GE Nuclear Energy

J. E. Quinn, Projects Manager
LMR and SBWR Programs

General Electric Company
175 Curtner Avenue, M/C 165 San Jose, CA 95125-1014
408 925-1005 (phone) 408 925-3991 (facsimile)

November 29, 1995

MFN 263-95
Docket STN 52-004

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington DC 20555

Attention: Theodore E. Quay, Director
Standardization Project Directorate

Subject: **SBWR - Non-Proprietary Handouts From the November 28 & 29, 1995, ACRS Thermal Hydraulic Subcommittee Meeting In San Jose, CA**

Enclosed are the non-proprietary handouts presented by GE during the November 28 and 29, 1995, ACRS Thermal Hydraulic Subcommittee Meeting in San Jose, CA.

Sincerely,

JEQ

James E. Quinn
Projects Manager

Enclosure: Non-Proprietary Handouts From the November 28 & 29, 1995, ACRS-Thermal Hydraulic Subcommittee Meeting In San Jose, CA

cc: P. A. Boehnert (NRC/ACRS) (2 paper copies w/encl. plus E-Mail w/ encl.)
I. Catton (ACRS) (1 paper copy w/encl. plus E-Mail w/ encl.)
S. Q. Ninh (NRC) (2 paper copies w/encl. plus E-Mail w/ encl.)
J. H. Wilson (NRC) (1 paper copy w/encl. plus E-Mail w/ encl.)

010052

9512010282 951129
PDR ADOCK 05200004
A PDR

D040 / 1

GE Nuclear Energy

Advisory Committee on Reactor Safeguards
Thermal Hydraulic Phenomena Subcommittee Meeting

SBWR Design and Certification Program
Review of Test & Analysis Program

November 28-29, 1995
San Jose, CA

Meeting Objectives

- *Update SBWR Program status.*
  - *Convey a sense of progress.*
  - *Demonstrate that have positively addressed issues.*
- *Progress toward closure of scaling. Specifically, gain . . .*
  - *Agreement that test facilities adequately represent the SBWR.*
  - *Acknowledgment that test results appropriate for qualifying TRACG.*
- *Initiate discussion of test results.*
  - *Early in evaluation process, formal documentation to follow.*
  - *Provide perspective on scaling.*
  - *Illustrate SBWR system behavior.*
- *Respond to two specific ACRS concerns.*
  - *Reactor startup behavior.*
  - *Chimney calculational basis.*

Meeting Agenda - November 28, 1995

0845	Welcome	Quinn
0850	Introduction/Program Status	Buchholz
0930	Test Program Overview	Torbeck
1015	Break	
1030	Scaling Evaluation Overview	Moody
	Closed Session	
1115	PCC/SBWR System Response	Shiralkar
1145	Lunch	
1230	Scaling Formulations/Application	Yadigaroglu/ Gamble
1640	Panthers Test Data/Evaluation	Billig/Fitch
1800	Recess	

[illegible]

Meeting Agenda - November 29, 1995

0805	PANDA Test Results	Yadigaroglu
1015	Break	
1030	GIRAFFE Helium Test Results	Herzog
1110	GIRAFFE SIT Test Results	Duncan
1200	Lunch	
1245	SBWR Startup Behavior	Tang
1330	Chimney Calculation Basis	Shiralkar
1415	GE Presentation Closure	

[illegible]

GE Nuclear Energy

Advisory Committee on Reactor Safeguards
Thermal Hydraulic Phenomena Subcommittee Meeting

SBWR Design and Certification Program
Technology Phase Update

November 28, 1995
San Jose, CA

Technology Phase Overview - Testing

- Significant progress since last meeting.
- Testing being conducted at three facilities in three countries.
  - Italy - PANTHERS PCCS and IC testing
  - Japan - GIRAFFE helium and systems interactions testing
  - Switzerland - PANDA steady state and transient integral systems testing
- As testing is completed, emphasis shifts to documentation.
- Maintaining constant contact with NRC staff.
- Challenges being encountered, but resolving in a timely manner.

Technology Phase -- Key Milestones

- ***Giraffe***
  - ***Perform shakedown/characterization testing . . . 19May95 (complete)***
  - ***Successfully complete NRC QA inspection . . . 14Jun95 (complete)***
  - ***Perform single and mixed gas testing . . . 27Jun95 (complete)***
  - ***Perform tie-back tests . . . 16Aug95 (complete)***
  - ***Perform systems interaction testing . . . 31Oct95 (complete)***
- ***Panda***
  - ***Perform facility shakedown tests . . . 28April95 (complete)***
  - ***Perform steady state tests S1-S6 . . . 10May95 (complete)***
  - ***Perform steady state tests S7-S9 . . . 18May95 (complete)***
  - ***Perform steady state tests S10-13 . . . 4Aug95 (complete)***
  - ***Perform 1st set of integral systems tests . . . 15Nov95 (complete)***
  - ***Perform 2nd set of integral systems tests . . . in progress***
  - ***Perform 3rd set of integral systems tests . . . 30Jan96***

Technology Phase -- Key Milestones (cont'd)

- ***Panthers***
  - ***Perform PCC T/H tests . . . 20Dec94 (complete)***
  - ***Perform IC facility shakedown tests . . . 27July95 (complete)***
  - ***Perform IC low pressure T/H tests . . . 4Aug95 (complete)***
  - ***Perform IC high pressure T/H tests . . . 13Oct95 (complete)***

Technology Phase Overview - Analysis

- *Completing blind pre-test predictions and transmitting to NRC to support testing schedule.*
- *Thus far, results consistent with test predictions.*
- *Focus to shift to post-test evaluations to support issue of Preliminary Validation Reports.*
- *Several significant documents submitted to NRC.*
  - *Revisions B and C to the TAPD, responded to Staff and ACRS comments*
  - *Large supplement to TAPD containing detailed PIRT information.*
  - *Significant expansion of Scaling Report.*
  - *Responded to meeting questions and RAIs.*

  These actions taken to resolve NRC/ACRS stated concerns, requests, and issues.

Technology Phase -- Key Milestones (cont'd)

- *Analysis Related*
  - *Issue TAPD Revision B . . . 18Apr95 (complete)*
  - *Issue TAPD Revision C & PIRT supplement . . . 30Aug95 (complete)*
  - *Issue Scaling Report revision . . . 17Oct95 (complete)*
  - *Perform PANTHERS PCC pre-test analysis . . . 28Sept94 (complete)*
  - *Perform PANTHERS IC pre-test analysis . . . 5Jul95 (complete)*
  - *Perform GIRAFFE helium pre-test analysis . . . 21Aug95 (complete)*
  - *Perform GIRAFFE SIT pre-test analysis . . . 29Sept95 (complete)*
  - *Perform PANDA M-3 pre-test analysis . . . 21Aug95 (complete)*
  - *Perform last PANDA transient pre-test analysis . . . 19Dec95*
  - *Issue TRACG Model Report update . . . 31Jan96*

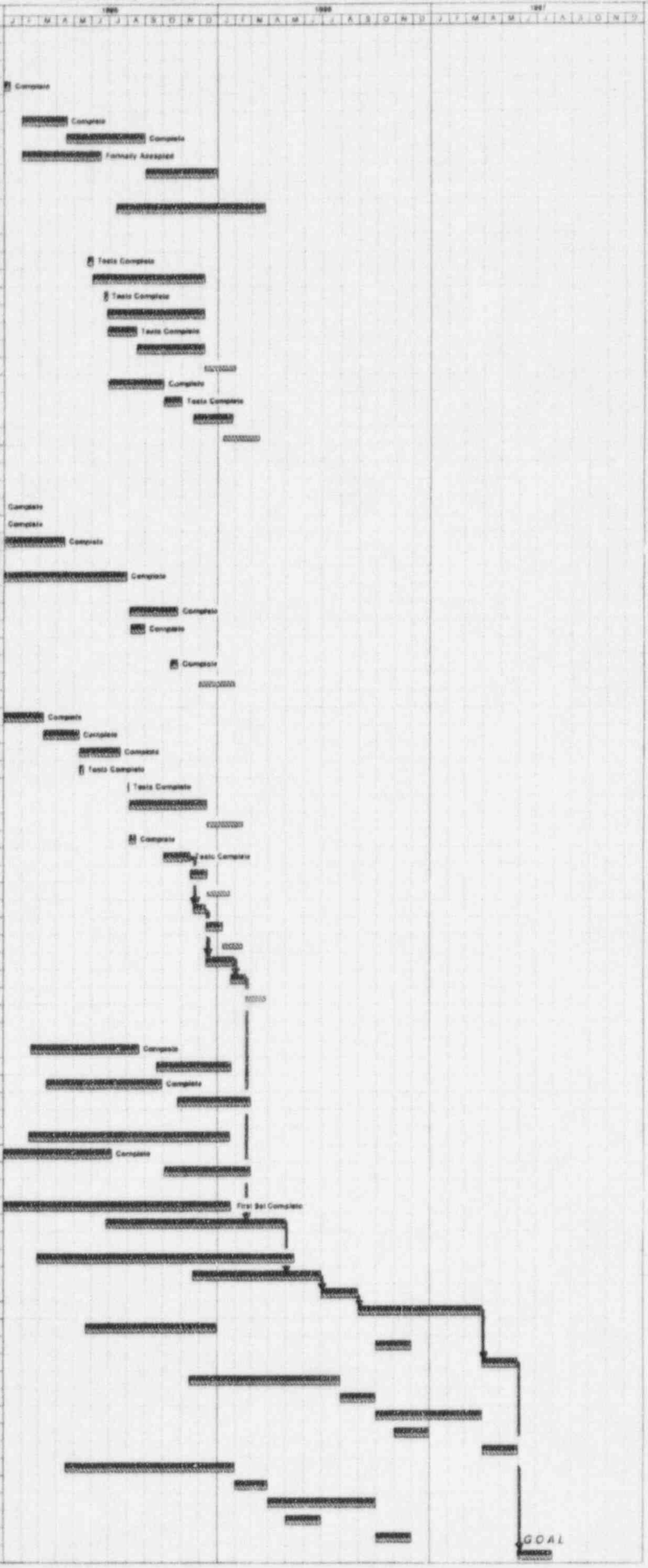
Summary

- ***Significant progress since last ACRS meeting.***
  - *Testing programs on-going toward completion.*
  - *Meeting commitments in support of testing/analysis/issue resolution*
- ***Today's challenges . . .***
  - *Competent, timely completion of testing and analysis activities.*
  - *Responsiveness, when faced with new technical issues/problems.*
  - *Maintaining support from the SBWR Team.*
  - *Continue dialogue with NRC and ACRS in support of Technology Phase completion.*

Timely, quality execution is essential to maintain momentum.

General Electric - Nuclear Energy
Simplified Boiling Water Reactor
Summary Testing & Analysis Schedule

ID	Activity Description	Start	Finish
1	***Documentation***	*Jul 1 94*	*Mar 28 96*
2	Test & Analysis Plan	Jul 1 94	Dec 28 95
3	GE Prepares Test & Analysis Program Description (TAPD)	Jul 1 94	Aug 10 94
4	NRC & ACRS TAPD Review	Aug 15 94	Jan 17 95
5	GE Revises TAPD - Revision A	Aug 11 94	Sep 16 94
6	GE Revises TAPD - Revision B	Feb 1 95	Apr 18 95
7	GE Revises TAPD - Revision C	Apr 18 95	Aug 30 95
8	NRC Endorses TAPD - Revision B	Feb 1 95	Jun 16 95
9	NRC Endorses TAPD - Revision C	Aug 1 95	Dec 29 95
10	Testing Topical Report	Jul 13 95	Mar 28 96
11	GE Prepares SBWR Testing LTR	Jul 13 95	Mar 25 96
12	***Testing***	*Jul 1 94*	*Mar 28 96*
13	GIRAFFE	May 24 95	Mar 15 96
14	Perform He Back/Single Gas Tests - Phase 1	May 24 95	Jun 7 95
15	ATR - Phase 1	Jun 2 95	Dec 8 95
16	Perform Mixed Gas Tests - Phase 2	Jun 22 95	Jun 27 95
17	ATR - Phase 2	Jun 27 95	Dec 8 95
18	Perform He Back Tests - Phase 3	Jun 28 95	Aug 16 95
19	ATR - Phase 3	Aug 17 95	Dec 8 95
20	DTR - Phases 1, 2, 3	Dec 9 95	Jan 31 96
21	Perform Facility Modifications & Shakedown	Jun 29 95	Oct 2 95
22	Perform System Interaction Tests	Oct 3 95	Oct 31 95
23	ATR	Nov 20 95	Jan 26 96
24	DTR	Jan 10 96	Mar 15 96
25	PANTHERS PCCs	Jul 18 94	Apr 14 95
26	Perform First Priority Thermal Hydraulic Tests	Jul 18 94	Aug 5 94
27	Perform Cyclic Performance Tests	Aug 29 94	Sep 15 94
28	Complete Thermal Hydraulic Tests	Sep 19 94	Dec 30 94
29	ATR	Nov 30 94	Dec 30 94
30	DTR	Dec 31 94	Apr 14 95
31	PANTHERS IC	Sep 19 94	Jan 31 96
32	Prepare Facility for Low Pressure Tests Phase 1	Sep 19 94	Jul 31 95
33	Perform Phase 1 Thermal Hydraulic Tests	Aug 1 95	Aug 4 95
34	ATR - Phase 1	Aug 5 95	Oct 25 95
35	Prepare Facility for High Pressure Tests Phase 3	Aug 7 95	Aug 31 95
36	Perform Phase 3 Thermal Hydraulic Tests	Oct 11 95	Oct 13 95
37	ATR - Phase 3	Oct 14 95	Oct 25 95
38	DTR - Phases 1, 3	Dec 1 95	Jan 31 96
39	PANDA	Jul 1 94	Mar 28 96
40	Prepare Facility At PSI	Jul 1 94	Mar 9 95
41	Perform Steady State Tests S1 - S6	Mar 10 95	May 10 95
42	ATR - S1 thru S6	May 11 95	Jul 30 95
43	Perform Steady State Tests S7-S9	May 11 95	May 16 95
44	Perform Steady State Tests S10-S13	Aug 3 95	Aug 4 95
45	ATR - S10 thru S13	Aug 5 95	Dec 13 95
46	DTR - S10 thru S13	Dec 14 95	Feb 14 96
47	Complete Facility Characterization Activities	Aug 5 95	Aug 18 95
48	Perform Transient Tests M3, M3a, M3b, M7	Oct 3 95	Nov 15 95
49	ATR - M3, M3a, M3b, M7	Nov 16 95	Dec 14 95
50	DTR - M3, M3a, M3b, M7	Dec 15 95	Jan 27 96
51	Perform Transient Tests M2, M10a, M10b	Nov 21 95	Dec 11 95
52	ATR - M2, M10a, M10b	Dec 12 95	Jan 9 96
53	DTR - M2, M10a, M10b	Jan 10 96	Feb 13 96
54	Perform Transient Tests M6, M8, M5	Dec 12 95	Jan 20 96
55	ATR - M6, M8, M5	Jan 21 96	Feb 20 96
56	DTR - M6, M8, M5	Feb 21 96	Mar 28 96
57	***Analyses***	*Apr 4 94*	*Jul 31 97*
58	Pre & Post Test Analyses	Apr 4 94	Apr 30 96
59	Perform GIRAFFE Helium Blind Test Analyses	Feb 17 95	Aug 21 95
60	Perform GIRAFFE Helium Post Test Analyses	Sep 21 95	Jan 24 96
61	Perform GIRAFFE SIT Blind Test Analyses	Mar 15 95	Sep 29 95
62	Perform GIRAFFE SIT Post Test Analyses	Oct 28 95	Feb 28 96
63	Perform PANTHERS PCC Pre Test Analyses	Apr 4 94	Sep 28 94
64	Perform PANTHERS PCC Post Test Analyses	Feb 15 95	Jan 27 96
65	Perform PANTHERS IC Pre Test Analyses	Dec 8 94	Jul 6 95
66	Perform PANTHERS IC Post Test Analyses	Oct 4 95	Feb 26 96
67	Perform PANDA Pre Test Analyses (S-series)	Aug 8 94	Sep 27 94
68	Perform PANDA Pre Test Analyses (M-series)	Aug 8 94	Jan 23 96
69	Perform PANDA Post Test Analyses	Jun 26 95	Apr 30 96
70	TRACG Qualification	Feb 27 95	Jul 31 97
71	Determine TRACG Model Bias & Uncertainty	Feb 27 95	May 15 96
72	Issue TRACG Qualification LTR Supplement	Nov 28 95	Jun 30 96
73	NRC Acceptance of TRACG Qualification LTR for Review	Jul 1 96	Aug 31 96
74	NRC Review TRACG Qualification LTR	Sep 1 96	Mar 31 97
75	GE Respond to 94 RAIs on TRACG Qualification LTR	May 22 95	Dec 29 95
76	GE Respond to RAIs on TRACG Qualification LTR	Oct 1 96	Nov 30 96
77	NRC Prepare SER on TRACG Qualification LTR	Apr 1 97	May 31 97
78	Issue TRACG Application LTR	Nov 15 95	Jul 31 96
79	NRC Acceptance of TRACG Application LTR for Review	Aug 1 96	Sep 30 96
80	NRC Review TRACG Application LTR	Oct 1 96	Mar 31 97
81	GE Respond to RAIs on TRACG Application LTR	Nov 1 96	Dec 31 96
82	NRC Prepare SER on TRACG Application LTR	Apr 1 97	May 31 97
83	Update/Expand TRACG Model LTR	Apr 17 95	Jan 31 96
84	NRC Acceptance of TRACG Model LTR for Review	Feb 1 96	Mar 31 96
85	NRC Review TRACG Model LTR	Apr 1 96	Sep 30 96
86	GE Respond to RAIs on TRACG Model LTR	May 1 96	Jun 30 96
87	NRC Prepare SER on TRACG Model LTR	Oct 1 96	Nov 30 96
88	GE Issue Approved Proprietary Document	Jun 1 97	Jul 31 97



Project Finish Date: July 31 1997
Plot Date: Nov 27 1995

Baseline Activity ▬ Baseline ATR ▬ Baseline DTR ▬ Forecast ▨ Critical Path →

C:\WINPROJ\SBWR\TESTANAL\1-BASE.MPP

GE Nuclear Energy

ACRS Thermal Hydraulic Subcommittee Meeting

SBWR Test Program Overview

J.E. Torbeck
November 28, 1995
San Jose, California

filename: ws1023

PANTHERS Testing

Purpose

- ***Demonstrate PCC & IC heat exchanger performance***

Description

- ***Full scale PCC and IC heat exchanger tests***
- ***Performed by ENEA/ENEL/Ansaldo/SIET in Italy***

Status

- ***PCC testing and reporting completed***
- ***IC thermal hydraulic performance testing complete***
- ***IC structural tests in progress***

PANTHERS Testing (cont'd)

PCC Results

- PCC meets design objectives
  - Condenses 10 MW of steam at design conditions
  - Condenses with significant fraction of non-condensable gases present
  - Venting of non-condensable gases demonstrated
- PCC thermal-hydraulic performance is well behaved
- Difference between performance with lighter-than-steam and heavier-than-steam gases established

IC Results

- Steady State performance tests preliminary results show it meets specifications.

PANDA Testing

Purpose

- ***Demonstrate containment systems thermal-hydraulic performance***

Description

- ***1/25 volumetric scale, full-height facility***
- ***Performed by Paul Scherrer Institut - Switzerland***

PANDA Testing (cont'd)

Status

- 10 Steady-state PCC performance tests complete
  - At scaled conditions corresponding to PANTHERS tests
- Facility characterization testing complete
  - Heat Loss Tests
  - Line Flow Loss Tests
- Transient integral systems tests initiated in October
- 5 transient tests complete (about half of planned tests)

PANDA Testing (cont'd)

Key Results

- *Steady state PCC performance test data trends are consistent with PANTHERS*
- *Transient results show drywell and wetwell pressure response consistent with expectations*
- *Data on noncondensible gas concentrations obtained in drywell and wetwell with oxygen sensors*

Remaining actions

- *Proceed with transient integral systems tests*

GIRAFFE/Helium Testing

Purpose

- Demonstrate containment system thermal-hydraulic performance in the presence of lighter-than-steam non-condensable gas (Four H-Series Tests)
- Repeat earlier GIRAFFE tests performed without NQA-1 Quality Assurance (Two T-Series Tests)

Description

- 1/400 volumetric scale, full height facility
- Performed by Toshiba Corp. - Japan

Status

- 6 transient tests completed in August

GIRAFFE/Helium Testing (cont'd)

Test Results

- *Tests show drywell and wetwell pressure response consistent with expectations*
- *Tests demonstrated the purging of non-condensable gases from the drywell and PCC to the suppression pool*
- *The PCCS maintains containment pressure well below design pressure for all tests, with drywell non-condensable gas concentrations as high as 27% by volume.*
  - *with helium, nitrogen or mixtures of helium and nitrogen.*
- *Direct sampling and measurement of gases provide further data on the movement of non-condensable gases*

GIRAFFE/SIT Testing

Purpose

- Provide data for GDCS period of LOCA
- Focus on RPV water level and potential systems interactions (IC, PCCS)

Description

- 1/400 volumetric scale, full height facility
- Performed by Toshiba Corp. - Japan

Status

- 4 tests completed in October

GIRAFFE/SIT Testing (cont'd)

Results

- ***Tests show RPV level response consistent with expectations***
- ***IC, PCCS have favorable effect on containment pressure***
- ***IC, PCCS have no adverse interaction on GDCS***
- ***IC has no adverse interaction on RPV level recovery***

Summary

- Testing in progress or completed for all test programs
- Large data base obtained
- No significant surprises
- International Partners' cooperation has been a key factor in progress

Tests are demonstrating significant margins in SBWR design

GE Nuclear Energy

Scaling of the SBWR Related Tests

Scaling Team:	*Robert Gamble*	*Andy Hunsbedt*
	Fred Moody	*Maureen Parker*
	George Yadigaroglu	

Presented By: Fred Moody

ACRS Meeting
San Jose, CA
November 28, 1995

SCALING OF THE SBWR RELATED TESTS

- *ACRS/NRC ISSUES ADDRESSED IN SCALING REPORT*
  - *Considerable expansion of earlier Scaling Report (Rev. 0)*
  - *Discussion of "Global System Scaling" added*
  - *Initial conditions and reference values addressed*
  - *GIRAFFE/Helium and SIT tests included*
  - *Manometric oscillations between large water volumes analyzed*
  - *Sections from TAPD integrated into Scaling Report*

COMPARISON OF REV. 0 AND REV. 1 OF SCALING REPORT

- ***The basic approach and results are the same (except for minor corrections)***
- ***Top-down Scaling***
  - ***Definition of alternate Π numbers in the momentum equation that make effect of piping inertia evident***
  - ***Use of $(h_{o,i} - h)$ in energy equation instead of $(h_{o,i} - e)$***
  - ***Consideration of scaling for constituent mass fractions***
- ***Major Additions***
  - ***Inclusion of PIRT for LOCA/ECCS Phenomena***
  - ***Consideration and scalin gof the important RPV phenomena***
  - ***Generic dynamic model of the entire system***
  - ***Use of this model to derive sets of "global" system descriptions for particular phases of the transients considered***

COMPARISON OF REV. 0 AND REV. 1 OF SCALING REPORT

- ***Application of the methodology to the various facilities (previously contained in TAPD)***
  - *Identifies important system parameters regarding top-down scaling*
  - *Identifies any distortions of the parameters (which can be "weighted" by their importance*
- ***Bottom-up Scaling***
  - ***Additional considerations***
    - *Natural circulation in SC air space*
    - *Stratification and mixing in DW*
    - *Expanded discussion on heat transfer from the condensers*
    - *Analysis of oscillations between large liquid pools*
    - *void distribution in the RPV*

PRESENTATION OUTLINE

- *Overview and consistency with H2TS methodology - Fred Moody*
- *Analytical basis for top-down and bottom-up scaling - George Yadigaroglu*
- *Comparison of SBWR and Test Facility scaling groups and scaling conclusions for each facility - Robert Gamble*

OVERVIEW AND CONSISTENCY WITH THE H2TS METHODOLOGY

- *APPLICATION OF THE H2TS METHODOLOGY TO SBWR SAFETY SYSTEMS MAKES IT POSSIBLE TO:*
  - *Show how well various experiments represent behavior of SBWR systems*
  - *Determine if experimental data is sufficiently representative for validation of TRACG code phenomenological models*

LOCA ACCIDENTS

- *MAIN STEAM LINE*
- *GRAVITY DRIVEN COOLING SYSTEM LINE*
- *BOTTOM DRAIN*

SBWR SAFETY SYSTEMS

- *GRAVITY DRIVEN COOLING SYSTEM (GDCS)*
- *ISOLATION CONDENSER SYSTEM (ICS)*
- *PASSIVE CONTAINMENT COOLING SYSTEM (PCCS)*

IMPORTANT PHENOMENA

- SYSTEM PRESSURE RATES
  - REACTOR PRESSURE VESSEL
  - DRYWELL
  - WETWELL
- MASS AND ENERGY FLOW RATES
  - REACTOR VESSEL BLOWDOWN
  - VENTS
  - VACUUM BREAKERS
  - ISOLATION CONDENSER
  - PASSIVE CONTAINMENT COOLING HEAT EXCHANGER
  - GRAVITY DRIVEN COOLING SYSTEM

TEST FACILITIES

- GIST
- GIRAFFE
- PANDA
- PANTHERS

H2TS METHODOLOGY AND PIRT

- ***INITIAL PIRT***
    - ***Initial PIRT for the SBWR includes phenomena based on current understanding, judgement and experience***
    - ***Highly ranked PIRT parameters are useful in guiding the design and scaling of test facilities***
    - ***Various PIRT phenomena are associated with nondimensional groups obtained from top-down or bottom-up scaling***
    - ***All highly ranked PIRT quantities are addressed by top-down or bottom-up scaling laws***

H2TS METHODOLOGY AND PIRT (Cont'd)

- *H2TS ANALYSIS*
    - ***Top-down scaling analysis is performed at the system level (e.g., RPV, DW, WW)***
    - ***Top-down scaling in combination with PIRT identifies important processes for bottom-up scaling analysis***
    - ***Characteristic time ratios help to distinguish between dominant and negligible parameters in a PIRT associated with various processes***
- *Top-Down scaling is addressed in Chapter 2*
- *Bottom-Up scaling is addressed in Chapter 3*
- *Time scales are addressed in Chapter 2*

CONCLUSIONS

- *THE EXPERIMENTS DESCRIBED, THOUGH NOT PERFECTLY SCALED FOR ALL PHENOMENA, PROVIDE RESULTS WHICH ARE REPRESENTATIVE OF SBWR BEHAVIOR OF SAFETY SYSTEMS THROUGHOUT ALL LOCA PHASES*
- *DOMINANT PHENOMENA ARE PRESERVED*
- *NONREPRESENTATIVE PHENOMENA ARE NOT INTRODUCED IN THE TESTS*
- *EXPERIMENTAL RESULTS ARE SUFFICIENTLY REPRESENTATIVE FOR TRACG CODE MODEL VALIDATION*

