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PRODUCTION TEST IP-486-D, IRRADIATION OF
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PT IP-486-D-IRRADIATION OF CORRUGATED FUEL ELEMENTS

HANFORD ATOMIC PRODUCTS OPERATION RICHLAND, WASHINGTON

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PRODUCTION TEST IP-486-D,
IRRADIATION OF CORRUGATED FUEL ELEMENTS

OBJECTIVE

The objective of this production test is to authorize the irradiation of three natural uranium corrugated I&E-type fuel elements in a KE Reactor front-to-rear test hole.

BASIS AND JUSTIFICATION⁽¹⁾

The ultimate exposure of Zircaloy-2 clad, coextruded, uranium-cored fuel elements may be limited by localized tensile necking and splitting of the jacket. The total deformation capability of a fuel element is increased by corrugating the outside surface so the perimeter is greater than that of a circle circumscribing the equivalent cross sectional area. Thus, swelling of the uranium core is accommodated by bending of the clad rather than by large clad tensile strains. The test is designed so the knowledge gained will be applicable to the NPR fuel assemblies.

TEST DETAILS

1. Fuel Elements

Each fuel element consists of an 18-inch long, natural uranium core of the internally-externally cooled type clad in Zircaloy-2. The externally cooled surface is corrugated, the internally cooled surface is not. Figure 1 is a drawing showing dimensions on a section through one of the elements. The element has nearly the same amount of uranium per unit length (0.643 lbs/in.) as the NPR fuel assembly inner tube (0.61 lbs/in.). The end caps are both braze-bonded and welded.

The fuel elements were ultrasonically tested for complete bonding of the cladding to the uranium and were autoclaved in 400 F steam for 72 hours.

2. Irradiation Facility

The fuel elements will be irradiated in KE Reactor in test hole 3565.

3. Test Assembly and Test Tube Loading

Each fuel element is concentrically mounted in a 2.00-inch OD by 1.625-inch ID tube called a basket. Transverse pins are located at each end of the basket to contain the fuel element. The over-all length of each assembly is approximately 19 inches. Three assemblies will be charged into the tube. The charge will be located in the central region of the reactor. Perforated tubular spacers will be located downstream.

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4. Charge, Discharge, and Special Pickup

- a. Charging - the assemblies will be charged into the test tube by hand from either the front or rear work platform.
- b. Discharging and Special Pickup - The assemblies will be discharged into the KER discharge tray, lowered to the bottom of the basin, and transferred to storage buckets.

5. Shutdown Time

Work Platform Time - Hours

	<u>Front</u>	<u>Rear</u>
Charging	1	0
Discharge and Pickup	2	4

6. Thermal-Hydraulics

At reactor equilibrium the total fuel element heat generation will be about 337 KW(74.9 KW/ft); the total coolant flow-rate through the tube will be about 49 gpm. Table I presents the flow distribution through and around the baskets, and the heat distribution to the fuel element bore and annulus.

TABLE I

	<u>Fuel Element</u>		<u>Basket</u>
	<u>Annulus</u>	<u>Bore</u>	<u>Annulus</u>
Per Cent of Total Coolant Flow	59	18	23
Per Cent of Total Heat Generated	63	37	0

The flow distribution was obtained from flow data gained by a hydraulic mock-up of the tube charged with the actual fuel elements to be irradiated. The heat distribution results were obtained from IBM 7090 computer program. (2)

The operating conditions are presented in Figure 2. The expected Panellit equilibrium point is 227 psig which indicates trip points of 202 psig and 252 psig. The maximum and minimum authorized trip pressures are 290 psig and 136 psig. Table II presents the calculated operating and burnout heat fluxes for the case of flow reduction to the minimum low scram point.

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TABLE II

	BTU/hr.ft. ²	
	Annulus	Bore
Surface heat flux at low scram trip	4.71×10^5	8.30×10^5
Burnout heat flux at min. low scram trip	8.62×10^5	1.07×10^6
Fuel element surface temperature at minimum low scram trip	281 F.	324 F.

7. Exposure

The charge will be irradiated to about 4000 MWD/T. This exposure will require about 300 operating days to attain.

