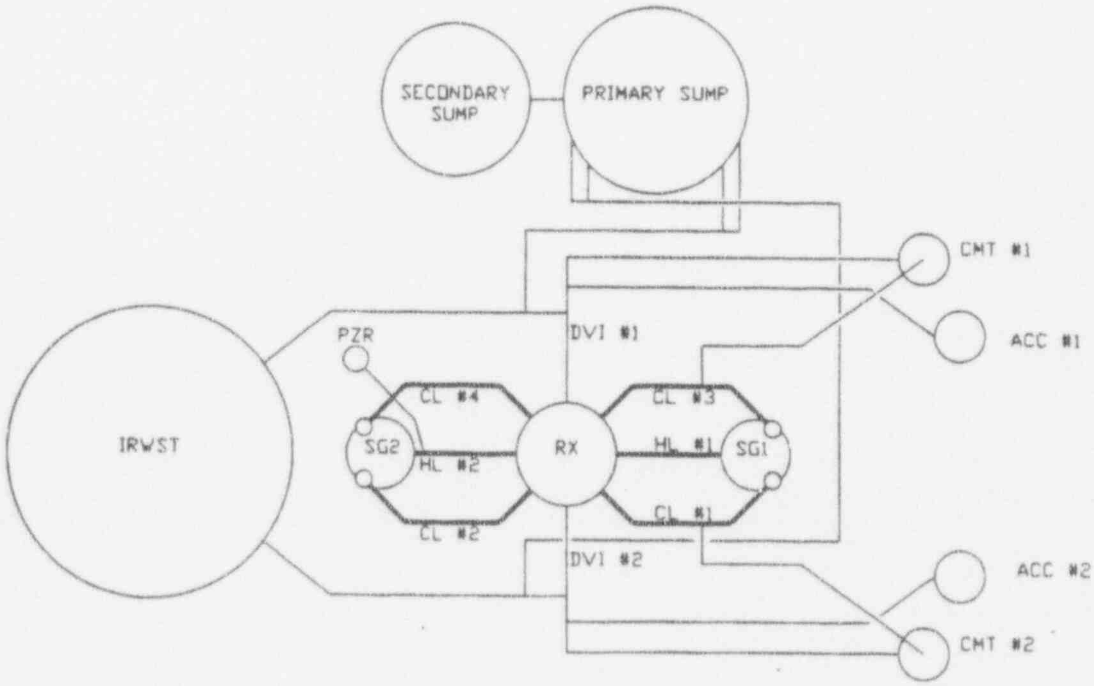
Westinghouse Non-Proprietary Class 3 WCAP-14136

AP600

LOW PRESSURE INTEGRAL SYSTEMS TEST

AT OREGON STATE UNIVERSITY



FACILITY DESCRIPTION REPORT

JULY 1994

VOLUME I

LOW PRESSURE INTEGRAL SYSTEMS TEST

FACILITY DESCRIPTION REPORT

Revision 0

July 1994

Principal Investigator and Thermal Hydraulic Analyses: L. E. Hochreiter, Westinghouse Electric Corp.

Scaling Analysis: J. N. Reyes, Oregon State University

Facility Lead Designer: L. K. Lau, Westinghouse Electric Corp.

Report Edited by: M. H. Cooper, Westinghouse Electric Corp.

Reviewed by: Design Certif. Project: R. B. Tupper, Westinghouse Electric Corp.

Test Engineering: E. J. Piplica, Westinghouse Electric Corp.

Approved by: M. Mahlab, Westinghouse Electric Corp.
OSU Project Manager

ABSTRACT

Westinghouse Electric Corporation and the Nuclear Engineering Department, Oregon State University have designed and constructed a one-quarter scale model of the AP600 plant design including the Reactor Coolant System, Steam Generators, Passive Safety Injection Systems, and Non-Safety Injection Systems, in the Radiation Center at the University in Corvallis, Oregon. The purpose of this facility is to test the performance of the AP600 passive safety systems in a reduced sized and lower temperature and pressure system for validation of the safety analysis codes. The test facility, fabricated completely from austenitic stainless steel which is designed for normal operation at 450°F and 400 psig, was scaled using the Hierarchical Two-Tiered Scaling (H2TS) analysis method developed by the U.S. Nuclear Regulatory Commission. Simulated piping breaks can be tested in the Hot Leg, Cold Leg, pressure balance line between the Cold Leg and the Core Makeup Tank, and the Direct Vessel Injection line. Decay heat which scales to 3 percent of the full power (about two minutes after shutdown) is supplied by electrically heated rods in the reactor vessel. Simulated accidents are programmed by the control system to proceed automatically. About 850 data channels are recorded every eight seconds by the Data Acquisition System and are downloaded to compact disks for subsequent data reduction and plotting.

ACKNOWLEDGMENTS

The editor expresses his appreciation for the extensive discussions and inputs obtained from the key designer of the test facility, Mr. L. K. Lau, and the developer of the scaling analyses, Prof. J. N. Reyes, whose report and scaling data have been abstracted in this report. Mr. R. B. Tupper assisted immeasurably in facilitating gathering of information and identification appropriate responsible personnel. The editor especially wishes to acknowledge the assistance provided by Mr. John Groome of Oregon State University, the assistance of Mr. J. Winters and the review comments by Mr. M. Mahlab. The document could not have been produced without the dedicated efforts of Ms. C. E. McCune, Ms. D. Kephart, and Mr. M. Wesolowski.

TABLE OF CONTENTS

Volume I

Section	Title	Page
ABSTRACT		1
1.0	INTRODUCTION	1-1
1.1	Overall Test Objectives	1-1
1.2	Specific Test Objectives	1-2
1.3	Documentation	1-2
2.0	DESIGN BASIS OF THE TEST FACILITY	2-1
2.1	Methodology	2-1
2.2	Facility Scaling Parameters	2-3
2.3	Mass/Energy Balances	2-5
3.0	FACILITY DESCRIPTION	3-1
3.1	Overall Facility Description	3-1
3.1.1	Reactor Coolant System (RCS)	3-1
3.1.2	Steam Generator System (SGS)	3-8
3.1.3	Passive Core Cooling System (PXS)	3-8
3.1.4	Automatic Depressurization System (ADS)	3-9
3.1.5	Lower Containment Sump (LCS)	3-10
3.1.6	Normal Residual Heat Removal System and Chemical Volume Control System (CVS)	3-10
3.1.7	Break and ADS Flow Measurement System (BAMS)	3-11
3.1.7.1	ADS1-3 Separator and Pipe Route	3-11
3.1.7.2	ADS4 Separator and Pipe Route	3-12
3.1.7.3	Break Separator and Pipe Route	3-12
3.1.8	Instrumentation System	3-13
3.1.9	Orifices and Nozzles	3-14
3.2	Reactor Vessel	3-15
3.2.1	Function	3-15
3.2.2	Reactor Vessel Scaling Basis	3-15
3.2.3	Vessel Design/Dimensions	3-16
3.2.4	Vessel Instrumentation	3-16

TABLE OF CONTENTS (Continued)

Section	Title	Page
3.3	Rod Bundle	3-16
	3.3.1 Function	3-16
	3.3.2 Rod Bundle Scaling Basis	3-16
	3.3.3 Rod Bundle Description	3-18
	3.3.4 Rod Bundle Instrumentation	3-19
3.4	Reactor Internals	3-22
	3.4.1 Function	3-22
	3.4.2 Reactor Internal Scaling Basis	3-22
	3.4.3 Reactor Internal Description	3-23
	3.4.3.1 Core Barrel	3-23
	3.4.3.2 Reflectors	3-23
	3.4.3.3 Grid Ring	3-26
	3.4.3.4 Upper Internals	3-26
3.5	Hot Leg Piping	3-26
	3.5.1 Function	3-26
	3.5.2 Hot Leg Scaling Basis	3-28
	3.5.3 Hot Leg Description	3-28
	3.5.4 Hot Leg Instrumentation	3-29
3.6	Cold Leg Piping	3-29
	3.6.1 Function	3-29
	3.6.2 Scaling Basis	3-29
	3.6.3 Description	3-29
	3.6.4 Instrumentation	3-30
3.7	Pressurizer Surge Line	3-30
	3.7.1 Function	3-30
	3.7.2 Scaling Basis/Key Thermal Hydraulic Phenomena	3-30
	3.7.3 Design/Dimensions	3-30
	3.7.4 Pressurizer Surge Line Instrumentation	3-31
3.8	Pressurizer	3-31
	3.8.1 Function	3-31
	3.8.2 Scaling Basis	3-31
	3.8.3 Description	3-31
	3.8.4 Instrumentation	3-34
3.9	Steam Generators	3-34
	3.9.1 Function	3-34
	3.9.2 Scaling Basis	3-35
	3.9.3 Description	3-35
	3.9.4 Primary Side Instrumentation	3-37
	3.9.5 Secondary Side Instrumentation	3-37

TABLE OF CONTENTS (Continued)

Section	Title	Page
3.10	Reactor Coolant Pumps	3-39
3.10.1	Function	3-39
3.10.2	Scaling Basis	3-39
3.10.3	Description	3-39
3.10.4	Instrumentation	3-39
3.11	Accumulators	3-41
3.11.1	Function	3-41
3.11.2	Scaling Basis	3-41
3.11.3	Description	3-41
3.11.4	Instrumentation	3-43
3.12	Core Makeup Tanks	3-43
3.12.1	Function	3-43
3.12.2	Scaling Basis	3-44
3.12.3	Description	3-44
3.12.4	Instrumentation	3-46
3.13	Incontainment Refueling Water Storage Tank	3-48
3.13.1	Function	3-48
3.13.2	Scaling Basis	3-49
3.13.3	Description	3-49
3.13.4	Instrumentation	3-50
3.14	Safety Injection Lines	3-53
3.14.1	Function	3-53
3.14.2	Scaling Basis	3-53
3.14.3	Description	3-53
3.14.4	Instrumentation	3-53
3.15	Containment Sumps	3-59
3.15.1	Scaling Basis	3-59
3.15.2	Description	3-59
3.16	Automatic Depressurization System, Stages 1-3	3-61
3.16.1	Function	3-61
3.16.2	Scaling Basis	3-61
3.16.3	Description	3-62
3.16.4	Instrumentation	3-62

TABLE OF CONTENTS (Continued)

Section	Title	Page
3.17	Automatic Depressurization System, Stage 4	3-66
3.17.1	Function	3-66
3.17.2	Scaling Basis	3-66
3.17.3	Description	3-66
3.17.4	Instrumentation	3-66
3.18	Non-Safety Injection Systems	3-68
3.18.1	Function	3-68
3.18.2	Scaling Basis	3-68
3.18.3	Description	3-68
3.18.3.1	CVS	3-68
3.18.3.2	RNS	3-69
3.18.4	Instrumentation	3-69
3.19	Passive Residual Heat Removal System	3-69
3.19.1	Function	3-69
3.19.2	Scaling Basis	3-69
3.19.3	Description	3-72
3.19.4	Instrumentation	3-72
3.20	Break System Simulators	3-74
3.20.1	Function	3-74
3.20.2	Scaling Basis for Break Sizes	3-74
3.20.3	Description	3-75
3.21	Break and ADS Measurement System (BAMS)	3-78
3.21.1	Function	3-78
3.21.2	Scaling Basis	3-78
3.21.3	Description	3-78
3.21.4	Instrumentation	3-79
3.22	Test Support Systems	3-79
3.22.1	Demineralization System	3-80
3.22.2	Fill and Drain System	3-80
3.22.3	RCP Seal Cooling System	3-80
3.22.4	Electrical System	3-80
3.22.5	Trace Heaters	3-81
3.22.6	Insulation	3-81
3.22.7	Heating, Ventilation and Air Conditioning System	3-83
3.22.8	Fire Protection System	3-83

TABLE OF CONTENTS (Continued)

Section	Title	Page
4.0	CONTROL SYSTEM	4-1
4.1	Function	4-1
4.2	Programmable Control System	4-1
4.3	Process Control System	4-4
4.4	Operator Panel	4-4
5.0	DATA ACQUISITION SYSTEM	5-1
5.1	System Hardware	5-1
5.2	Architecture	5-1
5.3	Software	5-1
5.4	LabVIEW Description	5-4
6.0	QUALITY ASSURANCE	6-1
6.1	Facility	6-1
6.2	Software	6-1
7.0	SUMMARY	7-1
References		R-1

TABLE OF CONTENTS (Continued)

Volume II

Section	Title
APPENDIX A	HOT FUNCTIONAL TESTS AND TEST MATRIX
APPENDIX B	KEY FACILITY DRAWINGS
APPENDIX C	DRAWING LIST
APPENDIX D	INSTRUMENTATION LISTING
APPENDIX E	ORIFICE SIZING DETAILS

LIST OF FIGURES

Figure	Title	Page
2-1	General Scaling Methodology	2-2
3.1	Reactor Vessel and Instrumentation/Power Lines	3-2
3.2	IRWST	3-3
3.2-1	Reactor Vessel and Its Internals	3-7
3.3	Primary and Secondary Sump Tanks	3-4
3.4	Upper Level (CMT in Foreground)	3-5
3.4-1	View from Top of Reactor Vessel Showing Partial Installation of Rod Bundle	3-27
3.5	Isometric Sketch of Test Facility	3-6
3.6	Simplified Flow Diagram	3-7
3.9-1	Stem Generator Tube Bundle During Shop Assembly	3-38
3.9-2	Steam Generator Arriving at Test Facility	3-38
3.10-1	RCP Performance, Head vs. Flow	3-40
3.12-1	CMT-2 Installation in Test Facility	3-47
3.13-1	PRHS Heat Exchange Located Inside the IRWST	3-52
3.16-1	Flow Schematic for Automatic Depressurization System	3-65
3.18.3-1	CVS Pump Head vs. Flow	3-70
3.18.3-2	RNS Pump Head vs. Flow	3-71
3.22-1	Electrical One-Line Diagram	3-82
4.4-1	Photograph of Operator Panel	4-6
4.4-2	Drawing of Operator Panel	4-7
5.1-1	DAS Hardware	5-2
5.2.1	DAS Architecture	5-3
5.4.1	DAS Software Hierarchy	5-5

LIST OF TABLES

Table	Title	Page
2-1	Summary of System Scaling Results for the 1/4 Length Scale Model Primary Loop	2-4
3.3-1	Rod Bundle Heater Power After Reactor Shutdown	3-20
3.3-2	Rod Bundle Characteristics	3-21
3.3-3	Upper Core Support Plate Perforation Scaling Ratio and Dimensions	3-24
3.3-4	Downcomer Scaling Ratios and Dimensions	3-25
3.8-1	Pressurizer Scaling Ratios	3-32
3.8-2	Pressurizer Scaling Ratios and Dimensions	3-33
3.9-1	Steam Generator Scaling Ratios and Dimensions	3-36
3.11-1	Model Accumulator Scaling Ratios and Dimensions	3-42
3.12-1	Model CMT Scaling Ratios and Dimensions	3-45
3.13-1	Model IRWST Scaling Ratios and Dimensions	3-51
3.14-1	Model Safety Injection Line Scaling Ratios and Dimensions	3-54
3.14-2	DVI Line Scaling Ratios and Dimensions	3-57
3.14-3	Safety Injection Line Instrumentation	3-58
3.15-1	Containment Sump Scaling Ratios and Dimensions	3-60
3.16-1	ADS Stage 1 through 3 Scaling Ratios and Dimensions	3-64
3.17-1	ADS Stage 4 Scaling Ratios and Dimensions	3-67
3.19-1	Passive Residual Heat Removal Heat Exchanger Scaling Ratios and Dimensions (Single Heat Exchanger)	3-73
3.20-1	Dimensions of Break Simulations	3-77
3.21-1	Separator Data	3-80
3.22-1	Insulation Applications	3-84
4.2-1	Programmable Controller Summary	4-2
4-3	Process Control System Components	4-5
7-1	Critical Attribute Summary	7-2

ACRONYMS

ACC	Accumulator
ADS	Automatic Depressurization System
ASME	American Society of Mechanical Engineers
BAMS	Break and ADS Measurement System
CD ROM	Compact Disk Read Only Memory
CMT	Core Makeup Tank
CRP	Condensate Return Pump
CVS	Chemical and Volume System
DAS	Data Acquisition System
DP	Differential Pressure
DVI	Direct Vessel Injection
GSM	General Scaling Methodology
H2TS	Hierarchical Two-Tiered Scaling Analysis
HPS	Heated Phase Switch
HX	Heat Exchanger
IRWST	In-Containment Refueling Water Storage Tank
LAN	Local Area Network
LCS	Lower Containment Sump
LOCA	Loss-of-Coolant Accident
LRGMS	Large Main Steam
NSS	Non-Safety Systems
OSU	Oregon State University
PC	Personal Computer
PIRT	Phenomena Initial Ranking Table
PPIRT	Plausible Phenomena Initial Ranking Tables
PQP	Project Quality Plan
PRHR	Passive Residual Heat Removal
PRHRS	Passive Residual Heat Removal System
PWR	Pressurized Water Reactor
PXS	Passive Core Cooling System
PZR	Pressurizer
RCP	Reactor Coolant Pump
RCS	Reactor Cooling System
RNS	Normal Heat Removal System
RV	Reactor Vessel
SASM	Severe Accident Scaling Methodology
SBLOCA	Small-Break Loss-of-Coolant Accident
SCR	Silicon Controlled Rectifier
SG	Steam Generator
SGS	Steam Generator System
VI	Virtual Instrumentation

1.0 INTRODUCTION

The Low Pressure Integral Systems Test Facility, also known as AP600 Long Term Cooling Test Facility is located in the Radiation Center Oregon State University, Corvallis, Oregon. This facility, which is designed for 400 psig and 450°F, models the following AP600 systems:

- Reactor Coolant System (RCS)
- Primary Side of Steam Generator System (SGS)
- Passive Core Cooling System (PXS)
- Partial Chemical and Volume Control System (CVS)
- Partial Non-Safety Grade Normal Residual Heat Removal System (RNS)
- Automatic Depressurization System (ADS)
- Lower Containment Sump Recirculation System (LCS)

The purpose of this test program is to provide thermal hydraulic data to validate the thermal hydraulic computer code being developed for transient and steady state safety analyses of the AP600. In particular, gravity-driven injection and natural circulation, passive cooling for long-term heat removal are investigated.

The normal operating conditions for this facility are:

Pressurizer pressure = 370 $\pm$ 2 psig
Hot leg temperature = 420 $\pm$ 2°F
Steam generator pressure = 285 $\pm$ 5 psig

1.1 Overall Test Objectives

Unique features of the AP600 will be tested in this program. In particular, Automatic Depressurization System (ADS) operation, Core Makeup Tank (CMT) injection, Accumulator (ACC) tank injection, In-containment Refueling Water Storage Tank (IRWST) injection, Passive Residual Heat Removal heat exchanger (PRHR HX) operation and Lower Containment Sump (LCS) recirculation will be tested. Integral operations of all these features will be investigated from transient to steady state long term cooling conditions.

Thermal hydraulic data for these integral system operations will be obtained for the following simulated loss of coolant accidents (LOCA):

- Cold leg break of various sizes and locations

- Hot leg break at pressurizer side

- Inadvertent ADS operation

- Direct Vessel Injection line break of different sizes, including double ended break. Break is located on CMT side

- CMT/cold leg pressure balance line break of different sizes, including double ended break. Break is located in CMT side.

In addition, a single-ended failure will be tested for each of the above LOCA cases.

1.2 Specific Test Objectives

The specific test objectives of this program are:

- Design, construct and operate a scale model that will provide thermal hydraulic data on system performance for the AP600, including long term cooling, for computer code validation.

- Measure flows, pressure drops, phase changes, heat fluxes, and temperatures in all loop flow paths and in the simulated reactor vessel, to characterize the operation of the safety features of the AP600 scaled model during small break LOCAs (SBLOCAs) and the long term cooling periods to obtain a mass and energy balance on the system.

- Provide valid thermal hydraulic data on the system behavior on a scaled basis for each of the different injection systems: CMT, ACC, IRWST and the LCS.

- Provide data on the interfacing effect from the CVS makeup pump and Non-Safety RHR pump on long term cooling,

- Provide a basis to scale the test results to high pressure core cooling transients,

- Investigate the performance of the PRHR,

- Investigate integral system behavior, particularly safety system interactions during SBLOCAs and long term cooling.

1.3 Documentation

A total of 19 tests will be performed. The test matrix is constructed with the AP600 2-inch Cold Leg break as the base case. Various single failures are tested to investigate transient and long term core cooling operation. In addition, other break sizes are used. Table 1, Appendix A is a detailed tabular listing of the test matrix and the hot functional tests. Appendix B contains the key drawings referred to in this report. Appendix C is the Test Facility drawing list. Appendix D contains the instrumentation list for the Test Facility. Appendix E the Orifice Sizing Details. The complete set of drawings (approximately 300) are available on request from Westinghouse in either microfiche or electronic file (Autocad) format.

2.0 DESIGN BASIS OF THE TEST FACILITY

The design basis of the Test Facility is the scaling analysis of the AP600 (Ref. 2-3). The purpose of scaling analysis is to guide the design of the test facility so that the thermal-hydraulic performance of the test facility will properly simulate the phenomena important to the passive safety features of the AP600. The test facility is designed with reduced dimensions and lower temperatures and pressures than the actual reactor. The scaling methodology and the overall results are provided in this section.

2.1 Methodology

To assure that the scaling objectives are met in an organized and traceable manner, a general scaling methodology (GSM) for the Low Pressure Integral Systems Test Facility has been developed. The model for this scaling methodology is partly drawn from the U.S. NRC's Severe Accident Scaling Methodology (SASM) presented in NUREG/CR-5809 (Ref. 2-1). A flow diagram describing the GSM is presented in Figure 2.1.

The first step is to specify the experimental objectives. The experimental objectives define the types of tests that will be performed to respond to specific licensing and design needs. The experimental objectives determine the general modes of operation that should be simulated in the test facility.

The second step is the development of Plausible Phenomena Initial Ranking Tables (PPIRTs) (Ref. 2-2). The nature of scaling forbids exact similitude between the AP600 and the test facility operating conditions. As a result, the design and operation of the test facility will be based on simulating the processes most important to passive safetv system performance and long term cooling. The function of the PPIRTs will be to identify the key thermal hydraulic phenomena that should be scaled in the context of LOCA transients. Many of the phenomena of importance to AP600 LOCA behavior have already been identified by existing Phenomena Identification and Ranking Tables (PIRTs) (Ref. 2-2). However, some of the AP600 modes of operation have never been verified. Therefore, the first series of tests may help identify additional thermal hydraulic phenomena of importance. Hence, the use of PPIRTs rather than PIRTs. The development of the AP600 LOCA PPIRTs is presented in the facility scaling analysis report (Ref. 2-3).

The third step is to perform a scaling analysis for each of the modes of operation specified by the experimental objectives and further defined by the PPIRTs. The Hierarchical Two-Tiered Scaling Analysis (H2TS) developed by the U.S. NRC (Ref. 2-1) has been selected for the scaling analysis of this facility. Detailed discussion of the application of this method to the Low Pressure Integral Systems Test Facility is provided in Ref. 2-3.

The fourth step is to use the scaling analysis results to develop a set of characteristic time ratios (dimensionless π groups) and similarity criteria for each mode of operation. Because it is impossible to identically satisfy all of the similarity criteria simultaneously, the set will only include those criteria which must be satisfied in order to scale the most important phenomena identified by the PPIRT.

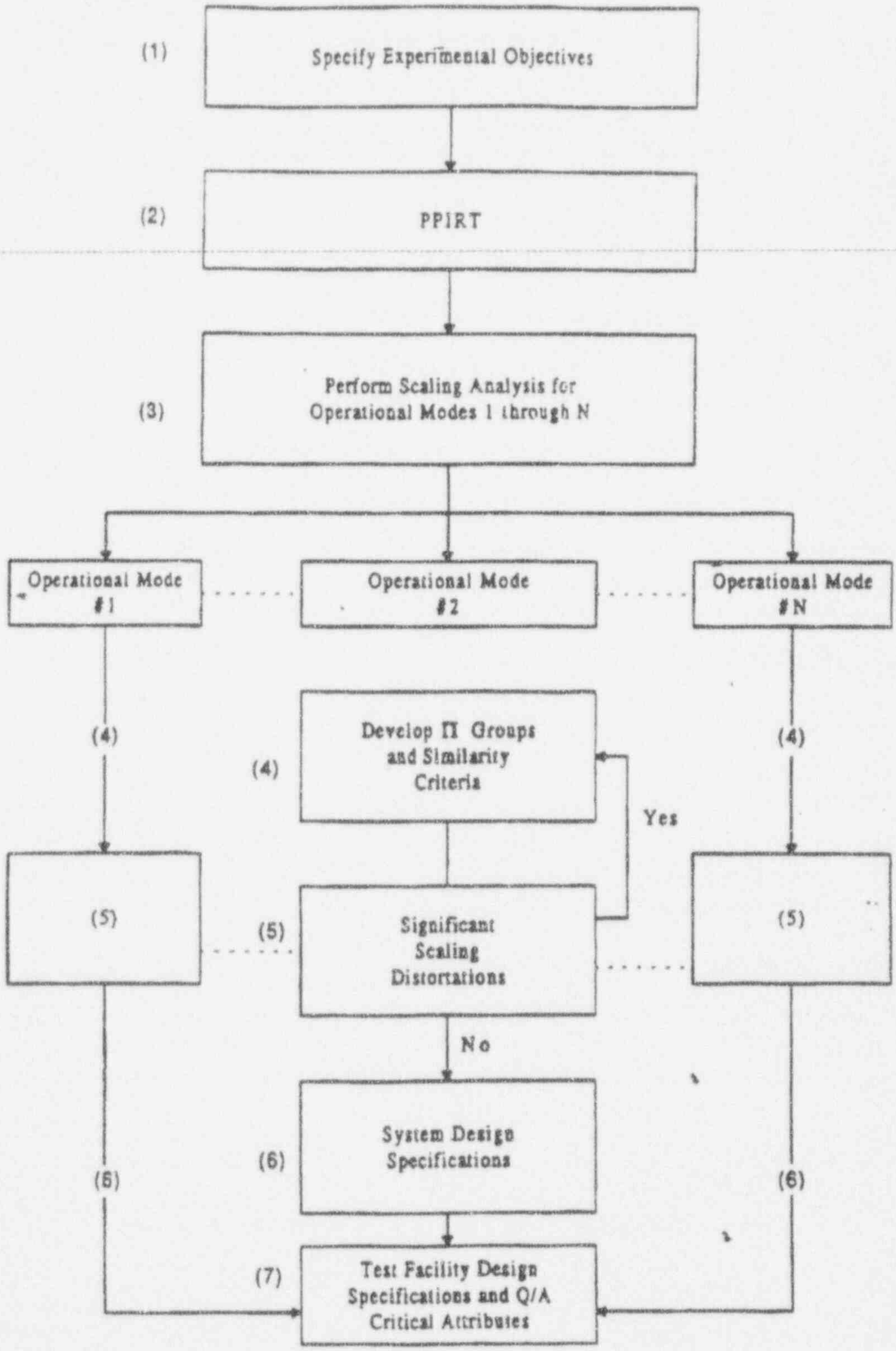


Figure 2.1 General Scaling Methodology

Step five is an evaluation of the scaling criteria to determine if the scale model geometry, boundary conditions or operating conditions would introduce significant scaling distortions. Distortions are also evaluated relative to other modes of operation.

2.2 Facility Scaling Parameters

The height scaling ratio has been set at 1:4 and the diameter scaling ratio, at 1:6.93. These ratios were based on the objective of minimizing power requirements while maximizing height and maintaining sufficient system volume to properly model loop pressure drop and three-dimensional flow in the downcomer, core, and plenum regions.

The important factors that were considered in determining the height scaling ratio were:

- Minimum diameter ratio to satisfy skin friction pressure drop requirements could be met easily with commercially available pipe and drawn tubing.
- Diameter choice was consistent with two-phase scaling and flow regime transitions
- Fluid volume requirements were reasonable [ ]^{a,b}
- Power requirements were reasonable (~ 600 kW).
- Time scale makes long term cooling test duration reasonable ($\tau_R = 0.5$).
- L/D ratio indicates that multidimensional flow effects will scale well under fluid property similitude [ ]^{a,b}
- Elevation is sufficient such that differential pressure measurements between hot and cold legs are well within instrument capability.
- Construction and material costs economical.

The scaling ratio for the piping was selected to ensure that the frictional losses because of the piping roughness do not bias the buoyancy effects which determine natural convection rates. Analysis of the buoyancy-friction balance equation resulted in a minimum diameter ratio of [ ]^{a,b} (Ref. 2-3). Therefore, a minimum diameter ratio of [ ]^{a,b} was selected because it was greater than the minimum and could be obtained with commercial pipe sizes. Also, thermal effects of this size piping (i.e., heat losses and heat storage effects) could be modeled.

Once the length and diameter scaling ratios were determined, the dimensions of the test facility could be geometrically scaled. Table 2-1 summarizes the scaling ratios for the test facility.

