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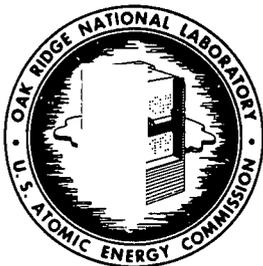
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TO: E. G. Bohlmann

FROM: J. C. Griess, H. C. Savage, J. L. English, R. S. Greeley, S. R. Buxton, D. N. Hess, W. C. Ulrich, and T. H. Mauney.

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I. SUMMARY

A third test of the mockup of the Zircaloy-2 stainless steel transition joint as used in the HRT reactor vessel was completed. No additional mechanical deflections of the bellows were made, but twelve additional thermal cycles of the unit were carried out. The joint and bellows functioned properly and were leak-tight.

Corrosion of stainless steel in 0.04 *m* UO₂SO₄ containing equimolal beryllium sulfate was no greater at 10-15 fps and much less at 15-75 fps, than in HRT solution at 200 and 225°C. Increasing the beryllium sulfate concentration to 0.08 *m* increased corrosion at 225°C and resulted in an unstable solution at 300°C.

Corrosion of a variety of materials in boiler water at 250°C was determined at several oxygen concentrations. Carbon steels showed a minimum in corrosion rate at 250 to 300 ppm oxygen but pitting attack occurred. Corrosion of stainless steels increased with increasing oxygen concentration. Zircaloy-2, titanium RC-55, and niobium showed low corrosion rates in all cases.

The effect of loop history was found to have a large effect on corrosion of stainless steel specimens in 0.17 *m* UO₂SO₄ containing 0.04 *m* H₂SO₄ and 0.03 *m* CuSO₄. The differences previously observed between 100A loop results and in-pile loop results can be explained by this effect.

The addition of 50 ppm chloride ion to 0.17 *m* UO₂SO₄ produced pitting at 250°C and stress-corrosion cracking at 200°C on type 347 stainless steel when oxygen exhaustion was allowed to occur. No pitting or cracking occurred if the stainless steel surface was in contact with oxygen-containing uranyl sulfate solution.

Bromide concentrations of 100 and 200 ppm in boiling and aerated 0.04 *m* UO₂SO₄ solution containing 0.02 *m* H₂SO₄, and 0.005 *m* CuSO₄ were found to produce cracking in stressed type 347 stainless steel. Cracking occurred during the 2000 to 2500 hr period in the 100 ppm bromide test and during the 1000 to 1500 hr exposure period in the 200 ppm bromide test. Cracking was also observed on stressed type 347 stainless steel exposed in a similar boiling and aerated uranyl sulfate solution containing 100 ppm chloride; the cracking took place during the exposure interval between 2000 and 2500 hr.

Pertechnetate concentrations of 60 ppm and less in oxygenated distilled water at 300°C containing 100 ppm chloride were completely ineffective in preventing stress-corrosion cracking of solution-exposed type 347 stainless steel U-bends during exposure periods up to 250 hr. A significant loss in the initial pertechnetate ion concentration was observed in the tests. At pertechnetate concentrations of 510 and 825 ppm, cracking was prevented during 100 and 350 hr runs, respectively. Some technetium was lost from solution during these tests.

Zirconium-base alloys with silicon, chromium, molybdenum, nickel, niobium, and vanadium were exposed for 1000 hr at 300°C in oxygenated 0.04 *m* UO₂SO₄ solution containing 0.02 *m* H₂SO₄ and 0.005 *m* CuSO₄. Alloys of 0.7 Cr - 99.3 Zr and 7 Mo - 20 Nb - 73 Zr exhibited corrosion behavior very comparable to that for Zircaloy-2.

The rate of attack by boiling 5 wt % HNO_3 solution on deposits of Stellite 6 was reduced markedly by pre-exposure in boiling 3 wt % Na_3PO_4 solution. In a number of tests, distilled water at 80°C with an oxygen overpressure of 150 psi caused localized attack of Stellite 6 specimens; in other similar tests, the specimens remained unaffected by the environment. Hard-chrome plated stainless steel specimens exhibited satisfactory corrosion resistance in distilled water and in simulated HRT core solution at 80°C .

Tests to detect porosity of gold plate on type 347 stainless steel bellows by exposure in boiling 10 wt % HCl solution showed that 0.2 and 2.0-mil thick gold plates were highly unsatisfactory. In both cases, severe blistering and cracking of the plate were encountered.

Alsimags 192 (TiO_2) and 652 (96 wt % Al_2O_3) exhibited superior corrosion resistance to high-purity Kearfott aluminum oxide in oxygenated 1.33 m UO_2SO_4 solution at 250°C . The apparent corrosion rates for the former were 15 to 17 mpy as compared with rates of 28 to 30 mpy for the Kearfott alumina after 1000 hr tests.

II. INTRODUCTION

The data presented in the following sections represent the detailed results obtained during the past quarter (January 31, 1957 to April 30, 1957) by the out-of-pile solution corrosion group of the Homogeneous Reactor Project. A summary of the data has been reported in the Homogeneous Reactor Project Quarterly Progress Report for the period ending April 30, 1957.

It should be pointed out that the data presented below are, for the most part, preliminary, and the interpretation of the results may change as further experimentation is completed.

III. 100A LOOP PROGRAM (J. C. Griess, H. C. Savage, R. S. Greeley, S. R. Buxton, W. C. Ulrich, T. H. Mauney)

A. Third Operating Test of the HRT Core-Pressure Vessel Flange and Transition Joint Mockup.

A third test of the mockup of the Zircaloy-2 - stainless steel transition and expansion joint as used in the HRT reactor vessel has been made in 100A dynamic loop F. The first two tests were mentioned previously^{1,2} and detailed reports were published elsewhere.^{3,4}

Prior to assembly of the flanged joint after the second test, several components were inspected for cracks by the "Super Pentrex" post-emulsified fluorescent penetrant method. The results were as follows:

10-in. oval-ring flanges: Two cracks or scratches on gasket mating surfaces of lower flange (blind end), each about 1/4 in. long. No cracks were observed on the upper (dome) flange surfaces.

10-in. oval-ring gasket: One tiny pit and two short cracks or scratches on the flange mating surfaces. These were not related in position to the cracks or scratches found on the flange.

Bellows seam weld: No cracks observed.

Bellows area underneath reinforcing rings: No cracks observed.

Bellows - transition piece circumferential weld: An inch-long crack found in weld. "Dy-Chek" inspection failed to reveal this crack, and thus it may have been present prior to the first test of the mockup, since only a "Dy-Chek" and not a "Super Pentrex" inspection was made at that time.

It should be noted that it is not possible to distinguish for certain between cracks and scratches without metallographic examination which would entail destruction of the specimen.

Following the "Super Pentrex" examination, the test unit was washed thoroughly with water and reassembled. The loop was filled with water to the desired volume, brought to 300°C, and concentrated fuel solution added to give a solution 0.04 m UO₂SO₄, 0.02 m H₂SO₄, and 0.005 m CuSO₄.

In order to determine if the pitting attack observed in the first two tests⁵ was caused by the mechanical action of the bellows, no mechanical deflections were made during the third test. However, thermal cycling was performed as before between 300°C at 1550 psig and 100°C at 100 psig.

The test lasted only 293 hr, 126 hr on water and 167 hr on fuel solution. Twelve complete thermal cycles were made. The test was terminated when samples of the water from the interior of the bellows contained uranium. The interior of the bellows was maintained at 45 to 50 psig below the pressure of the exterior of the bellows so that, if leakage occurred through the bellows or past the transition joint, samples of the water from the interior of the bellows would contain uranium. Thus leakage was indicated. However, after disassembly of the flanged joint, the bellows and transition joint were leak tested with 50 psig of helium and a mass-spectrograph-type leak detector, and no leakage was detected. Therefore, it is believed that the uranium in the bellows water came from carryover of fuel solution from the loop pressurizer into the condenser that supplied the bellows water. Another reason for terminating the test was that oxygen depletion occurred and roughly half of the uranium in the fuel solution precipitated. The uranium was redissolved by adding oxygen before the test was terminated.

Prior to disassembly, the 10-in. IPS, 1500-lb test vessel oval-ring joint was leak tested at 200 psig of helium with a mass-spectrograph-type leak detector. No leakage was observed. After disassembly of the joint and removal of the oval-ring gasket, examination of the flange grooves showed no leakage of fuel solution into the grooves.

The pitted areas on the bellows⁵ were examined closely by moving the reinforcing rings to reveal the entire crevice area between the rings and the bellows. A microscope-dial gauge indicator assembly was used again to measure the pit depths and the measurements showed no increase in depth. However, the run was too short to allow a conclusion to be drawn

as to the effect of mechanical deflections on the pits. Several of the pits broadened slightly and numerous small new pits (less than 1 mil deep) were observed over much of the transition and bellows area, possibly because of the oxygen exhaustion during part of the run.

The corrosion specimens in the loop and test unit were removed, scrubbed, and weighed. They were not defilmed but were replaced in the loop for further testing. The type 304L and 347 stainless steel pins at 17 fps and the type 347 stainless steel coupons at 7 to 64 fps exposed in the loop by-pass and the type 304L, 309 SCb, and 347 stainless steel specimens exposed to fuel solution inside the test unit at about 2 fps all lost small amounts of weight.

All of the titanium and zirconium alloys (Ti - 6% Al 4% V, Ti - 3% Al 5% Cr, Ti - 5% Al 2-1/2% Sn, Ti - 4% Al 4% Mn, Ti - 8% Mn, Ti-RC-55, crystal bar zirconium, and Zircaloy-2) exposed to fuel solution showed slight weight gains regardless of flow rate. As before, no significant effect of galvanic coupling or crevices was observed on the type 347 stainless steel, titanium 75A, and Zircaloy-2 specimens mounted in contact with one another inside the test unit. Also, no significant effect of stress was observed on type 347 stainless steel, titanium - 6% Al 4% V, and Zircaloy-2 specimens in the test unit.

For the first time since the test unit was constructed, the weld holding the transition joint in place was cut and the transition joint removed as a unit for examination. The joint itself was not disassembled and is shown in Fig. 1. The surfaces shown in the figure had been exposed to oxygen-containing distilled water at 100 to 300°C for 2900 hr and to approximately 0.02 *m* UO₂SO₄ for about 50 hr. The stainless steel surfaces were covered with a rough black film; the Zircaloy-2 surface was covered with a much smoother, more adherent black film, and the titanium surfaces showed bluish-green interference colors. The four type 347 stainless steel coupons had gained a slight amount of weight (undefilmed).

The removal of the transition joint allowed the interior of the bellows to be inspected. Figure 2 is a photograph of the interior of the bellows after removal of the transition joint. No pits or cracks were found, although a deposit of a red oxide, identified as Fe₂O₃ by x-ray diffraction, on top of a heavy dark scale prevented detailed examination of the metal surface.

The bellows area between the top convolution and the top circumferential weld was radiographed with a radium source. The crack in the circumferential weld, detected by the "Super Pentrex" method, was detected in the radiographs. Also, a small void in the same weld showed up and pits in the bellows⁵ were detected. No other defects were apparent.

Following the above examination, the transition joint was replaced and re-welded. Further testing of the bellows and transition joint to determine the cause of the pitting attack and to test the long-term reliability of the unit is planned. A larger pressurizer has been installed on the loop to minimize the possibility of carryover of fuel solution into the condenser. Also a tube has been provided to connect the top of the interior of the bellows with the vapor space of the condenser. Thermal circulation of water between the condenser and the interior of the bellows should minimize the tendency for oxygen gas to be trapped at the top of the interior of the bellows.

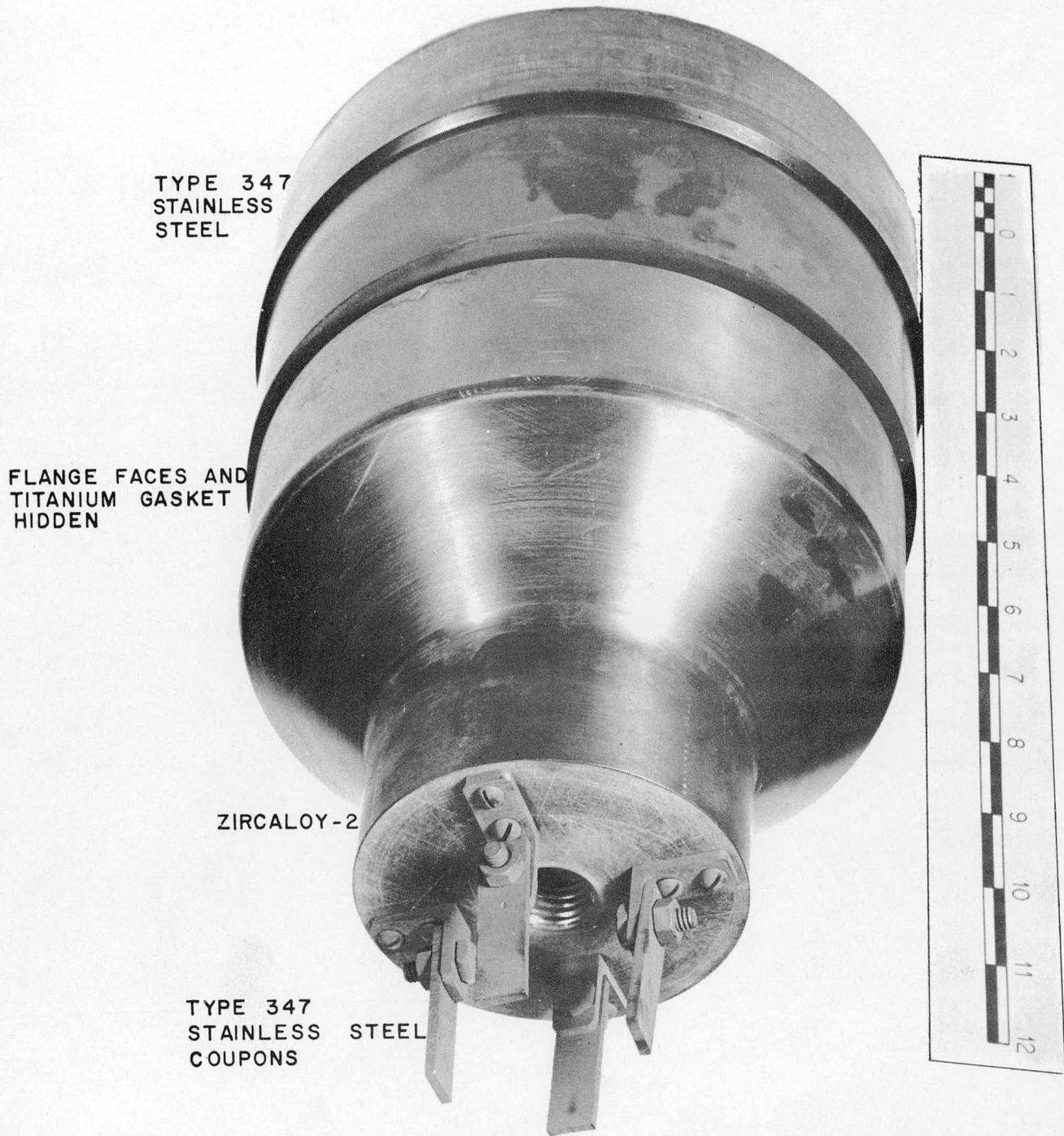


Fig. 1 Transition Joint Removed from Bellows Test Unit
after 2920 hr Exposure to Water at 100 - 300°C