GE Nuclear Energy

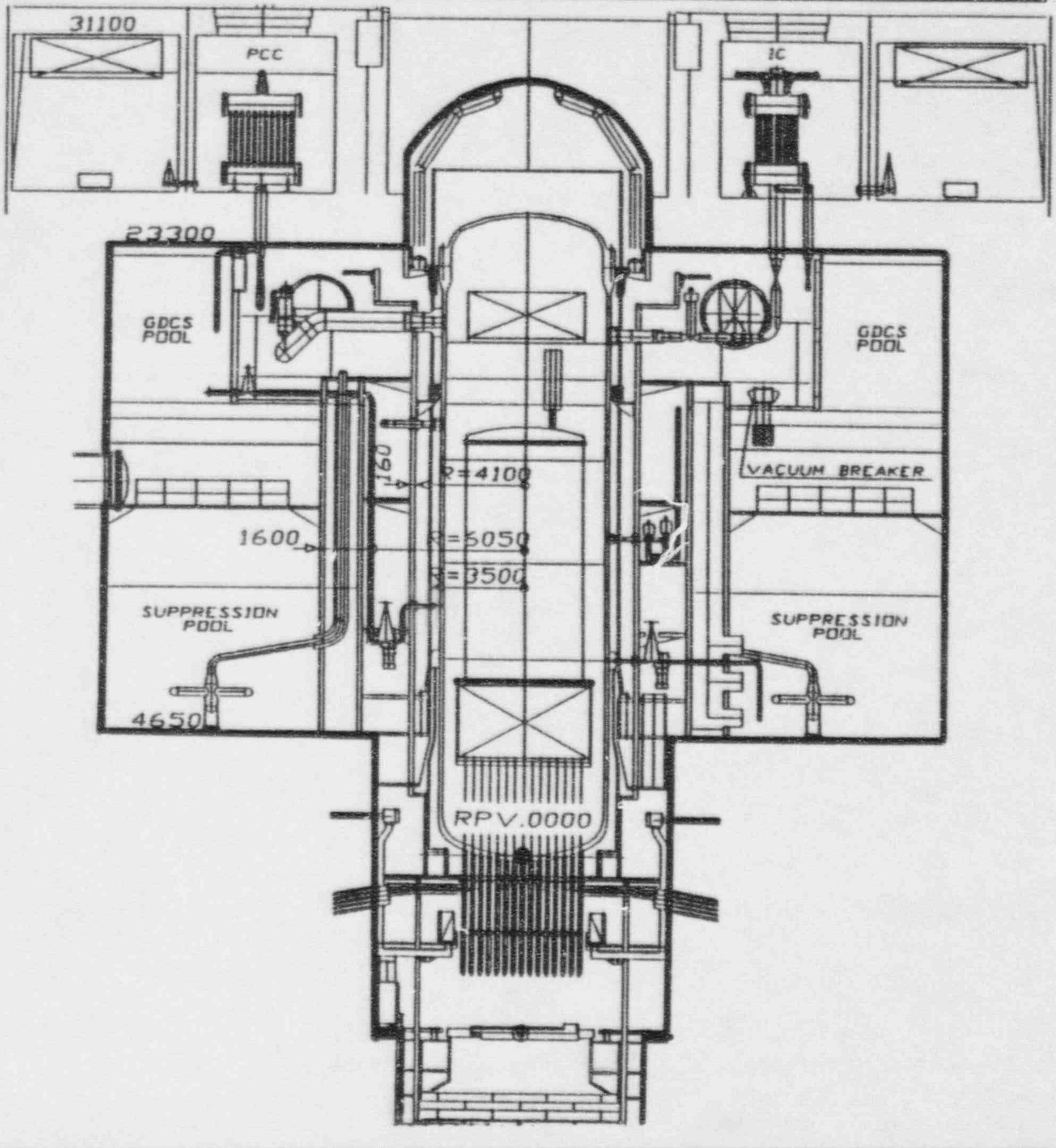
ACRS Thermal Hydraulics Subcommittee Meeting

SBWR Containment LOCA Overview

B. S. Shiralkar

November 28, 1995

SBWR Containment Arrangement



Break Scenarios

- Break scenarios generally similar
  - Scram, isolation on high drywell pressure
  - ADS (SRVs + DPVs) on low reactor vessel downcomer level

    Depressurizes vessel for liquid line breaks and small breaks
- Large Steam Line Break
  - Leads to highest containment pressure
  - Break in upper drywell (UDW)
  - Noncondensibles purged rapidly from UDW via main vents
  - Noncondensibles from lower drywell (LDW) enter UDW as pressure drops
  - Main vents closed post 1 hour
  - Decay heat removal through PCCs
- Large GDCS Line Break
  - Liquid line break in drywell annulus
  - Noncondensibles purged rapidly from UDW via main vents
  - Water from GDCS pool with broken GDCS line spills into drywell

    Steam condensation leads to vacuum breaker openings in first 1.5 hours
  - Longer term behavior similar to steam line break

Break Scenarios (contd.)

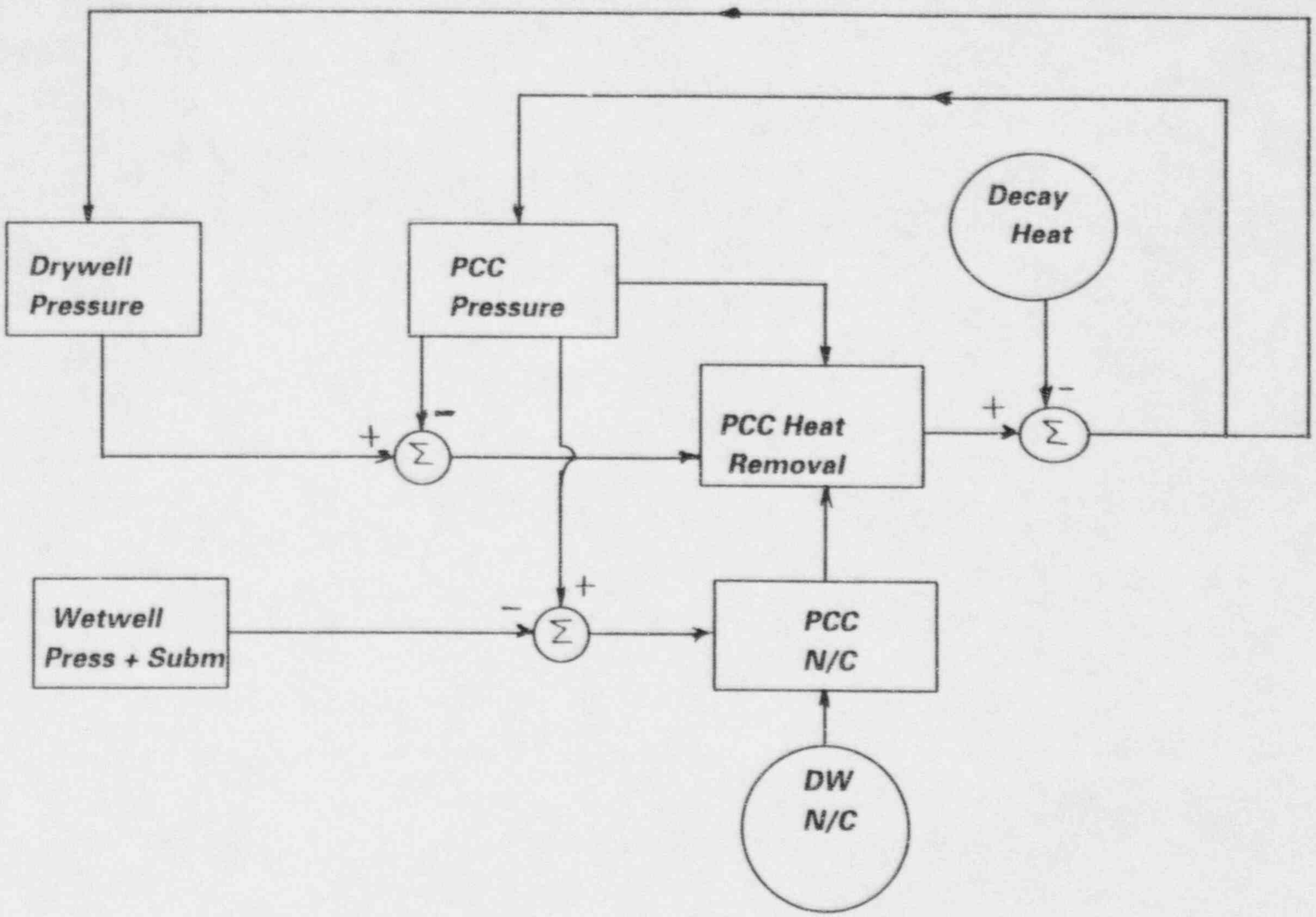
- *Bottom Drain Line Break*
  - *Liquid break in LDW*
  - *LDW noncondensibles purged earlier to UDW*
  - *Milder transient than large steam line break*
- *Small Break Inside Containment*
  - *Only top horizontal vent and PCC vents clear*
  - *Energy deposition near top of suppression pool*
  - *ADS on pool temperature*
  - *2.5% steam line break worst in small break spectrum for peak pressure*
- *Small Break outside Containment*
  - *Break isolated quickly*
  - *SRV discharge to suppression pool*
  - *ADS on low water level;*
    Discharge flow similar to inside containment breaks
  - *Not a limiting break*

Break Scenarios (contd.)

- Conclusions
  - Long term response similar for all breaks
  - ~ 85% of pressure rise due to transfer of noncondensibles to wetwell vapor space
  - ~ 15% due to energy deposition in the suppression pool (horizontal vent clearing) in the first hour
  - Pressure rise augmentation by bypass of uncondensed steam through PCCs

    Need to assure this is small

PCC "System Response" Characteristics

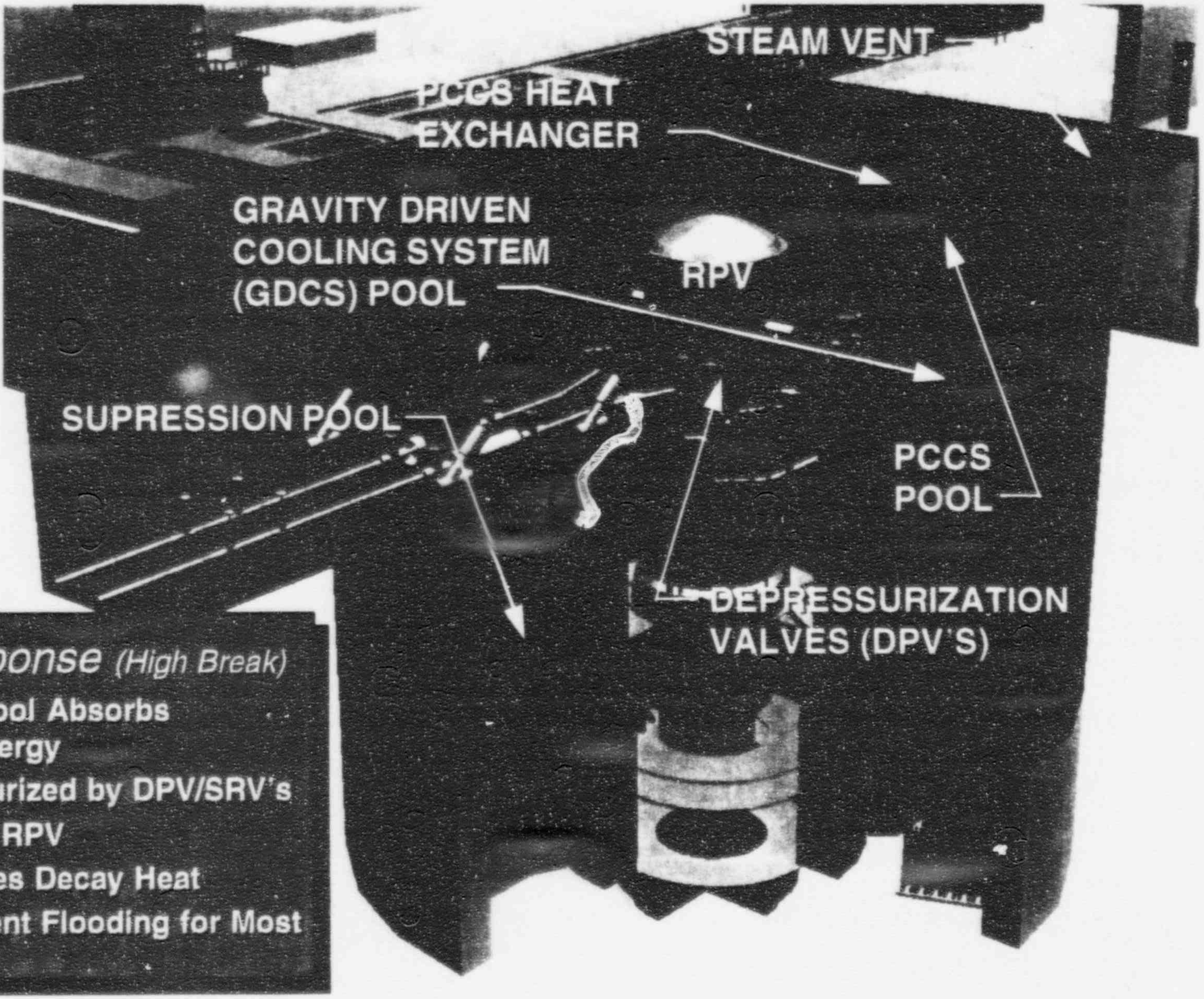


PCC "System Response" Characteristics

- *PCCS tends to maintain a balance between heat removal and decay heat*
  - *PCCs have excess heat removal capability under pure steam conditions*
  - *Feedbacks on noncondensible holdup and drywell pressure stabilize response*
    - *Reduction in heat removal increases PCC pressure*
      - *Noncondensibles are pushed out through vent*
      - *ΔT for heat transfer increases*
      - *Heat removal increases*
    - *Blanketing by noncondensibles reduces heat removal*
      - *Drywell pressure increases*
      - *Helps to purge noncondensibles to wetwell*
  - *Normally enough noncondensibles remain in drywell to reduce PCC heat removal to match decay heat*
    - *PCC volume is 0.16% of drywell volume*
  - *Noncondensible accumulation may occur preferentially in one of the PCC units, but overall heat removal matches decay heat*

Conclusions

- *Long term pressure response is insensitive to break location*
- *PCCs have excess capacity*
- *Tests being performed in PANDA to cover various scenarios*
  - *Should verify insensitivity to n/c transients and robustness of design*



LOCA Response *(High Break)*

- Supression Pool Absorbs Blowdown Energy
- RPV Depressurized by DPV/SRV's
- GDCS Floods RPV
- PCCS Removes Decay Heat
- No Containment Flooding for Most Breaks

OK

GE Nuclear Energy

Analytical Basis for Top-down and Bottom-up Scaling

Scaling Team:	Robert Gamble	Andy Hunsbedt
	Fred Moody	Maureen Parker
	George Yadigaroglu	

Presented By: George Yadigaroglu

ACRS Meeting
San Jose, CA
November 28, 1995

Outline

- *Top Down Approach (recall)*
  - *Phenomena of processes considered → set of governing equations*
- *General Approach/two parallel procedures:*
  - *Obtain general scaling criteria (ideally scaled facilities)*
  - *Identify/quantify distortions in real test facilities*
- *Global "Generic" Model of the SBWR System → a set of governing equations*
- *Generic model is specialized for cases considered*

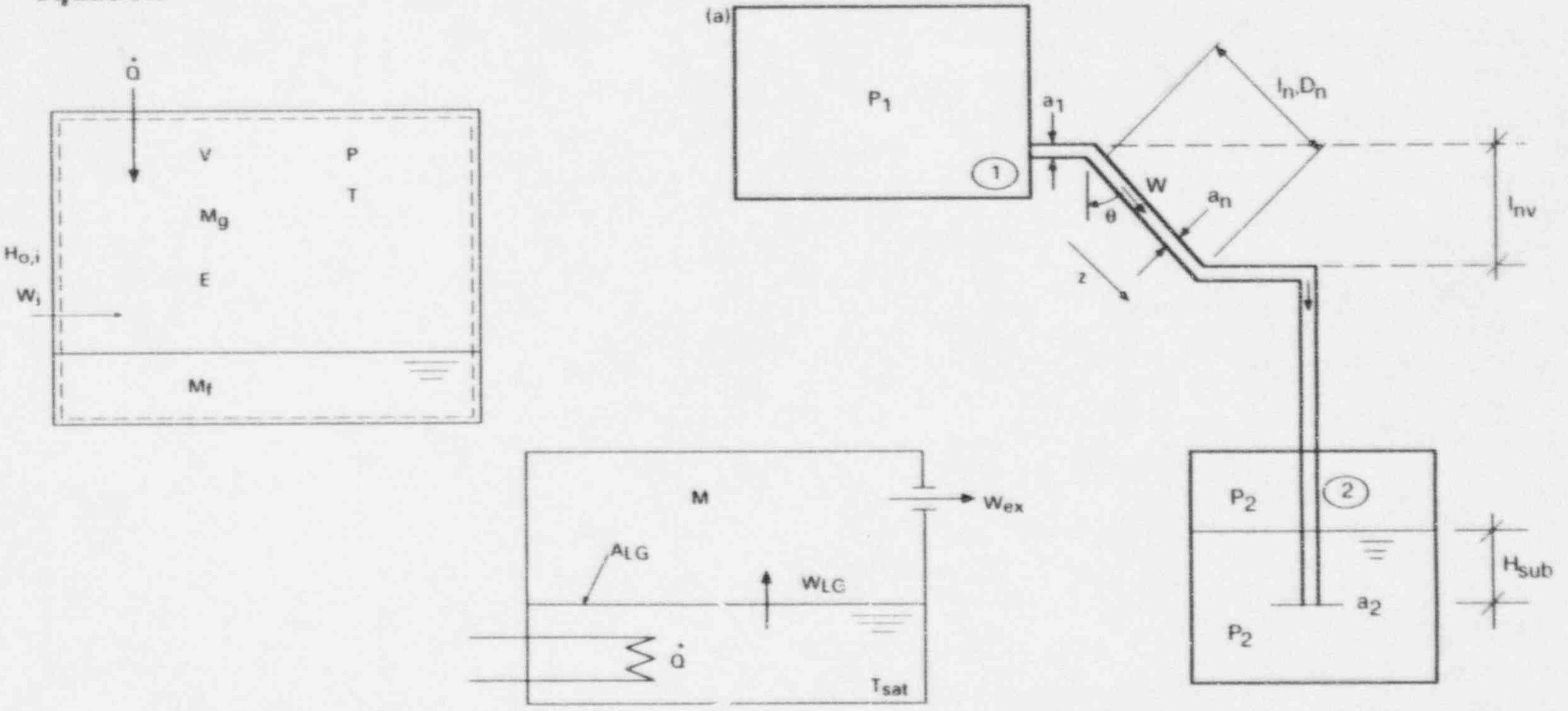
example: *Blowdown Phase*

flow path eqs in n/d matrix form

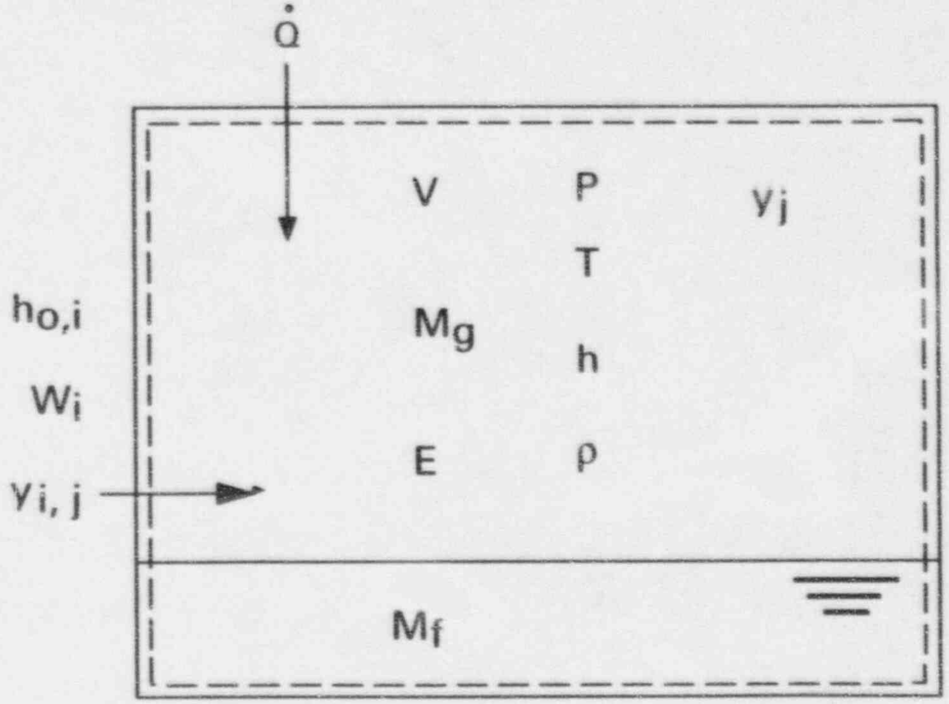
- *Examine/compare* Π *numbers and local factors to identify/quanitfy importance of distortions*

Top-Down Approach: Phenomena and Processes Considered

- *Thermodynamic state evolution of containment volumes with mass and energy additions ⟶ generic continuity, energy and pressurization rate equations*
- *Phase changes at interfaces ⟶ defines enthalpy scale*
- *Transfers of mass between volumes driven by pressure differences ⟶ generic junction flow rate equation*



Thermodynamic Evolution of Containment Volumes with Mass and Energy Additions - 1



$$e := \frac{E}{M} = e(P, v, y_j)$$

A containment volume receiving mass flow rates W_i with corresponding total enthalpies $h_{o,i}$, and heat at rate $\dot{Q}$

Thermodynamic Evolution of Containment Volumes with Mass and Energy Additions - cont'd - 2

- ***Mass conservation for constituent j:*** $\frac{dM_j}{dt} - \sum_i W_{i,j} = 0$
- ***Energy Conservation:*** $\frac{dE}{dt} = -p\frac{dV}{dt} + \dot{Q} + \sum W_i h_{o,i}$
- ***Obtain now dp/dt:*** $\frac{dP}{dt} = \frac{1}{Vf_2}\left\{\sum_i\left[W_i(h_i - h)\right] + \sum_i W_i \frac{P^*}{\rho} + \dot{Q} - P^*\frac{dV}{dt} - V\sum_j\left[f_{1,j}\frac{dy_j}{dt}\right]\right\}$

Short-hand notations for thermodynamic properties of the mixture:

$$P^* \equiv P + \left.\frac{\partial e}{\partial v}\right|_{P,y_j}$$

$$f_2 \equiv \frac{1}{v}\left.\frac{\partial e}{\partial P}\right|_{v,y_j} \quad \text{(nondimensional system compliance)}$$

$$f_{1,j} \equiv \frac{1}{v}\left.\frac{\partial e}{\partial y_j}\right|_{P,v,y} \quad \text{(units of energy per unit volume)}$$

y_j constant means all y_j are held constant, and
y constant means all y_j except the one in the derivative are held constant

Thermodynamic Evolution of Containment Volumes with Mass and Energy Addition - Cont'd - 3

Alternative sets:

$\frac{dM_j}{dt}$ and $\frac{dp}{dt}$

or

$\frac{dM_j}{dt}$ ***and the energy equation rewritten as:***

$$M\frac{de}{dt} = -P\frac{dV}{dt} + \dot{Q} + \sum_i W_i\left(h_{o,i} - h\right) + {}^{P}\!/_{\rho}\sum_i W_i$$

enthalpy <u>differences</u> appear in these equations

Case of Vessels Containing Only Steam and Water (e.g. RPV)

- ***The constituent mass fraction y_j is replaced by the vessel-average vapor volume fraction α***
- ***Combining the continuity and energy equations for the vapor phase:***

$$\rho_g \frac{d\alpha}{dt} = \frac{1}{V} \sum_i W_{g,i} + \frac{\sum_i \left(h_{\ell,i} - h_f\right) W_{\ell,i}}{h_{fg} V} + \frac{\dot{Q}}{h_{fg} V} + \frac{\psi}{h_{fg}} \frac{dp}{dt}$$

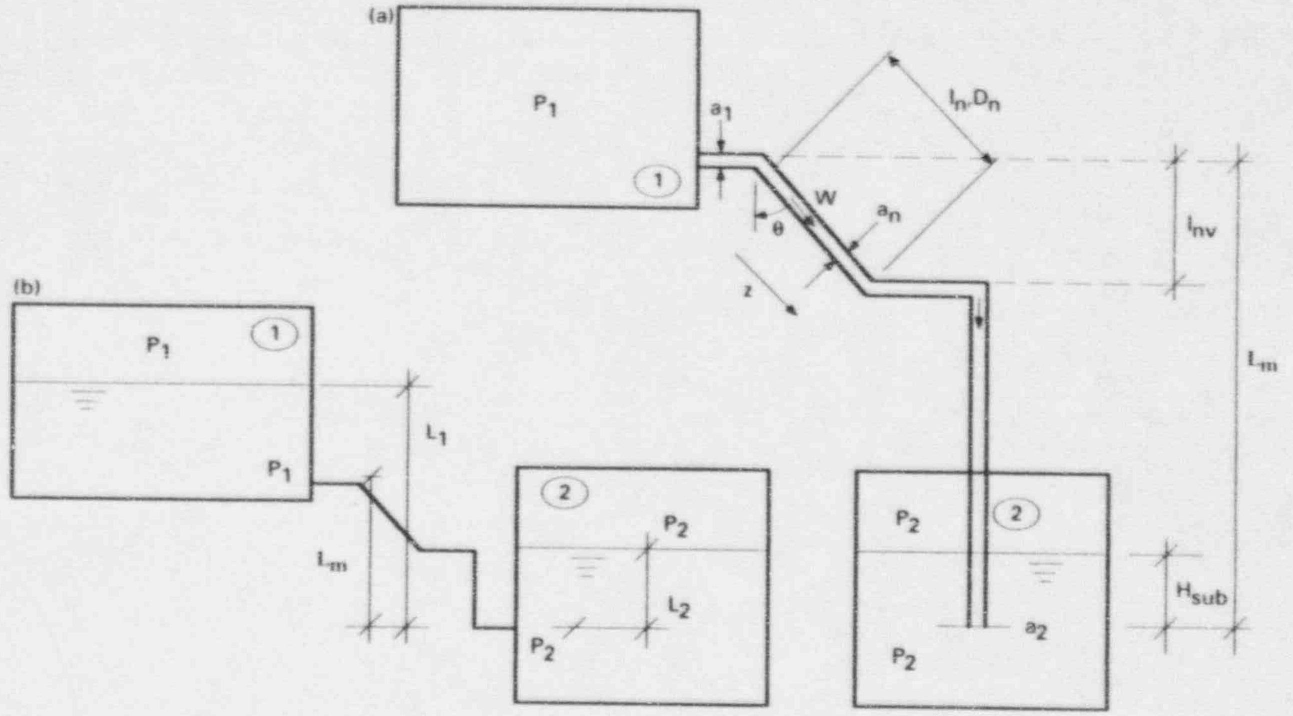
where

$$\psi = 1 - (1-\alpha)\, \rho_f h_f' - \alpha \rho_g h_g' - \alpha h_{fg} \rho_g'$$

where the $z' \equiv \left.\frac{dz}{dp}\right|_{sat}$ ***are thermodynamic properties***

Transfers of Mass Between Volumes Driven by Pressure Differences -1

Piping Configurations of Interest



(b) Pipe Connecting Two Pools;
$L_m = L_1 - L_2,\ H_m = 0$

(a) Pipe Connecting Two Volumes and Submerged in
Volume 2: $H_m = H_{sub},\ \rho_m g L_m = 0$

Momentum Equation for path 1-2:

$$\sum_n \frac{\ell_n}{a_n}\frac{dW}{dt} = \Delta P_{12} + \rho g \sum_n \ell_{nv} - \rho_L g H - \sum_n \frac{F_n}{a_n^2}\frac{W^2}{2\rho} \qquad F_n = \frac{f_n \ell_n}{D_n} + k_n \qquad L_m = \sum_n \ell_{nv} \quad \Delta P_{12} = P_1 - P_2$$

Transfers of Mass Between Volumes Driven by Pressure Differences - cont'd -2

Generic 1-D momentum equation for path m:

$$\left(\frac{L}{a}\right)_m \frac{dW_m}{dt} = \Delta P_m + \rho_m g L_m - \rho_L g H_m - \left(\frac{F}{a^2}\right)_m \frac{W_m^2}{2\rho_m}$$

where,

$$\left(\frac{F}{a^2}\right)_m = \sum_n \frac{F_n}{a_n^2} = \sum_n \left(\frac{f_n \ell_n}{D_n} + k_n\right) \frac{1}{a_n^2}$$

and

$$\left(\frac{L}{a}\right)_m = \sum_n \frac{\ell_n}{a_n}$$

are geometric parameters describing path m.

