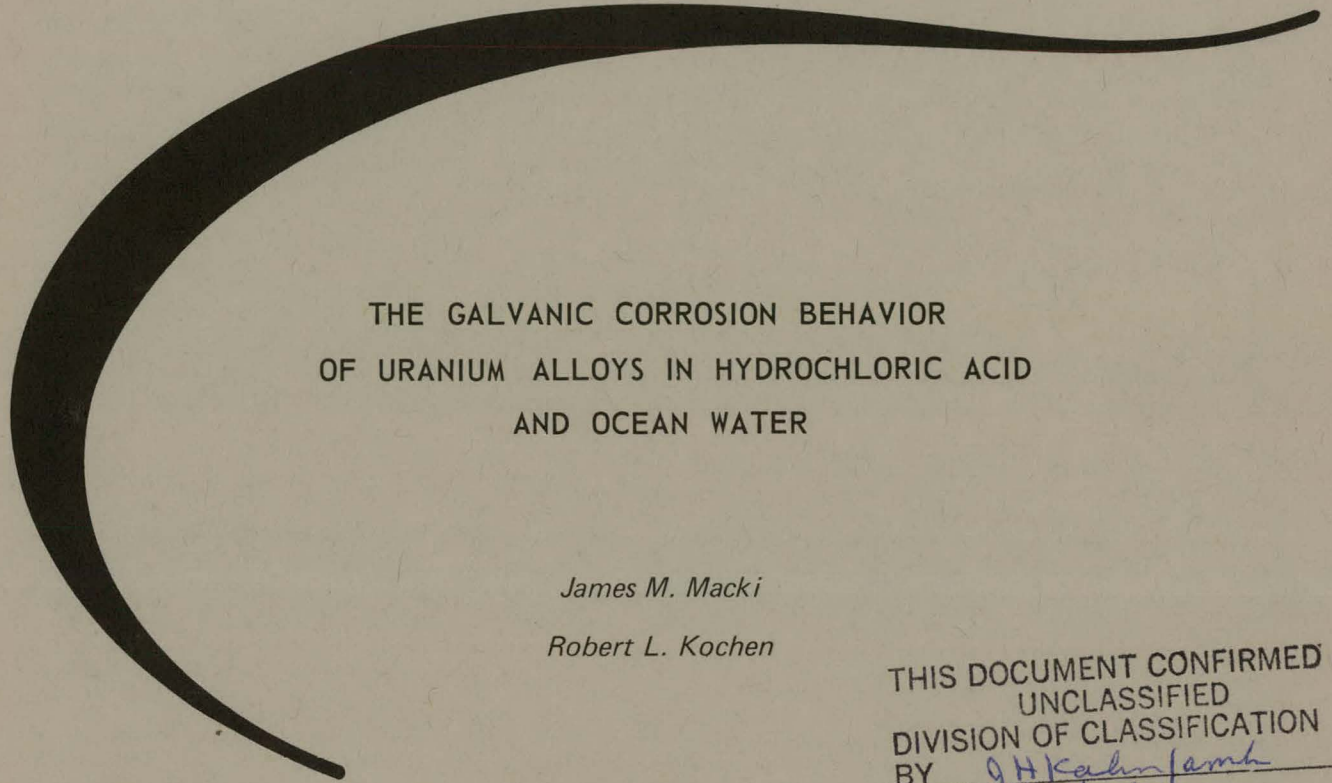


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February 24, 1971

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THE GALVANIC CORROSION BEHAVIOR
OF URANIUM ALLOYS IN HYDROCHLORIC ACID
AND OCEAN WATER

James M. Macki

Robert L. Kochen

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THE GALVANIC CORROSION BEHAVIOR OF URANIUM ALLOYS IN HYDROCHLORIC ACID AND OCEAN WATER

James M. Macki
Robert L. Kochen

Abstract. The galvanic corrosion behaviors of a selected group of alloys in ocean water and hydrochloric acid (HCl) were determined by measuring the gravimetric corrosion rates of galvanically coupled specimens and by constructing a galvanic series for each environment from electrode potential measurements. Based on the gravimetric-galvanic corrosion tests, the galvanic series of the alloys tested, in the order of increasing nobility in 0.1N HCl at 70°C is: 7178 Al, Tuballoy (depleted uranium), U-4.5 Nb, type 4340 steel, U-6 Nb, U-8 Nb, U-7.5 Nb-2.5 Zr (Mulberry), U-10 Mo, Ti-6 Al-4 V, and type 304 steel (passive). The galvanic series, based on electrode potentials, in 0.1N HCl at 25 and 70°C and in ocean water at 25°C, are the same as the series based on the gravimetric-galvanic corrosion tests except for Ti-6 Al-4 V, which occupies a more active position according to the potential measurements.

