UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D.C. 20555-0001

December 1, 1999

MEMORANDUM TO: ACRS Members

FROM: Paul Boehnert, Senior Staff Engineer
ACRS

SUBJECT: CERTIFICATION OF THE MINUTES OF THE ACRS THERMAL-HYDRAULIC PHENOMENA SUBCOMMITTEE MEETING, NOVEMBER 17, 1999 - ROCKVILLE, MARYLAND

The minutes of the subject meeting, issued November 24, 1999, have been certified as the official record of the proceedings of that meeting. A copy of the certified minutes is attached.

Attachment: As stated

cc: via E-mail
J. Larkins
R. Savio
H. Larson
S. Duraiswamy
ACRS Staff Engineers
ACRS Fellows

UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D.C. 20555-0001

December 1, 1999

MEMORANDUM TO: Paul Boehnert, Senior Staff Engineer
Technical Support Staff

FROM: G. Wallis, Chairman
Thermal-hydraulic Phenomena Subcommittee

SUBJECT: CERTIFICATION OF THE MINUTES OF THE ACRS SUBCOMMITTEE MEETING ON THERMAL-HYDRAULIC PHENOMENA SUBCOMMITTEE MEETING, NOVEMBER 17, 1999 - ROCKVILLE, MARYLAND

I hereby certify that, to the best of my knowledge and belief, the Minutes of the subject meeting issued November 23, 1999, are an accurate record of the proceedings for that meeting.

12/1/99

G. Wallis, Chairman Date

UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D.C. 20555-0001

November 23, 1999

MEMORANDUM FOR: G. Wallis, Chairman, Thermal-Hydraulic Phenomena Subcommittee

FROM: P. Boehnert, Senior Staff Engineer

SUBJECT: MINUTES OF THE ACRS THERMAL-HYDRAULIC PHENOMENA SUBCOMMITTEE MEETING, NOVEMBER 17, 1999 - ROCKVILLE, MARYLAND

A Working Copy of the subject meeting minutes is attached. I would appreciate your review and corrections as soon as possible. Copies are being sent to all ACRS members, and the Consultants who attended the meeting for their information.

Attachment: As Stated

cc: ACRS Members
V. Schrock
N. Zuber

cc via E-Mail:
J. Larkins
R. Savio
S. Duraiswamy
ACRS Staff Engineers
ACRS Fellows

DRAFT COPY - PREPARED FOR INTERNAL COMMITTEE USE

CERTIFIED BY:
G. Wallis - 12/1/99

Date: 11/24/99

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
THERMAL-HYDRAULIC PHENOMENA SUBCOMMITTEE MEETING
NRC/EPRI WATERHAMMER STUDY/CODE REVIEW GUIDELINES
NOVEMBER 17, 1999
ROCKVILLE, MARYLAND

INTRODUCTION:

The ACRS Subcommittee on Thermal-Hydraulic Phenomena held a meeting on November 17, 1999 with representatives of the NRC staff. The purpose of this meeting was to review the NRC code review guideline documents, the draft Regulatory Guide and Standard Review Plan Section. The Subcommittee also reviewed the NRC and Industry initiative with the Electric Power Research Institute to develop a methodology for addressing the issue of waterhammer in plant service water systems, pursuant to issues raised in NRC Generic Letter 96-06 ("Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions"). The entire meeting was open to the public. Mr. P. Boehnert was the cognizant ACRS staff engineer and Designated Federal Official (DFO) for this meeting. The meeting was convened by the Subcommittee Chairman at 8:30 am, November 17, 1999, and adjourned at 5:22 p.m. that day.

ATTENDEES

ACRS Members/Staff:

G. Wallis, Chairman
T. Kress, Member
D. Powers, Member
R. Seale, Member
V. Schrock, Consultant
N. Zuber, Consultant
P. Boehnert, DFO

NRC Staff:

J. Werrniel, NRR
N. Lauben, RES
J. Tatum, NRR
J. Staudenmeier, NRR

EPRI Waterhammer Study

V. Wagoner, CP&L
P. Griffith, MIT
T. Esselman, Altran Corp.

There were approximately 10-15 other members of the public in attendance during this meeting. A listing of those attendees who registered is available in the ACRS office files. Mr. R. Osterrider representing the Westinghouse Electric Company, PLC, participated in the meeting discussions.

The presentation slides and handouts used during the meeting are attached to the Office Copy of these Minutes. The presentations to the Subcommittee are summarized below.

CHAIRMAN'S COMMENTS

Dr. G. Wallis, Subcommittee Chairman, convened the meeting. He had no specific opening comments.

NRC CODE REVIEW GUIDELINE DOCUMENTATION

RES Draft Regulatory Guide for Generic Transient and Accident Analysis Methods

Mr. N. Lauben, RES discussed the background, content and status of the draft regulatory guide that addresses transient and accident analysis methods. The need to issue guidance on accident analysis code development, assessment and application resulted from the results of the Maine Yankee Independent Safety Assessment. Subsequent code reviews, including the staff's review of the RETRAN-03 code, reinforced this need.

The guide is based on use of an evaluation model (EM) development and assessment approach, consistent with risk-informed regulation. Three central tenets are included in the guide:

- Use analysis methods for all Chapter 15 transients with accompanying verification, validation, documentation, and quality assurance.
- Detail the EM concept, including all computer programs, to demonstrate compliance with 10 CFR 50.34 and 50.36.
- Describe an acceptable EM development and assessment process consistent with the principles of CSAU (Code Scaling, Applicability and Uncertainty methodology). Key here is development of a credible and scruitable PIRT (Phenomena Identification and Ranking Table) which informs the entire process.

Appendices to the guide will be prepared to address particular classes of transients and accidents. During discussion, Mr. Lauben provided a flow chart (copy attached) that describes the three tenets of the guide noted above (i.e., requirements for EM capability and assessment, EM description, and adequacy assessment). The Subcommittee cited the following points regarding the staff's presentation:

- Dr. Zuber argued that this guide needs to address the needs for future codes, given the industry's drive to open competition and reduction in margins. He said that he would provide a list of the needed requirements.
- The staff said that uncertainties will need to be addressed by the code applicants, pursuant to the guide's template.

- Dr. Zuber said that the PIRT will need to be quantified in some fashion to avoid "jawboning" the results.

- Dr. Powers said that criteria are needed in the guide to govern use of code-to-code comparisons. RES said that they would evaluate this issue for addition to the guide.

- Dr. Kress said that the uncertainty associated in code vs test data agreement needs to be quantified. RES noted, in passing, that a substantial amount of early LOCA test data has been lost; recovery actions are being attempted.

- Dr. Seale said that RES needs to specify the applicability of the guide with regard to Chapter 15 vs risk-informed type analyses.

NRR Standard Review Plan (SRP) Section

J. Staudenmeier, NRR, discussed the development of the SRP to support NRR review of thermal-hydraulic transient and accident codes. He reviewed the background, use, organization, proposed acceptance criteria, and future actions for this matter. NRR expects that this SRP Section will standardize and improve the consistency of the staff's code review process, which had previously been conducted on an ad hoc basis.

The Subcommittee noted the following comments/concerns during the above discussion:

- Dr. Seale cautioned the staff that substantial modifications to the current generation of T/H codes will be necessary to support a risk-based regulatory approach.

- In response to Dr. Powers, NRR said that both the draft Regulatory Guide and SRP Section will be issued for public comment.

- Dr. Zuber said that NRR's new review approach will demand a high caliber staff. He said that the Committee should make this point in any written comments it provides on this review.

- Dr. Powers suggested that NRR pilot the use of the SRP Section by reviewing RES's new TRACM code. Mr. Wermiel indicated that NRR would pursue that suggestion

- In response to Messrs. Boehnert and Seale, NRR said that they would ensure that the SRP Section and Regulatory Guide included specific wording stating that a working copy of the specific code to be reviewed is provided to the staff for its evaluation.

- A representative of Westinghouse asked that the ACRS and NRC staff inform them of any significant issues, such as dealing with uncertainties, that need to be addressed pursuant to use of the new code review process.

NRC/INDUSTRY COLLABORATIVE PROJECT TO SUPPORT RESOLUTION OF GENERIC LETTER (GL) 96-06 WATERHAMMER ISSUES FOR LOW-PRESSURE SYSTEMS

Messrs. J. Tatum, NRR, V. Wagoner, CP&L, P. Griffith, MIT, and T. Esselman, Altran Corp. provided presentations on the NRC/Industry collaborative project to address the issue of the susceptibility of the containment air cooling water systems to waterhammer (WH) loads during either a LOCA or main streamline break event, pursuant to the NRC concerns cited in NRC GL 96-06. Industry initiated this EPRI project to address NRC's concerns and to ensure that licensees could close out all relevant issues. Approximately 14 nuclear power plant licensees participated in this project.

The project activities were detailed. Two types of waterhammers were evaluated: column-closure and condensation-induced. Analyses were performed and validated against the test results. An Expert Panel consisting of Drs. F. Moody, B. Wylie, and P. Griffith (Chairman) assisted and participated in all major aspects of the Project. Guidelines will be prepared for use by licensees for individual plant assessments. The final product is an EPRI Technical Basis Report (TBR). The TBR is now under review by the NRC staff.

Concerns/issues identified by the Subcommittee during the above discussions included:

- Drs. Zuber and Wallis indicated that the TBR is poorly organized. EPRI needs to write an informed Executive Summary and the report itself needs rewriting to be more supportive of the user.

- Drs. Wallis and Zuber said that there appears to be a scaling effect to the pipe size for the condensation-induced WH test results.

- Professor Schrock, noting the stochastic nature of waterhammer phenomena, said EPRI needs to address the statistical aspects of this work.

- The data supporting the assumption for the amount of dissolved gas released for the column-closure event appears insufficient. This is significant, since this gas acts as a cushioning effect thereby mitigating the WH loads. EPRI should perform more testing here or determine the sensitivity of the analytical results (i.e., the margin) to the value chosen for this assumption.

- The rationale is lacking for assuming a constant value of hA (heat conductance) for determining steam condensation in a void for the method of characteristics model.

With the exception of the issues noted above, the Subcommittee expressed its appreciation of the project and the overall methodology employed.

SUBCOMMITTEE CAUCUS

The Subcommittee agreed that the issue of resolution of GL 96-06 did not need to be reviewed by the ACRS. Rather, Dr. Wallis will report the results to the Committee during its December Meeting. The Subcommittee Chairman asked that Members and Consultants provide him comments on this matter for input to his Committee report. Dr. Seale suggested that the Committee enter into the record that the EPRI methodology only applies to resolution of "96-06". The concerns regarding application of this methodology to individual plants noted above will be discussed with the full Committee. It was suggested that a memorandum to the staff citing these concerns be drafted for the Committee's consideration.

