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CORROSION OF URANIUM-ZIRCONIUM ALLOYS IN
WATER AT TEMPERATURES UP TO 100 C

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by

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For The Atomic Energy Commission

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Chief, Declassification Branch

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CORROSION OF URANIUM-ZIRCONIUM ALLOYS IN WATER AT TEMPERATURES UP TO 100 C

by

H. A. Pray and W. E. Berry

Under certain conditions, uranium - 5 w/o zirconium alloys exhibit remarkable corrosion resistance in distilled water at 100 C after 1 year's exposure. The alloy must be quenched rapidly (in water or oil) from above 700 C. Subsequent treatments to soften it by annealing at 500 or 600 C or by isothermal treatments have lessened its resistance. Corrosion resistance is also dependent on dissolved oxygen in the test water. The alloy is resistant to 97 C water saturated with hydrogen-oxygen mixtures in ratios up to 25:1 but not in excess of 35:1. It corrodes when part of a crevice. Harmful effects of surface abrasion can be removed by a nitric acid pickle, and long-time pickling does not impair corrosion resistance. Galvanic coupling uranium - 5 w/o zirconium with aluminum does not adversely affect the corrosion resistance of the alloy. Increasing the zirconium content to about 7.5 w/o eliminates the alloy's sensitivity to crevice effects and to dissolved oxygen in the test water, while additions in the range of 20 w/o eliminate the need for special heat treatments.

INTRODUCTION

Uranium has poor corrosion resistance to water. For reactor use, in contact with water, uranium must be protected with a more corrosion resistant material. Breaks in the protective jackets or cladding during reactor operation result in very rapid corrosion of the underlying uranium, frequently rupturing the assembly. This type of failure might be minimized if small additions of a second element greatly improved the corrosion resistance of uranium without affecting its other properties.

In a search for alloying additions to improve the corrosion resistance of uranium, the uranium-zirconium system has been explored. Particular attention has been given to the corrosion behavior of alloys in the 4 to 6 w/o zirconium range.

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TEST PROCEDURES

Sample Preparation

The alloys were prepared from biscuit uranium and Grade I crystal-bar zirconium. Arc melting was used in the preparation of the small 100-g ingots. Most of the work was done with 6-kg melts, which were most conveniently made by induction melting. No significant difference in corrosion properties could be attributed to either size of melt or melting method.

Test samples were shaper finished to remove the oxide scale resulting from heat treatment. Before testing, samples were degreased in acetone, pickled 1.5 min in 1:1 nitric acid-water (by volume) to remove tarnish film formed during storage, rinsed 30 min in tap water, dipped in acetone, air dried, weighed, and immediately placed on test.

After exposure, samples which corroded were scrubbed with a stiff brush to remove loose oxide before weighing. No attempt was made to strip the adherent tarnish film from corrosion-resistant samples.

Test Conditions

Test water was once distilled and then passed through an ion-exchange column to give specific resistivity of approximately 1,000,000 ohm-cm. Pyrex glassware was used in all test equipment.

Boiling-Water Beaker Units

Samples were supported on Pyrex glass holders in 1-liter electrolytic beakers. Cold water flowing through distilling flasks placed on top of beakers prevented the test water from boiling away.

Boiling-Water Reflux Units

Samples were supported on glass holders in 1-liter Erlenmeyer flasks. The test water was refluxed by means of standard laboratory condensers (approximately 24 in. long) which were open to the atmosphere.

Gas-Saturated Boiling Water

The setup was similar to reflux units described above. Gas at the rate of 60 ml/min was introduced near the bottom of the Erlenmeyer flasks through fritted gas-dispersion tubes. Samples were supported on glass holders in such a manner that bubbling gas did not impinge on them. Exit gas passed out the top of the condensers through gas traps to avoid back diffusion of air. Before each test, the water was boiled for at least 1 hr to remove dissolved gases.

