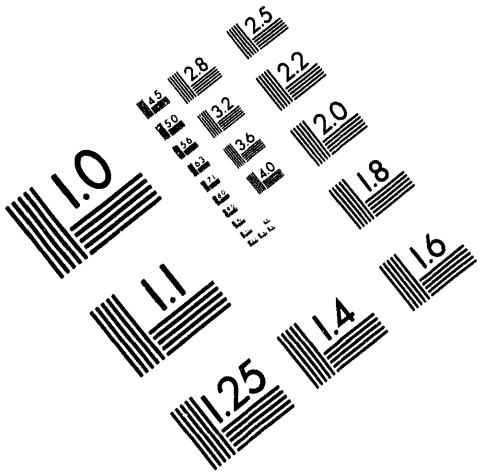

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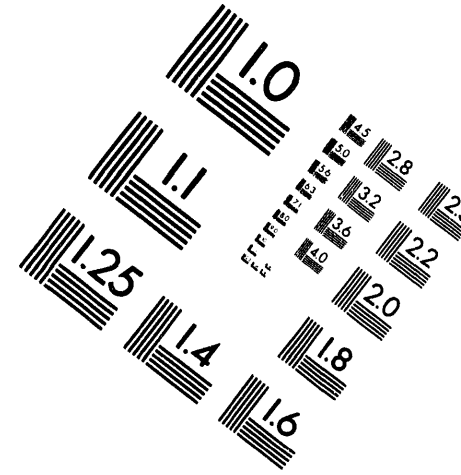

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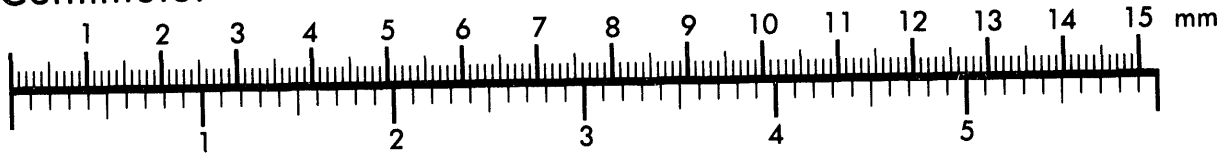

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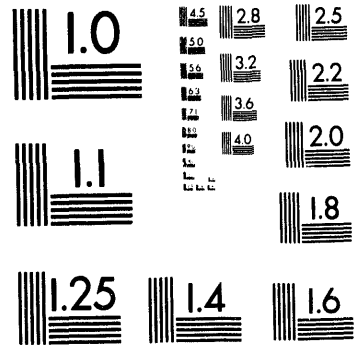

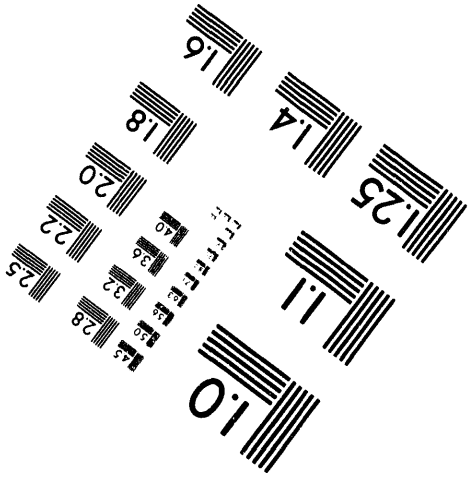

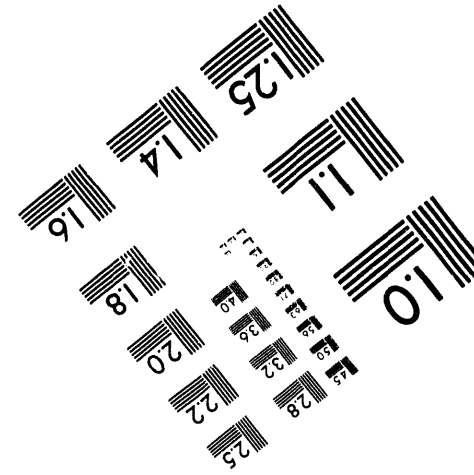

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HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