Regarding the staff's code review documentation, Dr. Wallis requested written comments from the Consultants. He said that this issue is scheduled for review by the ACRS during its February Meeting, and that another meeting of the Subcommittee will likely be scheduled for mid-January to continue review of this matter.

FOLLOW-UP ACTIONS

- The NRC staff will provide revised copies of the draft Regulatory Guide and SRP Section in a timely manner to support the Committee's review of this matter during its February 2000 Meeting.

BACKGROUND MATERIAL PROVIDED TO THE SUBCOMMITTEE PRIOR TO THIS MEETING

Memoranda, dated November 5 and 8, 1999 from P. Boehnert ACRS to T/H Phenomena Subcommittee Members and Consultants transmitting:

- Memorandum to J. Larkins, ACRS, from G. Holahan, NRR, Subject: Draft SRP Section on Analytical Computer Code Reviews, dated November 3, 1999

- Draft Regulatory Guide 1.XXX, Transient and Accident Analysis Methods, Undated, (**Predecisional**)

- Excerpt from Certified Copy of the December 16-17, 1998 Minutes of T/H Phenomena Subcommittee Meeting on Development of T/H Code Review Guidance, dated February 22, 1999

- U. S. NRC Generic Letter 96-06: Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions, dated September 30, 1996

- Electric Power Research Institute Report: Resolution of Generic Letter 96-06 Issues - EPRI Interim Report TR-113594- Volumes 1&2, July 1999 (**EPRI Proprietary**)

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NOTE: Additional details of this meeting can be obtained from a transcript of this meeting available in the NRC Public Document Room, 2120 L Street, Washington, D.C. 20006, (202) 634-3274, or can be purchased from Ann Riley & Associates, LTD., 1025 Connecticut Ave., NW, Suite 1014 , Washington, D.C. 20036, (202) 842-0034.

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

SUBCOMMITTEE MEETING ON THERMAL-HYDRAULIC PHENOMENA

NOVEMBER 17, 1999
Date(s)

NOVEMBER 17, 1999
Today's Date

NRC STAFF SIGN IN FOR ACRS MEETING

PLEASE PRINT

NAME	BADGE #	AFFILIATION
RALPH LANDRY	B-6634	NRR/DSSA/SRXB
ERIC WEISS	A-6820	NRR/DSSA/SRXB
Jared Wermiel	A-6824	NRR/DSSA/SRXB
FAROUK ELTAWILA	A-6364	RES/DSARE/SMSAB
Joseph Staudenmeier	B-7661	NRR/SRXB
FRANK ORR	B-6885	NRR/SRXB
Gary Hammer	B-7433	NRR/DE
Jim Tatum	A-7071	NRR/DSSA/SPLB
George Hubbard	B-6271	NRR/DSSA/SPLB
AL SERKIZ	B-7038	RES/DET/ERAB
MARK HARTZMAN	B-6223	NRR/DE/EMEB

END

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

SUBCOMMITTEE MEETING ON THERMAL-HYDRAULIC PHENOMENA

NOVEMBER 17, 1999
Date(s)

NOVEMBER 17, 1999
Today's Date

ATTENDEES - PLEASE SIGN BELOW

PLEASE PRINT

NAME	AFFILIATION
Bob Osterrieder	Westinghouse
Jens Andersen	GE
[redacted]	
LEE ROCHINO	RG+E
Ben Wylie	Univ. of Michigan
HAMILTON FISH	New York Power Authority
Vaughn Wagoner	CP&L
MATT ZWEIGLE	ALTRAN CORP.
Peter Griffith	MIT
ARTHUR SINGH	EPRI
Hossein Nourbakhsh	NRC Consultant
Tom Ryan	Sargent & Lundy / Consumers Energy
GREG ZISK	ALTRAN
TIM BROWN	DUKE ENERGY
BOB HAMMERSCEY	FAI
Leonard J. Azzarello	Duke Energy
Thomas C. Esselman	Altran Corporation

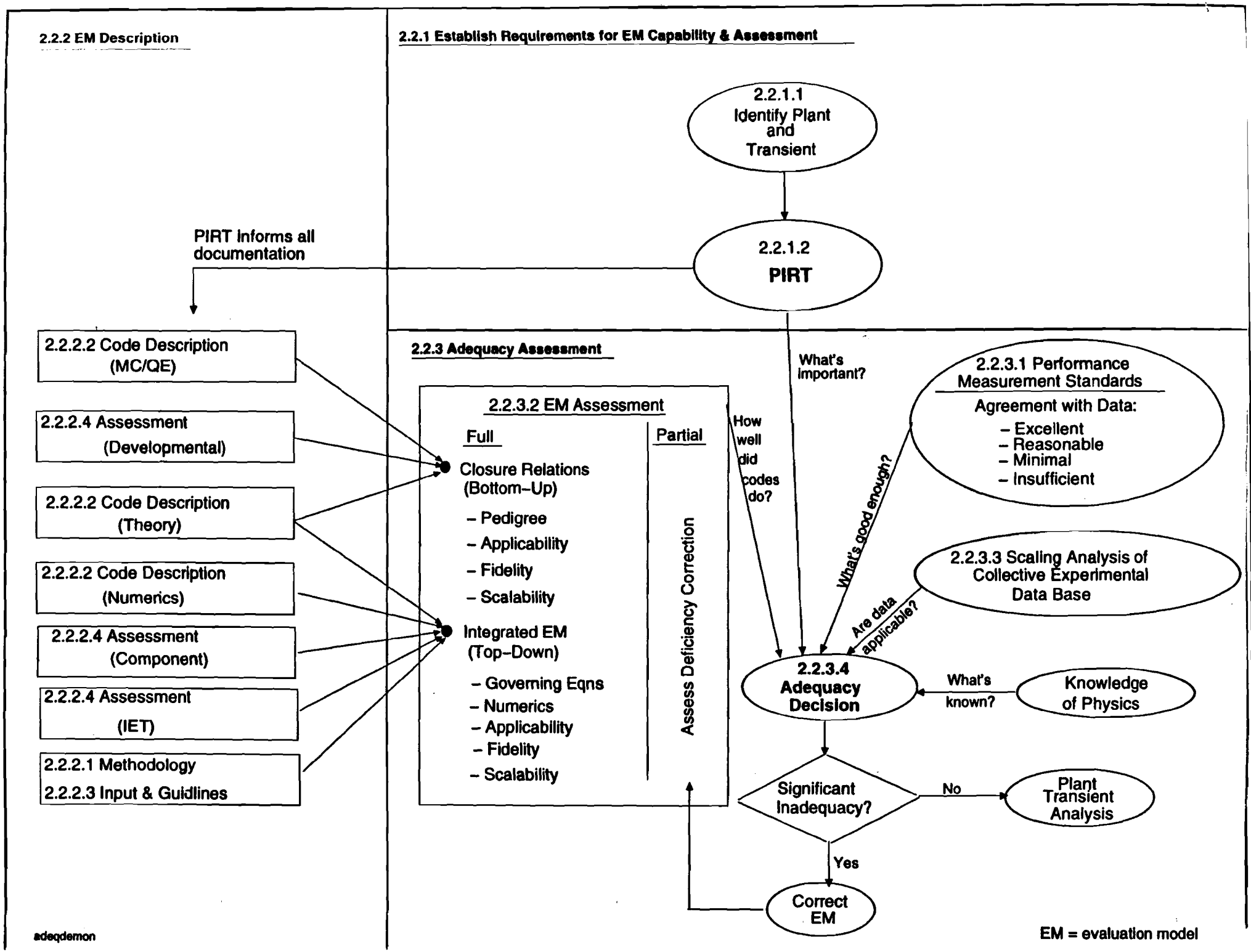
END

R

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
THERMAL-HYDRAULIC PHENOMENA SUBCOMMITTEE MEETING
EPRI WATERHAMMER STUDY/CODE REVIEW GUIDELINES
NOVEMBER 17, 1999
ROCKVILLE, MARYLAND

MEETING AGENDA

TOPIC	SPEAKER	TIME
I. Introduction	G. Wallis, Chairman	8:30 a.m.
II. Development of Code Review Guidelines		
A. Draft Regulatory Guide	N. Lauben, RES	8:40 - 9:45 a.m.
	BREAK	10:00 - 10:15 a.m
II. Resolution of GL-96-06 Waterhammer Issues		
A. NRC/Industry Resolution Approach (EPRI Study)	J. Tatum, NRR	10:15 - 10:25 a.m.
B. EPRI Report - Resolution Of GL-96-06 Waterhammer Issues	V. Wagoner, CP&L P. Griffith, MIT T. Esselman, Altran Corp.	10:25 - 12:30 p.m.
C. NRC Comments on EPRI Report	J. Tatum	12:30 - 12:45 p.m.
	LUNCH	12:45 - 1:45 p.m.
III. Development of Code Review Guidelines (Con't)		
B. Standard Review Plan Section	J. Staudenmeier, NRR	1:45 - 3:00 p.m.
IV. Subcommittee Caucus		3:15 - 3:45 p.m.
• Follow-on Items from this Meeting • Future Actions • Committee Action		
V. Adjourn		3:45 a.m.


2.2.2 EM Description
2.2.1 Establish Requirements for EM Capability & Assessment
2.2.1.1 Identify Plant and Transient
2.2.1.2 PIRT
PIRT informs all documentation
2.2.2.2 Code Description (MC/QE)
2.2.2.4 Assessment (Developmental)
2.2.2.2 Code Description (Theory)
2.2.2.2 Code Description (Numerics)
2.2.2.4 Assessment (Component)
2.2.2.4 Assessment (IET)
2.2.2.1 Methodology
2.2.2.3 Input & Guidlines
2.2.3 Adequacy Assessment
2.2.3.2 EM Assessment
Full
Partial
Closure Relations (Bottom-Up)
– Pedigree
– Applicability
– Fidelity
– Scalability
Integrated EM (Top-Down)
– Governing Eqns
– Numerics
– Applicability
– Fidelity
– Scalability
Assess Deficiency Correction
How well did codes do?
What's important?
What's good enough?
Are data applicable?
2.2.3.1 Performance Measurement Standards
Agreement with Data:
– Excellent
– Reasonable
– Minimal
– Insufficient
2.2.3.3 Scaling Analysis of Collective Experimental Data Base
2.2.3.4 Adequacy Decision
What's known?
Knowledge of Physics
Significant Inadequacy?
No
Plant Transient Analysis
Yes
Correct EM
adeqdemon
EM = evaluation model

R

REGULATORY GUIDE FOR GENERIC TRANSIENT AND ACCIDENT ANALYSIS METHODS

G. Norman Lauben
Safety Margins and Systems Analysis Branch, RES

ACRS Thermal-Hydraulic Subcommittee Meeting
November 17, 1999

acrs1199.01

PURPOSE

Present the status of the proposed regulatory guide on generic transient and accident methods, and seek comments from the ACRS.

