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BWR Refill-Reflood Program
Task 4.1-Program Plan

Prepared by G. W. Burnette

Nuclear Engineering Division
General Electric Company

Prepared for
U.S. Nuclear Regulatory Commission

and
Electric Power Research Institute

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BWR Refill-Reflood Program Task 4.2 - Core Spray Distribution Experimental Task Plan, T. Eckert, General Electric Company, NUREG/CR-1558, August 1980.

BWR Refill-Reflood Program Task 4.2 - Core Spray Distribution Final Report, T. Eckert, General Electric Company, NUREG/CR-1707, September 1980.

BWR Refill-Reflood Program Task 4.3 - Single Heated Bundle Experimental Task Plan, D. D. Jones, [illegible] Myers, J. A. Findlay, General Electric Company, NUREG/CR-1788, January 198[illegible]

BWR Refill-Reflood Program Task 4.3 - Single Heated Bundle Experimental Task Plan, Addendum I, Stage 3 - Separate Effects Bundle, D. D. Jones, General Electric Company, NUREG/CR-1708 - Add. I, July 1980.

BWR Refill-Reflood Program Task 4.4 - CCFL Refill System Effects Tests (30 Sector) Experimental Task Plan, D. G. Schumacker, General Electric Company, NUREG/CR-1846, December 1980.

BWR Refill-Reflood Program Task 4.7 - Model Development Task Plan, J. G. M. Andersen, General Electric Company, NUREG/CR-2057, March 1981.

BWR Refill-Reflood Program Task 4.8 - Model Qualification Task Plan, J. A. Findlay, General Electric Company, NUREG/CR-1899, January 1981.

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ABSTRACT

The BWR Refill-Reflood Program is described. This program will develop more detailed experimental information, particularly in large scale facilities, and realistic modelling capability for the refill and reflood phases of hypothetical loss-of-coolant accidents in BWRs. Included in this document are a general strategy discussion, brief descriptions of the experimental facilities to be used including capabilities and limitations, descriptions of the various experimental tasks, descriptions of the model development and model qualification tasks, the planned documentation and schedule information.

SUMMARY

An overview of the BWR Refill-Reflood Program is provided in this report. This program is jointly sponsored by the Nuclear Regulatory Commission, the Electric Power Research Institute, and the General Electric Company. General Electric is the contracting organization for completing this work.

This program will develop more detailed experimental information, particularly in large scale facilities, and realistic modeling capability for the refill and reflood phases of hypothetical loss-of-coolant accidents in BWRs.

Specific objectives include development of a better understanding of the phenomena controlling the refill and reflood phases and development and qualification of a best-estimate BWR system thermal-hydraulic code.

Included in this document are a general strategy discussion, brief descriptions of the experimental facilities to be used including capabilities and limitations, descriptions of the various experimental tasks, descriptions of the model development and model qualification tasks, the planned documentation, and schedule information.

Section 1

PREAMBLE

A major consideration in the design of engineered safety systems and licensing of Boiling Water Reactors (BWRs) is that sufficient Emergency Core Coolant (ECC) be provided to cool the reactor core, in the event of hypothetical* loss-of-coolant accidents (LOCAs). Historically, most limiting design basis LOCA calculations have been associated with postulated breaks or ruptures of recirculation loop coolant pipes, and have been treated according to three periods of system response known as the Blowdown, Refill, and Reflood phases. An existing research effort, the BWR Blowdown-Emergency Core Cooling (BWR BD-ECC) program, cosponsored by the Electric Power Research Institute (EPRI), the Nuclear Regulatory Commission (NRC), and the General Electric Company (GE), is currently addressing the blowdown and early ECC injection periods. The research effort described herein, the BWR Refill-Reflood program cosponsored by the same three organizations, will address the thermal-hydraulic behavior of most BWR plants (BWR 4 through 6) during the refill and reflood phases of postulated LOCAs on a generic basis. A central feature of these and related research efforts is the development and qualification of thermal hydraulic computer codes for realistic LOCA predictions of system and component behavior that are generally applicable to operating and planned BWR plants.

*It is understood that this program is concerned with studying physical phenomena associated with reactor accidents that are estimated to have an extremely low probability of occurrence, and are therefore termed hypothetical.

Section 2

PROGRAM BACKGROUND, OBJECTIVES, AND STRATEGY

2.1 BACKGROUND

For jet pump plants (BWR 4 through BWR 6), the refill phase extends from the time that ECC systems are activated until sufficient coolant fills the lower plenum to initiate reactor core reflood from the core inlet. The reflood phase extends from the time that coolant reenters the core inlet until the core heatup transient is terminated, and the fuel rods are quenched. Recent experience with the two-loop test apparatus (TLTA) and the single-heated bundle (SHB) test facilities indicates that a core reflooding commences simultaneously with lower plenum refilling. This can occur because of the flow restriction at the core inlet as explained below. However, for ease of discussion these two overlapping phases will be treated separately. Complex two-phase heat transfer and hydrodynamic phenomena would occur during these periods within reactor vessel regions (such as the reactor core, upper plenum, lower plenum, guide tubes, jet pumps, recirculation loop pipes, and downcomer annulus) as subcooled ECC interacts with steam, residual fluid, and hot internal surfaces. These phenomena could include:

1. Counter-current flow of steam and water at limiting locations (such as fuel bundle upper tie plates and spacer grids, core inlet orifices, top of the core bypass region, jet pump throats), which tend to restrict the downward penetration rate of liquid to the lower plenum.

2. Turbulent fluid mixing and condensation effectiveness, between the subcooled ECC and the residual fluid within vessel regions, that may enhance the downward penetration rate of liquid.

3. Steam generation due to system depressurization and energy transfer from heated surfaces within internal regions of the vessel.

4. Evolution of fluid thermodynamic states, phase distributions, and flow rates within and leaving the vessel.

5. Energy removal from the reactor core and vessel internals during the refill and reflood phases.

These phenomena would impact the core reflood timing, resultant peak clad temperatures, and the degree of cladding oxidation for a hypothetical BWR LOCA. Therefore, it is appropriate to improve the definition of these phenomena.

This program, which has been designated as the BWR Refill-Reflood Program, is jointly sponsored by the NRC, EPRI, and GE. GE is the contracting organization for completion of this work. There is a desire on the part of the sponsors and other organizations to develop more detailed experimental information and realistic modeling capability of the refill and reflood phases of hypothetical LOCAs in BWRs.

Application of the information could result in future improved licensing models and safety analysis.

2.2 PROGRAM OBJECTIVES

The objectives of this program are:

a. To develop a better understanding of the phenomena controlling the refill and reflood phases of BWR LOCAs;

b. To provide a basis for, and support to, the development and qualification of best estimate BWR system thermal hydraulic codes for LOCAs; and

c. To provide a basis for assessing assumptions used in establishing BWR LOCA safety margins.

2.3 REPORT OBJECTIVES

The objective of the BWR Refill-Reflood Program Plan document is to elaborate on the means of meeting the above stated program objectives. This document embellishes Appendix B of the BWR Refill-Reflood Contract in order to provide an overview of the program to the technical community. Included in this document are a general strategy discussion, brief descriptions of the experimental facilities to be used, including capabilities and limitations, descriptions of the various experimental tasks, descriptions of the model development and model qualification tasks, the planned documentation, and schedule information.

Appendix B, referenced above, includes the program work scope which was developed jointly by the program sponsors. The work scope is very specific and detailed; as such, it is incorporated into this document as in Appendix II. Further development of the program plan and experimental facilities will be provided in the individual task plan documents.

2.4 PROGRAM STRATEGY

Improved definition of BWR LOCA behavior could be met by either multiple complete full-scale demonstration experiments, or a judicious combination of realistic model development and appropriate supporting experiments. The latter approach has been selected as the strategy for this program. Specifically, this program integrates new large-scale experiments with existing technology, current NRC code development, and new supporting model development to provide qualified realistic models to predict the entire BWR LOCA thermal hydraulic transient. The combination of these elements is illustrated in Figure 2-1.

The new experiments of this program will provide data for model development, model qualification, and for facility simulation qualification. The primary utilization of data obtained under this program is shown in Table 2-1.

The facility qualification tests will evaluate and guide facility scaling. Decision points are provided to allow program redirection as a result of these evaluations, as illustrated in Figure 2-2.

The program will provide phenomena and component models suitable for incorporation into the TRAC code. It will further provide assistance on BWR TRAC code formulation, qualification, and application.

Table 2-1

PRIMARY PURPOSES OF PROGRAM EXPERIMENTS

Task No.	Title	Model Development	Model Qualification	Facility Qualification
2.	Core Spray Distribution		X	
3.	Single-Heated Bundle Task	X		X
4.	CCFL/Refill System Effects Tests (30° Sector)		X	
5.	360° Upper Plenum Tests		X	X
6.	Technical Support Task	X	X	

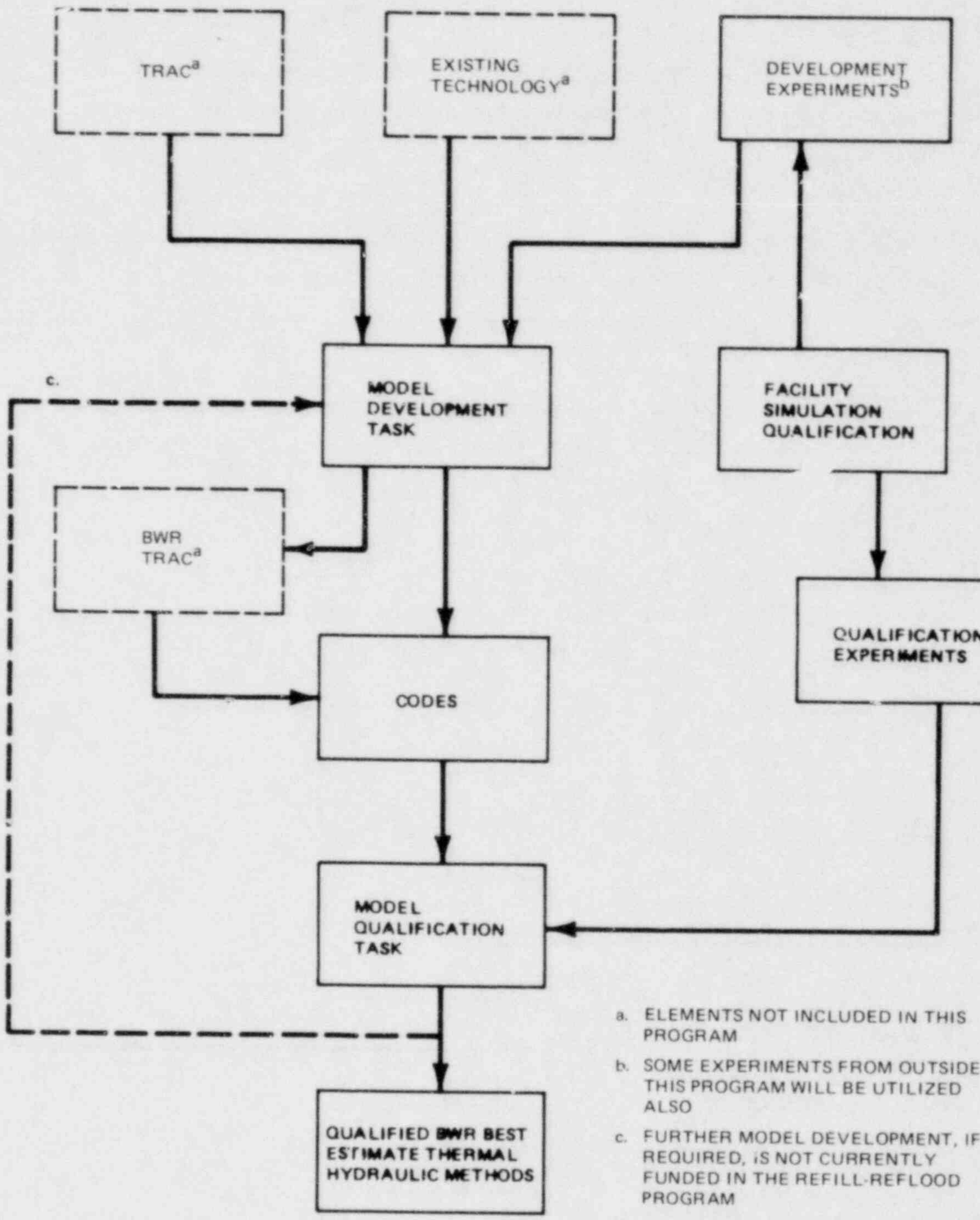


Figure 2-1. Program Element Integration

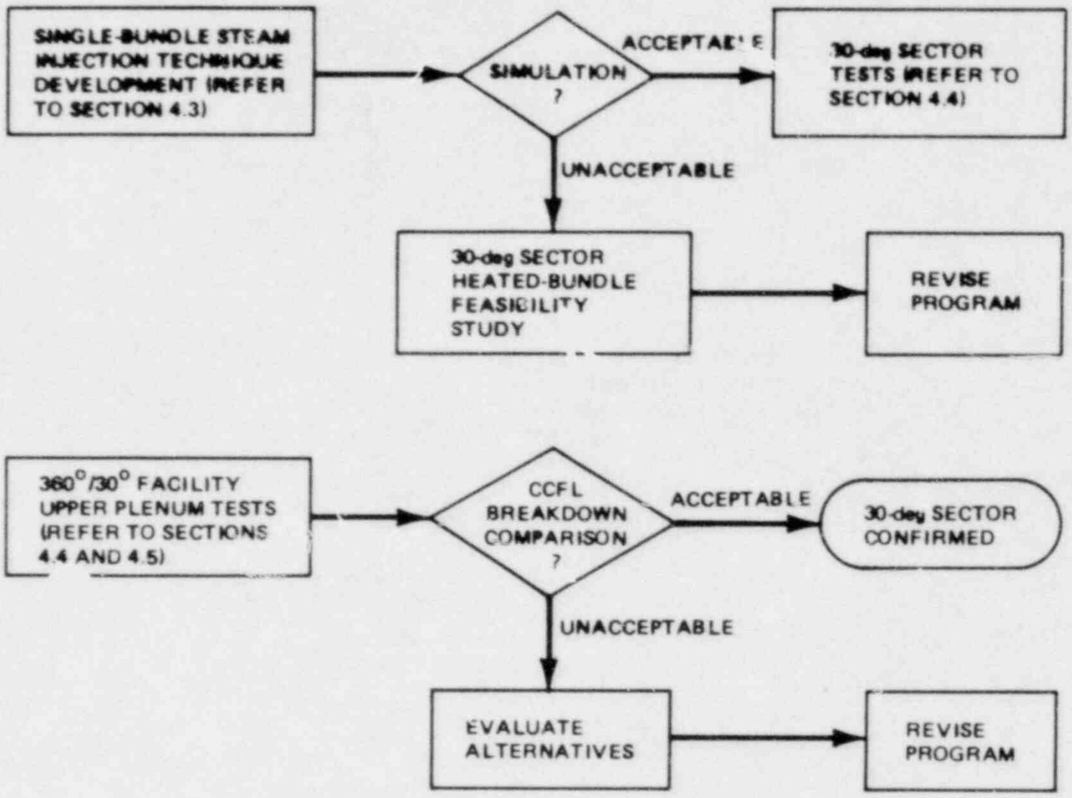


Figure 2-2. Facility Qualification Studies

An example of this support will be the GE contribution of existing core spray distribution methodology that will be compared to the 30° Sector core spray data to guide decisions on further best-estimate core spray modeling requirements, as illustrated in Figure 2-3. Note, however, that because of the empirical basis for this methodology, it will not be directly applicable for incorporation into TRAC.

