34x10	34x12				
				35x	35x				
				36x	36x				
				37x	37x				
				38x10	38x12				
				42x	42x				

■ 4"x4" post

→■ Wire terminal to post for electrical measurements

⇒■ Wire terminals (galvanic couple) to post for electrical measurements.

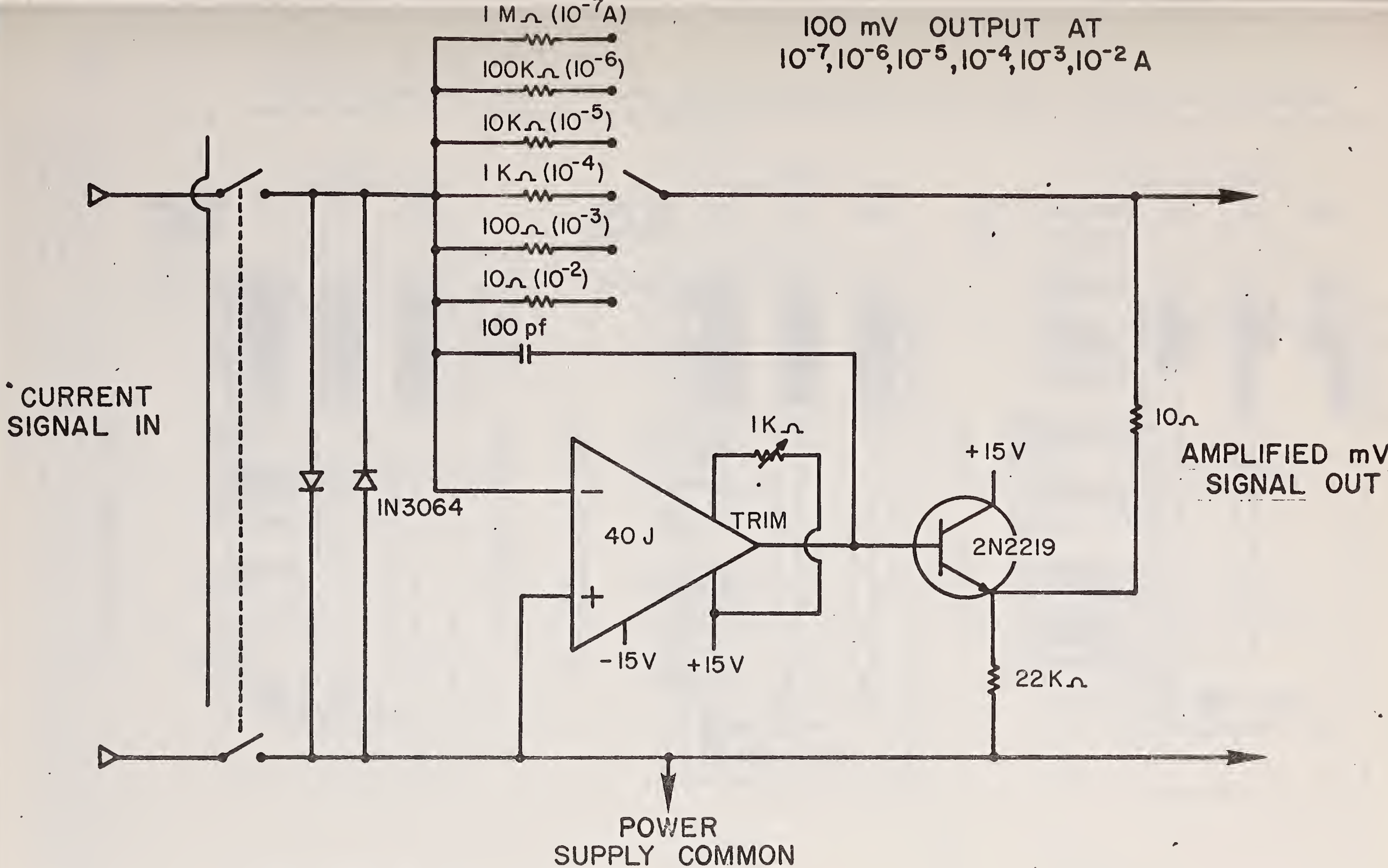
*Specimen identification: Digits preceding "x" denote system number (see Table 2) "x" represents site designation. Would be A, B, C, D, E or G depending upon where specimen was exposed. Digits following "x" are specimen numbers.

Figure 4c. Map Showing Burial Order for Specimens Exposed in 1972 at the Various Sites.

First Removal (1 Yr)		Second Removal (2 Yr)		Third Removal (4 Yr)		Fourth Removal (8 Yr)		Fifth Removal (X Yr)	
7x01*	7x03*	7x05*	7x07*	7x09*	7x11*	7x13*	7x15*	7x17*	7x19*
11	11	11	11	11	11	11	11	11	11
12	12	12	12	12	12	12	12	12	12
7x02	7x04	7x06	7x08	7x10	7x12	7x14	7x16	7x18	7x20
11	11	11	11	11	11	11	11	11	11
12	12	12	12	12	12	12	12	12	12

■ - 4"x4" post

*Specimen identification:
Digits preceding "x" denote system number (See Table 2) "x" represents site designation. Would be A, B, C, D, E, or G depending upon where specimen was exposed. Digits following "x" are specimen numbers.



Suggested by R.J. Carpenter
Electronics Instrumentation Section, NBS

Fig. 5. Solid state zero resistance amplifier.

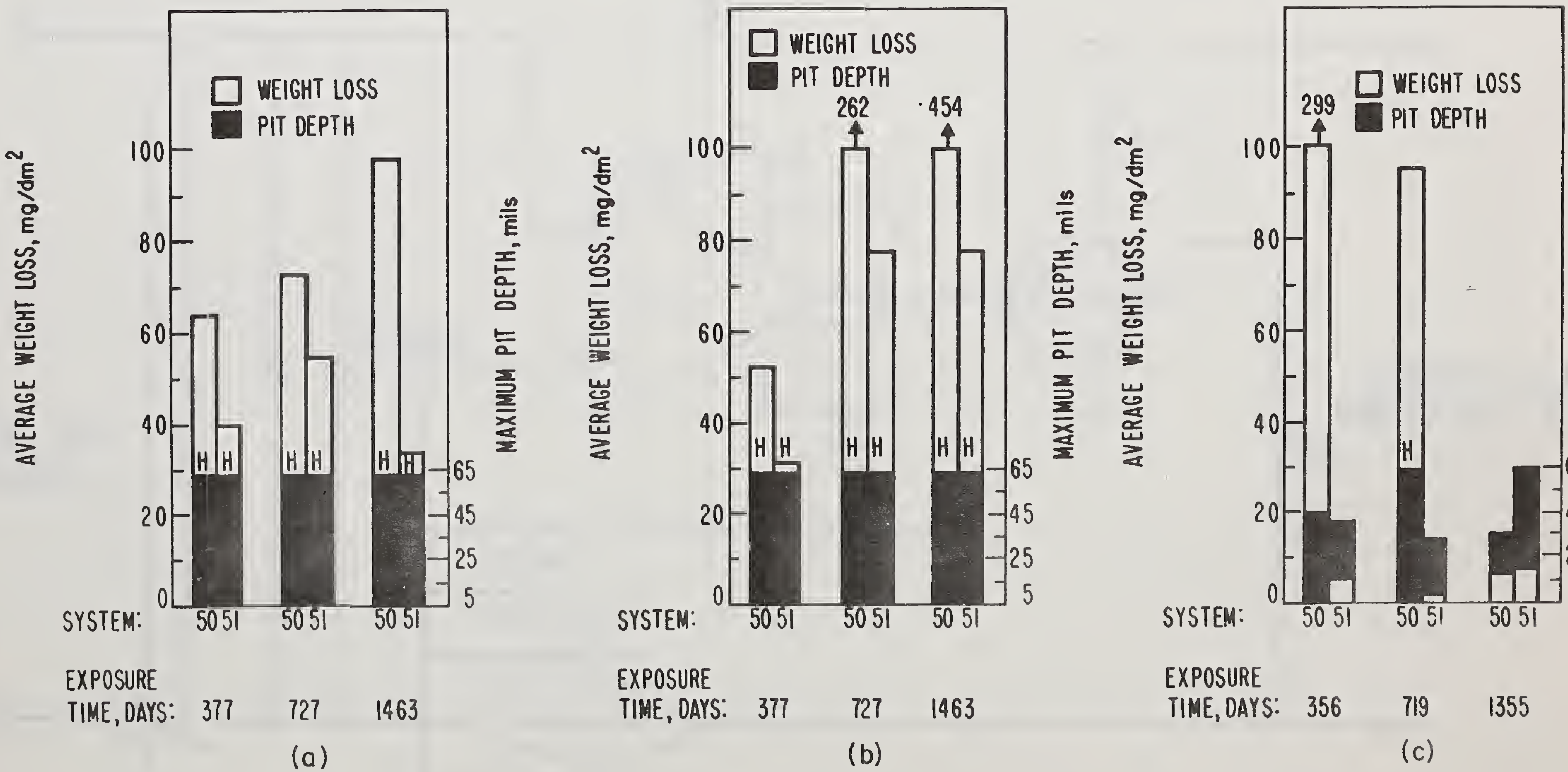


Fig. 6. Average weight loss (mg/dm^2) and maximum pit depth (mils) for AISI 200 series stainless steels after exposure in various soils. See Table 2 for descriptions of the systems. H denotes perforation.

(a) Site C; (b) Site E; (c) Site G

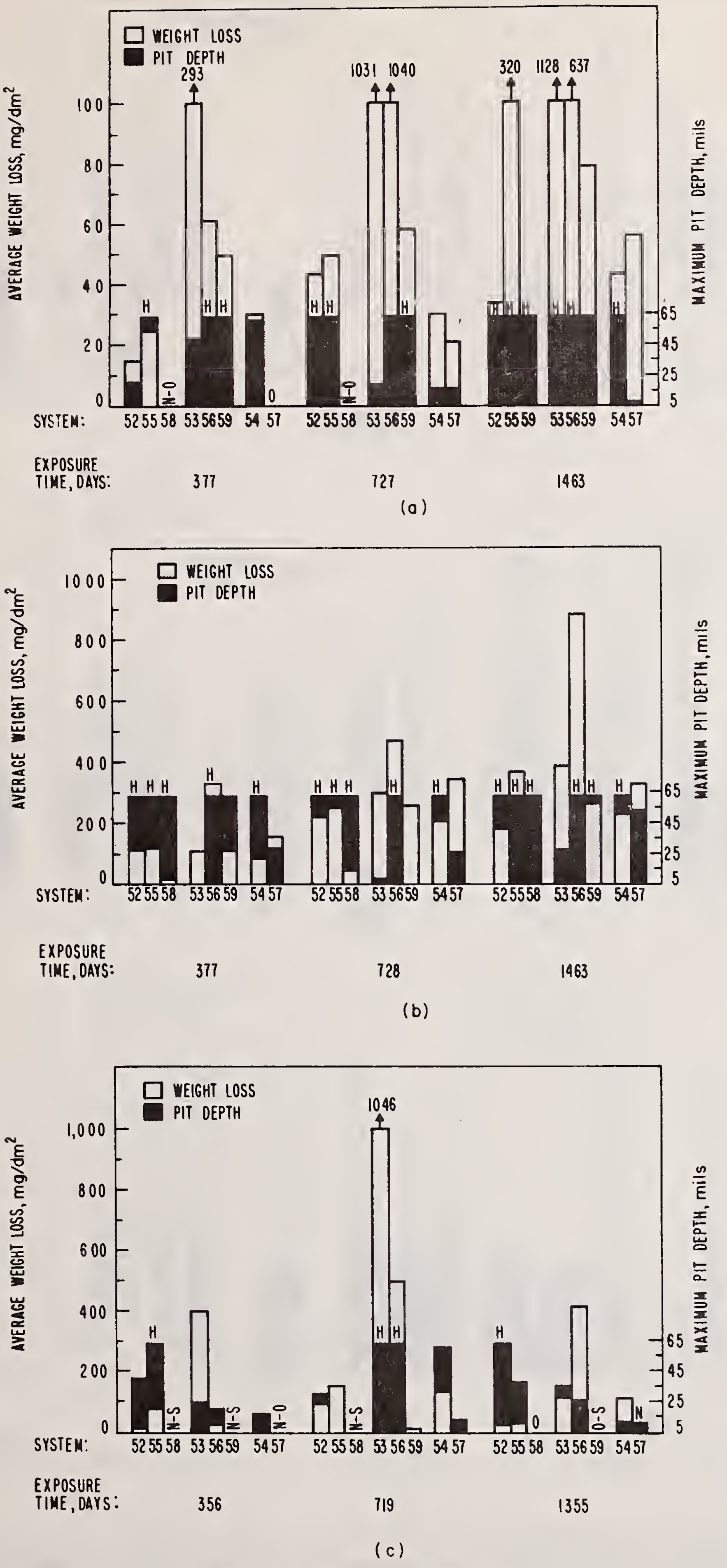


Fig. 7. Average weight loss (mg/dm^2) and maximum pit depth (mils) for AISI 300 series stainless steels after exposure in various soils. See Table 2 for descriptions of the systems. O-none, N-<1 mg/dm^2, H-perforated and T-tunneling.

(a) Site C; (b) Site E; (c) Site G

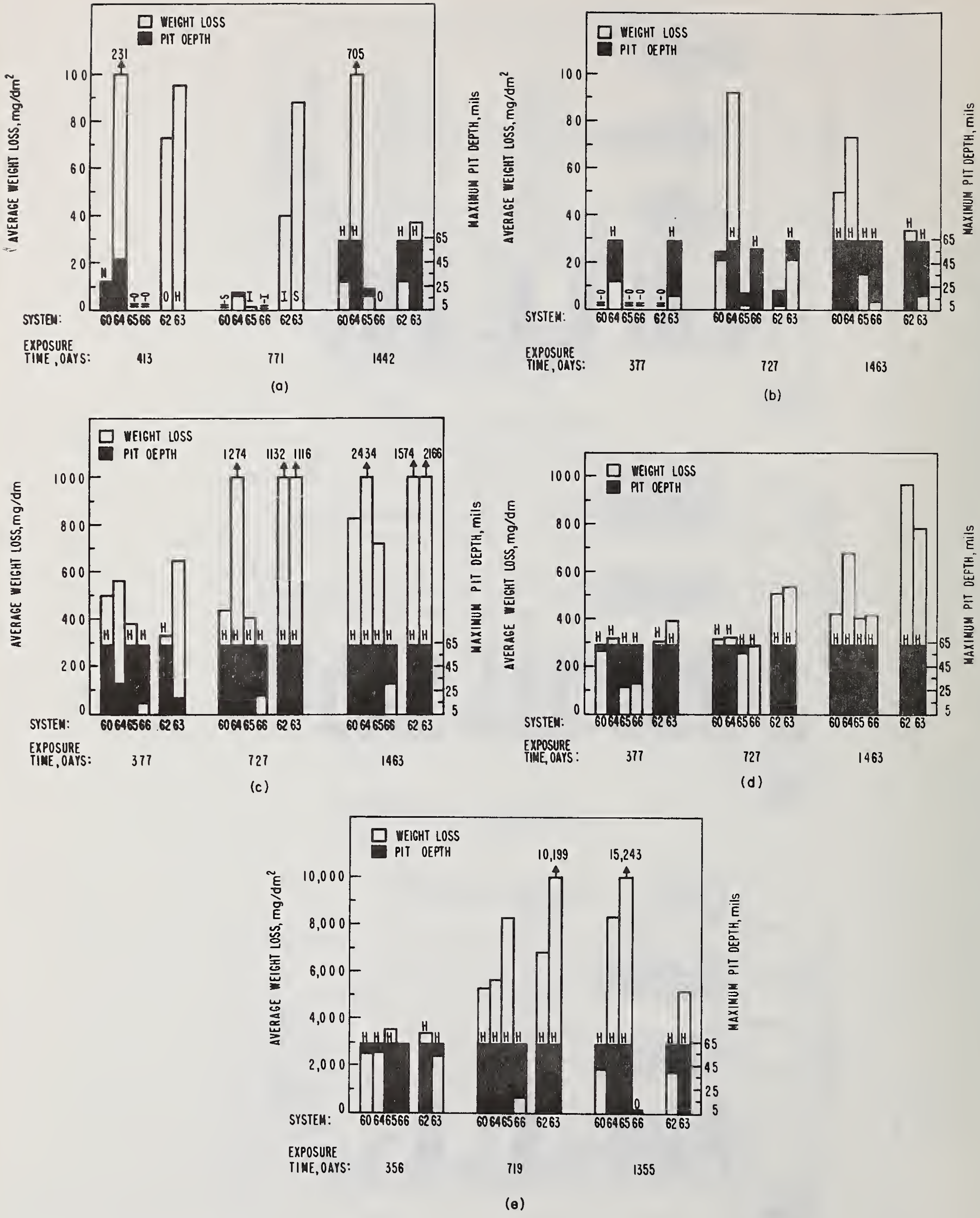


Fig. 8. Average weight loss (mg/dm^2) and maximum pit depth (mils) for AISI 400 series stainless steels after exposure in various soils. See Table 2 for description of the systems. O-none, N-<5 mg/dm^2, I-incipient pitting, S-<5 mils and H-perforated.

