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TRANSIENT IRRADIATION EXPERIMENTS
WITH VIBRATIONALLY COMPACTED UO₂ FUEL RODS IN TREAT*

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MASTER

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INTRODUCTION

A cooperative study was conducted by Argonne National Laboratory (ANL) and Pacific Northwest Laboratory (PNL) to investigate the behavior of Zircaloy-2-clad, vibrationally compacted UO₂ fuel rods undergoing nuclear excursions in the Transient Reactor Test Facility (TREAT). The irradiation furnished information of interest to the Reactor Safety Program at ANL as well as the Plutonium Utilization Program at PNL,

EXPERIMENTAL

Five experiments were performed to obtain high-speed (1000 frame/sec) color motion pictures of single fuel rods undergoing transient irradiations. The photography was accomplished through a series of mirrors and a rectangular container (Figure 1) with transparent windows specially designed for photographic experiments in TREAT.^(1,2,3)

Each fuel rod tested (Figure 2) contained between 166 and 168 grams of pneumatically impacted, vibrationally compacted UO₂ (5.01% enriched), densified to 86-88% of theoretical. To simulate thermal reactor fuel rods, each rod contained a 1.82 cm (0.72 in.) long plenum. In addition, a 1.27 cm (0.5 in.)

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diameter depleted UO_2 insulator pellet was located at each end of the fuel column. Pneumatic impaction is a closed die, hot forging technique that produces oxide fuel particles of nearly theoretical density.⁽⁴⁾ The fuel prepared by this process had an oxygen to uranium ratio of 2.013, an average sorbed gas content of 0.042 cc/gm, an average particle density of 10.64 g/cc, and a moisture content of 27 ppm.*

In all five experiments, thermocouples were attached to the outer surface of the rods at the center of the fuel column and near the bottom pellet-fuel interface. Each rod was submerged in three liters of demineralized water under one atmosphere of helium pressure.

Two of the five experiments resulted in complete fragmentation of the fuel rods. The three other fuel rods were subjected to less energetic excursion and displayed varying degrees of failure.

Experiment No. 236T

The oscillograph record for Experiment No. 236T (Figure 3) shows that the fuel rod was subjected to a maximum reactor power of 1118 MW. The reactor period was 75 msec and the reactor integrated power was 338 MW-sec which resulted in a total fission energy input of 223 cal/g UO_2 . The motion picture obtained during the transient showed a relatively mild event. The first indication of heating was boiling of the coolant water along the length of the rod at an integrated power near 200 MW-sec (130 cal/g UO_2). Reddening of the fuel rod in the region of the upper one-half of the fuel column was observed after reactor power had reached a maximum. A region about 0.5 inch long near the center of the fuel column appeared to remain at a maximum temperature longer than the rest of the rod. Inspection of the rod after the transient

* These analyses were determined from -65 +100 mesh particles.

(Figure 3) revealed that a small clad bulge was formed near the bottom of the fuel column, but the cladding was not breached. A postirradiation radiograph revealed that the fuel relocated into the bulged area. Thermocouples attached to the cladding failed early in the transient and no temperatures were recorded.

Experiment No. 235T

The oscillograph record for Experiment No. 235T (Figure 4) shows that the fuel rod was subjected to a maximum reactor power of 1297 MW. The reactor period was 71 msec and the reactor integrated power was 354 MW-sec which resulted in a total fission energy input of 236 cal/gUO₂. The events observed in the motion picture of this transient were almost the same as those observed in Experiment No. 236T. A peak cladding temperature of 1350 °C was recorded by the thermocouple near the center of the fuel column. Inspection of this rod after the transient (Figure 4) revealed that a clad bulge was formed about 3/8 in. above the bottom pellet-fuel interface. The cladding was not breached and the fuel relocated into the bulged area. The bulge was larger than the one formed in Experiment 236T, and the fuel rod bowed during the transient.

Experiment No. 237T

The oscillograph record for Experiment No. 237T (Figure 5) shows that the fuel rod was subjected to a maximum power of 1430 MW and a resultant integrated power of 392 MW-sec. The reactor period was 67 msec. The cladding bulged near the top and bottom pellet-fuel interfaces but clad penetration did not occur during the testing of this rod. The movie of this transient was more dramatic than the films obtained during Experiments 235T and 236T. The movie showed boiling commencing when the reactor integrated power was about 225 MW-sec (150 cal/g UO₂). A high temperature band

appeared to form around the rod near the bottom pellet-fuel interface when the integrated power was about 390 MW-sec (260 cal/g UO_2). The rest of the rod appeared to be a dull red. As the reactor power subsided the red portion of the rod increased in brightness. About one second later the fuel rod began to cool. The highest clad surface temperature recorded was 2090 °C. This temperature was recorded by a thermocouple that was attached to the cladding where the bulge appeared.

