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

OTHER OFFICIAL CLASSIFIED INFORMATION

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PRODUCTION TEST IP-310-A-FP,
DETERMINATION OF THE DIMENSIONAL STABILITY OF URANIUM FUEL CORES
CLASSIFIED BY THE FUEL CORE 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 (a form of dimensional instability) during irradiation; consequently, the structure of heat-treated uranium is a compromise between oriented fine-grained uranium and randomly oriented uranium having some larger grain size. This larger average grain size has served as a criterion for determining whether the uranium core has been transformed by the beta-phase heat treatment; and thus, extremely fine grained, transformed uranium has been arbitrarily rejected on a go-no-go basis by test equipment (UT-1) employing ultrasonic energy as a signal.

Recently, development of improved ultrasonic test equipment (UT-2) for determining grain size, heat treating refinements, and the effect of controlled chemical additions has made it possible to produce a heat-treated uranium core that is randomly oriented and which has a relatively finer average grain size. Therefore, an arbitrary limit for grain size is no longer a satisfactory method of segregating core material, and it is necessary to irradiate measured, transformed fuel cores, representing the full range of measurable grain sizes, in order to compare their relative dimensional stabilities. On the basis of these data, more meaningful limits may be selected for controlling the grain size of all fuel cores.

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:
 - a) no mixer.
 - b) mixer in 10th position from rear.
 - c) mixer in 7th and 15th position from rear.

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TEST SUMMARY

Fuel cores representing the full range of UT-2 voltage values (grain size converts to d-c voltage) of interest have been obtained and segregated into three categories: a) large grains; b) variations of grain size in an individual core; and c) small grains. Each category will be subdivided into three groups, each covering a small range of values. All finished elements will be of the OIIIIN-B geometry and will be assembled into twenty-seven (27) charges in three latin square patterns. Nine of the 27 columns will be charged into newly installed process tubes and equipped with downstream thermocouple probes. Goal exposure for columns charged into new tubes and equipped with downstream thermocouple probes will be 600 MWD/T and the goal exposure for the other 18 columns will be 900 MWD/T.

BASIS AND JUSTIFICATION

Uranium grain size and grain orientation 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 characteristic orientations to the grains which, during irradiation, cause dimensional distortions.^(1,2) This tendency has been minimized by a beta-phase heat treatment following rolling; however, the heat treatment which effectively randomizes the grain structure is of sufficient duration to cause uranium grain growth. The growth that takes place is used as an indicator as to whether the core has been transformed and extremely fine grained uranium approaching the grain size of alpha-rolled metal is rejected by test equipment employing ultrasonic energy as a signal.

Through the use of small amounts of chemical additives (primarily Fe and Si) to the uranium and maintenance of close control of the heat treatment variables, it is possible to produce cores having smaller, completely transformed grains which may exhibit a high degree of dimensional stability during irradiation. These cores, which may actually have the optimum texture, would be rejected by test equipment calibrated by existing criterion. Conversely, uranium cores having large grains or non-uniform variations of large and small grains which might result in other dimensional distortions (bumping, warp and ellipticity) would be accepted for irradiation. Therefore, use of an arbitrary limit for a minimum grain size is not a satisfactory means for segregating dimensionally unstable cores from stable material.

- (1) HW-51444, "Irradiation Effects in Uranium", S. H. Bush, 7/19/57, Unclassified.
- (2) HW-54605, "Effects of Various Preferred Orientations on the Dimensional Stability of Uranium", O. K. Shupe, W. V. Cummings, and E. C. Watts, 1/20/58, Unclassified.

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Statistical sampling of core lots may reveal some material having large grains, but there is no assurance that all would be detected. Destructive tests are slow and can be used only on small samples. SORT^(3,4) will not detect small untransformed areas or untransformed areas which are uniformly distributed; therefore, the major effort has been to modify the UT-1* in order to control uranium grain size within specified limits, as well as to insure complete transformation.

An improved ultrasonic tester, Fuel Core Tester-UT-2⁽⁵⁾, was developed by Testing Methods Sub-Section, FPD, and has been used to test all fuel cores since March, 1960. The UT-2, which was designed to measure grain size, measures the magnitude of 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, converted to a DC voltage, and recorded. 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.

The tester collects the pulse information from the grain size test and passes it into readout circuits where it is stored and analyzed for content. Through the use of preset limits the tester makes a quality decision for each sample and it is now possible to select and test the dimensional stability of small, completely random grained structures; and at the same time, segregate those cores suspected of severe dimensional instabilities because of large or non-uniform grain structures. The instrument has been calibrated to reject cores with grains larger or smaller than selected sizes and also with large differences in grain size. These limits have been selected arbitrarily and this production test outlines and authorizes the Irradiation Processing Department portion of a program to better define these limits.