Although they are adjacent to each other in the galvanic series, the type 4340 steel causes the U-4.5 Nb alloy to corrode an order of magnitude faster than the other more noble metals in the series in 0.1N HCl at 70°C.

INTRODUCTION

Some uses of uranium-base alloys require that they be in contact with other metals. Applications may require a welded joint between Tuballoy and a U-Nb binary alloy. Consequently, the purpose of this investigation was to determine the galvanic corrosion behaviors of a selected group of materials. This work is part of a project that was outlined in an earlier report.¹

Galvanic corrosion is one of the eight types of corrosion.^{2,3} When two dissimilar metals are electrically connected and immersed in a suitable electrolyte, a galvanic current flows between the two metals. The driving force for the current flow is the potential difference between the two dissimilar metals. Galvanic

corrosion denotes that corrosion which is attributable to the galvanic current passing from the cathode to the anode of the couple. When other variables are held constant, the amount of galvanic corrosion is usually proportional to the potential difference between the anode and cathode members of the couple.

A galvanic series is a list of metals and alloys arranged in order of the potentials generated when electrodes of each material are compared with one another in a specific environment. Since the sequence of the potentials assumed by the materials can vary with the environment, a galvanic series obtained in one environment is not necessarily valid for another environment. Thus, ideally a galvanic series for each potential environment is necessary, but this would require a prohibitively large number of tests. To reduce the number of tests, the galvanic series in ocean water is used for most applications and additional galvanic series are determined only for a few selected environments.

A galvanic series differs from a standard EMF series; the galvanic series is based on the potentials generated by corroding electrodes in any specific environment. The standard EMF series is based on the potentials generated by pure metals exposed to solutions containing one-gram-atomic-weight of their respective ions (unit activity) under reversible or noncorroding conditions. However, in actual corrosion situations, galvanic coupling between pure metals in equilibrium with their ions rarely occurs. Most galvanic corrosion results from the electrical connection of two corroding metals. Since most engineering materials are alloys, galvanic couples usually include one or two metallic alloys for which standard EMF values do not exist. Consequently, a galvanic series, obtained by actual potential measurements in an environment, yields a more accurate prediction of galvanic relationships in that environment than does the standard EMF series. Similarly, the galvanic series in ocean water usually yields a more accurate prediction of galvanic corrosion in a different environment than does the EMF series.

The relative positions of two materials in a galvanic series (potential differences) are not conclusive indicators of galvanic corrosion because of polarization. Polarization refers to the change in potential of an electrode resulting from current flow. The effect of polarization is usually to alter the potential assumed by the cathode in the direction of the anode, and the potential of the anode in the cathodic direction. The net result of polarization is to decrease the potential difference and thereby decrease the galvanic current and galvanic corrosion.

An important factor in galvanic corrosion is the ratio of the cathodic to anodic areas. When the galvanic couple is under cathodic control, the amount of galvanic current (hence the amount of galvanic corrosion on the anode) is proportional to the area of the cathode. For example, if copper sheet is fastened together with steel rivets and exposed to ocean water, the steel rivets (anodes) will rapidly fail because of the large galvanic current generated by the copper cathode, which imposes a large galvanic current per unit area on the smaller anodic areas (steel rivets). Another example would be a steel tank with a stainless steel bottom. A common error would be to paint the steel (anode) sides but leave the stainless steel (cathode) unpainted. This produces an essentially infinite cathodic to anodic area ratio between the stainless steel bottom and the steel exposed through flaws in the paint. The result is rapid failure caused by accelerated corrosion through the steel at the flaws in the paint. Painting only the stainless steel would eliminate the galvanic corrosion problem by minimizing the cathodic area. In general, when two dissimilar materials are connected together, galvanic corrosion can be minimized by painting the more noble material and thereby minimizing the cathodic to anodic area ratio. An excellent discussion of galvanic corrosion effects and polarization is contained in Fontana and Greene.²

The only known published data on the galvanic corrosion of uranium-base alloys is that of Love and Cole;⁴ this investigation involved materials for the SNAP-21 radioisotopically fueled power system which was designed for marine environment applications. The uranium-base alloy examined was U-8 wt% Mo which was tested with other SNAP-21 materials (Al, Cu, type 304 steel, Ta, Ti 621, Ni and Hastelloy C) in aerated and deaerated ocean water. Their results place U-8 Mo between Al (active) and copper (noble) in the galvanic series in both ocean water environments.