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Gas-Saturated 80 C Water

The setup was similar to that described above, except Erlenmeyer flasks were immersed in a constant-temperature bath. Thermometers were inserted in the flasks and the temperature of the test water maintained at 80 ± 1 C.

97 C Water Saturated With Hydrogen-Oxygen Mixtures

The setup was similar to that described above. Hydrogen-oxygen ratios were obtained by passing gases through calibrated flowmeters and mixing them prior to entry into the flasks. Temperature varied ± 1 C.

TEST RESULTS

The results of a survey of the corrosion resistance of uranium alloys containing 0 to 100 w/o zirconium additions are presented in Table 1 and include minimum alloy compositions, for each of four heat-treated conditions, which are still resistant after 10 months' exposure to distilled water at 100 C. Resistant material exhibited low weight change and adherent tarnish films or very thin oxide films, while poor material was covered with heavy loosely adherent oxide and underwent considerable change in weight.

The remarkable corrosion resistance of the 5 to 6 w/o zirconium alloy, water quenched from 800 C, is illustrated in Figure 1, a plot of weight change against length of exposure.

Effect of Heat Treatment

As evidenced by the results of the alloy series described above, zirconium additions as high as 20 w/o are necessary for corrosion resistance when the alloy is alpha annealed (furnace cooled from 600 C), while only 5 to 6 w/o zirconium is required when the alloy is gamma quenched (water quenched from 800 C).

Although the 5 per cent, gamma-quenched alloy is corrosion resistant, it is very hard and sometimes cracks and warps during quenching. The effects on its corrosion resistance of attempts to soften it and relieve quenching stresses by isothermal treatments are presented in Table 2. Of four treatments investigated, only one did not adversely affect the resistance of the alloy: quench from 900 to 300 C, hold 10 min at 300 C, and then water

TABLE 1. CORROSION RESISTANCE OF ARC-MELTED, HEAT-TREATED
URANIUM-ZIRCONIUM ALLOYS IN 100 C DISTILLED WATER

Heat Treatment	Zirconium Addition, w/o		
	Failed Within 24 Hr	Failed Within 1 Week	Resistant 10 Months
1 hr 600 C, furnace cooled (alpha)	0, 2.3, 3.6, 6, 9	10.9, 18	20 through 100
1 hr 800 C, water quenched (gamma)	0, 2.3, 3.6		6 through 100
1 hr 800 C, water quenched; plus 1 hr 600 C, furnace cooled (gamma plus alpha)	0, 2.3, 3.6	6, 9, 10.9	18 through 100
1 hr 700 C, water quenched (beta)	0, 2.3, 3.6		6 through 100

FIGURE 1. CORROSION RESISTANCE OF ARC-MELTED, GAMMA-TREATED URANIUM-ZIRCONIUM ALLOYS IN 100 C DISTILLED WATER

TABLE 2. CORROSION RESISTANCE OF INDUCTION-MELTED, ISOTHERMALLY TREATED URANIUM - 5 w/o
ZIRCONIUM ALLOY IN 100 C DISTILLED WATER

Heat Treatment	Total Weight Gain, mg/sq cm at Indicated Time, hr									Remarks
	24	48	96	168	336	672	1344	2016	2688	
1 hr 900 C, water quenched	0.07	0.09	0.09	0.17	0.17	-0.10	-0.13	-0.22	-0.34	Adherent tarnish film
1 hr 900 C, 10 min 650 C, water quenched	-12.1									Uniform loose dark oxide, 24 hr
1 hr 900 C, 10 min 575 C, water quenched	-0.02	0.47	0.71	-18.8						Uniform loose dark oxide, 168 hr
1 hr 900 C, 10 min 500 C, water quenched	0.11	0.11	0.12	0.11	-73.2					Uniform loose dark oxide, 336 hr
1 hr 900 C, 10 min 300 C, water quenched	0.12	0.12	0.13	0.13	0.13	0.07	0.13	0.11	0.02	Adherent tarnish film

quench. However, a sample which was quenched from 900 to 500 C, held 10 min at 500 C and water quenched was resistant for a week before failing. Additional corrosion data for arc-melted and induction-melted alloys heat treated at 300 C after quenching from 900 C are presented in Table 3.