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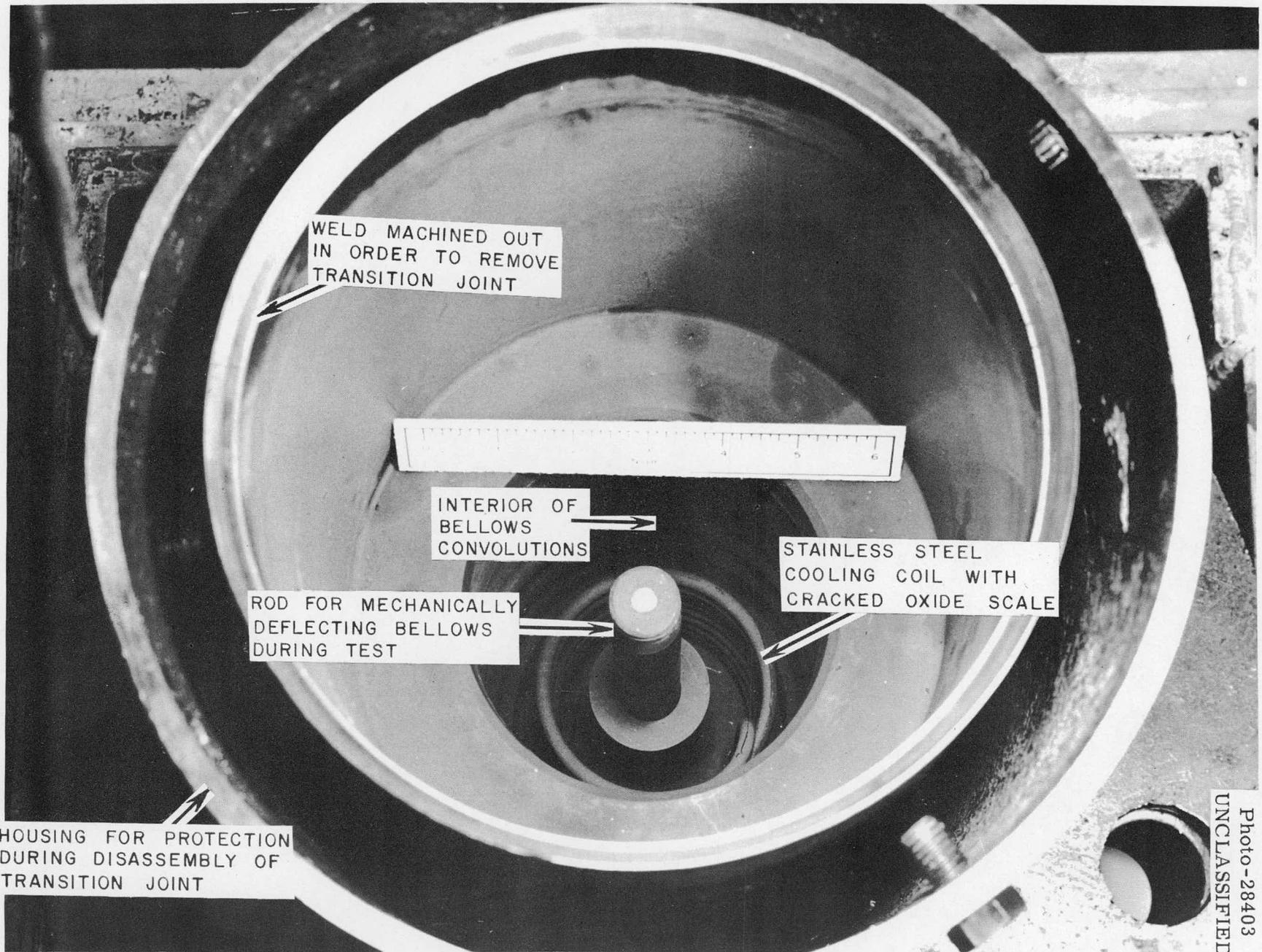


Fig. 2 Interior of Bellows after 2920 hr Exposure to Water at 100-300°C

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B. Runs With Dilute Uranyl Sulfate-Beryllium Sulfate Solution.

In a previous report⁶, results from two runs in which 0.04 m UO₂SO₄ - 0.04 m BeSO₄ - 0.005 m CuSO₄ solutions were circulated at 250 and 300°C were presented. The solutions appeared stable, although the pH decreased slightly during the runs. The corrosion results were similar to those observed in 0.04 m UO₂SO₄ - 0.02 m H₂SO₄ - 0.005 m CuSO₄ solutions (HRT fuel solutions) at the same temperature.

During the past quarter, runs were completed at 200 and 225°C in the 0.04 m UO₂SO₄ - 0.04 m BeSO₄ - 0.005 m CuSO₄ solution. Also, runs were made with 0.03 and 0.08 m BeSO₄ at 300°C; and one run was made at 225°C, using the latter solution. Table I gives the conditions of the runs with the beryllium-containing solutions.

The corrosion results for type 347 stainless steel obtained with the 0.04 m UO₂SO₄ - 0.04 m BeSO₄ - 0.005 m CuSO₄ solution at 200 and 225°C are shown in Fig. 3 and are compared with a similar run with the HRT fuel solution at 225°C. In the beryllium-containing solutions, the weight losses of the specimens were nearly independent of velocity at 200 and 225°C. At 225°C, the weight losses of the specimens were about the same as in the HRT solution up to 15 fps and very much lower at higher flow rates. The stainless steel specimens in the beryllium-containing solution at 200 and 225°C were not filmed over at any flow rate in contrast to those exposed in the HRT solution which were filmed over up to about 15 fps. Longer runs will be necessary to show whether corrosion continues at a constant rate. The solution appeared to be completely stable at 200 and 225°C.

Table I: Conditions of Beryllium Sulfate Runs in Loop "0"

Run No.	BeSO ₄ m	UO ₂ SO ₄ m	CuSO ₄ m	Temp °C	pH at 28° C	Time hr	Remarks
12	0.04	0.04	0.005	225	3.2	200	pH decreased slightly.
13	0.04	0.04	0.005	200	3.2	199	Solution appeared stable.
14	0.03	0.04	0.005	300	3.2	200	pH dropped from 3.2 to 2.2. Be concentration decreased by 15% at end of run.
15	0.08	0.04	0.005	225	2.7	197	Solution appeared stable.
16	0.08	0.04	0.005	300	2.7	200	pH decreased from 2.7 to 2.2. Beryllium concentration decreased by 20% at end of run.

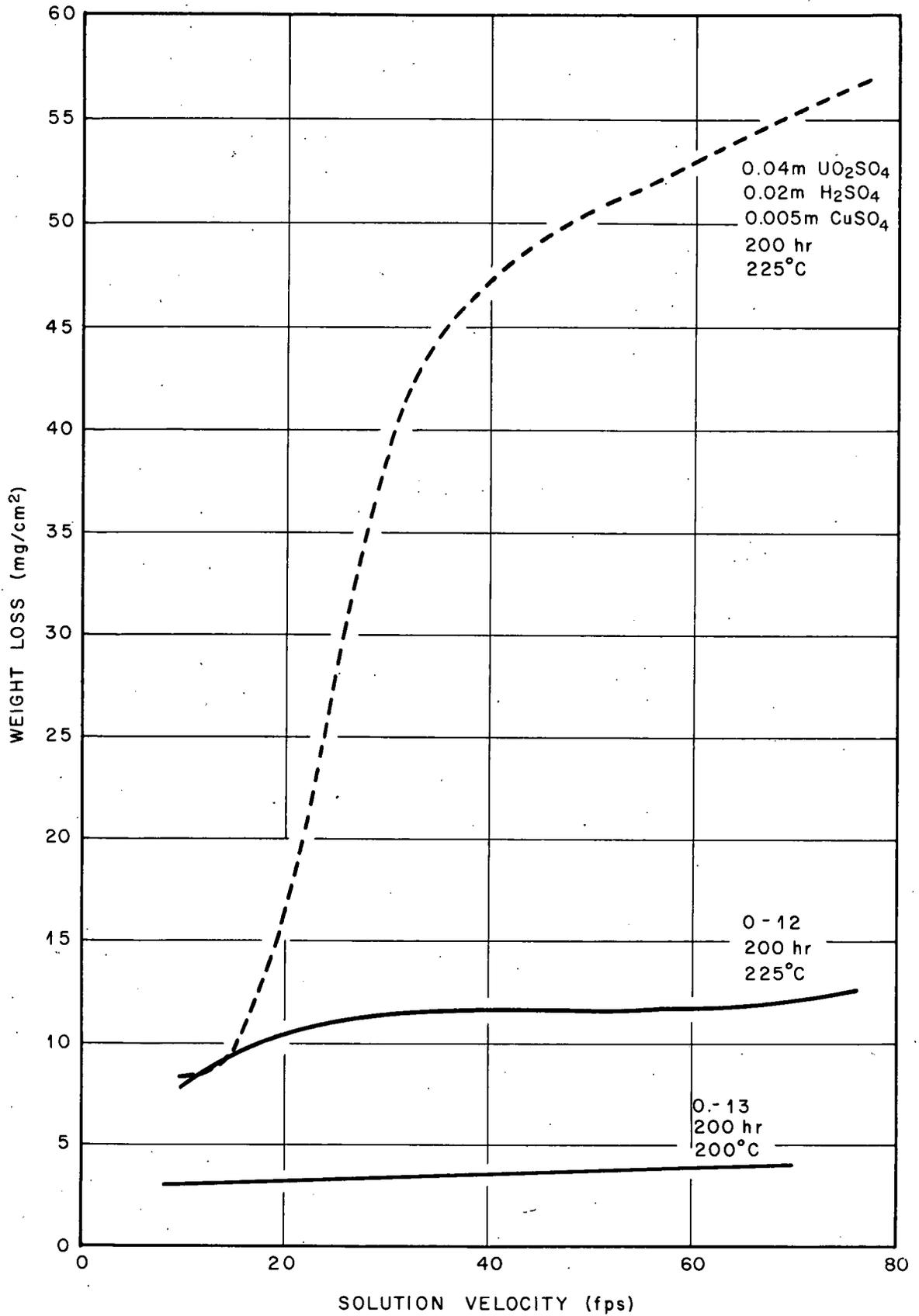


Fig. 3 Weight Losses of Type 347SS Coupons in 0.04m UO₂SO₄ + 0.04m BeSO₄ + 0.005m CuSO₄

Solutions with $0.04\text{ m UO}_2\text{SO}_4$ containing 0.005 m CuSO_4 and either 0.08 (Run 00 -16) or 0.03 m BeSO_4 (Run 00 -14) were not completely stable at 300°C ; during each run, 15 to 20% of the beryllium precipitated and the pH decreased from an initial value of approximately 3 to 2.2. The uranium and copper concentrations seemed to remain constant.

The corrosion of type 347 stainless steel in the above two solutions is shown in Fig. 4, as well as the data obtained under the same conditions with the solution containing 0.04 m BeSO_4 . It can be seen that the critical velocities were the same with the solutions containing 0.03 and 0.04 m BeSO_4 and that a slightly lower critical velocity was observed in the presence of the 0.08 m BeSO_4 .

Figure 5 compares the corrosion of stainless steel at 225°C in the $0.04\text{ m UO}_2\text{SO}_4 - 0.08\text{ m BeSO}_4 - 0.005\text{ m CuSO}_4$ solution with a similar solution containing 0.04 m BeSO_4 . It can be seen that the solution with the greater concentration of beryllium sulfate was the more corrosive. Both solutions were completely stable during the runs.

Future work with the uranyl sulfate-beryllium sulfate system will be concerned with the stability of dilute solutions both from a consideration of the rate at which hydrolysis occurs and from the reversibility of the precipitation.

C. Corrosion of a Variety of Materials in Boiler Water at 250°C .

A series of tests was made to study corrosion of a number of materials in water at 250°C as a function of water treatment and oxygen concentration. The loop, loop I, was defilmed with chromous sulfate solution^{7,8} prior to the first water run in order to avoid interference from the scale formed in previous runs using uranyl sulfate solutions. The conditions of the runs are given in Table II.

The first water run was made with de-aerated distilled water. De-aeration was accomplished by heating the water in the loop to 120°C , circulating for five minutes with 200 psi helium, and venting. The de-aeration procedure was repeated several times. The conductivity of the water was between 4 and 7×10^{-5} (ohm-cm)⁻¹ during the run.