OUTLINE

1. Background
2. Status
3. Summary

BACKGROUND

1. The requirement to issue guidance on accident analysis code development, assessment, and application originated from the Maine Yankee Independent Safety Assessment and the Maine Yankee Task Group reviews.

2. The Siemens review indicated similar needs.

3. The recent difficulties with the RETRAN03 review further reinforced the benefit that could be derived from such guidance.

4. On December 17, 1998, plans for this regulatory guide and companion revisions to the Standard Review Plan (SRP) were discussed with the Subcommittee.

5. Two drafts of this guide have been provided to the ACRS for their review.

6. The SRP revisions will be discussed by Dr. Staudenmeier later today.

7. The guidance for evaluation model development and assessment described in this regulatory guide, with its emphasis on PIRT-based importance measures, will be consistent with risk-informed regulation.

CONTENT OF DRAFT REGULATORY GUIDE

- In the 12/98 presentation, the following proposals were made regarding the reg. guide:

  1. Address analysis methods for all Chapter 15 transients stressing verification, validation, documentation, and quality assurance.

  2. Describe application of the evaluation model concept which includes all computer programs, other models, input, output, and methodology used to show compliance with analyses required by 10CFR50.34 and 50.36.

  3. Describe an acceptable evaluation model development and assessment process based on principles of CSAU derived and refined over the last dozen years. A key element of this process is a credible and scrutable Phenomena Identification and Ranking Table which is used to inform the entire process.

- The content proposed in the 12/98 presentation has been included in the draft guide.

- A section on nomenclature and definitions has been added.

- LOCA appendices are being prepared. Most information in these appendices will be incorporated by reference.

SUMMARY

1. The draft regulatory guide on generic transient and accident analyses methods addresses the findings of the Maine Yankee Reviews.

2. We would appreciate comments and recommendations from the ACRS.

MAINE YANKEE FINDINGS RELATED TO CODE DOCUMENTATION AND REVIEW

Maine Yankee Independent Safety Assessment (ISA) (10/1/96) -

YAEC did not have a documented process in place to identify and rank key phenomena for each of the transients and accidents in the safety analysis report and in turn identify needed code validation and parametric study efforts.

Maine Yankee ISA Staff Actions (11/27/96) -

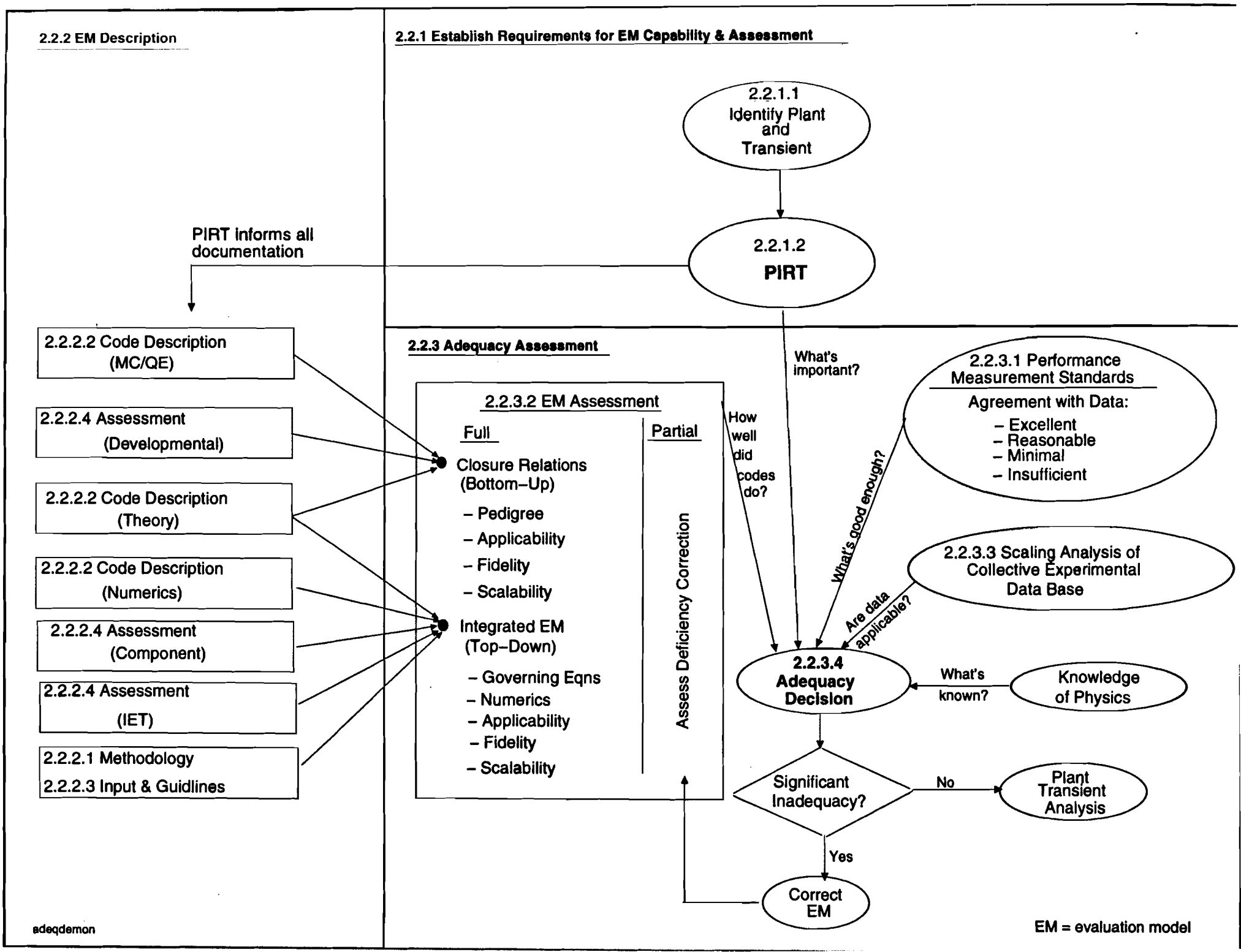
Evaluate the agency's expectations and policy relative to code validation. Develop and issue additional guidance and requirements if appropriate.

Evaluate the need to develop a standard review plan for code reviews. Develop and issue appropriate guidance.

NRR Maine Yankee Task Group (12/5/96) -

A standard format and content guide for topical reports documenting ECCS methodologies should be developed. The guide would provide assurance of uniformity and consistency in the level of documentation and validation that is provided.

While there is a clear regulatory requirement that ECCS analyses be performed using an NRC approved methodology (i.e., 10 CFR 50.46), the regulatory basis for staff review of other codes (e.g., physics codes, core thermal-hydraulics codes, fuel performance codes, and non-LOCA transient and accident codes) used to perform core reload design and safety analysis is not clear.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– Applicability
– Fidelity
– Scalability
Integrated EM (Top–Down)
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– Numerics
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– Fidelity
– Scalability
Assess Deficiency Correction
How well did codes do?
What's important?
What's good enough?
Are data applicable?
2.2.3.1 Performance Measurement Standards
Agreement with Data:
– Excellent
– Reasonable
– Minimal
– Insufficient
2.2.3.3 Scaling Analysis of Collective Experimental Data Base
2.2.3.4 Adequacy Decision
What's known?
Knowledge of Physics
Significant Inadequacy?
No
Plant Transient Analysis
Yes
Correct EM
adeqdemon
EM = evaluation model

J. TATUM R

GL 96-06/TBR INITIATIVE

A. <u>BACKGROUND INFORMATION -- INTRODUCTION</u>

- GL 96-06 WATERHAMMER & NUREG/CR-5220
- TBR INITIATIVE PROPOSED (8/98)
- NRC REVIEW STAFF
  - JIM TATUM, NRR/DSSA/SPLB
  - GEORGE HUBBARD, NRR/DSSA/SPLB
  - GARY HAMMER, NRR/DE/EMEB
  - B. P. JAIN, NRR/DE/EMEB
  - AL SERKIZ, RES
  - HOSSEIN NOURBAKHSH (CONSULTANT)

EPRI/Industry Collaborative Project to Support Resolution of GL 96-06 Waterhammer RAIs

Vaughn Wagoner, CP&L, Chairman, Utility Advisory Group
Dr. Peter Griffith, MIT, Chairman, Expert Panel
Dr. Tom Esselman, President, Altran Corporation
Dr. Avtar Singh, Project Manager, EPRI

NRC/ACRS Meeting
Washington D.C., Nov. 17, 1999

Issues Identified in GL 96-06

- **Susceptibility of the containment air cooler cooling water systems to waterhammer loads during either LOCA or MSLB**
- Impact of two-phase flow on heat removal capabilities of the cooling water systems serving the containment air coolers
- Impact of thermally induced overpressurization of isolated water-filled piping sections in containment penetrations

Background

- Licensees completed analyses to address waterhammer and two phase flow issues in response to GL 96-06 during 1997.
- NRC issued Requests for Additional Information (RAIs) during 1998.
- Industry/NRC meeting to clarify RAIs was held on 5/27-28/1998.
  - NRC expectations
    - ⇒ to assure that waterhammer issues have been adequately addressed
    - ⇒ to obtain sufficient information from licensees to complete review and close out issues
  - Industry initiated this EPRI project in 1998 to develop a Technical Basis Report (TBR) to address NRC RAIs