Studies on other alloys indicated the 5 per cent alloy can be heated as high as 400 C after water quenching from 900 C or can be quenched from 900 C to temperatures below 400 C and still retain its corrosion resistance. While alloys so treated are not markedly softened, there are not sufficient data to rule out the possibility that some similar heat treatment might sufficiently reduce brittleness to give a useful alloy of adequate corrosion resistance. Considerably more work would be required to prove the feasibility of developing such a heat treatment.

Jig quenching to prevent warpage resulted in areas of varying resistance on test samples, as illustrated in Figure 2. The two semicircular areas represent resistant material on the sample which had been exposed to nitrogen-saturated boiling water. The semicircular areas correspond in size and location to holes in the jig used in quenching, thus indicating a more rapid quench where water rushed through the openings and a delay in quenching the rest of the sample, allowing it to remain in the 400 to 600 C range for a short period of time and impairing its resistance somewhat.

Oil quenching from the gamma region (900 C) did not adversely affect the resistance of the 5 per cent alloys. Both oil-quenched and water-quenched samples of the same heat were still resistant to boiling water (beaker tests) after 4 months' exposure. These data are presented in Table 4.

Effect of Dissolved Gases in Test Water

The possibility that dissolved gases in the test water affect the corrosion resistance of the 5 per cent alloy (water quenched from 800 C) first arose when it was observed that samples from the same heat behaved differently under different test conditions. Samples tested in beakers were resistant, while those tested in reflux units failed within a 24-hr exposure. Samples were resurfaced several times and were alternately tested under one condition and then the other, but continued to fail in reflux units and not in beakers. However, the tarnish film formed in the beaker tests did not afford protection when the samples were transferred to reflux units. It was suspected that the amount of dissolved gases (probably oxygen) in the test water was different because of differences in the geometry of the two setups, since all other conditions appeared to be the same. This theory was confirmed by exposing one 5 per cent alloy sample to boiling water saturated

TABLE 3. CORROSION RESISTANCE OF URANIUM - 5 w/o ZIRCONIUM ALLOY
IN 100 C DISTILLED WATER

Heat Treatment					
<u>1 Hr 900 C, Water Quenched</u>		<u>1 Hr 900 C, Water Quenched; 2 Hr 300 C, Water Quenched</u>		<u>1 Hr 900 C, Quenched to 300 C; 2 Hr 300 C, Water Quenched</u>	
Test, hr	Weight Gain, mg/sq cm	Test, hr	Weight Gain, mg/sq cm	Test, hr	Weight Gain, mg/sq cm
<u>Arc Melted (5 Different Heats, All Low Carbon)</u>					
3648	-0.13	3600	-0.26	2976	0.06
	-0.09		-0.01		Not tested
	-0.04		-0.05		0.05
	-0.06		-0.12		Not tested
	-0.01		-0.10		Ditto
<u>Induction Melted (All From Same Heat; 5.01 w/o zirconium, 0.05 w/o carbon)</u>					
3648	-0.12	3600	0.09	2976	-0.11
	-0.32		-0.31		0.03
	-0.35		-0.19		Not tested

Note: All samples had adherent tarnish film.

Face view

N2031

Edge view

N2032

FIGURE 2. "JIG-QUENCHED" URANIUM - 5 w/o ZIRCONIUM ALLOY

Water Quenched From 800 C; Corrosion Tested 1920 Hr in Nitrogen-Saturated Distilled Water at 100 C

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TABLE 4. CORROSION RESISTANCE OF OIL-QUENCHED AND WATER-QUENCHED URANIUM - 5 w/o ZIRCONIUM ALLOYS^(a) IN DISTILLED WATER AT 100 C