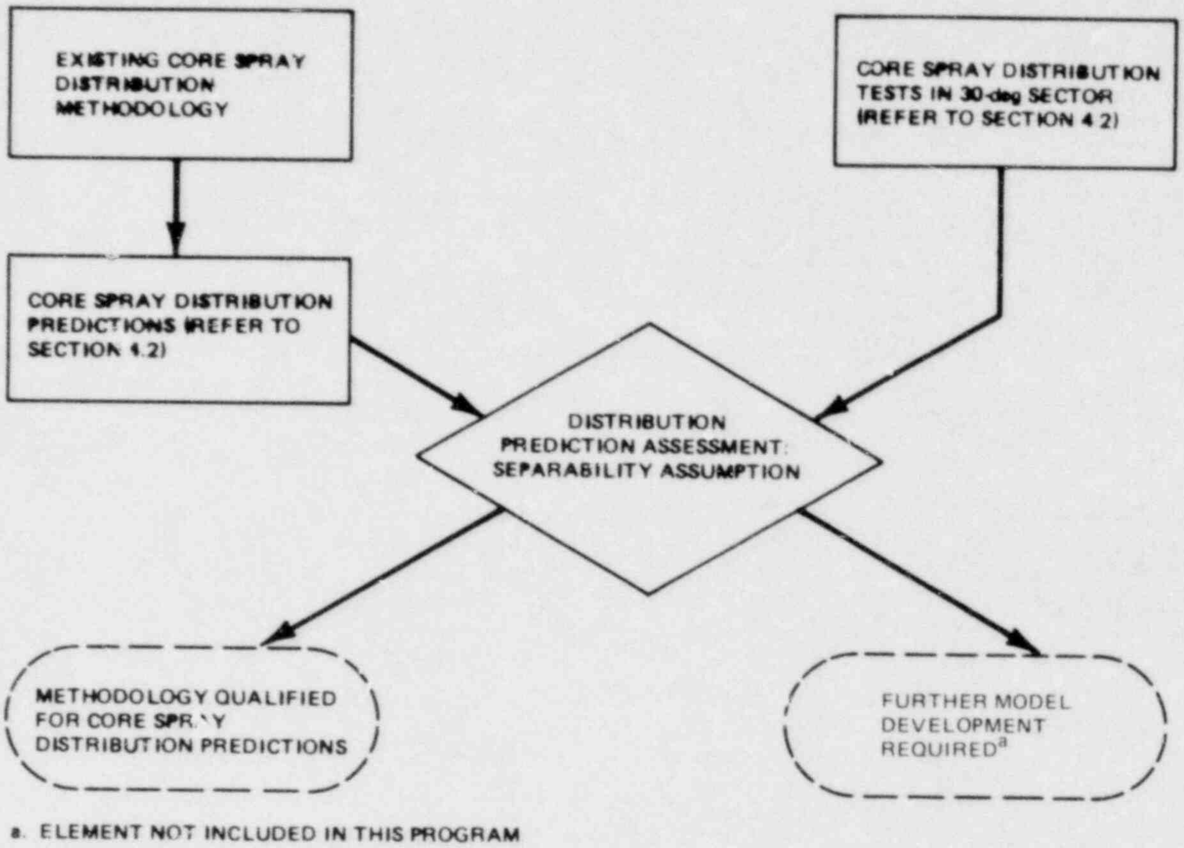


Figure 2-3. Core Spray Distribution Model Decision Process

Section 3

EXTERNAL TECHNOLOGY PROVIDED

3.1 GE EXPERIMENTAL FACILITIES

General Electric is contributing a range of existing and ongoing technology to support the objectives of this joint program. These contributions include existing experimental facilities, as well as previously proprietary experimental data and analytical methods. The following experimental facilities are relevant for BWR LOCA studies, and are available as described, for use in the program.

3.1.1 Lynn Facility and 30° Sector

The Steam Sector Test Facility (SSTF) was built by General Electric at the Lynn River Works site in Massachusetts during 1978, and was put into service early in 1979. The facility is a sector representative of the BWR/6 nuclear plant design, for use in large scale emergency core cooling system (ECCS) and interaction tests.

The basic element of the process loop (Figure 3-1) is the system pressure vessel. This vessel has a 14-ft. inside diameter, a 27-ft. inside height, and is rated for 150 psig operation. The vessel is designed with various nozzles and penetrations for passage of the process and instrument lines which connect to the test section. The vessel is surrounded by service platforms and walkways and is serviced by a 20 ton capacity traveling overhead crane.

The process equipment and loop hardware can be divided into two sets of systems, steam and water. The steam supply for the test facility is 200 psig, superheated (up to 800°F) turbine extraction steam. The current steam system capability is approximately 100,000 lbm/h. It is routed to the pressure vessel through 10-inch pipes to an upper plenum injection nozzle (≈50,000 lbm/h maximum) and to simulated fuel bundles in the test section (≈65,000 lbm/h maximum). The temperature of the steam injected into the test section is controlled by a desuperheater upstream of the measurement sections. A 12-inch vent system from the top of the pressure vessel is capable of handling up to 75,000 lbm/h at a vessel pressure of 125 psi. This system is used to control the vessel pressure during steady-state tests.

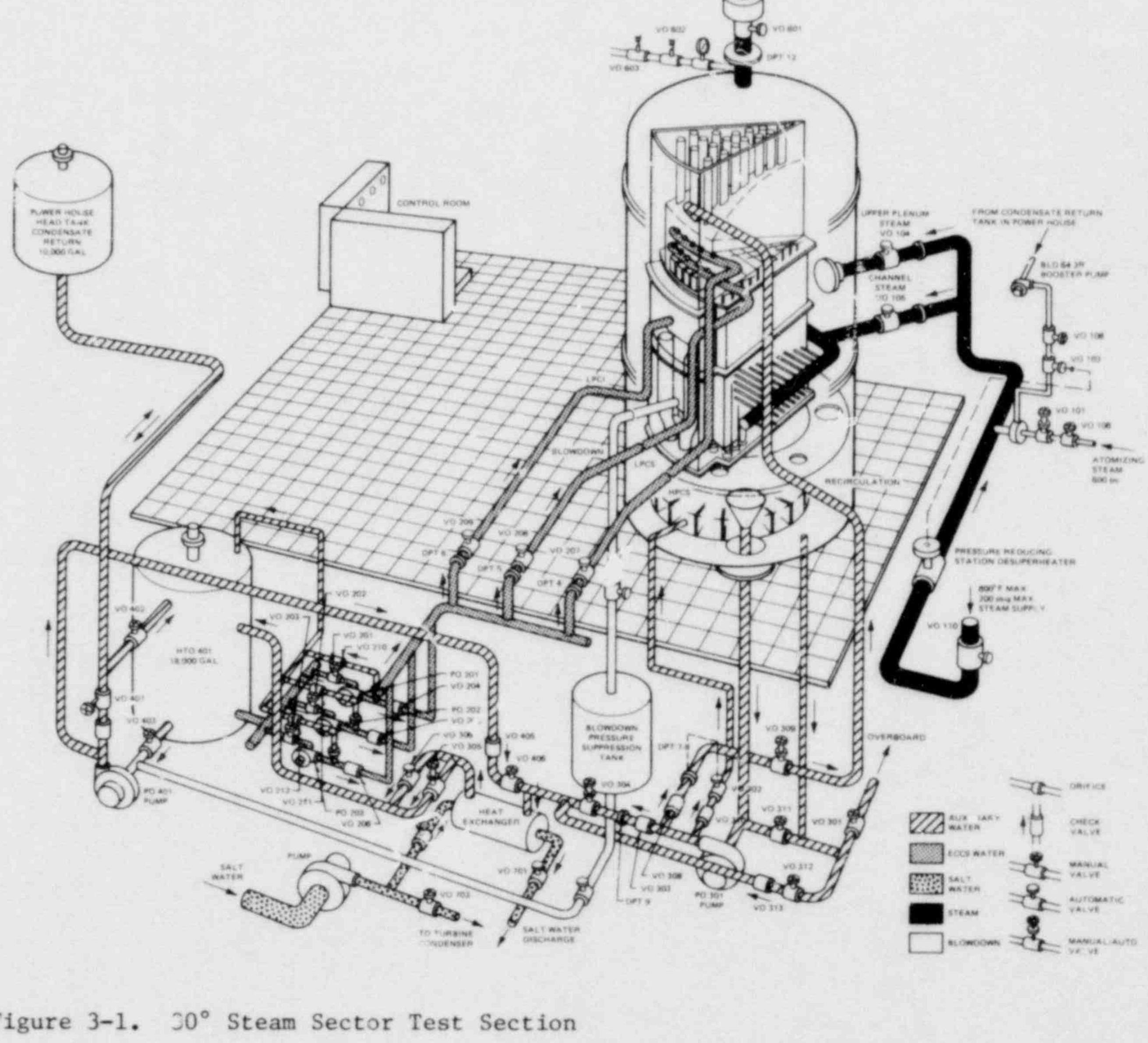


Figure 3-1. 30° Steam Sector Test Section

Water is supplied to the facility from a 10,000-gallon condensate return tank and is stored in an 18,000-gallon reservoir tank, which is part of the ECCS water supply, conditioning, and recirculation loop. The ECCS Supply System consists of three 600 gpm pumps connected in parallel to provide up to 1800 gpm at approximately 200 psi to the 10-inch main supply line. This main line in turn supplies a 6-inch high pressure core spray (HPCS) line with up to 533 gpm, a 6-inch Low Pressure Core Spray (LCPS) line with up to 533 gpm, and an 8-inch low pressure coolant injection (LCPI) line with up to 1333 gpm. The three individual ECCS lines are routed to separate pressure vessel nozzles. The water temperature of the reservoir tank can be adjusted by recirculation through a heat exchanger with a 500 gpm pump in a 6-inch piping loop. Water from the lower plenum in the pressure vessel can either be recirculated back to the upper plenum in the vessel or pumped to the heat exchanger and back to the reservoir tank at up to 1500 gpm. The heat exchanger is a single-pass unit utilizing salt water as the secondary side fluid. The unit is capable of reducing the temperature of 600 gpm of water from approximately 320 to 110°F.

A third major set of loops for a blowdown system was added to the facility in 1980 under the program. This system will provide the capability of conducting pressure transients from 150 psia, in partial simulation of the reactor LOCA case.

The SSTF test section is a 30° segment representation of the BWR/6-218 size (624 bundle) reactor design (Figure 3-2). The upper plenum is a full-scale mockup of a 30° sector of the reference reactor design, with the geometric shape, shroud head curvature, and height accurately simulated. Standpipes simulating the steam separators extend upward from the shroud head. The upper and lower core spray spargers are also full-scale mockups of the HPCS and LPCS spargers with regard to size, curvature, location, and nozzles. The core region is full scale in cross-section, but is approximately 5 feet shorter than the reactor due to overall height limitations. Fifty-eight simulated fuel bundles are used in the 30° Sector, including 42 complete bundles and 16 partial bundles (See Figure 3-3). The partial bundles have removable cover plates and baffles to simulate the 30° boundary within the partial bundle.

The individual simulated fuel bundles utilize production hardware for channels, channel fasteners, spacers, upper tie plates, and lower tie plates. Upper fuel rod simulation includes production expansion springs, end pins, locking tab washers, hexagon nuts, and one fuel rod spacer. A steam injector tube is provided in each

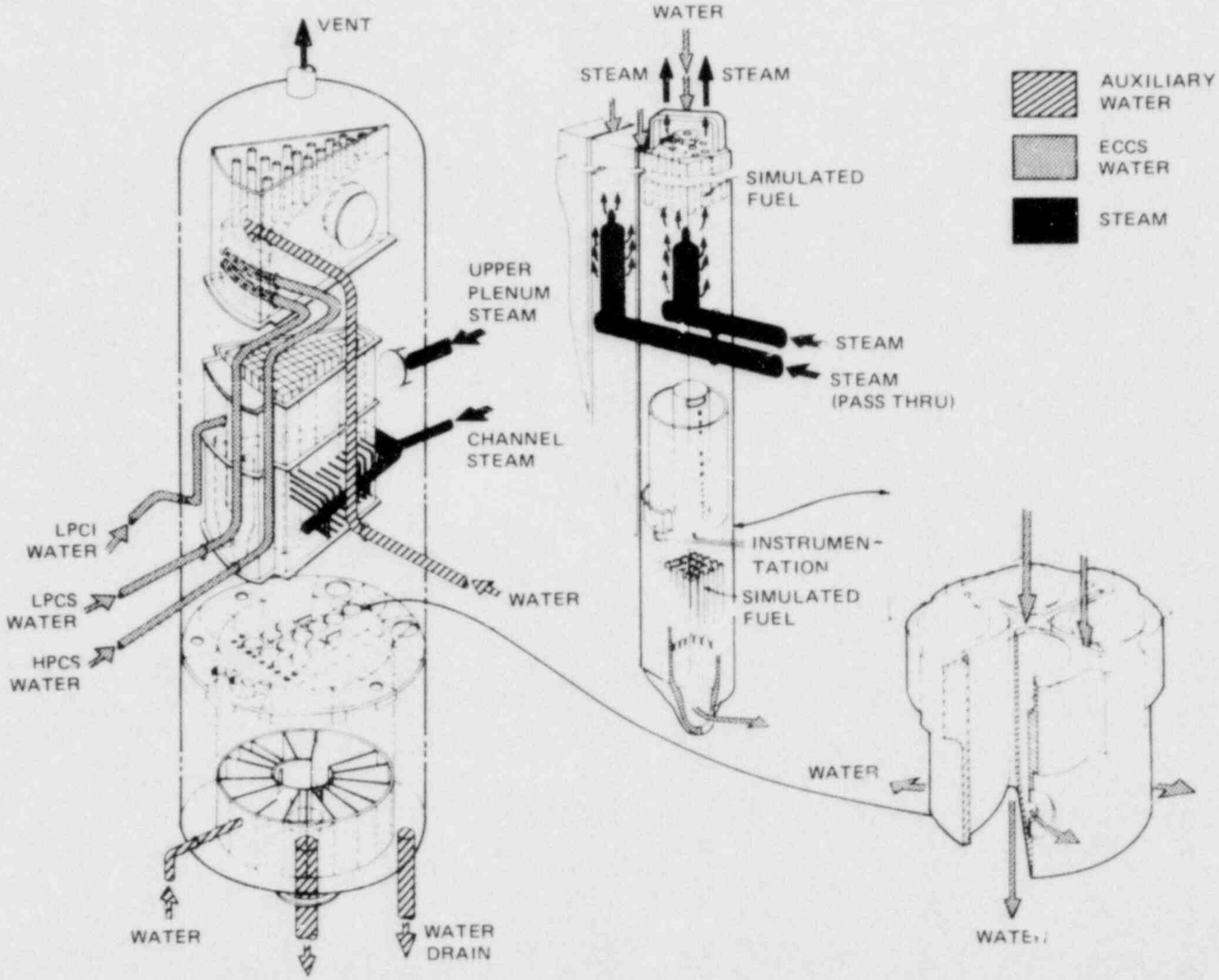


Figure 3-2. 30° Steam Sector Test Facility

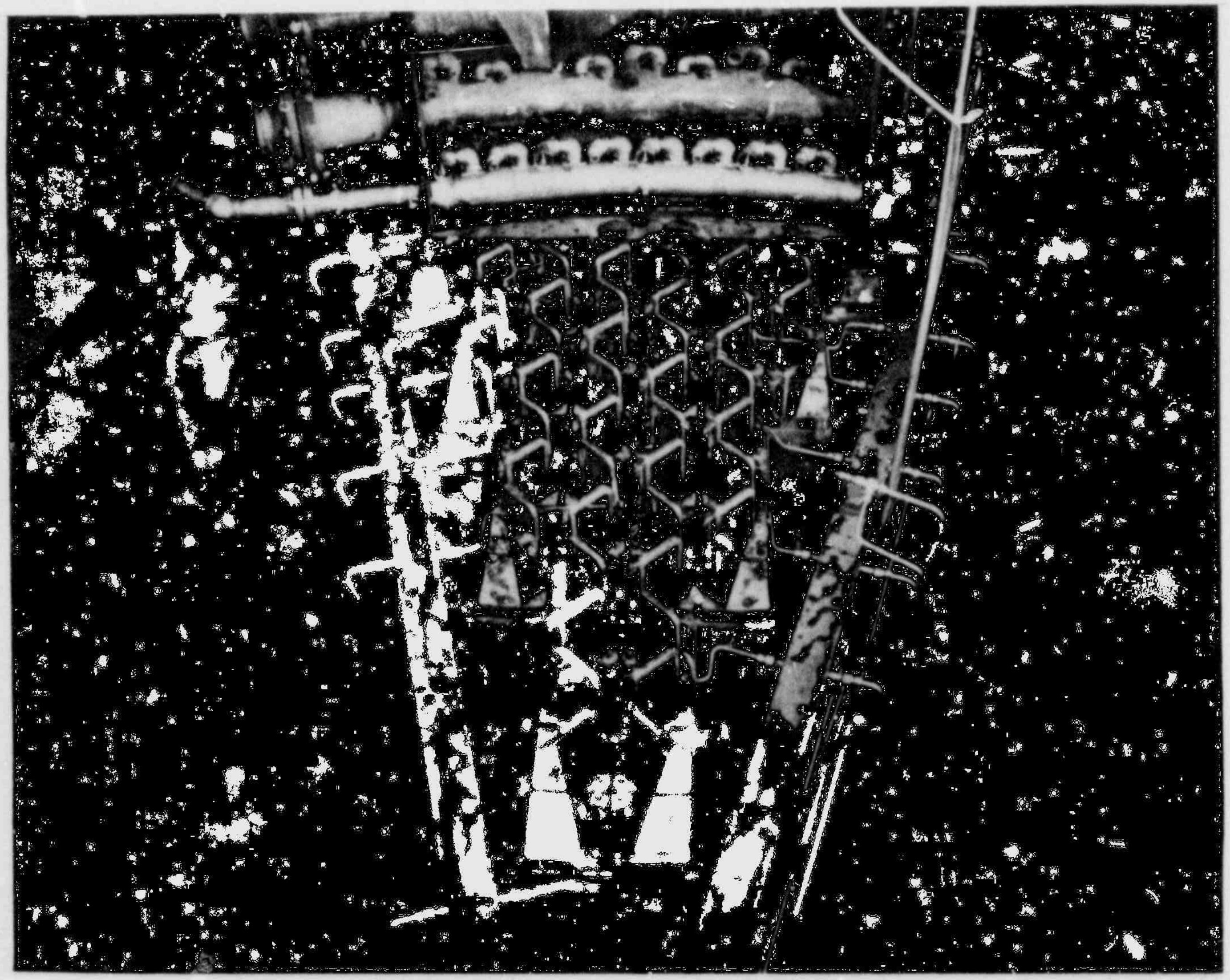


Figure 3-3. Top of Simulated Core Region

bundle to deliver the channel steam from the distribution manifold outside the 30° sector wall. A weir tube measuring device for downward water flow is also provided in each bundle.

