NRC FORM 658
(9-1999)

U.S. NUCLEAR REGULATORY COMMISSION

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DATE OF MEETING
12/15/2000

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Docket Number(s)	PROJECT NO. 669
Plant/Facility Name	EPRI
TAC Number(s) (if available)	
Reference Meeting Notice	11/15/00
Purpose of Meeting (copy from meeting notice)	TO DISCUSS STAFF REVIEW AND STATUS OF MODULAR ACCIDENT ANALYSIS PROGRAM (MAAP) COMPUTER CODE

NAME OF PERSON WHO ISSUED MEETING NOTICE	TITLE
L. N. OLSHAN	PROJECT MANAGER

OFFICE
NRR

DIVISION
DLPM

BRANCH
PD II-1

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MAAP Code Briefing for NRC Management

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Dec. 15, 2000

EPRI

History of NRC's MAAP Request

- Mid to late 1980s: Industry used MAAP (primarily MAAP-3B) to address severe accident questions
  - NUMARC informed NRC of intent; accepted w/o SER
  - Extensive briefings/familiarization for NRC ~1989-91
- Significant briefings for NRC on MAAP-4:
  - ALWR and ARSAP; SAMG support ~1993-4
  - Thermally induced SGTR (rulemaking context) ~1994-7
- Late 1999: RES (King) inquiry about MAAP
- Early 2000: NRR (Wermeil) request for review
  - Sr. Mgt. issue in context of thermally induced SGTR

Industry Understanding of Scope of NRC Review Request

- **May 2000 RETRAN-3D meetings:**
  - NRC comment: need to understand MAAP in order to reach level of confidence that it works well for conditions analyzed
- **July 17 conference call among tech. experts**
  - better understanding of concerns & explanations
- **Sept. 26 NRC/NEI Sr. Mgt. meeting:**
  - Discussion confirmed no NRC desire for SER; objective is sufficient basis for staff confidence

Meeting Objectives

- Review MAAP-4 capabilities
- Address SGTR concerns
- Mutual appreciation for likely applications
- Discuss potential need for NRC review:
  - scope, timing, participants
  - resource constraints

HISTORY OF MAAP AND ITS APPLICATIONS

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Presented at the
Nuclear Regulatory Commission
Rockville, Maryland

December 15, 2000

PRESENTATION OUTLINE

- What is MAAP – what is modeled?
- What is the status of MAAP4 verification?
- How can MAAP be used to develop success criteria/surface?

MAAP HISTORY

MAAP Version	Completion Date	Principle Objective
MAAP1	April, 1984	Represent core/RCS/containment thermal hydraulics under severe accident conditions.
MAAP2	June, 1984	Fully integrated thermal hydraulic and fission product behavior for severe accident conditions including "revaporization".
MAAP2B	December, 1984	Fully integrated thermal hydraulics and fission products with the chemical binding of tellurium and zirconium.
MAAP3	December, 1985	Issue resolution with the NRC for severe accident issues.
MAAP3B	1988	Fully integrated code for severe accident analysis to support plant specific IPE studies for BWRs and PWRs. Generally Rev. 7 for BWRs and Rev. 17 for PWRs.
MAAP3B-CANDU	1990	Evaluate severe accident behavior for the CANDU core/RCS/containment designs.
MAAP4	1994	Represent severe accident behavior and the influence of recovery actions to support SAMG development for BWRs and PWRs as well as the ALWR design features.
MAAP4-DOSE	1994	Provide capabilities to assess the doses associated with the accident spectrum considered in plant specific analyses.
MAAP4-VVER	1994	Represent the severe accident behavior and the influence of recovery actions for the VVER PWR designs.
MAAP4-CANDU	1998	Upgrade the MAAP3B-CANDU model to the MAAP4 technology with particular emphasis on the GCM.

MAAP3B

Uses

- Principally used to support plant specific IPE studies
  - General event timing for Level I studies.
  - Timing for the onset of core damage and containment failure.
  - Quantitative perspective of the issues related to liner melt-through (BWR Mark I/Mark II), DCH and the extent of hydrogen generated and consumed during the accident.
  - Included a representation of gas natural circulation in the RCS and its general influence on the SG tubes for PWRs.

Limitations

- Very simple models for the lower plenum response and RPV failure.
- No material creep model (Limited capabilities to evaluate recovery actions after core damage.
- Fixed containment nodalization.
- No mechanistic representation of external RPV cooling.
- Could encounter significant numerical chaos for sequences where the RCS remained very close to an injection system shutoff pressure.

MAAP4

Uses

- Principally developed to represent recovery actions after core damage, i.e., this was the basis for developing SAMGs.
- MAAP4 was also developed to represent the new systems (mostly passive) in the ALWR designs.

Capabilities

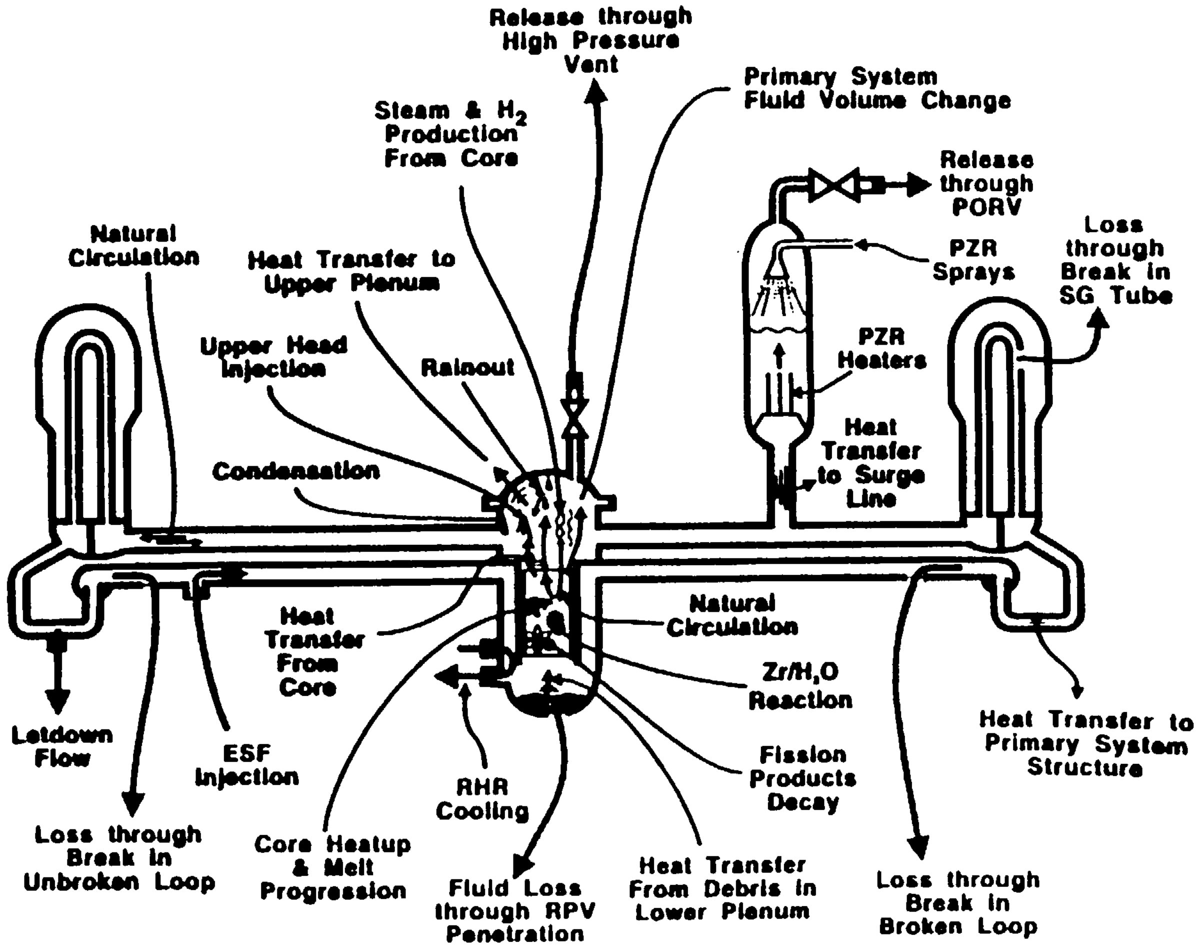
- Can evaluate recovery actions such as flooding of a damaged core as occurred in the TMI-2 accident.
- Vastly improved model for debris relocation to the lower plenum, net steaming rate and energy transfer to the RPV wall.
- Material creep model for the RPV, the hot legs and the SG tubes.
- Mechanistic thermal plume model for mixing in the SG inlet plenum.
- Model for external RPV cooling.
- Detailed RPV failure model that was benchmarked with a finite element code.
- Generalized Containment Model (GCM).
- Reduced numerical chaos.
- Dynamic benchmarking capabilities.

Limitations

- Containment pressures and temperatures in general agreement with experiments but consistently greater than the measured values.
- Consistent benchmark with the TMI-2 accident but always overpredicts the upper plenum temperatures.
- Does not represent individual SGs for 3 and 4 loop plants.
- Does not include a neutronics model.

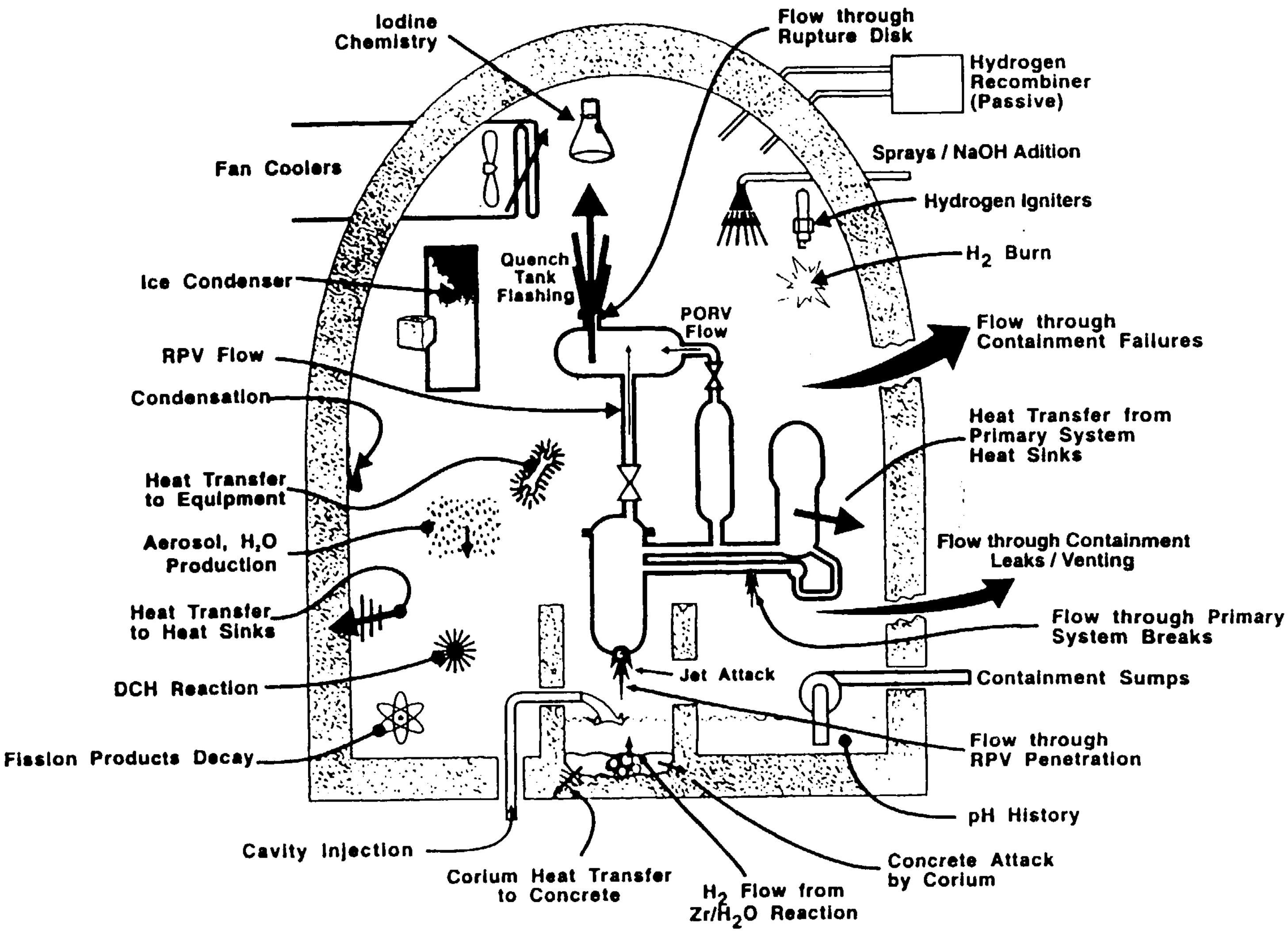
MAAP4 PWR RCS Functional Capabilities

PWR Primary System Modeling

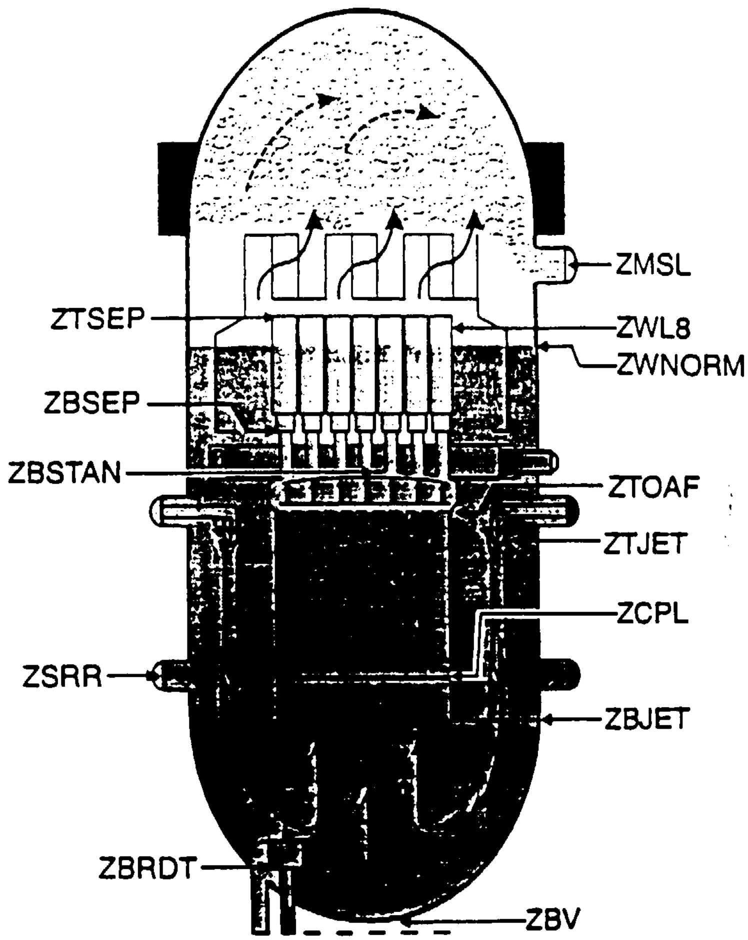


PWR Containment Modeling

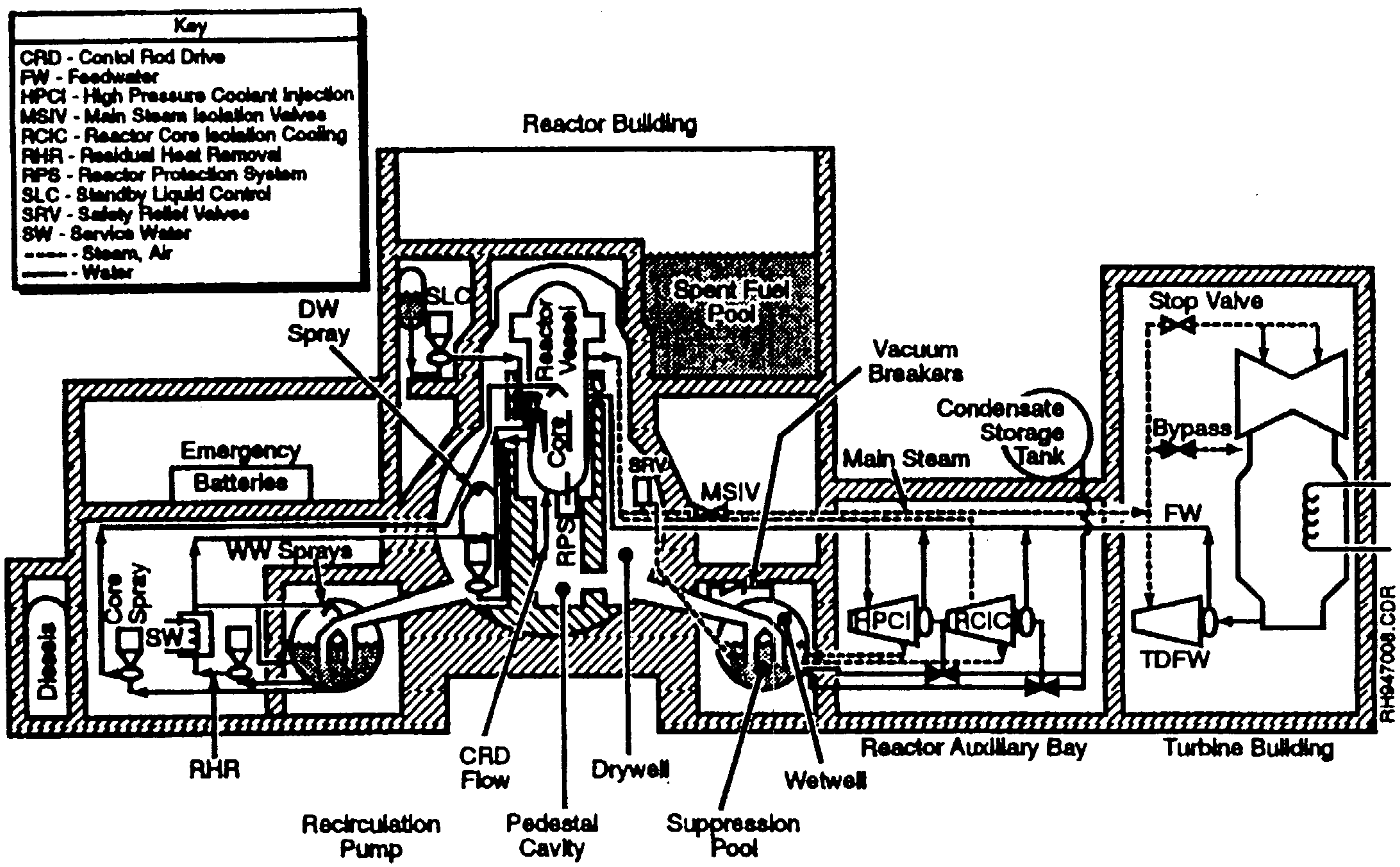
(Large Dry and Ice Condensor Configruation)



BWR Primary System



BWR/4 Mark I Safety and Other Systems (e.g., Peach Bottom)



MAAP4 USES

- MAAP4 has been used to validate plant specific implementation of EOPs and SAMGs.
- Support Level 1 and Level 2 success criteria for plant specific PRAs.
- Used to support AP600 PRA.
- MAAP4 has been the base code for assessing SG tube integrity.
- Design basis calculation for D.C. Cook recirculation sump inventory evaluation. These integral analyses (including the RCS) showed that ~ 20,000 gals is needed to keep the RCS full. Also these showed that the limiting case was for a small-small LOCA that was sufficient to initiate containment sprays with the minimum ice melting.
- The MAAP4 containment model is the analysis of record for the 50.44 hydrogen analysis at D.C. Cook using W hydrogen sources from degraded ECCS.
- MAAP4 has been used for a Swedish plant for success criteria in a shutdown PRA.

