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C2N - C5N FUEL SWELLING PROBLEM
RADIOMETALLURGY EXAMINATION

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DOUGLAS UNITED NUCLEAR, INC.

This document consists
of 13 pages

DATE February 6, 1968

TO P. A. Carlson

FROM R. W. Toivonen

SUBJECT C2N - C5N FUEL SWELLING PROBLEM
RADIOMETALLURGY EXAMINATION

DUN-3809
Hanford Code C-44

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Introduction

Fuel element swelling problems have been experienced in the high-exposure fuel irradiation program in C Reactor. In an effort to determine the mechanism responsible for this swelling, three elements from C Reactor, one of which was a rupture, were sent to the Radiometallurgy Laboratory for visual and metallographic examination. Exposures of the columns which showed swelling were between 1750-2000 Mwd/t. Because the swelled fuel was not numbered as to column position, the exact position of the examined elements is not known but they were believed to have come from the center of the charge and therefore exposures for these individual elements will be 25-50% higher than the column average exposures. (1) This percentage figure was determined from data from nine tubes of C2N fuel which exhibited swelling. These nine tubes operated under nearly the same conditions as the examined elements. Maximum core temperatures for the examined elements are believed to be between 300-340°C. (2)

The rupture of lot KJ-687-Q was from tube 2562. No destructive testing was performed on this element as it had been severely galled during discharge requiring 28,000 pounds force for removal. (3) The remaining two elements were from tubes 0966 and 0969, both lot KJ-686-Q, and were identified as A and B, respectively. Element A exhibited approximately 45 mils of ellipticity over a considerable portion of its length, and element B exhibited approximately 40 mils of ellipticity with 35 and 45 mils of swelling on the female and male ends, respectively, as determined by preliminary measurements taken in 105 C-Basin Fuel Examination Facility. Diameter measurements taken for the nine tubes mentioned above showed that elements A and B did not show isolated instances of swelling. Most of the elements examined showed some distortion usually between 0-15 mils

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diameter increase, but others showed increases of comparable magnitude to those of A and B. At this same time distortion was seen in a C5N piece from a low-exposure column. It too was examined in the Radiometallurgy Laboratory. This piece came from tube 3577 which had reached an exposure of 800 Mwd/t.

Summary and Conclusions

The mechanisms for swelling were different in the high and low-exposure fuels. The high-exposure fuel exhibited grain-boundary tearing along a wide circumferential band over the entire transverse section of the fuel examined. The areas near the OD and ID were relatively free from tearing. The low-exposure fuel showed no grain boundary tearing but it did contain angular voids in the same general shape of the typical carbide particles found in this alloy.

Examination Details

High-exposure C2N elements A and B were sectioned one-half inch from the male and female ends, Figure 1. Since visual examination of these transverse sections showed a more extensive swelling in element A, this fuel was selected for further examination. The ragged edges on the OD and ID resulted from aluminum smearing during the saw cutting operation. The photographs in Figure 1 were taken in the as-cut state. Swelled areas on the female end of element A are prominent in the upper and lower left portions of the cross-section, and a more general swelling can be noted on the entire right side of this piece. The male end has more closely retained its pre-irradiation size and shape.

A photo-enlargement of a pie-shaped cross-sectional piece, sectioned one and one-half inch from the male weld, reveals a prominent swelled area along the outer diameter of the element (upper right in photograph) lower half Figure 4. Metallographic examination was made in this swelled area taking photographs at seven locations labeled 1 through 7 going from ID to OD, Figures 2 through 4. These photographs were taken of the section in the as-polished state. A closer look at the photomacrograph (lower half of Figure 4) reveals a lighter bond of uranium surrounded by two bands of darker uranium. These bands correspond roughly to the area showing grain boundary tearing (lighter) and the area relatively free from grain boundary tearing (darker). Position 1 and position 7 corresponding to the areas adjacent to the ID and OD, respectively, show no tearing whereas positions 2 through 6 show varying degrees of tearing. The cracks in the uranium as seen in position 1, Figure 2 and those in the photomacrograph (bottom half of Figure 4) were probably induced during cutting of the sample and do not represent the typical as-irradiated condition of this fuel.

