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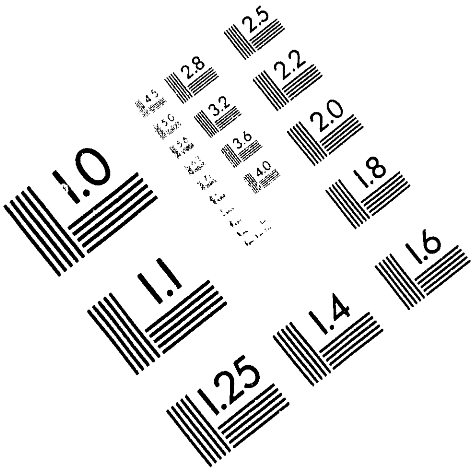

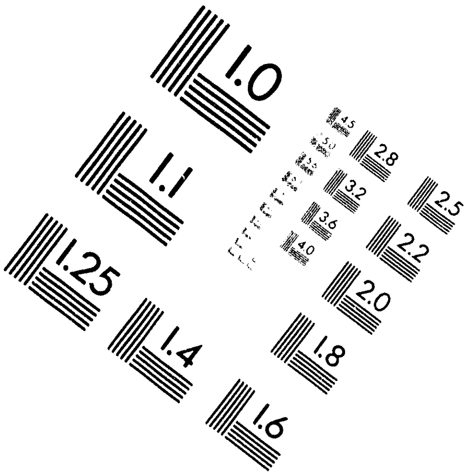

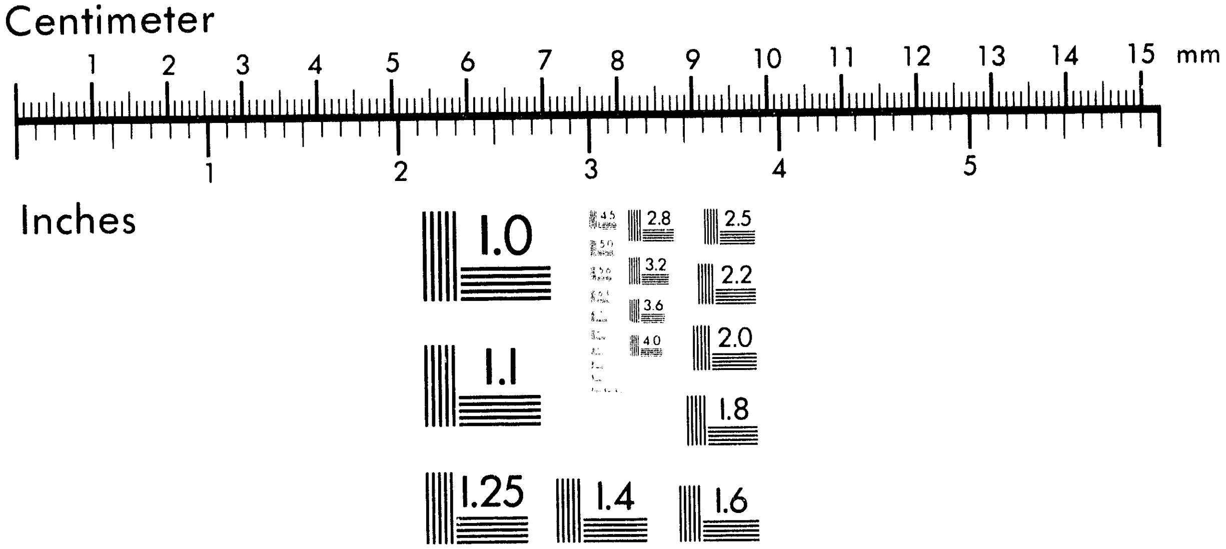

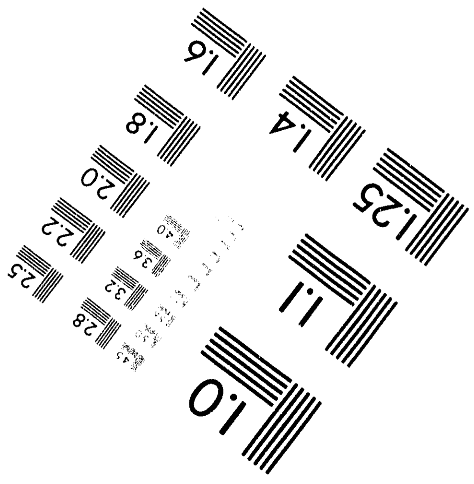

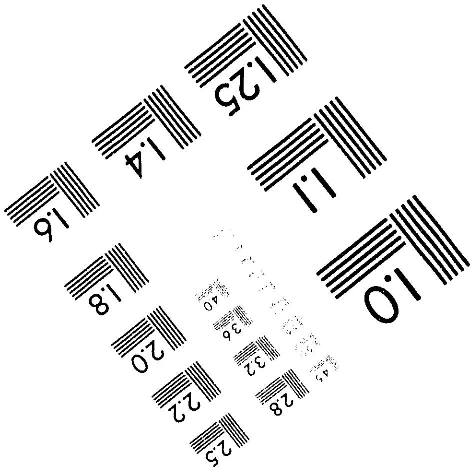

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TITLE
GEH-4-32, BONDED SEGMENTED FUEL ELEMENT IRRADIATION

(Letter to Ralph Fearnow.)

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GEH-4-32, BONDED SEGMENTED FUEL ELEMENT IRRADIATION
(Letter to R. E. Fearnow by R. Neidner.)

R. Neidner

September 16, 1958

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HW-57387
9/16/58

Mr. R. E. Fearnow
Project Engineering
Materials Testing Reactor
Phillips Petroleum Company
Idaho Falls, Idaho

Dear Ralph:

GEH-4-32, Bonded Segmented Fuel Element Irradiation

We have prepared what we call a bonded segmented fuel element. This fuel element has characteristics which make it an attractive prospect for high specific power operation at relatively low uranium temperatures. The fuel slug is made up of six longitudinal segments; each segment being bonded to the aluminum webbing and tubing which encases it. You will note from the figure of Appendix III that the can, or jacket, is the same type as that used in fabricating the "garbage can" fuel element, irradiated as GEH-4-I(HW-48747).

We are interested in the operating characteristics of this new fuel element. We want to learn the relation of power output to environmental flux; this will be done with special thermocouples to monitor the power output and attached flux wires. Further, by post irradiation analysis, we will be able to study bond stability, segment warpage, and possibly maximum uranium temperatures from changes in the grain structure.

