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PRODUCTION TEST IP-803
IRRADIATION OF ENRICHED
URANIUM OXIDE FUEL ELEMENTS

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HANFORD ATOMIC PRODUCTS OPERATION
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PRODUCTION TEST IP-803
IRRADIATION OF ENRICHED
URANIUM OXIDE FUEL ELEMENTS

INTRODUCTION

Operation of the Hanford site with a closed fuel cycle is under study.^{1,2} Both metallic and ceramic fuel elements are being considered. The main effort will be to develop the metallic fuel cycle because of its production advantages. Oxide fuel work will primarily consist of the development and demonstration of fuel designs. This production test authorizes the initial irradiation of uranium oxide fuel elements in a K Reactor to obtain preliminary fuel design data.

OBJECTIVE

The objective of the production test is to authorize the irradiation of aluminum-clad, uranium oxide fuel elements to obtain preliminary oxide fuel design and performance data.

TEST SUMMARY

This test authorizes the irradiation of up to three columns of 1.3 w/o U-235 enriched uranium oxide fuel elements of the KVN geometry in the KW Reactor. The fuel columns will contain 20 fuel elements each and will be equipped with downstream thermocouple probes. Ten dummy elements will be placed in the center positions within each column to limit the maximum specific power of the fuel elements. The thermocouple probes will contain a spacer pattern to adjust the coolant flow rate to the desired value. Two of the fuel columns will be made up of compacted-powder type of fuel and the remaining column will contain sintered-pellet type elements. One of the compacted powder element columns will be irradiated to an average exposure of 1600 Mwd/t; the other two columns will be irradiated to an average exposure of 800 Mwd/t, requiring about 35 full reactor power days. The elements will be specially picked up after discharge and subsequently examined in the 105-C Irradiated Fuel Examination Facility. In addition, selected fuel elements will be examined in the Radiometallurgy facility.

BASIS AND JUSTIFICATION

Closing the fuel cycle at Hanford offers potential cost savings and operating flexibility.¹ Use of either metallic or oxide fuel elements is being studied. Oxide

1. Compiled by O. F. Hill. Richland Integrated Process Development Program, Integrated Site Operation, RL-GEN-22 SUP3. June 30, 1965. (Secret)
2. Engineering Staffs of IPD, NRD, and CPD. Technical Feasibility of Using Uranium Oxide Fuels at Hanford, RL-REA-663. February 15, 1965. (Secret)

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fuel work will primarily consist of the development and demonstration of fuel designs for the Hanford reactors. While considerable basic technology and experience exists for oxide fuels for power reactors, there is little technology available concerning the fabrication and irradiation behavior of oxide fuels of the designs needed for the Hanford reactors.

Large numbers of oxide fuel elements have been irradiated in power reactors to high exposures. Most of these have been small-diameter rods clad in Zircaloy or stainless steel and irradiated in the vertical position. A few aluminum-clad oxide fuel elements in large-diameter tubular shapes have been successfully irradiated to exposures up to 5000 Mwd/t in the Savannah River reactors.³ These were all irradiated in the vertical position. In addition, the geometries were thin-wall tubes as opposed to the Hanford more massive I&E shapes. Thus, although there is reason to be optimistic about the potential performance of oxide fuels in the Hanford reactors, an irradiation testing program is essential to develop and demonstrate the aluminum-clad oxide fuels concept.

This test will provide the preliminary information required for the design of aluminum-clad oxide fuels of the I&E geometry. Specific fuel design problems which will be investigated include:

1. Density requirements to avoid cladding collapse due to densification of the oxide during irradiation.
2. Cladding strength requirements to contain internal gas pressures developed during irradiation.
3. Dimensional stability of the aluminum-clad, I&E, oxide fuel elements.
4. Power distribution between the inner and outer cooling passages.
5. Temperature distribution in the oxide fuel element to compare with theoretical predictions.
6. Cladding corrosion rates to compare with bonded metallic uranium elements.