TABLE 2-1 SUMMARY OF SYSTEM SCALING RESULTS FOR THE 1/4 LENGTH SCALE MODEL PRIMARY LOOP		
Geometry		[ ] a,b,c
	Length Scaling Ratio:	
	System Diameter Scaling Ratio:	
	Area Scaling Ratio:	
	Volume Scaling Ratio:	
Flow		
	Velocity Scaling Ratio:	
	Mass Flow Rate Scaling Ratio:	
Residence Time		
	Time Scaling Ratio:	
Power		
	Power Scaling Ratio:	
	Power Density Scaling Ratio:	
MODEL POWER REQUIREMENTS		
	Percent of Total Power	a,b
AP600 Decay Power (MW):	[	]
Model Power (kW):		

* Nominal power used to simulate the decay heat in the model was [ ][a,b]

2.3 Mass/Energy Balances

Since accurate measurements of the components of a two-phase flowing mixture are difficult and the equipment to accomplish these measurements is very expensive, it was decided to separate the two-phase flow into its single phases, and to measure the flows with conventional instrumentation. Therefore, all two-phase streams that are vented from the Reactor Coolant System are measured using conventional vapor-liquid separation devices. Where required to simulate AP600 systems, the resultant single phase flows are recombined before being returned to the system. In other cases, the steam is vented and hot water from an auxiliary storage tank is injected matching the mass of the steam that would have condensed had the steam been released into the AP600 containment. It should be noted that the heat transport processes in the containment are not modeled in this test facility; however, the condensate return process is modeled.

This approach permits accurate measurement of the two-phase flows released from the RCS with simple, relatively inexpensive components. Thermal hydraulic similitude is maintained either by recombining the single phase streams or by make-up of hot water for vented steam which would have been condensed.

3.0 FACILITY DESCRIPTION

The Low Pressure Integral Systems Test Facility has been designed for operation at 400 psig and 450°F within the requirements of the ASME Pressure Vessel Codes, Section VIII, Pressure Piping B31 (ANSI/ASME B31.1), OSHA Standards, and Oregon State Fire Protection Codes. In this section, the overall test facility and each component are described. All components and piping are fabricated from austenitic stainless steel; flanged, gasketed connectors are used throughout the test facility.

3.1 Overall Facility

The Low Pressure Integral Systems Test Facility is a scaled model of the AP600 RCS, SGS, PXS, ADS, LCS, CVS and RNS. In addition, the facility is capable of simulating the AP600 Passive Containment Cooling System condensate return process. Figures 3.1 through 3.4 are photographs of the completed facility; Figure 3.5 is an isometric drawing of the test facility. Figure 3.6 is a simplified flow diagram of the test facility; pages 1-1 through 1-19 of Appendix F are detailed Piping and Instrumentation Diagrams (P and ID) for the test facility and its systems. The facility accurately reflects the AP600 geometry including the piping routings. The relative locations of all tanks and vessels such as IRWST, CMT's and Accumulators, are properly modeled both horizontally and vertically. This facility uses a unique Break and ADS Flow Measurement System (BAMS) to measure two-phase break and ADS flow.

3.1.1 Reactor Coolant System (RCS)

The Reactor Coolant System (RCS) is comprised of a Reactor Vessel (RV) with electrically heated rods to simulate the decay heat in the reactor core and two primary loops. Each primary loop consists of two cold leg pipes and one hot leg pipe connecting a Steam Generator (SG) to the Reactor Vessel. Each cold leg has a Reactor Coolant Pump (RCP) which takes suction from the Steam Generator channel head (downstream of the Steam Generator U tubes) and discharges it into the downcomer region of the Reactor Vessel. A Pressurizer (PZR) with an electric heater is connected to one of the two hot legs through a uniquely designed surge line piping. The surge line is formed to a spiral geometry, and it acts as a spring which alleviates piping expansion loads at the pressurizer during thermal transients. The top of the Pressurizer is connected to the ADS1-3. ADS4 is connected to the Hot Leg.

The Reactor Vessel also consists of two Direct Vessel Injection (DVI) nozzles connecting to the DVI lines of PXS. A flow venturi is incorporated in each DVI nozzle to limit the loss of inventory from the Reactor Vessel in the event of DVI line break, particularly the double ended DVI line breaks. Each Hot Leg provides a connection to one of the two fourth stage ADS lines (part of ADS). The RCS details are shown in the system arrangement drawings, pages 3.1 and 3.2 of Appendix B. Detail descriptions of RCS components are discussed in Sections 3.2 to 3.10.

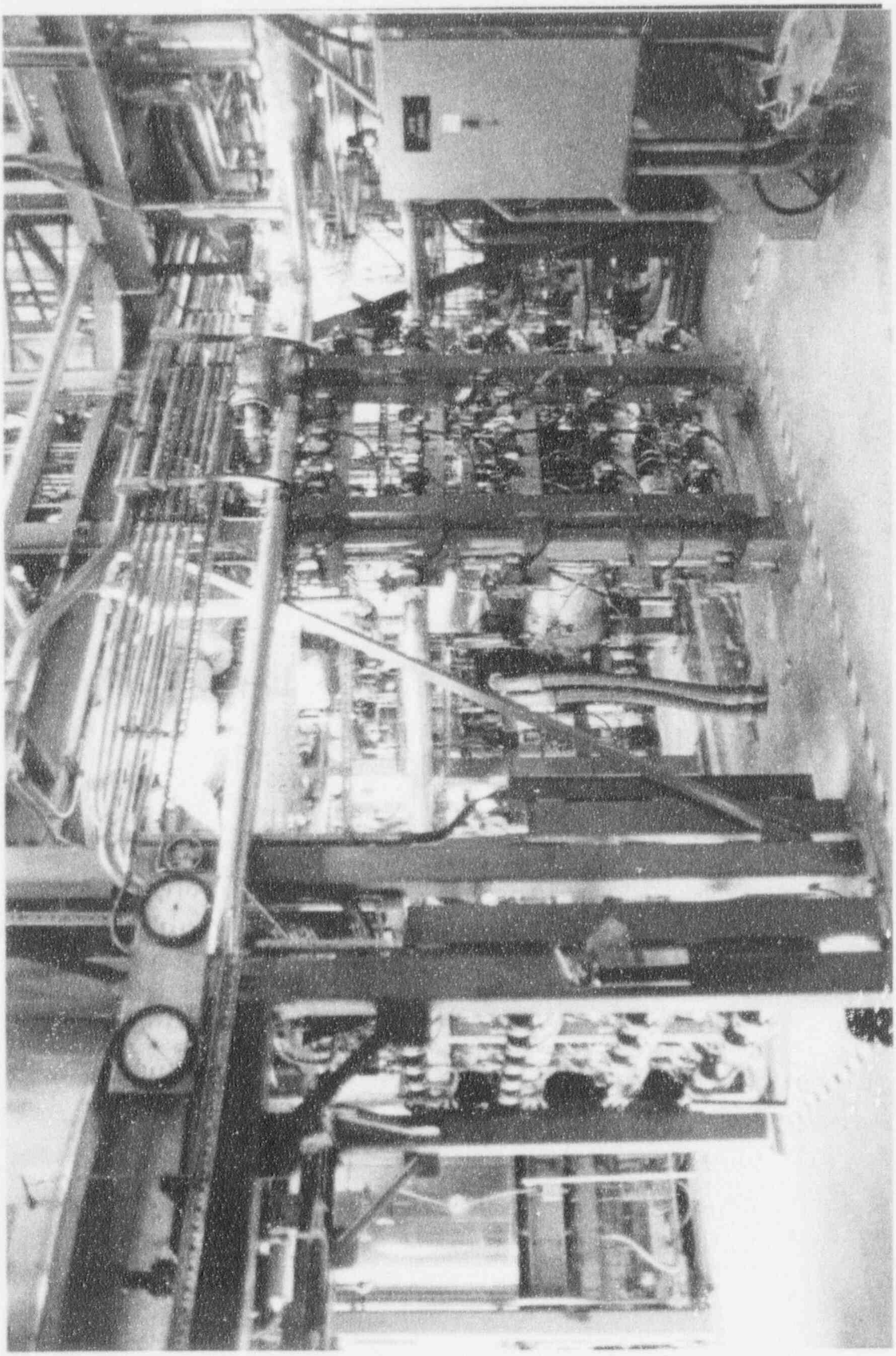


Figure 3.1 Reactor Vessel and Instrumentation/Power Lines

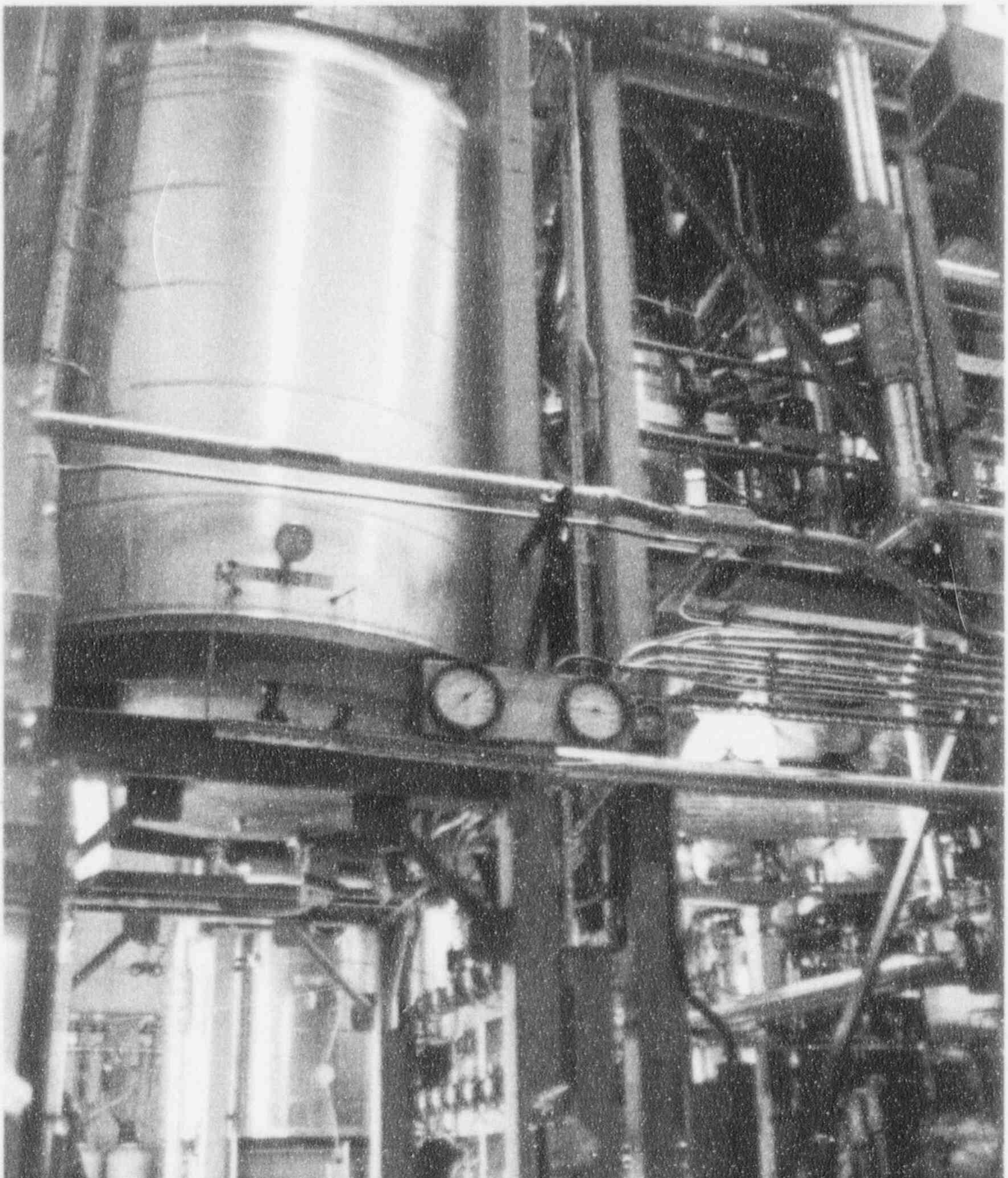


Figure 3.2 IRWST

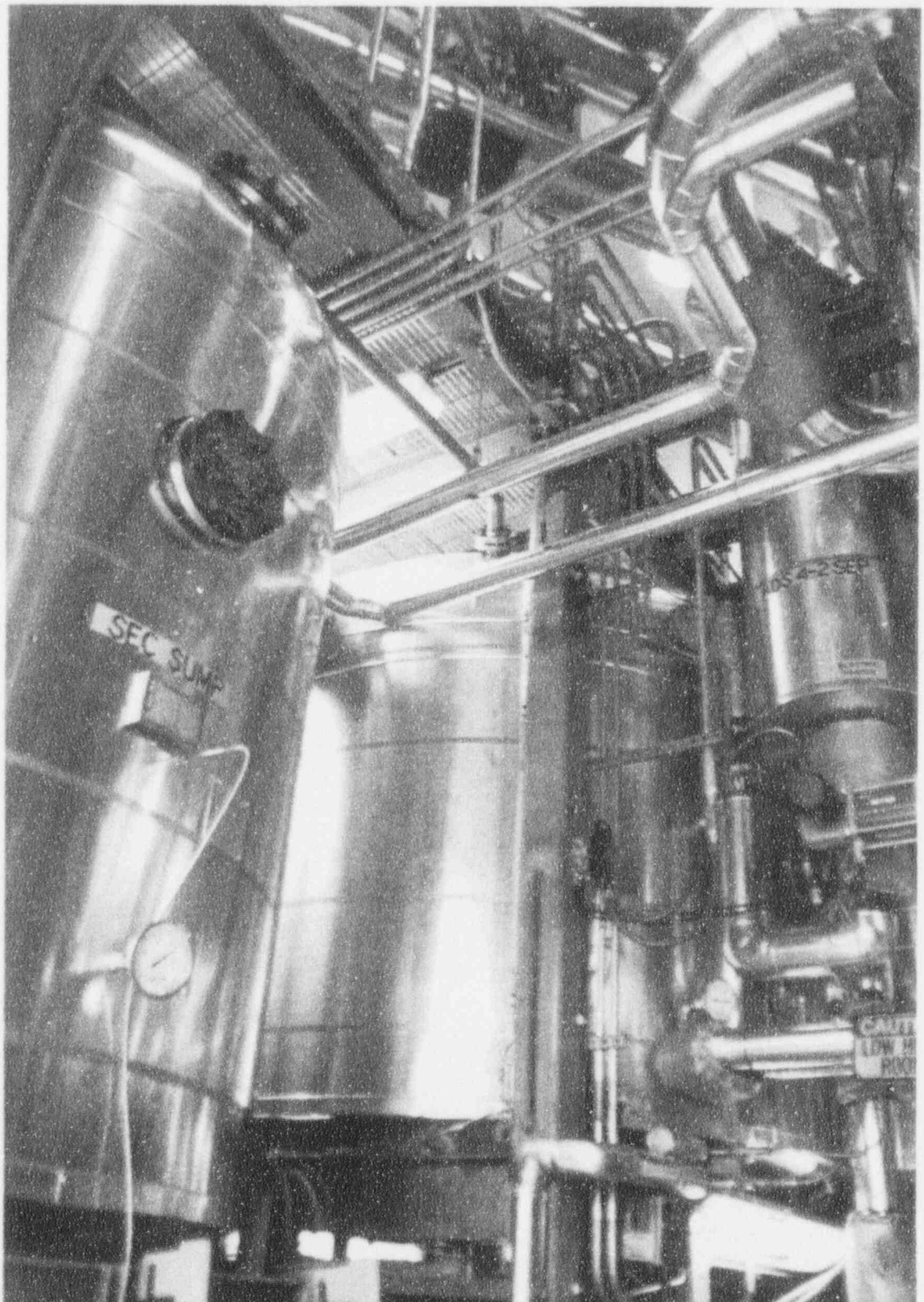


Figure 3.3 Primary and Secondary Sump Tanks

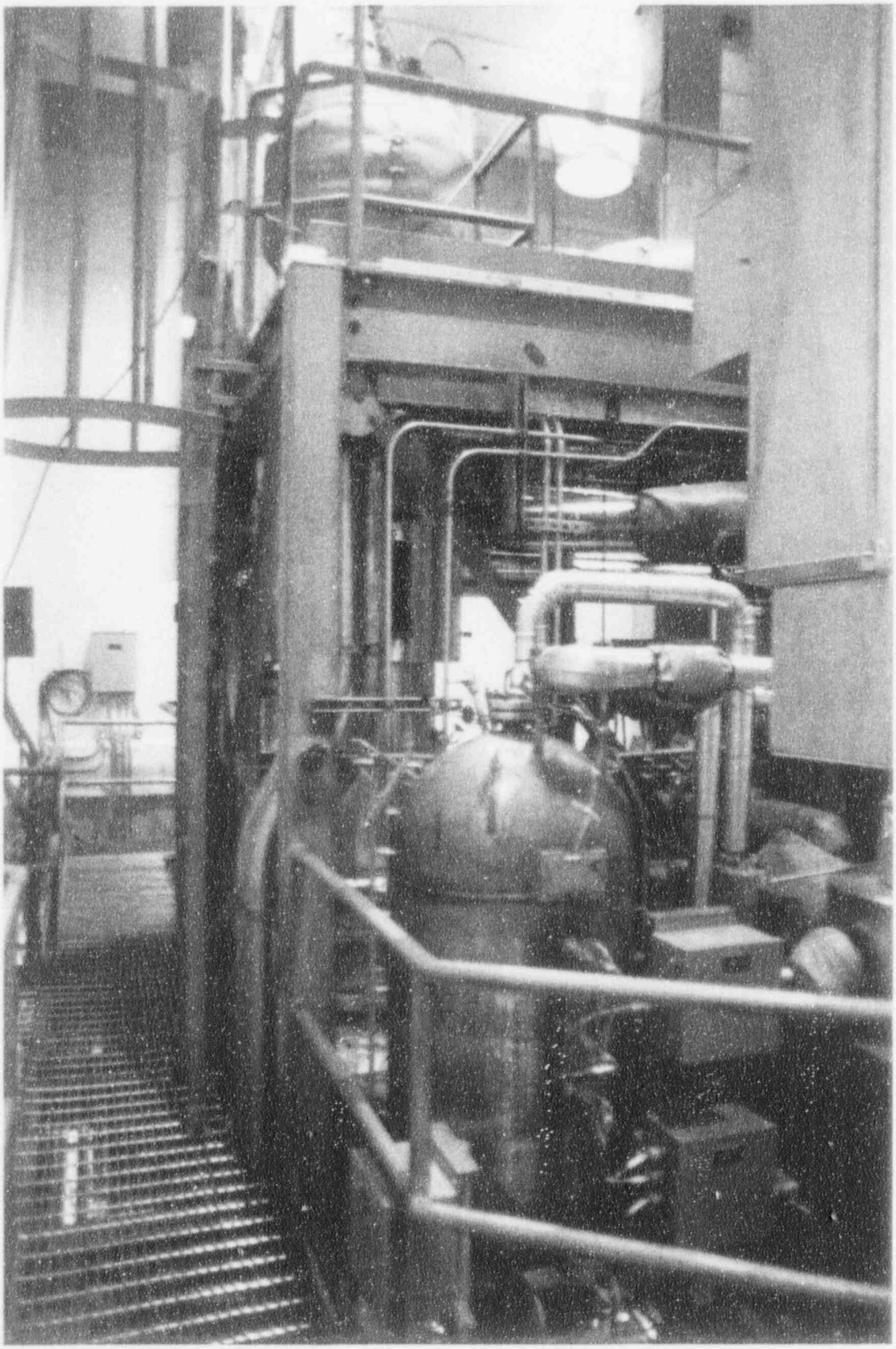


Figure 3.4 Upper Level (CMT in Foreground)

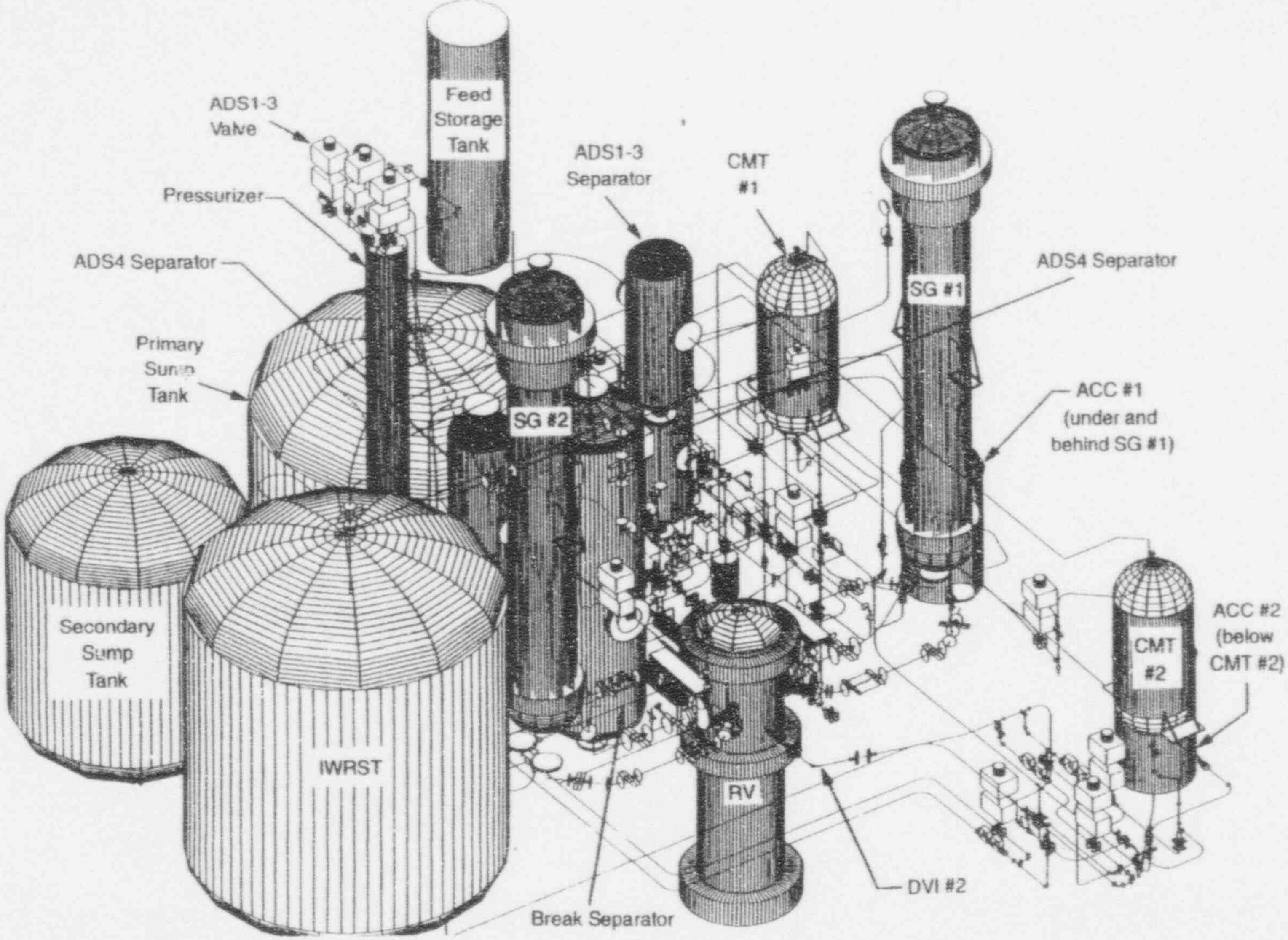


Figure 3.5 Isometric Sketch of Test Facility

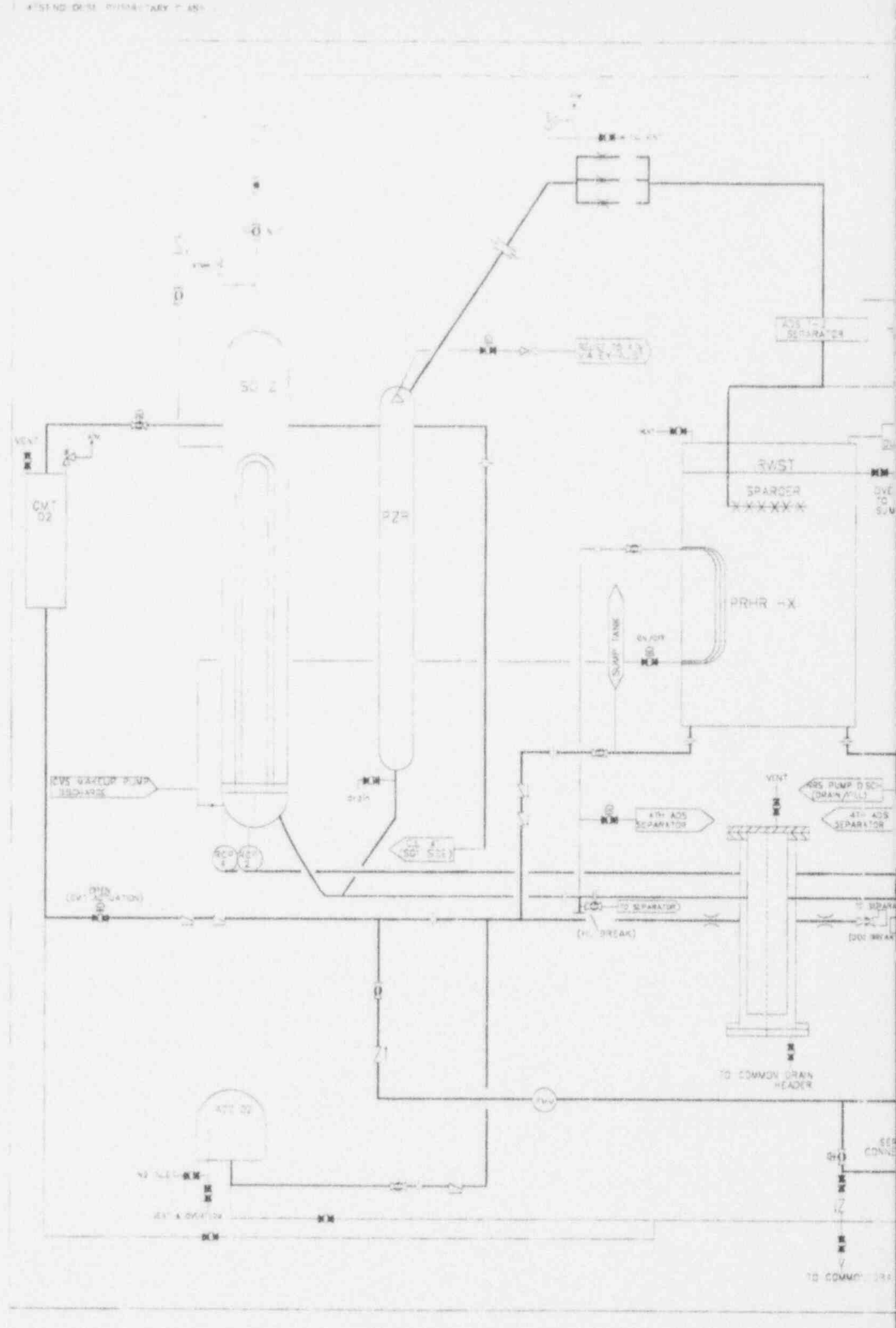
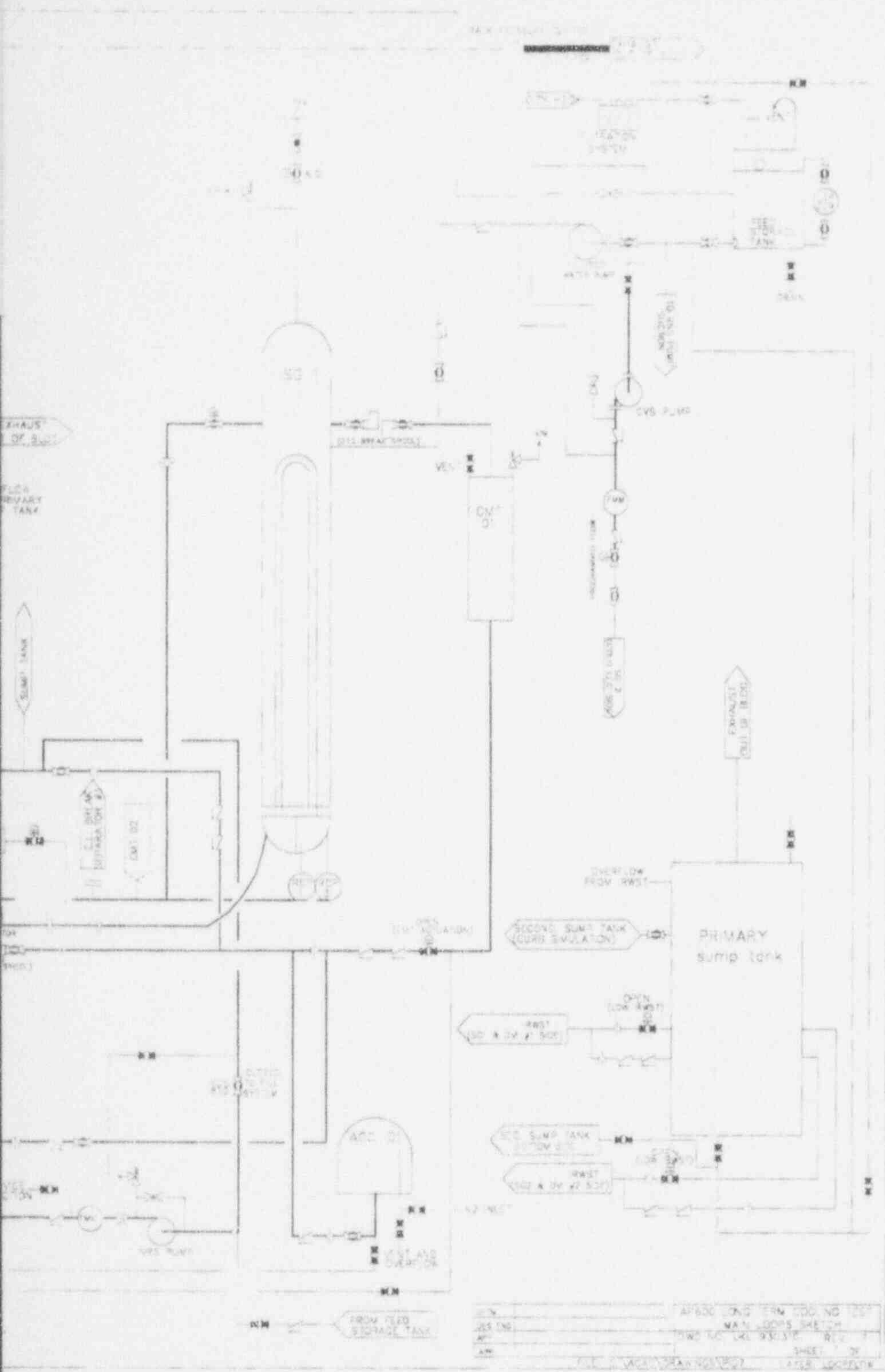


