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BWR BLOWDOWN EMERGENCY CORE COOLING TWELFTH QUARTERLY PROGRESS REPORT

OCTOBER 1 — DECEMBER 31, 1978

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BWR BLOWDOWN/EMERGENCY CORE COOLING TWELFTH QUARTERLY PROGRESS REPORT OCTOBER 1 — DECEMBER 31, 1978

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ABSTRACT

Blowdown/Emergency Core Cooling work completed in the fourth quarter of 1978 (October 1, 1978 through December 31, 1978) is summarized. The 64-Rod Blowdown Heat Transfer Test topical report was completed. Verified data packages for peak and average power bundle tests were completed. A preliminary analysis of the comparison between tests conducted with and without ECC injection was completed. No experiments were run during this quarter. The TLTA was disassembled and the heater bundle removed. Reassembly has been deferred pending PMG approval. Simulation of the TLTA loop using the TRAC code was begun.

1. INTRODUCTION

1.1 GENERAL

A major requirement in the design of power reactor systems is the limitation of fuel cladding temperatures below specified values during both normal operation and an unlikely, but postulated, loss-of-coolant-accident (LOCA). To meet this design requirement it is necessary to be able to predict system performance during a LOCA. Since this type of information is not obtainable from tests on actual reactors, scaled system test programs are used to provide basic system performance information. The BWR Blowdown/Emergency Core Cooling (BD/ECC) Program[1] extends the scope of the BWR Blowdown Heat Transfer (BDHT) Program to include ECC system operation. Results from the BD/ECC Program will provide a basis for evaluating BWR system phenomena throughout the entire LOCA transient from break initiation to core reflood.

1.2 PROGRAM OBJECTIVES

The BWR BD/ECC Program charter is to conduct an experimental program, jointly funded by the U.S. Nuclear Regulatory Commission (USNRC), Electric Power Research Institute (EPRI), and General Electric (GE), to obtain information on transient heat transfer following an unlikely, but postulated rupture of a steam line or recirculation line in a boiling water reactor (BWR). This program will:

1. obtain and evaluate basic BD/ECC data from test system configurations which have calculated performance characteristics similar to a BWR with 8x8 fuel bundles during a hypothetical LOCA; and

2. determine the degree to which models for BWR system and fuel bundles describe the observed phenomena and, as necessary, develop improved models which are generally useful in improved LOCA analysis methods.

Requirements of the BWR BD/ECC Program include use of a test apparatus which will provide LOCA test conditions representative of the environment expected in the postulated BWR LOCA. The scaling and design objectives are to provide a test apparatus for investigating, on a real time basis, the expected BWR fuel thermal-hydraulic response, using an electrically heated, full-sized, full-power test bundle.

1.3 ORGANIZATION OF THE PROGRAM

The BD/ECC Program contract was executed in December 1975. The total BD/ECC Program work scope is shown in Appendix A. A report schedule is contained in Appendix B.

1.4 STATUS OF THE PROGRAM

A number of the completed and reported major milestones are presented below. Appendix B indexes the significant publications pertaining to these milestones.

1. Formulation of program plan[1] and 8x8 BDHT test plan[2] (Task AA).*

2. An evaluation of electric heaters for use in the BD/ECC Program (Task BB).

3. Issuance of report on the transient thermal-hydraulic model, MAYUO4.[3]

4. Distribution of facility description report[4] for the BD/ECC1A phase.

5. Issuance of revised BD/ECC1A test plan.[5]

6. 64-Rod Bundle Test Topical Report completed.

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*See Appendix A for task description.

During the fourth quarter, verified data packages were issued for the BD/ECC1A Matrix Tests 6 (average bundle power) and 14 (peak bundle power). Measurement verification and data evaluation for other tests are continuing.

A preliminary analysis of the differences between tests with and without ECC injection has been completed.

The two-loop test apparatus (TLTA) was disassembled and the heater bundle was removed. Reassembly was delayed pending the Program Management Group's (PMG) approval.