Summary of System Equations

- ***For Volumes***
  - ***total mass*** $\frac{dM}{dt} - \sum_i W_i = 0$
  - ***conservation of constituent j*** $\frac{dM_j}{dt} - \sum_i W_{ij} = 0$
  - ***energy*** $V\rho\frac{de}{dt} = -P\frac{dV}{dt} + \dot{Q} + \sum_i (h_i - h)W_i + \frac{P}{\rho}\sum_i W_i$
  - ***rate of P change*** $\frac{dP}{dt} = \frac{1}{Vf_2}\left\{\sum_i \left[W_i(h_i - h)\right] + \sum_i W_i\frac{P*}{\rho} + \dot{Q} - P*\frac{dV}{dt} - V\sum_j\left[f_{1j}\frac{dy_j}{dt}\right]\right\}$
  - ***vapor volume fraction*** $\rho_g\frac{d\alpha}{dt} = \frac{1}{V}\sum_i W_{g,i} + \frac{\sum_i (h_{\ell,i} - h_f)W_{\ell,i}}{Vh_{fg}} + \frac{\dot{Q}}{V} + \frac{\psi}{h_{fg}}\frac{dP}{dt}$
- ***For Flow Paths***
  - ***momentum*** $\left(\frac{L}{a}\right)\frac{dW}{dt} = \Delta P - \frac{1}{\rho}\left(\frac{F}{a^2}\right)\frac{W^2}{2} - \rho gH$

General Scaling Approach - 1

- ***Two Parallel Procedures***

  a) obtain general scaling criteria (for <u>ideal</u> case of perfectly scaled facilities)

  b) detect the scaling distortions and evaluate their importance (for the <u>actual</u> test facilities)

- ***For a): A minimal set of unique (global) reference scales is used:***

$\{z_r\} = t_r, v_r, W_r, \dot{Q}_r, \rho_r, \Delta P_r, \Delta h_r$

non-dimensional variable: $z^+ = \dfrac{z}{z_r}$

- ***For b): the minimal set $\{z_r\}$ is:***
  - ***supplemented by additional specific reference scales:***

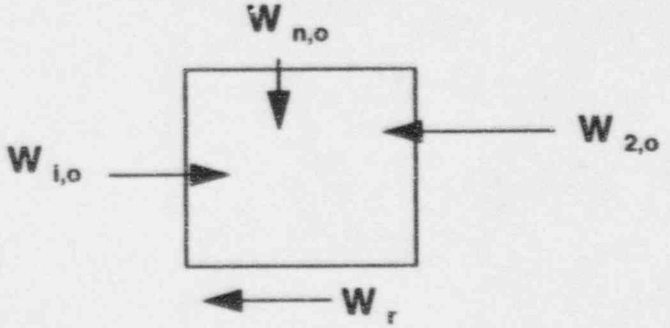
    $M_r, \Delta M_r, P_r, \Delta e_r, f_{2,r}, f_{1,j,r}, P_r^*$, etc.
  - ***local factors or Π numbers are introduced***

General Scaling Approach - cont'd -2

To make all non-dimensional groups of 0(1) and measure the scaling distortions:

b1) local scales $z_{n,o}$ or local Π numbers Π_i are introduced:

- ***global scale z_r (typically the most important value of z)***



- ***locally scaled variable,***

$$z_n^+ \equiv \frac{z_n}{z_{n,o}}$$

- ***local normalizing factor or weight,***

$$z_n^o \equiv \frac{z_{n,o}}{z_r}$$

- ***one obtains***

$$z_n = \left(\frac{z_n}{z_{n,o}}\right)\left(\frac{z_{n,o}}{z_r}\right)z_r = z_n^+ z_n^o z_r$$

General Scaling Approach - cont'd -3

---

b2) local Π values are defined, e.g., in energy equations:

$$\Pi'_Q = \frac{t_r \dot{Q}_r}{M_r \Delta e_r} = \Pi_t \Pi_{pch} \left(\frac{M_r}{\rho_r V_r}\right) \left(\frac{\Delta e_r}{\Delta h_r}\right)$$

$$\Pi'_V = \frac{p_r \Delta V_r}{M_r \Delta e_r} = \frac{1}{\Pi_{hp}} \left(\frac{p_r}{\Delta p_r}\right) \left(\frac{\Delta h_r}{\Delta e_r}\right) \left(\frac{\rho_r \Delta V_r}{M_r}\right)$$

$$\Pi'_{wh,i} = \frac{t_r W_{i,o} \Delta h_{i,o}}{M_r \Delta e_r} = \Pi_t \left(\frac{\rho_r V_r}{M_r}\right) \left(\frac{\Delta h_r}{\Delta e_r}\right) \left(\frac{W_{i,o}}{W_r}\right) \left(\frac{\Delta h_{i,o}}{\Delta h_r}\right) = \Pi'_{wh} W_i^o \Delta h_i^o$$

$$\Pi'_{mech,i} = \frac{t_r p_r W_{i,o}}{M_r \Delta e_r \rho_r} = \frac{\Pi_t}{\Pi_{hp}} \left(\frac{p_r}{\Delta p_r}\right) \left(\frac{\rho_r V_r}{M_r}\right) \left(\frac{\Delta h_r}{\Delta e_r}\right) = \Pi'_{mech} W_i^o$$

- ***where*** $W_i^o \equiv \dfrac{W_{i,o}}{W_r}$ and $\Delta h_i^o \equiv \dfrac{\Delta h_{i,o}}{\Delta h_r}$

  are local normalizing factors

- ***i refers to a particular flow path***

- ***The local reference scales for a particular system component can typically be chosen as the initial boundary values of the variable in question for the particular component considered.***

General Scaling Approach - cont'd -4

Identification of scaling distortions

- *Usually, one can define a variable that is of greatest importance for a particular test (e.g., the RPV water level or DW pressure)*
- *Examination of the n/d governing equation can show which term(s) dominate the behavior of this most important test variable(s) and identify the corresponding pairs of Π number(s) that should be matched.*
- *The governing equation may, however, contain many terms containing the same type of Π number. The relative magnitude of these terms will show which system components should be scaled most carefully.*

Procedure:

- *By proper choice of scales, all the n/d variables (including the derivatives of variables) appearing in the n/d governing equations are made of 0 (1).*
- *The dominant terms in the governing equations are identified by comparing the relative magnitude of the Π numbers appearing in front of the n/d variables.*
- *<u>Global</u> system reference scales making the most important and dominant Π number(s) also of 0(1) are used: these define global Π numbers for the particular process considered.*
- *This procedure brings <u>local normalizing factors</u> (or weights, multiplying the n/d term and the corresponding global Π number into the equation.*
- *The local normalizing factors will typically be the ratios of the local reference scales <u>for a particular system component</u> to the <u>global</u> reference scales.*

Derivation of General Scaling Criteria - 1

- *Definition of the minimal set of reference scales* $\{z_r\}$
  - *For time,* t_r
  - *For volume:* V_r
  - *For mass flow rates:* W_r
  - *For heat addition:* $\dot{Q}_r$
  - *For densities:* ρ_r
  - *For pressure, a reference pressure difference:* ΔP_r
  - *For constituent j fraction:* $y_{j,r}$
  - *For properties involving vapor mass fraction:* ψ_r
  - *For enthalpies and internal energies, a reference specific enthalpy difference:* Δh_r
- $z^{+} \equiv \frac{z}{z_r}$

Comparison of Time Scales

- *Five time scales produced:* t_r, $t_{m,r}$, $t_{flash,r}$, $t_{in,r}$ *and* $t_{tr,r}$

- *The systems considered here are made of large volumes connected by pipes of much lesser volumetric capacity.*

- *Δp's are not dominated by inertial effects*

  $0(t_r) = 0(t_{m,r}) >> 0(t_{in,r}) \approx 0(t_{tr,r}) \approx 0(t_{flash,r})$

→ *the time behavior of the system will be controlled by the pressurization rates.*

- *Numerical values of these different time scales are reported later.*

Global "Generic" Model of the SBWR System

- ***Obtained by applying the general conservation eqs derived for the containment volumes and flow paths to the actual SBWR and test facility components:***
  - *a set of governing eqs*
- ***Certain non-limiting simplifications can be made to arrive at a tractable model***
- ***The result is a set of ODEs for dW/dt, dM/dt, dp/dt, d-alpha/dt , dH/dt in terms of the various flow path and volume W, p, L, h, etc.***
  - ***11 path flow rates:***
    - *governed by 11 flow path momentum eqs*
  - ***5 volume gas phase pressures:***
    - *3 dp/dt eqs + 2 PCC and IC mass balances*
  - ***3 volume masses:***
    - *3 mass balances*
  - ***2 liquid inventories (RPV and WW):***
    - *d-alpha/dt eq for RPV and energy balance for WW*
  - ***2 liquid level differences:***
    - *GDCS and SP liquid mass balances*

Global Specific Models of the SBWR System

- *The particular behavior of the system during certain scenaria or phases of a scenario can be investigated using subsets of the "generic" model eqs (the eqs for "active" paths only)*
- *The flow-path eqs can be written in matrix form to show:*
  - *interactions between the flow paths*
  - *the relative importance of certain flow paths*
- *Example: Model for Blowdown Phase:*
  - *the system is described as 4 "loops"*

Nondimensionalization of the Global Momentum Eqn Set - cont'd - 3

- *Unique Π numbers (defined using the unique global scales) multiply the terms of the matrix*
- *Inside the matrix one finds the local normalizing factors or scales multiplying the nondimensional variables (of O(1))*
- *When scaling comparisons (SBWR-test facility) are made, the relative magnitude of the local scales is a measure of the importance of any distortion (the difference in the local values between prototype and model)*

Summary

- *A set of general scaling laws was derived*
  shows validity of scaling followed for SBWR tests
- *A global model of the system was used to write the eqs in a matrix form showing system interactions*
- *The nondimensionalization of the "matrix eqs" provided information on*
  - *The relative importance of phenomena*
  - *the importance of any scaling distortions*
- *Several bottom-up scalng issues were identified and addressed*

Application of Scaling to SBWR and Major Test Facilities

Scaling Team:	Robert Gamble	Andy Hunsbedt
	Fred Moody	Maureen Parker
	George Yadigaroglu	

Presented By: Robert Gamble

ACRS Meeting
San Jose, CA
November 28, 1995

Outline

- ***Basics of Application Method***
- ***Example of Scaling of Pressure Rate Equation***
- ***SBWR Results***
- ***Scaling of Facilities***
    - *GIRAFFE/SIT (Details)*
    - *GIRAFFE/He (Summary)*
    - *PANDA (Summary)*
    - *GIST (Summary)*

Selection of Reference Values

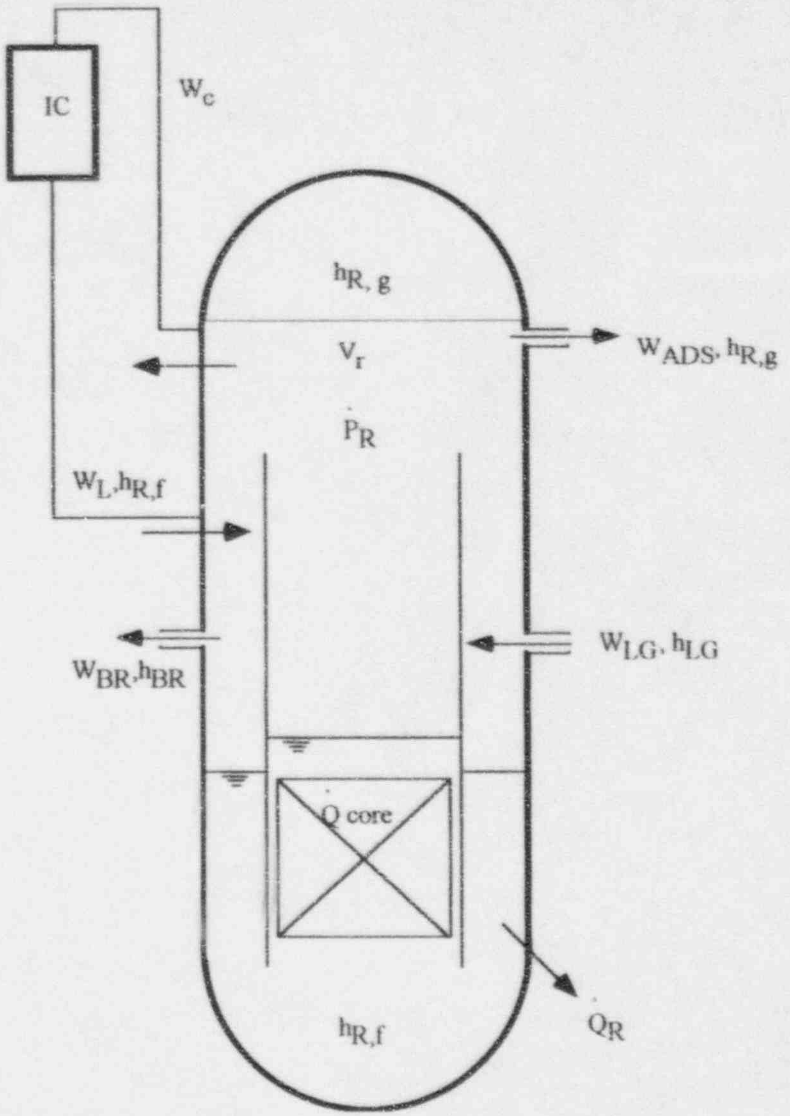
- Pressures, temperatures and mass fractions taken from test initial conditions
- Flows calculated using choked or unchoked flow formulations
- Reference flow, pressure and time changes selected to maintain variables and their derivatives of order one
- No code calculations used other than for test initial conditions
    - Tests cover range of initial conditions

Evaluation Points

- *Scaling was applied at discrete points in time representing the different phases of a LOCA and key transition points*
- *Point 1 corresponds to late blowdown where the transient was picked up in the GIST and GIRAFFE/SIT tests*
- *Point 2 corresponds to the beginning of GDCS initiation when Prpv-Pdw = ρgL*
- *Point 3 represents quasi-steady period when GDCS is flowing into RPV*
- *Point 4 represents quasi-steady period when PCCS is removing decay heat*
- *Pressure rate and vapor fraction equations were evaluated for the primary regions - RPV, DW, WW*
- *Evaluations were done at points of interest as shown in the Table*
- *The breaks selected for evaluation were based on the tests for that phase*
  - *GDCSL break for late blowdown and GDCS phases*
  - *MSL break for PCCS phase*

Example of Application of Pressure Rate Eq.- GDCS Initiation for RPV

Pressure Rate Ex. (cont'd) - System Diagram



Pressure Rate Ex. (Cont'd) - Numerical Evaluation

- ***The reference conditions are based on simple extrapolation of the GIRAFFE/SIT and GIST test initial conditions because the evaluation point is not at a test initial condition***
  - ***Pressure***
    - *DW pressure is based on the expected long-term pressure for the SBWR containment.*
    - *RPV pressure is the DW pressure plus the hydrostatic head of the GDCS (the point at which flow would begin)*
  - ***Temperatures are based on saturated conditions***
  - ***Mass fraction are based on simple hand calculations starting from the GIRAFFE/SIT test initial conditions***
  - ***Flow rates are the quasi-steady values (no inertia effects) calculated using choked and unchoked flow equations with the given pressures and line characteristics***
- ***Global Π-groups are not presented. Instead the local Π-groups are given. The global Π-groups can be taken as either the largest local Π-group or the summation of all local Π-groups of a given type.***

Pressure Rate Ex. (Cont'd) - Evaluation of Results

- *Results are first considered for the SBWR alone to determine which parameters are important to the SBWR behavior*
- *By doing this the importance of distortions found in the test facilities can be evaluated*
- *Later, the scaling groups for the test facilities are compared with those of the SBWR and conclusions are drawn as to the acceptability of the test facilities for the intended purpose*

Pressure Rate Ex. (Cont'd) - Numerical Results for SBWR

- Time constant is selected to normalize the dominant parameter of ADS enthalpy flow, Π_wh(ADS) thus making the nondimensional pressure rate 0(1)
- Even at this late stage of blowdown, ADS flow is the dominant contributor to depressurization and RPV averaged void generation
- Enthalpy associated with inlet and outlet flows are more important than the mechanical work associated with those flows
- The IC and decay heat have only a small effect on pressurization and void generation in the RPV

Overall Application to SBWR and Test Facilities

- *The process used in the example is repeated for the pressure rate, vapor mass fraction and global momentum equation at different phases of the SBWR LOCA as shown in Table 4.1-1 and Figure 4.1-1 of the report*
- *The tables showing the numerical results are given in chapter 4 (Tables 4.1-3 through 4.1-25)*
- *The results of these evaluations are summarized next*

Scaling Results for SBWR - PCCS Phase (Point 4)

- *RPV and DW pressure rate*
  - *Decay heat is balanced by PCC heat removal*
    - *PCC heat removal depends on n/c fraction in DW*
  - *All other processes are subordinate in determining pressure rate*
- *Important processes to long-term pressure are:*
  - *PCC heat removal*
  - *Volume of DW relative to WW*
  - *Submergence of Vents*
  - *Integrated energy deposition in SP*

Manometric Oscillations Between Water Volumes

Manometric Oscillations Between Water Volumes (Cont'd)

- ***RPV/GDCS Pool Level Movement Cases Considered***
  - ***Free Level Movements with Step Change in RPV Pressure***
    - *Reference amplitude equal to 0.75m head*
    - *Considered for 1 and 3 GDCS lines*
  - ***Forced Harmonic (Sinusoidal) Level Movements***
    - *Reference amplitude/forcing function cycle time (0.75m head/500s)*
    - *Considered for 3 lines only*
  - ***Parametric Evaluation of Uncertainties***
- ***RPV/SP Pool Level Movement Cases Considered***
  - ***Free level movements with step change in RPV Pressures***
    - *Reference amplitude (0.75m head)*
    - *Considered for 3 lines only*
  - ***Forced Harmonic Level Movement***
    - *Reference amplitude/forcing function (0.75m head/500s)*
    - *Considered for 3 lines only*

Manometric Oscillations Between Water Volumes (Cont'd)

- *CONCLUSIONS*
  - *The systems considered are significantly overdamped and stable for input pressure differences greater than about 0.5m head equivalent*
  - *The systems become more stable for higher inputs or if the system is flowing*
  - *Small pressure difference changes of less than 0.3m head equivalent may result in small amplitude, low frequency level oscillations.*
  - *The relatively small diameter connecting drain lines act to decouple the liquid masses and to damp-out free oscillations.*
  - *Natural cycle times for these systems are relatively long (Ranged from 91s to 245s)*
  - *The liquid level amplitude resulting from a harmonic forcing function input is lower than that of the step forcing function*
  - *For input magnitudes greater than 0.3m head, the magnification factor is less than unity even with a forcing function input frequency equal to that of the system's natural frequency (i.e., at resonance)*
  - *RPV liquid level rate of change is very slow (~0.005m/s maximum) for 0.75m head pressure change*
  - *The only nondimensional group governing the level movements is the average damping ratio for the connecting line and this ratio should be greater than one (1) for stability.*

Scaling of Test Facilities

General Facility Scaling

- *All facilities nominally scaled according to "General Scaling Criteria"*
  - *Full-vertical-scale*
  - *Flow area/Heat transfer area/Mass/Power/Flow scaled to system scale*
  - *Prototypical fluids*
  - *Prototypical initial conditions*

Comparison of Facility Non-Dimensional Π groups with SBWR

- *RPV - Late Blowdown*
  - ***Top-down parameters scaled very close to SBWR values in RPV***
  - ***Blowdown time constant longer in GIRAFFE due to increased volume and mass scale in RPV***
- *DW - Late Blowdown*
  - ***Dominant parameters are mechanical work of DPV and Main Vent flow and movement of noncondensibles***
  - ***Main vent greatly oversized so it can remove any energy additions to DW; thus, DW pressure controlled by main vent submergence***
  - ***Reference values used***
    - *Time constant taken from RPV blowdown*
    - *Reference pressure change taken from observed results*
    - *Use of "forced" reference values results in Π's greater than 1 (dp/dt > 1)*

Comparison of Facility Non-Dimensional Π groups with SBWR

- ***WW - Late Blowdown***
  - ***Pressurization dominated by enthalpy flow from main vent and to a lesser degree movement of noncondensibles***
  - ***Enthalpy flow in the main vent is based on full uncovery of the top horizontal vent***
    - *Distortion represents differences in maximum flow capability*
    - *Actual flow will be driven by need for DW to remove steam and noncondensibles*
  - ***DW to WW volume ratio different in GIRAFFE so some distortion in noncondensible effects***
  - ***Focus of GIRAFFE/SIT test is on RPV***
    - *WW parameters scaled adequately for this purpose*

Scaling Summary for PANDA

- *Paremeters important to facility behavior scaled adequately*
  - *All relevant systems present*
  - *Line flow resistances scaled adequately*
  - *All important top-down phenomena retained*
- *Facility scaled adequately for intended purpose*

CONCLUSIONS

- THE EXPERIMENTS DESCRIBED, THOUGH NOT PERFECTLY SCALED FOR ALL PHENOMENA, PROVIDE RESULTS WHICH ARE REPRESENTATIVE OF SBWR BEHAVIOR OF SAFETY SYSTEMS THROUGHOUT ALL LOCA PHASES
- DOMINANT PHENOMENA ARE PRESERVED
- NONREPRESENTATIVE PHENOMENA ARE NOT INTRODUCED IN THE TESTS
- EXPERIMENTAL RESULTS ARE SUFFICIENTLY REPRESENTATIVE FOR TRACG CODE MODEL VALIDATION

GE Nuclear Energy

PANTHERS-PCC Test Program

P. F. Billig, J.R. Fitch
SBWR Test Operations and Analysis

Presentation to the Advisory Committee on Reactor Safeguards
Thermal Hydraulics Subcommittee
November 28, 1995

filename: acrs1128

Outline

- ***PANTHERS/PCC Testing; P.F. Billig***
  - *Objectives and Test Matrix*
  - *Test Results*
    - *Steady-State Tests*
    - *Transient Tests*
      - *Water Level*
      - *Non-condensable Gas Buildup*
  - *Applicability of PANTHERS/PCC to SBWR*
- ***PANTHERS/PCC Analyses; J. R. Fitch***
  - *Inside/outside Heat Transfer Coefficients*

Objectives and Matrix

- ***Thermal-hydraulic performance of prototypical condenser***
  - *Demonstrate Prototype PCC meets design requirements for heat rejection (Component Performance)*
  - *Provide sufficient data base for TRACG analyses (Separate Effects)*
  - *Determine and evaluate differences in the effects of non-condensable gas buildup in PCC between lighter-than-steam and heavier-than-steam gases (Concept Demonstration)*
- ***Component test - Not system test***
  - *Fixed boundary conditions used to study condenser performance*
  - *PANDA and GIRAFFE study system performance and interactions*
- ***Test Matrix***
  - *Presented in TAPD (NEDO-32391, Rev. C), Tables A.3-2a-d and A.3-25, and T/H Data Report (SIET 00393RP95, Rev. 0)*
    - *97 steady-state tests*
    - *11 transient tests*

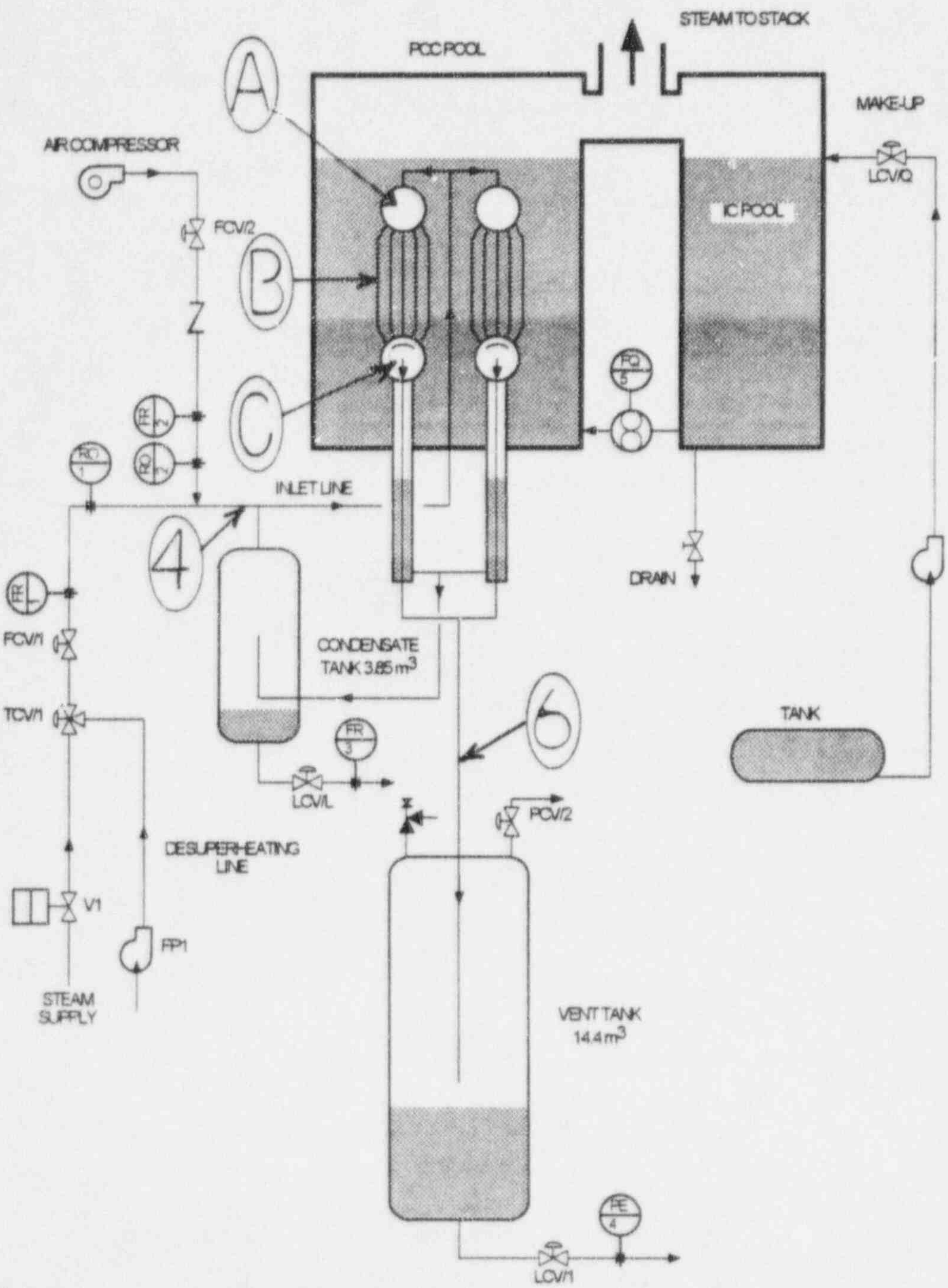


Figure A.3-2 PANTHERS/PCC Test Facility Schematic

Test Results (Steady-state tests)