Figure 3.6 Simplified Flow Diagram of the Lo



w Pressure Integral Systems Test Facility

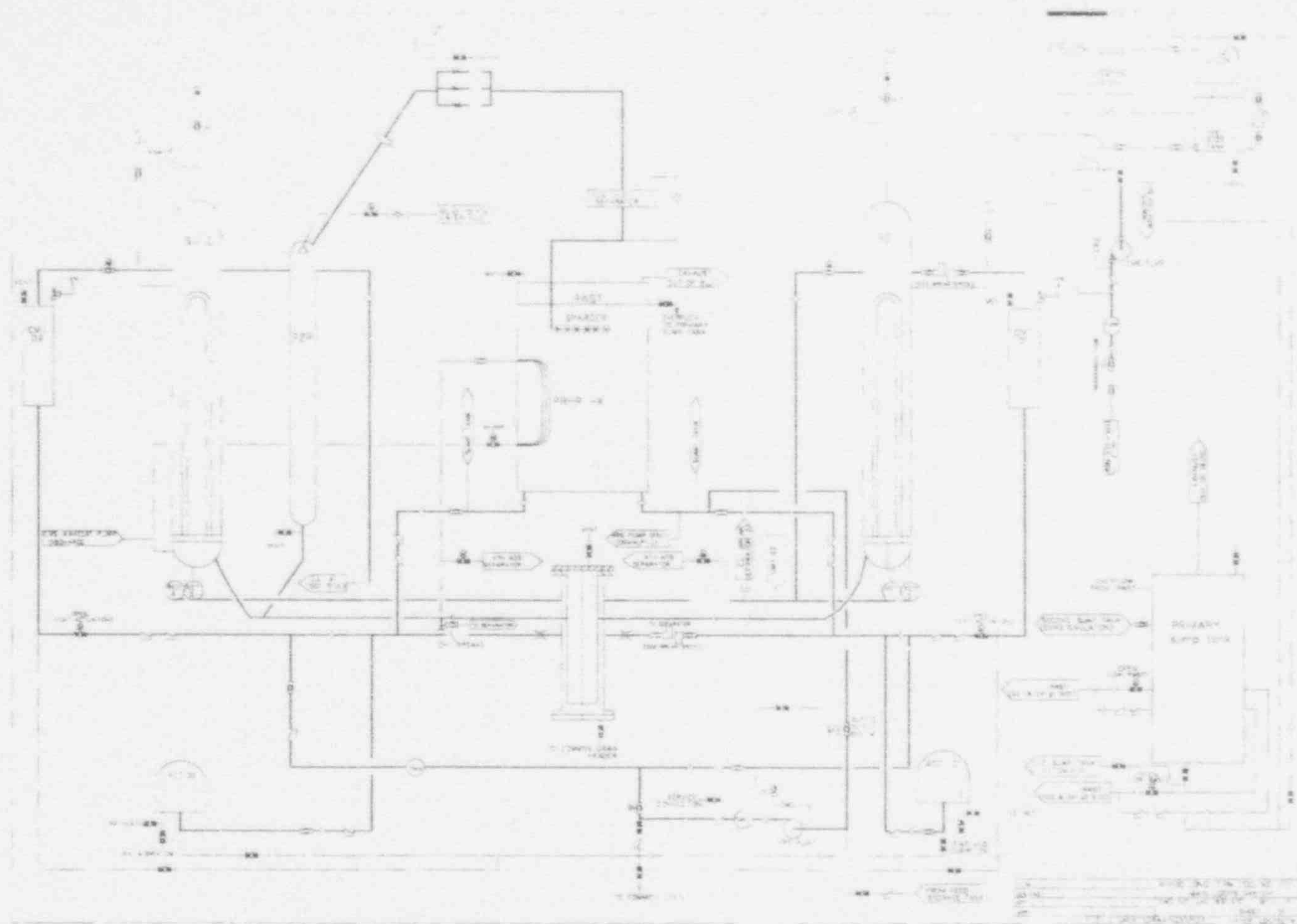


Figure 3.6 Simplified Flow Diagram of the Low Pressure Integral Systems Test Facility

3.1.2 Steam Generator System (SGS)

This test models the primary side of the SGS with two steam generators, one per primary loop. A simulated feedwater line is used for each steam generator to maintain proper steam generator water level. The steam produced in each steam generator is measured and exhausted to the atmosphere through a common diffuser and stack.

Proper AP600 SGS operations during LOCA transients are simulated in this facility. A drop in primary water level produces an "S" signal which shuts the feedwater supply and maintains SG secondary side pressure at its proper value. This control logic simulates that of AP600 and consequently provides proper boundary conditions for the transient behavior of the facility. A detailed description of the SGS is provided in Section 3.9.

3.1.3 Passive Core Cooling System (PXS)

The Passive Core Cooling System consists of two CMT's, two accumulators, one IRWST, one PRHR HX, and one ADS sparger and the associated piping and valves. A Separator (ADS1-3 Separator) is used to separate two phase flow into single phase steam and liquid to facilitate flow measurements. The test facility simulates the AP600 IRWST with a cylindrical tank with properly scaled water volume and height. It is located above the reactor core with two injection lines connecting to the two DVI injection lines-one per DVI injection line. Each IRWST injection line also communicates with the sump tank with inter-connecting piping and isolation valves. Venting of the IRWST to the Containment and overflowing of IRWST water to the sump are also simulated in the test model.

Two CMT's and two Accumulators are used in PXS. They are located at the opposite side of the pressurizer or the IRWST. One CMT and one ACC is connected to one DVI line while the other CMT and ACC are connected to the other DVI line. Both DVI lines enter the downcomer of the Reactor Vessel at the DVI nozzles. The PRHR HX is located inside the IRWST, using IRWST water as the cold reservoir. The inlet of the PRHR HX is connected to the PZR side hot leg, via a tee at the ADS4 line, and the outlet to the SG channel head at the cold leg side. Since the inlet is hot and the outlet is cold, water is circulated through this system by natural convection. The water volume and elevation of each CMT is properly scaled and modeled. They are elevated above the reactor vessel and the DVI lines. A line connecting the top of each CMT to its Cold Leg provides pressure balance between the RCS and the CMT. Therefore the CMT injects cooling water by its own elevation head. The Accumulators are also modeled with proper volume and height. However, they are pre-pressurized and therefore inject when RCS pressure is below the pre-selected ACC pressure.

The sparger is located inside the IRWST and is connected downstream to the ADS1-3 Separator. Its function is to distribute the ADS1-3 flow evenly into the IRWST.

Detail descriptions of PXS major components are provided in Sections 3.11 through 3.19.

The PXS, together with ADS, provides adequate reactor core cooling for the complete range of LOCA accidents. It also provides emergency core decay heat removal. In the event of a LOCA, the CMTs inject ambient water to the RV once the injection isolation valve opens. The Accumulators also inject water once the RCS pressure drops below the pre-set accumulator pressure. As the CMT water level drops, the ADS1 through ADS4 isolation valves open sequentially to depressurize the RCS. The opening of the 4th stage ADS valve would reduce the RCS pressure to equal the containment pressure, hence the IRWST would inject by its own elevation head. Finally, the sump would inject water to the RV once enough elevation head is established. This process, together with the Passive Containment Cooling System operation, provides long-term reactor core cooling.

Accurate, direct measurement of the two-phase flows vented from the system (simulated breaks, ADS flows) are difficult and expensive. A unique system, termed the Break and ADS Measurement System (BAMS), was designed specifically to measure these two-phase flows. BAMS is based on separating the two-phase flows into individual single phase flow streams which can be accurately measured with conventional instrumentation.

3.1.4 Automatic Depressurization System (ADS)

AP600 uses two 100%, fully redundant ADS1-4 trains. The test facility models both trains of ADS1-4 in the AP600 with only one train, using removable flow nozzles to match the flow characteristics.

The 1st stage, 2nd stage and 3rd stage of the ADS are arranged parallel to each other. Each stage consists of a pneumatically operated, full port ball valve and a flow nozzle. The ball valve simulates the isolation valve (gate) in AP600 and the flow nozzle simulates the flow control (globe) valve in AP600. The flow area is properly scaled and modeled for single train operation or double train operation. Therefore, two sets of flow nozzle will be used — one set for single train simulation and the other for double train simulation.

The first three stages of the ADS are connected to the top of the pressurizer. The discharge lines from the ADS1-3 valves are joined into one line which is connected to the ADS1-3 Separator and to the sparger inside the IRWST. These valves are opened by the logic controller. Once opened, the RCS pressure will drop and the flow flashes into two phase flow. This two phase flow is separated in the Separator with a swirl-vane separator and the liquid and vapor flows are measured to obtain the ADS total flow for mass and energy balance analysis. The separated flow streams are then recombined and discharged into the IRWST through the Sparger. Thus, the mass flow and energy flow from ADS1-3 into the IRWST are preserved.

Each train of 4th stage ADS is connected to the top of a Hot Leg. It consists of a pneumatically operated full port ball valve acting as the ADS4 isolation valve and a flow nozzle simulating the flow area in AP600. Again, two sets of flow nozzles are used in the test — one simulates 100% flow area and the other simulates 50% flow area. For those tests that require complete failure of an ADS4 train, the line is simply closed. In the AP600, the ADS4 line discharges into the containment. When the

ADS4 isolation valves open, the flow flashes into steam inside the containment. In the test, the ADS4 discharge flows to the ADS4 separator where the steam and liquid flows are separated. The steam flow is measured and exhausted to the atmosphere. The liquid flow is measured and directed to the Primary Sump Tank of the LCS. This two phase flow measuring scheme is part of the Break and ADS Flow Measurement System (BAMS) discussed in more detail in Section 3.2.1.

3.1.5 Lower Containment Sump (LCS)

The Lower Containment Sump in the AP600 consists of two volumes — normally flooded and normally non-flooded. The normally flooded volume consists of those compartments that would collect liquid break flow, ADS flow and other liquid flow leaking out of the AP600 inside the containment. For example, the compartments that house the Reactor Vessel or the Steam Generators are normally flooded. The normally non-flooded volume includes those compartments that do not collect any liquid flow. The only communicating path between the normally flooded volume and normally non-flooded volume is at the top of these compartments called the curb. In the test a cylindrical tank (Primary Sump Tank) is used to model the normally flooded volume. The normally non-flooded volume is modeled with another cylindrical tank identified as the Secondary Sump Tank. These two tanks are connected with a line at a level simulating the curb level in the AP600.

The Primary Sump Tank is designed to properly scaled volume and height. It includes sump injection lines injecting water into the DVI lines. These injection lines also communicate with the IRWST injection lines at properly scaled elevation and locations. The overflow from IRWST is also collected in this tank simulating the overflow path in the AP600.

The secondary sump is also designed to contain properly scaled water volume and height. It is connected to the Primary Sump Tank by a short length of 6 inch Sch. 40 pipe. This pipe is very short to minimize flow resistance since the flooded and non-flooded AP600 Containment volumes are only separated by the curb. The pipe also has a flange joint with a weir in between. The height of this weir models the curb level in the AP600.

Detail descriptions of LCS components are included in Section 3.15.

3.1.6 Normal Residual Heat Removal System (RNS) and Chemical and Volume Control System (CVS)

In the AP600, the RNS can be used to provide non-safety cooling water injection to the reactor core. In this case, the RNS pump takes suction from the IRWST and discharges it into the DVI lines. The delivered flow rate is a function of the RCS pressure. This process and its time-dependent flow are modeled in the test. The RNS pump in the test takes suction from IRWST at the properly scaled location and elevation and it discharges the flow to both DVI lines at properly scaled locations. These two lines are balanced so that equal flow can be delivered to each DVI line. The time-dependent flow

in the AP600 is also modeled and automatically controlled by the PID controller. Section 3.18 provides more details of the RNS components.

The makeup line in the AP600 CVS is modeled in the test. This line contains a pump taking suction from the feed storage tank and discharging to the Steam Generator #2 (Pressurizer side) channel head at the Cold Leg side. The makeup flow is scaled form AP600 makeup flow rate as a function of RCS pressure and is controlled automatically by the process controller.

3.1.7 Break and ADS Flow Measurement System (BAMS)

The mass and energy of the test facility, both on individual components and the overall system, must be maintained in order to properly simulate the long term cooling phenomenon in AP600. To do this the flow rate at various locations and equipment must be known. For those locations where a single phase flow exists, flow rate measurement is relatively simple and reliable. However, there exist some locations and equipment in the test facility with two-phase flows. Since direct measurement of two phase flow is not practical and is extremely expensive, an indirect method is used — the BAMS.

The BAMS system is uniquely designed for the test facility to measure two phase flow and energy indirectly. This system uses separators to separate the two phase flow into single phase liquid and single phase steam flows for direct flow rate and temperature measurements. This system also measures all break flows, i.e. LOCA, operations and inadvertent ADS operations. The heart of the BAMS consists of steam-liquid separators and the interconnecting pipes and valves to the various break sources, the primary sump tank, the ADS1-3 lines and the main steam header.

3.1.7.1 ADS1-3 Separator and Pipe Route

One separator is dedicated as the ADS1-3 moisture separator. It has one inlet and two outlets. Two phase flow (steam and water) form the ADS1-3 lines enter the ADS1-3 separator where the steam is separated from the mixture. The steam flows out of one outlet while the liquid drains down the other. These two lines are recombined at some distance downstream and are discharged into the IRWST via the sparger located inside the IRWST. To prevent the steam blowing through the liquid drain, a liquid loop seal is incorporated to the liquid drain line of the separator. Also, the steam and liquid lines are carefully sized such that, at full flow, the pressure drop from the steam outlet to the recombined common point is smaller than that from the liquid drain outlet to the same recombined point. This ensures the steam outlet pressure being less than the liquid drain line outlet pressure, hence, steam can only exit the dedicated steam line where it is measured by vortex flow meter and fluid vortex thermocouples.

The ADS1-3 Separator, the steam line and the liquid line, as well as the recombined line are all insulated to minimize heat loss to the atmosphere. Furthermore, both the Separator Tank and the steam line are heat traced to maintain a temperature of approximately 200°F to minimize non-prototypical steam condensation. Consequently prototypical quality is preserved. The liquid loop seal

is pre-filled with hot water at approximately 180°F prior to actual testing. All these features assure negligible energy flow to the atmosphere and proper energy transferred directly to the IRWST, as in the AP600.

3.1.7.2 ADS4 Separator and Pipe Route

Two ADS4 Separators are used — one for each 4th stage ADS line. The Separator connecting to ADS4 line from hot leg #1 (CMT side) is identified as ADS4 #1 Separator, and the other Separator is called ADS4 #2 Separator. ADS4 #2 Separator is sized to perform two functions — it serves to separate two phase ADS4 flow normally and to separate break flow for certain cases. ADS4 #1 Separator is designed to separate two phase ADS4 flow only, and it can handle 150% of normal ADS4 flow.

Each ADS4 separator separates the two phase mixture into single phase steam and single phase liquid for flow rate, pressure and temperature measurements. The steam exits of the top outlet nozzle while the liquid drains at the bottom outlet. Again, a loop seal is used in the liquid drain line to prevent steam blowdown through the liquid line. The steam line connects to a common steam header and the liquid line to the primary sump tank. This connection simulates the ADS4 operation process in AP600 where the steam flow rises to the containment wall and liquid drains to the sump.

Similar to the ADS1-3 Separator, the ADS4 Separators, the liquid lines and steam lines are all insulated to minimize condensation and heat loss. Also, the steam lines and separator are all heat traced to maintain a temperature of approximately 200°F and liquid line loop seal is pre-filled with hot water of approximately 180°F prior to actual testing.

3.1.7.3 Break Separator and Pipe Route

The following break simulations are tested:

- Small break at bottom of DVI line
- Double ended break at DVI line
- Small break at bottom of cold leg/CMT balance line
- Double ended break at cold leg/CMT balance line
- Small break at bottom of cold leg
- Small break at top of cold leg
- Small break at bottom of hot leg

The Break Separator is designed to receive two phase break flow from break source and separator steam and liquid for single phase flow pressure and temperature measurement. Again, the Separator and steam lines are heat traced and the loop seal is pre-filled with hot water to minimize heat loss and non-prototypical condensation.

In the event of double ended CMT/cold leg balance line break simulation, the Break Separator receives break flow from one end of the broken pipe. The ADS4 #2 Separator is used to receive break flow from the other end of the broken pipe, while ADS4 #1 Separator receives all ADS4 flow.

3.1.8 Instrumentation System

Instrumentation is provided to record the necessary data to calculate mass and energy balances for the test facility during transients simulating the accident events being investigated. Approximately 850 data channels are continuously recorded by the digital Data Acquisition System (DAS). Only conventional devices are used and they can be categorized as the following:

- Magnetic flow meters are used to measure single phase liquid flow rates
- Vortex flow meters are used to measure single phase steam flow rates
- Heated thermocouple phase switches are needed to indicate changes of phase, e.g. from single phase liquid to single phase steam, or vice versa and to provide local temperature measurements
- Thermocouples are used to measure fluid temperatures (TF) and component wall temperatures (WT)
- Heat flux meters are used to measure component wall heat dissipation rates (losses)
- Differential pressure cells are used to measure liquid levels
- Load cells are used to measure weights

The ranges for the instrumentation in the text of this report and in the Instrumentation List, Appendix D, are nominal values. For some tests, the ranges for several instruments were changed to provide more accurate data for the specific test conditions. The calibration ranges for the instrumentation are updated and included in each test report.

3.1.9 Orifices and Nozzles

Orifices or flow nozzles were used in critical lines to scale the line resistances in the Test Facility to the AP600. The bases for these devices are discussed in this section.

ADS1-3 Flow Nozzles

The test facility models both single and double trains of ADS1-3 lines in the AP600. This is accomplished by using an isolation valve in series with a flow nozzle in each of the ADS1-3 lines. The isolation valve simulates the gate isolation valve in AP600 while the flow nozzle simulates the globe control valve in the AP600. The flow nozzle models the proper flow area of the globe control valve in the AP600.

Proper scaling of the flow through the ADS1-3 model relief system requires that the quality of the flow be considered in sizing the nozzles. Since the mass flow through the nozzle depends upon the flow quality, two venturi-type flow nozzles, one for high quality flow and one for low quality flow, were designed. Sharp-edged orifice plates are not suitable for this application because since their discharge coefficients vary with Reynolds number leading to wide ranges in mass flow as the quality changes. The flow nozzles were be sized as follows:

- One set of flow nozzles for single train simulation with small break LOCA.
- One set of flow nozzles for double train simulation with small break LOCA.
- One set of the flow nozzles for single train simulation with large break LOCA.
- One set of flow nozzles for double train simulation with large break LOCA.

The sizes of these flow nozzles are tabulated in Table 7.5, Section 7.

<u>ADS4 Flow Nozzle</u>

Two types of flow nozzles are used in the test. The first type simulates 50 percent flow area of one AP600 ADS4 train and the second type simulates 100 percent flow area of one AP600 ADS4 train. Fluid similarity is the scaling basis.

Scaling Analysis requires that each line must be properly scaled to have proper fluid similarity. Among all scaling criteria, the pressure drop scaling ratio is an important criterion. The pressure drop ratio is [ ][a,b] Any line that does not meet this requirement must be fitted with an orifice plate to bring the pressure drop ratio to [ ][a,b] The AP600 line resistances used for this scaling were obtained from AP600 Safeguards Interface Data, Volume 1, NSSS, AP600 Doc. No. GWGL002, Rev. 0.

Table 7.4 lists the orifice plate sizes and locations. They are all sharp edge type orifice plates built to ISA standard and are sized to meet the pressure drop scaling criteria.

DVI Venturi

The DVI venturi scaling criteria is the same as break hole (venturi) scaling criteria. This is because the DVI venturi is used to restrict the break flow out of the reactor vessel. The geometry of the DVI venturi is the same as AP600 and the throat diameter as well as the L/D ratio are properly scaled.

3.2 Reactor Vessel

The reactor vessel is a right circular cylinder with a flanged hemi-spherical upper head and a flanged flat bottom. It models the following regions:

- Lower plenum
- Core
- Upper plenum
- Upper head

The lower plenum region is the region below the lower core plate of the reactor core. The net water volume in the AP600 lower region is modeled in the test. Since the reactor vessel inside diameter is determined by the proper scaling of upper plenum volume, core region volume and special downcomer region scaling criteria, the lower plenum region cross sectional area is slightly distorted on the scaling basis.

3.2.1 Function

The Reactor Vessel (RV) is the smallest and most economical volume required to contain the reactor core, control rods, in-core instrumentation, and the necessary supporting and flow directing internals. The RV also provides the nozzles for the primary loop piping and the Direct Vessel Injection Lines.

3.2.2 Reactor Vessel Scaling Basis

The Reactor Vessel is scaled on the following bases:

- Height [ ]a,b,c
- Volume

The upper and lower plenum volumes are designed to this same scaling ratio. The inside diameter of the Reactor Vessel is determined by the gap required between the Core Barrel and this surface to

provide the required downcomer flow area. Application of the ASME Pressure Vessel Code, Section VIII, Fired Pressure Vessel, determined the minimum thickness of the reactor vessel.

3.2.3 Vessel Design/Dimensions

All components of the RV are fabricated of Type 304 Stainless Steel. The RV, which is designed to Section VIII, Division 1 of the ASME Pressure Vessel Code, consists of a [ ]^{c} diameter, right circular cylinder made by rolling and welding [ ]^{c} thick stainless steel plate, with a flanged hemispherical top and a flanged flat plate bottom. Both the bottom and the top flanges are [ ]^{c} flanges, which are machined to fit the O.D. of the shell and are seal welded. To facilitate assembly, the RV is fabricated in two sections, a [ ]^{c} lower section. These two sections are joined by welded [ ]^{c} slip-on flanges which were also machined to fit the outside diameter of the shell. The vessel is fitted with four cold leg, flanged nozzles (300 lb), two hot leg flanged nozzles (300 lb), and DVI flanged nozzles (300 lb). The bottom flange carries an endplate through which the heater tubes penetrate for connection to the electric power source. The bottom flange is fitted with a 1/2-inch thick Teflon insert to minimize the effect of the heat capacity of this flange. A 1/8-inch thick stainless steel plate retains the Teflon insert in this flange. Figure 3.6 is a sketch showing the arrangement of the Reactor Vessel and its internals. Drawings for the RV are presented in Appendix B, pages 2.1 to 2.73.

3.2.4 Instrumentation

Thirty-three Type K thermocouples (1/4 inch diameter, Type 304 stainless steel sheathe) are installed in the RV to measure both wall and fluid temperature. Twenty-one differential pressure cells are connected to the various fluid volumes (upper plenum, lower plenum, downcomer, etc.) to measure liquid levels and eleven differential pressure cells measure pressure gradients. Specific instrument identifications and locations are tabulated in Appendix D and are shown on the P&IDs.

3.3 Rod Bundle

3.3.1 Rod Bundle Function

The function of the rod bundle is to furnish heat to the primary coolant in the RV to simulate the decay heat released by the AP600 following a plant trip or plant shutdown.

3.3.2 Rod Bundle Scaling Basis

The power scaling ratio for the Rod Bundle is [ ]^{a,b} and the power density scaling ratio is [ ]^{a,b} Since the maximum electrical power available at the test facility is [ ]^{a,b}, the Rod Bundle at this power and with the power scaling factor of [ ]^{a} simulates the AP600 decay heat at [ ]^{a} of full core power. This decay power occurs about 70 seconds after the reactor is shut down; therefore, the heat input from the core during this short period is not fully modeled. Most of the reactor transient tests will be performed with the heater power at [ ]^{a} which is equivalent to a decay heat power of about [ ]^{a} of full power.

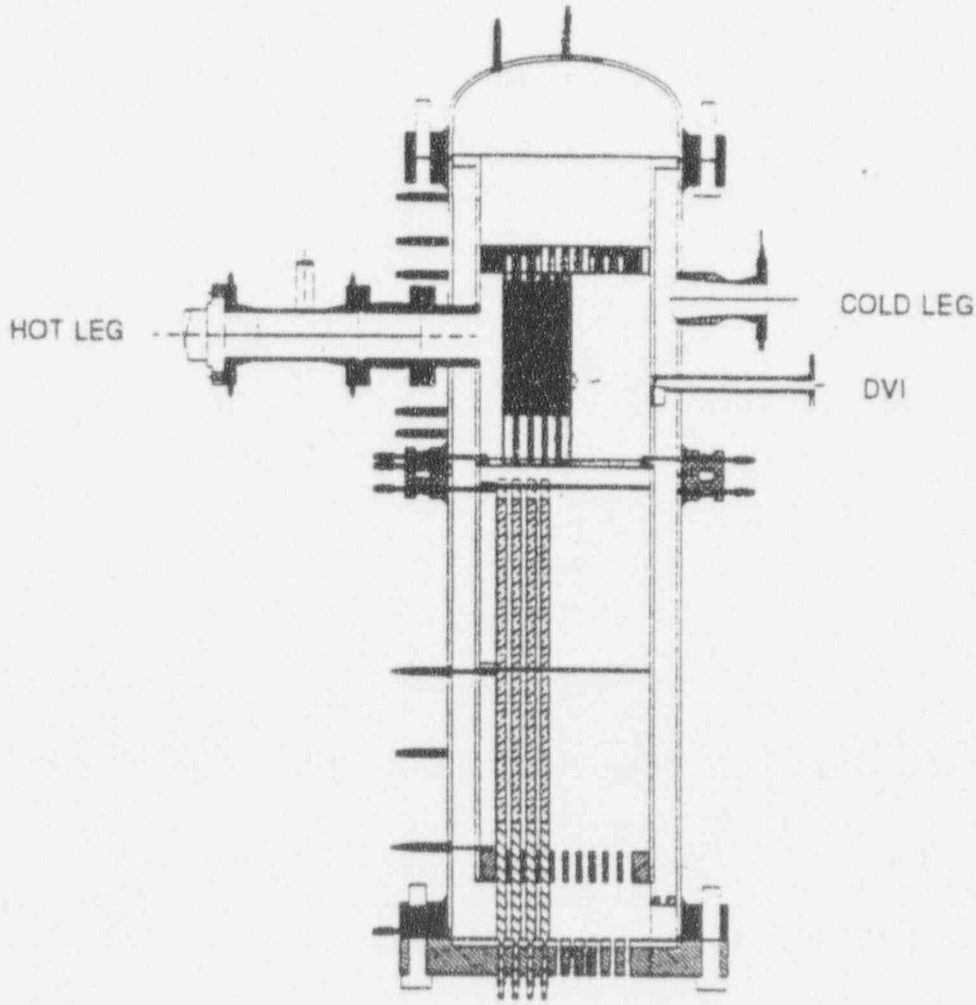


Figure 3.2-1 Reactor Vessel and Its Internals

The Rod Bundle heaters were programmed to follow the calculated decay heat power starting at 600 kW. The programmed Rod Bundle power is correlated with the time after reactor shutdown in Table. 3.3-1.