The pertinent information for this irradiation is summarized below while the details are appended in the following order:

Appendix I	Fabrication Details & Hazards
Appendix II	Thermal Aspects and Calculations
Appendix III	Figures

Summary of Proposed Conditions

Maximum Fuel Temperature, °F		537
Maximum Surface Temperature, °F		200
Weight of Natural-U, gm/inch		295
Total Weight of Natural-U, gm		2360
Maximum Power Generation, KW/in		5.2
Maximum Heat Flux, BTU/hr-ft^2		388,000
Water Flow Rate, gpm		17
Water Velocity, ft/sec.	Outer Annulus	14.1
	Inner Annulus	14.6
Film Coefficient, BTU/hr-ft^2 °F		4270
Outside Dimensions, Inches		1.535 O.D. x 0.563 I.D. x 8-3/4 lg
Cycles of Exposure		1

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General

Please arrange for the necessary approvals as soon as practical. The fuel element will be assembled in a standard, but expanded to 1.650" I.D., GEH-4 basket at Hanford along with two chromel-alumel thermocouples. The assembled basket will be shipped to the MTR early in September. Before insertion in the reactor, a 0.1% Co-Al flux wire should be attached to the outside of the basket adjacent to the fuel element. No maintenance time will be required prior to insertion. In addition to inserting the test assembly, please arrange to have two flux monitoring wires placed in the appropriate holes of the new B-3 block. We will supply the flux wires in the holders for operations to insert.