(a) Site A; (b) Site C; (c) Site D; (d) Site E; (e) Site G

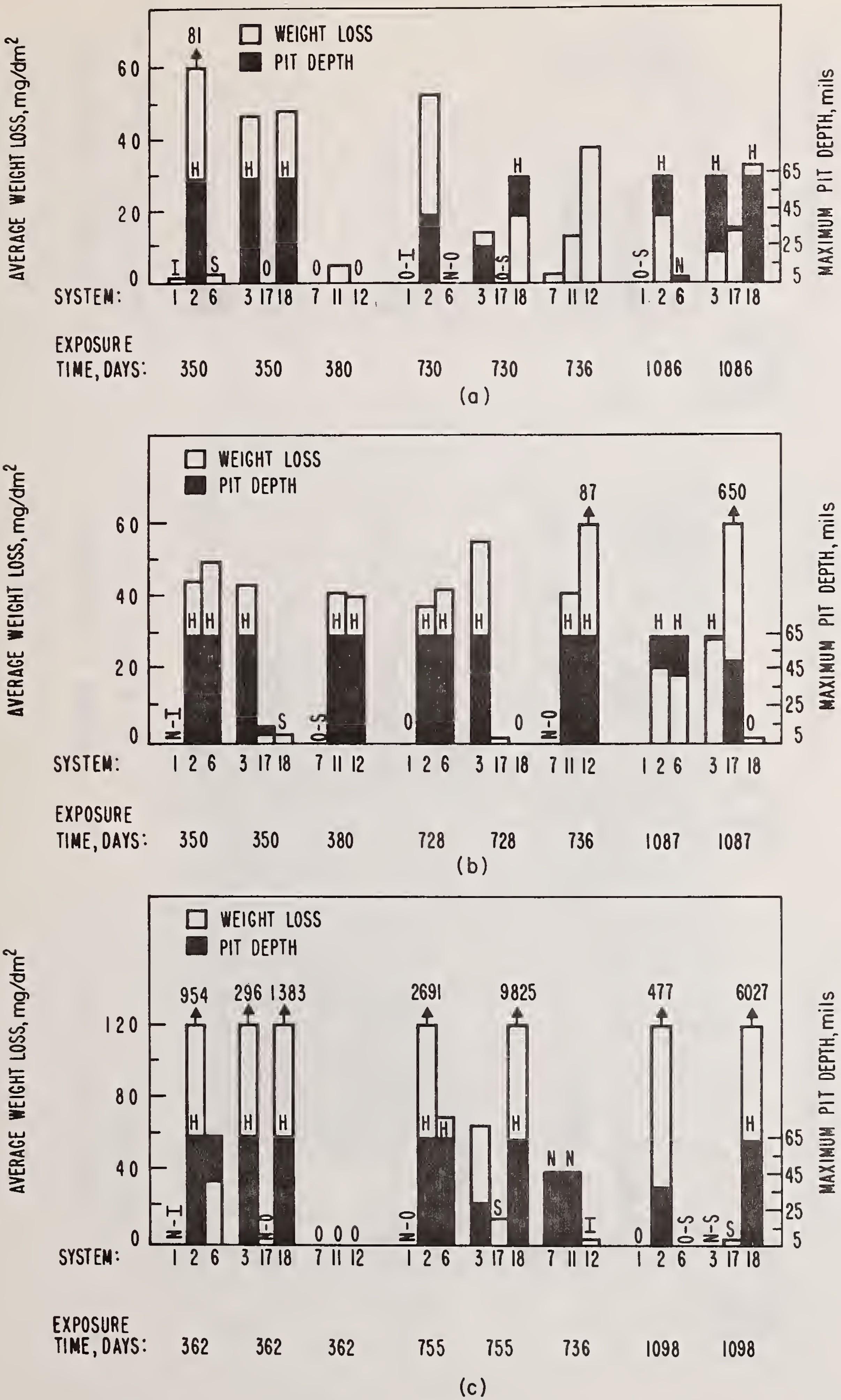


Fig. 9. Average weight loss (mg/dm^2) and maximum pit depth (mils) for Fe-Cr proprietary stainless steels after exposure in various soils. See Table 2 for description of the systems. O-none, N-<5 mg/dm^2, I-incipient pitting, S-<5 mils and H-perforated.

(a) Site C; (b) Site E; (c) Site G

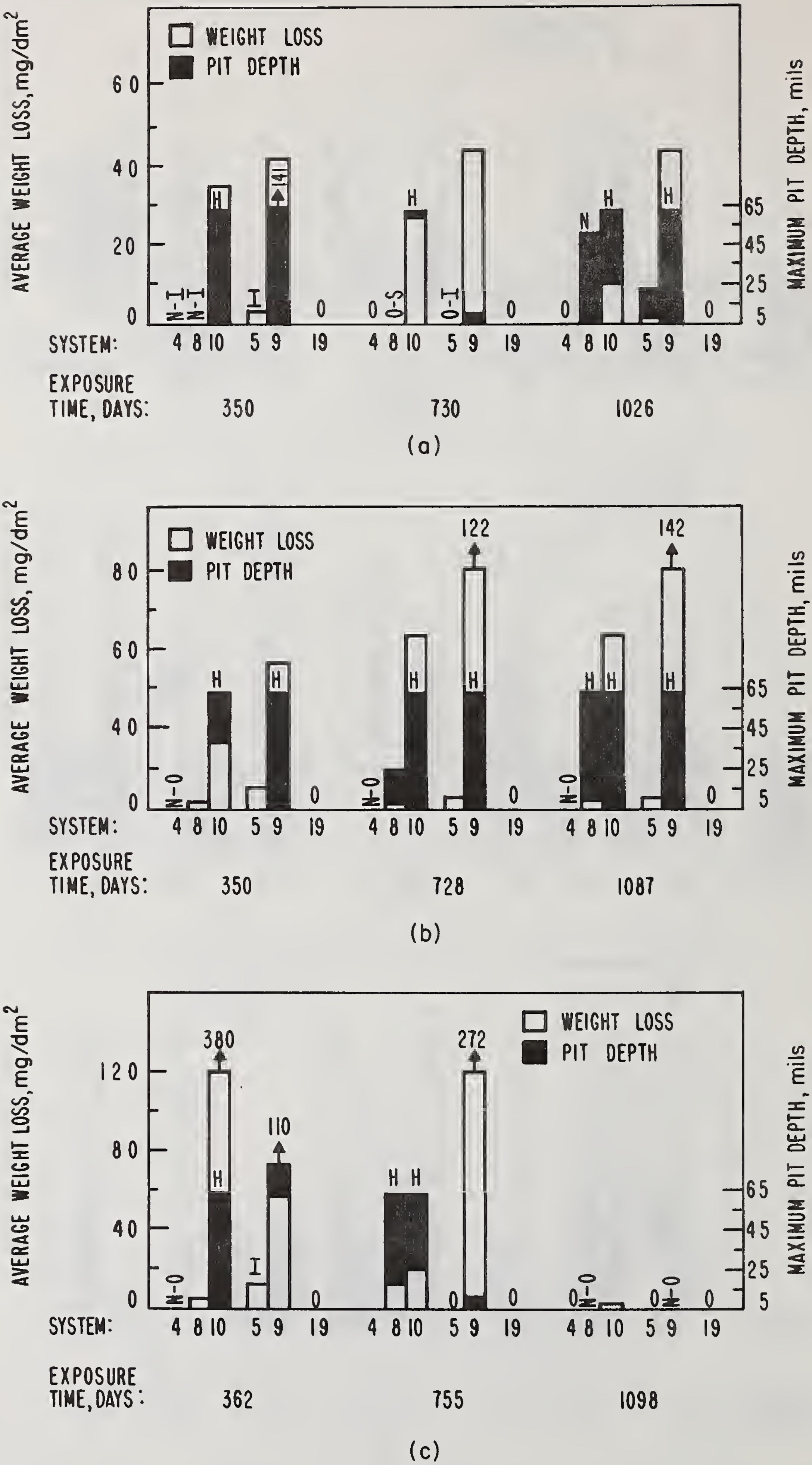


Fig. 10. Average weight loss (mg/dm^2) and maximum pit depth (mils) for Fe-Cr-Ni proprietary stainless steels after exposure in various soils. See Table 2 for description of the systems. 0-none, N-<5 mg/dm^2, I-incipient pitting, S-<5 mils and H-perforated.

(a) Site C; (b) Site E; (c) Site G

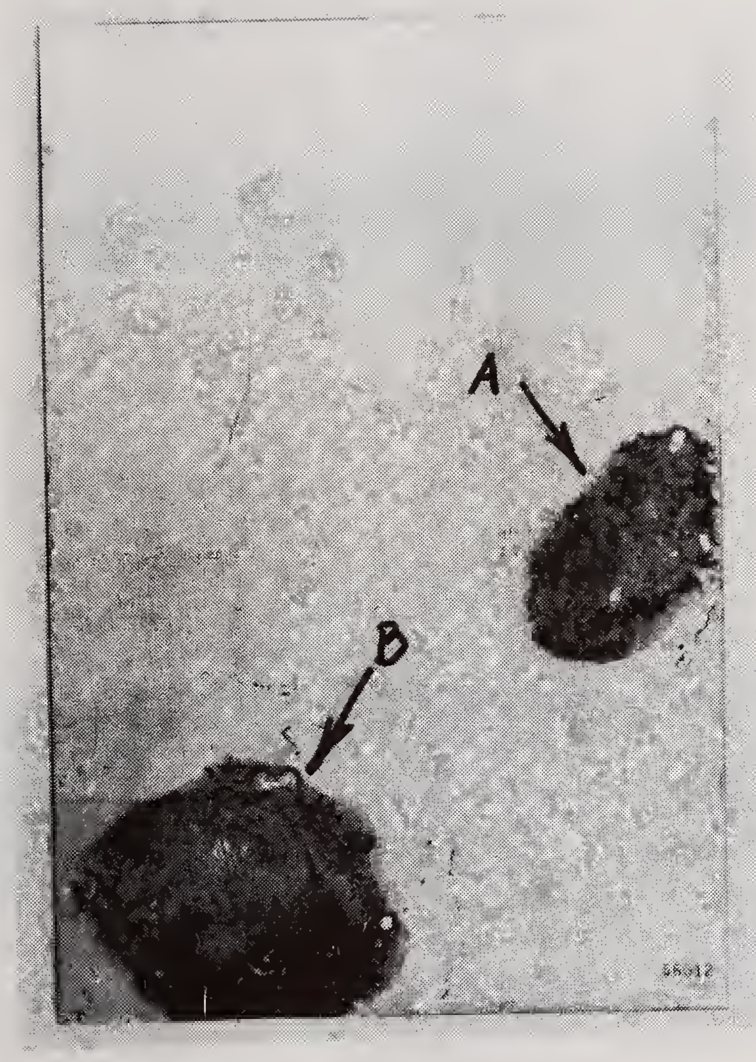


Fig. 11 Sensitized Type 304 stainless steel buried for approximately 4 years at Site G. Note severe etching and nonuniform attack at areas A and B. x0.375

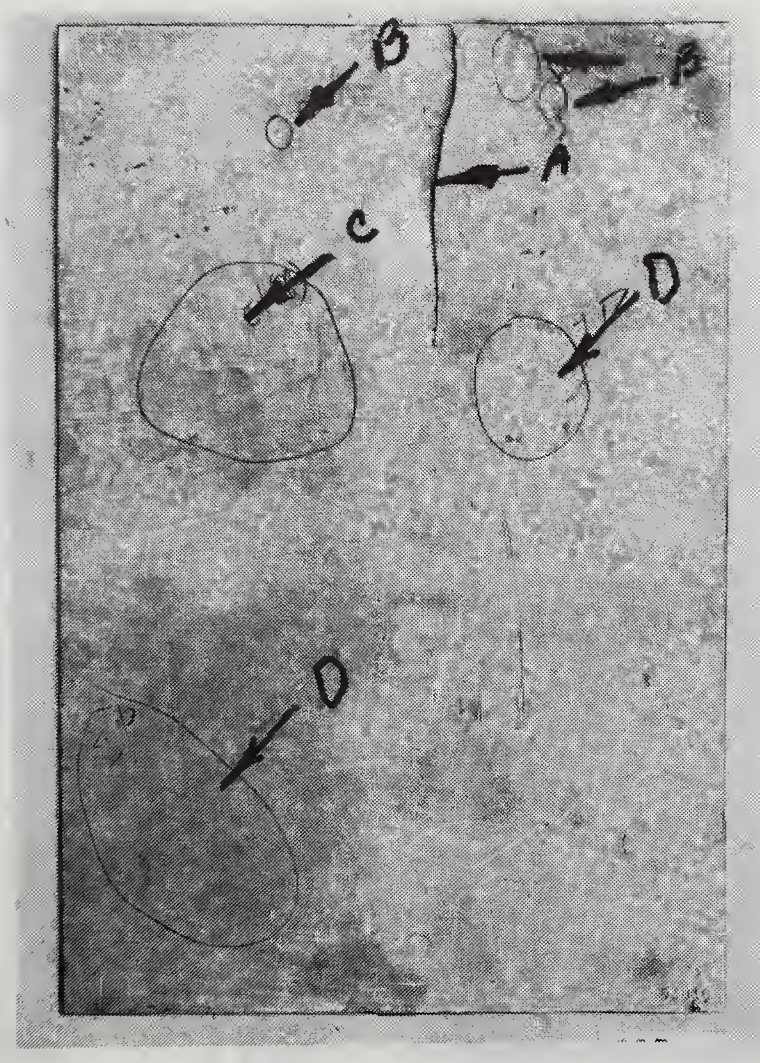


Fig. 12 Sensitized Type 301 stainless steel after exposure for approximately 4 years at Site D. Arrow A denotes crack. Areas exhibiting small blister-like eruptions are noted at arrow B. An area exhibiting slight etching is shown at arrow C, while areas where incipient pitting was observed is shown at arrow D. X 0.375.

Fig. 13 Type 301 stainless steel with cross-bead weld after exposure for 4 years at Site G. With the exception of the dark areas on the left side which are gray stains, this specimen was relatively unaffected by corrosion. X 0.375.

Fig. 14 Type 304 stainless steel after exposure for approximately 4 years at Site C. Upper right corner, arrow A was severely attacked. Areas shown at arrows B are light gray stains mixed with slight surface corrosion (etching). X 0.375.

Fig. 15 Sensitized Type 304 stainless steel buried for approximately 4 years at Site E. Dark areas at top are rust stains. Vertical stringers at the top of the specimen are areas where tunneling corrosion was observed. X 0.375.

Fig. 16. Type 409 stainless steel after exposure for 4 years at Site G. Note severe general corrosion in upper half of specimen. X 0.375.

