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TITLE

GEH-4-68, 69, 70: PROPOSAL FOR
VARIABLE BRAZE THICKNESS IRRADI-
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GEH-4-68, 69, 70: PROPOSAL FOR

VARIABLE BRAZE THICKNESS IRRADIATION

by

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June 27, 1961

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GEH-4-68, 69, 70: PROPOSAL FOR
VARIABLE BRAZE THICKNESS IRRADIATION

I. INTRODUCTION

Current NPR fuel production plans call for a thick layer (0.030 inch or greater) of 5% Be + 95% Zry-2 braze alloy in the closure region. This requirement was imposed to eliminate many of the production welding problems brought about by the presence of the low melting braze alloy between two surfaces of Zircaloy. All GEH-4 irradiations in the past have involved very thin braze lines (0.015 inch or less). As a part of the fuel evaluation program it is essential to run a comparative irradiation to determine what effect the braze line thickness has on the stability of the fuel closure. For this purpose three fuel elements were prepared, two with a braze thickness of 0.030 inch and one with a braze thickness of 0.015 inch. To provide a more severe thermal stress, the I&E geometry was used. Five MTR cycles should be sufficient to test this fuel concept.

II. DESCRIPTION OF FUEL ELEMENTS

This irradiation test consists of three fuel elements. The fuel material is normal metallic unalloyed uranium, Zircaloy-2 clad, of the tubular geometry and the I&E size. The fuel was coextruded at Hanford by the Fuels Preparation Department. Each element is 7.50 inches in length with contoured end caps. The Zircaloy-2 end caps were brazed to the jacket and uranium core with the 5% Be + 95% Zry-2 braze alloy, then TIG welded to further insure closure integrity. Braze line thickness was maintained by controlling the diameters of the end caps. The elements are 1.450 inches OD and 0.436 inch ID. For hydraulic purposes a 0.326 inch diameter flow restrictor has been fitted into the central flow channel of both elements. A one inch high perforated aluminum spacer supports the two elements. This entire fuel assembly is contained in a standard GEH-4 basket.

III. SUMMARY OF TEST CONDITIONS

Maximum Fuel Core Temperature	631 F (333 C)
Maximum Uranium Surface Temperature	310 F (155 C)
Maximum Jacket Temperature	175 F (80 C)
Normal Uranium Weight	0.928 lb/in
Total Uranium Weight (Three Elements)	19.21 lb (8,715 gm)
Weight U ²³⁵ (Three Elements)	0.13 lb (59 gm)
Maximum Power Generation	80.7 KW/ft
Maximum Heat Flux (Outer Surface)	482,000 BTU/hr-ft ²
Number of Fuel Elements	3
Number of MTR Cycles	5
Burnup Rate (Per Day)	14.5 MW/T
Water Flow Rate	20 GPM
Water Velocity	19.7 ft/sec
Film Coefficient	6,500 BTU/hr-ft ² -°F

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External Fuel Diameter	1.450 inches
Internal Fuel Diameter	0.436 inch
Internal Basket Diameter at Fuel	1.560 inches
Flow Restrictor Diameter	0.326 inch

IV. FABRICATION

The fuel tubes were coextruded by the floating mandrel process at 1170 F and an extrusion ratio of 18:1. Extruded dimensions were 1.459 ± 0.007 inches OD and 0.429 ± 0.005 inch ID, with a nominal 0.025 inch thick Zircaloy-2 cladding. Transverse and longitudinal sections were examined for dimensions, uranium quality and bond quality. Extrusion copper was removed by nitric acid pickling. The extrusions were cut into 7.65 inch lengths and the uranium removed to a depth of 0.36 inch on each end by immersion in a solution of sulfuric acid, nitric acid, copper sulfate and water.

The cladding was then vapor blasted to remove surface contamination, then bright etched in the HF-HNO_3 etch solution. A 0.315 inch thick Zircaloy cap was placed on the uranium and the Zircaloy walls were crimped to hold the cap tightly against the uranium. A braze alloy ring was placed on the cap and the assembly positioned in a vacuum brazing chamber and evacuated to 10^{-3} mm of Hg. The closure region was heated to 1035 C, and as soon as the braze alloy melted the vacuum valves were closed and the system pressurized with argon gas to force the braze alloy to flow under the cap.