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GEH-4-42, 47; Hot Pressed, I and E Cooled Fuel Element Irradiation

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GEH-4-42,47; HOT PRESSED, I AND E COOLED FUEL ELEMENT IRRADIATION

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By

Robert Neidner

Fuel Element Design
REACTOR AND FUELS RESEARCH
AND DEVELOPMENT OPERATION

November 2, 1959

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HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

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GENERAL ELECTRIC COMPANY
HANFORD ATOMIC PRODUCTS OPERATIONS
IDAHO FALLS, IDAHO

November 2, 1959

Mr. L. L. Porter
Phillips Petroleum Company
Project Engineering
Idaho Falls, Idaho

Dear Roy:

GEH-4-42, 47; HOT PRESSED, I AND E COOLED FUEL ELEMENT IRRADIATION

In our continual effort to improve the present fuel elments which are irradiated in the numerous Hanford reactors, we have made what we believe to be a significant improvement in the hot pressing process for jacketing uranium fuel slugs. We are proposing a large scale evaluation testing program in the Hanford reactors but need the vital and basic information on the operating characteristics of this type slug under known and controlled operating conditions. We, therefore, have prepared two typical fuel slugs and will want them irradiated to about 1000 MWD/T exposure (this will require about four to five total cycles).

The pertinent information concerning this proposal is summarized below. Details of the same are appended as follows:

Appendix I	Sample description and general details
Appendix II	Thermal aspects
Appendix III	Figures

Summary of Conditions

Maximum fuel temperatures, °F	654
Maximum surface temperature, °F	176
Maximum heat flux, BTU/hr-ft^2	648,000
Water flow rate, gpm	20
Water velocity, ft/sec	31.8
Film coefficient, BTU/hr-°F-ft^2	8,500
Maximum power generation KW/ft	92
Weight of natural-U, gm/in	435.5
Total gms/element	3,656
Fuel element dimensions, in	1.48 OD x 0.370 ID x 9.11 l
Flow restrictor dia, in	0.300
Number of fuel elements	2
Anticipated number of cycles	4 to 5

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Mr. L. L. Porter

November 2, 1959

General

Please arrange for the necessary approvals so that a Cycle 131 loading could be made if desirable. Two Chr-Al TC's will be installed immediately upstream and downstream of the fuel charge to measure the average power generation. No maintenance time will be required prior to insertion but we would like to have a pot reading made on the two TC's at the external posts of the TC head as soon as possible after the reactor has reached full power conditions. Before insertion in the reactor, a 0.1 per cent Co-Al flux wire should be attached to the outside of the basket adjacent to the fuel elements. Please arrange to have periscope pictures taken as soon as practical following discharging of the test to the canal.

If you need any further information Roy, please let me know and I'll be glad to obtain them for you. The test samples will be here prior to November 11, I'll try and let you know the exact time later.

Very truly yours,

Robert Neidner / J.C.T.

Robert Neidner
HAPO Sponsor Representative
General Electric Company

RN:lmh

[redacted]

APPENDIX I

A. DESCRIPTION OF FUEL ELEMENTS

Two identical fuel elements make up the irradiation. The tubular, natural uranium core was clad in a 1245 aluminum jacket. This jacket was bonded by an interface of nickel diffusion layer. The ends of the fuel elements have been machined with the "True-Line" feature which is used at Hanford to maintain the axial alignment of fuel trains in the reactor process tubes, see Figure I. Each element is 9.11 inches long and has an OD and ID of 1.480 inch and 0.370 inch, respectively. For heat transfer purposes, a flow restrictor has been fitted into the central flow channel. This restrictor is 0.300 inch diameter and extends through both fuel elements. A 1-1/2 inch perforated spacer supports the two elements. The entire assembly is contained in a standard GEH-4 basket.

