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PROPOSAL FOR THE IRRADIATION OF CLADDING STUDIES
CAPSULES

J. W. Weber

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II. TEST DESIGN

Because there may be failures of the Zircaloy-2 cladding of the fuel rods, it is necessary to irradiate them in capsules rather than in loop facilities, where they would have to be discharged after the first failure.

This test requires the irradiation of six test capsules and one thermocouple capsule per normal process tube. Three process tubes will be required to investigate the desired number of variables of cladding thickness, cladding temperature, cladding thickness variation, and exposure with the sufficient number of duplications. The six capsules are to be centrally located in the process tube to take advantage of the maximum flux and the minimum flux change front to rear. The thermocouple capsule will be located at the downstream end of the six capsules with the thermocouple leads extending out the rear face nozzle. No other fuel or poison elements are to be charged in these tubes during this irradiation. The process tubes selected for the charges should not be located near control rods. It is necessary to minimize the flux variations as the validity of the test results will depend upon a nearly constant cladding temperature during the irradiation.

Because of uncertainties in temperature calculations based on adjacent tube powers, it is necessary to measure the temperature at a known location in the capsule. The thermocouple capsule will accomplish this. From the measured temperature, the known dimensions of the capsules, and front-to-rear flux distributions it will be possible to calculate the cladding temperatures more accurately.

The proposed pattern for charging the capsules is shown in Figure 1.

The coding of the capsules, the cladding thickness, power required, cladding surface temperature, center uranium temperature, and exposure are given in Table I.

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TABLE I
EXPERIMENTAL CONDITIONS

Capsule Designation	Fuel	Cladding Thickness Inch	Temperature - C Uranium Axial Uranium Surface Cladding Surface	Exposure MWD/T	Power Required kw/ft	(See Appendix C)
✓ A3U11	1.47% E Unalloyed	0.030	477 318	1000	20	✓
✓ A3U21	"	0.030	477 318	1000	20	✓
✓ A3U22	"	0.030	513 358	1000	20	✓
✓ A3U31	"	0.030	548 398	1000	20	✓
✓ A3A21	1.47% E 2 w/o Zr	0.030	477 318	1000	20	✓
✓ A4U21	1.47% E Unalloyed	0.040	520 391	1000	19.2	✓
✓ B3U11	1.47% E Unalloyed	0.030	477 318	2000	20	✓
✓ B3U12	"	0.030	477 318	2000	20	✓
✓ B3A21	"	0.030	513 358	2000	20	✓
✓ B3A22	"	0.030	513 358	2000	20	✓
✓ B3U23	"	0.030	513 358	2000	20	✓
✓ B3U24	"	0.030	513 358	2000	20	✓
✓ B3U31	"	0.030	548 398	2000	20	✓
✓ B3A21	1.47% E 2 w/o Zr	0.030	477 318	2000	20	✓
✓ B3A22	"	0.030	513 358	2000	20	✓
✓ B4U11	1.47% E Unalloyed	0.040	520 391	2000	19.2	✓
✓ B4U21	"	0.040	520 391	2000	19.2	✓
✓ B4U22	"	0.040	520 391	2000	19.2	✓
A4U2TC1	1.47% E Unalloyed	0.040	520 391	2000	19.2	✓
B4U2TC1	"	0.040	520 391	2000	19.2	✓
B4U2TC2	"	0.040	520 391	2000	19.2	✓
B4U2TC3	"	"	"	"	"	✓
SRH	1.47% E Unalloyed	0.030	513	391	20	✓
SVH	"	"	"	"	"	✓
SV2 M1	"	"	"	"	"	✓
SV2 M2	"	"	"	"	"	✓
SV2 M3	"	"	"	"	"	✓

Figure 1
PROPOSED CHARGING PATTERN

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IV. DESCRIPTION OF IRRADIATION ASSEMBLIES

A. Sizes and Geometry

The design and calculations for the capsules are presented in HW-67263.

The assembled test capsule and thermocouple capsule are shown in Figure 2 and 3. Detail dimensions can be found on H-3-9599 and SK 3-9635.