- *Tabulated in T/H Data Report (SIET document 00393 RP 95) Tables 7.1 - 7.6*
- *Shown in Data Analysis Report (SIET document 00394 RA 95) Figures 3.1 - 3.15*
- *Saturated and Superheated Steam Tests*
  - *Demonstrate that required steam is condensed at required conditions*
  - *Test procedure*
    - *Purge air from system with steam through vent tank vent*
    - *Close vent tank vent - condensation driven mode*
    - *Bring pool to saturation*
    - *Increase steam flow to required flowrate and measure pressure*
    - *Time average data over 15 minutes*

Test Results (Steady-state tests, continued)

- *Saturated Steam Test Results*
  - *Performance is steady and well behaved*
    - *Pressure holds constant*
    - *Heat removal vs. inlet pressure is linear*
      - *Intercept (no condensation) corresponds to inlet conditions same as saturated conditions in pool*
  - *Condenser meets design requirement*
    - *Removes 10 MW of energy at 308 kPa*
- *Superheated Steam Test Results*
  - *Results similar to saturated tests*
  - *Except at high flow, steam desuperheats in inlet riser and upper header*

Test Results (Steady-state tests, continued)

- ***Saturated and Superheated Steam/air Tests***
  - *Provides broad database to characterize PCC at various steam/air mixtures*
  - *Range of test conditions above SBWR containment pressures*
    - *Tests up to 790 kPa*
    - *SBWR containment pressure is around 330 kPa during LOCA*
  - *Tests for same steam flow and gas fraction at various inlet pressures*
  - *Test procedure*
    - *Purge air from system with steam through vent tank vent*
    - *Bring pool to saturation*
    - *Increase steam flow and initiate air flow to required flowrates*
    - *Set inlet pressure with vent tank vent valve*
      - *pressure drop driven flow*
    - *Time average data over 15 minutes*

Test Results (Steady-state tests, continued)

- ***Saturated Steam/air Test Results***
  - *Smooth transition to complete condensation at high pressures*
    - *Heat rejection rate tends to asymptote at higher pressures*
    - *Limit = energy to condense steam and subcool to pool temperature*
    - *Heat transfer declines in lower tube region*
  - *Increase in air concentration => decrease in condensation*
  - *Tests demonstrate that large fraction of steam can be condensed in presence of non-condensable gases*
- ***Superheated Steam/air Test Results***
  - *Results similar to saturated tests*
  - *More than 50% of superheat lost in inlet riser in PCC pool*

Test Results (Transient tests)

- Shown in T/H Data Report (Figures 7.2 - 7.16) and Data Analysis Report (Figures 3.16 - 3.37)
- Water Level
  - Demonstrates change in condenser performance versus pool water level
  - Test procedure
    - Establish steady-state performance
      - Steam or steam/air flows fixed
      - Steam/air test: Lock vent tank flow area
    - Lower water level and measure change in system pressure
      - Decreased pressure means improved performance
      - Increased pressure means degraded performance
    - Stop at PCC design pressure and refill pool

Test Results (Transient tests, continued)

- ***Water Level (continued)***
  - *Performance improves slightly as level lowers to top of tubes*
    - *Less head => reduced pool saturation temperature*
    - *Range of water level for DBA LOCA*
      - *SBWR water sufficient to keep tubes covered around 72 hours*
  - *Performance degrades as tubes uncover*
    - *Less heat transfer surface => higher pressure needed to maintain condensation*
    - *Beyond design basis conditions*
      - *Demonstrates margin in system design and operator response time*

Test Results (Transient tests, continued)

- ***Non-condensable Gas Buildup (Air, Helium, & Air/Helium)***
  - *Determine and evaluate differences in the effects of non-condensable gas buildup in PCC between lighter-than-steam and heavier-than-steam gases*
  - *Test procedure*
    - *Start with vent pipe flanged off and specified steam flow*
      - *condensation induced flow*
    - *Slowly inject measured amount of gases*
    - *Pressure rises as gas accumulates in PCC and vent line*
- ***Air Injection Test Results***
  - *Gas builds up in vent line, lower header, and lower tube region*
  - *Temperatures in lower regions approach pool temperatures*
  - *Eventually all condensation occurs in top of tubes*
  - *Confirms expected stratification of gases in PCC*

Test Results (Transient tests, continued)

- ***Helium Injection Tests***
  - *Performance differs from air tests*
    - *Helium remains in PCC unlike air tests*
    - *Buoyancy prevents stratification in lower regions*
  - *Temperatures in various regions indicate wide dispersal of helium*
    - *Somewhat greater condensation occurs in lower than upper tube regions*
    - *Nonsymmetric temperature distribution within headers and between headers*
  - *Significantly less gas than air tests needed to degrade condenser performance*
    - *No large accumulation in vent line and lower headers*
    - *Higher accumulation within tubes*

Test Results (Transient tests, continued)

- Air/helium Injection Tests
  - Performance more similar to helium tests
    - Gases remain in PCC
  - Temperatures in various regions indicate wide dispersal of helium
    - Nonsymmetric temperature distribution within headers and between headers
  - Condensation in tubes vary among tubes
  - Less gas than air tests needed to degrade condenser performance
    - Similar to helium tests
    - Some accumulation in vent line and headers
  - Overall condenser performance is steady
    - No pressure oscillations seen
    - Insensitive to tube-to-tube performance variations
  - Similar PCC performance seen during GIRAFFE-Helium tests

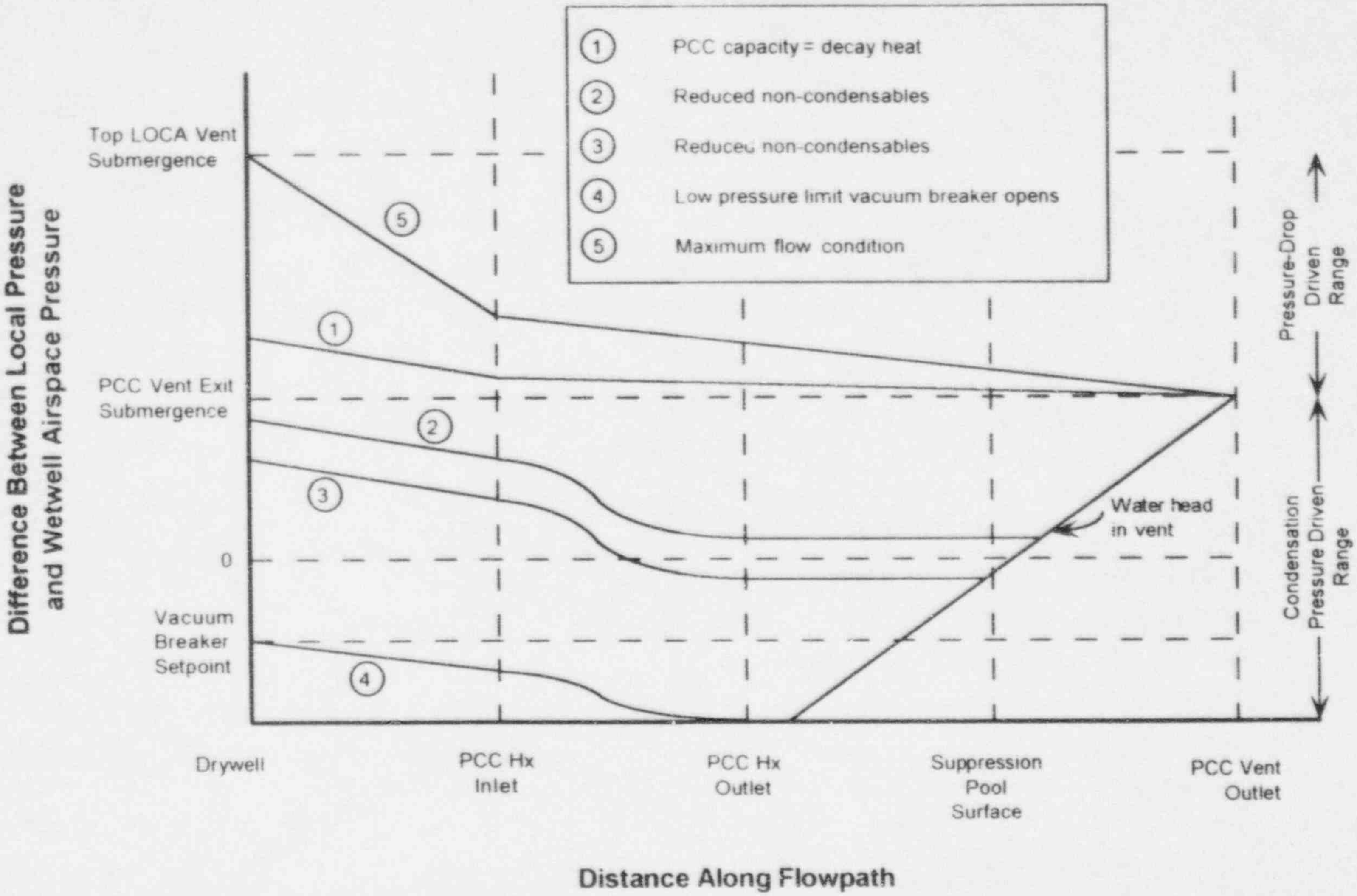
Test Results - Conclusions

- **PANTHERS/PCC achieved thermal-hydraulic test objectives**
  - PCC condenses steam at design conditions
  - PCC able to vent non-condensable gases
  - PCC performance is well behaved
- **Large database available for TRACG code qualification**
  - Steady-state tests at broad range of steam and air flows, and pressures
  - Transient performance at various pool water levels
  - Transient performance with gas buildup
- **Difference between performance with lighter-than-steam and heavier-than-steam gases established**
  - Heavier-than-steam gases stratify to lower regions of PCC
  - For lighter-than-steam gas, buoyancy overcomes downward flow under condensation induced flow conditions

Applicability of PANTHERS/PCC to SBWR

- ***TAPD, Sec. A.3.1.1.4 and Fig. A.3-3 describe PCC operational modes and applicability of PANTHERS-PCC data***
- ***Two main operating modes of PCC***
  - *Pressure Drop Driven Mode*
    - *PCC capacity $\leq$ core decay heat*
    - *PCC flow is forced by DW/WW ΔP*
  - *Condensation Pressure Driven Mode*
    - *PCC capacity $\geq$ core decay heat*
    - *Flow induced DW to PCC ΔP due to condensation*
- ***PCC tests capture both modes***

Fig. A.3-3: PCC Operational Modes



Applicability to SBWR (continued)

- ***Both PCC operational modes represented by PANTHERS***
- ***Pressure Drop Driven Mode***
  - *Steady-state steam/air mixture tests model this behavior*
  - *Test T23 captures high pressure drop through system similar to early blowdown when main vents are open*
  - *Test T9 captures range of conditions with flow through PCC but not main vent*
  - *Test T2 demonstrates conditions near crossover to condensation mode*
- ***Condensation Pressure Driven Mode***
  - *Steam only and gas injection tests model this behavior*
  - *Spectacle flange on vent pipe simulates pipe submergence in S/P*
  - *Steam only tests (T41, T43) show operation with all N/C gases purged*
  - *Injection tests of air (T51), helium (T76), and air/helium (T78) demonstrate how DW/WW ΔP is increased when gases accumulate in condenser*

Applicability to SBWR - Conclusions

- Conditions tested in PANTHERS/PCC are representative of conditions predicted in SBWR containment analysis for PCC operation (e.g., inlet flows, mass fractions, temperatures, and pressures)
  - Tests capture both pressure drop driven and condensation pressure driven modes
  - Steady-state tests cover range of steam/air fractions for SBWR
  - Transient tests demonstrate condensation pressure driven flows both with and without the presence of non-condensable gases in the PCC
- SBWR integrated systems tests (PANDA and GIRAFFE) complete the qualification database by demonstrating system performance

PANTHERS Structural Tests

- ***Objective: Be able to qualify the Hx for the life of SBWR***
  - *Different approaches for PCC and IC*
- ***PANTHERS/PCC - Verification by test***
  - *Subject unit to 5 times design number of pressure/temperature cycles*
  - *In accordance with ASME Code Section III, Appendix II, Article II-1000, Subarticle II-1500*
- ***PANTHERS/IC - Verification by analysis***
  - *Envelope all T/H loads expected to capture the largest temperature gradients and the fastest thermal transients with prototype pressure loads*
  - *Cycle sufficiently to reveal any thermal racheting where elastically calculated stress levels exceed ASME Code shakedown limits*
    - *Measured deformations can be used to envelop the ASME alternative shakedown analysis approach*

SBWR ACRS TH SC MEETING
ATTENDANCE

Tuesday, 11/28/95

NAME	AFFILIATION	PHONE
John Leatherman	GE SBWR Certification	408-925-2023
Don McPherson	NRC /NRR	301-415-1246
JACK KUDRICK	" "	" " -2871
NOVAK ZUBER	ACRS / consult.	301-424-3585
R H BUCHHOLZ	GE	408-925-4584
ALAN LEVIN	NRC/NRR/SRXB	301-415-2890
SON NINH	NRC/NRR/SRXB	301-415-1125
Gordon Wingate	GE	408 925 1073
Maryann Herzog	GE	408 925 1921
Andy Hunsbedt	GE	408 925 1655
Bill Usry	GE	408 925-3460
JESUS FAIG	DTN-GE	408 925-1854
Robert Gamble	GE	408 925-3352
JACK DUNCAN	GE	408 925 6947
JOHN TORBECK	GE	408 925-6101
Susumu Takada	EPRI/JAPC	415-855-8725
Klaus Kirschenmann	EPRI/EVS	415-855-2704
Joseph Yedidia	EPRI	415 855 8724
TOM MULFORD	EPRI	415-855-2766
Tom Fernandez	EPRI Consult	415-855-8733
ERNIE CONDON	DOE	301-903-5501
George Yadigaroglu	ETH, Swiss Fed. Inst. Techn	+41-1-632.4615
FRED MOODY	GE	408 925-6434
Jim QUINN	GE	408 925 1005
Bharat Shiralkar	GE	408 925-6889
PAUL BOEHNERT	NRC/ACRS	301-415-8065
Robert L. Seale	ACRS Member	520/298-7118
Tom KRESS	ACRS	423-483-7548
Ivan Catton	"	310 825 5320
James C. Carroll	"	510-254-6324
Virgil Schrock	ACRS Consultant	510-642-6431
Vijay Dhir	ACRS Consultant	310-825-8507
Sol Levy	EPRI Consultant	408-369-6500

Additional slides used at the end of G. Yadigaroglu presentation on "Analytical Basis for Top-down and Bottom-up Scaling" to discuss results of global momentum scaling for GIRAFFE/SIT and PANDA

Additional slides used at the end of R. Gamble presentation on "Application of Scaling to SBWR and Major Test Facilities" to discuss detailed scaling results for PANDA

Scaling Summary for PANDA

- *Paremeters important to facility behavior scaled adequately*
  - *All relevant systems present*
  - *Line flow resistances scaled adequately*
  - *All important top-down phenomena retained*
- *Facility scaled adequately for intended purpose*

ACRS Thermal Hydraulic Phenomena Subcommittee Meeting
SBWR Test and Analysis Program
November 28-29, 1966
San Jose, CA

PANDA Test Results

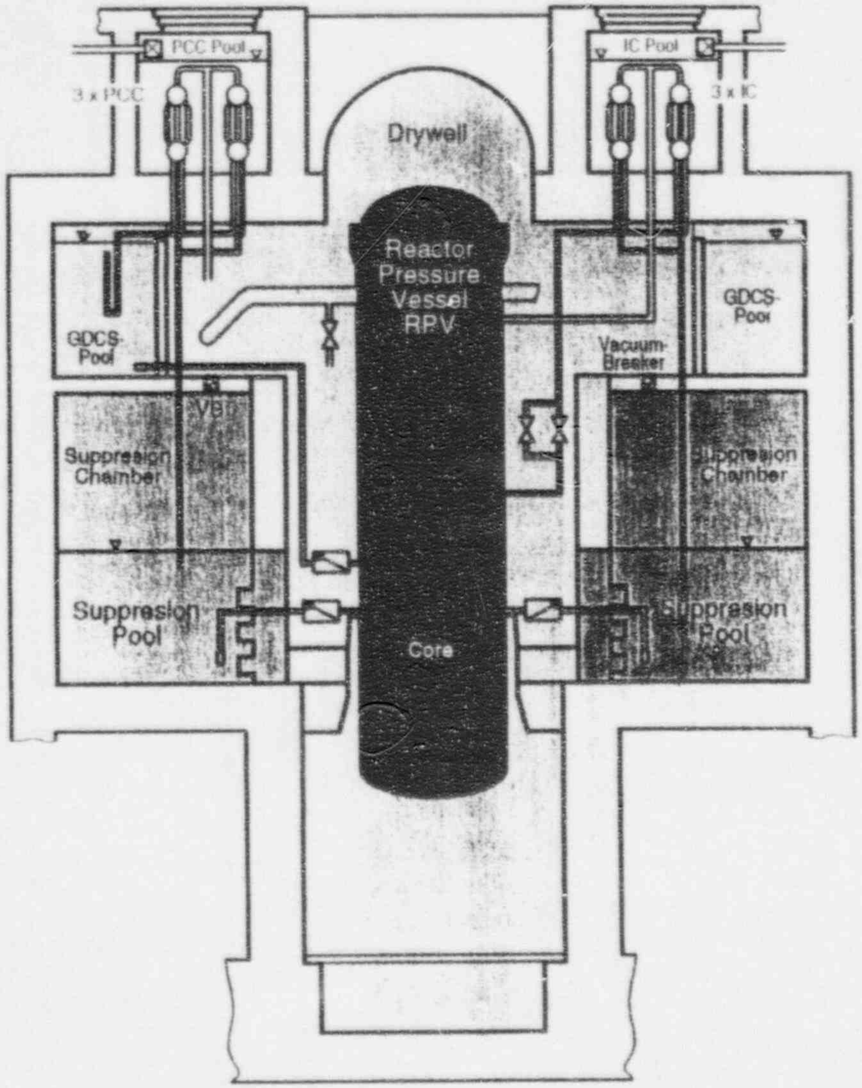
PANDA Team: G. Varadi, J. Dreier, M. Huggenberger, J. Healzer, C. Aubert, T. Bandurski, O. Fischer, S. Lomperski, and H.-J. Strassberger

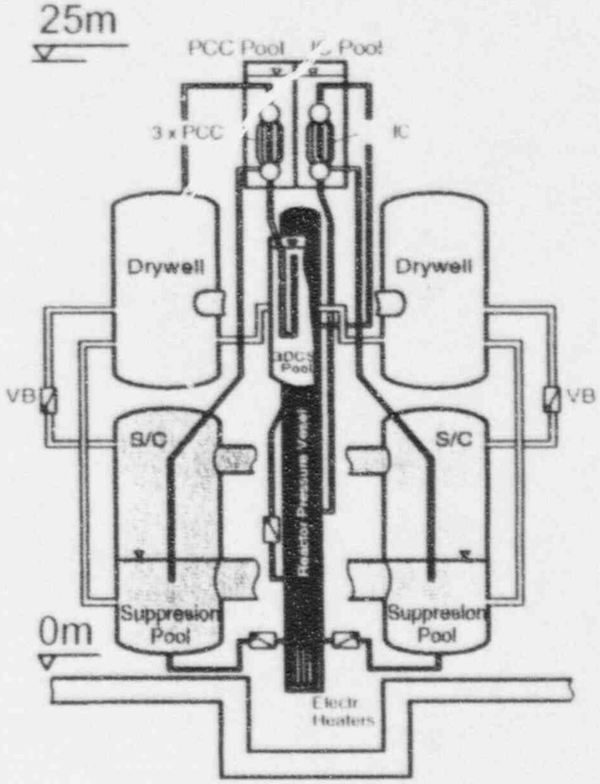
presented by
G. Yadigaroglu

Contents

- Test Objectives
- Facility Characterization Tests
- Steady-state PCC Condenser Characterization Tests
- First M3 Series of Transient Tests: M3, M3A, M3B
- "Startup" Test M7

Correspondence between SBWR and PANDA





Scaling:

Height	1 : 1
Volume	1 : 25
Power	1 : 1

PANDA - Test Objectives

In relation to the SBWR certification effort;

TAPD objectives

1. Provide additional data to:
   - (a) support the adequacy of TRACG to predict the quasi-steady heat rejection rate of a PCC heat exchanger, and
   - (b) identify the effects of scale on PCC performance

   → *Steady State Performance Tests*
2. Provide a sufficient data base to confirm the capability of TRACG to predict SBWR containment system performance, including potential systems interaction effects

   → *Integral Systems Tests*
3. Demonstrate startup and long-term operation of a passive containment cooling system

   → *Concept Demonstration*

Additional objectives:

- Containment performance is similar in a larger-scale, multidimensional system to that previously demonstrated with the smaller-scale GIRAFFE tests.
- Any non-uniform distributions in the containment do not create significant adverse effects.
- There are no adverse effects associated with multi-unit PCCS operation and interactions with other reactor systems.

First tests indicate that objectives are being achieved

PANDA TESTS - Summary

Facility Characterization Tests

(July 1995)

- Hydrotests and cold gas leakage tests
- Heat loss tests
- Pressure drop vs. flow rate characteristics
- Data used as inputs to code calculations

Steady-state PCC Condenser Characterization Tests

(May through Aug 1995)

- 10 valid tests
- Good repeatability and agreement with other data and pre-test calculations

M3 Series Transient Tests (M3, M3A, M3B).

(Oct.-Nov. 1995)

- Operability of facility (initial conditions, power decay, etc.) and quality of instrumentation and equipment demonstrated.
- Certain difficult PCC flow measurements (range, oscillations, noise) were supplemented by pool heat balances
- Preliminary conclusions (tests still being analyzed)

"Startup" Test M7

(Nov. 1995)

- Demonstrated PCCS startup
- Oscillations in the RPV were detected

Facility Characterization Tests

Cold gas leakage tests

- 62 hr tests
- Met or exceeded expectations
- DW, WW, GDCS vessels: < 0.08 % per day
- RPV: 3.7 % per day (the least important one)

Heat loss tests

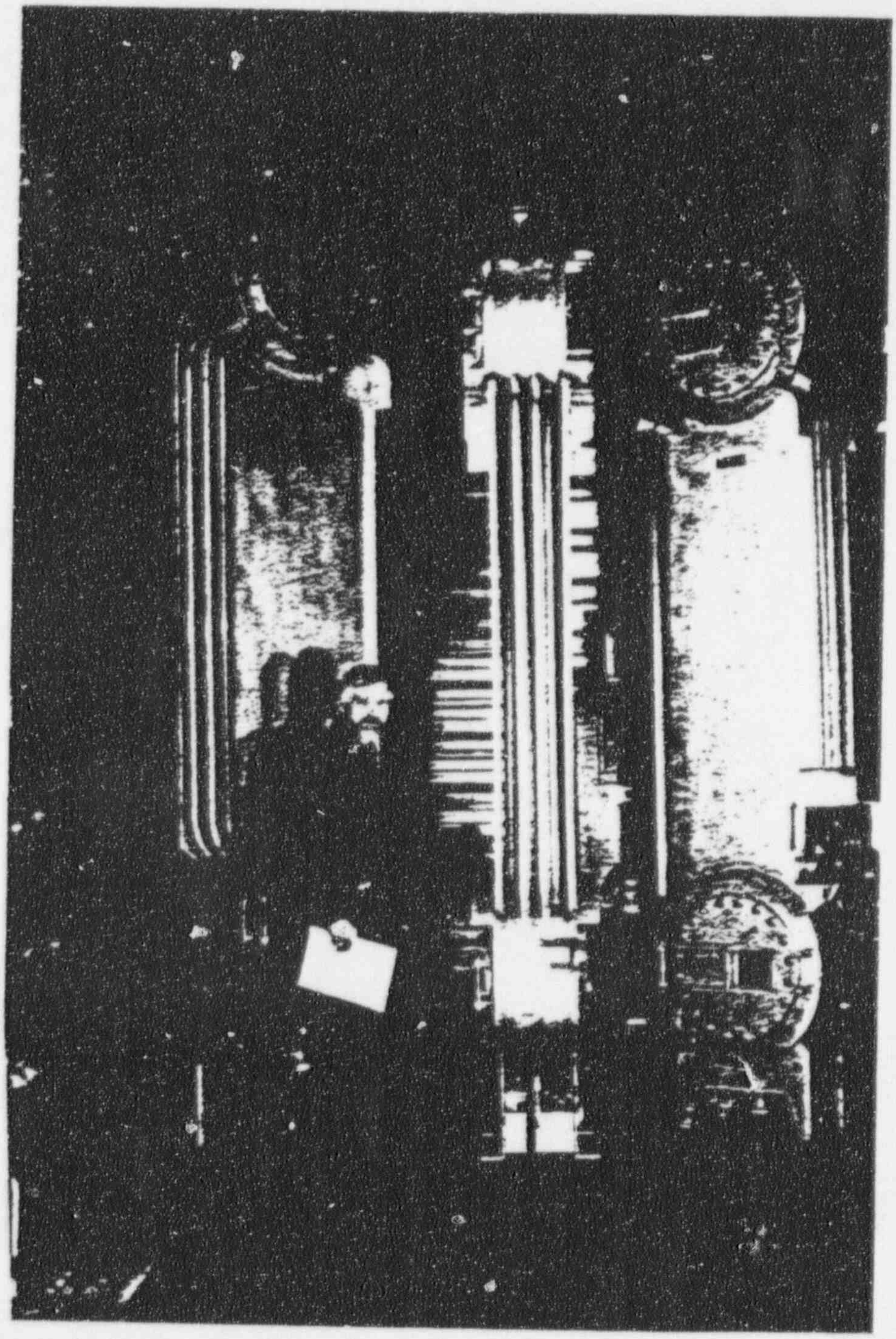
- Do not exceed 7 % of decay heat at 24 hrs after scram
- Design target was 10 %