B. FABRICATION

Each tubular core was beta heat treated to assure a random orientation and small grain size. Each core was vacuum outgassed at 600 C to remove residual hydrogen. The processing or canning cycle began by electroplating an 0.8 mil nickel sweater coat on each core in a modified Thompson bath. Each core was inspected and then placed in a carefully cleaned can. For each element, a cap-tube was inserted into the ID of the core, then both the OD and ID were sized to the uranium core. Punches and the ID pin were added to the assembly and the entire units placed in a die and preheated to 600 C. The dies were then placed in the hot-press die blocks and held three minutes at 600 C prior to application of pressure. A pressure of 12 tons per square inch (tsi) was then applied for five minutes; the dies and enclosed fuel elements were then water quenched. The fuel elements were then cleaned in 50 per cent nitric acid and the ends machined with the "True-Line" feature.

The fuels elements were then thoroughly inspected, which included: A thermoinductive heat transfer test to assure completely bonded surfaces; fluoroscopic investigation to determine end cap thickness; a visual check for marred surfaces or surface inclusions; and a final step consisting of a 40 hour autoclave run in 180 C, 180 psi steam. The elements were then given a final etch and were then precisely measured by our pre-irradiation measurement group at HAPO.

C. HAZARDS

Because of the low water and uranium temperatures associated with this irradiation, fission product release in the case of an unexpected rupture would be extremely small. This conclusion has been established by GEH-4-25, an intentional high temperature metallic fuel failure, and GEH-4-32, an unintentional low temperature metallic fuel failure. Our contamination catch facility has proven very adequate for all failures incurred to date.

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APPENDIX II

A. THERMAL ASPECTS

The specific power generation for calculating purposes was taken from data obtained from the nuclearly similar test, GEH-4-31. The power measured from 4-31 was approximately 8 KW/# of natural uranium. Since these elements contain 0.96 # Natural-U/inch, a power generation of about 92 KW/ft is expected. The maximum heat flux will be about 650,000 BTU/hr-ft^2.

B. SAMPLE CALCULATIONS

Basic Conditions:

Fuel Element:

Uranium Core:

Length	8.400 inches
O.D.	1.410 inches
I.D.	0.436 inches

Cladding:

Length	9.110 inches
O.D.	1.480 inches
I.D.	1.412 inches

Heat generation - 92 KW/ft

Flow - 20 gpm

Bulk water exit temperature - 100 °F

I. Flow Areas:

$$\text{Basket} = \frac{\pi}{4}(1.550)^2 = 1.886 \text{ in}^2 = 0.0131 \text{ ft}^2$$

$$\text{Outer Annulus} = \frac{\pi}{4}(1.550)^2 - (1.480)^2 = 0.166 \text{ in}^2 = 0.00115 \text{ ft}^2$$

$$\text{Inner Annulus} = \frac{\pi}{4}(0.370)^2 - (0.300)^2 = 0.0368 \text{ in}^2 = 0.000256 \text{ ft}^2$$

II. Peripheries:

$$\text{Basket} = \pi(1.550) = 4.87 \text{ in} = 0.406 \text{ ft}$$

$$\text{Fuel OD} = \pi(1.480) = 4.65 \text{ in} = 0.388 \text{ ft}$$

[redacted]

Appendix II Cont'd.

