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**POSTIRRADIATION EVALUATION
OF ZIRCALOY PRESSURE TUBES
FROM KER-1 AND KER-2**

MARCH, 1965

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FROM KER-1 AND KER-2

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POSTIRRADIATION EVALUATION OF ZIRCALOY PRESSURE TUBES FROM KER-1 AND KER-2

INTRODUCTION

Four test loops, called the "KER loops" are located in the KE production reactor at Hanford. They are recirculating loops isolated from the main reactor coolant system and capable of operation at higher temperatures and pressures than the reactor proper. The Zircaloy-2 pressure tubes in these loops may be subjected to operating conditions similar to those in pressure tube reactors. Examination of tubes discharged from these loops can provide information indicative of results to be expected from operation of pressure tube reactors. Several tubes have been discharged from the loops and the results of postirradiation tests reported⁽¹⁾⁽²⁾⁽³⁾ in the past 6 or 7 yr.

SUMMARY

Two Zircaloy-2 pressure tubes representing different fabrication processes have been subjected to postirradiation examination after significant exposure in a production reactor. The tubes were discharged from KER loops 1 and 2 in July, 1963. One was fabricated by cold drawing to 30% reduction in area and the other by tube reducing to 50% reduction. Neither was autoclaved prior to exposure, but both developed thin, tenacious, abrasion resistant, oxide films. No increase in hydrogen content resulted from the oxidation.

The microstructure of tube reduced material showed a marked agglomeration of second phase particles that becomes more severe as radiation dosage increases. This effect was not noted in the drawn tubing. There is no evidence of recrystallization or grain growth in either tube as a result of exposure. In high temperature (300 C) burst tests, both types of tubes show a greater percentage strength improvement from irradiation than at room temperature. The high temperature ductility of the drawn material is maintained during irradiation to a greater degree than that of the tube reduced material.

Initial stress rupture tests on the drawn tubing show a 5% improvement in rupture strength for the degree of irradiation achieved in this program (unknown nvt). Secondary creep rate is also improved.

Slot type brittle fracture tests show no reduction in resistance to crack propagation at this level of irradiation.

DISCUSSION

In the ensuing discussion two tubes discharged from the KER loops in July, 1963, will be designated KER-1-63 and KER-2-63 to differentiate them from tubes discharged in earlier years from the same channels. The tube from loop 1 was produced by a process almost identical with that used to fabricate most of the pressure tubes for N-Reactor. The process is essentially one of hot extrusion followed by a 30% reduction in area by cold drawing. A complete description of the method is included in the Company "F" section of Reference (4).

The tube from Loop 2 is a mate to the one discharged earlier from KER-3 and described completely in Reference (3). As described in that document the process involved hot extrusion, cold drawing to 18% reduction in area, full anneal, and a final 50% reduction in area by tube reducing at room temperature.

The principal irradiation damage in the process tube material must arise from the fast flux associated with the charge in the tube. This effect is superimposed upon any effect from the cosine flux distribution of the entire reactor. Calculation of the actual integrated exposure in nvt is extremely difficult, and any information that might allow calculation of production reactor flux levels is classified. Therefore, we have resorted to expressing the relative fast flux distribution over the length of the tubes in arbitrary units based upon position of the various test charges in the tube, and the power level and duration of each test. This flux distribution is presented in Figure 1. Coolant temperatures during test operations ranged as high as 290 C.

FIGURE 1

**Flux Distribution and Test Specimen Locations
for KER-1-63 and KER-2-63**

The tubes were discharged from the reactor and sectioned and marked in such a way that each 3 to 4 ft length could be identified. ⁽³⁾ These sections were transported to the radiometallurgy facility where they were accurately cut into 15 in. lengths for burst test and stress rupture test specimens. Smaller samples for metallography and hydrogen analysis were taken from the end trimmings produced in cutting these 15-in. sections. Figure 1 shows the location and disposition of each of the test sections. The identifying number associated with each test section is an indication of its location in the reactor as measured in feet from the downstream end of the tube. Number 24 represents the approximate center of the reactor active zone with front and rear shielding falling at about 38 and 10 ft, respectively.

Thus a section of tubing between 20 and 24 ft has received maximum irradiation from the fuel charge. Those from 15 to 20 ft and 24 to 30 ft received moderate fast flux exposure, and those below 10 ft and above 38 ft were entirely surrounded by shielding and thus received virtually no irradiation.

