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EFFECT OF SATURATION OF WATER WITH DISSOLVED
CORROSION PRODUCT ON THE IN-REACTOR CORROSION
RATE OF ALUMINUM IN DEIONIZED WATER.
PROPOSAL FOR TEST IN 1706 KER.

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EFFECT OF SATURATION OF WATER WITH DISSOLVED CORROSION
PRODUCT ON THE IN-REACTOR CORROSION RATE OF ALUMINUM IN
DEIONIZED WATER. PROPOSAL FOR TEST IN 1706 KER.

SUMMARY

It is proposed to measure the corrosion rate of aluminum-clad DOE elements in deionized water in one of the KER Loops at the highest obtainable surface temperatures under conditions where the bulk water adjacent to the elements is saturated with aluminum corrosion product. This will determine whether in-reactor corrosion may be reduced by controlling the aluminum concentration in the water and also provide corrosion data in deionized water at higher temperatures than is now available. A thermocouple slug will be included.

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OBJECTIVES

The objectives of the proposed test are to:

1. Measure the corrosion rate of aluminum under conditions where the water is saturated or nearly saturated with aluminum. This will be done for fuel elements with high temperature difference between the surface and bulk water, for fuel elements with a low temperature difference, and for coupons.
2. Provide data on in-reactor aluminum corrosion at surface temperatures up to 250 C in deionized water.
3. Measure the cladding temperature of an aluminum-clad fuel element in deionized water and determine how much build-up of thermally insulating scale occurs.

BASIS AND JUSTIFICATION

Since the exact design of the NPR has not been established, there remains a good possibility that it may be desirable to operate with coolant piping of carbon steel together with aluminum-clad fuel elements, particularly if operation is for production only. Since carbon steel has a high corrosion rate at low pH and aluminum at high pH, this combination will require approximately neutral conditions. There is, therefore, a need for further work with the corrosion of aluminum alloys in deionized water in order to obtain, if possible, corrosion rates low enough to permit use as fuel element cladding at surface temperatures of up to about 250 C.

One method which has been found greatly to reduce corrosion rates is the saturation of the water with aluminum corrosion product. Aluminum is protected from corrosion by an adherent oxide film of low solubility, and the rate at which this film dissolves is believed to be the principal factor determining the corrosion rate in deionized water in high-temperature flow systems. If the water is kept saturated, dissolution of oxide is prevented. In out-of-reactor tests in ELMO-6 the total rate of dissolution of oxide in deionized water from all the corroding aluminum surface present was found to be approximately constant, over a considerable variation of surface, and equal to the rate at which the dissolved oxide was removed in the clean-up system.

One important reason for the high rates in reactor is believed to be the unsaturation of the water produced by raising it considerably above its inlet temperature. The increase in concentration from the corroding pieces is generally considerably less than the increase in solubility with increased temperature. One difficulty in greatly reducing the corrosion of heat generating pieces by increasing the aluminum concentration in the water may lie in the impossibility of achieving saturation at the surface temperature even when the bulk water is saturated.

The degree of saturation very likely affects the corrosion rate at other water qualities, and in-reactor data on this effect would thus be of value with respect to corrosion at pH 4.5 as well. The solubility of aluminum corrosion product in deionized water has been measured as a function of temperature by Dr. R.L.Dillon, Corrosion and Coatings Operation, HLO. Therefore, tests of the effect of saturation are most advantageously made in deionized water.

Existing in-reactor-corrosion data of aluminum in deionized water is limited to the H-Loop tests with inlet temperatures of 45 to 60 C and maximum surface temperatures

of 187 to 214 C, and one test in KER Loop 3 with 122 C inlet temperature and 195 C maximum surface temperature. In these tests the water was not near saturation in the region of high surface temperature because of the heating of the presumably saturated inlet water by the upstream elements. The upstream elements exposed to saturated water in these tests were at too low temperature to measure significant corrosion rates. No thermocouple slug has been or is scheduled to be exposed to deionized water.

The NPR will operate at fairly high inlet temperatures, and therefore at higher aluminum concentration (assuming saturation of inlet water) than in the H-Loop tests. Therefore, if corrosion is reduced by higher aluminum concentrations, the corrosion under NPR conditions should be less than predicted by extrapolation of present data to NPR temperatures.

A test of the effect of saturation on the corrosion of aluminum coupons in deionized water is now in progress in the KER Loop 3 mock-up tube.