3.3.3 Rod Bundle/Heater Description

The Rod Bundle consists of 48 Type 304 stainless steel clad heaters, each with a maximum power of 15 kW. The 1-inch diameter heater rods are 60-inches in overall length, with a 36-inch heated length and a wall thickness of 0.061-inch. Power is skewed to provide higher heat fluxes at the top of the core by means of the resistance heater coil winding density. The power produced in each six inch incremental length of each heater rod (beginning at the bottom, i.e., the end closest to the electrical and thermocouple leads) is:

Section	Heated Length, Inches	Power, Watts	Heater Wire Size, AWG No.	Heater Length, Inches
1	6	623	31	55 1/2
2	6	1758	28	39 1/4
3	6	2697	27	32 1/2
4	6	3373	26	32 1/2
5	6	3644	26	30 1/2
6	6	2905	26	37 3/4
Total	36	15000		

A section of the heater with reduced diameter of 0.5-inch passes through the lower flange and is sealed by a Swagelok fitting. Key characteristics of the Rod Bundle are summarized in Table 3.3-2. Page 2.60a of Appendix B is the drawing showing the details of the heater rods.

Materials used in the heated section and their available pertinent physical properties are:

Electrical Insulation:	Thermal Conductivity Btu/°F in-ft^2	Specific Heat Btu/lb°F
80% Boron Nitride 20% Magnesium Oxide	95	0.306
Resistance Wire: 80% Ni 20% Cr (ASTM B-344)	—	—
Conductor: 10 Ga Nickel (ASTM B-160/E-39)	—	—

3.3.4 Rod Bundle Instrumentation

Type K thermocouples are installed in two groups of the heater rods. One group of heater rods does not have thermocouples. These groups and the location of the thermocouples are tabulated below:

Heater Group	No. of Heaters	Location of Thermocouples (inches from lower end of heated zone)
H-A	32	None
H-B	10	15, 21, 27, 33
H-C	6	3, 9, 21, 27

The leads for these thermocouples exit the rod at the lower end, together with the electrical power leads, after the Swagelok pressure seal. These thermocouples are provided as overtemperature protectors and are also recorded by the Data Acquisition System.

Core coolant temperatures are measured by five thermocouple rods, each carrying three Type K thermocouples. Diagrams showing the heaters and thermocouple rod arrangement and the thermocouple locations are shown on Pages 1.5 through 1.7 of Appendix B.

TABLE 3.3-1
ROD BUNDLE HEATER POWER AFTER REACTOR SHUTDOWN

Time After Shutdown (Sec.)	Calc. Power (kW)
0.5	600
0.75	600
1	600
2	600
3	600
4	600
5	600
7.5	600
10	600
20	600
30	600
40	600
50	600
75	600
100	600
140	600.0
200	523.7
300	455.4
400	414.8
500	386.7
750	341.6
1000	313.4
2000	255.7
3000	297.3
4000	209.2
5000	196.2
7500	174.1
10000	160.9
20000	132.0
30000	117.6
40000	106.3
50000	101.6
75000	90.5
100000	83.4

TABLE 3.3-2 ROD BUNDLE CHARACTERISTICS		
	Metric	English
Number of Heater Rods		
Maximum Power per Rod		
Rod Diameter		
Heated Length		
Heated Surface Area		
Rod Cross-Sectional Area		
Heated Volume		
Total Heated Surface Area		
Total Heated Cross-Sectional Area		
Total Heated Volume		
Heater Rod Pitch		
Pitch/Diameter Ratio		
Subchannel Flow Area		
Hydraulic Diameter		
Average Rod Heat Flux		
Radial Power Peaking Factor		
Axial Power Peaking Factor		
Hot Channel Factor		

3.4 Reactor Internals

3.4.1 Reactor Internals Functions

The Reactor Internals have several functions related to core support and fluid flow. Specifically, the following components of the Reactor Internals provide these functions:

Core Barrel - separates core flow from downcomer.

Lower Core Plate - supports the fuel rods and distributes the flow.

Upper Core Plate - retains fuel rods in axial position and provides support for the upper internals

Upper Support Plate - supports upper head components

Upper Internals -provide guide tubes for the insertion of the in-core instrumentation and control rods.

Downcomer - provides flow path for cold leg fluid from the cold leg nozzles to the core inlet plenum.

3.4.2 Reactor Internals Scaling Basis

The Core Barrel was sized to maintain the total core volume scaling ratio at [ ][a] and the length ratio of [ ][a] The Upper and Lower Core Plates and Reflectors were sized to provide the heated volume of the model at these same ratios. In order to limit the stored energy in the reflector region to the same magnitude as that in a full size core, the reflectors are made of Purocast® XR High Alumina Castable ceramics manufactured by National Refractories and Minerals.

The thicknesses of the Upper and Lower Support Plates were scaled according to the length ratio and designed to provide adequate support of the simulated core. The Upper Support Plate flow characteristics were scaled to provide appropriate liquid-steam interactions during liquid drainage through this component following a depressurization transient. Table 3-2 summarizes the Upper Support Plate scaling ratios and dimensions.

The total flow volume at the Upper Core Plate is scaled to a ratio of [ ][a] and the thickness to a ratio of [ ][a] Therefore, the flow area is properly scaled to a ratio of [ ][a]

The Upper Internals provide the guide tubes for the In-Core Instrumentation and control rods and are scaled [ ][a] for length. The flow volume is scaled [ ][a]

The downcomer is scaled to a height ratio of [ ]^{a} A flow area scaling ratio of [ ]^{a} was found to be required to prevent flooding in the downcomer. Therefore, the theoretical scale ratio of [ ]^{a} was modified for the component. The downcomer length to gap ratio is 1:1. Table 3.3 summarizes the resulting downcomer scaling ratios and dimensions.

3.4.3 Reactor Internals Design/Description

3.4.3.1 Core Barrel

The Core Barrel is composed of two sections of 20-inch Sch. 30, Type 304 stainless steel pipe [ ]^{c}, flanged together at the center. The top section is [ ]^{c} and the bottom section is [ ]^{c} long. The Top Barrel Plate is a ring [ ]^{c} O.D., welded to the top of the core barrel. This ring is sealed to the inside diameter of the Reactor Vessel by two radial O-rings installed on outside diameters, thus permitting vertical expansion while limiting leakage. This plate includes ten 1/4-inch tapped holes which may be blocked with screws to adjust the leakage flow for the downcomer volume to the upper plenum. To obtain the desired [ ]^{c} bypass flow, it was found during cold testing that all of these holes were needed. The loss coefficients (K) measured for one tapped hole are [ ]^{a,b} (upward flow) and [ ]^{a,b} (downward flow).

The bottom of the lower core barrel is welded to the lower core support plate. The lower core support plate, which is [ ]^{a} thick, is drilled with [ ]^{a,b} and [ ]^{c} diameter holes for the heater rods. This plate is supported from the reactor vessel on four pads, 90° apart, on Belleville washers retained by a plunger that passes through the lower core support plate and the support pads.

3.4.3.2 Reflectors

The Reflectors are simulated by cast ceramic inside a cylindrical shell that fits inside the barrel. A stainless steel liner is welded to the shell to provide the stepped cruciform flow volume for the simulated core. The reflectors are fabricated in two sections, separated horizontally at the simulated core mid-plane to facilitate assembly. The reflector sections are secured by four tie rods that pass through the two reflector sections and connect the upper reflector plate with the lower core support plate.

TABLE 3.3-3 UPPER CORE SUPPORT PLATE PERFORATION SCALING RATIO AND DIMENSIONS				
Parameter	**Ideal Scaling Ratio**	**AP600**	**Low Pressure Integral System Test**	
			Ideal	**Actual (TBM)**
Hole Diameter				a,b
Number of Drain Holes				
Drain Hole Flow Area				
*Additional Flow Area				
Total Flow Area				

*Additional flow area is modeled using four 0.83 in (2.11 cm) diameter holes.

TABLE 3.3-4
DOWNCOMER SCALING RATIOS AND DIMENSIONS

Parameter	Ideal Scaling Ratio	AP600	Low Pressure Integrated System Test	
			Ideal	Actual (TBM)
Outside Diameter of Core Barrel				a,b
Inside Diameter of RV				
Average Annulus Circumference				
Annulus Gap				
Downcomer Length				
Downcomer Length to Gap Ratio				
Core Barrel Inside Diameter				

*Standard pipe used.

3.4.3.3 Grid Ring

A gridded support for the heater rods consists of 0.109-inch thick by 0.19-inch high bars welded to form an egg crate. Four bolts are used to attach the grid ring to the core barrel at the joint between the upper and lower core barrel. Pages 2.49, 2.50 and 2.51 of Appendix B show the details of the grid ring. Figure 3.4-1 is a photograph showing the rod bundle being installed in the gridded support.

3.4.3.4 Upper Internals

The upper internals are simulated by forty-one guide tubes each consisting of a rod [ ]^{c} with a one-inch long threaded lower end. The threaded section screws into the upper core support plate. The guide tube top consists of a [ ]^{c} Page 2.65 of Appendix B illustrates the upper guide tube.

3.5 Hot Leg Piping

3.5.1 Function

The function of the Hot Leg piping is to provide a flow path from the outlet nozzle of the reactor vessel to the inlet to the steam generator. It also provides connections to the pressurizer surge line and to the fourth stage of the ADS and the PRHR.

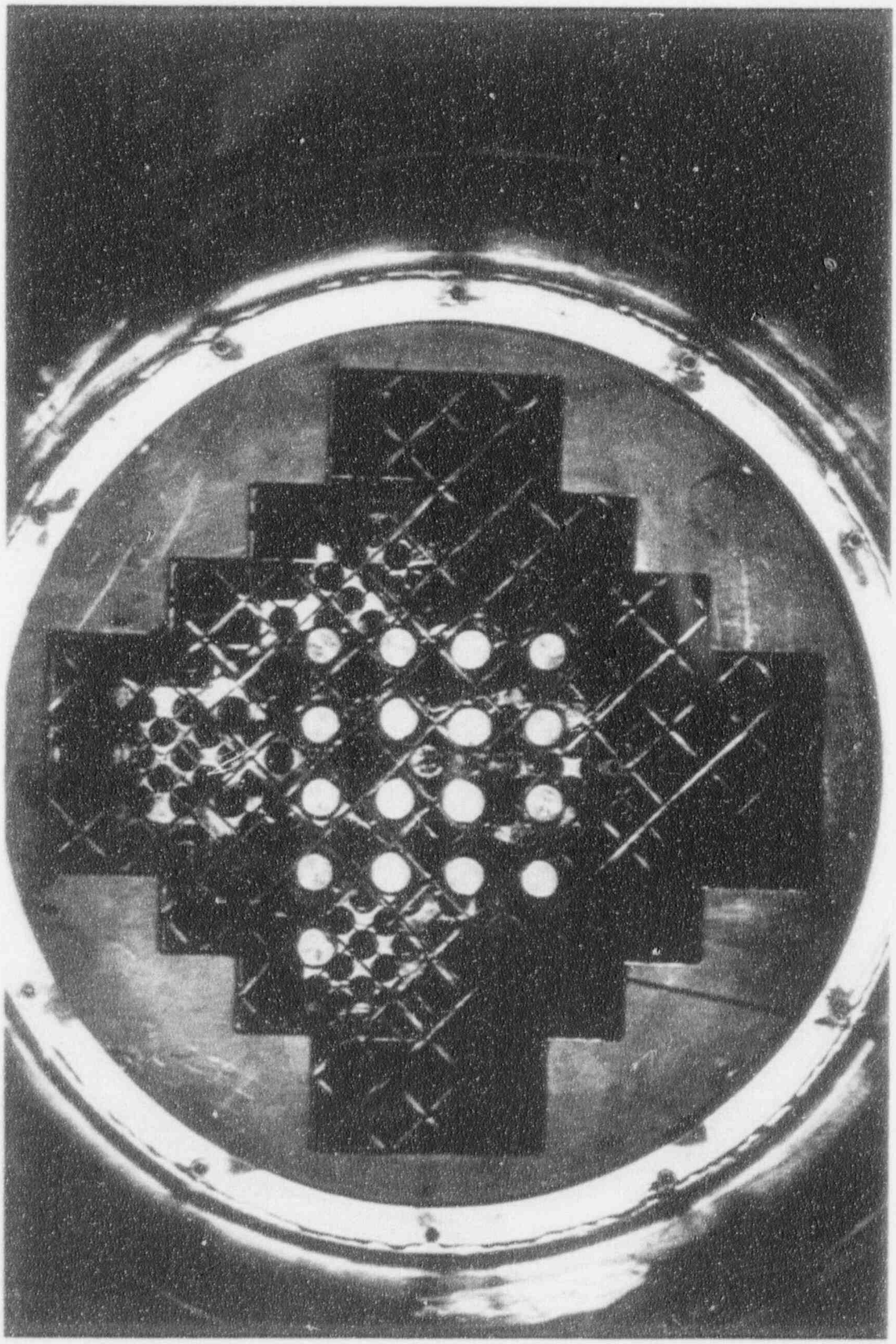


Figure 3.4-1 View from Top of Reactor Vessel Showing Partial Installation of Rod Bundle

3.5.2 Hot Leg Scaling Basis

The length of the Hot Leg piping was scaled [ ][a] based on the length scaling factor selected for the test facility. The velocity scaling factor for this length scaling factor is [ ][c] The minimum diameter ratio was calculated to be [ ][a,b] based on a surface roughness of e/d = 1×10^{-5} and a Reynolds number of 1×10^{7}. This minimum diameter ratio is necessary to ensure that distortions to the flow phenomena from the surface roughness do not occur. The actual diameter ratio selected was based on Froude number scaling and meets the minimum diameter requirements. The scaling ratios for the Hot Leg Pip.ng are:

Length Scaling Ratio (Vertical Piping, Elbows, and Inclined Lines)	a,b
Length Scaling Ratio (Horizontal Piping)	
Pipe Diameter Ratio	
Pipe Flow Area Ratio	
Pipe Volume Scaling Ratio	
Velocity Ratio	
Residence Time Scaling Ratio	
Mass Flow Rate Ratio	

* This ratio is necessary to preserve the bending radii for elbows and the [ ][a,b] ratio for the heights of the steam generator.

3.5.3 Hot Leg Piping Design/Description

Each primary loop has an identical Hot Leg made of [ ][c] Sch. 40 stainless steel pipe with an inside diameter of [ ][c] The piping is a straight run in the vertical plane with upward bend, [ ][c], between the Reactor Vessel and the Steam Generator. The vertical rise of the Hot Leg (centerline of the horizontal run to the centerline of the Steam Generator nozzle) is [ ][c] A flanged spool piece is provided at the Reactor Vessel nozzle.

The Hot Leg piping arrangement is shown on pages 3.1 and 3.2, and the as-built drawings are on pages 5.76 and 5.77 of Appendix B.

3.5.4 Instrumentation

Each Hot Leg is provided with th: following instrumentation:

- 1 - Differential pressure (0 - 25 inches water)
- 1 - Heat flux meter (C - 10 Btu/hr-ft^2)
- 1 - Heated thermocouple (fluid phase) (70 - 550°F)
- 1 - Differential pressure (liquid level)
- 1 - Differential pressure (liquid level) (0 - 30 inches of water)
- 1 - Pressure transducer (0 - 600 psig)
- 1 - Thermocouple (40 - 450°F)
- 1 - Thermocouple (40 - 550°F)

3.6 Cold Leg Piping

3.6.1 Cold Leg Function

The Cold Leg provides the coolant flow conduit from the outlet coolant nozzles of the steam generator to the coolant inlet nozzles of the reactor vessel. It also provides a connection for the line to the Core Make-up Tank (CMT).

3.6.2 Cold Leg Scaling Basis

The bases and scaling ratios for the Cold Leg piping are the same as those presented for the Hot Leg piping in Section 3.5.2.

3.6.3 Cold Leg Piping Design/Description

Each of the two reactor coolant loops has two Cold Legs, each made of [ ][a] inch Sch. 40 stainless steel pipe. The Cold Legs, which are entirely horizontal, are fitted with 300 lb. 45° flanged elbows at each end and a horizontal spoolpiece with 300 lb. flanges. One end of each Cold Leg is connected to the discharge flange of the reactor coolant pump and the other end is connected to the coolant inlet flange of the Reactor Vessel. The Cold Leg arrangements are shown in pages 3.1 and 3.2, and the as-built drawings for the four cold legs are on pages 5.65 to 5.70 of Appendix B.

3.6.4 Instrumentation

The following instrumentation is provided for each of the four cold legs:

- 2 - Differential pressure (0 - 25 inches of water)
- 1 - Magnetic flowmeter (with transmitter) (0 - 250 gpm)
- 1 - Heat flux meter (0 - 10 Btu/hr-ft^2)
- 1 - Heated thermocouple (liquid phase) (70 - 550°F)
- 1 - Differential pressure (liquid level) (0 - 25 inches of water)
- 1 - Thermocouple (fluid temperature) (70 - 450°F)
- 1 - Thermocouple (metal temperature) (70 - 550°F)

3.7 Pressurizer Surge Line

3.7.1 Pressurizer Surge Line Function

The Pressurizer Surge Line provides the flow path between the reactor flow system and the pressurizer to transmit the pressures from the pressurizer to the flow system and to transfer fluid during volume changes.

3.7.2 Scaling Basis

The Pressurizer Surge Line was scaled to a length ratio of [ ][a] and a diameter ratio of [.][a] The diameter ratio is larger than the rest of the primary loop piping [ ][a] in order to provide the proper scaling ratio for the flow pattern transitions and for flow resistance in the bends which match the AP600 line. The key thermal hydraulic characteristics that are scaled are from resistance, elevation, length, and flow area.

3.7.3 Design/Dimensions

The Pressurizer Surge Line consist of [ ][a] Sch. 40 Type 304 stainless steel piping which connects hot leg 2 with the bottom of the pressurizer. The line is provided with two sets of 300 lb. flanges to facilitate assembly. The piping is arranged with six 90° bends to form a full 360° loop with a vertical line leading to the bottom of the pressurizer. As-built drawings of the pressurizer surge line are provided on pages 5.78 and 5.79 of Appendix B.

3.7.4 Pressurizer Surge Line Instrumentation

The Pressurizer Surge Line is fitted with the following instrumentation:

- 6 - Differential Pressure (Liquid level) (3 - 0 to 20 inches of water; 1 - 0 to 5 inches of water; 1 - 0 to 10 inches of water, 1 - 0 to 40 inches of water)
- 1 - Differential Pressure (0 to 1 inch of water)
- 1 - Heat flux meter (0 to 100 Btu/hr.-ft^2)
- 3 - Heated thermocouple (fluid) (2 - 0 to 100°F, 1 - 70 to 500)
- 2 - Pressure Cell (1 - 0 to 500 psig; 1 - 0 to 400 psig)
- 2 - Thermocouple (fluid) (70 - 450°F)
- 1 - Thermocouple meter (70 - 450°F)

3.8 Pressurizer

3.8.1 Function

The Pressurizer provides the pressure control for the Reactor Coolant System. The pressure in the pressurizer is maintained at the required level by modulating the power input to the pressurizer heater. The control pressure is transmitted to hot leg 2 through the Pressurizer Surge Line described in Section 3.7. The Pressurizer also must provide degassing for the primary coolant.

3.8.2 Pressurizer Scaling Basis

The pressurizer is scaled to ratios based on property similitude for the primary system tanks; these are summarized in Table 3.8-1 and 3.8-2.

3.8.3 Pressurizer Design/Dimensions

The pressurizer consists of a shell of [ ][a] Type 304 stainless steel pipe with [ ][a] Sch. 40 welded pipe caps at each end and an overall length of [ ][a] inches.

The [ ][c] inch pressurizer surge line is butt-welded to the bottom weld cap. Four electrically heated [ ][c] diameter rods, with an active length of [ ][c] are installed through the bottom weld cap and are sealed by Swagelok fittings. Each heater rod is rated at [ ][c] at full power. A [ ][a] Sch. 80 line with a 90° elbow is provided on the top weld cap near the outer diameter for connection to the Automatic Depressurization System (ADS).

TABLE 3.8-1
PRESSURIZER SCALING RATIOS

<u>Geometry</u>	[ ]c
Length Scaling Ratio	
System Diameter Scaling Ratio	
Area Scaling Ratio	
Volume Scaling Ratio	
<u>Flow</u>	
Velocity Scaling Ratio	
Mass Flow Rate Scaling Ratio	
<u>Residence Time</u>	
Time Scaling Ratio	
<u>Power</u>	
Power Scaling Ratio	
Power Density Scaling	

TABLE 3.8-2
PRESSURIZER SCALING RATIOS AND DIMENSIONS

Parameter	Ideal Scaling Ratio	AP600	Low Pressure Integral Systems Test		
			Ideal	Actual	
Pressurizer Volume					a,b
Shell Inside Diameter					
*Overall Internal Length					
Immersion Heater Power					
Wall Thickness					
Mass of Pressurizer Cylindrical Shell					
**Stored Energy Release					

* Test Model uses elliptical end caps instead of hemispherical heads.

** Assumes full depressurization transient with uniform metal temperatures.

A one-inch diameter vent line is connected through a blind 300 lb. flange with a high pressure seal located at the center of the top weld cap. The vent line is controlled by a 3/4 inch, electrically operated valve with a manually operated globe type, shut-off valve.

Page 4.5 of Appendix B is the drawing showing the details of the Pressurizer.

3.8.4 Pressurizer Instrumentation

The following instrumentation is installed in the pressurizer:

- 1 - Heat flux meter (0 - 100 Btu/hr-ft^2)
- 1 - Electric power (0 - 15 kW)
- 1 - Differential pressure (liquid) (0 - 120 inches of water)
- 1 - Pressure cell (100 - 400 psig)
- 1 - Pressure cell (0 - 500 psig)
- 2 - Thermocouple (fluid) (70 - 450°F)
- 3 - Thermocouple (fluid M?) (70 - 450°F)
- 4 - Heater thermocouples (70 - 450°F)
- 1 - solenoid-open (spray line)
- 1 - Limit switch-closed (spray line)
- 1 - Limit switch-open (spray line)

3.9 Steam Generators

3.9.1 Function

The steam generators transfer heat from the primary coolant and generate steam from the secondary coolant. The steam generators of the test model must meet the following additional functional requirements:

- Each of the test model Steam Generators must be capable of removing 360 kW of thermal energy from the primary fluid while single-phase natural circulation conditions exist on the primary side. This represents a combined energy removal rate for both Steam Generators equivalent to 3.8% of scaled decay power, which is the maximum rated power of the core heaters. The actual maximum heat rejection by the Steam Generators will be slightly less than the core heater input because of system heat losses.

- To properly model the initial conditions of SBLOCA scenarios, the test model steam generators must be capable of removing the core energy deposited in the primary fluid while operating with secondary side pressures that are very close to primary side pressures. This requires that the tube surface area be sufficiently large to permit heat transfer with small temperature differences between the primary and secondary sides.

3.9.2 Steam Generator Scaling Basis

The test model steam generators are scaled on ratios based property similitude as summarized in Table 3.9-1. In addition, to maintain the time scaling for the facility, the steam generator dry out time ratio must be [ ]^c

Since the tube diameter and pitch in the model are the same as in the AP600 steam generator, the tube area ratio is [ ]^c Because the area scaling ratio is [ ]^c and the tube area ratio is unity, the ratio of the number of tubes in the model is also [ ]^a With the length ratio at [ ]^a and the number of tubes ratio equal to [ ]^a the tube surface area ratio is [ ]^a Table 3.9-2 summarizes the scaling ratios and the actual test steam generator dimensions.

3.9.3 Steam Generator Design/Description

Each steam generator is fabricated of Type 304 stainless steel and is installed with its axis vertically oriented. The shell is [ ]^c in length, and the total length including axial nozzles, is [ ]^c A hemispherical head, [ ]^c inch inside diameter, and 3/8 inch minimum thickness is attached at the bottom by a flange. A conical section at the top enlarges the inside diameter to [ ]^c inches to facilitate vapor separation. Steam is discharged from a [ ]^c inch diameter, flanged nozzle located axially at the center of the top semi-elliptical head, [ ]^c inches in outside diameter, [ ]^c inch minimum thickness. An air-operated ball valve is installed in the steam discharge line. This valve is controlled by a logic controller to maintain the appropriate pressure in the steam-side during the test transients.

The tube bundle consists of [ ]^c U-tubes, [ ]^c inches average length, 11/16 inch outside diameter, 0.040 inch wall welded into a 2 inch thick flange at both the front and back faces. A shroud of [ ]^a inch thick Type 304 stainless steel plate surrounds the tubes and is welded to [ ]^c inch support rods which attach it to the tubesheet. The tubesheet is captured between the flanges of the lower head and is sealed by gaskets on both faces. Moisture is separated by a chevron type device manufactured by Dyna-Therm. This separator is located in the expanded diameter, upper section of the steam generator.

Feedwater is supplied to the shell-side of the steam generator through a [ ]^c diameter line connected to an [ ]^c diameter spray ring made of [ ]^c Sch. 80 pipe supported inside the vessel by brackets. The hot leg is connected to the steam generator by a [ ]^c nozzle connected to the lower head and supplies hot coolant to the tubes. Primary coolant is discharged from the tubeside header through two [ ]^c diameter nozzles. Upon an "S" signal, the motor-operated feedwater isolation globe valve is closed.

TABLE 3.9-1
STEAM GENERATOR SCALING RATIOS AND DIMENSIONS

Parameter	Ideal Scaling Ratio	AP600	Low Pressure Integral Systems Test	
			Ideal	Actual
Total Tube Volume				
Number of Tubes				
Tube Inside Diameter				
Tube Outside Diameter				
Average Tube Length				
Cross-sectional Flow Area (Tubesize)				
Total Inside Surface Area				
Steam Shroud Inside Diameter				
Tube Pitch (Triangular)				
Tube Pitch/O.D. Ratio				
Heat Removal Rate (~3.5% Decay)				
Steam Generator Initial Liquid Mass				

* Based on AP600 secondary side pressure of 1050 psia and model secondary side pressure of 400 psia.

The design drawings of the steam generator are shown on pages 4.23 to 4.25 of Appendix B. Figure 3.9-1 is a photograph of the steam generator tube bundle during shop assembly; Figure 3.9-2 shows the arrival of one assembled Steam Generator on a flat-bed truck. Table 3.9-1 summarizes the scaling ratios and the actual test steam generator dimensions.

3.9.4 Primary Side Instrumentation

The following instrumentation measures the important characteristics on the primary (tube) side of each steam generator:

- 2 - Differential pressure
- 7 - Differential pressure (liquid level)
- 5 - Thermocouple (wall)
- 6 - Thermocouple (fluid)
- 1 - Pressure cell
- 1 - Heat flux meter

[ ]c

3.9.5 Secondary Side Instrumentation

The following instrumentation is provided to measure the secondary side conditions during steady-state or transient operations:

- 2 - Differential Pressure (liquid level)
- 4 - Thermocouples (fluid)
- 2 - Heat Flux Meter

[ ]c

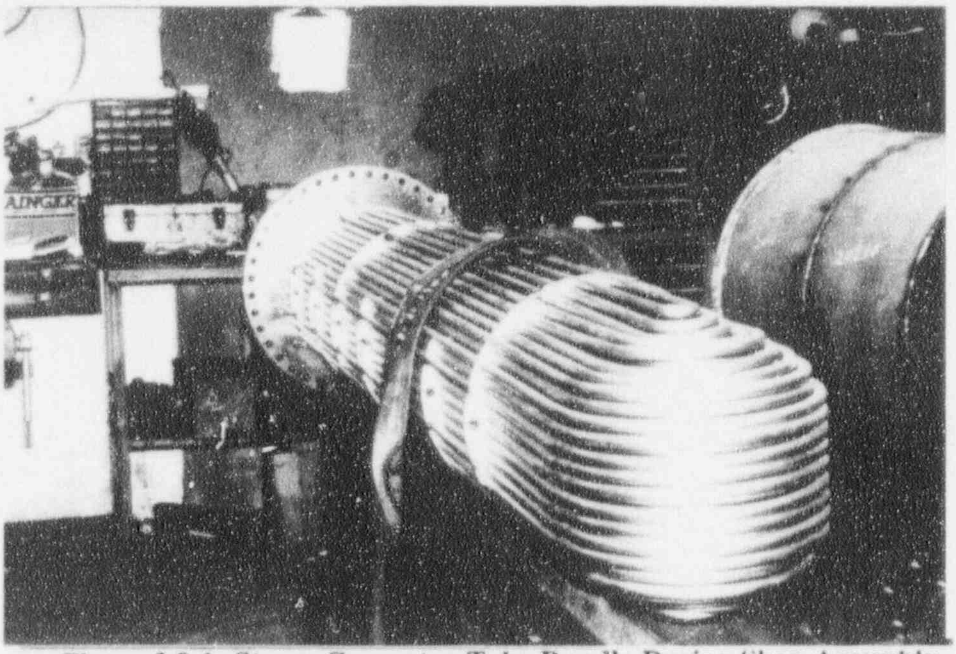


Figure 3.9-1 Steam Generator Tube Bundle During Shop Assembly

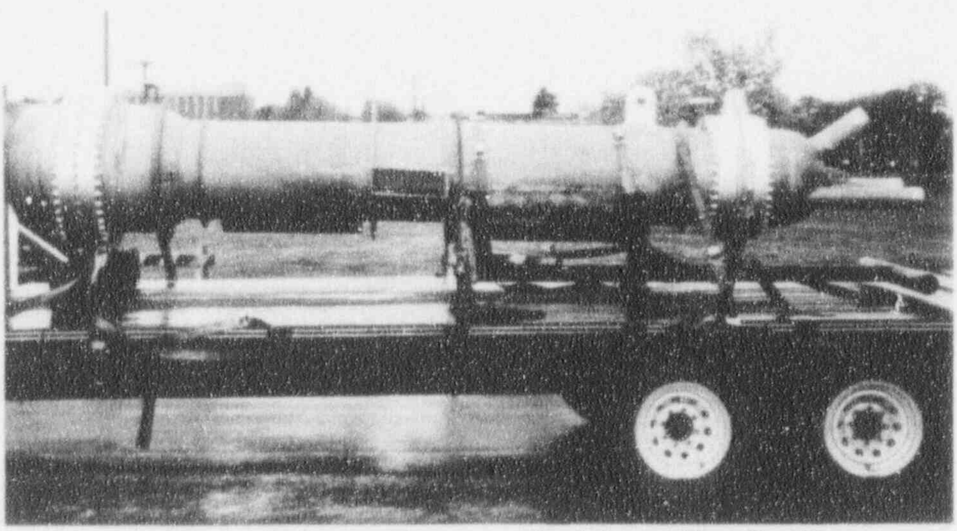


Figure 3.9-2 Steam Generator Arriving at Test Facility

3.10 Reactor Coolant Pumps

3.10.1 Function

The Reactor Coolant Pumps provide the mechanical energy to circulate the primary coolant at its required flow rate through the Reactor Coolant System. Extended coast down of the pump is also required to provide coolant flow through the core following a loss of power or a pump trip.

