AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

**Cover Sheet for a Hanford
Historical Document
Released for Public Availability**

Released 1994

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

DISCLAIMER

This is a **historical document** that is being released for public availability. This was made from the best available copy. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes any **warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.** The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DECLASSIFIED

AEC RESEARCH AND DEVELOPMENT REPORT

HW-66267
COPY No. 24

**TESTING OF ZIRCALOY-2-CLAD URANIUM
SEVEN-ROD FUEL ELEMENTS**

(FINAL REPORT - PT IP-146-A - RM-277)

G. T. GEERING

JULY 5, 1960

HANFORD LABORATORIES

**HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON**

GENERAL ELECTRIC

RESTRICTED DATA
THIS DOCUMENT CONTAINS RESTRICTED DATA AS DEFINED
IN THE ATOMIC ENERGY ACT OF 1954. INFORMATION
RELATES TO THE DESIGN, APPLICATION, OR ATOMIC
CYCLES TRANSFER OR THE DISSEMINATION OF
TECHNICAL INFORMATION TO AN AUTHORIZED PERSON IS
PROHIBITED.

DECLASSIFIED

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

DECLASSIFIED

HW-66267

This document classified by
G. A. Last

C-65, Plutonium Production
(M-3679, 24th Ed.)

This document consists
of 27 pages. Copy No. 24
of 85 copies.

TESTING OF ZIRCALOY-2-CLAD URANIUM
SEVEN-ROD FUEL ELEMENTS

(Final Report - PT IP-146-A - RM-277)

Classification Cancelled and Changed To

By

DECLASSIFIED

By Authority of W A Snyder

CGPR-2 1-25-94

By J E Savely 2-2-94

Verified By J Mally 2-11-94

G. T. Geering

Fuels Development

Reactor and Fuels Research and Development Operation

July 5, 1960

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

Work performed under Contract No. AT(45-1)-1350 between the
Atomic Energy Commission and General Electric Company

RESTRICTED DATA

This document contains Restricted Data as defined by the Atomic
Energy Act of 1954. Transmittal or the disclosure of its
contents in any manner to an unauthorized person is prohibited.

Route To:	P. R. No.	Location	Route Date	Signature and Date
<u>G.A. Last</u>	<u>13067</u>	<u>306</u>		<u>MA Last 10/2/67</u>

Printed in USA. Charge 75 cents. Available from the U. S. Atomic
Energy Commission, Technical Information Service Extension, P. O.
Box 1001, Oak Ridge, Tennessee. Please direct to the same address
inquiries covering the procurement of other classified AEC reports.

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	4
SUMMARY AND CONCLUSIONS	4
EXPERIMENTAL.	5
Fabrication.	5
Operating Conditions	7
Post-irradiation Examination	8
Measurements	10
DISCUSSION	13
ACKNOWLEDGEMENTS.	16
REFERENCES.	16

LIST OF TABLES

I	CHEMICAL ANALYSIS OF URANIUM	5
II	CHEMICAL ANALYSIS OF ZIRCALOY-2	5
III	NOMINAL DIMENSIONS OF THE TEST ELEMENTS.	7
IV	SEVEN-ROD ELEMENT OPERATING CONDITIONS IN HANFORD KER LOOP 1	8
V	PRE- AND POST-IRRADIATION LENGTH AND DIAMETER MEASUREMENTS.	11
VI	DENSITY DATA	12
VII	HARDNESS OF URANIUM CORES	12
VIII	URANIUM-235 BURNUP	13
IX	AVERAGE DIAMETER CHANGES IN SEVEN-ROD ELEMENT EXPOSED TO 1250 MWD/T	14
X	VOLUME INCREASE OF SEVEN-ROD ELEMENT AFTER 1250 MWD/T	15
XI	AVERAGE 'R' VALUES FOR A SEVEN-ROD ELEMENT EXPOSED TO 1250 MWD/T	15

DECLASSIFIED

-3-

HW-66267

LIST OF FIGURES

	<u>Page</u>
1. Seven-rod Fuel Element Mockup.	17
2. End and Isometric Views of Seven-rod Element	18
3. Side Views of Seven-rod Cluster Element	19
4. Effect of Exposure on End Clearance	20
5. Macrostructure of Coextruded Zircaloy-2-Clad Fuel Rod	21
6. Microstructure of Uranium Core after 1250 MWD/T	22
7. Condition of the Zircaloy-2-Uranium Bond.	23
8. Electron Micrographs of the Uranium Core	24
9. Effect of Coolant on Zircaloy-2 Cladding	25