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:

- a) no mixer.
- b) mixer in 10th position.
- c) mixer in 7th and 15th positions.

The above categories incorporate and implement suggestions expressed by N. R. Miller⁽⁶⁾ and are based upon appraisals of previous water mixer performance.

(3) HW-58447, "PT-IP-219-A-FP, Preliminary Evaluation of SORT for Segregation of Fuel Cores", R. E. Hall, 10/8/59, Secret.
SORT means Sonic Orientation Resonance Tester.

(4) HW-66671, "Final Report on PT-IP-219-A-FP", R. E. Rowley, 9/1/60.

* Ultrasonic Transformation Tester "Sonotest".

(5) HW-65701, "Fuel Core Tester - UT-2", C. L. Frederick and G. L. Waldkoetter, 7/18/60.

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

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Performance data for mixers in bumper fuel columns has been limited and more data are needed to adequately predict fuel-tube corrosion behavior. In brief, the data are limited to that obtained from six columns of three rail bumper fuel elements, charged into new tubes in D Reactor⁽⁷⁾, three with no mixers and three with a mixer in the seventh position from the rear. Thermocouple probe readings showed the TOA (top-of-annulus) water temperatures to be higher for those tubes without water mixers, up to 155 C. Probolog data confirmed that more corrosion had occurred in the no-mixer tubes and continued use of the mixer elements with bumper fuel was recommended. Although these data indicate a need for continued use of the water mixer with bumper fuel, it was obtained with an obsolete bumper fuel geometry and new temperature measurements are required to determine the proper number and location of water-mixer elements to be used with the bumpered fuel element.

This test authorizes charging nine of the twenty-seven columns into newly installed process tubes such that each of the following conditions is represented by three tubes:

- 1) No Mixer - Three columns are to be charged without a water mixer to obtain base data to evaluate and interpret data obtained from columns with mixers.
- 2) Single Mixer - Recently the mixer location was changed from the seventh to the tenth position. This will be the first data to evaluate this location.
- 3) Two Mixers - Should both the process tube and the fuel cladding corrosion become limiting, it may become necessary to use two water mixers. It is anticipated that the fifteenth position will be best to minimize jacket corrosion effects and the seventh position will be best for extending tube life.

Further testing will be required to fully evaluate the fuel-tube corrosion problem; however, this information will aid in predicting corrosion rates. Additional data will be justified in another production test.

TEST DETAILS

1. Reactor

Two old reactors are equipped to handle bumper fuel elements; however, D Reactor was chosen to run this test since H Reactor is scheduled to charge an E-N loading and is therefore unavailable.

2. Material

A. Fuel Elements

- 1) Cores - Both ingot and dingot natural uranium fuel cores are to be used in each category to permit evaluation of any possible differences between the two. All cores shall be the eight-inch OIII size.
- 2) Cladding - All cladding components shall be Alcoa X-8001 alloy aluminum in the OIII size.

(7) HW-60444 E, "Supplement B to PT-IP-262-A-FP, Evaluation of Projection Fuel Elements for Use in Ribbed Process Tubes", M. A. Clinton, 6/20/60, Secret.

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- 3) Projections - Bumper rails shall be X-8001 alloy aluminum and shall conform to 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.

- 4) Nominal Dimensions - The finished fuel elements shall be regular production OIIIN-B elements and shall have the following nominal dimensions:

<u>Dimension (Inches)</u>	<u>OIIIN-B</u>
Canned OD	1.445
Canned ID	0.310
Effective Element Length	8.865
Bumper Height	0.040
Bumper Length	1.875
Maximum Bumper Diameter	1.530
Distance Bumper from End of Fuel Element	1.500

All components will meet requirements set forth in fuel element process specifications⁽⁸⁾ and all finished dimensions shall be within normal fuel tolerances⁽⁹⁾.

- 5) Assembly - Improved innovations such as pressurized quench, contoured base cans, cap pulsing, and 25 MC bond testers will be incorporated in the fabrication of the material only if all material receives the same treatment.
- 6) Water-Mixers - Regular production water-mixer elements will be used in this test.
- 7) Quality - All elements shall pass the normal quality control specifications in effect at the time this material is prepared.
- 8) Quantity - Twenty-seven columns of OIIIN-B fuel will be required by this test. A total of about 900 acceptable pieces, 300 in each grain size category, will be required.
- 9) Column Makeup - All cores will be segregated at the bare core transformation testing station on the basis of UT-2 voltage values. The cores will be divided into the three main categories of large grain,

(8) HW-47029, "Process Specifications, Fuel Element Manufacturing Processes", FPD.