The bypass region flow area between bundles is simulated and includes dummy control rods mounted on product hardware in conjunction with accurate representations of the top fuel grids and core plate. Twelve volume-scaled guide tube regions are provided, one for each of the 12 centrally located side entry fuel supports. The lower plenum volume represents the scaled volume of the reference reactor lower plenum region outside the guide tubes. The lower plenum volume above the jet pump discharge is also scaled. The elevation of the jet pump inlet and outlet and the height of the steam separator above the shroud in relation to the core height and the fuel support casting orifice location are matched to the reference reactor. The SSTF section has been designed with numerous instrument tap locations to permit flexibility in the use of pressure, level, temperature, and other measuring devices.

The SSTF process control equipment and data acquisition system (DAS) are housed in an air conditioned control room. Process instrumentation and control valves are provided to monitor and control the temperatures, pressures, and flows in the steam supply headers, water recirculation lines, ECCS lines, and vent system. The process instrumentation and controls are used to establish and maintain loop conditions without use of the data system.

The data acquisition system includes a Hewlett-Packard processor with a 32K memory, 320 channels of multiplexer input, and a 50 megabyte disk unit. This DAS hardware, in conjunction with the associated data acquisition and reduction software, provides quick-look capability in engineering units through the use of the operator's graphics terminal and two color television monitors for displaying the results of on-line data handling. The rapid generation of hard copy test results is provided by an on-line Versatec printer/plotter. Permanent raw data storage is provided by a nine-track tape recorder, which uses a format compatible with General Electric's Honeywell 6000 computer in San Jose.

The facility test instrumentation and signal conditioning includes numerous pressure and differential pressure transducers, thermocouples, and conductivity sensors. The differential pressure sensing lines for measuring water downflow in the individual simulated bundles are routed to a mechanical multiplexing Scanivalve unit. This unit has a total of six 48-channel modules which can be used to scan

144 differential pressures while using only three differential pressure transducers. The Scanivalve system is controlled by the computer so that the scan rate and ports scanned can be varied by the test engineer.

All pressure and differential pressure lines inside the vessel are compensated for environmental effects (i.e., water loss due to flashing). The test system uses standard iron-constantan thermocouples conditioned by a 150°F reference junction. The conductivity sensors are specially designed units for indicating liquid levels in various test section volumes.

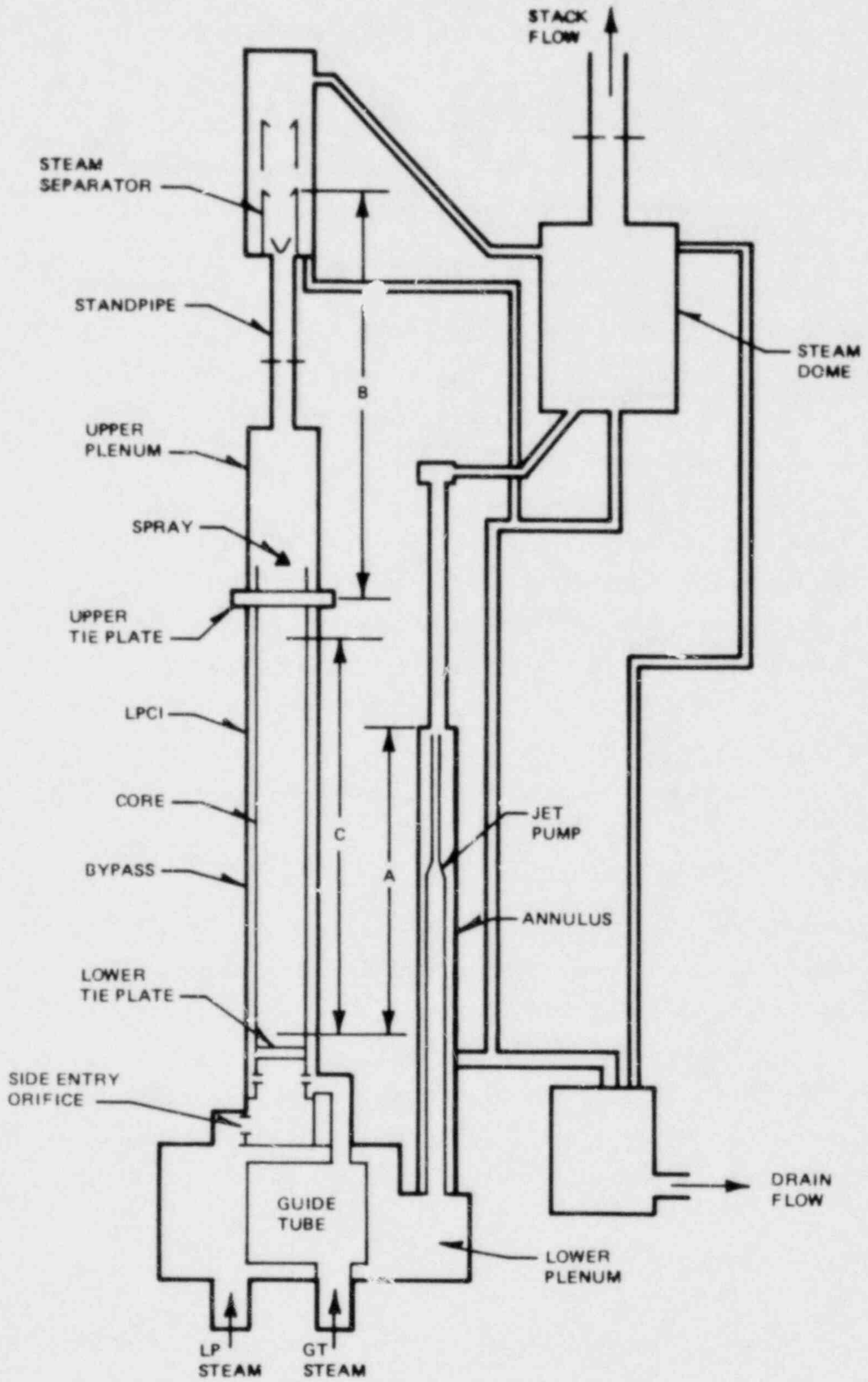
Although the facility is built to a BWR/6 design, it can be modified to simulate earlier BWR designs with regard to the core spray and low pressure coolant injection systems. T e facility can be used in either a steady state or a transient mode over a wide range of pressure, temperature, and flow conditions.

The main uses of the facility are to investigate core spray distribution and counter-current flow limiting (CCFL) phenomena. Core spray distribution is investigated using various injection modes, water temperatures, steam flow , and system pressures. The output from such tests includes a bundle-by-bundle flow distribution at a given set of steady-state conditions. CCFL tests can be either steady state or transient and focus on the location of water and its rate of transfer between volumes as a function of the specified conditions.

3.1.2 R-Tower Test Center and Associated Test Facilities

R-Tower is a thermal hydraulic test center which has been the site of many varied tests in past years. R-Tower is flexible and can be configured in numerous ways in order to .form several types of tests. The basic facility includes a 6000/lbm/h steam boiler, a 1/2 MW, 240/280 V SCR dc power supply, and a central control room which houses process control instrumentation and the data acquisition system (DAS). The DAS includes a Hewlett-Packard 21MX minicomputer with capability for 1056 high and low level inputs. R-Tower currently houses three separate test facilities: the Single-Bundle Facility, 16° Sector Facility, and the Horizontal Spray Facility.

The Single Bundle Facility is a 1/624th scale mockup of the BWR/6-218 reactor with capabilities to achieve a range of test conditions representative of earlier BWR plant designs. The single-heated bundle facility is capable of tests only at atmospheric pr ssure. The main features of the facility, as indicated in Figure 3-4, inclu e a full scale electrically heated simulated fuel bundle (8x8), and



NOTE: A, B AND C ARE FULL SCALE DIMENSIONS

Figure 3-4. Single-Bundle Facility

system volumes to complete the mockup. System volumes include the lower plenum, guide tube, core, bypass, upper plenum, steam separator, steam dome, annulus, and jet pump. The heights of the core, upper plenum, steam separator, and the relationship of the simulated jet pump height to the core are full scale. Other system regions are scaled only by volume. The existing bundle is made up of electrically heated simulated fuel rods with a double peak axial power profile. A new bundle will be installed with a chopped cosine power profile,

The 16° Sector Facility, as shown schematically in Figure 3-5, is a mockup of the upper plenum region of a BWR/6-218 (624 fuel bundle) reactor. The bundle simulations include prototypical BWR upper tie plates with controlled steam input to each bundle to simulate reactor core steam distribution. Facility instrumentation includes individual liquid downflow measurements for each bundle, absolute and differential pressure transducers, and thermocouples. The 16° Sector Facility may be used to perform studies of steam/water interactions in the upper plenum and multiple bundle CCFL studies of the upper regions of a BWR. The facility can be operated at pressures up to two atmospheres.

The Horizontal Spray Facility (HSF) was designed to simulate a portion of the top of the reactor core for testing a single core spray nozzle in a pressurized steam environment. The facility, shown schematically in Figure 3-6, includes a 6 ft. diameter by 21 ft. long test vessel with a pressure capability of 250 psig. Current operation is limited by the existing steam boiler capacity to a maximum of 45 psig. Inside the vessel, a prototypical core spray nozzle/sparger section is used to spray water into collector tanks which are arranged in an array simulating the upper grid/bundle arrangement typical of BWRs. The collector tanks are instrumented with conductivity probes which allow for bundle flow rate determination by recording the time required to fill the tanks. Tests are conducted to determine spray distribution for 120 fuel bundle locations. The HSF may be used for the evaluation of core spray nozzle candidates in an air or pressurized steam environment and for development and qualification of analytical spray distribution models.

3.2 GE EXPERIMENTAL DATA

3.2.1 Purpose and Format

The experimental information provided will include basic data for model development and specific component performance data. The latter may be used both for analytical model development and for model qualification. The purpose of these contributions is to complement the information to be obtained under this program, so that the realistic models for the BWR LOCA can be developed and qualified.