DECLASSIFIED

-4-

HW-66267

TESTING OF ZIRCALOY-2-CLAD URANIUM
SEVEN-ROD FUEL ELEMENTS

INTRODUCTION

In 1955 the Fuels Development Operation began irradiation testing of fuel elements in high temperature water. It was assumed that if a new reactor were built at Hanford, it would be cooled by high-temperature, pressurized water. Corrosion tests showed that aluminum-clad production fuel elements could not be used in high-temperature water. Therefore, while work to improve the resistance of aluminum to high-temperature water proceeded, the Fuel Design Operation began irradiation of stainless steel- and Zircaloy-2-clad fuel elements. During 1956 and 1957, stainless steel-clad elements were tested in the Materials Testing Reactor (MTR), Hanford H Reactor Loop, and the KE Reactor Recirculating (KER) Loops. During 1957, a coextrusion method for cladding uranium rods with Zircaloy-2 was developed. The first irradiation of Zircaloy-2-clad fuel from an off-site supplier began in late 1958.

The objective of the irradiation was to study the dimensional stability of the fuel rods and a seven-rod fuel assembly. Two coextruded, seven-rod elements were irradiated in KER Loop 1.

SUMMARY AND CONCLUSIONS

Two seven-rod cluster fuel elements were exposed without incident in high-temperature water to 1250 MWD/T. These coextruded, Zircaloy-2-clad uranium rods attained maximum surface and central temperatures of 297 C and 407 C, respectively. The triangular end rings used to position the seven rods in the element apparently functioned well during operation, but were damaged in post-irradiation handling. No significant bowing of the fuel rods occurred during the test. The uranium cores did not swell or crack and the clad was free of excessive film deposits and corrosion damage. The clad-core bond remained intact.

DECLASSIFIED

EXPERIMENTAL

Fabrication

The 14 fuel rods forming the two elements used for this test were fabricated by bonding a Zircaloy-2 clad to uranium cores by coextrusion. A chemical analysis of the uranium billet used in the coextrusion of the fuel rods is given in Table I.

TABLE I
CHEMICAL ANALYSIS OF URANIUM
(Parts per million)

Fernald Casting No.	C	N	B	Cd	Cr	Fe	Mg	Mn	Ni	SiO ₂
56245	610	45	<0.2	<0.2	11	90	4	17	40	30

The Zircaloy-2 was arc-melted at Henderson, Nevada and forged into bar by Allegheny Ludlum Steel Corp. The chemical analysis of the Zircaloy-2 is reported in Table II.

TABLE II
CHEMICAL ANALYSIS OF ZIRCALOY-2
(Heat No. Z-868)

Element	Weight Per Cent	Average
Sn	1.46 - 1.58	1.50
Fe	0.110 - 0.130	0.120
Cr	0.146 - 0.169	0.153
Ni	0.046 - 0.053	0.049
N ₂	0.007 - 0.014	0.009
Cu	0.000 - 0.003	0.001
O ₂	0.0128 - 0.113	0.0129
C	0.0021 - 0.0023	0.0032

DECLASSIFIED

-6-

HW-66267

The uranium was received as a 7-inch-diameter, 15-inch-long casting. It was extruded to a 2.7-inch diameter billet so as to break up the cast grain structure.⁽¹⁾ Prior to coextrusion, it was also heated into the beta phase (1350 F) and water quenched to further randomize and refine grain structure. The Zircaloy-2 was initially a 7-1/2-inch-diameter forged bar. It was first extruded to 4-1/2-inch diameter and then cut, bored, and re-extruded into tubing suitable for coextrusion as the fuel cladding.

The uranium and Zircaloy-2 components were cleaned, assembled, and sealed in a copper can. The billet thus formed was then extruded through a 0.690-inch diameter die at an extrusion ratio of 19.4:1. After removal of the copper jacket with nitric acid solution, the rods were cold swaged to 0.630-inch diameter. A beta heat treatment was used to randomize grain orientation due to extrusion and swaging. The rods were held in a 1350 F salt bath for five minutes and then air cooled.