3.10.2 Scaling Basis

Since the velocity ratio for the primary coolant is [ ][a] and the area ratio is [ ][a] the flow ratio (volumetric or mass) for the primary coolant is [ ][a] Because the RCPs are tripped at the beginning of each transient test, pump head scaling is not required. Therefore, the functional requirement of maintaining adequate flow to establish steady-state critical conditions takes precedence. The RCP volume, flow area, length, and resistance have been scaled.

3.10.3 Design/Dimensions

Four reactor coolant pumps are installed in the Low Pressure Integral Systems Test, one close-coupled to each of the cold primary coolant outlet nozzle from the lower head of each steam generator. These pumps are mounted vertically with the motor in the downward direction. The pump, which is a Model QPHT5-4, manufactured by the Queen Pump Co., Portland, Oregon, is a centrifugal pump with an internal fluid volume of 0.306 cubic foot and is driven by a 5 hp motor. The pump head versus flow correlation is shown in Figure 3.10-1. The coastdown of this pump was so rapid that the flow became immeasurably low as soon as the power was interrupted.

3.10.4 Instrumentation

The following instrumentation is provided for each of the pump seal cooling systems:

Flowmeter (visual)	0 - 5 gpm
Temperature (fluid)	40 - 450°F
Overtemperature Cutoff	

Flowmeters and pressure devices which monitor and record pump performance are included with the Cold Leg piping instrumentation.

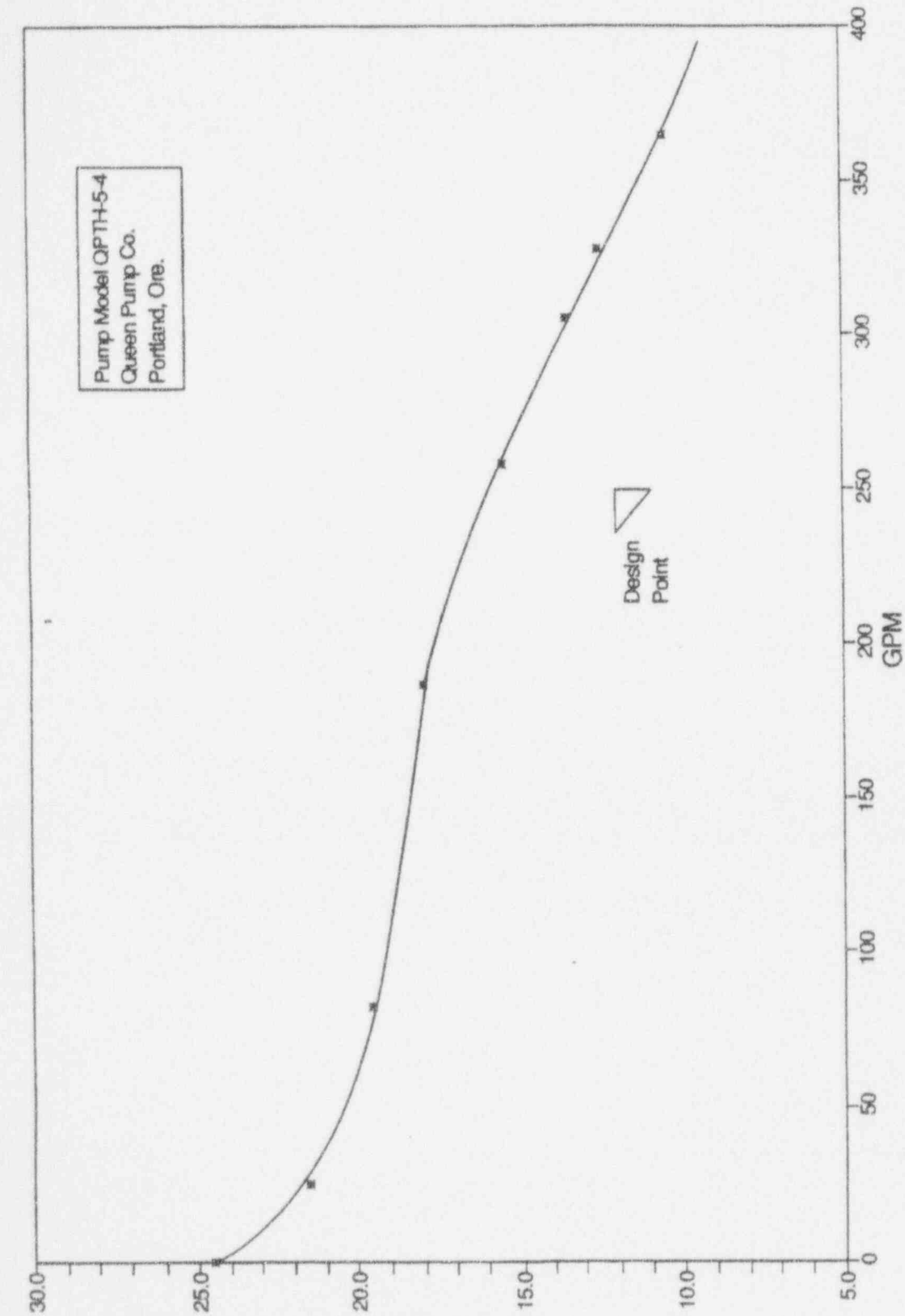


Figure 3.10-1 RCP Performance Head vs. Flow

3.11 Accumulators

3.11.1 Function

The Accumulators provide automatic, passive injection of water into the primary coolant system following a loss of primary coolant.

3.11.2 Scaling Basis

The two processes that are significant for the proper simulation of the accumulators are:

- Accumulator Injection Rate
- Charging Gas Carryover

First, a top-down scaling analysis is performed to determine the transport time scaling factor and the time ratios for the injection process. Then, a bottom-up analysis is performed to scale the nitrogen carryover from the accumulator pressurization gas.

The initial and final pressures in the accumulator were set to meet the depressurization requirements to provide proper timing of injections and flow rates. Table 3.11-1 summarizes the Accumulator scaling ratios and characteristics. In order to properly scale the amount of nitrogen introduced into the primary system, an additional [ ]^{a} of nitrogen per accumulator must be introduced into the RCS subsequent to the emptying of liquid in the Accumulator. This nitrogen can be supplied from a small nitrogen charging flask attached to each of the Accumulator injection lines. However, this feature was not used in the test program.

Table 3.11-1 is a summary of the required scaling ratios for the accumulators and the resultant accumulator dimensions.

3.11.3 Design/Description

Two accumulator tanks are connected to the Direct Vessel Injection (DVI) System. The two tanks are identical, except that the coolant discharge line for the second tank is about [ ]^{c} further below the bottom of the tank than the discharge line for the first tank. The tanks are designed to the ASME Pressure Vessel Code, Section VIII, Division 1.

Each tank consists of a [ ]^{c} Type 304 stainless steel pipe. The top head is a welded [ ]^{c} stainless steel pipe cap and the bottom is a [ ]^{c} inch thick plate which is welded to the barrel. Each tank is supported from the floor by a stand comprised of 61.3 inch long, 20-inch diameter, carbon steel pipe, welded to 1/2 inch thick carbon steel, base, 26 inches outside diameter by 18 inches inside diameter. The base ring is anchored to the floor and

TABLE 3.11-1
MODEL ACCUMULATOR SCALING RATIOS AND CHARACTERISTICS

Parameter	Ideal Scaling Ratio	AP600	Low Pressure Integral Systems Test	
			Ideal	Actual
Internal Volume				a,b
Initial N_2 Volume				
Initial Liquid Volume				
Initial Liquid Temperature				
Initial N_2 Charging Pressure				
N_2 Pressure at Liquid Empty Condition				
Mass of N_2 in Solution				
Mass of N_2 Ejected				
*Total N_2 Mass Into Primary				

the upper end of the support is welded to the bottom plate of the tank. The centrally located discharge line, 1-1/4 inch Sch. 160, is fitted with a 90° elbow and exits horizontally through a cut-out in the tank support.

The vent/N_2 inlet line enters the bottom of the tank through a Swagelok seal. The 1/2 inch, 0.045 inch wall line is supported by a 6 inch long guide tube welded to the inside of the tank, with its center 9 inches from the barrel-top head weld. The height of this line can be adjusted by loosening the Swagelok, moving the tube to its new location and resealing the Swagelok. Teflon ferrules are used for this Swagelok to facilitate this adjustable length. However, during the test program the height of this line remained fixed 36.8 inches from the inside surface of the bottom flange.

As-built drawings for the Accumulators are provided on pages 4.8 and 4.9 of Appendix B.

3.11.4 Instrumentation

Each of the Accumulators is equipped with the following instrumentation:

- 1 - Differential Pressure Cell (liquid level) (0 - 55 inches of water)
- 1 - Magnetic Flowmeter with transmitter (0 - 40 gpm)
- 1 - Heat Flux Meter (0 - 100 Btu/hr, ft^2)
- 1 - Pressure Indicator (0 - 500 psig)
- 1 - Pressure Meter (0 - 400 psig)
- 3 - Thermocouples (40 - 450°F)

3.12 Core Make-Up Tanks

3.12.1 Function

The Core Make-up Tanks (CMT) provide a volume of water that is maintained at Cold Leg pressure by a balance line so the water will flow by gravity into the Cold Leg of the RCS upon a loss of coolant.

The processes that are important to scale in the CMT are:

- CMT draining rate
- Steam condensation rate
- Steam-liquid interface interaction

The parameters that are scaled for these processes are:

- Metal mass
- Internal volume
- Diameter
- Heat transfer time constant
- Cold leg balance line nozzle inside diameter
- Fluid initial conditions
- Relative elevation

A top-down scaling analysis was used to determine the coolant drainage ratios and transport scaling ratios. Then a bottom-up analysis was performed to scale the specific processes: condensation heat transfer, and steam-liquid surface interactions.

During testing of the CMT at a separate facility, pressure pulses occurred with the original sparger through which steam flow from the cold leg balance line entered the CMT. The sparger was then replaced in this test by a steam distributor consisting of a pipe with a number of radial holes. The basis for this design was the reduction of the steam momentum until the pressure pulses disappeared. This was experimentally verified in the CMT test and has been incorporated into the design of the sparger.

The results of these analyses and the dimensions of the model CMT are summarized in Table 3.12-1.

3.12.3 CMT Design/Description

Each CMT is a cylindrical vessel oriented vertically and designed for operation at 400°F and 400 psi according to the ASME Pressure Vessel Code, Section VIII, Division 1. The vessel consists of a

[

]^{c}

TABLE 3.12-1 MODEL CMT SCALING RATIOS AND DIMENSIONS				
Parameter	Ideal Scaling Ratio	AP600	Low Pressure Integral Systems Test	
			Ideal	Actual
Head Inside Radius				a,b
Cylinder Inside Radius				
Internal Length				
Internal Volume				
Metal Volume				
Head Wall Thickness				
Cylinder Wall Thickness				

The cold leg balance line, which is made of [ ]^a pipe, enters the CMT through the steam distributor. The steam distributor consists of a [ ]^a inches long with a welded plug at the bottom. The stub is drilled with [ ]^a inch diameter through-holes from a distance [ ]^a inch above the end plug for a length of [ ]^a inches. The steam distributor is retained between the faces of a [ ]^a 300 lb flange joint with o-ring seals installed at the top of the CMT.

A vent line consisting of [ ]^a is welded to the top head. A [ ]^a inch outside diameter nipple is welded to the center of the bottom head for connection to the Direct Vessel Injection piping.

Drawings for the two CMT's are on pages 4.6 and 4.7 of Appendix B; page 4.13 shows the steam distributor details. Figure 3.12-1 is a photograph of CMT-2 installed in the facility before thermal insulation was applied.

3.12.4 Instrumentation

Each CMT has the following instrumentation:

- 4 - Differential pressure (liquid level) (1 - 0 to 12 inches of water, 1 - 0 to 40 inches of water, 1 - 0 to 20 inches of water, 1 - 0 to 65 inches of water.)
- 3 - Heat Flux Meter (0 to 100 Btu/hr, ft^2)
- Pressure Cell
- 26 - Thermocouples (fluid) (40 - 450°F)
- 3 - Thermocouples (Heat Flux Meter) (40 - 450°F)
- 28 - Thermocouples (wall) (40 - 450°F)

The locations of these instruments are shown in Figures 1.13 and 1.14 of Appendix B.

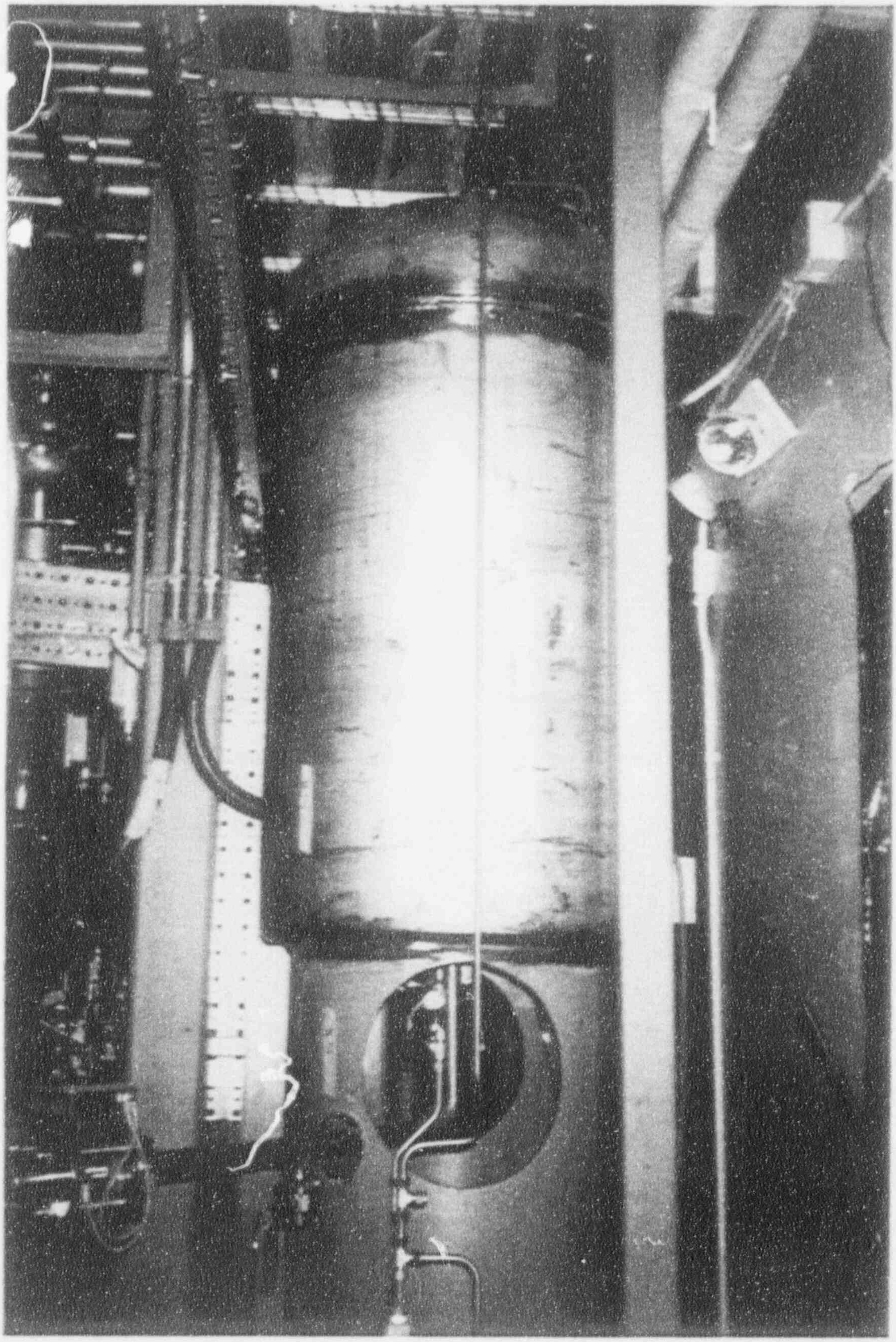


Figure 3.12-1 CMT-2 Installation in Test Facility

In addition to the instrumentation on the CMT's, the following sensors are located on the cold leg pressure balance line:

- 1 - Differential Pressure
- Magnetic Flowmeter (with transmitter)
- 1 - Heat Flux Meter
- 3 - Heated Thermocouple (fluid phase)
- 1 - Differential Pressure (liquid level)
- 2 - Thermocouples (fluid)
- 1 - Thermocouple (heat flux meter)
- 1 - Visual Temperature Indicator
- 2 - Solenoids (closed)
- 2 - Solenoids (open)
- 2 - Limit switches (closed)

3.13 Incontainment Refueling Water Storage Tank

3.13.1 Function

In the AP600, the Incontainment Refueling Water Storage Tank (IRWST) supplies the water that fills the Refueling Cavity during refueling and stores the water during normal plant operation. The IRWST also supplies water for emergency core cooling during a loss of coolant event after the RCS has been depressurized and the water from the CMT's and Accumulators has been exhausted. It also serves as the heat sink for the PRHS during a normal shutdown. In the test model, the injection during loss of coolant events and the PRHS operation are modeled and investigated.

3.13.2 Scaling Basis

The factors which govern the performance of the IRWST are:

- Draining rate
- IRWST liquid heating rate
- Containment condensate heating rate
- Containment backpressure

The parameters which have been scaled to match these factors are:

- Internal liquid volume
- Liquid initial conditions
- Liquid height
- Liquid surface area
- Heat sources
- Relative elevations

The containment backpressure and the condensate return rates can be parametrically varied covering their full scale ranges which are within the capability of the test facility. Table 3.13-1 summarizes the IRWST scaling ratios and dimensions.

3.13.3 Design/Description

The IRWST is fabricated entirely of Type 304 stainless steel and is designed to meet the ASME Section VIII, Division 1 code for [ ]^c The vertically oriented tank consists of a cylindrical section, [ ]^c It is made of [ ]^c inch thick plate, rolled and welded, with a 2:1 elliptical top head, [ ]^c inches thick. The bottom head is a [ ]^c The top and bottom differ because these components were available at the time the tank was fabricated. The bottom head is filled with ceramic covered with a [ ]^c to simulate the flat bottom of the AP600 IRWST.

A 30 inch, 150 lb. blind flange is welded to the top head to provide a manway for access to the tank internals. Steam vented from the ADS is condensed in the IRWST through a sparger. This component is discussed with the ADS Systems in Section 3.16 and 3.17.

Two discharge lines are inserted through the bottom head to the beginning of the cylindrical tank barrel. The line to DVI No. 1 is [ ]^c and the line to the DVI No. 2 is [ ]^c

[ ]^c is installed at the bottom of the cylindrical section to simulate the flat bottom of the AP600 IRWST. Two 1-1/2 inch, 150 lb. flanges are welded to the

bottom head for mounting of two tubes carrying thermocouples for internal fluid temperature measurements. Figure 3.13-1 is a photograph of the PRHS Heat Exchanger installed inside the IRWST.

The PRHS Heat Exchanger is mounted inside the IRWST and the inlet/outlet piping connections are made through welded 3 inch, 150 lb. flanges. Details of the PRHS Heat Exchanger are described in Section 3.19.

IRWST drawings are provided on pages 4.1 and 4.2 of Appendix B. Sparger details are shown on page 4.17 of the same appendix.

3.13.4 Instrumentation

The following instrumentation measures the significant parameters of the IRWST during the transients being investigated:

- 3 - Heat Flux Meters
- 4 - Load Cells
- 1 - Differential Pressure (Level)
- 1 - Pressure Cell
- 19 - Thermocouples (fluid)

TABLE 3.13-1
MODEL IRWST SCALING RATIOS AND DIMENSIONS

Parameter	Ideal Scaling Ratio	AP600	Low Pressure Integral Systems Test	
			Ideal	Actual
Normal Liquid Volume				a,b
Liquid Surface Area				
Normal Water Depth				
Model Tank Diameter				
Initial Water Temperature				
Tank Pressure*				
Condensate Return Rate*				

* Varied parametrically; value of 0 used in Test Matrix.

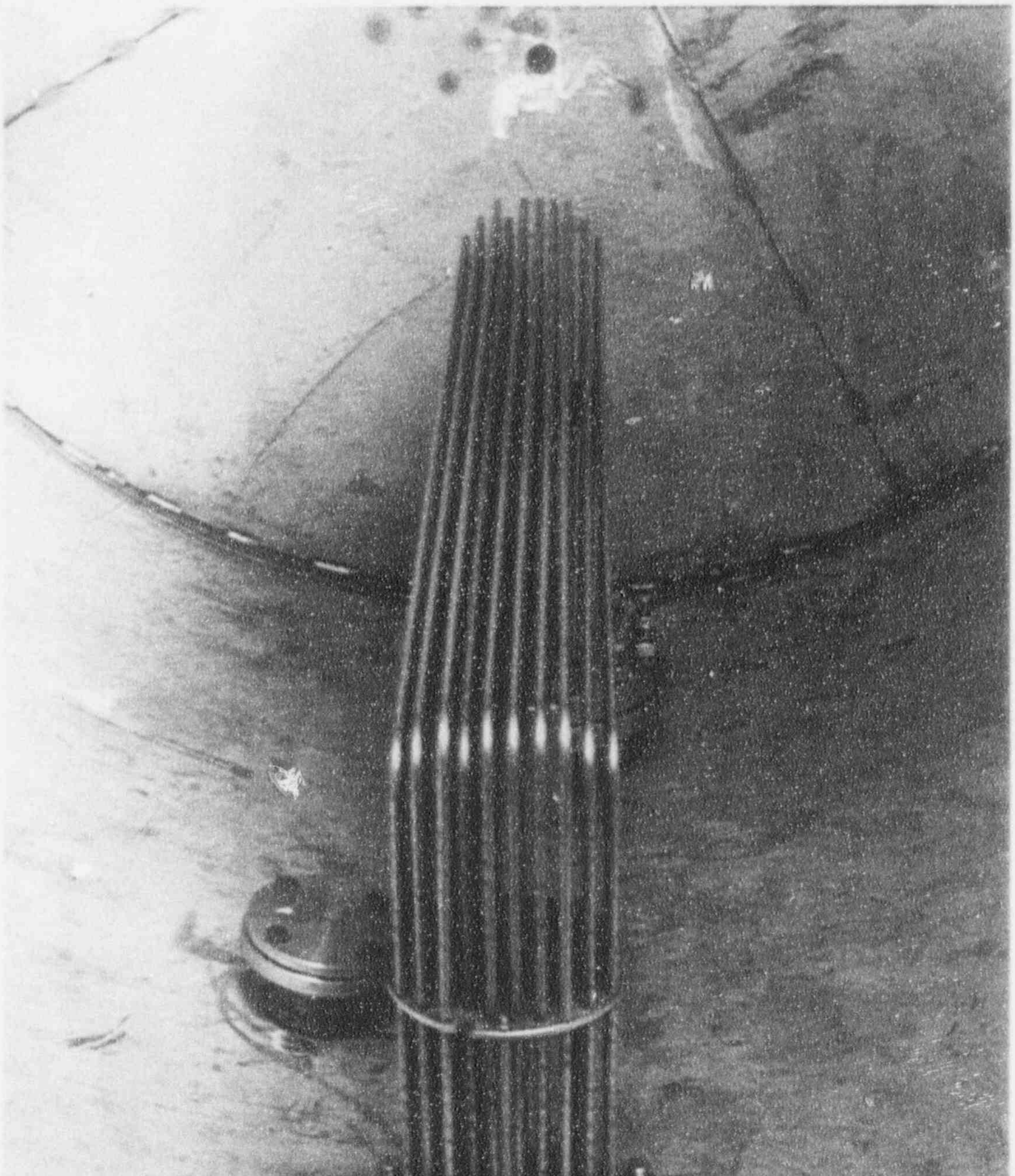


Figure 3.13-1 PRHS Heat Exchanger Located inside the IRWST

3.14 Safety Injection Lines

3.14.1 Function

The function of the Safety Injection Lines is to provide flow conduits for the water that is injected directly into the Reactor Vessel from the CMT's, Accumulators, and IRWST.

3.14.2 Scaling Basis

Injection mass flow rate is the critical process to be modeled for the Safety Injection System. Scaling for mass flow rate consisted of a top down analysis to determine the characteristic time ratio that determines the mass flow rate. Then a bottom-up scaling analysis was performed to determine the pressure drop of each line. Measured flow coefficients for these lines are provided in the summary, Section 7, Table 7-1. The injection line diameters and the vertical heights were scaled for the CMT, Accumulators, and IRWST injection lines, and the line diameter and length were sealed for the DVI line. Orifices were used in the model injection lines to adjust the flow resistance to yield the desired mass flow rate. Dimensions of these orifices are provided in Table 7-2, Section 7.

The scaling ratios and the dimensions of both the AP600 and the Low Pressure Integral Systems Test model for the CMT, Accumulator, and IRWST injection lines are summarized in Table 3.14-1 and the same data are provided for the DVI in Table 3.14-2. Commercial piping on tubing was used with the closest dimensions to the scaled dimensions. The differences, which are relatively small, can be seen by comparing the ideal and actual dimensions in Table 3.14-2.

3.14.3 Design/Description

As-built drawings for the Safety Injection lines showing dimensions, elevations, and instrumentation locations are provided in Appendix B as follows:

- DVI No. 1: Pages 5.9, 5.10, 5.11
- DVI No. 2: Pages 5.12, 5.13, 5.14
- CMT No. 1: Page 5.15
- CMT No. 2: Page 5.16
- ACC No. 1: Page 5.17
- ACC No. 2: Page 5.18
- IRWST: Page 5.19

3.14.4 Instrumentation

The instrumentation for the Safety Injection Lines is summarized in Table 3.14-3.

