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IRRADIATION PROCESSING DEPARTMENT

January 5, 1961

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PRODUCTION TEST IP-381-A-FP,
IRRADIATION OF OVERSIZE FUEL ELEMENTS IN THE C REACTOR
OVERBORED PROCESS CHANNEL FACILITY

INTRODUCTION

A significant portion of the planned production gain expected from the FY 60 Reactor Plant Improvement Program was directly related to overboring the existing graphite channels. The overbore contemplated was a modest 200 mil enlargement (which would not require enlarging the reactor shield penetrations) at those reactors which were the last to require tube replacement. This was all that appeared feasible in view of the developmental work which had been accomplished at the time the program was prepared. Recent studies⁽⁸⁾ have confirmed that large incentives exist for overboring the reactor process channels approximately 500 mils in the C and 5 old reactors. Conservative estimates of the incentives for overboring indicate a payout period of about two years for the proposed work based on an increase in plutonium production of 15-18% derived from increased conversion ratio, and a reduction in plant unit cost. The proposal to overbore the graphite channels approximately 500-550 mils in one or more of the present Hanford reactors will require fuel elements about 0.5 inch larger in diameter than the present I&E fuel elements. Since there is only limited experience at HAPO in fabrication and irradiation of large diameter fuel elements*, parallel development of large fuel elements is necessary to ensure that fuel element technology will be available for full scale reactor use, should overboring of the old reactors be realized. This report presents the design of the test to irradiate these oversize fuel elements.

OBJECTIVE

The objective of this Production Test is to authorize the installation of large size process tubes in graphite channels which have been enlarged to 550 mils at C Reactor and to charge these tubes with large diameter fuel elements** to obtain preliminary qualitative data regarding irradiation behavior of larger fuel element designs.

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SUMMARY

This test authorizes installation of up to twenty large size process tubes in C Reactor and continued charging of these tubes with CVIN oversized fuel elements until authorized by Process Standards or until it is deemed impractical to convert C Reactor to this fuel geometry.

While this test is primarily directed toward the demonstration of large size self-supported I&E fuel elements in smooth bore Zircaloy-2 process tubes, the test will also authorize the use of both smooth bore aluminum and ribbed aluminum process tubes. Smooth bore aluminum tubes are authorized as an expedient in the event

* A few charges of 1,000 inch OD fuel elements were irradiated to low exposure at low temperature in the KER loops in 1957.

** CVIN fuel type - 1.991 inch nominal OD.

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that the Zr-2 tubes cannot be obtained on a schedule consistent with the over-all demonstration schedule. The ribbed aluminum tubes are authorized as an alternate to Zr-2 tubes in the event that Zr-2 tubes are not utilized in the Plant Improvement Program.

Since both smooth bore and ribbed process tubes are authorized, the fuel element may be either a three-bumper fuel element for use in the ribbed tubes or a four-footed self-supported fuel element for use in the smooth bore tubes. The fuel will be irradiated up to a maximum of 800 MWD/T under authorization of this test.

BASIS AND JUSTIFICATION

A program to develop larger fuel elements has two major inherent problem areas; 1) can existing fuel technology be extrapolated to characterize in-reactor behavior of fuel elements possibly as much as an inch larger, and 2) can the existing fabrication technology be directly applied to a larger fuel element? Fuel element design still depends heavily upon extrapolation of empirical data and since full pile overboring at C Reactor is planned for FY'62, assembly of fuel element performance data for the larger elements must be initiated now. It is desirable to take full advantage of the C Reactor Overbore Facility to further our understanding of large fuel element behavior under irradiation, particularly dimensional instability, since projection fuel elements are proposed for a fuel-tube geometry which has smaller annular clearances than our present fuel-tube geometry.

The bases for overboring of reactor process channels in the C and 5 old reactors, the production gains, and the economic evaluations of overboring have been thoroughly discussed in references 1 through 12. The highlights of the current fuel and tube design numbers presented below have been extracted from reference 11.

Overbore Size Determination

From the results of the scoping study a limit of $.600 \pm .008$ inch was obtained by applying the following criteria:

1. Adding water to the local lattice void spaces shall either, a) cause a decrease in reactivity, or b) cause an initial increase in reactivity which peaks and subsequently decreases upon further addition of water.
2. The maximum pile reactivity, when all lattices are flooded to the maximum reactivity point shall not exceed the strength of the Ball 3X safety system plus any in-place supplemental total control devices.

Fuel Element Design Bases (13)

The design procedure used was to choose the dimensions of the ribbed aluminum tube, then design a bumper fuel element for this tube. The fuel element dimensions obtained were fixed, self-support feet were added, and Zircaloy tube dimensions were found which would provide the same flow and pressure drop as obtained in the aluminum tube. All calculations were performed with the "FLEX-1" '69 program of R. J. Shields.