After heat treatment, the rods were cut to length and straightened. Uranium was removed from the ends of each rod to a depth of 0.250 inch by machining. Hydrochloric acid was used to remove any uranium adhering to the Zircaloy-2 walls of the recess. Each wall was then cleaned with HF-HNO₃ solution prior to insertion of the end plugs. The end plugs were welded in place by an electron beam welder. The seven rods were then joined to the support rings by tungsten arc inert gas welding. A mock-up element is shown in Figure 1. The nominal dimensions of the elements are given in Table III.

TABLE III
NOMINAL DIMENSIONS OF THE TEST ELEMENTS

Number of rods	7
Rod diameter	0.630 inch
Clad thickness	0.030 inch
Uranium length	12.00 inches
End plug length	0.650 inch
End clearance	0.025 inch
Over-all length	13.30 inches
Circumscribed diameter	2.090 inches
Inter-rod spacing	0.05 inch
End support thickness	0.060 inch
End support width	0.250 inch

Operating Conditions

The two test elements were exposed in Hanford KER Loop 1. Figure 1 shows a stainless steel mockup of the seven-rod element in a section of horizontal KER pressure tube.⁽²⁾ Water coolant was supplied to the loop at a rate of 50 gpm. The bulk outlet temperature was held at 270 C about 75 per cent of the operating time. A tabulation of operating conditions is given in Table IV.

The elements were irradiated to 1250 MWD/T and discharged in February, 1959.

TABLE IV
SEVEN-ROD ELEMENT OPERATING CONDITIONS
IN HANFORD KER LOOP 1

Number of elements	2
Location (front to rear)	Reactor center
Specific power (average)	12 watts/gm U
Maximum fuel surface heat flux	213,000 Btu/hr-ft ²
Bulk outlet temperature	270 C
Maximum fuel surface temperature	297 C
Maximum uranium temperature	407 C
Loop flow rate	50 gpm
Fuel element equivalent diameter	1.236 inch
Process tube ID	2.090 inch

Post-irradiation Examination

Both test elements were transferred to the Hanford Radiometallurgy Laboratory in February, 1959.⁽³⁾ In Figure 2 an end view of one of the elements is compared with an isometric view of the same element before irradiation. The triangular support ring was broken after discharge from the reactor. Scratches on the irradiated element are due to handling tools. Side views of the element before and after irradiation are compared in Figure 3. A post-irradiation cathetometer traverse over the length of each rod indicated there was little, if any, warp.

Prior to irradiation there was an 0.025-inch clearance between the end of the uranium core and the Zircaloy-2 end plug. This is shown in Figure 4a. Volume increase during irradiation caused a barrel-shaped protrusion to develop on the end of the uranium. In one of the higher burn-up

DECLASSIFIED

-9-

HW-66267

rods (Figure 4c), the uranium has contacted the end cap at its center. For higher burnups, a larger clearance will be needed if it is desired to avoid axial force on the end cap.

The grain size of the as-extruded rod varied from fine at the edge to very large at the center (about 1.0 mm). Beta heat treatment refined the structure so that the grain size prior to irradiation was 0.35 mm. The pre- and post-irradiation macrostructures (Figures 5a and 5b, respectively) are similar. There is no evidence of beta phase transformation during in-reactor testing.

The microstructures of the uranium cores of three rods were examined. All three specimens exhibited distorted grains and also many twin bands near the edge. Near the rod centers some annealing of the irradiation distortion had occurred. At the center, grain boundaries proved more distinct than at the edges. The twin bands at the center were more linear than those toward the outside. Both of these observations are evident in Figures 6a and 6b.

The Zircaloy-2 cladding of three rods was examined metallographically. There was no visible hydrogen pickup, surface corrosion, or radiation damage. Because irradiation alters the etch rate of both metals, it was difficult to compare the pre- and post-irradiation condition of the clad-core bond. Nevertheless it appears that the bond does not change thickness during irradiation. The pre- and post-irradiation bond structure of rod #14 (Figures 7a and 7b, respectively) were compared using 1000X magnification. No cracks or discontinuities were found in this bond following irradiation.

The core of rod #14 was sectioned, polished, and prepared by ion bombardment. Replicas of the surface were used for electron microscopy. Two electron micrographs made with UO_2 -shadowed carbon replicas are shown in Figure 8. Depressions in the uranium core appear as bumps on

the replica. The white raised areas in Figure 8b are redeposition bumps formed during ion bombardment. No fission gas bubbles were found. However, this replication technique has been very successful in locating bubbles formed in uranium irradiated at higher temperatures.