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Examination Details (cont'd)

Figures 5 and 6 are photomicrographs of the as-etched fuel. The swirled structure is typical of a "worked" uranium whose crystallographic structure has been altered and stressed during irradiation. This swirled structure is characteristic of irradiated uranium at burnups as low as 0.03 w/o.⁽⁴⁾ Burnup for an element of average exposure from a C2N column of fuel exhibiting swelling would be .22 w/o. For element A, this figure would be somewhat higher.

Figure 7 shows the extent of swelling over the circumference of the fuel. The cracks are thought to have been induced during cutting of the element.⁽⁵⁾ This transverse section is the mate face to the uranium segment in Figure 4, upon which macro-photography was performed. Grain boundary tearing was seen over the entire transverse section with the exception of a relatively undisturbed band along the OD and another along the ID as described previously. Except for the transition zone between the undisturbed bands and the area of grain boundary tearing, the extent of tearing is not significantly different at the core's center than, say, 200 mils from its center. In other words, even though the severity of tearing changes throughout the portion of the core exhibiting tearing, a severely torn area is as likely to be found at some specified distance from the core's hottest operating area as at the hottest operating area itself.

Table I gives the compositions of elements A and B and those for a typical uranium core. All of the compositions are well within the bounds of specified limits.

Figure 8 shows the condition of the C5N fuel which showed evidence of swelling. A comparison with the C2N fuel photomicrographs reveal no grain boundary tearing. The black areas of Figure 8 are holes, left possibly from carbide particle pull-out.⁽⁵⁾ In an appreciable number of instances the holes are adjacent to remaining carbide particles. The evidence indicates that this fuel distortion was due to anisotropic growth. Anisotropic growth can occur if the crystal planes of uranium are not randomly oriented, i.e., if the uranium shows preferred orientation (crystallographic planes aligning themselves to a greater degree in one direction than another). It should be noted that a prediction of growth G3 index for this particular element is not available.

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TABLE I

COMPOSITION OF ELEMENTS A AND B

	<u>Element A</u>	<u>Element B</u>	<u>Typical Uranium Average</u>	<u>Std. Dev.</u>
Cr	19 ppm	22 ppm	17 ppm	2
Fe	135	163	135	14
Mg	3	3	3	.1
Mn	9	9	7	1
Ni	58	59	58	9
Si	84	108	97	11
Al	15	10	13	7
Cu	12	9	10	3
Zr	19	19	19	1.8
Be	1	1	--	--
C	--	--	549	142
Density	18.95	18.95	18.93	.06

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- 3) Personal Communication with E. R. Marx.
- 4) Leggett, R. D., Bierlein, T. K., Mastel, B., "Irradiation
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November, 1963. (Unclassified)
- 5) Personal Communication with J. W. Weber.

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1X

Male End Element A

1X

Female End Element A

1X

Male End Element B

1X

Female End Element B

FIGURE 1
Traverse Section C2N Fuel

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Position 1 Inner Diameter 250X

Position 2 250X

Position 3 250X

FIGURE 2
Grain Boundary Tearing As Polished

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Position 4

250X

Position 5

250X

Position 6

250X

FIGURE 3
Grain Boundary Tearing As-Polished

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Position 7

250X

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Grain Boundary Tearing Specimen 4.6X
As Etched

FIGURE 4
Grain Boundary Tearing As Polished

Position 1 Inner Diameter 250X

Position 2 250X

Position 3 250X

FIGURE 5
Grain Boundary Tearing As Etched

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Position 4

250X

Position 5 Outer Diameter

250X

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FIGURE 6
Grain Boundary Tearing As Etched

FIGURE 7
Swelled Fuel

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Inner Diameter

250X

Center

250X

Outer Diameter

250X

FIGURE 8
C5N Fuel As Polished

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