The outer diameter of the clad fuel rods and the inner diameter of the capsule body are constant for each capsule. By varying, the capsule wall thickness in the region of the fuel specimens, the desired temperature conditions can be achieved. Table II lists the outer diameters of the capsules for each set of test conditions. Proper functioning of the NaK expansion chamber syphon depends on the rotational orientation of the capsule. Rails on the outer aluminum sleeve which are matched with the ribs of the process tube guide the capsule in proper orientation during charging and maintains the orientation during irradiation.

An aluminum perf train will run from the thermocouple capsule to the rear face of the reactor to provide support for the thermocouple lead and to locate the capsules at the desired position in the process tube.

B. Materials

The capsules are machined from Zircaloy-2 rod and extruded tubing.

The fuel rod is 1.47 per cent enriched uranium coextruded with Zircaloy-2 cladding.

The NaK is a liquid alloy of 44K - 56 Na composition.

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TABLE II

CAPSULE OUTER DIAMETERS

<u>Capsule Designation</u>	<u>Outer Diameter-inch</u>
A-B3A2(1-2)	0.996 ✓
A-B3U2(1-4)	0.888 ✓
A-B3U3(1)	0.938 ✓
A-B3U(1-2) A-B3A2(1-2)	0.920 0.842
B4U1(1)	0.838 0.858 ✓
A-B4U2(1-2)	0.910 ✓

C. Fabrication

1. Test Capsules - The end caps are welded to the fuel rods by the TIG (tungsten inert gas) process. The fuel rods are then assembled in the capsules and the expansion chamber and capsule end caps welded on. The capsules are placed vertically in an inert gas welding glove box and then evacuated. The fuel rod chamber is filled with a predetermined amount of NaK through the syphon. Additional NaK is added until it overflows and covers the syphon. The screw plug on the chamber end cap is inserted, tightened, and welded closed.

2. Thermocouple Capsule

The fuel rod and capsule fabrication for this assembly is the same as the test capsule except that the thermocouple seals are made and tested before the NaK is added. The Swageloks bodies are made of Zircaloy-2 so they can be welded to the capsule.

D. Inspection and Proof Testing

Inspections of welds and Swagelok seals are made by X-ray and helium leak checking at various stages of the assembly.

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V. EXPECTED PERFORMANCE

A. Mechanical Behavior

To prevent distortion of the capsule by internal pressures from the NaK and uranium swelling, the expansion chamber is provided at one end of the capsule. Basis and calculations for the expansion chamber are presented in HW-67263. No other mechanical problems are anticipated.

B. Failure Behavior

There has been no experience on the in-reactor failure behavior of these capsules; however, tests were run on aluminum NaK-filled capsules deliberately failed in a 98 C water flow loop. The results of these tests, fully described in HW-56588 "Results of NaK Capsule Failures in Hot Water Flow Tube," J. W. Weber, showed no serious distortion or reaction would occur if water gains access to the NaK.

C. Charge and Discharge of Capsules

The capsules will be charged from the rear of the process tube. A special holding tool and spline will be used to maintain the orientation of the test capsules as they are being charged, until the rails engage on the ribs. The thermocouple capsules will also require a spline and handling tool.

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

VI. OPERATIONAL LIMITATIONS

A. Temperature

The thermocouple temperatures should be watched during the reactor startup and the increase to full power. If, during the startup, the measured temperature exceeds the calculated temperature by more than

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250 C and remains at this high value long enough to determine that it is not a short-term transient, the tube should be discharged. If a steady increase in uranium measured temperature of more than 150 C over a period of 1 to 2 days occurs without an accompanying increase in adjacent tube power, the tube of capsules should be discharged. The heat generating material should raise the water temperature 10-15 C.