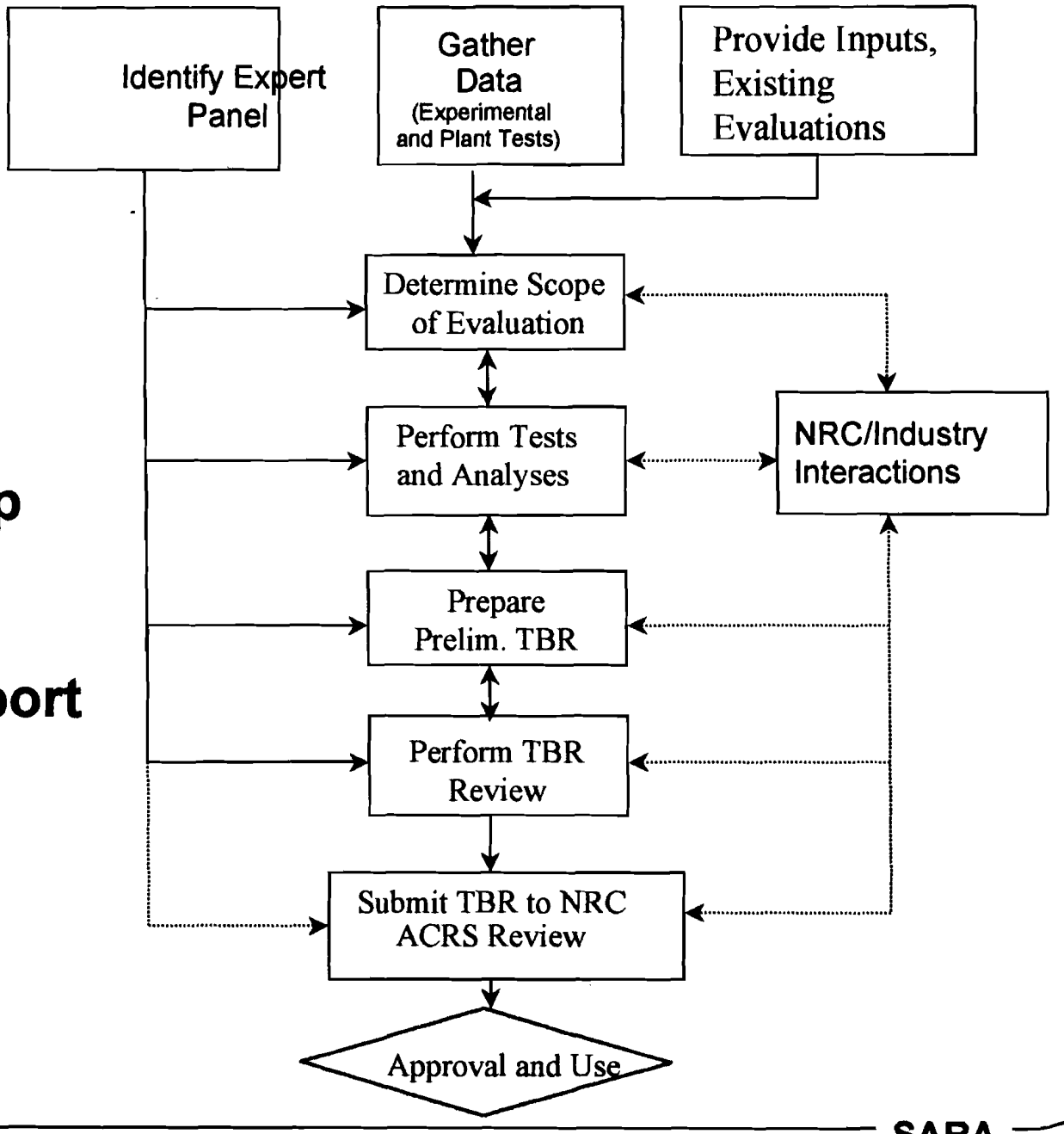
EPRI GL 96-06 Waterhammer Project Participants

Baltimore Gas & Electric
Carolina Power & Light
ComEd
Consolidated Edison
Consumers Power
Duke Power
Florida Power & Light
New York Power Authority
Northern States Power
Rochester Gas & Electric
Southern California Edison
Southern Nuclear Operating Co.
Wisconsin Electric
Wisconsin Public Service

Objectives of the EPRI/Industry Collaborative Project

- Prepare a generic Technical Basis Report for resolving GL 96-06 issues.
- Develop information that can be used by participating utilities to support their selected methodology.
- Develop a clearer understanding of low pressure waterhammer phenomena that can be used broadly for waterhammer evaluation.

Industry Approach to Develop a Generic Technical Basis Report



Project Status and Activities

• Project Kickoff Meeting	10/98
• First Expert Panel Meeting	2/99
• Second Expert Panel Meeting	4/99
• Third Expert panel Meeting	7/99
• Interim Technical Basis Report (TBR) completed	9/99
• TBR submitted to NRC for review	9/99
• Meeting with ACRS	11/99
• Issue approved TBR (target)	12/99

Expert Panel

- Expert Panel is comprised of:
  - Dr. Fred Moody - GE Consultant, Retired
  - Dr. Ben Wylie - U of Michigan, Retired
  - Dr. P Griffith - MIT, Retired, Chairman
- Expert Panel independently interacted with EPRI, industry representatives, NRC, and consultants.
- Expert Panel will perform final review, comment, and provide anticipated endorsement of the Technical Basis Report at the conclusion of the work.

Specific Expert Panel Activities

- Assisted in construction of the PIRT.
- Participated in all of the project review meetings.
- Identified existing tools and information that could be useful in the project.
- Helped to shape and review the experimental and analysis program.
- Reviewed the work as it progressed.
- Reviewed three drafts of the TBR.
- Consulted individually as requested, on specific aspects of the work as it progressed.

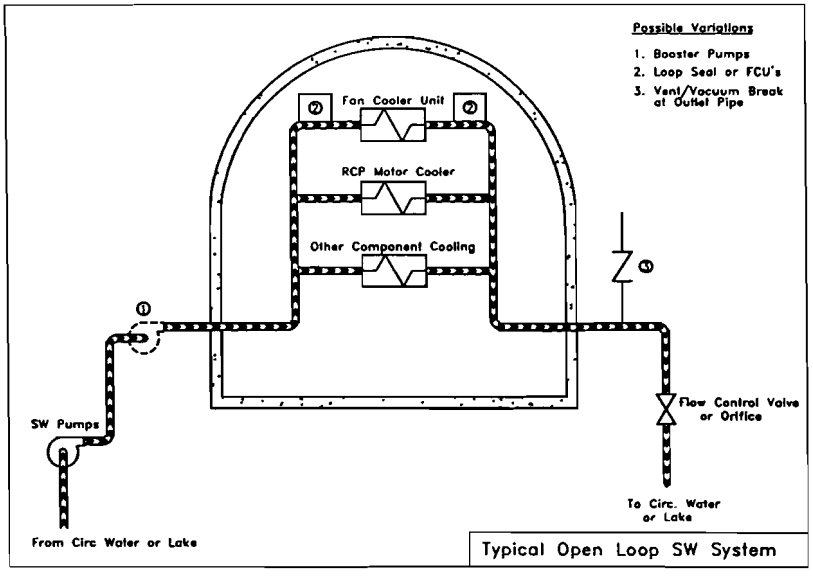
Project Activities

- Characterize system behavior during LOOP/LOCA (or MSLB) event
- Determine waterhammers to be evaluated
- Perform testing for CCWH and CIWH
  - Determine waterhammer pressure magnitude and duration
  - Quantify effects of non-condensables and steam condensation rates
  - Determine support reaction forces
- Perform analyses and validate with test results
- Prepare guidelines to use for individual plant assessment of waterhammer

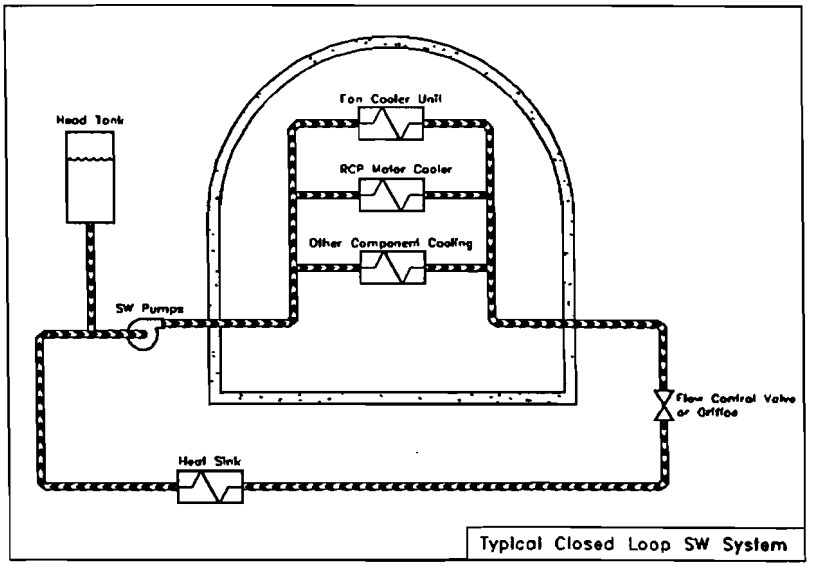
Primary Conclusions

- If voiding occurs in a plant due to LOOP only, the resulting waterhammer loads are more severe than those produced by LOOP and LOCA or MSLB
- Non-condensables in the water are released in to the steam void and, together with the steam condensation rate, mitigate the severity of the postulated waterhammer loads
- Condensation induced waterhammer that can occur during the void formation phase of the LOOP plus LOCA (or MSLB) will not pose a credible threat to pressure boundary integrity

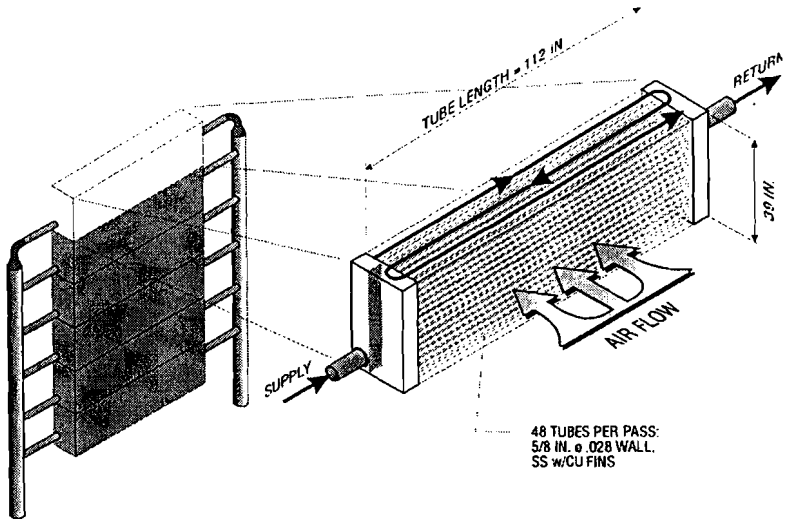
System Description: Open Loop System



System Description: Closed Loop System



Typical Fan Cooler Design

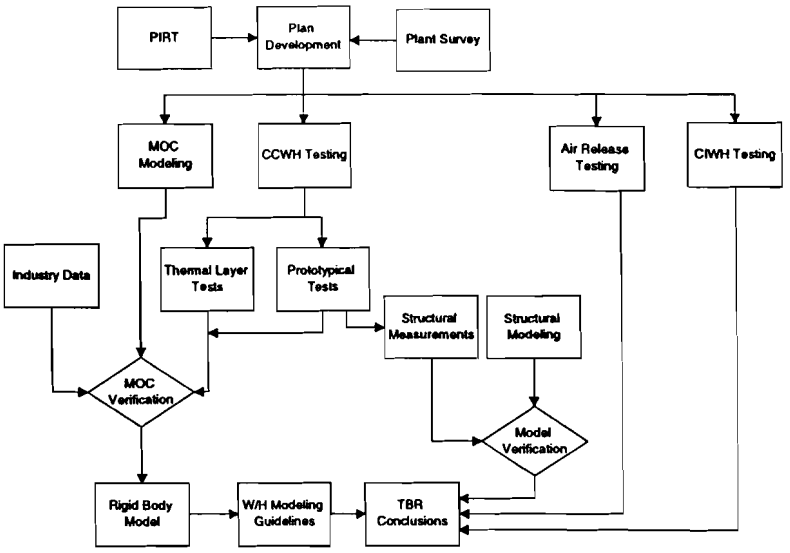


LOOP/LOCA (MSLB) Event

(all times are approximate and vary based on plant specific parameters)

