NON-UNIFORM HEAT GENERATION
EXPERIMENTAL PROGRAM

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PREFACE

The Babcock & Wilcox Company and the United States Atomic Energy Commission, acting for the Joint U. S. - Euratom Research and Development Board signed an agreement for a non-uniform heat generation experimental program.

The program will include experimental and analytical investigations to determine how non-uniformly distributed heat flux along lengths of tubular and annular channels affect the onset of burnout (departure from nucleate boiling). The experimental program will be conducted on the 1.8-MW heat transfer facility at B&W's Research Center, Alliance, Ohio. The analytical program will be conducted by the Atomic Energy Division, Lynchburg, Virginia.

The first calendar quarter of this program has been spent planning, scheduling, designing, and initiating procurement. Design work, procurement, and facility modification are expected to be completed in the second quarter. Test work will begin and experimental data will be obtained early in the third quarter.

ABSTRACT

The Babcock & Wilcox Company, as part of the Joint U.S.-Euratom Research and Development Program, is conducting experimental and analytical investigations to determine the effects of irregular heat flow through reactor channels on the operating conditions that cause burnout (departure from nucleate boiling). This program seeks to improve design correlations that will be suitable for direct use by reactor designers. Tubular specimens having four axial power shapes and annular specimens having five power shapes will be used, and an effort to correlate the experimental data with empirical and analytical models will be made.

The experimental program will be conducted on a vertical test section in a closed loop through which water is circulated at a given rate. A 1.8-MW d-c power supply will heat the test section.

The first calendar quarter of this program has been spent planning, scheduling, designing, and initiating procurement. Design work, procurement, and facility modification are expected to be completed in the second quarter. Test work will begin and experimental data will be obtained early in the third quarter.

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1. INTRODUCTION

Nuclear reactors and modern boilers require more and more knowledge about the limitations on the transfer rates of heat from channel walls to flowing liquids. A very serious design problem still facing the reactor designer is the phenomenon called burnout (departure from nucleate boiling). The result of this phenomenon is that the heat transfer conductance is reduced considerably, causing the metal and fuel temperatures to rise and initiate failure of the fuel element. Although considerable attention has been given to this problem in recent years, the predictability of the occurrence of burnout conditions is still quite uncertain. In fact, there is still much disagreement on the effect of the channel geometry and operating conditions upon burnout.

In an effort to clarify some of the areas of disagreement, Babcock & Wilcox, as part of the Joint U. S. -Euratom Research and Development Program, is conducting an experimental and analytical program to determine the effects of non-uniform heat generation rates in tubular and annular flow channels on the operating conditions causing burnout, under experimental conditions representative of water reactor systems. The objective of the program is to seek improved design correlations suitable for direct use by reactor designers, with the technical approach to the work emphasizing the development of an improved understanding of the physical phenomena involved and their relation to design variables.

2. DESCRIPTION OF TEST APPARATUS

The experimental program will be conducted on a vertical test section in a closed loop through which water is circulated at a given rate. A 1.8-MW d-c power supply will heat the test section. A photograph of the test site is shown in Figure 1, and a schematic diagram of the test apparatus is shown in Figure 2. The circuit consists of a Westinghouse 150-D canned motor centrifugal circulating pump, an air-operated Annin flow control valve, flow measuring elements, a 60-kw immersion-type main loop heater, a tubular or an annular test section, a boiling water heat exchanger unit, and a loop pressurizer system. These components are joined with 3.25-inch-OD, 0.380-inch-wall SA-210 tubing to complete the closed loop. A burnout detector system is used for observing transition and film boiling in the test section.

Feedwater is demineralized plant steam condensate having NH_4OH added for pH control.

Test section flow rates are measured with a calibrated flow nozzle assembly located ahead of the test section. A turbine-type flow meter is used in conjunction with the nozzle to detect and record variations in flow rates or hydraulic instability during test operation.

The boiling water heat exchanger and the main loop heater make up the heat removal and temperature control unit for the test loop. Since a boiling water heat exchanger alone provides a rather sluggish control of heat removal rate, the exchanger is used only for coarse control of the heat removal rate. The main loop heaters are used for fine temperature control. In operation, the heat exchanger is adjusted to remove a little more heat from the system than is required to keep the system in thermal equilibrium. A small controlled amount of heat is added to the system to adjust the over-all heat removal rate to that required. This heat addition is made by means of the main loop heaters, the signal

for the heater controls originating from a thermocouple used to measure the test section inlet fluid temperature.

Pressure is maintained with the pressurizer system by automatically controlling the rate of steam generation in the pressurizer vessel. Immersion-type electric heaters are used for heating.

The test apparatus is sufficiently automated to permit continuous stand-by operation without attending personnel; however, the d-c power supply will be operated only during periods of obtaining test data. The only time the loop is to be completely shut down is for maintenance or changing test sections.

The test sections are heated by passing direct current through the tube wall. The current is supplied from two d-c rectifier units, the input of each being 3-phase, 60-cycle, 4160-volt ac and the output being 100-volt dc at 9000 amperes. The two units can be operated in parallel and controlled with one controller, or operated independently with individual controllers.

The burnout detector is based on the principle that metal resistivity varies with metal temperature. Voltage taps are distributed along the length of the test sections, and the drop across each segment is continuously monitored and recorded. When burnout occurs, the metal temperature of the tube segment involved will rise and cause an increased voltage drop across that segment. The change in voltage drop will provide the warning that burnout has been obtained. This warning signal will automatically reduce the power if the test section temperature approaches a pre-set limit. The objective of the automatic setback is to prevent physical damage to the test section.