After brazing the elements were beta heat treated in chloride salt at 730 C and quenched into nitrate salt. The elements were then machined to the proper end contour, vapor blasted to remove the heat treating scale and bright etched. The elements were then TIG welded, inspected and autoclaved for 72 hours in 400 C (750 F) 1500 psi steam to insure adequate corrosion resistant welds and good quality Zircaloy-2 surfaces. Final inspection included a visual check for marred surfaces, pre-irradiation measurements, radiographs of the closure, an ultrasonic bond check and a clad thickness Eddy Current Test.

V. FLUX WIRES

One flux wire shall be attached to the basket and remain attached throughout the irradiation. Two flux wires, one toward the reactor core and one away from the core, shall be placed in the flux wire slots and shall be replaced at the startup of each cycle. The flux valves shall be forwarded to the experimenter as soon as they become available. It is imperative that this be done so that a complete record is obtained of the flux for each cycle and for the entire irradiation.

VI. REQUIRED FUEL EXAMINATION

Periscope photographs shall be taken as soon as possible following final discharge of the irradiated elements in the canal. A complete radiometallurgical examination will be done at HAPO.

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VII. SPECIMEN INSERTION AND REMOVAL

The fuel elements and an MTR basket will be shipped to the MTR/ETR site after approval of this irradiation proposal. The element shall be placed in the basket with the numbered end up, and with GEH-4-68 as the upper element (thin braze), GEH-4-69 as the center element (wide braze) and GEH-4-70 as the bottom element (wide braze). The pointed end shall be oriented in the upward direction. Inlet and outlet thermocouples will be provided.

VIII. HAZARDS

There are no unusual hazards associated with this irradiation because of the very low uranium temperature. The cladding, braze alloy and welds have been subjected to autoclave conditions much more severe than actual reactor operating conditions.

IX. APPENDICES

Details of all pertinent information are appended in the following order:

APPENDIX I: Thermal and Hydraulic Calculations

APPENDIX II: Figures

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APPENDIX I - THERMAL AND HYDRAULIC CALCULATIONS

A. For calculation purposes, the specific power generation was taken from data obtained from the nuclearly similar test GEH-4-57, 58. This test produced a measured average power generation of 74 KW/ft or 7.25 KW/lb of natural uranium. As these elements, GEH-4-68,69,70, contain 0.928 lb of natural uranium per inch, a power generation of 80.7 KW/ft may be expected. The maximum heat flux will be approximately 482,000 BTU/hr-ft² on the outer surface.

B. Sample Calculations

Basic Conditions:

Uranium Core

Length	6.90 inches
Outer Diameter	1.400 inches
Inner Diameter	0.486 inch

Fuel with Cladding

Length	7.50 inches
Outer Diameter	1.450 inches
Inner Diameter	0.436 inch
Cap Thickness	0.280 inch
Clad Thickness (Both Inner and Outer)	0.025 inch

1. Flow Areas

Basket	$= \pi/4 (1.560)^2 =$	1.911 in ²	$= 0.0133 \text{ ft}^2$
Outer Annulus	$= \pi/4 [(1.560)^2 - (1.450)^2] =$	0.260 in ²	$= 0.00180 \text{ ft}^2$
Inner Annulus	$= \pi/4 [(0.436)^2 - (0.326)^2] =$	0.066 in ²	$= 0.000458 \text{ ft}^2$

2. Peripheries

Basket	$= \pi (1.560) =$	4.900 in	$= 0.408 \text{ ft}$
Fuel OD	$= \pi (1.450) =$	4.555 in	$= 0.3796 \text{ ft}$
Fuel ID	$= \pi (0.436) =$	1.370 in	$= 0.114 \text{ ft}$
Flow Restrictor	$= \pi (0.326) =$	1.024 in	$= 0.0853 \text{ ft}$

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3. Power Generation

The specific power generation in GEH-4-57, 58 was measured at 7.25 KW/lb of natural uranium.

$$Q = \frac{0.928 \text{ lb natural U}}{\text{in}} \times \frac{7.25 \text{ KW}}{\text{lb natural U}} \times \frac{12 \text{ in}}{\text{ft}} = 80.7 \text{ KW/ft}$$

