Status of EPRI/MRP Boric Acid Corrosion (BAC) Testing Program

Craig Harrington – TXU Energy

Al Ahluwalia – EPRI

Allan McIlree – EPRI

John Hickling – EPRI

Glenn White – Dominion Engineering, Inc.

Meeting on Status of Research Activities
NRC Offices, Rockville, Maryland
March 22, 2004

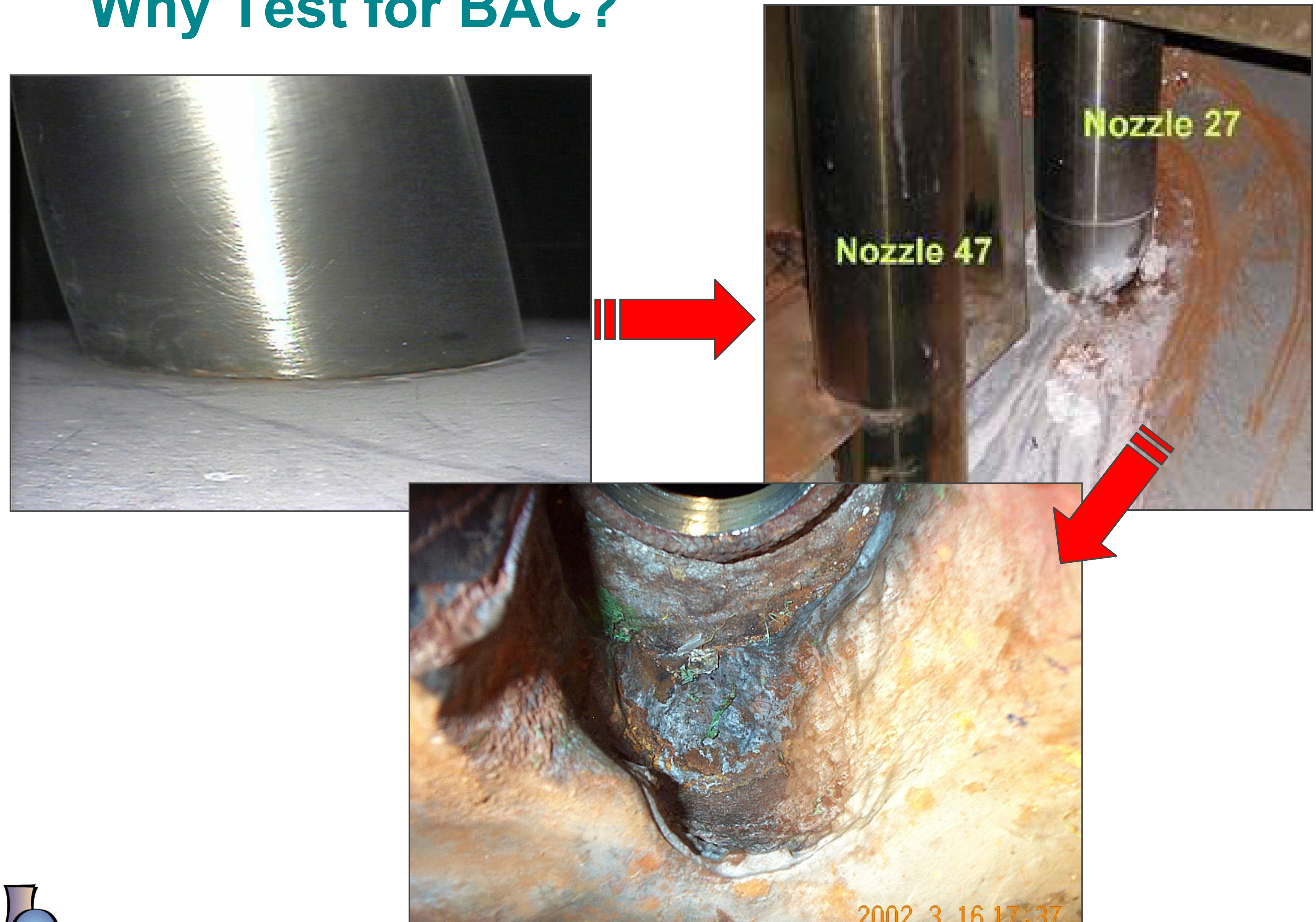
Presentation Outline

- Background and Overview
- EPRI BAC Guidebook Revision
- Schedule
- Reactor Vessel Steel Material Source
- Task 1: Highly Instrumented Heated Crevice
- Task 2: Impact Flow Loop
- Task 3: Separate Effects Testing
  - 3a: Immersion Tests
  - 3b: Primary Water Chemical Concentration Tests
  - 3c: Electrochemical Tests
  - 3d: pH and ECP Electrode Development
- Task 4: Full-Scale Mockup Testing

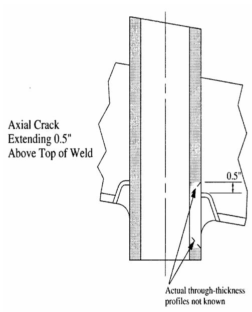
Background and Overview
Program Organizations

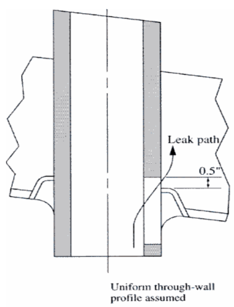
- Program Management
  - MRP (Craig Harrington—TXU Energy, Larry Mathews—SNOC)
  - EPRI (Allan McIlree, Al Ahluwalia, John Hickling)
- Task 1: Heated Crevice
  - Rockwell Scientific (Jesse Lumsden)
- Task 2: Impact Flow Loop
  - University of New Brunswick (Derek Lister)
- Task 3: Separate Effects Testing
  - Dominion Engineering, Inc. (Chuck Marks)
  - Pennsylvania State University (Digby Macdonald)
- Task 4: Full-Scale Mockup Testing