The TLTA test loop has been set up on the Transient Reactor Analysis Code (TRAC). Evaluation of the TRAC code simulation of the jet pumps, separator and critical flow nozzle was begun.

2. PROGRAM PLANNING AND ADMINISTRATION

The program plan for the fourth quarter was consistent with the PMG's direction as follows:

1. To change the emphasis from testing to data evaluation with the focus being on understanding the phenomena.

2. Defer procurement of the BD/ECC1B hardware pending further evaluation of alternate configurations that would improve the simulation.

3. Use the TRAC code for TLTA analysis.

3. EXPERIMENTAL WORK

3.1 BD/ECC1A TESTING

No tests were run during the fourth quarter. This was consistent with the PMG's decision to concentrate on data evaluation rather than testing.

4. ANALYTICAL EFFORT

4.1 BD/ECC1A DATA EVALUATION

Data reduction, measurement verification, and evaluation of the ECC injection data continued during the reporting period. The main emphasis was placed on understanding the phenomena in the TLTA and the observed differences between tests with and without ECC injection.

Data packages were issued for Matrix Test 6 (reference Test 6406 Run 1; average power, nominal ECC flow conditions) and Matrix Test 14 (peak power Test 6414 Run 3; peak power, low ECC flow, high ECC temperature). See Table 4-1.

The main conclusions reached to date regarding the average power test (Matrix Test 6) are summarized below. The TLTA test with ECC injection results in lower depressurization rates than observed without ECC injection. A comparison of the effects of ECC injection is shown in Figure 4-1. The decrease is observed because the condensation of steam by the ECC fluid is offset by additional heat transfer to the fluid and by the lower volumetric blowdown flow when some liquid is entrained in the blowdown steam flow.

Part of the additional heat transfer is in the TLTA bundle as evidenced by the lower temperatures observed in the bundle in the ECC injection test. The lower cladding temperature and generally lower bundle heatup with ECC injection are shown in Figures 4-2 and 4-3. However, a substantial part of the additional heat transfer is elsewhere in the system. Heat transfer in the lower plenum is essentially the same for both tests during the period of interest and is of the same order of magnitude as the bundle heat transfer. Comparison of fluid thermocouple measurements in the downcomer region indicate an increased heat transfer from the downcomer vessel walls for the ECC injection test. This source of heat could contribute up to several times that due to the bundle alone.

A preliminary evaluation of the peak power test, Matrix Test 14, indicates additional ECC cooling effects, particularly at the top of the bundle, even for this most severe combination of parameters.

Preparatory effort on the thermal-hydraulic system code, TRAC, was initiated to provide an additional basis for an evaluation and analysis of the TLTA phenomena. An input file representing a simulation of the TLTA has been set up. Preliminary computer runs of up to 1 second transient time have been made to test the accuracy of the input data and to judge computer running time. The results indicate that the running time appears far too excessive using the current simulation and numerical criteria. Efforts in the next quarter will be directed at reducing the running time.

Some of the components from the system simulation have been run open loop to provide a separate assessment of their model capabilities. These include the jet pump, separator, and break flow nozzle. After some changes were made in the jet pump model, some good first order results were obtained. Further detailed evaluation is still in progress. The separator studies indicate that further work needs to be done on this model. The break flow nozzle representation so far is very good and these studies are being completed.

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Table 4-1
MATRIX TESTS

Matrix Number	1	5	6	7	11	14
Bundle power (MW)	1.62	5.05	5.05	5.05	6.49	6.49
Spray flow	high	low	rated	low	rated	low
LPCI pumps	1	1	1	1	1	1
ECC water temp. (°F)	120	120	120	80	120	200
System timing (sec)	nominal*	nominal	nominal	nominal	nominal	nominal

*27 seconds for HPCS, 37 seconds for LPCS and LPCI.
HPCS = high pressure core spray
LPCS = low pressure core spray
LPCI = low pressure coolant injection