If you need any further information Ralph, please let me know and I will be glad to obtain it for you.

Very truly yours,

Robert Neidner

R. Neidner
HAPO Sponsor Representative
General Electric Company

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APPENDIX I

A. Fabrication Details

The fuel element is composed of six pie shaped natural uranium rods, each eight inches long. Each rod, or segment, weighs 394 grams, giving a total uranium weight to the entire fuel element of 2360 grams (5.2#). Each uranium segment was coated with one mil of nickel over its entire surface. The plated segments were then pressed into the compartments of a special aluminum can. The special can resembles two concentric tubes united by six full length fins. The end cap was then welded in place. The fuel segments and cladding were then bonded by placing in an autoclave for eight hours at conditions of 550°C and 1500 psi. Destructive tests of identical fuel elements have shown complete bonding on all surfaces of each uranium segment.

The outside diameter of the bonded element is 1.535", being a little larger than our standard slugs. To accommodate the hydraulic and heat transfer requirements, it was necessary to expand a standard GEH-4 basket to an I.D. of 1.650"/ Also for the same reason, a flow restrictor was positioned in the center of the fuel element hole, thereby forming an annulus, hydraulically compatible to the slug-basket annulus.

Assembling of the basket for shipment was done the same as with our previous tests in which basket thermocouples have been used. Two basket thermocouples were installed with this test, one for measuring the inlet water temperature just above the fuel, the other the exit water temperature at the bottom of the basket. Chromel-Alumel, 30 gauge, couples, swaged in 0.062" diameter stainless steel tubing with zirconium oxide as an insulator were the type used. The thermocouple leads are about 27 feet long, the excess length above the top of the basket being coiled up for shipment. As before, it will be necessary to splice a 12 foot length of 1/4" stainless tube over the two couples prior to reactor insertion for protection and a means of penetrating the access flange at the top of the reactor tank.

The fuel element is supported by a 5-3/4" spacer. This arrangement will place the center of the fuel about 1-1/2" below the midplane of the reactor.

B. Hazards

Because of the low uranium temperatures and the compartmental technique of fabrication, fission products release in case of a rupture would be extremely small, probably only enough to trip the GEH-4 fission break monitor. Further, because of the severe autoclaving involved in the bonding process, the cladding is assured to be complete and sound; thus the possibility of a fission break is very remote.

[redacted]

[redacted]

APPENDIX II

A. Thermal Aspects

The basis of the fuel element is to maintain relatively low uranium temperatures at high specific power generations. The power generation predicted for this fuel element was based on actual data from our GEH-4 irradiations. GEH-4-31, which was also a natural uranium irradiation, generated a maximum power of 85 KW/ft. Since 10.7#/ft of uranium were involved, the maximum specific power was about 8 KW/# of natural-U. Therefore the expected power generation for this test is predicted to be about 8 KW/# x 7.8 #/ft = 62.5 KW/ft of fuel. The maximum temperature calculated for each uranium segment is 537°F and that of the cladding surface to be about 200°F. Agreeably the method of calculation is approximate, as shown below, but nevertheless should be reasonable for this particular configuration. Both of these pertinent temperatures are far below anything critical (water saturation temperature is 409°F @ 250 psig, uranium melting temperature is about 2240°F). Therefore refinement of the calculations was not warranted.