TEST DETAILS

1. Loading

The proposed charge, reading from the downstream end, is as follows:

2	8" Spacers	}	
1	8" Coupon Holder		
12	8" Spacers		
1	8" Coupon Holder		
4	8" Spacers		
1	8" Coupon Holder		
1	8" Spacer		
1	8" Thermocouple Slug		
3	6.6" Doe Elements		
1	8" Coupon Holder		
4	6.6" Doe Elements	}	
1	8" Coupon Holder		
4	6.6" Doe Elements		
1	8" Coupon Holder		
4	6.6" Doe Elements		
1	8" Coupon Holder		
4	6.6" Doe Elements		
1	8" Coupon Holder		
11	8" Aluminum Surface Pieces		
1	8" Coupon Holder		
6	6.6" Doe Elements		
1	8" Coupon Holder		
13	8" Aluminum Surface Pieces		
1	8" Coupon Holder		

2. Elements to be Charged

A. Doe Elements

These will be Doe alloy (U^{235} in Al) canned in X-8001 aluminum tubulars. This

will give an O.D. of 1.44 inches and a can wall thickness of 0.12 inches, and permit higher corrosion penetration without danger of rupture. This element will contain about 77% as much U^{235} as a Doe element of regular diameter.

The upstream group of six Doe elements will be exposed to saturated or nearly saturated water with a low temperature drop across the water film; therefore, the surface as well as the bulk should be near saturation. The next group of four elements will likewise be exposed to nearly saturated bulk water, but with higher surface temperature. The downstream elements will be exposed to less saturated water as the water becomes heated. However, because of the high flow rate and small temperature change, this unsaturation will be much less than for similar elements in the H-Loop tests.

B. Thermocouple Slug

This will also be of Doe alloy, canned in an X-8001 aluminum tubular, with thermocouples in the jacket. It will be the same as the thermocouple slug recently exposed in KER Loop 4.

C. Aluminum Surface Pieces

These are non-heat-generating pieces designed to expose a large corroding surface of X-8001 aluminum to the water in order to bring it to saturation. The exact design has not been determined; the most promising configuration consists of a bundle of aluminum tubes. The pieces will be designed for high integrity, low pressure drop, and a pushing strength at least that of an aluminum tubular.

D. Coupon Holders

These will be of stainless steel. X-8001 aluminum coupons will be supported externally, permitting use between Doe elements without requiring provision to channel the water flow to the inside of the holder. The holders will be in three groups:

1. In the downstream thermocouple train, to determine the effect of radiation on corrosion at constant water temperature. The thermocouple leads will pass through a hole drilled through the center of the holder. Existing data indicate that the degree to which radiation affects aluminum corrosion depends on the temperature and/or water quality; therefore, tests of this kind are being made over a range of conditions.
2. Between the Doe elements. These will space the Doe elements to avoid overheating the graphite and provide corrosion data on non-heat-generating surfaces exposed to water at increasing degrees of unsaturation.
3. At either end of the extended surface pieces to determine the efficiency of such pieces in bringing the water to saturation, and to check the assumption which has been made up to now that the loop inlet water is saturated.

3. Test Conditions

Facility: KER Loops 2, 3, or 4. Loop 3 is preferred since it has been operating with deionized water.

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Water Quality: Deionized water, pH 6.
Water Flow: 60 gpm.
Temperatures: As high as possible for the proposed loading. This should give a maximum surface temperature of 250 C and inlet and outlet temperatures of 203 and 225 C. Solubilities of aluminum corrosion produce at these temperatures are respectively 100, 67, and 82 ppb Al. These temperatures are based on an assumed power level of 20 KW/Doe (equivalent to 25 KW for a Doe element of regular diameter).
Duration: 30 days at temperature plus time to the next outage.
Scheduling: If time permits, this test should be run in Loop 3 following the bond diffusion test and before the extended outage. Otherwise it should be scheduled for after the outage.

CORROSION EXPECTED

At a surface temperature of 250 C and a power of 20 KW per 6.6 inch Doe element, a corrosion rate of 21 mils/month is predicted by the correlation⁽¹⁾

$$\log CR = 6.477 - \frac{2890}{T_s + 1.4 P_s}$$

where CR = corrosion rate, mils/mo.
T_s = surface temperature, °K
P_s = slug power, KW per standard 8.9 inch fuel element.

An alternate method, in which the corrosion rate is calculated as the rate of dissolution of the aluminum oxide corrosion product, has shown fair agreement with the existing in-reactor corrosion data in high-temperature deionized water.

$$DR = k (C_s - C_b)$$

where DR = dissolution rate of corrosion product
C_s = solubility of corrosion product at surface temperature
C_b = concentration existing in bulk water
k = mass transfer coefficient across water film

This method predicts a corrosion rate of only 4.5 mils/month.

Both these methods correlate the H-Loop data rather well, but in the present case give results differing by a factor of almost 5. Therefore, existing data are inadequate to predict whether corrosion rates under conditions similar to those of NPR would be excessive in pH 6 deionized water.

(1) Lobsinger, R.J., Final Report, Production Test 105-506-E, Recirculation of Reactor Cooling Water, HW-42656, Sept. 16, 1957.

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The former method is based on the concept of a corrosion rate dependent on an effective corroding temperature, $T_s + 1.4 P_s$; the latter on a dissolution rate dependent on a driving force, $C_s - C_b$. This test should, therefore, be able to distinguish between these two concepts of corrosion. This cannot be done in out-of-reactor tests, because in the existing isothermal loops the difference, $C_s - C_b$, is very small and not measurable.

D. R. Dickinson

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