VII. IRRADIATION CONDITIONS

A. Desired Conditions for Test

1. Power generation in fuel - See Table I.
2. Tube power required (See Appendix A) 750 KW
3. Time of Exposure

Tube 1	1000 MWD/T	<u>48</u> days
Tube 2	2000 MWD/T	<u>96</u> days
Tube 3	2000 MWD/T	<u>96</u> days

4. Temperatures - C (See Appendix B)

<u>Sample</u>	<u>Local Coolant</u>	<u>Capsule Surface</u>	<u>Cladding Surface</u>	<u>Uranium Axial</u>
A-B3U1(1-2)	20	50	240	477
A-B3U2 A-B3A2 (1-4)	20	50	280	513
A-B3U3(1)	20	50	320	548
A-B3A2(1-2)	20	50	280	454
B4U1(1)	20	50	240 247	465 503
A-B4U2(1-2)	20	50	280 283	520 537

B. Acceptable Deviations

The uranium temperature is not important in these experiments except that it be high enough (~ 475 C) to cause some uranium swelling during the irradiations. It is more important for

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worthwhile results of the tests that the cladding temperatures not exceed the desired values by more than 15 per cent, and then only for short periods of time. The acceptable deviations in specific power and tube powers are then also $\pm 15\%$. A tube power increase of 50% would give the following maximum temperatures in each tube:

<u>Tube</u>	<u>Capsule</u>	<u>Cladding Surface - C</u>	<u>Uranium Axial - C</u>
1	A3U31	470	810
2	B3U31	470	810
3	B3U2(3-4)	410	760

VIII. INSTRUMENTATION

Each process tube will have a thermocouple in the downstream capsule to measure the core temperature. The leads will be removed through the rear nozzle by a special adaptor.

IX. REACTOR DATA REQUIRED

A. At eight-hour intervals during the reactor operation, the following information is desired:

- a. Date.
- b. Time.
- c. Reactor Power Level.
- d. Water Inlet Temperature.
- e. Temperatures from each Thermocouple Capsule,

and from at least two adjacent process tubes surrounding each tube in which the capsules are charged.

- f. Outlet Temperature.
- g. Panellit Dial and Base.
- h. Header Dial and Base.

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B. One tube adjacent to each tube of capsules should be charged with a numbered column of fuel elements at the same time the capsules are charged. This tube should be discharged when the capsules are discharged and weasel readings made on the numbered slugs.

X. DISPOSITION OF CAPSULE

After discharge, the capsules are to be stored for a sufficient decay period and then shipped to the HAPO Radiometallurgy Operation for opening and examinations of the fuel rods.

JW Weber

J. W. Weber
Fuel Element Design Operation

JWW/lh

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APPENDIX A TUBE POWER CALCULATION

I This experiment was designed so that all capsules require the same specific power in the adjacent process channels.

The assumption is made that the flux distribution will follow similar to that found in the swelling capsule experiments described as DT-IP-227 A. The results of this experiment are described in HWN 2115. The maximum factor f or $\frac{\text{Specific power at capsule position}}{\text{Avg specific power in the tube}}$ is 1.50.

The active length of the 34 elements is $(34)(8.2') = 23.52'$

II For the various combinations of cladding thickness, fuel alloy, and capsule wall thickness the factors R or $\frac{\text{Specific capsule power } \text{kw/ft}}{\text{Specific power in adj. fuel elements } \text{kw/ft}}$ are:

<u>CASE</u>	<u>FUEL</u>	<u>CLADDING</u>	<u>CAPSULE O.D.</u>	<u>R</u>
1	1.47% Enr. unalloyed	0.030"	0.842"	0.4228
2	"	0.030"	0.888"	0.4155
3	"	0.030"	0.938"	0.4230
4	1.47% Enr. 2% Zr	0.030"	0.996"	0.3074
5	1.47% Enr. unalloyed	0.040"	0.858"	0.4021
6	"	0.040"	0.910"	0.4041

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III CALCULATIONS

For the capsules with the 0.030" cladding with the unalloyed uranium fuel.

$$\begin{aligned}\text{TUBE POWER} &= \left(\text{Capsule power } \frac{\text{kw}}{\text{ft}} \right) \left(\frac{1}{R} \right) \left(\frac{1}{f} \right) L \\ &= (20) \left(\frac{1}{0.420} \right) \left(\frac{1}{1.5} \right) (23.52) \\ &= 750 \text{ kw} \leftarrow\end{aligned}$$

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APPENDIX B HEAT TRANSFER CALCULATIONS

TEMPERATURE DROPS

Assumptions

Thermal Conductivity

Uranium

Zr-2

Nak

20.2 $\frac{\text{Btu}}{\text{in-ft}^2\text{-}^\circ\text{F}}$ at 435°C
8.1 " avg uranium
15 " temp.

