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**Quarterly Progress Report
on Blowdown Heat Transfer
Separate-Effects Program
for April-June 1980**

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D. H. Cook	R. C. Hagar
W. G. Craddick	G. S. Mailen
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DEPARTMENT OF ENERGY**

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QUARTERLY PROGRESS REPORT ON BLOWDOWN HEAT TRANSFER SEPARATE-EFFECTS PROGRAM FOR APRIL-JUNE 1980

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QUARTERLY PROGRESS REPORT ON BLOWDOWN HEAT TRANSFER
SEPARATE-EFFECTS PROGRAM FOR APRIL-JUNE 1980

J. D. White

D. H. Cook	R. C. Hagar
W. G. Craddick	G. S. Mailen
D. K. Felde	L. J. Ott
R. M. Flanders	G. L. Yoder

ABSTRACT

Bundle 3 was removed from the Thermal-Hydraulic Test Facility (THTF), refurbished, then reinstalled into the THTF. This refurbishment was necessary to replace the elastomer O-ring seals, which had suffered deterioration during previous testing. The bundle has performed very well during the ensuing tests. During the downtime for refurbishment, the test section was modified to include ten differential pressure (dP) cells located along the axis.

Analysis of the first series bundle uncover/reflood tests run (December 9, 1979, and January 9, 1980) is nearly complete. Experimentally determined heat transfer coefficients ranged from 17 to 34 B/hr-ft²-°F. Comparison of these experimental heat transfer coefficients with heat transfer coefficients predicted using correlations supplied by the vendors (Westinghouse, Babcock and Wilcox, Combustion Engineering) led to the following preliminary conclusions:

1. None of the correlations appears to follow the data trends accurately.
2. The correlations predict the data to within ±40%.
3. In some cases, the correlations for fully developed turbulent flow overpredict the data by as much as 40%.
4. No well-defined dependence on pressure was found for the ratio $h_{\text{correlation}}/h_{\text{experimental}}$.

The heat losses to the cold shroud wall (insulated from the pressure vessel wall by a two-phase mixture of steam and water) range from a low of 2% for one test to a high of 22% for another test. The magnitude of the heat loss seems to be a strong function of the duration of bundle uncover, leading to the conclusion that transient shroud wall heatup is the primary source of heat loss. The THTF will be modified before the next series of bundle uncover tests to allow the measurement of the shroud wall temperature distribution. Analysis of the reflood transients using the computer code COBRA TRAC has begun at Pacific Northwest Laboratory.

During this quarter, two transient film boiling tests were run — one in upflow, the other in downflow. The purpose of these tests was to provide experimental heat transfer data that

could be used in an assessment of several film boiling correlations used in current thermal-hydraulic computer codes. The tests were designed to provide accurate posttest calculations of heat fluxes, surface temperatures, and local fluid conditions. The Upflow Film Boiling Test 3.03.6AR was run on May 21, 1980, in the THTF. This test resulted in single-phase fluid flow at the test section inlet (subcooled) during the time the bundle was in high-flow film boiling. Furthermore, no flow reversal occurred during the test. Preliminary posttest analysis indicates that the calculation of mass flows at the inlet to the test section should result in numbers with relatively small uncertainties. We are optimistic that local fluid conditions can be calculated for this test with an accuracy sufficient for correlation evaluation.

The Downflow Film Boiling Test was run on June 19, 1980. Preliminary results are not encouraging. Apparently, the bundle rewet shortly after film boiling began. Analysis to determine the quantity of film boiling data obtained has begun. Results will be reported later.

Keywords: pressurized-water reactor, blowdown heat transfer, separate effects, loss-of-coolant accidents (LOCAs), Thermal-Hydraulic Test Facility, electrical heater rods, bundle hydraulics, two-phase flow, RELAP4, double-ended break, dynamic response, fuel pin simulator, THTF bundle 3, PINSIM, ORINC, ORTCAL, COBRA, ORMDIN, ORRAN, bundle uncover tests, small break LOCAs, high-pressure reflood.