- Time = 0 sec. Concurrent LOOP and LOCA (or MSLB) events
- Time = 5 sec. Pumps coast down, Fans slow gradually
- Time = 10 sec. Fan coolers boil and void formation egins
- Time = 30 sec. Pumps restart
- Time = 37 sec. Water column rejoins closing the void

Program Technical Approach



Plant Waterhammer Experience

- Many plants have had waterhammers from LOOP testing
- LOOP test conditions are often similar to LOOP/LOCA conditions
- Six plants recorded pressure data during the events
- No challenges to pressure boundary integrity
- Several minor support damage incidents noted

PIRT Process

- Phenomena Identification and Ranking Table (PIRT) performed with the Expert Panel
- Process identified important phenomena and components
- The results of the PIRT indicate that two waterhammer types are of concern. These are:
  - Condensation induced waterhammers that can occur during the voiding of horizontal pipes, and
  - Column closure waterhammers that can occur when the void is closed. This generally occurs at the end of refill for the transient of interest.

Column Closure Waterhammer (CCWH) Scope

- Perform separate-effects tests to demonstrate the effects of the thermal layers and steam and gas contents on the magnitudes of column closure waterhammers.
- Perform prototypical tests of CCWH to simulate the conditions experienced in the plant.
- Develop an analytical model to predict CCWH pressure. Correlate and validate the model against test data.
- Characterize the system in-plant behavior using the validated analytical model.
- Identify method to be used to obtain piping segment forces and to attenuate the pressure wave as the wave travels through the piping.

Condensation Induced Waterhammer (CIWH) Scope

- Perform testing to define the Condensation Induced Waterhammer magnitude and duration during the voiding phase.
- Provide scaling justification to apply the results to prototypical pipe sizes.

Waterhammer Analysis

- From Basic Principles, the Joukowski Equation:

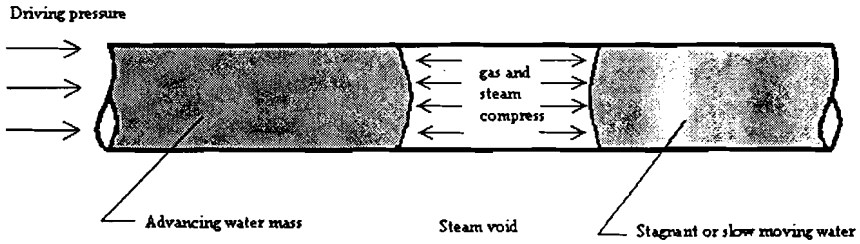
$$\Delta P = k\rho C \Delta V$$

- ΔP = waterhammer pressure pulse
- k = constant (1/2 or 1)
- ρ = water density
- C = sonic velocity
- ΔV = velocity change

- The constant and water density terms are well understood.
- The sonic velocity and velocity change terms warrant further investigation.

Column Closure Waterhammer

- CCWH occurs when steam voids are collapsed by refilling water.
- The pressure magnitude is proportional to impact velocity.
- Pressurization within the void will reduce impact velocity and waterhammer magnitude (cushioning).
- Pressure in the void results from the rate of steam condensation and released non-condensable gases under compression from the fluid.



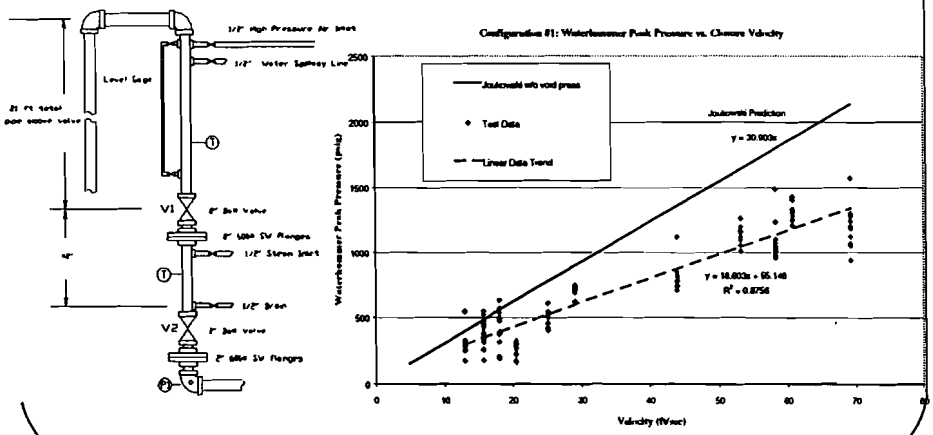
CCWH Testing

- Configuration #1: Tested closure of a pure steam void using subcooled water driven by a known pressure. Pressure and force data recorded at pipe supports.
- Thermal layer tests: Tested the effects of the temperature of the water adjacent to the void. Temperature and pressure data recorded.
- Configuration #2a, 2b: Tested closure of a void with steam created from boiling water in the test loop. Oxygen concentration in the water and pressure data were recorded.

<u>Test data from all three tests were used to benchmark the analytical model</u>

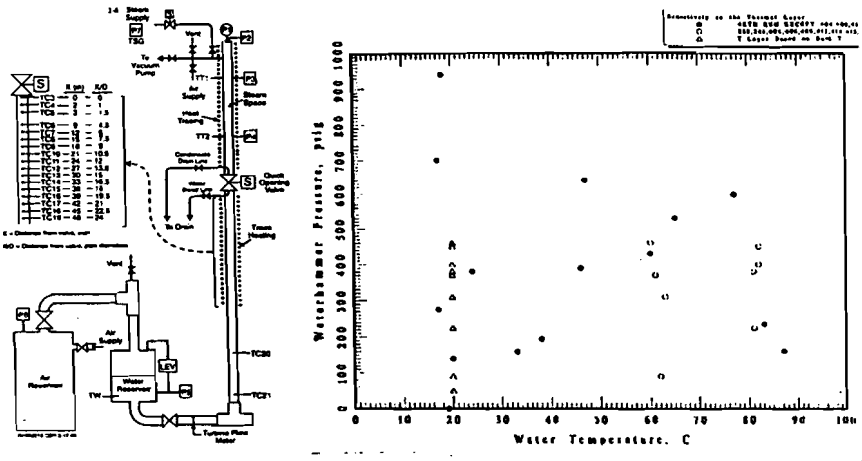
CCWH Test Results – Configuration #1

- Steam cushioning at high closure velocities
- Cold water used to close void
- No non-condensables in the void



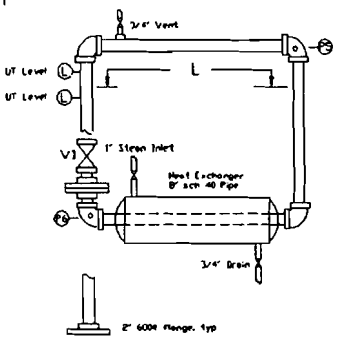
CCWH Test Results - Thermal Layer Tests

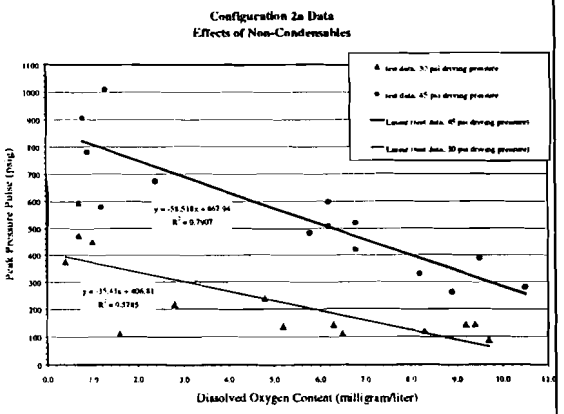
- condensation in the void is controlled by the temperature of the thermal layer adjacent to the void not by the bulk fluid temperature



CCWH Tests – Configuration #2a, #2b

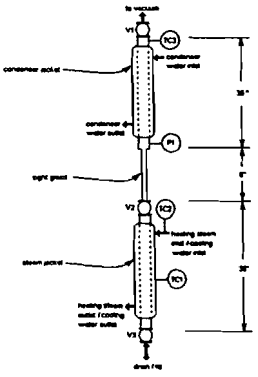
- The configuration #2a and #2b tests and modeling effort showed that air can significantly cushion the CCWH.