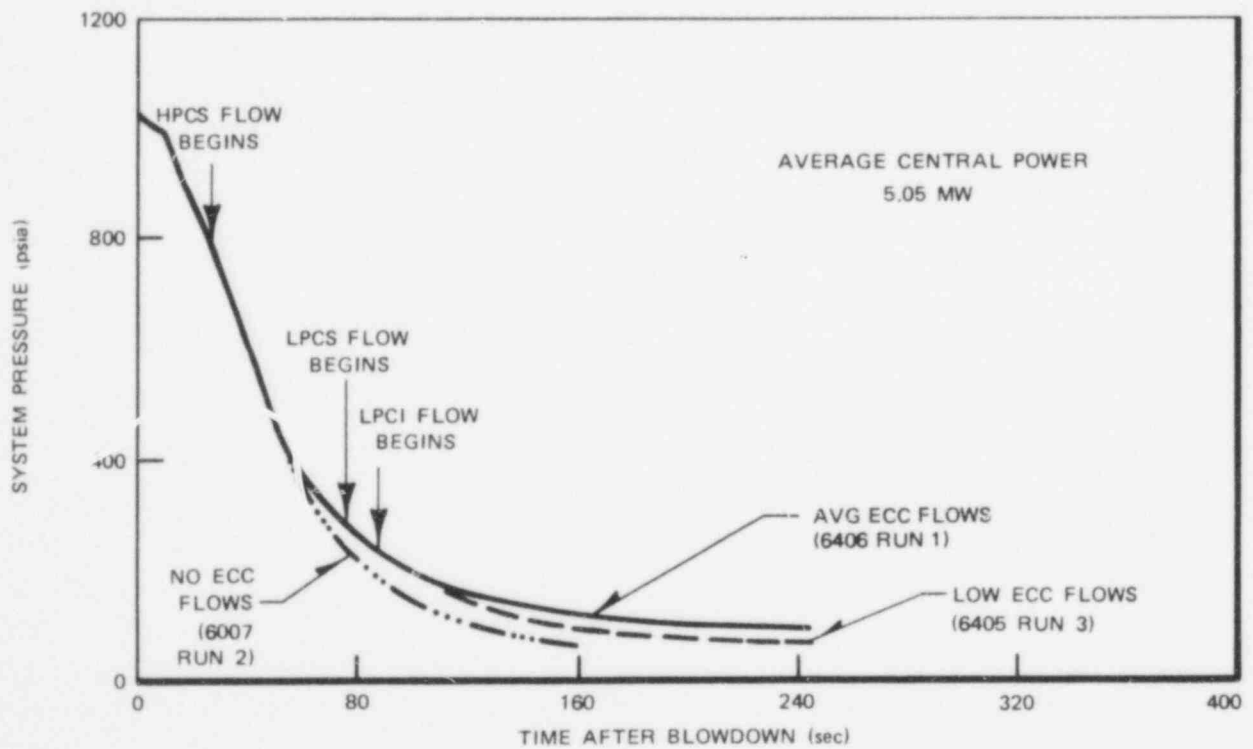

Figure 4-1. Effect of ECC Flows on System Pressure Response

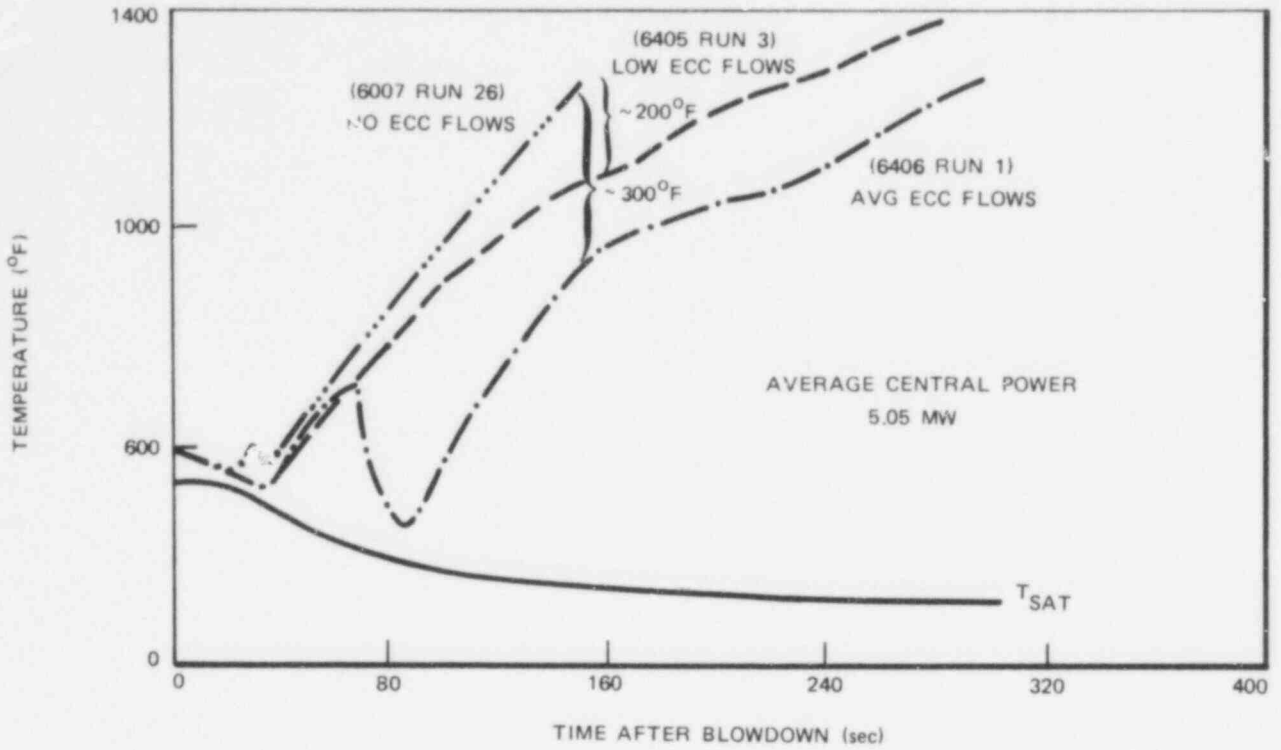

Figure 4-2. Effect of ECC Flows on Cladding Temperature at Peak Power Elevation

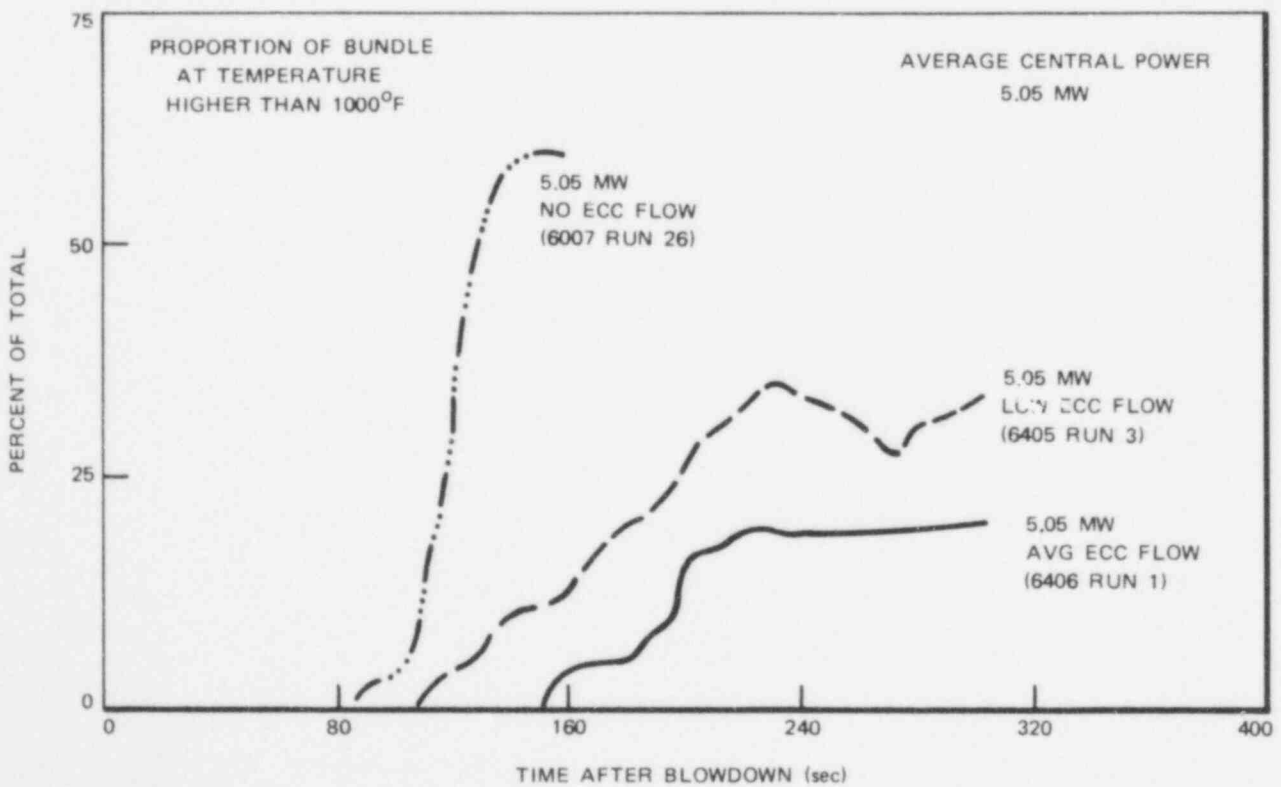

Figure 4-3. Effect of ECC Flows on Bundle Heat Up

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5. TWO-LOOP TEST APPARATUS

5.1 TEST SECTION DESIGN AND FABRICATION

After a leak was detected, the TLTA vessel was disassembled and the bundle removed. It was determined that the heater rods had reached the end of their useful life and must be replaced. Reassembly of the TLTA has been deferred pending PMG approval.

During the third quarter design concepts for improving the scaling fidelity of the TLTA-6 facility BD/ECC1B-Reflood Phase were proposed. During the fourth quarter, costs and schedule estimates