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ENGINEERING DEVELOPMENT DEPARTMENT QUARTERLY REPORT*
APRIL, MAY, JUNE, 1966

By

Engineering Development Department - H. Harty, Manager

Reactor Engineering Section - J. M. Batch, Manager

Mechanical Engineering Section - L. T. Pedersen, Manager

Engineering Materials and Mechanics Section - R. G. Wheeler, Manager

Engineering Analysis Section - J. C. Fox, Manager

July, 1966

RESTRICTED DATA

This [redacted] restricted [redacted] in the Atomic [redacted] transmittal or the [redacted] to [redacted] person is prohibited.

*The unclassified activities are reported in BNWL-367.

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RICHLAND, WASHINGTON

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ASSISTANCE TO GENERAL ELECTRIC N-REACTOR DEPARTMENT

ENGINEERING DEVELOPMENT DEPARTMENT QUARTERLY REPORT
APRIL, MAY, JUNE, 1966
FOR
DIVISION OF PRODUCTION
AND HANFORD PLANT ASSISTANCE PROGRAMS

ASSISTANCE TO GENERAL ELECTRIC N-REACTOR DEPARTMENT

N-Reactor Component Evaluation - R. C. Aungst

Pressure Tube Evaluation

Previously reported tests (BNWL-SA-179) have shown that cracks up to 3 in. long in Zircaloy-2 N-reactor pressure tubing will not propagate at temperatures above 125 °C. This crack arrest temperature for unhydrided tubing is illustrated in the left hand position of the curves in Figure 1.

Recent work has determined a crack arrest temperature for the same kind of tubing containing 275 ppm hydride. The tests at 300 °C and above were delayed for several months pending development of a satisfactory method of sealing a tube with a through-crack at those temperatures. The rubber sealants used at lower temperatures were not adequate and no substitutes were found that would withstand the high temperature, pressurized water environment. The problem was finally solved by lining the entire tube with a 20 mil copper bladder backed by a stainless steel patch in the immediate area of the crack. This device sustained the pressure in the tube until it failed either by catastrophic propagation or by ductile tearing beyond the end of the patch.

Figure 1 includes the results of elevated temperature tests of hydrided tubing at two slot lengths--0.81 and 3 in. Tests of the tubes with the shorter slot length up to 320 °C showed full length brittle failure. A tube with a 3 in. slot at 360 °C failed by a slight extension of the crack by ductile tearing. These results outline a crack arrest temperature of about 350 °C for tubing hydrided to 275 ppm.

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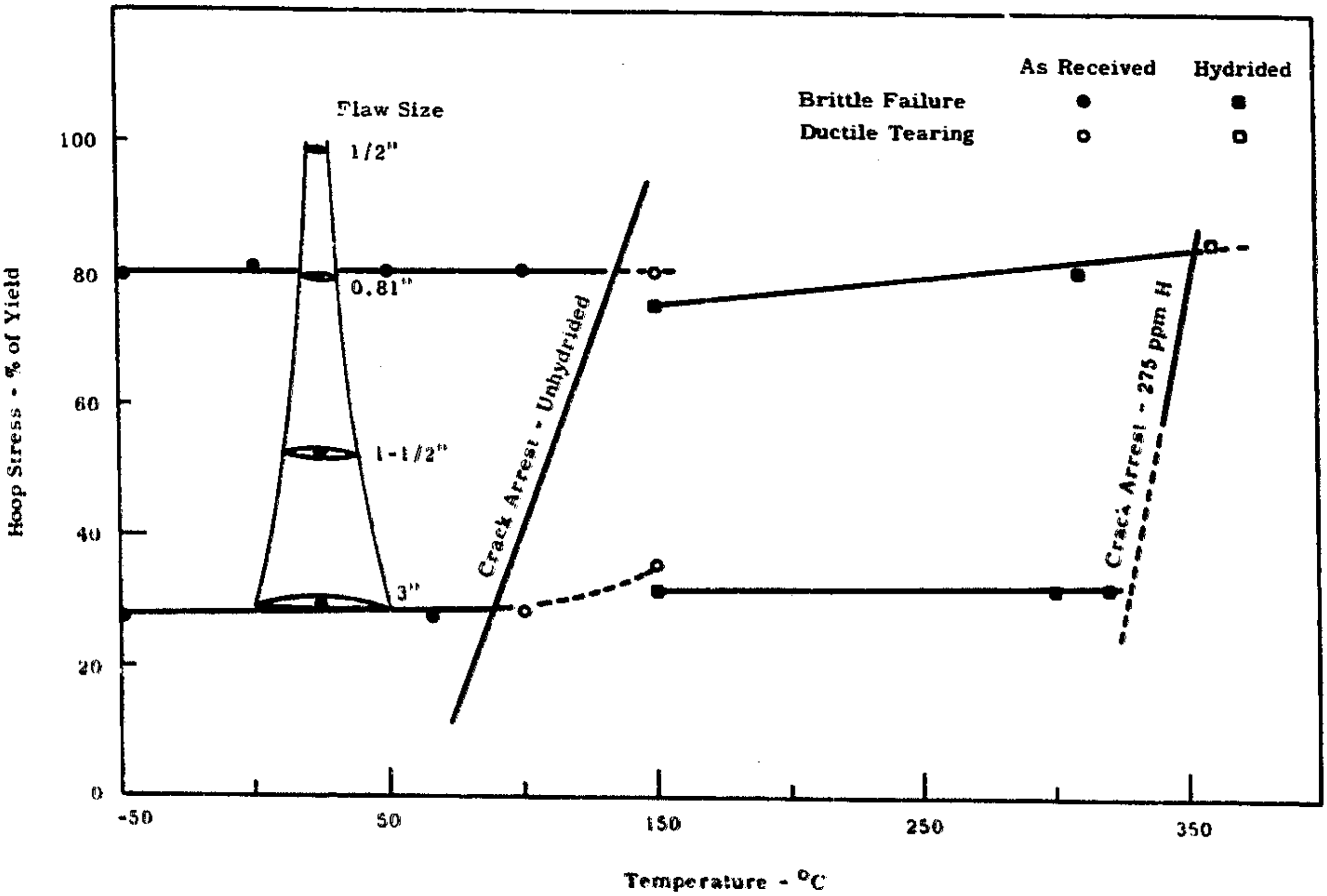

