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HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

DATE

February 15, 1961

TITLE

DESIGN OF PRODUCTION TEST IP-310-A-FP,
DETERMINATION OF THE DIMENSIONAL STABILITY
OF URANIUM FUEL CORES CLASSIFIED BY THE
FUEL CORE TESTER (UT-2)

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DESIGN OF PRODUCTION TEST IP-310-A-FP,
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OF URANIUM FUEL CORES CLASSIFIED BY THE FUEL CORE TESTER (UT-2)

W. H. Hodgson & M. A. Clinton

February 15, 1961

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DESIGN OF PRODUCTION TEST IP 310-A-FP,
DETERMINATION OF THE DIMENSIONAL STABILITY
OF URANIUM FUEL CORES CLASSIFIED BY THE FUEL CORES TESTER (UT-2)

INTRODUCTION

Uranium as it comes from the rolling mill at Fernald is extremely fine grained (0.05 mm or less) and highly oriented in the direction of rolling. From the standpoint of dimensional stability during irradiation, as-rolled uranium is unsatisfactory because of the tendency to grow in the direction of its preferred orientation even though it is believed that the extremely fine grains are desirable. In order to randomize the grain orientation, the uranium is heated into the beta phase (above 660 C) and quenched into water. This heat treatment effectively randomizes the grain structure but causes some of the grains to grow. The amount of grain growth that takes place to produce some larger average grain size in the final heat-treated uranium is a function of the heat-treating variables and the chemical composition (quantity and type of impurity) of the uranium. If too much grain growth takes place during heat treating, large grains (over about 0.45 mm) are produced which cause the phenomenon of bumping (another form of dimensional instability) during irradiation. Thus, the structure of heat-treated uranium is a compromise between preferredly oriented fine-grained uranium and randomly oriented uranium having some larger grain size. The grain growth that takes place during heat treatment is currently used as an indicator of whether the uranium core has been transformed by beta-phase heat treating. In the past, extremely fine-grained uranium approaching the grain size of as-rolled metal was rejected on a go-no-go basis by test equipment employing ultrasonic energy as a signal. Ultrasonic energy is attenuated by passage through uranium and the magnitude of the attenuation is a function of the average grain size.

More recently the development of improved ultrasonic test equipment (UT-2)¹ for grain size, refinements in heat treating, and the controlled addition of certain impurities (Fe and Si) to the uranium to achieve grain refinement has made it possible to produce heat-treated uranium that is randomly oriented and which has a relatively finer average grain size than has hitherto been possible.

The UT-2 fuel core tester was designed to determine uranium grain size. The instrument measures the magnitude of the ultrasonic pulses transmitted through the uranium as the core revolves and moves longitudinally under the testing head. The pulses passing through the core are amplified and converted to a DC voltage. Since large grains attenuate ultrasonic pulses more than small grains, changes in grain size appear as differences in voltage values. In addition to measuring small and large grain size, the instrument is capable of detecting variations in grain size along the length of each fuel core. Any large differences in attenuation or relative grain size may indicate areas of stress within a fuel core.

Transformed fuel cores, representing the full range of UT-2 voltage values will be irradiated to compare their relative dimensional stability. On the basis of these data, optimum limits can be selected for controlling the grain size of all fuel cores.

¹ HW-65701, "Fuel Core Tester - UT-2". C. L. Frederick & G. L. Waldkoetter. July 18, 1960 (Unclassified).

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This report presents the design of a test to compare UI-2 grain size measurements (voltage values) with the dimensional changes of fuel elements during irradiation.

OBJECTIVE

The objectives of this test are:

1. To establish grain size limits for acceptable uranium fuel element cores.
2. To establish, if possible, criteria for predicting core dimensional stability during irradiation by comparing the relative dimensional stabilities associated with grain size and with variations in grain size in individual cores.
3. To obtain process tube and fuel corrosion data associated with bumper fuel elements in new tubes with no mixer, one mixer in the 10th position and two mixers in the 7th and 15th position from the rear.

SUMMARY OF TEST

Fuel cores representing the full range of UI-2 voltage values (grain size converts to d-c voltage) of interest are segregated into three categories:

- a. Large grains.
- b. Variations of grain size in an individual core.
- c. Small grains.

Each category will be subdivided into three groups, each covering a small range of values. After canning, the finished fuel elements will be assembled into twenty-seven (27) charges in three latin square patterns⁽²⁾ for irradiation to a 900 MWD/T exposure goal in D Reactor.