Fuel ID = $\pi(0.370)$ = 1.16 in
0.097 ft

Flow Restrictor = $\pi(0.300)$ = 0.94 in
0.078 ft

III. Power Generation:

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

$$Q = \frac{8.06 \text{ \#Nat-U/element}}{8.4 \text{ in/element}} \times 8 \frac{\text{KW}}{\text{\#Nat-U}} \times 12 \frac{\text{in}}{\text{ft}} = 92 \text{ KW/ft}$$

IV. Heat Flux: (Assumed to be essentially equal for all surfaces.)

$$H = \frac{92 \times 3412}{(0.388 + 0.097) \times 1} = 648{,}000 \text{ BTU/hr-ft}^2$$

V. Required Film Coefficient: (Ave. film Δt_f assumed to be 117°F (65°C))

$$h_f = \frac{H}{\Delta t} = \frac{648{,}000}{1170} = 5530 \text{ BTU/hr-°F-ft}^2$$

VI. Flow Rate Required to Maintain Assumed Δt_f:

Outer Annulus

1. Equiv. Dia:

$$De = \frac{4A}{S} = \frac{4(0.166)}{4.87 + 4.65} = 0.070 \text{ in}$$

2. Required Velocity:

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

$$Vo^{0.8} = \frac{h_f De^{0.2}}{150 \left[1 + 0.011 (t_b)\right]} = \frac{5540 (0.070)^{0.2}}{150 \left[1 + 0.011 (100)\right]}$$

$$Vo^{0.8} = \frac{(5540)(0.588)}{315} = 10.3$$

$$Vo = 18.5 \text{ ft/sec}$$

Appendix II Cont'd.

3. Flow:

$$Q = VA$$

$$Q = 18.5 \text{ ft/sec } (60 \text{ sec/min} \times 62\#/\text{ft}^3 \times \frac{\text{gal}}{8.33\#}) \; 0.00115 \text{ ft}^2$$

$$Q = (18.5)\,(0.00115)\,(446) = 9.5 \text{ gal/min}$$

Inner Annulus

1. Equiv. Dia:

$$De = \frac{4\,(0.0368)}{1.16 + 0.94} = 0.070 \text{ in}$$

2. Required Velocity:

$$Vi^{0.8} = \frac{5540\,(0.070)^{0.2}}{150\left[1 + 0.011\,(100)\right]}$$

$$Vi^{0.8} = 10.3$$

$$Vi = 18.5 \text{ ft/sec}$$

3. Flow:

$$Q = VA\,(446)$$

$$= 18.5 \times 0.000256 \times 446$$

$$= 2.11 \text{ gal/min}$$

VII. Pressure Balance

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

1. Annulus Velocities:

Outer = 18.5 ft/sec

Inner = 18.5 ft/sec

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

$$\text{Outer Annulus} = \frac{(18.5)^2}{2\,(32.2)} \times \frac{62}{144} = 2.29 \text{ psi}$$

Inner Annulus = 2.29 psi

Appendix II Cont'd.

3. Reynolds Number: $\frac{DVP}{\mu}$

Outer Annulus $= \frac{0.070}{12} \times \frac{(18.5 \times 3600)}{1.66} \times 62 = 14{,}500$

Inner Annulus = 14,500

4. Friction Factor, f

Outer Annulus = 0.028

Inner Annulus = 0.028

5. Friction loss, $\Delta P = \frac{fL}{De}$ (Vel Head)

Outer Annulus $= \frac{0.028 \times 18.2}{0.070} (2.29) = 16.6$ psi

Inner Annulus = 16.6 psi

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

Outer Annulus:

Contraction at end, $\frac{A_o}{A_b} = \frac{0.166}{1.886} = 0.088$

Kc = 0.39

$\Delta P = (0.39)(2.29) = 0.88$ psi

Expansion from end,

Ke = 0.82

$\Delta P = (0.82)(2.29) = 1.88$ psi

Inner Annulus:

Contraction at end, $\frac{A_i}{A_b} = \frac{0.0368}{1.886} = 0.0195$

$K_e = 0.40$

$\Delta P = (0.40)(2.29) = 0.91$ psi

Expansion from end,

Ke = 0.98

$\Delta P = (0.98)(2.29) = 2.24$ psi

[redacted]

Appendix II Cont'd.