(9) H-3-7350 Rev. 9, "Canned Uranium Fuel Elements", 8/4/60.

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small grain, and variation in grain size. Each category will be further subdivided into three groups, each subgroup covering a narrow range of grain sizes within the main category. As an example, the large grain category will consist of a small-large grain group, a medium-large grain group, and a large-large grain group. The pieces in each subgroup will be half ingot uranium and half dingot uranium thereby creating six sub-categories for each main category as follows:

<u>Main Category</u>	<u>Sub-Category</u>	<u>Type Metal</u>	<u>UT-2 Voltage</u>	<u>Description</u>
Large Grain	A	I(Ingot)	0.2v	Cores having large grain size. This category is to be utilized to establish a limit for acceptance of cores having large grains. Present reject point is 0.3 volt.
	B	D(Dingot)	0.2v	
	C	I	0.2 to 0.4v	
	D	D	0.2 to 0.4v	
	E	I	0.4 to 0.6v	
	F	D	0.4 to 0.6v	
Variation in Grain Size	G	I	3v	Cores exhibiting various difference readings between peak voltage and average voltage. The larger the voltage the larger is the variation in grain size within a core. Present reject point is 5.5 volts.
	H	D	3v	
	I	I	3.95 to 4.44v	
	J	D	3.95 to 4.44v	
	K	I	4.44v	
	L	D	4.44v	
Small Grain	M	I	2.11v	Cores having various readings in peak voltage. Present reject point is 5.5 volts.
	N	D	2.11v	
	O	I	2.5 to 3.5v	
	P	D	2.5 to 3.5v	
	Q	I	4.24v	
	R	D	4.24v	

The sub-categories for each main category will be assembled into 9 charges in a latin square pattern as follows:

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

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- a) One of the charges beginning with "A" will be 32 pieces long - no mixer.
- b) One of the charges beginning with "C" will have water mixer elements located at the 7th and 15th positions from the downstream end.
- c) The remaining seven columns will have a water mixer 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.

- 10) Pre-Irradiation Measurements and Marking - Each finished piece will be stamped with a series number which will identify it by column and position within the column. This series number will be in addition to the pilot plant code and bare core identification code.

The following measurements are required for all pieces prior to canning.

- a) Bare cores will be stamped with an identifying number.
- b) Cores will be measured by UT-2 and readings recorded.
- c) Cores will be measured by SORT* and data recorded.
- d) Cores will have length, OD and ID (3 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 the canned elements.

After canning, the following measurements are required on the finished fuel elements:

- a) Total external and internal bond count.
- b) Length, OD and ID (3 places), and warp of all pieces will be recorded.
- c) All pieces in the downstream half (1 thru 15) of each charge will be weighed.

B. Process Tube

Existing ribbed aluminum process tubes located in the central flow zone shall be utilized for eighteen tubes of this test. The other nine tubes must be newly installed central zone tubes.

* Sonic Orientation Resonance Tester

C. Dummies and Seating

The downstream dummy pattern and seating method in use at the time this test is charged shall be used.

D. Thermocouple Probes

Nine downstream thermocouple probes will be used in nine new tubes. Three probes will be used to monitor each of the following:

- 1) No mixer.
- 2) Mixer at 10th from rear.
- 3) Mixer at 7th and 15th from rear.

E. Probolog

Tubes equipped with downstream thermocouple probes shall be probologged after discharge of the test material.

F. Nozzles and Charge Machine

Tubes selected for this test must be equipped with approved nozzles modified to pass OIIIN-B elements. All elements should be charged with the prototype clip charging machine.

3. Irradiation

A. Charging

All columns will be serially numbered and will be charged in numerical order with piece number one downstream. Each column shall have the series number recorded opposite the tube number on the front face sequence sheets. Charging will be followed by a representative of Research and Engineering.

While it is desirable to charge all 27 columns in one localized group, the test is actually composed of three component parts and each main category may be considered, if necessary, a separate test group. The nine charges in each category are to be considered as individual latin square configurations and will be irradiated together in the same area in the reactor. The location should provide similar irradiation conditions for all tubes in the group and will be selected by the assigned Process Engineer and Physicist with the concurrence of the test author. The tubes will be selected from those available as a result of scheduled discharge.

B. Irradiation

Daily temperature data will be recorded for all tubes equipped with downstream thermocouple probes on data sheets which will be provided by the test author. No special data recordings will be required routinely for tubes not equipped with T/C probes.