for implementing these changes were developed. Procurement of hardware and implementation of these changes have been deferred pending PMG approval.

6. REFERENCES

1. R. J. Muzzy, *Preliminary BWR Blowdown/Emergency Core Cooling Program Plan*, June 1976 (GEAP-21255).

2. J. P. Walker, *BWR Blowdown/Emergency Core Cooling Program — 64-Rod Bundle Blowdown Heat Transfer Test Plan*, September 1976 (GEAP-21333).

3. W. C. Punches, *MAYU04 — A Method to Evaluate Transient Thermal Hydraulic Conditions in Rod Bundles*, March 1977 (GEAP-23517).

4. W. J. Letzring, Editor, *BWR Blowdown/Emergency Core Cooling Program Preliminary Facility Description Report for the BD/ECC1A Test Phase*, December 1977 (GEAP-23592).

5. J. C. Wood and A. F. Morrison, *BWR Blowdown/Emergency Core Cooling Program — 64-Rod Bundle Core Spray Interaction (BD/ECC1A) Test Plan*, February 1978 (GEAP-NUREG-21638A).

APPENDIX A

WORK SCOPE FOR BD/ECC PROGRAM — CONTRACT NO. NRC-04-76-215

PURPOSE

OVERALL PURPOSE

The purposes of the EPRI/NRC/GE Integral Blowdown/Emergency Core Cooling, BD/ECC, test program are to:

1. obtain and evaluate basic BD/ECC data from test system configurations which have calculated performance characteristics similar to a BWR with 8x8 fuel bundles during a hypothetical LOCA; and

2. determine the degree to which models for BWR system and fuel bundles describe the observed phenomena, and as necessary, develop improved models which are generally useful in improved LOCA analysis methods.

SPECIFIC OBJECTIVES

The specific objectives of the integral BD/ECC interaction test program are:

1. **Scaling Analysis:** evaluate and document the scaling basis of the TLTA in the configurations selected for BD/ECC interaction tests as compared to reference BWR designs.