4. Equivalent Diametersa. Outer Annulus

$$De = \frac{4A}{S} = \frac{4 (0.260)}{4.900 + 4.555} = 0.1099 \text{ inch}$$

b. Inner Annulus

$$De = \frac{4 (0.066)}{1.370 + 1.024} = 0.1102 \text{ inch}$$

5. Flow Split

$$\text{Inlet water flow} = 20 \text{ gpm}$$

$$V_1 = \left(\frac{De_1}{De_2} \right)^{-1.8} V_2$$

$$\text{Let } V_1 = 1$$

$$\text{Then } V_2 = \left(\frac{De_1}{De_2} \right)^{1.8} = \left(\frac{0.1099}{0.1102} \right)^{1.8} = (0.997)^{1.8} = 0.995$$

For all practical purposes, consider the velocities equal in both the inner and outer annuli.

The flow split will then be:

$$Q_T = Q_0 + Q_1 = V_0 A_0 + V_1 A_1$$

$$\text{But } V_0 = V_1$$

$$Q_T = V_0 (A_0 + A_1)$$

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$$\frac{20 \times 0.1337}{60} = V_o (0.00180 + 0.000458)$$

$$V_o = 19.7 \text{ ft/sec}$$

$$Q_o = (19.7) (0.00180) (448.8) = 15.9 \text{ gal/min}$$

$$Q_i = (19.7) (0.000458) (448.8) = 4.1 \text{ gal/min}$$

6. Film Coefficients

The Modified Colburn Equation was used to compute the film coefficients.

$$h = 0.023 \frac{K_f}{D_e} \left[\frac{D_e G}{\mu} \right]_f^{0.8} \left[\frac{C_p \mu}{K} \right]_f^{0.3}$$

where

h = film coefficient BTU/hr-ft²-°F

D_e = equivalent diameter - ft

G = mass velocity lb/hr-ft²

μ = dynamic viscosity lb/hr-ft

C_p = specific heat BTU/lb-°F

K = thermal conductivity BTU/hr-ft-°F

Outer Annulus

Assume a film temperature of 170 F.

$$D_e = 0.00916 \text{ ft}$$

$$\mu = 0.90 \text{ lb/hr-ft}$$

$$C_p = 1.00 \text{ BTU/lb-°F}$$

$$K = 0.388 \text{ BTU/hr-ft-°F}$$

$$G = \frac{15.9 \text{ Gal/Min} \times 8.122 \text{ lb/gal} \times 60 \text{ min/hr}}{0.00180 \text{ ft}^2} = 4,300,000 \text{ lb/hr-ft}^2$$

$$\begin{aligned}
 h &= \frac{0.023 \times 0.388}{0.00916} \left[\frac{0.00916 \times 4.3 \times 10^6}{0.9} \right]^{0.8} \left[\frac{1 \times 0.9}{0.388} \right]^{0.3} \\
 &= 0.974 \left[4.37 \times 10^4 \right]^{0.8} \left[2.32 \right]^{0.3} \\
 &= 0.974 \left[5.16 \times 10^3 \right] \left[1.287 \right] \\
 &= 6,450 \text{ BTU/hr-ft}^2\text{-}^\circ\text{F}
 \end{aligned}$$

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Inner Annulus

$$D_e = 0.00916 \text{ ft}$$

$$\mu = 0.90 \text{ lb/hr-ft}$$

$$C_p = 1.0 \text{ BTU/lb-}^\circ\text{F}$$

$$K = 0.388 \text{ BTU/hr-ft-}^\circ\text{F}$$

$$G = \frac{[4.1] [8.122] [60]}{[0.000458]} = 4,360,000 \text{ lb/hr-ft}^2$$

$$\begin{aligned}
 h &= \left[\frac{0.023 \times 0.388}{0.00916} \right] \left[\frac{9.16 \times 10^{-3} \times 4.36 \times 10^6}{0.90} \right]^{0.8} \left[\frac{1 \times 0.9}{0.388} \right]^{0.3} \\
 &= (0.974) (4.44 \times 10^4)^{0.8} (2.32)^{0.3} \\
 &= (0.974) (5.22 \times 10^3) (1.287) \\
 &= 6,500 \text{ BTU/hr-ft}^2\text{-}^\circ\text{F}
 \end{aligned}$$

$$\begin{aligned}
 r_{\max T} &= \sqrt{\frac{(.490 - (0.059))}{2 \ln 2.88}} = \sqrt{\frac{0.431}{2.116}} = \sqrt{0.2037} \\
 &= 0.451 \text{ inch}
 \end{aligned}$$