A concurrent study of surface fouling was also performed with this element.⁽⁴⁾ Replicas of the Zircaloy-2-clad surface were obtained before and after the irradiation (Figures 9a and 9b, respectively). The replicas were then examined and compared using an optical microscope. Before irradiation the clad surface had been extruded, swaged, heat treated in molten salt, pickled with HF-HNO₃ solution, and autoclaved in 1000 psi, 400 C steam. An oxide film estimated to be 5000 to 10,000 Å thick was formed during autoclaving. The surface prior to irradiation is shown in Figure 9a.

Figure 9b shows the effect of about three months' exposure in 297 C water. The pH of this coolant, controlled with LiOH, was 9.5 at room temperature. At low magnification, the surfaces of the elements appeared similar to the pre-irradiated surfaces. However, the post-irradiation photomicrograph (Figure 9b) shows that the surface layer has been lightly etched by the coolant. Grain boundaries and twins are apparent. Examination of the post-irradiation surface replica by electron microscopy showed a few widely spaced cubic crystals. These were identified as γ -Fe₂O₃, which is known to be deposited from the coolant.

Measurements

Table V lists the length and diameter measurements before and after irradiation.

The corresponding changes in density are found in Table VI.

TABLE V

PRE- AND POST-IRRADIATION LENGTH AND DIAMETER MEASUREMENTS

Rod No.	Diameter in Inches						Length in inches
	Numbered End		Mid Length		Plain End		
	0°	90°	0°	90°	0°	90°	
9*Pre Post	0. 6315	0. 6315	0. 6315	0. 6315	0. 631	0. 632	13. 218
	0. 631	0. 630	0. 632	0. 631	0. 631	0. 631	13. 245
10 Pre Post	0. 6325	0. 6325	0. 633	0. 634	0. 633	0. 634	13. 213
	0. 634	0. 631	0. 634	0. 634	0. 635	0. 633	13. 228
11 Pre Post	0. 632	0. 632	0. 632	0. 632	0. 631	0. 631	13. 228
	0. 632	0. 634	0. 632	0. 634	0. 632	0. 634	13. 240
12 Pre Post	0. 632	0. 632	0. 631	0. 632	0. 631	0. 631	13. 230
	0. 632	0. 631	0. 631	0. 631	0. 632	0. 632	13. 234
13 Pre Post	0. 633	0. 633	0. 633	0. 634	0. 631	0. 631	13. 211
	0. 628	0. 628	0. 633	0. 635	0. 629	0. 628	13. 299
14 Pre Post	0. 632	0. 632	0. 632	0. 632	0. 632	0. 632	13. 232
	0. 632	0. 633	0. 639	0. 638	0. 633	0. 633	13. 238
15 Pre Post	0. 632	0. 632	0. 633	0. 633	0. 631	0. 632	13. 208
	0. 633	0. 634	0. 636	0. 635	0. 631	0. 628	13. 230

* Central Rod

DECLASSIFIED

TABLE VI

DENSITY DATA
(gm/cm³)

Pre-irradiation		18.89	
Post-irradiation	At Midpoint		At End
Central Rod	18.88		18.80
Peripheral Rod	18.72		18.89

The hardness of the uranium was taken at about twelve locations across the diameter of three rods. The average values are given in Table VII.

TABLE VII

HARDNESS OF URANIUM CORES

Pre-irradiation Hardness	61 R _A	
Post-irradiation Hardness		
Peripheral Rod #10	68.7 ±2	Rockwell 'A'
Peripheral Rod #14	69.0 ±2	Rockwell 'A'
Central Rod #9	68.3 ±2	Rockwell 'A'

The average exposure of 1250 MWD/T (0.159 per cent burnup) was calculated from in-reactor heat output data. Radiochemical measurements of burnup are given in Table VIII.