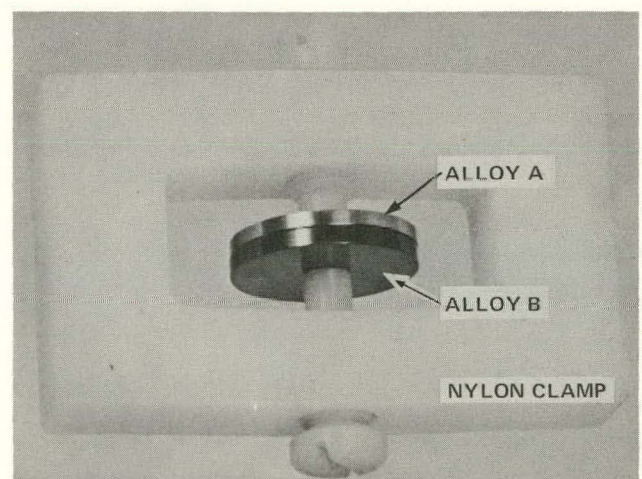
EXPERIMENTAL

The alloys used in the galvanic corrosion tests are listed in Table I. The specimens for each alloy were 1-inch diameter by 0.080-inch-thick disks. The uranium alloy disks were machined from hot-rolled material produced from ingots that had been homogenized for 6 hours at 1100°C in a vacuum after vacuum-induction melting and casting. All the uranium alloy disks, except Tuballoy, were in the solution-quenched (unaged) condition. The solutionizing temperatures were 850°C for Mulberry and 800°C for the binary alloys. In the solution-quenched condition, the Mulberry and U-8 Nb alloys probably possess the tetragonal γ^0 structure whereas the U-4.5 Nb and U-6 Nb alloys possess the alpha-double-prime (α'') structure.^{5, 6} The U-10 Mo alloy would possess the gamma structure. Specimens of each uranium alloy were analyzed to determine the compositions and impurity levels.

The uranium alloy disks were machined from the same sheet material as were the disks for the gravimetric immersion tests reported earlier;⁷ stress-corrosion cracking specimens were obtained from the same sheets of material and will be tested at a later date.¹

The faces of each disk were abraded on a 240-grit silicon carbide belt using distilled water as a coolant. The dimensions of the ground disks were measured with a micrometer to the nearest 0.001 inch. After measuring, the disks were cleaned with acetone, dried, and weighed to the nearest 0.1 mg. The weighed disks were assembled into galvanic couples by mounting them in the nylon, galvanic-corrosion apparatus shown in Figure 1. As shown in Figure 1, the couples

Figure 1. Apparatus Used for Gravimetric-Galvanic Corrosion Tests.



were made by clamping two alloy disks together with the nylon screws and coating the exposed edges of the disks with silicone adhesive (Dow Corning 3145) so that only one face of each disk was exposed to the environment. The electrical resistance of each couple was checked before and after exposure to ensure electrical contact between the disks. The adhesive required 24 hours to set, so the couples were exposed to laboratory air for 24 to 30 hours prior to exposure to the 0.1N HCl.

The galvanic couples were immersed in 0.1N HCl from 4 to 96 hours. The exposure period was determined by the corrosion rate; couples exhibiting rapid-corrosion rates were exposed for 4 hours, whereas those exhibiting low-corrosion rates were exposed for 72 to 96 hours to achieve detectable weight losses.

At the end of the exposure period, each couple was disassembled and the silicone adhesive was stripped off.

The disks were rinsed in distilled water and acetone, then dried and reweighed to determine the weight losses. The weight losses were converted into corrosion rates in mpy (mils penetration per year) according to the equation

$$\text{mpy} = \frac{(534) \Delta W}{DAT}$$

where ΔW is the weight loss in mg, D is the density in g/cm³, A is the exposed surface area in square inches, and T is the exposure time in hours.

