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TO: J. W. Flora *

COPIES TO: R. K. Stitt * D. I. Sinizer *
 D. P. Gamble * M. E. Remley
 M. S. Dunenfeld * E. E. Motta
 R. J. Beeley * L. E. Wilkinson *
 T. L. Gershun *

SUBJECT:

TRANSIENT HEATING OF UC FUEL ELEMENTS IN THE KEWB FACILITY

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I STATEMENT OF PROBLEM

To examine the feasibility of using the KEWB reactor as a pulse neutron radiation source for studies of transient heating of fuel elements; a prototype test on representative fuel samples was conducted. The first of these tests was made using a 100 gm sample of natural uranium monocarbide and a 100 gm sample of 8% enriched uranium monocarbide. These samples were irradiated in the KEWB reactor with five neutron pulses during which the reactor released from 1.5 to 5.4 Mws during each pulse. Thermocouples were attached to the samples for temperature measurements.

II SUMMARY OF RESULTS

Uranium monocarbide fuel rod samples 0.8 inch in diameter and one inch long were heated in the KEWB reactor. Average temperature changes observed were 95°C/% U²³⁵ in natural UC and 35°C/% U²³⁵ in 8% enriched UC. These temperature increases correspond to a 4 Mws reactor energy release. The temperature distribution in the natural UC sample is nearly uniform. The outside temperature increase of the enriched sample was approximately twice as great as the center immediately after the neutron pulse.

Thermal neutron measurements using gold foils (reported in TDR No. 4228) show the flux distribution to be uniform to within 7% in the reactor region

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used in these tests. Further data showing the distribution of radiation heating in U^{235} in the core and reflector were taken during tests made on reactor safety fuses in the KEWB reactor. (Figure 1) The fuse heaters were stainless steel clad 93% enriched uranium metal. The temperatures induced in the fuses agree with a uniform flux distribution to within $\pm 30\%$.

The heating of the UC samples is reduced 22% for natural and 37% for 8% enriched when the billets are irradiated in the reflector rather than in the core. (Figure 2) When the 8% enriched sample was moved to position F in the reflector, the heating was reduced only 8% relative to position G. This shows that the heating effect on UC is fairly uniform in the reflector irradiation facility. On this basis, the temperature of a natural sample at position F is estimated.

III METHOD USED, SAMPLES

Two sample billets were cut from the best portions of natural and enriched UC cast by the Fuel Fabrication Group. Each sample was approximately 0.8 inches in diameter and 1 inch long. A hole 0.1 inches in diameter and 1/2 inch deep was drilled in one end of the samples along the axis. (Figure 3) After machining and cleaning, the samples were stored in a desiccator until they were mounted in the capsules.

The capsules provide double enclosure of the samples. (Figure 4) The inner chamber was fabricated by welding a plate into one end of a stainless steel pipe. The opposite end was threaded to accept a ring which held a brass plate cover plate in compression against the pipe to provide the first seal. A metal gasket (gold or aluminum) was used to implement the hermetic seal.

A length of 1/8 inch stainless steel rod was silver soldered to the inner surface of the brass plate. A piece of .010 inch thick stainless steel shim stock was spot welded to the other end of the rod and formed into a cylinder to hold the sample billet. Two stainless steel sheathed MgO-insulated thermocouple leads were soldered to the brass plate at their exit location from the capsule. These leads were extended to the sample

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by means of 16 inches of 26 AWG glass insulated duplex thermocouple wire. Gas tight junctions between the steel sheathed and duplex thermocouple wire were made using a steel sleeve and epoxy cement technique developed by the A. I. R & D Shop. The brass plate was tapped to accept a small Bourdon type vacuum gauge and an evacuation tube. The outer chambers were made by welding stainless pipe and plates together. The large ends of these chambers provided space to enclose the seal ring and vacuum gauge of the inner chamber. This chamber was closed by a stainless steel plate held in place by eight cap screws and was hermetically sealed by an "O" ring.