Total Pressure Drop

Loss	Outer Ann.	Inner Ann.
Contraction	0.88	0.91
Expansion	1.88	2.24
Friction	16.60	16.60
Total	19.36 psi	19.75 psi

VIII. Temperature Drop Through Cladding

Outer Annulus

$$\Delta t_j = \frac{H \times \text{thickness (ft)}}{K} \quad (K_{al} = 118 \text{ BTU/hr-°F-ft})$$

$$\Delta t_j = \frac{648{,}000}{118} \times \frac{0.035}{12} = 16°F$$

Inner Annulus

$$\Delta t_j = \frac{648{,}000}{118} \times \frac{0.033}{12} = 15°F$$

IX. Temperature Drop Through Nickel Bond Interface

h_i for nickel = 40,000 BTU/hr-ft^2-°F

$$\Delta t_i = \frac{H}{h_i}$$

$$\Delta t_i = \frac{648{,}000}{40{,}000} \times \frac{1.480}{1.410} = 17°F$$

X. Approximate Uranium Surface Temperature

$$t_s = T_{Bulk} + \Delta t_f + \Delta t_j + \Delta t_i$$

$$t_s = 100° + 117° + 16° + 17° = 250°F$$

XI. Temperature Drop Through Uranium

1. Adiabatic Radius: (Forming an imaginary boundry through which no heat will flow.)

$$r_{maxT} = \sqrt{\frac{r_o^2 - r_i^2}{2 \ln \frac{r_o}{r_i}}}$$

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Appendix II Cont'd.

Where:

r_o = Radius to outside of U-tube = 0.705"

r_i = Radius to inside of U-tube = 0.218"

$$r_{maxT} = \sqrt{\frac{(0.705)^2 - (0.218)^2}{2 \ln \frac{705}{218}}}$$

$$r_{maxT} = \sqrt{\frac{0.497 - 0.075}{2 \ln 3.24}} = \sqrt{\frac{0.422}{2.34}}$$

$$r_{maxT} = \sqrt{0.180} = 0.424"$$

Temperature drop from adiabatic radius to outside of tubular core: (Reference is made to P. 9 of ANL-4690, Case III).

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

Where:

$$q = \frac{Q/ft}{Vol/ft} = \frac{92 \times 1000 \times 3.412}{\pi/4\ (1.41^2 - 0.436^2) \times 12} = 18{,}600 \text{ BTU/hr-in}^3$$

K = Thermal conductivity of Uranium

$$K = \frac{1196 + t(°C)}{83.4} = \frac{1196 + 200°}{83.4} = 16.8 \text{ BTU/hr-°F-ft}$$

$$= 1.4 \text{ BTU/hr-°F-in}$$

$$\Delta t(r_{max} - r_o) = \frac{18{,}600}{2\ (1.4)}\left(\frac{(0.705)^2 - (0.424)^2}{2} - (0.424)^2 \ln \frac{705}{424}\right)$$

$$= 6650\left[\frac{(0.447 - 0.180)}{2} - 0.180 \ln 1.66\right]$$

$$= 6650\ (0.158 - 0.091)$$

$$\Delta t\ (r_{max} - r_o) = 445°F$$

[redacted]

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Appendix II Cont'd.

XII. Temperature Summary

Water	100°F	(38°C)
Clad Surface	217°F	(103°C)
Clad Inside	233°F	(112°C)
Uranium Surface	250°F	(121°C)
Uranium Maximum	695°F	(368°C)

The flow rate required for a film drop of 117°F is only 9.5 + 2.1 gpm or 11.6 gpm. Actual flow conditions should be 20 gpm. Therefore, a velocity increase ratio of about 1.72 $(\frac{20}{11.6})$ will actually exist. This will increase the hf and thereby reduce the Δt_f to:

$$\frac{117°}{(1.72)^{0.8}} = \frac{117°}{1.54} = 76°F$$

The maximum surface temperature will then be about 176°F instead of 217°F. There, of course, will be about 41°F reduction in internal temperatures also.