The electrical potentials generated by electrodes fabricated from disks of each alloy immersed in ocean water at 25°C (ASTM Designation D-1141-52) and 0.1N HCl at 25 and 70°C were measured relative to a saturated calomel electrode. The room temperature measurements were made using both oxygen-saturated and air-equilibrated solutions. Oxygen saturation was achieved by continuously bubbling oxygen through the solution during the tests; air-equilibration was obtained by the natural convection of the room air and the solutions. The voltages were measured with a Hewlett-Packard Model 405AR high impedance digital voltmeter. The voltages were monitored from 5 to 30 minutes until a steady state potential was observed.

The electrode potentials were used to establish a galvanic series for the alloys tested in each environment. Only one electrode of each alloy was used for the potential measurements; however, the surface of each elec-

trode was reground on a 240-grit silicon carbide belt and the type 304 steel surface was repassivated between tests.

RESULTS

The compositions and impurity levels of the uranium alloys are summarized in Tables II and III. The results of the gravimetric-galvanic corrosion tests are shown in Tables IV through XI. The galvanic series of the alloys listed in Table I are summarized in Tables XII and XIII.

DISCUSSION

The results of the gravimetric-galvanic corrosion tests as shown in Tables IV through XI are consistent with the electrode potentials measured in the same environment as shown in Table XII.

These results show that the corrosion of Tuballoy will be accelerated by galvanically coupling it to any of the metals tested except the 7178 Al alloy. The 7178 Al alloy may cathodically protect Tuballoy in 0.1N HCl and aerated ocean water. These results also show that a welded joint between Tuballoy and a U-Nb binary alloy will produce a galvanic corrosion cell (when placed in suitable electrolyte) in which the corrosion rate of the Tuballoy will be accelerated.

The U-4.5 Nb alloy is anodic with respect to 4340 steel; consequently, a joint (or another type of electrical connection) between the two alloys in a suitable electrolyte will cause accelerated corrosion on the U-4.5 Nb alloy and reduced corrosion on the steel. In an equal area galvanic couple in 0.1N HCl at 70°C, as shown in Table VI, the U-4.5 Nb alloy corrodes at a rate of 450 mpy while the steel corrodes at a much faster rate of 5,800 mpy. However, the uncoupled corrosion rates are 9 mpy for the U-4.5 Nb and 9,800 mpy for the steel. Thus, the corrosion rate of the steel is reduced by coupling it to the U-4.5 Nb alloy, which acts as a sacrificial anode in the acid environment. The galvanic corrosion rate of the U-4.5 Nb alloy is an order of magnitude greater when the binary alloy is coupled to the 4340 steel than when it is coupled to the other alloys more noble than steel. Evidently, the potential assumed by the U-4.5 Nb/4340 steel couple corresponds to a peak

in the anodic dissolution (potential versus corrosion rate) curve and the potentials of the U-4.5 Nb alloy and the other more noble alloys correspond to a passive type region in the anodic dissolution curve. Actual anodic dissolution curves will have to be generated to verify this conjecture.

The U-6 Nb and U-8 Nb alloys exhibit a regular increase in corrosion rate when progressively coupled to the more noble alloys in the galvanic series (Tables VII and IX). Both binary alloys exhibit zero corrosion rates when coupled to less noble alloys. The results of four different gravimetric-galvanic couples made from eight U-6 Nb alloy disks are summarized in Table VIII. The results indicate that in all cases, one of the "duplicate" disks cathodically protected the other disk so that corrosion was zero or relatively smaller on the protected disk and relatively larger on the other disk. This type of behavior between duplicate disks was observed on all the couples containing two disks of the same uranium alloy, but the behavior was most pronounced on the U-6 Nb/HCl/U-6 Nb galvanic cells. This effect is a surface phenomena and does not necessarily imply a variation in bulk niobium concentration although variations in niobium concentration at the surfaces of the disks could account for the galvanic corrosion effects between disks of the same alloy.

The corrosion rates of the U-8 Nb, Mulberry, and U-10 Mo alloys are only slightly accelerated by coupling to more noble alloys. However, when these alloys act as cathodes in a galvanic couple, the cathodic reaction on their surfaces probably generates hydrogen which could result in hydrogen embrittlement of the cathode.