INTEGRAL MAAP4 BENCHMARKS

Primary Focus	Experiment/Experience	Status
RCS Response	- TMI-2 Accident - Davis-Besse LOFW[(a)] - Oyster Creek LOFT - Prairie Island SGTR[(b)] - Crystal River Stuck Open PORV[(c)] - Doel 2 SGTR (<u>ISP #20</u>) - GE Blowdown Tests - Marviken Critical Flow Tests	Complete Complete Complete Complete Ongoing Ongoing Will be Repeated as a Dynamic Benchmark To Be Done
Core Damage	- TMI-2 Accident - Phebus FPT0 - SFD 1-3 & SFD 1-4 - CORA Test 13 (<u>ISP #31</u>) - CORA Tests 7, 12, 16, 17 and 18 - LOFT FP-2	Complete Complete Complete Complete Complete Done With MAAP3 and Will be Repeated as a Dynamic Benchmark
• LOFW – Loss of Feedwater • SGTR – Steam Generator Tube Rupture • PORV – Pilot Operated Relief Valve		

INTEGRAL MAAP4 BENCHMARKS
(Continued)

Primary Focus	Experiment/Experience	Status
Steam Generator Response	- 1/7 Scale Westinghouse (EPRI/NRC) Tests - MB-2 MSLB Tests	Complete Ongoing
Hot Leg Rupture	- Stutgart MPa Tests	Complete
RPV Lower Plenum	Table 2	Ongoing
Fission Product Release	- ORNL Tests VI1 through VI7 - TMI-2	Complete Complete
Fission Product Aerosol Behavior	ABCOVE2 ABCOVE5 CSE Tests LACE Tests	Will Be Repeated as Dynamic Benchmarks Will Be Repeated To Be Done
Containment	- HDR Test E11.2 (<u>ISP #29</u>) - HDR Test T31.5 (<u>ISP #23</u>) - HDR Test V44 (<u>ISP #16</u>) - CVTR - CSTF Tests - Westinghouse Ice Condenser Tests - PNL Ice Condenser Tests - Marviken Blowdown 18 (<u>ISP #17</u>) - S&L Tests	Complete Complete Ongoing Complete Complete Complete Complete Ongoing Ongoing

MAAP4 BENCHMARKING PLAN FOR THE RPV LOWER HEAD MODELS

Phenomenon	Experiments to be Benchmarked	MAAP4 Model/Subroutine	Status
Penetration Response at Melt Relocation	EPRI Tests	CRUST	Complete
Melt Quenching (Steaming Rate)	FARO COTELS	DBJET DBJET	Ongoing To Be Done
Steam Explosions	KROTOS FITSB ALPHA Buxton Tests ZREX Tests	STMEXP STMEXP STMEXP STMEXP STMEXP	Completed Completed To Be Done To Be Done To Be Done
Lower Head Cooling	FAI Tests	LPBED	To Be Done
Lower Head Failure	LHF Tests	CREEP	To Be Done

RECENT DEVELOPMENTS WITH THE MAAP4 CODE

- MAAP4 has been used for DBA evaluations of the D.C. Cook containment – an SER was received on these evaluations.
- Easy to incorporate vendor results for mass and energy releases to the containment for special purpose analyses.
- NRC D.C. Cook SER – "The staff finds the proposed changes to the TSs for the Donald C. Cook Nuclear Plant, Units 1 and 2, to be acceptable. This approval is based on the licensee's analyses which show that all licensing criteria are satisfied. Analyses of water level in containment, performed with the MAAP code, are acceptable, based on comparisons of the MAAP code with relevant experimental data and approved computer codes and independent analyses performed by the LANL for the staff."
- MAAP4 has been used for 50.44 analyses (Reg. Guide 1.7) for the D.C. Cook containment. This will be the AEP analysis of record.
- The MAAP4 containment model has been integrated into the D.C. Cook full scope control room simulator.
- The entire MAAP4 code is being integrated into the Krsko and KSNP full scope control room simulators to represent severe accident behavior. KSNP will also use the MAAP containment model for all conditions.

MAAP4 INCLUDES THE CAPABILITIES TO MODEL SYSTEM SET POINTS AND OPERATOR ACTIONS

- These actions can be based on:
  - time,
  - set points (pressure, temperature, level, etc.),
  - or a combination of these.
- Set points are characterized in the plant specific parameter file or the input deck.
- Operator actions are characterized in the accident sequence specific input deck.

EXAMPLE OF AN OPERATOR ACTION
SG COOLDOWN AT 100°/HR

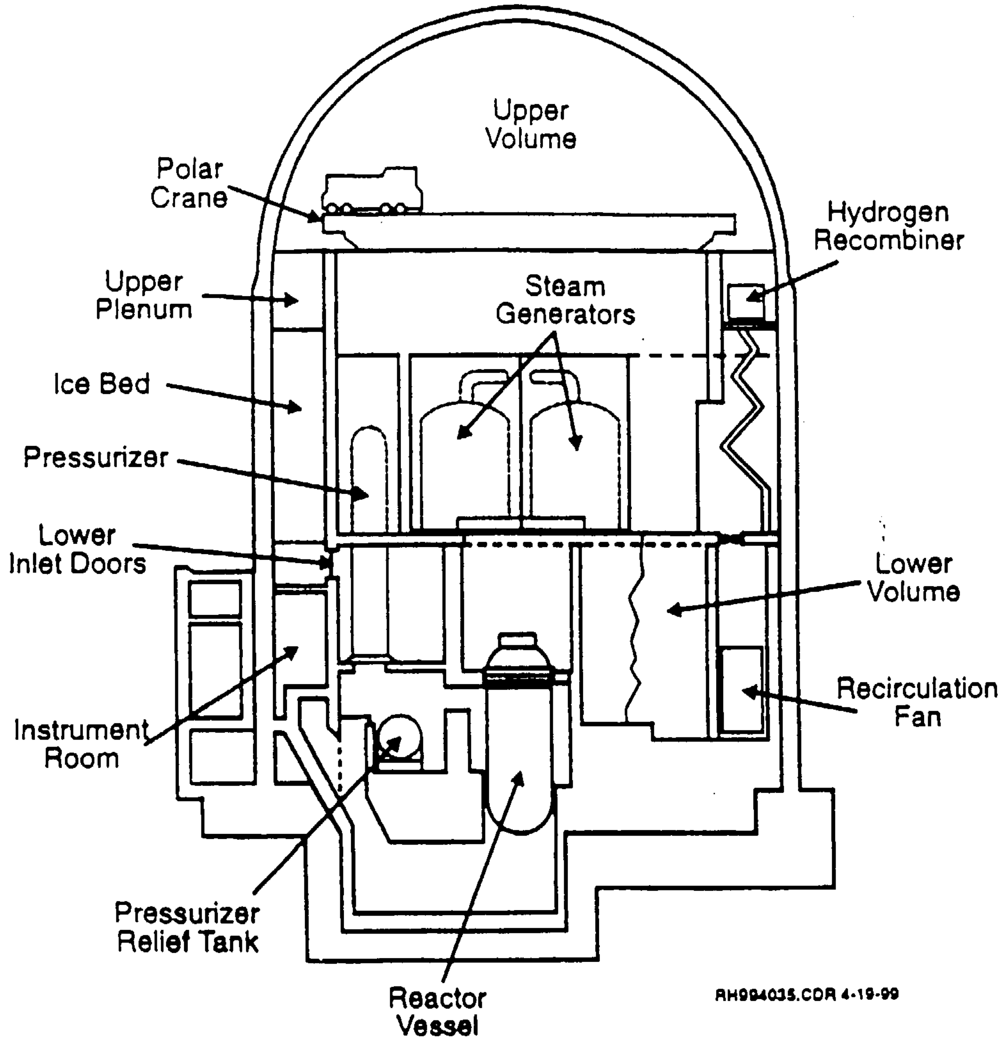
```
** -- COOLDOWN IN STEPS EVERY HOUR FOLLOWING SATURATION CURVE

      IF COOLDOWN TIME > 0.1 HR
            SG PORV SETPOINT = 910 PSI   // TSAT= 533 F
       END
**
       IF COOLDOWN TIME > 0.2 HR
            SG PORV SETPOINT = 830 PSI   // TSAT= 523 F
       END
**
       IF COOLDOWN TIME > 0.3 HR
            SG PORV SETPOINT = 770 PSI   // TSAT= 513 F
       END
**
       IF COOLDOWN TIME > 0.4 HR
            SG PORV SETPOINT = 700 PSI   // TSAT= 503 F
       END
**
       IF COOLDOWN TIME > 0.5 HR
            SG PORV SETPOINT = 640 PSI   // TSAT= 493 F
       END
```

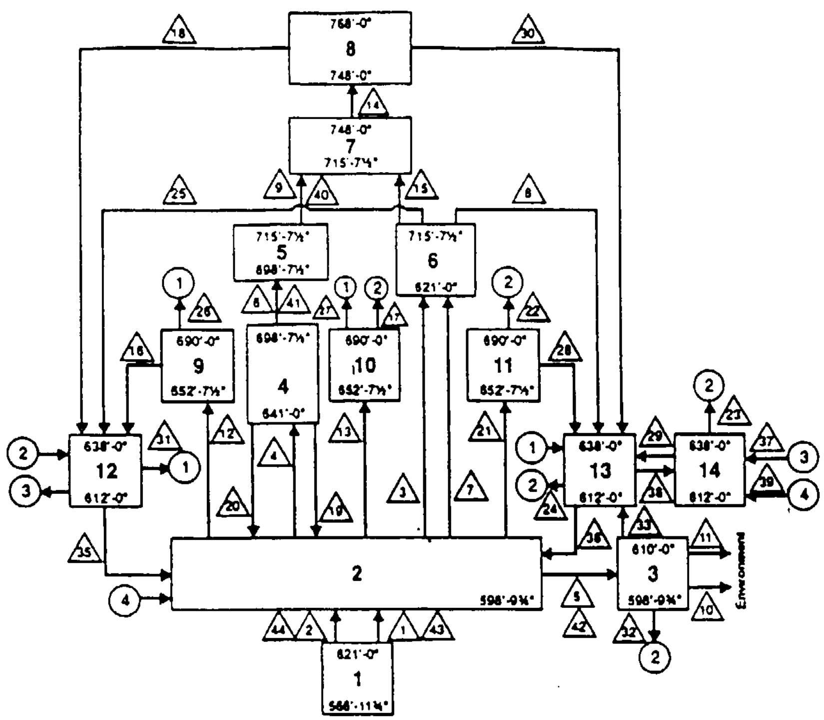
FLEXIBLE ANALYTICAL TOOL

- As indicated by its name, MAAP is a modular program. This enables it to be used as an integral model of the core, RCS and containment or as individual stand along models, i.e.
  - core model only (CORA benchmark),
  - RCS model only,
  - containment model only (D.C. Cook simulator implementation).
- With this modular framework, the individual models can also be used with input generated by another code. For example:
  - Westinghouse generated M&Es for a DBA LOCA used as input to the generalized containment model.

Example of a GCM Application
Basic Layout for an Ice Condenser Containment



D.C. Cook Containment Nodalization Revision 4
MAAP4 Parameter File (14 nodes/44 junctions)



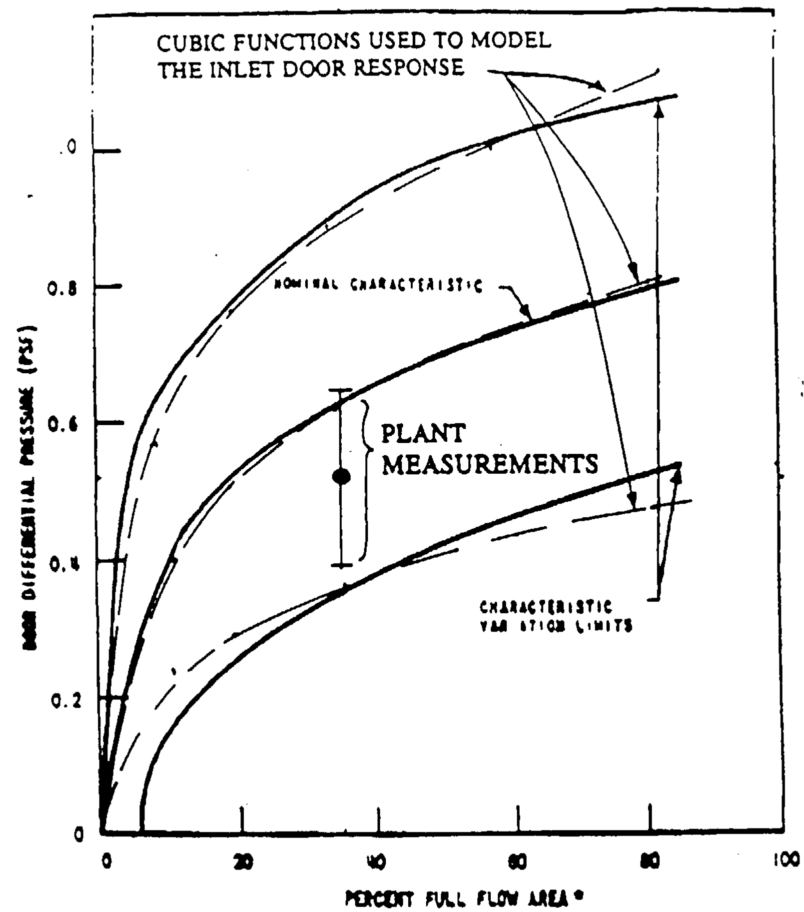
1 - Cavity
2 - Lower Compartment
3 - Pipe Annular Region
4 - Ice Condenser
5 - Ice Upper Plenum
6 - Upper Compartment Cylinder
7 - Lower Dome Region
8 - Upper Dome Region
9 - PZR Enclosure
10 - SG 1 & 4 Enclosure
11 - SG 2 & 3 Enclosure
12 - East Fan Room
13 - West Fan Room
14 - Instrument Room

△ - Junctions

○ - Indicates Connected Flow Paths

RR00A004.COR 8-3-99

Example of a Detailed Model for the Ice Condenser Doors Comparison of the Measured Plant Behavior for a 40° Door Opening and the Cubic Function Used to Model the Door Response With the D. C. Cook FSAR Door Characterization



USE OF MAAP TO REPRESENT LEVEL 1 SUCCESS CRITERIA FOR THE CORE

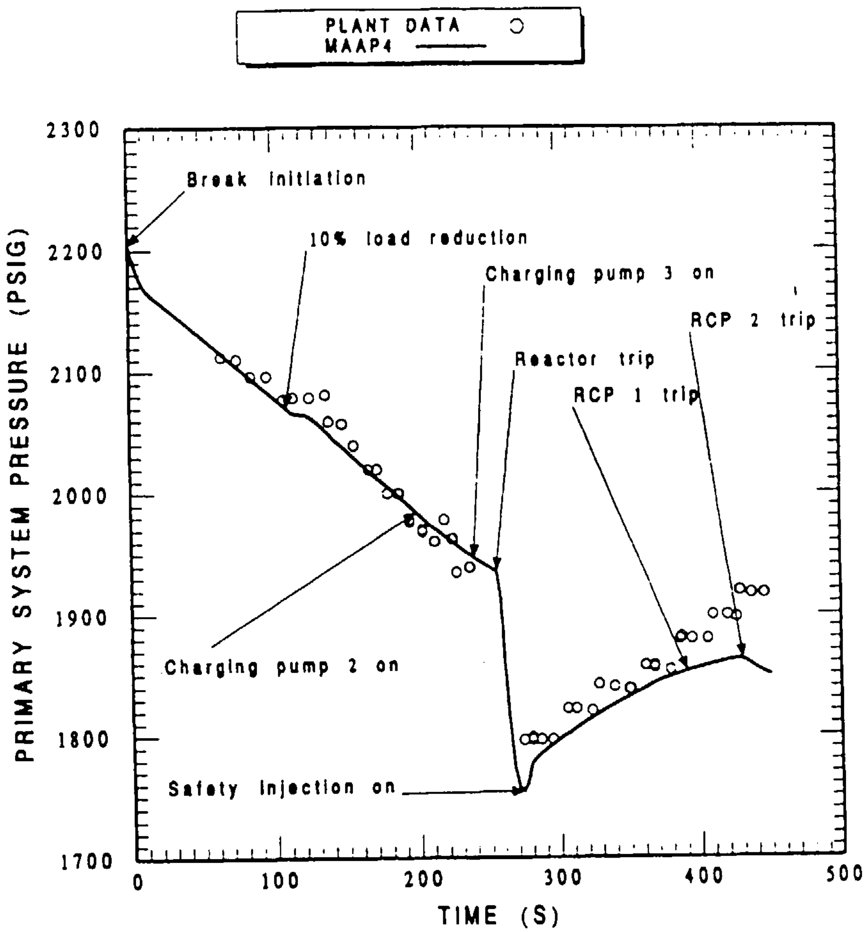
Accident Definition	Comment
Double Ended Guillotine Cold Leg Break	Since the accident causes the flow to reverse initially, do not use MAAP until reflood is complete. Use DBA codes during this interval. After reflood MAAP will track the accident sequences.
Double Ended Hot Leg Rupture	Flow in the core does not reverse and MAAP can be used.
Large Break Cold Leg LOCA but Less Than a DECL Break (Leak-Before-Break)	If the flow within the core is not reversed, MAAP will calculate the appropriate heatup and potential shutdown of the nuclear reaction; benchmark with LOFT FP-2 demonstrates the code capabilities.
Medium LOCA	Since the flow does not reverse within the core, MAAP can be used for such success criteria.
Small Break LOCA	MAAP treats the behavior under small break LOCAs quite well. This is evidenced by the successful benchmark with the TMI-2 accident behavior. Also, the MAAP model has been successfully benchmarked with the Prairie Island steam generator tube rupture.
Loss of Heat Sink Accidents	MAAP represents the behavior of the core under these conditions quite well. This is best evidenced by the benchmarks with the Davis-Besse loss-of-feedwater event (PWR) and the Oyster Creek loss-of-feedwater event (BWR).
Main Steam Line Break	This is a rare initiating event for severe core damage, but the MAAP model has been benchmarked with the Westinghouse MB-2 experiments for steam generator response to loss-of-feedwater, MSLB, etc.

THE USE OF MAAP TO REPRESENT LEVEL 1 SUCCESS CRITERIA FOR THE RCS

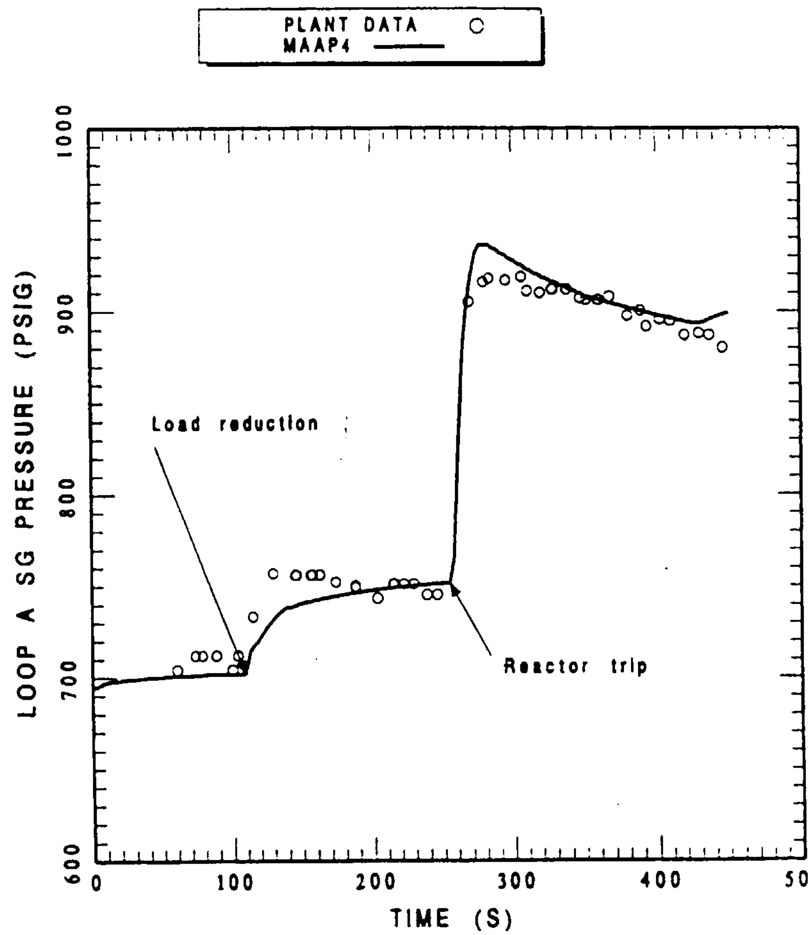
- The capabilities for representing the RCS are best defined by the system benchmarks that have been performed with respect to plant experiment and analyses. Some examples are:
  - benchmark with the LOFT FP-2 tests (LLOCA),
  - benchmark with the TMI-2 accident behavior (SLOCA),
  - benchmark with the Prairie Island SGTR event (SSLOCA),
  - benchmark with the Davis-Besse loss-of-feedwater event,
  - benchmark with the Crystal River stuck open PORV event (SLOCA), and
  - comparison with the NOTRUMP mass and energy releases for D.C. Cook (MLOCA and SLOCA).
- Comparisons with the above experience and analyses indicate that MAAP4 correctly represents the accident sequence specific capabilities to maintain core cooling.