FIGURE 1. Crack Arrest Temperatures for Zircaloy-2 N-Reactor Pressure Tubes With and Without Hydriding

These tests show that while N-reactor tubing with 275 ppm hydride may fail in a brittle manner at 300 °C it should be safe from that type failure at 350 °C and above. The stress for failure is at essentially the same percent of yield for a given slot length regardless of the presence or absence of hydride. No test in this entire series failed at a stress lower than about 2 1/4 times reactor operating stress.

Special Fuel Studies - J. K. Anderson

Experiments investigating the boiling burnout conditions for the N-Reactor special fuel element were performed in the Thermal Hydraulics Laboratory heat transfer facility. Earlier, the boiling burnout conditions were found experimentally for three different electrically heated models of the fuel geometry with slightly different dimensions than the final design.

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Each of these models consisted of an unheated tube mounted concentrically in an electrically heated outer tube; cooling water flowed in the annulus between the two tubes. The dimensions of these earlier models are given under Models I, II, and III in Table I. During the current report period, a fourth electrically heated test section of fuel geometry was considered. This test section was exactly equivalent to the current fuel element (Model IV).

TABLE 1. Dimensions of Special Fuel Models

	Model I	Model II	Model III	Model IV
Heated Length, ft	2	2	8	2
Inner Tube OD, in.	1.220	0.739	0.739	1.364
Outer Tube ID, in.	1.775	1.364	1.364	1.753
Annulus Thickness, in.	0.277	0.312	0.312	0.195

The experiments with Model IV were conducted in the high pressure apparatus in the Thermal Hydraulics Laboratory at a system pressure of 1500 psig. Other operating conditions covered the following ranges:

Coolant mass velocity	0.5 to 6 million lb/hr-ft^2
Coolant inlet temperature	530 to 590 °F (275 to 310 °C)
Burnout heat flux	0.37 to 1.7 million Btu/hr-ft^2

Originally, 34 sets of burnout conditions were scheduled for investivation with this model. However, abnormal temperatures measured by burnout monitoring thermocouples welded to the outer surface of the heated tube forced an interruption of the program. During attempts to determine additional sets of burnout conditions, steady-state temperatures up to 1900 °F (1040 °C) were noted at heat fluxes well below the predicted burnout heat fluxes. These temperatures were approaching values at which serious weakening of the Hastelloy C heater tube would occur, and it appeared that destruction of the model would result from continued attempts to reach film boiling "burnout" conditions. A rerun of one of the earlier

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burnout experiments demonstrated that the high temperatures represented some change in the model behavior. Burnout heat fluxes for the two experiments, as indicated by large, rapid temperature rises, agreed within 5%. However, steady-state temperatures prior to burnout were about 1650 °F (895 °C) during the second experiment, as compared with 1050 °F (560 °C) at the same conditions during the first experiment.