Upon arrival at the radiometallurgy facility the 3- to 4-ft lengths of tubing were examined visually on the outside surface and internally with a borescope. Although neither of the two tubes had been autoclaved prior to installation in the reactor, both had a dark gray surface film after exposure. The film appeared to be thin and adherent and resistant to mechanical damage. The inside surface bore superficial longitudinal striations (Figure 6) probably caused by passage of fuel elements, but there were no scratches or gouges of any appreciable depth. The outside surfaces were free of any evidences of damage other than the obviously recent marks from the discharging operations. No evidence of localized corrosion was found anywhere on the surface of either tube.

Metallography was performed on samples of both tubes taken from the 3, 16, and 24 ft locations. These represent areas exposed to the full reactor environment as regard temperature, pressure, and chemical action of the coolant; however, the areas varied in irradiation exposure from zero in the Number 3 samples to a maximum in the Number 24 samples. Sections were taken in such a manner that the structure at the surface of the tube could be examined for any superficial surface hydriding that might have occurred. Transverse sections of the inside surface regions are shown in bright field illumination in Figure 2. Outside surface sections appear the same, and none show evidence of any hydrogen pick-up. This appearance is confirmed by the vacuum fusion analyses for hydrogen listed in Table I. These values are well within the limits of the purchase specifications for reactor pressure tubing.

Another feature noted in Figure 2 is the apparent agglomeration of second phase material in the irradiated specimens of KER-2-63. This effect was noted earlier in the examination of KER-3-61 reported in Reference (3).

Shielded

Shielded

Moderate Irradiation

Moderate Irradiation

Maximum Irradiation

Maximum Irradiation

KER-1-63KER-2-63FIGURE 2

Bright Field Micrographs of Transverse Sections
at Inner Surface of KER Tubing
(Note absence of hydrides; note also agglomeration of second phase
in irradiated specimens from KER-2-63.)

TABLE I
VACUUM FUSION HYDROGEN ANALYSES

Sample	Hydrogen, ppm
3-1	26 to 29
16-1	37 to 41
24-1	24 to 27
3-2	26 to 30
16-2	14 to 17
24-2	4 to 6

It is also apparent in longitudinal sections where the particles appear to cluster in chains or stringers in the working direction. It has been suggested that this is not truly a second phase but is rather an etching effect. In any event the effect is consistent in the present and in previously reported tubes and appears definitely to be influenced by irradiation. These two tubes as mentioned earlier were from the same lot and had identical fabrication histories.

The effect noted above is remarkably absent in the series of photomicrographs for KER-1-63 in Figure 2. The second phase distribution shows no dependence on irradiation being essentially the same for each of the three specimens. This tube differed markedly from KER-2-63 in fabrication having received less total cold work, no anneal, and no fabrication by tube reducing. Irradiated tubing from N-Reactor will soon be available for testing. These tubes were fabricated by the same process as KER-1-63. Effects of irradiation on second phase distribution will be closely observed.

Figure 3 shows polarized light micrographs of transverse sections of irradiated and unirradiated specimens from both tubes. The grains in KER-2-63 are somewhat larger and show a greater amount of distortion from cold work than those in KER-1-63. This is probably a result of the anneal and the greater amount of reduction received by the former. Neither tube shows evidence of any change in structure brought about by the irradiation.

As-Received

As-Received

Shielded

Shielded

Maximum Irradiation

KER-1-63

Maximum Irradiation

KER-2-63FIGURE 3

Polarized Light Micrographs of Transverse Sections of KER Tubing
(Note virtual absence of recrystallization or grain growth
resulting from reactor exposure.)

Burst tests have been performed on sections from both tubes at room temperature and at 300 C in the facility shown in Figures 4 and 5. Results of the tests are shown in Table II. Included in this table are results of similar tests performed earlier on tube KER-3-61. Inspection of that tube was covered in HW-75052⁽³⁾ including room temperature burst test results. Since that document was issued, 300 C burst tests have been performed on this material, and the results are in Table II. As mentioned earlier, KER-3-61 was fabricated at the same time and by the same process as KER-2-63.

