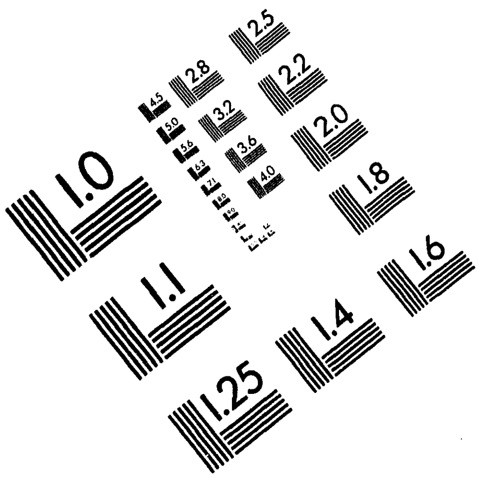

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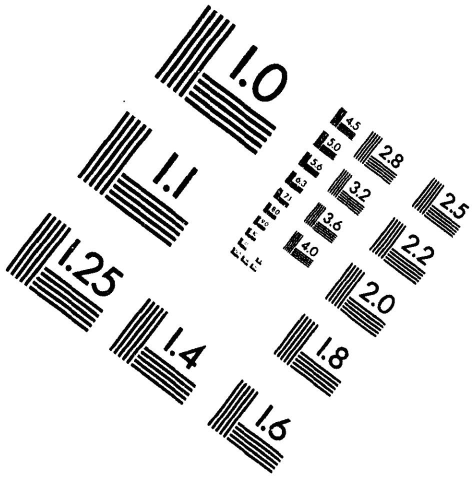

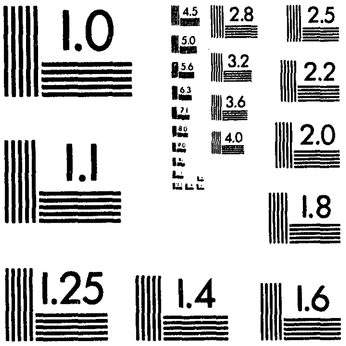

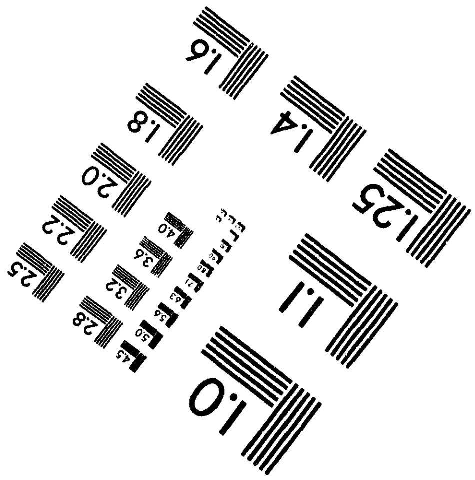

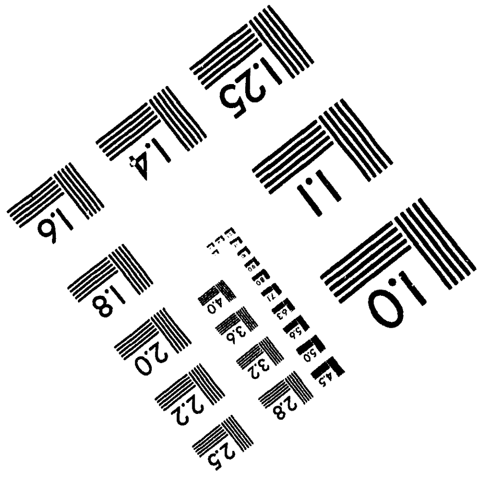

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EIGHTH HIGH TEMPERATURE FUEL MEETING
PRELIMINARY DATA ONLY

AUTHOR

G. A. Last and J. E. Minor

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EIGHTH HIGH TEMPERATURE FUEL MEETING
PRELIMINARY DATA ONLY

G. A. Last and J. E. Minor

I. METALLIC URANIUM IRRADIATION STUDIES

A. Coextruded Zr-2 Clad 1.6% Enriched Uranium Rods, 0.590 inch Diameter with 20 and 30 mil Clad

			20 mils
Calculated cladding temperature			254 C
Calculated uranium surface temperature			297 C
Calculated uranium maximum temperature			432 C
Calculated burnup - 2240 MWD/T	-	0.26 a/o	- 1.3×10^{20} fissions/cm^3

Discharged because of rupture of a 20 mil clad rod. The failure occurred in the center of one rod and appears similar to out-of-pile defect test failures obtained in electrically heated rods. The size of the "bumped" area is somewhat larger than might be expected. Qualitatively, this enlarged area of corrosion indicates some degradation of the corrosion properties of the U-Zr bond as the result of irradiation. The cause of failure has not yet been determined. (One photograph.)