Pressure drop vs. flow rate characteristics

- All loss coefficients measured for a range of flow rates
- All lines found to be properly scaled

PANDA Experimental Facility

Isolation Condenser (IC) and Passive Containment Coolers (PCC)



Scaled SBWR IC-Unit (left) and two PCC-Units

[PSI-LTH B13/24 April 13, 1993]

M3 Series of Tests

- MSL Break (MSLB) tests
- Initial conditions: the state of the system 1 hr after scram (the DW contains mostly steam)
- PCC condensers: PCC-1 to DW-1 and PCC-2 and PCC-3 to DW-2
- IC condenser valved off
- Identical initial and power decay conditions
- Initially saturated water in PCC pools
- Similar to a GIRAFFE MSLB test with uniform DW conditions

Investigated the effect of the water level and inventory in the PCC pools on system performance:

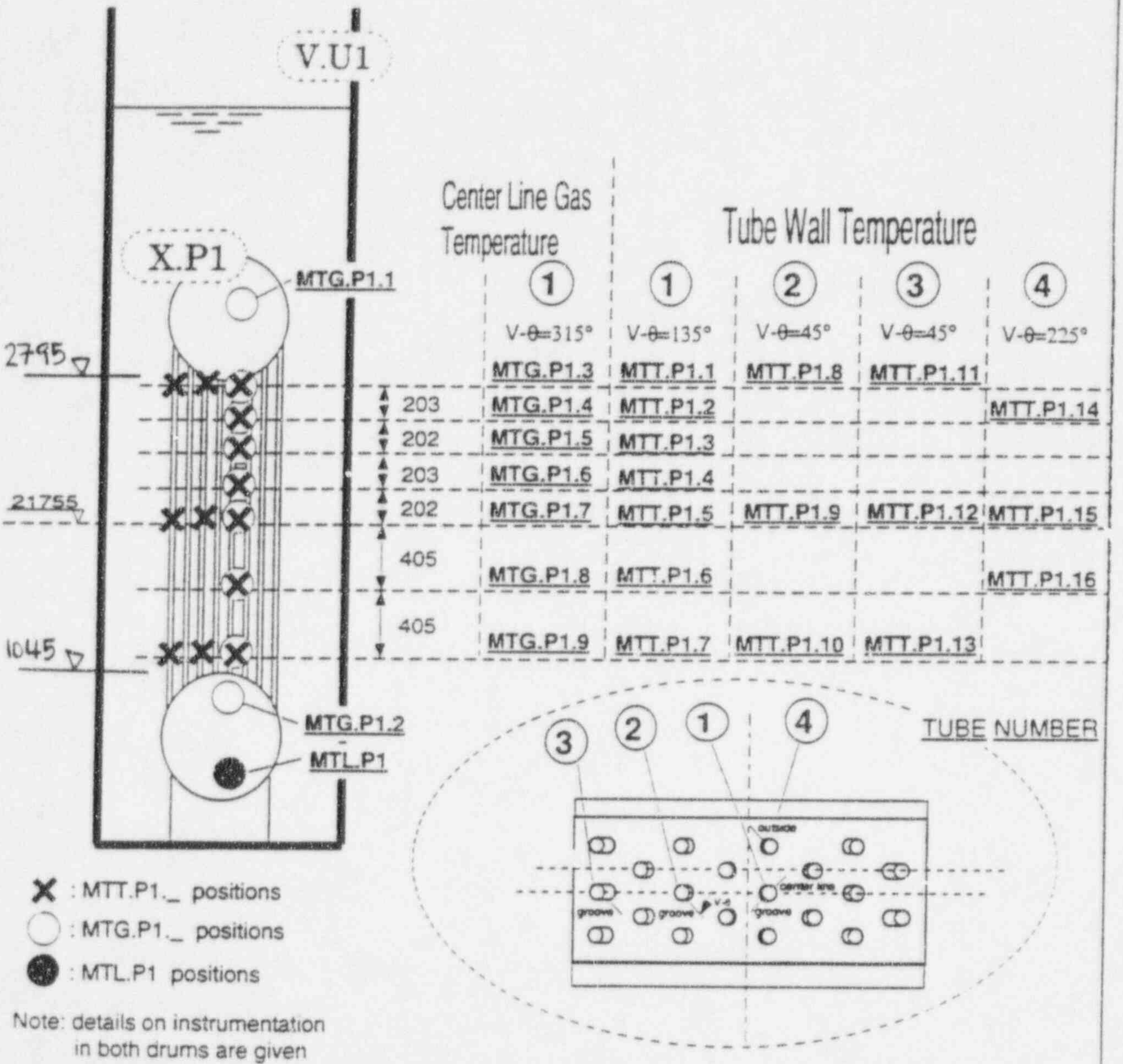
- M3: the three PCC pools interconnected - no water makeup. At the end of this 20 hr test, the water level in the PCC pools had dropped about 0.5 m below the top of the tubes.
- M3A: three PCC pools isolated - cold water added from the bottom fill line to each pool individually - nominal water level constant within ± 0.3 m.
- M3B: the three pools interconnected - cold water added simultaneously to all three (using the connecting bottom-fill line) - nominal water level constant within ± 0.2 m.

PSI PAUL SCHERRER INSTITUT

As-Built Drawing

PANDA Instrumentation

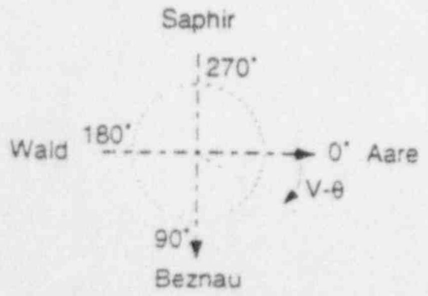
PCC1 Condenser Gas & Wall TC Positions



	Center Line Gas Temperature	Tube Wall Temperature			
	①	①	②	③	④
	V-θ=315°	V-θ=135°	V-θ=45°	V-θ=45°	V-θ=225°
2795	MTG.P1.3	MTT.P1.1	MTT.P1.8	MTT.P1.11	
203	MTG.P1.4	MTT.P1.2			MTT.P1.14
202	MTG.P1.5	MTT.P1.3			
203	MTG.P1.6	MTT.P1.4			
202	MTG.P1.7	MTT.P1.5	MTT.P1.9	MTT.P1.12	MTT.P1.15
405	MTG.P1.8	MTT.P1.6			MTT.P1.16
405	MTG.P1.9	MTT.P1.7	MTT.P1.10	MTT.P1.13	

✕ : MTT.P1._ positions
○ : MTG.P1._ positions
● : MTL.P1 positions

Note: details on instrumentation in both drums are given separately.



Tolerances:

Elevation: ± 15 mm
Hight difference: ± 2 mm
Angle: ± 10°

AC 42 / TC_PCC1.ISD
14.06.95 / VERSION 2

Preconditioning:
Establishment of the Proper Initial Conditions

Typical preconditioning procedures:

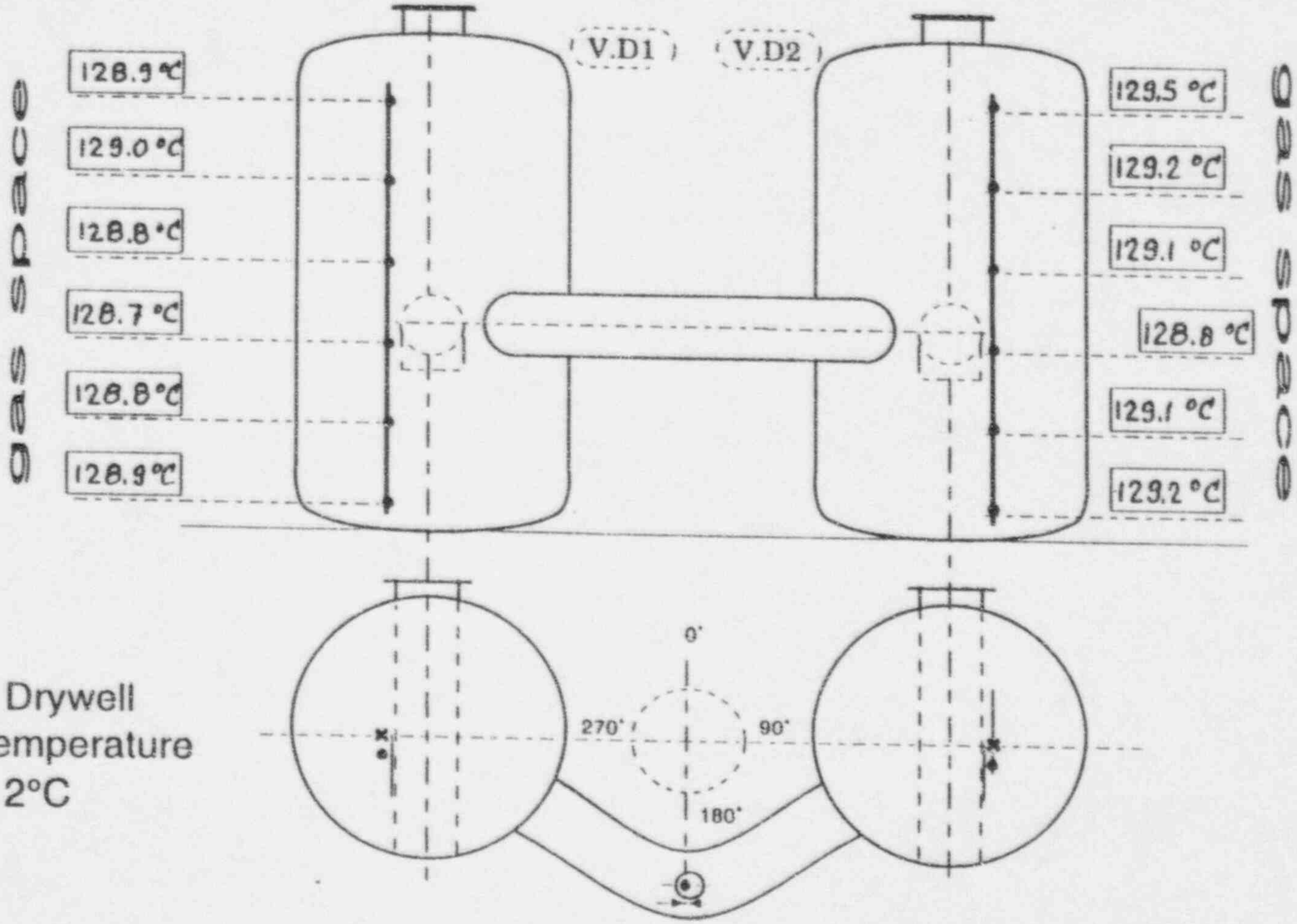
- The various containment volumes are isolated, filled with demineralized water, steam from the RPV or air, and further heated, as necessary, using heat from the RPV via the preconditioning-system heat exchanger.
- Air is eliminated, by purging with steam, when necessary.
- The RPV is first heated to about 170 °C (T_{sat} = 7.5 bar) with a sufficiently high water inventory, in anticipation of the heating needs for the entire facility.
- The two SCs are filled with water at the desired (uniform) initial T
- The preconditioning is conducted in a way assuring a uniform SC air space T; steam is injected to heat up the structure and the air space.
- On the long term, the partial pressure of the steam in the gas spaces of the two SCs is set by the water temperature.
- The required amount of air is injected to adjust the partial p of air in the two SCs at its specified initial value.
- To achieve a uniform (air space and wall) T in the GDCS vessel: structure is steam heated. Vessel is initially filled with hot water; this water is then transferred to the PCCS pools.
- The PCCS (and whenever used, also the ICS) pools are simply filled with hot water to the desired level(s).

Preconditioning:
Establishment of the Proper Initial Conditions cont'd

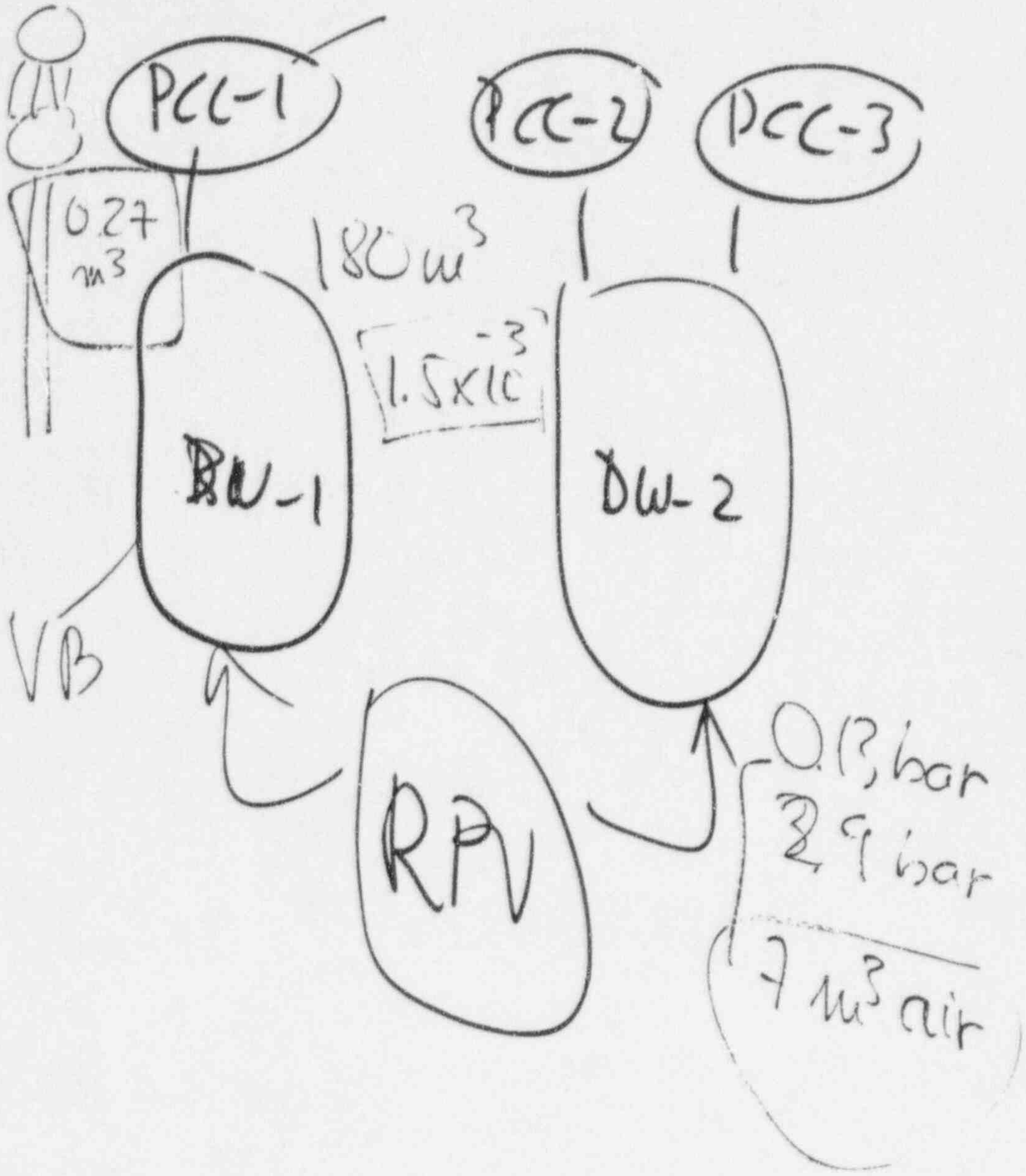
- Accurate adjustment of the initial air partial p in the DWs:
    - the vessels are first heated and purged of practically all air by steam injection. (*some* air accumulates during this time in the PCC condensers)
    - The p in the DWs is then recorded and a sufficient amount of air is injected to increase the vessel p by the amount of the required initial partial p of air (procedure relies upon the measurement of a p *difference* and is therefore quite accurate)
- When the required initial conditions are reached, vessel connections are opened to bring the system into the required configuration.
- The tests are started by opening the MSL valves and starting the power transient.

Test M3 (3/4 Oct 1995) Preliminary Data

Initial Conditions for Drywell Gas Temperature



Specified Drywell
Mean Gas Temperature
131 ± 2°C


PCC-1
PCC-2
PCC-3
0.27 m3
180 m3
1.5x10-3
DW-1
DW-2
VB
RPV
0.13 bar
2.9 bar
7 m3 air

GE Nuclear Energy

GIRAFFE HELIUM SERIES TESTS

ACRS Thermal Hydraulic Subcommittee Meeting

Maryann Herzog
November 29, 1995
San Jose, CA

GIRAFFE Helium Test Objectives

- Demonstrate PCCS operation in the presence of noncondensible gases that are lighter than and heavier than steam
- Demonstrate the purging of noncondensible gases from the Drywell to the Suppression chamber via the PCC condenser
- Provide a database for TRACG qualification
- Repeat previous GIRAFFE tests, including appropriate QA documentation

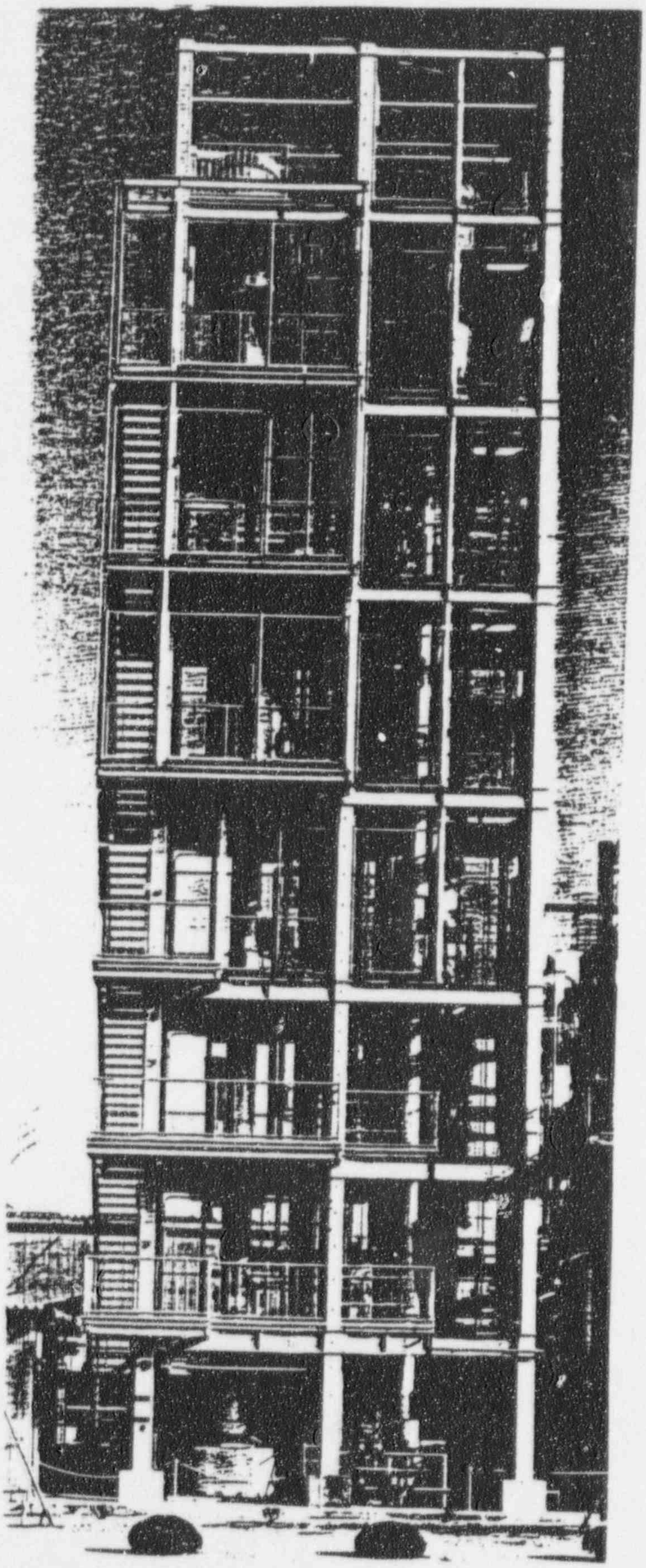


Figure 2.3-1 GIRAFFE Facility Photograph

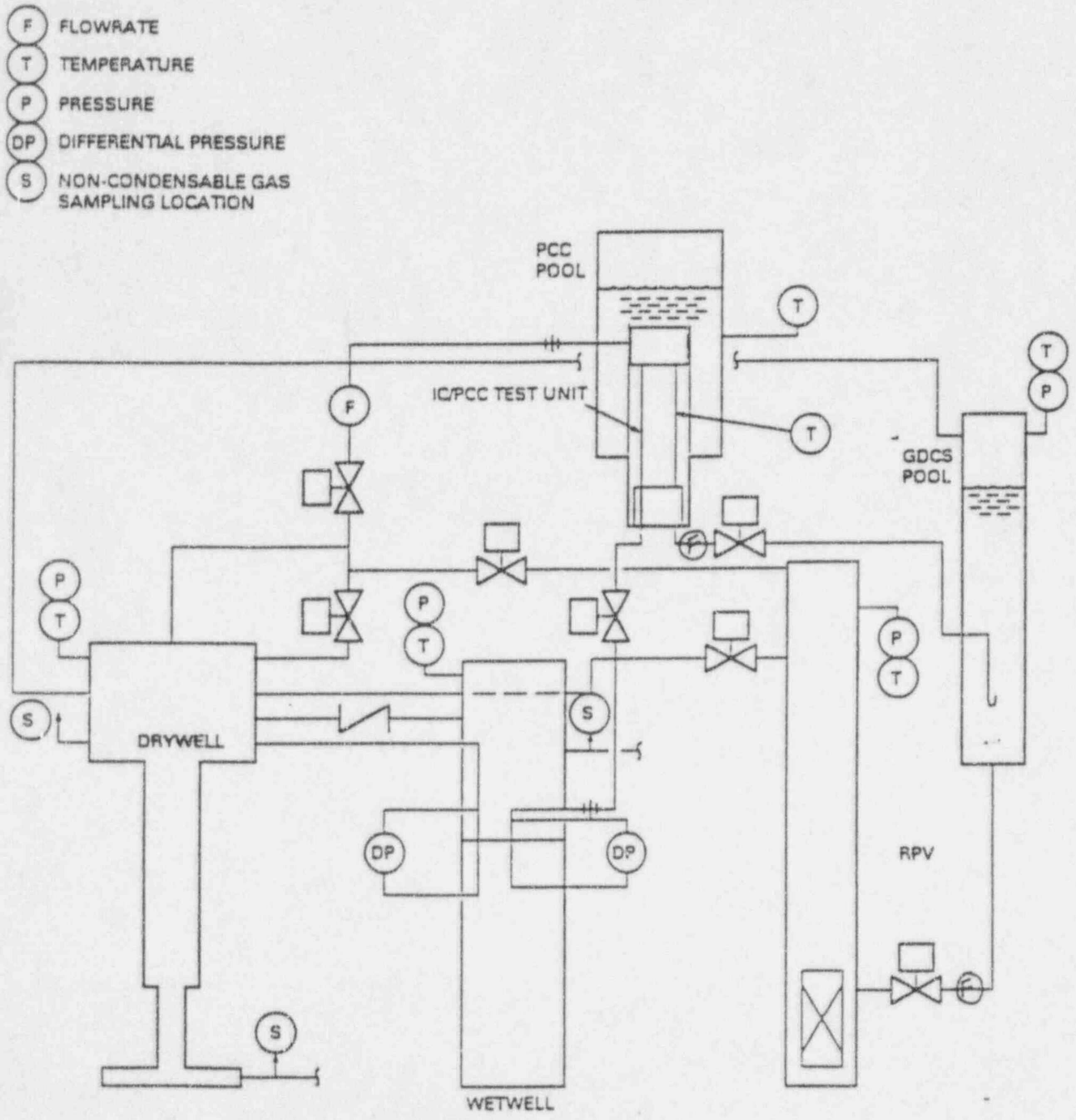


FIGURE 3-1. GIRAFFE Test Facility Schematic

TEST MATRIX

- Test H1: Main Steam Line Break, test starts at t=1 hour.
  Initial conditions = SBWR conditions calculated by TRACG.
  (4% Nitrogen in Drywell)
- Test H2: Same as H1 except Helium used instead of Nitrogen.

Tests H1 & 2 results will be used to compare the PCC system performance in the presence of heavier & lighter than steam gases. Test H1 will also be compared to PANDA Test M3 to determine any effects of scale on test results.

- Test H3: Main Steam Line Break plus metal water reaction,
  test starts at t=1 hour. Maximum initial He concentration,
  equivalent to 20% of a 100% m-w reaction.
  (4% N & 23% He in D/W)
- Test H4: Same as H3 except helium is injected during the first hour.

Tests H3 & 4 results will be used to investigate the PCCS system performance for high concentrations of helium.

Direct Measurement of Noncondensible Gas Concentrations

- Samples are collected simultaneously at three locations: upper & lower D/W and the S/C.

  Each location is near a thermocouple to enable comparisons of measured and calculated noncondensible gas concentrations.
- Samples are collected at 1 hour intervals.
- Two samples are collected at each location:
  - First sample is used to determine ratio of steam to noncondensible gases.
  - Second sample is used to measure the ratio of helium to nitrogen.
- Samples are measured using a gas chromatograph to determine the concentrations of each gas.
- The accuracy of the measurement is +/- 3%.