Total Weight Gain ^(b) , mg/sq cm, for Indicated Time, hr							
24	72	168	336	672	1344	2016	2688
1 Hr at 900 C, Water Quenched							
0.03	-0.02	0.01	0.03	0.08	-0.15	-0.23	-0.51
0.03	0	0.03	0.07	0.14	0.15	0.13	-0.24
0.03	-0.02	0.04	0.06	0.10	-0.13	-0.23	-0.43
0.02	0.05	0.03	0.05	0.05	0.05	0.01	-0.07
0.05	0.05	0.05	0.08	0.05	-0.04	-0.07	-0.30
1 Hr at 900 C, Oil Quenched							
0.04	0	0.03	0.06	0.10	0.02	-0.19	-0.31
0.02	-0.03	0	0	0.03	0.20	-0.02	-0.23
-0.01	0	-0.01	0.01	0.01	-0.02	-0.13	-0.28
0.05	0.08	0.12	0.17	0.17	0.14	0.09	0.03
0.05	0.05	0.06	0.09	0.08	0.08	0.08	-0.12

(a) Induction-melted. Analysis: 4.88 w/o zirconium, 0.14 w/o carbon, 0.018 w/o nitrogen.

(b) Several oxide flecks appeared on samples at 1344 hr, rest of surface has adherent tarnish film.

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with each of several gases (sample was resurfaced after each exposure). The results of these tests are presented in Table 5. Samples exposed to hydrogen-, helium-, and nitrogen-saturated water were heavily oxidized, while those exposed to water saturated with air or oxygen exhibited adherent tarnish films, thus indicating the corrosion resistance of the 5 per cent alloy is dependent upon the presence of dissolved oxygen in the test water.

The following experiments were conducted to study the effect of dissolved gases and to define the minimum oxygen content necessary to impart corrosion resistance to the 5 per cent alloy. Samples used in all tests were water quenched from 800 C and were from one heat, an induction-melted alloy, with the following analysis (w/o): 4.89 zirconium, 0.15 carbon, and 0.001 nitrogen.

Boiling Water Saturated With Air, Oxygen, Nitrogen, and Hydrogen

Samples of the 5 per cent alloy were exposed to boiling water saturated with each of the following gases: air, oxygen, nitrogen, and hydrogen. Corrosion results are summarized in Table 6. After 24 hr exposure, samples appeared as follows: (1) hydrogen, covered with loose dark oxide; (2) nitrogen, adherent black film; and (3) air and oxygen, adherent tarnish film. Upon extended exposure (6 weeks), all samples failed. Duplicate 5 per cent alloy samples were resistant to boiling water in beaker tests for as long as 4 months. Since it had already been shown that the corrosion resistance of the 5 per cent alloy depends upon dissolved oxygen in the test water, several things appeared at fault in the above tests. It is believed the dissolved gas content was not constant throughout the test nor uniform throughout the solution because of the sparging action of boiling and differences in boiling rates and sites of bubble formation. This could account for the early failure of samples tested in air and oxygen-saturated water. The amount of oxygen in the nitrogen used (tank nitrogen, 99 per cent pure) may have been sufficient to prolong the resistance of the sample exposed to nitrogen-saturated water. With this in mind, tests were conducted at temperatures below boiling and use of tank nitrogen discontinued.

80 C Water Saturated With Air, Oxygen, and Hydrogen

Results are summarized in Table 7 for 5 per cent alloy samples exposed 2 months to 80 C water saturated with air, oxygen, and hydrogen. Samples exposed to air- and oxygen-saturated water were covered with adherent tarnish films and changed very little in weight, while the sample exposed to hydrogen-saturated water lost some weight and was covered with an adherent dark film, except for several areas of thin dark oxide. These results have been duplicated in additional tests. However, a question arose as to whether equilibrium with hydrogen was reached during the early

TABLE 5. EFFECT OF DISSOLVED GASES IN BOILING WATER
ON RESISTANCE OF URANIUM - 5 w/o ZIRCONIUM
ALLOY(a), SHORT-TIME EXPOSURE

Gas Saturating Water(b)	Remarks After 24-Hr Exposure
Hydrogen	Uniform loose dark oxide
Oxygen	Adherent tarnish film
Nitrogen	Uniform loose dark oxide
Helium	Ditto
Oxygen	Adherent tarnish film
Air	Ditto

(a) Induction-melted, water quenched from 800 C. Analysis:
6.26 w/o zirconium, 0.11 w/o carbon, and 0.003 w/o
nitrogen.