Basis for Location of 20 Tube Test

Calculations (14) indicate that the oversized natural uranium fuel element designed for the 20 tube test will generate about $1.5 \pm .08$ times more power per unit length

than adjacent normal sized I&E natural uranium columns. To make test results as representative as possible of future operating conditions it appears necessary that most of the 20 overbored channels be located in a region of the reactor where present tube powers are about 67% of central zone tube powers (3rd lattice unit). Alternatively, within engineering limitations (TAI limits, etc) the test channels may be located to provide various degrees of operating severity up to a maximum of about 1.5 times the anticipated future power levels at present reactor flows (central zone).

Basis for Tube Burnout Protection

Tube burnout protection procedures are not expected to be different from those currently in use because the variables that effect transient flow instability (front and rear header pressure, Panellit pressure, and pressure drop in the rear fittings) are not changed by this test.

Basis for Rib Height in Ribbed Aluminum Tubes

The rib height was designed on the basis of obtaining maximum tube life. This requires an initial eccentric positioning of the fuel element towards the top of the tube. Initially the top of the tube corrodes more rapidly than the bottom. But as the ribs wear and corrode, this trend is reversed. Thus, proper positioning will result in maximum allowable corrosion at both the top and bottom of the tube. Corrosion rates will be reduced by the coolant mixing caused by the presence of bumpers. However, it is also advisable to use mixer elements if ribbed tubes are used from both the standpoint of tube and fuel element corrosion.

Fuel Element Performance Consideration

Recent calculations have shown that the elastic stress level within the core of the overbore fuel element should lie somewhere between that calculated for the present I&E geometry and that experienced with the solid geometry in which cleavage-type failures were observed. The data are summarized below:

Comparative Stress Values

<u>Fuel Geometry</u>	<u>Operating Level (kw/foot)</u>	<u>Relative Stress psi</u>
Solid	50	102,000
Solid	55	111,000
Solid	60	119,000
Overbore Size	74	70,000
KIII I&E Natural	75	59,000
KIII I&E Enriched	88	65,000

While it cannot be predicted that cleavage-type failures will occur with this overbore geometry, it is believed this fuel is nearer the "splitting" threshold than current fuel sizes. It is not expected that this question can be answered with any degree of assurance as a result of limited irradiation experience with a 20 tube test. Limited advance power testing can be obtained by special location of some of the 20 tubes.

Geometry is an important variable in the heat treatment of uranium cores. Since

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a particular heat treatment is used to control the irradiation stability of uranium, it is reasonable to believe the dimensional stability of oversize fuel elements may be different from present core sizes. Although the magnitude and direction of such changes cannot be estimated at this time, it is believed the stability should decrease with increased core size.

Fuel Temperatures

Fuel surface temperatures would not be significantly changed by the use of larger diameter fuel elements in an overbored channel. It was calculated that the increased surface area of the larger elements for the 0.55 inch overbore would decrease the aluminum jacket temperature by 5 F. The use of self-supported fuel elements will provide an increased amount of water mixing within the coolant channel, and this mixing action should result in a more uniform temperature distribution around the fuel surface. Maximum uranium temperatures in the neighborhood of 320 C are expected. Currently, maximum uranium temperatures are calculated to be 275 C.

Fuel Testing Program

About 1,000 CVIN fuel elements were being canned in the 306 pilot plant during December 1960 with completion scheduled for about January 15, 1961. This is expected to yield a sufficient quantity of acceptable fuel elements for 26 tube charges.

Using a fixed fuel geometry and enrichment, the irradiation severity can be adjusted for testing purposes by choosing various locations or charge lengths within the reactor. Thus, it is proposed that the tubes be divided into two groups, such that the span of operating conditions expected after a full reactor conversion may be investigated. Post-irradiation measurements should be directed toward dimensional changes, deterioration of uranium or the braze layers, and fuel distortion.

Tables of process tube size, fuel size, tube location, and flow assumption are appended to reference 11.

TEST DETAILS

1. Material

A. Fuel Elements

- 1) Cores - All cores will be natural uranium of type CVIN.
- 2) Cladding - Can and spire components will be X-8001 alloy aluminum with a modified contour as shown in Dwg. H-3-7350, Rev. 9.
- 3) Projections - All supports will be fabricated from X-8001 alloy aluminum and attached to the fuel element by ultrasonic welding techniques. The projection rails will be attached as per H-3-7250, Rev. 3.
 - a) Bumper Element - Six solid rails, three each end on 90° centers.
 - b) Self-Support Element - Eight collapsible rails, four each end on 90° centers. Each rail will have about 30 mils of collapsibility.