Figure 1. Test Site

Figure 2. Schematic Diagram of Test Apparatus

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3. MODIFICATIONS TO TEST APPARATUS

Modifications to the test apparatus are required to conduct this test program. These modifications, discussed in the following paragraphs, are being studied.

3.1. Flow Control and Measurement

A flow control valve that was used on previous tests is being checked and rebuilt as required. Two new calibrated nozzle assemblies, one for tubular test sections and one for annular test sections, will be procured. A turbine-type flow meter will be used to detect flow instabilities.

3.2. Pressure Fluctuations and Pressure Drop Measurements

Provisions are being made to monitor pressure fluctuations at the test section inlet that may be caused by a transition from nucleate to film boiling. Present plans include installing a pressure transducer ahead of the test section and recording the fluctuations. This monitoring instrumentation is available at the Research Center.

Provisions are also being made to obtain two-phase pressure drop measurements during the heat transfer tests. These measurements will be made with a high-pressure manometer and a gage.

3.3. D-C Power Supply and Control

An existing Research Center power control unit suitable for use in the tubular test section will be used as one of the two units required for the annular test section. One additional control unit is being designed for the annular test section. The instrumentation used with the power supply system is being studied and specifications established for changes and additions. New current-measuring shunts as well as changes to the ammeter and voltmeter ranges and panel boards will be required.

The bus-bar system from the rectifiers to the test section will be rerouted to the test section location. The design work for this change is almost complete.

3.4. Burnout Detector System

The burnout detector setpoints will be modified for the various operating conditions. Instrumentation connections will also be rerouted. The recorders of the voltage drop across the test section segments are being studied from the standpoint of being adapted to the burnout detector without causing electrical interference with the detector.

4. TEST SECTIONS

Considerable effort has gone into the preliminary design of the tubular and annular test sections. Work on both types is progressing in parallel so that the installation of each in the test apparatus will be mutually compatible. The effort so far has been directed toward establishing the specifications of the tube wall thicknesses so that the electrical load represented by the test sections will give the desired heat generation rate variation along the tube length and match the rectifier output, and so that the allowable stresses in the tubes will not be exceeded.

4.1. Conditions for Tubular and Annular Test Sections

The following burnout conditions are to be run in all combinations for each test section:

Pressure, psia	Mass velocity $\times 10^4$, lb/hr-ft ²	Inlet subcooling, °F
2000	0.5	20
1500	1.5	50
1000	2.5	100
--	--	150

4.2. Dimensions and Flux Shapes of Tubular Test Sections

The dimensions of the tubular test sections are as follows:

Nominal ID, in.	0.446
Nominal OD, in.	0.607
Nominal length, in.	72

The longitudinal flux shapes of the tubular sections include the following:

- T1. Uniform
- T2. Chopped cosine, max/avg = 1.4 (see Figure 3)

T3. Maximum flux near entrance (see Figure 4)

T4. Maximum flux near exit (see Figure 5)

4.3. Dimensions and Flux Shapes of Annular Test Sections

The dimensions of the annular test sections are as follows:

Nominal ID of annulus, in.	0.607
Nominal OD of annulus, in.	1.053
Nominal length, in.	72

The longitudinal flux shapes of the outer and inner tubes of the annular sections include the following:

<u>Outer tube</u>	<u>Inner tube</u>
A1. (Unheated)	A1. Uniform
A2. Uniform	A2. (Unheated)
A3. Uniform	A3. Uniform
A4. Chopped cosine (see Figure 3)	A4. (Unheated)
A5. Chopped cosine	A5. Uniform

Figure 3. Heat Input Rate Distribution (Chopped Cosine)

Figure 4. Heat Input Rate Distribution (Maximum Rate at Channel Entrance)

Figure 5. Heat Input Rate Distribution (Maximum Rate at Channel Exit)

5. SCOPE OF WORK

Tubular specimens having four axial power shapes and annular specimens having five power shapes will be tested, and an effort to correlate the experimental data with empirical and analytical models will be made. The program schedule is shown in Figure 6.

5.1. Experimental Data

The following experimental data will be reported for each set of test conditions:

1. Test section specification*.
2. System pressure referred to test section outlet.
3. Temperature of coolant entering and leaving the test section.
4. Continuous flow recording.
5. Enthalpy of coolant entering and leaving the test section.
6. Heat generation shape*.
7. Location of heater segment indicating burnout.
8. Heat flux on burnout segment.
9. Total pressure drop across test section.
10. Power input to test section.
11. Continuous voltage recording of burnout segment.
12. Continuous recording of test section inlet pressure fluctuations.

*Common to each test section.

5.2. Data Analysis

Accumulated data will be analyzed in an effort to determine whether steady or unsteady burnout is represented by each value. The consistency

of each kind of data with regard to correlatability will be determined for empirical and analytical models. An error analysis will be made as part of the evaluation of the models used for the correlations.

5.3. Desired Conclusions

Successful completion of experimental and analysis portions of this program should produce useful conclusions that will answer certain questions. At the present time, these questions are determined to be as follows:

1. Does the behavior of the system or the appearance of the data suggest a burnout model?
2. What part of the data supports the suggested model?
3. How does each of the following parameters affect the channel power limit caused by burnout (power distribution, cross-sectional shape of flow channel, pressure, inlet subcooling, and mass velocity)?
4. How do the data compare with selected correlations previously reported in the literature?
5. Beyond the scope of the preceding questions, what new observations or discoveries resulted from the program?

Figure 6. Non-Uniform Heat Generation Experimental Program Schedule Starting July 1963

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