The treated water runs were all made with distilled water containing 60 ppm phosphate as tri-sodium phosphate. This solution has been recommended for the treatment of the HRT boiler water⁹. In run I-40, three 10-ml additions of 85% hydrazine hydrate solution were made to the water in the loop to remove completely any residual oxygen. Excess hydrazine evidently decomposed thermally within a few hours at 250°C since chemical analysis showed less than 1 ppm of hydrazine eight hours after an addition. In run I-41, the air dissolved in the water upon loading the loop was allowed to remain in order to have a low concentration (20 to 40 ppm) of oxygen in the water during the run. In runs I-42 and I-43, oxygen gas was added to give 300 and 1500 ppm respectively at 250°C .

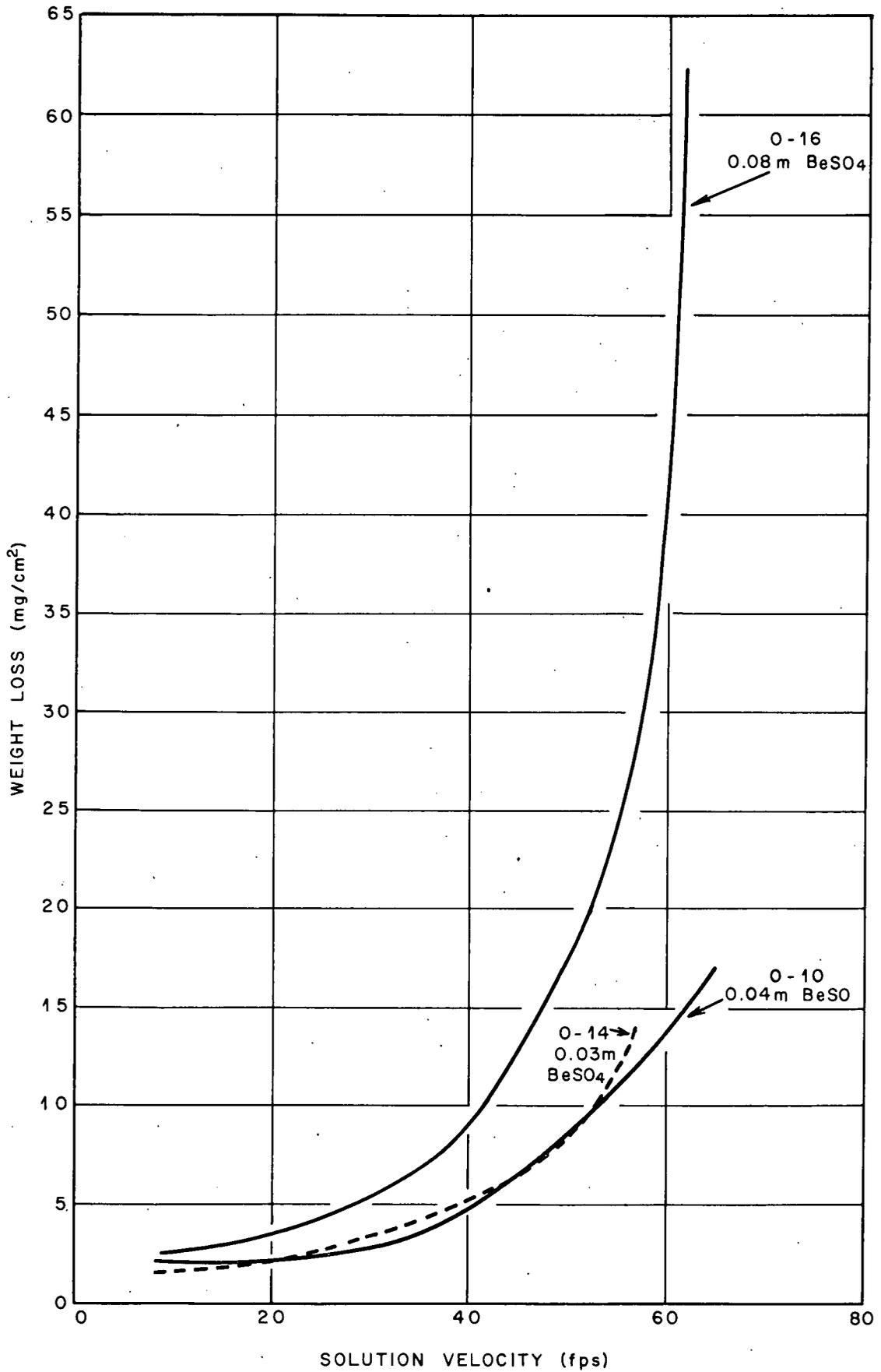


Fig. 4 Weight Losses of Type 347SS Coupons in 0.04 m UO₂SO₄ + 0.005 m CuSO₄ + BeSO₄ at 300°C (200 hr)

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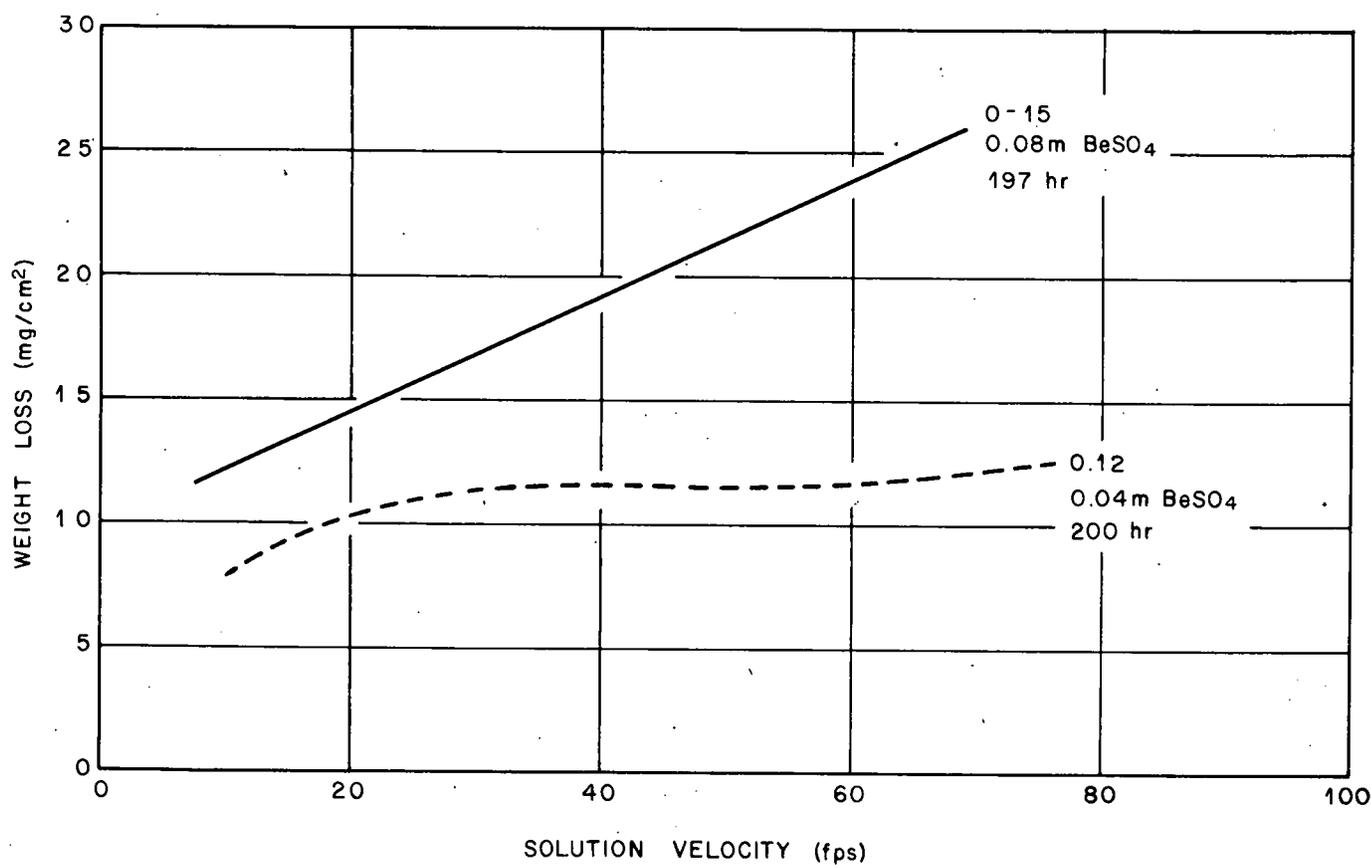


Fig. 5 Weight Losses of Type 347 SS Coupons in 0.04m UO₂SO₄ + 0.005m CuSO₄ + BeSO₄ at 225°C

The phosphate concentration remained constant during the runs in which it was added. No attempt was made to maintain a constant pH in the water during a run, and in runs I-42 and I-43, the pH decreased due to the oxidation of some chromium to chromium(VI) with the resulting production of hydrogen ions. Chloride ions were detected only in run I-40; and the concentration was so low, 3 ppm, that it may have been due to contamination of the solution samples during handling or analysis.

Table III is a condensation of the corrosion results. Pins exposed at flow rates between 18 and 44 fps were averaged since little velocity effect was observed on any alloy. Generally, the specimens were filmed over and hence it would be expected that corrosion rates would decrease with time. Table IV lists the compositions of the alloys used. The corrosion observations were as follows:

1. 300-Series Stainless Steels: The four types tested behaved very much alike and showed low corrosion rates in all five runs. There was little difference between runs I-39 and I-40, showing that the phosphate and hydrazine additions produced little effect. There was also little difference between runs I-40 and I-41, showing that a small amount of oxygen produced little effect. However, there were significant differences in runs I-41, I-42, and I-43 in that the corrosion rate was higher the higher the oxygen concentration. Thus larger oxygen concentrations appeared to increase the corrosion rates, but this effect was probably related to the formation of chromium (VI) and the simultaneous decrease in pH.

In each run except the first (I-39), five type 347 stainless steel stressed specimens were exposed at about 3 fps in a special holder inserted in a standard sample barrel. The specimens, having a No. 32 machine finish, were stressed beyond their elastic limit over a double fulcrum. Microscopic examination of the defilmed specimens after each run indicated no cracks on any specimen. Corrosion rates of the stressed specimens were no greater than the corrosion rates of the type 347 stainless steel pins except in run I-40. It is not known whether the higher corrosion rates of the stressed specimens in run I-40 were due to the 3 ppm chloride that may have been present in solution.

2. Carpenter Alloys: The Carpenter alloys 10, 20, and 20Nb behaved very much alike, and showed low corrosion rates, about the same as the 300-series stainless steels.
3. Miscellaneous Stainless Steels: Types 202, 414, 446, Croloy 16-1, and SRF-1132 stainless steel showed low corrosion rates generally similar to the 300 series. The exception was type 414 in run I-39 which corroded at 21 mpy.
4. Carbon Steel and Armco Iron: Carbon Steel ASTM grade A212B and Armco iron behaved similarly. In run I-39 at pH 4 to 6 in de-aerated distilled water they corroded at about 30 mpy. Addition of phosphate in run I-40 to adjust the pH to 9 to 10 decreased the corrosion rates by a factor of about five. A small amount of

oxygen, 20 to 40 ppm in run I-41, was deleterious; but a larger concentration, 250 to 300 ppm in run I-42, gave the lowest corrosion rates observed on A212B and Armco iron. The highest concentration of oxygen, 1500 to 2000 ppm in run I-43, caused slightly increased rates, possibly because the pH decreased to 5 during the run.

Carbon steel ASTM grade A-7 coupons were exposed in runs I-42 and I-43. The coupons appeared to be filmed over and showed weight losses of about 1 mg/cm² between 10 and 100 fps. These weight losses were slightly less than observed on the grade A212B pins at the same velocity.

The carbon steel pins and coupons in runs I-42 and I-43 in which the oxygen concentrations were relatively high had numerous shallow pits. These pits appeared to be of the typical oxygen-cell type usually associated with the corrosion of carbon steel in oxygen-containing water. The number and depth of the pits did not seem to depend on either flow rate or oxygen concentration.

5. Other Alloys: Zircaloy-2, titanium RC-55, and niobium showed very low corrosion rates.

In summary; it was found that the addition of phosphate to oxygen-free water at 250°C was beneficial to carbon steel and type 414 stainless steel and had little or no effect on the other alloys tested. The effect of oxygen concentrations between zero and 2000 ppm in the phosphate-treated water could not be separated from the effects of chromium(VI) concentration and pH, but the net effect on stainless steel was an increase in corrosion rate with increasing oxygen concentration. Zircaloy-2, titanium RC-55, and niobium were relatively unaffected by oxygen concentration changes. Carbon steels showed a minimum in corrosion rate at 250 to 300 ppm oxygen, but pitting occurred at that oxygen level and at the 1500 to 2000 ppm level.

Table II: Conditions of Water Runs at 250°C. (All Runs 200 Hr)

Run No.	Solution Composition	Phosphate Conc'n. (ppm)	Oxygen Conc'n. (ppm)	pH	Final Concentration of Ions, ppm				
					Ni	Cr(III)	Cr(VI)	Fe	Cl
I-39	H ₂ O	0	0	4-6	< 1	< 1	< 1	< 1	< 2
I-40	H ₂ O + PO ₄ + hydrazine	60	0	9-10	1	< 1	< 1	< 1	3
I-41	H ₂ O + PO ₄	60	20-40	9-10	< 1	< 1	< 1	2	< 2
I-42	H ₂ O + PO ₄	60	250-300	9→6	< 1	< 1	21	7	< 2
I-43	H ₂ O + PO ₄	60	1500-2000	9→5	< 1	< 1	19	< 1	< 2

Table III: Average Corrosion Rate (mpy) of Alloys
in Water Runs at 250°C in 200 hr

<u>Alloy</u>	<u>I-39</u>	<u>I-40</u>	<u>I-41</u>	<u>I-42</u>	<u>I-43</u>
304L SS	0.36	0.23	0.32	0.74	2.0
316L SS	0.36	0.17	0.11	0.54	1.8
318 SS	0.30	0.39	0.20	1.4	2.0
347 SS	0.27	0.26	0.17	0.68	2.6
347 SS Stress Specimen	‡	0.73	0.12	0.23	0.64
Carpenter 10 SS	0.13	0.17	0.13	0.38	1.2
Carpenter 20 SS	0.05	0.09	0.05	1.5	0.80
Carpenter 20 Nb SS	0.20	0.21	0.09	1.4	1.5
202 SS	0.22	0.34	0.09	0.56	0.56
414 SS	21	1.1	0.72	1.1	1.3
Croloy 16-1	1.8	0.81	0.22	1.2	1.6
446 SS	0.22	0.22	0.05	1.8	2.2
SRF-1132 SS	1.7	0.47	0.39	0.56	2.1
A-212B Steel — <i>Carb. 0.1%</i>	27	7.4	11	3.1	5.3
Armco Iron — <i>Iron</i>	34	4.8	7.3	3.7	6.1
Zircaloy-2	0.09	0.0	+	+	+
Titanium RC-55	0.00	0.35	0.01	0.00	0.16
Niobium —	+	0.34	0.30	0.15	0.85

‡ No stress specimens exposed.