The outer capsule was provided with a compound vacuum-pressure gauge. A Hoke valve was threaded into the seal plate to provide a means of evacuation and back-filling with helium. The stainless steel sheathed thermocouple leads were passed through the plate by means of Conax packing glands.

The thickness of both chamber walls was reduced to 1/16 inch for a distance of approximately 24 inches from the sample end.

Both chambers of each capsule were given and passed a helium leak test. The thermocouple installation was completed by attaching 20 AWG plastic insulated lead wire to the outside ends of the sheathed thermocouple leads by means of sleeves and epoxy cement. The cold junctions were made in the plastic insulated duplex wire and the leads were then terminated in BNC cable connectors. The thermocouples were calibrated by the Measurements and Standards Unit. They agreed within $\pm 1^{\circ}\text{C}$ at 147.2°C and 218°C with standard chrome-alumel thermocouples. ⁽¹⁾

The UC billets were taken from the desiccator and the thermocouples were attached. One thermocouple was bound by means of 30 AWG nichrome wire to the outside surface of each sample. A second thermocouple was inserted into the hole in the end of the sample. The sample was then placed inside the steel shimstock holder and inserted into the inner chamber. The chamber was closed, evacuated, helium leak checked and sealed. The inner chamber was inserted in the outer chamber which was then closed, evacuated, helium leak checked, backfilled with helium to one atmosphere pressure, and sealed.

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IV. INSTRUMENTATION

At the KEWB facility, four recording oscillograph channels were calibrated for use with the capsule thermocouples. Each channel consisted of coax lead cables from the reactor room to the control room, a Kintel Model 111AF amplifier, and a CEC 7-316 galvanometer mounted in a CEC Model 5-119 oscillograph. Each channel was calibrated by using a chromel-alumel thermocouple placed first in a melting ice bath and then in a boiling water bath, and recording the galvanometer displacement with the amplifier gain set at 1000. The galvanometers were deflected approximately .35 inches for a temperature change of 97°C.

V. TEST PROCEDURES

The capsules were inserted into the reactor. During reactor transient 1, 2, and 3, the natural UC sample was in the through tube in position C, as indicated in Figure 1. During transients 1 and 2, the 8% enriched sample was in the reflector exposure facility at the position marked G. For transient 3, the enriched sample was withdrawn 8 inches to the position marked F.

During transients 4 and 5, the capsules were interchanged, placing the natural UC sample at position G in the reflector and the enriched sample in the through tube at position C.

VI. DATA

The thermocouple data during transient 1 was so obscured by noise that it was not useful. The data taken during the last four transients are presented in Table 1. The temperature changes recorded in Column 2 are extrapolated values from the time-temperature data graphed in Figures 5, 6, 7, 8, 9, and 10. The cooling time constant of the samples can be measured using Figures 9 and 10 which show the cooling curves for the 8% sample located in the graphite. The figures show that the capsule loses 63% of its temperature above ambient in approximately 5 minutes. An approximate value for the average sample temperature immediately after irradiation can be found by extrapolating the cooling data with an

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exponential curve back to time zero.

The response of the thermocouple attached to the outside of the natural UC sample was so low and erratic, that it was assumed to have failed.

The heat capacity of a 100 gr sample of UC is 5.3 cal/°C. The total heat capacity of the sample-holder system is 5.7 cal/°C.

The time-temperature curves in Figure 11 show that the outside thermocouple was responding to a temperature step with nearly twice the magnitude of the inside thermocouple. This large temperature difference is overcome quickly by the delivery of heat from the outside surface of the sample to its cooler inner portion and to the steel holder.