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Heat Flow

$$\begin{aligned} \text{Area to inner annulus } A_i &= \pi (r_{\max}^2 - r_i^2) \\ &= \pi (0.2037^2 - 0.059^2) = 0.455 \text{ in}^2 \end{aligned}$$

$$\begin{aligned} \text{Area to outer annulus } A_o &= \pi (r_o^2 - r_{\max}^2) \\ &= \pi (0.4900^2 - 0.2037^2) = 0.899 \text{ in}^2 \end{aligned}$$

Heat flow to outer surface

$$= \frac{0.899}{0.899 + 0.455} \times 100 = 66.4\%$$

Heat flow to inner surface

$$\frac{0.455}{1.354} \times 100 = 33.6\%$$

8. Heat Flux

Outer Annulus

$$80.7 \frac{\text{KW}}{\text{ft}} \times 3412 \frac{\text{BTU}}{\text{KW-hr}} \times 0.664 \times \frac{1}{0.380 \text{ ft}} = 482,000 \text{ BTU/hr-ft}^2$$

Inner Annulus

$$80.7 \frac{\text{KW}}{\text{ft}} \times 3412 \frac{\text{BTU}}{\text{KW-hr}} \times 0.336 \times \frac{1}{0.114 \text{ ft}} = 81,000 \text{ BTU/hr-ft}^2$$

9. Film Temperature Drop

Outer Annulus

$$\frac{482,000}{6,450} = 74.7 \text{ F } (41.5 \text{ C})$$

Inner Annulus

$$\frac{81,000}{6,500} = 12.5 \text{ F } (6.9 \text{ C})$$

10. Cladding Temperature Drop

$$\Delta t_o = \frac{543.5 Q}{K} \ln \frac{r_2}{r_1}$$

(Fuel Element Design Handbook,
Page A-100-6)

where

Q = specific power KW/ft

r₂ = outer radius

r₁ = inner radius

K = thermal conductivity-Zircaloy @ 212 F = 8.12 BTU/hr-ft-°F

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Outer Annulus

$$Q = 80.7 \times .664 = 53.6 \text{ KW/ft}$$

$$r_2 = 0.725 \text{ inch}$$

$$r_1 = 0.700 \text{ inch}$$

$$\begin{aligned} \Delta t_o &= \frac{(543.5)(53.6)}{8.12} \ln \frac{0.725}{0.700} = (66.9)(53.6)(0.036) \\ &= 129 \text{ F } (71.7 \text{ C}) \end{aligned}$$

Inner Annulus

$$Q = 80.7 \times 33.6 = 27.1 \text{ KW/ft}$$

$$r_2 = 0.243$$

$$r_1 = 0.218$$

$$\begin{aligned} \Delta t_o &= (66.9)(27.1) \ln \frac{.243}{.218} = (1813)(0.109) \\ &= 197.6 \text{ F } (109.8 \text{ C}) \end{aligned}$$

11. Coextruded Bond Temperature Drop

Δt assumed to be zero

12. Uranium Temperature Drop

The temperature drop is calculated from the adiabatic radius to the outside of the tubular core. (Reference: ANL-4690, Page 9, Case III)

$$\Delta t (r_o - r_{\max} T) = \frac{q}{2K} \left(\frac{r_o^2 - r_{\max}^2}{2} - r_{\max}^2 \ln \frac{r_o}{r_{\max} T} \right)$$

where

$$q = \frac{Q/\text{ft}}{\text{Vol}/\text{ft}} = \frac{(80.7) (3412) (4)}{12 (1.400^2 - 0.486^2) (\pi)} = 16,950 \text{ BTU/hr-in}^3$$

$$K = \text{uranium thermal conductivity} = \frac{1196 + t (^{\circ}\text{C})}{83.4}$$

$$= \frac{1196 + 200}{83.4} = 16.8 \text{ BTU/hr-}^{\circ}\text{F-ft} = 1.4 \text{ BTU/hr-}^{\circ}\text{F-in}$$

$$\Delta t = \frac{16,950}{(2) (1.4)} \left[\frac{(0.700^2 - 0.451^2)}{2} - 0.451^2 \ln \frac{0.700}{0.451} \right]$$

$$= 6,054 (0.143 - 0.090)$$

$$= 320.8 \text{ F } (178.2 \text{ C})$$

13. Temperature Summary

	<u>Outer Annulus</u>	<u>Inner Annulus</u>
Inlet Water	100 F (38 C)	100 F (38 C)
Clad Surface	175 F (80 C)	112 F (45 C)
Uranium Surface	304 F (152 C)	310 F (155 C)
Uranium Core (Max)	625 F (330 C)	631 F (333 C)