DECLASSIFIED

TABLE VIII
URANIUM BURNUP

	Per Cent
Central Rod #9	0.138
Peripheral Rod #10	0.172
Peripheral Rod #14	0.153

DISCUSSION

The fission product atoms generated in a clad fuel element are retained in the uranium core. Since each fission produces two fragments and many of the daughter atoms have radii greater than uranium's, a volume increase takes place as burnup proceeds. The element volume as a function of burnup is very important to the fuel designer. As the fuel expands, the coolant channel cross section is reduced. If the fuel expands unsymmetrically, it may cause hot spots and element failure. Important reactivity changes occur as the fuel expands, especially in light water cooled reactors. In this test the fuel elements were measured after irradiation to detect bowing or other distortion. There was no significant bow, however the rods had increased in length and diameter. The fuel volume increase has also been computed from both surface measurements and submersion weighing of small samples cut from the irradiated elements. Taking data from Tables IV and V, the average volume increases determined by either method can be compared. This comparison is compiled in Tables IX, X, and XI.

Table IX is based on micrometer measurements at six stations on each of the seven fuel rods. Similar measurements were made at the same stations following irradiation. The volume increases of the rods were

DECLASSIFIED

-14-

HW-66267

computed from external length and diameter changes and the internal length increase of the uranium. A summary of the volume changes is given in Table X. Based on radiometallurgy examination of the end cap region of three rods, it was estimated that 2/3 of the clearance area had been filled with uranium. This estimate would account for a $\Delta V/V$ contribution of 0.28 per cent due to internal expansion of the uranium. A total $\Delta V/V$ based on internal and external changes in the fuel rod dimensions is 0.47 per cent. This value is reasonably close to the value (0.43 per cent $\Delta V/V$) obtained from density measurements taken from two fuel rods. In Table XI the fuel volume increase is divided by the burnup to give an 'R' value. The value for this experiment is very close to the theoretical 'R' computed on the basis of fission product volume added to the uranium volume. This would indicate that the fuel volume increase measured during this experiment is not due to swelling. In similar fuel elements tested at higher core temperatures, 'R' values of about 10 have been measured. In these elements fission gas bubbles and internal cracks had occurred.

TABLE IX
AVERAGE DIAMETER CHANGES IN SEVEN-ROD ELEMENT
EXPOSED TO 1250 MWD/T

	Number of Measurements	Mean Diameter (inch)	Range (rms) (inch)	Standard Deviation Due to Measurement Error
Pre- irradiation	42	0.6321	0.00089	0.000079 inch
Post- irradiation	42	0.6326	0.00248	0.000147 inch

DECLASSIFIED

-15-

HW-66267

TABLE X
VOLUME INCREASE OF SEVEN-ROD ELEMENT
AFTER 1250 MWD/T

	$\Delta V/V$	Standard Error
External $\Delta V/V$	0.19%	0.16%
Internal $\Delta V/V$	0.28% estimated	-----
Total $\Delta V/V$	0.47%	-----
Total $\Delta V/V$ Based on Density Measurements	0.43%	-----

TABLE XI
AVERAGE 'R' VALUES FOR A SEVEN-ROD ELEMENT
EXPOSED TO 1250 MWD/T

Average Burnup - 0.159%	
	'R' $\% \Delta V/V / \% \text{ Burnup}$
By Rod Measurements	3.0
By Density Measurements	2.7
Theoretical Volume Expansion	2.5

DECLASSIFIED

HW-66267

ACKNOWLEDGEMENTS

The author is indebted to several Hanford Laboratories personnel who aided in the post-irradiation testing of these seven-rod cluster elements. The radiometallurgical examinations were performed most capably by W. J. Gruber. The majority of the metallography was accomplished by L. A. Hartcorn, T. K. Bierlein and B. Mastel; they were also most helpful in interpretation of the results.

REFERENCES

1. Sawyer, H. F. Development and Properties of Coextruded Zircaloy-2 Clad Uranium Fuel Elements with Integral End Seals, NMI-4710. November, 1958.
 2. Kratzer, W. R. Production Test IP-146-A, Irradiation of Coextruded Zircaloy-2 Jacketed Seven-rod Cluster Fuel Elements, HW-55813. April, 1958. (SECRET).
 3. Gruber, W. J. Post Irradiation Examination of KER Seven Rod Cluster Fuel Elements, HW-62426. October, 1959. (SECRET).
 4. Perrigo, L. D. Hanford Atomic Products Operation. Personal communication, September, 1959.
 5. Call, R. L. and T. T. Claudson. Interim Report: Development of NPR Rod Cluster Fuel Elements, HW-60895. (To be published) (SECRET).
-

DECLASSIFIED

-17-

HW-66267

FIGURE 1

Seven-rod Fuel Element Mockup
(Shown in Section of Pressure Tube with 2.090-inch ID)

Photograph Unclassified
AEC-66 RICHLAND, WASH. No. 058145-2

DECLASSIFIED

-18-

HW-66267

(a) Pre-irradiation

(b) Post-irradiation; Exposed to 1250 MWD/T

FIGURE 2

End and Isometric Views of Seven-rod Element

Photographs Unclassified

AEC-GE RICHLAND, WASH.