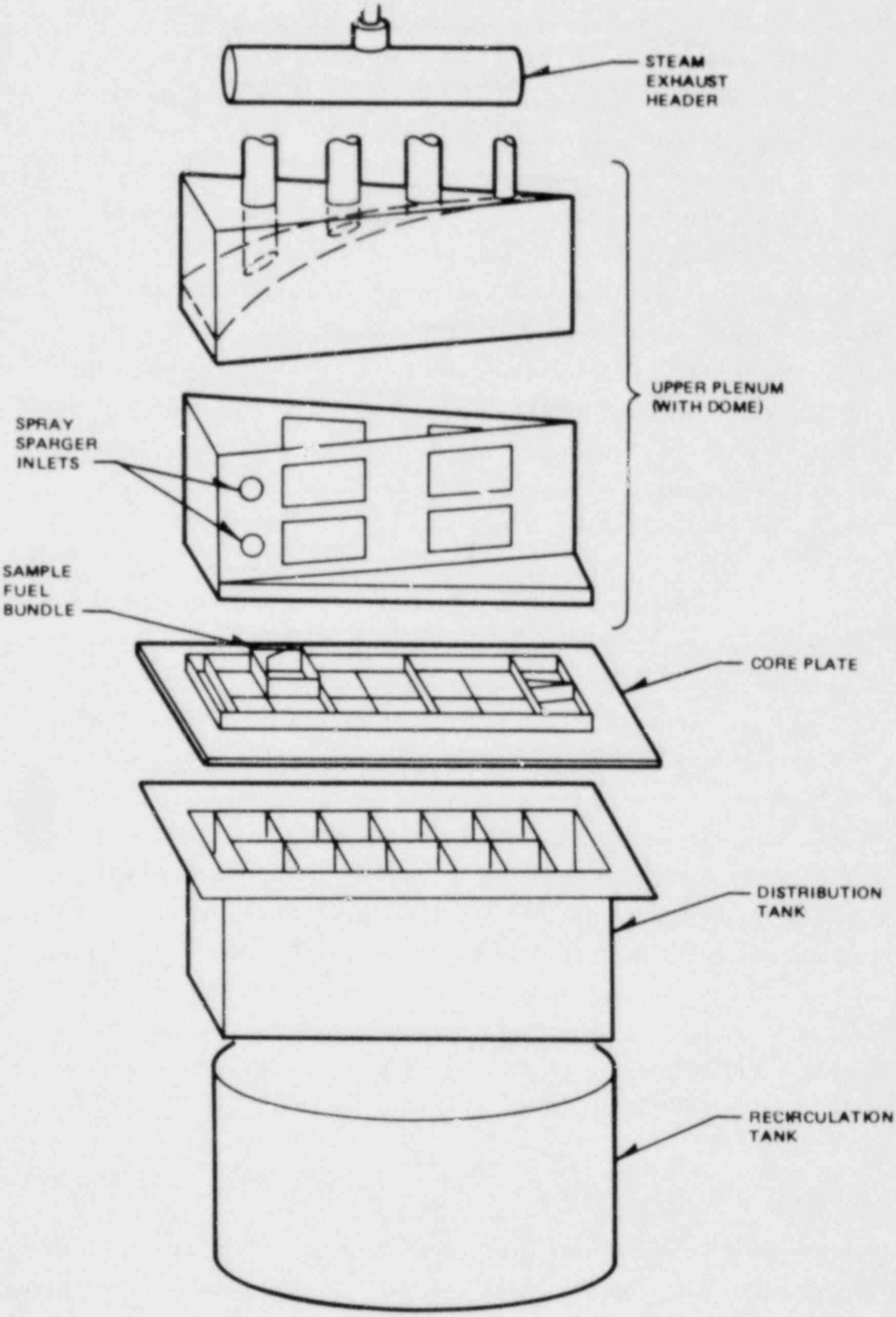


Figure 3-5. 16° Sector Facility

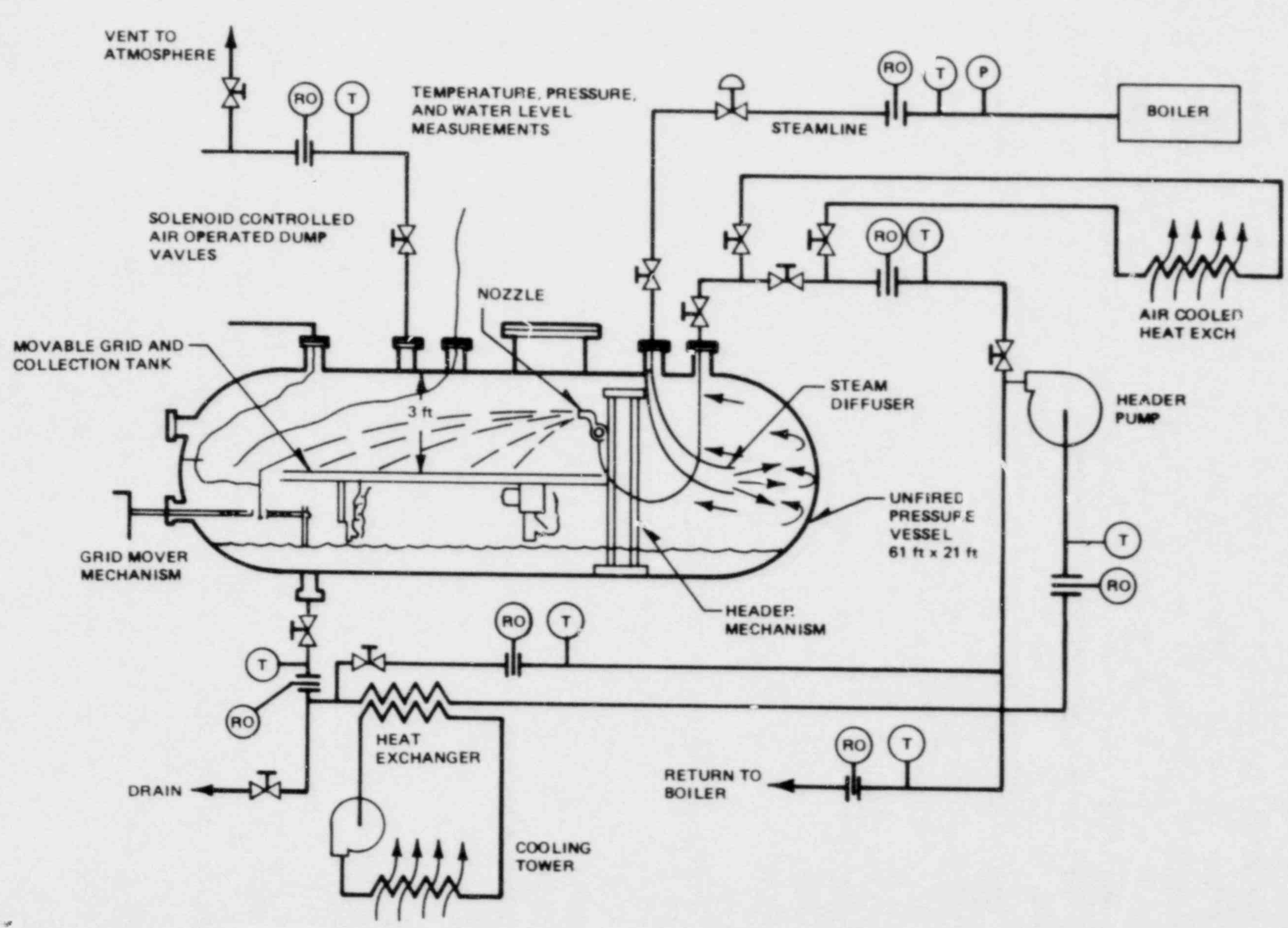


Figure 3-6. Horizontal Spray Facility

The contributed data will be provided in documents that are produced under this program and will include the objectives, facilities tested, measurements made, and the resultant data.

3.2.2 Data for Development of Interfacial Momentum Transfer/Void Fraction

These data were obtained in GE facilities at San Jose and consist of pressure drop (void fraction) data in large vessels as well as full scale rod bundles at low flow. Steady state and blowdown data were obtained. This information on void fractions with low cocurrent and counter-current flows can be used to guide the development or refinement of interfacial momentum transfer or drift flux correlations which define the relative velocities between the phases. These data will be reported in several parts. Rod bundle pressure drop data taken in 1973 (ATLAS Heat Transfer Loop) is currently available and will be appended to the Model Development Task Plan Document; more recent ATLAS data will be issued as a Class I document about mid-1981. Simple vessel blowdown level swell and void data will be available for incorporation into the Model Qualification Task Plan Document. Critical flow data is now available in "Prediction of Critical Two-Phase Flow" (NEDO-13017) and "Critical Flow of Saturated and Subcooled Water at High Pressure" (NEDO-13418).

3.2.3 Recirculation and Jet Pump Data

Two-phase pump performance characteristics data have been obtained for a scaled BWR recirculation loop which include:

1. A centrifugal drive pump
2. A 1/6th scaled BWR/4 jet pump
3. A pressure vessel operated at 1000 psia with saturated steam-water system
4. A blowdown system

Data were obtained during both steady-state and blowdown conditions with single and two-phase fluid injected in each pump at 1000 psia. The centrifugal pump speed was varied during steady-state operation with two-phase suction flow. These data, presented in terms of basic data and normalized pump performance characteristics, are generally useful for model development or for qualification of existing models. These data are contained in "Two-Phase Pump Performance During Steady-State Operation and During a Simulated LOCA Blowdown", NEDE-13239.

3.2.4 Core Spray Distribution Data

The BWR/6 core spray distribution data obtained by GE (outside this joint program) from tests in the Horizontal Spray Facility, the Vallecitos Core Spray Facility, and the 30° Sector Facility at Lynn, Massachusetts will be made publicly available. Specifically these data are as follows:

1. Single Nozzle Data: Horizontal spray distribution data from the four individual core spray nozzles tested in steam will be provided. Horizontal spray distribution data from the respective simulators for these four nozzles, tested in air, will be provided. These data, taken at pressure of about two atmospheres, will be available for appending to the Core Spray Distribution Task Plan.

2. Vallecitos Multinozzle Data: Data from 30° Sector tests, performed at Vallecitos with reactor nozzles in air, will be provided. These data will provide tieback to similar tests in the 30° Sector Facility at Lynn, Massachusetts. In addition, data from tests performed using simulator nozzles in a 30° Sector configuration in an air environment, will be provided. These data, which can be used to determine multiple nozzle interaction effects, will be available for appending to the Core Spray Distribution Task Plan.

3. Lynn 30° Sector Data: Data will be provided from 30° Sector tests performed with BWR/6 reactor nozzles and spargers in an air environment. These data will also be available for the Core Spray Distribution Task Plan. These tests will be compared to those performed in the Vallecitos 30° Sector to confirm that similar spray distribution performance is obtained in the Lynn 30° Sector Facility. Data from BWR/6 spray distribution tests, performed in a steam environment in the 30° Sector, will be provided. Comparison of BWR nozzle performance in air between the 30° Sectors, as well as the Lynn 30° Sector BWR nozzle performance in steam, are contained in "Core Spray Design Methodology Confirmation Tests", NEDO-24712.

3.2.5 16° Sector Test Data

As part of the program, General Electric will combine the important results of previous 16° Sector test series. Types of results to be reported will include visual observations, temperature and pressure measurements, and conclusions regarding performance of several core spray header configurations as they relate to upper plenum steam/water mixing and CCFL breakdown. These data will be available for inclusion into the CCFL/Refill System Effects Task Plan Document.

3.2.6 Steam Injector Development

General Electric will provide the results and data from tests which have been performed to develop methods of injecting steam adiabatically into test bundles to simulate the generation of steam by vaporization from heated rods. These tests have been performed using the current steam injector design by General Electric at the R-Tower facilities using a Lexan bundle mockup and by Creare, Inc. Results of these tests have included both visual observation and flow data which has been used to define CCFL correlation. These data will be available for appending to the CCFL/Refill System Effects Task Plan Document.

3.2.7 Instrumentation Development

General Electric will contribute the results of design studies and tests which have been performed to develop methods of measuring both the collapsed liquid level (liquid inventory) and the height for two-phase steam-water mixtures. These investigations performed for General Electric by Creare, Inc., include the development of a buoyant float and a coupled conductivity probe. Results for these devices include response measurements and methods for using the devices in combination to provide data about void fraction, mixture level, and water mass. These results also will be available for appending to the CCFL/Refill System Effects Task Plan. Table 3-1 summarizes where the foregoing background information can be found.

3.3 GE ANALYTICAL MODELS AND METHODOLOGY

Models to be contributed include a single nozzle spray distribution model, a multiple nozzle superposition analysis, and an advanced single-channel drift flux thermal hydraulic model. The former two are part of the existing core spray distribution methodology whose adequacy will be evaluated under this program. The thermal hydraulic model will require addition of the dispersed droplet flow regime physics, to be developed under this program, in order to be generally applicable for an entire BWR-LOCA transient.

3.3.1 Core Spray Distribution Methodology

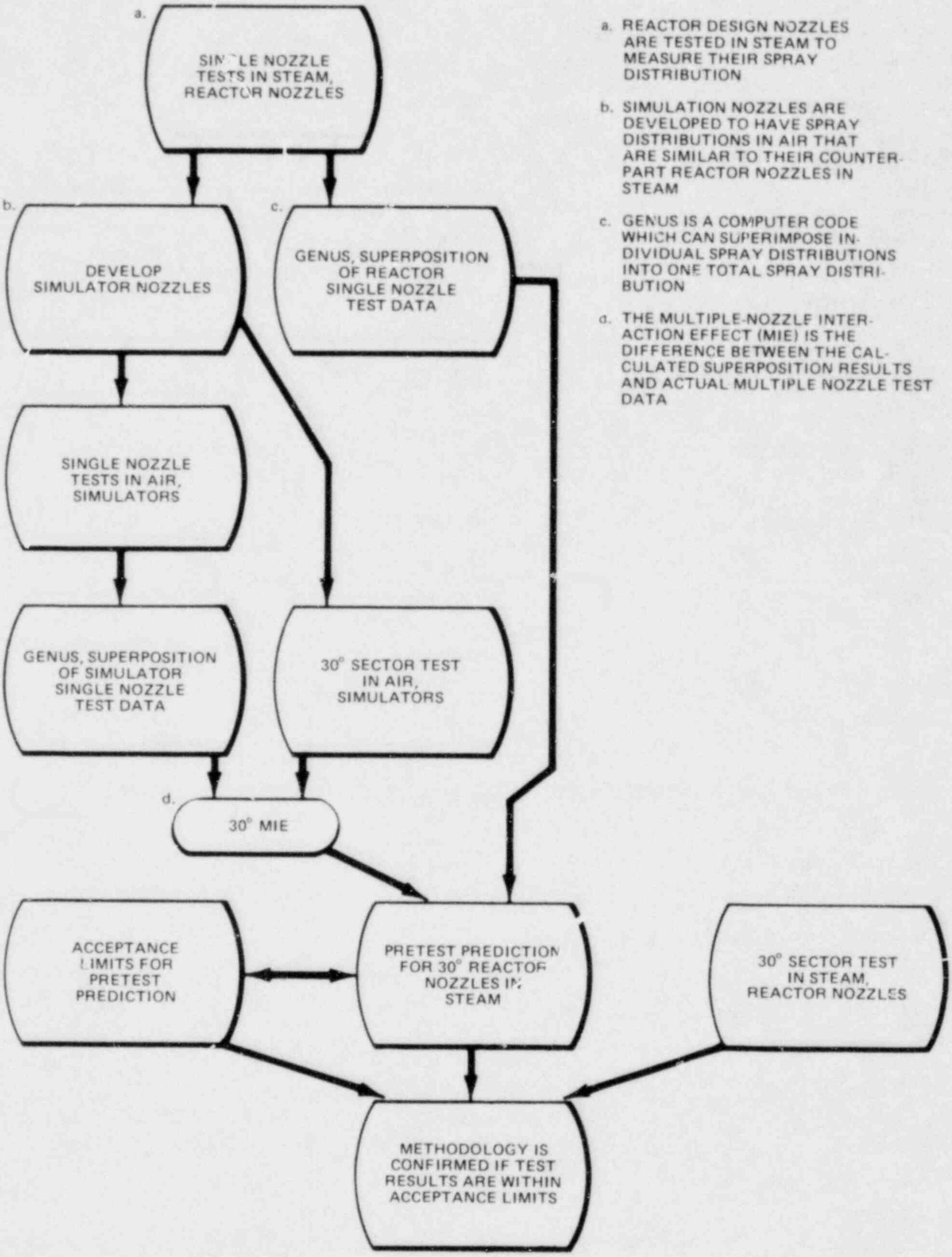
The core spray distribution methodology developed by General Electric is a combined experimental and analytical model procedure. The elements are shown graphically in Figure 3-7. Reactor spray nozzles are tested individually in a reactor steam environment to obtain their spray distribution pattern. A physically-based analytical model can then be calibrated with these data and used to extrapolate the data to other flows and nozzle aiming angles.

Simulator nozzles are then developed, which produce spray distribution in air which closely match the distributions obtained from the individual reactor nozzle tests in steam (i.e., modifications are made to the nozzle hardware to simulate the condensation effects of a steam environment).

Table 3-1

GE BACKGROUND INFORMATION

	Item	Contract Section	Reporting Plan
1.	Low Flow Pressure Drop Data (1973)	3.2.2	Append to Item 2 Below
2.	Low Up- and Down-flow Data	3.2.2	Class I Document Issue Midyear 1981
3.	Simple Vessel Blowdown Data	3.2.2	Model Qualification Task Plan
4.	Recirculation and Jet Pump Data	3.2.3	Class I Document (NEDE-13239)
5.	Single Nozzle Data	3.2.4A	Core Spray Distribution Task Plan
6.	VNC Multinozzle Data	3.2.4B	Core Spray Distribution Task Plan
7.	Lynn 30° Sector Data	3.2.4C	Class I Document (NEDO-24712) and Core Spray Distribution Task Plan
8.	16° Sector Test Data	3.2.5	CCFL/Refill System Effects Task Plan
9.	Steam Injector Development Data	3.2.6	CCFL/Refill System Effects Task Plan
10.	Instrumentation Development Results	3.2.7	CCFL/Refill System Effects Task Plan
11.	Spray Distribution Methodology	3.3	Document (NEDO-24712)



a. REACTOR DESIGN NOZZLES ARE TESTED IN STEAM TO MEASURE THEIR SPRAY DISTRIBUTION

b. SIMULATION NOZZLES ARE DEVELOPED TO HAVE SPRAY DISTRIBUTIONS IN AIR THAT ARE SIMILAR TO THEIR COUNTERPART REACTOR NOZZLES IN STEAM

c. GENUS IS A COMPUTER CODE WHICH CAN SUPERIMPOSE INDIVIDUAL SPRAY DISTRIBUTIONS INTO ONE TOTAL SPRAY DISTRIBUTION

d. THE MULTIPLE-NOZZLE INTERACTION EFFECT (MIE) IS THE DIFFERENCE BETWEEN THE CALCULATED SUPERPOSITION RESULTS AND ACTUAL MULTIPLE NOZZLE TEST DATA

Figure 3-7. Core Spray Methodology

Multiple nozzle air tests are then performed using the simulator nozzles. The spray distribution from these multiple nozzle tests are compared with direct superposition predictions from the individual nozzle results. The differences between the measured multiple nozzle distributions and the direct superposition results represent the effects of interactions among the multiple nozzles. Steam environment predictions for multiple nozzles are then made by combining superposition of the individual reactor nozzle distributions in steam with the multiple nozzle interaction effects derived above from air simulator nozzle tests. This procedure includes the assumption that the multiple nozzle interaction effects in steam are controlled by the same hydrodynamic phenomena as, and therefore are equivalent to, the interaction effects observed in air. While this assumption is well supported by small basic studies, evaluation with large scale multiple nozzle steam tests is appropriate.

General Electric has made publicly available the BWR/6 superposition predictions of the 30° air experiments and evaluation of the multiple-nozzle interaction effects (MIE), and pretest predictions of the 30° steam multiple-nozzle distributions (Core Spray Design Methodology Confirmation Tests, NEDO-24712). The prediction model used for single-nozzle distribution is documented in an ASME paper, "Modeling Environmental Effects on Nozzle Spray Distribution", ASME 76-WA/FE-39. Additional information on the single-nozzle model and the superposition code is available in NEDO-23582, Genus System Overview and User's Guide and NEDO-21764, SNAP-01 User's Guide.

3.4 NRC ANALYTICAL MODELS AND METHODOLOGY

3.4.1 TRAC Code Status

The first version of TRAC, designated TRAC-P1 and intended for PWR LOCA type analyses, was released in March, 1978. An improved version, TRAC-P1A, became available in March, 1979. Two further versions are under development. A detailed version similar to TRAC-P1A, TRAC-PD2, should be available in 1981. A fast running version, TRAC-PF1, may be available in late 1981.