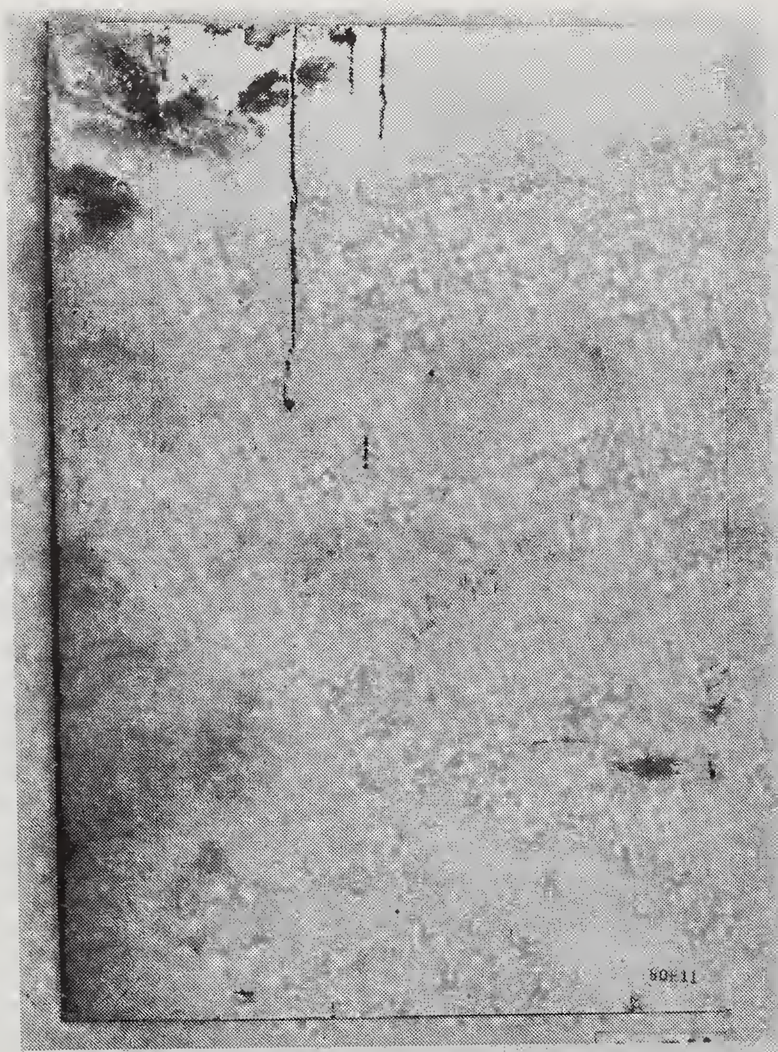


Fig. 17. Type 409 stainless steel after exposure for 4 years at Site E showing tunneling corrosion (vertical stringers) and scattered localized pitting corrosion. X 0.375.

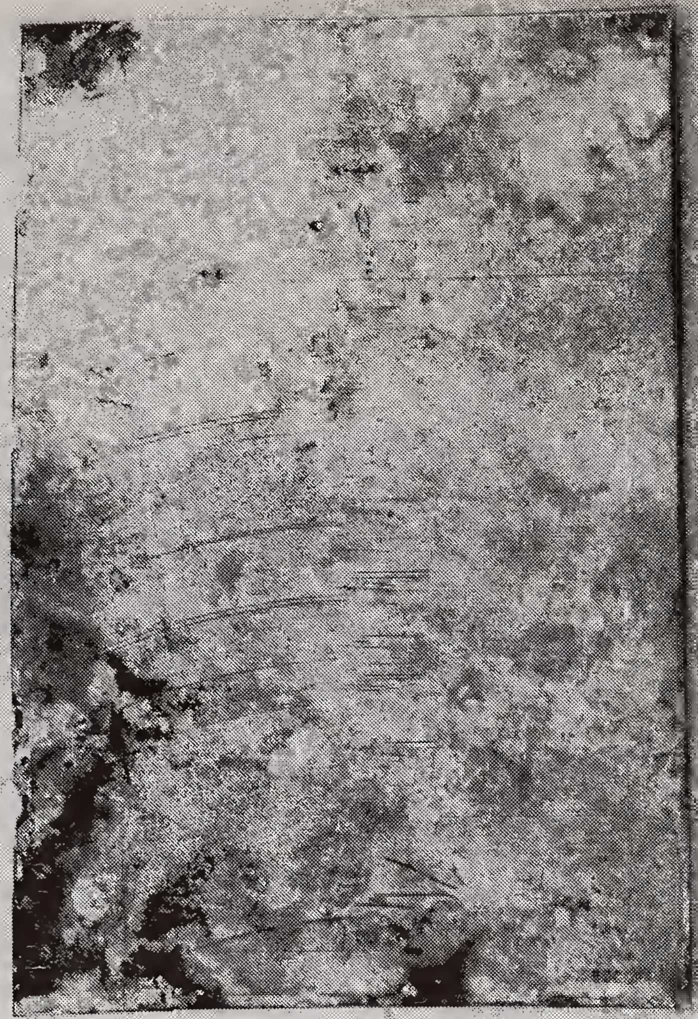


Fig. 18. Type 409 stainless steel exposed for approximately 4 years at Site C. There was slight general attack over much of the surface with localized pitting corrosion and subsequent perforation of the specimen due to pitting corrosion. X 0.375.

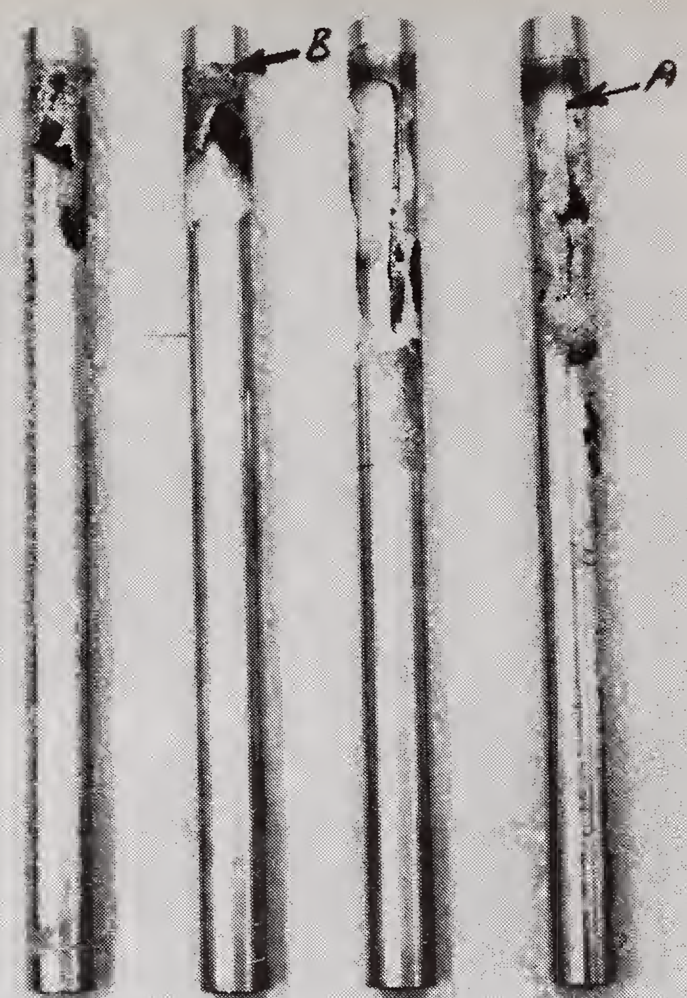


Fig. 19. Type 409 stainless tube with a high-frequency welded seam after exposure for 4 years at Site G. Note corrosion at weld seam, arrow A and crevice corrosion at arrow B. All specimens were perforated due to corrosion. X 0.375.

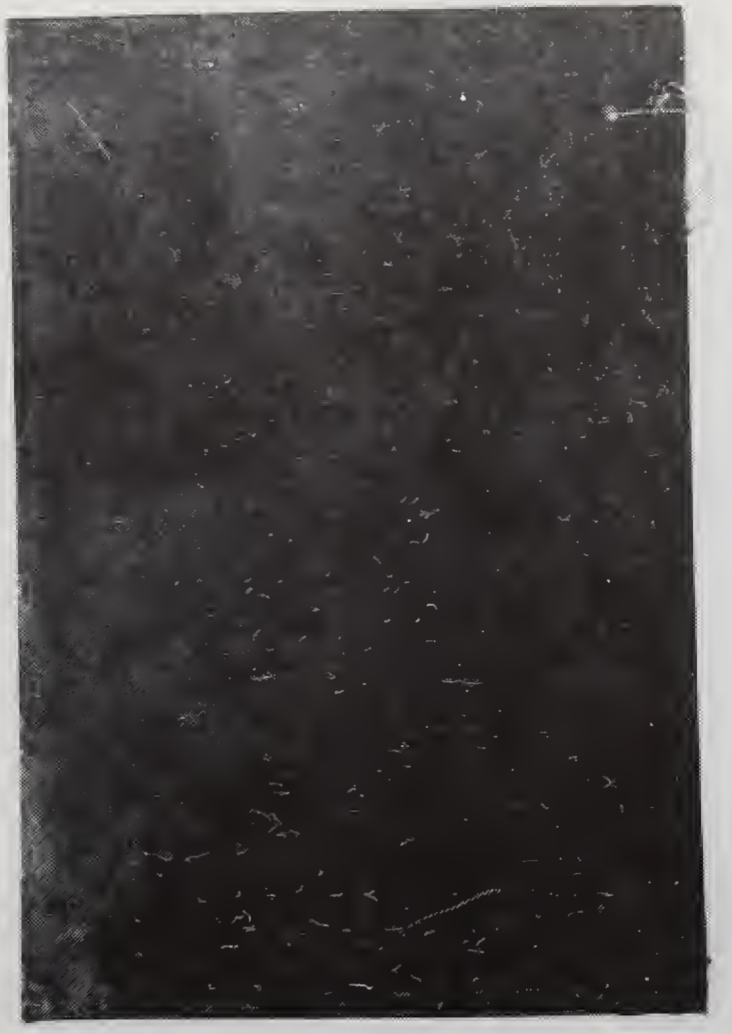


Fig. 20. Coal-tar epoxy coated Type 409 stainless steel after exposure for approximately 4 years at Site G. Dark areas within scribed X are rust stains, whereas lighter areas were unaffected by corrosion. X 0.375

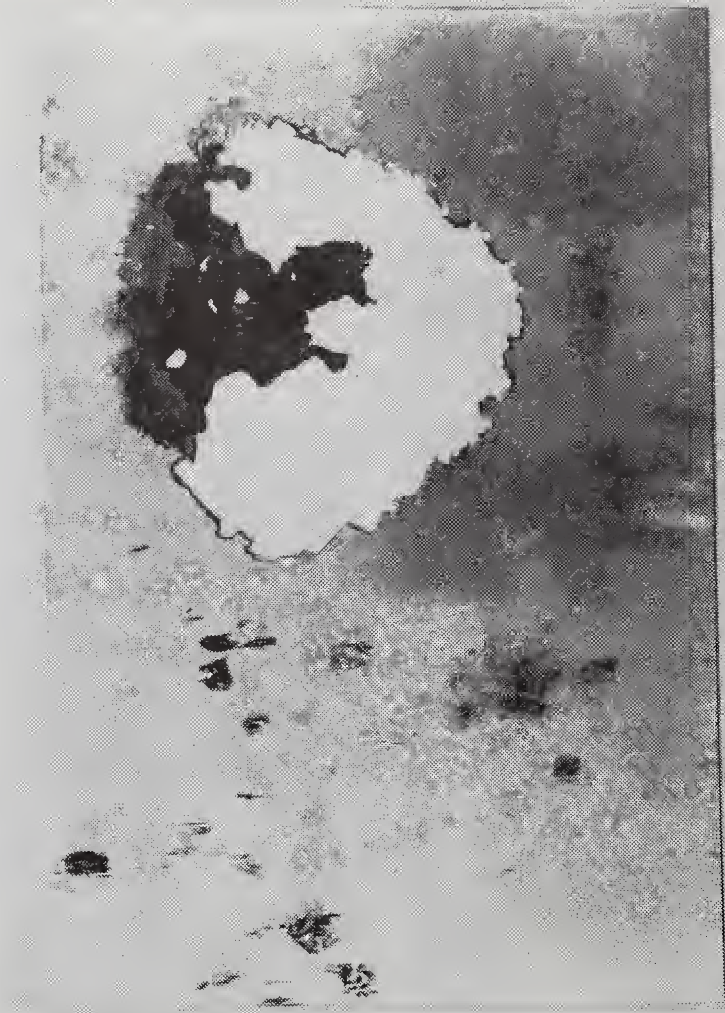


Fig. 21. Type 410 stainless after burial for approximately 4 years at Site G. Note severe localized corrosion with subsequent perforation of the material at area towards center of the specimen. The luster of the remaining original surface is shown by the reflection of the camera on the surface to the right of the corroded area. X 0.375

Fig. 22. Type 430 stainless steel buried for 4 years at Site G. Note severe corrosion has resulted in the dissipation of over 1/4 of the specimen while most of the remainder retains the original luster. X 0.375

Fig. 23. Companion specimen of that shown in Fig. 20. Note slight etching at localized areas (light gray areas) and severe localized pitting corrosion within dark area at lower left. X 0.375

Table 1. Properties of soils at test sites.

Site Iden	Soil	Location	Internal Drainage of Test Site	Resistivity[a] (ohm - cm)	Composition of Water Extract (Parts per Million)									
					pH	TDS[b]	Ca	Mg	Na + K as Na	CO_3	HCO_3	SO_4	Cl	NO_3
A	Sagemoor sandy loam	Toppenish, Wash.	Good	400	8.8	7,080	108	23	1,960	0.0	5,002	216	330	6
B	Hagerstown loam	Loch Raven, Md.	Good	12,600-34,760	5.3	(c)	-	-	-	-	-	-	-	-
C	Clay	Cape May, N.J.	Poor	400-1,150	4.3	14,640	540	754	2,242	0.0	0.0	6,768	3,529	118
D	Lakewood sand	Wildwood, N.J.	Good	13,800-57,500	5.7	(c)	-	-	-	-	-	-	-	-
E	Coastal sand	Wildwood, N.J.	Poor	1,320-49,500	7.1	11,020	302	329	3,230	0.0	55	1,133	5,765	31
G	Tidal marsh	Patuxent, Md.	Poor	400-15,500	6.0	11,580	140	165	2,392	0.0	0.0	1,709	3,259	37
						(Milligram equivalents per 100 grams of soil)								
A	-	-	-	-	-	-	0.54	0.19	8.50	0.0	8.20	0.45	0.93	0.01
B	-	-	-	-	-	(c)	-	-	-	-	-	-	-	-
C	-	-	-	-	-	-	2.70	6.18	9.51	0.0	0.0	14.0	9.94	0.19
D	-	-	-	-	-	(c)	-	-	-	-	-	-	-	-
E	-	-	-	-	-	-	1.51	2.70	13.9	0.0	0.09	2.36	16.2	0.05
G	-	-	-	-	-	-	0.70	1.35	10.2	0.0	0.0	3.56	9.18	0.06

(a) Resistivity determinations made at the test site by Wenner's 4-pin method [5] except for Site A where Shepard's cane [6] was used.

(b) TDS, total dissolved solids - residue dried at 105°C.

(c) Analysis not made for soils at Sites B and D because of the very low concentration of soluble salts in these soils.

