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PROPOSAL FOR IRRADIATION OF URANIUM SWELLING CAPSULE

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June 30, 1958

PROPOSAL FOR IRRADIATION OF URANIUM SWELLING CAPSULE

J. W. Weber

I. INTRODUCTION

To date, no ^{data} is available on the swelling rates of ^{restrained} unrestrained unalloyed uranium rods operating at 450-630 C core temperature and 250-350 C surface temperature. These temperature ranges are of extreme interest in the Hanford fuel element development program. To obtain information on the effect of cladding restraint, exposure, and the above temperatures, on uranium swelling rates, a series of experiments is being designed for irradiation in Hanford reactors. The experimental assembly consists of a uranium fuel rod supported concentrically in an aluminum capsule. Surrounding the fuel rod is an annulus of liquid NaK to serve as a heat transfer agent.

II. OBJECTIVE

To provide a check on the operation and temperature calculations of the capsules, it is proposed initially to make a single irradiation in a normal process tube. The uranium core temperature will be continuously monitored by a thermocouple, and flux measurements will be made in the capsule to determine the specific power of the fuel.

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III. DESCRIPTION OF IRRADIATION ASSEMBLY

A. Size of Geometry

The basis for the capsule design is explained in HW-56132. The complete dimensions are shown on the accompanying drawings. A sketch of the assembled capsule is shown in Figure 1. To provide the required power generation, the capsule must be located in the central high flux region of the process tube. A perf train will run from the capsule extension to the rear face of the reactor to provide support for the thermocouple lead.

B. Materials

The capsule body is machined from rod stock of ALCOA C-64 aluminum alloy. The end plugs and capsule extension is made from aluminum alloy 1100. The end caps are machined from standard Hanford end caps.

The fuel rod is 1.6 per cent enriched uranium coextruded with Zr-2 cladding. Separating the fuel rod and capsule body is an annulus of liquid NaK.

C. Fabrication

The fuel rod end cap and thermocouple thimble, both Zr-2, are welded together by the electron gun welder, as are the capsule end plugs and body. The end caps are welded to the body in the helium atmosphere welding box. Then the lower swagelok will be sealed holding an atmosphere of He in the capsule. The upper swagelok will also be sealed in the helium atmosphere.

D. Inspection and Proof Testing

The capsule will be helium leak checked then hot water autoclaved after complete assembly.

IV. EXPECTED PERFORMANCE

A. Mechanical Behavior

For the period of exposure (1 reactor cycle) and the temperatures involved previous British data shows no swelling of the fuel should occur. Sufficient space for thermal expansion of the NaK is provided in the design to prevent distortion by internal pressure.⁽¹⁾

(1) Weber, J. W., "In-Reactor Restrained Swelling Experiments, HW-56132, 5-20-58.

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B. Failure Behavior

There has been no experience on the in-reactor failure behavior of these capsules, however, tests were run on 8 NaK filled capsules that were deliberately failed in 98 C water in the 314 Building flow tubes(2). After running for two hours the NaK had been completely flushed from the capsule. There was no distortion and no serious corrosion of the inside or outside of the capsule. Once the NaK is gone from the capsule, the fuel will become hot and must be discharged from the reactor. Failure of the capsule can be detected by the presence of Na_2HPO_4 in the process water outlet.

C. Charge and Discharge of Capsule

The entire capsule train with thermocouple and perfs will be charged from the front face. Because of the nature of the rails on the capsule, it will be necessary to remove the front face nozzle before charging.

Discharging should present no further difficulties than the discharge of any other lead type experiment.

V. OPERATIONAL LIMITATIONS

A. Temperature

Because of the small amount of heat generating material that will be present in the process tube there will be no problem from boiling.

As the irradiation is partially a check on the accuracy of the temperature calculations, the thermocouple temperature should be watched during the initial reactor startup and the increase to full power. If the measured temperature exceeds the calculated temperature by more than 250 C the capsule should be discharged.

Immediately after discharge and during the initial decay period, the capsule should be stored in approximately the same rotational orientation as during the irradiation.

VI. IRRADIATION CONDITIONS

A. Desired Conditions for Test:

Power generation desired in fuel - 23 kw/ft
Time of exposure - 1 reactor cycle
Temperature - Uranium core 513 C
 Cladding surface - 233 C
 Capsule surface - 43 C
 Local coolant - 10 C

(2) Weber, J.W., "Results of NaK Capsule Failures in Hot Water Flow Tube,"
HW-56588, 6-30-58.

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B. Acceptable Deviations

The check on the temperature calculations will be made by comparing the measured temperature with the calculated temperature based on flux measurements in the capsule. Therefore, the allowable deviation from the desired power generation may be ± 50 per cent.

This corresponds to:	+50 per cent	-50 per cent
Uranium core	76 $\frac{1}{2}$ C	261 C
Cladding Surface	340 C	121 C
Capsule Surface	60 C	26.5 C

However because discrepancies in the temperature calculations would be easier to recognize if the core temperature is in the range of 500 C or higher, it is desirable to have the power generation at 23 kw/ft or higher.

VII. INSTRUMENTATION

The thermocouple to measure the uranium core temperature will require a special rear nozzle seal which is being designed by B. Marshall in Special Irradiations.

In addition, it is desired to measure the outlet water temperature.

VIII. DISPOSITION OF CAPSULE

After discharge, the capsule will be opened at the HAPO Radiometallurgy Facility and the flux wires removed for counting. A cursory examination will also be made of the inside and outside of the capsule and the fuel rod to determine if any unusual or unexpected phenomenon has occurred.