Example of Level I Benchmark
Prairie Island SGTR

Reactor Coolant System Pressure

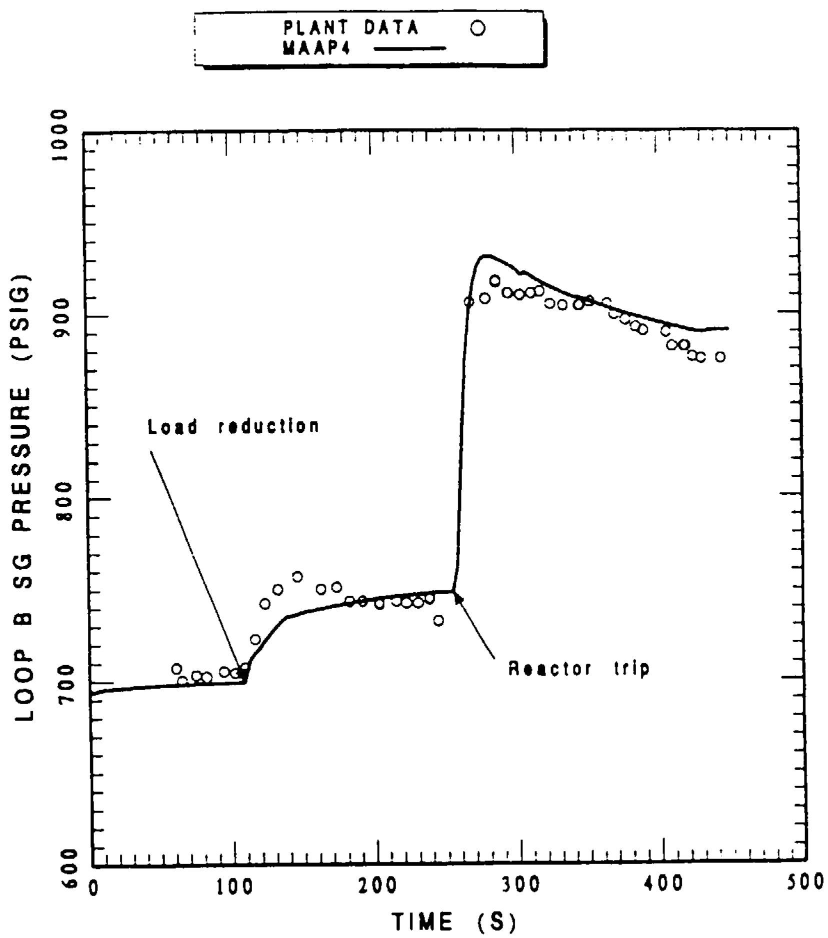


Loop A Steam Generator Pressure

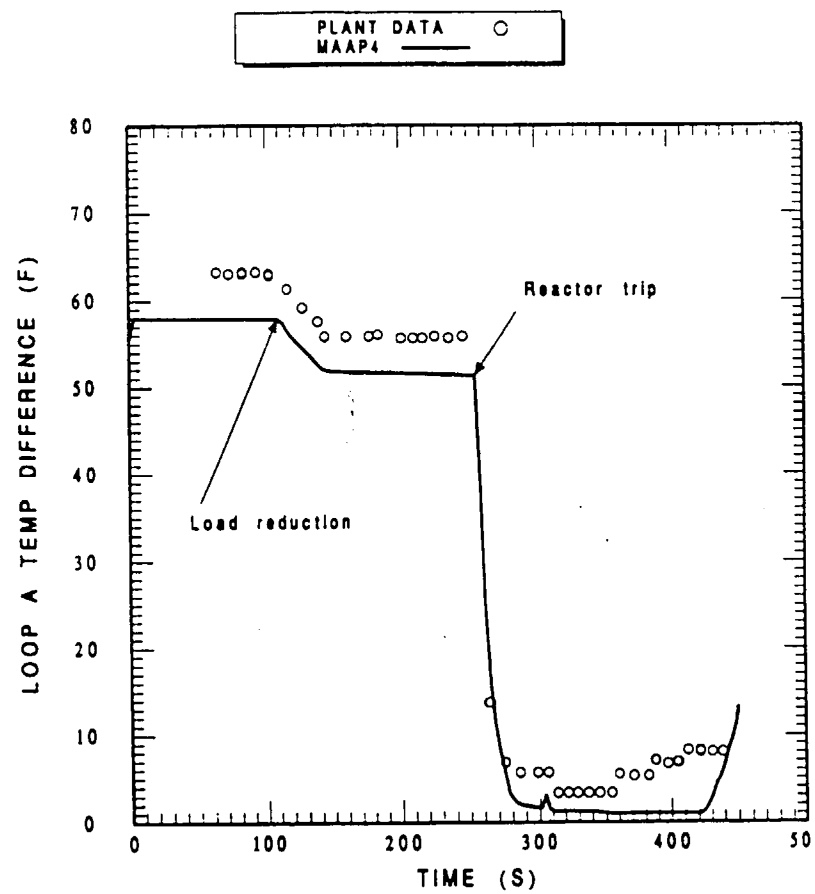


Prairie Island SGTR

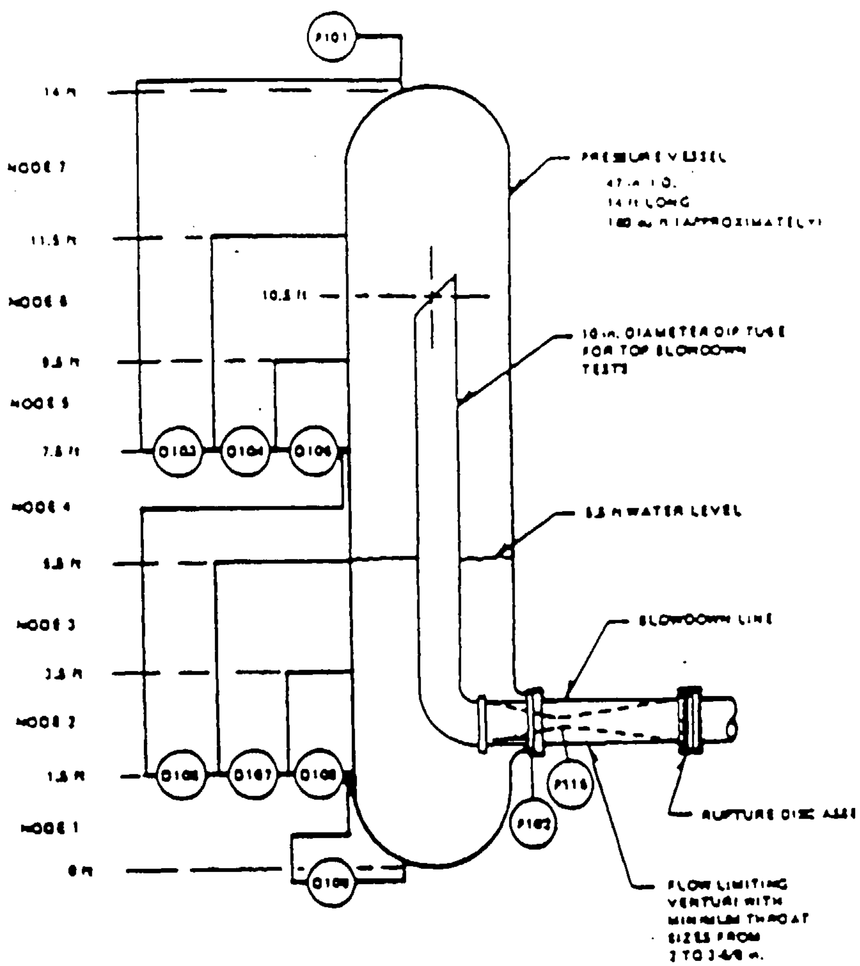
Loop B Steam Generator Pressure

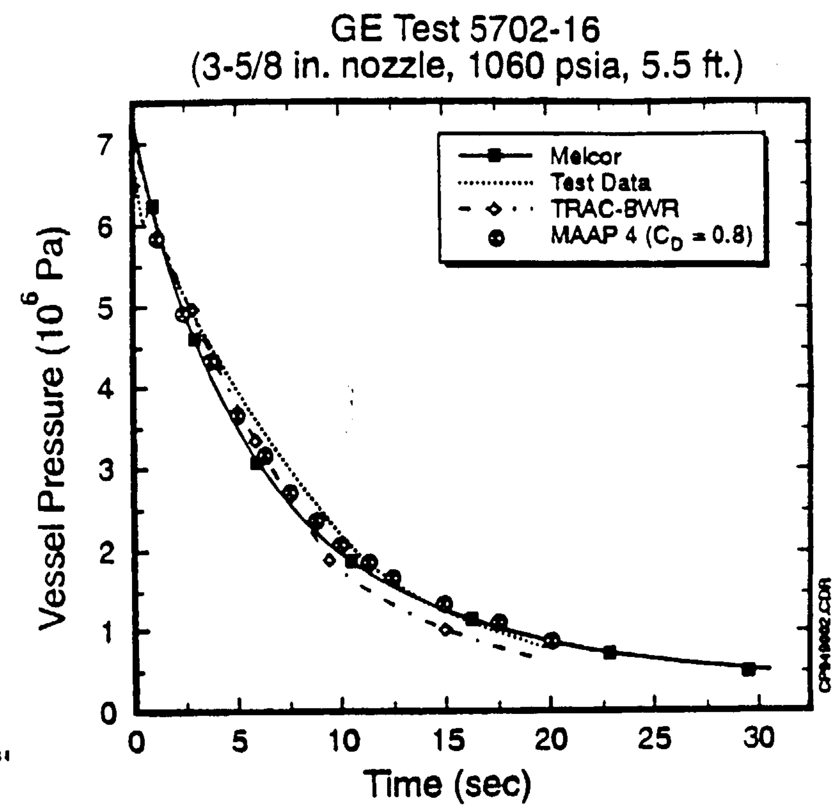


Loop A Temperature Difference



Example of Level I RCS Separate Effects Model Benchmark
Schematic of GE Large Blowdown Vessel Test Facility



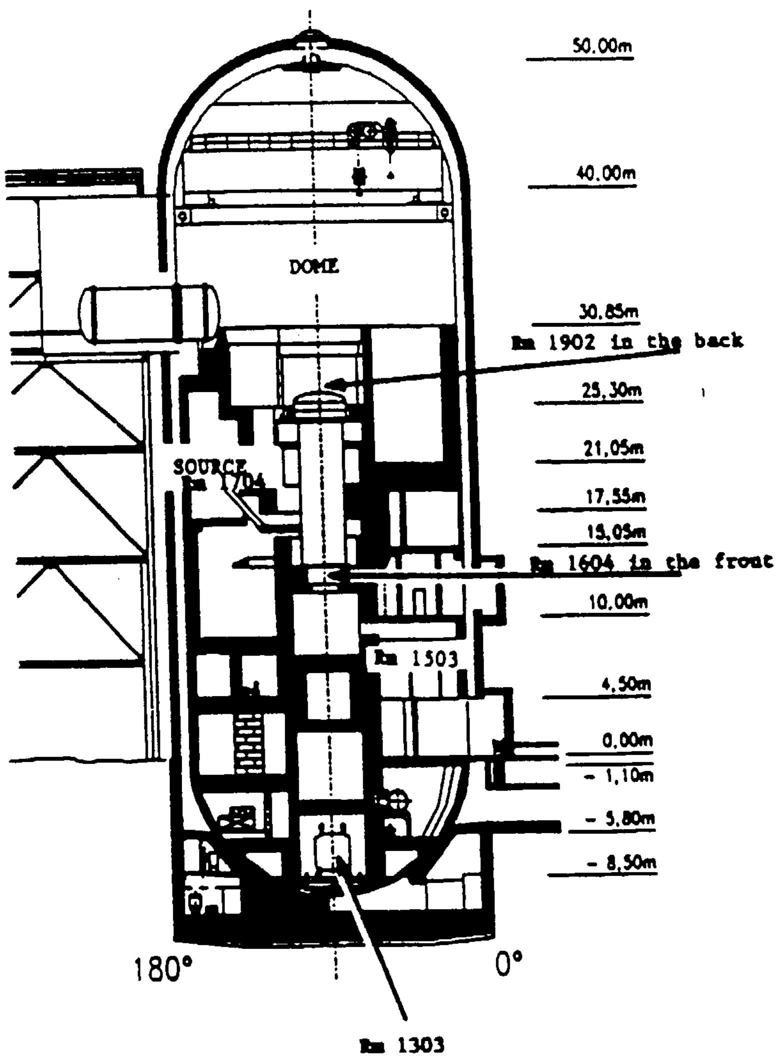


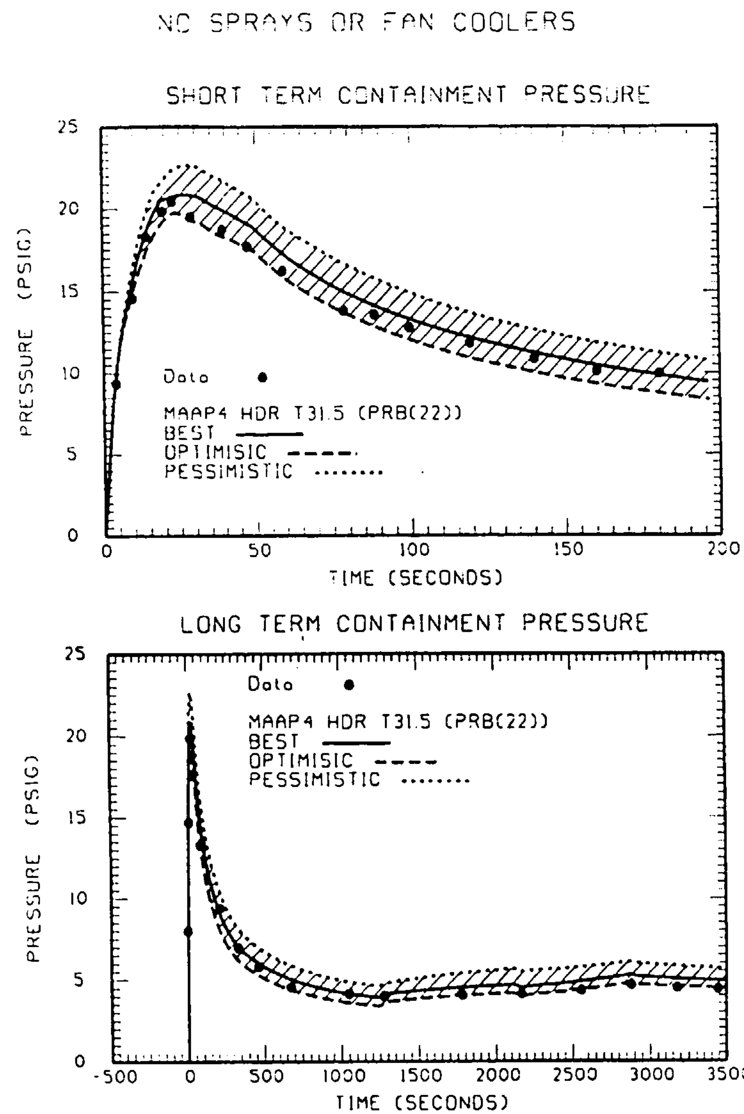
USE OF MAAP TO REPRESENT LEVEL 1 SUCCESS CRITERIA FOR THE CONTAINMENT

The most appropriate way to develop success criteria for the containment behavior is to compare the MAAP Generalized Containment Model (GCM) with the spectrum of large scale containment experiments. These include:

- HDR
  - small break LOCA tests (ISP #23),
  - large break LOCA tests (IPS #29),
  - main steam line break tests (ISP #16).
- CVTR experiments simulating main steam line break conditions.
- Westinghouse ice condenser experiments.
- PNL ice condenser experiments.
- EPRI sponsored CSTF experiments.
- Sargent and Lundy blowdown experiments.
- NUPEC compartmentalized containment experiments with hydrogen release (ISP #35).

HDR Facility With Key Locations for T31.5

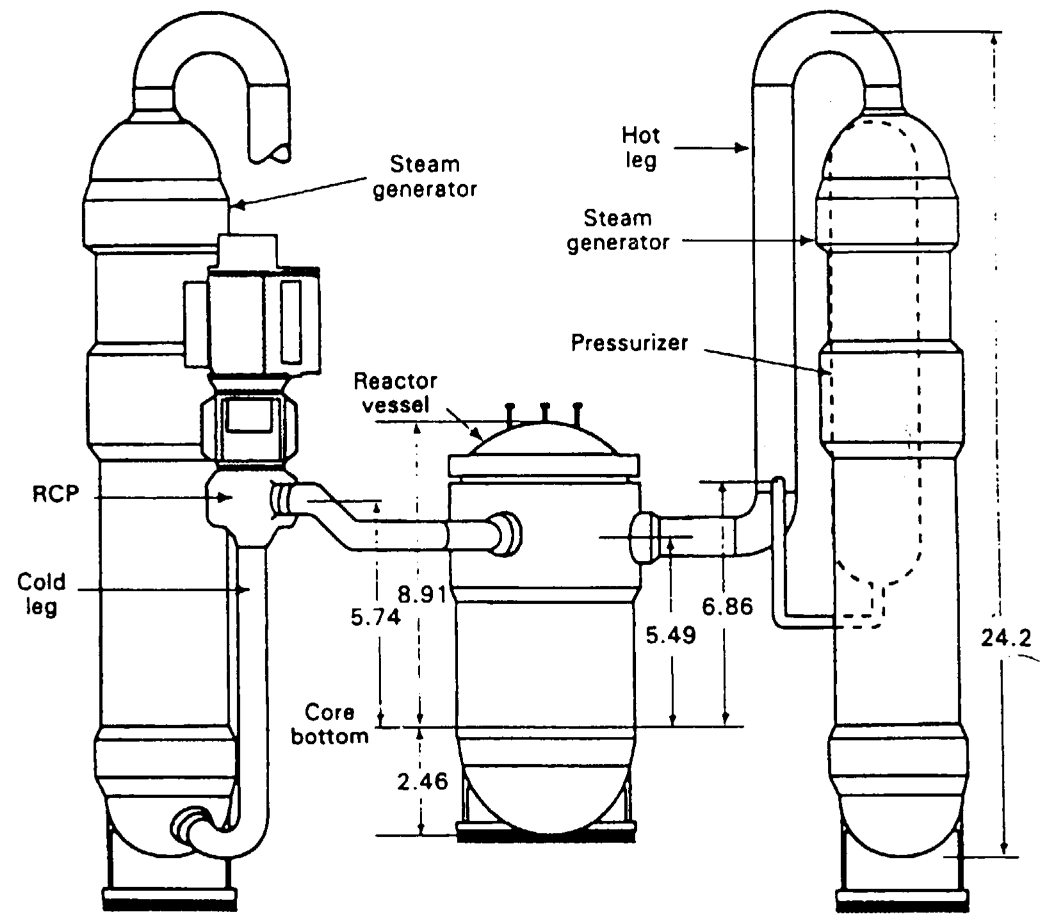




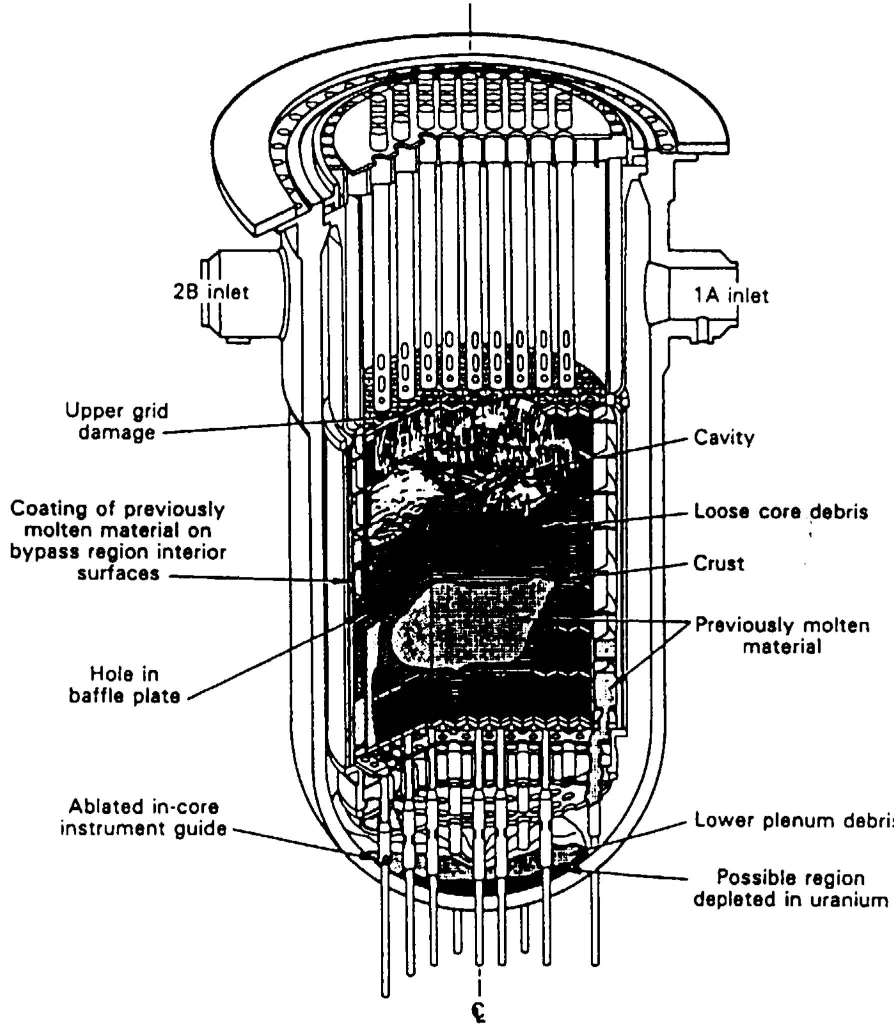
USE OF MAAP TO REPRESENT LEVEL 2 SUCCESS CRITERIA

- Once core damage has been initiated, there are a spectrum of phenomena which are important to the accident progression and accident management considerations. These include:
  - core geometry changes,
  - cladding oxidation and hydrogen formation,
  - natural circulation within the RCS,
  - challenges to the RCS pressure boundary,
  - formation of a molten debris pool,
  - relocation of core material within the RPV,
  - quenching of molten debris due to this relocation,
  - potential for RPV failure,
  - dynamic interactions following vessel failure including steam explosions,
  - debris transport within the containment,
  - the ultimate coolability of debris in containment,
  - hydrogen mixing in containment,
  - the potential for hydrogen stratification in the containment,
  - hydrogen combustion,
  - natural circulation flows within the containment, and
  - fission product release, transport and deposition within the RCS and containment.
- MAAP4 has models for all of these physical processes.