  - Southwest Research Institute (Richard Page)

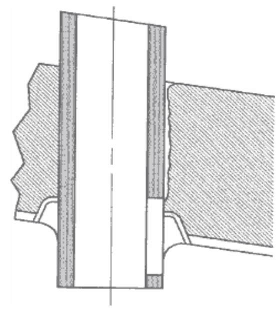
Why Test for BAC?

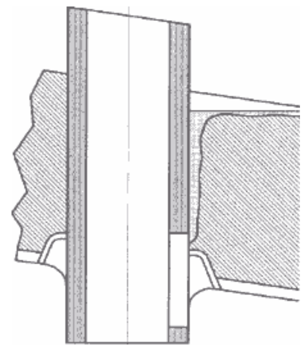


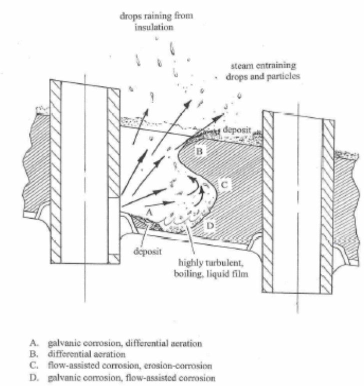
Background and Overview
Phases of RV Head Wastage











Phase 1–Task1
Stagnant/Low Flow
- ***Crevice Tests***

Phase 2—Task 2
Flowing/Impingment
- ***Loop Tests***

Phase 3—Task 3
Concentrated
Boric Acid Corrosion
- ***Lab Tests***

Phase 4—Task 4
Full-Scale Mockup
- ***Design***
- ***Testing***

Need to determine the relative length of time for each phase of the degradation to effectively establish inspection intervals

Background and Overview
BAC Testing Objectives

Support the determination of inspection intervals to ensure boric acid corrosion does not result in wastage that causes stresses to exceed ASME Code allowables

The BAC Testing Program is structured to:

- Improve understanding of the progression of boric acid wastage at RPV head penetrations
- Identify the influence of plant specific parameters on wastage
- Support development of required inspection intervals for PWR plants with various penetration designs

Background and Overview
BAC Task Descriptions

Task 1 - Heated Crevice test device to address stagnant and low flow chemistry definition and their influence on corrosion rates.