Table 2. Stainless steel systems in underground corrosion tests

System	Burial Year	Stainless Steel	Spec. Config. & Size[a]	Treatment[b]	Passivation[c] Procedure	Stressed[d]	Spec. Coupled To
1	1971	26 Cr-1 Mo	Sheet (8"x12")	--	I	--	--
2	"	18 Cr (Ti)	" "	--	I	--	--
3	"	"	" "	XBW	I	--	--
4	"	20 Cr-24 Ni-6.5 Mo	" "	--	I	--	--
5	"	"	" "	S	I	--	--
6	"	18 Cr-2 Mo	" "	--	I	--	--
7	1972	18 Cr-2 Mo (Nb)	" "	--	I	--	--
8	1971	18 Cr-8 Ni(N)	" "	--	I	--	--
9	"	"	" "	XBW	I	--	--
10	"	26 Cr-6.5 Ni	" "	--	I	--	--
11	1972	18 Cr-2 Mo (Nb)	" "	XBW	I	--	--
12	"	"	Tube (2" ODx12")	HW	I	--	--
14	1971	Composite A	Sheet (8"x12")	--	--	--	--
15	"	Composite B	" "	--	--	--	--
16	"	Composite C	" "	--	--	--	--
17	"	26 Cr-1 Mo	Tube (2" ODx12")	HW	I	--	--
18	"	18 Cr (Ti)	(1 1/8" ODx12")	HW	I	--	--
19	"	20 Cr-24 Ni-6.5 Mo	(7/8" ODx12")	HW	I	--	--
20	"	26 Cr-1 Mo	Sheet (1"x12")	--	I	(UU)	--
21	"	"	" "	--	I	U	--
22	"	20 Cr-24 Ni-6.5 Mo	" "	--	I	(UU)	--
23	"	"	" "	--	I	U	--
24	"	"	" "	S	I	UU	--
25	"	18Cr-2Mo	" "	--	I	(UU)	--
26	"	"	" "	--	I	U	--
27	"	18 Cr-8 Ni(N)	" "	--	I	(UU)	--
28	"	"	" "	--	I	U	--
30	"	26 Cr-6.5 Ni	" "	--	I	U	--
33	"	26 Cr-1 Mo	" "	--	I	U	Zn
34	"	"	" "	--	I	U	Mg
35	"	"	" "	--	I	U	Fe
36	"	26 Cr-6.5 Ni	" "	--	I	U	Zn
37	"	"	" "	--	I	U	Mg
38	"	"	" "	--	I	U	Fe
42	"	"	" "	--	I	--	Cu
50	1970	201	Sheet (8"x12")	--	I	--	--
51	"	202	" "	--	I	--	--
52	"	301	" "	--	I	--	--
53	"	"	" "	S	I(f)	--	--
54	"	"	" "	XBW	I	--	--
55	"	304	" "	--	I	--	--
56	"	"	" "	S	I(f)	--	--
57	"	"	Tube (2" ODx12")	HW[e]	I	--	--
58	"	316	Sheet (8"x12")	--	I	--	--
59	"	"	" "	S	I	--	--
60	"	409	" "	--	III	--	--
61	"	"	" "	C	--	--	--
62	"	"	Tube (1-1/8" ODx12")	HW	III	--	--
63	"	"	Tube (7/8" ODx12")	HFW	III	--	--
64	"	410	Sheet (8"x12")	--	III	--	--
65	"	430	" "	--	II	--	--
66	"	434	" "	--	I	--	--
67	"	301	Sheet (1"x12")	HH	I	U	--
68	"	"	" "	HH	I	(UU)	--
69	"	"	" "	HH+S	I(f)	UU	--
70	"	"	" "	FH	I	U	--
71	"	"	" "	FH	I	(UU)	--
72	"	304	" "	--	I	U	--
73	"	"	" "	--	I	(UU)	--
74	"	"	" "	HH	I	U	--
75	"	"	" "	HH	I	(UU)	--
76	"	"	" "	S	I(f)	UU	--
77	"	316	" "	--	I	U	--
78	"	"	" "	--	I	(UU)	--
79	"	"	" "	S	I(f)	UU	--
80	"	434	" "	--	I	U	--
81	"	"	" "	--	I	(UU)	--
82	"	301	" "	HH	I	U	Zn
83	"	"	" "	HH	I	U	Mg
84	"	"	" "	HH	I	U	Fe
85	"	"	" "	FH	I	U	Zn
86	"	"	" "	FH	I	U	Mg
87	"	"	" "	FH	I	U	Fe
88	"	304	" "	--	I	U	Zn
89	"	"	" "	--	I	U	Mg
90	"	"	" "	--	I	U	Fe
91	"	"	" "	--	I	--	Cu
92	"	409	" "	--	III	--	Cu

(a) All sheet and tube specimens 0.064" thick.
(b) All specimens in the annealed condition unless noted otherwise.

Key: S - Sensitized (by heating at 1200°F for 2 hours, followed by air cooling and descaling in sodium hydroxide);
XBW - Cross bead weld (specified to be done in accordance with Welding Research Council recommendations. On half of these specimens, the welds were cleaned prior to exposure. The other half of the specimens were to be exposed "as welded".
HW - Heliarc weld.
HFW - High frequency weld;
C - Coated;
HH - Half hard;
FH - Full hard.

(c) Passivation procedure:

I. 20 to 40% by volume of 67% nitric acid at 120-160°F for 20-30 minutes.
II. 20% by volume of 67% nitric acid puls 2-6% sodium dichromate at 110-140°F for 20-30 minutes.
III. 20 to 40% by volume of 67% nitric acid at 110-140°F for 20-30 minutes.

(d) Key:
-- = Unstressed.
U = Single U-bend specimen;
UU = Double U-bend specimen, not spot weld;
(UU)= Double U-bend specimen joined by spot weld.

(e) Welded with a full finish per ASTM Specification A249.

(f) Minimum specified concentration of acid, temperature and time for sensitized materials.

Table 3. Chemical analyses of non-ferrous constituents in stainless steels buried at various NBS underground test sites.

Weight %

Stainless Steel	SYSTEMS	C	Mn	Si	S	P	Cr	Ni	Mo	N	Cu	Ti	OTHERS
Type 201	50	0.066	6.90	0.47	0.009	0.034	16.76	5.10		0.078			
Type 202	51	0.10	8.05	0.41	0.004	0.003	17.50	5.13	0.15	0.15	0.12		
Type 301	52,53,54	0.092	1.1	0.49	0.006	0.015	16.1	7.1					
Type 301	67,68,69,82,83,84	0.10	1.02	0.34	0.016	0.030	17.43	7.14	0.22				Co-0.09
Type 301	70,71,85,86,87	0.13	0.86	0.54	0.013	0.020	16.98	7.23					
Type 304	55,56,72,73,76,88,89,90,91	0.048	1.46	0.50	0.012	0.030	18.2	9.80	0.17	0.042	0.19		
Type 304	57	0.06	0.82	0.68	0.015	0.024	18.45	9.11	0.40		0.25		
Type 304	74,75	0.051	1.0	0.64	0.009	0.022	17.6	9.8	0.15	0.16	0.11		Al<0.01,V-0.026
Type 316	58,59,77,78,79	0.049	1.62	0.53	0.009	0.020	17.48	13.53	2.28		0.11		
Type 409	60,61,92	0.058	0.47	0.57	0.005	0.014	10.75	0.61	0.12		0.37	0.60	Al-0.13
Type 409	62	0.05	0.51	0.44	0.013	0.024	11.22	0.67				0.65	
Type 409	63	0.05	0.41	0.44	0.018	0.022	11.20	0.34				0.55	
Type 410	64	0.14	0.55	0.14	0.014	0.016	12.53						
Type 430	65	0.060	0.46	0.50	0.010	0.017	16.67						
Type 434	66,80,81	0.076	0.42	0.43	0.011	0.017	18.2	0.32	0.76	0.046	0.05		Al-0.046,V-0.025
26Cr-1Mo	1,17,20,21,33,34,35	0.002	0.01	0.21	0.011	0.010	26.18	0.10	0.94	0.010			
18Cr(Ti)	2,3,18	0.046	0.32	0.40	0.013	0.023	18.22	0.49				0.55	
20Cr-24Ni-6.5Mo	4,5,19,22,23,24	0.038	1.73	0.81	0.004	0.013	20.41	23.61	6.50				
18Cr-2Mo	6,25,26	0.013	0.91	0.10	0.010	0.023	18.90	0.15	2.15	0.023	0.08		Nb-0.07,Pb-0.00 Sn-0.005,Al-0.0
18Cr-8Ni(N)	8,9,27,28	0.035	1.64	0.36	0.012	0.029	19.29	8.15	0.26	0.25	0.18		
26Cr-6.5Ni	10,30,36,37,38,42	0.015	0.49	0.40	0.020	0.022	26.5	6.2	0.04	0.021	0.08		Al<0.01,V-0.054
18Cr-2Mo (Nb)	7,11,12	0.03	0.91	0.78	0.016	0.02	18.54	0.28	1.97	0.031	0.13		Nb-0.47,Al-0.01 Pb-0.003
Composite Alloys[(a)]:													
A Type 430	14	0.06	0.16	0.31	0.008	0.015	16.86	0.28					
B Type 430	15	0.06	0.16	0.31	0.008	0.015	16.86	0.28					
C Type 304	16	0.02	1.26	0.48	0.018	0.02	17.3	10.2					
Carbon steel	14,15,16	0.042	0.32	0.009	0.012	0.007					0.017		Al-0.048

(a) A. Carbon Steel/430/Carbon Steel
B. Galv. Steel/430/Galv. Steel
C. Carbon Steel/304/Carbon Steel

Table 4. Mechanical properties[a] of stainless steels studied in this investigation

Alloy Designation	Treatment[b]	System	Tensile Strength, Ksi(d)	Yield Strength, Ksi(d)	Percent, Elongation in 2-in	Hardness
Type 201	--	50	103.5	53.0	52.5	R_B 92.5
Type 202	--	51	100.6	52.0	52.0	R_B 90.5
Type 301	--	52	120.1	42.1	64.0	R_B 85
Type 301	Sensitized	53	107.9	38.1	46.0	R_B 87
Type 301	Half-hard	67,68,82,83,84	162.0	116.0	25.0	R_C 34
Type 301	Half-hard + sensitized	69	147.0	97.5	26.0	R_C 28
Type 301	Full-hard	70,71,85,86,87	203.0	174.7	9.0	R_C 44
Type 301	Welded cross bead	54	See Type 301 (annealed)			
Type 304	--	55,72,73,88,89,90,91	86.9	46.4	52.0	R_B 85
Type 304	Sensitized	56,76	85.3	41.3	53.0	R_B 81.5
Type 304	Half-hard	74,75	144.7	129.3	14.0	R_C 33
Type 304	Heliarc weld	57	81.8	44.9	75.7	R_B 72
18Cr-8Ni(N)	--	8,9,27,28	103.0	60.0	45.0	R_B 91
Type 316	--	58,77,78	91.6	43.4	42.0	R_B 81
Type 316	Sensitized	59,79				
Type 409	--	60,92	70.6	46.6	31.0	R_B 77
Type 409	Heliarc weld	62	70.7	59.1	40.0	R_B 79
Type 409	Hi-Freq. weld	63	69.8	64.7	37.0	R_B 68
Type 410	--	64	74.5	52.8	29.5	R_B 84
Type 430	--	65	71.0	45.6	30.5	R_B 81
Type 434	--	66,80,81	79.8	56.3	26.0	R_B 86
26 Cr-1 Mo	--	1	71.5	54.0	26.0	R_B 88.5
26 Cr-1 Mo	--	17	79.5	48.1	31.0	R_B 78
26 Cr-1 Mo	--	20,21,33,34,35	67.0	48.6	26.5	R_B 79
18 Cr(Ti)	--	2,3,18	74.2	46.4	28.5	R_B 80
20 Cr-24 Ni-6.5 Mo	--	4,15,19,22,23,24	92.0	45.0	47.0	R_B 78.5
26 Cr-6.5 Ni	--	10,30,36,37,38,42	131.8	120.6	13.5	R_C 31
18 Cr-2 Mo	--	6,25,26	83.8	60.8	26.6	
18 Cr-2 Mo (Nb)	--	7,11,12	81.0	61.8	36.0	R_B 86

(a) Properties are as furnished by supplier
(b) All materials were in the annealed condition unless otherwise noted.
(c) Welded with a full finish per ASTM Specification A249.
(d) 1 Ksi = 6.8948 MPa.

Table 5. Summary of results[a] obtained from visual examination of stainless steel sheet specimens buried in the soils at the NBS soil corrosion test sites. Specimens of System Nos. 1 through 6, 8, 10, 14, 15, and 16 were buried for approximately 3 years. System No. 7 was buried for approximately 2 years while others were buried for approximately 4 years.

System	Stainless steel	Specimen Type and Treatment	Test Site (c)	Results of Visual Examination of Specimens (d) Exposed 1 year	Exposed 2 years	Exposed 4 years
Exposed in 1970						
50	Type 201	Sheet, annealed	A	N	N	N
			B	N	RS	RS
			C	T,P,H	P(F,E),T,IP	H,P,T
			D	IP	P,IP	N
			E	H,P,T	H,T,P,IP,Et(sli)	H,T(E,F),P
			G	A,P,IP,Et(sli)	H(E),P,A(sev),IP	P+T(E,AE)
51	Type 202	Sheet, annealed	A	N	IP	DS
			B	N	RS	DS+RS(sli)
			C	T,P,H	H,P(F,E),T,IP	H,P,T,RS
			D	IP	DS	DS
			E	H,T(E),P,IP	H,P,T,IP,IF	H,P,T,RS
			G	P,IP	P,IP	H,P,RS,DS,IP
52	Type 301	Sheet, annealed	A	N	IP	N
			B	IP	RS	DS(sli)
			C	T,P,IP	H,P(F,E),IP	H,P,T(E,AE)
			D	IP	IP	RS+DS(sli)
			E	H	H,P,T,IP	H,P+T
			G	P,T(E),IP	T,P,A+Et(sev),IP	H,P,RS,IP
53	Type 301	Sheet, sensitized	A	IP,Et	Et(E),P,IP	P(sli),IP,RS,DS,Bl
			B	IP(E)	P(sli),IP	RS,DS
			C	P,Et	Et(sev),P(F,E),IP	H,P,A(sev-mod)
			D	IP(E)	P,Bl,IP	Bl,P,IP,Et,A(E)
			E	A(E),P(E,AE),IP,Et	Et(sev),Bl,A(E),P,IP	P(AE,F),Bl,Cr,RS,IF
			G	Et(mod-sev),P,IP	H,A+Et(sev),P,IP	P+DS,IP
55	Type 304	Sheet, annealed	A	N	IP	DS
			B	N	RS	N
			C	H,T,IP	T,P,IP	H,P+T(E,AE),Et
			D	IF	N	DS
			E	H,P,IP	H,T,P,IP	H,T+P"
			G	H(E),P,IP,Et(sev)	A(sev),P,IP	P,Et,DS,RS
56	Type 304	Sheet, sensitized	A	Et[E(sli)],IP	P(sli),IP	Et(sli),IP
			B	Et(sli),IP	N	Et(mod)
			C	H,T(E),P	H,P(E,AE),T,A(E),IP	H,P,A(sev),IP
			D	IF	T,P(E,AE),IP,Bl	Et,P(AE),T(E,AE),Bl
			E	H,P,IP	H,T,P,IP	H,T,P,Et,RS
			G	H(E),P,IP	H,A,P,IP,Et(sev)	A(sev),P+Et(sli),IP,Et
58	Type 316	Sheet, annealed	A	N	IP	RS(sli)
			B	N	N	DS(sli)
			C	Et,IP	IP	P(E),RS
			D	N	N	N
			E	A+T(E),P(E,F)	H,T,P,IP	H,P(E,AE)
			G	IP	IP	N
59	Type 316	Sheet, sensitized	A	IP(E)	P(sli),IP	P(sli),IP,RS,Et
			B	N	DS	Et,RS
			C	P(E,F),H(E)	A+P(E),T,Et(sli)	P,A(E),Et
			D	IP	N	Et,P,DS
			E	P(E)	P,A(E),Et(sli)	A(E),T(E,F),RS,IF
			G	P(E)	P,IP,Et(sli)	IP,P,RS
60	Type 409	Sheet, annealed	A	IP	N	H,P(E,AE,F),DS
			B	N	P(sli)	DS,RS
			C	P,H(E),Et(sev)	H,P,Et(sev),T,IP	H,P(E,AE,F),A,RS,IP
			D	IF,RS	P,T	H,P(E,AE,F),T,Et
			E	H,T(E,F),P	H,T(AE,F),P,IP,Et(sli)	H,T(E,AE,F),RS,IF
			G	H,Et(sev),P,IP	H,P,A(sev),Et,IP	H,P(E,AE,F),A(sev)

Table 5 (Cont'd.)