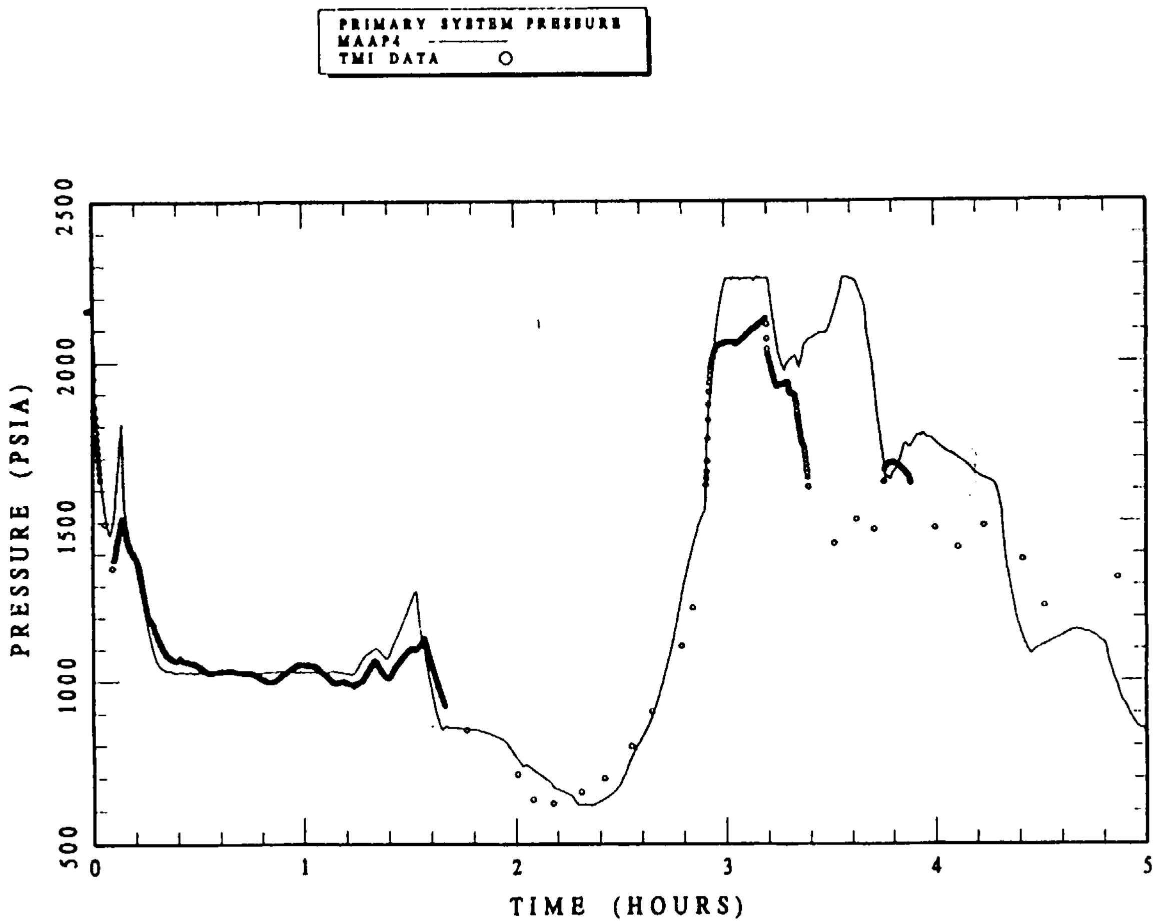
Side view of TMI-2 primary system components (measurements in meters).



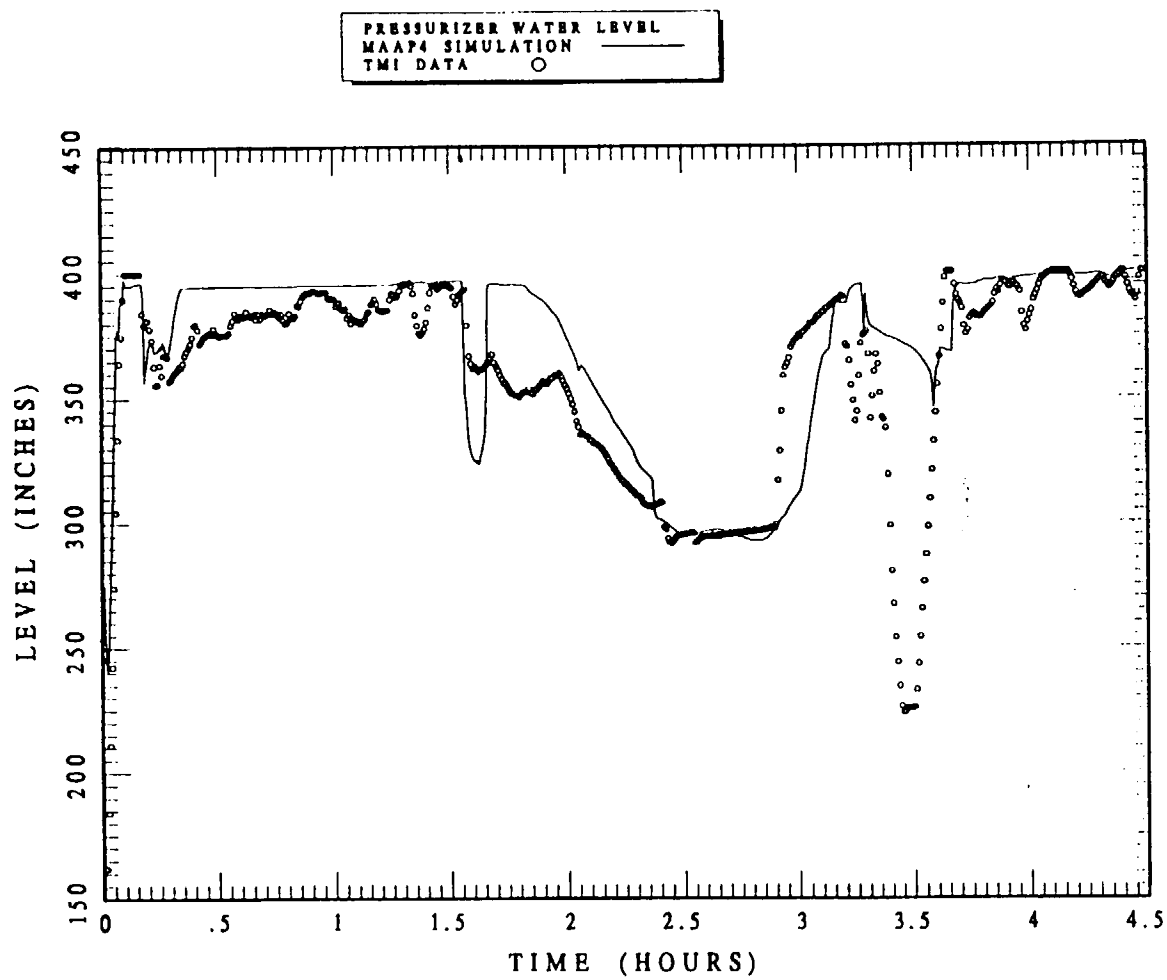
TMI-2 core end-state configuration.



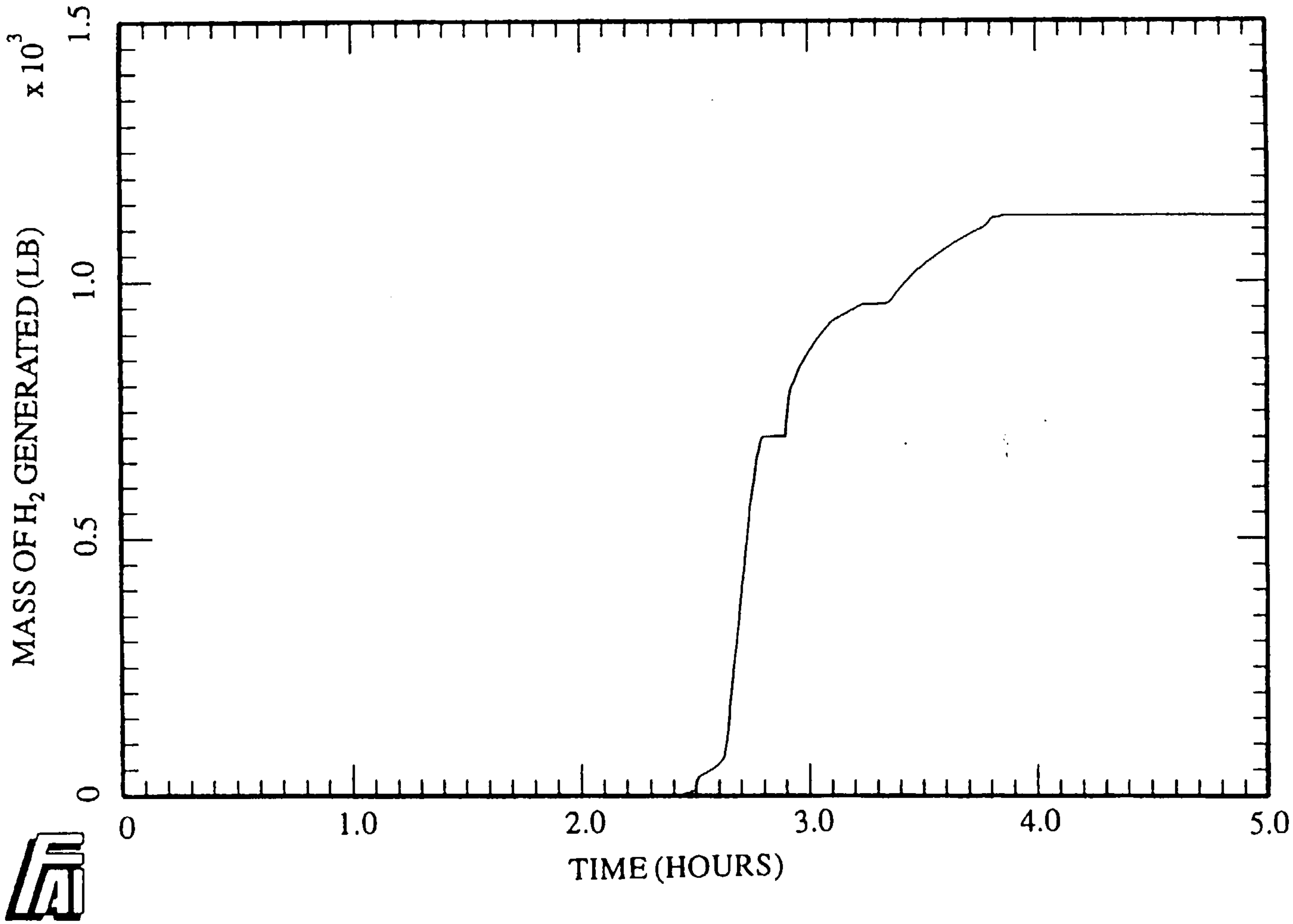
Calculated and measured primary system pressure during the first five hours of the accident.



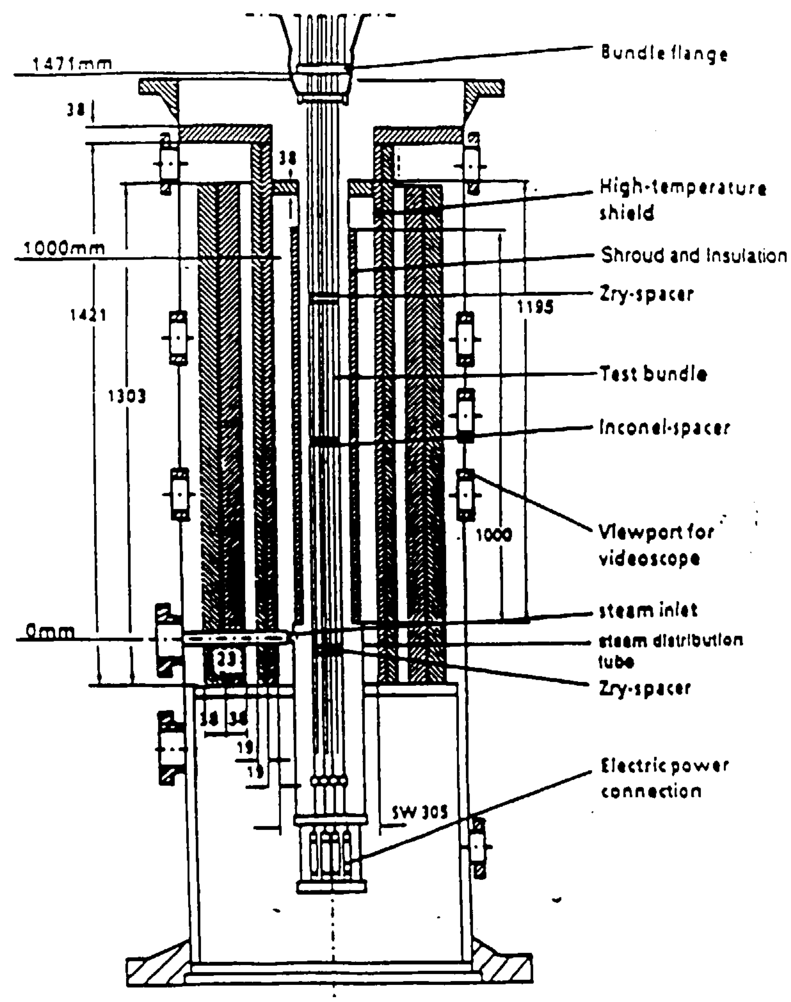
Comparison of the calculated and measured pressurizer water level.

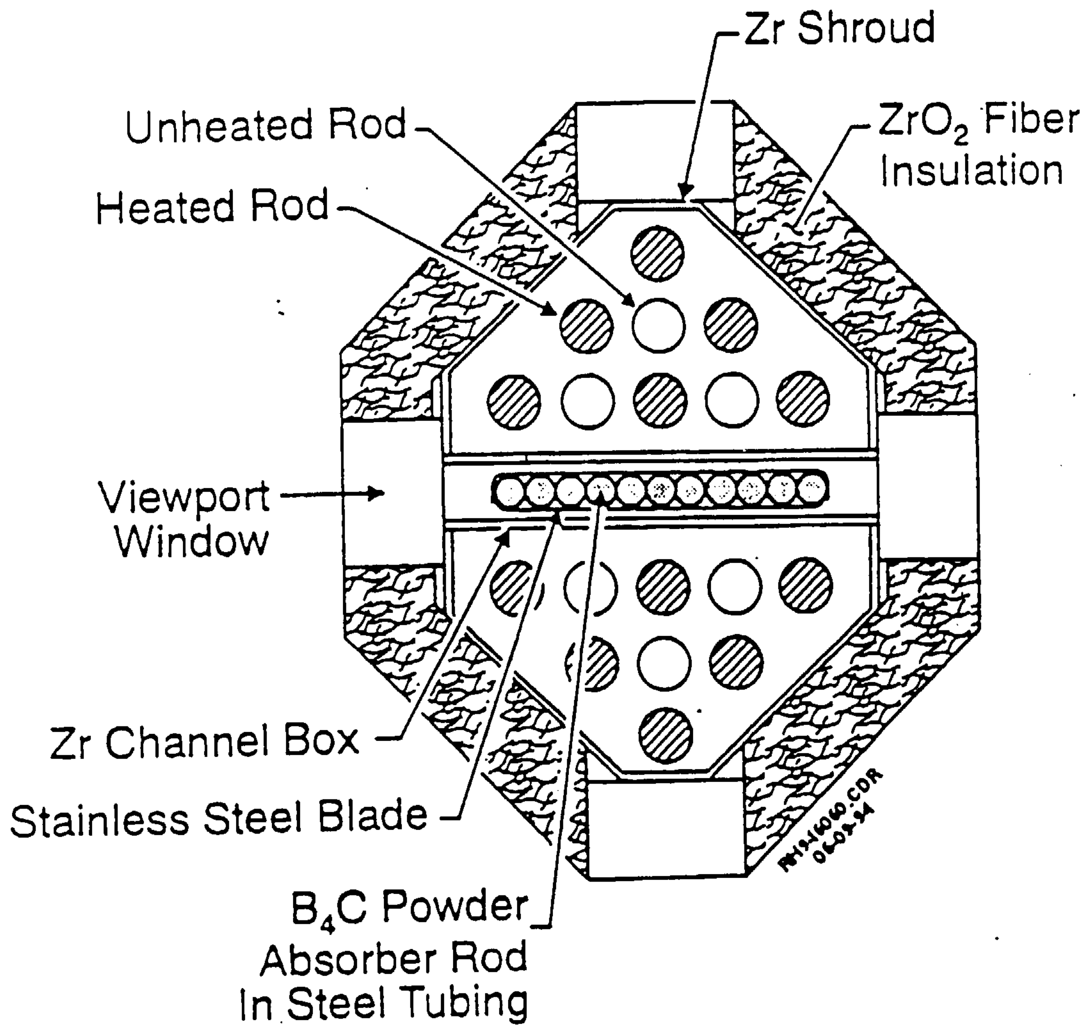


Calculated hydrogen generation history.

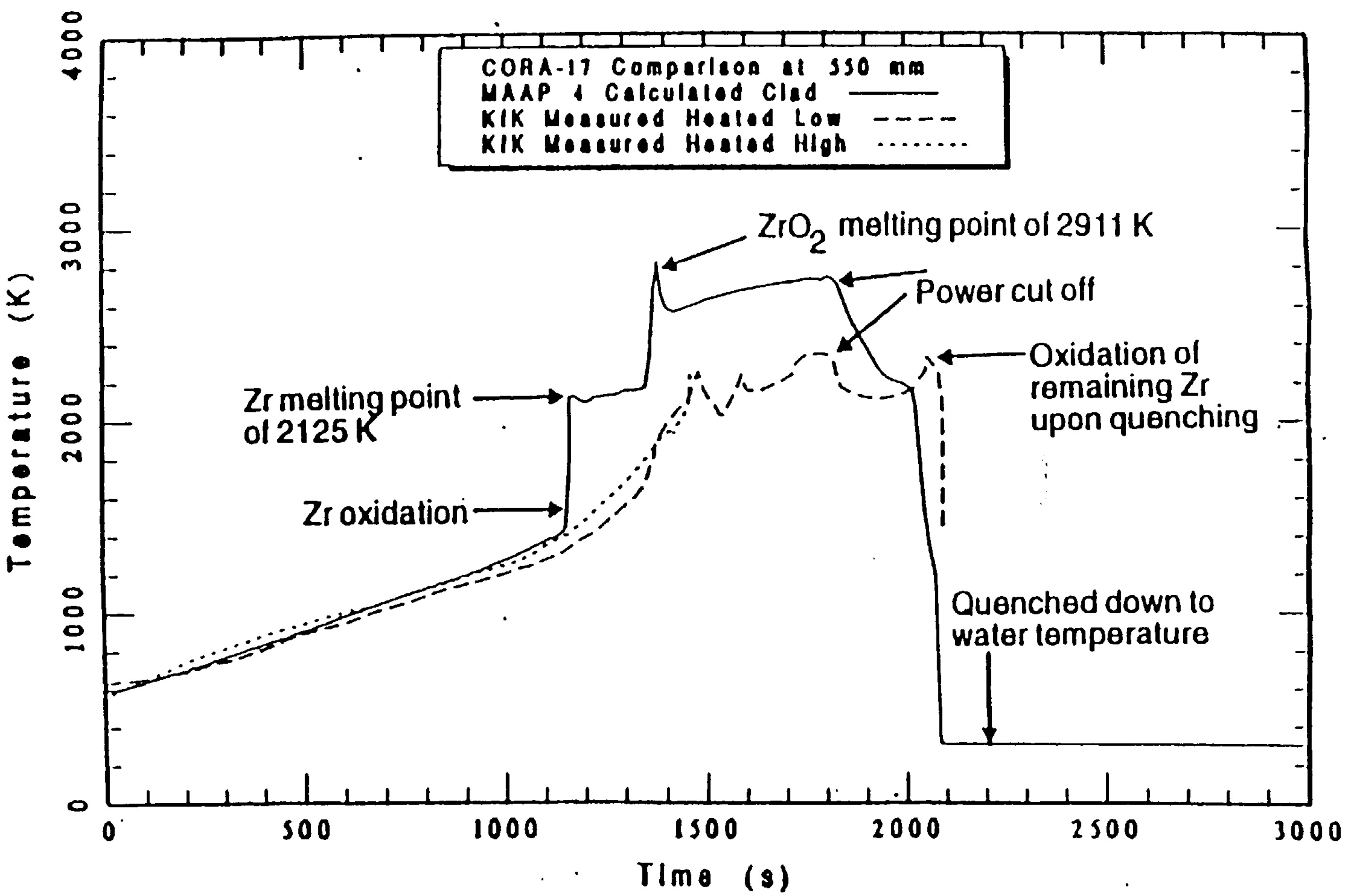


CORA Bundle Arrangement

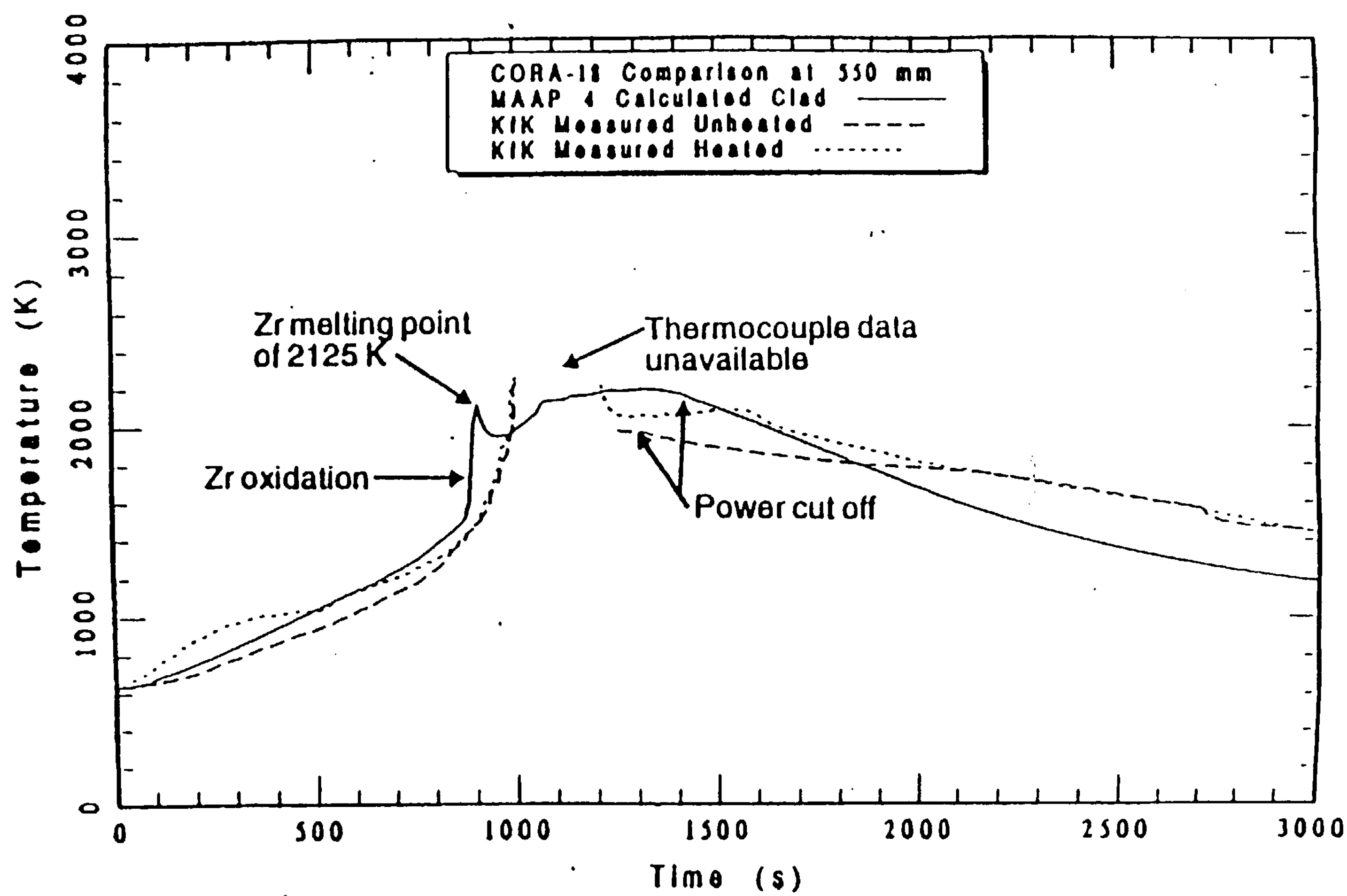



Zr Shroud
Unheated Rod
ZrO_2 Fiber Insulation
Heated Rod
Viewport Window
Zr Channel Box
Stainless Steel Blade
B_4C Powder Absorber Rod In Steel Tubing