Task 2 – Test in a flowing loop to address moderate and high flow condition with ability to monitor real time corrosion rates and ECP under laminar and impact flow.

Task 3 – Separate effects tests to obtain data on corrosion rates for conditions not previously tested such as galvanic coupling and corrosion in contact with molten boric acid.

Task 4 – Full scale mockup testing to determine corrosion rates under prototypical CRDM nozzle leakage conditions including full-size nozzles, interference fits, simulated crack geometries, range of leak rates from 0.0001 to 0.3 gpm, and controlled thermal conditions.

EPRI BAC Guidebook
Purpose

- Purpose of original *BAC Guidebook* (1995) was to provide utilities with information to:
  - Establish or refine a boric acid corrosion control (BACC) program
  - Assess whether components can be left in service with continued leakage or degradation
- Purpose of the Rev. 1 guidebook (EPRI 1000975, *Boric Acid Corrosion Guidebook*, Revision 1, November 2001) was to:
  - Update the industry experience from 1995–2001
  - Provide additional test data on materials and prototypical joints
  - Provide additional information from the Fluid Sealing Technology Program (FSTP) regarding means to prevent leaks

EPRI BAC Guidebook
Program Overview

Rev. 0 Guidebook 1995 → **BAC Programs 1995 - 2001** → **Rev. 1 Guidebook 2001** → **BAC Programs 2002 - 2006** → **Rev. 2 Guidebook Late 2006 - Early 2007**

Rev. 0 Guidebook 1995

- Introduction
- Industry Experience
- BAC Corrosion Mechanisms
- BAC Corrosion Tests
- Regulatory Bases
- Detecting Leakage
- Preventing Leaks and Degradation
- Operation with Leaks/BAC
- BAC Management

BAC Programs 1995 - 2001

Industry Experience 1995 - 2001

Supplemental BAC Tests
- Materials Tests
- Flange Tests
- Annulus Tests

Fluid Sealing Technology Program
- Working Group
- Spiral Gaskets
- Flat Gaskets
- Valve Packing
- Threaded Joints
- Training Aids
- Plant Training
- Leak Reduction Progams
- LeakTRAC Software

BAC Programs 2002 - 2006

Industry Experience 2001 - 2006

Additional BAC Tests
- Heated Crevice
- Impact Flow
- Galvanic Corr.
- Molten BA
- CRDM Mockup

Modeling of BAC Wastage
- Crack models
- Leak models
- Thermal models
- Chemical models
- Corrosion/ electrochemistry models

