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

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

INTRODUCTION

Recent studies[8] have confirmed that large incentives exist for overboring the reactor process channels approximately 500 mils in the C and five old reactors, under the updated Plant Improvement Program. Conservative estimates of the incentives for overboring indicate a payout period of about two years for the proposed work, 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,* it is highly desirable to secure additional experience to assure that large fuel element technology will be available for full scale reactor use in advance of the time when extensive overboring of the old reactors is implemented. This report presents the design of the test to fabricate and irradiate the oversize (PIP-1) 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 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.

SUMMARY

This test authorizes installation of up to 20 large size process tubes in C Reactor and continued charging of these tubes with CVIN oversized fuel elements.

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

* A few charges of 1.800 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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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 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.

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 features: (1) the extent to which existing fuel technology can be extrapolated to characterize in-reactor behavior of fuel elements possibly in excess of one inch larger, and (2) to predict the extent to which existing fabrication technology can be directly applied to a larger fuel element. Fuel element design still depends heavily upon extrapolation of empirical data and although full pile overboring may be two to three years away, 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 basis for overboring of reactor process channels in the C and five 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 .550 inch was selected 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-I" 709 program of R. J. Shields.

Basis for Location of 20-Tube Test

Calculations[13] indicate that the oversized natural uranium fuel element designed for the 20-tube 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 1/1.5 or 67% of central zone tube powers/3rd lattice unit. Alternatively, within engineering limits (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.

Fuel Element Performance Considerations

Recent calculations have shown that the 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

Fuel Geometry	Operating Level (kw/foot)	Relative Stress (psi)
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

There seems to be no valid reason to expect that cleavage-type failures will occur with this overbore geometry, however, it is believed this fuel is nearer the "splitting" threshold than current fuel sizes. Limited data can be secured by this test, however, it is not expected that this question can be answered with any degree of assurance as a result of this irradiation experience. Initial advance power testing will be obtained by special location of some of the 20 tubes.

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Geometry is an important variable in the heat treatment of uranium cores. Since a particular heat treatment is used to control the irradiation stability of uranium, it is desirable to know the extent to which oversize fuel elements will be different from present core sizes.

Any increases in power in the future will push the stress levels in these large I & E's even higher. If the splitting threshold is encountered, fuel geometries with intrinsic lower stress levels will be required. Analytical investigations of rod-in-tube (nongenerating and generating rods) and tube-and-tube geometries are being started. If any of these should appear at all attractive from a conversion ratio standpoint, fabrication and cost studies will be commenced.

Fuel Temperatures

Fuel surface temperatures will 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 only 3 C. 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 1000 fuel elements were in production in the 306 pilot plant during December 1960 with completion scheduled about January 15, 1961. This is expected to yield a sufficient quantity of acceptable fuel elements to load 20 tubes, plus about six additional columns as needed to replace tubes prematurely discharged for measurements.

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 20 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.

Process tube size, fuel size, tube location, and flow assumption tables are appended to Reference 11.

TEST DETAILS

1. Material

   A. Fuel Elements
      1) Cores - All cores will be natural uranium of type CVIN. Core code - X-2.
      2) Cladding - Can and spire components will be X-8001 alloy aluminum with a modified end contour as shown in Dwg. H-3-7350, Rev. 9. Component code - X-2.
      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-3-7950, Rev. 4.

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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.

Nominal Dimensions (Inches)	CVINS	CVINB
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 Fuel Element	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.

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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 PWR 126-84 and HW-68085.[16] A more detailed description of the assembly process is contained in PWR 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 20 tubes. The number is arrived at by breaking the 20 tubes into two groups:

a) Sixteen (16) columns at 32 pieces with two spares/column.
b) Four columns at 20 pieces with two spares/column.

Eight additional charges will be required to support the four central zone columns (20 pieces/column) in an eight-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:

Test	Purpose	Core Status	Data
Bare Core Numbering	Identify Cores	Bare	Record Slug No. & 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	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.

2. Irradiation

Twenty (20) 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.

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

Charge Number	Goal Exposure
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.

3. Post-Irradiation Examination

All fuel elements will be: (1) visually examined and weasled; (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.

LIMITATIONS OR HAZARDS

1. 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 (ruptured or non-ruptured) due to the fact that fuel element displacement in the process tube is restricted. This in turn could cause troublesome tube removal and replacement difficulties, particularly with zirconium tubes.

2. 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.

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TEST AUDIT

Notebook HW-67720 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.

W. H. Hodgson

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AlSi Product Engineering
Fuels Preparation Department

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Reactor Fuels Operation
Irradiation Processing Department

[redacted]

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APPENDIX

Data to be Recorded in Production Test Notebook

I. Fuel Element Core

A. Lot Numbers

1. Ingot Numbers and Chemical Analysis
2. Unusual Treatment
3. Fabrication Technique

B. Finished Dimensions (Pre-Assembly)

II. Aluminum Components

A. Lot Numbers

1. Alloy Type
2. Unusual Treatment

B. Finished Dimensions (Pre-Assembly)

III. Pre-Assembly Treatment of Cores

A. UT-2, Record Data
B. Surface Tester, Record Data

IV. Assembly Process

A. Process Used
B. Brief Explanation of Each Process
C. Attendant Conditions
D. Total Bond Count, Record Data

V. Post-Assembly Treatment

A. Support Attachment
B. Autoclaving
C. UT-4 Test, Record Data
D. Stud Pulling, Record Data
E. Inspection
F. Other Treatment

VI. Irradiation

A. Coolant Temperature

1. Inlet
2. Outlet

[redacted]

B. Panellit and Crossheader Pressures
C. Number of Shutdowns (Controlled and Scram)
D. Other

VIII. Post-Irradiation Examination

A. Visual
B. Warp
C. Total Bond Count, Record Data
D. Critical Examination of Bond Quality by Stud Pulling and Metallography

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.

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