+ Specimen gained weight (after defilming).

* ...

Table IV: Composition of Alloys Exposed in Water Runs at 250°C

Type Metal	Cr	Ni	C	Mn	Si	Mo	Fe	Other
304L	19.3	9.3	0.022	0.60	1.0 max*	0.0	bal	-
316L	17.6	13.4	0.029	1.66	0.45	2.32	bal	-
318	17.9	14.6	0.06	1.86	0.50	2.69	bal	Nb+Ta 0.95
347	18.6	10.0	0.07	1.58	0.61	-	bal	Nb+Ta 0.92
Carpenter 10*	16	18	0.08 max	-	-	-	bal	-
Carpenter 20*	20	29	0.07 max	0.75 max	1.0 max	2.0 min	bal	Cu 3 min
Carpenter 20Nb	20.40	27.9	0.07	0.77	0.74	2.41	bal	Cu 3.25, Nb+Ta 0.95
202	18.0	5.18	0.094	7.85	0.51	0.31	bal	-
414	12.1	1.90	0.11	0.48	0.38	0.11	bal	-
Croloy 16-1	15.9	1.42	0.018	0.74	0.31	-	bal	Cu 0.90
446*	25	-	0.35 max	1.0 max	1.0 max	-	bal	N ₂ 0.25 max
SRF 1132*	12	13.5	0.12	0.8	0.5	7.0	bal	Cu 5.5
ASTM Grade A212B	-	-	0.16	0.58	0.24	-	bal	S 0.04, P 0.02
ASTM Grade A 7	-	-	0.34 max	0.90 max	0.30 max	-	bal	S 0.05, P 0.04
Armco Iron	< 0.05	< 0.05	0.017	0.032	< 0.05	< 0.02	bal	Cu 0.05, S 0.01, P 0.005
Zircaloy-2	0.05	0.04	-	-	-	-	0.1	Sn 1.3
Titanium RC-55	-	-	< 0.1	-	-	-	-	N ₂ < 0.03
Niobium	-	-	-	-	-	-	-	"Pure"

* Nominal Analysis. Actual values not available.

D. Effect of Loop History on Corrosion of Type 347 Stainless Steel.

A number of runs in "in-pile" loops have shown that the "in-line" corrosion specimens (those not exposed to the pile neutron flux near the lattice) do not show the same corrosion rates as are observed in 100A loops operated under similar conditions. A previous report has discussed the effects of geometry, steam over pressure, pretreatment, and loop history¹⁰. It was shown that the latter three effects were all possible reasons for the discrepancy between 100A loop and in-pile results, but that loop history affected the results to the greatest extent.

Therefore, following the construction of the new 100A type 347 stainless steel loop J, two identical series of runs were made as nearly like an in-pile loop run as possible (without, of course, the pile exposure). The only difference between the two series was, then, that the first was made in a new loop and the second in a filmed-over loop. Thus, the effect of loop history alone was investigated. Since every "in-pile" loop is a new loop, the results from the first series should agree with "in-pile" "in-line" results.

The conditions of the two series of runs J-87 and J-88, and of a comparison in-pile run, L-4-8¹¹, are given in Table V. The weight losses of type 347 stainless steel coupons are plotted versus solution velocity in Fig. 6.

The results showed that stainless steel specimens exposed in a new loop (J-87) had markedly lower weight losses and a higher critical velocity than specimens exposed in a filmed-over loop (J-88); also, good agreement was obtained between specimens exposed in a new loop (J-87) and "in-pile" "in-line" specimens (L-4-8)¹¹. The results from run J-88 agreed very closely with those from run E-67¹², a previous run made under similar conditions, except the critical velocity was slightly higher in run J-88. The higher critical velocity may have been due to the slightly higher steam overpressure in run J-88 (about 350 psi) than in run E-67 (about 250 psi)¹³.

Therefore, it appears conclusive that a large area of film-free metal which actively corrodes during a run can inhibit corrosion of stainless steel specimens. This phenomenon has been observed previously¹⁴, but the mechanism of the inhibition process is not known.

E. Runs with Uranyl Sulfate Containing Added Chloride.

The effects on corrosion of stainless steel caused by chloride in uranyl sulfate solution were investigated in several runs. Previous runs^{15,16} showed pitting attack with 100 and 200 ppm but not with 50 ppm chloride in 0.17 M UO₂SO₄ at 250°C. However, the possibility of stress-corrosion cracking was not specifically looked for in these particular tests. The conditions of the present runs are given in Table VI. Type 347 stainless steel specimens machined from material acceptable by HRP specifications were stressed over a double fulcrum (four point loading) to 75% of room temperature yield strength (25,600 psi) and exposed in loop H pressurizer. The top-most specimen was exposed to vapor only and the other specimens were continuously wet, either by being in the spray from the mixing line outlet near the top of the pressurizer or by being below the liquid level in the pressurizer.

Table V: Conditions of Runs to Investigate Effect of Loop History on Corrosion

Run No.	Time (hr)	Temperature (°C)		Steam Over-pressure (psi)	Solution Composition	Gas (psi at Room Temperature)	Remarks
		Loop	Suritizer				
J-87	4	100	100	0	3% TSP	200 psi He	New loop.
	12	100	100	0	5% HNO ₃	200 psi He	---
	24	250	285	350	Dist. H ₂ O	No gas	Steam Calibration.
	24	250	285	350	Dist. H ₂ O	150 psi O ₂	---
	200	250	285	350	0.17 m UO ₂ SO ₄ 0.04 m H ₂ SO ₄ 0.03 m CuSO ₄	150 psi O ₂	---
J-88	Identical to J-87						Loop filmed over.
L-4-8	3	90	90	0	3% TSP	60 psi He	New loop.
	14	100	100	0	5% HNO ₃	60 psi He	---
	46	250	280	350	Dist. H ₂ O	60 psi O ₂	---
	2	250	280	350	Dist. H ₂ O	60 psi O ₂	---
	53	250	280	350	0.17 m UO ₂ SO ₄ 0.04 m H ₂ SO ₄ 0.03 m CuSO ₄	60 psi O ₂	Out-of-pile checkout
	16	250	280		Dist. H ₂ O	60 psi O ₂	
	1637	250	280		0.17 m UO ₂ SO ₄ (88.8% U ²³⁵) 0.04 m H ₂ SO ₄ 0.03 m CuSO ₄	60 psi O ₂	In-pile exposure

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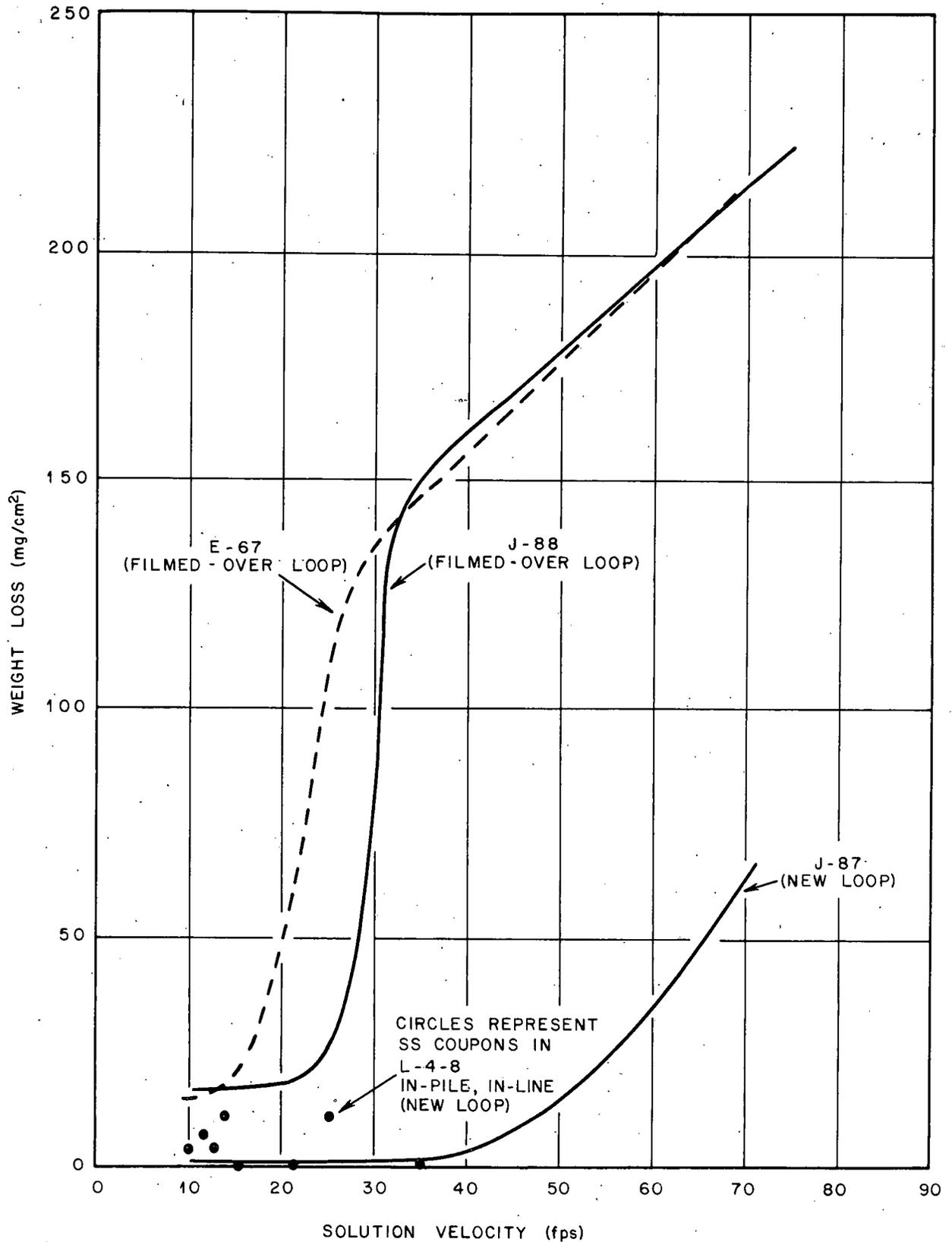


Fig. 6 Effect of Loop History on Corrosion of Type 347 Stainless Steel Coupons in 0.17m UO₂SO₄ + 0.04m H₂SO₄ + 0.03m CuSO₄ at 250°C

Table VI: Conditions of Runs to Investigate Stress Corrosion
Cracking in Chloride-Containing Uranyl Sulfate Solution

Run No.	Time (hr)	Temp. (°C)	UO ₂ SO ₄ (m)	Chloride (ppm)	Oxygen (ppm)	Remarks
H-103	98	250	0.17	0	~ 1000	Pretreatment
H-104a	143	250	0.17	40	1500-1800	
H-104b	250	250	0.17	40	1500-1800	Same solution as H-104a
H-104c	260	250	0.17	60	20-170	New solution
H-104d	111	250	0.17	50	0-40	Oxygen exhaustion occurred and uranium precipitated
H-105a	211	200	0.17	50	1000-3000	
H-105b	200	200	0.17	50	0-25	Oxygen exhaustion occurred and uranium precipitated
H-107	22	250	0.02	3500	1000-2000	Run interrupted by stress-cracks

To see if filmed-over specimens would withstand attack by chloride-containing solution better than new specimens, five stressed specimens were exposed at 250°C in H-103 to 0.17 *m* UO₂SO₄ containing no chloride and then were exposed along with five new specimens in H-104a to 0.17 *m* UO₂SO₄ containing 40 ppm chloride. The pretreated specimens showed a heavier film than the new specimens after H-104a, but none showed any cracks. Further exposure to chloride-containing solution in H-104b did not produce any cracks.

To see if cracking might be caused by low oxygen concentration, the run was continued as H-104c with only 20 to 170 ppm oxygen. No cracks were found after this exposure.

The run was continued as H-104d, with no oxygen until precipitation occurred and the pH of the solution dropped from 2.5 to 1.7. Examination of the specimens after H-104d showed no cracks; however, all specimens showed extensive, general pitting. The pits were shallow, roughly 1 mil deep, which suggests that the pitting attack occurred only during H-104d when oxygen exhaustion occurred. Fig. 7 is a photomicrograph of the surface of one of the stressed specimens exposed to spray in H-104, showing the dark pits. Fig. 8 is a photomicrograph of several of the pits showing the absence of cracking.