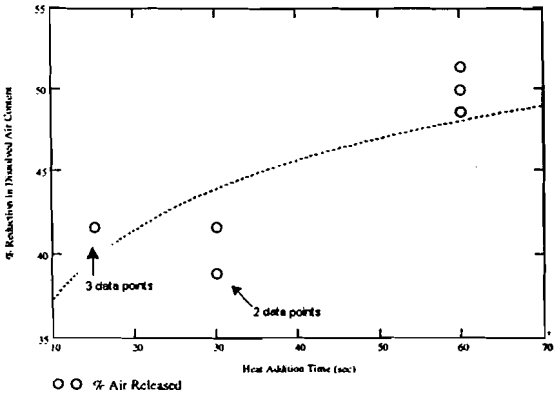




Gas Release Tests

- Air or Nitrogen have decreased solubility during boiling
- The testing program showed the rapid release of non-condensables
- Approximately 40% dissolved gas released in 30 second event



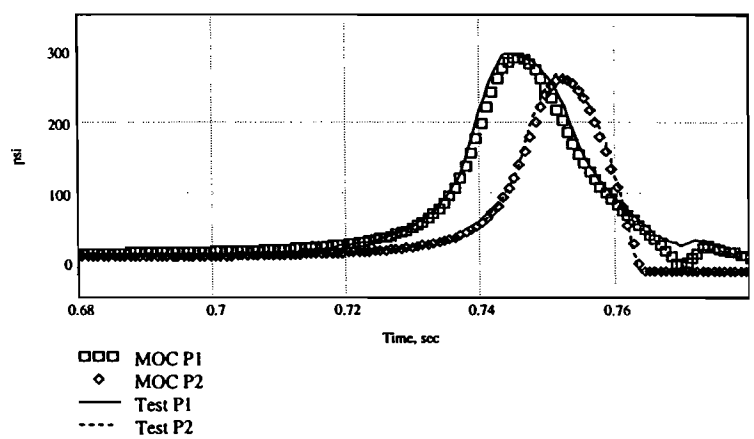


○ ○ % Air Released
---- Curve Fit: % Reduction = 6 ln(time) + 23.5

MOC Model

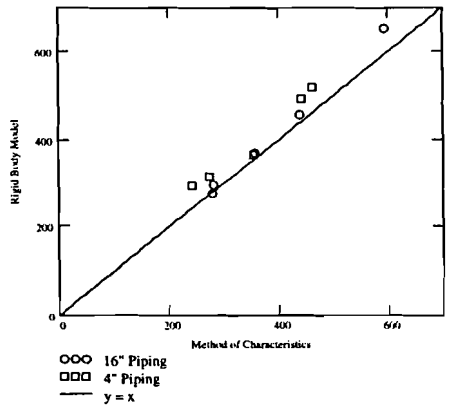
- Solves equations for momentum and continuity using finite difference techniques
- Method developed by E. B. Wylie
- Effects of non-condensables
  - Discrete Free-Gas Model (distributed voids)
  - Air Compression (in steam void)
- Steam condensation in void
  - steam temperature at saturation
  - hA assumed constant
- Code Benchmarked
  - Wylie examples
  - Test Data
  - Other Data

MOC Verification



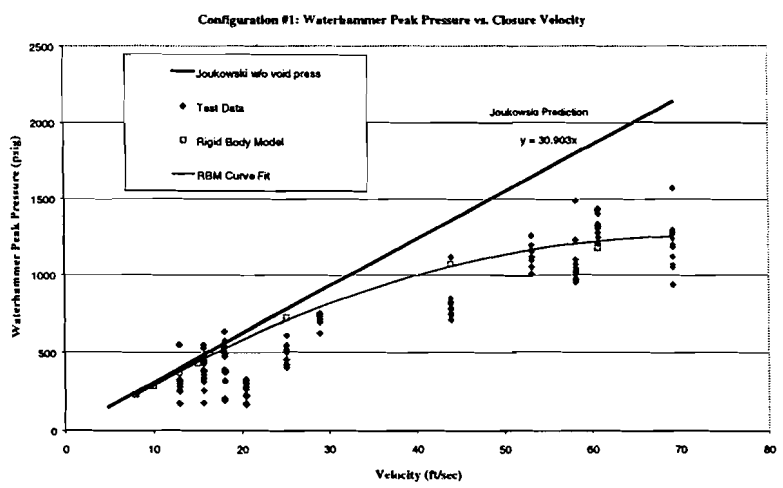
Rigid Body Model (RBM)

- considers closing water column as a rigid body
- considers pressurization in the void from steam condensation and gas compression as an ideal gas
- does not include wave travel through closing column
- benchmarked against MOC model and test data



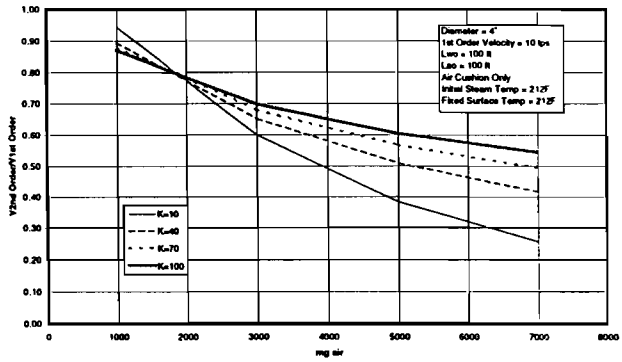
Peak Pressure Pulse

RBM Test Data Comparison-Configuration #1



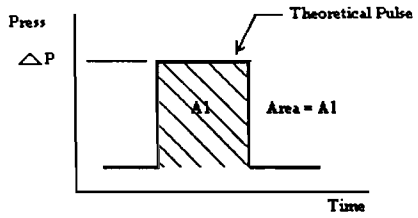
TBR Application for Waterhammer Pulse

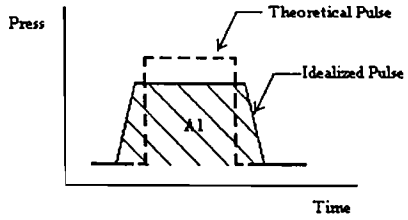
- The RBM was run for a range of input conditions.
- Charts were provided to simplify use of the RBM approach
- Guidance was added to clarify conservative direction for data and assumptions.
- $V_{2nd\ order}/V_{1st\ order}$ is the ratio of cushioned to non-cushioned velocity



Pulse Shape Definition

- Pulse shape is defined by magnitude, duration, and rise time
- Cushioning reduces waterhammer magnitude but also affects pulse shape by increasing rise time and duration.
- Impulse (area under pressure time curve) remains constant within a set of conditions.

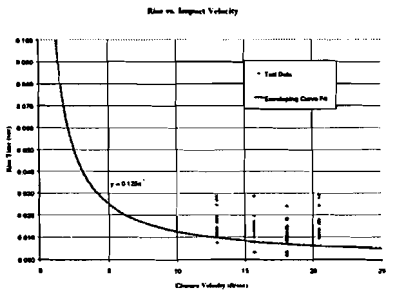


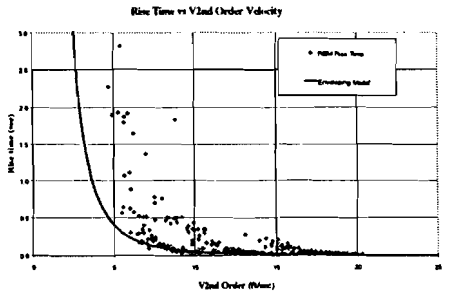


Pulse Shape Definition – Rise Time

- Rise Time Model Conservatively bounded test data and analytical model.

$T_R = 1(ft)/(8V)$ where: T_R = rise time (sec)
V = closing velocity (ft/sec)





Pulse Shape Definition – Duration

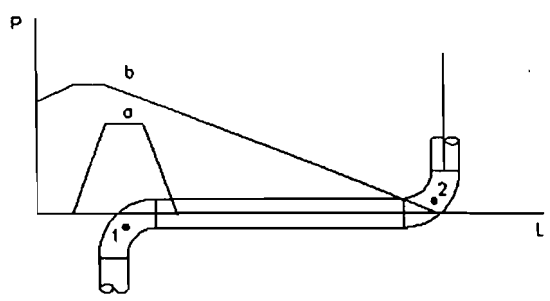
- Duration Model:
  - The duration is predicted based on the partial reflections of the pressure wave reaching area changes.
  - When 90% reflection of the pressure pulse has occurred, the system is assumed to revert to the original pressure.
  - The total time required for the pulse to travel to the reflection points and back is used as the duration (2L/C).
  - Combined with rise time and pulse magnitude, the recommended pulse shape is simplified to a trapezoid.

Pulse Propagation

- Provided guidance for:
  - Attenuation due to flow area, pipe movement, and friction
  - Clipping of the peak due to reflection
    - partial reflection of the pulse during the rise time
  - Fluid structural interaction (FSI)
    - limited potential for amplification
  - Pulse travel velocity
    - sonic velocity calculated
    - test results confirm calculation

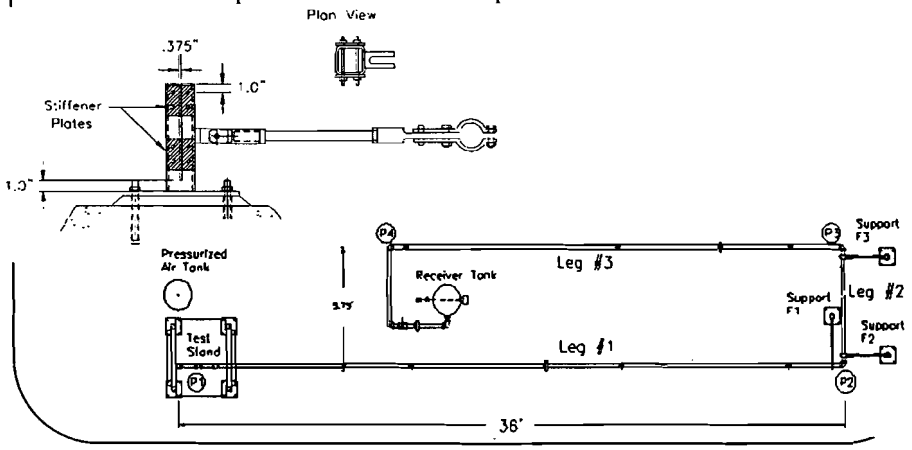
System Qualification Model

- Pipe loading is based on the differential pressure across a pipe segment as a pressure wave travels through the system
- A force time history can be developed for each elbow and applied to a piping model.



