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IN-REACTOR RUPTURE TESTING OF ZIRCALOY-2 CLAD SEVEN-ROD CLUSTER FUEL ELEMENTS

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IN-REACTOR RUPTURE TESTING OF ZIRCALOY-2 CLAD SEVEN-ROD
CLUSTER FUEL ELEMENTS

R. L. Call and D. C. Kaulitz

April 15, 1960

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IN-REACTOR RUPTURE TESTING OF ZIRCALOY-2 CLAD SEVEN-ROD
CLUSTER FUEL ELEMENTS

R. L. Call and D. C. Kaulitz

INTRODUCTION

One of the problems involved in the design of the Hanford New Production Reactor (NPR) is determining the rapidity with which a fuel element would fail once water had penetrated the cladding. A series of three in-reactor rupture tests have been performed in the GEH R3X3P7 loop at the Engineering Test Reactor (ETR) to determine the failure delay time or incubation period of unirradiated and irradiated fuel elements.

SUMMARY

Three tests have been run in the ETR in high temperature, high pressure, recirculating water. In one test, previously unirradiated fuel elements were used and in the other two the fuel was irradiated to 2400 MWD/T at HAPO prior to insertion in the ETR.

Failure was initiated by shearing off a projection on the surface of one rod of a fuel element, thus opening a 25-mil hole through the cladding. The projection was sheared off by a hydraulically operated chisel controlled from outside the reactor.

The first test was operated seven hours after the defect was opened with no failure. Failure is defined as having occurred when sufficient uranium oxide has formed to split open the cladding and release large amounts of fission products into the loop water. The second test was operated for fourteen hours after the defect was opened with again no failure. The third test was operated for only 33 minutes after the defect cap was sheared off before fission product activity in the loop water caused the test to be terminated.

DISCUSSION

Description of Fuel Elements and Rupture Mechanism

The fuel elements used in this series of in-reactor rupture tests were fabricated from rod stock coextruded in Zircaloy-2 cladding at Nuclear Metals, Inc. of Cambridge, Massachusetts. The rods were a nominal 0.593 inches O.D. with a cladding thickness of 0.020 inches for the first test and 0.030 inches for the second and third tests. The inter-rod spacing was 0.055 inches. The rods were welded to triangular end supports.

A projection was welded to the surface of one rod of each cluster which was to be ruptured. A 25-mil hole was then drilled through the projection and into

[REDACTED]

the uranium. The open end of the hole was then welded shut. All rods were autoclaved in 400 C, 1500 psi steam for 72 hours before they were assembled into clusters. Figure 1 is a close-up view of a defected rod.

Each cluster containing a defected rod had a fitting welded to one end to which could be attached a device for shearing off the defect projection at the time desired. Figure 2 shows an assembled cluster with the fitting welded in place. The rupturing device consisted of a hydraulic cylinder with a chisel attached to the piston. A hydraulic line was run from the cylinder to a hand operated pump outside the reactor. Loop water pressure was used to retract the chisel after the defect had been sheared off. Figure 3 is a cross sectional view of a defected fuel element with the rupture mechanism attached. Also shown is the basket or container into which the fuel elements and rupture mechanism were placed before they were charged into the reactor.

Irradiation Prior to Rupture Testing

The defected clusters for the second and third rupture tests were irradiated to 2400 MWD/T at Hanford prior to charging them into the ETR. These clusters were placed inside aluminum baskets and charged into a single-pass, reactor test hole cooled by reactor process water. Figure 4 shows one of these fuel elements and its basket. The uranium used for the irradiated cluster rupture tests was 1.6 per cent enriched so that the desired exposure could be accumulated in a short time. The fuel elements were shipped to the ETR where they were removed from their baskets just prior to their irradiation in the ETR.

First Rupture Test

As was noted above, the first test of the series used previously unirradiated clusters. Three clusters (one defected) were used in making up the fuel charge. Each cluster was 9.5 inches long with a uranium length of eight inches. All three clusters contained natural uranium. After the clusters were charged, the reactor was operated at full power for one hour and then the defect projection was sheared off. An increase of 40 mr of gamma activity in the loop water was noted at that time. No further activity increase was noted although the reactor was operated for seven hours after the defect had been opened. After the seven-hour period, the reactor was shut down and the rupture test removed. The defected rod was sectioned through the defect and polished. A small lens-shaped pocket of uranium oxide, approximately 40 mils in diameter by 12 mils deep was observed under the defect. An estimated 1.5 milligrams of uranium had been converted to oxide. The oxide pocket can be seen in both Figure 5, a macro of the cross section through the defect, and in Figure 6, a photomicrograph of the defect. Tests performed at Hanford in high temperature, high pressure, out-of-reactor, recirculating loops in the same manner as the in-reactor tests and using similar material showed that failure should occur in two hours or less after the defect was opened to the loop water. As can be seen from Figure 6, failure in the sense of sufficient oxide formation to split open the cladding, did not occur.

Irradiation and temperature conditions for the first test were:

Loop inlet temperature

234 C

[REDACTED]

Loop outlet temperature	258 C
Flow	70 gpm
Loop pressure	2000 psia
Specific power	22.2 kw/ft of rod or 24.8 watt/gm
Surface heat flux	488,000 BTU/hr-ft ²
Cladding surface temperature	286 C
Uranium core temperature	501 C

Second Rupture Test

The charge for the second rupture test consisted of a 1.6% enriched irradiated cluster and two unirradiated natural uranium clusters as heaters. The irradiated cluster was 11.6 inches long with a 10.0-inch uranium length and the heater clusters were 10.0 inches long with an 8.4-inch uranium length. It was necessary to attach the rupture mechanism to the defected cluster under several feet of water. Figure 7 shows the jig and assembly tool used to perform this operation. The defected cluster and the rupture mechanism were then inserted into the basket.

