SUMMARY OF THE IRRADIATION HISTORY OF THE TRIST-ER1 CAPSULE.

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OBJECTIVE

The objective of this work is to determine the existence or absence of radiation induced electrical degradation (REID) in Al_2O_3 with and without voltage applied to the sample.

SUMMARY

The TRIST-ER1 capsule was assembled and irradiated in a large Removable Beryllium (RB☆) position of the High Flux Isotope Reactor (HFIR) during this reporting period. Irradiation began on March 8, 1996, was completed on June 20, 1996, during operating cycles 344, 345, and 346. This report describes the thermal operation of the capsule.

PROGRESS AND STATUS

Background

The TRIST-ER1 capsule was designed to irradiate 15 alumina specimens at 450°C. The specimens were 8.5-mm O.D. disks 0.75-mm thick. Three electrodes were connected to the specimens so they could be electrically biased during irradiation and the electrical resistance could periodically be measured. The specimens were housed in sealed subcapsules which were contained in a holder sleeve and separated into three temperature zones to form the experimental region of the capsule. The subcapsules and capsule are described in Reference 1.

The total amount of heat generated in a subcapsule during reactor operation is dependent upon its location in the experimental region. The neutron and gamma fluxes responsible for the heating are reduced from their peak values near the reactor mid-plane by approximately 40% towards the ends of the experimental region. The size of the gas gap between the subcapsule enclosures and the holder were decreased for subcapsules located closer to the reactor mid-plane to compensate for increased heating in those regions. A heat transfer model was developed to determine the required operating gas gap thickness for each of the 15 subcapsules. Each subcapsule was essentially identical, except for its axial location in the experimental region and every other subcapsule was inverted (which makes almost no difference in the result). The design gas gap dimensions were determined by assuming a thermal conductivity equal to the average value of neon and helium in the gas gaps and a heat generation rate across the experimental region equal to the average of the measured value[2] near the beginning and end of an operating cycle. After the operating gas gap dimensions were set, the fabrication dimensions of the enclosure were determined by calculating the expected thermal expansion of the holder sleeve and the subcapsules from ambient to operating temperatures. Due to the evolution of the heating profile in the RB☆ facilities, the relative amount of neon required to maintain temperatures was expected to be greater than that of helium at the beginning of a reactor cycle, and the neon flow would be reduced over the course of the reactor cycle to compensate for the increased heat generated in the subcapsules.

Vanadium was chosen for the enclosure material because its low thermal expansion permitted the alumina pedestal to be brazed to the enclosure. Vanadium has a low thermal conductivity however, which decreased the heat loss characteristics of the subcapsules. This was compensated for by reducing the temperature control gas gap dimension. The operating gas gap dimensions for those subcapsules located near the reactor mid-plane were approximately .0025 cm. Small errors in gas gap dimensions of this size (due to fabrication errors or miscalculations) can result in large deviations in the actual specimen temperature. For subcapsules 7, 8, and 9, the expected temperature change for a deviation of .00025 cm was approximately 6 °C. It was anticipated that the specimens could be controlled to within +/- 20°C of the design temperature of 450°C. The expansion of the subcapsules with increasing temperature reduces the gas gap dimension and increases the heat loss from the component. Because the thermal expansion of subcapsules 7, 8, and 9 were predicted to be significant compared to the operating gas gap dimension, the available temperature adjustment was expected to be reduced. It was anticipated that a large degree of temperature adjustment would not be possible for those subcapsules.

Operation

The capsule was irradiated during HFIR cycles 344, 345, and 346 in an unshielded RB☆ position and was rotated 180° with respect to the reactor center-line for successive cycles. Cycles 344 and 345 were fairly typical, however the reactor scrammed 13 days into Cycle 346 and was down for approximately 2 days. Cycle 346 also terminated approximately 24 hours before the scheduled end-of-cycle due to equipment failure. The subcapsule temperatures were inadvertently increased above the desired temperature range during cycle 344 due to an improperly performed instrumentation test. The central specimen temperatures were increased approximately 100°C above their normal operating temperatures for approximately 6 minutes. (This is not observed in the presented data due to the short duration of the event.) The temperature of other specimens were increased less severely. The subcapsules were designed to withstand these temperatures and based on a comparison of temperature readings and electrical resistance measurements taken before and after the event, no damage was incurred in any of the subcapsules. Other than this event, the operation of the capsule was very consistent.