In comparing the galvanic series in Tables XII and XIII with the results of the gravimetric-galvanic corrosion tests it is evident that the galvanic series based only on electrode potential measurements are useful for indicating potential galvanic corrosion effects; however, the potential measurements cannot predict the anomalous gravimetric-galvanic corrosion behaviors exhibited by the U-4.5 Nb/HCl/4340 steel couple or the U-6 Nb/HCl/U-6 Nb couples.

The galvanic series deduced from the results of the gravimetric-galvanic corrosion tests agrees with the galvanic series based on the electrode potentials measured in air-equilibrated, 0.1N HCl at 25 and 70°C.

The only disagreement between the two types of series is in the position of the titanium alloy, and since titanium cathodically polarizes readily,² the position of the titanium alloy in a galvanic series will depend on the degree of polarization in the environment.

CONCLUSIONS

1. Based on the gravimetric-galvanic corrosion tests, the galvanic series of the alloys tested, in order of the increasing nobility, in 0.1 N HCl at 70°C, is: 7178 Al, Tuballoy, U-4.5 Nb, 4340 steel, U-6 Nb, U-8 Nb, Mulberry, U-10 Mo, Ti-6 Al-4V, and 304 steel (passive).
2. The galvanic series, based on electrode potentials, in 0.1N HCl at 25 and 70°C, and in oxygen-saturated ocean water, are the same as the series based on the gravimetric-galvanic corrosion tests except for the position of Ti-6 Al-4 V which occupies a more active position according to the potential measurements.
3. When Tuballoy is coupled to the more noble uranium alloys, accelerated corrosion occurs on the Tuballoy. The corrosion rate of Tuballoy coupled to the other uranium alloys tested is increased by 25 to 100 percent of the corrosion rate of uncoupled Tuballoy in 0.1N HCl at 70°C.
4. Although they are adjacent to each other in the galvanic series, the U-4.5 Nb/4340 steel couple results in accelerated corrosion on the binary alloy in 0.1N HCl at 70°C. The 4340 steel causes the U-4.5 Nb alloy to corrode an order of magnitude faster in the acid than the other more noble metals in the series.
5. In applications where U-4.5 Nb and 4340 steel are exposed to corrosive environments, both components should be protected from the environment to minimize galvanic corrosion effects. A galvanic couple between painted U-4.5 Nb and unpainted 4340 steel will have a large cathodic (4340 steel) to anodic (flaws in the paint coating on the U-4.5 Nb) area ratio and rapid penetration of the U-4.5 Nb structure would be expected, assuming that the galvanic behaviors of the two alloys in 0.1N HCl at 70°C can be extrapolated to other corrosive environments.

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APPENDIX I

Table I. Alloys Used in Galvanic Tests.^a

Tuballoy (depleted uranium)	U-10 wt% Mo
U-4.5 wt% Nb	7178 Al
U-6 wt% Nb	Ti-6Al-4V
U-8 wt% Nb	4340 steel
Mulberry (U-7.5 wt% Nb-2.5 wt% Zr)	304 steel (passivated)

^aThe compositions of the uranium-base alloys are given in Table II.

Table II. The Compositions of the Uranium Alloys.

Alloy	Composition (wt%)		
	Nb	Zr	Mo
U-4.5 Nb	4.2 ^a	—	—
U-6 Nb	5.7 ^b	—	—
U-8 Nb	7.7 ^c	—	—
Mulberry	7.5 ^d	2.44 ^d	—
U-10 Mo	—	—	9.4 ^e

^aAverage of 12 samples. Nb concentrations reported ranged from 4.0 to 4.7 wt%.

^bAverage of 10 samples. Nb concentrations reported ranged from 5.4 to 6.0 wt%.

^cAverage of 10 samples. Nb concentrations reported ranged from 7.2 to 8.4 wt%.

^dAverage of 3 samples. Nb concentrations reported were 7.4, 7.6, and 7.6 wt% while Zr concentrations reported were 2.43, 2.44, and 2.44 wt%, respectively.

^eAverage of 3 samples. Mo concentrations reported were 9.2, 9.5, and 9.6 wt%.

Table III. Typical Impurity Levels in the Uranium Alloys.