System	Stainless steel	Specimen Type and Treatment	Test Site (c)	Results of Visual Examination of Specimens (d) Exposed 1 year	Exposed 2 years	Exposed 4 years
61	Type 409	Sheet, painted	A	N	N	N
			B	N	N	N
			C	N	N	N
			D	N	N	N
			E	N	N	RS(c)
			G	N	N	N
61	Type 409	Sheet, painted and scored	A	RS(s)	N	RS(s)
			B	RS(s)	RS(s)	N
			C	RS(s,c)	RS[s(sli)],U	RS(s)
			D	c,RS(s)	RS[s(sli)]	Bl+U(s)
			E	c,RS(s)	P+RS(s),U,Bl	RS(s)
			G	RS(s)	P+RS(s),U,Bl	RS(s)
64	Type 410	Sheet, annealed	A	P+IP(E,F)	T,P,A(E)	H,P(E,AE,F),DS,IP
			B	IP	N	P,IP,RS
			C	H,P,IP	H,P,Et(sev),A,IP	H,P(E,AE,F),Et+A(sli)
			D	H,P,T,IP	H,T,P,A(E),Et(sev),IP	H,T(E,AE,F),P(E,F),A(E)
			E	H(E)T	H,T,P,IP	H,T(E,AE,F),P,RS,DS
			G	Et(sev),H,P,IP	H,A+Et(sev),P,IP	H,P(E,AE,F),A(sev)
65	Type 430	Sheet, annealed	A	Et(sli),IP	IP	P,T,IP
			B	N	N	IF
			C	H(E)	H,P,T,Et	H,P(E,AE,F),Et(sli),A(sev)
			D	IF	T(F)	H,T(E,AE,F),P
			E	H,T,IP	H,T,P,IP	H,P+T(E,AE,F),IP,RS
			G	H,Et(sev),P,IP	H,P,A+Et(sev),IP	H,P(E,AE,F),A(sev),IP
66	Type 434	Sheet, annealed	A	N	IP	N
			B	IP	N	N
			C	H(E)	H,P,T,IP	H,P(E,AE,F),T(E,AE),Et,IP
			D	N	P(F),IP(E)	H,T(AE),P(AE,F)
			E	H,P,IP	H,T,P,IP	H,P,T(E,AE,F),RS
			G	H(E),P,IP	H,P,A+Et(sev),IP	P(E,AE),Et(sli),RS
Exposed in 1971						
1	26 Cr-1 Mo	Sheet, annealed	A	IP	N	DS
			B	N	RS	DS
			C	IP(E)	IP,RS	P,RS,IP,IF
			D	IP	Et(sli)	RS
			E	IP	N	IF,RS
			G	Et(sli),IP	N	N
2	18 Cr(Ti)	Sheet, annealed	A	P(sli),IP	N	Et(sli),P,RS
			B	N	Et(sli),RS	DS
			C	H,P,Et,IP	Et,P(E,F),IP,RS	H,P(E,F),Et(sli),IP
			D	P(AE),T,IP	N	RS
			E	H,P,T	H,P(E,AE,F),T	H,P(E,AE,F),IP
			G	H,P,A+Et(sev),IP	H,P(E,AE,F),Et,IP	P,A(sev),IP,RS
4	20 Cr-24 Ni-6.5 Mo	Sheet, annealed	A	IP	N	DS
			B	N	Et(sli),RS	N
			C	IP(E)	N	N
			D	N	Et(sli),RS	RS
			E	N	N	N
			G	N	N	RS
5	20 Cr-24 Ni-6.5 Mo	Sheet, sensitized	A	IP	N	DS
			B	N	N	DS
			C	IP	Et(sli),IP,RS	Et(sli),P(E),RS
			D	IP	Et(sli)	IF,DS
			E	A(E)	Et(sli)	DS
			G	P(E),Et(sli),IP	Et(sli)	Et(sli),DS
6	18 Cr-2 Mo	Sheet, annealed	A	IP	N	DS
			B	IP	N	DS,IF
			C	T,P(E,F),IP	RS	P(AE),RS,DS
			D	N	Et(sli)	RS,IF
			E	H,P,IP	H,P(E,AE,F),RS	H,P(E,AE,F)
			G	H,T,A,P,IP	H,P(E,AE,F),Et	P(E),RS,DS

Table 5 (Con't.)

System	Stainless steel	Specimen Type and Treatment	Test Site (c)	Results of Visual Examination of Specimens (d) Exposed 1 year	Exposed 2 years	Exposed 4 years
8	18 Cr-8 Ni(N)	Sheet, annealed	A	IP	N	N
			B	N	RS	DS,IF
			C	IP	P,IP,RS	P(E),RS,IF
			D	N	Et(sli)	DS
			E	P(E)	P(E)	H,P(E,AE),RS,IF
			G	P(E,F),IP	H,P,T(E,AE),Et,IP	A(mod),Et(sli),IP
10	26 Cr-6.5 Ni	Sheet, annealed	A	P(sli),IP	P[sli(AE)]	DS
			B	N	RS	DS
			C	H,T,P,IP	H,T(E),P,IP	H,P(E,AF,F),Et(sli)
			D	N	IP	N
			E	H,P,IP	H,P,T(E,AE,F),IP	H,P(E,AE,F),IP
			G	H,P,A+Et(sev),IP	H,P,T(E,AE),IP	P,IP,DS,RS
14	Composite A	Sheet, hot rolled and pickled	A	Et(sev),P	P,Et[(sev)AE,F]	P(E,AE,F),Et
			B	Et(sev),P,IP	P,Et[(sev),AE,F],A(E)	P(E,AE,F),Et
			C	Et(sev),P	P,Et(AE,F),A(E)	P(E,AE,F),Et
			D	Et(sev),P	P,Et(AE,F)	RS,P(E,AE,F),Et
			E	Et[E+F(sev)]	P,Et(AE,F)	RS,P(E,AE,F),Et
			G	Et(sev),Bl,P(AE)	P,Et(AE,F),A(E)	P(E,AE,F),Et
15	Composite B	Sheet, hot-dip zinc coated (4.5 oz/sq. ft.-Zn)	A	N	N,c	N
			B	N	N	N
			C	N	N	N
			D	N	N	N
			E	A[F(sli)]	N	A[F(sli)]
			G	P(F),Fl(E,AE)	P[F(sli)]	A[F(sli)]
16	Composite C	Sheet, hot rolled and pickled	A	Et(sev),P(AE,F)	P,Et(AE,F)	P(E,AE,F),Et
			B	Et(sev),P	P,Et(AF,F),A(E)	P(E,AE,F),Et
			C	Et(sev),P	P,Et(AE,F)	P(E,AE,F),Et,RS
			D	Et(sev),P	P,Et(AE,F)	RS,P(E,AE,F)Et
			E	Et(sev),P	P,Et(AE,F)	RS,P(E,AE,F)Et
			G	Et(sev),P	P,Et(AE,F)	P(E,AE,F),Et
Exposed in 1972						
7	18 Cr-2 Mo(Nb)	Sheet, annealed	A	N	P,DS	
			B	N	DS	
			C	N	P(E,AE),RS,IF	
			D	N	N	
			E	P,IP	P(AE,F),RS	
			G	N	P(E,F)	

(a) Results given for each system at each of the six soil test sites are a summary tabulation for four individual specimens.

(b) Specimen dimensions and treatment for each system are given in Table 2.

(c) Properties of the soils for each of the test sites are given in Table 1.

(d) Abbreviations used:

A- Metal attack
AE- Adjacent to edge
Bl- Blisters
BS- Black stain
c- Coating chipped
cr- Specimen cracked
DS- Dark stain
E- Edge
Et- Etched
F- Face
Fl- Coating flaked
H- Perforation
IF- Iridescent film
IP- Incipient pitting
mod- Moderate
N- No apparent attack
P- Pitting
RS- Rust stain
s- Scored area
sev- Severe
sli- Slight
T- Tunneling
U- Undercutting

Table 6. Summary of results[a] obtained from visual examination of welded stainless steel sheet and tube specimens buried in the soils at six NBS soil corrosion test sites for up to 4 years.

System	Stainless Steel	Material and Treatment	Test Site (c)	Body or Face	Cap	End or Edge	Weld[e]	Body or Face	Cap	End or Edge	Weld[e]	Body or Face	Cap	End or Edge	Weld[e]
Exposed in 1970				Exposure Time, 1 Year				Exposure Time, 2 Years				Exposure Time, 4 Years			
54	Type 301	Sheet with	A	N	N/A	N	N	IP	N/A	P(AE)	P(AW)	N	N/A	N	N
		cross-bead	B	N	N/A	N	N	IP	N/A	N	RS(W,AW)	DS,IF	N/A	N	N
		weld	C	N	N/A	P	P(AW)	P	N/A	P	P(W,AW)	H,P	N/A	P+T(E,AE)	P(W,AW)
			D	IP	N/A	N	N	N	N/A	N	P(AW)	RS	N/A	N	P+RS(W)
			E	H	N/A	N	N	H,T,P,IP	N/A	P	P(AW)	H,P,T,RS	N/A	P+T(E,AE)	RS(W)
			G	P	N/A	P	P(W,AW)	P,Et(sev),IP	N/A	P	P+A(W,AW)	A(sev),P	N/A	A(sev)+P	A(sev),P(W,AW)
57	Type 304	Tube with	A	Et(sli)	N	N	N	Et	N	N	N	P,Et(sli)	P(AC)	N	P(AW)
		heliarc weld-	B	Et(sli)	N	N	N	Et(sli)	Et(UC)	N	N	Et(sli),RS	N	N	N
		ed seam (2-in	C	Et(sli)	N	N	N	P	P(UC,AC),A(UC)	N	P(W,AW)	P	P(AC),Et(UC)	N	N
		OD)	D	Et(sli)	N	N	N	Et(sli)	N	N	N	P,RS	RS(UC)	N	N
			E	Et(mod to sev)	N	N	N	Et(sev),P,IP	P(AC,UC)	N	N	P	P+Et(AC,UC)	N	N
			G	Et(mod),P,IP	N	N	N	P,Et(sli),IP	P(AC,UC)	N	P(W)	P	N	N	P(AW)
62	Type 409	Tube with	A	P,IP	P+IP(UC)	N	P+IP(W)	Et(sli),IP	N	N	IP(AW)	H,P,T,Et	P+T(AC)	N	N
		heliarc weld-	B	N	N	N	N	P,IP	N	N	N	Et,IF	N	N	N
		ed seam	C	H	N	N	N	H,P,Et,IP	H+P(AC,UC)	N	P(W)	H,P,Et,IP	P(AC,UC)	N	P(W,AW)
		(1-1/8-in OD)	D	N	N	N	N	P,Et(sli),IP	N	N	N	H,P	P(AC)	N	N
			E	H,P	N	N	N	H,P,Et(sli),IP	H+P(AC,UC)	N	P(W)	H,P,T,IP	P+T(AC,UC)	N	N
			G	H,Et+A(sev),P	N	N	N	H,P,A(sev),Et,IP	H+P(AC,UC)	N	H+P(W,AW)	H,P,IP	P(AC,UC)	N	P(W,AW)
63	Type 409	Tube with	A	Et,P	IP(AC)	N	IP(W)	IP	N	P	IP(AW)	H,P,T	P(AC)	N	P(AW)
		high frequency	B	N	N	N	N	P,IP	N	N	EP(W,AW)	N	N	N	N
		welded seam	C	P	N	N	N	H,P,Et,IP	H(AC)	N	H(W),P(W,AW)	H,P,Et	P(AC,UC)	N	P(W,AW)
		(7/8-in OD)	D	N	N	N	H,P(AW)	H,P,Et(sli),IP	N	N	H+P(W,AW)	H	P(AC)	N	P(W,AW)
			E	H,P,IP	N	N	N	H,T,P,IP	H+P(AC,UC)	N	H+P(W,AW)	H,P,IP	P(AC,UC)	N	P(W,AW)
			G	H,A(sev),P	P(AC)	N	N	H,P,A(sev),Et	H+P(AC)	N	H+P(W,AW)	H,P,IP	P(AC)	N	P(W,AW)
Exposed in 1971				Exposure Time, 1 Year				Exposure Time, 2 Years				Exposure Time, 3 Years			
3	18 Cr(Ti)	Sheet with	A	IP,Et	N/A	N	N	P	N/A	N	N	P,RS,DS	N/A	N	N
		cross-bead	B	N	N/A	N	N	N	N/A	N	N	DS	N/A	N	N
		weld	C	P,T,IP	N/A	P,T	P(W,AW)	P,Et(sli),IP	N/A	P	P(W)	H,P,Et,IP	N/A	P(E,AE)	P(W;AW)
			D	P	N/A	N	P(W,AW)	N	N/A	N	N	DS	N/A	N	N
			E	H,P,IP	N/A	H,P	P(W,AW)	H,P,Et,IP	N/A	P(AE,E)	P(W)	H,P,DS,IF	N/A	P(E,AE)	N
			G	H,P,IP	N/A	H,P	P(W,AW)	P,Et,T	N/A	P(AE,E)	N	RS	N/A	P(E)	P(W)
9	18 Cr-B Ni(N)	Sheet with	A	IP	N/A	N	Et(W),IP(AW)	N	N/A	N	N	N	N/A	N	N
		cross-bead	B	RS	N/A	N	Et(W)	RS	N/A	N	RS(W)	DS	N/A	N	N
		weld	C	A,P	N/A	N	Et+P(W),IP(AW)	Et,IP	N/A	Et(AE)	P(W,AW),Et(AW)	H,Et(sev)	N/A	N	P(W,AW)
			D	N	N/A	N	Et(W),IP(AW)	Et(sli)	N/A	N	N	RS	N/A	N	N
			E	P,T,Et	N/A	N	P(W,AW),H(AW)	Et(sli)	N/A	N	P(W,AW)	H,RS	N/A	A	P(W,AW)
			G	P,Et,IP	N/A	P	P+Et(W),IP(AW)	P	N/A	P(AE,E)	Et(W,AW)	Et(sli),RS	N/A	N	P(W,AW)
17	26 Cr-1 Mo	Tube with	A	N	N	N	N	N	N	N	N	DS	N	P(E)	N
		heliarc weld-	B	N	N	N	N	N	N	N	N	Et(sli),DS	N	N	N
		ed seam	C	N	N	N	N	N	P(AC,UC),RS(UC)	N	N	RS,IP	P+Et[(sev)UC]	N	N
		(2-in OD)	D	N	N	N	N	N	N	N	N	N	N	N	N
			E	N	P(UC)	N	N	N	P+Et(UC)	N	N	P,IF	P+Et[(sev)UC]	N	N
			G	P	RS(AC)	N	N	N	P(UC)	N	N	P	N	N	N

Table 6. (Con't.)