The specimen and enclosure temperature soon after the initial startup is shown in Figure 1. The specimen thermocouple of subcapsule 12 was not fully inserted into the specimen pedestal and was not indicative of the specimen temperature.

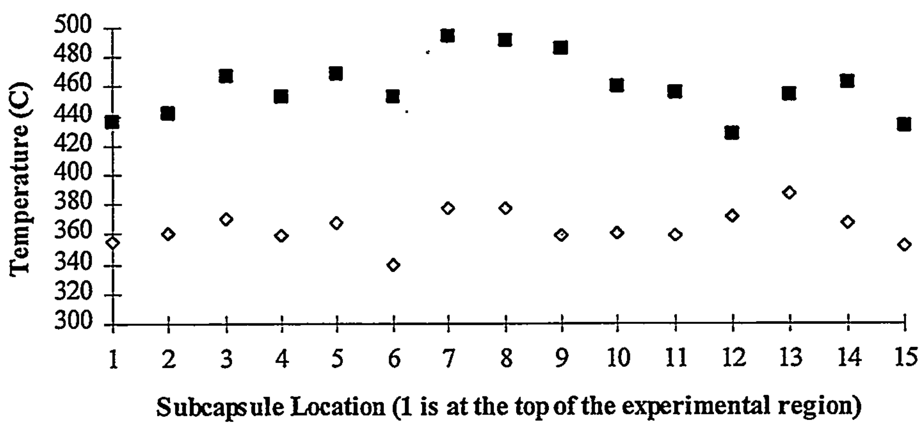

Figure 1: Temperature of the specimens (squares) and the base of the enclosures after the reactor reached full power for the first time. The temperature of the end zones (1- 4 and 12 -15) was being controlled.

The average temperature of the specimens was approximately 459°C, and the average deviation of the specimen temperatures from the design temperature of 450°C was approximately 17°C at the time of the initial start-up. The temperature of the specimens located closest to the reactor mid-plane (7, 8 and 9) averaged approximately 40°C above the design temperature. The temperature of the specimens in the upper zone (1-4) and lower zone (12-15) operated within a controllable range, however the required neon flow rate was lower than anticipated. The subcapsules tended to operate at lower inherent temperatures as the experiment progressed, which resulted in an increased ability to control specimen temperatures. The difference is most notable in the central temperature zone, where by the third irradiation cycle the specimen temperatures were actively controlled by introducing neon into the gas mixture. It is not yet known if the reduction in operating temperature was due to cycle-to-cycle variations in the operation of the reactor or if the heat transfer characteristics of the subcapsules were actually changing.

A plot of the average specimen temperature in the three temperature zones over the course of the three cycles is shown in Figure 2. The lower temperature zone operated at a higher inherent temperature than the upper zone and it was not possible to maintain the temperature in the lower zone at 450°C during the final week of a cycle. It is suspected that the temperature difference in the end zones is due to differences in the heat loss from the subcapsule holder sleeve to the capsule housing at those locations. The outer surface of the holder sleeve housed axial grooves to provide paths for the thermocouples, gas tubing and electrical leads used to monitor the subcapsules and control the temperatures. At the base of the experimental region these grooves were occupied by fewer leads, and the void areas of the grooves were greater than at the top of the experimental region, where the grooves were filled to capacity. It is possible that the heat loss from the holder sleeve to the housing was reduced in the lower end, resulting in a higher housing temperature and ultimately higher specimen temperatures.

The fact that all of the subcapsules operated at slightly higher than predicted temperatures suggests that either the heat transfer calculations or the predictions of subcapsule thermal expansion used to determine the fabrication dimensions of the subcapsule enclosure were incorrect. For the central subcapsules (7, 8 and 9), little could have been done about the high temperatures. The minimum operating temperature of subcapsules with vanadium enclosures was essentially reached at this location for this combination of subcapsule and capsule design. The gap between the central subcapsules and the holder sleeve was approximately .00015 cm at ambient temperature. The enclosures could not have been made much larger and still fit into the holder sleeve. If similar experiments at colder temperatures are desired, then the enclosure material must be changed or the subcapsule and capsule redesigned.

