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EXAMINATION OF ENRICHED RUPTURED ELEMENT FROM 2955C (RM 452)

By

W. J. Gruber

Radiometallurgy Laboratory Operation
Materials Development Operation
Reactor & Fuels Research & Development Operation

August 21, 1962

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EXAMINATION OF ENRICHED RUPTURED ELEMENT FROM 2955C (RM 452)

INTRODUCTION

A GIIIE (enriched) element, one of two elements which failed April 5, 1962 in tube 2955C, was shipped to the Radiometallurgy Laboratory for detailed examination. The element was 21st from the downstream end. A more severe rupture which occurred in the 19th piece from the downstream end was believed to have caused the initial rupture indication.

After a hot startup a heat cycle developed in the part of the reactor containing tube 2955 increasing the bulk water temperature about 20 per cent. At about the same time the temperature rise was noted, the first rupture indication was seen. (1) The reactor was shutdown 40 - 45 minutes later, tube 2953 was pushed, and the two ruptures were found.

The element was classed as a "hot spot" failure. Detailed examination was requested to determine the cause of failure and characterize the nature of any observed corrosion. The history of the element appears below.

Radiomet #	452-A
Tube-Reactor	2955-C
Parent Lot	KC-097-A
Date Charged	1-5-62
Date Discharged	4-5-62
Exposure	671 MWD/T
Average Tube Power	1150 KW
Tube Power at Failure	1585 KW

(1) Personal communication with M. A. Clinton.

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SUMMARY AND CONCLUSIONS

Overheating of the element during a heat cycle in 105-C Reactor caused the failure. Formation of steam on the cladding surface resulted in melting and penetration of the X 8001 aluminum alloy cladding to expose the uranium to the coolant.

Temperatures during the heat cycle were high enough that reaction between the Al-Si and uranium formed an intermetallic compound at both the internal and external bonds over the entire length of the element.

The uranium adjacent to the rupture area had operated in the beta phase.

DETAILS

Visual Examination

The element as received is shown in Figure 1. The rupture occurred in a "hot area"⁽²⁾ about one inch wide that extended from the male end to the midpoint of the element diametrically opposite the ribs. The ruptured area was a blister of raised canwall in the "hot area" about two and one-half inches long and nearly as wide as the "hot area". Two penetrations in the X 8001 aluminum alloy cladding were observed about one and one-fourth inches and three inches from the male end. The appearance of the blister suggested that these were two independent water entry sites whose two associated areas of reaction had joined along one side to form one larger area. Both penetrations were quite small, slightly less than one-eighth inch in diameter. Along one side of the blister the cladding had failed in tension, probably as relief of the pressure from the formation of uranium oxide after initial water entry.

The spire surface was visually examined and nothing abnormal was seen. No irregular flow patterns were observed at either end to indicate the element

(2) Fouts, J. M., "Post-Irradiation Fuel Element Examination Data," HW-64590, Rev. 3, March 3, 1961, Unclassified.

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had been misaligned. Figures not previously observed on production elements were stamped on each end of the piece. A star was seen on the male end and a fleur-de-lis appeared on the female end.

Sample Procurement

Three wafers, one-half inch thick, were sectioned from the element for metallographic examination. One wafer was removed to show a cross section through the penetration site about three inches from the male end. The second wafer was cut to show a cross section approximately through the midpoint of the "hot area" about two inches from the male end. The third was removed three-fourths inch from the female end for comparison of the parts of the element which experienced the highest and lowest operating temperatures. The wafer through the penetration was mounted in plastic to preserve the cladding during preparation and was not etched.

Observations

Evidence of operation at extreme temperature was observed in the cross section through the penetration. (Figure 2) The aluminum cladding rimming the edge of penetration site had been in a molten or semi molten state and there was evidence of severe localized corrosion. (Figures 3 and 4) The corrosion and melting occurred only at the rim of the penetration. Diffusion of uranium into the aluminum was seen in the area adjacent to the aluminum melt. The area was damaged when gross rupturing occurred, but the estimated maximum thickness of the intermetallic was about 20 mils. Silicon in the Al-Si within one-fourth inch of the penetration site had completely dispersed. The transition period from normal to grossly heated Al-Si was extremely short, (Figure 5) indicating a high temperature gradient and/or melting of the Al-Si. Diffusion of Al-Si into the uranium was observed at both the internal and external bonds around the entire wafer. Except at the area adjacent to the penetration site diffusion of uranium into the Al-Si was not observed. The intermetallic layer was quite uniform.

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ranged from 1 to 2 mils thick, the average thickness being slightly greater at the internal bond. The external bond was cracked completely around the wafer while the spire bond was intact. The uranium adjacent to the rupture area was severely cracked and numerous smaller cracks were in the remainder of the wafer. The cracks can be seen clearly in the macro photograph (Figure 2).