Test specimens were cut to length and measured for diameter and wall thickness with remote equipment in a radiometallurgy hot-cell. Pressure in the specimen was continuously monitored during the test, and the ultimate hoop stress was calculated on the basis of original measurements and the maximum pressure attained. The stress recorded is the maximum stress on the fibers at the inner surface as calculated by the Lamé thick-wall formula. Elongations were determined on the room temperature tests from measurements made on a photograph of a transverse section through that portion of the specimen showing maximum enlargement (Figure 6). On the later tests at elevated temperature a method was devised for measuring the piece directly in the basin with a modified steel tape at great saving in time and expense. Neither method is as accurate as one would like and so the results are indicative only and are not to be interpreted too rigidly.

Because of a limited number of specimens it was not feasible to perform more than one test for each condition. Thus there is more scatter in the results than would have been true had there been an opportunity to average two or three tests for each point. However some conclusions can be drawn. The tests show that there is considerably more improvement in high temperature strength than in low temperature strength as a result of neutron exposure. This effect is more noticeable in the tube reduced than in the drawn material. Material protected by the shielding from neutron exposure but experiencing the reactor coolant environment showed little strength improvement and in some instances a slight loss in strength. The elongation measurements in this series of tests indicate that the high temperature ductility of the drawn tubing is retained better under irradiation than is that of the tube reduced material.

FIGURE 4
Irradiated Pressure Vessel Testing Facility

FIGURE 5

Detail of Underwater Stress Rupture Cell

TABLE II
BURST TEST RESULTS

Specimen ^(a)	Exposure	Test Temperature, C	Ultimate Hoop Stress	Elongation, %	Increase in Strength from Exposure, %
Tube KER-1-63					
- -	As-Received	20	116,000	10.8	- -
3-1	Rear Shield	20	108,200	10.4	-6.7
16-1	Near Maximum	20	130,000	2.2	12.0
- -	As-Received	300	67,000	12.4	- -
9-1	Front Shield	300	64,500	13.3	-3.7
34-1	Moderate	300	79,000	7.0	18.0
28-1	Near Maximum	300	74,100	15.6	10.6
Tube KER-2-63					
- -	As-Received	20	107,000	11.7	- -
3-2	Rear Shield	20	102,000	6.8	-4.7
16-2	Moderate	20	112,000	3.9	4.7
24-2	Maximum	20	111,000	4.9	3.7
- -	As-Received	300	58,700	19.2	- -
9-2	Front Shield	300	64,200	1.5	8.5
34-2	Moderate	300	58,800	6.5	0
28-2	Near Maximum	300	67,900	4.0	15.7
Tube KER-3-61 ^(b)					
- -	As-Received	20	106,500	9.5	- -
- -	Rear Shield	20	108,000	3.6	1.4
- -	Moderate	20	114,000	4.6	7.1
- -	Maximum	20	115,000	4.0	8.0
- -	As-Received	300	58,700	19.2	- -
- -	Rear Shield	300	60,500	11.7	3.1
- -	Moderate	300	71,200	0.7	21.2
- -	Maximum	300	70,200	2.8	19.7

(a) These specimen numbers, referred to Figure 1, will help to estimate the relative exposures of the specimens.

(b) The examination of this tube was covered in Reference (3). The values in this table for 20 C are taken from that document. Those for 300 C were obtained since publication of the document and have not previously been published.

FIGURE 6

Transverse Section Through Area
of Maximum Elongation
of Burst Test Specimen
from KER-1-63

(Note typical superficial striations
on inner surface; break shows
cleavage failure with very little
shear lip typical of room tempera-
ture tests of this material.)

Stress rupture tests have been performed at 300 C on sections of tubing having received maximum or near maximum exposure. Since the 30% cold drawn tubing of KER-1-63 is more nearly representative of the tubing later to be removed from N-Reactor, the stress rupture work has been concentrated on that tube. The results are shown in Figure 7. Here it is seen that the stress rupture strength for equivalent times to failure has been increased by about 5% due to irradiation. Creep rates are difficult to determine because it is not feasible to make many measurements during the test. The only way measurements can be made is by the expensive and time consuming method of shutting down and removing the specimen from the furnace. In only one test is it possible to report a secondary creep rate. That is on the test shown on the curve of Figure 7 as continuing beyond 4000 hr. It is running at a secondary creep rate of 2.85×10^{-5} %/hr. A test at the same stress level on unirradiated material⁽⁵⁾ showed a minimum creep rate of 4.5×10^{-4} %/hr and failed in 3024 hr. Additional creep tests are in progress and will be reported later.