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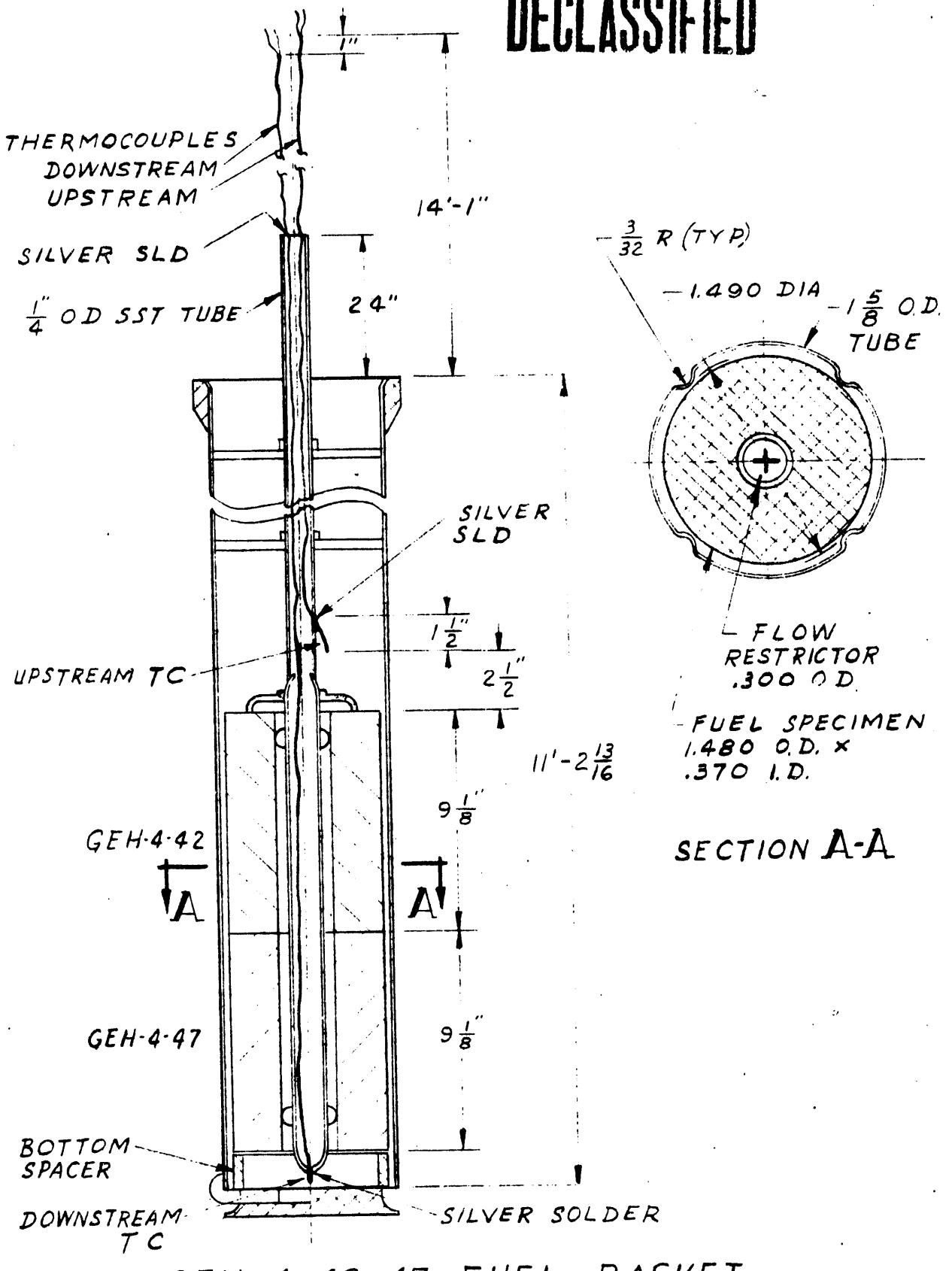

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