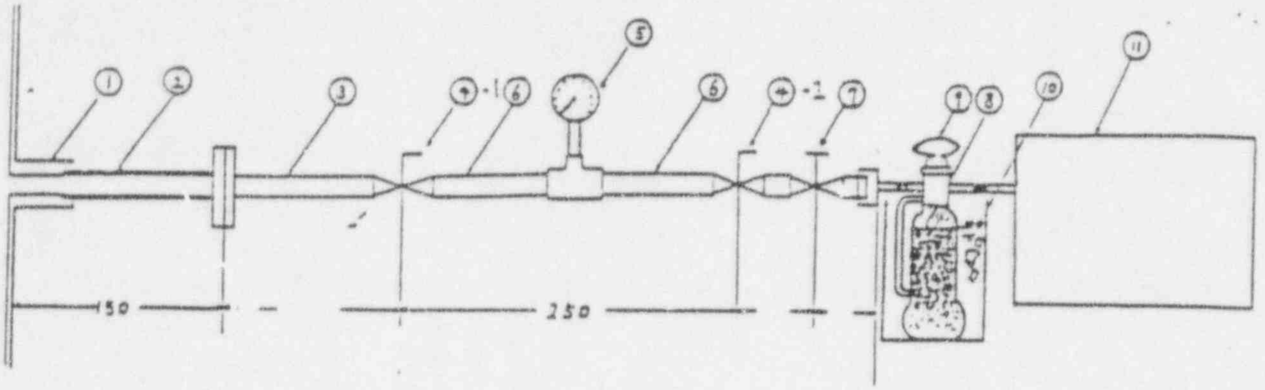


Fig-2.1 Equipment and instruments for water sampling

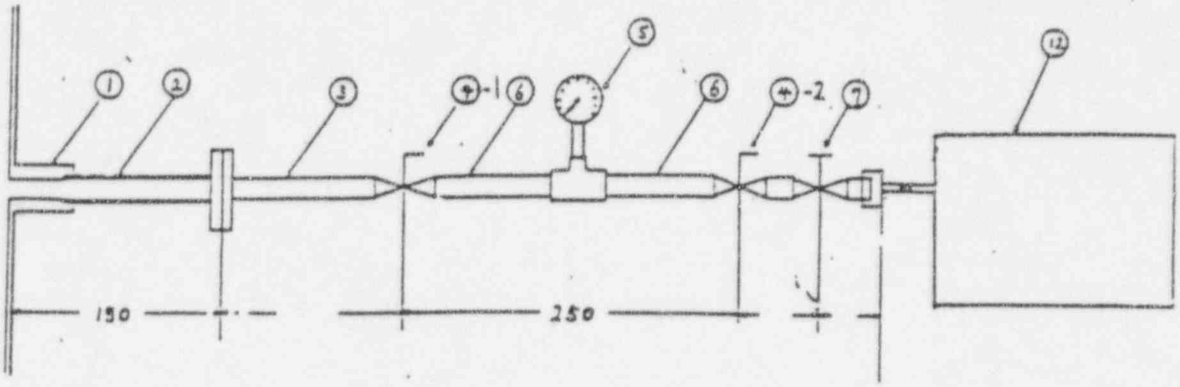


Fig-2.2 Equipment and instruments for non-condensable gas sampling

NO.	Tite	Quality	Remarks
1	Bass	SUS 304	OD:35φ. ID:15.7φ
2	pipe	SUS 304	1/2B. SCH:40
3	pipe	SUS 304	3/8B. SCH:40
4 -1, -2	stop valve	SUS	Ball Valve
5	pressure gage	SUS	AMU3/8PT. 10Kg/cm^2
6	pipe	SUS 304	3/8B. SCH:40
7	Needle valve	SUS	
8	absorption Battle	Glass	Filling up $CaCl_2$ and poly-wool
9	Cock	Glass	
10	Cooling Bath	SUS	Filling up $CaCl_2$ and Dry-Ice
11	gas sampling Bag 1	PVF	maximum 2 litters
12	gas sampling Bag 2	PVF	maximum 2 litters

TEST RESULTS

- During each of the helium tests, purging of noncondensible gases from the PCC condenser occurred.The LOCA vent remained covered during all tests.
- The helium tests confirm that even for large quantities of noncondensible gases, the PCCS can purge the noncondensibles within less than one hour.
- V/B only opened during Test H1, the 4% nitrogen case.

  The nitrogen present in the PCC condenser tubes was concentrated in the bottom 20 % of the tubes (near thermocouple TEP 28). The PCCC heat removal was thus very high and within approximately one hour it exceeded the RPV decay heat. The D/W pressure dropped below the S/C pressure and the vacuum breaker valve opened for a few seconds at t= 12,500 sec. & 17,500 sec.

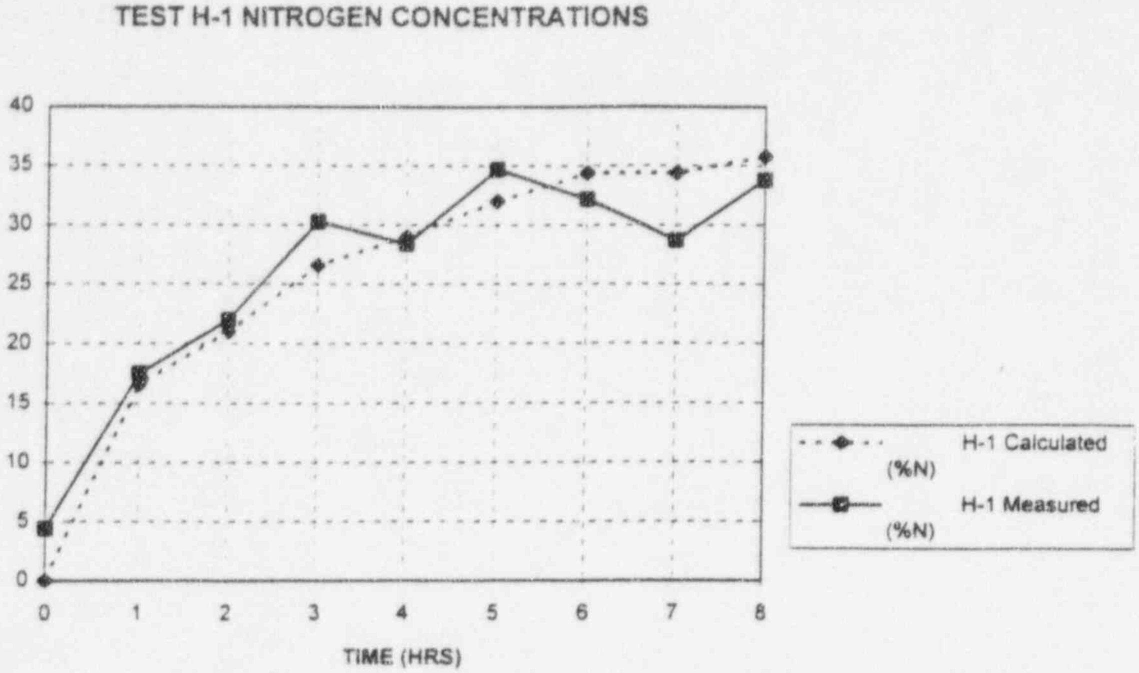
DIRECT GAS SAMPLING RESULTS

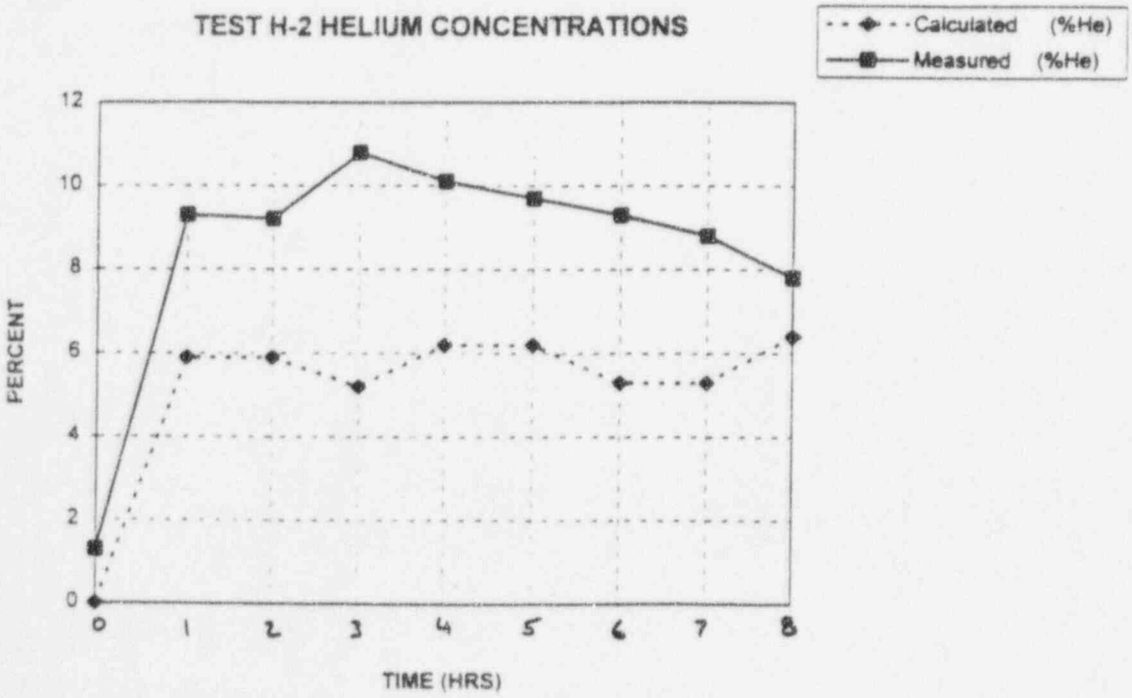
- Direct gas sampling results show that for each test approximately 50% of the noncondensible gases were vented by the PCCS to the S/C.
- For Tests H3&4, 50% of the initial helium volume is equal to 30 times the PCC condenser volume.
- Preliminary review of test data indicates good agreement between calculated and measured n/c gas concentrations.

  - Tests H-1 and H-4 results compare very well.
  - Tests H-2 and H-3 results do not compare as well.

  Test H-2 has a low concentration of helium, therefore the differences may be related to measurement accuracy. H-3 results require further review to determine reason for differences in calculated and measured concentrations.

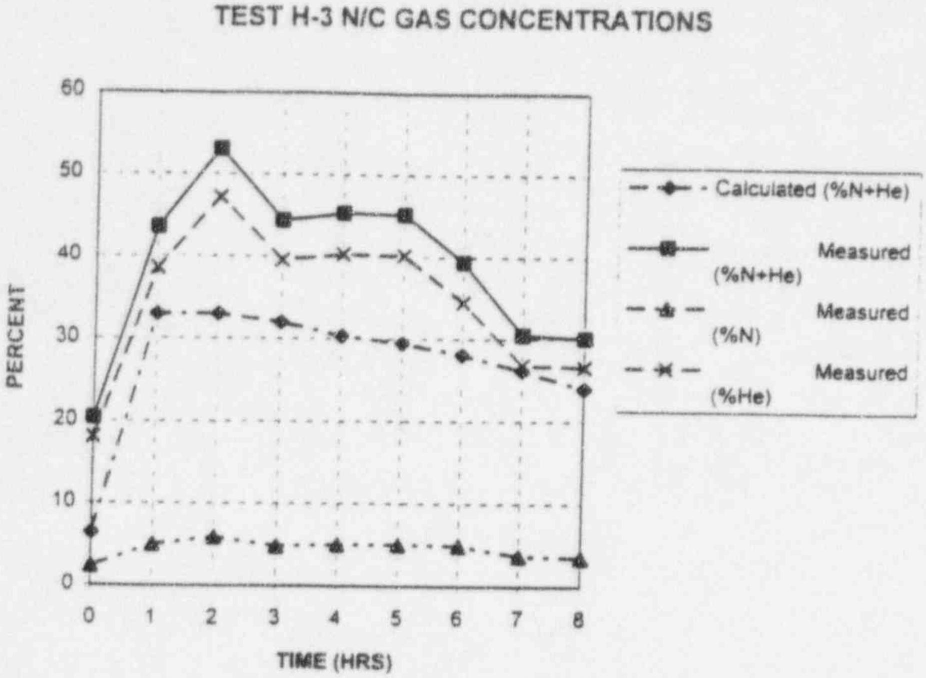
COMPARISON OF MEASURED & CALCULATED CONCENTRATIONS
LOWER DRYWELL

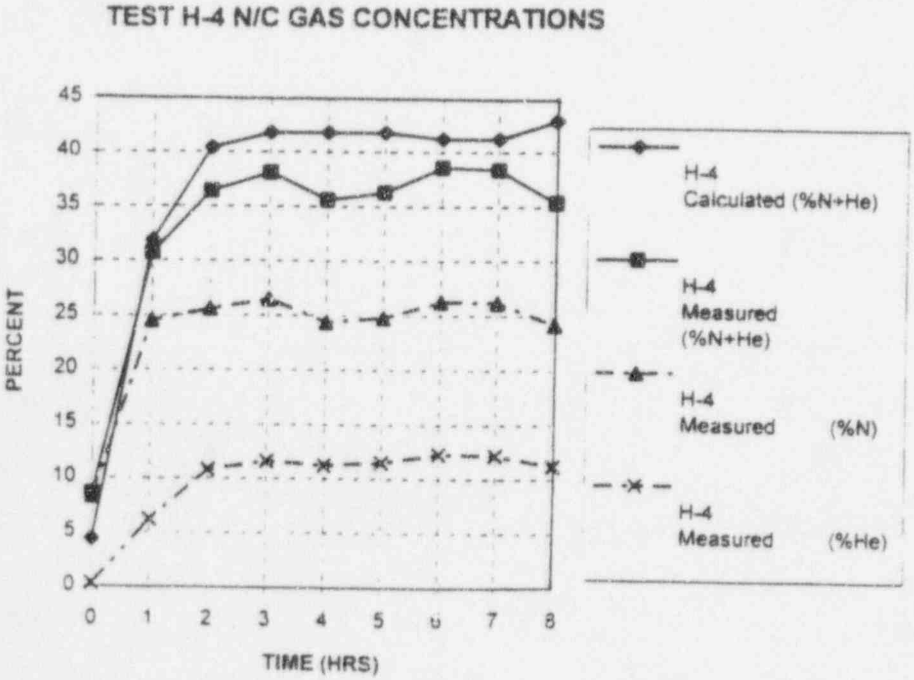




COMPARISON OF MEASURED & CALCULATED CONCENTRATIONS

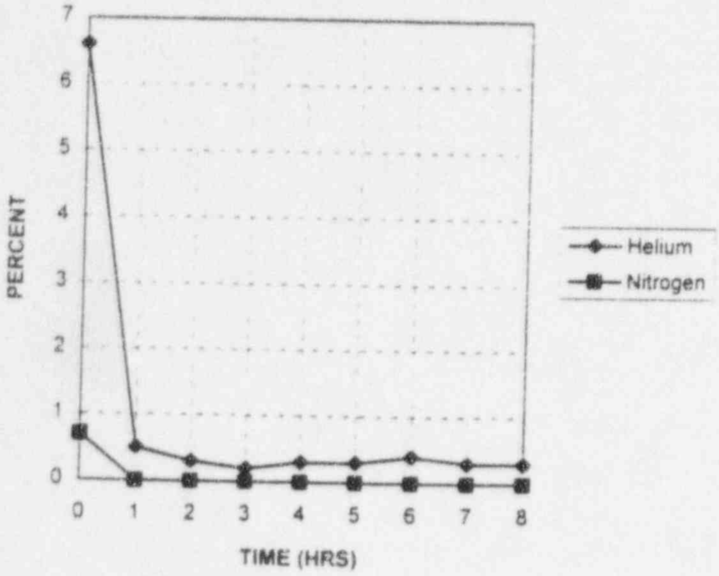
LOWER DRYWELL



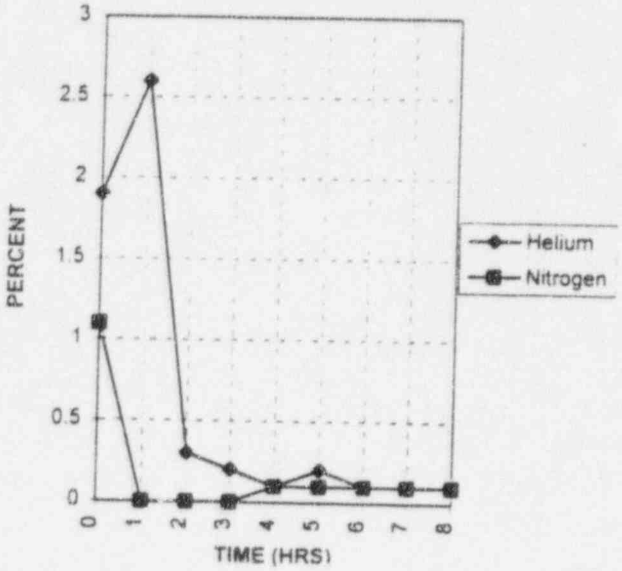


TESTS H3 & H4 UPPER D/W & S/C MEASURED GAS CONC.

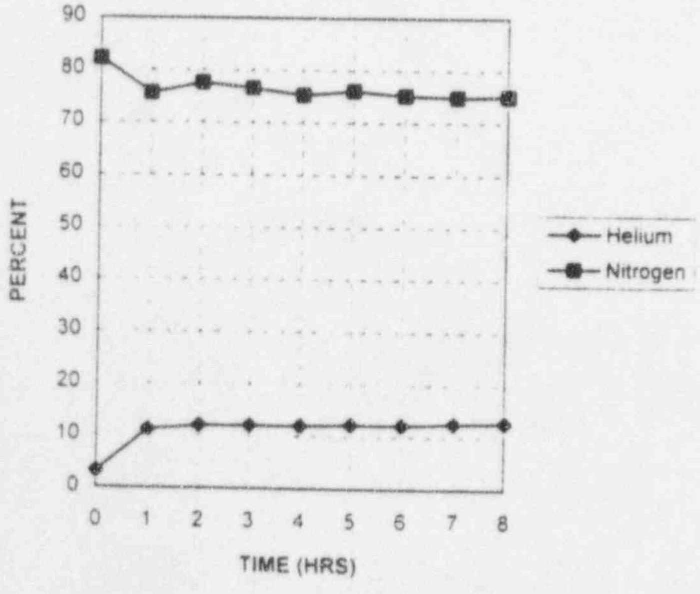
Test H-3 UPPER D/W GAS CONCENTRATIONS



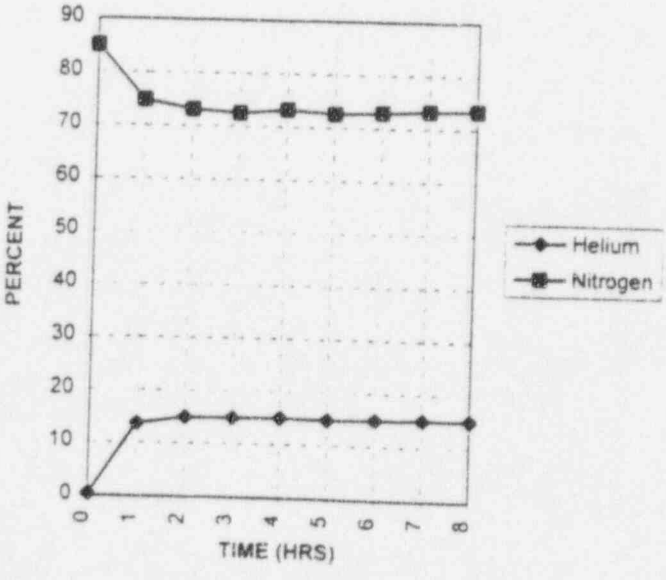
TEST H-4 UPPER D/W GAS CONCENTRATIONS



TEST H-3 S/C GAS CONCENTRATIONS



TEST H-4 S/C GAS CONCENTRATIONS



OUTLINE

- OBJECTIVE
- TEST MATRIX
- FACILITY DESCRIPTION
- PRELIMINARY RESULTS: FAVORABLE

OBJECTIVE

- MAINSTEAM LINE BREAKS LIMITING FOR CONTAINMENT PERFORMANCE
- GDCS (GRAVITY DRIVEN COOLING SYSTEM) AND BDL (BOTTOM DRAIN LINE) BREAKS LIMITING FOR REACTOR VESSEL RESPONSE
- NRC CONCLUDED ADDITIONAL INTEGRAL TESTING NEEDED
- OBJECTIVE
  - DATA BASE FOR TRACG QUALIFICATION,
  - FOCUS ON POTENTIAL SYSTEM INTERACTIONS (IC, PCCS)

TEST MATRIX

Table A.3-21 GIRAFFE/SIT Test Matrix

Test	Break	Single Failure	IC/PCCS on?
GS1	GDL	DPV	No
GS2	GDL	DPV	Yes
GS3	BDL	DPV	Yes
GS4	GDL	GDCS	Yes

GDL = Gravity Drain Line
BDL = Bottom Drain Line
DPV = Depressurization Valve
GDCS = GDCS Injection Valve

Table A.3-23 Basis for GIRAFFE/SIT Test Conditions

Objective	Option			Test ID
	Break	Failure	IC/PCC Operation	
Worst Break/Single Failure Combination	GDL	DPV	No	GS1
Benefit of IC/PCC	GDL and GDL	DPV DPV	No Yes	GS1 GS2
Slow Water Level Recovery	GDL	GDCS	Yes	GS4
Fast Water Level Recovery	BDL	DPV	Yes	GS3
Case showing GDCS void quenching and break flow depressurizing drywell	GDL GDL	DPV DPV	Yes No	GS2 GS1

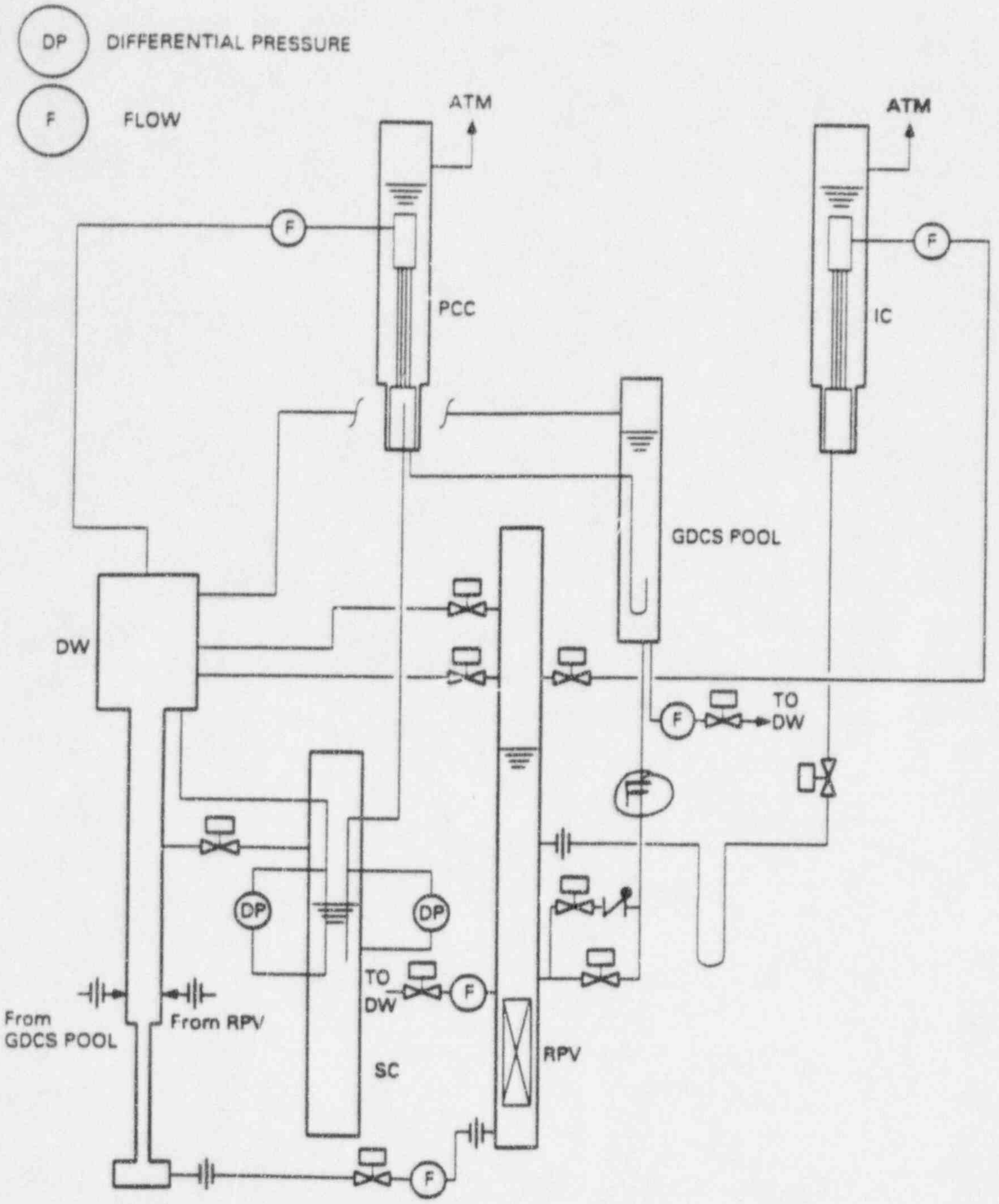


FIGURE 3-1. GIRAFFE Test Facility (System Interaction Tests)

PRELIMINARY RESULTS

- PRESSURES
- GDCS FLOWS
- RPV WATER LEVELS
- SUMMARY

GE Nuclear Energy

SBWR Design & Certification Program
Reactor Startup Behavior

ACRS Thermal Hydraulic Phenomena Subcommittee Meeting
Nov. 29, 1995
San Jose, CA

C. K. Tang

Natural Circulation BWR Plant Startup

Discussion Topics:

- Dodewaard plant startup
- SBWR plant startup procedure
- TRACG analyses of SBWR startup
- Summary

Dodewaard Natural Circulation BWR

Dodewaard plant

- *Natural circulation BWR with internal free surface steam separation*
- *Rated thermal power output of 183 MWth*
- *Rated generator output of 60 MWe*
- *Initial startup in 1969, continuously operation since commercial operation*

REACTOR VESSEL AND INTERNALS

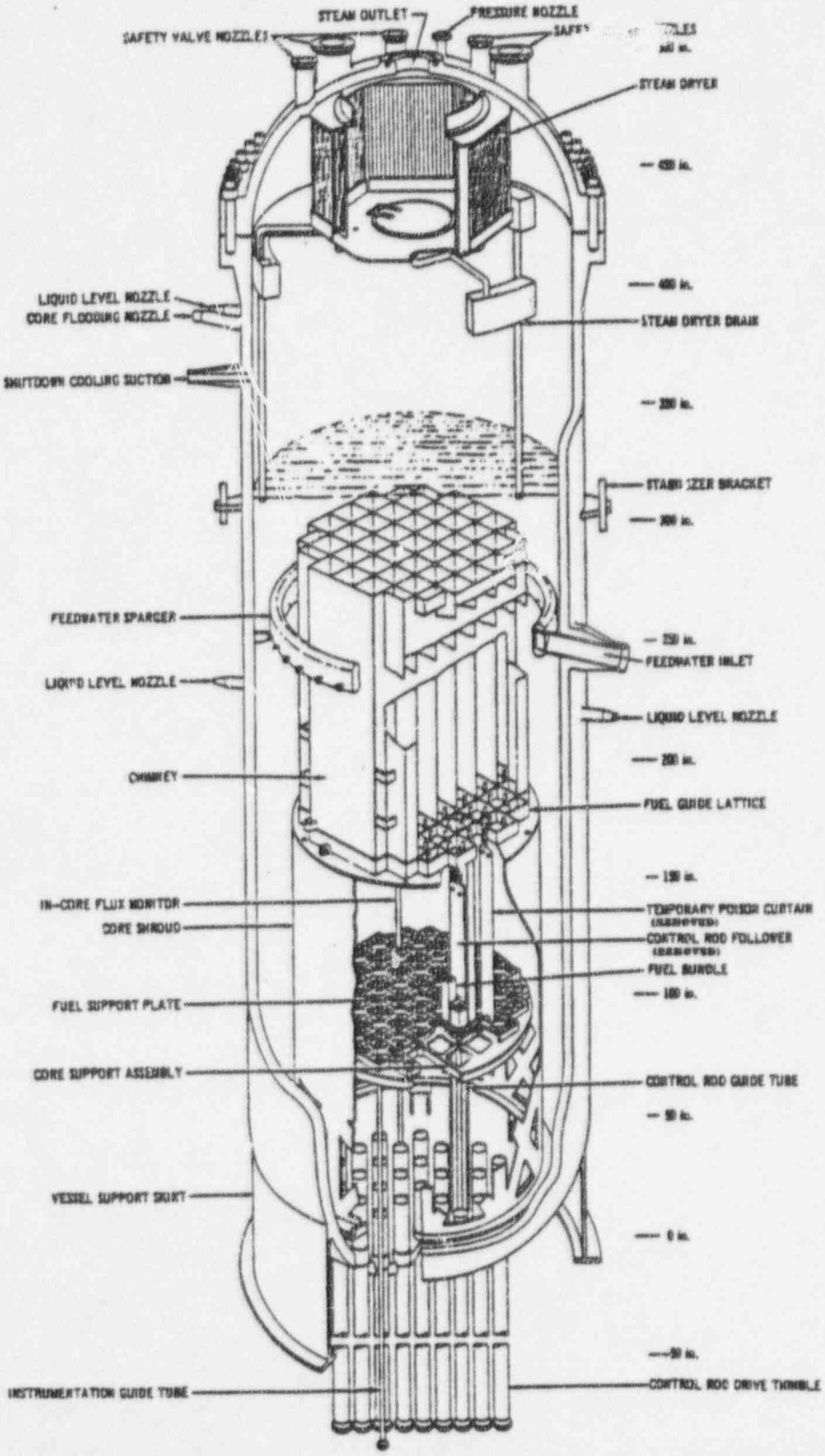


Figure 1

Dodewaard Plant Startup

Summary of normal plant startup procedure

- *Heat reactor coolant to 95-100 deg. C at atmosphere pressure*
  - *Terminate shutdown cooling*
  - *Operate electric heaters in Reactor Shutdown Cooling system*
  - *Terminate temporally CRD cooling flow*
- *De-aerate reactor coolant*
  - *Establish vacuum at main condenser*
  - *Open isolation condenser vent line and main steam drain line to main condenser (turbine bypass valves closed)*
  - *Continue de-aeration to reduce dissolved oxygen to specified limit*
- *Withdraw control rods to establish criticality*