Refined BAC Management Guidelines

EPRI BAC Guidebook
Planned Revision 2

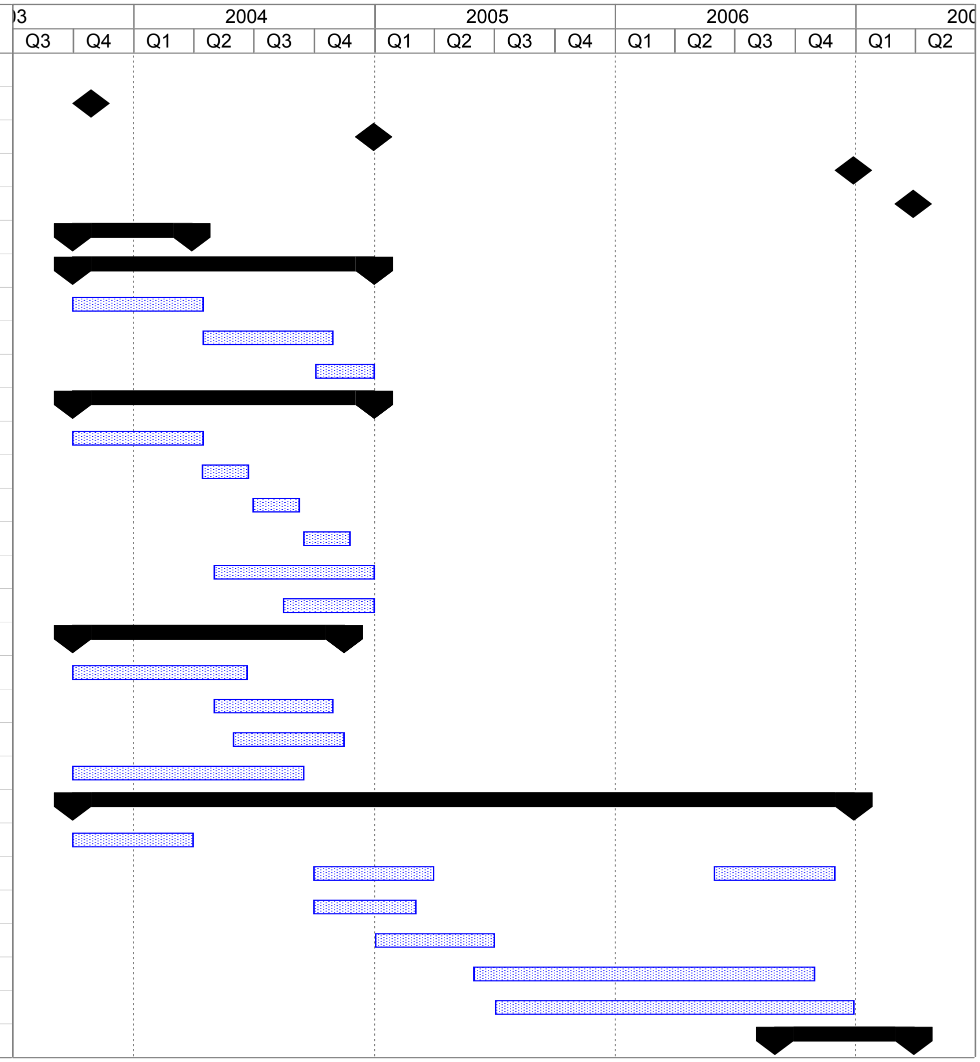
- Revision 2 to the BAC Guidebook is planned after the results and conclusions of the 2003-2006 BAC testing program are available.
  - Late 2006 or early 2007
- The likely contents of Revision 2 would include
  - Results of 2003-2006 BAC testing program
  - Results of NRC/ANL BAC testing program
  - Industry experience from 2001 through 2006
  - Results of wastage modeling efforts
  - Latest leakage reduction and inspection guidance
- The MRP safety assessment report for reactor vessel closure heads (currently under final MRP reviews) includes an update on BAC plant experience through 2003

Program Schedule
Summary

- Program Kickoff Meeting
  - October 29–30, 2003, Reston, Virginia
  - Participation of MRP, EPRI, Program Test Labs, NRC Research, and ANL
- Tasks 1, 2, and 3
  - Initiated in fall of 2003
  - Scheduled for completion by the end of 2004
- Task 4 Mockup Testing
  - Planned for 2005 and 2006
- Revision 2 to BAC Guidebook
  - Planned for late 2006 / early 2007