System	Stainless Steel	Material and Treatment	Test Site (c)	Body or Face	Cap	End or Edge	Weld[e]	Body or Face	Cap	End or Edge	Weld[e]	Body or Face	Cap	End or Edge	Weld[e]
18	18 Cr(Ti)	Tube with heliarc welded seam (1-1/8-in OD)	A	N	N	N	N	N	N	N	N	N	N	N	N
			B	N	N	N	N	N	N	N	N	Et(sli)	N	N	N
			C	P,IP,Et	H+P(AC)	N	P(W,AW)	P	H+P(AC)	N	P(W,AW)	H,P	P(AC)	N	P(W,AW)
			D	N	N	N	N	N	N	N	N	N	N	N	N
			E	P,IP	H(AC)	N	N	N	P(UC)	N	N	N	N	N	N
			G	H,P,Et,IP	N	N	H+P(W,AW)	H,P,Et	H,P+Et(AC)	N	N	H,P,IP	P(AC)	N	P(W,AW)
19	20 Cr-24 Ni-6.5 Mo	Tube with heliarc welded seam	A	N	N	N	N	N	N	N	N	N	N	N	N
			B	N	N	N	N	RS	N	N	N	N	N	N	N
			C	RS	N	N	N	RS	N	N	N	N	N	N	N
			D	RS	N	N	N	N	N	N	N	N	N	N	N
			E	N	N	N	N	N	N	N	N	N	N	N	N
			G	N	N	N	N	N	RS(AC)	N	N	N	N	N	N
Exposed in 1972															
11	18 Cr-2 Mo(Nb)	Sheet with cross-bead weld	A	N	N/A	N	N	DS	N/A	N	N				
			B	N	N/A	N	N	N	N/A	N	N				
			C	Et(sli)	N/A	N	P(W),Et(W,AW)	H,P,Et(sev)	N/A	P(E)	P(W,AW)				
			D	N	N/A	N	N	RS,IF	N/A	N	RS(W,AW)				
			E	P	N/A	N	P(W,AW)	H,P,IF	N/A	P(E)	P(W,AW)				
			G	N	N/A	N	N	P,RS	N/A	N	P(W)				
12	18 Cr-2 Mo(Nb)	Tube with heliarc welded seam	A	N	N	N	N	P	N	N	P(AW)				
			B	N	N	N	N	N	N	N	N				
			C	N	N	N	N	P,IP	N	N	N				
			D	N	N	N	N	N	N	N	N				
			E	N	P(UC)	N	N	H,P	P(AC,UC)	N	P(AW)				
			G	N	N	N	N	RS,DS	IP(AC,UC)	N	N				

(a) Results given for each system exposed at the six soil test sites are a summary tabulation for 4 individual specimens.

(b) Specimen dimensions and treatment for each system are given in Table II.

(c) Properties of the soils are given in Table I.

(d) Abbreviations used:

A-metal attack	mod-moderate	UC-undercap
AC-adjacent to cap	N-no apparent attack	W-weld
AE-adjacent to edge	N/A-not applicable	
AW-adjacent to weld	P-pitting	
E-edge	RS-rust stain	
Et-etched	sev-severe	
H-perforation	sli-slight	
IP-incipient pitting	T-tunneling	

(e) W or AW do not necessarily signify that more severe attack occurred in the weld than in the parent metal.

Table 7. Average Weight Loss (mg/dm^2) and Pit Depth (mils) for Stainless Steel Sheet and Tube Specimens Buried in Sagemoor Sandy Loam (Site A) for up to Four Years

System*	Material	Treatment (a)	Exposure, Time, Days	Average[b] Weight Loss		Pit Depth, mils[d]	
				mg	mg/dm^2	Maximum	Average of 5 Deepest (e)
Exposed in 1970							
50	Type 201	--	413	--	--	--	--
			791	4	<1	--	--
			1442	--	--	--	--
51	Type 202	--	413	--	--	--	--
			791	--	--	IP	--
			1442	--	--	--	--
52	Type 301	--	413	--	--	--	--
			791	--	--	<5	--
			1442	--	--	--	--
53	Type 301	S	413	68	6	IP	--
			791	201	15	<5	--
			1442	1247	98	<5	--
54	Type 301	XBW	413	2	<1	--	--
			791	2	<1	<5	--
			1442	--	--	--	--
55	Type 304	--	413	--	--	--	--
			791	2	<1	--	--
			1442	--	--	--	--
56	Type 304	S	413	285	21	--	--
			791	256	21	<5	--
			1442	618	49	--	--
57	Type 304	HW	413	1	<1	--	--
			791	--	--	--	--
			1442	--	--	18	--
58	Type 316	--	413	3	<1	--	--
			791	--	--	--	--
			1442	--	--	--	--
59	Type 316	S	413	20	2	IP	--
			791	86	6	<5	--
			1442	384	12	7	--

Table 7 (Con't.)

System*	Material	Treatment (a)	Exposure, Time, Days	Average(b) Weight Loss mg	mg/dm²	Pit Depth, mils(d) Maximum	Average of 5 Deepest (e)
60	Type 409	--	413	6	<1	29	--
			791	6	<1	<5	--
			1442	150	12	H	H
62	Type 409	HW	413	186	73	--	--
			791	101	40	IP	--
			1442	32	12	H	--
63	Type 409	HFW	413	187	95	IP	--
			791	149	88	<5	--
			1442	75	37	H	H
64	Type 410	--	413	3510	281	48	--
			791	82	6	20	7
			1442	8843	705	H	H
65	Type 430	--	413	4	<1	--	--
			791	10	1	IP	--
			1442	66	6	22	--
66	Type 434	--	413	4	<1	--	--
			791	2	<1	IP	--
			1442	--	--	--	--
Exposed in 1971							
1	26 Cr-1 Mo	--	496	2	<1	IP	--
			860	--	--	--	--
			1147	--	--	--	--
2	18 Cr(Ti)	--	496	10	1	IP	--
			860	2	<1	--	--
			1147	1	<1	<5	--
3	18 Cr(Ti)	XBW	496	1	<1	<5	--
			860	4	<1	<5	--
			1147	4	<1	--	--
4	20 Cr-24 Ni-6.5 Mo	--	496	4	<1	IP	--
			860	1	<1	--	--
			1147	1	<1	--	--
5	20 Cr-24 Ni-6.5 Mo	S	496	1	<1	IP	--
			860	--	--	--	--
			1147	--	--	--	--
6	18 Cr-2 Mo	--	496	3	<1	IP	--
			860	1	<1	--	--
			1147	--	--	--	--

Table 7 (Con't.)

System*	Material	Treatment (a)	Exposure, Time, DDays	Average[b] Weight Loss mg	Average[b] Weight Loss mg/dm^2	Pit Depth, mils[d] Maximum	Pit Depth, mils[d] Average of 5 Deepest (e)
8	18 Cr-8 Ni(N)	--	496	--	--	IP	--
			860	--	--	--	--
			1147	--	--	--	--
9	18 Cr-8 Ni(N)	XBW	496	20	2	IP	--
			860	--	--	--	--
			1147	2	<1	--	--
10	26 Cr-6.5 Ni	--	496	7	<1	<5	--
			860	--	--	<5	--
			1147	3	<1	--	--
14	Composite A[c]	--	496	81500	6412	N/A	
			860	116350	9154	N/A	
			1147	165175	12995	N/A	
15	Composite B[c]	HDZ	496	9075	714	N/A	
			860	21975	1729	N/A	
			1147	27875	2193	N/A	
16	Composite C[c]	--	496	83775	6591	N/A	
			860	112175	8825	N/A	
			1147	149075	11728	N/A	
17	26 Cr-1 Mo	HW	496	11	3	<5	--
			860	--	--	--	--
			1147	--	--	16	--
18	18 Cr(Ti)	HW	496	--	--	--	--
			860	--	--	--	--
			1147	4	2	--	--
19	20 Cr-24 Ni-6.5 Mo	HW	496	--	--	--	--
			860	--	--	--	--
			1147	--	--	--	--
Exposed in 1972							
7	18 Cr-2 Mo(Nb)		364	--	--	--	--
			651	4	<1	<5	--
11	18 Cr-2 Mo (Nb)	XBW	364	--	--	--	--
			651	13	1	--	--
12	18 Cr-2 Mo (Nb)	HW	364	--	--	--	--
			651	8	2	<5	--

Table 7 (Con't.)

*Systems 12, 17, 18, 19, 57, 62, and 63 were tube specimens fabricated from sheet material, welded at the seams and then plugged and capped at each end to minimize internal corrosion. Specimens of all other systems were flat sheet material.

(a) All materials were in the annealed condition unless noted otherwise. Abbreviations used:

S-sensitized
XBW-cross-bead weld
HW-heliarc weld
HFW-high frequency weld
HDZ-hot-dip zinc coated (galvanized, 4.5 oz/ft^2) after bonding. See footnote (c).

(b) Average for four specimens.

(c) All composites were metallurgically bonded.
Composite A-Carbon steel/Type 430/Carbon steel.
Composite B-Carbon steel/Type 430/Carbon steel.
Composite C-Carbon steel/Type 304/Carbon steel.

(d) 1 mil = 0.025 mm. IP - incipient pitting. H - perforated. N/A - not applicable

(e) Average of five deepest pits on each of four individual specimens unless noted otherwise.

(f) Average of ten deepest pits on each of four individual specimens.

Table 8. Average Weight Loss (mg/dm^2) and Pit Depth (mils) for Stainless Steel Sheet and Tube Specimens Buried in Hagerstown Loam (Site B) for up to Four Years

System*	Material	Treatment (a)	Exposure, Time, Days	Average(b) Weight Loss mg	Average(b) Weight Loss mg/dm^2	Pit Depth, mils(d) Maximum	Pit Depth, mils(d) Average of 5 Deepest (e)
Exposed in 1970							
50	Type 201	--	371	--	--	--	--
			736	6	<1	--	--
			1513	--	--	--	--
51	Type 202	--	371	--	--	--	--
			736	1	<1	--	--
			1513	--	--	--	--
52	Type 301	--	371	--	--	--	--
			736	--	--	--	--
			1513	--	--	--	--
53	Type 301	S	371	23	2	IP	--
			736	43	3	--	--
			1513	206	15	--	--
54	Type 301	XBW	371	--	--	--	--
			736	--	--	--	--
			1513	--	--	--	--
55	Type 304	--	371	--	--	--	--
			736	--	--	--	--
			1513	--	--	--	--
56	Type 304	S	371	814	64	--	--
			736	690	55	--	--
			1513	707	55	--	--
57	Type 304	HW	371	--	--	--	--
			736	--	--	--	--
			1513	--	--	--	--
58	Type 316	--	371	--	--	--	--
			736	3	<1	--	--
			1513	--	--	--	--
59	Type 316	S	371	--	--	--	--
			736	36	3	--	--
			1513	361	21	--	--

Table 8 (Con't.)

System*	Material	Treatment (a)	Exposure, Time, Days	Average[b] Weight Loss mg	Average[b] Weight Loss mg/dm^2	Pit Depth, mils[d] Maximum	Pit Depth, mils[d] Average of 5 Deepest (e)
60	Type 409	--	371	--	--	--	--
			736	4	<1	--	--
			1513	--	--	--	--
62	Type 409	HW	371	1	<1	--	--
			736	1	<1	IP	--
			1513	--	--	--	--
63	Type 409	HFW	371	1	<1	--	--
			736	2	1	IP	--
			1513	--	--	--	--
64	Type 410	--	371	1474	116	--	--
			736	1207	98	--	--
			1513	72	6	--	--
65	Type 430	--	371	13	1	--	--
			736	13	1	--	--
			1513	--	--	--	--
66	Type 434	--	371	4	<1	--	--
			736	6	<1	--	--
			1513	--	--	--	--
Exposed in 1971							
1	26 Cr-1 Mo	--	394	2	<1	--	--
			777	--	--	--	--
			1170	1	<1	--	--
2	18 Cr(Ti)	--	394	12	1	--	--
			777	--	--	--	--
			1170	--	--	--	--
3	18 Cr(Ti)	XBW	394	--	--	--	--
			777	--	--	--	--
			1170	2	<1	--	--
4	20 Cr-24 Ni-6.5 Mo	--	394	7	<1	--	--
			777	--	--	--	--
			1170	--	--	--	--
5	20 Cr-24 Ni-6.5 Mo	S	394	--	--	--	--
			777	--	--	--	--
			1170	--	--	--	--
6	18 Cr-2 Mo	--	394	6	<1	--	--
			777	--	--	--	--
			1170	6	<1	--	--

Table 8 (Con't.)

System*	Material	Treatment (a)	Exposure, Time, Days	Average[b] Weight Loss mg	Average[b] Weight Loss mg/dm²	Pit Depth, mils[d] Maximum	Pit Depth, mils[d] Average of 5 Deepest (e)
8	18 Cr-8 Ni(N)	--	394	--	--	--	--
			777	--	--	--	--
			1170	--	--	--	--
9	18 Cr-8 Ni(N)	XBW	394	--	--	--	--
			777	--	--	--	--
			1170	--	--	--	--
10	26 Cr-6.5 Ni	--	394	--	--	--	--
			777	--	--	--	--
			1170	--	--	--	--
14	Composite A[c]	--	394	66575	5238	N/A	
			777	87425	6878	N/A	
			1170	100400	7899	N/A	
15	Composite B[c]	HDZ	394	10175	800	N/A	
			777	5875	462	N/A	
			1170	4275	336	N/A	
16	Composite C[c]	--	394	78333	6163	N/A	
			777	107350	8445	N/A	
			1170	110900	8725	N/A	
17	26 Cr-1 Mo	HW	394	4	1	--	--
			777	--	--	--	--
			1170	--	--	--	--
18	18 Cr(Ti)	HW	394	2	1	--	--
			777	--	--	--	--
			1170	2	1	--	--
19	20 Cr-24 Ni-6.5 Mo	HW	394	--	--	--	--
			777	--	--	--	--
			1170	--	--	--	--
Exposed in 1972							
7	18 Cr-2 Mo(Nb)	--	395	--	--	--	--
			801	1	<1	--	--
11	18 Cr-2 Mo(Nb)	XBW	395	--	--	--	--
			801	8	<1	--	--
12	18 Cr-2 Mo(Nb)	HW	395	--	--	--	--
			801	3	<1	--	--

Table 8 (Con't.)

*Systems 12, 17, 18, 19, 57, 62, and 63 were tube specimens fabricated from sheet material, welded at the seams and then plugged and capped at each end to minimize internal corrosion. Specimens of all other systems were flat sheet material.

(a) All materials were in the annealed condition unless noted otherwise. Abbreviations used:

S-sensitized
XBW-cross-bead weld
HW-heliarc weld
HFW-high frequency weld
HDZ-hot-dip zinc coated (galvanized, 4.5 oz/ft^2) after bonding. See footnote (c).

(b) Average of four specimens.

(c) All composites were metallurgically bonded.
Composite A-Carbon steel/Type 430/Carbon steel.
Composite B-Carbon steel/Type 430/Carbon steel.
Composite C-Carbon steel/Type 304/Carbon steel.

(d) 1 mil = 0.025 mm. IP - incipient pitting. N/A - not applicable.

(e) Average of five deepest pits on each of four individual specimens unless noted otherwise.

(f) Average of ten deepest pits on each of four individual specimens.

Table 9. Average Weight Loss (mg/dm^2) and Pit Depth (mils) for Stainless Steel Sheet and Tube Specimens Buried in Clay (Site C) for up to Four Years

System*	Material	Treat-ment (a)	Exposure, Time, Days	Average(b) Weight Loss mg	Average(b) Weight Loss mg/dm^2	Pit Depth, mils(d) Maximum	Pit Depth, mils(d) Average of 5 Deepest (e)
Exposed in 1970							
50	Type 201	--	377	797	64	H	--
			727	902	73	H	--
			1463	1242	98	H	H
51	Type 202	--	377	509	40	H	--
			727	686	55	H	H
			1463	435	34	H	H
52	Type 301	--	377	193	15	20	--
			727	529	43	H	H
			1463	405	34	H	H
53	Type 301	S	377	3672	293	48	15
			727	12951	1031	19	14
			1463	14163	1128	H	--
54	Type 301	XBW	377	384	30	63	--
			727	395	30	16	6
			1463	522	43	H	H
55	Type 304	--	377	326	24	H	--
			727	635	49	H	--
			1463	4013	320	H	H
56	Type 304	S	377	768	61	H	--
			727	1774	140	H	--
			1463	8022	637	H	H
57	Type 304	HW	377	--	--	--	--
			727	89	21	16	5
			1463	223	55	7	6
58	Type 316	--	377	2	<1	--	--
			727	6	<1	--	--
			1463	6	<1	63	--
59	Type 316	S	377	596	49	H	--
			727	735	58	T	--
			1463	988	79	120(T)	--

Table 9 (Con't.)