The second wafer from the midpoint of the "hot area" about one inch from the first wafer is shown in Figure 6. Effects of high temperature operation were present but there were some marked differences between the rupture areas of the two wafers. No corrosion attack to the cladding, melting of aluminum, dispersion of silicon from the Al-Si, or diffusion of uranium into the Al Si was observed in the second wafer. The external bond was cracked completely around the wafer and the spire bond was intact. Diffusion of Al-Si into the uranium was observed to the same degree as in the first wafer. The cladding thickness was uniform around the wafer except for mechanical deformation incurred at rupture. The uranium adjacent to the rupture area was severely cracked and had operated in the beta phase.

In the wafer from the female end, the only visible effect of high temperature operation was diffusion of Al Si into the uranium. An intermetallic layer was observed on the uranium side of the interface at both the internal and external bonds. The external bond was intermittently cracked while the internal bond was sound. Abnormal heating could not be detected from the appearance of the Al-Si. The Al-Si and intermetallic layer are shown in Figure 7.

Discussion

The probable sequence of events resulting in failure were as follows:

1. As evidenced by the appearance of the cladding the element was operating with a "hot area" prior to the heat cycle.

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2. When the heat cycle developed two small pockets of steam formed on the cladding surface in the "hot area". Also accelerated diffusion of Al-Si into the uranium probably began at this time.
3. Formation of the steam disrupted heat transfer in the two locations and the resulting local temperature was sufficient to melt the aluminum.
4. Reaction between the steam and molten or semi-molten aluminum exposed the uranium to initiate the rupture.

The formation of an intermetallic at the fuel bond with no other visible heat effects and the fact that gross diffusion progressed only one direction from the interface were of particular interest. A study of diffusion between uranium and Al-Si was made at Hanford⁽³⁾. In these studies the diffusion couples were clamped together but were not initially bonded and there was no temperature gradient across the interface during heating. The rate of diffusion from the interface into the Al-Si was found to be about twice as great as it was into the uranium. D. R. Green, the author, was consulted and stated that there was no simple explanation as to why the diffusion apparently progressed in only one direction from the interface of the fuel bond, nor could the operating temperature be reliably estimated without experimental work. A subsequent literature survey offered no applicable information along this line.

The appearance of the Al-Si was used to calculate a maximum temperature⁽⁴⁾ outside the rupture area. Assuming a constant temperature during the heating period, the Al-Si could have been as high as at 400°C for 45 minutes or 450° for 15 minutes without changing appearance.

W. J. Gruber

W. J. Gruber, Engineer
Radiometallurgy Laboratory

- (3) D. R. Green, "Diffusion of Uranium & Aluminum Silicon Eutectic," April 15, 1957, Unclassified.
- (4) Todd, R. H., "Metallographic Study of the Annealing Behavior of Aluminum Silicon Eutectic Alloy," HW-69401, June, 1961, Unclassified.

Fuel Element As Received

B-53

0.6X

B-52

0.6X

Lines indicate where element was sectioned

B-67

Male End

2X

B-68

Female End

2X

FIGURE 2

Cross Section Through Penetration Site

15417

4.5X

Cracks in the uranium can be seen over the entire surface. Severe cracking under penetration occurred in area which was heated into the beta phase. The wafer was photographed as polished. Photomicrographs of penetration site are shown in Figures 3 and 4.

FIGURE 3

B 160 and 161

60X

Cladding at edge of penetration site. The portion which had been molten was shaded. Intermetallic compounds can be seen at the edges of the uranium and aluminum. The islands of bright material are also intermetallics. The dark grey material at the right is the product of the U - H₂O reaction. The area at the tip is shown at higher magnification in Figure 4.

B-144 and 145

250X

Tip of cladding at penetration site outlined in Figure 3. The upper left portion shows the normal appearance of X-8001 aluminum cladding.

FIGURE 5

B 166

60X

B 146

250X

The area where dispersion of the silicon in the Al-Si began.
The 250X photomicrograph was about one-fourth inch from penetration site.

15417

4.5X

Wafer #2 through midpoint of "hot area". Oval shaped area adjacent to rupture had operated in the beta phase.

B 355

2X

Wafer #3 from female end of element

Figure 7

Diffusion of Al-Si into Uranium

B-350

Spire Bond

250X

B 353

External Bond

250X

Spire and external bond of Wafer #1 from the male end

B 348

Spire Bond

250X

B 351

External Bond

250X

Spire and external bond of Wafer #3 from the female end.

The intermetallic compound that formed when diffusion occurred can be seen on the uranium side of the interface.

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