1. ANALYSIS

W. G. Craddick

1.1 Data Management

R. M. Flanders

Data from two Hot Test Section Fill Tests, which were run during this quarter, have been reduced and used to verify the locations of thermocouples in the Thermal-Hydraulic Test Facility (THTF) test section.

Data reduction was begun on the THTF Upflow Film Boiling Test during this quarter. Both uncalibrated and calibrated engineering units tapes were generated and then were used, by comparing the data, to determine what modifications need to be made to the Instrument Data Base (IDB). A process tape containing composite density data calculated from a triple-beam densitometer, individual rod powers, and total bundle power was

generated for this test. This task is ~60% complete and is progressing on schedule.

Processing of the data from the Downflow Film Boiling Test was started during this period. Appropriate tapes are presently being generated. About 25% of the tasks associated with the processing of these data are complete.

1.2 Electric Pin Analysis

L. J. Ott

The preprocessor program for ORINC (ORNL Inverse Code) and ORMDIN (ORNL Multidimensional Inverse Code) was debugged and verified (on schedule). The preliminary run on THTF Test 3.03.6AR (Upflow Film Boiling Test) was completed on schedule. This program basically restructures and combines the coefficient data tape (generated by ORTCAL, ORNL Thermocouple Calibration Code) and the engineering units tape for a given THTF test into a single one-pass tape input for ORINC and ORMDIN — thus limiting these codes to computational-type work.

The development of version 3.1 of ORINC (specifically for the THTF-Mod 2) has been completed, and debugging and verification of the code have been finished (on schedule). The preliminary run of ORINC on THTF test 3.03.6AR has been completed and reviewed (on schedule).

The ORMDIN code has been updated to interface with the preprocessor tape, and this version of the code has been debugged (on schedule). The code is now fully automated to process blowdown heat transfer (BDHT) tests in the THTF. A test run has been made at four locations in the THTF core for Test 3.03.6AR.

THTF Test 3.03.6AR has been processed by parts 1 and 2 of ORTCAL (on schedule). Part 1 of ORTCAL accumulates, on a "history" tape, the in-bundle conditions for each fuel rod simulator (FRS) thermocouple for each steady-state and preblowdown scan taken when the bundle is at power. Part 2 of ORTCAL reads the history tape generated by Part 1 of ORTCAL and determines the in situ thermal conductivity of the annular boron nitride (BN) insulator at each sheath/middle thermocouple position in each FRS in the THTF bundle. Part 2 also determines the BN/stainless steel sheath

contact resistance at each FRS sheath thermocouple position and generates the coefficient data tape for a specified THTF test.

The final segment (part 3) of the ORTCAL calibration package for THTF bundle 3 has been coded, programmed, debugged, and verified (prior to receiving actual data from operations). ORTCAL-Part 3 essentially determines the effective thermal diffusivity of the FRS BN core at each FRS sheath/middle thermocouple location in the THTF bundle.

The core and loop heat balance code for THTF-Mod 2 has been restarted. (It is slightly behind schedule and is ~50% complete.) This code will make a total core and loop heat balance from available THTF instrumentation.

Earlier testing of bundle 3 prototype FRS in the single-rod test loop indicated the existence of multidimensional effects on the FRS surface heat flux due to azimuthally varying fluid conditions. The development of a "transfer function" for correlating these multidimensional effects with one-dimensional results of the inverse problem is continuing. Emphasis is currently being placed on selection criteria to determine when one-dimensional computations are adequate and/or when multidimensional computations must be made. This effort requires the solution of the forward heat conduction problem in cylindrical geometry for 0 through 360° azimuthally. Currently, HEATING5 cannot handle such a problem; therefore, work was delayed until a modification of ORMDIN was made to solve the forward heat conduction problem. This new version is called ORRAN (Oak Ridge Rod Analysis), and test problems have been solved to verify the code.