B. Sample Calculations

Following is a summary of the calculations which were made. The final balanced conditions are presented, although several trial and error solutions were previously tried:

Cross-Sectional Flow Areas

$$\text{Basket} = \pi/4\ (1.650)^2 = 2.14\ \text{in}^2$$

$$= 0.01485\ \text{ft}^2$$

$$\text{Outer Annulus} = \pi/4\ (1.650)^2 - (1.535)^2 = 0.282\ \text{in}^2$$

$$= 0.00196\ \text{ft}^2$$

$$\text{Inner Annulus} = \pi/4 \left[(0.573)^2 - (0.426)^2\right] = 0.102\ \text{in}^2$$

$.259\ \text{in}^2$

$$= 0.00071\ \text{ft}^2$$

Peripheries

Basket = $\pi(1.650)$ = 5.18 in
0.431 ft

Outer Diameter = $\pi(1.535)$ = 4.82 in
0.401 ft.

Inner Diameter = $\pi(0.563)$ = 1.77 in
0.147 ft.

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Power Generation

Specific power generation taken from GEH-4-31 was measured to be 8 KW/# of natural U.

$$Q = 5.2\ \# \frac{\text{nat. U}}{8\ \text{in.}} \times 8 \frac{\text{KW}}{\#} \times 12\ \text{in/ft}$$

$$Q = 62.5\ \text{KW/ft}$$

$$= 213{,}000\ \text{Btu/hr-ft.}$$

Heat Flux (Assumed essentially equal for all surfaces)

$$H = \frac{213{,}000}{(0.401 + 0.147) \times 1} = 388{,}000\ \text{Btu/hr-ft}^2$$

Film Coefficient - (Assumed film drop to be 65°(117°F)

$$h_f = \frac{H}{\Delta t} = \frac{388{,}000}{\Delta 117°} = 3320\ \text{Btu/hr °F-ft}^2$$

Flow ~~Rate Re~~quired to Maintain Assumed Film Drop

Outer Annulus

$$De = 4\frac{A}{S} = \frac{4(0.282)}{5.18 + 4.82} = 0.113\ \text{in}$$

$$h_f = 150\left[1 + 0.011\ (t_b)\right] \frac{Vo^{0.8}}{De^{0.2}}$$ (P. 228 McAdams 3rd Edition)

$$Vo^{0.8} = \frac{3320\ (0.113)^{0.2}}{150\ (1 + 0.011 \times 108°)} = \frac{3320(0.647)}{328}$$

$$Vo^{0.8} = 6.35$$

$$vo = 10.1\ \text{ft/sec}$$ [illegible]

$$\text{Flow } Q_o = VA \left(60 \frac{\text{sec}}{\text{min}} \times 62\ \#/\text{ft}^{\cancel{2}\,3} \times \frac{\text{gal}}{8.33\#}\right)$$

$$Q_o = 10.1\ (0.00196)(448)$$

$$Q_o = 8.86\ \text{gpm}$$

Inner Annulus

$$De = \frac{4(0.102)}{(1.77 + 0.426)} = 0.131\ \text{in.}$$

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$$V_i^{0.8} = \frac{3320(0.131)^{0.2}}{328}$$

$$V_i^{0.8} = 6.55$$

$$V_i = 10.5 \text{ ft/sec}$$

$$\text{Flow } Q_i = 10.5\ (0.0071 \text{ ft}^2)\ 448$$

$$Q_i = 3.34 \text{ gpm}$$

The pressure balance of each channel follows. The "Velocity Head" method of determining pressure drops was used. Reference was made to the Reactor Handbook - Engineering Volume.

Velocities

Outer Annulus = 10.1 ft/sec.

Inner Annulus = 10.5 ft/sec.

Velocity Head $\frac{V^2}{2\ g}$

Outer Annulus = $\frac{(10.1)^2}{64.4} \frac{(62)}{(144)} = 0.685$ psi

Inner Annulus = $\frac{(10.5)^2}{64.4} \frac{(62)}{(144)} = 0.740$ psi

Reynolds Number $\frac{DV}{\mu}$

μ for water at 108°F = 4.22×10^{-4}#/ft-sec.