CORA-17 Heated Rod Temperature History at Elevation = 550 mm



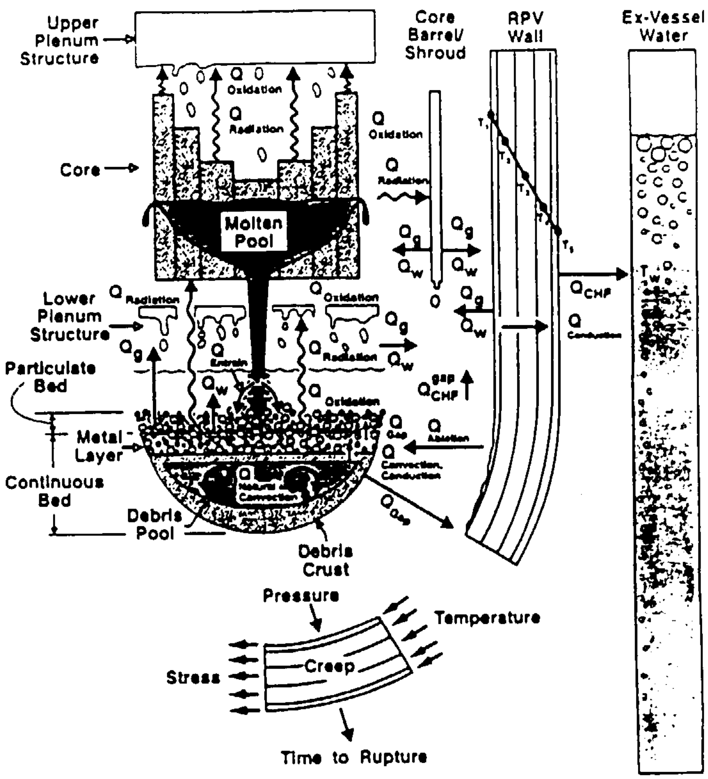
CORA-18 Temperature History at Elevation = 550 mm

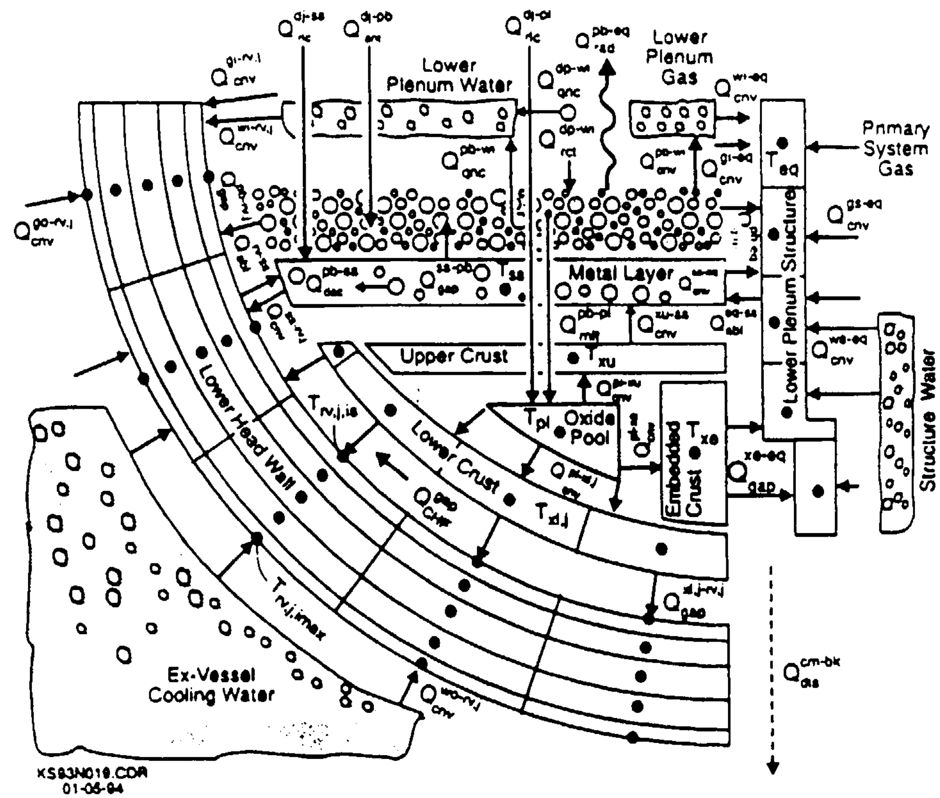


HYDROGEN GENERATION OF BWR-CORA BENCHMARKS

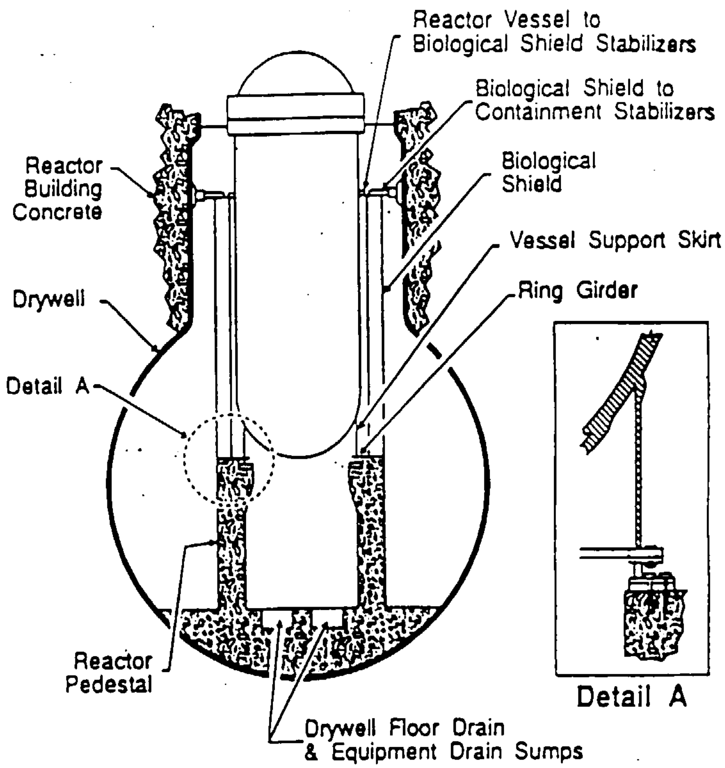
	MAAP4 Prediction (g)	CORA Data (g)
CORA-16	107	167
CORA-17	110	150
CORA-18	112	106

LOWER PLENUM ENERGY TRANSFER DIAGRAM

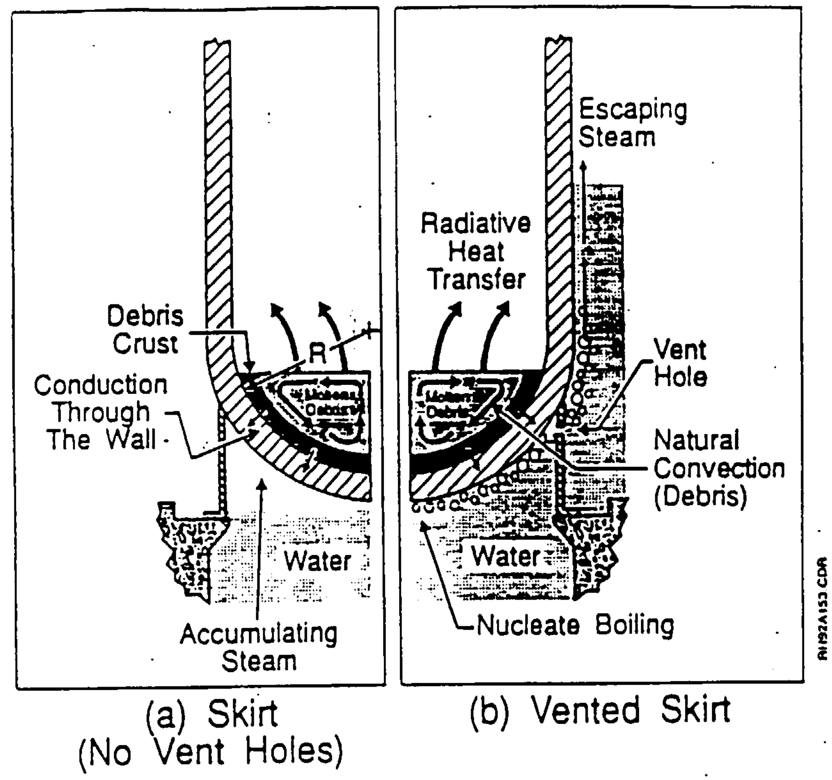




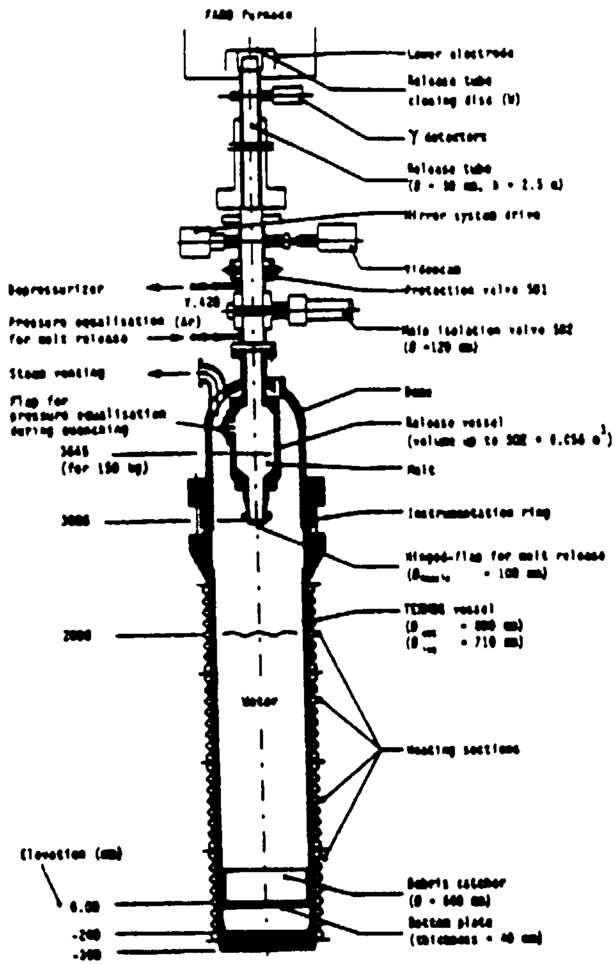
Reactor Vessel Supports (BWR) (Skirt)



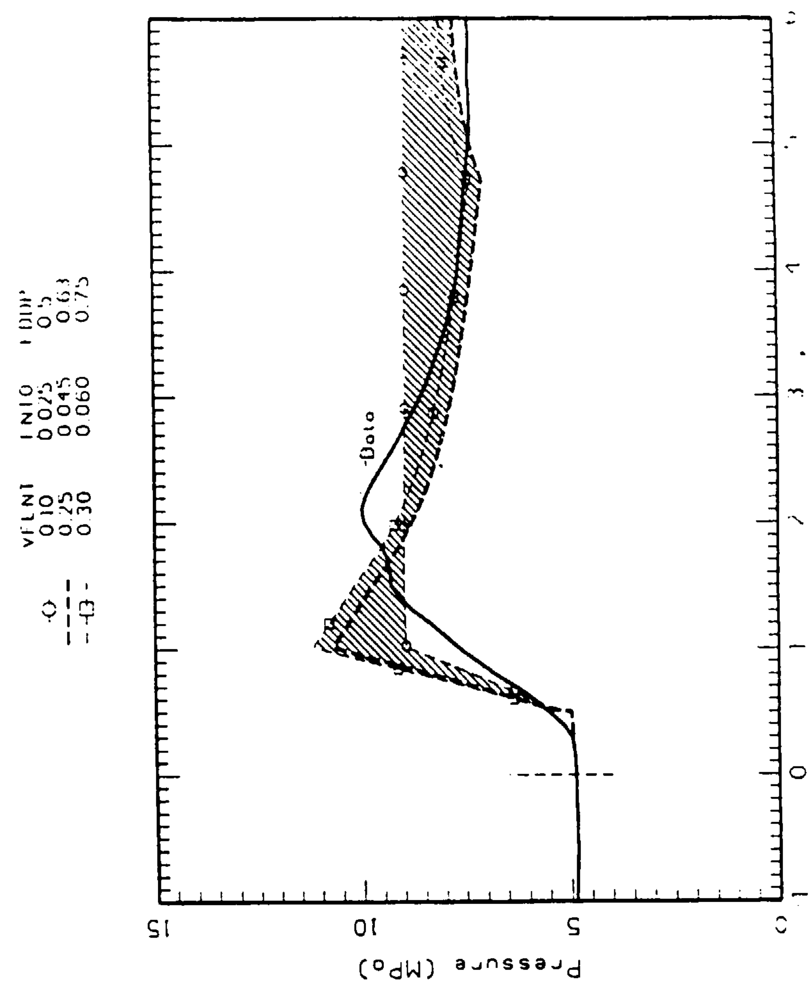
Possible Heat Transfer Paths for RPV Lower Plenum



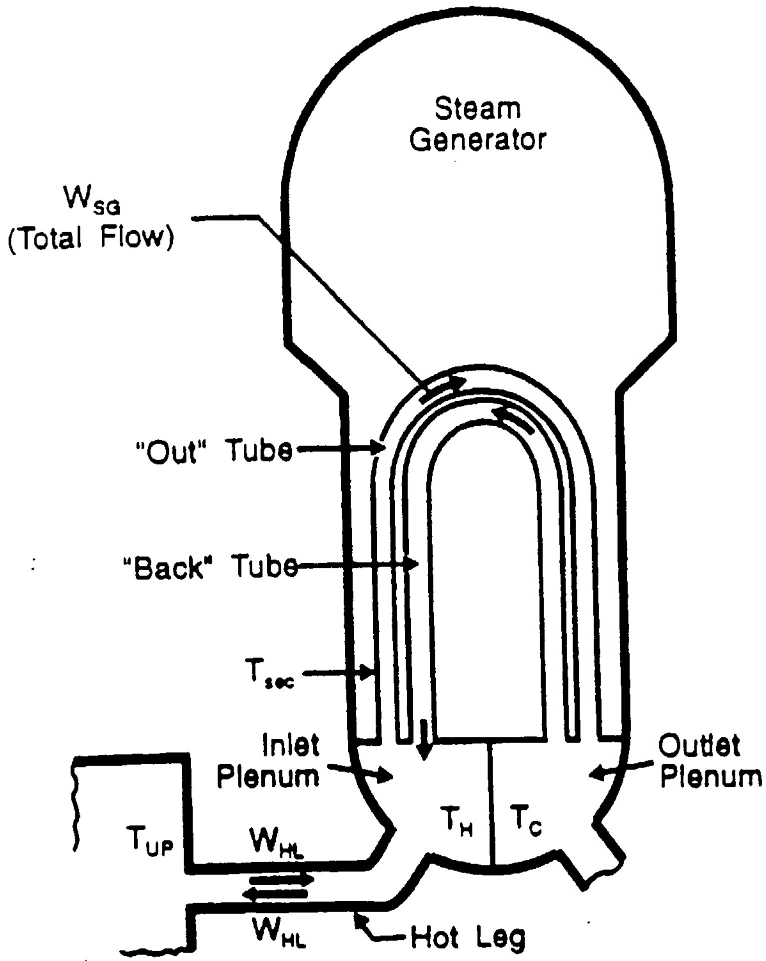
FARO Test Arrangement



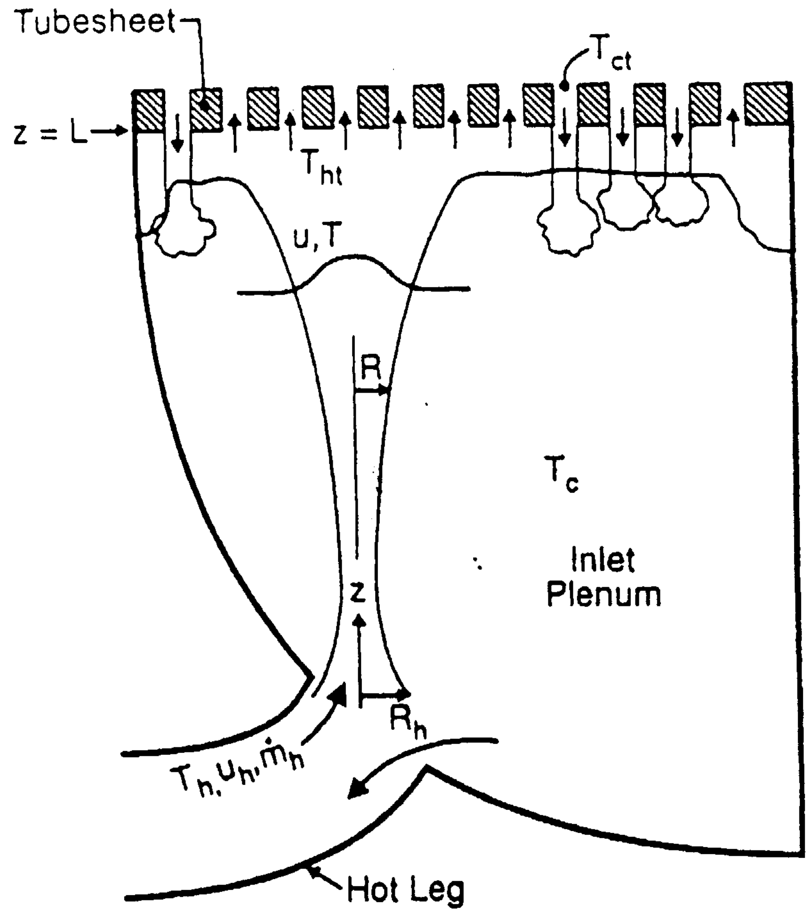
Comparison of the MAAP Calculated Pressure Increase and the Measured FARO Vessel Pressure for Test L-11



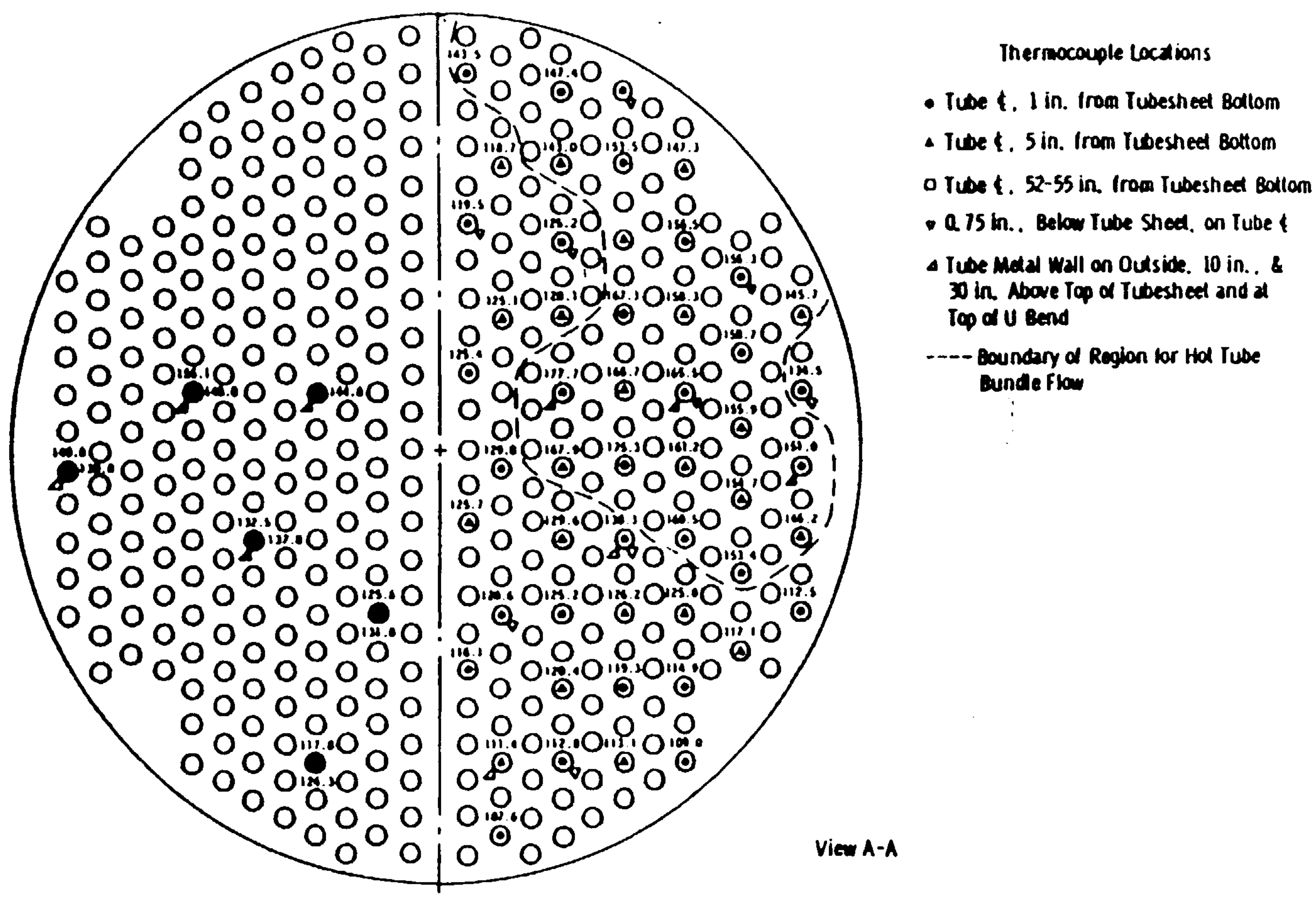
Hot Leg and Steam Generator Natural Circulation Flows



Schematic of the Inlet Plenum Mixing Model



Temperatures (°C) of SF_6 in Steam Generator Tubes Shown in Plan View; Transient Test SG-T4; Data at 3362 s (taken from Stewart et al., 1993)



CONCLUSIONS

- MAAP4 represents the core, the RCS and the containment response during plant upset and accident conditions for both BWRs and PWRs.
- MAAP4 supports utility assessments for both Level 1 and Level 2 PRA success criteria.
- MAAP4 represents the system responses to recovery actions following core damage event.
- MAAP4 has a continually evolving dynamic benchmarking plan to demonstrate the code (or individual model) capabilities. These also provide demonstrations for the users on how to use and interpret the code results.