It is difficult to infer anything from the temperature data without a more detailed analysis, however based on preliminary examination some general conclusions can be made.

Expected change in thermal conductivity of alumina

It was expected that the thermal conductivity of alumina would begin to decrease upon the initial irradiation and stabilize after approximately .1 dpa (after about 2 to 3 days). The value of the thermal conductivity of the alumina used in the thermal analysis of the subcapsules was 1/3 the value given in the literature for un-irradiated alumina. Because the primary heat conduction path between the two thermocouples was through the alumina pedestal, the difference between the thermocouple readings was expected to increase as the thermal conductivity of the alumina decreased. However, the actual difference in the specimen and enclosure temperature at the time of the initial startup was very close to the value predicted by the thermal analysis and while the temperature difference did increase over the first week of irradiation, the increase was only on the order of 2 - 3%, which was smaller than anticipated. The data will need to be examined in greater detail and the heat transfer analysis revisited to determine if and to what extent the thermal conductivity actually changed.

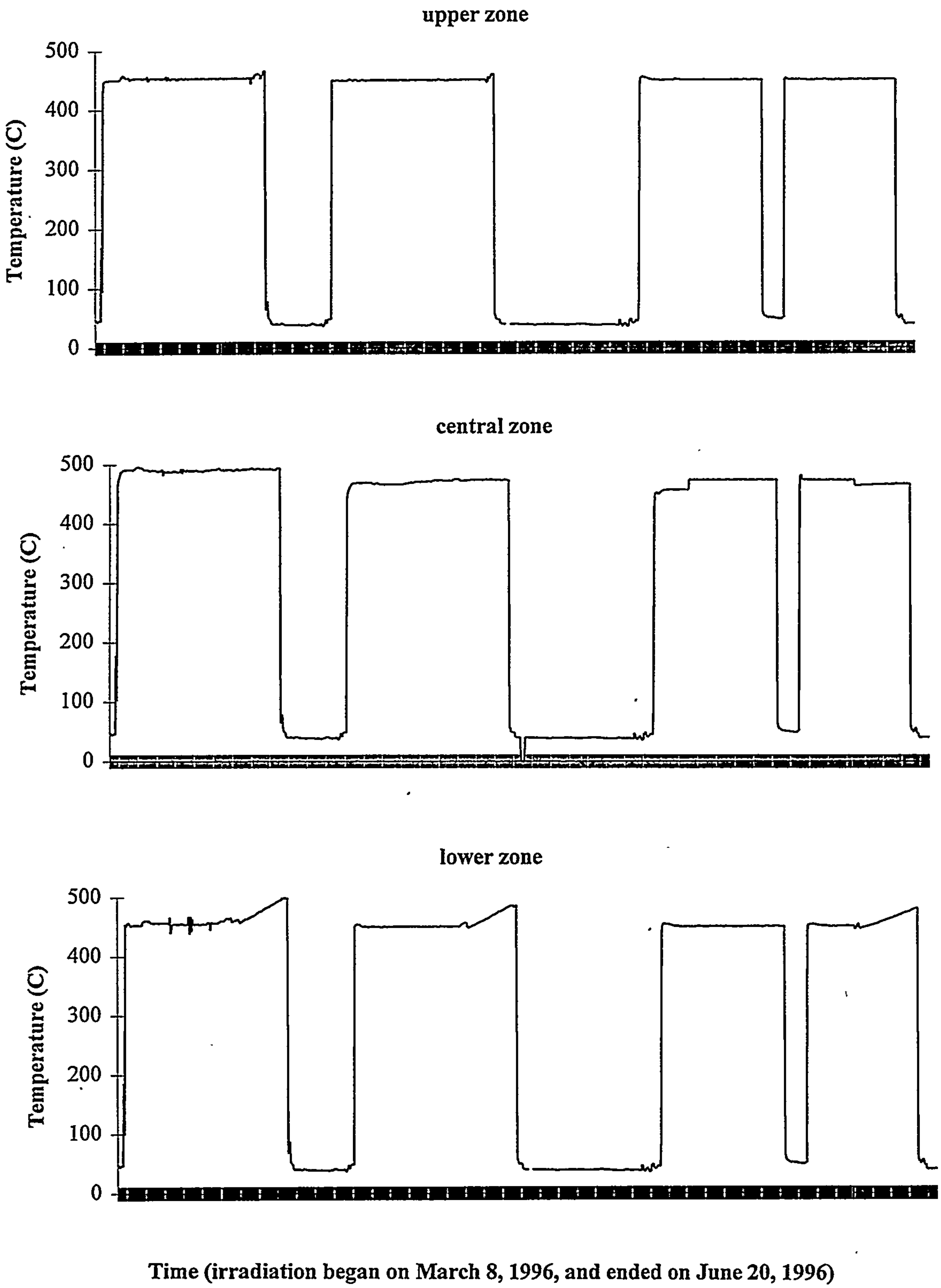

Figure 2: Average temperature of the three temperature zones over the course of the irradiation. The third irradiation cycle was interrupted for approximately 2 days.

Evolution of the heating profile during a reactor cycle

One area in which the data suggests the need for further examination is the evolution of the nuclear heating profile in the RB☆ facility during a reactor cycle. The difference in the specimen and enclosure temperatures increases with increased heat generation within the subcapsule. A