Outer Annulus = $\left(\frac{0.113}{12}\right) \frac{(10.1)\quad(62)}{4.22 \quad x\ 10^{-4}}$

= 1.4×10^4

Inner Annulus = $\frac{0.131}{12} \quad \frac{10.5\quad 62}{4.22 \times 10^{-4}}$

= 1.68×10^4

Friction Factor, f

Outer Annulus	0.028
Inner Annulus	0.027

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Friction Loss, $\Delta P = \frac{f\,L}{De}$ (Vel. Head)

$$\text{Outer Annulus} = \frac{0.028\ (9)}{0.113}\ (0.685)$$

$$= 1.53 \text{ psi}$$

$$\text{Inner Annulus} = \frac{0.027\ (9)}{0.131}\ (0.740)$$

$$= 1.38 \text{ psi}$$

Contraction and Expansion Loss, $\Delta P = K$ (Vel. Head)

Outer Annulus

Contraction at end $\frac{A_o}{A_b} = \frac{0.282}{2.14} = 0.13$

$K_c = 0.394$

$\Delta P = (0.398)(0.685) = 0.272$ psi

Expansion from end

$K_e = 0.75$

$\Delta P = 0.75\ (0.685) = 0.514$ psi

Inner Annulus

Contraction at end $\frac{A_i}{A_b} = \frac{0.102}{2.14} = 0.048$

$K_c = 0.398$

$\Delta P = 0.398\ (0.740) = 0.294$ psi

Expansion from end

$K_e = 0.90$

$\Delta P = 0.90\ (0.740) = 0.294$ psi

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Total Pressure Drop, ΔP

Loss	Outer Annulus		Inner Annulus
Contraction	0.272		0.294
Expansion	0.514		0.666
Friction	1.530		1.380
Total	2.316 psi	$\simeq$	2.340 psi

Temperature Drop Through Cladding

$$\Delta t_; = \frac{H(\text{Btu/hr-ft}^2)}{K\ \text{Btu/hr-ft-}^\circ\text{C}} \times \text{thickness(ft)}$$

$$\Delta t_; = \frac{388{,}000}{216} \quad \frac{(0.0625)}{12}$$

$$= 9.4^\circ\text{C} \quad (17^\circ\text{F})$$

Temperature Drop Across Bonded Interface

$$H_c = 40{,}000\ \text{Btu/hr-ft}^2\text{-}^\circ\text{F}$$

$$\Delta t_; = \frac{H}{h_c} = \frac{388{,}000}{40{,}000(1.8)} = 5.4^\circ\text{C}\ (9.7^\circ\text{F})$$

Surface Temperature of U-Segments

$$t_s = \text{Water} + \Delta t_f + \Delta t_; + \Delta t_i$$

$$t_s = 108^\circ + 117^\circ + 17^\circ + 10^\circ$$

$$t_s = 252^\circ\text{F}\ (122^\circ\text{C})$$

Temperature Drop Through U-Segment

Assume heat to flow effectively out of a small natural-U, 0.45" dia. rod for each of the six segmented sections.

Power per section

$$q = \frac{Q}{6} = \frac{62.5}{6}\ \text{KW/ft} = 10.4\ \text{KW/ft}$$

$$K_u = \frac{1196 + t(^\circ\text{C})}{83.4} = \frac{1196 + (275^\circ\text{C})}{83.4}$$

$$K_u = 17.7\ \text{Btu/hr ft}^\circ\text{F}$$

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$$\Delta t = \frac{q}{4\pi K} = \frac{10.4\ (3412)}{4\ K\ (17.7)}$$

$$\Delta t = 160°F\ (89°C)$$

Temperature Distribution Summary

Water	108°F
Clad Surface	225°F
Clad Inside	242°F
Uranium Surface	252°F
Uranium Maximum	504°F

The flow rate required to maintain the satisfactory film drop of 117°F only totals about 12 gpm. However, since the standard flow rate for the GEH-4 irradiations is 17 gpm, it is recommended that this higher flow rate be used so as not to cause operational confusion. By using 17 gpm, the film drop will be reduced by approximately the following:

$$\left(\frac{12.2}{17}\right)^{0.8}; \text{ or } \Delta t_{actual} = 117°\ (.77) = 91°F$$

Therefore the actual surface temperature will be approximately 200°F instead of 225°F. Other internal temperatures, of course, will also be reduced by about the same amount.