TABLE 3.14-1
MODEL SAFETY INJECTION LINE SCALING RATIOS AND DIMENSIONS

Parameter	Ideal Scaling Ratio	AP600	Low Pressure Integral Systems Test	
			Ideal	Actual a,b
CMT Injection Line Inside Diameter				
CMT Injection Line Volume				
CMT Vertical Elev. [ ]				
CMT Maximum Injection Flow Rate				
CMT ($F_{T,inj}$)				
CMT Injection Line $\Delta P_{Loss}=(F_{T,inj})\rho_l u^2_{inj}/2g_c$				
ACC Injection Line Inside Diameter				
ACC Injection Line Volume				
ACC Maximum Injection Flow Rate				
ACC ($F_{T,inj}$)				
IRWST #1-Sump Tee Inside Diameter				
IRWST #1 Sump Tee Volume				

TABLE 3.14-1 (Continued MODEL SAFETY INJECTION LINE SCALING RATIOS AND DIMENSIONS				
Parameter	Ideal Scaling Ratio	AP600	Low Pressure Integral Systems Test	
			Ideal	Actual
IRWST #1 Vertical Elev. [ ]				a,b
IRWST #1 Maximum Injection Flow Rate				
IRWST #1-Sump Tee (FT,inj)				
IRWST #1 - Sump Tee $\Delta P_{Loss}=(F_{T,inj})\rho_l u_{inj}/2g_c$				
IRWST #1-Sump-DVI Inside Diameter				
IRWST #1-Sump-DVI Volume				
IRWST #1-Sump-DVI ($F_{T,inj}$)				
IRWST #1 - Sump-DVI $\Delta P_{Loss}=(F_{T,inj})\rho_l u^2_{inj}/2g_c$				
IRWST #2-Sump Tee Inside Diameter				
IRWST #2 Sump Tee Volume				
IRWST #2 Vertical Elev. [ ]				

TABLE 3.14-1 (Continued) MODEL SAFETY INJECTION LINE SCALING RATIOS AND DIMENSIONS				
Parameter	Ideal Scaling Ratio	AP600	Low Pressure Integral Systems Test	
			Ideal	Actual
IRWST #2 Maximum Injection Flow Rate				a,b
IRWST #2-Sump Tee ($F_{T,inj}$)				
IRWST #2 - Sump Tee $\Delta P_{Loss}=(F_{T,inj})\rho_l u^2_{inj}/2g_c$				
IRWST #2-Sump-DVI Inside Diameter				
IRWST #2-Sump-DVI Volume				
IRWST #2-Sump-DVI ($F_{T,inj}$)				
IRWST #2 - Sump-DVI $\Delta P_{Loss}=(F_{T,inj})\rho_l u^2_{inj}/2g_c$				

*Based on NOTRUMP calculation (Ref. 3.1)

**Adjusted using orifice to satisfy $(\Pi_{m})_{sys,R} = 1$

TABLE 3.14-2
DVI LINE SCALING RATIOS AND DIMENSIONS

Parameter	Ideal Scaling Ratio	AP600	Low Pressure Integral Systems Test	
			Ideal	Actual
DVI Line Inside Diameter				
DVI Line Volume				
DVI Maximum Injection Flow Rate				
DVI ($F_{T,inj}$)				
DVI Line $\Delta P_{Loss}=(F_{T,DVI})\rho_l u^2_{inj}/2g_c$				

*Based on NOTRUMP calculation (Ref. 3.1)

**Adjusted using orifice to satisfy $(\Pi_m)_{sys,R} = 1$

TABLE 3.14-3
SAFETY INJECTION LINE INSTRUMENTATION

Instrumentation	CMT	ACC	IRWST	DVI
Differential Pressure Cell	1	1	2	
Magnetic Flowmeter	1	1	2	2
Magnetic Flowmeter Transmitter	1	1	2	2
Thermocouple (Fluid)	3	2	4	---
Solenoid (close)	1		2	---
Solenoid (open)	1		2	---
Limit Switch (close)	1		2	---
Limit Switch (open)	1			

3.15 Containment Sumps

The Lower Containment System (LCS) recirculates water from the Containment Sump through the Reactor Vessel to provide passive cooling for removal of decay heat. Recirculation will start when the water level in the lower containment sump has reached the elevation of the DVI. At this level, the recirculation line is filled and a density driving force will exist as the boiling in the core will reduce the density of the liquid in the core compared to the cooler water in the sump. Steam will be released to the containment through the fourth ADS valves on the hot legs and will be condensed in the containment, eventually returning to the sump.

3.15.1 Function

The function of the model containment sumps is to simulate the volume in which water can collect from the leakage during hypothetical loss-of-coolant accidents. In most of the break locations, the reactor sump will fill and recirculation through the LCS will be initiated as soon as the water level reaches the DVI. However, some breaks may occur in compartments which are hydraulically isolated from the reactor sump and those compartments must flood above a given elevation before the reactor sump begins to fill. This flow behavior is modeled by a primary sump tank which represents the reactor sump, and a secondary sump tank which simulates the isolated compartments.

3.15.2 Scaling Bases

Both the primary sump tank and the secondary sump tank are scaled to model the behavior of the normally flooded reactor sump and the hydraulically isolated compartments within the containment. The parameters which are scaled are:

- Primary sump internal liquid volume
- Primary sump cross-sectional area
- Primary sump relative elevations
- Secondary sump internal volume
- Secondary sump cross-section area
- Secondary sump relative elevations

Table 3.15-1 summarizes the scaling ratios and dimensions for these sumps.

TABLE 3.15-1
CONTAINMENT SUMP SCALING RATIOS AND DIMENSIONS

Parameter	Ideal Scaling Ratio	AP600	Low Pressure Integral Systems Test	
			Ideal	Actual
*Containment Sump Water Volume (DVI to Flood-up Elev.)				
Containment Sump Water Volume (Below DVI Elev.)				
Elevation Difference Between DVI and Flood-up Level				
Elevation Difference Between Flood-up Level and Curb Level				
Elevation Difference Between DVI and Sump Screen				
Containment Sump Water Surface Area (DVI to Flood-up Elev.)				
Primary Sump Inside Diameter				
**Normally Non-Flooded Compartment Water Volume				
Secondary Sump Inside Diameter				
Secondary Sump DVI to Curb Elevation Difference				

* The AP600 containment sump is modeled by a "primary" sump consisting of a cylindrical tank with elliptical heads.

**The AP600 normal non-flooded compartments are modeled by a "secondary" sump consisting of a cylindrical tank with elliptical heads.

3.16 Automatic Depressurization System, Stages 1-3

The Automatic Depressurization System (ADS) consists of four stages. Stages 1 through 3 are described in this section.

3.16.1 Function

The function of the ADS is to reduce the pressure in the RCS by venting steam in a controlled manner to permit injection of cooling water from the CMTs, Accumulators, and IRWST.

3.16.2 Scaling Basis

The system level phenomena that affect depressurization are:

- System depressurization rate
- Net system power
- ADS flow area (number of trains)

The following processes related to the system level phenomena are evaluated:

- Fluid property scaling
- Critical flow through ADS valves and system breaks
- Core decay power

The analytical approach consisted of a top-down scaling based on the system phenomena and a bottom-up scaling based on the above related process. The resultant Π groups and similarity criteria were evaluated for scaling distortions.

The ADS should meet the following scaling ratios:

- Length - [ ]^{a,b}
- Volume - [ ]^{a,b}
- Maximum pressure drop - [ ]^{a,b}
- Total frictional form loss - [ ]^{a,b}

Since standard commercial piping and tubing did not match these dimensions exactly, a slightly larger line diameter was selected for the ADS and the friction loss ratio was adjusted to meet the scaling requirements through use of nozzles. Dimensions of these nozzles are included in Table 7-2, Section 7. Table 3.16-1 summarizes the dimensions and characteristics of the ADS. While the AP600 has two complete, independent ADS systems for redundancy, the Low Pressure Integral Systems Test Model has a single system with piping sized to model the largest flow through the two ADS trains in the AP600. By exchanging flow nozzles in the model ADS, a single ADS with smaller breaks can be modeled.

Table 3.16-1 summarizes the scaling ratios and dimensions for single and combined trains, each with a large break (single phase flow) and a small break (two-phase flow).

3.16.3 Design Description

The ADS1-3 shown schematically in Figure 3.16-1, is connected to the top of the pressurizer through a [ ]^c inch Sch. 80 pipe. Separate branch lines are provided for each of the valves and flanged nozzles are installed in each branch to permit adjustment of the flow resistance in each branch. A [ ]^c inch relief valve is tied into this line before the line is reduced for each of the ADS valves. The first ADS valve, which opens at the highest pressure, is a [ ]^c valve joined by [ ]^c Sch. 80 piping to the [ ]^c ADS line 2 from the [ ]^c ADS valve 3. The combined line from valves 1 and 3 is expanded to [ ]^c tubing with a [ ]^c wall thickness by a welded reducer. The [ ]^c inch line carrying valve 2 is connected to the [ ]^c tubing. The ADS valves are pneumatically operated ball valves; each valve is programmed to open at descending pressures.

Two-phase flows vented through the three valves flow through a vapor-liquid separator in the BAMS. The stream mass flow rates are measured and they are recombined and flow to the IRWST sparger through a [ ]^c pipe. Steam vented from the ADS enters the IRWST through a [ ]^c 300 lb. flanged connection and is dispersed at about mid-level in the tank by a sparger. This consists of a [ ]^c inlet line which is expanded to [ ]^c Sch. 40 at the hub. [ ]^c sparger arms are connected to the hub in a cruciform arrangement including 60 degrees to the horizontal. Each Sparger Arm has an active length of about [ ]^c which is drilled with [ ]^c inch diameter holes.

3.16.4 Instrumentation

The following instrumentation is installed in the ADS1-3:

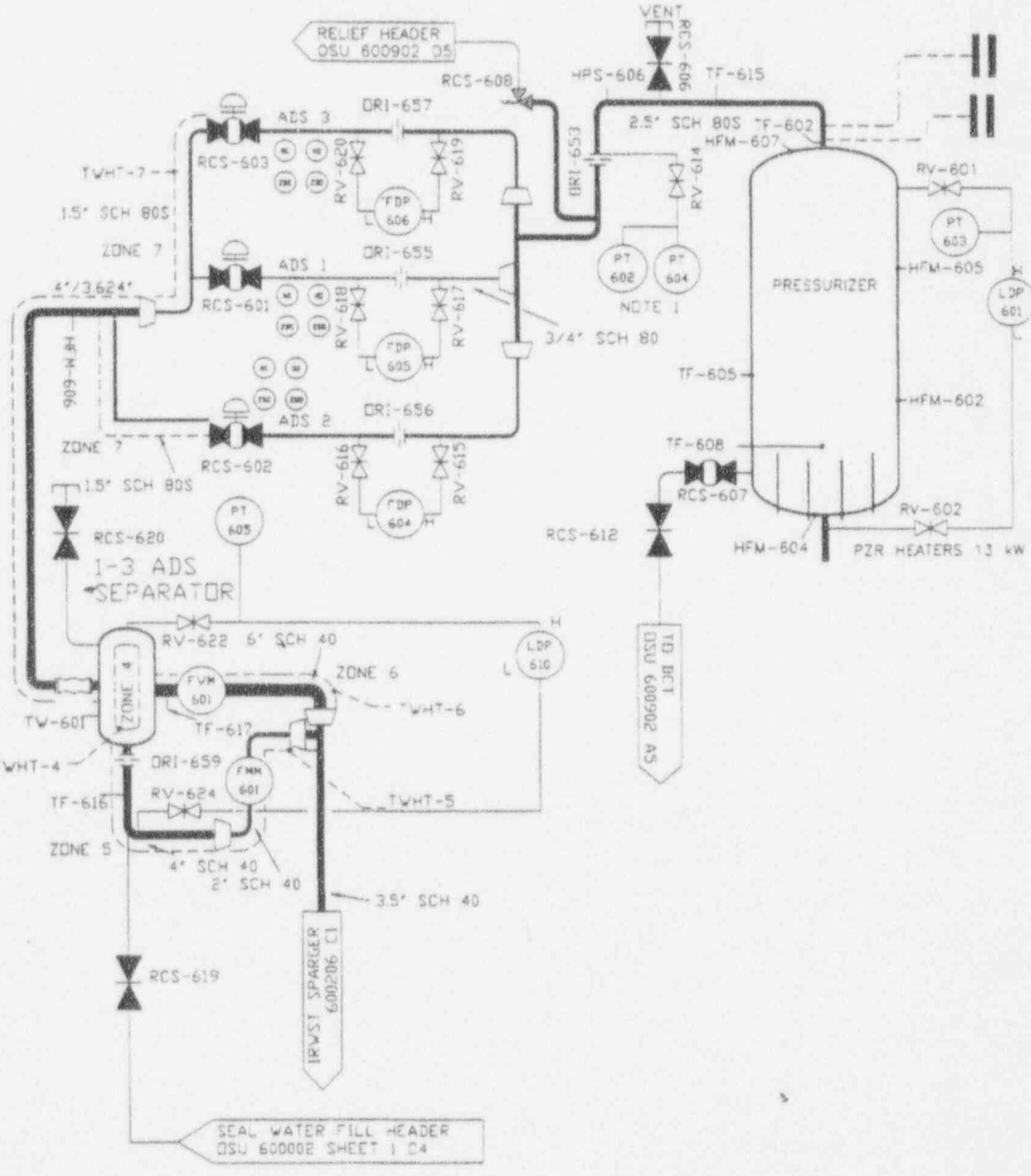
• 3 - Flow Meter (Differential Pressure)	(2 - 0 to 60 inches of water 1 - 0 to 325 inches of water)
• 2 - Magnetic Flow Meter	(0 - 60 gpm)
• 1 - Heat Flux Meter	(0 - 100 Btu/hr ft^2)
• 3 - Heated Thermocouple Determining Fluid Phase	(2 - 0 to 100°F 1 - 0 to 500°F)
• 1 - Differential Pressure (liquid level)	(0 - 140 inches of water)
• 2 - Pressure Cells	(0 - 500 psig)

- 3 - Thermocouples (40 - 450°F)
- 1 - Thermocouple (heat flux meter) (40 - 450°F)
- 3 - Solenoids (close)
- 3 - Solenoids (open)

TABLE 3.16-1
ADS1-3
SCALING RATIOS AND DIMENSIONS

	Scaling Ratio	AP600	Low Pressure Integral Systems Test
LARGE BREAK-SINGLE PHASE VAPOR			
1st Stage ADS			
Single Line			
Throat Diameter (in.)			
Throat Area (in.^2)			
Two Lines Combined			
Throat Diameter (in.)			
Throat Area (in.^2)			
2nd and 3rd Stage ADS			
Single Line			
Throat Diameter (in.)			
Throat Area (in.^2)			
Two Lines Combined			
Throat Diameter (in.)			
Throat Area (in.^2)			
SMALL BREAK-TWO PHASE FLUID			
1st Stage ADS			
Single Line			
Throat Diameter (in.)			
Throat Area (in.^2)			
Two Lines Combined			
Throat Diameter (in.)			
Throat Area (in.^2)			
2nd and 3rd Stage ADS			
Single Line			
Throat Diameter (in.)			
Throat Area (in.^2)			
Two Lines Combined			
Throat Diameter (in.)			
Throat Area (in.^2)			

a,b,c



a,b,c

Figure 3.16-1 Flow Schematic for Automatic Depressurization System

3.17 Automatic Depressurization System, Stage 4

3.17.1 Function

Stage 4 of the Automatic Depressurization System ensures that the RCS pressure is reduced to near containment pressure. RCS pressure must be near the containment pressure in order for the IRWST water to be injected.

3.17.2 Scaling Basis

The fourth stage ADS valve will accurately model the AP600 when fluid property similitude exists. This requires the area ratio for valve 4 to be [ ]^{c} Table 3.17.1 summarizes the dimensions and characteristics of this valve for large breaks (two phase flow) and small breaks (single phase flow).

3.17.3 Design Description

Two stage 4 vent lines are provided, each connected to one of the Hot Legs. Each line which models two lines in the AP600 consists of [ ]^{c} which is connected to the Hot Leg through a flanged tee. The [ ]^{c} pneumatically operated ball valve which is programmed to open after the first three ADS valves. After passing through a flanged flow nozzle used to adjust the line resistance, the two-phase flow enters a separator which is not part of the BAMS. The liquid from the separator flows to the primary sump, while the steam flow is measured and then exhausted to the atmosphere.

3.17.4 Instrumentation

Each ADS stage 4 vent system is provided with the following instrumentation:

- 1 - Vortex Flow Meter (0- 2000 SCFM)
- 1 - Differential Pressure (liquid level) (0 - 90 inches of water)
- 1 - Pressure Cell (0 - 100 psig)
- 2 - Pressure Cells (0 - 500 psig)
- 3 - Thermocouples (40 - 450°F)
- 1 - Thermocouple (heat flux meter) (40 - 450°F)

TABLE 3.17-1 ADS STAGE 4 SCALING RATIOS AND DIMENSIONS			
	Scaling Ratio	AP600	Low Pressure Integral Systems Test
ADS 4TH STAGE (FLUID PROPERTY SIMILARITY)			
Single Hot Leg - 100% flow (no failures)*			
Flow Nozzle Diameter (in.)			
Flow Nozzle Area (in.^2)			
Single Hot Leg - 50% flow (single failure)**			
Flow Nozzle Diameter (in.)			
Flow Nozzle Area (in.^2)			

a,b,c

* Represents both parallel paths open for one AP600

** Represents one of two parallel flow paths open for one AP600 Hot Leg

- 3 - Solenoids (close)
- 3 - Solenoids (open)
- 3 - Limit Switches (close)
- 3 - Limit Switches (open)

3.18 Non-Safety Injection Systems

Two non-safety injection systems, the Chemical and Volume Control System (CVS) and the Normal Residual Heat Removal System (RNS), are included in the facility to simulate these systems during transient tests specifically in which these systems were in operation. Descriptions of these systems are provided in this section.

3.18.1 Function

3.18.1.1 CVS

The function of the CVS in the test facility is to provide injection of additional feedwater into the Steam Generator Channel Head. In the AP600, this system is used to adjust the RCS water chemistry and to maintain the system liquid volume.

3.18.1.2 RNS

The function of the RNS in the test facility is to inject demineralized water into the CMT/DVI line simulating properties of the AP600 RNS.

3.18.2 Scaling Basis

Since these systems do not have a safety function, only the mass flow ratio of 1 : 96 was scaled.

The pumps were programmed to follow the flow characteristics of their respective systems during each transient investigated.

3.18.3 Design/Description

3.18.3.1 CVS

The CVS pump inlet is connected to the Steam Generator Main Feed Header by 3/4-inch pipe. The pump, Model 3333, Type CB5-45, manufactured by Gould, is a multistage centrifugal pump with a 5 hp motor. Figure 3.18.3-1 is the head-flow correlation for this pump. It discharges through a 3/4-inch pipe and

check valve to an expanded section of 1-inch x 0.87-inch inside diameter tubing with a motor operated ball valve to the channel head of Steam Generator No. 2. A 1-inch diameter branch line with manually operated ball is connected to the feed line to Steam Generator No. 1.

3.18.3.2 RNS

The RNS pump, Grundfos Pumps Corp., Clovis, CA, Series C, Model CR4-100N, receives flow from the Main Feed Line through a 2-inch pipe.

Flow from the pump discharge is piped through 1-inch pipe and 1 1/4-inch diameter (1.0 inch inside diameter) tubing with a 1-inch check valve and a 1-inch pneumatically operated ball valve. The pump performance curve is illustrated in Figure 3.18.3-2. A 2-inch diameter line is also connected to the discharge line from the pump to the IRWST injection line. This line is equipped with a 2-inch manually operated ball valve.

3.18.4 Instrumentation

The following instrumentation is provided for these systems.

Instrument	CVS	RNS
Magnetic Flow Meter	0 - 8 gpm	0 - 60 gpm
Visual Pressure Indication	0 - 600 psig	0 - 300 psig
Pressure Cell	0 - 500 psig	0 - 250 psig
Temperature	40 - 450°F	40 - 450°F

3.19 Passive Residual Heat Removal System

3.19.1 Function

The Passive Residual Heat Removal System removes decay heat from the core completely passively during an emergency shutdown in which heat cannot be rejected through the steam generators or RNS.

3.19.2 Scaling Basis

The AP600 has two, 100 percent capacity, passive residual heat removal heat exchangers each capable of removing 2 percent of the core power using natural circulation. The C-type tube heat exchangers are located in the IRWST and can operate at full system pressures.

Figure 3.18.3-1: CVS Pump Head vs. Flow

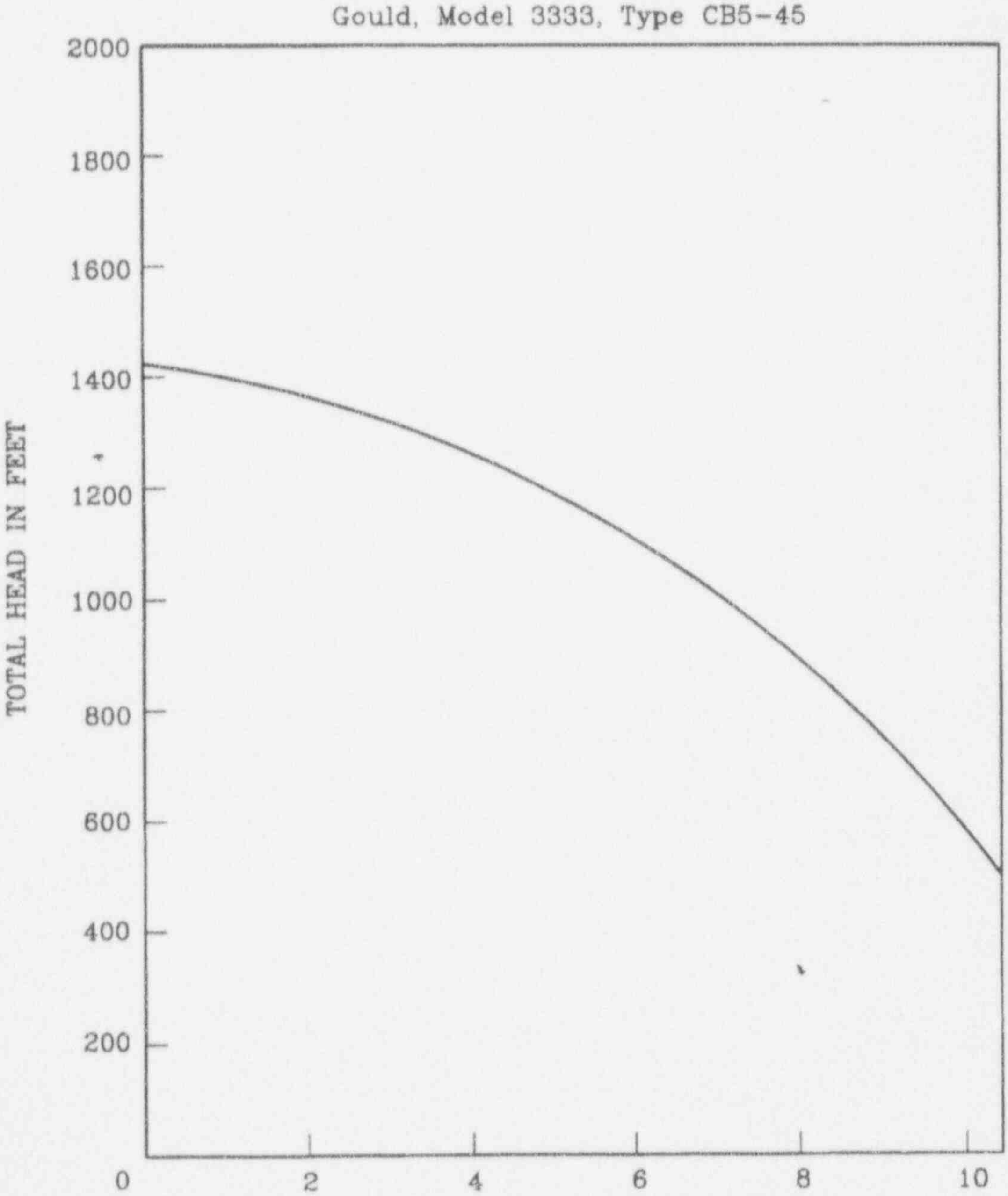


Figure 3.18.3-1 CVS Pump Head vs. Flow

Figure 3.18.3-2: RNS Pump Head vs. Flow

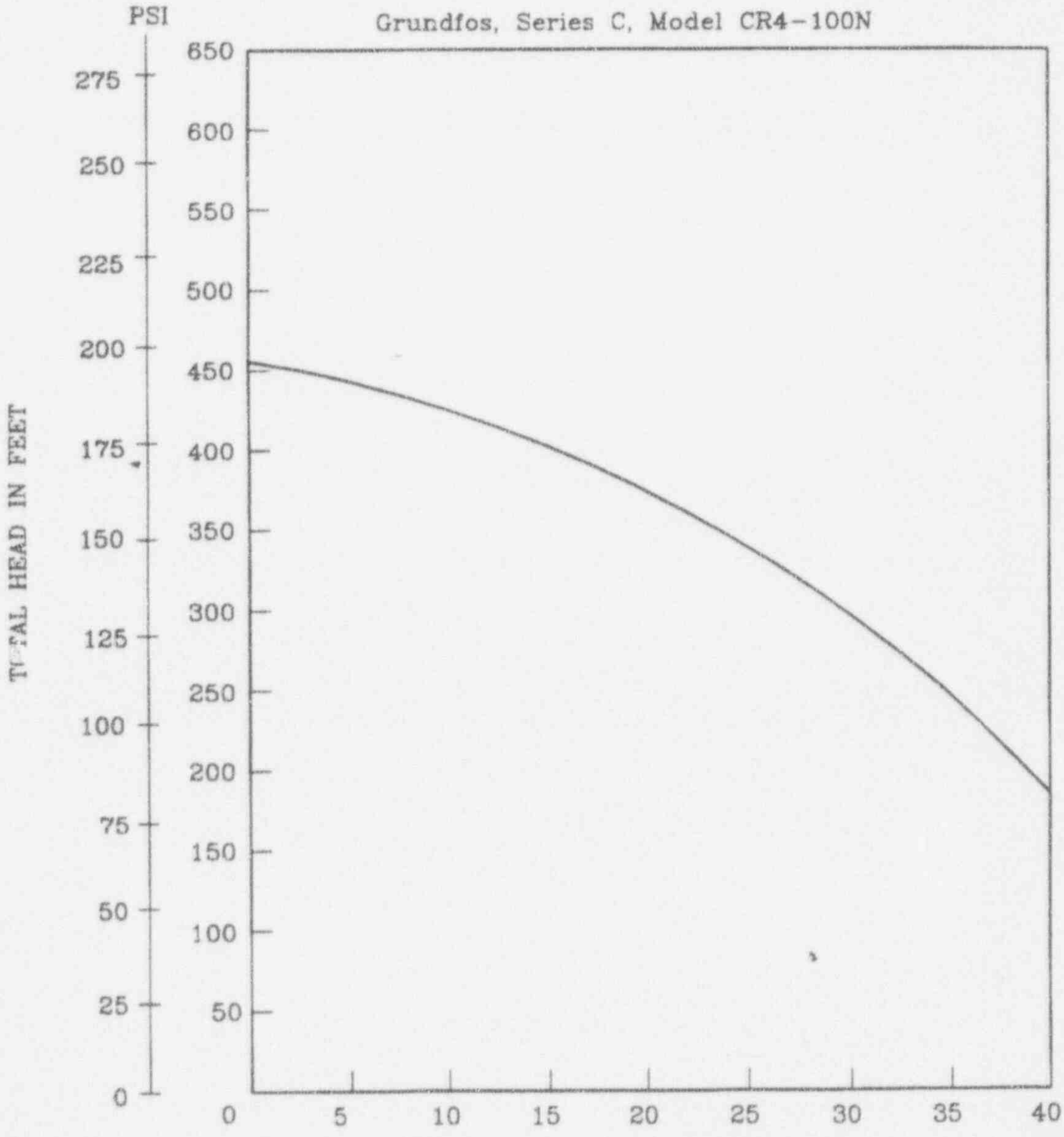


Figure 3.18.3-2 RNS Pump Head vs. Flow

The Low Pressure Integral Systems Test includes a single C-type heat exchanger scaled using the criteria in Table 2.1. Table 3.19-1 presents the scaling ratios and dimensions for the PRHR heat exchanger. All tube lengths, the total tube side volume and the total cross-sectional flow area have been ideally scaled.

Because the test system will operate at reduced pressure and reduced height, the heat exchanger transfer area must be selected such that [ ][a,b] can be removed by natural circulation. As IRWST fluid temperature increases, more flow is needed on the tube side to remove the energy from the primary side. Table 3.19-1 shows the maximum flow in the PRHR tubes which occurs at the design operating temperature of [ ][a] in the IRWST. At 212°F, the required primary coolant flow is [ ][a,b]

3.19.3 Design/Description

A single PRHRS is installed in the Low Pressure Integral Systems Test. This loop consists of piping from the Reactor Vessel to the C-tube heat exchanger mounted inside the IRWST. Heat is transferred from the C-tubes to the water in the IRWST by conduction and natural convection. Flow from Hot Leg-2 enters the C-tube heat exchanger through a 1-1/2 inch Sch 80 line with a normally open ball valve and a magnetic flowmeter. The cooled liquid flows from the bottom header of the C-tube exchanger through 1-1/2 inch tubing (1.26-inch inside diameter) with a normally closed pneumatically operated ball valve and magnetic flowmeter to the channel head of Steam Generator 2. A drain line with a normally closed needle valve is connected to the Condenser Drain Header.

3.19.4 Instrumentation

The following instrumentation is provided for the PRHS:

- 2 - Magnetic Flowmeter (with transmitter) (0 - 15 gpm)
- 2 - Heat Flux Meters (0 - 100 Btu/hr, ft^2)
- 3 - Heated Thermocouple Determining Fluid Phase (2 - 0 to 100°F
1 - 0 to 500°F)
- 2 - Differential Pressure (liquid level) (1 - 0 to 10 inches of water
1 - 0 to 70 inches of water)
- 9 - Thermocouples (fluid) (40 - 450°F)
- 2 - Thermocouples (heat flux meter) (40 - 450°F)

TABLE 3.19-1
PASSIVE RESIDUAL HEAT REMOVAL HEAT EXCHANGER SCALING RATIOS AND DIMENSIONS (SINGLE HEAT EXCHANGER)

Parameter	Ideal Scaling Ratio	AP600		Low Pressure Integral Systems Test			
				Ideal		Actual	a,b
Total Tube Volume							
Number of Tubes							
Tube Inside Diameter							
Tube Outside Diameter							
Average Tube Length							
Average Vertical Length							
Average Horizontal Length							
Cross-sectional Flow Area							
Total Inside Surface Area							
Total Heat Load (2% Decay Heat)							
Primary Coolant Rate at 2% Decay							

- 1 - Visual Temperature Indicator [ ]^c
- 8 - Thermocouples (wall) [ ]^c
- 1 - Solenoid (closed)
- 1 - Solenoid (open)
- 1 - Limit Switch (open)
- 1 - Limit Switch (closed)

3.20 Break Simulators

3.20.1 Function

The Break Simulators provide controlled leakages that simulate failures of RCS piping in the AP600.