Thermal Coefficients

Water film

5000 $\frac{\text{Btu}}{\text{in-ft}^2\text{-}^\circ\text{F-h}}$

Dimensions

These are for the 0.030" cladding thickness
high cladding temperature case.

Uranium OD	0.540"	- d ₁
Cladding OD	0.600"	- d ₂
Nak annulus OD	0.720"	- d ₃
Capsule body OD	0.938"	- d ₄

Calculations - (Sample for A+B 303)

$$\Delta T_{\text{fuel rod}} = \Delta T_{\text{uranium}} + \Delta T_{\text{cladding}}$$

$$Q = 20 \frac{\text{kw}}{\text{ft}}$$

$$\Delta T_{\text{uranium}} = \frac{Q}{4\pi k} = \frac{(20)(3413)}{4\pi(20.2)(1.8)} = 150^\circ\text{C}$$

$$\Delta T_{\text{cladding}} = \frac{Q}{2\pi k} \ln \frac{d_2}{d_1} = \frac{(20)(3413)(0.1053)}{2\pi(8.1)(1.8)} = 78^\circ\text{C}$$

$$\ln \frac{0.600}{0.540} = 0.1053$$

$$\Delta T_{\text{fuel rod}} = 228^\circ\text{C}$$

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$$\Delta T_{\text{neck annulus}} = \frac{Q}{2\pi K} \ln \frac{d_3}{d_2} = \frac{(20)(3413)(0.1823)}{2\pi(15)(1.8)} = 73^\circ\text{C}$$

$$\ln \frac{0.720}{0.600} = 0.1823$$

$$\Delta T_{\text{capsule body}} = \frac{Q}{2\pi K} \ln \frac{d_4}{d_3} = \frac{(20)(3413)(0.2645)}{2\pi(8.1)(1.8)} = 197^\circ\text{C}$$

$$\ln \frac{0.938}{0.720} = 0.2645$$

$$\Delta T_{\text{water film}} = \frac{Q}{hA} = \frac{(3413)(20)(12)}{(5000)(0.926)\pi(1.8)} = 31^\circ\text{C}$$

The water temperature will vary between 20 and 30°C based on information from a previous capsule test PT-IP-227A.

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APPENDIX C

SPECIFIC POWERS - $\frac{KW}{FT}$

The selection of 20 KW/ft for the $0.030''$ thick clad unalloyed fuel rods was based on the necessity to have as high as possible center uranium temperature and a capsule body of sufficient thickness.

As the other fuel rods with $0.040''$ cladding unalloyed uranium and $0.030''$ cladding U-2% Zr fuel will be in the same reactor flux zone it is necessary to correct the specific power generations for the flux perturbation for the different conditions of fuel and cladding.

The values for R or the $\frac{\text{Specific capsule power}}{\text{specific power in adj elements}}$ are given in Appendix A. The ratios of these R values would give the relative power generations for the various conditions. The R values for the $0.030''$ clad unalloyed fuel are taken as approximately 0.42. The R value for the $0.040''$ clad unalloyed is approximately 0.403. For the $0.030''$ clad U-2% Zr alloy the R value is taken as 0.31.

Assuming 20 KW/ft for $0.030''$ clad unalloyed $R = 0.42$

$$\begin{aligned} \text{Power for } 0.040'' \text{ unalloyed} &= \frac{0.403}{0.42} (20) \\ &= 19.2 \text{ KW/ft} \leftarrow \end{aligned}$$

$$\text{Power for } 0.030'' \text{ alloy} = \frac{0.31}{0.42} (20) = 14.6 \frac{\text{KW}}{\text{ft}} \leftarrow$$

MEANS

3"

Na

FIGURE 2

SPECIMENS

NaK

EXPANSION CHAM

A

FIGURE 3

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Nak

A ←

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SECTION A-A

CLADDING STUDIES CAPSULE

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