(b) Sample exposed to gases in the order listed.

TABLE 6. EFFECT OF DISSOLVED GASES IN BOILING WATER ON RESISTANCE OF
URANIUM - 5 w/o ZIRCONIUM ALLOY(a), EXTENDED EXPOSURE

Gas Saturating Water	Total Weight Gain, mg/sq cm, for Indicated Time, hr							Remarks
	24	48	168	336	504	672	912	
Air	0.03	0.02	0.02	0.04	0.02	-0.08	-36.5	Uniform loose dark oxide, 912 hr
Oxygen	0.02	0.01	0.01	-2.15	-2.12	-80.3		Oxide spots, 336 hr; uniform oxide, 672 hr
Nitrogen	0.07	0.04	-0.23	-0.42	-22.3			Uniform loose dark oxide, 504 hr
Hydrogen	-4.87							Uniform loose dark oxide, 24 hr

(a) Induction melted, water quenched from 800 C. Analysis: 4.89 w/o zirconium, 0.15 w/o carbon, and 0.001 w/o nitrogen.

TABLE 7. EFFECT OF DISSOLVED GASES IN 80 C WATER ON RESISTANCE OF
URANIUM - 5 w/o ZIRCONIUM ALLOY^(a)

Gas Saturating Water	Total Weight Gain, mg/sq cm, at Time Indicated, hr								Remarks
	24	48	168	336	504	672	1104	1440	
Air	0.01	-0.02	0.01	-0.01	-0.01	0.01	-0.03	-0.03	Adherent tarnish film
Oxygen	0.05	0.03	0.05	0.05	0.08	0.07	-0.02	-0.04	Ditto
Hydrogen	0	-0.01	-0.09	-0.30	-0.31	-0.57	-0.74	-2.93	Dark film, thin oxide at either end
Hydrogen	-	-	-12.6						Uniform loose dark oxide
Hydrogen	-	-	-3.18						Ditto

(a) Induction melted, water quenched from 800 C. Analysis: 4.89 w/o zirconium, 0.15 w/o carbon, and 0.001 w/o nitrogen.

stages of the test (when samples were examined every 24 hr) and whether some oxygen dissolved in the test water during the short handling time and thus built up a protective film on the sample. To investigate this possibility, several samples were exposed to hydrogen-saturated 80 C water for 1 week before examination, and these samples failed (also in Table 7), thus lending support to the above theory.

97 C Water Saturated With Hydrogen-Oxygen Mixtures

To determine the minimum amount of oxygen required to maintain corrosion resistance, 5 per cent alloy samples were exposed to 97 C water saturated with several ratios of hydrogen to oxygen. Preliminary work indicated samples were resistant for several weeks to ratios as high as 200 hydrogen to 1 oxygen (by volume). However, these samples were removed from test and examined every 24 hr for the first week of the test. When samples were exposed 1 week before being examined, the maximum ratio to which the alloy was resistant (6-week exposure) appeared to be between 25:1 and 35:1. Results of these experiments are presented in Table 8.

Crevice Effect and Galvanic Effect

The behavior in boiling water of the 5 per cent zirconium alloy when in contact with itself and other materials (to form a crevice) was investigated because of the alloy's sensitivity to dissolved oxygen in test water. Tests were conducted in which the alloy was wired to itself, to 2S aluminum, and to glass and then exposed 1 week in boiling water (in beakers). Evolution of gas (probably hydrogen) was observed in the contact area under the glass-covered sample. After 1 week's exposure, all samples were covered with loose dark oxide under the covered portions only and exhibited about equal corrosion rates, indicating corrosion by oxygen depletion in the crevice rather than by galvanic attack. Electrical contact between the alloy and aluminum was lost during the test.