3.20.2 Scaling Basis for Break Sizes

The scaling ratio for the flow areas of the break simulations derived from the overall flow scaling and relaxation model is:

$$\left[C_D a\right]_{Break,R} = \frac{1}{96}\left[\frac{\rho_{sys}}{G_{RLM}\phi(x)}\right]_{Break,R} \tag{1}$$

where $C_D a$ = effective break flow area

ρ_{sys} = liquid density in system

G_{RLM} = critical flow determined by relaxation length model

ϕ = modifier for two phase flow

$$G_{RLM} = \frac{h_{\ell g}}{v_{\ell g}}\left[\frac{J\ g_c}{NC_p T}\right]^{1/2} \tag{2}$$

where h_{fg} = latent heat vaporization

v_g = change in specific volume between liquid and vapor state

J = constant (778.2 lb_f-ft/Btu)

C_p = specific heat of saturated liquid

T = absolute temperature of saturated liquid

N = non-equilibrium number

g_c = acceleration of gravity

For breaks greater than the relaxation length (λ=3.94 inches), equilibrium will be achieved and N=1 (Ref. 3-2). For non-equilibrium conditions, N is defined below:

$$N = \left(\frac{h_{fg}}{v_{fg}}\right)^2 \left[\frac{J}{2\Delta P \rho_f k^2 C_{pf}\, T}\right] + \frac{\ell_w}{\lambda} \tag{3}$$

$$\phi(x) = 0.325 + e^{(-3.812x) + 0.562} \tag{4}$$

where x = vapor quality at the inlet to the break

Solution of equations (1) through (4) yield the model break areas for the hypothetical AP600 breaks which are summarized in Table 3.20.1. Details of these scaling analysis are presented in References 2-3 and 3-2.

3.20.3 Design/Description

Each break simulation for the hot leg and cold leg consists of a flanged spool piece installed in the line in which the break is to be simulated. A line with a pneumatically actuated ball valve is connected to the spool piece and conducts the leakage flow to the BAMS, which is described in Section 3.21.

There are four break simulation locations in the test facility - one at the Hot Leg, one at the Cold Leg, one at the Direct Vessel Injection line (DVI) and one at the core makeup tank (CMT) to cold leg balance line. The relative elevations of these break locations are shown in the Break Isometric Sketches, pages 5.87 through 5.89 of Appendix B. All break locations are capable of simulating a single ended break of a desired size. In addition, the DVI line break and the CMT to cold leg balance line break can also simulate double ended, guillotine piping failures. The flow out of each of these breaks is two phase.

The Break Separator is equipped with four inlets and two outlets. Only one of these four inlets is used at a time and their locations are critical. There are three inlets located below the curb/overflow level - one at cold leg elevation for cold leg break simulation, one at hot leg elevation for hot leg break simulation, and one at DVI elevation for DVI break simulation. These elevations are very important. For example, the cold leg break inlet must be at the same elevation as the cold leg break location. If it is located at a higher elevation, it will create back pressure at the break source (i.e., break hole at the cold leg) and subsequently will change the thermal hydraulic characteristics of the break flow. Similarly, the hot leg break inlet is located at the hot leg break hole elevation; and the DVI break inlet is located at the DVI break elevation.

The fourth inlet of the Break Separator is located at a level between the curb/overflow level and the lowest break above the curb/overflow level. This inlet is used for CMT to cold leg balance line break. This arrangement allows one inlet for several break locations above the curb/overflow level without introducing improper back pressure on the break source. The Break Separator also has a loop seal at the liquid drain line to prevent steam from blowing out of the liquid drain line and ensure valid liquid flow measurements.

Instrumentation for the Break System is included in the discussion of the BAMS, Section 3.21.4.

TABLE 3.20-1
DIMENSIONS OF BREAK SIMULATIONS

	Scaling Ratio	AP600	Low Pressure Integral Systems Test
HOT LEG BREAKS			a,b
Wall Thickness (in.)			
Break Throat Diameter (in.)			
Break Area (in.^2)			
(L/D) Thickness/Diameter			
COLD LEG BREAKS			
Wall Thickness (in.)			
Break Throat Diameter (in.)			
Break Area (in.^2)			
(L/D) Thickness/Diameter			
Break Throat Diameter (in.)			
Break Area (in.^2)			
(L/D) Thickness/Diameter			
Break Diameter (in.)			
Break Area (in.^2)			
COLD LEG/CMT BALANCE LINE BREAK			
Wall Thickness (in.)			
2" COLD LEG BALANCE LINE BREAK			
Break Throat Diameter (in.)			
Break Area (in.^2)			
(L/D) Thickness/Diameter			
DOUBLE-ENDED COLD LEG/CMT BALANCE LINE Break			
Break Diameter (in.)			
Break Area (in.^2)			
Tube Length/Diameter:			
DVI LINE BREAKS			
Wall Thickness (in.)			
2" DVI Line Break			
Break Diameter (in.)			
Break Area (in.^2)			
(L/D) Thickness/Diameter			
Double-Ended DVI Line Break			
Break Diameter (in.)			
Break Area (in.^2)			
Tube Length/Diameter:			

The steam outlet line is directed to the common header, as described before. The Separator, the loop seal lines, and the steam line are preheated and insulated to minimize heat loss to the atmosphere and to prevent steam condensation. Heating the loop seal lines also ensures that the temperature of the condensate is close to the temperature at which it would collect in the AP600 containment sump.

3.21 Break and ADS Measurement System (BAMS)

3.21.1 Function

The BAMS accurately measures the steam and liquid flows from the four ADS stages and each break simulator being tested.

3.21.2 Scaling Bases

Since BAMS is only a measurement system for this test facility and is not present in the AP600, it is not necessary to scale the components of this system. The tanks and separators were sized to handle the maximum two-phase flows expected from the break simulators and the ADS. Scaling of the lines prior to the separators are discussed in Section 3.16.2 (ADS1-3), Section 3.17.2 (ADS, Stage 4), and 3.20.2 (Break Simulators).

3.21.3 Description

The approach used to measure these two-phase flows accurately is to separate each two-phase flow stream into its liquid and vapor components and then to measure the flow rate and temperature of each single-phase flow stream. For ADS and the Break Separators, the vapor streams are vented to the atmosphere and the liquid phases are collected in the Primary Sump which simulates the Containment Sump in the AP600. Heated water from the Condensate Tank is pumped into the Primary Sump Tank at a mass flow rate equivalent to the rate of vented steam. This water simulates the flow of condensate from the steam vented into the containment which would be condensed and would drain into the Containment Sump. The steam and liquid flows from the ADS1-3 Separator are recombined and flow into the IRWST through the sparger.

Equipment

The BAMS consists of four separators and the associated piping and instrumentation to measure the single-phase flows and to conduct streams to the appropriate location. Table 3.21-1 provides the data for the Separators, which are made of Type 304 stainless steel by Wright-Austin Company, Detroit, Michigan.

3.21.4 Instrumentation

Instrumentation provided for the BAMS fluid measurements are:

- 3 - Magnetic Flowmeters (Liquid)

- 5 - Vortex Flowmeters (Steam)

- 3 - Pressure Cells

- 10 - Thermocouples (Liquid)

- 14 - Thermocouples (Trace Heater)

- 3 - Solenoids (Closed)

- 3 - Solenoids (Open)

- 3 - Limit Switches (Closed)

- 3 - Limit Switches (Open)

3.22 Test Support Systems

Several systems that are not AP600 models are required to operate the test facility. These systems, which are described in this section, are:

- Demineralized Water System
- Fill and Drain System
- RCP Seal Cooling System
- Electrical System
- Trace Heaters
- Insulation
- Heating, Ventilation, and Air Conditioning System
- Fire Protection

TABLE 3.21-1
SEPARATOR DATA

Tank	Model No.	Length, in.	Diameter, in.	Inlet	Vapor Outlet Dia., in.	Liquid Outlet Dia., in.
ADS1-3						
ADS4 (2 tanks)						
Break						

3.22.1 Demineralized Water System

City water is passed through two filters, connected in parallel, each with a differential pressure cell to indicate plugging. The combined flow from the filters is split into two streams, each passing through a separate and isolatable bank of demineralizers. After passing through another set of filters, the demineralized water flows to the feed storage tank. Feed lines which bypass the demineralizers are also provided to fill the RCP seal cooling system and the direct condensate tank. All lines are 1 inch stainless steel tubing with manually operated ball valves.

The piping and instrumentation diagram for this system is shown on page 1.4 of Appendix B; pages 5.62 and 5.63 of the same appendix are as-built piping isometrics for the Demineralized Water System.

3.22.2 Fill-and-Feed System

Demineralized water from the feed storage tank is pumped by a single feedwater pump to the steam generators. The feedwater line is 2-inch Sch 80 pipe from the feedwater tank and is 1-inch tubing, 0.87-inch inside diameter from the feedwater pump to the steam generators.

Fill lines to the primary and secondary sumps are connected to the Main Feed Header upstream of the feedwater pump. The RNS pump suction also is connected to the Main Feed Header.

The piping and instrumentation diagram for this system is provided on page 1.3 of Appendix B. Pages 5.25 through 5.32 of Appendix B are as-built drawings of the fill system piping

3.22.3 RCP Seal Cooling System

Heat is removed from the seals of the four RCPs by the closed circuit, RCP seal cooling system. Water is circulated by a centrifugal pump, through a jacket surrounding each pump seal. Heat is

mounted on the building roof. Thermocouples measure the temperature at each seal and the flow to each seal is monitored by a visual flow indicator.

The piping and instrumentation diagram for this system is on page 1.19, Appendix B.

3.22.4 Electrical System

The electrical system for the Low Pressure Integral Systems Test is shown in Figure 3.22-1. Three phase, 480 volt electric power is supplied to the facility from a 1000 kVA, 4160V transformer located outside the building. Power is divided into five circuits, two 600 amp circuits and three 200 amp circuits. The 600 amp circuits supply the Rod Bundle Heaters and the 200 amp circuits power the pressurizer heater, trace heaters, and motors. Current transformers connected to the 600 amp circuits and the 200 amp circuit to the pressurizer supply input to the Power Meters for each bank of Reactor Heaters and the Pressurizer Heater. Redundant current transformers and power meters are provided for the Reactor Heaters to verify these important data and to provide instrumentation back-up.

[

][c]

[

][c]

A 200 amp line supplies power to the trace heaters. Power to the Motor Control Panel is furnished by the 100 amp line.

Figure 3.22-1 Electrical One-Line Diagram

3.22.5 Trace Heaters

The BAMS separators and piping (up to and including the flowmeters) are heated to about 220°F to prevent condensation of the steam content, which would affect the steam/water mass ratios and the accuracy of the energy balances being measured. These trace heaters, which are arranged in 14 separate zones, each with on-off control, are Raychem Chemelex Heat Tracing Systems, Model 20XTV2-CT, rated at 20 kW/ft and 277 volts. Heater density was based on raising the BAMS tanks to 220°F from an initial temperature of 180°F in four hours, including heating water in the tanks. Piping heaters were based on preheating the piping in the BAMS to the same temperature.

3.22.6 Insulation

Thermal insulation is installed on all tanks and piping except the CMTs and ACCs which are uninsulated. Four types of insulation are used:

- 2-inches Fiberglass, Manville Micro-lok, k_{eff} = 0.31 Btu-in/hr-ft^2°F at 200°F
- 1-inch Fiberglass, Manville Micro-lok, k_{eff} = 0.31 Btu-in/hr-ft^2 °F at 200°F
- 1 1/2 inch, Polyisocyanurate Foam, Dow Plastics, k_{eff} = 0.141 Btu-in/hr-ft^2 °F at 75°F
- Removable Blankets, Ceramic Fiber, Lewco Specialty Products, k_{eff} = 0.55 Btu-in/hr ft^2 °F at 600°F

Table 3.22-1 is a matrix listing the insulation types for the major components and piping systems.

3.22.7 Heating, Ventilation, and Air-Conditioning System

The Test Facility is located in an enclosed building with a Heating, Ventilation, and Air-Conditioning designed to maintain relatively constant ambient temperatures during testing.

3.22.8 Fire Protection System

A Fire Protection System consisting of smoke sensors strategically located in the Test Facility and an audible alarm provides personnel and equipment protection.

TABLE 3.22-1
INSULATION APPLICATIONS

	Insulation		
	2" Fiberglass	**1" Fiberglass**	**1 1/2" Urethane**
RCS	X		
Pressurizer	X		
ADS1-2		X	
ADS - common line	X		
Steam Generators	X		
Condensate Return Tank	X		
Steam Line		X	
Condensate Piping		X	
IRWST			X
Primary Sump			X
Primary Sump Piping			X
Secondary Sump			X
DVI System Piping		X	
ADS Separators and Piping			X
Drain Collection Tank			X
Break Separator Tank & Piping to Primary Sump			X

4.0 CONTROL SYSTEM

In this section, the Control System is described. It is organized into two major subsystems: programmable controls and process controls.

4.1 Function

The Control System provides the necessary signals to:

- Operate the test system at steady-state simulating full power fluid conditions in the AP600
- Initiate the simulated loss-of-coolant transient
- Control the reactor heaters to simulate the decay heat production of an AP600 core
- Operate the BAMS
- Provide appropriate flows in the CVS and RNS
- Provide a controlled cooldown to standby on ambient conditions
- Provide safety trips for out-of-specification conditions affecting safety of personnel or damage to the facility

4.2 Programmable Control System

Seven Fischer/Porter Controllers, Micro-DCI-53MC522A21AAXXXXXXX, are used to provide dynamic and logic control functions that are programmed to produce AP600 scaled parameters during the tests and to provide protection during operations. These units provide control functions for the Reactor Heaters, Steam Generator No. 1, Steam Generator No. 2, BAMS, Pressurizer Heater, CVS and RNS Pumps, and Steam. Table 4.2-1 summarizes the functions, inputs, and safety trips for each of these controllers.

All of the programmable controllers function similarly: scan inputs, make necessary calculations, perform proportional, integral, or derivative functions, process alarms, process trip functions, and process outputs. They are "fail safe" logic in that a trip signal is externally a LOW and a normal condition is a HIGH.

TABLE 4.2-1
PROGRAMMABLE CONTROLLER SUMMARY

Controller	Inputs	Outputs	Trip Signals	Alarms
Reactor Heaters	SCR #1 Power SCR #2 Power Hot Leg #2 Temp Hot Leg #1 Temp Emergency Pushbutton Signal Sheathe Temp 2/4 Logic PZR Pressure Hi Hi Trip "S" Signal (Test Start)	Current Output to SCR #1 Current Output to SCR #2 Reactor Water Temp. High (Panel Alarm)	SCR 1 Hi Output Power SCR 2 Hi Output Power Total Output Power Hi Avg. Hot Leg Temp. Hi Emergency Pushbutton 2/4 Rod Sheathe Temp. Hi TH-3/4-3/304-3 Temp. Hi Key Switch in "OFF" SCR Cabinet Temp. Hi Pressurizer Pressure Hi Hi	SG1 Level Hi SG1 Level Low
Steam Generator No. 1	SG1 Wide Range Level SG1 Temp SG1 Narrow Range Level SG1 Feed Flow "S" Signal SG1 Steam Flow	Control Signal to Valve Motor SG1 Level Hi/Low (Panel Alarm) Input to Feed Pump Trip Logic	"S" Signal (Test Start) SG1 Level Hi Hi	SG1 Level Hi SG1 Level Low
Steam Generator No. 2	SG2 Wide Range Level SG2 Temperature SG2 Narrow Range Level SG2 Feed Flow "S" Signal (Test Start) SG2 Steam Flow	Control Signal to Valve Motor SG2 Level Hi/Low (Panel Alarm) Input to Feed Pump Trip Logic	"S" Signal (Test Start) SG2 Level Hi Hi	SG2 Level Hi SG2 Level Low

TABLE 4.2-1 (Continued)
PROGRAMMABLE CONTROLLER SUMMARY

Controller	Inputs	Outputs	Trip Signals	Alarms
BAMS	Condensate Flow to Sump Condensate Flow to IRWST Break Steam Flow (6" Line) Break Steam Flow (8" Line) Break Pressure Steam Flow Main (6" Line) Steam Flow Main (10" Line) "S" Signal (Test Start)	Control Signal to Valve Motor Control Signal to Valve Motor Indication Control Signal to Valve Motor Shut Signal for Air Operated Valve Shut Signal for Air Operated Valve Break Separator Pressure	Low Steam Flow Shut Signal Low Steam Flow-Shut Signal	
Pressurizer Heater	Pressurizer Level Pressurizer Temperature Narrow Range Pressurizer Press. Wide Range Pressurizer Press. External Trip	Pressurizer Level Bargraph Current Output to Press. SCR Pressurizer Press. Hi Trip Pressurizer Press. High/Low (Panel Alarm) Pressurizer Press. Hi Hi (Logic) Pressurizer Press. (Analog)	Pressurizer Press. Hi Hi Pressurizer Level Low Low Pressurizer Level Temp. Hi "S" Signal (Test Start) SCR Cabinet Temp Hi	
CVS and RNS Pumps	CVS Discharge Pressure CVS Discharge Flow RNS Discharge Pressure RNS Discharge Flow CVS Pump Start Signal RNS Pump Start Signal Pressurizer Pressure	Control Signal to Valve Motor Control Signal to Valve Motor Speed Signal to CVS Speed Controller	Pressurizer Pressure	
Steam Out	SG1 Pressure SG1 Steam Flow Total Steam Flow SG2 Pressure "S" Signal (Test Start) Break Pressure Flow BAMS Controller	Control Signal to Valve Control Motor Break Separator Pressure Hi Hi Temp SG1 Steam Flow (Analog) SG2 Steam Flow (Analog)		

4.3 Process Control System

The Process Control System consists of those devices necessary to control the test facility, but are not programmable. This system is used primarily during the establishment of the pre-test flow and temperature conditions, monitoring the system conditions during the tests, and in the post-test cooldowns to standby or ambient. Table 4-3 lists the Process Control System components and their functions.

4.4 Operator Panel

Figure 4.4-1 is a photograph of the Operator Panel, which is located in the Facility Control Room. It contains the Programmable Controllers and their displays and the Process Control System components listed in Table 4-3. Figure 4.4-2 is a drawing showing the arrangement of these components in the Operator Panel. The Control System instruments are incorporated into a simplified flow diagram with the approximate spatial relationships of the components being controlled.

TABLE 4-3 PROCESS CONTROL SYSTEM COMPONENTS			
Component	**Mfr/Model No.**	**Number**	**Function**
Temperature Scanner	Omega CN34025-DC	2	Indicates temperatures of trace heaters; off-on control at adjustable set-point
Temperature Scanner	Omega CN101K-1000F	1	Provides alarm if RCP seal cooling water exceeds adjustable set-point
Power Meters	Power Measurements, 3710 ACM	2	Indicates power to each bank of Rod Bundle Heaters
Bargraph Indicators	Universal VB-120-2-4	14	Indicates % of range for the following parameters: ADS1-3 Steam Flow, CMT2 Level ADS4-1 Steam Flow, IRWST Level ADS4-2 Steam Flow, Acc 1 Level LRGMS Steam Flow, Acc 2 Level CRP Temp., Primary Sump Level CVS Level, Secondary Sump Level CMT1 Level, Pressurizer Level
Panel Switches and Lights	Square D	33	Provides off-on control for air operated and motor operated valves; pump power with off-on indicator lights
Alarms	Panalarm Series 90	1	Alarm annunciator with 14 individual lights and a horn
Process Indicators	Newport Model 82	31	Indicates value of process parameter

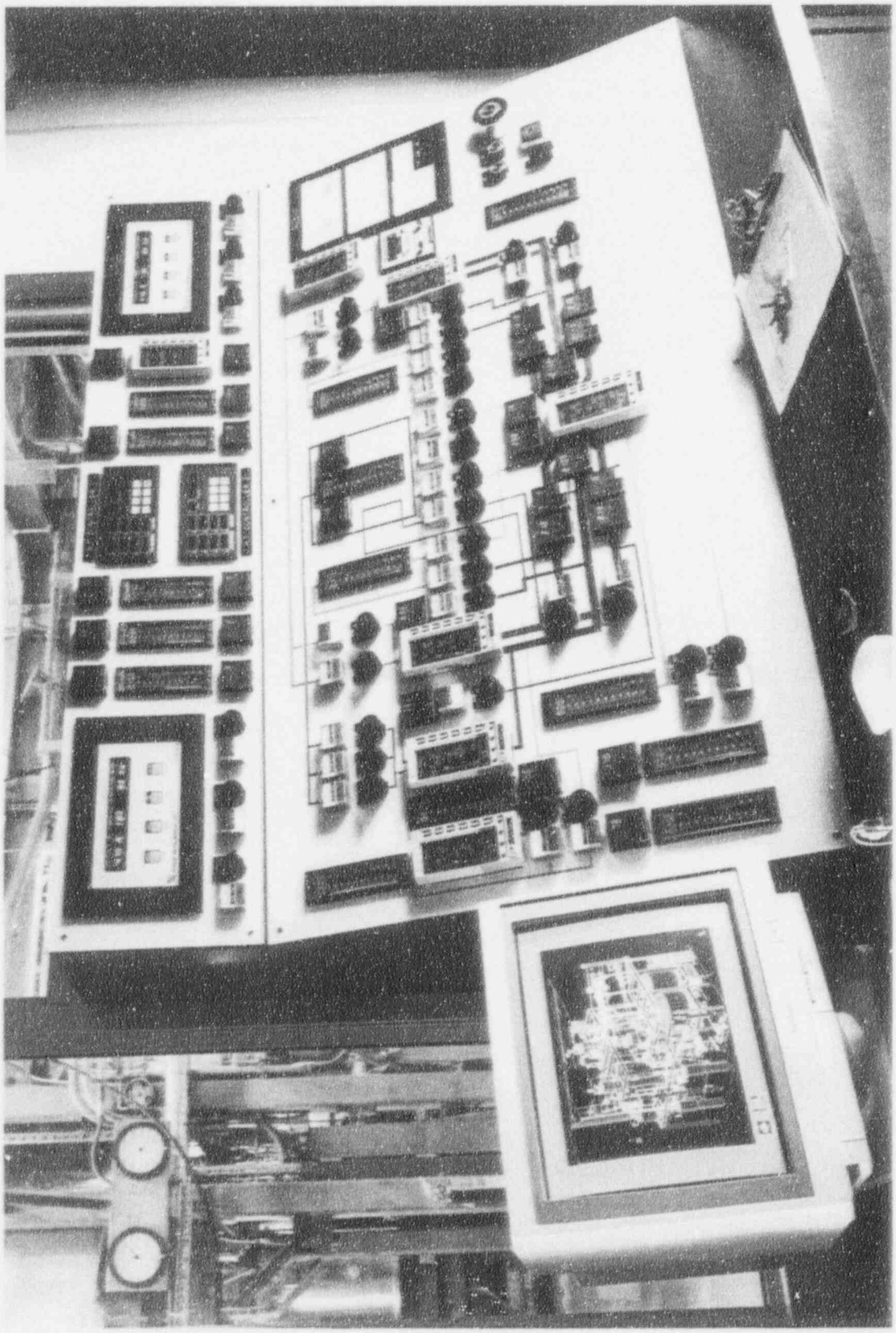


Figure 4.4-1 Photograph of Operator Panel

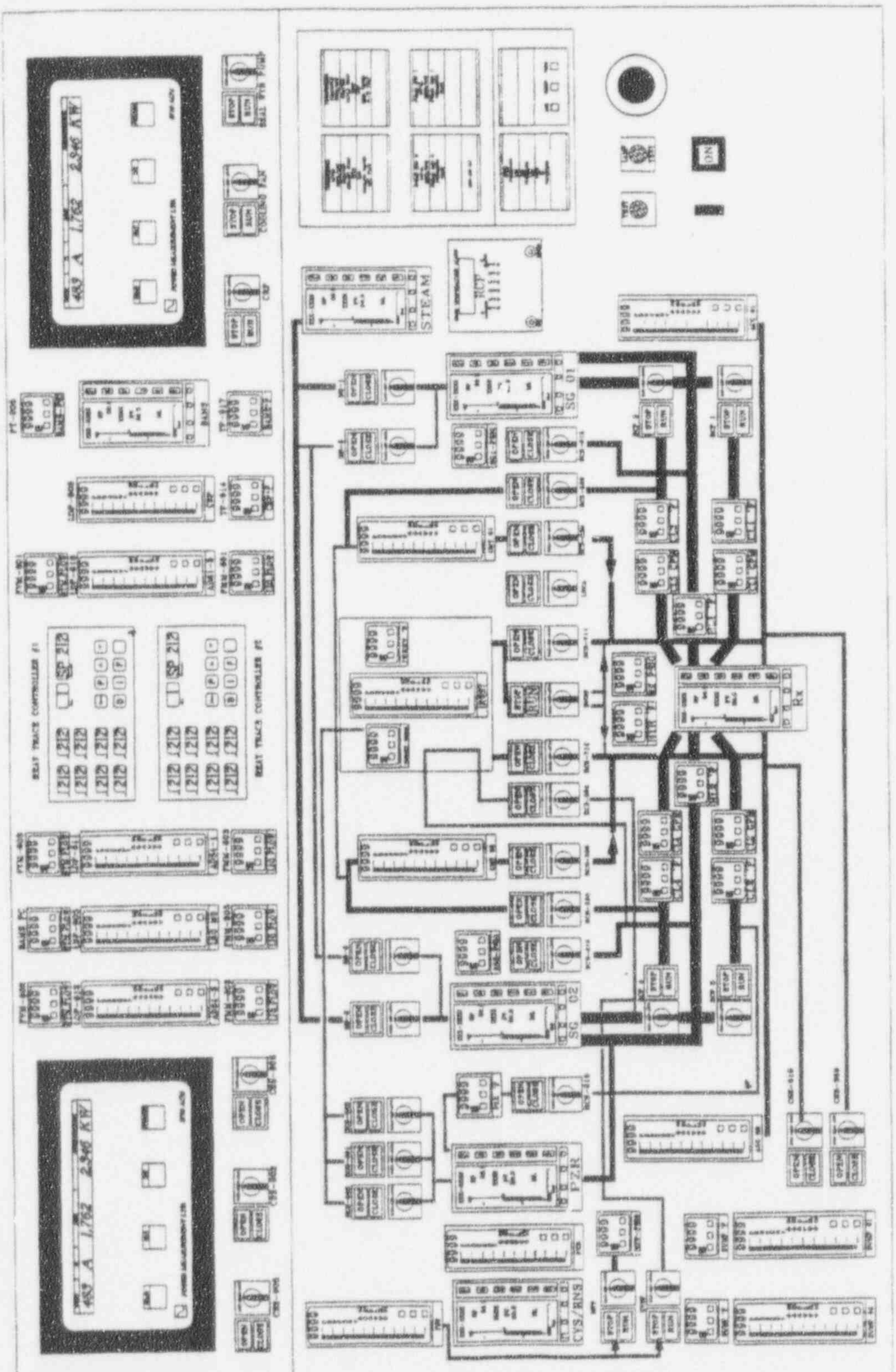


Figure 4.4-2 Drawing of Operator Panel

5.0 DATA ACQUISITION SYSTEM

The Data Acquisition System (DAS) receives the data from the test instrumentation, records it, and prepares it for analysis. This section describes the Data Acquisition System, including the architecture, hardware, and processing software.

5.1 System Hardware

The DAS consists of approximately 850 data channels which are being monitored during test operations. Figure 5.1-1 illustrates the system hardware. The channels are distributed among three separate racks tied to Fluke Helios Data Acquisition Units. Each rack is serially connected directly to a separate 486DX PC system. Each system PC is tied to the others via an Ethernet connection. The system software used for the LAN is Workgroup for Windows using NETBIOS. Rack 1 Helios contains approximately 300 channels and acquires data from the rapid responding inputs such as pressure or flow instruments. The remaining channels, primarily thermocouples, are split between rack 2 and rack 3.

5.2 DAS Architecture

Figure 5.2-1 is a schematic of the DAS system architecture. The system is initialized by the user from his PC together with the time and the system configuration database. Upon triggering, either by input from the user or by signal input at the start of a test, the Fluke Helios begins acquiring the data. Data are sent from the Helios to the PCs for all channels with instrument inputs and are stored by the PCs. From the incoming data, predefined channels are processed and displayed. The burst data are acquired at a higher rate for all channels and stored in the Helios until the end of the test. The data files are then recorded on a writable CD ROM.

5.3 Software

The DAS software is divided into five (5) main functions: Initialization, Data Acquisition, Burst Data Acquisition, Display Channel Monitoring, and Data Storage. Before the DAS execution can start, the system configuration file must be extracted from the system database, formatted, and transferred to the DAS PCs. The system configuration files are distributed in three main files sorted by rack and row, where each row is an A/D converter card. As a convenience, each row is also separated into a file which correlates with the burst data acquisition. From the configuration file, a set of channels is chosen to be displayed. A file is created containing parameters for the display channels that will be monitored during test operations.