TEST DETAILS

1. Reactor

This test will be performed at the KW Reactor.

3. Savannah River Laboratory Monthly Report, DP-65-1-1. January, 1965. (Secret)

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2. Fuel Elements

a. Description

The oxide fuel elements have been canned in standard KVN components. All elements are self-supported and contain uranium oxide enriched to 1.3% U-235. Dimensions and other pertinent data are as follows:

	<u>Powder-Compact Fuel Elements</u>	<u>Sintered-Pellet Fuel Elements</u>
Dimensions:		
Clad OD, Inches	1.520	1.520
Clad ID, Inches	0.420	0.420
Clad Length, Inches	8.915	8.915
Core OD, Inches	1.446	1.446
Core ID, Inches	0.520	0.520
Core Length, Inches	8.450	8.450
Density, % of Theoretical	87	93
Weight, Lbs/Fuel Element	4.1	4.4

b. Self-Supports

All supports used on the fuel elements of this test will be of the arch-type and fabricated in accordance with revision 14 of drawing H-3-7950 as specified for KVN fuel elements. Placement of the supports on the fuel element will be as specified on the same drawing. Minimum attached support heights will be 0.087 inch; the maximum circumscribed support circle will be 1.700 inches for all fuel elements of this test.

c. Quantity

This test requires 40 powder-compact fuel elements and 20 sintered-pellet fuel elements. A spare element of each type will be supplied with the test columns.

d. Column Makeup

This test authorizes the irradiation of up to three fuel columns of 20 fuel elements each. Two columns will contain powder-compact fuel elements and the third will contain sintered-pellet fuel elements. Each of the fuel columns will contain in the center 10 positions of the column, i.e., positions 11 through 20, aluminum dummy elements of the KVN

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geometry. The dummy elements placed in these positions to preclude operation of the uranium oxide elements at higher specific powers than desired. The aluminum dummy elements shall be painted yellow for identification. The columns will be centered in the process tube by downstream thermocouple trains of 147-inch length.

The coolant flow rates will be adjusted to about 70 gpm by the use of solid aluminum spacers in the downstream thermocouple probes. The spacer pattern will be confirmed adequate by tests in the hydraulic laboratories prior to charging the fuel elements in the reactor.

All fuel elements in this test will be identified as to position number within the fuel columns, number one piece being downstream. A series letter will identify each fuel type. These identifying numbers will be stamped on the base end of each fuel element.

e. Enrichment

All fuel elements in this test will contain uranium oxide enriched to 1.3 ± 0.01 w/o U-235. The enrichment will be obtained by blending natural uranium oxide with uranium oxide enriched to 87 w/o U-235 in 45-pound batches. Isotopic analyses will be made of each batch to confirm that the enrichment specification is being met.

f. Pre-irradiation Testing and Measurements

In addition to the normal applicable quality tests and measurements, all fuel elements will have OD and ID at the three standard locations, warp-ellipticity, and length measurements recorded. The weight and oxide density of all fuel elements will be recorded. A sample of each element type will be tested in the 305 Test Reactor for reactivity. The reactivity values will be analyzed by the test authors prior to charging the fuel elements into the reactor.

3. Process Tubes

These fuel elements will be irradiated in normal K-Reactor Zircaloy-2 process tubes. It is necessary that each oxide fuel column be surrounded by six to eight natural fuel columns to obtain the desired power levels. It is desirable to use process tubes located in lower portion of the far side of the reactor central zone to minimize discharging problems.

The test authors, assigned Process Engineer, and assigned Reactor Physicist, with the concurrence of the Manager, KW Processing, will select the specific tubes for this test.

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4. Irradiation

a. Charging

The test columns will be hand charged in numerical sequence, number one piece being downstream. The elements will be charged after installation of the downstream thermocouple probes and shall be seated against the probes by hand. Each column series letter will be recorded as to the tube into which it was charged. The location and number of any spare pieces will be recorded. The charging will be monitored by a representative of Research and Engineering.