Program Schedule
Gantt Chart

ID	Task Name
1	**Major Milestones**
2	Program Kickoff Meeting
3	Final Report for Tasks 1, 2, and 3
4	Final MRP Report on BAC Testing Program
5	Revised BAC Guidebook
6	**RV Steel Material Source**
7	**Task 1: Heated Crevice**
8	Test Setup and Commissioning
9	Testing
10	Analysis and Reporting
11	**Task 2: Impact Flow Loop**
12	Test Loop Setup and Commissioning
13	Phase 1 Experiments
14	Phase 2 Experiments
15	Phase 3 Experiments
16	Data Analysis
17	Preparation of Final Report
18	**Task 3: Separate Effects Testing**
19	Immersion Tests and Plan for Other Tests
20	Primary Water Chemical Concentration Tests
21	Electrochemical Tests
22	pH and ECP Electrode Development
23	**Task 4: Full-Scale Mockup Testing**
24	Conceptual Design and Preliminary Plan
25	Additional Analytical Modeling
26	Preparation of Detailed Test Plan
27	Loop Modifications and Specimen Fabrication
28	Testing
29	Analysis and Reporting
30	**Revision 2 to BAC Guidebook**

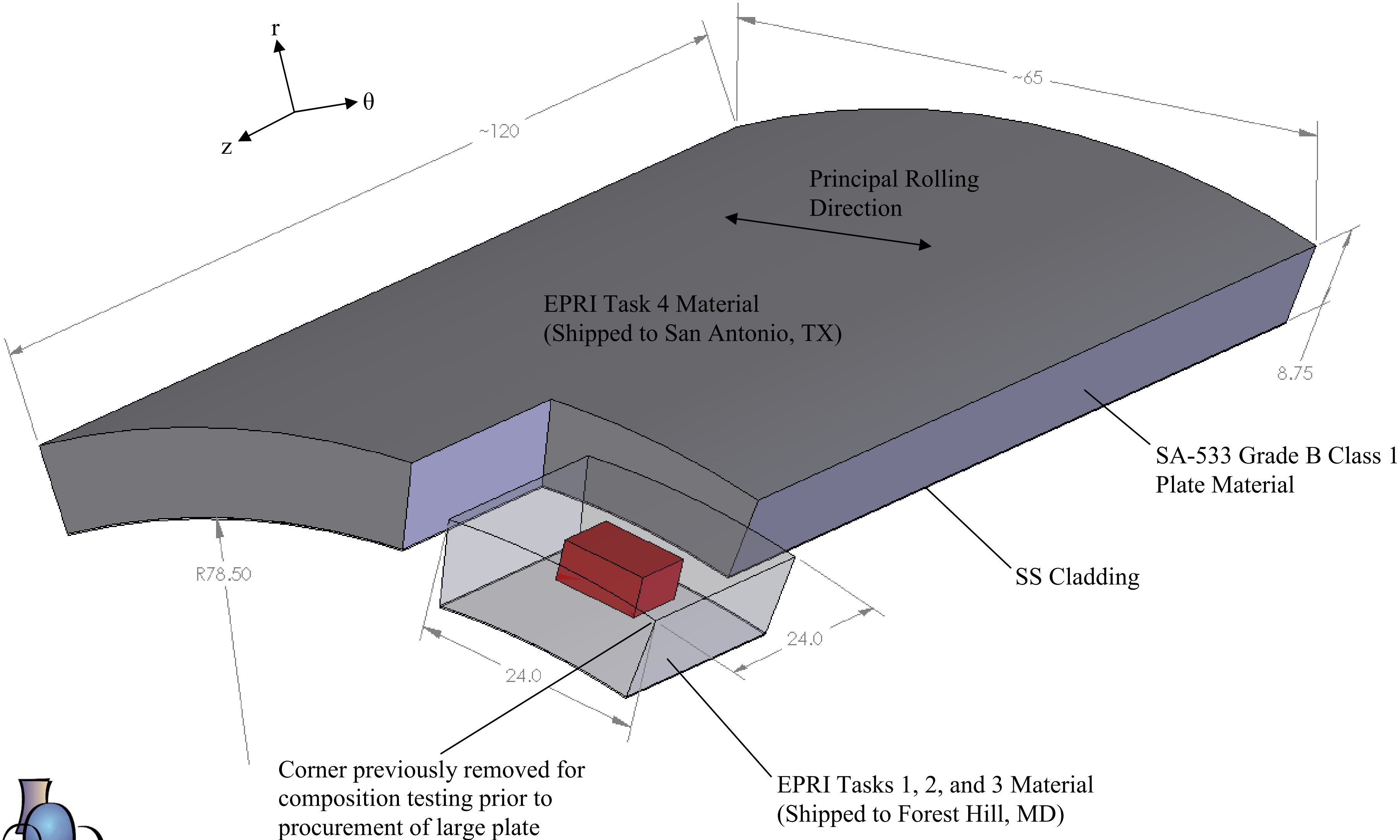


Reactor Vessel Steel Material Source
Summary

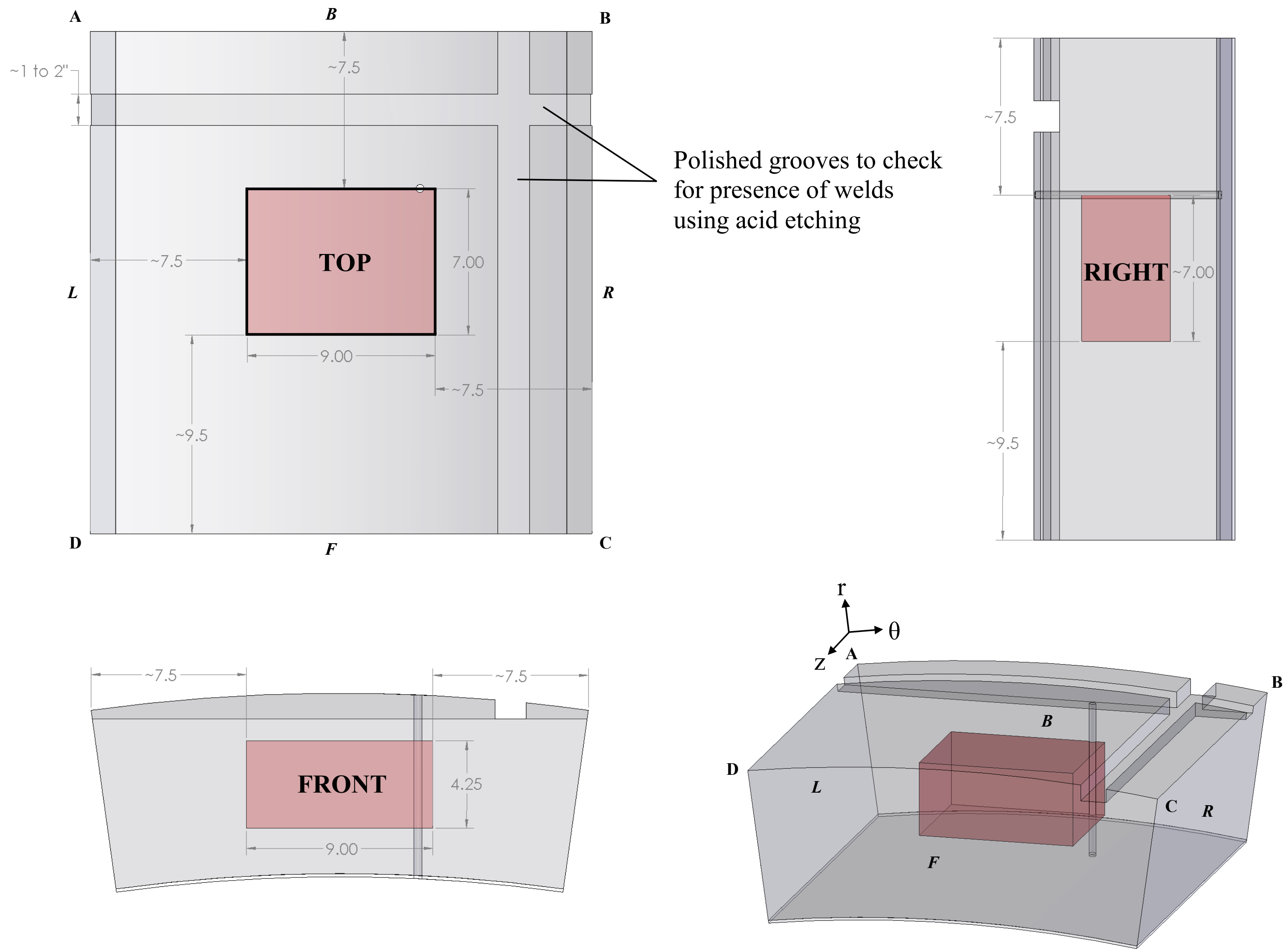
- Original RPV heads were fabricated from low alloy steel reactor vessel plate material
  – SA 302 Grade B
  – SA 533 Grade B Class 1
- A common material source for BAC testing is desirable to minimize influence of any processing / microstructural effects although such effects are expected to be small
- A 20,000 lb section of reactor vessel shell from a canceled plant has been procured
  – Cut from center cylindrical portion of vessel
  – Representative material processing and microstructure
  – Cr content (0.04%) at low end of range typical for PWR vessels