BASIS (3)(4)

Uranium grain size and grain orientations are important factors in fuel core dimensional stability. Both variables are controlled by core fabrication and heat treatment techniques. The alpha-rolling process used to produce essentially all HAPO fuel cores imparts a characteristic orientation to the grains which, during irradiation, may cause dimensional distortions. This tendency has been almost eliminated by a beta-phase heat treatment following rolling. The beta-phase heat treatment, which randomizes the grain structure, is of sufficient duration to cause growth of the uranium grains. Since it is easier and faster to detect

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- 2 Personal Communication - J. L. Jaech, Operations Research & Synthesis Operation, HLO.
 - 3 HW-51444, "Irradiation Effects in Uranium", S. H. Bush. July 19, 1959 (Unclassified)
 - 4 HW-54605, "Effects of Various Preferred Orientations on the Dimensional Stability of Uranium", C. K. Shupe, W. V. Cummings and E. C. Watts. January 20, 1958. (Unclassified)

[REDACTED]

differences in grain size than it is to make reliable measurements of orientation, the limit used to reject untransformed uranium cores is actually based on a minimum grain size. By the use of small amounts of additives (Fe and Si) to the uranium and a close control of the heat treating variables, it is possible to produce cores having smaller, completely transformed grains that may exhibit a higher degree of dimensional stability during irradiation. These cores, which may actually have the optimum texture, were rejected by the Sonctest equipment (UT-1). Conversely, uranium cores having large grains or a non-uniform combination of large and small grains, which may ultimately result in bumped core surfaces or warped fuel elements, were not detected by the UT-1 and were accepted for irradiation. Statistical sampling of core lots may reveal some material having large grains, but there is no guarantee that all would be detected.

The Fuel Core Tester (UT-2) developed by Testing Methods Sub-section, Fuels Preparation Department, and used for testing all cores since May 1960, will record voltages corresponding to the smallest grain size, the average grain size and the differences in grain size between the smallest and average grain. The instrument has been calibrated to reject for grains larger or smaller than selected sizes and for large differences in grain size. With this instrument, it is possible to segregate cores into groups having discrete ranges of grain size. It is also possible to determine the effect of a small, completely random grain structure on the dimensional stability of cores, and at the same time, segregate those cores suspected of bumping or severe dimensional instability because of a larger or non-uniform grain structure. Both ingot and dingot cores are used in each category tested to permit the evaluation of any possible difference between dingot and ingot uranium.

In addition to acquiring data to establish uranium grain size limits and/or texture, the test will be used to obtain data to aid in assessing tube corrosion behavior associated with bumper fuel elements in new process tubes with:

- 1) No mixer.
- 2) Mixer in tenth position
- 3) Mixer in seventh and fifteenth positions

The above categories incorporate and implement suggestions by N. R. Miller⁽⁵⁾ and are based on appraisals of previous water-mixer performance. Performance data for mixers in bumper fuel columns has been limited and more data are needed to adequately predict fuel and process tube corrosion behavior. In brief, the data are limited to that obtained from six columns of three rail bumper fuel elements, irradiated

5 HW-68424, "Relocation of Water-Mixing Elements at the Five Oldest Reactors",
N. R. Miller, February 8, 1961. Secret.

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in new tubes in D Reactor. (6) Three columns were charged with no mixers and three with a mixer in the seventh position from the rear. Thermocouple probe readings showed the TCA (top of annulus) water temperature to be higher for those tubes without water mixers, up to 155 C. Probolog data confirmed the need for continued use of mixer elements with bumper fuel. Although these data indicated a need for continued use of the water-mixer with OII size bumper fuel, additional data are required to determine the proper number and location of water-mixer elements with the current CIII model fuel element.