- 4) Nominal Dimensions - Test fuel should be of the following nominal dimensions.

<u>Nominal Dimensions (Inches)</u>	<u>CVINS</u>	<u>CVINB</u>
Core OD	1.883	1.883
Core ID	0.452	0.452
Core Length	8.325	8.325
Canned OD	1.991	1.991
Canned ID	0.339	0.339
Effective Charge Length	8.865	8.865
Support Height	0.069	0.040
Support Length	2.313	1.873
Distance Support from end of F.E.	1.250	1.250
Maximum Support Diameter	2.127	2.080

All components are to meet requirements of fuel element process specifications⁽¹⁴⁾ and all finished dimensions will be within normal fuel tolerances. Cores will conform to specifications⁽¹⁴⁾ for chemical, nuclear, and physical properties.

- 5) Water-Mixers - will be required for fuel columns charged into ribbed aluminum process tubes. The water mixer will not be used with the initial columns charged into smooth bore tubes but may be specified in subsequent chargings. Mixer location will be specified by the test author.
- 6) Assembly - All fuel elements will be fabricated in accordance with the fuel element process specifications⁽¹⁴⁾ incorporating the following improvements:
- a) Core preheat of 32-35 seconds using lead plugs to facilitate AlSi wetting of the internal channel.
 - b) Sleeve-can preheat of 75-85 seconds.
 - c) Pressure quench following canning to reduce braze porosity.
 - d) A modified end contour as shown in Dwg. H-3-7350, R-9 will be utilized since bumpers and self-supports will assure alignment during irradiation.
 - e) A caustic etch may be used before rail attachment and autoclave testing. The etch procedure is described in Dwg. H-3-16790.

A more detailed description of the process is contained in FWR-141-89.

- 7) Quality - All elements accepted for reactor charging must pass the normal quality control specifications in effect at the time this test material is prepared.
- 8) Quantity - About 632 acceptable CVIN fuel elements will be required to supply the initial loading of up to 20 tubes. The number is arrived at by breaking the 20 tubes into two groups:
- a) 16 columns at 32 pieces with 2 spares/column.
 - b) 4 columns at 20 pieces with 2 spares/column.

Eight additional charges will be required to support the 4 central zone

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columns (20 pieces/column) in an 8 month period. Replacement columns for the fringe zone tubes (3rd lattice unit) will be required in about 4-1/2 months after initial charging.

- 9) Pre-Irradiation Measurements and Testing - All columns charged in this test will carry a piece number and a series number in addition to other required numbers. The following tests and measurements will be made:

<u>Test</u>	<u>Purpose</u>	<u>Core Status</u>	<u>Data</u>
Bare Core Numbering	Identify Cores	Bare	Record Slug Number and Ingot Number
UT-2	Grain Size Measure	Bare	Record Data
Surface Tester	Core Surface Quality	Bare	Record Data
Length	Core Dimensions	Canned	Record Data
Outer Diameter (3)	Core Dimensions	Canned	Record Data
Inner Diameter (3)	Core Dimensions	Canned	Record Data
*Weight (1-15)	Core Dimensions	Canned	Record Data
Warp ALL	Core Dimensions	Canned	Record Data
Ellipticity	Core Dimensions	Canned	Record Data
Total Bond Count	Braze Porosity	Canned	Record Data
Stud Pulling	Bond Strength	Canned	Record Data
Metallography	Bond Quality	Canned	Photo-Micrographs

* Weight all pieces 1 through 15 in each charge.

B. Process Tubing ●

Process tubes utilized in this test are described in Table I, reference 11. These tubes will be installed into channels chosen by the test author with the concurrence of the Manager, C Processing. The first five tubes installed will be smooth bore zircaloy process tubes. Subsequent selection of type of process tube will be accomplished by a representative of R&ES/PARDSS.

C. Dummies

Downstream dummies will be 8" expendable perforated aluminum spacers with supports stud-welded as follows:

- 1) Four studs each end on 90° centers in line.
- 2) Support height is about .300". The nominal rib diameter is 2.000".
- 3) Supports are at least 1" from ends of spacer.

D. Thermocouple Probes

Downstream thermocouple trains to measure annular temperature distribution may be utilized as specified by the test author. While it is anticipated that up to twenty probes may be used during the life of this program, not more than ten probes are authorized in-reactor at any one time.

E. Hardware

New prototype hardware which includes donuts, gunbarrels, nozzles, pigtails, caps, venturis, and other miscellaneous parts to be used with the oversized process tubes authorized by this test are authorized by reference 15.

