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FLOW LOOP DEFECT-TEST BEHAVIOR OF NPR SIZE
COEXTRUDED FUEL TUBES

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June 7, 1960

FLOW LOOP DEFECT-TEST BEHAVIOR OF NPR SIZE COEXTRUDED FUEL TUBES

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FLOW LOOP DEFECT-TEST BEHAVIOR OF NPR SIZE COEXTRUDED FUEL TUBESINTRODUCTION

Ex-reactor high temperature, high pressure recirculating water loop defect-tests have been made on NPR size coextruded fuel tubes. The behavior in terms of fuel corrosion loss and fuel shape distortion for "pin-hole" type defects has been determined. Effects of variable annular spacing on the defect-test behavior and the influence on the mechanical and metallurgical conditions of adjacent components has been observed.

SUMMARY AND CONCLUSIONS

NPR size fuel tubes with "pin-hole" type defects were tested in an ex-reactor loop at 300 C, 1650 psi, and 16 fps flow. The defected tubes were tested in different geometric arrangements to simulate a variety of possible operating conditions.

Fuel tubes with the defects in the outside surface and with annular spacing between the process tube and the fuel tube in the range of 0.060-0.120 inch, and between the fuel tubes in the range of 0.105-0.210 inch display a consistent behavior. Fuel corrosion losses are about the same for both tube sizes during the early stages of failure. In advanced stages of failure the thick-walled inner fuel tube corrodes faster than the thin-walled outer fuel tube. Distortion of both the inner and outer shapes is a minimum during the early stage of failure with little interaction between components. In the advanced stage of failure, the inner tube is damaged more than the outer tube, but this additional damage appears unimportant.

When annular spacing between components is zero (jam fit) at the site of the defect, the behavior is not consistent. Defect incubation periods may be extended by the jam fits of the components. When failure does occur, a higher fuel corrosion rate with an accompanying severe fuel shape distortion results. Considerable mechanical force may accompany the severe fuel shape distortion and evidence of this was observed in the tests. Forces were sufficient to break 1/4-inch stainless steel set-screws used in positioning the fuel tubes and to damage a tubular end closure so that failure at the closure occurred. Permanent deformation of the Zircaloy-2 process tube sections was not observed. There was no mechanical or metallurgical (Zircaloy-hydride formation) damage imparted to either adjacent fuel tubes or Zircaloy-2 process tubes at the sites of the failures.

O.D. pin-hole type defects on NPR size tube-tube fuel material (unirradiated) behave in a tolerable fashion when there is sufficient coolant annulus. When the annulus is reduced to zero, defect behavior becomes more of a problem because of increased fuel corrosion, distortion, and component interaction. The poor behavior in the case of a restricted annulus may result because of decreased localized flow, increased restraint of fuel corrosion products, and retention of hydrogen corrosion product at the site of the failure.

Based upon in-reactor failures of irradiated coextruded rod material,⁽¹⁾ it is expected that in-reactor failure of tube material may be more severe than indicated in these tests.

EXPERIMENTAL PROCEDURE

Fuel material samples were NMI coextruded NPR size inner and outer tubes with nominal 0.020-inch clad. Dimensions of the tubular fuel will be found in the

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-3-

HW-65563
6/7/60

Appendix. Four pieces of each size were cut from two-foot sections of extrusions so that metal quality factors, etc., would be equivalent. These were end-capped with welded Zircaloy-2 discs, beta treated for 10 minutes at 725 C, quenched and held 10 minutes in 590 C salt, and air-cooled. Each sample was then defectured with a 0.025-inch hole through the O.D. side wall to the uranium fuel.

A piece of NPR size Zircaloy-2 process tube was cut into 4-8 inch sections to be used as holders for the fuel tube samples and to provide the proper clearance for coolant flow. Stainless steel set screws through the wall at the ends of the process tube were used to position and hold the fuel tubes in place. The process tube sections were bright and clean so that their ability to pickup hydrogen during the defect-testing would be enhanced.

The fuel tubes and process tubes were assembled in four arrays, as shown in Figure I. In this manner, failure behavior for a variety of conditions was simulated.

The assemblies were tested simultaneously in a high temperature, high pressure recirculating water loop at 100-D Area. Total exposure time at 300 C, 1650 psi was five hours in one-hour increments. Coolant velocity was 16 fps during the first three and the fifth hour, but was accidentally reduced during the fourth hour to 2 fps. Examinations and measurements were made at the end of each one-hour test period. Destructive metallographic examination was made of the component parts of the test assemblies at the conclusion of the tests.