To insure electrical contact and thereby study the galvanic effect of aluminum coupled to the 5 per cent alloy, holes were drilled in test pieces and the samples clamped together with aluminum nuts and bolts. However, electrical contact was again lost and the alloy not only corroded under the aluminum cover piece but also under the aluminum nuts and screw heads.

To eliminate the crevice effect and insure electrical contact between aluminum and the alloy, samples consisting of aluminum tubing* drawn

* Alcoa Utilitube, maximum allowable analysis: 1.00-1.60 magnesium, 0.20 copper, 0.65 iron, 0.30 silicon, 0.10 manganese, 0.25 zinc, 0.10 chromium, other each 0.05, total 0.15.

TABLE 8. EFFECT OF VARYING RATIO OF DISSOLVED HYDROGEN AND OXYGEN
IN 97 C WATER ON RESISTANCE OF URANIUM - 5 w/o ZIRCONIUM
ALLOYS(a)

Volume Ratio of Hydrogen to Oxygen	Total Weight Gain, mg/sq cm, at Indicated Time, hr								Remarks
	24	48	96	168	336	504	672	1008	
2:1	0.05	0.02	0.06	0.02	0.02				Adherent tarnish film
5:1	0.05	0.06	0.05	0.03	0.04	0.06	0.08	0.02	Ditto
10:1	0.04	0.04	0.05	0.03	0.04	0.05	0.08	0.06	"
10:1	--	--	--	-0.22	-0.23	-0.28	-0.27	-0.27	"
15:1	--	--	--	-0.05	-0.04	-0.02	-0.18		"
20:1	--	--	--	-0.11	0.02	0.04	0.04	0.02	"
25:1	--	--	--	-0.21	-0.33	-0.33	-0.33	-0.21	"
35:1	0.12	0.02	0.03	-0.11	-0.41	-98.4			Uniform loose oxide at 504 hr
35:1	--	--	--	-34.0					Uniform loose oxide at 168 hr
35:1	--	--	--	-79.3					Ditto
230:1	0.03	0.05	0.03	0.09	0.05	-14.3			Uniform loose oxide at 504 hr
230:1	--	--	--	-51.4					Uniform loose oxide at 168 hr
230:1	--	--	--	-14.8					Ditto
Hydrogen only	-7.93								Uniform loose oxide at 24 hr

(a) Induction melted, water quenched from 800 C. Analysis: 4.89 w/o zirconium, 0.15 w/o carbon, and 0.001 w/o nitrogen.

over 5 per cent zirconium alloy rods were exposed to boiling water. Electrical contact was maintained throughout the test. No attack was observed on the alloy or the alloy-aluminum interface at the exposed ends of the test samples after more than 3 months' exposure, indicating no adverse effects on the alloy because of the galvanic couple. Oxide formed at the bottom of small holes drilled into the walls of the aluminum tubing to expose the alloy, but, once the oxide formed, the attack stopped and no undercutting was observed. Some undercutting did occur in the holes on similarly prepared samples exposed 6 weeks to 97 C water saturated with hydrogen-oxygen mixtures in ratios of 10:1, 35:1, and 200:1. The alloy at the exposed ends of the above samples corroded uniformly and the aluminum did not appear to retard or accelerate the attack.

Effect of Surface Preparation and Pretreatment

Alloy samples which were pickled 30 min in 1:1 nitric acid-water were as resistant to boiling water (beaker tests) after 2 months' exposure as were samples which were pickled only 1.5 min before testing. Thus, long-time pickling does not appear to affect the resistance of the 5 per cent alloy.

Surface-ground specimens developed a thin oxide film where they touched glass holders after 24 hr exposure to boiling water (beaker tests). Extended exposure did not increase the amount or extent of attack. Pickling the surface-ground specimens in 1:1 nitric acid-water before testing eliminated this effect.