F. Charge Machine

A modified machine is being developed to eliminate the need for hand charging. The machine will be capable of exerting normal charge machine pushing forces against the fuel column and will handle one piece at a time. The machine must be manually loaded and will thus charge at a reduced rate. The machine will attach to the oversized inlet nozzle and will be capable of handling both oversize and normal size material.

2. Irradiation

A. Charging

Twenty columns of CVIN fuel elements are scheduled for irradiation to 800 MWD/T in overbored channels in C Reactor. The first loading will probably consist of three charges of self-supported elements in ribless Zircaloy-2 process tubes. Subsequent loadings will be scheduled in accordance with tube procurement and reactor outage availability with the concurrence of the Manager, C Processing.

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

- 1) High Power - Columns selected to pilot high specific powers will be short charged and will contain about 20 pieces. The channels will be chosen by the assigned Process Engineer and Physicist and will be agreed upon by the Test Author with concurrence of the Manager, C Processing. Sufficient solid dummies shall be inserted in the downstream dummy train to adjust the tube flow to a maximum of 55 gpm. At least two perforated dummies shall separate the solid and I&E portions in any tube.
- 2) Average Power - Fuel charged into the third lattice unit will operate at specific powers typical of existing central zone tube powers. The column length will be 32 pieces and will be positioned with a normal length downstream dummy pattern. Flow is expected to be between 50-51 gpm and this will be confirmed with flow lab tests.

B. Operating Conditions

Desired operating conditions for columns charged under authorization of this test are: (Assume 95 C bulk and 94,000 gpm)

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	<u>3rd Lattice Overbore</u> (Average Power)	<u>Central Zone Overbore</u> (High Power)
Max. Power 0°C/20°C T1	1566 KW/1235 KW	1385 KW/1092 KW
Outlet Temperature	117°C/112°C	104°C/102°C
Max. Outlet Temperature		120°C

Contingent to reactor charging, flow laboratory data shall be reported to either verify the 32 and 20 piece column length flows or to modify the column length or downstream dummy pattern to obtain the desired flow. Downstream dummy patterns will be chosen by the test author with the concurrence of the Manager, C Processing.

C. Irradiation

During irradiation, daily temperature and flow data shall be recorded for each column. Based on these data, the loading pattern may be modified to either produce a higher power or surface temperature by adding one to three pieces upstream or lower surface conditions by removing downstream solids in order that desired operating conditions may be achieved. In addition, thermocouple probe data will be recorded daily where appropriate. Data sheets will be provided by the test author.

D. Goal Exposure

The exposures for the initial irradiation of fuel elements of this geometry shall be as follows:

<u>Charge Number</u>	<u>Goal Exposure</u>
1	200 MWD/T
2	400 MWD/T
3	800 MWD/T
4-20	800 MWD/T

Goal exposure changes will be made by request from the test author with the concurrence of the Manager, C Processing. Changes may be required depending on the loading patterns and overbore program schedules.

E. Discharging

All columns will be monitor columns and will require special pickup and shipment to 105-C MEF for post-irradiation examination and measurement.

Examination of the discharged fuel elements can with the concurrence of the test author and the Manager, C Processing alter the scheduled goal exposures of material under irradiation. Special rear face "tip-offs" will be provided for by this test.

Up to two ruptures are authorized by this test. Should a failure occur in any of the test columns, it will be extremely desirable to obtain the failed piece for examination along with the remainder of the column. If a charge should stick, regardless of the cause, stuck charge and rupture removal procedures will be reviewed by representatives of R&E before use. If a tube can not be recharged, procedures for operation with an empty tube will be reviewed by representatives of R&E before startup.

F. Water Shutoff Times

Water shutoff times prepared by PARDSS and approved by Process Technology Operation will be submitted to C Reactor Operation prior to startup.

G. Schedule

For planning and scheduling purposes, the following tentative schedule is provided.

<u>Approximate Date</u>	<u>Test</u>
1-16-61	Charge three columns into ribless zirconium tubes in about third lattice unit.
2-61	Charge two columns into ribless zirconium tubes to pilot high specific power fuel performance.

Subsequent loading dates, column location, and type of oversized process tube to be used have not been established. This information will be furnished as it becomes available. ©

H. Duration

This test shall continue until full scale reactor use of this material is initiated or until the test results indicate that insufficient justification for this program exists; and thereafter, until the oversized tubes have been removed from the reactor.

I. Post-Irradiation Examination

All fuel elements will be: 1) visually examined and weaseled; 2) have warp, ellipticity, diameter and length growth recorded; 3) be bond tested (total count); and 4) have post-irradiation weight recorded on all downstream pieces 1 through 15.