TEST RESULTS

First Hour Exposure

The appearance of the test pieces after one hour exposure at 300 C, 1650 psi, and 16 fps flow is shown in Figure IV. Pieces N_1 , R_1 , and R_2 appear as might be expected after this exposure.^(2,3) In each of these cases, a blister developed at the defect and split open. The blister on piece N_2 developed to the point of imminent failure. Defects on samples N_3 , N_4 , R_3 , and R_4 are shown in various stages of incubation with R_3 the most advanced. Weight loss and dimensional data are in the Appendix. Figure II and III are plots of the fuel tube weight losses.

Second Hour Exposure

The appearance of the test pieces after the second hour of exposure is shown in Figure V. Samples N_1 , N_2 , R_1 , and R_2 , pieces with appreciable annular spacing, behaved consistently. Each lost uranium fuel but did not distort much. Sample R_3 , with zero annular spacing, failed by the development of a very large blister which split open and lost 3-4 times more fuel than either R_1 or R_2 . Samples N_3 and N_4 appear unaffected by their exposure indicating that the jam fit of these components effectively sealed the defect. Sample R_4 , although a jam fit, had incubated and failure appears imminent. The degree of defect sealing achieved by the jam fits is probably influenced by the match of the mating surfaces (See Figure I).

Third Hour Exposure

Figure VI shows the test samples after the third hour of exposure in the loop. N_1 and N_2 behaved consistently in both fuel weight loss and fuel shape distortion.

HW-65563
6/7/60

R₁ and R₂ also behaved consistently, but lost fuel at a greater rate than their companion outer tubes, N₁ and N₂ (Figure III). Jacket failure had occurred by corrosion product break-through of the clad remote from the initial defect as the site of fuel corrosion has receded from the initial defect. The defect of N₃ incubated somewhat and N₄ is still unaffected. R₃ doubled its weight loss with minor additional fuel shape distortion. Incubation of R₄ was completed with the development of a larger than normal blister which split open to expose a large fuel surface area to the coolant.

Fourth Hour Exposure

During the fourth hour of exposure the coolant flow in the test loop was inadvertently reduced to about 2 fps compared to the previous flow of 16 fps. An error made during a maintenance operation on the loop by-pass valve was responsible for the reduced flow during the fourth hour. Figures II and III (weight loss data) reveals that the defect behavior in terms of fuel loss continued in what appears to be a normal fashion. There is no photograph showing the appearance of the test sample after the fourth hour of exposure, but a noticeable change was the formation of many small mounds in the fuel clad away from the site of the initial defect. The nature of these small mounds is shown in Figure VII. It is believed that these small mounds developed as a result of the reduced flow during the fourth hour of exposure. Outer tube sample N₄ remained unaffected during the fourth hour.

Fifth Hour Exposure

Coolant flow during the fifth hour exposure was returned to the intended 16 fps. During the fifth hour fuel corrosion and fuel shape distortion for the failing samples continued as indicated in Figure II, III, and VII. Outer tube sample N₄ remained unaffected. Outer tube sample N₃ completed its defect incubation period and failed in a rather severe fashion as illustrated in Figure VII. Mechanical forces produced by formation of the large blister on N₃ were apparently sufficient to jam the fuel piece against a set screw and damage the end closure. Corrosion losses of N₃ are a total of both the side wall blister and the failed end cap. Figure II shows that the weight loss of N₃ attained that of both N₁ and N₂ by its performance during this one-hour exposure. It is believed that the major part of this corrosion loss occurred at the side wall defect.

Additional Exposure of N₄

Since sample N₄ (outer tube - jam fit) had not incubated to failure during its five hours of exposure, it was given additional test time. An exposure of three hours followed by another exposure of four hours did not change the appearance of N₄ from that shown in Figure VII. The maintenance of a tight jam-fit during the total 12 hours of exposure must have sealed the defect sufficiently to prevent the access of a sufficient amount of water to the uranium to produce failure. This sample was later used, with a normal annular spacing, in a programmed reactor shut-down defect-test and failed in a manner similar to N₃ of this test program.⁽⁴⁾ The behavior of N₄ in the programmed shut-down test suggests the possibility of considerable bond damage, such as might be produced by uranium or Zr-2 hydride reaction, by a slow incubation period during its previous 12 hours of exposure.

Metallographic Examinations

All of the failed tubes were sectioned through the initial defects and the cross-sections are shown in Figure VIII. It is seen that a considerable portion of the fuel cross-section has been corroded and washed out. In the cases with normal (N_1 , R_1) and half normal (N_2 , R_2) annular spacing, very little distortion of the fuel shape has occurred. In the case of jam fits (N_3 , R_3 and R_4) severe shape distortion has accompanied the fuel corrosion. Sample N_4 , which appeared unaffected by the test, was used for additional testing purposes as will be described in another report. Examination of the clad-fuel bond revealed that it performed in a desirable manner as there was no evidence of preferential mechanical or corrosion failure in this area.