Development of a TRAC-BWR code is being undertaken at Idaho National Engineering Laboratory (INEL) in parallel with the pressurized water reactor (PWR) work at Los Alamos Scientific Laboratory (LASL). Maximum use is being made of the LASL work in this effort. The first BWR version, designated TRAC-BD0, is based on TRAC-P1A, and was released in January, 1980. This code has limited applicability and there are no plans for external release to the public. The code is an interim version to provide analysis capability until TRAC-BD1 can be released in late 1980 or early 1981. Updates will be provided later for applications such as analysis of the GE Lynn facility.

TRAC-BD0 uses a drift flux modeling for counter-current flow in 1D components, with many GE models, such as shear, CCFL, and a TEE model for the jet pump. Leakage from multiple core channels to the bypass is provided. TRAC-BD1 will utilize a TF1D modeling with as many of the TRAC-PD2 improvements as can be incorporated. Additional improvements will include better 1D component critical flow, jet pump, and constitutive package modeling.

3.4.2 TRAC-B Assessment

NRC plans to assess (qualify) TRAC through comparisons with many tests, including basic experiments, separate effects tests, and integral systems tests. TRAC-B assessment planning is underway. Information that will be considered includes the level swell and critical flow tests obtained at Battelle Frankfort, Marviken III critical flow tests, INEL 1/6 scale jet pump tests, CE tests on centrifugal pumps, ROSA tests at Japan Atomic Energy Research Institute, (JAERI), GE TLTA tests, Swedish GOTA loop (BWR integral system) ECCS tests, FLECHT-BWR, as well as selected tests from the NRC/EPRI/GE Refill-Reflood Program. Some of the code results versus test data comparisons will be performed blind and their schedules will be tied to the test schedules. (Blind comparisons involve the use of actually measured initial and boundary conditions and the code results are compared with measurements which are not released until completion of the calculations.)

3.4.3 NRC Contribution

The NRC will transmit TRAC-B versions to GE for their use in this program, together with help from INEL to make the code operational at GE or a mutually acceptable computer facility, and for resolving computational problems when such arise. The NRC's government contractor(s) will take part in formulating test matrices and selecting measurement types, desired accuracy, and measurement locations required for code assessment. The government contractor will not perform pretest predictions or post-test analyses of any tests performed in this program. The results of this program will, however, feature prominently in the assessment of TRAC as previously explained.

3.5 NRC INSTRUMENTATION SUPPORT

NRC agrees to review, with the TRAC code developers and the BWR Refill-Reflood program participants, the instrumentation needs and requirements for this joint program. NRC will endeavor to use its existing capability on advanced instrumentation technology to meet the BWR Refill-Reflood program instrumentation needs, subject to the resource limitations of instrumentation development organizations and the NRC funding limitation specified for this program.

3.6 EPRI-CONTRIBUTED TECHNOLOGY

Information derived from several EPRI research and development projects will be made available to complement efforts undertaken in this joint program. This will include both analytical and experimental results relevant to understanding and modeling BWR LOCA phenomena. The information will generally be made available in the form of published reports.

EPRI-sponsored projects which complement this program are tabulated in Appendix I, along with their expected contributions.

Section 4

PROGRAM WORK DESCRIPTION

The program work is divided into a number of tasks. Each task is further broken down into a number of specific, detailed subtasks. This detailed workscope, which is Section 4 of Appendix B of the BWR Refill-Reflood contract (1), is included in its entirety as Appendix II of this document.

In this section, the individual task objectives will be stated along with a summary description of how these objectives will be met. Further discussion of the tasks will be included in the individual task plan documents, most of which have been drafted and are being reviewed by the program sponsors. Each task number has the program workscope section number (4.) as a prefix. For example, the first task (Program Plan) is designated as Task 4.1.

4.1 PROGRAM PLAN

This task calls for preparation of the BWR-Reflood Program Plan per Section 5.0* that elaborates on the means of meeting the program objectives stated in Section 2.0.

This document describes the overall program plan.

4.2 CORE SPRAY DISTRIBUTION

Objectives: To provide core spray distribution data from steam environment tests (including long term cooling conditions) for model qualification and to provide additional confirmation of the existing methodology (see Subsection 3.3.1).

Single-nozzle tests performed in steam and air have shown different spray distributions between the two environments (3). A methodology incorporating air and steam testing was developed for predicting full core spray distributions in a steam environment. The methodology was confirmed with the BWR/6 design as described in NEDO-24712 (2). The current test program will demonstrate the application of the

*Section 5.0 refers to Section 5 of Appendix B of the BWR Refill-Reflood Contract and provides guidance as to the content of various reports.

methodology to the BWR/4 and 5 designs. These designs have different core spray sparger locations and different nozzle types than the BWR/6 design.

The hardware design basis for the BWR/4 and 5 Core Spray Program is the BWR/4-218 core spray system (BWR/5-218 is identical). The lower sparger will be tested in a 30° sector. Sparger-to-sparger interaction effects for various nozzle types will be investigated using a double sparger segment with one nozzle on each sparger segment. The upper sparger will not be tested in a 30° sector due to hardware limitations (it would mechanically interfere with the BWR/6-218 spargers at the 30° SSTF).

The selection of independent parameters will be developed in the task plan document. The criteria used for selection of these parameters is based on both previous experience and current evaluation of the LOCA transient. Areas of interest considered in choosing the parameters include: (1) separability of thermal and hydraulic effects on the spray, (2) representative reactor conditions, and (3) steam flow to the core spray during operation.

Parameter effects on core spray distribution to be evaluated include flow rate, steam source, and sparger-to-sparger interaction.

The BWR/4 and 5 30° Sector core spray test results will be compared directly with the distribution calculated with the core spray methodology. An assessment of the methodology will then be made, as indicated in Figure 4-1. Data from the balance of the 30° Sector test matrix can be used for qualification of existing and any future best-estimate core spray distribution models.

4.3 SINGLE-HEATED BUNDLE TASK

The objectives of the Single-Heated Bundle Task are:

a. To provide and utilize test data, obtained at near-atmospheric pressures, to identify and evaluate phenomena controlling heated-bundle thermal-hydraulic performance during the refilling and reflooding phase of a BWR LOCA.

b. To evaluate single-heated bundle system interaction performance in support of model development, and to provide reference single-bundle system response data as a basis for developing the adiabatic steam injection technique.

c. To develop an adiabatic steam injection technique for use in the 30° Sector facility that simulates steam generation resulting from heated bundles.

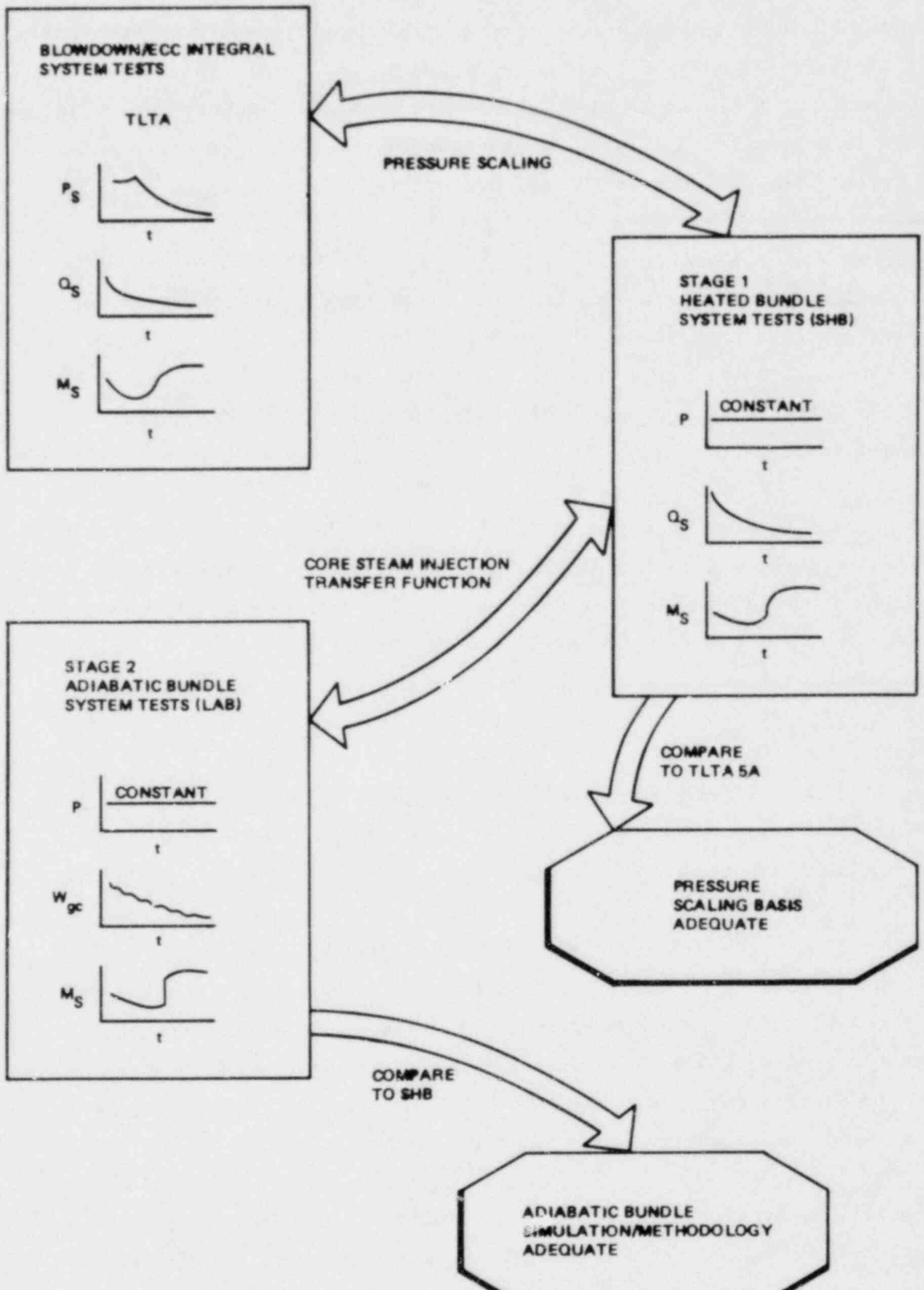


Figure 4-1. Adiabatic Bundle Simulation Qualification

4.3.1 Single-Heated Bundle Testing

Tests under the Single-Heated Bundle (SHB) Task will be performed for the purposes of facility qualification and model development. The facility qualification tests involve the evaluation of adiabatic steam injection into a bundle to simulate the generation of steam by a heated bundle. Verification of the adiabatic steam injection technique is necessary to ensure the adequacy of the technique for use in the CCFL/Refill System Effects Tests in the 30° Sector Steam Test Facility (SSTF) under Task 4.4.

The SHB tests will also provide a data base for developing the methodology for analytically determining the adiabatic injection rates to be used for the SSTF. The model development tests involve the collection of core spray heat transfer and bundle hydraulic data over a wide range of conditions to develop and qualify low flow heat transfer models.

Three stages of testing have been identified for the Single-Heated Bundle Task. Each stage will be performed in the Single-Bundle Facility (Subsection 3.1.2), but will utilize different bundle test assemblies. The inherent simplicity of this ECCS test loop, and the relative ease with which test parameters and facility configuration may be varied, make it ideal for performing tests with the varied objectives of this task.

Stage 1 Tests will be performed using an existing bundle which has electrically-heated simulated fuel rods. The tests are characterized as system performance for comparison with adiabatic bundle (Stage 2) tests.

Stage 2 Tests will be performed using a bundle which simulates the bundles installed in the 30° SSTF to be used for Task 4.4. The bundle has an adiabatic steam injection tube rather than heater rods. The tests are system effects tests with an adiabatic bundle, and will be used to demonstrate the validity of adiabatic injection and to achieve the best simulation of heated bundle system response so that steam injection rates can be specified for the Task 4.4 tests at the 30° SSTF.

Stage 3 Tests will be performed using a new bundle having electrically-heated simulated fuel rods. The tests are characterized as separate-effects tests with a heated bundle and will be used to identify and evaluate phenomena and subsystem interactions, and to provide data to support model development and model qualification tasks.

The ECCS Test Loop operates only at atmospheric pressure and therefore cannot reproduce a depressurization transient which is important in evaluating refill/reflood phenomena. A pressure-scaling technique has been formulated so that initial conditions and boundary conditions can be determined which will produce a system response in the heated bundle that closely represents a transient BWR response. Data obtained in the two-loop test apparatus (TLTA) under the BWR BD/ECC Program will be used as a scaling basis to establish conditions for SHB tests. The approach used to verify the pressure-scaling technique involves: (1) application of scaling technique to a TLTA transient test to define base case initial conditions and independent test parameter values, (2) running a base case test in the ECCS test loop with a heated bundle (Stage 1) to simulate the TLTA transient, and (3) comparison of the SHB response to the TLTA response to determine if the responses meet acceptance criteria for similarity.

The relationships between the SHB tests and the TLTA tests are shown in Figure 4-1 as a graphical interpretation of the approach to meeting the objectives.

The figure indicates the direct use of the heated bundle (Stages 1 and 2) and adiabatic steam injection test (Stage 2) results to demonstrate the adequacy of the pressure scaling basis and the adiabatic bundle simulation/methodology.

4.4 CCFL/REFILL SYSTEM EFFECTS TESTS (30° SECTOR)

The objectives of the CCFL/Refill System Effects Tests are to provide data from a large-scale sector mockup of a BWR, and to identify and evaluate the phenomena controlling the system behavior during the refill phase of BWR LOCAs.

The 30° Sector is the focal point of this program. The full radius sector mockup of the BWR core and upper plenum regions, coupled with its mockup of other regions and interconnecting flow paths, including parallel (unheated) channels in the core region, constitute a good experimental vehicle for identification and evaluation of the multidimensional effects on the phenomena of interest. The 30° Sector facility will also provide a data base for use in qualification of best-estimate (BE) models as discussed in Section 2. Furthermore, this data base can be utilized to address the assumption and models currently used in the evaluation of the BWR LOCA conditions. Note how these three utilizations of the data parallel the overall program objectives, i.e., (1) to develop a better understanding of phenomena, (2) to provide a basis for support to development and qualification of BE models, and (3) to provide a basis for assessing assumptions in establishing safety margins.

To provide this data base the existing 30° Sector Facility, commonly referred to as the Sector Steam Test Facility (SSTF), located in Lynn, Massachusetts, will be upgraded to meet the requirements of transient LOCA simulation testing. BWR system refill* will be investigated during system blowdown from 150 psia to ambient pressure conditions. Contained in Subsection 3.1.1 is a summary description of the SSTF. A more detailed description will be provided in the Facility Description Document.

The model qualification role for the SSTF CCFL/Refill task will be accomplished through the coordinated effort of three major tasks of the R/F program (i.e., Model Qualification Task, Model Development Task, CCFL/Refill System Effects Tests [30° Sector]). The Model Qualification Task will provide the link between 30° SSTF CCFL/Refill tests and the Model Development task by specifying facility and measurement requirements, specific qualification tests, required ranges of test conditions needed for qualification of the best-estimate BWR models, and providing pretest predictions and acceptance criteria using the models developed in the model development task.

More specific and detailed objectives have been developed for this task and divided into three general categories as follows: (1) overall task objectives (Table 4-1), (2) facility hardware objectives (Table 4-2), and (3) test strategy objectives (Table 4-3).

Table 4-1

OVERALL TASK OBJECTIVES

OVERALL TASK OBJECTIVES (REQUIRED)

To provide a data base for qualification of best-estimate models per model qualification task plan.

To identify and evaluate phenomena controlling the refilling phase of BWR LOCA.

To evaluate ECC mixing phenomena.

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*Single-bundle system effects tests will provide key information with regard to LOCA refill/reflood sequencing, and the simulation adequacy of adiabatic core steam injection under refill/reflood conditions as discussed previously (Figure 2-2 and Section 4.3). Dependent on the outcome of the single-bundle tests, the SSTF experimental program may be directed toward a greater emphasis on the reflood phase of the LOCA transient.