Comparison of MAAP4 and SCDAP/RELAP5 Results

Marc Kenton

Creare Inc.

Presentation to NRC Staff

December, 2000

Work Performed For EPRI

Purpose

- Compare the two codes' predictions of RCS behavior in high pressure severe accidents
- Focus on results used to assess thermally-induced SG tube rupture when cold leg loop seals are full
- This application is a good first start for comparing the two codes because:
  - TISGTR evaluations are an important use of the two codes
  - Expect results to be relatively insensitive to complicated details of degraded core modeling until very late in sequence
- Also present some results on loop seal clearing

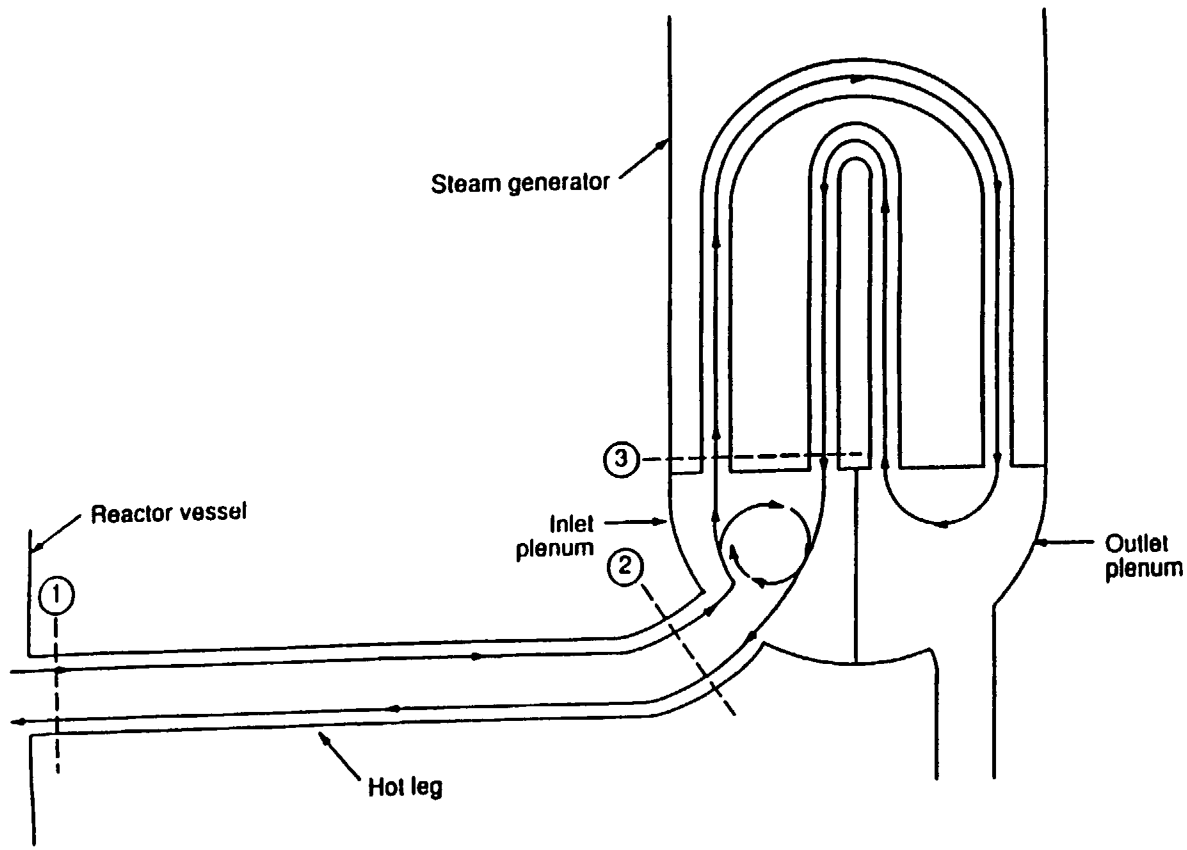
Specific Issues to Resolve

- Why does MAAP generally predict hot leg fails first when S/R5 predicts surge line fails first?
- How do calculated tube temperatures compare?
- Why does the S/R5-calculated core water level continue to drop rapidly after the core is fully uncovered, whereas in MAAP the water level drops slowly once the fuel is uncovered?

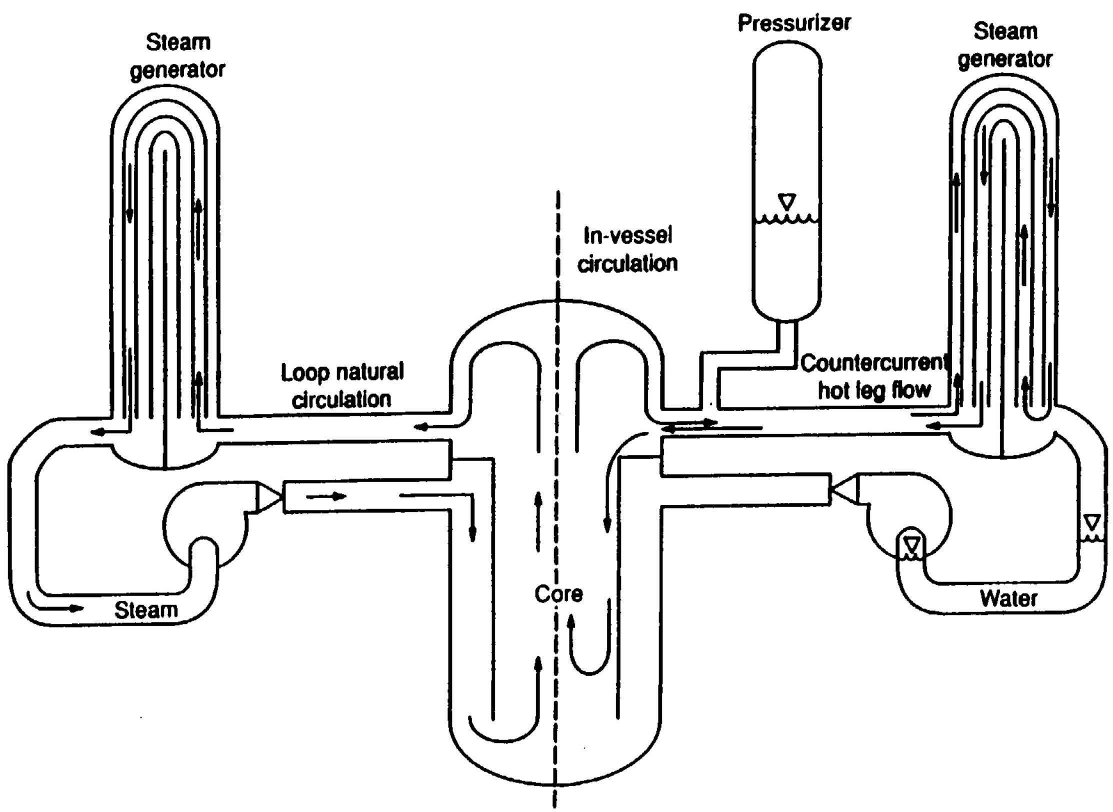
Why is Core Water Level Important?

- With full cold leg loop seals, counter-current natural circulation develops in hot legs and SG
- In this case, SG inlet plenum mixing greatly reduces tube temperatures relative to hot leg
- If a loop seal <u>and</u> the core barrel both clear, vigorous, full loop natural circulation develop
- This eliminates inlet plenum mixing phenomena, so tubes see about same temperature gas as hot leg

Flow Patterns with Intact Loop Seals



Full Loop Flow Pattern (loop on left)



Organization of Presentation

- First present detailed comparison of MAAP and S/R5 results for a sequence with full loop seals and counter-current flow
- Then present observations on differences in the two codes' assessments of the likelihood of having sequences with cleared loop seals and full loop flow

Method Used to Compare Codes

- Selected high/dry/high Surry sequence documented in NUREG/CR-6285 (loop seals intact)
- This calculation selected because INEEL provided hot leg gas as well as pipe temperatures
- First compared these results to a MAAP “base case” whose assumptions mimic S/R5 calculation
- Then performed sensitivity calculations to evaluate importance of each individual altered assumption
- Utilized an available 3-loop Westinghouse plant MAAP model, modified slightly to match Surry

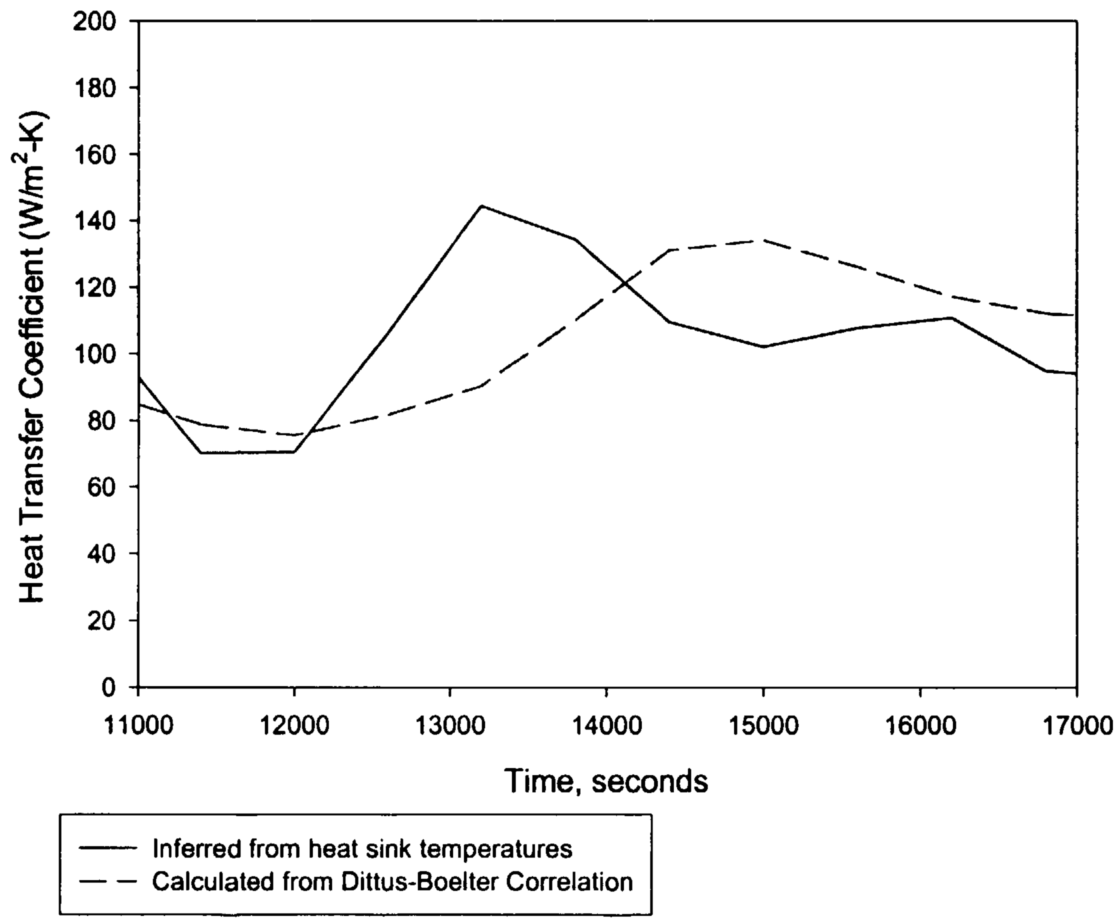
“Base Case” Calculation Assumptions

- Eliminated thermal radiation to reactor coolant system components (not modeled in RELAP)
- Assumed 35 percent of tubes carry flow from inlet to outlet (matches assumptions used in pre-NUREG 1570 calculations)
- Directed 1x black body radiation from bottom row of active core or decay heating (whichever is less) to lower plenum water after active fuel uncovers
- Don’t allow water draining from pressurizer to cool surge line (mimics “split” surge line representation in S/R5 Surry model)

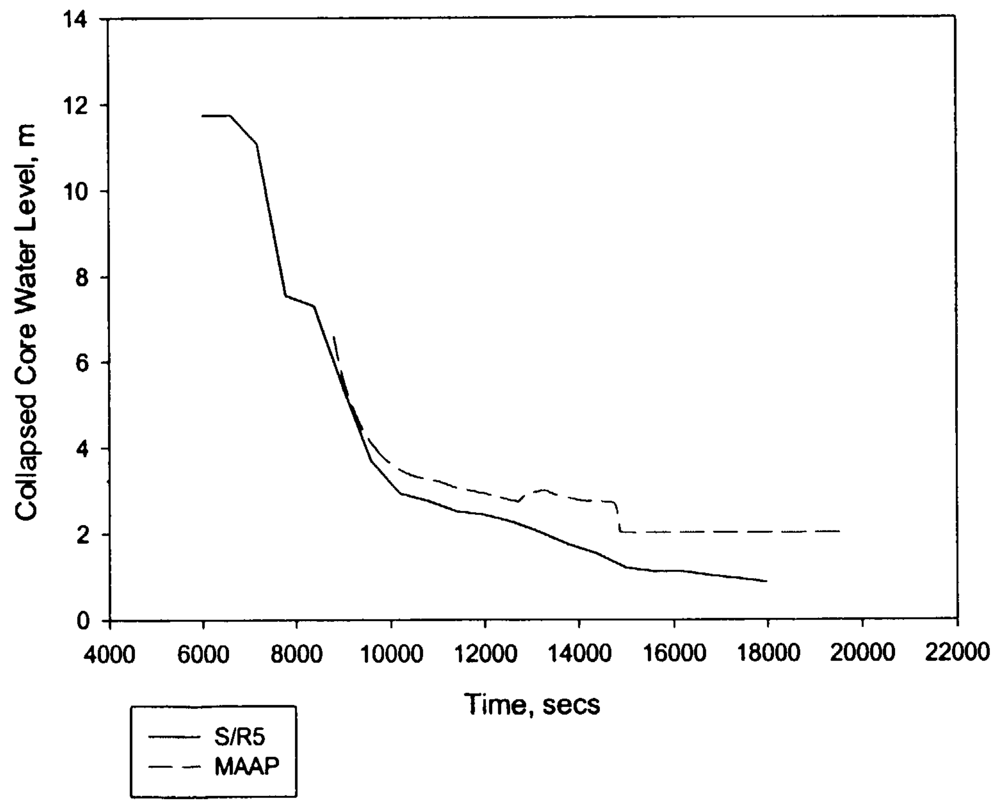
"Base Case" Assumptions (cont.)

- Roughly model heat transfer to upper head structures by doubling mass of upper plenum internals (natural convection to upper head from upper plenum modeled in S/R5, not MAAP)
- Adjusted discharge coefficient in MAAP hot leg counter current flow model to match S/R5 flow*
- Adjusted friction factor in MAAP to replicate target SG/HL recirculation ratio in S/R5 (~2)*
- *S/R5 model explicitly tuned to produce hot leg and SG flow rates obtained from 1/7-scale data

Thermal Radiation Not Modeled in RELAP



Collapsed Core Water Level



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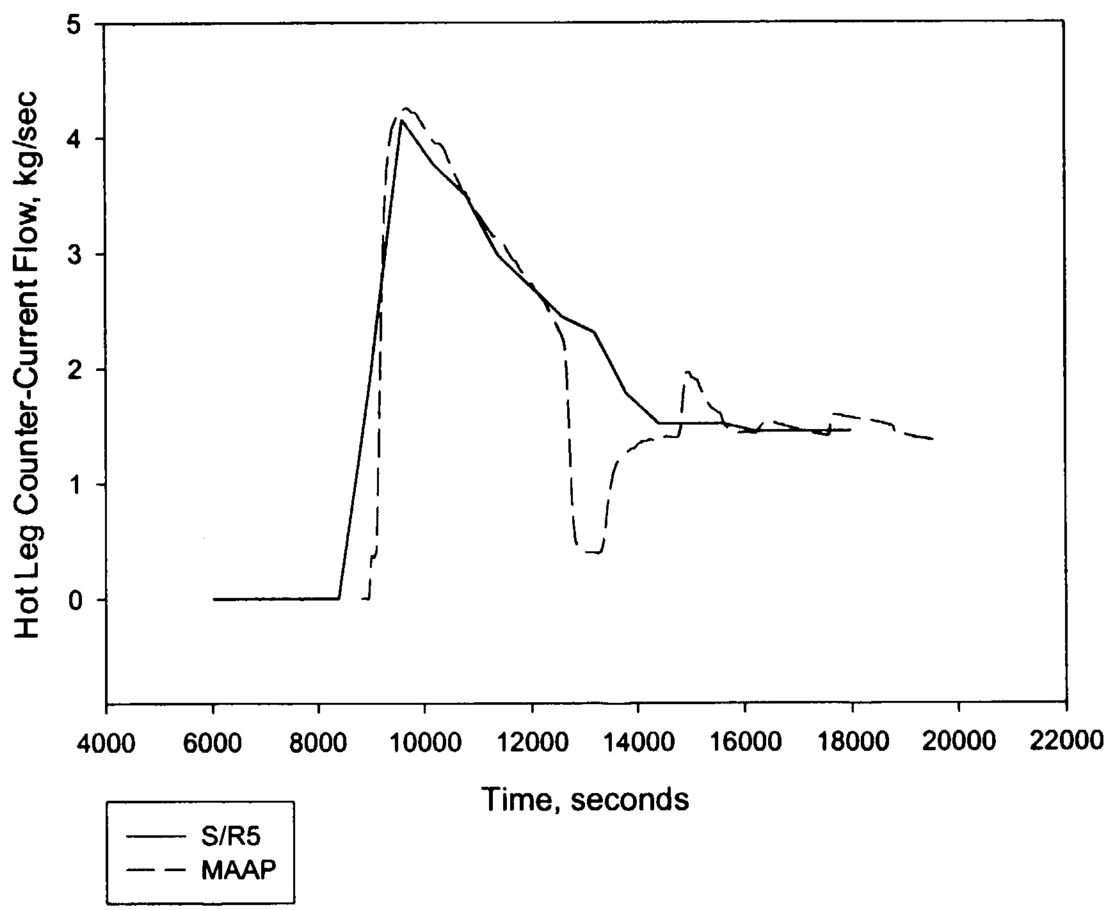
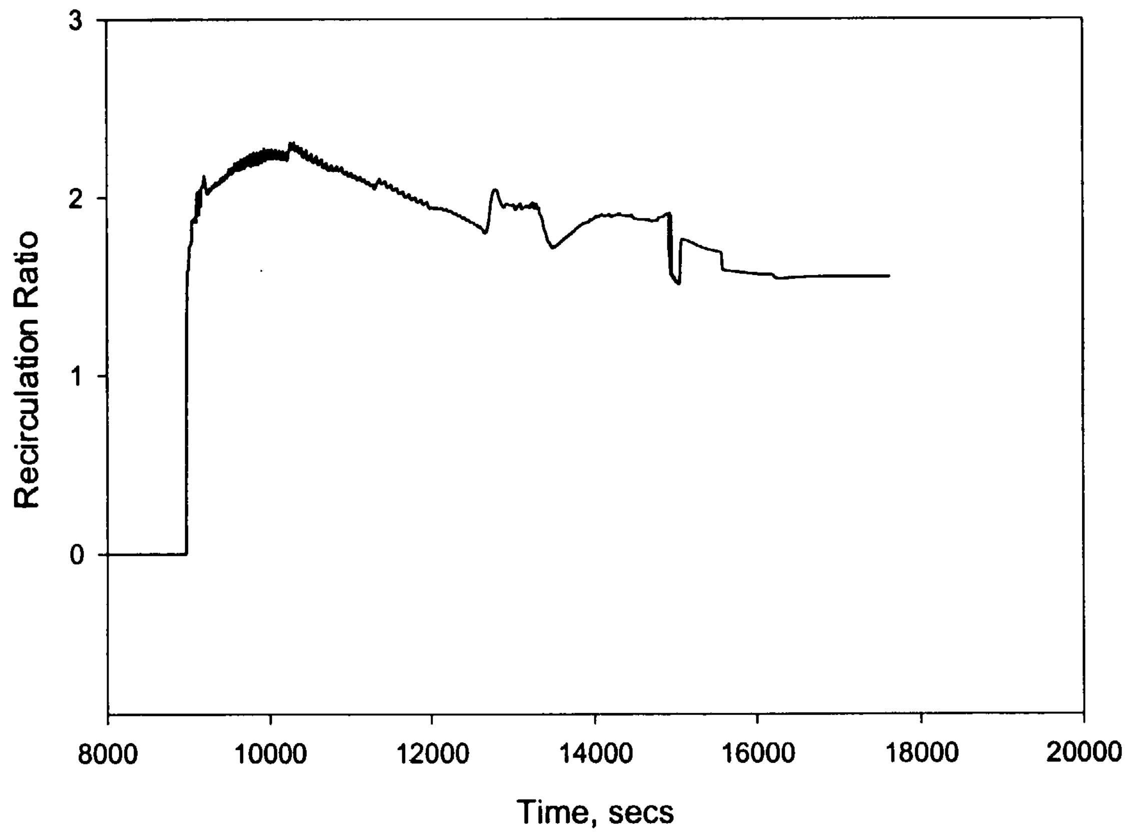
Hot Leg Counter-Current Flow