The exposed surfaces and the cross-sections of the Zr-2 material of both the fuel tubes and the process tubes in the areas where there were jam-fits failures were examined. There was no evidence of either mechanical damage or the formation of ZrH_2 .

APPENDIXTABLE IWeight Losses of NPR Inner and Outer Tubes - Grams

Sample	Annulus - inches	Weight loss in grams at times in hours					
<hr/>							
Outer tubes - initial							
Wt. 2855 g.		0 hr	1 hr	2 hr	3 hr	4 hr	5 hr
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N ₁	0.120"	0 g.	9	27	68	123	197
N ₂	0.060	0	0	23	63.5	127	200
N ₃	0.0	0	0	0	0	0	195
N ₄	0.0	0	0	0	0	0	0
<hr/>							
Inner tubes - initial							
wt. 2415 g.							
<hr/>							
R ₁	0.210	0	9	36	109	209	327
R ₂	0.105	0	4.5	23	77	159	277
R ₃	0.0	0	0	91	200	340	537
R ₄	0.0	0	0	0	45.5	145	296

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-6-

HW-65563
6/7/60

TABLE II

Maximum Diameters of NPR Inner and Outer Tubes - Inches

Sample	Annulus - Inches	Maximum Diameter in Inches at Times in Hours					
		0 hr	1 hr	2 hr	3 hr	4 hr	5 hr
<u>Outer Tubes</u>							
N ₁	0.120"	2.47"	2.58	2.58	2.58	2.58	2.58
N ₂	0.060	2.47	2.54	2.56	2.56	2.56	2.56
N ₃	0.0	2.47	2.47	2.50	2.50	2.56	2.56
N ₄	0.0	2.47	2.47	2.47	2.47	2.47	2.48
<u>Inner Tubes</u>							
R ₁	0.210"	1.43"	1.64	1.49	1.55	1.56	1.56
R ₂	0.105	1.43	1.54	1.54	1.54	1.54	1.54
R ₃	0.0	1.43	1.47	1.66	1.62	1.62	1.62
R ₄	0.0	1.43	1.43	1.47	1.62	1.61	1.61

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- 7 -

HW-65563

FIGURE I

Geometric Arrangement of Defected NPR Size Fuel Tubes in NPR Size Zr-2 Process Tube for 300°C, 1650 psi Loop Test. The Process Tube Section was 8" Long, the Inner Fuel Tube 6", the Outer Fuel Tube 5" and the Fuel Tubes were Positioned with Set-Screws Through the Process Tube Wall.

FIGURE II

Weight Loss Data for Defect-Tested NPR Inner and Outer Tubes with Varying Annular Spacings in an Ex-reactor Flow Loop at 300°C, 1650 psi.

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FIGURE II

Comparison of NPR Inner & Outer Tube Fuel Weight Losses with Annular Spacings which do not Affect the Defect Behavior (flow loop @ 300°C, 1650 psi).

FIGURE IV

Appearance of Defected NPR Size Coextruded Fuel Tubes After 1 Hour at 300°C, 1650 psi and 16 fps. Blisters have Developed and Opened on N1, R1 and R2. Failure is Emminent on N2. The Others are in Various Stages of Incubation.

DECLASSIFIED

-11-

HW-65563

FIGURE V

Appearance of Test Pieces After 2 Hours Exposure. . Samples N1, N2, R1, R2 and Performing Consistently. Samples N3, N4 Appear Unaffected. Sample R3 has Failed with a Greater Weight Loss and More Severe Distortion Than R1 and R2 Because of Restraint by the Jam Fit. Sample R4 is in a Stage of Incubation.

FIGURE VI

Appearance of Test Pieces After 3 Hours Exposure. The Defect of N3 is Incubating and N4 is Unaffected. Incubation of R4 has been Completed with the Development of a Large Than Normal Blister.

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-13-

HW-65563

FIGURE VII

Appearance of Test Pieces After 5 Hours Exposure. N3 Has Incubated to Failure and Mechanical Forces Produced by the Blister Have Damaged the End Closure so that it too has Failed. N4 has Remained Unaffected.

Cross-sections of outer tubes through sites of initial defects. Fuel weight losses of each about 200 grams. N3 was a jam fit sample and I.D. distortion resulted. N4 was unaffected by the test.

Cross-sections of inner tubes through sites of initial defects. Fuel weight losses of each, except R3, about 300 grams. R3 lost about 550 grams. Note that I.D.'s have not been distorted.

FIGURE VIII

Cross-Section Appearances of NPR Size Coextruded Fuel Tubes
After 5 Hour Test at 300°C, 1650 psi, in Ex-Reactor
Recirculating Loop

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