B. Coextruded Zr-2 Clad 1.6% Enriched Uranium Rods, 0.590 inch Diameter, with 30 mil Clad

			30 mils
Calculated cladding surface temperature			225 C
Calculated uranium surface temperature			295 C
Calculated uranium maximum temperature			430 C
Calculated burnup - 1500 MWD/T	-	0.18 a/o	- 9.2×10^{19} fissions/cm^3

Discharged as a suspect rupture.

Post-irradiation measurements showed an average 0.001-inch increase in rod diameter with 0.007-inch ellipticity. The center rod of one cluster (30 mil clad) was found to be 0.030-inch under nominal size at one end. Sectioning of this rod showed the uranium in this area to be 6 to 13 mils over nominal dimensions and the Zr-2 clad to be only 3 to 17 mils thick. Both the uranium and Zr-2 clad in this region were full of inclusions.

A "pipe" through the cladding was found at the base of the cap, although no evidence of corrosion of the uranium could be observed in the area of the pipe. (Two photographs to be shown.)

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C. Tube and Rod Elements, Coextruded Zr-2 Clad Natural Uranium, 30 mil Clad

Maximum water temperature	-	245 C*
Maximum uranium temperature - Tube	-	385 C*
Rod	-	650 C*
Burnup - 2000 MWD/T - 0.23 a/o	-	1.2×10^{20} fissions/cm^3

Pre-Irradiation Measurements

	Tube		Rod	
No.	O.D.	I.D.	Diameter	Length
BF-3	1.790	1.380	1.002	39.0
D-2	1.783	1.380	1.002	36.0

(*) These fuel elements were irradiated in low pH water and a considerable crud film was deposited on the clad. Surface examination indicated that some corrosive attack had occurred on the fuel element surfaces. The presence of this crud film would result in a considerable film drop and hence the calculated irradiation temperatures are low by an unknown amount.

These fuel elements are being examined at Battelle Memorial Institute. Preliminary data indicate a consistent increase in rod diameter equal to a $\frac{\Delta V}{V}$ value of 7 to 8 percent per a/o burnup. This low value is believed to be the result of having irradiated the uranium under high pressure (1500 psi).

Examination of one pie-shaped segment of D-2 tube showed cracks which extended across the full thickness of the uranium. It is not known whether these cracks are "real" or the result of sample preparation. A similar segment of BF-3 tube showed no cracking.

D. Tube-in-Tube Elements, 1.6% Enriched Uranium Clad in 20 mils Zr-2.

Nominal Dimensions

Inner Tube		Outer Tube		Length
I.D.	O.D.	I.D.	O.D.	
0.500	1.050	1.450	1.820	36.0

Failed after three weeks' operation in 280 C, low pH water. Failure occurred on the inner surface of an inner tube as the result of severe pitting corrosion of the clad. Examination of the failed element indicated that a crud film of up to 10 mils thickness had formed. The temperature drop through this 10 mil film was estimated to be 690 F. Evidence indicates that the crud film produced surface temperatures high enough to result in catastrophic corrosion of the Zr-2 clad. (Five photographs.)

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E. MTR-ETR Irradiation in NaK Capsules

(1) Natural Uranium (0.570" diameter) Clad in 0.030" Zr-2 (GEH 3-32)

		Avg.	Max.
U center temperature	-	435 C	540 C
U-Zr surface temperature	-	300 C	370 C
Zr outer surface temperature	-	230 C	280 C

Burn up 3500 MWD/T; 0.41 a/o - -2.1×10^{20} fissions/cm^3

The split in the cladding, described at the previous meeting, extends across the uranium core to the cladding on the opposite side. There is some evidence of NaK-U reaction at the outer regions of the uranium crack. No evidence of NaK-Zr reaction can be seen near the upper crack, however there is apparently a thin reaction or diffusion zone at the NaK-Zr interface in the region of the lower and smaller crack. Further metallography should be done on this to establish definitely the presence of this interaction layer.