2. **7x7 Counter-Current-Flow-Limited (CCFL) Flooding Characteristics:** conduct CCFL flooding characteristic tests of the present TLTA bundle geometry to establish the need, or lack thereof, to modify the present test apparatus design for the initial BD/ECC interaction experiments.

3. **8x8 Blowdown Heat Transfer Tests:** conduct 8x8 BDHT tests for comparison with 7x7 BDHT data and to serve as a BDHT baseline for BD/ECC interaction experiments.

4. **BD/ECC Interaction Tests:** evaluate system response and heat transfer and evaluate effectiveness of ECC during the blowdown period, and extending well beyond the initial flow coastdown and lower plenum "flashing" periods of the calculated BWR-LOCA in one or more system configurations.

5. **Alternate Power Shape BD/ECC:** determine the effects of axial power shape on the system response and bundle heat transfer behavior during the calculated BWR LOCA.

6. **Non-Jet Pump Plant BD/ECC:** investigate the ECC interaction with the system during blowdown in a representative non-jet pump test system configuration.

7. **Reporting of Data:** report all data (including pertinent error bands) in conventional parametric form suitable for correlation by others.

8. **Model Development:** develop, verify, and document an improved bundle thermal-hydraulic model that can be incorporated into analyses of BWR LOCA's.

9. **Application of Data:** specify how General Electric intends to use the data to qualify the degree of conservativeness of BWR LOCA evaluation models.

SCOPE

Task AA — Program Planning and Administration

1. General Electric will prepare a Preliminary BD/ECC Program Plan that elaborates on the means for meeting the program objectives. The program plan will include, but not be limited to: (a) BWR configurations and LOCA conditions to be tested; (b) test parameters and their ranges; (c) updated conceptual designs and testing strategies; (d) an outline of model development and verification activities; and (e) the method of relating previous 7x7 rod bundle data to the 8x8 rod bundle data. Sufficient discussion of the above items will be included to substantiate the basis for the preliminary program plan. The program plan will also include an updated schedule, a proposed data verification and reporting plan, and the planned utilization of data by General Electric to assess current BWR LOCA evaluation methods.

   The preliminary program plan will be provided for EPRI and NRC review, comment and approval on an agreed upon time schedule. If comments are not supplied to General Electric by NRC or EPRI within the agreed schedule, General Electric may proceed as proposed.

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2. Following mutual agreement on the results from Task AA-1, and the appropriate phase of Tasks BB and CC-1, General Electric will prepare a detailed test plan for each major testing phase. Each detailed test plan will include the test objectives, test phase description, test matrices, parameter ranges and reasons for selection, test execution plan, planned utilization of the data, and the planned schedule for completing that phase.

   The preliminary test plans will be provided for EPRI and NRC review, comment, and approval on an agreed upon time schedule. If comments are not supplied to General Electric by EPRI or NRC with the agreed schedule, General Electric may proceed as proposed.

Task BB — Heater Evaluation

1. Perform appropriate analysis relating electrical heater performance to predicted nuclear fuel rod temperature performance during an ECC transient. This analysis will describe the method of programming initial and decaying electrical power to produce representative BWR LOCA thermal response and will describe how differences in thermal properties are accounted for in the electrical simulations.

2. Evaluate the need for tests to demonstrate the validity of the above analyses. The heater evaluation including documentation of the above item will be provided by EPRI and NRC review, comment and approval on an agreed upon time schedule. If comments are not supplied to General Electric by EPRI or NRC within the agreed schedule, General Electric may proceed as proposed.

Task CC — Test Facility Design and Fabrication

1. Scaling and design analyses to define each system configuration will be performed and documented. Particular attention will be given to attaining a real time simulation of calculated BWR system and fuel bundle thermal-hydraulic LOCA response.