FABRICATION OF TEST MATERIAL

1. Fuel Components

- a. Fuel element jacketing components will be X-8001 aluminum alloy for eight-inch CIIIN I&E cores. Component code, Z-2. All components are to meet all requirements of fuel element process specifications. (7)
- b. Fuel element cores will be eight-inch natural uranium CIIIN I&E selected on the basis of UT-2 tester voltage values into groups as described under "Testing". Equal quantities of ingot and dingot cores will be used.
- c. Finished fuel elements will have bumpers attached. Bumper rails shall be X-8001 alloy aluminum and shall conform to the specifications shown on the latest revision of H-3-17003. Three rails will be attached on each end on 90° centers, inline, by ultrasonic welding techniques.
- d. Nominal finished fuel dimensions shall be:

<u>Dimension (Inches)</u>	<u>CIIINB</u>
Canned OD	1.445
Canned ID	0.310
Effective Element Length	8.865
Bumper Height	0.040
Bumper Length	1.875
Maximum Circumscribed Circle	1.530
Distance bumper from end of element	1.500

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- 6 HW-60444E, "Supplement B to PI-IP-262-A-FF, Evaluation of Projection Fuel & Elements for Use in Ribbed Process Tubes", M. A. Clinton, 6-20-60. Secret.
 - 7 HW-47029, "Process Specifications, Fuel Element Manufacturing Processes." Fuels Preparation Department. (Confidential)

2. Assembly

All fuel elements will be fabricated in accordance with the fuel element process specifications⁽⁸⁾ incorporating any improved processes, such as pressurized quench, contoured base cans, cap pulsers, and 25 MC bond testers. Those process changes utilized will be applicable to all elements assembled for this test.

3. Quality of Material

The quality of all cores must meet the requirements of the fuel element process specifications.⁽⁹⁾

All standard quality control measures will be applied in the fabrication of fuel elements.

4. Quantity of Material

To make up each of three categories of elements graded by grain size, approximately 288 acceptable finished fuel elements of each category are required. Total requirements - 864 acceptable elements. Twenty-seven (27) OIIN water-mixer elements will be required for this test.

5. Standard Controls

Standard Controls will not be required for this test.

8 op. cit., HW-47029

9 op. cit., HW-47029

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TESTING

Pre-irradiation Testing & Measurements

At the bare core transformation testing station, the cores will be segregated on the basis of the UT-2 voltage values into three categories having a total of eighteen categories as follows:

Cate- gory	Type Metal	Pilot Plant Code	Bare Core Ident.	UT-2 Range	Test	Proposed Description	
A	I	X--0	X0(1-70)	Low	Large Grain	Cores having large grain size. This category is to be utilized to establish a limit for acceptance of cores having large grains, by UT-2. Present reject point is 0.3 volt. These ranges obtained by adjusting UT-2 reject point.	Category I
B	D	X--1	X1(1-70)	Low	Large Grain		
C	I	X--2	X2(1-70)	Medium	Large Grain		
D	D	X--3	X3(1-70)	Medium	Large Grain		
E	I	X--4	X4(1-70)	High	Large Grain		
F	D	X--5	X5(1-70)	High	Large Grain		
G	I	X--6	X6(1-70)	Low	Difference	Cores exhibiting various difference readings between peak voltage & average voltage. The larger the voltage the larger is the variation in grain size within a core. Present reject point is 5.5 volts. These ranges obtained by recorded UT-2 difference voltages.	Category II
H	D	X--7	X7(1-70)	Low	Difference		
I	I	X--8	X8(1-70)	Medium	Difference		
J	D	X--9	X9(1-70)	Medium	Difference		
K	I	Y--0	Y0(1-70)	High	Difference		
L	D	Y--1	Y1(1-70)	High	Difference		
M	I	Y--2	Y2(1-70)	Low	Small Grain (Peak)	Cores having various readings in peak voltage. Present reject point 5.5 volts. These ranges obtained by recorded UT-2 peak voltages.	Category III
N	D	Y--3	Y3(1-70)	Low	Small Grain (Peak)		
O	I	Y--4	Y4(1-70)	Medium	Small Grain (Peak)		
P	D	Y--5	Y5(1-70)	Medium	Small Grain (Peak)		
Q	I	Y--6	Y6(1-70)	High	Small Grain (Peak)		
R	D	Y--7	Y7(1-70)	High	Small Grain (Peak)		

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Each of the Pilot Plant codes will be a lot number and the entire test will be processed together. Following final inspection, the fuel elements will be transferred to the pre-irradiation measurement station where sub-categories will be made up in latin square arrangement as charges in each of the following configurations:

<u>Number of Charges</u>	<u>Makeup</u>
2	ABCDEFABCDEF through 31 pieces
2	BCDEFABCDEF " " "
2	CDEFABCDEFAB " " "
1	DEFABCDEFABC " " "
1	EFABCDEFABCD " " "
1	FABCDEFABCDE " " "

- One of the charges beginning with A will be 32 pieces long - no mixer.
- One of the charges beginning with C will have watermixer elements located at the 7th and 15th positions from the downstream end.
- The remaining seven columns will have a watermixer element located at the 10th position from the downstream end.