Cladding strain calculated from diameter increases is approximately 2% at the region of the small crack. (One photograph.)

(2) Natural Uranium (0.570" diameter) Clad in 0.030" Zr-2 (GEH 3-57).

Avg. U center temperature - 495 C
Avg. U-Zr interface temperature - 340 C
Avg. Zr outer surface temperature - 265 C

Burn-up 2100 MWD/T; 0.25 a/o - 1.2×10^{20} fissions/cm^3

Max. diameter change	+ 1.7%
Avg. diameter change	+ 1.1%
Volume change	+ 1.6%

The uranium contains large numbers of macrocracks both transgranular and intergranular. A feature seen on optical micrographs and plastic replicas, which appears to be a crack extending across single grain, is apparently a region that resists etching by ion bombardment. There appears to be some crystallographic relationship between the "raised material" and the real cracks as evidenced by the fact that both are approximately normal to the deformation bands. Electron micrographs of this unknown raised material will be made at higher magnifications. (One photograph.)

(3) Natural Uranium (0.570" diameter) Clad in 0.030" Zr-2 (GEH 3-58)

	Avg.	Max.
Center uranium temperature °C	637	815
U-Zr interface temperature °C	435	550
Zr outer surface temperature °C	330	420

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(3) Con'td.)

Exposure 2100 MWD/T - 0.26 a/o - 1.3×10^{20} fissions/cm^3

Max. diameter change - +6.4%
Avg. diameter change - +3.8%
Volume change - +8.3%

This sample has not been examined metallographically.

(4) Natural Uranium (0.570" diameter) Clad in 0.030" Zr-2 (GEH 3-59).

Calculated average center uranium temperature 825 C; possible maximum center uranium temperature of 940 C (Thermocouple failed during irradiation). No dimensional measurements as yet. One end cap was "pulled off" during opening of the capsule. From the little force used in dislodging the end cap and the corroded appearance of the uranium, it is apparent that the cladding around the end cap had probably failed during irradiation. (One photograph.)

[redacted]

II. BASIC SWELLING STUDIES

A. Pore Size and Distributions in Irradiated Uranium

A statistical study has been conducted to determine the extent to which fission gas pores are being faithfully replicated in electron microscopy studies of irradiated uranium. Statistical comparison of shadow length vs. pore diameter, as obtained from replicas, has shown a higher-than-expected occurrence of "deep but narrow" pores. This is interpreted as being distortion, or "extrusion," of the replica as it is stripped from the spherically-shaped pores which have been intersected above the mid-plane. The results of this analysis also indicates that replica distortion is more pronounced for small diameter pores than for large ones.

The influence of irradiation temperature and post-irradiation annealing on void fraction and pore density in 0.29 a/o burnup uranium is shown in the following table:

Approximate Temperature of Irradiation	Post-Irradiation Annealing History	Void Fraction	Pore Density (pores/μ^3)
300 C	None	0.020	2.81
300 C	100 hrs 880 C	0.105	1.50
500 C	None	0.018	3.31
500 C	100 hrs 880 C	0.039	5.41

The above data indicate that there is little difference in swelling, pore size, or pore distribution for the two irradiation temperatures. However, post-irradiation annealing has resulted in a decrease in pore density in the case of the 300 C sample and an increase in the pore density in the 500 C sample. The above data were obtained from examining the pore size and distributions within a 350 sq. micron area of each sample, and additional data is needed before statistical significance can be placed on these conclusions.

Annealing of 0.29 and 0.41 a/o burnup uranium at temperature above 700 C and 650 C respectively has resulted in the development of discontinuous irregular bonds, many of which contain cracks, within the irradiated uranium. Optical microscopy suggests that these bonds represent a second phase which has resulted from migration of fission products to the grain boundaries. Electron microscopy shows these bonds to contain relatively fewer, but larger, gas pores than the surrounding matrix.

It has also been observed in this study that pore sizes are considerably smaller in the vicinity of inclusions than they are in the surrounding matrix.

G. A. Last/J. E. Minor
Fuel Element Design
November 18, 1959
Richland, Washington

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