Impurities ^a (ppm)	Alloy				
	U-4.5 Nb	U-6 Nb	U-8 Nb	Mulberry	U-10 Mo
Al	15	15	15	125	5
B	<1	<1	<1	<1	<1
Ba	<100	<100	<100	<50	<10
Be	<1	1	1	6	25
Bi	<10	<10	<10	<10	<10
Ca	<25	<25	<25	10	<1
Cd	<25	<25	<25	<10	—
Co	<10	<10	<10	<10	<10
Cr	<50	<50	<50	10	<10
Cu	20	20	15	30	15

Table III (continued)

Impurities ^a (ppm)	Alloy				
	U-4.5 Nb	U-6 Nb	U-8 Nb	Mulberry	U-10 Mo
Fe	40	50	60	100	10
K	<10	<10	<10	10	<1
Li	<1	<1	<1	<1	<1
Mg	<1	<1	<1	<10	<1
Mn	<10	<10	<10	<10	11
Mo	<10	<10	<10	230	—
Ni	<25	25	25	15	10
Pb	<1	<1	<1	<1	<1
Sb	<10	<10	<10	<10	<10
Si	58	73	30	600	90
Sn	<1	<1	<1	<10	15
Ti	<50	<50	<50	<100	<1
V	<10	<10	<10	<10	<1
Zn	<50	<50	<50	<50	<50
Zr	—	—	—	—	—
C	90	100	60	—	—

^aThe Fe and Si contents were determined by atomic absorption. The other impurity levels were determined by spectrographic analysis.

Table IV. Gravimetric-Galvanic Corrosion Rates in 0.1N HCl at 70 ± 2°C for the Galvanic Cell: Alloy A | HCl | Alloy A.^a

Alloy	Corrosion Rates (mpy) ^b	
7178 Al	9,900	13,000
Tuballoy	2,100	2,300
U-4.5 Nb	8	9
4340 Steel	9,600	9,800
U-6 Nb	0 ^c	16 ^c
U-8 Nb	1	6
Mulberry	2	6
U-10 Mo	0	6
Ti-6 Al-4 V	0	0
304 Steel ^d	0	0

^aThat is, for the cell fabricated by coupling two disks of the same alloy together.

^bmpy = mils penetration per year. There is one corrosion rate for each of the two disks in the couple.

^cTable VIII has additional corrosion rates for the U-6 Nb couple.

^dPassive.

Table V. Gravimetric-Galvanic Corrosion Rates in 0.1N HCl at 70 ±2°C for the Galvanic Cell: Tuballoy |HCl| Couple Alloy.

Couple Alloy	Corrosion Rates (mpy) ^a	
	Tuballoy	Couple Alloy
Tuballoy	2,100	2,300
U-4.5 Nb	2,700	0
U-6 Nb	2,500	0
U-8 Nb	2,700	0
Mulberry	3,200	0
U-10 Mo	3,900	0

^ampy = mils penetration per year.

Table VI. Gravimetric-Galvanic Corrosion Rates in 0.1N HCl at 70 ±2°C for the Galvanic Cell: U-4.5 Nb |HCl| Couple Alloy.

Couple Alloy	Corrosion Rates (mpy) ^a	
	U-4.5 Nb	Couple Alloy
7178 Al	0	16,000
Tuballoy	0	2,700
U-4.5 Nb	9	8
4340 Steel	450	5,800
U-6 Nb	28	0
U-8 Nb	30	0
Mulberry	36	0
U-10 Mo	47	0
Ti-6 Al-4 V	40	0
304 Steel	200	0

^ampy = mils penetration per year.

Table VII. Gravimetric-Galvanic Corrosion Rates in 0.1N HCl at 70 ±2°C for the Galvanic Cell: U-6 Nb |HCl| Couple Alloy.

Couple Alloy	Corrosion Rates (mpy) ^a	
	U-6 Nb	Couple Alloy
7178 Al	0	17,000
Tuballoy	0	2,500
U-4.5 Nb	0	28
4340 Steel	0	9,700
U-6 Nb	0	16
U-8 Nb	15	0
Mulberry	17	0
U-10 Mo	16	0
Ti-6 Al-4 V	20	0
304 Steel	95	0

^ampy = mils penetration per year.

