NON-UNIFORM HEAT GENERATION
EXPERIMENTAL PROGRAM

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Atomic Energy Division
Lynchburg, Virginia

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LIST OF PRINCIPAL INVESTIGATORS

ATOMIC ENERGY DIVISION

D. F. Judd
Technical Manager

R. H. Wilson
Analytical Program

ALLIANCE RESEARCH CENTER

H. S. Swenson
R. A. Lee
J. W. Ackerman
Experimental Program

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

The fourth calendar quarter of this program has been spent completing some details of system modification, installing the first test sections, obtaining data, fabricating tubular test sections, and making detailed drawings for the annular test sections.

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 fourth quarter of this program has been spent designing, fabricating, and installing test sections; and obtaining data from the uniformly heated test section. These first data were obtained using thermocouples for critical heat flux detection.

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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. Burnout (departure from nucleate boiling) is a very serious design problem still facing the reactor designer. 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 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 (B&W), 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. The technical approach to the work emphasizes the development of an improved understanding of the physical phenomena involved and their relation to design variables.

The experimental program, which was discussed in the first quarterly report (BAW-1287)*, will be conducted on a B&W heat transfer facility at its Research Center in Alliance, Ohio. The controlled variables for the tests are pressure, inlet subcooling, and mass velocity. The

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* D. F. Judd et al., Non-Uniform Heat Generation Experimental Program, Quarterly Technical Report No. 1, The Babcock & Wilcox Company, BAW-1287, Lynchburg, Virginia, July - September 1963.

tests will be performed in 6-foot-long tubular and annular test sections having both uniform and non-uniform axial heat flux distributions. The analytical program will then be conducted by the Atomic Energy Division in Lynchburg, Virginia.

Problems that developed in the power supply have not been completely remedied; however, the power supply has operated satisfactorily for the start of this test work. Data have been obtained from the uniformly heated test section for the conditions originally planned in the program, which include pressures of 2000, 1500, and 1000 psia; mass velocities of 0.5, 1.5, and 2.5 million lb/hr-ft²; and inlet subcoolings of 20, 50, 100, and 150 F.

A computer program for comparing either uniform or non-uniform heat flux data from round geometries with existing published burnout correlations is being written. When more data become available from this test work, it is planned to show comparisons with some of the burnout equations.

2. PROGRAM

2.1. Test Facility Modifications

The plans for the burnout detection method in this program have sought to make use of the fact that the electrical resistance of the test section wall changes with temperature. Thus, by monitoring resistance changes in segments of the tube, critical heat flux can be detected when the location is not predictable. This consideration is especially applicable in the case where the axial heat flux distribution is non-uniform. This detection system has been in operation, but since it is not completely free of imperfections, test work with the uniform heat fluxes was initiated using thermocouples for critical heat flux detection. All testing during this quarter was performed while using the thermocouples. Efforts to improve the original detector continued along with test operation.

2.2. Test Sections

2.2.1. Tubular Test Sections

To evaluate the acceptability of two different machining techniques developed by the Machine Shop, two non-uniform wall tubes were fabricated. The first tube was machined as follows;

1. A Vidi-gage was used to determine tube eccentricities before machining was started.
2. Based on information from Item 1, the tube was machined completely without additional use of the Vidi-gage.
3. Actual wall dimensions were checked with the Vidi-gage and recorded after all machining was completed.

The second tube was machined while using the Vidi-gage continuously. Comparison of the final machined dimensions of both

tubes with design dimensions showed that their final dimensions are within the required tolerances. However, the first method described required less time and expense than the second; therefore, it was selected for machining subsequent test sections.

During this quarter, two tubes of Test Section 2 (chopped cosine) and three tubes of Test Section 3 (inlet peak) were completed. (Test Section 3 is interchangeable with Test Section 4, the outlet peak configuration.) The machined dimensions of Test Sections 2 and 3 to be tested first are tabulated in Tables 1 and 2, respectively. Owing to the relatively short machining time now required for these tubes, no scheduling problem resulting from a lack of test sections is expected.

2.2.2. Annular Test Sections

Detail drawings for the annular test sections are almost complete and most of the material has been purchased. Since tube sizes required for the outer tube are not commercially available, plans are being made to machine the tubes from oversized tubing by using the Vidi-gage.

Table 1. Geometry of Test Section 2-A

Distance from inlet end of heated length, in.	Required wall thickness, in.	Required tolerance, in.	Actual measured variation, in.
0	0.1645	± 0.002	+0.001
2	0.1314	± 0.002	+0.002
4	0.1071	± 0.002	+0.001
6	0.0928	± 0.002	+0.001
8	0.0810	± 0.001	+0.001
10	0.0731	± 0.001	+0.001
12	0.0656	± 0.001	± 0.001
14	0.0604	± 0.001	+0.001
16	0.0566	± 0.001	+0.001
18	0.0535	± 0.001	+0.001
20	0.0505	± 0.001	± 0.000
22	0.0482	± 0.001	+0.001
24	0.0467	± 0.001	± 0.000
26	0.0455	± 0.001	+0.001
28	0.0440	± 0.001	+0.000
30	0.0432	± 0.001	-0.001
32	0.0423	± 0.001	± 0.001
34	0.0423	± 0.001	± 0.000
36	0.0420	± 0.001	+0.000
38	0.0423	± 0.001	+0.001
40	0.0423	± 0.001	+0.001
42	0.0432	± 0.001	+0.001
44	0.0440	± 0.001	+0.001
46	0.0455	± 0.001	+0.001
48	0.0467	± 0.001	+0.001
50	0.0482	± 0.001	+0.001
52	0.0505	± 0.001	+0.001
54	0.0535	± 0.001	+0.001
56	0.0566	± 0.001	+0.001
58	0.0604	± 0.001	+0.001
60	0.0656	± 0.001	± 0.001
62	0.0731	± 0.001	+0.001
64	0.0810	± 0.001	+0.001
66	0.0928	± 0.002	+0.001
68	0.1071	± 0.002	+0.001
70	0.1314	± 0.002	+0.002
72	0.1645	± 0.002	-0.002