Several pretreatments were investigated to determine whether films could be formed on the 5 per cent alloy which would make it resistant to hydrogen-saturated boiling water. Before treatment, samples were degreased in acetone, degreased in boiling alkaline cleaner, rinsed in distilled water, pickled 1.5 min in 1:1 nitric acid-water, rinsed, dipped in acetone, and immediately placed in the treatment chamber. The treatment chamber (Pyrex glass) was then flushed for at least 1 hr before heating. Results are presented in Table 9 for 24 hr exposure to hydrogen-saturated boiling water of alloys pretreated in room-temperature air, 400 C tank argon, 400 C tank nitrogen, and dynamic vacuum (0.13 mm mercury) at 400 C. Treatment in air, argon, and nitrogen did not improve the resistance of the 5 per cent alloy. Treatment in dynamic vacuum did improve its resistance, but the film thus formed was not completely uniform and pitting resulted.

TABLE 9. EFFECT OF SURFACE PRETREATMENT ON RESISTANCE OF URANIUM - 5 w/o ZIRCONIUM ALLOY^(a) EXPOSED 24 HR TO HYDROGEN-SATURATED DISTILLED WATER AT 100 C

Pretreatment	Weight Gain, mg/sq cm	Remarks
None	-4.87	Uniform loose dark oxide
28 days in air at room temperature	-4.75	Ditto
24 hr in flowing tank argon at 400 C	-18.0	"
24 hr in flowing tank nitrogen at 400 C	-14.6	"
24 hr in dynamic vacuum (0.13 mm mercury) at 400 C	-0.74	Adherent film; numerous deep pits

(a) Induction melted, water quenched from 800 C. Analysis: 4.93 w/o zirconium, 0.13 w/o carbon, and 0.018 w/o nitrogen.

Extended Exposure to Boiling Water

In addition to the arc-melted uranium - 5 w/o zirconium alloy samples described earlier in this report, samples from an induction-melted alloy (4.94 w/o zirconium, 0.14 w/o carbon, 0.018 w/o nitrogen) were still resistant to boiling water (beakers) after 1 year's exposure (tarnish film with some oxide flecks; total weight loss, 0.65 mg/sq cm).

Effect of Increasing Zirconium Content

Both induction-melted and arc-melted uranium - 10 w/o zirconium alloys (water quenched from 800 C) were still resistant to hydrogen-saturated boiling water after 3 months' exposure (5 w/o alloys failed within 24 hr). There was no corrosion in the crevice of two 10 w/o alloy samples coupled together and exposed 1 week to boiling water (beakers). Preliminary results indicate about 7.5 w/o zirconium (alloy specimen water quenched from 800 C) is necessary for resistance to hydrogen-saturated boiling water.

CONCLUSIONS

The results of this investigation indicate the uranium - 5 w/o zirconium alloy may have some reactor applications, since, under certain conditions, it exhibits remarkable resistance to distilled water at or near 100 C. These conditions are:

The alloy must be rapidly quenched (in oil or water) from above 700 C. Various heat treatments which softened it by annealing or isothermal treatments (500 to 600 C) have adversely affected its resistance.

Test water must contain a certain amount of dissolved oxygen. In 97 C water saturated with hydrogen-oxygen mixtures, the alloy is resistant to ratios up to 25:1 but not to those in excess of 35:1.

Crevice must be avoided. The alloy corrodes where it is in close contact with itself or other material to form a crevice.

The surface must be properly prepared. Samples are resistant only if oxide scale from the heat-treating operation is completely removed (abrading, grinding, or shaper finishing) and if they are then pickled in nitric acid to remove effects of surface abrasion.

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When exposed under the above conditions, the corrosion resistance of the alloy is unaffected by long-time pickling in nitric acid or by galvanically coupling it with aluminum.

By increasing the zirconium content to 20 w/o, the need for special heat treatments can be eliminated, while at 7.5 w/o zirconium, the alloy (rapidly quenched) is no longer sensitive to crevice effects or to dissolved oxygen in the test water.

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