Elements showing more than 20 mils warp, length increase, diameter increase, ellipticity, or surface bumping shall be set aside for: 1) stripping and bare core measurements of length, diameter, ellipticity, bumping and warp; or 2) shipment to Radiometallurgy Laboratory for further examination. Special attention is to be given to any new or unusual observations.

J. 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 special charging.

<u>Job</u>	<u>Processing Time</u>	<u>Elevator Time</u>
1. Charge tubes	3/4 mh/tube	1/4 hr/tube
2. Install T/c probes	2 mh/tube	1/2 hr/tube
3. Remove T/c probes	1/2 mh/tube	1/4 hr/tube
4. Discharge and special pickup	1-1/2 mh/tube	1/4 hr/tube

In addition up to two ruptures are authorized.

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K. Hazards

- 1) The primary hazard associated with this test is essentially that of fuel element failure. Since this fuel geometry has been selected without the benefit of irradiation experience, a higher probability exists of encountering fuel element failures than in normal metal. Every attempt will be made to avoid fuel element failures by making laboratory hydraulic flow checks, and by following a cautious loading schedule. Since this fuel element is larger (~ 500 mils) than any previously used, it is possible, but not likely that a threshold has been crossed and failures will be encountered. The biggest concern is that the core splitting threshold could be encountered. (11)
- 2) Another hazard is the possibility that the entire concept may be deemed infeasible. This could arise from a cancellation of the graphite overbore program due to any number of subsequent decisions, depending on a choice of assumptions.
- 3) A slight hazard exists in the use of projection fuel elements, in that it is conceivable that unusual dimensional instabilities could induce stuck fuel elements (ruptures or non-ruptured) due to the fact that fuel element displacement in the process tube is restricted by the projection supports. This in turn could cause troublesome tube removal and replacement difficulties, particularly with zirconium tubes.
- 4) A potential hazard exists for damaging portions of the discharge chutes (mattress pads) with the heavier fuel elements. This is being evaluated and is considered a slight problem at this stage of the program.
- 5) It appears that no extreme risk is involved in this testing program with regards to safety; and no production losses other than those normally involved in any fuel development program are expected, excepting the time required to accomplish the graphite overboring and hardware installations.

RESPONSIBILITIES

Fuels Preparation Department

Manufacturing Section shall be responsible for canning all pieces by the "F" process, finishing and testing the fuel elements, quality control, segregation of test material, maintenance of normal production records, recording data on non-standard operations, providing for attachment of projections, and pre-irradiation measurements and marking of the finished fuel elements.

Engineering Section shall be responsible for procurement and fabrication of material not used in regular production, supplying supplemental operating procedures, proving technical assistance, liaison in the 300 Area, and collection of test data.

Irradiation Processing Department

Research and Engineering Section

Process and Reactor Development Subsection shall be responsible for over-all coordination of the test, data analysis, reporting of irradiation experiences, assistance in choosing test channels, recommending column modifications and discharge exposures, and water shutoff times. Specifically, Reactor Engineering Unit shall be responsible for the process tubes and providing flow lab data and analysis as a basis for operating limits. Reactor Fuels shall be responsible for liaison contact with the affected Processing Subsection, for scheduling of fuel elements, and for technical assistance with regards to fuel elements. Both groups shall be responsible for reporting their phase of the program when necessary.

Process Technology Subsection shall be responsible for assistance to both the Processing Subsection and Process and Reactor Development Subsection in scheduling, in charging of the test, in choice of test channels, and for forwarding of operating data to the author, and for specification of operating limits.

Component Testing Unit shall be responsible for obtaining and reporting post-irradiation fuel examination data.

Operational Physics Subsection shall be responsible for aiding the test author in choice of test channels and reactivity changes required.

Facilities Engineering Section

Equipment Development Subsection shall be responsible for overboring in all its facets, for providing special equipment and detailed procedures for the entire program, for collecting data, initiating design changes, for all non-standard components installed, and issuance of interim and final reports. In addition, Equipment Development Subsection shall be responsible for providing a special "tip-off" and a charging aid to support the test program.

Manufacturing Section

B-C Reactor Subsection

C Processing Operation shall be responsible for scheduling of the test, operational safety and production continuity of the reactor, for collection of operating data and for charging all columns of the test under the direction of the Research and Engineering representative.

B-C Maintenance Operation shall be responsible for thermocouple probe installation and removal.

M. A. Clinton

Reactor Fuels Unit
Process and Reactor Development Subsection
Research and Engineering Section
IRRADIATION PROCESSING DEPARTMENT

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