Experiment No. 233T

The fuel rod (Figure 6) in Experiment 233T was tested at a peak reactor power of 2472 MW and a reactor period of 48 msec which resulted in an integrated power of 507 MW-sec and a total fission energy input of 335 cal/g UO_2 . Boiling of the coolant along the fuel rod at an integrated power near 85 MW-sec (56 cal/g UO_2) was the first activity noted on the film. At an integrated power near 420 MW-sec (280 cal/g UO_2), a bright flash started near the top pellet-fuel interface, on the surface farthest from the camera, and caused complete overexposure of the film. The residue (Figure 6) of this test showed that the fuel did not melt during this experiment. The quartz window ~~of the inner photographic~~ ^{one edge of inner photographic} container was separated from the container ~~along one edge~~ during this transient.

Experiment No. 234T

The fuel rod (Figure 7) in Experiment No. 234T was tested at a peak reactor power of 3541 MW and a reactor period of 43 msec which resulted in an integrated power of 634 MW-sec and a total fission energy input of 418 cal/g UO_2 . The film of this experiment showed a more violent reaction than occurred during Experiment No. 233T. The first indication of activity was the start of a flash in the middle of the fuel column on the surface farthest from the camera. This occurred

at a reactor integrated power of 355 MW-sec (235 cal/g UO_2). Three milliseconds after the start of this flash, the ~~inner~~^{window} quartz[^] was blown from one edge of the inner container. The residue (Figure 7) of ~~this test~~^{the fuel rod} showed that a portion of the fuel melted during this experiment.

CONCLUSIONS

A summary of the nuclear energy inputs and final fuel rod appearances for the five experiments is shown in Table I. Comparison of the films and data obtained from these tests with those of fuel rods containing UO_2 pellets (previously tested by ANL) indicates that:

1. The fission energy required to produce clad failure in vibrationally compacted fuel rods is between 260 and 330 cal/g UO_2 . The fission energy required to produce clad failure in pelleted fuel rods is about 290 cal/g UO_2 .⁽⁵⁾
2. The mechanisms leading to clad failure in pelleted and vibrationally compacted fuel rods appear to be different. Localized clad bulging was observed with vibrationally compacted fuel rods subjected to fission energies 10-20% below that required to cause clad failure in pelleted fuel rods. At threshold[#], the cladding of pelleted fuel rods failed by clad melting. Clad bulging was not observed with pelleted fuel rods. Although the mechanisms leading to clad failure appear to be different for the two types of fuel rods, the effects of these failures have not been established.

[#] For the purpose of this paper, threshold is defined as initial clad penetration.

3. These preliminary experiments indicate that, in the energy range resulting in clad failure, the percent of metal-water reaction is less for vibrationally compacted fuel than for pelleted fuel. This is attributed to the difference in the postulated failure mechanism of the two types of fuel rods. Fuel was expelled from vibrationally compacted fuel rods before any appreciable amount of clad-water reaction occurred. Pelleted fuel remained in the cladding longer and melted more of the cladding than the vibrationally compacted fuel did.

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Figure 1 - Container for Photographic Experiments in TREAT

Figure 2 - Cross-Section of Fuel Rods Tested

PHOTOGRAPH OF FUEL ROD
AFTER TRANSIENT

Figure 3 - Oscilloscope Record and Residue
of Experiment No. 236T

PHOTOGRAPH OF FUEL ROD
AFTER TRANSIENT

Figure 4 - Oscilloscope Record and Residue
of Experiment No. 235T

PHOTOGRAPH OF FUEL ROD
AFTER TRANSIENT

Figure 5 - Oscillograph Record and Residue
of Experiment No. 237T

PHOTOGRAPH OF FUEL ROD
AFTER TRANSIENT

Figure 6 - Oscilloscope Record and Residue
of Experiment No. 233T

PHOTOGRAPH OF FUEL ROD
AFTER TRANSIENT

Figure 7 - Oscilloscope Record and Residue
of Experiment No. 234T

Table I - Summary of Experiments

<u>Experiment</u>	<u>Energy Input (cal/g UO₂)</u>	<u>Fuel Appearance After Transient</u>
236T	223	Clad bulged near bottom of fuel.
235T	236	The Rod bowed. Cladding bulged near bottom of fuel.
237T	259	Cladding bulged near top and bottom of fuel.
233T	335	Complete fragmentation.
234T	418.	Complete fragmentation.