Table 2. Geometry of Test Section 3-A

Distance from inlet end of heated length, in.	Required wall thickness, in.	Required tolerance, in.	Actual measured variation, in.
0	0.1752	±0.002	--
2	1.1172	±0.002	--
4	0.0868	±0.002	-0.001
6	0.0712	±0.001	-0.001
8	0.0605	±0.001	±0.000
10	0.0537	±0.001	+0.001
12	0.0493	±0.001	+0.001
14	0.0466	±0.001	+0.001
16	0.0447	±0.001	±0.000
18	0.0445	±0.001	-0.001
20	0.0447	±0.001	±0.000
22	0.0462	±0.001	+0.001
24	0.0475	±0.001	+0.001
26	0.0505	±0.001	+0.001
28	0.0537	±0.001	+0.001
30	0.0583	±0.001	+0.001
32	0.0655	±0.001	±0.000
34	0.0734	±0.001	+0.001
36	0.0823	±0.001	+0.001
38	0.0919	±0.001	±0.000
40	0.0997	±0.002	±0.000
42	0.1063	±0.002	+0.001
44	0.1172	±0.002	+0.001
46	0.1233	±0.002	+0.001
48	0.1341	±0.002	+0.002
50	0.1379	±0.002	+0.001
52	0.1467	±0.002	+0.002
54	0.1518	±0.003	±0.000
56	0.1570	±0.003	+0.002
58	0.1626	±0.003	+0.002
60	0.1686	±0.003	+0.001
62	0.1686	±0.003	+0.002
64	0.1699	±0.003	+0.002
66	0.1739	±0.003	-0.001
68	0.1752	±0.003	+0.002
70	0.1752	±0.003	+0.003
72	0.1752	±0.003	+0.003

3. TEST OPERATION

A uniform-wall tube (Test Section 1-C) was instrumented with thermocouples (Figure 1) and installed. Using this arrangement, all of the planned tests on the uniform-wall tube were then completed.

Figure 1. Location of Thermocouples on Test Section 1-C

Data were obtained in all of these tests in the following manner:

1. Test section thermocouples were monitored manually on a Bailey High-Speed Recorder.
2. A given test section mass flow, inlet fluid temperature, and outlet pressure were established.
3. The test section heat input rate was increased gradually until one or more of the test section thermocouples indicated a temperature rise, which was identified as critical heat flux. In many cases, the

critical condition was immediately preceded by a tube-wall temperature drop of as much as 15 F, and this phenomenon was eventually used as an indication that the next power increase would cause critical conditions. (This same phenomenon was observed in earlier tests at the Research Center.)

4. Data were always taken at selected time intervals prior to the critical conditions. Depending upon the severity of the temperature rise accompanying the criticality, data were also taken while operating under critical conditions. When critical conditions were reached, test section failure was prevented either by manually reducing the heat input rate or by tripping out the d-c power supply circuit breakers.

The second tubular test section, Section 2A having a chopped cosine longitudinal heat input rate distribution, is scheduled for testing next.

4. TEST DATA

The test data obtained are shown graphically in Figure 2. Points on these plots represent the conditions at which critical heat flux occurred during the tests.

Figure 2. Critical Heat Flux Data at 1000, 1500, and 2000 psia

During the testing period, other data concerning the stability of test section metal temperature, flow rate, and inlet pressure were obtained. When critical conditions were reached, the thermocouples indicated a fairly steady temperature rise. However, since d-c heating is being used, the thermocouples are electrically insulated from the test section. This means that they are also thermally insulated, to some extent, from the test section, which in turn would tend to reduce the amplitude of any temperature fluctuations that occurred. Flow and inlet pressure data recorded indicate that critical conditions cause no apparent instability of these variables.

5. PROGRAM SCHEDULE

The schedule in Figure 3 indicates the work expected to be done during the next two quarters.

Figure 3. Schedule of Non-Uniform Heat Generation Experimental Program

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3. United States Contractors (18)

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Attn: K. F. Neusen

Argonne National Laboratory
Reactor Engineering Division
9700 South Cass Avenue
Argonne, Illinois
Attn: Dr. Paul Lottes

Argonne National Laboratory
Reactor Engineering Division
9700 South Cass Avenue
Argonne, Illinois
Attn: Dr. M. Petrick

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San Jose 12, California
Attn: Dr. S. Levy

General Electric Company
Atomic Power Equipment Dept.
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San Jose 12, California
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Massachusetts Institute of Tech.
Dept. of Mechanical Engineering
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Division of Reactor Development
Washington 25, D. C.
Attn: R. M. Scroggins

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Sezione Energia Nucleare
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Torino
Italy
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Reactor Centrum Nederland
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's Gravenhage
Netherlands
Attn: M. Pelser

CNEN
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Roma
Italy
Attn: Prof. F. Ippolito

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