System Qualification Tests

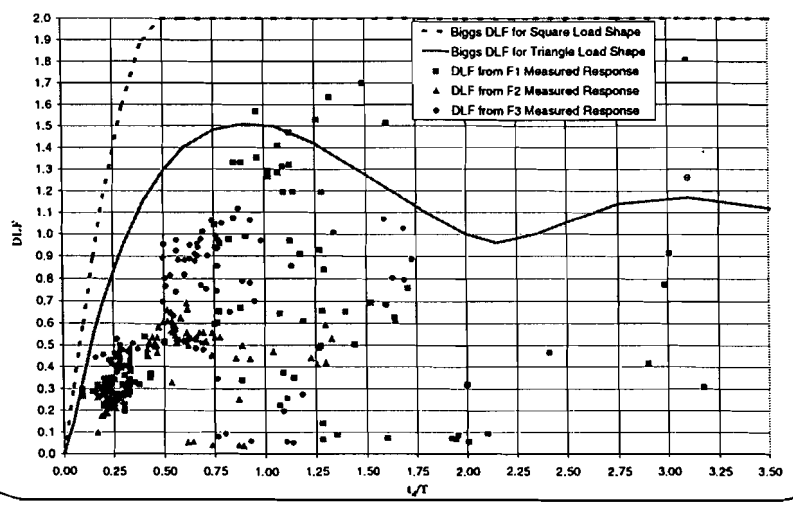
- The structural response of test configuration was measured
  - Support Stiffness (could be varied)
  - System Frequencies
- The structural response from an ANSYS model of system was compared to the measure response



Structural Response

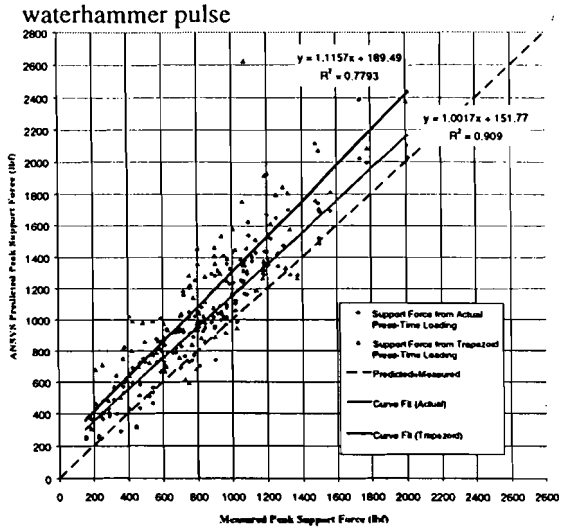
Data showed the importance of system dynamics

DLF Data Comparison to Single Degree of Freedom Model with Square and Triangle Load Profiles



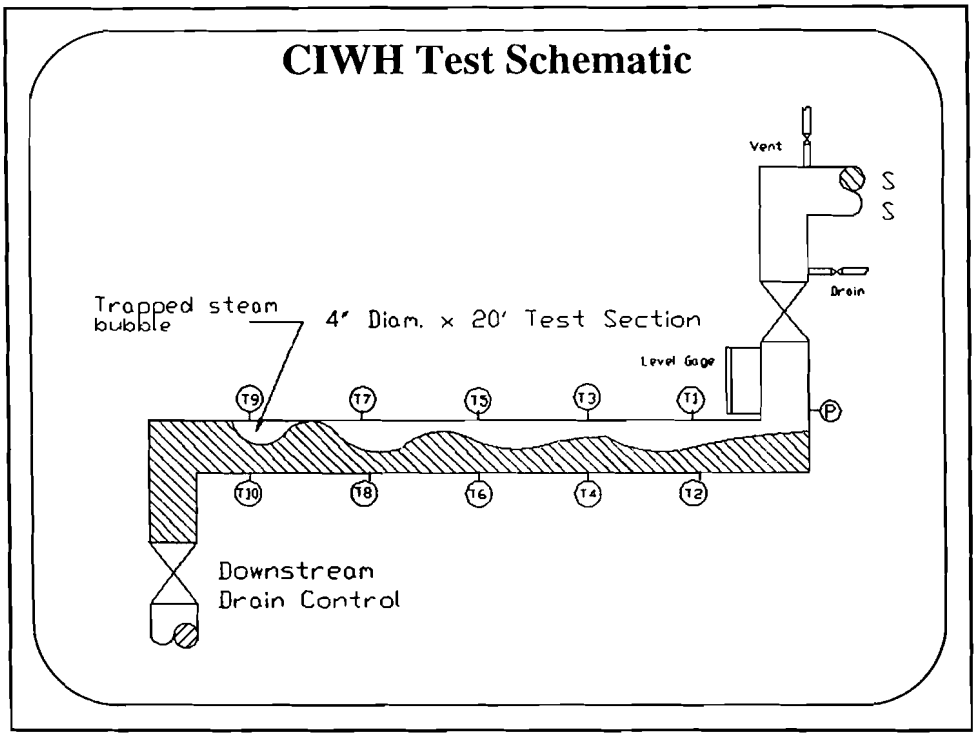
Structural Response Model Comparison

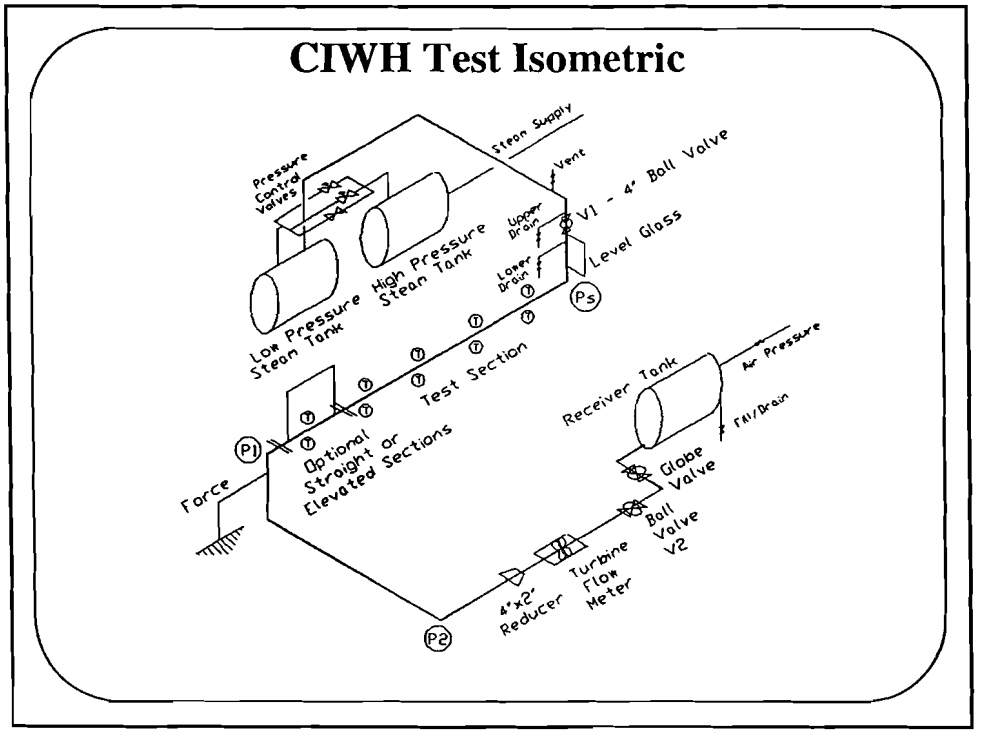
- Showed accuracy of trapezoidal pulse characterization
- Showed accuracy of dynamic modeling of the primary waterhammer pulse



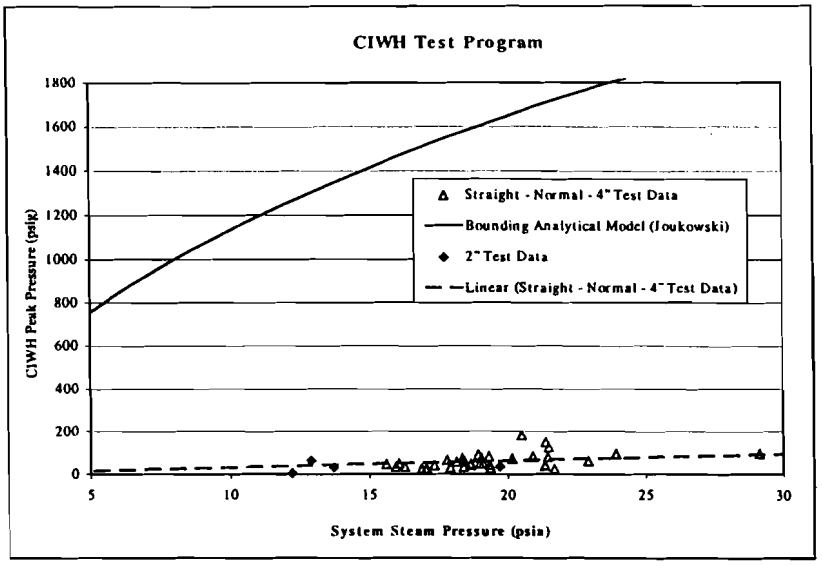
Condensation Induced W/H Testing

- Test section constructed of 4" schedule 40 pipe
- Hot steam supplied at prototypical pressure for draining system (10-30 psia)
- Steam created from deaerated water
- Subcooled water drained at a range of drain rates
- Water non-condensable level controlled (normal tap water or deaerated through boiling)
- Temperature along horizontal pipe measured
- Pressure in draining fluid measured
- Force on axial support measured

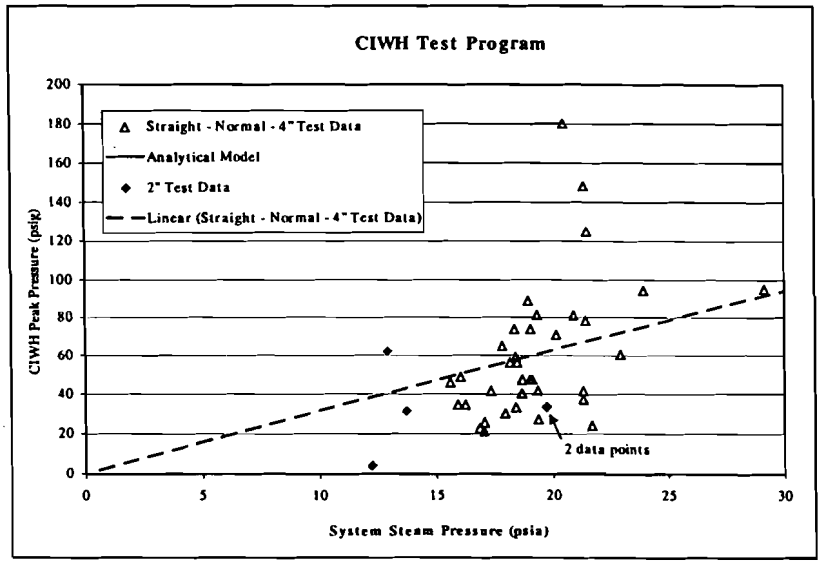

CIWH Test Schematic
Vent
S
S
Drain
Trapped steam bubble
4" Diam. x 20' Test Section
Level Gage
T9
T7
T5
T3
T1
P
T10
T8
T6
T4
T2
Downstream Drain Control