Dodewaard Plant Startup (Cont'd)

- *Plant Heatup*
  - *Control reactor power with control rods to heatup at < 55 deg. C/h*
  - *Control reactor pressure with turbine bypass valves*
  - *Terminate electric heating of reactor coolant*
  - *Place RWCU system into operation to control reactor water level, reduce thermal stratification, and maintain water chemistry*

- *Turbine warmup and acceleration*
  - *Begin warming at approximately 30 bars*
  - *Accelerate to rated speed*

- *Turbine synchronization and loading*
  - *Synchronized at rated reactor pressure of approximately 70 bars*
  - *Continued power ascension by control rod withdrawals*

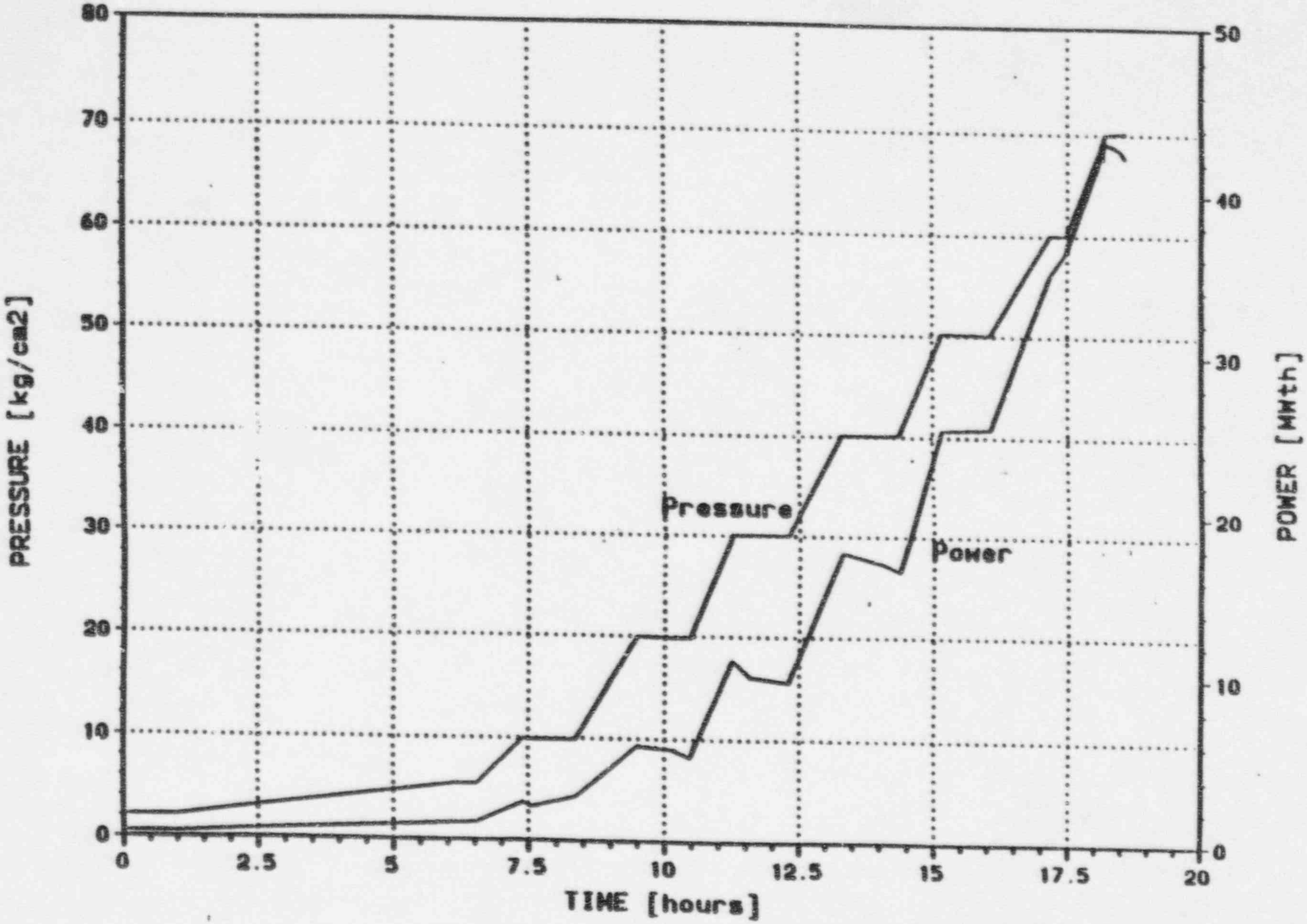


Figure 5-2. Reactor Pressure and Power during the February 1992 Startup

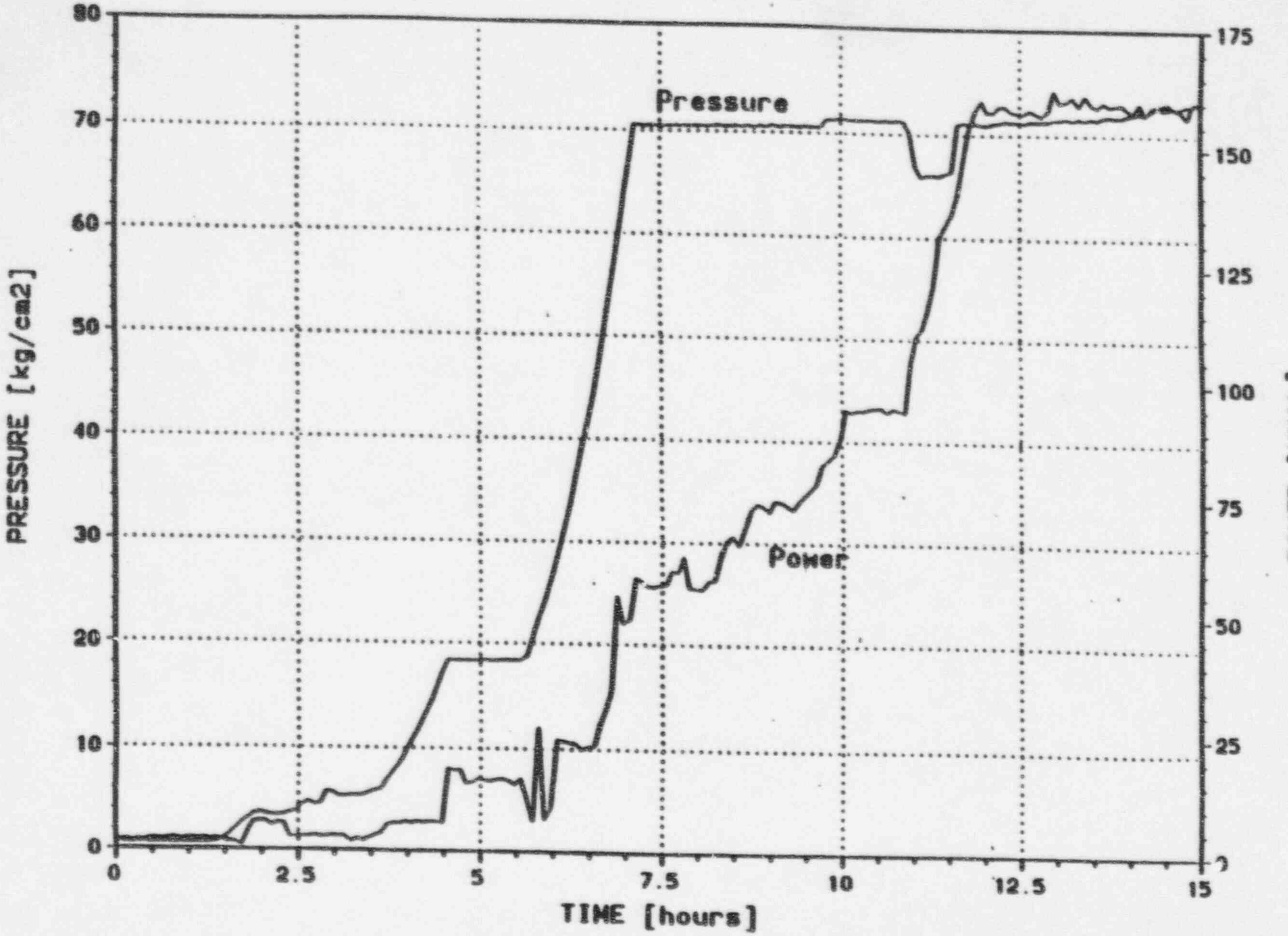
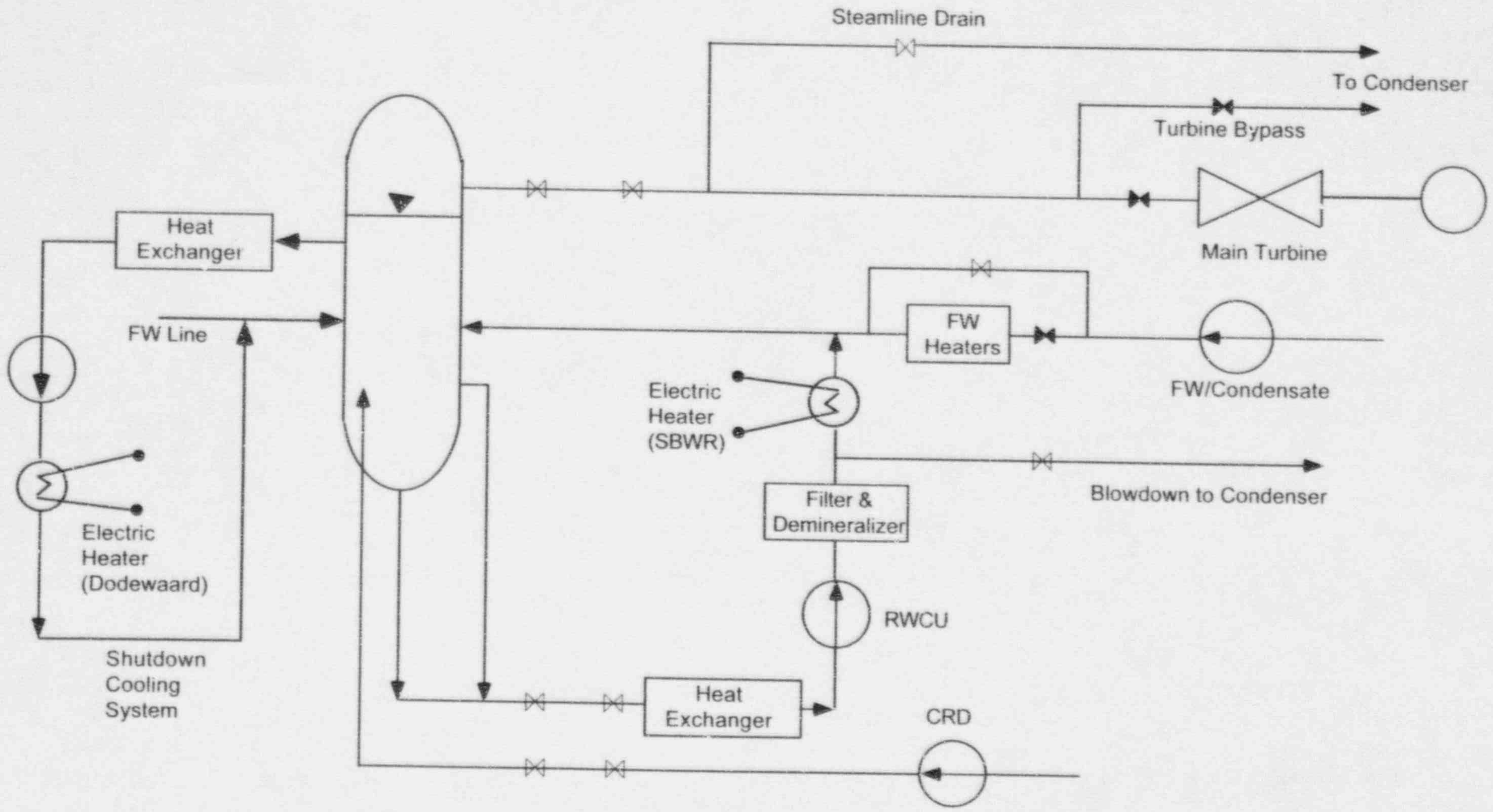


Figure 5-3. Reactor Pressure and Power during the June 1992 Startup

Simplified Configuration for Startup



SBWR Plant Startup

Plant Startup

- Complete prerequisites
  - Systems operable and lined up for startup (e.g., CRD in operation purging drives, RWCU rejecting water to condenser, MSIVs open, one condensate pump in operation, etc.)
  - Containment clear of personnel
  - Complete required surveillance tests
  - Normal reactor water level
  - Temperature meets requirements for operation on P/T limit curve

- Commence plant startup
  - Seal the main turbine glands with auxiliary steam
  - Establish a vacuum in the main condenser by vacuum pump
  - Terminate reactor shutdown cooling to begin warming of RPV coolant by decay heat
  - Operate RWCU in the reactor coolant heatup mode (electric heaters) to heat coolant to 80 deg. C to de-aerate reactor

Reactor Criticality & Heatup

- *Approach to criticality*
  - *Withdraw control rods in specified sequence to achieve criticality*
  - *Maintain a reactor period greater 100 seconds (typically 100 to 150 seconds) until the heating range is reached*
- *Plant heatup*
  - *Maintain turbine bypass valves closed during heatup*
  - *Continue rod withdrawal to develop a heatup rate <55°C in any one hour*
  - *Maintain normal reactor water level by rejecting water during heatup using the Reactor Water Cleanup System*
  - *Utilize the Condensate and Feedwater systems to add water to the RPV to maintain normal water level as required*
  - *At approximately 100 psig,*
    - *Begin warm-up of steam jet air ejectors*
    - *Begin warm-up of the main turbine and the off-gas system*
    - *Shift turbine gland sealing steam source from auxiliary steam to main steam*
  - *At approximately 250 psig,*
    - *Place steam jet air ejectors and off-gas system into operation*
    - *Shutdown mechanical vacuum pump*

Plant Heatup (Cont'd)

- Plant heatup (continued)
  - At approximately 600 psig
    - Start one reactor feedpump and establish automatic level control
    - Terminate water rejection via RWCU
  - As rated reactor pressure is approached, adjust the pressure regulator setpoint to appropriate value (bypass valves will begin to open when rated pressure is exceeded)
  - Continue rod withdrawal until approximately 15% power (bypassing steam to main condenser)

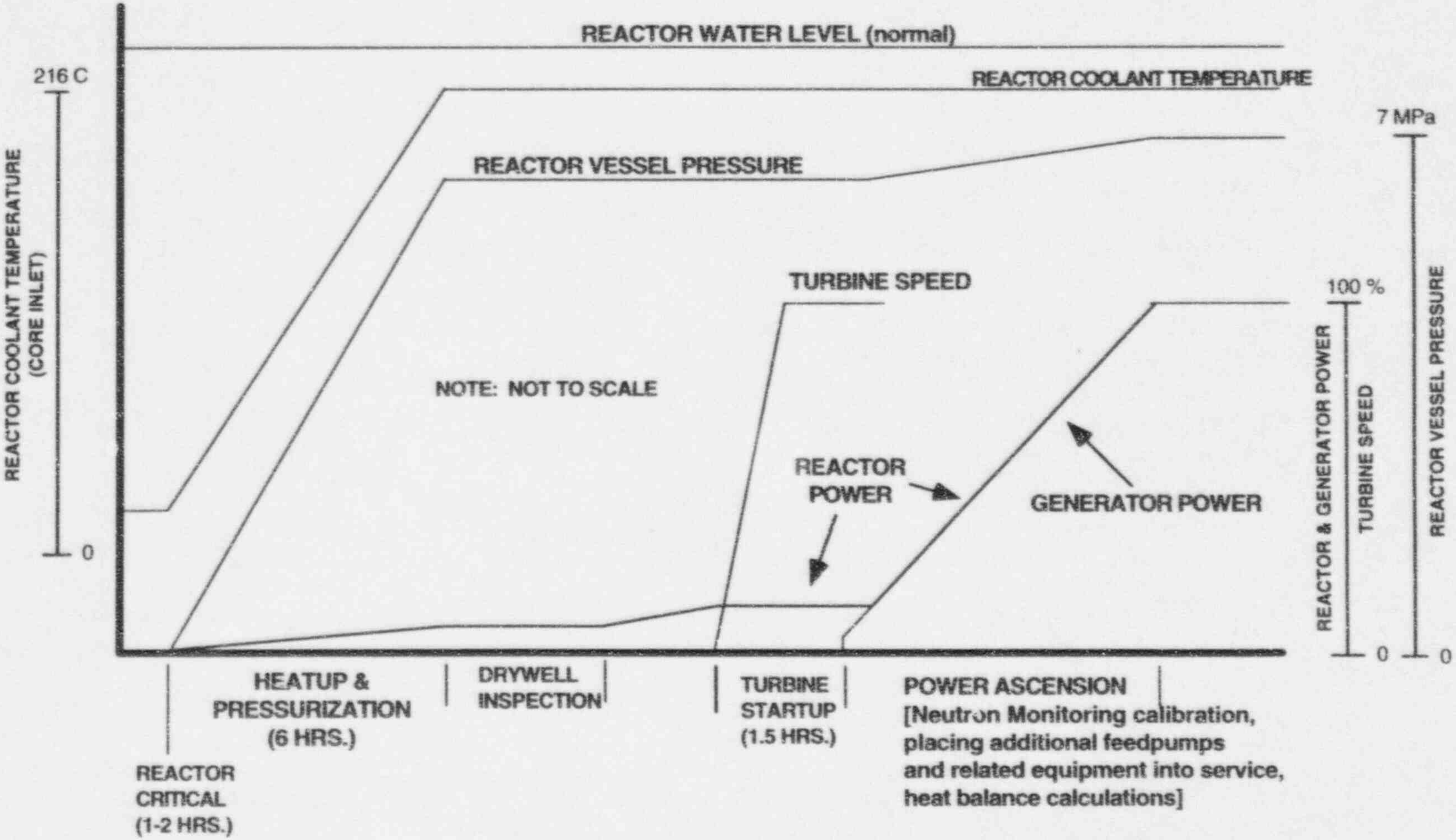
Turbine Startup and Synchronization

- *Turbine startup and initial loading*
  - *Upon completion of turbine warming, roll the main turbine to rated speed*
  - *Synchronize the generator to the grid*
  - *Increase the turbine load setpoint to raise load on the generator and to close the bypass valves*
  - *Start additional circulating water pumps as required to maintain proper condenser vacuum*
  - *Start condensate and feedwater pumps as required to continue to maintain proper reactor water level*

Power Ascension to Rated Power

- *Power Ascension*
  - *Complete inerting the primary containment within 24 hours after reaching 15% power*
  - *Verify the fuel is maintained within the thermal limits throughout power ascension when above 25% power*
  - *Continue control rod withdrawal to reach rated power*
  - *Place additional condensate and feedwater pumps into operation during power ascension*

Startup Trends



TRACG Analysis of SBWR Startup

Typical startup analyzed, heatup rate 42 °C /hr.

- *Refer to Figures 4-4a, 4-4b, 4-5 attached*
- *Condensation induced geysering oscillation is possible during startup only when chimney is subcooled and vapor is generated at the exit of the fuel bundles*
- *No geysering is predicted to occur (minimal subcooling)*

Unstable region

- *To identify conditions for condensation induced geysering oscillation*
- *Initial conditions of normal startup*
- *Increase reactor suddenly to specified level and hold constant*
- *Reactor pressure held to lowest possible by fully opening of turbine bypass valves*

Results:

- *Unstable region: 100 - 140 MWth and reactor pressure less than 0.3 MPa*

Unstable region is not attainable during normal heatup process. Entry into unstable region is constrained by Technical Specification requirement on heatup rate.