Brittle fracture tests have been performed⁽⁶⁾ on specimens of tubing from KER-1-63 and KER-2-63. These tests, fully described in Reference (6), are performed by milling slots of various lengths in the tube wall and plotting the effects of these slots on the bursting strength of the tubing as shown in Figure 8. Tubes KER-1-63 and KER-2-63 reacted in virtually identical manner in this test so the points plotted in Figure 8 represent a composite of the two tubes. The irradiated specimens were from the maximum and moderate irradiation sections of the tubes (Figure 1). As indicated by the curve, irradiation at the levels achieved in these tests appears to have no effect on the resistance of these tubes to brittle fracture.

CONCLUSIONS

Neither of the tubes described in this report was autoclaved before being charged in the reactor. Both attained a dark gray, thin, tenacious, oxide film that resisted well the abrasive action of the charge-discharge operations. No fret marks were apparent, nor were there any localized

FIGURE 7

Effect of Irradiation on Stress Rupture Properties of KER-1-63

FIGURE 8

Effect of Irradiation on Crack Propagation Properties of KER-1-63 and KER-2-63

areas of accelerated corrosion. No increase in hydrogen content accompanied the formation of the oxide film. The differences in fabrication history of the two tubes did not appear to influence their reactions to the corrosive effect of the reactor environment.

The tube reduced specimen showed the same effect of irradiation on microstructure described in Reference (3) for a tube identical in fabrication. Both exhibited a marked agglomeration of second phase particles in those specimens subjected to the greatest irradiation. This effect was absent in the drawn tubing. No explanation for this behavior is apparent at this time.

There is no evidence of recrystallization or grain growth in any of the specimens examined from either tube. This confirms the conclusion reached in Reference (3) that 30 to 50% cold work is below the threshold value necessary to cause recrystallization to begin in Zircaloy-2 under the KER exposure conditions.

Some minor differences between the two types of material are indicated in the series of biaxial burst tests at room temperature and 300 C. Both types show a greater percentage strength improvement from irradiation in elevated temperature tests than at room temperature; this effect is more marked in the tube reduced material. The high temperature ductility of the drawn material, however, is maintained during irradiation to a greater degree than that of the tube reduced material. These effects on high temperature strength and ductility may result from the differences in second phase dispersion mentioned above.

Initial stress rupture tests on the drawn tubing show a 5% improvement in rupture strength for the degree of irradiation achieved in this program (unknown nvt). Also the secondary creep rate at a hoop stress of 57000 psi is more than 10 times better. Whether such improvements will continue with increased amount of irradiation must await the removal of tubing with a similar fabrication history from N-Reactor after increasing periods of exposure. There are tentative indications from work by others on tubes from the Plutonium Recycle Test Reactor (PRTR) that an initial increase in stress rupture life with short exposure may be followed by some decrease with continuing exposure.

Slot type brittle fracture tests⁽⁶⁾ on both types of tubes showed no effect of this level of irradiation on resistance to crack propagation. This behavior is borne out by Fraser⁽⁷⁾ in his work on irradiated PRTR tubing. All his crack propagation tests on material from 0 to 6×10^{20} nvt plot virtually on a single line.

REFERENCES

1. V. E. Kahle. Burst Testing of Irradiated Zircaloy Tubing, HW-64168, General Electric Company, Richland, Washington. March 4, 1960.
2. L. J. Defferding. Evaluation of Properties of Irradiated Zircaloy-2 Pressure Tubes-Interim Report, HW-67949 REV, General Electric Company, Richland, Washington. December 16, 1960.
3. R. C. Aungst. Postirradiation Evaluation of Zircaloy-2 Pressure Tubes from KER-3, Preliminary Report, HW-75052, General Electric Company, Richland, Washington. September 25, 1962.
4. R. C. Aungst and D. H. Curtiss. Procurement of Zircaloy-2 Process Tubes for N-Reactor, HW-80566, General Electric Company, Richland, Washington. March 1964.
5. R. C. Aungst. Stress Rupture Tests on Zircaloy-2 Process Tubes for N-Reactor, BNWL-8. January 1965.
6. R. C. Aungst and L. J. Defferding. Crack Propagation Tests on Normal and Hydrided Zircaloy-2 Reactor Pressure Tubing, HW-80567, General Electric Company, Richland, Washington. August 1964.
7. M. C. Fraser. Postirradiation Evaluation of Zircaloy-2 PRTR Pressure Tubes-Part III, BNWL-5. January 1965.

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