Table 4-2

FACILITY HARDWARE OBJECTIVES

OBJECTIVES (IN GENERAL ORDER OF DECREASING PRIORITY)

Simulate initial conditions over representative BWR range

Ensure representative BWR response through refill phase of BWR LOCA by simulation of controlling BWR geometry and components

Use existing 30° sector facility as the base facility for the 30° SSTF CCFL/Refill Tests

Simulate BWR ECC injection hardware

Simulate ECC transient flow response during LOCA simulation

Simulate the major thermodynamic conditions driving ECC mixing phenomena

Provide test instrumentation sufficient to supply a data base for qualification of BE models, and identification of controlling BWR refill phenomena

Provide facility hardware features necessary to perform separate effect qualification tests

Provide capability to simulate the time of CCFL breakdown through representative test initiation, and sequencing of ECC systems and core steam injection

Maximize the use of existing equipment

Minimize hands-on control (integral system response)

Simulate global real-time response (including initiation time of core reflood) by representative scaling of BWR component volumes, flow paths, initial conditions, and the sequencing of controlled inputs (ECCS and core steam injection)

Operate from initial pressure of 150 psia to atmospheric pressure

Minimize deviations from full length/volume scaling basis

Represent BWR hydraulic response during reflood phase of BWR LOCA

Minimize existing hardware modification (e.g., bundle removal)

Table 4-3

TESTING STRATEGY OBJECTIVES

OBJECTIVES (IN GENERAL ORDER OF DECREASING PRIORITY)
Provide calibration/shakedown tests of as-built hardware.
Perform transient system effects tests to provide a data base for qualification of BE models per qualification plan.
Perform transient system effect tests to identify and evaluate phenomena controlling the refill phase of a BWR LOCA.
Perform tests to evaluate ECC mixing phenomena.
Provide separate effects test for final qualification of BE submodels.
Provide separate effects tests for tieback to 16° Sector test.
Provide tieback to adiabatic SHBT tests (evaluate scaling basis).
Provide tieback to transient TLTA tests.

Incorporated in the SSTF-CCFL/Refill task are the several major elements listed below:

1. Evaluation of the existing facility adequacy with regard to BWR simulation and model qualification needs.
2. Facility redesign and modification, as necessary, to provide the capability to perform separate effect tests and transient blowdown refill tests (from 150 psia to ambient pressure) simulating relevant BWR phenomena.
3. Facility shakedown and qualification.
4. Test operation to provide a model qualification data base through separate effect and system tests.
5. Data evaluation with regard to overall system response and prediction.

To meet the overall task objectives, the SSTF will be modified to allow transient blowdown/refill test operation. The modification has been divided into several categories as follows: (1) facility hardware (2) test instrumentation (3) process control and instrumentation and (4) data acquisition system.

Major facility hardware modifications include:

1. Blowdown/suppression pool system to allow BWR prototypical blowdown response and management of effluents.

2. Guide tube and lower plenum steam injection for separate-effect testing, setting of initial conditions, and tailoring of steam generation in those regions.

3. Guide tube and annulus water injection and drain lines for setting initial conditions.

4. Excess volume isolation system to correct the SSTF test vessel volume to the scaled value for prototypical blowdown response.

5. Expanded ECCS flow capacity to provide capability to perform tests with all five scaled ECC systems (LPCS, HPCS, and three LPCI).

6. LPCI modification to provide BWR/4 injection location.

7. Miscellaneous mechanical features to allow separate effect tests in the SSTF.

The test instrumentation modification will enhance the existing SSTF measurement capability to coincide with the transient refill aspects of the CCFL/Refill test program. In particular, the following new measurement capabilities will be added:

1. Void fraction and fluid level measurement in the major test section regions (i.e., upper plenum, core, bypass, annulus, guide tubes, lower plenum).

2. Temperature profile measurements in the upper plenum, bypass, annulus lower plenum, and selected fuel bundles.

3. Temperature measurements at controlling CCFL locations (selected upper tie plates and side entry orifices).

4. Blowdown mass flow measurement.

5. Mass flow measurements associated with new system inputs (i.e., guide tube and lower plenum steam injection).

6. Internals differential pressure chain relating pressure of major components.

A significant modification in the process instrumentation and control systems will be necessary to provide the operational control required in performing the transient CCFL/Refill tests. Primary control functions include:

1. Transient programmed control of ECCS injection rate.

2. Transient programmed control of core steam injection.

3. Pressure control of excess vessel volume.

4. Transient control of guide tube and lower plenum steam injection.

5. Injected steam superheat control.

6. Overall test operation sequencing device to control the transition from initial steady state conditions to LOCA simulation during transient tests.

The SSTF data acquisition/data reduction system will be upgraded to accommodate the measurements and data processing requirements of the CCFL/Refill System Effects tests. To accommodate the required CCFL/Refill instrumentation, the DAS input channel capacity will be increased to approximately 400 channels. A corresponding data acquisition software effort will be required to access the additional data channels.

The nature of the transient phenomena studied in the CCFL/Refill tests will require data processing in addition to the existing data reduction capability. Inherent in this data reduction software upgrade will be a conversion of software to facilitate added data processing capability and improve DAS utilization efficiency.

Selection of test types and test parameters will be developed in the task plan document. Types of tests selected include facility qualification tests (shakedown, calibration, and tieback tests), steady-state and transient separate-effects tests for phenomena evaluation, and overall model qualification. Parameters selected include initial fluid mass and distribution, core steam injection rates, break area, and ECC system geometry configuration (i.e., BWR/4 and 5 variations).

4.5 360° UPPER PLENUM TESTS

The objective of the 360° Upper Plenum tests is to evaluate the 30° Sector wall effects on CCFL breakdown as compared to the 360° CCFL breakdown performance.

These tests will be used to qualify 30° Sector tests of Task 4.4 as indicated in Section 2.4. Separate-effects, steady-pressure CCFL breakdown studies will be performed using a scaled 360°, (minimum size [4-6 ft diameter]) upper plenum mockup operated at near atmospheric pressure. The effects on CCFL breakdown performance with and without 30° Sector walls will be evaluated. The facility will be fabricated for independent operation at near atmospheric pressure and also compatible with installation into the pressure vessel of Task 4.4 for elevated pressure studies (not included in the current program). Experimental parameters to be varied include ECC flow rate and subcooling, and core steam flow rate.

4.6 TECHNICAL SUPPORT TASK

The Technical Support Task provides technical support for the experimental design, instrumentation, measurements, operation, data interpretation, and analytical efforts associated with various project tasks.

Technical Support is a general purpose task which includes provisions for:

1. 16° Sector Facility testing, as needed to assist in phenomena evaluation and instrument reading interpretation, associated with the 30° Sector and 360° experiments (Task 4.4 and 4.5),

2. Survey state-of-the-art transient two-phase flow measurement techniques with possible adaptation of techniques to the Refill-Reflood Program, and

3. Survey state-of-the-art LOCA analysis techniques for possible additional analytical efforts to meet program needs.

4.7 MODEL DEVELOPMENT

This task consists of the three major activities listed below, along with their individual objectives.

4.7.1 Basic Models and Correlations

Objective: To provide models and correlations for realistic representation of governing basic phenomena that are suitable for incorporation into TRAC-BWR. Specifically, to establish correlations for CCFL and CCFL breakdown at the fuel bundle upper tie plate, core inlet region, and top of core bypass, to improve the constitutive relations for BWR LOCA flow regimes, and to survey and improve bundle heat transfer models during CCFL conditions.

4.7.2 Development of a Single-Channel Model

Objective: To develop an efficient, fast-running, accurate analytical thermal-hydraulics model for a single BWR core channel applicable to an entire BWR LOCA transient. The code will be self-standing for single-channel analyses, and compatible with boundary conditions calculated by TRAC-BWR.

4.7.3 Support Development of TRAC-BWR

Objective: To support the development by the NRC of a comprehensive realistic (best-estimate) system code (TRAC) for BWR/LOCAs. The GE contributions will consist of technical recommendations, development of suitable component and heat transfer models, and assistance on a faster running version.

The overall Refill/Reflood program seeks to develop a better understanding of phenomena controlling the refill and reflood phases of BWR LOCAs and to provide a basis for assessing assumptions used in establishing BWR LOCA safety margins. A key objective is to provide a basis for, and support to, the development of best-estimate BWR system thermal-hydraulic codes for LOCAs. This task is especially important because full scale experiments are impractical and the system code will be utilized to synthesize the information from various smaller scale tests. The vehicle chosen for this purpose is the TRAC code developed at Los Alamos Scientific Laboratory (LASL) for PWR analysis which will be modified and adapted to the BWR in cooperation with the Idaho National Engineering Laboratory (INEL). The model development activities are thus primarily centered around the TRAC code and the schedules are also closely linked to TRAC milestones. At the present time, INEL has assumed the responsibility for the development of the BWR series of TRAC codes, while LASL will continue to play an advisory role through the Code Change Control Committee meetings. Models and correlations for phenomena basic to BWR will be developed under Subtask 4.7.1. The development of component models for the BWR and TRAC code support and improvements will be covered under Subtask 4.7.3 (these subtasks are closely related).

The strategy is to develop intermediate models first based on available data, correlations, and physical principles. The objective is to develop a working version of TRAC-BWR rapidly as a tool for analysis of the test facilities, test planning and pretest predictions. This initial effort will also serve to identify areas in TRAC where further effort is needed. Subsequently, these models will be further refined, if necessary, for the final version of TRAC-BWR. Under Subtask 4.7.2, a core or hot channel computer code will be developed for the transient thermal-hydraulic analyses of a BWR-type fuel bundle. This single-channel code will be based on TRAC and use the two-fluid model developed for TRAC. The end product will be an accurate code capable of rapid execution which will be compatible with the boundary conditions from the system code, TRAC.

A detailed discussion of the individual models to be developed, the correlation development approach, and the planned techniques for application in the best-estimate method (TRAC) development is contained in the Model Development Task Plan document.

4.8 MODEL QUALIFICATION TASKS

Objective: To qualify the adequacy of thermal-hydraulic and core heat transfer methods for realistic predictions of component and system behavior under BWR LOCA-ECCS conditions.

Secondary objectives are to evaluate data for their applicability to BWR simulation and to determine the relative importance of relevant BWR LOCA-ECCS phenomena. Preliminary assessment of models under development (prior to final model qualification) will be essential in determining model and data deficiencies and needs.

The elements of the qualification plan are outlined below.

a. Identify and describe the relevant data base.

b. Perform test facility qualification studies to determine the applicability of the data base to the governing phenomena.

c. Organize the data into a readily useable format in preparation for subsequent model comparisons.

d. Classify the data base into categories of intended application: model development, model preliminary assessment, and final model qualification relative to the controlling phenomena.

e. Perform preliminary assessment of the best-estimate models. This preliminary assessment process is essential in order to identify model and data base deficiencies prior to final qualification.

f. Develop an acceptance criteria for final qualification of the model.

g. Perform final qualification of the best-estimate BWR LOCA model. Compare code predictions to the qualification data base that was not used in model development or preliminary assessment. Determine the range of applicability for the model by application of the acceptance criteria.

The model qualification task, which includes preliminary assessment, is closely related to the model development task and the experimental tasks of the BWR Refill-Reflood Program.

Each of the above elements is described in detail in the Model Qualification Task Plan.

4.9 HEATED BUNDLE FEASIBILITY STUDY (30° SECTOR)

An evaluation of the feasibility of installing full-length heated bundles into the 30° Sector will be made contingent upon the result from the adiabatic core simulation evaluation of Task 4.3 (see Figure 2-2). Such an evaluation would include analysis and design studies, as required, to define the approach, cost, and schedule of heated-bundle alternatives for program revision considerations. No separate funds are currently allocated for this task.

4.10 TECHNICAL CONSULTATION TO CONTRACTING PARTIES

Objective: To provide technical consultation to NRC, EPRI, and their consultants on related programs which complement this program.

As mutually agreed to by the program sponsors, technical consultation will be provided on related programs which complement the BWR Refill-Reflood Program. No separate funds are currently allocated for this task.

4.11, 4.12 OTHER TASKS

Task 4.11 describes the conditions under which General Electric Proprietary Codes will be used in this program. Task 4.12 covers the activity of summarizing the program results into the Program Final Report.

Section 5

PROGRAM DOCUMENTATION

In addition to the various financial and administrative reports, a number of reports will be issued to document the technical progress of this program. The technical reports are described in this section.

Informal monthly progress letters will be issued each month. These reports will cover both technical and administrative matters and may include preliminary test and analytical results.

In addition to this document (BWR Refill-Reflood Program Plan), individual task plan documents will be prepared for each major task. Experimental task plans will be documented for Core Spray Distribution, Single-Heated Bundle, CCFL/Refill System Effects Tests, and 360° Upper Plenum Tests. Analysis task plans will be documented for model development and model qualification.

Facility Description Reports will be prepared for the 30° Sector (SSTF) and for the 360° Upper Plenum Facility. Data reports are planned for the Single-Heated Bundle and the 30° Sector tests and topical reports will be written for each major task. A number of special reports, described in the Work Scope (Appendix II), have also been identified. Table 5-1 summarizes the reporting plan for the various tasks. A program final report will also be issued.

Table 5-1

TASK REPORT PLAN

Program Tasks	Experimental Task Plans	Analysis Task Plans	Facility Description Reports	Data Reports	Topical Reports	Special Reports
4.2 Core Spray Distribution	X				X	
4.3 Single-Heated Bundle Task	X			X	X	
4.4 CCFL/Refill System Effects Tests (30° Sector)	X		X	X	X	
4.5 360° Upper Plenum Tests	X		X		X	
4.6 Technical Support Task						X
4.7 Model Development:		X				
4.7.1 Basic Models and Correlations					X	3[a]
4.7.2 Single-Channel Thermal-Hydraulic Mo[illegible]					X	X
4.7.3 Support Development of TRAC-BWR					X	2[a]
4.8 Model Qualification		X			X	b
4.9 Heated-Bundle Feasibility Study for 30° Sector						X

[a]Numbers indicate number of reports.

[b]Number of reports to be specified in Task Plan.

Section 6

PROGRAM SCHEDULE

The current overall task schedules are shown in Figure 6-1. This schedule is subject to review and change by the sponsor Program Management Group (PMG). Task activities are indicated in the bar chart, and major PMG decision points 'e identified by diamond symbols.

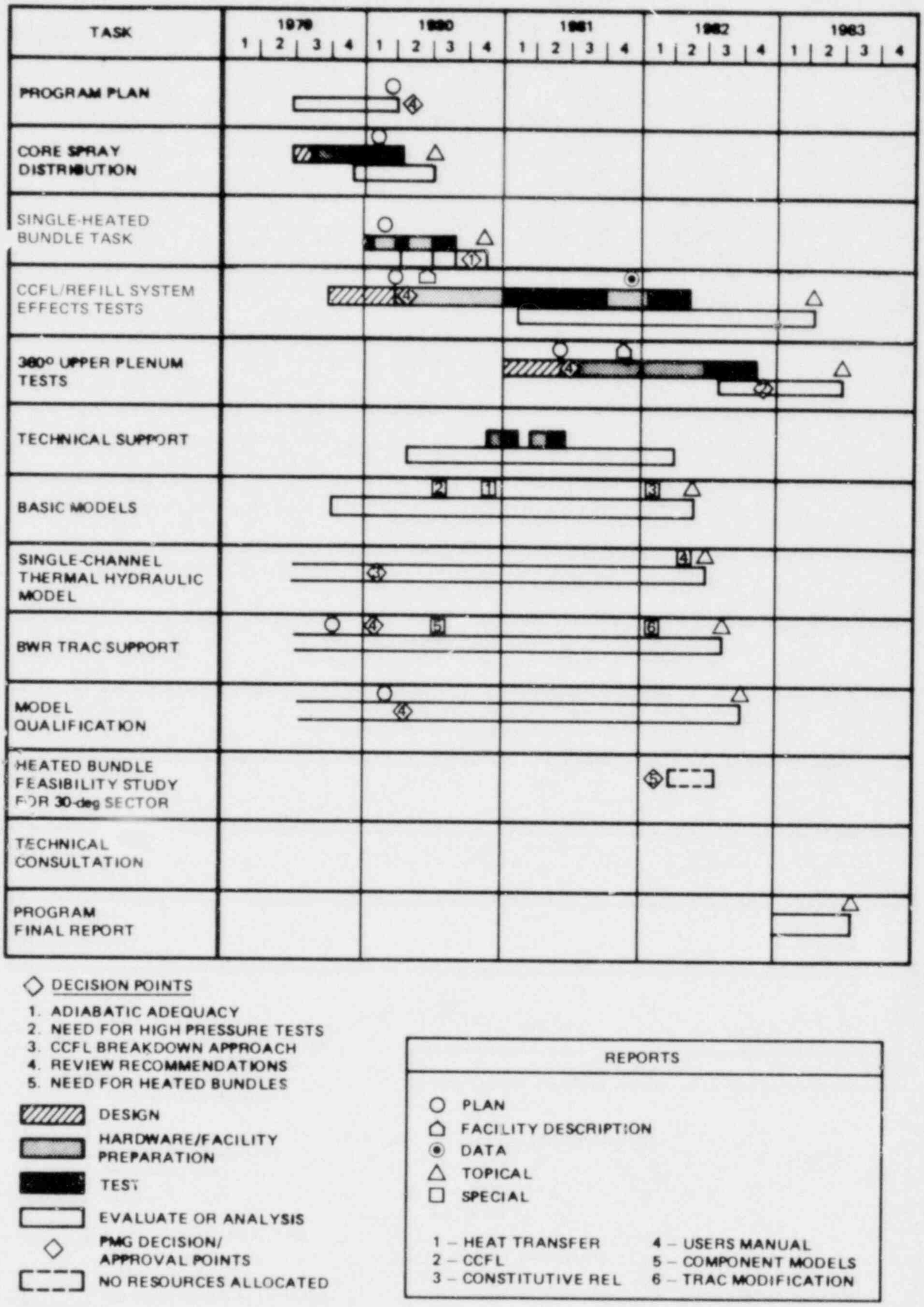

Figure 6-1. BWR Refill-Reflood Program Schedule

REFERENCES

1. *BWR Refill-Reflood Program*, NRC, EPRI, GE-NED, Contract NRC-04-79-184.