MAAP SG/HL Recirculation Ratio



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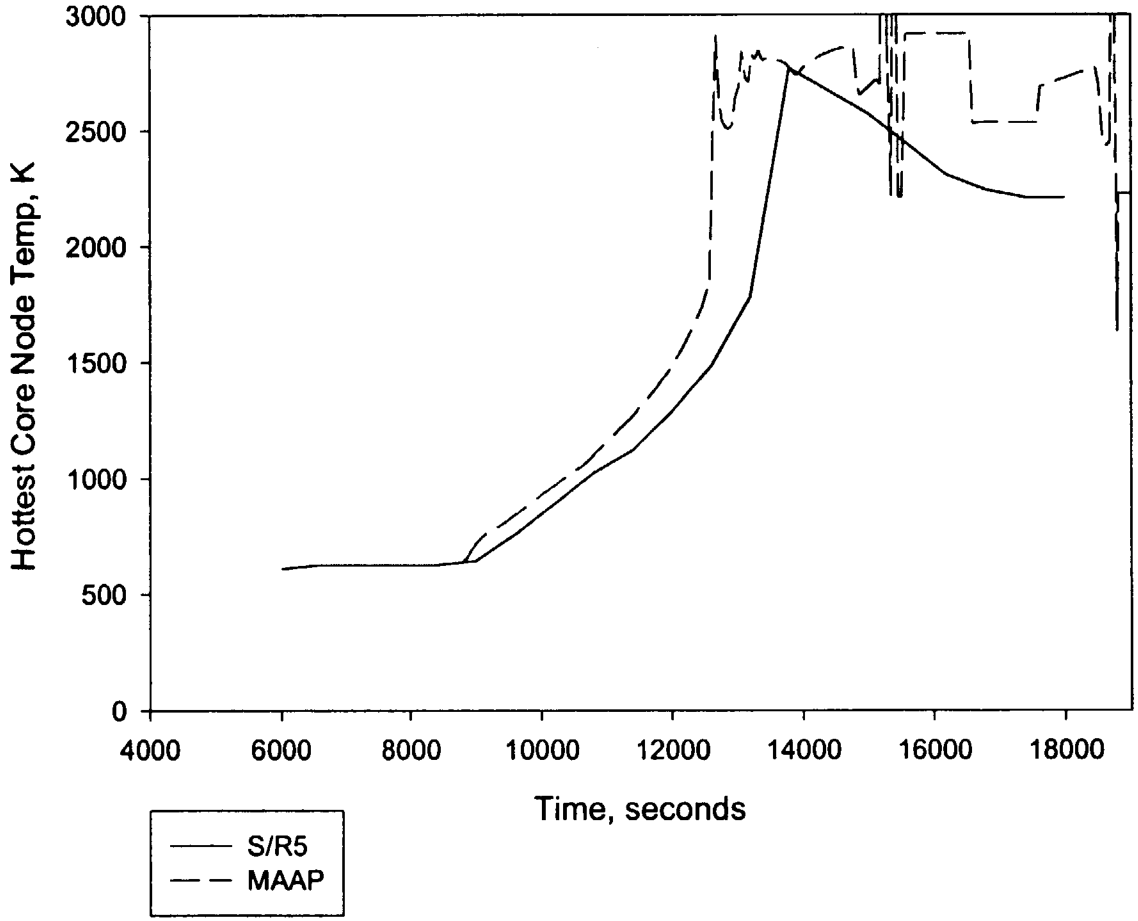
Hottest Core Node Temperature



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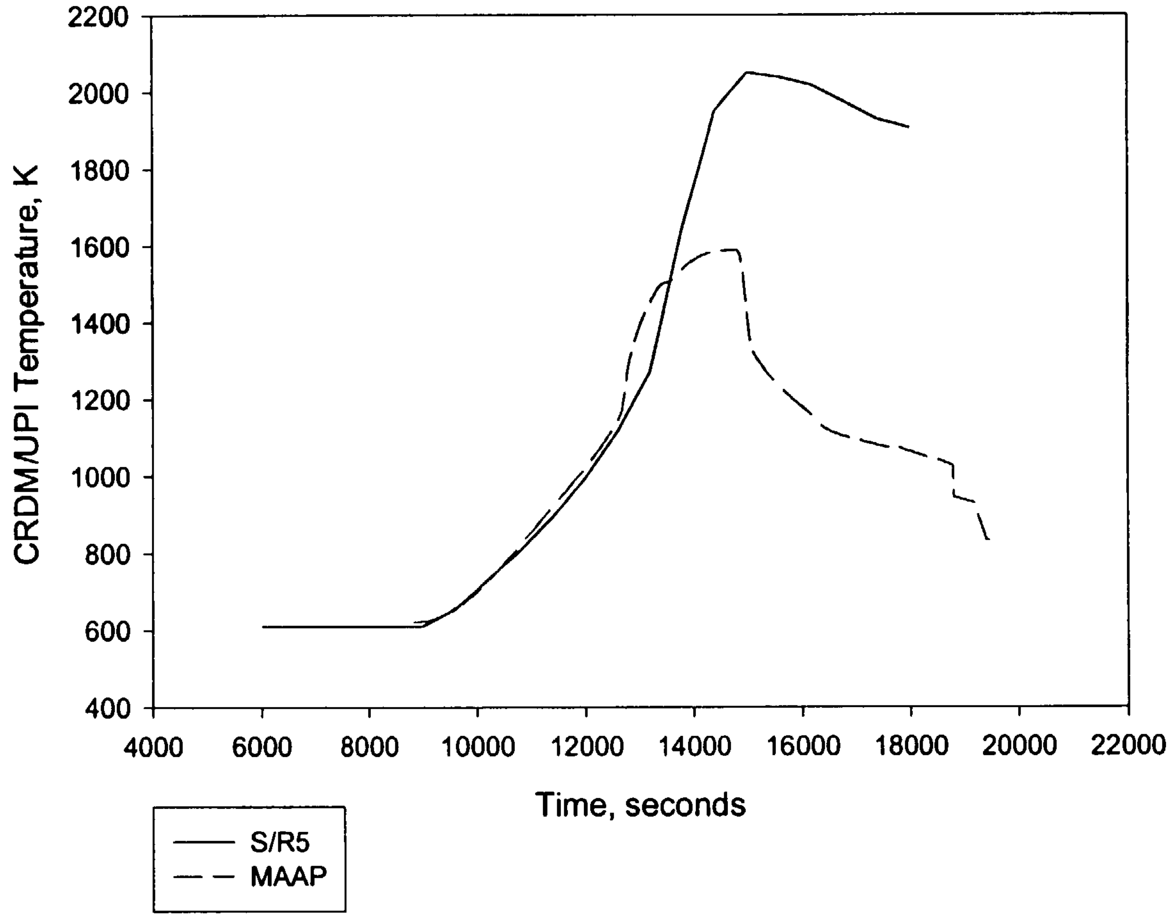
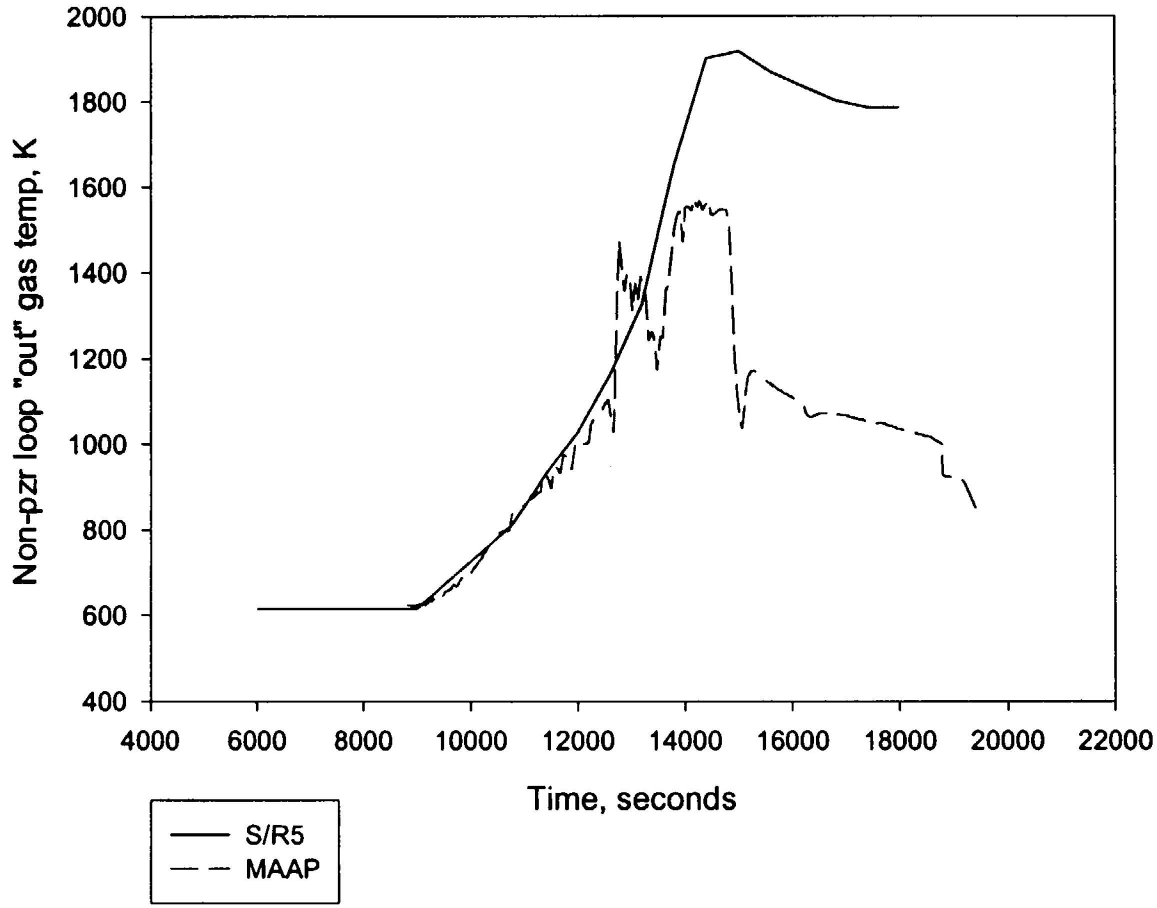
Upper Plenum Internals Temp



Codes' Temps Diverge >14000 Secs

- MAAP core-upper plenum natural circulation degraded due to core geometry, and high steaming rates, especially after core relocates at 14800 secs
- Subsequently, cooling from returning hot leg flow larger than heating from core, so UP temps drop
- S/R5 core relocation occurs after 18000 secs (end of run)
- However, these differences irrelevant for induced SGTR analysis, because surge line fails before 14000 secs in both S/R5 and MAAP "base case"

Hot Leg (upper half) Gas Temp



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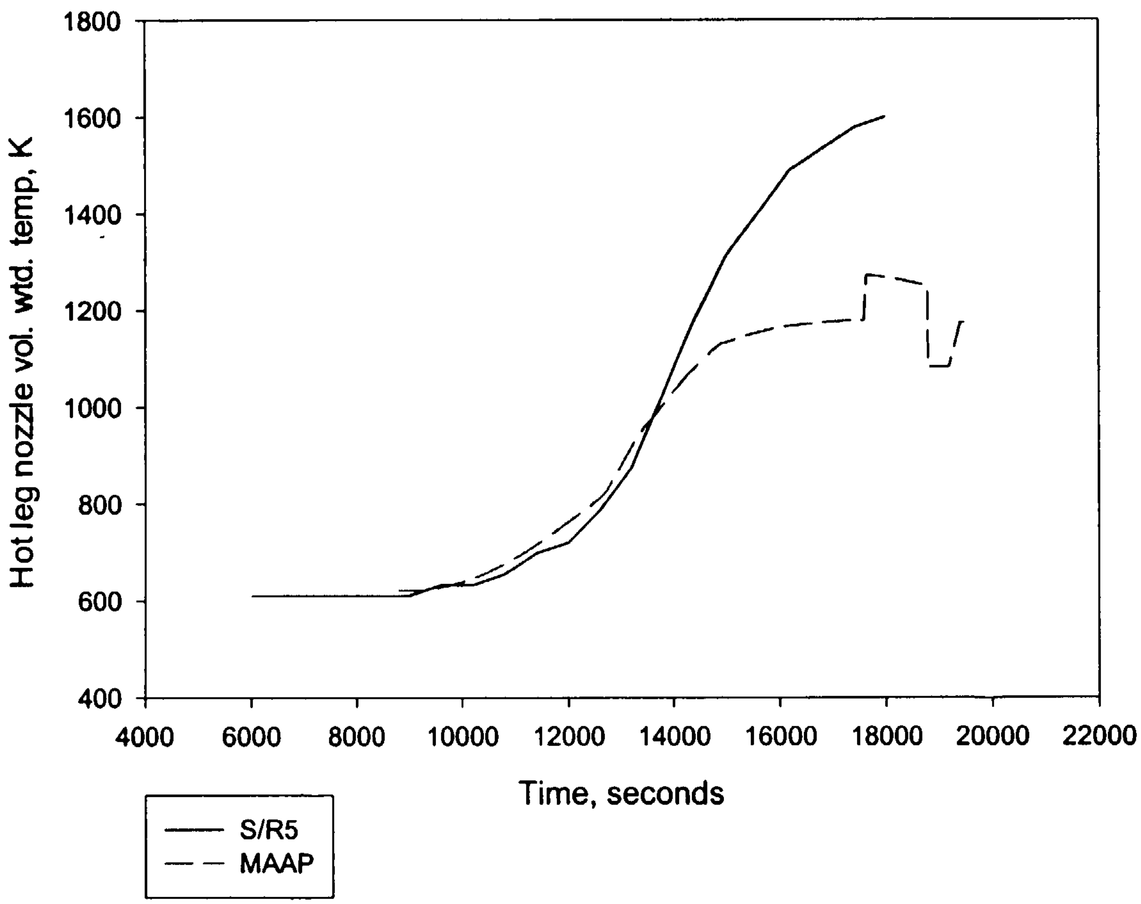
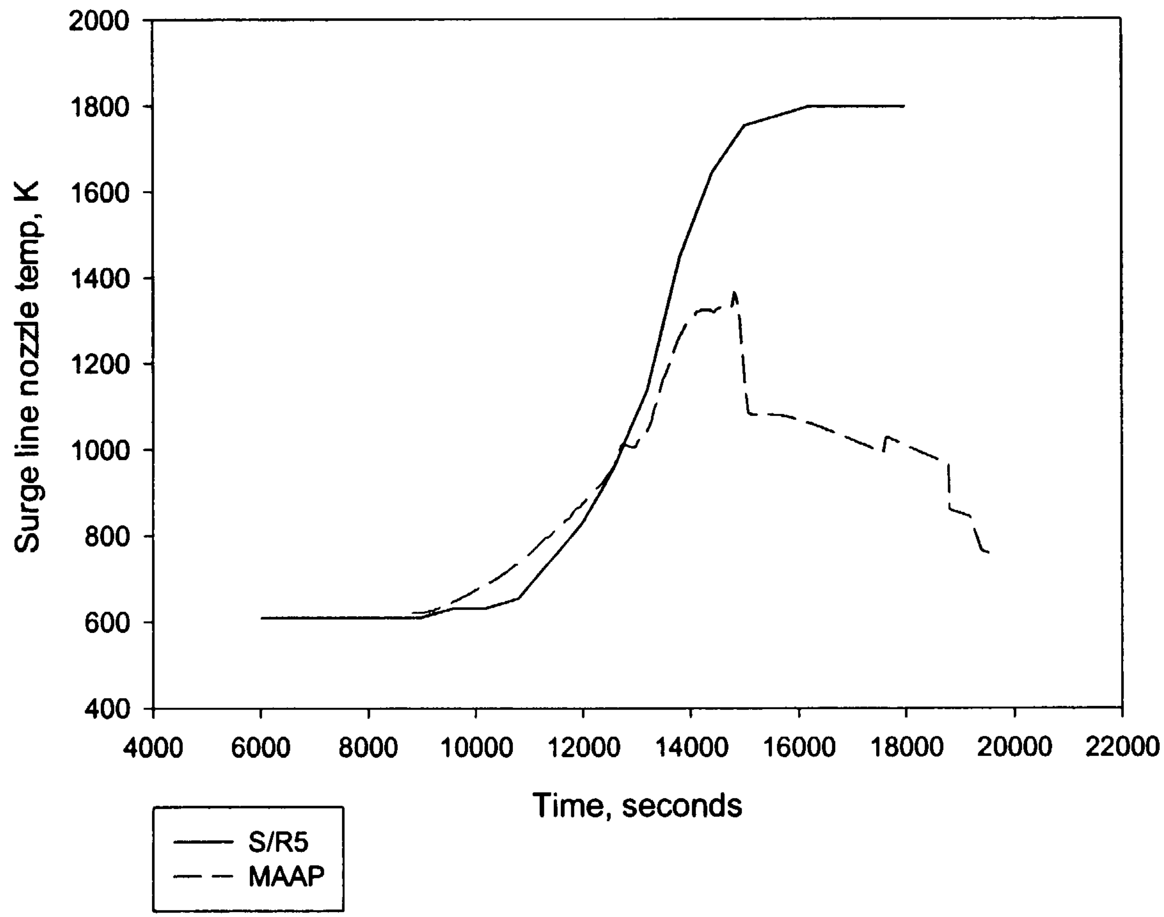
Upper Hot Leg Average Wall Temp