This same pattern will be followed for making up the columns for the other two main categories. Each piece will be stamped to show charge number and location of the piece in the charge as well as Pilot Plant code and pre-canning piece number. An example is shown in the sketch in Fig. 1 of the appendix.

The following measurements are required prior to canning:

- All bare cores will be stamped with an identifying number.
- All UT-2 data recorded.
- All SORT data recorded.
- All pieces will have bare core length, OD (three places), ID (three places), and warp measurements recorded.

During canning, the individual core number will be located at the cap end and the identity of all pieces carefully retained for stamping on canned fuel elements.

Prior to irradiation, the following measurements are required on the finished fuel elements:

- Total external and internal count by bond tester.
- Length, OD (three places), ID (three places), and warp of all pieces will be recorded.
- All pieces in the downstream half (1-15) of each charge will be weighed.

Irradiation

This test is composed of three component parts. All parts are to be irradiated together in the same reactor. The six charges in each category are to be considered as individual latin square configurations (parts) and will be irradiated together. Exposure goal for all charges will be 900 MWD/T, except one charge in each category having no watermixer.

Post-Irradiation Examination

1. All fuel elements will be measured for length, warp, OD (three places), and ID (three places), to determine tube-filling capacity of each piece.
2. All fuel elements will be visually inspected for surface conditions, particularly bumping and hot spots.
3. Pre-weighed elements will be weighed to determine weight loss.
4. All fuel elements will be weaseled to permit determination of specific exposure and specific power.
5. All fuel elements will be bond tested, if possible.
6. Selected elements will be stripped for measurement of length, warp, OD (three places), and ID (two places), on the bare cores. If deemed advisable, selected elements will be sent to Radiometallurgy Laboratory for more complete examination. Photographs will be made of pieces showing unusual surface conditions (bumping, severe hot spots, etc.).

Test Audit

Notebook HW-68448 is to be used to record all data pertaining to this test. Any unusual incidents, whether or not they seem important at the time, are to be recorded in the notebook.

The appendix of this report contains a list of items to be used as a guide of the notebook.

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Test Limitations and Hazards

No unusual limitations or hazards are anticipated.

W. L. Hodgson

Engineer
ALSi Product Engineering
Fuels Preparation Department

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Engineer
Process & Reactor Development
Irradiation Processing Department

WH Hodgson: MA Clinton:gw

APPENDIX I

Data to be Recorded in Production Test Notebook

- I. Fuel Element Core
 - A. Lot Numbers
 - 1. Ingot or Dingt Numbers & Chemical Analysis
 - 2. Core Fabrication
 - B. Finished Dimensions (Pre-assembly)
- II. Aluminum Components
 - A. Lot Numbers
 - 1. Alloy Type
 - 2. Unusual Treatment
 - B. Finished Dimensions (Pre-assembly)
 - C. Pre-assembly Treatment (Cutoff, Sizing, Inspection)
- III. Pre-assembly Treatment of Cores
 - A. UT-2 - Record Data
 - B. SORT - Record Data
 - C. Measure Length, OD, ID, and Warp of All Cores
- IV. Assembly Process
 - A. Process Used
 - B. Brief Explanation of Each Process
 - C. Attendant Conditions
- V. Post-Assembly Treatment
 - A. Support Attachment
 - B. Autoclaving

C. Other Treatment

D. Inspection

VI. Pre-irradiation Examination & Measurements

A. Total Bond Count

B. Dimensions, Length, OD, ID

C. Warp

D. Weight

VII. Irradiation

A. Coolant Temperature

1. Inlet
2. Outlet

B. Panellit & Crossheader Pressures

C. Number of Shutdowns (Controller & Scram)

D. Other

VIII. Post-irradiation Examination

A. Visual

B. Warp (& Other Profilometer Data)

C. Total Bond Count

IX. Log

Running account with dates recording the progress of the PT, unusual incidents (such as slight change in process during assembly), and other deviations, whether or not they seem pertinent at the time of occurrence.

APPENDIX II

EXAMPLES OF FUEL STAMPING

Pilot Plant PWR & Treatment Identification (Lot Number)

Fig. 1

TYPICAL EXAMPLE OF FUEL ELEMENT CODING FOR PRODUCTION TEST IP-310-A-FP

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