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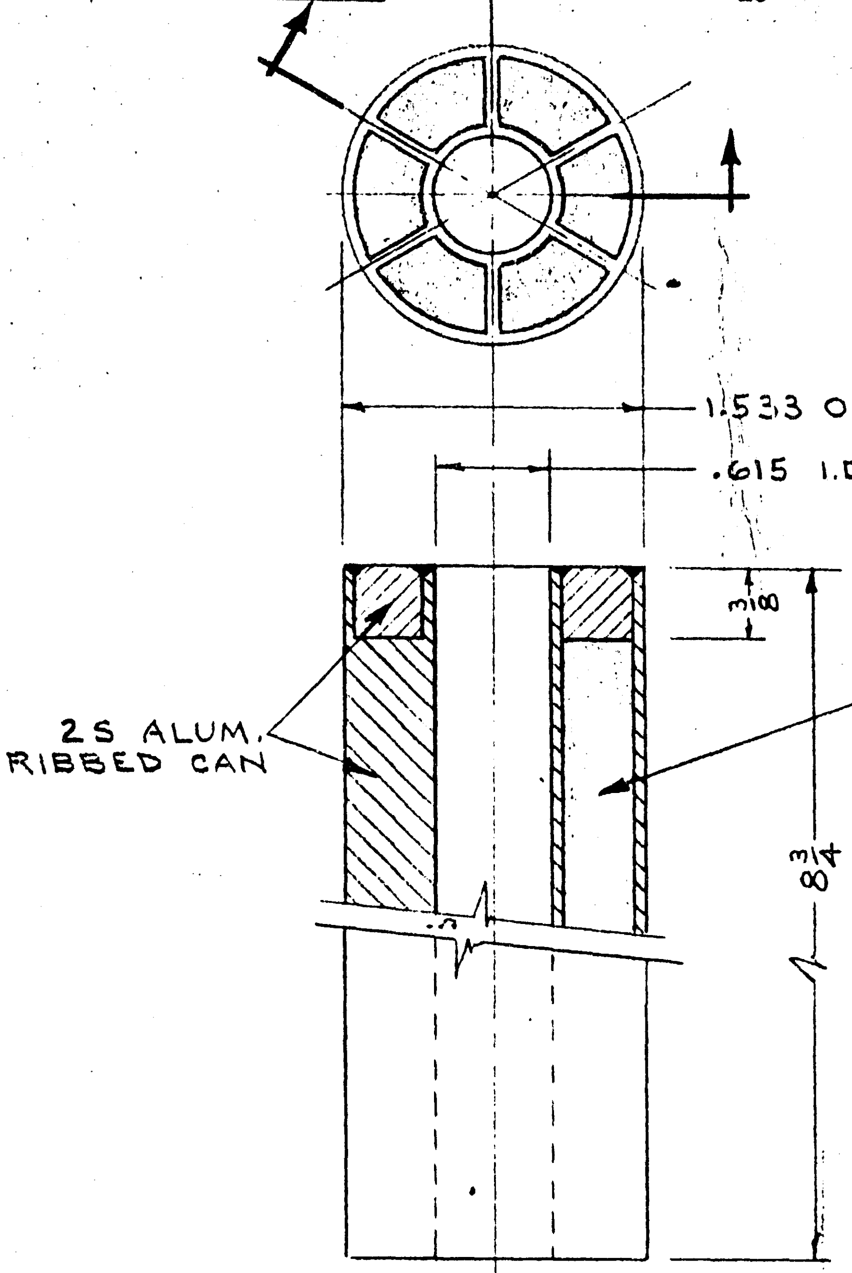

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