CIWH Test Isometric
Steam Supply
Vent
Pressure Control Valves
V1 - 4" Ball Valve
Upper Drain
Lower Drain
Level Glass
High Pressure Steam Tank
Low Pressure Steam Tank
Ps
Test Section
Receiver Tank
Air Pressure
Fill/Drain
P1
Force
Optional Straight or Elevated Sections
Globe Valve
Ball Valve V2
Turbine Flow Meter
4"x2" Reducer
P2

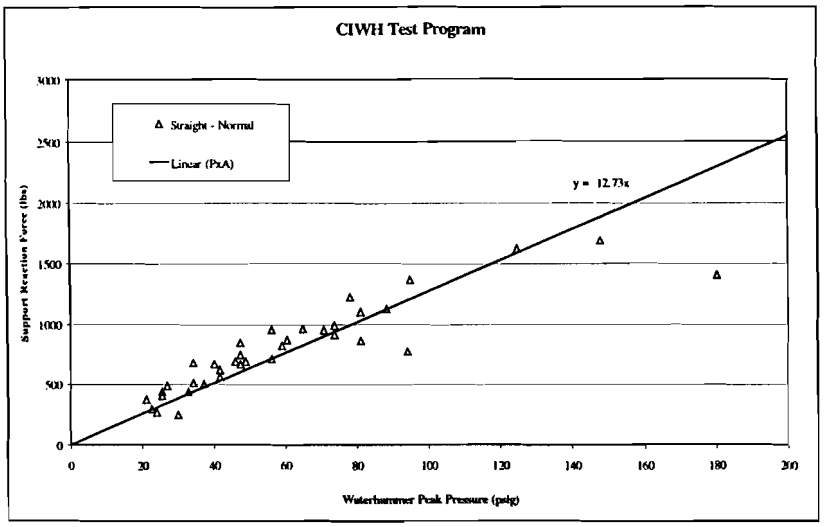
CIWH Test Results



CIWH Test Results - Scaling



CIWH Test Results - Support Loads



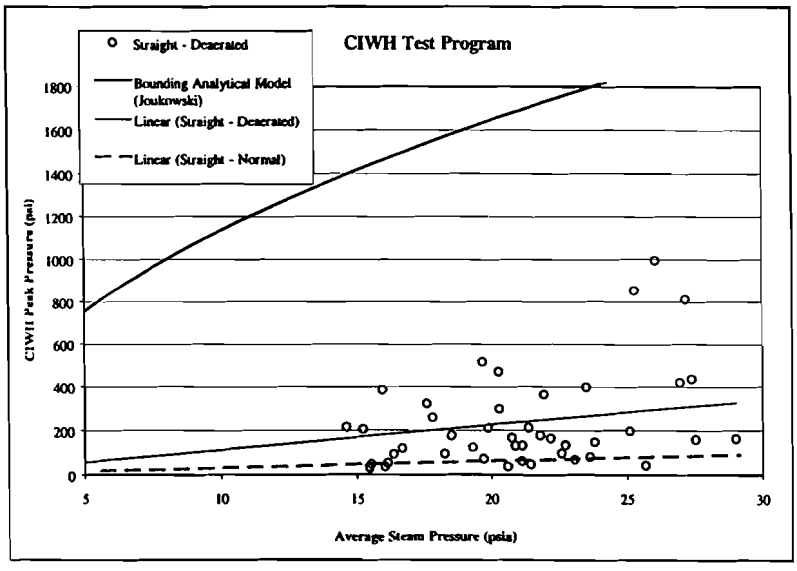
CIWH Test Results

- Normal water (tap water without any attempts to limits dissolved oxygen)
- Pressure Pulse magnitudes were <200 psig for prototypical system pressures (10-30 psia), most <100 psig
- Pressure pulse magnitude and duration inversely proportional (i.e. impulse is a constant for a specific system pressure)
- Force on the support increases linearly with waterhammer pressure pulse up to about 120 psig
- For the Froude numbers ($Fr = V/(gD)^{1/2}$) of 0.2 to 1.4, no relationship was found between drain rate and waterhammer magnitude
- Data included both 2" and 4" pipe.

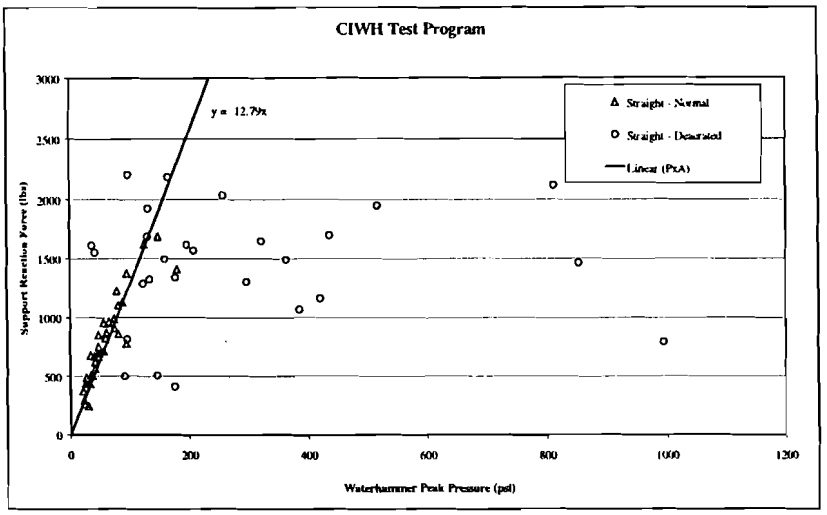
CIWH Results for Deaerated Water

- Water deaerated by boiling and cooling, before filling test section
- Pressure pulses were higher magnitude (up to 500 – 1000 psi) but of lower duration
- Pressure pulse duration and magnitude inversely proportional (constant impulse)
- Force on the support increased linearly up to about 200 psig.

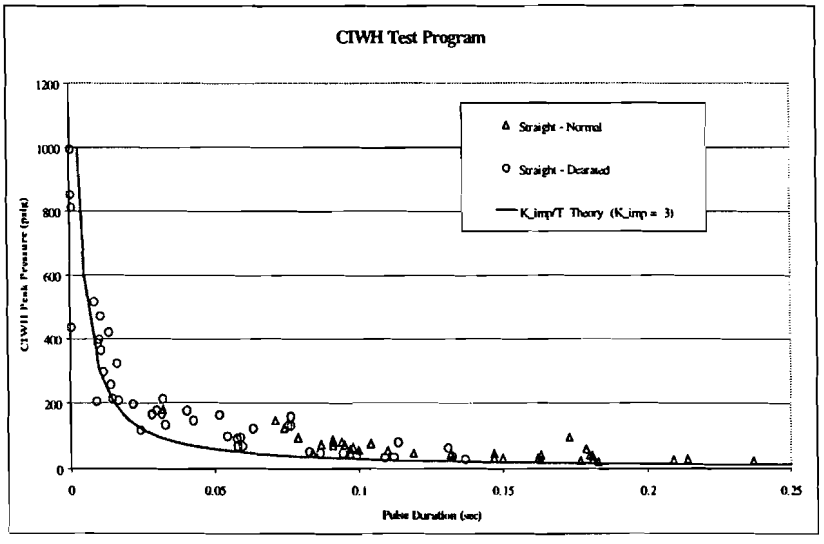
CIWH Results for Deaerated Water



CIWH Results for Deaerated Water



CIWH Results for Deaerated Water



CIWH Conclusions

CIWH waterhammers for low pressure service water systems are limited in magnitude or duration such that they are not a credible threat to pressure boundary integrity. This conclusion applies to systems that meet the following conditions:

- the system steam pressure at the time of the postulated CIWH is less than 15 psig
- the system draining water contains non-condensables
- the piping has been shown by test or analysis to be capable of withstanding a CCWH following LOOP, LOOP/LOCA, or LOOP/MSLB

Conclusions

- The postulated concurrence of the LOCA (or MSLB) and the LOOP events create the potential for:
  - Column closure waterhammer (CCWH) following pump restart, and
  - Condensation induced waterhammer (CIWH) during the void formation phase prior to pump restart
- The CIWH can occur during the void formation phase of the event. They are characterized by the following:
  - The CIWH has limited energy and is controlled not by the magnitude of the pressure but by the impulse.
  - The response in the pipe supports is also limited and is controlled by the impulse.
  - The 4" testing results are applicable to larger pipes.
  - In prototypical service water piping systems, the CIWH will not pose a credible threat to pressure boundary integrity.

Conclusions

- The CCWH will occur when the pumps are restarted at locations of "trapped" intermediate water and at the final closure location. They are characterized by the following:
  - Non-condensables (air or nitrogen) and steam in the void play a significant role in the velocity of the closing columns.
  - Analytical models can be correlated to the test data and extended to prototypical plant configurations.
  - The closure velocity utilized in the Joukowski equation can be adjusted to achieve more realistic values by calculating a reduction due to the cushioning effects of non-condensables and/or steam.
  - The shape of the pressure pulse (duration and rise time) can be predicted.
  - If voiding occurs in a plant due to LOOP only and if the system line-ups are the same, the waterhammers produced from the LOOP only event bound those produced by LOOP plus LOCA (or MSLB) events

Conclusions

- Following the occurrence of a waterhammer, the pulse will propagate in the piping. The pulse propagation characteristics are tabulated below:
  - The pressure pulses attenuate and the attenuation can be calculated.
  - The potential for pulse amplification is limited and generally is not significant.
  - The speed of wave propagation in the fluid is not impacted unless the dissolved non-condensables come out of solution.
- The waterhammer pressure pulses will cause unbalanced pressure loads in pipe segments that will load the piping supports.
  - Accurate representation of the stiffness of the system and the dynamics of the loading is important to obtain accurate support loads.
  - Support loads that were measured in tests were smaller than loads that were calculated by dynamic analysis or by simplified calculations.

R

SRP Development for T/H Code Reviews

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Presentation to ACRS T/H Subcommittee
November 17, 1998

The Code SRP Organization

Areas of Review are consistent with the Reg. Guide. General principles applicable to all analytical computer codes covering key areas of review:

- Documentation
- Accident Scenario and Process Identification
- Code Theory
- Code Assessment
- Plant Modelling
- Quality Assurance
- Confirmatory Analysis
- Revisions to Previously Approved Models

Details will be provided for certain accident and accident classes in Appendices for:

- Modeling Requirements (Physical and Plant)
- Code Assessment

Future Actions

Incorporate ACRS comments into Draft SRP Section and Reg. Guide

Develop Appendices for review of specific types of analytical codes

Solicit public comments on Draft SRP Section and Reg. Guide

Provide for CRGR Review

Issue final versions