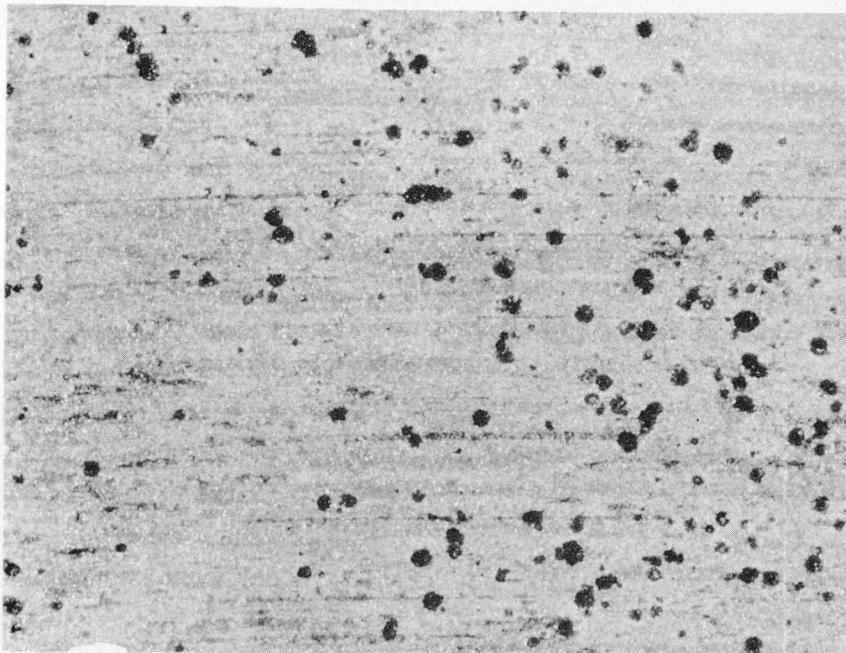
A similar series of runs was carried out at 200°C without, however, the pretreatment run since the pretreatment at 250°C did not appear to have influenced the results significantly. After H-105a, in which 0.17 *m* UO₂SO₄ containing 50 ppm chloride and 1000 to 3000 ppm oxygen was circulated at 200°C, one crack was found on a type 347 stressed specimen. The crack occurred not in the region of maximum applied stress but underneath the head of the bolt used to fasten the specimen. Figures 9 and 10 are a photomicrograph and photomicrograph, respectively, of this crack and show the transgranular cracking typical of chloride stress-corrosion cracking. After H-105b, in which 0.17 *m* UO₂SO₄ containing 50 ppm chloride was circulated without oxygen, all of the stressed specimens were cracked. Most of the cracks occurred where the identification numbers were stamped on the specimens. Several cracks, one of which is illustrated in Figures 11 and 12, occurred parallel to the applied tensile stress. All of the cracks were transgranular and typical of chloride stress-corrosion cracking.

In all of the above runs, annealed stainless steel pin and coupon specimens were exposed. No large effect of the added chloride ion was observed.

Thus it was shown that 50 ppm chloride ion need not produce stress-corrosion cracking in 0.17 *m* UO₂SO₄ if a sufficient concentration of oxygen is maintained. In the absence of oxygen at 250°C, pitting but not cracking was produced, although cracks might have developed from the pits after longer exposure. At 200°C loss of oxygen, either in a crevice or generally throughout the solution, produced cracks.

(T 11824)

Figure 7

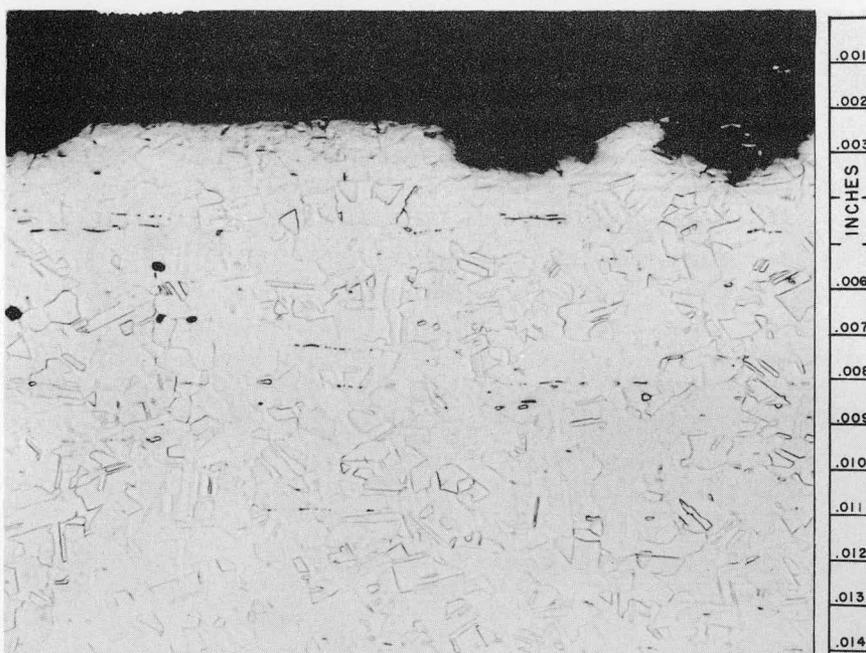


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Photomicrograph of Pitted Surface of Type 347 Stainless Steel Stressed Specimen Exposed at 250°C to 0.17 *m* UO₂SO₄ Containing 50 ppm Chloride.

(T 11823)

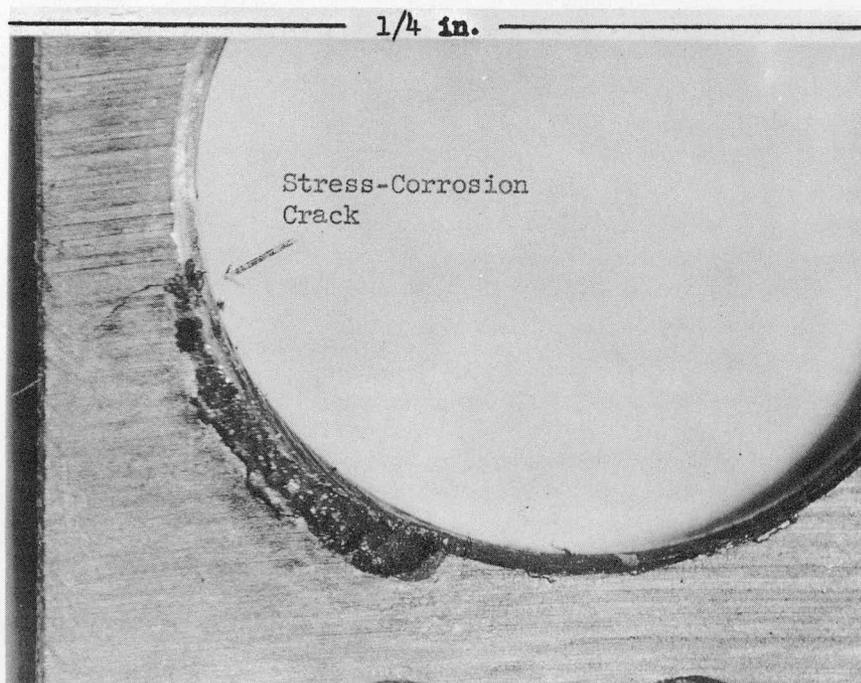
Figure 8



Photomicrograph of Pits Shown in Figure 7.

(T 11967)

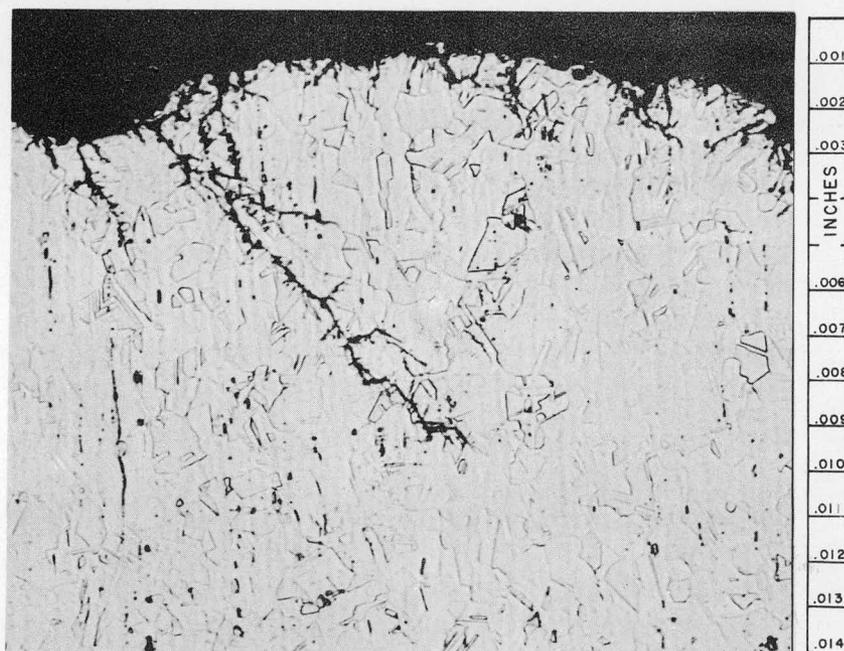
Figure 9



Stress-Corrosion Crack on a Type 347 Stainless Steel Stressed Specimen Underneath a Bolt Head After 211 hr in 0.17 *m* UO₂SO₄ Containing 50 ppm Chloride and 1000-3000 ppm Oxygen at 200°C

(T 11968)

Figure 10



Photomicrograph of Stress-Corrosion Crack Shown in Figure 9
Magnification 250X

(T 11976)

Figure 11



————— 1/4 in. —————

Stress-Corrosion Crack on a Type 347 Stainless Steel Stressed Specimen After 200 hr in 0.17 m UO_2SO_4 Containing 50 ppm Chloride in the Absence of Oxygen at 200°C. 16 X

(T 11978)

Figure 12



Photomicrograph of Stress-Corrosion Crack Shown in Figure 11. Magnification 250 X

One other run with added chloride was attempted. In connection with another test, 3500 ppm chloride as 0.05 *m* CuCl₂ was added to 0.02 *m* UO₂SO₄ and circulated with 1000 to 2000 ppm oxygen at 250°C (run H-107). After 22 hr, a stress-corrosion crack developed in a 3/8-in. type 347 stainless steel pipe and solution slowly leaked out, forcing termination of the run. Therefore, there does appear to be a level of chloride concentration above which cracking will occur even in the presence of large concentrations of oxygen during short exposure periods.

F. Titanium and Stainless Steel Inserts Exposed to 1.3 *m* UO₂SO₄ at 250°C.

The previous report¹⁷ described the appearance of two titanium inserts exposed to a variety of solutions in loop N for 9900 hr. These inserts were replaced by two new titanium inserts and two stainless steel inserts.

The design of the inserts was as follows:

1. A flanged titanium-75A insert identical to the flanged insert described previously¹⁷.
2. A sleeve titanium-75A insert 4-in.-long machined from 1-1/2-in.-OD pipe to fit snugly into a stainless steel pipe section and rolled to prevent movement. The insert is shown in Fig. 13. Ten series of holes were drilled along the length of the insert - two series each 1/4, 1/8, 1/16, 1/32, and 1/64 in. in diameter - to determine the largest diameter hole that would prevent the highly turbulent solution from reaching the stainless steel surface and thereby minimize corrosion of the stainless steel. Two 1/4-in. holes in the previously discussed inserts did not prevent corrosion of the underlying steel¹⁸. Upon rolling this insert into the piping section, it cracked as shown in Fig. 13.
3. Two sleeve-type 347 stainless steel inserts identical to the titanium sleeve insert but without the holes. The purpose of the stainless steel inserts was to observe corrosion in the crevice thus formed.

The two titanium inserts were placed in one section of piping, and the two stainless steel inserts were placed in another, and the sections of piping were mounted in the loop as shown in Fig. 14. To give the inserts a severe initial test, 1.3 *m* UO₂SO₄ was circulated for 200 hr at 250°C with a bulk solution flow rate of about 40 gpm or 7 fps over the titanium inserts and 10 gpm or 2 fps over the stainless steel inserts.

At the end of the initial test, the titanium inserts were covered with a black film and had suffered no apparent corrosion. The flanged insert was loose enough to be easily removed and inspection of the underlying stainless steel showed no apparent corrosion. A sample of loose oxide from beneath the flanged insert was analyzed by x-ray diffraction; but, except for a small percentage of Fe₂O₃, could not be identified. Therefore, it is not known whether oxygen depletion occurred in the crevice between the insert and the stainless steel piping as occurred previously¹⁷. The stainless steel piping areas exposed by the holes in the

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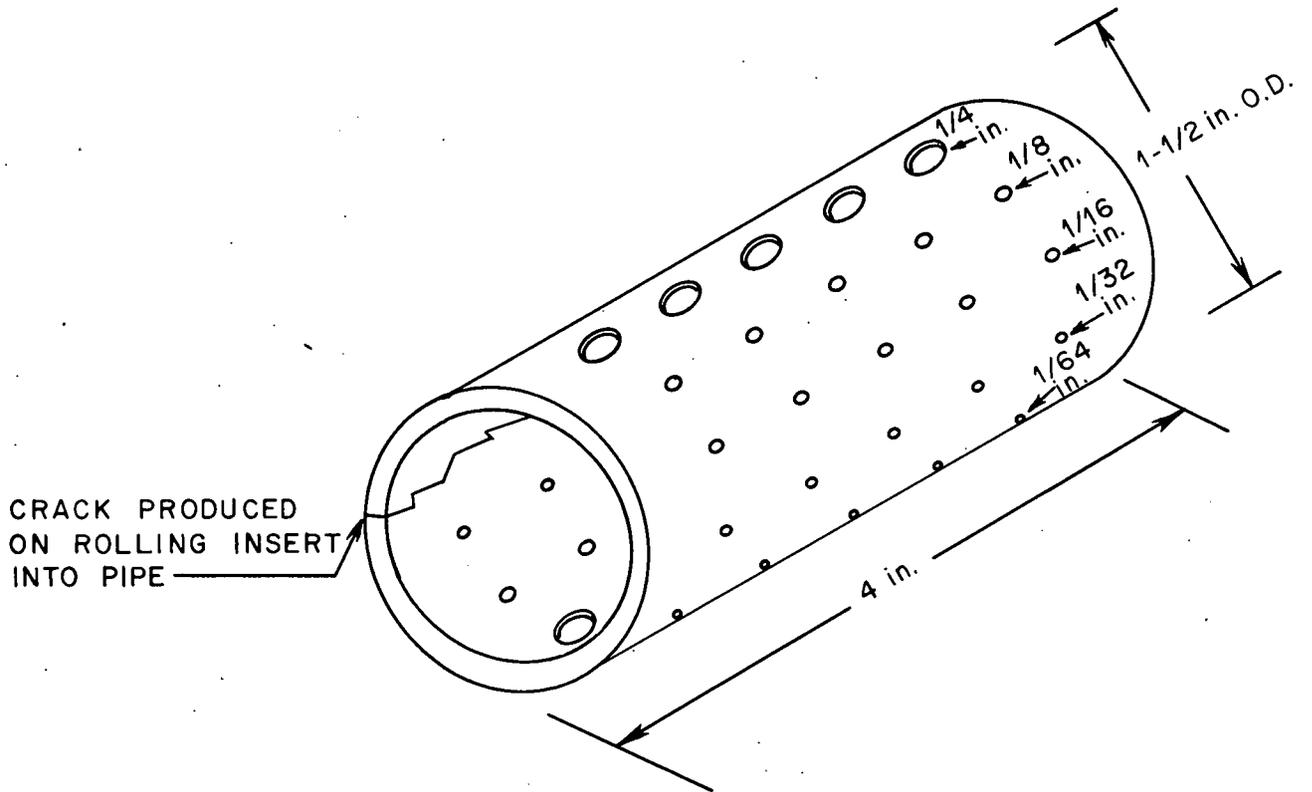