14. Pressure Balance

Pressure drop estimates were determined by the "velocity head" method, with reference made to the Reactor Handbook, Engineering Volume.

a. Annular Velocities:

$$V_o = 19.7 \text{ ft/sec}$$

$$V_i = 19.7 \text{ ft/sec}$$

b. Velocity Head = $\frac{v^2}{2g}$

Outer Annulus:

$$\frac{(19.7)^2}{2 (32.2)} \times \frac{62}{744} = 2.595 \text{ psi}$$

Inner Annulus:

= 2.595 psi

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c. Reynolds Number

$$N_R = \frac{DeV\rho}{\mu}$$

N_R = Reynolds Number

De = Equivalent Diameter (ft)

V = Velocity (ft/sec)

μ = Viscosity of Water at 100 F
= 4.58×10^{-4} lb/sec-ft

ρ = Density of Water at 100 F
= 62 lb/ft³

Outer Annulus:

$$N_R = \frac{(0.1099) (19.7) (62.0)}{(12) (4.58 \times 10^{-4})}$$

$$= 2.44 \times 10^4$$

Inner Annulus:

$N_R = 2.46 \times 10^4$

d. Friction Factor

Read from Reactor Handbook, Engineering Volume, Figure 1.5.2

Outer Annulus:

$f_o = 0.025$

Inner Annulus:

$f_i = 0.025$

e. Friction Loss

$$\Delta P = \frac{(f) (L) (V_h)}{D_e}$$

f = friction factor
 L = fuel column length (inches)
 D_e = equivalent diameter
 ΔP = pressure drop (psi)

Outer Annulus:

$$\Delta P = \frac{(0.025) (22.5) (2.595)}{0.1099} = 13.282 \text{ psi}$$

Inner Annulus:

$$\Delta P = \frac{(0.025) (22.5) (2.595)}{0.1102} = 13.246 \text{ psi}$$

f. Contraction and Expansion Loss

$$\Delta P = K (V_h)$$

Coefficient "K" read from Reactor Handbook,
Engineering Volume, Figures 1.5.6 and 1.5.7

Outer Annulus:

$$A_o = \text{Annulus Area} = 0.260 \text{ in}^2$$

$$A_b = \text{Basket Area} = 1.911 \text{ in}^2$$

$$\frac{A_o}{A_b} = \frac{0.260}{1.911} = 0.136$$

$$K_c = 0.39$$

$$\begin{aligned} \Delta P &= (0.39) (2.595) \\ &= 1.012 \text{ psi contraction loss} \end{aligned}$$

$$K_e = 0.74$$

$$\begin{aligned} \Delta P &= (0.74) (2.595) \\ &= 1.920 \text{ psi expansion loss} \end{aligned}$$

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Inner Annulus:

$$A_1 = \text{Inner Annulus} = 0.066 \text{ in}^2$$

$$A_b = \text{Basket Area} = 1.911 \text{ in}^2$$

$$\frac{A_1}{A_b} = \frac{0.066}{1.911} = 0.035$$

$$K_c = 0.40$$

$$\Delta P = (0.40) (2.595)$$

$$= 1.038 \text{ psi contraction loss}$$

$$K_e = 0.95$$

$$\Delta P = (0.95) (2.595)$$

$$= 2.465 \text{ psi expansion loss}$$

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Total Pressure Drop

<u>Loss</u>	<u>Outer Annulus</u>	<u>Inner Annulus</u>
Friction	13.282	13.246
Contraction	1.012	1.038
Expansion	<u>1.920</u>	<u>2.465</u>
Total -	16.214 psi	16.749 psi

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FIGURE 1

Cross Sectional View of Fuel Elements for MTR Irradiation
GEH-4-68, 69, 70

FIGURE 2
Basket Arrangement for GEH-4-68, 69, & 70

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