2. *Core Spray Design Methdology Confirmation Tests*, S. A. Sandoz, L. L. Myers, D. G. Schumacher, W. A. Sutherland, and G. E. Dix, General Electric Company, August 1979 (NEDO-24712).

3. *General Electric Company Analytical Model for Loss-of-Coolant Analysis in Accordance with 10CFR50 Appendix K Amendment No. 3 — Effect of Steam Environment on BWR Core Spray Distribution*, Licensing Topical Report, April 1977 (NEDO-20566-3).

Appendix I

EPRI-SPONSORED PROJECTS THAT COMPLEMENT THE BWR REFILL-REFLOOD PROGRAM

3.6.1 Basic Phenomena Studies

RP 248: Study of Reflood Heat Transfer During LOCA

- Heat transfer model for film boiling conditions
- Droplet heat transfer model

RP 443: Separated Flow Model of Two-Phase Flow

- Interfacial momentum exchange model for two-phase counter-current annular flow
- Basic study of subcooling effects on CCFL

RP 688: Investigation of Transition Boiling

- Transition boiling heat transfer data, in tube, over extensive range of two-phase flow conditions
- Transition boiling model

RP 1160: Basic Investigation of Single-Channel Counter-Current Flooding Models

- Effects of surface tension, viscosity, entrained droplets, and multi-passage geometry on CCFL in small scale air-liquid experiments

RP 1227: Experimental Assistance for Reactor Safety and Analysis Research

- Basic study of CCFL breakdown conditions in small scale plenum experiment
- Identification of some CCFL breakdown mechanisms
- Effects of initial inventory, steam flow rate, and injection geometry, flow rates, and subcooling

Appendix II

BWR REFILL-REFLOOD PROGRAM WORKSCOPE

General Electric will perform the following tasks to achieve the program objectives stated in Section 2.0.

4.1 PROGRAM PLAN

General Electric will prepare a BWR-Reflood Program Plan per Section 5.0 that elaborates on the means of meeting the program objectives stated in Section 2.0.

4.2 CORE SPRAY DISTRIBUTION

Objectives: To provide core spray distribution data from steam environment tests (including long term cooling conditions) for best-estimate model qualification. Provide additional confirmation of the existing methodology (see Section 3.3.1) and identify any further model requirements.

Scope:

4.2.1 Prepare an Experimental Task Plan according to Section 5.0 that describes the planned experiments, core spray distribution analysis method, and model qualification acceptance criteria. The experiments will include the following:

a. Facility and instrumentation checkout

b. BWR/4 lower header 30° Sector spray distribution tests in air

c. BWR/4 single nozzle spray distribution tests in steam

d. Development of air simulators for BWR/4 nozzles

e. Dual nozzle (adjacent nozzles from BWR/4 upper and lower headers) test in steam environment

f. Spray distribution tests in air using the BWR/4 lower header with simulator nozzles in the 30° Sector Facility

g. Spray distribution tests in a steam environment using the BWR/4 nozzles and lower header in the 30° Sector Facility

4.2.2 Complete the design, fabrication, and installation of BWR/4 type lower header and nozzles into the 30° Sector Facility (Subsection 3.1.1). The facility will also include capability to test a dual nozzle combination (adjacent nozzles from upper and lower headers) typical of BWR/4 nozzle configurations. Document the facility design for these tests per Section 5.0.

4.2.3 Perform pretest predictions of the spray distribution using the Core Spray Distribution Methodology (Section 3.3).

4.2.4 Perform the test system calibration, instrumentation calibration, facility checkout, and shakedown tests.

4.2.5 Perform the tests per the approved Experimental Task Plan or as modified by the PMG.

4.2.6 Reduce the data to obtain spray flows, header system pressure, upper plenum pressure, and distribution of flow to individual bundles; for steam environment tests, additionally obtain steam flow rates and temperatures.

4.2.7 Verify the test data as specified in the Experimental Task Plan.

4.2.8 Process and store measured and derived data on computer tape.

4.2.9 Analyze and evaluate the experimental data to assess spray distribution in steam and air environments.

4.2.10 Provide post-test comparisons of predictions with data, evaluate the adequacy of the core spray distribution prediction methodology, and determine any prediction deficiencies requiring further model development. (This modification is not included in current scope.)

4.2.11 Prepare a task topical report per Section 5.0.

4.3 SINGLE-HEATED BUNDLE TASK

Objective:

a. To provide and utilize test data, obtained at near-atmospheric pressures, to identify and evaluate phenomena controlling heated-bundle thermal-hydraulic performance during the refilling and reflooding phase of a BWR LOCA.

b. To evaluate single-heated bundle system interaction performance in support of model development, and to provide reference single-bundle system response data as a basis for developing the adiabatic steam injection technique.

c. To develop an adiabatic steam injection technique for use in the 30° Sector Facility that simulates steam generation resulting from heated bundles.

Scope:

4.3.1 Prepare an Experimental Task Plan per Section 5.0 that elaborates on the means for meeting the above objectives. Separate effects tests will be performed to identify and evaluate separate effects phenomena and subsystem interactions described below, and to provide data to support the model development or model qualification tasks. System configuration and test parameters will be varied to obtain the following information:

a. Liquid vaporization rates for the heated bundle

b. Void distributions in the coolant as it flows through the heated bundle

c. CCFL and associated differential pressure at the upper tieplate, bundle inlet region, and top of core bypass

d. CCFL breakdown conditions with a heated bundle

e. Bundle and bypass channel heat transfer characteristics

f. Flow distributions between regional volumes

g. Condensation effects associated with lower tieplate leakage paths

Test parameters to be varied will include:

a. Bundle power level

b. Initial rod temperatures

c. Initial mass inventories and two-phase levels in system volumes as identified in Subtask 4.3.2

d. System pressure within facility capabilities

e. ECC injection system combinations, flow rates, and temperatures

f. Amount of steam injection in the guide tube and lower plenum to stimulate flashing

Integral heated-bundle system and CCFL tests will be performed at near-atmospheric pressure to evaluate system performance. Comparable adiabatic system tests will be conducted with variations in core steam injection rates to achieve the best simulation of the heated-bundle system response (primarily CCFL flows and breakdown conditions) for a range of BWR LOCA conditions. The resultant core steam injection rates are to be used in the CCFL/Refill System Effects Tests of Task 4.4.

4.3.2 Complete the design, fabrication, and assembly of the single-bundle test apparatus for installation in the R-Tower Test Facility. The main portion of the test section is a full scale, electrically heated 8x8 simulated fuel bundle. The test section will feature a prototypical channel, upper tieplate and grid spacers. Attached to the bundle will be simulated system volumes, including the bypass, upper plenum, steam separator, lower plenum, guide tube, jet pump, and steam dome/annulus. The test system will be scaled using the BWR/6-218 (624 fuel bundles) as the reference. The facility will have capability for: LPCS and HPCS injection into the upper plenum, LPCI injection into the bypass region or jet pump simulator, and steam injection into the lower plenum and guide tubes to simulate flashing due to depressurization. Document the facility design for these tests per Section 5.0.

4.3.3 Perform test system calibration, instrument calibration, facility checkout, and shakedown tests.

4.3.4 Perform the single-heated bundle separate-effects tests per the approved Experimental Task Plan, or as modified by the PMG.

4.3.5 Reduce the data to obtain the measured and derived parameters in engineering units. This will include parameters such as:

a. ECC flows and enthalpies

b. Steam injection flows and enthalpies

c. System effluent flow rates and enthalpies

d. Regional (such as steam dome, steam separator, upper plenum, bundle, bypass, lower plenum, guide tube, annulus, jet pump simulator) fluid masses, pressures, fluid temperatures, and appropriate mixture levels

e. Bundle power, temperatures, and axial differential pressures

f. Channel wall temperatures

Additional data may be required as a result of the Experimental Task Plan development and review.

4.3.6 Verify the test data as specified in the Experimental Task Plan.

4.3.7 Process and store the measured and appropriate derived data on magnetic tape.

4.3.8 Analyze and evaluate the experimental data to obtain the information identified in Subtask 4.3.1 and elaborated upon in the Experimental Task Plan.

4.3.9 Prepare a data report per Section 5.0.

4.3.10 Prepare the facility identified in Subtask 4.3.2 for the single-heated bundle system effects tests. Conduct scaling analyses to evaluate and improve, as necessary, the reactor simulation accuracy of the facility.

4.3.11 Perform test system calibration, instrumentation calibration, facility checkout, and shakedown tests.

4.3.12 Perform the single-heated bundle system effects tests according to the approved Experimental Task Plan or as modified by the PMG.

4.3.13 Reduce the data to obtain the measured and derived parameters in engineering units. This will include parameters such as:

a. ECC flows and enthalpies

b. Steam injection flows and enthalpies

c. System effluent flows and enthalpies

d. Regional (such as steam dome, steam separator, upper plenum, bundle, bypass, lower plenum, guide tube, annulus, jet pump simulator) fluid masses, pressures, fluid temperatures, and appropriate mixture levels

e. Bundle power, temperatures, and axial differential pressures

f. Channel wall temperatures

Additional [illegible] may be required as a result of the Experimental Task Plan development and re[illegible]

4.3.14 Verify the test data as specified in the Task Plan.

4.3.15 Process and store measured and derived data on computer tape.

4.3.16 Analyze and evaluate the experimental data to identify key events, evaluate heat transfer mechanisms, and explain observed phenomena.

4.3.17 Complete the design, fabrication, and assembly of an adiabatic test section for installation into the Single-Bundle Facility. Steam will be injected into the bundle to simulate vaporization from heated-bundle surfaces. Document the facility modification per Section 5.0.

4.3.18 Repeat Items 4.3.11 through 4.3.15 of this Task using the adiabatic bundle.

4.3.19 Compare the results for the CCFL flow rates and breakdown conditions, from the heated and adiabatic bundle tests and prepare for PMG review.

4.3.20 The PMG will review the adequacy of the adiabatic steam injection technique and reach a decision on whether or not to use this technique for the CCFL/REFILL tests to be performed in the 30° Sector Facility (Task 4.4).

4.3.21 Prepare a Task Topical Report per Section 5.0.

4.4 CCFL/REFILL SYSTEM EFFECTS TESTS (30° SECTOR)

Objective: To provide data from a large scale sector mockup of a BWR, and to identify and evaluate the phenomena controlling the system behavior during the refill phase of BWR LOCAs.

Scope:

4.4.1 Prepare an Experimental Task Plan as per Section 5.0 describing both preliminary and system effects tests. Preliminary tests to be described include system component and measurement checkout tests to ensure proper functioning, tests under simplified conditions for use in code qualification, and tieback tests to relate 30° Sector performance to single-bundle experiments. Consideration will be given to the following types of tests:

a. Fluid draining tests

b. Blowdown tests with and without ECC injection

c. Blowdown tests with and without steam injection

d. CCFL tests without blowdown

In specifying CCFL/Refill system effects tests, consideration will be given to parameter variations including:

e. Initial fluid inventory and distribution

f. Core steam injection rates and distribution

g. Combinations of ECC systems in operation

h. ECC system thermal-hydraulic parameters

i. Break sizes

j. LPCI location

k. Core spray header geometry

4.4.2 Testing under this task will be done using the 30° Sector Facility located at Lynn, Massachusetts. Modification to the facility will be performed as necessary to conduct transient depressurization simulation of the refill phase considering the results of Tasks 4.3, 4.6, and 4.8, the shakedown tests in 4.2, and the PMG review and approval of the Experimental Task Plan (item 4.4.1 above).

4.4.3 Conduct scaling analyses to evaluate and improve, as necessary, the reactor simulation accuracy of the facility.

4.4.4 Prepare the design and modify the test facility to perform transient CCFL/Refill system effects tests for operation at pressures between atmospheric and 150 psig. NRC, EPRI, and/or their consultants will be invited to the GE facility design review(s). The as-modified facility design will be documented per Section 5.0.

4.4.5 Perform the test system calibration, instrumentation calibration, facility checkout and shakedown tests.

4.4.6 Subject to the PMG decision under subtask 4.3.20, perform the tests according to the approved Experimental Task Plan or as modified by the PMG.

4.4.7 Reduce the data to obtain:

a. ECC flows and enthalpies.

b. Steam injection flow and enthalpy.

c. System effluent flow rates and enthalpies.

d. Regional (upper plenum, core, core bypass, lower plenum, guide tubes, and downcomer) fluid masses, pressures and fluid temperatures.

e. Upper plenum fluid temperature and two-phase mixture level.

f. Lower plenum mixture level.

g. Differential pressures between connected regions identified in Item 4.4.7.d.

Additional data may be required for the Model Qualification Task (4.8) or as a result of the Experimental Task Plan development and review.

4.4.8 Verify the test data as specified in the Experimental Task Plan.

4.4.9 Process and store measured and derived data on computer tape.

4.4.10 Prepare a Data Report per Section 5.0.

4.4.11 Analyze and evaluate the experimental data to determine the overall system response (pressure, fluid inventory, and distribution) to ECC injection. Specific evaluations will include ECC mixing with the initial fluid inventories, time and extent of CCFL breakdown at the top and bottom of the simulated core, ECC flow paths from injection location to the lower plenum, lower plenum refilling rate, and the core reflood initiation time and hydraulic conditions (fluid density and flow rates).

4.4.12 Prepare a Task Topical Report per Section 5.0.

4.5 360° UPPER PLENUM TESTS

Objective: Evaluate 30° Sector wall effects on CCFL breakdown as compared to 360° CCFL breakdown performance.

Scope:

4.5.1 Prepare an Experimental Task Plan per Section 5.0. Separate effects, steady pressure CCFL breakdown studies will be performed using a scaled 360° upper plenum mockup operated at near atmospheric pressure. The effects on CCFL breakdown performance with and without 30° sector walls will be evaluated. The facility will be fabricated for independent operation at near atmospheric pressure and also compatible with installation into the pressure vessel of Task 4.5 for elevated pressure studies. These tests will be used to qualify the 30° Sector tests of Task 4.4.

Experimental parameters to be varied include:

a. ECC flow rates

b. ECC subcooling

c. Core steam flow rate

4.5.2 Conduct scaling analyses and design studies for a facility capable of performing the above tests. The facility will represent a scaled version of the reference BWR/6 upper plenum with a minimum size of about 4-6 ft active core diameter. The design will include a capability for visual observation of flow patterns at near atmospheric pressure. The following BWR features will be incorporated: upper plenum, core spray spargers (header and nozzles), LPCI, upper core simulation, and separator standpipes. Prototypical hardware will be used where possible. NRC, EPRI, and/or their consultants will be invited to participate in the GE facility design review(s).

4.5.3 Fabricate and assemble the test facility. The as-built facility design shall be documented in a Facility Description Report per Section 5.0.

4.5.4 Perform test system calibration, instrumentation calibration, facility checkout, and shakedown tests.

4.5.5 Perform the CCFL breakdown tests at near atmospheric pressure with and without the sector walls per the Experimental Task Plan or as modified by the PMG.