   Design trade-off and scaling compromise studies will be performed to establish the final scaling basis to be used for design and operation of each configuration. Appropriate analytical methods including, but not necessarily limited to, those used for BWR performance analyses will be applied to obtain best estimate performance predictions of the BWR reference plants and the test system configurations. These pre-test predictions will include time to boiling transition (BT), lower plenum flashing effects, post-BT heat transfer, and response to ECCS operation. Differences in anticipated dynamic response of the test apparatus as compared to a BWR will be identified by appropriate analysis. Measurement requirements to obtain program objectives, including type, number, location and accuracy of instruments will be specified and an instrumentation plan to meet these requirements will be developed. A preliminary Facility Description including documentation of the above items, presenting the technical basis for the preliminary design, will be provided for EPRI and NRC review; comment and approval on an agreed upon time schedule. If comments are not supplied to General Electric by EPRI or NRC within the agreed schedule, General Electric may proceed as proposed.

2. Upon resolution of comments, if any, the contractor shall provide a revised Facility Description as necessary.

   The final design and procurement of necessary material for each configuration will be completed and the system will be prepared for calibration testing.

Task DD — Test Section Design and Fabrication

Upon completion of Task BB and an evaluation of the BDHT test section counter-current-flow-limiting (CCFL) characteristics, General Electric will complete the design, procurement and assembly of the 8x8 rod test sections for BD/ECC testing. The test section designs will be documented in the appropriate Facility Description reports.

Task EE — System Startup Tests

Upon assembly of each configuration, conduct performance and flow calibration tests. Perform hydrostatic, hydrodynamic and transient startup tests for each configuration to establish system operational characteristics including adequacy of heater and instrumentation response. Conduct steady-state and/or transient separate effects tests necessary to provide the basis for interpretation of BD/ECC experimental results.

Task FF — BD/ECC Interaction Tests

For each configuration, perform tests as detailed Tasks AA-2 and CC-2.

Task GG — Data Evaluation and Model Development

1. Analyze and document the as-built system performance characteristics based on system startup tests. Evaluate the test apparatus design for meeting program objectives on the basis of system startup performance tests. Determine what, if any, minor modifications and/or adjustments should be made on the test facility and update the predictions of system response as appropriate.

2. Upon completion of a specified test series, reduce, evaluate, and report the experimental data. Provide the experimental basis for confirming or modifying the assumptions and models used in LOCA evaluations such as the onset of boiling transition (BT), the subsequent heat transfer rates, effects of lower plenum flashing on core thermal response, and the effects of ECC on core and system response. Document the data obtained, the storage format and how it can be accessed by others.

3. As appropriate, develop and document improved analytical models, which can be incorporated into best estimate analyses of BWR LOCA's. This will include, but not be limited to, the development of a self-standing transient thermal-hydraulic model for the prediction of local thermodynamic parameters in rod bundles during LOCA's. These local parameters are necessary for the phenomenological understanding and correlation of local heat transfer coefficients. Values for local heat transfer coefficients are desired which may be expressed as a function of local conditions such as temperature differences, flowrates, pressure and quality.

4. Indicate how the data obtaining can be used to assess current BWR LOCA evaluation models including a quantitive determination of safety margins.

APPENDIX B

BD/ECC PROGRAM REPORTS

B.1 LIST OF REPORTS PREPARED AS PART OF THE BWR BD/ECC PROGRAM DOCUMENTATION

Report No./Type	Title/Author(s)	Principal Contents
GEAP-21207 Informal	BWR 8x8 Fuel Rod Simulation Using Electrical Heaters, J. P. Dougherty, R. J. Muzzy, March 1976.	Analysis of electrical heaters to simulate nuclear fuel rods.
GEAP-21304-1 Quarterly	BWR Blowdown/Emergency Core Cooling First Quarterly Progress Report, January 1— March 31, 1976.	
GEAP-21255 Topical Report	Preliminary BWR Blowdown/ Emergency Core Cooling Program Plan, R. J. Muzzy, June 1976.	Design consideration leading to various test configurations. Test parameters and ranges. Test strategy.
GEAP-21304-2 Quarterly	BWR Blowdown/Emergency Core Cooling Second Quarterly Progress Report, April 1--June 30, 1976.	
GEAP-21333 Topical Report	64-Rod Bundle BDHT Test Plan, J. P. Walker, September 1976.	Test matrix and test strategy for 8x8 plan.
GEAP-21304-3 Quarterly	BWR Blowdown/Emergency Core Cooling Third Quarterly Progress Report, July 1—September 30, 1976.	
GEAP-21304-4 Quarterly	BWR Blowdown/Emergency Core Cooling Fourth Quarterly Progress Report, October 1—December 31, 1976.	
GEAP-21304-5 Quarterly	BWR Blowdown/Emergency Core Cooling Fifth Quarterly Progress Report, January 1—March 31, 1977.	
GEAP-21304-6 Quarterly	BWR Blowdown/Emergency Core Cooling Sixth Quarterly Progress Report, April 1—June 30, 1977.	
GEAP-21304-7 Quarterly	BWR Blowdown/Emergency Core Cooling Seventh Quarterly Progress Report, July 1--September 30, 1977.	