The initialization function prompts the user for input data and sends the channel configuration to the Helios equipment and waits for an acknowledgment of the channel definitions. Other configuration data sent to the Helios include the burst rate, system time, and other setup parameters. This function also initializes the PCs with the display channel information and the burst delay time.

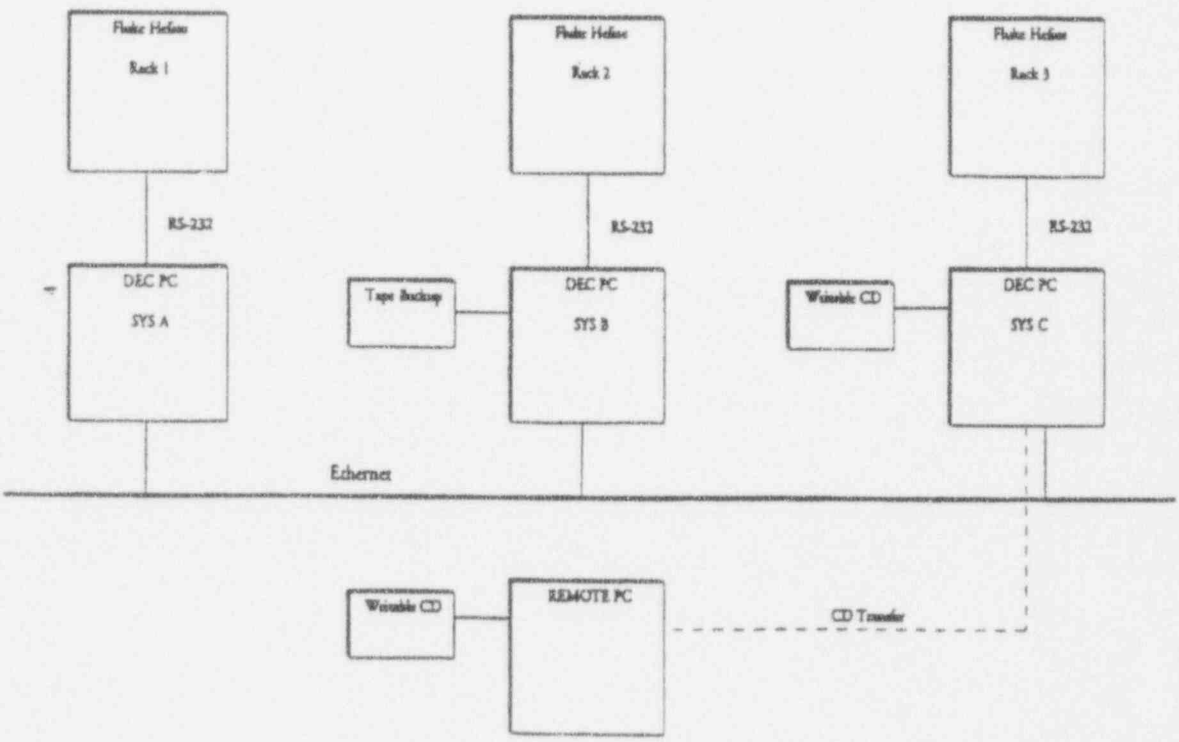


Figure 5.1-1 DAS Hardware

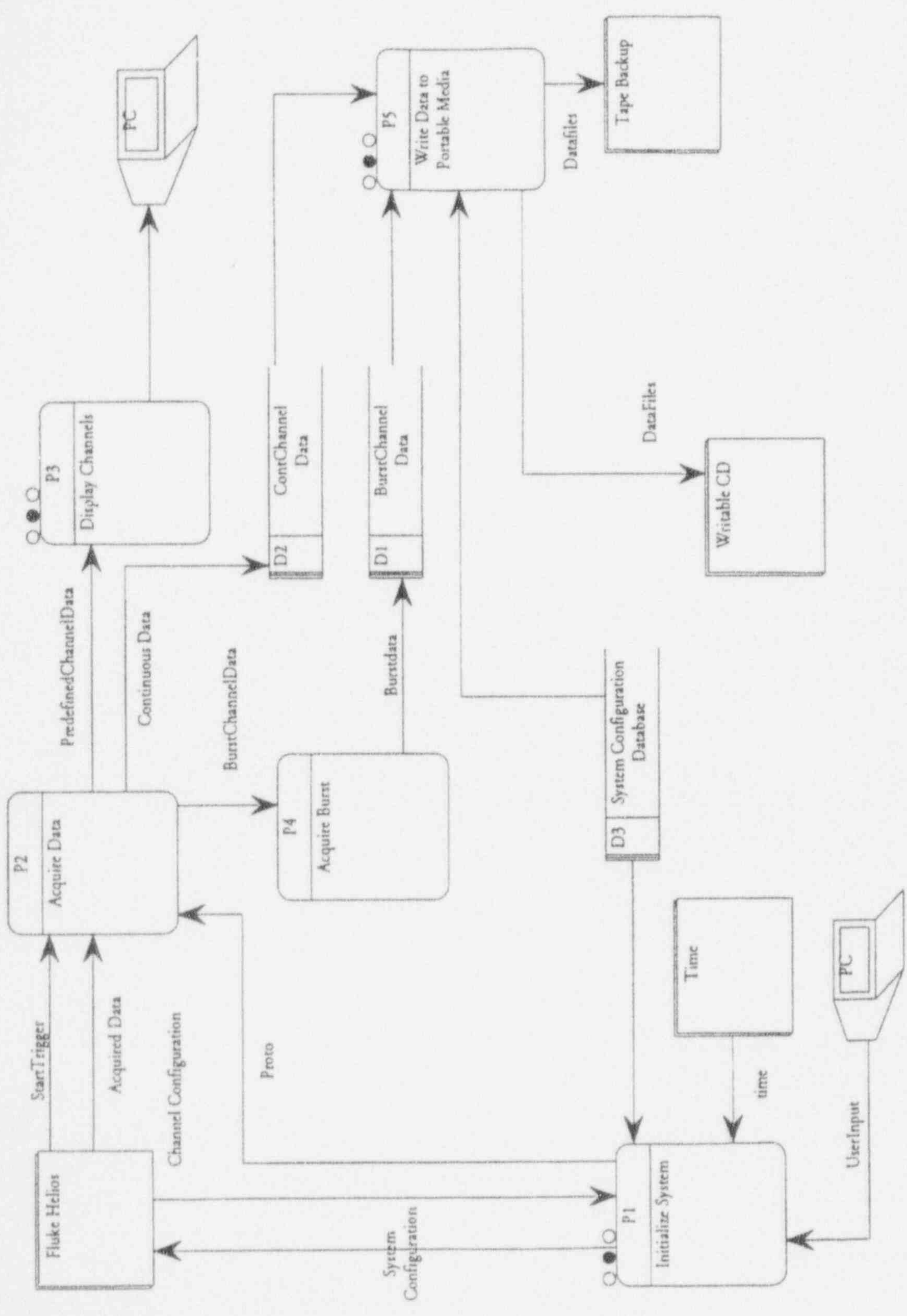


Figure 5.2-1 DAS Architecture

The data acquisition function is designed to retrieve the channel data and write it to a system disk continuously every 8 to 10 seconds from the start of test until the end of test operations. The start of acquisition is either triggered by a transient signal or by operator input. Operator action is required to stop the acquisition.

The burst data acquisition acquires data at a faster rate, but for a shorter length of time than the continuous acquisition. The burst rate is user defined from once per second to once every 10 seconds. The start of burst is input by the test operator and can begin immediately with the start of continuous acquisition or can be delayed minutes or hours. This means that at a burst rate of once per second, the burst data can be acquired for about 1/2 hour. The burst data system can store up to 1900 scans for each channel.The burst data are stored on the Helios until the end of test operations. The operator then initiates the transfer of data from the Helios to the system PC and stores it in an ASCII file.

The display channel monitor function selects the channel values from the continuous data stream for the predefined channels. These channel values are converted from voltages into engineering units and displayed on the PC monitor. From the predefined channels the test operator can choose up to 4 channels to be dynamically charted on the monitor. The channel display indicates an alarm condition if the channel value falls outside the alarm value limit.

The data storage function accumulates all the configuration files, continuous data files, display data files, and burst data files and transfers them all to a single system via the LAN. The Scribe software is invoked to write the data files onto a CD ROM.

Further processing of the data files may be done at this point. One example of a post-processing activity includes generating files that are easily managed by Excel or another application software.

5.4 LabVIEW Description

The software is implemented in LabVIEW for Windows which uses a graphical programming language to create programs in block diagram form. LabVIEW is a general-purpose programming system, but it also includes libraries of functions and development tools designed specifically for data acquisition and instrument control. LabVIEW programs are called virtual instruments (VIs) because their appearance and operation imitate actual instruments. VIs have an interactive user interface, a source code equivalent, and accept parameters from higher level VIs. Figure 5.4-1 illustrates the AP600 DAS hierarchical VI.

The interactive user interface of a VI is called the front panel, because it simulates the panel of a physical instrument. The front panel can contain knobs, push buttons, graphs, and other controls and indicators. Data are input using a mouse and keyboard, then the results are viewed on the computer screen.

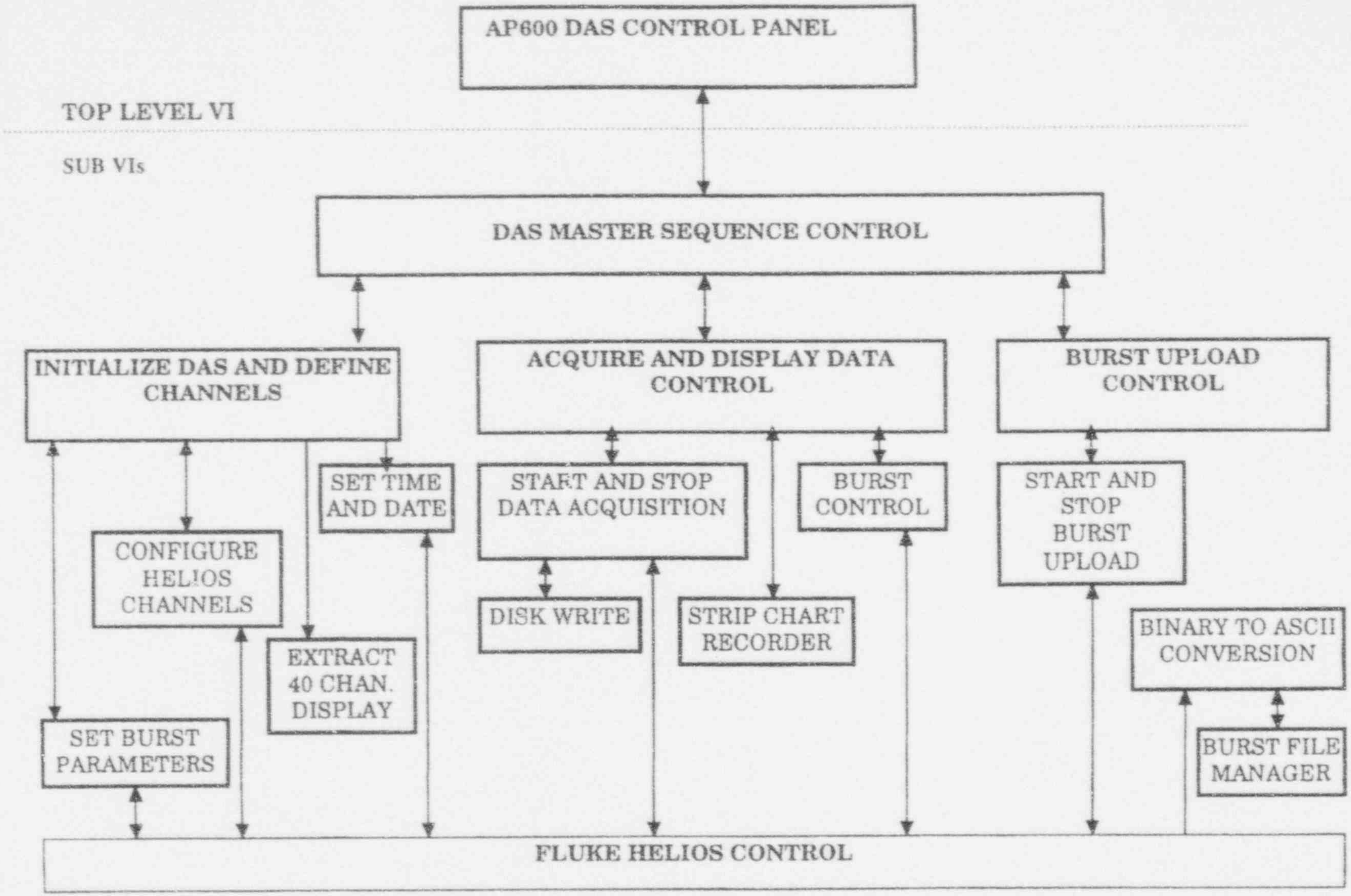


Figure 5.4.1 DAS Software Hierarchy

6.0 QUALITY ASSURANCE

The Quality Assurance requirements for the test facility and the data software are discussed in this section. The Quality Assurance requirements are defined in the Westinghouse AP600 Long Term Cooling Test Project Quality Plan, LTCT-GAH-001 and in Oregon State University, APEX Test Facility, PQP Site Implementation Plan (OSU-AP600-94-05-139).

6.1 Facility

The facility was designed and constructed in accordance with Section VIII, Division 1 of the ASME Pressure Vessel Code for the tanks and Power Piping Code B31.1 for the piping. Since the facility is electrically heated and contains no radioactive materials, the requirements of 10CFR50 are applicable to the facility only to the extent necessary to ensure the quality of the test date. The facility is licensed for operation by the State of Oregon Boiler Division.

The following quality records are maintained at the test site until they are transferred to the AP600 Central Files:

- Sketches (including as-builts)
- Calculations
- Procedures and instructions
- Quality related correspondence, transmittal and approval documentation
- Test results
- Code data reports
- Calibration documentation
- Personnel training and qualification records
- Computer program documentation (functional specification, validation packages, etc.)
- Installation vendor turnover packages

6.2 Software

Since the data for the tests resulting from this program will be used to validate safety codes for the AP600, data acquisition and reduction software are validated and controlled.

Software, whether purchased or internally developed within this project, has been validated by comparing its output with data secured from all of the following sources:

- Hand calculations
- Alternate verified calculational methods
- Results of other verified programs
- Known solutions for similar or standard problems
- Measured and documented plant data

- Confirmed published data and correlations
- Comparisons to known inputs and outputs (for data acquisition software only)

After validation, the software has been placed under configuration control. At this point, access to the source code and DAS Configuration File is limited to the Configuration Control contact. No other personnel are permitted access to the source code, except as hard copy, unless approved by the Project Manager.

7.0 SUMMARY

The Low Pressure Integral Systems Tests Facility has been scaled to represent the safety related components and thermal hydraulic behavior of the AP600. The Test Facility has been designed for operation at 450°F and 400 psig with a fully automated Data Acquisition System and automatic programmed control of the test parameters. This system will provide useful data for validating AP600 passive safety injection system models and analyses.

In order to verify that the components were fabricated to the design requirements and to provide accurate data for data analysis, critical attributes including tank volumes and flow resistances of certain flow lines were measured during the functional testing phase of the program. Tank volumes were measured by filling with water to the required level and then draining the tanks into a weight tank with calibrated weights. The tank volumes were then calculated from the weight of water collected. Line resistances were determined by measuring pressure drops across each line with a calibrated differential pressure cell at several flow ratios. The flow coefficients were then calculated from these data. Inside diameters of the Hot and Cold Leg piping were manually measured prior to installation. Table 7-1 summarizes these critical attributes.

Table 7-2 provides the time delays after the initiation of a transient for the automatic valve operations.

Weights of those components necessary for computer modeling the test facility are provided in Table 7-3.

The following Appendices include detailed information for this test facility:

Appendix A:	Hot Functional Tests and Test Matrix
Appendix B:	Key Drawings
Appendix C:	Drawing List
Appendix D:	Instrumentation Listing
Appendix E:	Orifice Sizing Details

The complete set of drawings are available from Westinghouse either as microfiche or in electronic file (Autocad) format.

Table 7-4 provides the characteristics of the orifices used to simulate the appropriate line flow resistances. Flow nozzles, which model line flow areas, are summarized in Table 7-5.

TABLE 7-1
CRITICAL ATTRIBUTE SUMMARY

Attribute	Value	Units	Reference
CMT1 Volume		ft^3	LTCT-T2R-001
CMT2 Volume		ft^3	LTCT-T2R-001
CMT1 Injection Line Loss Coeff.* (1)		Dimensionless	West. Calc.
CMT2 Injection Line Loss Coeff.* (1)			West. Calc.
ACC #1 Volumes: Gas Liquid		ft^3 ft^3	LTCT-T2R-001
ACC #1 Loss Coeff.* (1)		Dimensionless	West. Calc.
ACC #2 Volumes: Gas Liquid		ft^3 ft^3	LTCT-T2R-001
ACC #2 Loss Coeff.* (1)		Dimensionless	West. Calc.
ADS1-3 Line Loss Coeff.* (2)		Dimensionless	West. Calc.
IRWST Normal Volumes: Liquid Gas		ft^3 ft^3	LTCT-T2R-001
IRWST - DVI1 Injection Line Loss Coeff.* (1)		Dimensionless	West. Calc.
IRWST - DVI2 Injection Line Loss Coeff.* (1)		Dimensionless	West Calc.
Primary Sump Volume		ft^3	LTCT-T2R-001
Sump Recirculation Line 1* (3)		Dimensionless	West. Calc.
Sump Recirculation Line 2* (3)		Dimensionless	West. Calc.
Secondary Sump Volume		ft^3	LTCT-T2R-001
Large Break Separator Volume		ft^3	LTCT-T2R-001
ADS1-3 Separator Volume		ft^3	LTCT-T2R-001
ADS4-1 Separator Volume		ft^3	LTCT-T2R-001
ADS4-2 Separator Volume		ft^3	LTCT-T2R-001
Pressurizer Volume		ft^3	LTCT-T2R-001
Steam Generator #1 Shell-Side Vol.		ft^3	LTCT-T2R-001
Steam Generator #2 Shell-Side Vol.		ft^3	LTCT-T2R-001

TABLE 7-1 (Continued)
CRITICAL ATTRIBUTE SUMMARY

Attribute	Value	Units	Reference
Piping Inside Diameter:			
Hot Leg		in.	Manually measured, TIC
Cold Leg		in.	Manually measured, TIC
Reactor Vessel Volume (net liquid volume)		ft^3	OSU-V-08

* The loss coefficients are the total line losses, including both form and friction losses.

(1) Velocity is based on line cross-sectional area (0.985 in^2)

(2) Velocity is based on cross-sectional area of common inlet line (4.24 in^2)

(3) Velocity is based on the sum of the cross sectional areas of both parallel check valve lines (1.38 in^2)

TABLE 7-2
AUTOMATIC VALVE ACTUATION DELAYS

Valve		Normal Position	Time after "S" Signal for Actuation, Seconds
Number	Location		
MF-011	SG1 Feed	N-O	3.1 sec.
MF-012	SG2 Feed	N-O	3.1 sec.
RCS-535	CMT-01 Disch.	N-C	5.6 sec.
RCS-536	CMT-02 Disch.	N-C	5.6 sec.
MS-08	Main Steam	N-C	Depends upon SG Pressure
CSS-901	BAMS	N-C	0 sec.
RCS 529	CMT-01 Bal.	N-C	5.6 sec.
RCS 530	CMT-02 Bal.	N-C	5.6 sec.
RCS 601	ADS - 1st Stage	N-C	Open on CMT1 or CMT2 level of 41" and delay 15 sec., or cold leg pressure >400 PSIG
RCS 602	ADS - 2nd Stage	N-C	47 seconds after 1st stage
RCS 603	ADS - 3rd Stage	N-C	60 seconds after 2nd stage
RCS 604	ADS - 4th Stage	N-C	58 seconds after 3rd stage and CMT1 or CMT2 level < 17.14"

TABLE 7-3 AP600 COMPONENT WEIGHTS	
Reactor	
Pressure Boundary	
Reactor Internals	
Ceramic Reflector Ring	
Heater Rods	
Core Make Up Tank	
Accumulator	
Pressurizer	
IRWST	
Ceramic	
Tank	
Cover Plate	
PRHRX	
Primary Sump	
Secondary Sump	

TABLE 7-4
ORIFICE CHARACTERISTICS

Orifice Number	Location	Line I.D. Inch	Orifice Diameter Inch	Loss Coefficient (Dimensionless)
ORI-555	CMT to DVI Line 1			
ORI-556	CMT to DVI Line 2			
ORI-553	CMT01 - Cold Leg Balance Line No. 1			
ORI-554	CMT02 - Cold Leg Balance Line No. 2			
ORI-451	ACC01 - DVI No. 1			
ORI-452	ACC02 - DVI No. 2			
ORI-751	IRWST to DVI Line No. 1 (IRWST to Sump Tee)			
ORI-753	IRWST to DVI Line No. 1 (Sump Tee to DVI Tee)			
ORI-752	IRWST to DVI Line 2 (IRWST to Sump Tee)			
ORI-754	IRWST to DVI Line 2			
ORI-912	Sump Recir. at DVI Line 2 (Sump Tee - Sump)			
ORI-910	Sump Recirc. at DVI Line 2 (Sump Recirc. Parallel Line)			
ORI-909	Sump Recirc. at DVI Line No. 1 (IRWST/Sump Tee to Sump)			
ORI-911	Sump Recirc. at DVI Line No. 1 (Sump to Sump Branch)			
ORI-855	PRHR HX Outlet		Orifice not required	
ORI-854	PRHR Tee to Hx Inlet Nozzle		Orifice not required	
ORI-853	RNS Pump Discharge Branch Line No. 1			
ORI-857	RNS Pump Discharge Branch Line No. 2		Orifice not required	
ORI-653	Pressurizer - ADS1-3 Header		Orifice not required	
ORI-659	ADS1-3 Sep. Liquid Drain Line			

TABLE 7-4 (Continued)
ORIFICE CHARACTERISTICS

Orifice Number	Location	Line I.D. Inch	Orifice Diameter Inch	Loss Coefficient (Dimensionless)
ORI-603	5-inch ADS4 Sep. Line			
ORI-602A	8-inch ADS4 Sep. Line			
ORI-602B	8-inch ADS4 Sep. Line			
ORI-905	Break Sep. Liquid Line			

TABLE 7-5
FLOW NOZZLE CHARACTERISTICS

Line Identification	Flow Nozzle Throat ID, Inch	Flow Nozzle Nozzle Id No.	Location
ADS1-3 simulating double ended DVI line break and single train of ADS 1, 2, 3		FN-601-1L FN-602-1L FN-603-1L	Between node ADS9 - ADS9a (ADS stage 1) Between node ADS7 and ADS8 (2nd Stage ADS) Between node ADS5 and ADS10 (3rd Stage ADS)
ADS1-3 simulating double ended DVI line break and two train of ADS 1, 2, 3		FN-601-2L FN-602-2L FN-603-2L	Between node ADS9 - ADS9a (ADS Stage 1) Between node ADS7 and ADS8 (2nd Stage ADS) Between node ADS5 and ADS10 (3rd Stage ADS)
ADS1-3 simulating small break (smaller than 4") single train of ADS 1, 2, 3		FN-601-1S FN-602-1S FN-603-1S	Between node ADS9 - ADS9a (ADS stage 1) Between node ADS7 and ADS8 (2nd Stage ADS) Between node ADS5 and ADS10 (3rd Stage ADS)
ADS1-3 simulating double ended (smaller than 4") single train of ADS 1, 2, 3		FN-601-2S FN-602-2S FN-603-2S	Between node ADS9 - ADS9a (ADS Stage 1) Between node ADS7 and ADS8 (2nd Stage ADS) Between node ADS5 and ADS10 (3rd Stage ADS)
ADS4 on hot leg #1 (CMT side) simulating 50% AP600 flow area (8" ADS4 separator side)		FN-615-1	Downstream of ADS4 valve, RCS-615
ADS4 on hot leg #1 (CMT side) simulating 100% AP600 flow area (8" ADS4 separator side)		FN-615-2	Downstream of ADS4 valve, RCS-615
ADS4 on hot leg #2 (PZR side) simulating 50% AP600 flow area (5" ADS4 separator side)		FN-615-1	Downstream of ADS4 valve, RCS-615
ADS4 on hot leg #2 (PZR side) simulating 100% AP600 flow area (5" ADS4 separator side)		FN-615-2	Downstream of ADS4 valve, RCS-615

REFERENCES

2-1 N. Zuber, "Appendix D. A Hierarchical, Two-Tiered Scaling Analysis", An Integrated Structure and Scaling Methodology for Severe Accident Technical Issue Resolution, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, NUREG/CR-5809, November 1991.

2-2 R. A. Shaw et al, "Development of a Phenomena Identification and Ranking Table (PIRT) for Thermal Hydraulic Phenomena during a PWR Large-Break LOCA", U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, NUREG/CR-5074, November 1985.

2-3 J. N. Reyes, "Scaling Analysis for the OSU AP600 Integral System and Long Term Cooling Test Facility", Department of Nuclear Engineering, Oregon State University, Corvallis, Oregon 97331-5902, OSU-NE-9204, July 1993.

3-1 AP600 NOTRUMP Calculations, Westinghouse Electric Corporation, May 26, 1992.

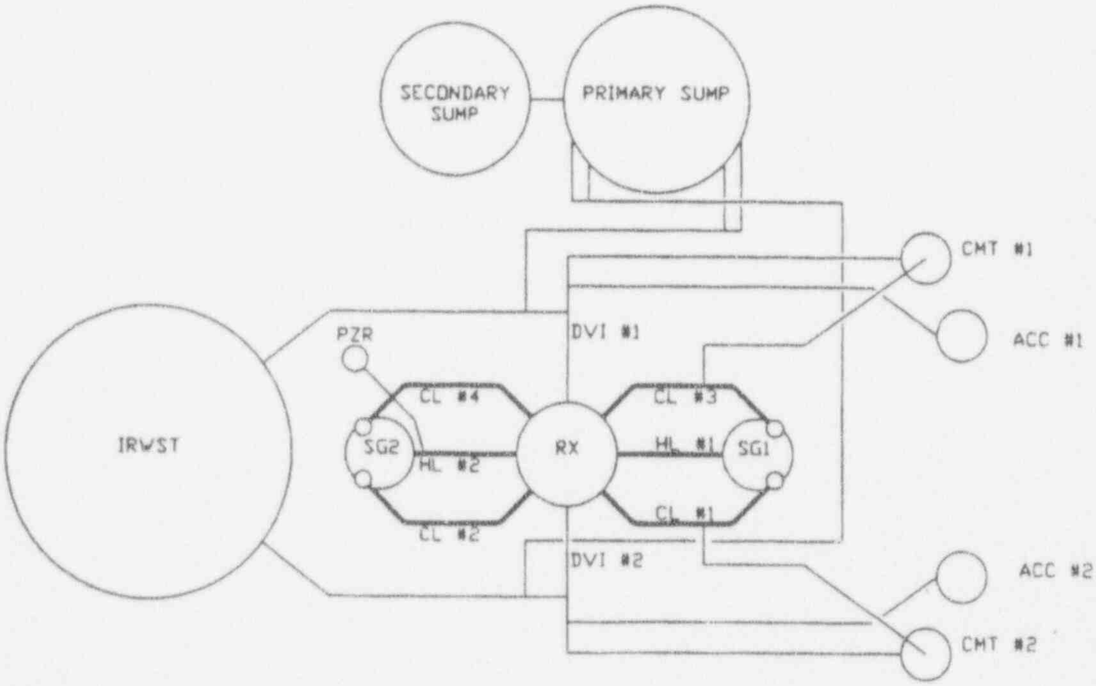
3-2 H. K. Fauske, "Flashing Flows or: Some Practical Guidelines for Emergency Releases", Plant/Operations Progress, Vol. 4, No. 3, July 1985.

Westinghouse Non-Proprietary Class 3 WCAP-14136

AP600

LOW PRESSURE INTEGRAL SYSTEMS TEST

AT OREGON STATE UNIVERSITY



FACILITY DESCRIPTION REPORT

JULY 1994

VOLUME II
Appendices

WCAP-~~14124~~ 14136

APPENDICES

Appendix A	Test Listing
A-1	Hot Functional Tests
A-2	Test Matrix
Appendix B	Key Facility Drawings
Appendix C	Long Term Cooling Facility Drawing List
Appendix D	Instrumentation List
Appendix E	Orifice Sizing Details

Appendix A
Test Listing

OSU-HS-01, Hot Functional Testing, Rev. 1 (RETEST), was performed on May 22-24, 1994.

Appendix A-1
OSU-HW-02

Appendix A-2
Test Matrix

Appendix B

Key Facility Drawings are Westinghouse Proprietary Class 2

Appendix C

AP600 Long Term Cooling Test Facility Drawings are Westinghouse Proprietary Class 2

Appendix D

The Instrumentation List is Westinghouse Proprietary Class 2

Appendix E

Orifice Sizing Details are Westinghouse Proprietary Class 2