Fig. 13 Sleeve Insert in N-Loop

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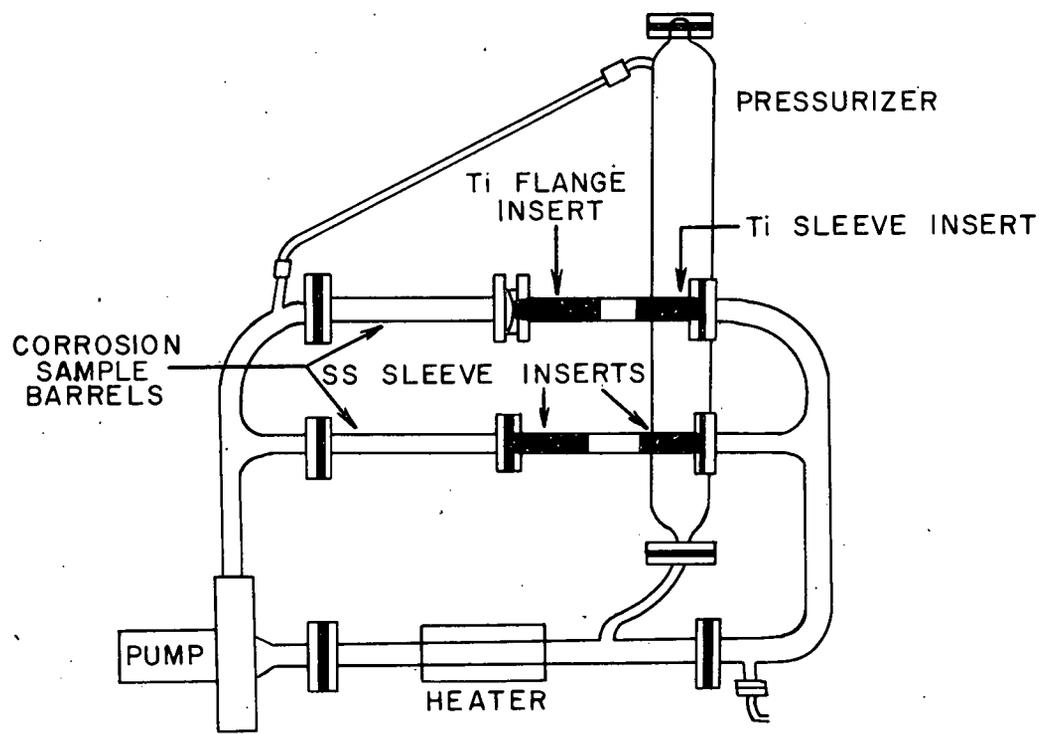


Fig. 14 Position of Titanium and Stainless Steel Inserts in Loop N During Run N-25

tst titanium sleeve insert were covered with a black film and the steel showed no apparent corrosion. However, this titanium sleeve insert was not exposed to the severe turbulence immediately downstream from the corrosion sample holders that the previous insert had been exposed to¹⁸.

The stainless steel sleeve insert in the same relative position as the titanium sleeve insert was also not apparently corroded and was covered with a black film. However, the stainless steel sleeve insert immediately downstream from the corrosion sample barrel was severely corroded. For about 1/2 in. downstream from the corrosion sample barrel, there was no apparent corrosion and the insert was covered with a black film. Then very sharply, the insert was corroded the remainder of its length to a depth of about 5 mils (a corrosion rate of about 200 mpy). The stainless steel piping at the end of the insert was also severely attacked. The critical velocity observed on type 347 stainless steel coupons was 15 to 20 fps, yet the bulk solution velocity past the stainless steel insert was only 2 fps. This fact illustrates the effect of turbulence on the critical velocity. The stainless steel inserts were not removed at this time for inspection of the crevice area.

IV. LABORATORY CORROSION STUDIES (J. L. English, J. C. Griess, D. N. Hess, P. D. Neumann)

A. Stress-Corrosion Cracking of Type 347 Stainless Steel:

1. Effect of Halides in Uranyl Sulfate Solutions. Tests to determine the susceptibility of type 347 stainless steel to stress-corrosion cracking in aerated and boiling 0.04 M UO_2SO_4 solution containing 0.02 M H_2SO_4 , 0.005 M $CuSO_4$, and various concentrations of halide ions have been continued. Although it has been reported¹⁹ that cracking was not observed in boiling uranyl sulfate solution containing bromide ions, studies during the past quarter have demonstrated that bromide ions are capable of inducing apparent stress-corrosion cracking in type 347 stainless steel. In boiling and aerated uranyl sulfate solution containing 100 ppm bromide, cracking occurred during the exposure interval between 2000 and 2500 hr on the tension side of a simple beam-type specimen stressed at 15,000 psi. A companion specimen in the same environment that was stressed at 30,000 psi showed no cracks during the entire 2500-hr test.

The single crack on the 15,000 psi stress specimen was located in the region of the initially-applied maximum stress and extended across the full width of the specimen, 3/4-in. However, there were indications that the crack was not completely continuous over this distance. A mild pitting attack was closely associated with the orientation of the crack, but it was not possible to determine whether the crack was initiated at pit sites or whether the pits formed after propagation of the crack. Metallographic examination will be performed on the specimen to ascertain if the crack was transgranular or intergranular in character.*

* A preliminary metallographic examination received after writing this report has indicated that the "crack" is actually a break in the metal surface caused by severe sub-surface attack and is not a typical stress-corrosion crack.

A second occurrence of bromide-induced stress-corrosion cracking in type 347 stainless steel was observed on specimens exposed in boiling and aerated uranyl sulfate solution containing 200 ppm bromide. Numerous severe cracks were found on the simple-beam specimen stressed at 15,000 psi during the 1000 to 1500-hr exposure interval. The cracks were located near the region of maximum stress. An incipient cracking was also noted on a companion specimen stressed at 30,000 psi after the 1000 to 1500-hr interval.

The presence of bromide ions in the uranyl sulfate solution accelerated the general rate of attack of type 347 stainless steel. With 100 ppm bromide, the stainless steel corroded at an average rate of 2 to 3 mpy during the 2500-hr test period. With 200 ppm bromide, average corrosion rates were 3 to 5 mpy during the 1500-hr test. The corrosion rates were independent of stress level and were increasing slightly with exposure time. In the same solution free of bromide ions, corrosion rates of less than 0.1 mpy are observed.

Previous experience with the effect of chloride ion on stress-corrosion cracking of type 347 stainless steel in boiling and aerated 0.04 *m* UO₂SO₄ solution containing 0.02 *m* H₂SO₄ and 0.005 *m* CuSO₄ showed that cracking was produced on specimens stressed at 15,000 and at 30,000 psi during the 100 to 200-hr exposure interval in the presence of 25 and 50 ppm chloride ion concentrations²⁰. Cracking was also suspected to have occurred in solutions containing 200 and 500 ppm chloride during the initial 500 hr of test. No cracking was reported on specimens exposed in solutions containing 0, 5, 10, and 100 ppm chloride after 2000 hr of test.

Continuation of the chloride tests during the past quarter has resulted in additional information on the sensitivity of type 347 stainless steel to chloride-induced cracking. In the solution containing 100 ppm chloride, a large crack developed near the region of maximum stress on a specimen initially stressed at 15,000 psi. The cracking occurred during the 2000 to 2500-hr exposure interval in the boiling and aerated uranyl sulfate solution. The crack was approximately 1/2-in. in length and the orientation was unique in that rather than propagating in a plane normal to the direction of the applied stress as is generally the case, the crack - based upon outward appearance - extended in a direction that was parallel with the direction of applied stress. A second specimen stressed at 30,000 psi exhibited no tendency toward cracking during the entire 2500-hr exposure period. The defilmed corrosion rate for the 15,000 and the 30,000 psi stress specimens after 2500 hr was 6 mpy.

The suspected cracking previously reported¹⁹ of stressed type 347 stainless steel after 500 hr in boiling and aerated uranyl sulfate solutions containing 200 and 500 ppm chloride was confirmed by the appearance of well-defined cracks on the specimens at the suspected sites during a subsequent 500-hr exposure period. With one exception, cracking occurred in both environments on specimens stressed at 15,000 and at 30,000 psi during the 500 to 1000-hr exposure interval. No cracks were found on the 30,000 psi specimen exposed in the 500 ppm

chloride-containing solution. However, three small cracks were noted on the stress specimen support (base) plate which was under some undetermined magnitude of stress. Generalized corrosion rates for the stress assemblies exposed in the two media ranged from 5 to 13 mpy after 1500 hr; the rates were decreasing with increased exposure time.

A total of 2500 hr has been accumulated with stress specimens of type 347 stainless steel exposed in boiling and aerated $0.04 \text{ m } \text{UO}_2\text{SO}_4$ - $0.02 \text{ m } \text{H}_2\text{SO}_4$ - $0.005 \text{ m } \text{CuSO}_4$ solution containing an initial iodide concentration of 100 ppm. No cracking was observed on specimens stressed at two levels, 15,000 and 30,000 psi; the defilmed corrosion rate for both stress specimens at completion of the 2500-hr test was 1 mpy. Difficulty was experienced in maintaining a constant iodide concentration during test because of losses due to volatilization from the solution. Accordingly, the iodide concentration was adjusted to 100 ppm by the addition of potassium iodide to the solution at the start of each 500-hr run. At completion of the 500-hr runs, the analyzed dissolved iodide content was generally less than 10 ppm.

A summary of the presently-known information on the susceptibility of type 347 stainless steel to stress-corrosion cracking in boiling and aerated halide-containing uranyl sulfate solutions is included in Table VII. It should be noted that chloride concentrations as low as 25 ppm, and perhaps even lower, in the solution to be used in the HRT are capable of producing cracks in even moderately stressed type 347 stainless steel. Thus, the necessity of keeping the chloride concentration in the HRT dump tank very low is evident. While the cracking of stainless steel in the bromide-containing environment was unexpected, bromide ions are an unlikely contaminant, and the control of bromide ions should represent no particular problem. Similarly, the presence of an appreciable iodide concentration is not likely since iodide ions are oxidized to iodine in the presence of uranyl sulfate and are volatilized from the solution.

2. Special Studies on Stress-Corrosion Cracking Behavior in Chloride-Containing Uranyl Sulfate Solutions. A number of exploratory-type laboratory tests to study the effects of several variables on the stress-corrosion cracking behavior of type 347 stainless steel in boiling and aerated chloride-containing uranyl sulfate solutions was initiated. It is felt that such tests will provide information on the mechanism of the stress-corrosion cracking process, and thereby be useful in resolving certain problems in stress-corrosion cracking.

The initial tests on the stress-corrosion cracking behavior of type 347 stainless steel were concerned with the effect of oxygen and with the effect of coupling the stainless steel with a noble metal of low hydrogen overvoltage. For these tests, a boiling solution containing $0.04 \text{ m } \text{UO}_2\text{SO}_4$, $0.02 \text{ m } \text{H}_2\text{SO}_4$, $0.005 \text{ m } \text{CuSO}_4$ and approximately 50 ppm chloride ions was used.

Table VII: Stress-Corrosion Behavior of Type 347 Stainless Steel in Boiling and Aerated 0.04 m UO_2SO_4 - 0.02 m H_2SO_4 - 0.005 m $CuSO_4$ Solution Containing Chloride, Bromide, and Iodide Additions

Test No.	Additive		Total Hr	Applied Stress(psi)	Incidence of Cracking
	Species	Conc'n(ppm)			
P-9	None	0	2500	15,000	No cracking observed
				30,000	No cracking observed
P-10	Cl ⁻	5	2500	15,000	No cracking observed
				30,000	No cracking observed
P-11	Cl ⁻	10	2500	15,000	No cracking observed
				30,000	No cracking observed
P-12	Cl ⁻	25	1000	15,000	Cracking during 100 to 200-hr exposure interval
				30,000	Cracking during 100 to 200-hr exposure interval
P-13	Cl ⁻	50	1000	15,000	Cracking during 100 to 200-hr exposure interval
				30,000	Cracking during 100 to 200-hr exposure interval
P-14	Cl ⁻	100	2500	15,000	Cracking during 2000 to 2500-hr exposure interval
				30,000	No cracking observed
S-25	Cl ⁻	200	1500	15,000	Cracking during 200 to 500-hr exposure interval
				30,000	Cracking during 200 to 500-hr exposure interval
S-26	Cl ⁻	500	1500	15,000	Cracking during 200 to 500-hr exposure interval
				30,000	Cracking during 200 to 500-hr exposure interval (a)
S-27	Br ⁻	50	1500	15,000	No cracking observed
				30,000	No cracking observed
P-15	Br ⁻	100	2500	15,000	Cracking during 2000 to 2500-hr exposure interval
				30,000	No cracking observed
S-28	Br ⁻	200	1500	15,000	Cracking during 1000 to 1500-hr exposure interval
				30,000	Cracking during 1000 to 1500-hr exposure interval
P-16	I ⁻	100(b)	2500	15,000	No cracking observed
				30,000	No cracking observed

(a) No cracking on stress specimen; cracks occurred on stress specimen support plate stressed at an undetermined value.