This test authorizes the discharge of up to three fuel columns at subgoal exposures to permit charging of test fuel columns.

b. Thermocouple Probes

This test authorizes the installation of thermocouple probes in the downstream pattern of each test column. These probes, 147-inches long, will center the fuel columns in the reactor, and will contain solid aluminum spacers to limit coolant flows to the desired rates. The probes will therefore extend into the active zone of the reactor. The installation of the thermocouple probes shall be monitored by a representative of Research and Engineering.

c. Operating Limits

The operating conditions and limits that apply to normal KVN fuel columns apply to the test columns. Existing process standards will be used as the basis for all operating conditions and limits.

d. Operating Conditions

Expected operating conditions for the test columns are listed below:

Fuel Elements/Column	20
Coolant Flow Rate, gpm	70
Tube Power, kw	950
Maximum Specific Power, kw/ft	70
Average Specific Power, kw/ft	61
Inlet Coolant Temperature, C	15
Outlet Coolant Temperature, C	65
Fuel Temperatures, C	
UO ₂ Maximum	2250
UO ₂ Surface	250
Clad Surface Maximum	113
UO ₂ Melting Temperature, C	2800

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The enrichment has been determined to provide the same specific power for comparable KVN fuel positions. The UO_2 temperatures have been calculated by Ceramics Research and Development Section, BNW, using programs developed from other oxide fuel irradiations. In general, the limiting UO_2 temperature is regarded to be the melting temperature because no provision is provided in the fuel design to accommodate the volume expansion which would result from operation with a molten UO_2 core.

- e. Water Shutoff Time - Multiply actual tube power by 1.4 to obtain equivalent tube power. Use curve in Fig. 3, page 3-13 and 3-12 of HW-46000 K to obtain water shutoff time to 170 C and 100° respectively. Water shutoff to temperatures above 170 C are not authorized.

- f. Data

Daily flow and temperature data for this test will be recorded on data sheets provided by the test authors.

- g. Goal Exposure

One compacted- and one sintered-pellet type fuel column will be scheduled for discharge at average tube exposures of 800 Mwd/t. The one additional compacted element column will be irradiated to 1600 Mwd/t. Changes in this goal exposure plan may be made by the test authors, with the concurrence of the Manager, KW Processing.

- h. Discharge

Hand discharging of the fuel columns is desired. The fuel column to be discharged at 1600 Mwd/t will be selected by the test authors, with the concurrence of the Manager, KW Processing. Maximum discharge forces for the UO_2 columns will be limited to 1100 pounds. The test fuel columns will require special pickup after discharge and subsequent shipment to the 105-C Irradiated Fuel Examination Facility. The pickup chutes must be clear of all fissionable material when the test columns are discharged. All fuel elements must be accounted for. Critical mass limits require that each column be stored in a separate bucket.

No fuel element failures are anticipated in this test; should a failure occur, the disposition of the remaining column will require the concurrence of the Manager, KW Processing. If an oxide fuel element fails, it is not expected to swell, for unlike thorium, UO_2 does not react with water. However, in the event a stuck charge occurs, a procedure similar to that established for the discharge of thorium ruptures is applicable.

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5. General

a. Schedule

The fuel elements for this test will be available for charging during September, 1965, and will be charged during the first available outage of KW Reactor. These test charges may displace Thoria charges if required.

b. Duration

The fuel columns with a goal exposure of 800 Mwd/t are expected to complete their irradiation period in approximately 35 full reactor power days from the time of charging; the column scheduled for 1600 Mwd/t will require about 70 full reactor power days. This test authorization will expire August 1, 1967.

c. Post-irradiation Examination

All fuel elements in this test will receive the normal post-irradiation visual and dimensional measurements in the 105-C Irradiated Fuel Examination Facility. Weights of all fuel elements in each column will be required. Selected elements may require additional examination as requested by the test authors. Upon completion of the post-irradiation measurements, all fuel elements will be retained by the Irradiated Fuel Examination Facility until released by the test authors. Selected fuel elements will be sent to the Radiometallurgy Laboratory for destructive examination.