In addition to the generally high temperatures, random temperatures fluctuations of as much as 200 °F (110 °C) were noted, with powers held constant. This behavior was noted over wide ranges of heat fluxes, including values far below expected burnout heat fluxes. These fluctuations would have made accurate identification of "burnout-induced" temperature excursions impossible in many cases. Consequently, the model was removed from the high pressure apparatus and disassembled for examination. This examination disclosed a heavy scale deposit on the heat transfer surface of the test section. Apparently, the high temperatures observed were caused by thermal resistance of this film. The reason for the random temperature variations is not clear, but it might have resulted from buildup and flaking off of scale patches. Efforts to pinpoint and eliminate the source of filming are in progress and will be completed before the rest of the experiments are run with a new model.

The successful data from Model IV and the earlier models were examined to determine operating conditions at which burnout occurred. These burnout conditions were compiled, and burnout heat fluxes were plotted as functions of coolant mass velocity and coolant enthalpy at the burnout position. Also, burnout heat fluxes were calculated using an equation developed from earlier experiments with a model having dimensions identical to those of Model I, but with heat generated in both the inner and outer tubes. Comparison of the observed and calculated burnout heat fluxes were made to determine if the equation would adequately predict behavior of the fuel geometry models. A summary of the experimental results and the comparisons are shown in Table II.

TABLE II. Summary of Results of N-Reactor Special Fuel Boiling Burnout Experiments

Model	Mass Velocity, lb/hr-ft^2	Experimental Burnout Heat Flux, Millions of Btu/hr-ft^2	Coolant Enthalpy, Btu/lb	Heat Flux Ratio[(a)]
I	0.5 x 10^6	0.232-0.370	582-654	0.741-1.167
II	0.5 x 10^6	0.162-0.388	555-641	0.549-1.358
III	0.5 x 10^6	0.141-0.233	568-717	0.461-0.826
IV[(b)]	0.5 x 10^6	0.35 -0.40	628-716	1.20 -1.39
I	1 x 10^6	0.576-0.861	568-651	0.917-1.144
II	1 x 10^6	0.767-0.979	572-673	1.239-1.310
III	1 x 10^6	0.380-0.721	656-753	0.825-1.168
IV[(b)]	1 x 10^6	0.59 -0.75	630-688	1.06 -1.10
I	2 x 10^6	0.935-1.401	554-642	1.020-1.115
II	2 x 10^6	0.922-1.506	557-648	1.111-1.195
III	2 x 10^6	0.657-1.079	592-737	0.987-1.837
IV[(b)]	2 x 10^6	0.79 -0.95	628-656	1.03 -1.04
I	3 x 10^6	1.077-1.228	595-633	1.000-1.123
II	3 x 10^6	1.040-1.936	545-636	1.115-1.222
III	3 x 10^6	0.801-1.029	625-715	1.015-2.206
IV[(b)]	3 x 10^6	0.87 -1.09	615-645	0.95 -0.96
I	4 x 10^6	1.166-1.513	589-620	1.043-1.065
II	4 x 10^6	1.176-2.313	540-630	1.152-1.268
III	4 x 10^6	0.933-1.194	609-698	0.990-2.342
IV[(b)]	4 x 10^6	1.00 -1.28	612-637	1.03 -1.05
I	5 x 10^6	1.235-1.545	587-620	1.074-1.106
II	5 x 10^6	1.276-2.466	572-628	1.209-1.478
III	5 x 10^6	1.073-1.453	605-690	1.106-2.686
IV[(b)]	5 x 10^6	1.08-1.50	606-633	1.06 -1.12
I	6 x 10^6	1.756-2.889	494-558	1.080-1.116
IV[(b)]	6 x 10^6	1.23 -1.67	603-631	1.15 -1.16

(a) Ratio of experimental burnout heat flux to burnout heat flux calculated from equation

(b) Values for Model IV are estimated based on preliminary analysis of data.

The results listed in Table II show that at all except the lowest mass velocities, the burnout equation tends to underestimate the burnout heat fluxes. Generally, the difference was 5 to 15% for Model I and 10 to 20% for Model II. The experimental burnout heat fluxes for Model III generally agreed well with the calculated values for subcooled or low steam quality cases. However, they departed from, and fell above the predicted values, by increasing amounts as steam qualities were increased into the range of 10 to 25 wt%. With Model IV, the experimental burnout heat fluxes appear to be slightly higher (up to 15%) than the predicted burnout heat fluxes

The burnout equation, which was developed from data for subcooled and low steam quality conditions, has a form which predicts a linear decrease in burnout heat flux with increasing mass velocity. At the higher mass velocities, this equation can be extrapolated to a burnout heat flux of zero at steam qualities of 20 to 30%. It had been recognized that such extrapolations were not valid, and it was believed that the burnout heat flux versus enthalpy curve would flatten at the higher steam qualities. However, in the limited steam quality range attainable with the short (2 ft) models, experimental evidence of such flattening could not be obtained. The results of the experiments with the 8 ft long model do demonstrate the expected flattening, and provide information on the shape of the heat flux versus enthalpy curves at higher enthalpies.