(b) Initial iodide concentration adjusted to 100 ppm at start of each 500-hr run; iodide level at end of 500-hr runs approximately 10 ppm and less.

Effect of Oxygen. Reference has been made in the literature to the role of oxygen as a promoter of the stress-corrosion cracking process in austenitic stainless steels by high-temperature high-purity water containing chlorides^{21,22}. It has been stated that maintenance of dissolved oxygen at a value below one ppm (and preferably below 0.5 ppm) will provide reasonable assurance against cracking failures at chloride levels likely to be encountered in the operation of steam generation equipment. Even though there was no reason to expect uranyl sulfate solutions to behave like a pure water system, it was of interest to determine if cracking could be eliminated by the complete removal of oxygen from chloride-containing uranyl sulfate solutions.

The removal of dissolved oxygen from a high-temperature homogeneous reactor uranyl sulfate fuel system as a means for controlling stress-corrosion cracking of type 347 stainless steel in the presence of chlorides is not feasible since in the absence of oxygen, the uranyl sulfate-stainless steel system is not compatible. However, a study to determine the effectiveness of oxygen removal for mitigation against chloride-induced cracking in uranyl sulfate solution at temperatures up to the boiling point is feasible since under these conditions, there is no apparent problem with solution instability.

The solution, 0.04 *m* UO₂SO₄, 0.02 *m* H₂SO₄, 0.005 *m* CuSO₄, and 50 ppm chloride (as KCl), had a pH of 1.65. Prior to the start of the test, the solution - while at the boiling temperature of approximately 101°C - was sparged for one to two hr with tank helium gas (containing nominally from 2 to 6 ppm of oxidizable gases O₂, CO, CO₂, etc.²³ to reduce the dissolved oxygen to a negligible level. The sparging process was repeated at the start of each test period before the introduction of specimens in the solution and was maintained on a continuous basis during operation of the test. A similar environment with air bubbled into the solution rather than helium was found to produce cracks in mechanically-abraded simple beam-type specimens of type 347 stainless steel stressed at 15,000 and at 30,000 psi within 200 hr from the start of the exposure²⁰.

The present tests used stress specimens that were made by cold-forming pickled 0.020-in. thick type 347 stainless steel strip into a U-bend. An elastic stress was then applied to the U-bend by means of a type 347 stainless steel tie rod inserted through the open ends of the U-bend. Duplicate specimens were exposed in the solution. Frequent examinations were made during the test for crack detection.

No cracking was observed during the first 200 hr; specimens were examined six times microscopically in this period. At the end of the seventh exposure period which was of 100 hr duration, one of the U-bend specimens exhibited a single crack originating from an edge surface near the region of maximum stress. No cracking was observed on the companion specimen during the entire 300-hr period. The helium-sparged test will be continued for a reasonable time to follow extension of the observed crack and to determine if new cracks are initiated.

The time required for cracking to occur in the absence of oxygen was considered in good agreement with the time required for cracking to occur in a similar environment in the presence of oxygen. In the former case, cracking took place during the exposure interval between 200 and 300 hr; in the latter case, the cracking took place during the 100 to 200-hr exposure period. The agreement in time to cracking was considered especially good in view of the fact that two different geometries of stress specimens were used in the two tests and that two different types of surface finish were present on the stress specimens, mechanically-abraded and pickled.

With regard to the effect of surface condition on susceptibility of austenitic stainless steel to cracking, it has been reported²⁴ that in boiling 42 wt. % $MgCl_2$, no cracking occurred on pickled surfaces of type 302 stainless steel specimens stressed at 90 per cent of the yield point after 21 hr, whereas, 200 cracks were found on similar specimens with mechanically-abraded surfaces after an exposure period of 30 hr. These data in effect corroborate the present findings in that the time required for cracking to occur on a pickled surface can be appreciably longer than that required for cracking to take place on a mechanically-abraded surface. The residual stresses introduced into the metal surface by the abrading operation, or any other cold-working operation, appear to be a contributing factor for increasing the susceptibility of austenitic stainless steel to stress-corrosion cracking in chloride-containing environments.

Previously-unreported information from laboratory tests indicated that the presence or the absence of oxygen in boiling (154°C) 42 wt % $MgCl_2$ had no effect on the incidence of cracking of stressed type 347 stainless steel. Tests were run with stressed U-bends of the stainless alloy exposed in the boiling magnesium chloride solution. In one test, the solution was sparged thoroughly for 30 to 45 min with hydrogen gas before the start of the test and was continued during operation of the test. In the second test, operating conditions were normal atmospheric boiling with no hydrogen sparging. After an accumulated exposure period from 2 to 5 hr, numerous cracks were observed on stress specimens in both environments.

Although the oxygen-removal test results must necessarily be regarded as preliminary at the present stage of the investigation, the experimental indications are that in boiling acidic uranyl sulfate solution or in boiling 42 wt. % $MgCl_2$, the occurrence of stress-corrosion cracking in type 347 stainless steel is entirely independent of the presence or the absence of dissolved oxygen in solution. Cracking was produced in the two environments when oxygen removal was effected by either helium or hydrogen gas sparging within times that were not appreciably different from the times required to produce cracking in the presence of oxygen.

Effect of Coupling with Platinum. The general phenomenon of stress-corrosion cracking is, at least partially, an electrolytic process. The metal at the tip of the crack presumably serves as anode and the walls of the crack and/or the surface of the metal adjacent to the crack serve as cathode of the corrosion cell. It is generally the

cathodic reaction that limits the current in the corrosion cell as is shown by the fact that cathodic protection will usually eliminate cracking in most environments when cracking would occur in its absence.

From the results in the preceding section, it is clear that the primary cathodic reaction is not the reduction of oxygen. It thus seemed plausible that the cathodic reaction was the reduction of hydrogen ions to hydrogen gas. If the cathodic reaction were the discharge of hydrogen, then coupling the stainless steel with a noble metal of lower hydrogen overvoltage than stainless steel should facilitate cracking. That is, a metal such as platinum should polarize much less than stainless steel, thereby allowing a greater corrosion current and consequently, an accelerated cracking rate.

To determine whether the coupling of platinum to stressed stainless steel would shorten the time to cracking, U-bends of stainless steel coupled with platinum metal were exposed to a boiling uranyl sulfate solution containing 0.04 *m* UO₂SO₄, 0.02 *m* H₂SO₄, 0.005 *m* CuSO₄, and 50 ppm chloride. The bends were placed under elastic stress by a stainless steel tie rod through the legs of the U. Platinum metal was mechanically-coupled to each leg of the U-bend on one specimen; on a second specimen, the platinum metal was tack-welded to each leg of the U to obtain a good electrical contact with the stainless steel. The two specimens were exposed for 25-hr runs in the boiling and aerated uranyl sulfate solution of the composition described above. Without the platinum coupling, cracking was usually observed in 100 to 200 hr²⁰.

No cracking was observed on either specimen during the initial 25 hr. At the end of the second 25-hr run, a small crack was found on the U-bend with the tack-welded platinum couple. The crack originated from an edge surface near one of the pieces of platinum metal. By the end of the fourth 25-hr run, a second crack appeared on the specimen near the location of the first crack. Both cracks exhibited pronounced extension during an accumulated exposure time of 300 hr. The companion specimen with mechanically-coupled platinum did not show any susceptibility to cracking during the entire 300-hr test period. The absence of cracks in the latter was attributed tentatively to the fact that good electrical contact was not achieved by mere mechanical coupling with the stainless steel. The specimen will undergo further exposure, however.

In view of the fact that the coupling of platinum to stainless steel did accelerate the cracking process, it was of interest to determine whether the addition of platinum chloride to the solution would produce a similar effect. Since platinum is a noble metal, it should be selectively plated at the cathodic sites and present a cathode of low hydrogen overvoltage.

Therefore, tests were run in which the chloride in the 0.04 *m* UO₂SO₄ - 0.02 *m* H₂SO₄ - 0.005 *m* CuSO₄ solution was added as platinum chloride. The initial concentrations of platinum and chloride in solution (by chemical analysis) were 50 and 40 ppm, respectively; the pH of the solution was 1.55.

With air passing into the boiling solution, cracking was produced on duplicate elastically-stressed U-bends of type 347 stainless steel during the first 25 hr of exposure. The cracks were located in the region of maximum stress on both specimens. Chemical analysis of the solution after the 25-hr run showed the dissolved platinum content to be less than 5 ppm. From the physical appearance of the specimens which were randomly-spotted with dull gray-colored patches, it was strongly suspected that the platinum ion had undergone reduction to metallic platinum at these sites.

The effect of oxygen removal on the sensitivity of stressed type 347 stainless steel U-bends to cracking in the boiling uranyl sulfate solution containing platinum and chloride ions was examined also. The test solution, similar in composition to that previously described, was sparged thoroughly with tank helium gas for one hr before the introduction of the stressed U-bends; helium sparging was continued during operation of the test. At the completion of the first 25 hr, a total of five cracks were observed on the specimens, two on one and three on the second specimen. The cracks were located in the region of maximum stress. The dissolved platinum content after the 25 hr was found to be approximately 15 ppm, and again, the indications were that platinum metal plated out on the surface of the stainless steel.

Thus, the above experiments clearly showed that the presence of platinum chloride in the uranyl sulfate solutions greatly influenced the rate at which cracks appear on stressed type 347 stainless steel. Probably the reason why platinum in the solution was more effective than coupling platinum to the stress specimen was because the platinum in solution plated on cathodic sites which were closely associated with the development of cracks, whereas the platinum mechanically coupled with the stainless steel was farther removed from the anodic sites. Furthermore, the experiments again showed that in the particular environment, the presence of oxygen was not necessary for the development and propagation of cracks.

3. Inhibition of Stress-Corrosion Cracking. A number of tests to determine the effectiveness of the pertechnetate ion as an inhibitor of stress-corrosion cracking in type 347 stainless steel has been completed. The environment for the tests was oxygenated distilled water containing 100 ppm of chloride (as NaCl and HCl) at a pH of 2.8. The test temperature was 300°C. In the absence of the pertechnetate ion, the environment was found to produce cracks consistently in stressed U-bends of type 347 stainless steel within periods of 100 to 340 hr²⁵.

Pertechnetate concentrations of 6, 15, 30, 60, 510, and 825 ppm added as potassium pertechnetate were examined in the present tests; the results are summarized in Table VIII. With the exception of the 6 ppm test which was operated for a period of 100 hr only, pertechnetate concentrations of 60 ppm and less failed to inhibit stress-corrosion cracking of the solution-exposed stainless steel U-bends during exposure periods up to 200 and 250 hr. Furthermore, appreciable loss

of the initial pertechnetate ion concentration occurred in every test. Microscopic examination of the specimen surfaces disclosed that in concentrations up to and including 60 ppm, the pertechnetate ion was not an effective inhibitor of pitting attack. Pitting was found to range from moderate to heavy in both frequency and intensity with the most severe damage being along the edges of the specimens in the region of maximum applied stress. Most of the cracks appeared to originate in the pits.

Table VIII. Effect of Pertechnetate Ion as a Stress-Corrosion Cracking Inhibitor for Type 347 stainless Steel U-bends at 300°C in Oxygenated Distilled Water Containing 100 ppm Chloride Ion

Pertechnetate Conc'n (ppm) ^a		Total Hr	Specimen Number	Incidence of Cracking
Initial	Final			
6	1	100	1	No cracks in 100 hr
			2	No cracks in 100 hr
15	2	250	1	Cracked between 100 and 250 hr
			2	Cracked between 100 and 250 hr
30	2	250	1	Cracked between 100 and 250 hr
			2	Cracked between 100 and 250 hr
60	6	200	1	Cracked before 100 hr
			2	Cracked between 100 and 200 hr
510	447	200	1	No cracks in 200 hr
			2	No cracks in 200 hr
825 ^b	590	350	1	No cracks in 350 hr
			2	No cracks in 350 hr

a Solutions analyzed for pertechnetate ion polarographically.

b Estimated initial concentration.

At the higher pertechnetate levels, 510 and 825 ppm, no cracking was found on stressed stainless steel U-bends exposed in the solution after 200 hr in the 510 ppm test nor after 350 hr in the 825 ppm test. The nature of the corrosion attack was generalized. However, a few random areas on edge surfaces of the specimens exhibited fairly-severe pitting attack.

The analytical data indicated a possible loss of 30 per cent of the initial pertechnetate concentration in the 825 ppm test during the 350-hr exposure. In view of the fact that the initial concentration of 825 ppm was a calculated value determined from a weighed quantity of potassium pertechnetate, it is possible that the actual loss of pertechnetate from solution may have been less. In the test with

510 ppm pertechnetate, about 12% of the technetium was lost from solution during the 200 hr test. Thus it appears that in the solution under test, the pertechnetate ion is not completely stable. It is probable that in the acid solution, the pertechnetate ion is slowly reduced and precipitated as technetium dioxide. However, in the presence of 500 to 800 ppm of pertechnetate, stress-corrosion cracking of type 347 stainless steel does appear to be inhibited for periods as long as 350 hr.

Solutions from the above two tests contained voluminous quantities of insoluble corrosion products at completion of the respective runs. Chemical analysis of the residues showed only trace quantities of technetium, less than 0.1 wt per cent. The major constituents were found to be iron and chromium. Converted to the anhydrous oxides, the residues contained approximately 13% Fe₂O₃ and 14% Cr₂O₃. The balance, 73 per cent, was presumably, moisture.

Tests are now in progress to determine the effectiveness of the pertechnetate ion in reducing the susceptibility of type 347 stainless steel to cracking in chloride environments in neutral or basic solutions and to determine the chemical stability of such solutions.