Preliminary calculations caused some doubt of the enrichment of the purported 8% sample. A sample of the enriched UC was analyzed using a multichannel gamma spectrometer. The enrichment was reported to be $3.2 \pm 0.4\%$ U^{235} . A gram sample each of natural UC and the enriched UC were irradiated in the L-77. The activation of both samples was read with a Juno survey meter. The activity ratio in the enriched to natural sample was approximately 2 to 1. The irradiated samples were then analyzed by the multichannel gamma spectrometer using the natural sample as a control sample. The enrichment of the other sample was found to be less than 3%. Next, a sample of the enriched UC was given an isotopic analysis using an emission spectrograph which gave the enrichment as $8.6 \pm 0.2\%$ U^{235} .⁽⁴⁾ Finally, a sample of the enriched UC was burned to uranium oxide and analyzed in the multichannel gamma spectrometer using uranium oxide calibration control samples. This analysis gave the enrichment to be 8.0%.⁽⁵⁾

VII CALCULATIONS

The temperature change of a UC fuel sample billet containing 1% U^{235} irradiated in the KEWB reactor core may be calculated as shown below using the following constants:

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Density UC	13.6 g/cm ³
U content of UC	12.97 g/cm ³
Specific heat of UC	0.053 cal/gm-°C.
Energy release in sample (per Mws)	492 watt sec/gm U ²³⁵
Ratio watt seconds to calories	4.18 watt sec/cal

$$\Delta t \Big|_{1.0\% U^{235}} = \frac{\text{Heat produced}}{\text{Heat capacity}} = \frac{12.97 \times 492 \times 10^{-2}}{13.6 \times 0.053 \times 4.18} = 21.1^{\circ}\text{C}$$

Using a disadvantage factor of 1.09 for the natural UC sample⁽³⁾ the expected temperature raise is

$$\frac{21.1}{1.09} \approx 19.4^{\circ}\text{C}/\% U^{235} \text{ Mws.}$$

which is 20% lower than the value measured in transient 2, which was 24.2°C (see Table I).

Using a disadvantage factor of 2.1 for the 8% enriched rod (Figure 12) the expected temperature raise is

$$\frac{21.1}{2.1} = 10^{\circ}\text{C}/\% U^{235} \text{ Mws}$$

which is 15% greater than the average of the values measured in transients 4 and 5.

CONCLUSIONS

Figure 13 shows the average temperature changes which can be induced in a sample UC fuel rod as a function of enrichment up to 10% U²³⁵ when it is irradiated in the KEWB reactor. Further extension of this calculation to higher enrichments would require modifications of the theory used or computer assistance; both are beyond the intended scope of this work. The observed temperature changes in this experiment agree with the calculated temperature change within 20% for observation made in the center

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of the core, and within 45% for observation made in the reflector. Three factors which may account for the difference in the observed and calculated temperature changes are flux depression caused by the UC samples and radiant heat loss from the sample, and the application of an improper value for the disadvantage factor.

It may be observed in Table I when the samples were heated to high temperatures (245°C average temperature change corresponds to an outside temperature change of 514°C in transient 2), the observed temperature change was always less than the calculated temperature change.

The disadvantage factors used were derived using Successive Generations Method data developed by Stuart and Woodruff. (3)

The flux distribution in a fuel sample could be mapped and thermal conductivity measurements for UC could be made by using fast response thermocouples distributed radially in the sample.

ACKNOWLEDGEMENTS

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Isotopic analyses of the UC sample were made by R. L. Koontz, B. L. Bickley, T. B. Crockett, and J. C. McKinley.

Assistance in conduction of the experiment was given by the KEWB reactor operating personnel.

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TABLE I
TEMPERATURE DATA

Transient No.	Percent U^{235}	Location	Energy Release Megawatt - Sec.	Temperature Change °C	°C/% U^{235} -Mws Observed-Calcu.		Percent Difference
2	0.7	C	5.42	92	24.2	19.4	20%
	8.0	G		245	5.3	8.7	39%
3	0.7	C	3.21	53	23.4	19.4	16%
	8.0	F		134	5.2	9.2	44%
4	0.7	G	1.15	15	18.6	16.8	10%
	8.0	C		83	9.0	10	10%
5	8.0	C	3.45	220	8.0	10	20%

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Figure 3

Figure 4

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