B.1 LIST OF REPORTS PREPARED AS PART OF THE BWR BD/ECC PROGRAM DOCUMENTATION (Continued)

Report No./Type	Title/Author(s)	Principal Contents
NEDG-NUREG-23732	TLTA Components CCFL Tests D. D. Jones, December 1977.	Results of CCFL testing of TLTA-1 and -3 core inlets and TLTA jet pump. Results of single phase liquid pressure drops across TLTA-3 core inlet and single phase reverse flow steam pressure drops across TLTA jet pumps.
GEAP-23592	BWR Blowdown/Emergency Core Cooling Program Preliminary Facility Description Report for the BD/ECC-1A Test Phase. W. J. Letzring, editor, December 1977.	Detailed description of TLTA configuration for BD/ECC-1A.
GEAP-NUREG-21304-8	BD/ECC 8th Quarterly Progress Report October 1—December 31, 1977.	
GEAP-NUREG 21304-9	BD/ECC 9th Quarterly Progress Report January 1—March 30, 1978.	
GEAP-NUREG-21638A	BWR Blowdown/Emergency Core Cooling Program 64-Rod Bundle Core Spray Interaction (BD/ECC1A) Test Plan, J. C. Wood and A. F. Morrison, February 1978.	Test matrix and test strategy for BD/ECC1A phase.
GEAP-21304-10 Quarterly	BWR Blowdown/Emergency Core Cooling Tenth Quarterly Progress Report April 1—June 30, 1978	
GEAP-21364-11 Quarterly	BWR Blowdown/Emergency Core Cooling Eleventh Quarterly Progress Report July 1—September 30, 1978	
GEAP-NUREG-23977	64-Rod Bundle Blowdown Heat Transfer (8x8) Final Report September, 1978	Topical report covering blowdown heat transfer without ECC injection.

B.2 LIST OF REPORTS PLANNED AS PART OF BWR BD/ECC PROGRAM DOCUMENTATION

Title	Principal Contents	Scheduled Date
BD/ECC1B Test Plan	Preliminary plan and test strategy for BD/ECC1B testing	July 1978*
BD/ECC1B Facility Description	Detailed description of TLTA configuration for BD/ECC1B	October 1978*
BD/ECC1A Final Report	Results from BD/ECC1A testing	November 1978**
BD/ECC2 Test Plan	Test matrix and test strategy for BD/ECC2 testing	August 1979**
BD/ECC2 Facility Description	Detailed description of TLTA configuration for BD/ECC2 testing	October 1979**
BD/ECC1B Final Report	Results from BD/ECC1B testing	February 1980**
Non-Jet Pump Test Plan	Test matrix and test strategy for non-jet pump testing	March 1980**
Non-Jet Pump Facility Description	Detailed description of TLTA configuration of non-jet pump testing	April 1980**
BD/ECC2 Final Report	Results from BD/ECC2 testing	August 1980**
Non-Jet Pump Final Report	Results from non-jet pump testing	February 1981**
Final BD/ECC Report	Summary and Conclusions from BD/ECC program	April 1981**

* Deferred by PMG

** Original Buff Book estimate dates — subject to revision.

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