B. Corrosion of Zirconium Alloys by Uranyl Sulfate Solutions.

A second group of corrosion tests with zirconium-base alloys was completed during the past quarter; the corrosion results for the first group of tests have been reported²⁶. The test program is a cooperative effort with the HRP Metallurgy Group to evaluate the general corrosion behavior of a number of binary, ternary, and quaternary alloys of zirconium in oxygenated uranyl sulfate solution at 300°C. As a second objective, the program is planned to provide corrosion specimens for study of the structure of the oxide films by both x-ray and electron diffraction techniques.

The specific environment employed in the zirconium alloy study was oxygenated 0.04 M UO₂SO₄ solution containing 0.02 M H₂SO₄ and 0.005 M CuSO₄. The alloy specimens were generally exposed for 1000 hr at a temperature of 300°C. Included in the second group of alloys were the following combinations: Si-Zr, Cr-Zr, Mo-Zr, Mo-Nb-Zr, Ni-Nb-Zr, and V-Nb-Zr. The composition of the alloys in weight per cent and the corrosion data from the present tests are included in Table IX. The observed corrosion rates were determined from as-scrubbed weight losses; no attempt was made to defilm the specimens.

Of the entire group of alloys undergoing test, two alloys exhibited a corrosion resistance that was comparable with that for Zircaloy-2 exposed under similar conditions. One of the two alloys, 0.7 Cr - 99.3 Zr, was corroded at a near-negligible rate of 0.1 mpy during the 1000 hr. The second alloy, 7 Mo-21 Nb-73Zr, exhibited a slight weight gain of 0.1 mg/cm² during the same period. The alloys containing 1Ni-20Nb-79Zr and 3V-15Nb-82Zr also exhibited good corrosion resistance, although the specimens showed slightly higher weight gains than the 7Mo-20Nb-73Zr alloy.

Table IX: Corrosion of Zirconium-Base Alloys by Oxygenated 0.04 m UO_2SO_4 -
 0.02 m H_2SO_4 - 0.005 m CuSO_4 Solution After 1000 hr at 300°C

Lab No.	Material Identity	Alloy Composition (wt. %)	Heat Treatment	Surface Condition	Specimen Number	Corrosion Rate (mpy)	Specimen Appearance
T-52	Zr-59	0.5Si-99.5Zr*	As cast	Abraded	1	0.5	Dull gray-brown mottled film; roughened surfaces
					2	0.3	
T-55	Zr-61	0.5Si-99.5Zr	As cast	Abraded	1	0.6	Dull uniform gray film; roughened surface
T-53	Zr-60	2Si-98Zr*	As cast	Abraded	1	10.1	Dull gray film with black stains heavily-roughened surfaces
					2	8.9	
T-54	Zr-62	2Si-98Zr	As cast	Abraded	1	3.1	Dull gray with brown stains; moderately-roughened surfaces
T-56	Zr-65	0.7Cr-99.3Zr	Cast; hot-rolled at 700°C; ground, etched, and filed to 0.093-in.	Abraded	1	0.1	Lustrous thin dark gray film
S-98	Zr-18	10Mo-90Zr	Cast; hot-rolled at 700°C to 0.1 in.; cold-rolled to 0.070 in.	Chemically-polished	1	3.6	Mottled green-brown film; roughened surfaces
					2	4.5	
S-81	Zr-47	7Mo-20Nb-73Zr	Cast; cold-rolled	Chemically-polished	1	(+0.1mg/cm ²)	Lustrous metallic gray film with yellow stains
S-82	Zr-48	1Ni-20Nb-79Zr	Cast; cold-rolled	Chemically-polished	1	(+0.8mg/cm ²)	Lustrous dark gray-brown film with small black deposits
S-83	Zr-68	3V-15Nb-82Zr	Cast; cold-rolled	Chemically-polished	1	(+1.1mg/cm ²)	Lustrous dark black film with yellow streaks
					2	(+1.1mg/cm ²)	

* Alloy prepared directly from zirconium sponge; all other alloys prepared from crystal bar zirconium.

The effect of increasing the silicon content in the zirconium was to lower the corrosion resistance of the alloy. In the case of the alloys where the zirconium metal source was sponge zirconium, instead of crystal bar, the observed corrosion rates were increased from approximately 0.4 mpy to between 9 and 10 mpy as the silicon content was increased from 0.5 to 2.0 per cent, respectively. When crystal bar zirconium was used as the metal source, the effect of increasing the silicon content was not quite so detrimental. The 0.5 per cent silicon alloy corroded at a rate of 0.6 mpy, whereas the 2.0 per cent silicon alloy corroded at a rate of 3.1 mpy.

The 10Mo-90Zr alloy also exhibited mediocre corrosion resistance to the high-temperature uranyl sulfate environment. In a hot-rolled condition, the alloy corroded at rates of 3.6 and 4.5 mpy for duplicate specimens.

Additional zirconium-base alloys will be tested in high-temperature uranyl sulfate solution during the next quarter. The alloying elements will include chromium, indium, iron, manganese, niobium, palladium, platinum, silver, tin, titanium, uranium, and yttrium.

C. Miscellaneous Corrosion Tests.

1. Corrosion of Stellite 6. Recently in the HRT and in related engineering test equipment, various components such as valve seats and trim that were fabricated from Stellite 6 have failed during service operation with distilled water and other solutions. In particular, leaks have developed in valves where the Stellite 6 was deposited from weld rod by an inert-arc welding technique and in pulsafeder pumps where the seats were ground Stellite 6 castings. A test program was initiated to examine the behavior of Stellite 6 under conditions of exposure corresponding to those encountered in practice.

Three types of specimens were tested: (1) polished sections of as-received weld rod; (2) small cylinders of machined and polished deposits that were prepared by the inert-arc melting of the weld rod; and, (3) an actual pulsafeder valve seat. The environments included distilled water at two temperatures, 80°C and boiling, and boiling solutions of 3 wt % Na_3PO_4 and 5 wt % HNO_3 . Results of the tests indicated that Stellite 6 specimens of weld rod and inert-arc deposits were seriously affected by the boiling 5 wt % HNO_3 solution and by distilled water at 80°C with an overpressure of 150 psi of oxygen. No measurable corrosion attack was observed on Stellite 6 exposed in boiling and aerated distilled water. In the 5 wt % HNO_3 solution, specimens were corroded uniformly at rates of approximately 11 mpy, whereas in the oxygenated distilled water at 80°C, the attack was localized resulting in average corrosion rates of about 2 mpy.

The tests also showed - in some cases - that pre-exposure of specimens in boiling 3 wt % Na_3PO_4 solution for periods of 100 hr diminished the adverse effects experienced in the two fore-mentioned environments. For example, a deposit corroded at a rate of 11 mpy in

the boiling 5 wt % HNO_3 solution; however, a similar specimen that was pre-exposed for 100 hr in the boiling trisodium phosphate solution corroded at a rate of less than 4 mpy during a subsequent 800-hr test in boiling 5 wt % HNO_3 solution. In one experiment, the corrosion rate in boiling 5 wt % HNO_3 solution was less than 1 mpy after 500 hr on a trisodium phosphate - pretreated specimen. Similarly, after the trisodium phosphate pretreatment, specimens of Stellite 6 were completely unreactive in the oxygen-pressurized distilled water environment.

On the other hand, some experiments gave results that were not consistent with the apparent enhancement of the corrosion resistance of Stellite 6 as a result of pre-exposure in boiling trisodium phosphate solution. In one test, a deposit was exposed to the boiling 5 wt % HNO_3 solution for approximately 500 hr. It was then placed in boiling 3 wt % Na_3PO_4 solution for 150 hr. After being returned to the boiling nitric acid solution, it proceeded to corrode at the original rate. In other words, the trisodium phosphate treatment was ineffectual in diminishing the corrosion rate. Another experiment consisted in determining how abrasion of a pretreated deposit would affect its reactivity in the oxygenated distilled water at 80°C . Since un-pretreated specimens were found to behave poorly in the environment, the removal of a protective film that may have formed during the trisodium phosphate exposure by abrasion of the surfaces should result in a similarly-poor behavior. However, when a pretreated specimen was abraded to remove any protective film, the corrosion resistance in the distilled water-oxygen system was found to be entirely satisfactory. No measurable weight loss occurred. A third bit of evidence which discounted the theory of a protective phosphate-induced film was the fact that although on most occasions both weld rod and deposit specimens showed evidence of localized attack in the distilled water-oxygen environment, one weld rod specimen was completely unaffected. Finally, a pulsafeder check valve seat, many of which have deteriorated during water service in component testing, was subjected to the same environment and in 100 hr, no indications of corrosive attack were observed.

A single test was conducted to determine whether small concentrations of chromate ion in distilled water would affect the corrosion behavior of Stellite 6. The test was operated with aeration at 80°C and with 10 ppm of chromate (as CrO_3) present in the water. After 500 hr, no measurable weight loss was found on weld rod or deposit-type specimens.

The possibility exists that adverse effects observed on certain of the Stellite 6 specimens may simply have been the result of non-homogeneities such as inclusions, gas pockets, etc. in the specimens themselves. Further experiments will be necessary to resolve the problem.

2. Corrosion of Hard-Chrome Plate. As a means for circumventing some of the difficulties encountered in using Stellite alloys in pulsafeder pumps, the proposal was made to substitute hard chromium-plated austenitic stainless steel check-valve balls for the Stellite Star J balls presently used. In consideration of the application, it was decided to examine the corrosion behavior of the hard-chrome plate in two media at 80°C: aerated 0.04 m UO_2SO_4 solution containing 0.02 m H_2SO_4 and 0.005 m CuSO_4 , and aerated distilled water.

Three hard-chrome plated type 304 stainless steel balls were tested for approximately 500 hr in the above environments. In the course of the tests, certain changes occurred on the surfaces of the balls that warranted comment. Otherwise, no measurable weight losses were observed in any of the tests. The distilled water-exposed ball developed a mottled, greenish-brown stained appearance during the 500-hr exposure period, whereas the ball exposed in the simulated HRT core solution remained bright and shiny throughout the test. When placed in distilled water, the latter ball developed a blue discoloration of intensity considerably less than had been observed on the original water-exposed ball.

The third ball after a 90-hr exposure in distilled water during which period it acquired fairly heavy staining and discoloration was placed in the uranyl sulfate solution for 400 hr. At the end of the latter exposure, the surfaces of the hard-chrome plate were bright and shiny with no indications of staining. Thus, the stain was soluble in the acidified uranyl sulfate solution, but its identity remains unknown.

3. Porosity Tests on Gold-Plated Bellows. As a protective measure against early failure of stainless steel bellows due to excessive corrosion attack that could result under certain operating conditions from an oxygen-deficient HRT uranyl sulfate fuel solution, some consideration has been given to the possibility of plating the type 347 stainless steel bellows with gold. To assess the practicability of using such equipment in corrosive environments, it was first decided to examine the integrity of the gold plate by suitable tests.

Two bellows were used for the tests. The first bellows was plated with several tenths of a mil of gold; the second bellows was endowed with a considerably thicker plate, 2 mils (0.002 in.). A ferroxyl test²⁷ run on the first bellows indicated extreme porosity of the plating. The bellows was then inserted in boiling 10 wt % HCL solution, and in a matter of minutes, bubbles of gas - presumably hydrogen from attack on the base metal - appeared along the gold-plated surface. After 10 min of exposure, the bellows was removed from the hydrochloric acid solution. Extreme blistering, cracking, and flaking of the gold plate were evident, and it was also readily apparent that the underlying stainless steel was badly pitted as a result of attack by the acid solution.

The second bellows plated with 2 mils of gold was immersed in 10 wt. % HCL solution at room temperature, and again, within minutes, hydrogen gas was copiously evolved from the surface of the bellows. After

a period of 48 hr, the acid solution had acquired a deep blue-green color. Visual examination of the plated bellows disclosed no direct evidence of having undergone attack. However, within 2 hr after returning the bellows to the hydrochloric acid solution at boiling temperature, the plating was sufficiently undercut and cracked to give visual proof of the unsuitability of the plate.

Thus, the results of the above tests and other related tests carried out during the past few years show the impracticability of relying on noble electrodeposits for protection of the less noble base metals.

4. Corrosion of Sintered Alumina and Titania. Many corrosion tests have been run with high-purity sintered alumina produced by Kearfott and presently used in 100A and 5-gpm-in-pile-loop pumps. Comparison tests have recently been run with a commercial-grade sintered aluminum oxide designated as Alsimag 652 and with a sintered titanium dioxide, Alsimag 192; both materials are produced by the American Lava Corporation.

To evaluate the merits of the Alsimag materials as a possible replacement material for the Kearfott material presently used, specimens of the three materials were subjected to test in oxygenated 1.33 m UO_2SO_4 at 250°C. The results of the tests are presented in Table X.

From the data, it appeared that the Kearfott alumina was initially more resistant than the Alsimag alumina; but as the test continued, the situation was reversed. At the end of 1000 hr, the cumulative corrosion rates based on weight losses for the duplicate specimens of the Kearfott material were approximately twice as great as for the Alsimag material. Both the polished and the unpolished titanium dioxide (Alsimag 192) showed corrosion rates approximately equal to the Alsimag alumina.

Thus, Alsimag 192 (TiO_2) and Alsimag 652 (Al_2O_3) have better corrosion resistance than the Kearfott high purity alumina under the conditions of this test. While the above data indicate the possible usefulness of the Alsimag materials in pump bearings, they do not necessarily mean the Alsimag materials would be better bearing materials than the Kearfott alumina.

Table X: Corrosion of Sintered Alumina and Sintered Titania
in 1.33 M UO₂SO₄ at 250°C

Total Hr	Specimen Number	Cumulative Corrosion Rate, mpy			
		Kearfott ^a	Alsimag 192 ^b	Alsimag 192 ^c	Alsimag 652 ^d
50	1	47	111	75	91
	2	65	124	69	81
98	1	-	68	--	66
	2	-	70	-	63
171	1	48	--	46	-
	2	51	-	43	-
337	1	30	-	30	-
	2	31	-	-	-
500	1	29	21	22	17
	2	30	21	-	12
1000	1	28	13	13	16
	2	26	13	-	13

a High-purity Al₂O₃

b Unpolished TiO₂

c Polished TiO₂

d Al₂O₃, 96% min.

V. REFERENCES

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