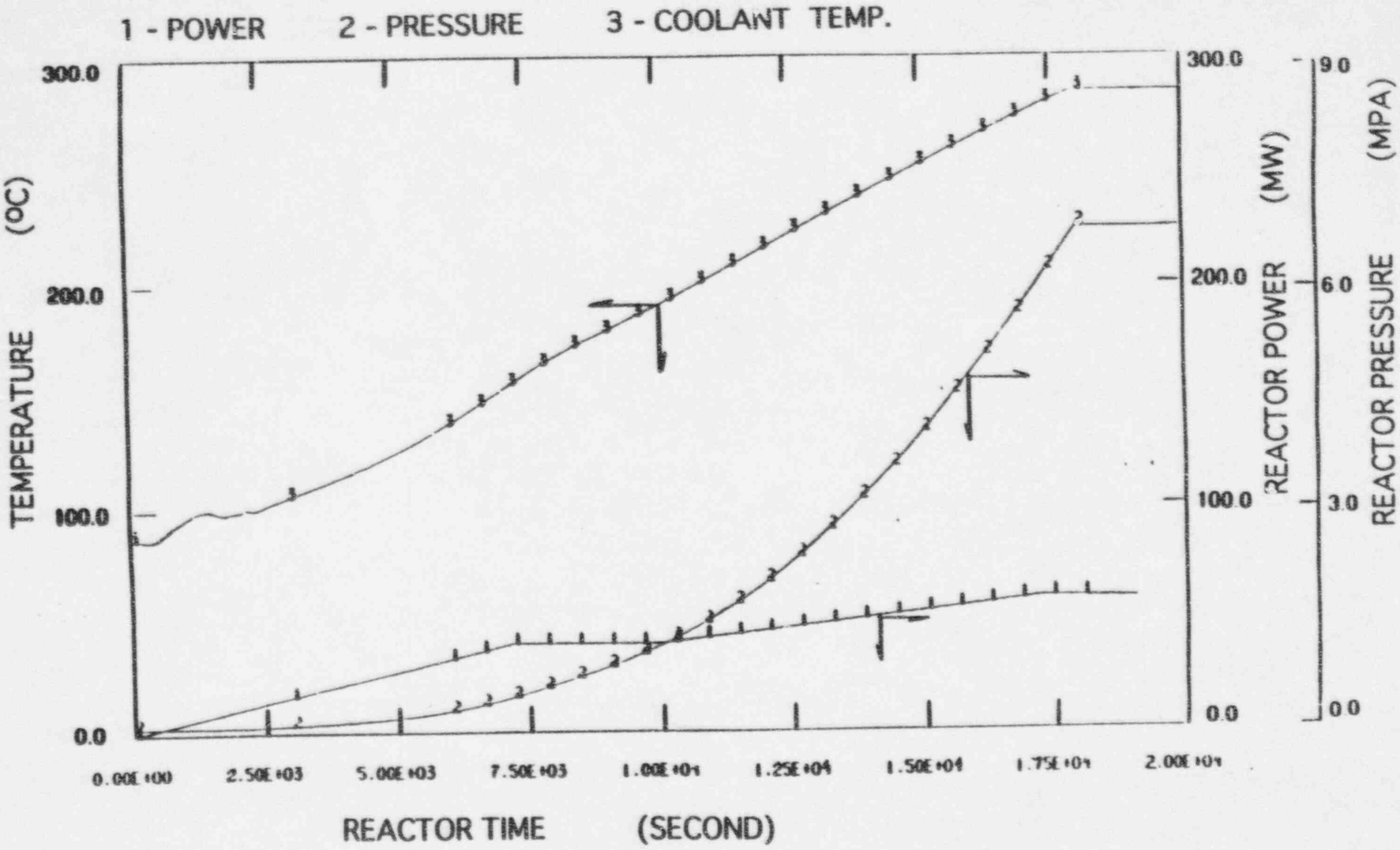


Figure 4-3. Reactor Power, Pressure, and Temperature

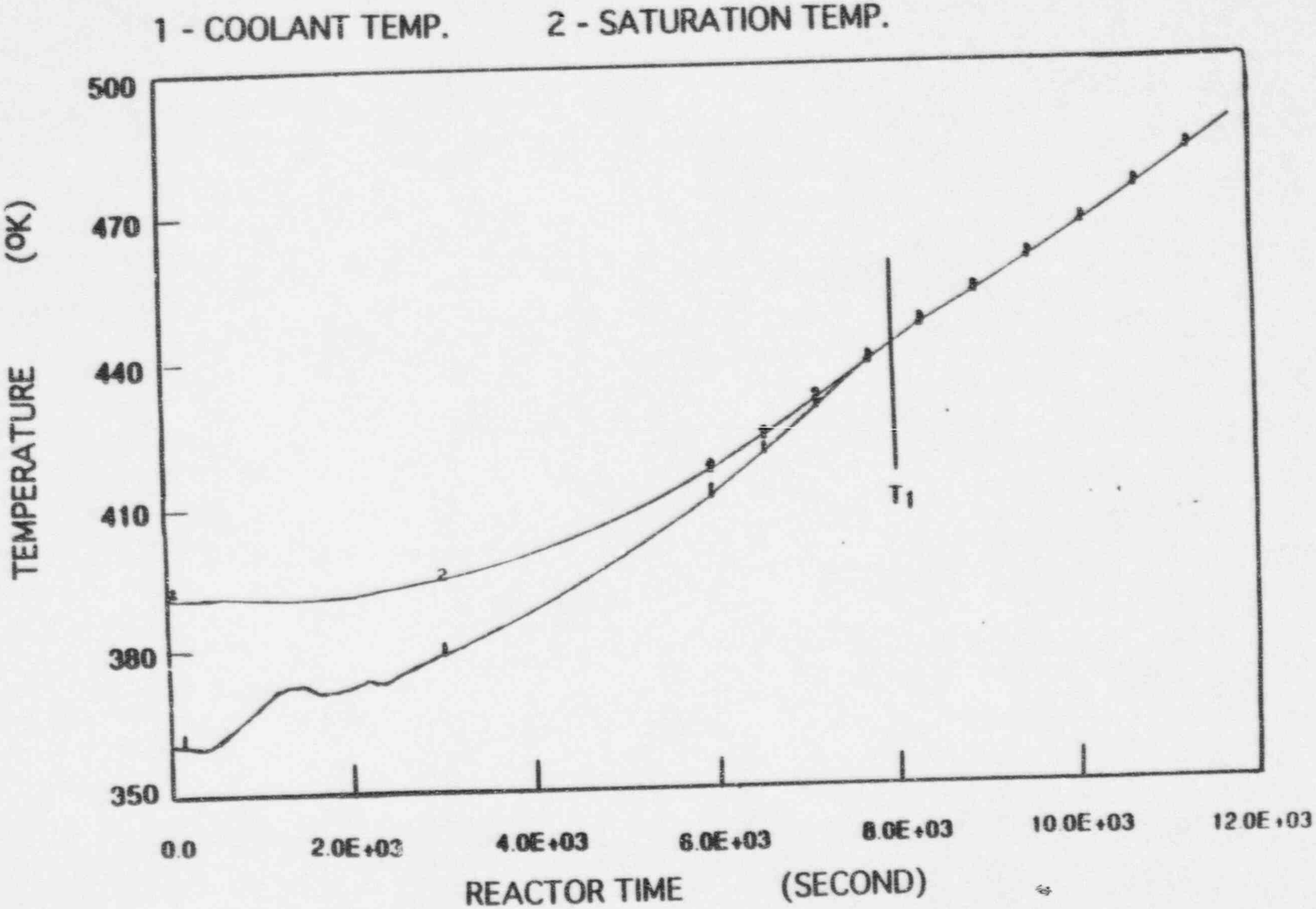


Figure 4-4a. Coolant and Saturation Temperatures at Channel Exit

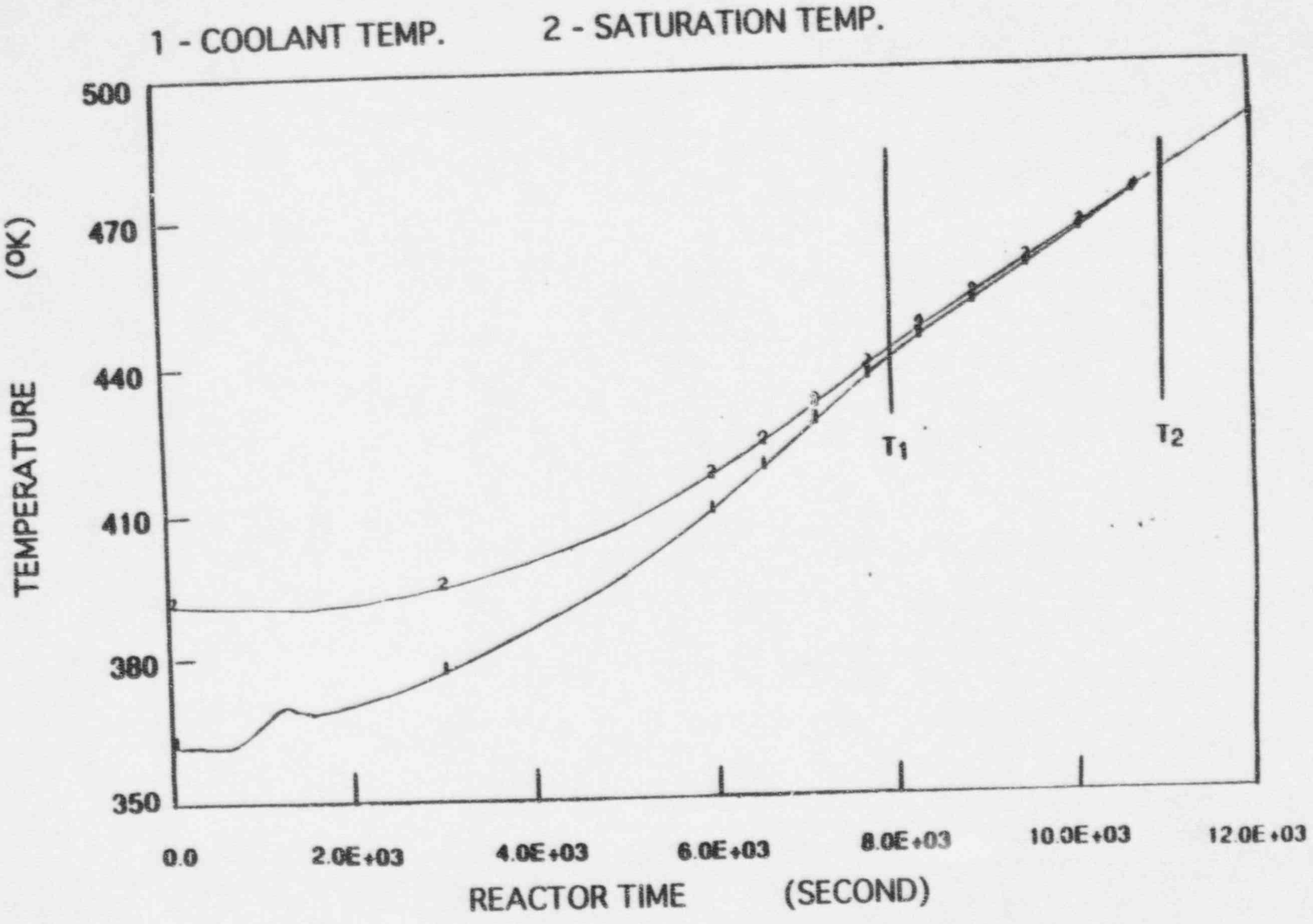


Figure 4-4b. Coolant and Saturation Temperatures at Chimney Bottom

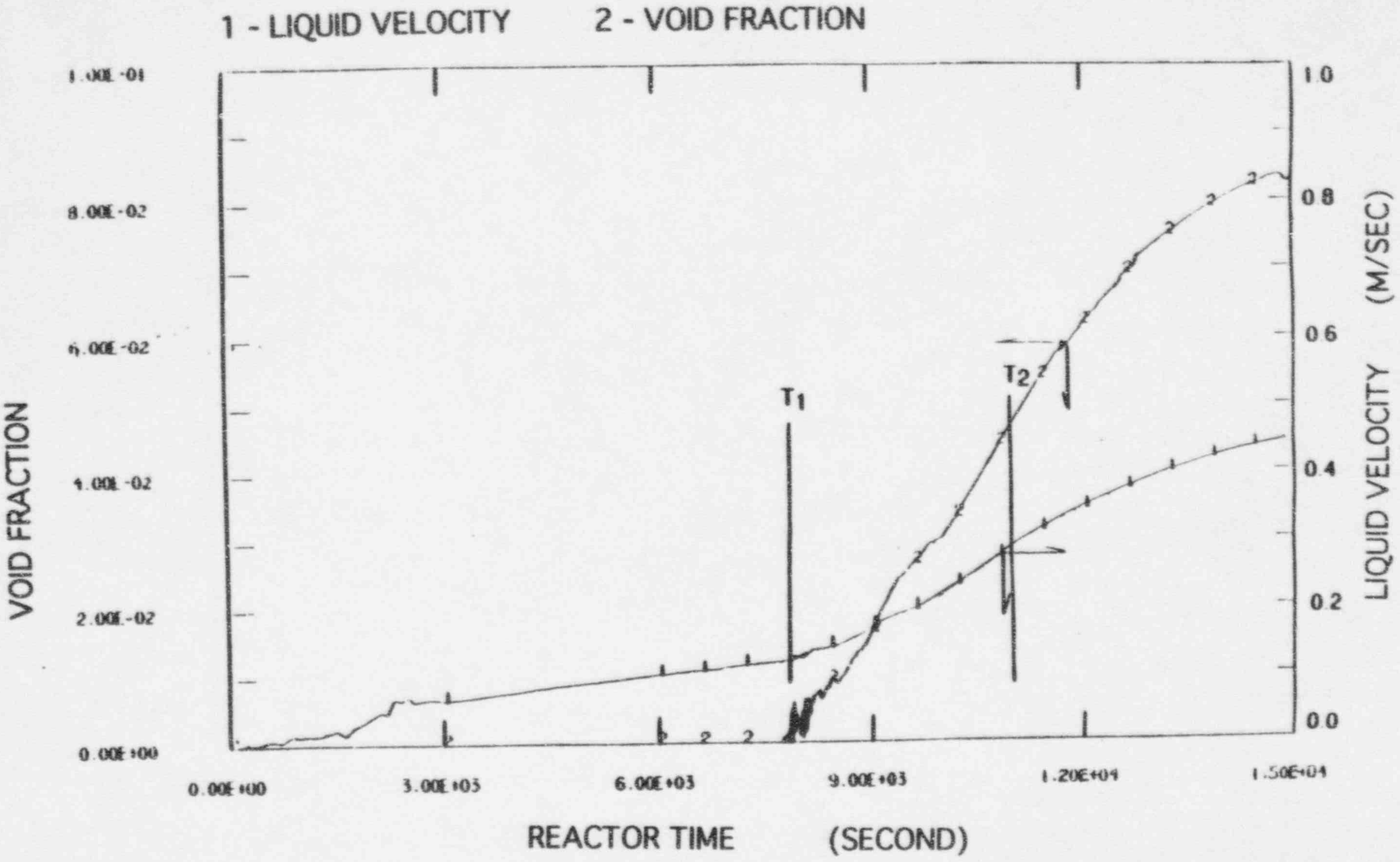


Figure 4-5. Coolant Velocity and Void Fraction at Channel Exit

Summary

SBWR plant startup

- Follows typical BWR startup procedures
- Similar to Dodewaard plant
- Performance expected to be similar to Dodewaard
- TRACG analysis of SBWR startup concludes no flow instability for normal startup; instability region not attainable for SBWR

ACRS Thermal Hydraulics Subcommittee Meeting

SBWR Chimney Issues

B. S. Shiralkar

November 29, 1995

SBWR Partitioned Chimney

- Geometry
  - 22 partitions covering 732 fuel channels and core bypass region
  - Unit cell covers 6 x 6 bundle array with associated bypass region
  - Unit cell size ~ 1m x 1m x 9m high
- Operating range of conditions
  - Rated operation :

    Pressure : 7.2 MPa

    Mass flux : 530 Kg/m^2-s

    Average quality : 0.124

    Average void fraction : 0.7

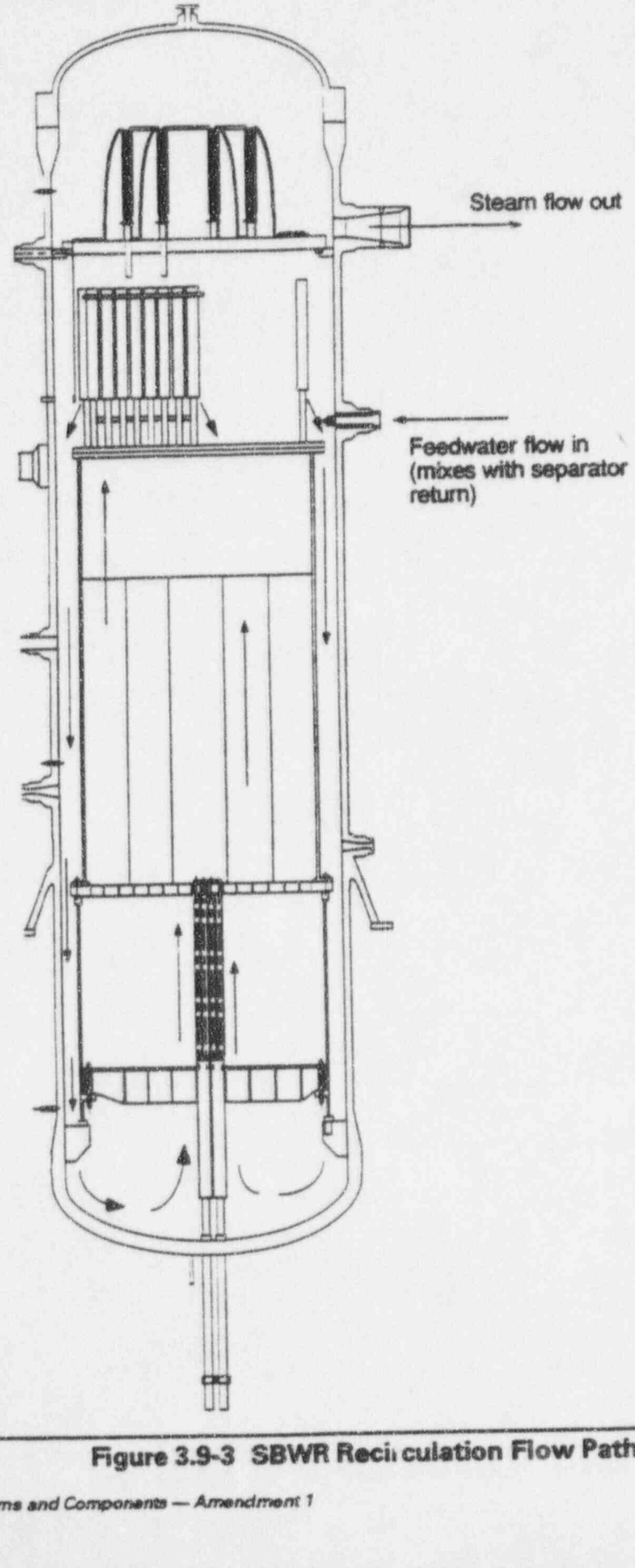
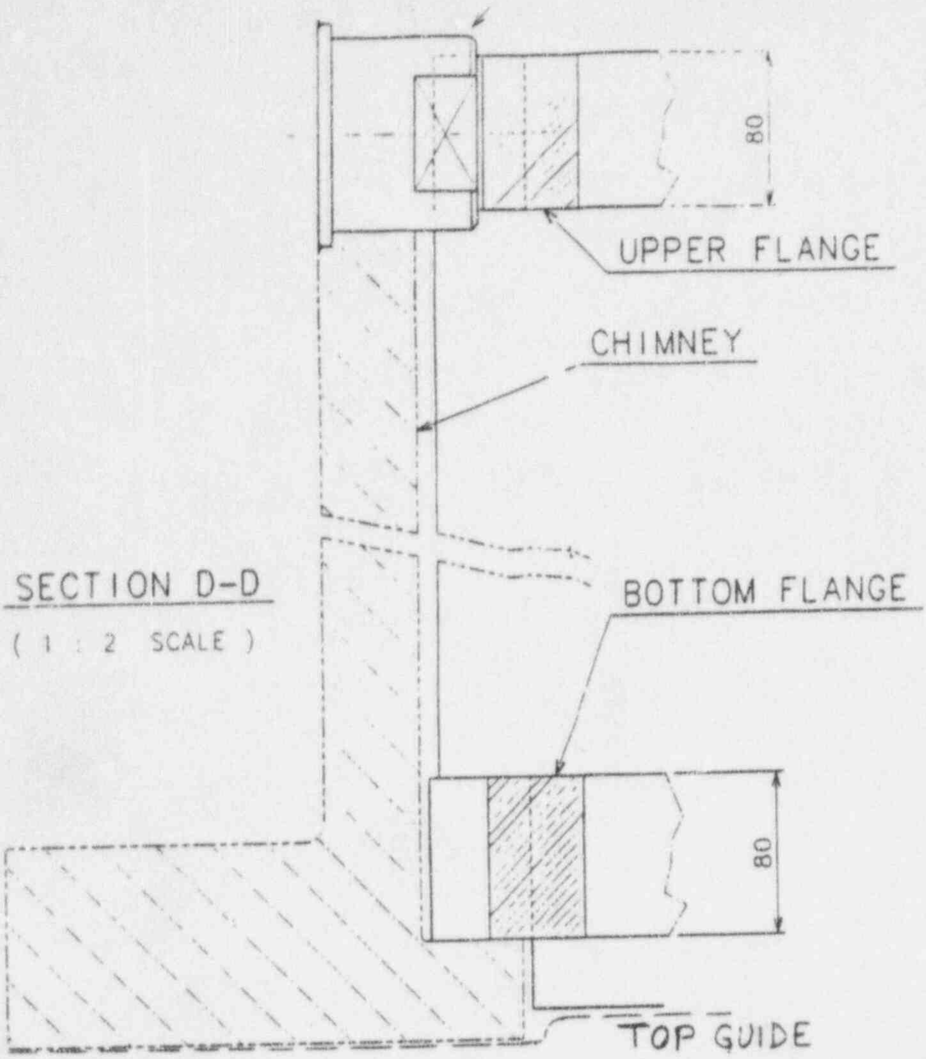
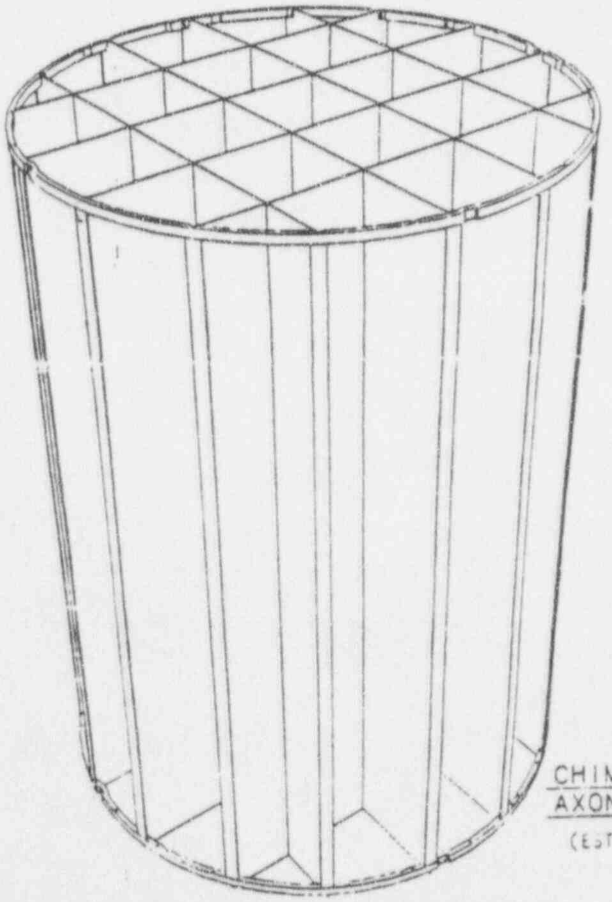


Figure 3.9-3 SBWR Recirculation Flow Path



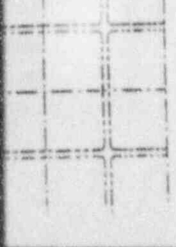
SECTION D-D

(1 : 2 SCALE)



CHIMNEY PARTITIONS
AXONOMETRIC VIEW

(ESTIMATED WEIGHT 23220 KG)



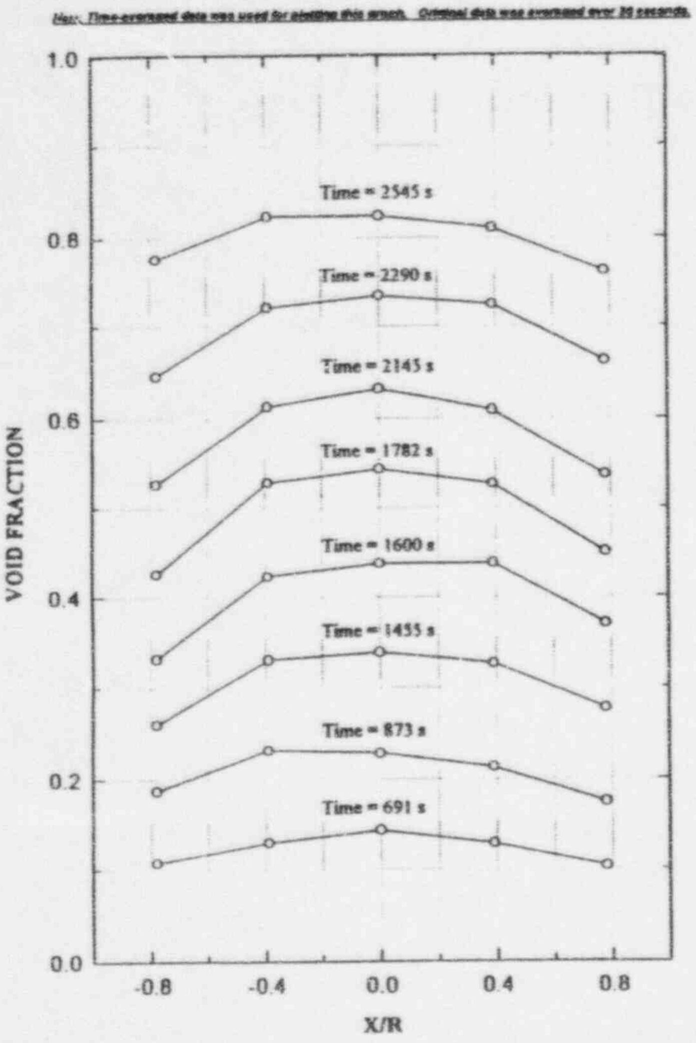
Key Issues

- Chimney cell flow regime and void fraction
  - Average void fraction
  - Cross sectional variation
- Flow/pressure fluctuations
- Multi-cell performance of chimney
  - Steady state and transient conditions

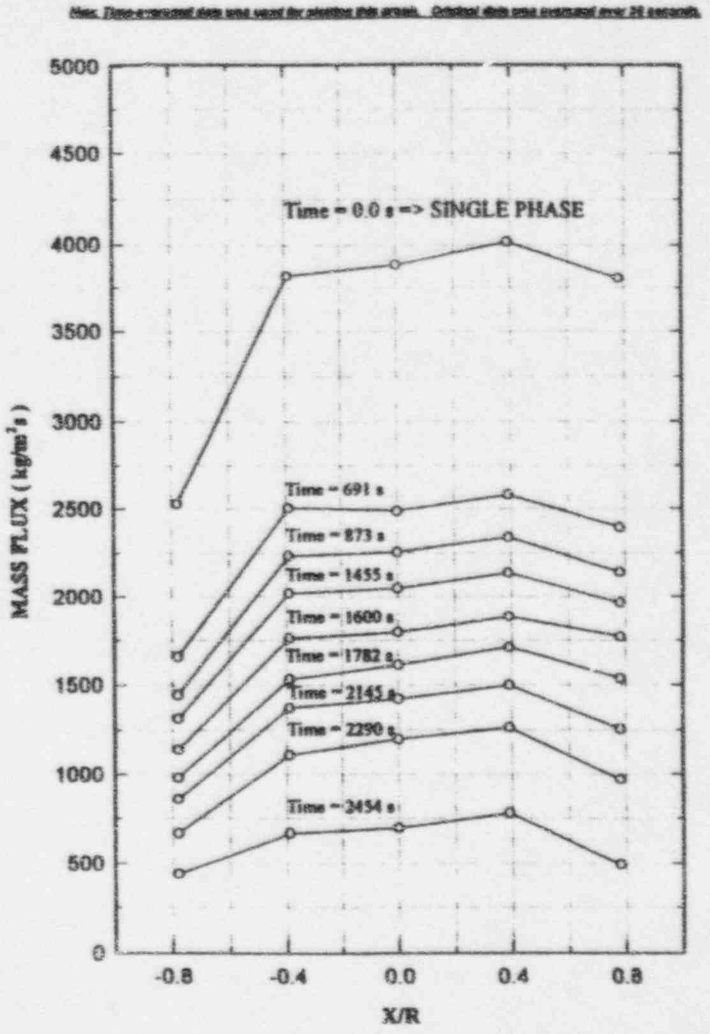
Ontario Hydro Data

- *Configuration*
  - *Vertical riser (0.51 m i.d.) downstream of bend from horizontal pipe*
  - *Flow straightener at inlet*
- *Instrumentation*
  - *Multi-beam gamma densitometer for sectional void fraction*
  - *Pitot tube rake for dynamic head distribution*
  - *Measurements made 4.2 m from flow straightener outlet*
- *Test Procedure*
  - *Voids created by draining loop*
  - *No direct measurements of mass flow rates*
    Calculated from local dynamic head and void fraction data
- *Results*
  - *Data obtained at two pressures up to void fraction of 0.8*
  - *Measurement uncertainties: Mass flow rate ~15%, void fraction ~5%*
  - *Effects of bend persist in velocity distribution, but not in void distribution*
  - *Local void fluctuations small at high pressure, increase at low pressure*

Ontario Hydro Data



Void Distribution at 280 C (6.4 MPa)



Local Mass Flux Distribution at 280 C (6.4 MPa)

Multi-cell Chimney Performance

- SBWR steady state chimney parameters compared with Dodewaard

Parameter	SBWR	Dodewaard
Average bundle power (MW)	2.73	1.16
Chimney L/D	9	10
Average void fraction	0.68	0.57
Liquid velocity (m/s)	1.6	1.1
Vapor velocity (m/s)	2.4	1.9

SBWR ACRS TH SC MEETING
ATTENDANCE

Wednesday, 11/29/95

NAME	AFFILIATION	PHONE
John Leatherman	GE SBWR Certification	408-925-2023
PAUL BOEHNERT	NRC/ACRS	301/415-8065
Robert L. Seale	ACRS	520/298-7118
TOM KRESS	ACRS	423/483-7548
MARIO FONTANA	ACRS	423/483-8310
IVAN CATTON	ACRS	310 825 5320
James C Carroll	ACRS	(510) 254-6324
VIRGIL SCHROCK	ACRS Consultant	(510) 642-6431
NOVAK ZUBER	ACRS Consultant	(301) 424-3585
VIJAY DHIR	ACRS Consultant	310-825-8507
JACK KUDRICK	NRR/DSSA	〃 -415-2871
G Donald McPherson	NRC/NRR	301 415 1246
SON NINH	NRC/NRR/DRPM	301-415-1125
ALAN LEVIN	NRC/NRR/SRXB	301-415-2890
RH BUCHHOLZ	GE	408-925-4584
Bharat Shiralkar	GE	408-925-6889
JIM FITCH	GE	408-925-6148
Jim Quinn	GE	408 925 1005
C Yadigaroglu	ETH/PSI	+41-1-632.4615
JOHN TORBECK	GE	(408) 925-6101
RAM SRINIVASAN	EPRI	415-855-2703
ERNIE CONTON	DOE	301-903-5501
Tom Fernandez	EPRI Consultant	415-855-8733
TOM MULFORD	EPRI	415-855-2766
SALOMON LEVY	EPRI CONSULTANT	408-369-6500
Susumu Takada	EPRI/JAPC	415-855-8725
Klaus Kirschenmann	EPRI/EVS	415-855-2704
Joe Yedidia	EPRI	415 855 8724
Robert Gamble	GE	408 925 3352
Jack Duncan	GE	408 925 6947
K. Kobayashi	GE/JAPC	408-925-2119
Andy Hunsbedt	GE	408-925-1655
MARYANN HERZOG	GE	408-925-1921
JESUS FMG	DTN-GE	408-925-1854
FRED MOODY	GE	'08-925-0474
Gomba "Ricky" Wingate	GE	5-925-1075
PAUL F. BILLIG	GE - PANT-ACRS	408-925-1585