plot of the percentage change in the temperature difference between the specimen and enclosure thermocouples from the beginning to the end of the cycles (averaged over the three cycles) is shown in Figure 3. The subcapsules located towards the end of the experimental region show an increasing temperature difference as the reactor cycle progresses. This is indicative of the increased heating in that region and is consistent with the gradual reduction in the flow of neon to those regions required to maintain specimen temperature. For subcapsules 6 through 11, the temperature difference decreased as the reactor cycle progressed, which implies that the heating rate in this region decreases during a cycle. Data used in the design of the capsule does not reflect such a reduction. The magnitude of the change for subcapsules 1 and 15 does not follow the pattern of the other subcapsules. These subcapsules may be located in a portion of the experimental region in which the fluxes behave differently than in the portion of experimental region bounded by subcapsules 2 and 14.

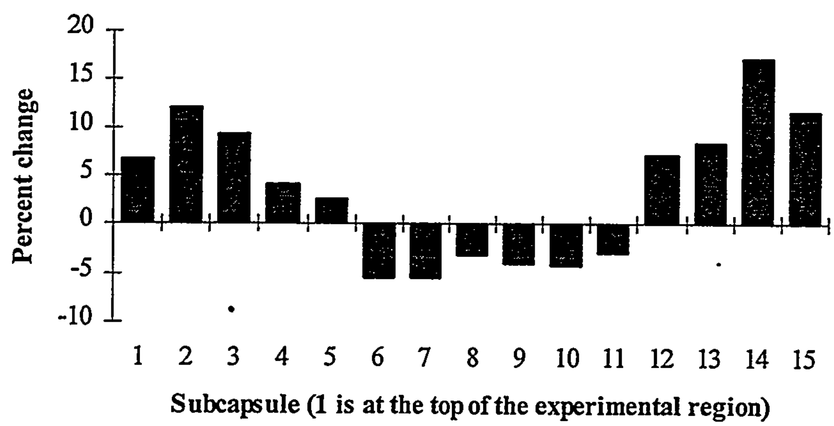

Figure 3: Plot of the percentage change in the temperature difference across the subcapsules over the course of a reactor cycle. The temperature difference is indicative of the heat generation within a subcapsule.

FUTURE WORK

In order to effectively address the issues raised concerning the operation of the TRIST-ER1 capsule, additional analysis must be undertaken. These investigations may be helpful in answering questions concerning the heat generation profile in the RB☆ position in order to assist in the design of future capsules.

REFERENCES

1. W.S. Eatherly et. al., in Fusion Materials Semiannual Progress Report for the Period Ending December 31, 1995, DOE/ER-0313/19, PP. 241-248.

2. Senn and Mixon, Nuclear Technology, 12, 1971, p235.