Table VIII. Gravimetric-Galvanic Corrosion Rates in 0.1N HCl at 70 ±2°C for the Galvanic Cell: U-6 Nb |HCl| U-6 Nb.^a

Couple Alloy	Corrosion Rates (mpy) ^b	
	A	B
U-6 Nb	2	20
U-6 Nb	0	16
U-6 Nb	0	23
U-6 Nb	2	24

^aThat is, for the cell fabricated by coupling two U-6 Nb alloy disks, designated A and B, together.

^bmpy = mils penetration per year. There is one corrosion rate for each of the two disks, A and B, in the couple.

Table IX. Gravimetric-Galvanic Corrosion Rates in 0.1N HCl at 70 ±2°C for the Galvanic Cell: U-8 Nb |HCl| Couple Alloy.

Couple Alloy	Corrosion Rates (mpy) ^a	
	U-8 Nb	Couple Alloy
7178 Al	0	14,000
Tuballoy	0	2,700
U-4.5 Nb	0	30
4340 Steel	0	5,400
U-6 Nb	0	15
U-8 Nb	1	6
Mulberry	8	0
U-10 Mo	9	0
Ti-6 Al-4 V	11	0
304 Steel ^b	22	1

^ampy = mils penetration per year.

^bPassive.

Table X. Gravimetric-Galvanic Corrosion Rates in 0.1N HCl at 70 ±2°C for the Galvanic Cell: Mulberry |HCl| Couple Alloy.

Couple Alloy	Corrosion Rates (mpy) ^a	
	Mulberry	Couple Alloy
7178 Al	0	19,000
Tuballoy	0	3,300
U-4.5 Nb	0	36
4340 Steel	0	8,900
U-6 Nb	0	17
U-8 Nb	0	8
Mulberry	2	6
U-10 Mo	9	0
Ti-6 Al-4 V	4	0
304 Steel ^b	15	1

^ampy = mils penetration per year.

^bPassive.

Table XI. Gravimetric-Galvanic Corrosion Rates in 0.1N HCl at 70 ±2° C for the Galvanic Cell: U-10 Mo |HCl| Couple Alloy.

Couple Alloy	Corrosion Rates (mpy) ^a	
	U-10 Mo	Couple Alloy
7178 Al	0	19,000
Tuballoy	0	3,900
U-4.5 Nb	0	47
4340 Steel	0	10,000
U-6 Nb	0	16
U-8 Nb	0	9
Mulberry	0	9
U-10 Mo	0	6
Ti-6 Al-4 V	8	0
304 Steel ^b	11	0

^ampy = mils penetration per year.

^bPassive.

Table III (continued)

Alloy ^a	Electrode Potentials (millivolts) ^b		
	Oxygen-Saturated	Air-Equilibrated	
Mulberry	305	340	410
U-10 Mo	170	190	240
Ti-6 Al-4 V	-310	-385	374
304 Steel ^c	+230	+75	-230

^aThe alloys are listed in order of the increasing nobility from top to bottom as determined from the gravimetric-galvanic tests in air-equilibrated 0.1N HCl at 70° C (Tables IV-XI).

^bExcept for 304 Steel at 25° C, all electrode potentials are negative with respect to the saturated calomel electrode at the temperature of the test.

^cPassive.

Table XIII. A Galvanic Series of Selected Materials in Ocean Water at 25° C^a

Alloy ^b	Electrode Potential (millivolts) ^c	
	Air-Equilibrated	Oxygen-Saturated
7178	800	800
Tuballoy	795	770
U-4.5 Nb	530	525
4340 Steel	540	480
U-6 Nb	460	470
U-8 Nb	415	430
Ti-6 Al-4 V	350	390
Mulberry	-	370
U-10 Mo	-	300
304 Steel ^d	250	225

^aThe ocean water was prepared according to ASTM Designation D-1141-52.

^bThe alloys are listed in order of the increasing nobility from top to bottom as determined by the electrode potentials in oxygen-saturated ocean water.

^cAll electrode potentials are negative with respect to the saturated calomel electrode.

^dPassive.

Table XII. A Galvanic Series of Selected Materials in 0.1N HCl.

Alloy ^a	Electrode Potentials (millivolts) ^b		
	Oxygen-Saturated	Air-Equilibrated	
	25° C	25° C	70° C
7178 Al	-740	-760	-805
Tuballoy	740	755	790
U-4.5 Nb	465	475	600
4340 Steel	445	460	470
U-6 Nb	395	420	465
U-8 Nb	375	400	445