4.5.6 Reduce the data to obtain measured and derived parameters in the engineering units. These include, but are not limited to, CCFL breakdown time and location.

4.5.7 Verify the tes data specified in the Experimental Task Plan.

4.5.8 Report the data according to Section 5.0.

4.5.9 Process and store the measured and appropriate derived data on magnetic tape.

4.5.10 Compare the results and assess differences in CCFL breakdown performance with sector walls installed.

4.5.11 Recommend to the PMG whether to proceed with the 360° Upper Plenum tests at elevated pressures. The scope, schedule, and cost associated with the elevated pressure tests are not within the currently funded program.

4.5.12 Prepare a Task Topical Report per Section 5.0.

4.6 TECHNICAL SUPPORT TASKS

Objective: To provide technical support for the experimental design, instrumentation, measurements, operation, data interpretation, and analytical efforts associated with various project tasks.

Scope:

4.6.1 Following PMG concurrence, perform upper plenum experiments, in the 16° Sector Facility, needed to assist in phenomena evaluation and instrument reading interpretation, associated with the 30° Sector and 360° experiments (Tasks 4.4 and 4.5). This may include visual identification of upper plenum conditions and flow patterns, during CCFL and CCFL breakdown to identify phenomena and supplement data interpretation.

4.6.2 Survey the ongoing NRC and industry-sponsored programs which are developing and applying two-phase transient and other related measurement devices. From this survey, determine which devices are most suitable for augmenting the measurement system planned for this program. Consistent with available resources and PMG concurrence, design systems, procure and install devices, and develop the techniques and expertise to utilize these devices in the program.

4.6.3 Survey ongoing programs for analysis of LOCAs. Determine which analysis methods are needed to meet the technical objectives of the joint program.

Recommend to the PMG any additional analytical efforts required to adapt appropriate analytical techniques to the needs of the joint program.

4.6.4 Define resources required for additional support tasks as may be determined necessary by the PMG.

4.7 MODEL DEVELOPMENT

This task consists of the following three subtasks.

4.7.1 Basic Models and Correlations

Objective: To provide models and correlations for realistic representation of governing basic phenomena that are suitable for incorporation into TRAC-BWR. Specifically, to establish correlations for CCFL and CCFL breakdown at the fuel bundle upper tieplate, core inlet region, and top of core bypass, to improve the constitutive relations for BWR LOCA flow regimes, and to survey and improve bundle-heat transfer models during CCFL conditions.

Scope:

4.7.1.1 Prepare an Analysis Task Plan, per Section 5.0, to achieve the Subtask 4.7.1 objectives.

4.7.1.2 Correlate the saturated CCFL test data obtained from Tasks 4.3 and other appropriate data.

4.7.1.3 Correlate saturated CCFL test data obtained from the 16° Upper Plenum Sector Tests (Section 3.2), compare to Item 4.7.1.2, and resolve any differences.

4.7.1.4 Correlate saturated CCFL data obtained from CCFL/Refill Systems Effects tests in the 30° Sector Facility. Compare these results to those obtained from Subtask 4.7.1.3 and other appropriate results in the open literature, and resolve any differences. Assess the significance of assumptions, range of applicability, and uncertainties inherent in these correlations.

4.7.1.5 Develop an approach to model CCFL breakdown phenomena and review with the PMG. Upon PMG approval, implement the approach utilizing test data from Task 4.3, the 16° Upper Plenum Sector tests, and other appropriate data, for incorporation into the TRAC-BWR code. Assess the significance of assumptions, range of applicability, and uncertainties inherent in the model.

4.7.1.6 Prepare a Special Report, per Section 5.0, documenting the studies and resultant CCFL correlations and subcooled CCFL breakdown model(s) developed under Subtasks 4.7.1.2 through 4.7.1.5.

4.7.1.7 Compile a list of available data to be used in the development of interfacial shear stress relations and drift flux parameters. Develop appropriate interfacial shear relations, as needed for TRAC hydraulic models, and drift flux parameters for BWR/LOCA flow regimes, consistent with available data and compatible with TRAC-BWR. Compare to other interfacial shear stress and drift flux relations, as appropriate, that are available in the open literature.

4.7.1.8 Review literature on interfacial heat transfer correlations and recommend appropriate relationships to be used in TRAC-BWR and the Single-Channel Model (Subtask 4.7.2) for BWR LOCA calculations.

4.7.1.9 Identify and assess further data requirements for improved specification of constitutive relations for TRAC-BWR LOCA analyses. This includes the following:

a. Interfacial mass, momentum, and energy transfer between fluid phases

b. Phase distribution and transitions

c. Interfacial areas associated with various phase distributions

d. Phase interactions with solid surfaces within the system

Document recommendations to satisfy these requirements

4.7.1.10 Prepare a Special Report per Section 5.0, documenting the results from Subtasks 4.7.1.7 through 4.7.1.9.

4.7.1.11 Review recent literature on bundle-heat transfer mechanisms important during CCFL conditions, including radiative heat transfer, droplet production, quench front movement, and convective heat transfer from the hot surfaces.

4.7.1.12 Develop appropriate mathematical models to describe bundle-heat transfer mechanisms that are important during CCFL conditions, utilizing the results from Subtask 4.7.1.11.

4.7.1.13 Conduct developmental qualification on models from Task 4.7.1.12 using selected-heat transfer data from Tasks 4.3 and other appropriate sources.

4.7.1.14 Prepare a Special Report, per Section 5.0, documenting the results from Subtask 4.7.1.11 through 4.7.1.13.

4.7.1.15 Prepare a Task Topical Report which combines the three Special Reports required under Subtasks 4.7.1.6, 4.7.1.10, and 4.7.1.14.

4.7.2 Development of a Single-Channel Model

Objective: To develop an efficient, fast-running, accurate analytical thermal hydraulics model for a single BWR core channel applicable to an entire BWR LOCA transient. The code will be self-standing for single-channel analyses, and compatible with boundary conditions calculated by TRAC-BWR.

Scope:

4.7.2.1 Prepare an Analysis Task Plan per Section 5.0.

4.7.2.2 Document technical specifications of the model, and transmit to the PMG for review and approval.

4.7.2.3 Complete the development of a single-dimensional transient hydraulics model based on provided technology (Section 3.3.2). The model will include non-equilibrium capabilities, and explicit treatment of two-phase levels in the core.

4.7.2.4 Incorporate radial conduction, axial conduction effects at quench fronts, boiling transition, and rod heatup models.

4.7.2.5 Incorporate core heat transfer models developed under Task 4.7.1.

4.7.2.6 Incorporate drift flux parameters developed under Task 4.7.1.

4.7.2.7 Perform development qualification of the model using appropriate, selected data.

4.7.2.8 Prepare a Task Topical Report, per Section 5.0. This report will contain a detailed technical description of the single-channel thermal-hydraulic model and include sample calculations from the model.

4.7.2.9 Prepare a user's manual report for the thermal-hydraulic model per Section 5.0.

4.7.3 Support Development of TRAC-BWR

Objective: To support the development by the NRC of a comprehensive realistic (best-estimate) system code (TRAC) for BWR/LOCAs. The GE contributions will consist of technical recommendations, development of suitable component and heat transfer models, and assistance on a faster running version.

Scope:

4.7.3.1 Prepare an Analysis Task Plan per Section 5.0.

4.7.3.2 Provide technical recommendations to the PMG on TRAC-BWR needs and modeling techniques. Upon PMG approval, transmit these recommendations to the designated government contractor.

4.7.3.3 Develop a jet pump model, consistent with applicable data, suitable for incorporation into TRAC-BWR. Assess the significance of assumptions, range of applicability, and uncertainties inherent in the model.

4.7.3.4 Develop models for BWR steam separators and dryers consistent with applicable data, suitable for implementation into TRAC. Assess the significance of assumptions, range of applicability, and uncertainties inherent in the models.

4.7.3.5 Develop a realistic boiling transition (CHF) prediction routine, consistent with applicable data, suitable for implementation into TRAC. Assess the significance of assumptions, range of applicability, and uncertainties inherent in this routine

4.7.3.6 Prepare a Special Report documenting studies and models developed under Task 4.7.3.3 through 4.7.3.5.

4.7.3.7 Provide assistance to the designated government contractor in implementing the models from Tasks 4.7.3.3 through 4.7.3.5 into the TRAC-BWR code.

4.7.3.8 Review with the designated government contractor the possibilities for reducing computational costs of TRAC-BWR. Report the conclusions in letter format, highlighting areas of most significant potential gain. Review actions with the PMG.

4.7.3.9 Undertake effort, agreed upon by the PMG under Task 4.7.3.8, to test recommended methods to improve TRAC-BWR running time and cost.

4.7.3.10 Prepare a Special Report per Section 5.0 describing the changes made under Task 4.7.3.9 and defining the effects on predicted quantities and code running cost.

4.7.3.11 Prepare a Task Topical Report by combining the Special Reports required under Subtasks 4.7.3.6 and 4.7.3.10.

4.8 MODEL QUALIFICATION TASKS

Objective: To qualify the adequacy of thermal-hydraulic and core heat transfer methods for realistic predictions of component and system behavior under BWR LOCA-ECCS conditions.

Scope:

4.8.1 The following efforts will be made:

a. Conduct a literature search to identify model development needs and available data. Recommend which data are to be used for model development and which are to be reserved for independent qualification.

b. Apply available versions of TRAC to selected experiments to obtain preliminary qualification assessment.

c. Conduct sensitivity studies using available analysis methods (e.g., TRAC, other codes, data evaluations) to identify and quantify the effect and importance of controlling phenomena and parameters on BWR/LOCA response.

4.8.2 Based upon the results of Task 4.8.1, complete the development and documentation of the Analysis Task Plan per Section 5.0. The task plan will identify data sources and criteria to be used for the model qualification efforts. This task will utilize available BWR/TRAC versions and other appropriate methods to perform selected pretest predictions for each test series before conducting the first test of that series. Selected post-test calculations will also be performed and comparisons made with data for models such as:

a. Critical flow

b. CCFL

c. Jet pump

d. Steam separator

e. Recirculation loop

f. Simple vessel blowdown thermal hydraulics (e.g., void distribution, level swell, mass inventory, and pressure response)

g. Upper plenum thermal hydraulics

h. Heated-bundle thermal hydraulics

i. Core region thermal hydraulics

j. Integral system response covering blowdown, refill and reflood phases.

4.8.3 Implement the Analysis Task Plan per the approved plan, or as modified by the PMG.

4.8.4 Document the results from the above qualification efforts and identify areas for TRAC model improvements, as necessary.

4.8.5 Provide input to experimental tasks on facility and measurement requirements, test matrices, and range-of-test conditions for model qualification purposes.

4.8.6 Document the results per the following:

a. Prepare special reports on model qualification activities that will be identified in the approved Model Qualification Task Plan.

b. Prepare a Topical Report on the Model Qualification Task per Section 5.0.

4.9 HEATED BUNDLE FEASIBILITY STUDY (30° SECTOR)

Contingent upon the result from the adiabatic core simulation evaluation of Task 4.3, Parallel Channel System Effects experiments anticipated to be incorporated into the current BWR BD-ECC program, and the PMG decisions, evaluate the feasibility of installing full-length heated bundles into the 30° Sector Facility. The evaluation will include analysis and design studies, as required, to define the approach, cost, and schedule of heated-bundle alternatives for program revision considerations. No separate funds are currently allocated for this task.

4.10 TECHNICAL CONSULTATION TO CONTRACTING PARTIES

Objective: To provide technical consultation to NRC, EPRI, and their consultants on related programs which complement this program.

Scope:

4.10.1 Perform technical consultation, as mutually agreed to by the PMG, on related programs which complement the BWR Refill/Reflood program, provided that program funds allocated for this task are available and the program schedule will not be adversely affected. Results of any technical consultation will be documented in informal letter reports.

4.11 USE OF GENERAL ELECTRIC PROPRIETARY COMPUTER CODES

General Electric Proprietary Computer Codes may be used in this project only upon the prior mutual agreement of the PMG members and will be consistent with the terms and conditions of the contract.

General Electric shall, subject to the direction of the PMG, perform selected pretest predictions and post-test comparisons with data, using General Electric Proprietary Computer Codes. The specific tests and items to be analyzed will be only those which have been agreed upon by the PMG. However, evaluations will not be made, within the program, of the differences, if any, between the General Electric calculational results and the calculational results of others. The General Electric calculational results, and a nonproprietary description of the General Electric Proprietary Computer Codes used in the selected pretest predictions, will be provided to the PMG for release to the public.

The General Electric Proprietary Computer Codes used in this program shall be made available for inspection by NRC and the Institute on a proprietary basis at the location at which General Electric Maintains such computer codes.

4.12 PROGRAM FINAL REPORT

Contractor will prepare a BWR Refill-Reflood Program Final Report per Section 5.0.

ACRONYM LIST

A

ADS.....................Automatic Depressurization System

ASME....................American Society of Mechanical Engineers

ATLAS...................17.2 MW Heat Transfer Loop for Thermal Hydraulic testing of full-size BWR bundles

ATWS....................Anticipated Transient Without Scram

B

BAF.....................Beginning of Active Fuel

BD/ECC..................Blowdown Emergency Core Cooling Program

BDHT....................Blowdown Heat Transfer Program

BE......................Best Estimate

BHL.....................Beginning of Heated Length

BP......................Bypass

BT......................Boiling Transition

BWR.....................Boiling Water Reactor

BWR/R-R.................Boiling Water Reactor Refill-Reflood Program [Cooperatively (NRC/EPRI/GE) funded program to understand and complete models for loss-of-coolant accident (LOCA)]

C

CCFL....................Counter-Current Flow Limiting

CPR.....................Critical Power Ratio

CS......................Core Spray

D

DAS.....................Data Acquisition System

DBA.....................Design Basis Accident

DP......................Differential Pressure

E

ECCS....................Emergency Core Cooling System

EHL.....................End of Heated Length

EM......................Evaluation Models

F

FIST....................Full Integral Simulation Test
(Facility to be located in San Jose, CA for use in BD/ECC Program)

FW......................Feedwater

G

GT......................Guide Tube

H

HPCS....................High Pressure Core Spray

HPCI....................High Pressure Core Injection

HSF.....................Horizontal Spray Facility
(GE facility located in San Jose, CA)

HTC.....................Heat Transfer Coefficient

J

JP......................Jet Pump

L

LABT....................Lynn Adiabatic Bundle Test

LOCA....................Loss-of-Coolant Accident

LPCI....................Low Pressure Coolant Injection

LPCS....................Low Pressure Core Spray

M

MSIV....................Main Steam Isolation Valve

P

psi....................pounds per square inch

psia....................pounds per square inch absolute

psig....................pounds per square inch gauge

PWR....................Pressure Water Reactor

R

RCICS....................Reactor Core Isolation Cooling System

R-R....................Refill-Reflood
Refill-(period of LOCA transient when the lower plenum is being refilled with liquid)
Reflood-(period of LOCA transient when the fuel region is being reflooded with liquid)

Rewet....................Quenching of a hot surface

RTE....................Responsible Test Engineer

S

SEO....................Side Entry Orifice
(located in fuel support casting to orifice bundle inlet flow)

SHB....................Single Heated Bundle

SRV....................Safety Relief Valve

SSTF....................Steam Sector Test Facility (30°)
(Facility located at GE in Lynn, Mass., used to study CS , UP and system response for LOCA)

T

TAF.....................Top of Active Fuel

TC ....Thermocouple

TLTA................... Two Loop Test Apparatus
(GE Facility located in San Jose, CA)

TMI...... ....Three Mile Island

TRAC....................Transient Reactor Analysis Code

TRACBD1.................BWR version of TRAC (B), Detailed Version (D), First Version (1)

U

UP......................Upper Plenum

UTP.....................Upper Tie Plate

V

VSF.....................Vallecitos Spray Facility
(GE spray distribution facility located near Livermore, CA)

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The BWR Refill-Reflood Program is described. This program will develop more detailed experimental information, particularly in large scale facilities, and realistic modelling capability for the refill and reflood phases of hypothetical loss-of-coolant accidents in BWRs. Included in this document are a general strategy discussion, brief descriptions of the experimental facilities to be used including capabilities and limitations, descriptions of the various experimental tasks, descriptions of the model development and model qualification tasks, the planned documentation and schedule information.

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