J. W. Weber
Fuel Element Design
Operation
Hanford Laboratories

JWW/lh

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APPENDIX A

HEAT TRANSFER CALCULATIONS

ASSUMPTIONS

Water Temperature 10°C
 Water Flow 30 GPM
 Power $23 \frac{\text{kw}}{\text{ft}}$

FILM COEFFICIENT

$$\frac{h D_e}{k} = 0.027 \left(\frac{\rho V D_e}{\mu} \right)^{0.8} \left(\frac{C_p \mu}{k} \right)^{0.33}$$

$$k = 0.33 \frac{\text{Btu}}{\text{hr-ft-}^{\circ}\text{F}}$$

$$\rho = 62.4 \frac{\text{lb}}{\text{ft}^3}$$

$$\mu = 3.24 \frac{\text{lb}}{\text{hr-ft}}$$

$$C_p = 1 \frac{\text{Btu}}{\text{lb-}^{\circ}\text{F}}$$

$$D_e = 0.0167 \text{ ft}$$

$$V = 71200 \frac{\text{ft}}{\text{hr}}$$

$$\frac{h(0.0167)}{0.33} = 0.027 \left[\frac{(62.4)(71200)(0.0167)}{3.24} \right]^{0.8} \left[\frac{(1)(3.24)}{0.33} \right]^{0.33}$$

$$\begin{aligned} h &= 0.027 (22900)^{0.8} (9.818)^{0.33} (19.76) \\ &= (0.027) (3015) (2.125) (19.76) \\ &= 3485 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^{\circ}\text{F}} \end{aligned}$$

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TEMPERATURE DROPSThermal ConductivitiesUranium K_1 Zr-2 K_2 NaK K_3 Aluminium K_4

$$\frac{\text{Btu}}{\text{in} \cdot \text{ft} \cdot ^\circ\text{F}}$$
 18.8 (500°C)

8.2

14.

127

Thermal Coefficients

$$\frac{\text{Btu}}{\text{in} \cdot \text{ft}^2 \cdot ^\circ\text{F}}$$
Zr-2 and Uranium Bond h_1 30,000Water Film h_2 3,485Dimensional Nomenclature ΔT FUEL ROD

$$\Delta T_{\text{ROD}} = \Delta T_{\text{URANIUM}} + \Delta T_{\text{ZR-U BOND}} + \Delta T_{\text{CLADDING}}$$

$$\begin{aligned} \Delta T_{\text{URANIUM}} &= \frac{Q}{4\pi K_1} \\ &= \frac{(3413)(23)}{4\pi(18.8)(1.8)} \\ &= 185^\circ\text{C} \end{aligned}$$

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$$\begin{aligned}\Delta T_{\text{Zr-U Bond}} &= \frac{Q}{h_1 A} \\ &= \frac{(3413)(23)(12)}{(30,000)(\pi)(0.570)(1.8)} \\ &= 10^\circ\text{C}\end{aligned}$$

$$\begin{aligned}\Delta T_{\text{CLADDING}} &= \frac{Q}{2\pi K_2} \ln \frac{d_2}{d_1} & \ln \frac{d_2}{d_1} &= \ln \frac{0.630}{0.570} \\ &= \frac{(3413)(23)(0.0998)}{2\pi (8.2)(1.8)} & &= 0.0998 \\ &= 84.5^\circ\text{C}\end{aligned}$$

$$\Delta T_{\text{ROD}} = 185 + 10 + 84.5 = 279.5^\circ\text{C}$$

$\Delta T_{\text{NAK ANNULUS}}$

$$\begin{aligned}\Delta T_{\text{NAK}} &= \frac{Q}{2\pi K_3} \ln \frac{d_5}{d_2} & \ln \frac{d_5}{d_2} &= \frac{0.875}{0.630} \\ &= \frac{(3413)(23)(0.3287)}{2\pi (14)(1.8)} & &= 0.3287 \\ &= 163^\circ\text{C}\end{aligned}$$

$\Delta T_{\text{ALUMINUM CAPSULE}}$

$$\begin{aligned}\Delta T_{\text{AL}} &= \frac{Q}{2\pi K_4} \ln \frac{d_6}{d_5} & \ln \frac{d_6}{d_5} &= \ln \frac{1.44}{0.875} \\ &= \frac{(3413)(23)(0.4982)}{2\pi (127)(1.8)} & &= 0.4982 \\ &= 27^\circ\text{C}\end{aligned}$$

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ΔT WATER FILM

$$\begin{aligned}\Delta T_w &= \frac{Q}{h A} \\ &= \frac{(3413)(23)(12)}{(3485)(\pi)(1.44)(1.8)} \\ &= 33^\circ \text{C}\end{aligned}$$

CAPSULE SURFACE TEMPERATURE

$$\begin{aligned}T_{\text{CAPSULE}} &= T_w + \Delta T_w \\ &= 10 + 33 = 43^\circ \text{C}\end{aligned}$$

CLADDING SURFACE TEMPERATURE

$$\begin{aligned}T_s &= T_w + \Delta T_w + \Delta T_{\text{AL}} + \Delta T_{\text{NAK}} \\ &= 10 + 33 + 27 + 163 \\ &= 233^\circ \text{C}\end{aligned}$$

URANIUM AXIAL TEMPERATURE

$$\begin{aligned}T_a &= T_s + \Delta T_{\text{ROD}} \\ &= 233 + 279.5 \\ &= 512.5^\circ \text{C}\end{aligned}$$

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