1.3 Thermal-Hydraulic Analysis

G. L. Yoder

Work on the bundle uncover/recovery test analysis is continuing. Preliminary heat transfer coefficients have been calculated. Comparisons between bundle uncover/recovery experimentally determined heat transfer coefficients and heat transfer coefficients predicted by existing correlations have been done. These comparisons seem to indicate that none of the correlations follow the trends in the data; however, in all cases,

the existing correlations predicted the data to within $\pm 40\%$. Results of bundle recovery testing seem to indicate the development of inverted annular flow in high inlet flooding rate tests.

Planning for THTF Test 3.03.6AR (Film Boiling in Upflow) was completed, and the experiment was run on May 21, 1980. Analysis of the data is presently under way. The quick-look report for this test was completed on June 20, 1980. Overall, the Upflow Film Boiling Test was a successful experiment.

The THTF Test 3.04.7R (Film Boiling in Downflow) was also planned this period and was run on June 19, 1980. The transient test was initiated at elevated temperature and pressure by blowing down through the test section inlet. During the test, valve FCV-18 was closed to cause all loop flow to be routed through the test section. The power was ramped up at blowdown initiation to enhance the onset of film boiling. Only a limited amount of film boiling data was obtained.

Planning for the next Upflow Film Boiling Test (3.06.6B) is under way and is $\sim 40\%$ complete. Efforts are being made to extend the range of conditions over which post-CHF heat transfer data were obtained in Test 3.03.6AR.

COBRA/TRAC calculations for THTF test 3.02.10E were completed by Pacific Northwest Laboratory (PNL). The steady-state rod temperature profile is presented in Fig. 1, and collapsed liquid level vs time is shown in Fig. 2. The collapsed liquid level is seen to be generally low in the calculation during the early part of the reflood and is believed to be caused by the interphase shear stress relationships used in the code. Quench times as calculated by COBRA/TRAC vs thermocouple data for levels F and G are presented in Fig. 3. Code-calculated quench times are late because of the low minimum film boiling temperature predicted by COBRA/TRAC. COBRA/TRAC calculations for the Upflow Film Boiling Test 3.03.6AF were initiated. Steady state was reached, and about 2 s of transient calculations were performed before problems developed in the execution of the code. Efforts are being made by PNL staff to determine the source of the problem.

Development of a correlation comparison computer code is continuing and is $\sim 65\%$ complete. The correlation comparison program is designed to

Fig. 1. THTF test 3.02.10E: uncover data — rod temperature.

Fig. 2. Bundle recovery test 3.02.10E — comparison of collapsed liquid level and quench front propagation.

Fig. 3. THTF test 3.02.10E: recovery data.

use experimental surface temperatures along with RELAP-calculated local fluid conditions to calculate local heat transfer coefficients. Correlations presently used in several reactor analysis codes are used to calculate heat transfer coefficients. Local heat fluxes predicted by these correlations are compared with experimentally determined heat fluxes.

1.4 Nuclear Pin Simulation Analysis

R. C. Hagar

Review of the report describing the nuclear pin simulation analysis of THTF Test 105 has been completed. Reviewers' comments were incorporated, and the report was forwarded for publication.

The PINSIM-MOD2 validation study was completed on schedule. The report describing that study has been written and is undergoing review prior to publication.

Pretest analysis associated with the upcoming double-ended blowdown has been completed. Both the hydraulics analysis (to determine appropriate rupture disk orifice sizes and operating conditions for the THTF) and the power programming analysis were completed soon enough to allow the test to be run two weeks ahead of schedule. (The test will be run on July 2, rather than July 17, as originally planned.) Plans for conducting posttest analysis of the test data have been developed.