System*	Material	Treatment (a)	Exposure, Time, Days	Average[b] Weight Loss mg	Average[b] Weight Loss mg/dm^2	Pit Depth, mils[d] Maximum	Pit Depth, mils[d] Average of 5 Deepest (e)
60	Type 409	--	377	6335	503	H	--
			727	5468	436	H	--
			1463	10349	824	H	H
62	Type 409	HW	377	832	332	H	--
			727	2852	1138	H	H[f]
			1463	3950	1574	H	H
63	Type 409	HFW	377	1255	644	18	--
			727	2176	1116	H	H
			1463	4226	2166	H	H
64	Type 410	--	377	7068	563	30	--
			727	15991	1274	H	--
			1463	30574	2434	H	H
65	Type 430	--	377	4755	379	H	--
			727	5102	406	H	H
			1463	8978	715	H	H
66	Type 434	--	377	541	43	H	--
			727	955	76	H	H[f]
			1463	1614	129	H	H
Exposed in 1971							
1	26 Cr-1 Mo	--	350	13	1	IP	--
			730	--	--	IP	--
			1086	--	--	<5	--
2	18 Cr(Ti)	--	350	1016	81	H	--
			730	652	52	42	--
			1086	227	18	H	--
3	18 Cr(Ti)	XBW	350	582	46	H	--
			730	163	13	24	--
			1086	101	8	H	--
4	20 Cr-24 Ni-6.5 Mo	--	350	10	<1	IP	--
			730	--	--	--	--
			1086	--	--	--	--
5	20 Cr-24 Ni-6.5 Mo	S	350	33	3	IP	--
			730	--	--	IP	--
			1086	14	1	22	--
6	18 Cr-2 Mo	--	350	32	2	<5	--
			730	6	<1	--	--
			1086	1	<1	7	--

Table 9 (Con't.)

System*	Material	Treat-ment (a)	Exposure, Time, Days	Average[b] Weight Loss mg	mg/dm^2	Pit Depth, mils[d] Maximum	Average of 5 Deepest (e)
8	18 Cr-8 Ni(N)	--	350	2	<1	IP	--
			730	--	--	<5	--
			1086	5	<1	50	--
9	18 Cr-8 Ni(N)	XBW	350	529	42	141	--
			730	552	44	10	--
			1086	554	44	H	--
10	26 Cr-6.5 Ni	--	350	441	35	H	--
			730	330	26	H	H
			1086	132	10	H	H
14	Composite A[c]	--	350	39200	3084	N/A	
			730	60975	4797	N/A	
			1086	133000	10463	N/A	
15	Composite B[c]	HDZ	350	56825	4470	N/A	
			730	57950	4559	N/A	
			1086	80600	6341	N/A	
16	Composite C[c]	--	350	41000	3226	N/A	
			730	59175	4655	N/A	
			1086	126100	9920	N/A	
17	26 Cr-1 Mo	HW	350	--	--	--	--
			730	--	--	<5	--
			1086	58	14	35	7
18	18 Cr(Ti)	HW	350	121	48	H	--
			730	44	18	H	H
			1086	81	32	H	H
19	20 Cr-24 Ni-6.5 Mo	HW	350	--	--	--	--
			730	1	<1	--	--
			1086	--	--	--	--
Exposed in 1972							
7	18 Cr-2 Mo (Nb)	--	380	--	--	<5	--
			736	6	<1	<5	--
11	18 Cr-2 Mo (Nb)	XBW	380	60	5	<5	--
			736	136	11	H(T)	--
12	18 Cr-2 Mo (Nb)	HW	380	--	--	--	--
			736	160	39	7	--

Table 9 (Con't.)

*Systems 12, 17, 18, 19, 57, 62, and 63 were tube specimens fabricated from sheet material, welded at the seams and then plugged and capped at each end to minimize internal corrosion. Specimens of all other systems were flat sheet material.

(a) All materials were in the annealed condition unless noted otherwise. Abbreviations used:

S-sensitized
XBW-cross-bead weld
HW-heliarc weld
HFW-high frequency weld
HDZ-hot-dip zinc coated (galvanized, 4.5 oz/ft^2) after bonding. See footnote (c).

(b) Average for four specimens.

(c) All composites were metallurgically bonded.
Composite A-Carbon steel/Type 430/Carbon steel.
Composite B-Carbon steel/Type 430/Carbon steel.
Composite C-Carbon steel/Type 304/Carbon steel.

(d) 1 mil = 0.025 mm. IP - incipient pitting. H - perforated. T - tunneling. N/A - not applicable.

(e) Average of five deepest pits on each of four individual specimens unless noted otherwise.

(f) Average of ten deepest pits on each of four individual specimens.

Table 10. Average Weight Loss (mg/dm^2) and Pit Depth (mils) for Stainless Steel Sheet and Tube Specimens Buried in Lakewood Sand (Site D) for up to Four Years

System*	Material	Treatment (a)	Exposure, Time, Days	Average (b) Weight Loss, mg	Average (b) Weight Loss, mg/dm^2	Pit Depth, mils (d), Maximum	Pit Depth, mils (d), Average of 5 Deepest (e)
Exposed in 1970							
50	Type 201	--	377	3	<1	IP	--
			727	9	<1	40	--
			1463	--	--	--	--
51	Type 202	--	377	--	--	--	--
			727	--	--	--	--
			1463	9	<1	--	--
52	Type 301	--	377	--	--	IP	--
			727	1	<1	IP	--
			1463	--	--	--	--
53	Type 301	S	377	272	21	--	--
			727	1121	88	--	--
			1463	1499	119	30	7
54	Type 301	XBW	377	2	<1	--	--
			727	2	<1	IP	--
			1463	--	--	<5	--
55	Type 304	--	377	21	2	IP	--
			727	7	<1	--	--
			1463	--	--	--	--
56	Type 304	S	377	297	24	--	--
			727	740	59	H	--
			1463	1243	99	57	--
57	Type 304	HW	377	--	--	--	--
			727	--	--	--	--
			1463	--	--	8	--
58	Type 316	--	377	1	<1	--	--
			727	--	--	--	--
			1463	--	--	--	--
59	Type 316	S	377	127	10	--	--
			727	172	14	--	--
			1463	179	14	<5	--

Table 10 (Con't.)

System*	Material	Treat-ment (a)	Exposure, Time, Days	Average(b) Weight Loss mg	mg/dm^2	Pit Depth, mils(d) Maximum	Average of 5 Deepest (e)
60	Type 409		377	3	<1	--	--
			727	264	21	54	--
			1463	620	49	H	H
62	Type 409	HW	377	1	<1	--	--
			727	5	2	21	--
			1463	83	34	H	H
63	Type 409	HFW	377	10	6	H	--
			727	44	21	H	--
			1463	10	6	H	H
64	Type 410	--	377	160	12	H	--
			727	1159	92	H	--
			1463	920	73	H	H
65	Type 430	--	377	2	<1	--	--
			727	29	2	18	--
			1463	186	15	H	H
66	Type 434	--	377	3	<1	--	--
			727	8	<1	56	--
			1463	56	3	H	H
Exposed in 1971							
1	26 Cr-1 Mo	--	350	2	<1	IP	--
			727	--	--	--	--
			1086	3	<1	--	--
2	18 Cr-(Ti)	--	350	17	1	23	--
			727	--	--	--	--
			1086	--	--	--	--
3	18 Cr (Ti)	XBW	350	8	<1	26	14
			727	--	--	--	--
			1086	--	--	--	--
4	20 Cr-24 Ni-6.5 Mo	--	350	6	<1	--	--
			727	--	--	--	--
			1086	--	--	--	--
5	20 Cr-24 Ni-6.5 Mo	S	350	6	<1	IP	--
			727	--	--	--	--
			1086	--	--	--	--
6	18 Cr-2 Mo	--	350	4	<1	--	--
			727	1	<1	--	--
			1086	1	<1	--	--
8	18 Cr-8 Ni (N)	--	350	4	<1	IP	--
			727	--	--	--	--
			1086	--	--	--	--

Table 10 (Cont'.)

System*	Material	Treatment (a)	Exposure, Time, Days	Average[b] Weight Loss mg	Average[b] Weight Loss mg/dm^2	Pit Depth, mils[d] Maximum	Pit Depth, mils[d] Average of 5 Deepest (e)
9	18 Cr-8 Ni (N)	XBW	350	30	2	--	--
			727	--	--	IP	--
			1086	--	--	--	--
10	26 Cr-6.5 Ni	--	350	6	<1	--	--
			727	--	--	--	--
			1086	--	--	--	--
14	Composite A[c]	--	350	27000	2124	N/A	
			727	32075	2523	N/A	
			1086	45100	3548	N/A	
15	Composite B[c]	HDZ	350	5375	423	N/A	
			727	Lost		N/A	
			1086	1200	94	N/A	
16	Compsite C[c]	--	350	26750	2104	N/A	
			727	38900	3060	N/A	
			1086	48000	3776	N/A	
17	26 Cr-1 Mo	HW	350	6	2	--	--
			727	--	--	--	--
			1086	--	--	--	--
18	18 Cr (Ti)	HW	350	--	--	--	--
			727	--	--	--	--
			1086	3	1	--	--
19	20 Cr-24 Ni-6.5 Mo	HW	350	--	--	--	--
			727	--	--	--	--
			1086	--	--	--	--
Exposed in 1972							
7	18 Cr-2 Mo (Nb)	--	380	--	--	--	--
			736	2	<1	--	--
11	18 Cr-2 Mo (Nb)	XBW	380	4	<1	--	--
			736	36	3	--	--
12	18 Cr-2 Mo (Nb)	HW	380	--	--	--	--
			736	6	2	--	--

Table 10 (Con't.)

*Systems 12, 17, 18, 19, 57, 62, and 63 were tube specimens fabricated from sheet material, welded at the seams and then plugged and capped at each end to minimize internal corrosion. Specimens of all other systems were flat sheet material.

(a) All materials were in the annealed condition unless noted otherwise. Abbreviations used:

S-sensitized
XBW-cross-bead weld
HW-heliarc weld
HFW-high frequency weld
HDZ-hot-dip zinc coated (galvanized, 4.5 oz/ft^2) after bonding. See footnote (c).

(b) Average for four specimens.

(c) All composites were metallurgically bonded.
Composite A-Carbon steel/Type 430/Carbon steel.
Composite B-Carbon steel/Type 430/Carbon steel.
Composite C-Carbon steel/Type 304/Carbon steel.

(d) 1 mil = 0.025 mm. IP - incipient pitting. H - perforated. N/A - not applicable

(e) Average of five deepest pits on each of four individual specimens unless noted otherwise.

(f) Average of ten deepest pits on each of four individual specimens.

Table 11. Average Weight Loss (mg/dm^2) and Pit Depth (mils) for Stainless Steel Sheet and Tube Specimens Buried in Coastal Sand (Site E) for up to Four Years

System*	Material	Treatment (a)	Exposure, Time, Days	Average (b) Weight Loss mg	Average (b) Weight Loss mg/dm^2	Pit Depth, mils (d) Maximum	Pit Depth, mils (d) Average of 5 Deepest (e)
Exposed in 1970							
50	Type 201	--	377	1302	104	H	--
			727	3324	262	H	--
			1463	5705	454	H	H (f)
51	Type 202	--	377	778	62	H	--
			727	1948	155	H	H (f)
			1463	1939	155	H	H
52	Type 301	--	377	1339	107	H	--
			727	2737	217	H	H (f)
			1463	2320	183	H	H
53	Type 301	S	377	1396	110	<5	--
			727	3744	299	8	--
			1463	4873	387	28	14
54	Type 301	XBW	377	1768	85	H	--
			727	2558	204	H	H (f)
			1463	2828	225	H	H
55	Type 304	--	377	1425	113	H	--
			727	3162	250	H	--
			1463	4564	363	H	H
56	Type 304	S	377	2820	232	H	--
			727	5912	470	H	H
			1463	11088	881	H	H
57	Type 304	HW	377	641	156	38	--
			727	1432	348	26	--
			1463	1352	329	53	21
58	Type 316	--	377	174	14	H	--
			727	534	46	H	--
			1463	83	6	H	--
59	Type 316	S	377	1350	107	62	--
			727	3302	262	<5	--
			1463	3306	262	H	--
60	Type 409	--	377	3309	262	H	H
			727	3952	314	H	H (f)
			1463	5235	418	H	H

Table 11 (Con't.)

System*	Material	Treatment (a)	Exposure, Time, Days	Average[b] Weight Loss mg	Average[b] Weight Loss mg/dm^2	Pit Depth, mils[d] Maximum	Pit Depth, mils[d] Average of 5 Deepest (e)
62	Type 409	HW	377	752	299	H	H
			727	1270	506	H	H
			1463	2417	964	H	H
63	Type 409	HFW	377	763	390	H	H
			727	1033	531	H	H
			1463	1521	781	H	H
64	Type 410	--	377	4005	317	H	H
			727	4012	320	H	H[f]
			1463	8477	674	H	H
65	Type 430	--	377	1448	115	H	H
			727	3174	253	H	H[f]
			1463	5084	405	H	H
66	Type 434	--	377	1603	128	H	H
			727	3113	247	H	H[f]
			1463	5174	412	H	H
Exposed in 1971							
1	26 Cr-1 Mo	--	350	6	<1	IP	--
			728	--	--	--	--
			1087	1	<1	--	--
2	18 Cr (Ti)	--	350	555	44	H	H[f]
			728	464	37	H	H
			1087	250	20	H	H
3	18 Cr (Ti)	XBW	350	544	43	H	--
			728	688	55	H	H
			1087	350	28	H	H
4	20 Cr-24 Ni-6.5 Mo	--	350	2	<1	--	--
			728	1	<1	--	--
			1087	1	<1	--	--
5	20 Cr-24 Ni-6.5 Mo	S	350	121	10	--	--
			728	65	5	--	--
			1087	65	5	--	--
6	18 Cr-2 Mo	--	350	615	49	H	--
			728	534	42	H	H
			1087	224	18	H	H

Table 11 (Con't.)

System*	Material	Treatment (a)	Exposure, Time, Days	Average[b] Weight Loss mg	Average[b] Weight Loss mg/dm^2	Pit Depth, mils[d] Maximum	Pit Depth, mils[d] Average of 5 Deepest (e)
8	18 Cr-8 Ni (N)	--	350	25	2	--	--
			728	12	1	24	--
			1087	56	4	H	--
9	18 Cr-8 Ni (N)	XBW	350	922	73	H	--
			728	1536	122	H	--
			1087	1776	142	H	--
10	26 Cr-6.5 Ni	--	350	403	32	H	--
			728	1082	86	H	H
			1087	1093	87	H	H
14	Composite A[c]	--	350	24200	1904	N/A	
			728	27125	2134	N/A	
			1087	39100	3076	N/A	
15	Composite B[c]	HD2	350	12175	958	N/A	
			728	1350	106	N/A	
			1087	12575	989	N/A	
16	Composite C[c]	--	350	20275	1595	N/A	
			728	17750	1396	N/A	
			1087	38450	3025	N/A	
17	26 Cr-1 Mo	HW	350	6	2	13	--
			728	4	1	5	--
			1087	2660	650	50	16
18	18 Cr (Ti)	HW	350	6	2	--	--
			728	--	--	--	--
			1087	3	1	--	--
19	20 Cr-24 Ni-6.5 Mo	HW	350	1	<1	--	--
			728	--	--	--	--
			1087	1	<1	--	--
Exposed in 1972							
7	18 Cr-2 Mo (Nb)	--	380	--	--	<5	--
			736	4	<1	<5	--
11	18 Cr-2 Mo (Nb)	XBW	380	515	41	H	--
			736	516	41	H	--
12	18 Cr-2 Mo (Nb)	HW	380	162	40	H	H
			736	356	87	H	

Table 11 (Con't.)

*Systems 12, 17, 18, 19, 57, 62, and 63 were tube specimens fabricated from sheet material, welded at the seams and then plugged and capped at each end to minimize internal corrosion. Specimens of all other systems were flat sheet material.