DECLASSIFIED

-19-

HW-66267

(a) Pre-irradiation

(b) Post-irradiation;
Exposed to 1250 MWD/T

FIGURE 3

Side Views of Seven-rod Cluster Element

Photographs Unclassified
AEC-GE RICHLAND, WASH. (b) No. RM11692

DECLASSIFIED

HW-66267

-20-

(a) Pre-irradiation

(b) 0.136% Burnup

(c) 0.172% Burnup

FIGURE 4

Effect of Exposure on End Clearance

Photographs Unclassified

AEC-GE RICHLAND, WASH. No. 4W-D804; RM-11706 and 11695

DECLASSIFIED

-21-

HW-66267

(a) Pre-irradiation
(Cladding Removed)

(b) Post-irradiation;
1250 MWD/T. Rod #10

FIGURE 5

Macrostructure of Coextruded Zircaloy-2-Clad Fuel Rod

Photographs Unclassified
AEC-GE RICHLAND, WASH. No. 4W-E1603 and RM11530

DECLASSIFIED

-22-

HW-66267

(a) Uranium Near Center
250X

(b) Uranium Near Edge
250X

FIGURE 6

Microstructure of Uranium Core after 1250 MWD/T

Photographs Unclassified
AEC-GE RICHLAND, WASH RMI1534 and I1532

DECLASSIFIED

-23-

HW-66267

Zr

U

(a) Pre-irradiation
1000X

Zr

U

(b) Post-irradiation
1000X

FIGURE 7

Condition of the Zircaloy-2-Uranium Bond
(Rod #14)

DECLASSIFIED

-24-

HW-66267

(a)

1 μ

(b)

1 μ

FIGURE 8

Electron Micrographs of the Uranium Core

Photographs Unclassified
AEC-GE RICHLAND, WASH. BM 982 and BM 981

DECLASSIFIED

-25-

HW-66267

(a) Pre-irradiation Surface
250X

(b) Irradiated Surface
250X

FIGURE 9

Effect of Coolant on Zircaloy-2 Cladding

Photographs Unclassified

AEC-GE RICHLAND, WASH. No. 4W-F634A and 4W-F634B

INTERNAL DISTRIBUTIONCopy Number

1	F. W. Albaugh
2	W. K. Alexander
3	G. S. Allison
4	T. W. Ambrose
5	E. R. Astley
6	J. A. Ayers
7	T. K. Bierlein
8	J. H. Brown
9	S. H. Bush
10	J. J. Cadwell
11	R. L. Call
12	D. R. Dickinson
13	R. L. Dillon
14	R. V. Dulin
15	E. A. Evans
16	T. W. Evans
17	J. C. Fox
18	M. C. Fraser
19	R. M. Fryar
20	G. T. Geering
21	S. M. Gill
22	W. J. Gruber
23	W. K. Kratzer
24	G. A. Last
25	L. H. McEwen
26	K. R. Merckx
27	J. E. Minor
28	J. W. Nickolaus
29	W. A. Oldham
30	R. E. Olson
31	L. D. Perrigo
32	J. W. Riches
33	J. C. Tobin
34	R. G. Wheeler
35	O. J. Wick
36	E. C. Wood
37	F. W. Woodfield
38 - 42	Extra
43	300 File
44	Record Center

DECLASSIFIED

EXTERNAL DISTRIBUTION

Copy Number

45 - 46	Atomic Energy Commission, Washington
47	Chicago Patent Group
48 - 51	duPont Company, Aiken
52	duPont Company, Wilmington
53	Hanford Operations Office
54	Patent Branch, Washington
55 - 60	Savannah River Operations Office
61 - 85	Technical Information Service Extension

**DATE
FILMED**

6/22/94

END