C. Goal Exposure

- 1) Material charged into new tubes and equipped with downstream thermocouple probes will be irradiated to 600 MWD/T.
- 2) All other material will be irradiated to 900 MWD/T.
- 3) Goal exposure changes may be made by request from the test author with the concurrence of the Manager, D Processing Operation.

D. Discharge

All columns of this test will require special pickup and shipment to the 105-C MEF for post-irradiation examination and measurement. During discharge operations particular care should be taken to report pertinent observations relative to post discharge handling.

All columns may be discharged before reaching goal discharge exposures after two failures have occurred providing all columns can be specially picked up.

E. Operating Conditions and Limits

Unless specifically excepted within this test, all operating limits and conditions currently in use for OIIN-B fuel elements in D Reactor will apply toward this test material.⁽¹⁰⁾

4. General

A. Duration and Further Testing

Irradiation of this material will require about 5 months following charging. Further testing will require either a new supplement or a new test. This test authorization will terminate on June 1, 1962.

B. Schedule

The fuel elements have been fabricated and are currently receiving pre-irradiation measurements. The fuel elements will be ready for shipment to D Reactor in early June. Nine thermocouple probes are being assembled. It is estimated that all preparations will be completed by June 15, 1961.

C. Post-Irradiation Examination

- 1) All fuel elements will be weaseled and visually inspected for surface conditions, particularly bumping and hot spots.

(10) HW-67414, "PITA-IP-14-I, D Reactor Full Pile Loading of Bumper Fuel Elements", J. L. Benson, 11/18/60.

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- 2) All fuel elements will be measured for diameter (OD and ID at 3 places), warp, ellipticity, and bumping. Elements having unusual measurements or corrosion patterns shall be set aside for further examination.
- 3) Pre-weighed elements will be weighed to determine weight loss. (Downstream 15 pieces).
- 4) Fuel elements will be bond tested for total count if equipment is available.
- 5) Selected elements will be stripped for measurement of length, diameter (OD and ID at three places), warp, ellipticity, and bumping on the bare cores.
- 6) Photographs will be made of pieces showing unusual surface conditions (bumping, severe hot-spots, etc.).
- 7) If deemed advisable, selected elements will be sent to Radiometallurgy Laboratory for more complete examination.

D. Costs

All incremental costs associated with the performance of this test may be charged to XXXX-5R24-XXX.73. Outage time requirements are listed below for scheduling purposes.

<u>Job</u>	<u>Processing Time</u>	<u>Elevator Time</u>
1) Charge Tubes	1/4 mh/tube	1/6 hr/tube
2) Install T/C Probes	1/2 mh/tube	1/2 hr/tube
3) Remove T/C Probes	1/2 mh/tube	1/4 hr/tube
4) Probolog (Includes Flushing)	1 mh/5 tubes	1 hr/5 tubes
5) Special Pickup	1/2 mh/tube	---

E. Hazards

Hazards peculiar to this test are primarily associated with the presence of the bumper projections on the fuel surface. It is conceivable that these bumpered elements could stick tighter than do non-bumpered elements since the bumpers restrict fuel displacement within the ribbed process tube; however, it appears that no extreme risk is involved in this testing program with regards to safety.

RESPONSIBILITIES

Fuels Preparation Department

Manufacturing Operation shall be responsible for fabrication of all elements used in this test, providing the elements to others for attachment of the projections, element quality, and pre-exposure measurements of all pieces.

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Engineering Operation shall be responsible for segregating the material according to UT-2 voltage values, maintaining accurate data records for each core, attachment of the projections, liaison contact and overall coordination of the 300 Area portion of the test.

Irradiation Processing Department

Research and Engineering Operation

Process Technology Operation will be responsible for providing assistance in pre-shutdown scheduling and charging, reporting of operating data to the author, for specifying of operating limits and for specifying column locations.

Process and Reactor Development Operation shall be responsible for coordination of the test, analysis of operating data, reporting of inreactor performance, and for provision of bases for operating limits.

Operational Physics Operation shall be responsible for assistance in choice of test location and reactivity changes required.

Component Testing Operation shall be responsible for post-irradiation fuel element examination and measurement.

Manufacturing Operation

D-DR Reactor Operation

D Processing Operation shall be responsible for scheduling, the operational safety, and production continuity of the reactor, charging of test material under the direction of representatives of Research and Engineering, and for collection of operating data.

D Maintenance Operation shall be responsible for all maintenance required by this test to include nozzle modifications, charge machine availability, and thermocouple probe installation and removal.

M. A. Clinton

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Process and Reactor Development Subsection
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