Several months elapsed between the discharge of the defected clusters for the second and third rupture tests from a Hanford reactor and their testing in the ETR. Therefore, after the second rupture test was charged, the ETR was operated for three days to build up short half-life fission products in the defected cluster before the defect was opened. Two hours after the defect was opened up, a seven mr burst of activity was observed in the loop water. No further activity was observed so permission was obtained to cycle the reactor from zero power to full power several times. Full power operation produced a core temperature of approximately 800 C in the defect cluster and it was hoped that this thermal cycling would promote failure of the defected rod. Fourteen hours after the defect was opened the reactor was shut down and the test assembly removed.

The defected rod was sectioned through the defect and a spherical pocket of uranium oxide approximately 60 mils in diameter was found under the defect. An estimated five milligrams of uranium were converted to oxide. Cracks were found in the uranium both in the above section and in a section cut approximately midway between the ends of the rod. Figure 8 shows the cross section through the defect in a rough-polished condition. Large cracks can be seen in the uranium. Figure 9 is a photomicrograph of the defect itself. As can be seen in this photograph, the uranium around the defect is badly cracked. Figure 10 is a photomicrograph of the uranium-cladding-oxide junction in the upper left part of Figure 9. A crack can be seen in the cladding starting from this junction. The appearance of the crack in the cladding indicates that the rod was very close

to failure.

Irradiation and temperature conditions during ETR testing were:

Loop inlet temperature	278 C
Loop outlet temperature	287 C
Flow	70 gpm
Pressure	2000 psia
Specific power	27.0 kw/ft of rod or 32.5 watt/gm
Surface heat flux	594,000 BTU/hr-ft ²
Cladding surface temperature	323 C
Core temperature	633 C

Third Rupture Test

The third rupture test was similar to the second except that the defect projection was sheared off four hours after the reactor reached the power level requested for the test. Thirty-three minutes after the defect was opened the loop water activity was so great that reactor shutdown was required. The loop was cooled as rapidly as possible and the test assembly removed. Figure 11 shows the cluster as it appeared when it was received in the examination cell. The defected rod was swollen so that it touched the three rods adjacent to it. Figure 12 is a view of the defected rod after it was cut from the cluster. As can be seen, the uranium was gone from this region of the rod except for two loose pieces, one of which can be seen through the split in the cladding. An estimated 53 grams of uranium were converted to oxide in this test.

The defected rod was put in a tube which was poured full of a thermosetting clear plastic to immobilize the loose pieces. A longitudinal section was made through the end cap. This section can be seen in Figure 13. A loose piece of uranium can be seen in this section. A transverse section through the rod near the defect is shown in Figure 14. The uranium in this section is badly cracked. A longitudinal section through the swollen part of the rod away from the end cap is shown in Figure 15. The uranium in this area is also severely cracked.

CONCLUSIONS

The system described herein is a workable and successful means for opening a defect in the cladding of a fuel element during irradiation. It is easily built and easily operated and can be adapted to geometries other than clusters. It permits fuel elements to be irradiated in a production reactor

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until they have obtained the desired exposure and then be discharged and shipped to another reactor for testing. The method does suffer from two drawbacks, however. The projection which covers the defect must be welded in place and there is a heat affected zone in the uranium under the weld bead. The uranium immediately around the defect is not affected. Also, the saddle, by which the projection is attached to the surface of the fuel element is, in effect, a thickening of the cladding and may affect the time to failure. In ex-reactor tests defected rods with a rupture saddle welded over the defect had incubation time about one-half hour longer than defected rods with no rupture saddle.

It is apparent from the three in-reactor tests that have been run, that even with very similar material there can be a great difference between the time to failure of two separate tests. Further tests are needed to establish whether these tests were representative tests. It is possible that the cracking observed in the third test was responsible for the rapid failure.

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FIGURE 1

Close-Up of a Defected Rod Showing the Rupture Saddle Welded in Place.

FIGURE 2

One of the Seven-Rod Cluster Fuel Elements Used in the In-Reactor Rupture Tests.

FIGURE 3

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FIGURE 4

A Defected Seven-Rod Cluster Element and the Basket in Which it Was Irradiated at Hanford Prior to the Rupture Test at the ETR.

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FIGURE 5

Cross Section Through the Defected Rod
of the First ETR Rupture Test. 1-1/2X.

FIGURE 6

Photomicrograph of a Cross Section Through
the Defect of the First Rupture Test. 50X.

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ASSEMBLY TOOL

RUPTURE EXPERIMENT

FIGURE 7

FIGURE 8

Rough-Polished Cross Section Through the Defect of the Second Rupture Test. 4X.

FIGURE 9

Photomicrograph of the Defect in the Second Rupture Test. Note the Cracks in the Uranium. 50X.

FIGURE 10

Photomicrograph of the Uranium-Cladding-Oxide Junction in the Upper Left of Figure 9. . Note the Crack in the Cladding at the Junction. Surface Prepared by Ion Bombardment. Polarized Light. 250X.

FIGURE 11

Defected Cluster of the Third Rupture Test "As Received". 2X.

FIGURE 12

Defected Rod of the Third Rupture Test.

FIGURE 13

Longitudinal Section Through the End Cap of the Defected Rod of the Third Rupture Test. 1-1/2X.

FIGURE 14

Transverse Section Through the Defected Rod of the Third Rupture Test. The Section was Made Near the Defect. 3X.

FIGURE 15

Longitudinal Section Through the Swollen Part of the Rod
Away from the End Cap. Third Rupture Test. 1-1/2X.

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