8. Reactivity Change

The test will cause a reactivity increase of about -17 nominal cmk.

9. Monitoring

A 25-75 Panellit gauge will monitor the coolant flow-rate through the test tube. The gauge will be in the reactor safety circuit. Tube outlet temperature will be monitored and read out from a standard thermohm. The gamma activity of the effluent water will be monitored with the reactor gamma monitor system. If the water from the header into which the test tube flows indicates a fuel element rupture, a sample of the effluent water from the test tube can be taken from the sampling manifold located in the hot storage room (18-foot level) and analyzed for fission products.

CONDITION FOR REACTOR SHUTDOWN

A significant flow restriction upstream or downstream of the charge will automatically shut down the reactor.

The reactor should be manually shut down according to standard procedures and the test discharged if the analyses of the effluent water from the test tube give positive indications of a ruptured fuel element.

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HAZARDS

The primary hazard from the test is the entrance of fission products into the coolant stream from a ruptured fuel element. The consequences of such an occurrence should be no greater than those associated with the rupture of a standard reactor fuel element.

RESPONSIBILITIES

IRRADIATION PROCESSING DEPARTMENT - KE Processing Operation

Maintain safety and production continuity of the reactor, except for conditions associated with this test.

IRRADIATION PROCESSING DEPARTMENT - Irradiation Testing

1. Charge and discharge the fuel element assemblies.
2. Collect data.
3. Operate the test facility.
4. Maintain reactor safety and production continuity as determined by the conditions of this test.

RK Marshall
Irradiation Testing

RK Marshall/rch

W K Kratzer
Process and Reactor Development

WK Kratzer/rch

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REFERENCES:

1. Letter from RG Wheeler to RK Marshall, "Test Irradiation of Tubular Fuel Elements", dated September 22, 1961.
2. Letter from RG Wheeler to RK Marshall, "KE-3565 Irradiation of Tubular Fuel Element", dated November 21, 1961.
3. Bernath, Louis, Prediction of Heat Transfer Burnout; AIChE, Volume 52, Number 18. Dated 1956.

FIGURE 1

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CORRUGATED FUEL ELEMENT COEXTRUDED WITH
ZIRCALOY-2 CLAD ON NATURAL URANIUM CORE

FIGURE 2
TEST ROTE HYDRAULIC CHARACTERISTICS FOR THREE CORRODED TYPICAL
RESIDENT ASSEMBLIES

APPENDICES

THERMAL HYDRAULIC CALCULATIONS

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I. DATA

1. Fuel Element

Maximum diameter----- 1.514 in.
 Diameter of cladding bore----- .435 in.
 Diameter of uranium bore ----- .485 in.
 Length of uranium in each fuel element-----18.00 in.
 Number of fuel elements in charge----- 3.
 Heated perimeter of fuel element----- 4.105 in.
 Area of 6 lens-shaped areas----- .599 in.²
 Hydraulic diameter of fuel element annulus (De_2)----- .0316 ft.
 Cross sectional area of fuel element annulus (A_2)----- .00606 ft.²
 Cross sectional area of bore (A_1) ----- .001236 ft.²
 Weight of uranium /inch ----- .643 lbs/in.

2. Basket and Test Tube

Test Tube ID----- 2.125 in.
 Basket OD ----- 2.000 in.
 Basket ID ----- 1.625 in.
 Hydraulic diameter of basket annulus (De_3) ----- .0105 ft.
 Cross sectional area of basket annulus (A_3)----- .00284 ft.²

3. Heat Generation

Rate of heat generation/g U^{235} @ $1 \times 10^{13} \text{ n/cm}^2\text{-sec.}$ ----- .484 KW
 Volume average neutron flux in adjacent uranium ----- $4.3 \times 10^{13} \text{ n/cm}^2\text{-sec.}$
 Ratio of volume average flux in corrugated fuel element
 to flux in adjacent uranium ----- 1.44