Surge Line Temperature



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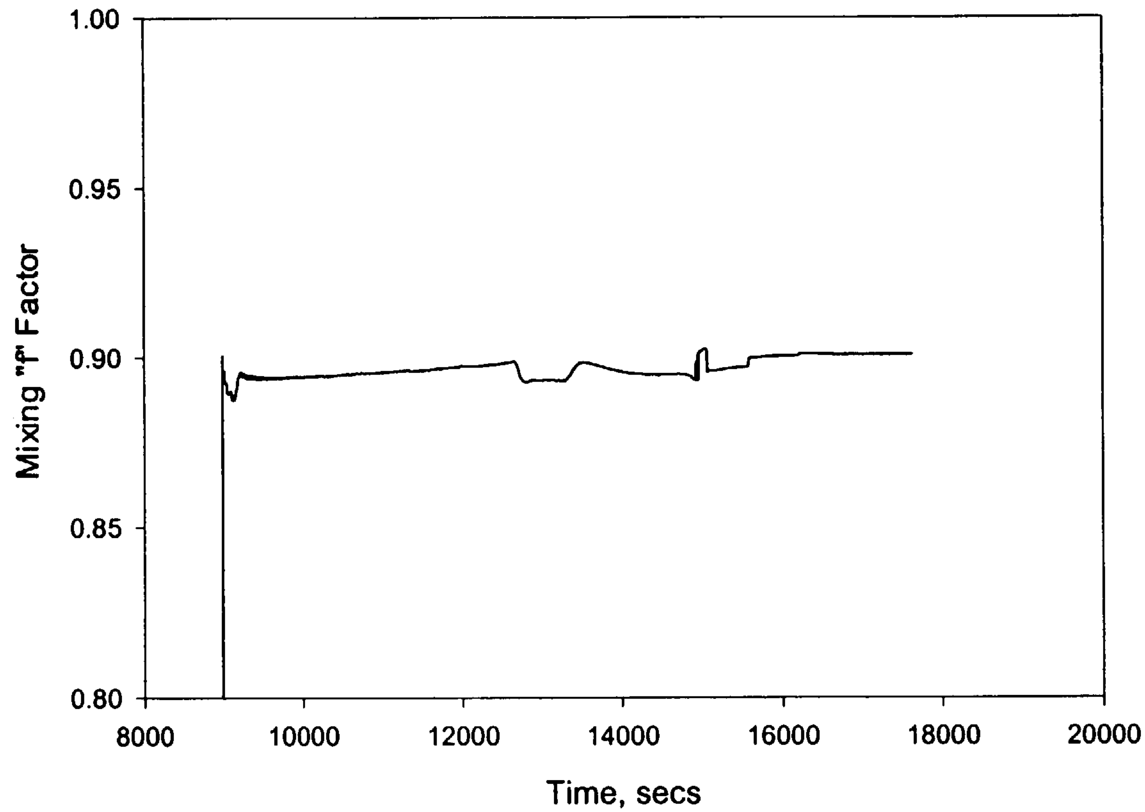
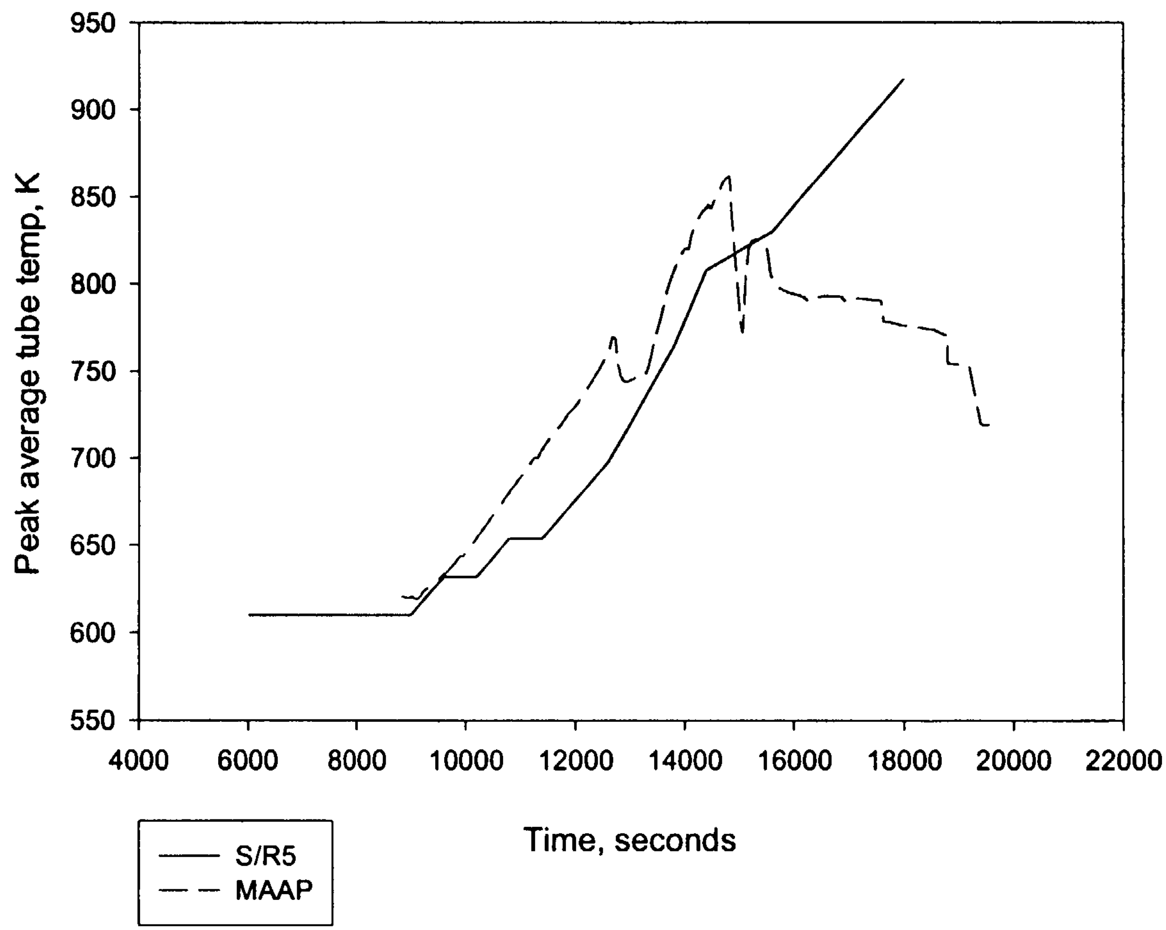
Inlet Plenum Mixing "f" Factor



Maximum Tube Temp ("average" tubes)



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Conclusions About "Base Case"

- When configured to mimic S/R5 modeling, MAAP results very similar to S/R5's until ~14000 secs
- At later times, S/R5 RCS temperatures generally higher, probably because faster hydrogen production and core melt progression, and earlier relocation in MAAP
- However, times > 14000 seconds not of interest for TISGTR, since surge line calculated to fail at 13619 (MAAP "base case") and 13368 secs (S/R5)
- Note: this unique comparison "base case" represents the only time MAAP has ever calculated surge line failure prior to hot leg failure

Sensitivity Calculations

- Investigate relative importance of each of the altered assumptions used in MAAP "base case" calculation
- Use these to support judgements on whether the normal MAAP assumptions or the altered ones used in the "base case" calculation make the most sense

Summary of Results

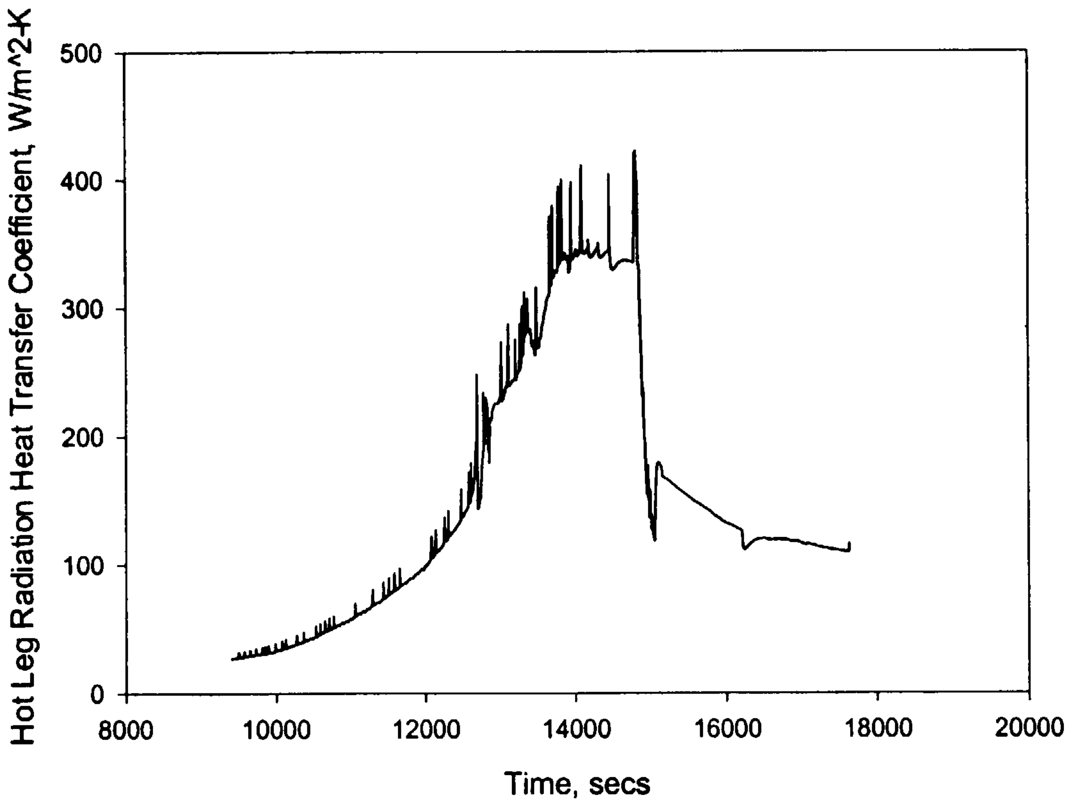
Table 1. Median Hot Leg and Surge Line Creep Rupture Times (Seconds)			
Case	Earliest Median Hot Leg Creep Rupture Time	Median Surge Line Creep Rupture Time	Difference between hot leg and surge line rupture times
"Base case"	14083	13619	460
"Base case" (but use RELAP5 creep rupture correlations)	14126	13703	420
SCDAP/RELAP5	14508	13368	1140
Nominal upper plenum mass	13645	13050	600
No downward heat transfer	14255	13566	690
Nominal gas/wall radiation	13117	13614	-500 *
Nearly-nominal MAAP assumptions	13574	13978	-400 *

* hot leg fails prior to surge line

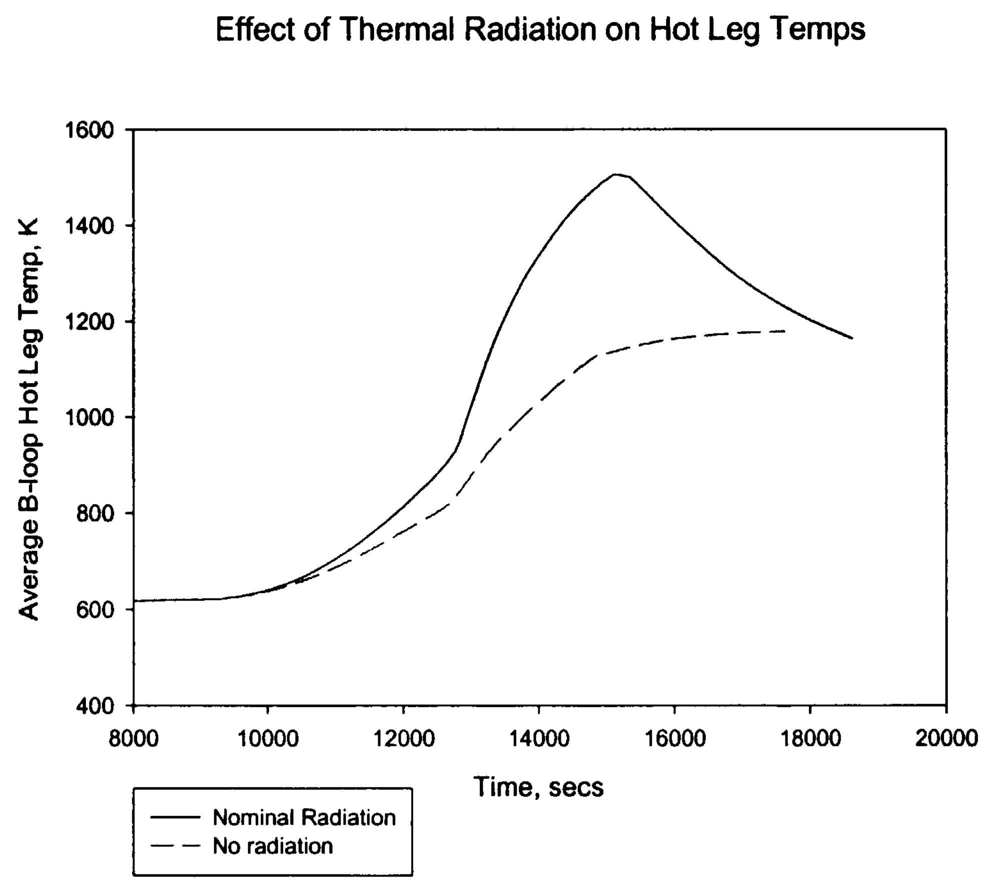
Sensitivity Analysis Conclusions

- By far the most important of the assumptions in the "base case" analysis is the neglect of thermal radiation
- All cases with thermal radiation result in hot leg failure prior to surge line failure, and vice versa
- Absence of thermal radiation in S/R5 is inconsistent with detailed hand calculations presented in Appendix C of NUREG/CR-6285: radiation ~ twice as strong as convection at 1000 K
- The importance of thermal radiation has been confirmed by EPRI calculations

Radiation Heat Transfer Coefficient



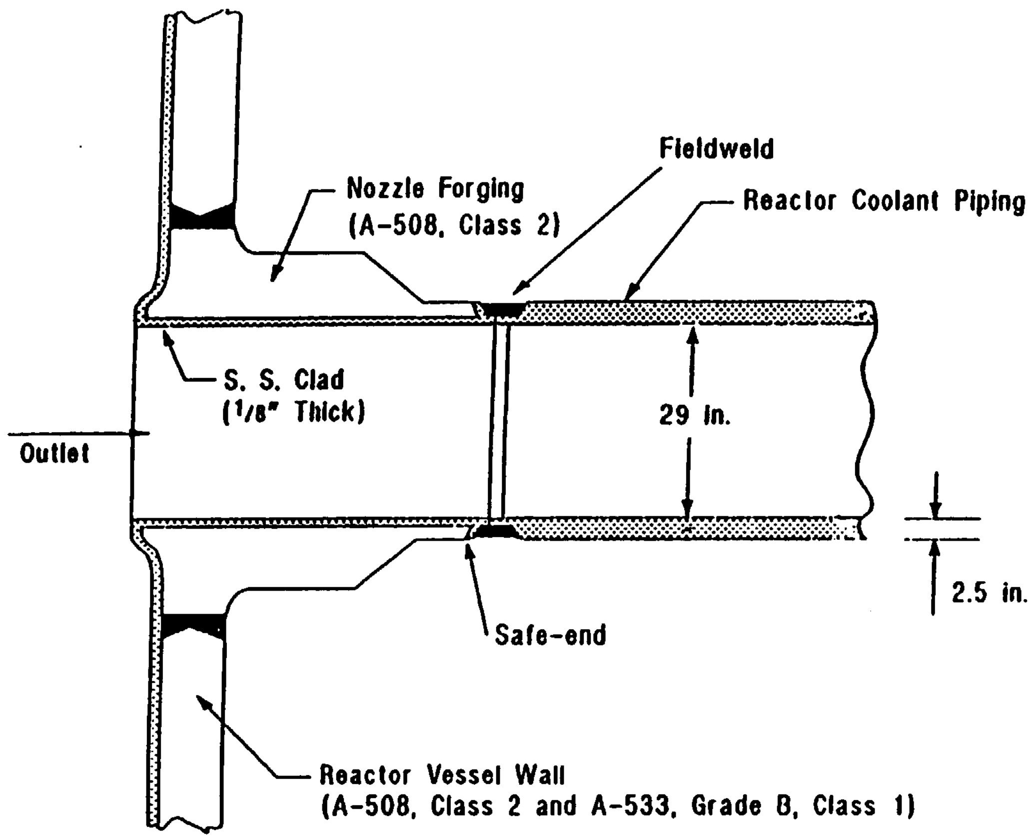
Effect of Radiation



RELAP Hot Leg Rupture Times

- For the same input temperatures, MAAP calculates far earlier hot leg rupture than does RELAP
  - This is also true for NUREG-1570 results
- Appears that RELAP inputs are configured to model hot leg rupture in the stainless steel pipe, not the alloy steel outlet nozzle as in MAAP
  - Larson-Miller correlations are similar in both codes
- If so, we believe this is inconsistent with most previous work, e.g., NUREG-1150 elicitations

Westinghouse Hot Leg Configuration



Recommendations (RELAP)

- Provide a model for thermal radiation: based on EPRI work, may be sufficient in the short-run to merely allow user to model a specified fraction of black-body radiation (recommend ~0.45)
- Model creep rupture of hot leg nozzle, not the pipe, in Westinghouse plants
- Provide creep rupture models for carbon steel piping used in CE and B&W plants

Recommendations (MAAP)

- Consider an option to effectively split the surge line pipe as in S/R5
- Model natural convection between the upper head and the upper plenum
- Update creep rupture correlations implemented in the code to be consistent with post-processor used in EPRI SG program (PROBFAIL code)

Suggestion (both codes)

- If warranted, compare the two codes for a similar sequence in which:
  - Inputs are better controlled, e.g., hot leg creep rupture assumptions are made consistent
  - More complete output is generated, e.g., core/upper plenum natural circulation flow rates

Overall Conclusions (loop seals full)

- The most important differences between MAAP and S/R5 for thermally induced SGTR in high/dry sequences with full loop seals will be effectively resolved if:
  - Thermal radiation is modeled in RELAP
  - Consistent creep rupture inputs are used
- Differences in core melt progression eventually do affect the results; these matter for TISGTR only in unlikely event an RCS component has not already failed

Conclusions (loop seals full) (cont.)

- Differences in natural circulation modeling "philosophy" appear to affect average tube temperatures less than expected because of counter-balancing factors
- Since MAAP also models "peak" tubes receiving fluid from center of plume, its results could be less favorable (more conservative) than S/R5's, if hot leg modeling is made consistent in two codes

Issues if Loop Seals Clear

- Both codes predict severe tube challenge if cold leg loop seal clears and core barrel uncovers, especially if affected SG depressurized
  - even pristine tubes can fail under this scenario
- If either core barrel uncovering or cold leg loop seal clearing does not occur, the issue is resolved

Is Core Barrel Uncovering Likely?

- Relatively high downward heat transfer in S/R5 is associated with presence of core/upper plenum flow (NUREG/CR-5214)
- Inferred S/R5 downward heat transfer rate is approximately 2 MW
- Based on 1/7-scale data and physical reasoning, don't expect natural circulation flow to penetrate below lower core support plate; useful to compare calculated RELAP flow patterns to 1/7-scale data
- Surprising that such a large energy flux can be continuously delivered to lower plenum water

Is Loop Seal Clearing Likely?

- S/R5 predicts that loop seals can clear if relatively large RCP seal LOCAs occur (~250 gpm or larger)
- MAAP mechanistically models the effects of loop seal clearing, but not the clearing process itself; guide decisions on whether to force clearing based on insights from S/R5 predictions
- S/R5 calculations model RCP seal LOCAs based on results of detailed mechanical/fluid flow analyses performed by WOG and ETC (NUREG/CR-4294)

Seal LOCA Sizing is Inconsistent

- Quoted seal LOCA flow rates (e.g., 250 gpm, 480 gpm) in detailed calculations based on post-trip RCS conditions (2250 psia, 550 F)
- S/R5 calculations are instead based on obtaining these flow rates at saturated conditions (2315 psia)
- Absence of subcooling leads to a required flow area that is >50 percent too large
- This leads to over-prediction of likelihood of loop seal clearing
- Flow rates also expected to be lower if new O-rings installed

Recommendations (loop seal clearing)

- Configure future S/R5 calculations to develop desired seal LOCA flow at nominal post-trip conditions, as assumed in the original analyses that determined these flow rates
- Further work needed to decide whether RELAP or MAAP downward radiative heat transfer rates are most realistic
- If conclude that either cold leg or core barrel clearing unlikely, severe threat to tubes is precluded

Anticipated MAAP Usage

Presentation to NRC

15 Dec. 2000

Jack Haugh

Area Manager

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EPRI

Informal MUG Survey

- EPRI requested input from MAAP User Group regarding anticipated MAAP use
  - 14 responses from domestic operating companies
- Eight respondents indicated "No plans for licensing submittals based on MAAP"
- Six respondents anticipate MAAP-based submittals in Y2001-2003; seventh respondent offered a general comment about "guidance"

Survey Questions

1. Do you have any plan to use MAAP to perform analysis for risk informed licensing submittals?
2. If so, what version of MAAP do you plan to use?
   - For example, MAAP 3.0B, MAAP 4, MAAP 4.0.3, or MAAP 4.0.4?
3. If so, on what specific topic this submittal would be?
   - For example, this could be on "Steam Generator electro-sleeving," or others

Survey Questions (cont.)

4. In what time frame do you plan to do such submittal,
    - (A) short term (1-2 years),
    - (B) mid term (2-3 years), or
    - (C) long term (3-4 years)
5. What kind of guidance or guidance documents you would like to have to perform MAAP analysis for such submittal?

Summary of Responses

1. MAAP 4.0.4; Allowed Outage Times, input to HRA (time to core damage, - to suppression pool overheating, - to containment over-pressurization); 2-3 years; no specific guidance requested from EPRI
2. MAAP 5.0; accident-induced containment pressure and temperature profiles; mid-2001, no specific guidance requested from EPRI
3. MAAP 4.0.4; Alternate Source Term application (not MAAP-DOSE); work in progress; no specific guidance requested from EPRI
4. MAAP 4.0.4; Alternate Source Term application (not MAAP-DOSE); Y2001; no specific guidance requested from EPRI

Summary of Responses (cont.)

5. MAAP 4.0.4; Success Criteria modeling to support Maintenance Rule, AOV risk ranking, IST STI extensions, ISI inspection risk and consequence evaluations, 10 CFR 50.59 Risk Informed Regulation Option 2 trials; 1-2 & 2-3 years; application guidance re:
   - problem description and high level summary, conclusions and input file with annotations of code steps
   - precautions and limitations of intended results usage
   - an understanding problem statement, solution, and simple justification

Summary of Responses

6. MAAP 4.0.4; SGTR/electrosleeving; two years; no specific guidance requested from EPRI
7. General guidance to assure we're not using MAAP inappropriately; desire ability to identify which benchmark results best support MAAP's being appropriate for specific applications

Conclusions

- Limited number of MAAP-based risk-informed licensing submittals anticipated for Y2001-2003
- AOTs, STIs and inspection intervals appear to be the main applications being considered
- Additional guidance re MAAP applicability, limitations, and supporting benchmarks might be helpful