(a) All materials were in the annealed condition unless noted otherwise. Abbreviations used:

S-sensitized
XBW-cross-bead weld
HW-heliarc weld
HFW-high frequency weld
HDZ-hot-dip zinc coated (galvanized, 4.5 oz/ft^2) after bonding. See footnote (c).

(b) Average for four specimens.

(c) All composites were metallurgically bonded.
Composite A-Carbon steel/Type 430/Carbon steel.
Composite B-Carbon steel/Type 430/Carbon steel.
Composite C-Carbon steel/Type 304/Carbon steel.

(d) 1 mil = 0.025 mm. IP - incipient pitting. H - perforated. N/A - not applicable

(e) Average of five deepest pits on each of four individual specimens unless noted otherwise.

(f) Average of ten deepest pits on each of four individual specimens.

Table 12. Average Weight Loss (mg/dm^2) and Pit Depth (mils) for Stainless Steel Sheet and Tube Specimens Buried in Tidal Marsh (Site G) for up to Four Years

System*	Material	Treatment (a)	Exposure, Time, Days	Average (b) Weight Loss mg	Average (b) Weight Loss mg/dm^2	Pit Depth, mils(d) Maximum	Pit Depth, mils(d) Average of 5 Deepest (e)
Exposed in 1970							
50	Type 201	--	356	3754	299	45	--
			719	1199	95	H	--
			1355	78	6	35	--
51	Type 202	--	356	60	5	40	--
			719	18	1	33	7
			1355	85	7	H	H
52	Type 301	--	356	165	12	40	--
			719	1117	88	30	--
			1355	218	18	H	H
53	Type 301	S	356	5016	400	25	--
			719	13123	1046	H	--
			1355	2185	108	36	13
54	Type 301	XBW	356	49	4	13	--
			718	1603	128	62	9
			1355	1400	112	12	--
55	Type 304	--	356	930	73	H	--
			719	1829	146	36	11
			1355	304	24	37	6
56	Type 304	S	356	322	24	20	--
			719	6191	494	H	--
			1355	5146	409	26	8
57	Type 304	HW	856	1	<1	--	--
			719	4	<1	10	3
			1355	2	<1	11	5
58	Type 316	--	356	7	<1	<5	--
			719	3	<1	<5	--
			1355	--	--	--	--
59	Type 316	S	356	11	<1	<5	--
			719	92	6	<5	--
			1355	--	--	<5	--
60	Type 409	--	356	31407	2501	H	H(f)
			719	66328	5283	H	H(f)
			1355	23206	1848	H	H(f)

Table 12 (Con't.)

System*	Material	Treatment (a)	Exposure, Time, Days	Average[(b)] Weight Loss mg	mg/dm^2	Pit Depth, mils[(d)] Maximum	Average of 5 Deepest (e)
62	Type 409	HW	356	8448	3367	H	H[(f)]
			719	17055	6795	H	H[(f)]
			1355	4218	1681	H	H
63	Type 409	HFW	356	4691	2403	H	H[(f)]
			719	19912	10199	H	--
			1355	10034	5139	H	H
64	Type 410	--	356	31997	2547	H	H[(f)]
			719	70709	5630	H	H[(f)]
			1355	104434	8314	H	H
65	Type 430	--	356	44284	3528	H	H[(f)]
			719	103642	8256	H	H[(f)]
			1355	191351	15243	H	H
66	Type 434	--	356	99	8	H	--
			719	7327	584	H	--
			1355	--	--	6	--
Exposed in 1971							
1	26 Cr-1 Mo	--	362	5	<1	IP	--
			755	3	<1	--	--
			1098	--	--	--	--
2	18 Cr (Ti)	--	362	11974	954	H	--
			755	33777	2691	H	H
			1098	5984	477	37	13
3	18 Cr (Ti)	XBW	362	3712	296	H	--
			755	815	65	28	--
			1098	3	<1	<5	
4	20 Cr-24 Ni-6.5 Mo	--	362	1	<1	--	--
			755	--	--	--	--
			1098	--	--	--	--
5	20 Cr-24 Ni-6.5 Mo	S	302	152	12	IP	--
			755	--	--	--	--
			1098	--	--	--	--
6	18 Cr-2 Mo	--	362	402	32	H	--
			755	630	50	H	H
			1098	--	--	<5	--
8	18 Cr-8 Ni (N)	--	362	56	4	5	--
			755	159	13	H	H
			1098	2	<1	--	--

Table 12 (Con't.)

System*	Material	Treatment (a)	Exposure, Time, Days	Average[b] Weight Loss mg	mg/dm^2	Pit Depth, mils[d] Maximum	Average of 5 Deepest (e)
9	18 Cr-8 Ni (N)	XBW	362	905	72	110	--
			755	3409	272	11	--
			1098	2	<1	--	--
10	26 Cr-6.5 Ni	--	362	4770	380	H	--
			755	248	20	H	H
			1098	14	1	7	6
14	Composite A[c]	--	362	113275	8912	N/A	
			755	380200	29911	N/A	
			1098	398800	31374	N/A	
15	Composite B[c]	HDZ	362	57825	4549	N/A	
			755	66250	5212	N/A	
			1098	49300	3878	N/A	
16	Composite C[c]	--	362	105400	8292	N/A	
			755	256400	20172	N/A	
			1098	358000	28165	N/A	
17	26 Cr-1 Mo	HW	362	2	<1	--	--
			755	57	14	<5	--
			1098	4	1	<5	--
18	18 Cr (Ti)	HW	362	3468	1383	H	--
			755	24641	9825	H	H
			1098	15115	6027	H	H
19	20 Cr-24 Ni-6.5 Mo	HW	362	--	--	--	--
			755	--	--	--	--
			1098	--	--	--	--
Exposed in 1972							
7	18 Cr-2 Mo (Nb)	--	362	--	--	--	--
			736	11	<1	45	--
11	18 Cr-2 Mo (Nb)	XBW	362	--	--	--	--
			736	7	<1	45	--
12	18 Cr-2 Mo (Nb)	HW	362	--	--	--	--
			736	9	2	IP	--

Table 12 (Con't.)

*Systems 12, 17, 18, 19, 57, 62, and 63 were tube specimens fabricated from sheet material, welded at the seams and then plugged and capped at each end to minimize internal corrosion. Specimens of all other systems were flat sheet material.

(a) All materials were in the annealed condition unless noted otherwise. Abbreviations used:

S-sensitized
XBW-cross-bead weld
HW-heliarc weld
HFW-high frequency weld
HDZ-hot-dip zinc coated (galvanized, 4.5 oz/ft^2) after bonding. See footnote (c).

(b) Average for four specimens.

(c) All composites were metallurgically bonded.
Composite A-Carbon steel/Type 430/Carbon steel.
Composite B-Carbon steel/Type 430/Carbon steel.
Composite C-Carbon steel/Type 304/Carbon steel.

(d) 1 mil = 0.025 mm. IP - incipient pitting. H - perforated. N/A - not applicable.

(e) Average of five deepest pits on each of four individual specimens unless noted otherwise.

(f) Average of ten deepest pits on each of four individual specimens.

Table 13. Summary of Results Obtained from Non-Galvanically Coupled Stressed 1-in x 12-in Stainless Steel Specimens After Exposure for up to 4 Years at the Six NBS Soil Corrosion Test Sites

System	Stainless steel	Treatment (a)	Stressed Specimen (b)	Exposure Time-years	Number of Specimens Failed Site A	Site B	Site C	Site D	Site E	Site G
Exposed in 1970										
67	Type 301	HH	U	1	0	0	0	0	0	0
				2	0	0	1(c)	0	0	0
				4	0	0	0	0	0	0
68	Type 301	HH	(UU)	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				4	0	0	0	0	0	0
69	Type 301	HH+S	UU	1	1(d)	1(d)	2(d)	2	2	1
				2	1	0	2	2	2	1
				4	2	1	2	2	2	2
70	Type 301	FH	U	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				4	0	0	0	0	0	0
71	Type 301	FH	(UU)	1	0	0	0	0	0	0
				2	0	0	0	0	0	1(d)
				4	0	0	0	0	0	0
72	Type 304	--	U	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				4	0	0-NR*	0	0	0	0
73	Type 304	--	(UU)	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				4	0	0	0	0	0	0
74	Type 304	HH	U	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				4	0	0	0	0	0	0
75	Type 304	HH	(UU)	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				4	0	0	0	0	0	0
76	Type 304	S	UU	1	0	0	0	0	1	0
				2	0	0	1-1(d)	0	0	0
				4	0	0-NR*	0	0	0	0
77	Type 316	--	U	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				4	0	0	0	0	0	0
78	Type 316	--	(UU)	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				4	0	0-NR*	0	0	0	0
79	Type 316	S	UU	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				4	0	0	0	0	0	0
80	Type 434	--	U	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				4	0	0-NR*	0	0	NR*	0
81	Type 434	--	(UU)	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				4	0	0	0-NR*	0	0	0
Exposed in 1971										
20	26 Cr-1 Mo	--	(UU)	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				3	0	0	0	0	0	0

Table 13 (Con't.)

System	Stainless steel	Treatment (a)	Stressed Specimen (b)	Exposure Time-years	Number of Specimens Failed Site A	Site B	Site C	Site D	Site E	Site G
21	26 Cr-1 Mo	--	U	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				3	0	0	0	0	0	0
22	20 Cr-24 Ni-6.5 Mo	--	(UU)	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				3	0	0	0	0	0	0
23	20 Cr-24 Ni-6.5 Mo	--	U	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				3	0	0	0	0	0	0
24	20 Cr-24 Ni-6.5 Mo	--	UU	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				3	0	0	0	0	0	0
25	18 Cr-2 Mo		(UU)	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				3	0	0	0	0	0	0
26	18 Cr-2 Mo		U	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				3	0	0	0	0	0	0
27	18 Cr-8 Ni(N)		(UU)	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				3	0	0	0	0	0	0
28	18 Cr-8 Ni(N)		U	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				3	0	0	0	0	0-NR*	0
30	26 Cr 6.5 Ni		U	1	0	0	0	0	0	0
				2	0	0	0	0	0	0
				3	0	0	0	0	0	0

*Specimen not retrieved

(a) All specimens in the annealed condition unless noted otherwise
HH-half hard
FH-full hard
S-sensitized

(b) U-single U-bend specimen
UU-double U-bend specimen
(UU)-double U-bend specimen, joined by a spot weld

(c) Micro crack on face, specimen considered failed

(d) Micro crack on edge, specimen considered failed

Table 14. Average[a] couple current vs. failure.

System	Specimen	Coupled to	Site A Washington		Site B Loch Raven		Site C Cape May		Site D Wildwood (Dry Sand)		Site E Wildwood (Wet Sand)		Site G Patuxent	
			μA/cm²	Failures	μA/cm²	Failures	μA/cm²	Failures	μA/cm²	Failures	μA/cm²	Failures	μA/cm²	Failures
82	301 HH[b]	Zn	2.58	0	1.43	2	20	2	0.94	2	1.14	2	10.3	2
83	"	Mg	17.2	1	4.81	2	122	2	3.95	2	34.7	2	237	2
84	"	Fe	0.06	0	0.48	0	1.45	2	0.17	0	0.48	0	4.08	0
85	301 FH[b]	Zn	4.17	0	1.51	2	20.5	2	1.23	2	0.98	2	14.7	2
86	"	Mg	20.5	2	8.66	2	120	2	3.79	2	34.7	2	249	2
87	"	Fe	0.05	0	0.56	0	1.29	2	0.23	0	0.59	0	4.65	1
88	304[b]	Zn	2.57	0	1.86	0	26.3	0	0.96	0	0.71	0	11.5	0
89	"	Mg	25.3	0	6.38	0	117	0	5.25	0	30.2	0	258	0
90	"	Fe	0.09	0	0.45	0	0.99	0	0.06	0	0.59	0	8.27	0
33	26Cr-1Mo[c]	Zn	7.75	0	1.49	0	33.8	0	1.39	0	2.47	0	18.5	0
34	"	Mg	22.7	0	3.57	0	133	0	3.77	0	24.0	0	353	0
35	"	Fe	4.73	0	0.54	0	0.87	0	0.25	0	2.4	0	-0.21	0
36	26Cr-6.5Ni[c]	Zn	7.30	0	1.72	0	27.8	0	1.31	0	5.01	0	13.1	0
37	"	Mg	47.4	0	4.0	0	138	0	4.53	0	28.4	0	375	0
38	"	Fe	0.37	0	0.98	0	1.57	0	0.35	0	0.94	0	6.52	0

[a]Average of two specimens - 16 readings.

[b]Four year exposure.

[c]Three year exposure.

Table 15. Galvanic current[(a)]/potential[(b)] and visual data of stainless steel couple.

System	Stainless Steel	Observation	Site A Washington mA (V)	Site B Loch Raven mA (V)	Site C Cape May mA (V)	Site D Wildwood (Dry Sand) mA (V)	Site E Wildwood (Wet Sand) mA (V)	Site G Patuxent mA (V)
42[c]	26Cr-6.5Ni Alloy	electro-chemical[e]	-0.0002 (-0.111)	-0.004 (-0.004)	+0.005 (-0.148)	+0.004 (-0.138)	-0.120 (-0.021)	-0.004 (-0.427)
		visual[f]	no attack	no attack	few pits (3 mil)	edge pits (1 mil)	corrosion under solder	few pits (7 mil)
91[d]	Type 304	electro-chemical[e]	-0.0001 (-0.061)	-0.027 (+0.001)	-0.010 (-0.130)	+0.003 (-0.163)	-0.016 (-0.101)	+0.017 (-0.443).
		visual[f]	no attack	no attack	scattered etching	scattered etching	no attack	pitted (30 mil)
92[d]	Type 409	electro-chemical[e]	+0.002 (-0.059)	-0.022 (-0.007)	+0.045 (-0.358)	+0.003 (-0.147)	+0.013 (-0.158)	+0.158 (-0.497)
		visual[f]	one edge pit (22 mil)	no attack	perforated (10% wt. loss) [gh]	pitted (2 mil)	perforated (5% wt. loss) [gh]	perforated (30% wt. loss)[h]

[a]Negative current indicates stainless steel is cathode.

[b]Potential vs. Cu-$CuSO_4$.

[c]Three year exposure.

[d]Four year exposure.

[e]Four specimens per system at each site - average of minimum of 20 readings.

[f]1 mil = 0.025 mm.

[g]One specimen lost.

[h]Approximate weight loss based on visual observation. All other specimens in Table <2% weight loss maximum.

Table 16. Visual results[(a)] of copper connected to stainless steel.

System	Material	Site A Washington	Site B Loch Raven	Site C Cape May	Site D Wildwood (Dry Sand)	Site E Wildwood (Wet Sand)	Site G Patuxent
42[b]	Copper (connected to 26Cr-6.5Ni Alloy)	slight cluster etching (<1 mil)	pitted (5 mil)	gen. corrosion (3 mil)	gen. corrosion (2 mil)	gen. corrosion (2 mil)	etched (<1 mil)
91[c]	Copper (connected to SS Type 304)	etched & few pits (2 mil)	pitted (5 mil)	gen. corrosion (2 mil)	gen. corrosion (3 mil)	gen. corrosion (1 mil)	etched (<1 mil)
92[c]	Copper (connected to SS Type 409)	etched (<1 mil)	pitted (5 mil)	gen. corrosion (2 mil)	gen. corrosion (2 mil)	gen. corrosion (1 mil)	etched (<1 mil)

[a] 1 mil = 0.025 mm.

[b] Three year exposure.

[c] Four year exposure.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

In order to obtain more definitive information regarding the corrosion and stress corrosion of stainless steels in soil environments, NBS in cooperation with the Committee of Stainless Steel Producers, AISI, initiated in 1970 a soil burial program in representative soil environments. Test materials included coated and uncoated sheet specimens in the annealed and sensitized condition, uncoated welded tubing specimens and galvanically coupled and uncoupled stressed and unstressed specimens. To date approximately 10,000 specimens have been buried at six soil test sites. This report contains the results obtained for specimens buried for up to approximately four years.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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