d. Costs

The outage time lost as a direct result of this test may be charged to cost code XXXX-5R23-XXX.71. Anticipated times required for charging and special pickup are:

Charging - 20 min/tube	1 hr total
Installation of T/C probes - 30 min/tube	1-1/2 hr total
Special pickup - 10 min/tube	1/2 hr total

HAZARDS

The fuel elements of this test contain UO_2 enriched to 1.3 w/o U-235. The normal precautions used in handling enriched fuel elements must, therefore, be exercised in this test. The reactivity of these UO_2 elements has been determined to be equivalent to an enrichment of 1.1 w/o U-235 in metallic fuel elements. For conservatism, the critical mass limits to be applied to the handling of these test fuel elements are the same as those for 1.2 w/o enriched metallic fuel elements as follows:

* Memorandum from R. E. Rowley, dated July 14, 1965.

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Safe Mass	843 lbs
Safe Slab Height	7.5 inches
Safe Mass per Unit Area	155 lbs/ft ² (34 fuel elements)

In addition, the minimum distance between this material and other fissile material shall be three feet in air and one foot in water. Thus, the 60 elements of this test comprises only 30 per cent of the safe mass limit. The storage of the irradiated elements as determined by the safe mass per unit area limit requires that the fuel columns be stored in separate buckets after discharge.

Should the improbable event of a test fuel element failure occur, there may be some potential in the case of the compacted-powder fuel elements for release of a portion of the UO_2 . Examinations of irradiated oxide fuel elements have shown that there is sufficient sintering of the uranium oxide during operation to prevent fuel material being removed, even for large cladding failures.⁴ Therefore, it is not expected that the total fission product released to the effluent system would be greater than for a metallic uranium fuel failure. Normal failure detection equipment and methods will be sufficient to detect UO_2 failures.

PROCESS STANDARDS

Reactor Process Standard F-010 is modified for this test to allow use of aluminum dummy elements and for them to be painted with an Amercoat-type paint. Use of this type of paint on nonheat generating pieces should have no detrimental influence on either fuel elements or process tubes. Standard F-010 is also modified to allow irradiation of uranium oxide fuel elements.

PA Carlson

Supervisor, Reactor Engineering
Process and Reactor Development

K. L. Hladik

Reactor Engineering
Process and Reactor Development

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⁴ N Reactor Department. Alternate Fuel Cycles for Power-Only Operation of N Reactor - Appendix B. RL-NRD-173 PT2. February 1, 1965. Confidential.

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RESPONSIBILITIES

1. Production Fuels Section will be responsible for providing aluminum components and assistance as required to Battelle-Northwest for fabrication of the test elements, and for inspection and reactivity testing of the finished elements.

MM

2. Research and Engineering Section

- a. Process and Reactor Development Subsection will be responsible for over-all coordination and design of the test, arranging for the canning, finishing, testing, and pre-irradiation measurements of fuel elements, selection of process tubes, analyzing hydraulic laboratory results for coolant flow rates, analysis of reactivity data of the test elements, reporting in-reactor performance of the test material, analyses of the reactor operating data, and providing data for the determination of fuel element exposures and discharge dates.

RMH

- b. Process Technology Subsection will be responsible for providing assistance to both Processing Operation and Process and Reactor Development Subsection in preshutdown scheduling and process tube selection, for forwarding operating data to the authors, and for specification of operating limits.

WBL

- c. Operational Physics Subsection will be responsible for making reactivity adjustments as required by this test and for assistance in process tube selection.

RMA

- d. Testing Subsection will be responsible for post-irradiation fuel element examination and measurement.

CBR

3. Manufacturing Section

- a. Production Scheduling will be responsible for maintaining accurate records of material charged under this program and for scheduling discharge of the test columns.

TP

- b. KW Processing Unit will be responsible for operational safety and production continuity of the reactor, for charging and special pickup of the test material, for installation of downstream thermocouple probes, and for recording data as requested.

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PK

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