2. THTF FACILITY OPERATIONS

G. S. Mailen

During the past quarter, the entire THTF bundle was removed, refurbished, and placed back into operation at the test facility. Severe leaks in the O-ring seal areas at the top of bundle 3 encountered after the completion of the January bundle uncover tests (3.02.10C through H) necessitated the removal of each individual fuel pin simulator. New O-ring sleeves were designed and installed on each heater rod (Fig. 4), along with new O-rings and several spare O-rings. Each heater rod was electrically inspected and checked prior to being reinstalled in the test section bundle. Each heater rod lead-in was electrically insulated to minimize arcing between rods and to eliminate the crowbar power trips experienced during earlier tests. The inner and outer seal plates were also refurbished to ensure that the O-rings sealed properly, thus allowing successful completion of scheduled tests.

Modifications were completed for the installation of ten in-bundle differential pressure measurement instruments. This modification permits the measurement of pressure differentials at various levels inside the heater rod bundle, providing information important to the analysis of the test results from future experiments. Plans are being finalized for the installation of an in-bundle densitometer and two new thermocouple array rods and for the installation of thermocouples in the test section shroud box wall (Fig. 5). These modifications are of paramount importance for obtaining unique and extremely useful information for analysis of further bundle uncover tests scheduled for before the end of the fiscal year.

The bundle was operated on five occasions during the last quarter. The first was a 90-kW/rod power drop test completed on May 2, 1980. This test provided information on the operating characteristics of the refurbished bundle and served as a check on the safety and integrity of the bundle for future tests. Two attempts were made for each of the tests — Upflow Film Boiling Test 3.03.6A (outlet break) and Downflow Film Boiling Test 3.04.7R (inlet break) — resulting in successful test completion on May 21, 1980, and June 19, 1980, respectively. Plans are being finalized for completion of future tests and schedule dates for the remainder of the fiscal year.

Fig. 4. O-rings, sleeve, and electrical insulation details for fuel pin simulators.

Fig. 5. Shroud thermocouple locations and detail.

3. TWO-PHASE INSTRUMENT DEVELOPMENT

D. K. Felde D. H. Cook

Design, procurement, and fabrication of the in-bundle densitometer system is near completion. The hollow instrument rod tubes in which the source-detector linkages will be installed are in place in the THTF bundle. A cross section of the bundle is shown in Fig. 6. The densitometer systems will be located in rod positions 36 and 46. The two source-detector systems will be axially spaced 59.7 cm (23.5 in.), corresponding to the FRS thermocouple spacing in bundle 3. A schematic of the axial positioning of the source and detectors (ion chambers) is shown in Fig. 7.

Development of the fabrication technique for the semiannular source capsule has been completed and tested successfully. Delivery of the ion chambers is expected in early July 1980, and initial testing of the in-bundle densitometer system is scheduled for mid-July 1980. The motor drive system for remote axial positioning of the measurement sites is being fabricated and is scheduled for installation prior to the bundle uncover tests.

A methodology has been developed for pretest mass flow uncertainty analysis using the RELAP thermal-hydraulic code and the mass flow code AMICON. The time-dependent inlet and outlet flow conditions generated by the RELAP code will be transformed into pseudo-spool piece data for input to AMICON. An interface code has been developed to produce the simulated spool piece instrument data. Pretest uncertainties in mass flows will be generated by combining the pseudo-spool piece data with the instrument uncertainties expected for the actual test configuration.

Design has begun on a new thermocouple array rod for in-bundle fluid temperature measurements and also on modification of the test section barrel and shroud box to provide thermocouples for shroud wall temperature and energy storage measurements. Both measurement improvements are intended for the upcoming bundle uncover tests.

FUEL ROD SIMULATORS

INSTRUMENT RODS

T/C - THERMOCOUPLE ARRAY ROD

LLD - INEL LIQUID LEVEL DETECTOR

 γ - D - IN-BUNDLE GAMMA DENSITOMETERS

Fig. 6. THTF bundle 3 array.

Fig. 7. Axial positioning of the source-detector measurement location.

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