4. Subscripts

1 = bore
 2 = fuel element annulus
 3 = basket annulus

II. EQUILIBRIUM THERMAL HYDRAULICS

1. Heat Generation/Lineal Foot

$$(.643)(.454)(12)(.00715)(.484)(4.3)(1.44) = 74.9 \text{ KW/ft.}$$

2. Total Heat Generated

$$(74.9)(3)(1.5) = 337 \text{ KW}$$

3. Coolant Temperature Rise at 49 gpm

$$\frac{337}{(.264)(49)} = 26 \text{ C}$$

4. Surface Heat Flux

a. Fuel element annulus.

$$\frac{(74.9)(.63)(3413)(12)}{(4.105)} = 471,000 \text{ BTU/hr.ft.}^2$$

b. Fuel element bore

$$\frac{(74.9)(.37)(3413)(12)}{\pi (.435)} = 830,000 \text{ BTU/hr.ft.}^2$$

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III. NON-EQUILIBRIUM THERMAL HYDRAULICS

1. Flow Restriction Upstream of Charge

The burnout heat flux is calculated at minimum low scram trip. The calculations are based on Reference 3.

$$[q/A]_{bo} = h_{bo}[(T_w)_{bo} - (T_b)_{bo}] \quad (2)$$

$$h_{bo} = 5710 \left(\frac{De}{Di} \right)^{0.6} + 48 \frac{V}{De^{0.6}} \quad (3)$$

$$(T_w)_{bo} = 57 \ln P - 54 \left(\frac{P}{P + 15} \right) - \frac{V}{4 \left(\frac{De}{Di} \right)^{0.6}} \quad (4)$$

Notation:

q = Heat generated/unit length, Pcu/hr.ft.
 A = Heat transfer surface/unit length of element, ft.²/ft.
 h = Film heat transfer coefficient, Pcu/hr.ft.² °C.
 T = Temperature, °C.
 De = Hydraulic diameter of the coolant passage, ft.
 Di = Heated perimeter divided by π , ft.
 V = Velocity, ft./sec.
 P = Absolute pressure, psia.
 ln = Natural logarithm symbol.
 P.c.u. = Pound-centigrade heat unit.

Subscripts:

b = Bulk coolant.
 bo = Burnout.
 w = Heated surface.

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a. Fuel element annulus (at minimum low trip scram).

Total flow = 33 gpm (from Figure 2).

P = 115 psig (at downstream end of charge, obtained by hydraulic mockup at a Panellit pressure of 136 psig.)

From equation (3):

$$h_{bo} = 5710 \left[\frac{.0316}{\frac{4.105}{12 \pi}} \right]^{.6} + \frac{48}{(.0316)}^{.6} \left[\frac{(33)(.59)(2.228) \times 10^{-3}}{(6.06) \times 10^{-3}} \right]$$

$$= 5330 \text{ Pcu/hr.ft.}^2 \text{ C.}$$

From equation (4):

$$(T_w)_{bo} = 57 \ln 115 - 54 \frac{115}{130} - \frac{(33)(.59)(2.228) \times 10^{-3}}{(6.06 \times 10^{-3})(4)} \left[\frac{.0316}{\frac{4.105}{12 \pi}} \right]^{.6}$$

$$= 185 \text{ C.}$$

$$(T_b)_{bo} = 95 \text{ C.}$$

From equation (2):

$$\left(\frac{q}{A} \right)_{bo} = 5330 (185-95)$$

$$= 8.62 \times 10^5 \text{ BTU/hr.ft.}^2$$

b. Fuel element bore (at minimum low trip scram).

Total flow = 33 gpm (from Figure 2).

P = 115 psig (at downstream end of charge).

From equation (3):

$$h_{bo} = 5710(1) + \frac{48}{\frac{.435}{12}}^{.6} \left[\frac{33(.18)(2.228)}{1.236} \right]$$

$$= 9470 \text{ Pcu/hr.ft.}^2 \text{ C.}$$

From equation (4):

$$(T_w)_{bo} = 57 \ln 115 - 54 \frac{115}{130} - \left[\frac{33(.18)(2.228)10^{-3}}{(1.236)10^{-3}(4)} \right]$$

$$= 186 \text{ C.}$$

$$(T_b)_{bo} = 123 \text{ C.}$$

From equation (2):

$$\left(\frac{q}{A} \right)_{bo} = 1.073 \times 10^6 \text{ BTU/hr.ft.}^2$$

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