Reactor Vessel Steel Material Source
Photograph of Procured Vessel Section

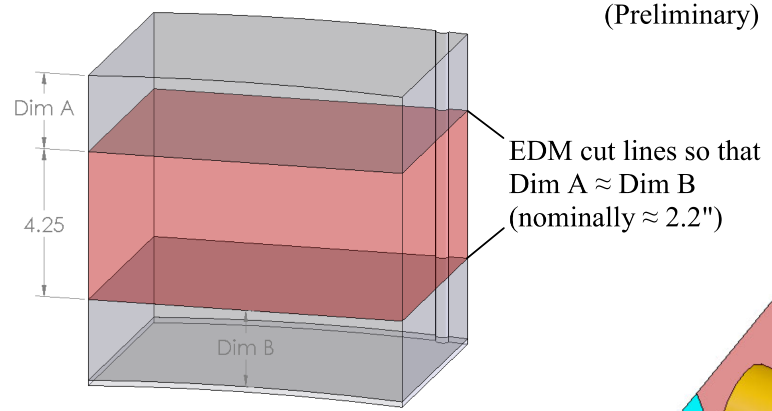
Reactor Vessel Steel Material Source
Sectioning Plan—1

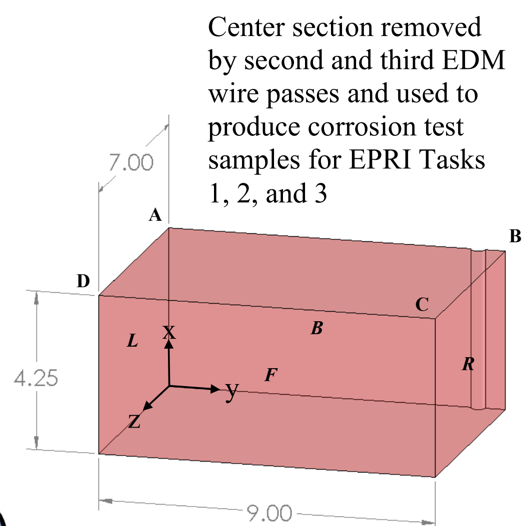


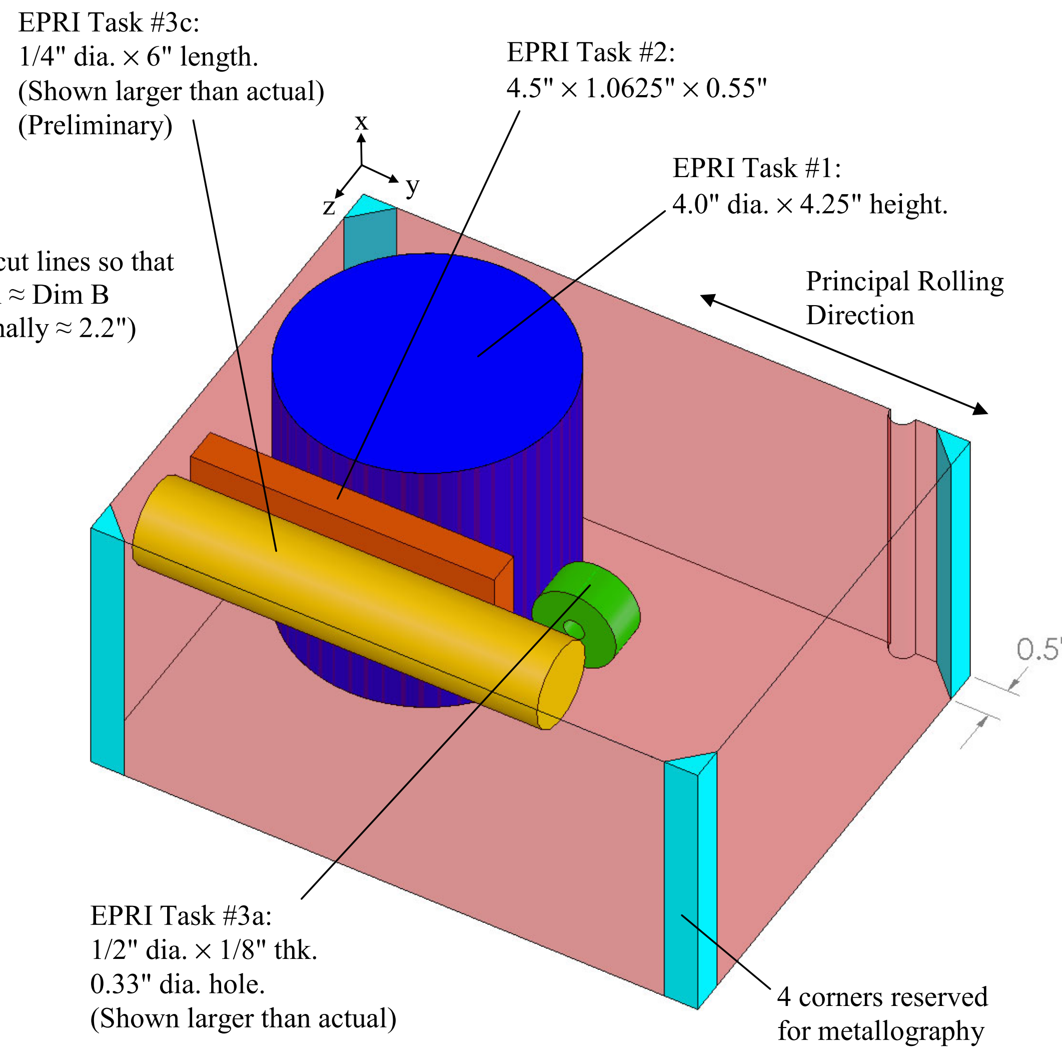
Reactor Vessel Steel Material Source
Sectioning Plan—2



Reactor Vessel Steel Material Source
Sectioning Plan—3







EPRI

Reactor Vessel Steel Material Source
Microstructural Comparisons

Procured Canceled Plant Material for
Current MRP BAC Testing Program
Bainitic Microstructure

Typical Davis-Besse Low Alloy Steel
Bainitic Microstructure

Examination of the Reactor Vessel (RV) Head Degradation at Davis-Besse, Final Report, BWXT Services, Inc., Lynchburg, VA: 2003. 1140-025-02-24.

EPRI

BAC Task 1: Heated Crevice
Program Description

Task 1 - Heated Crevice test device to address stagnant and low flow chemistry definition and their influence on corrosion rates.

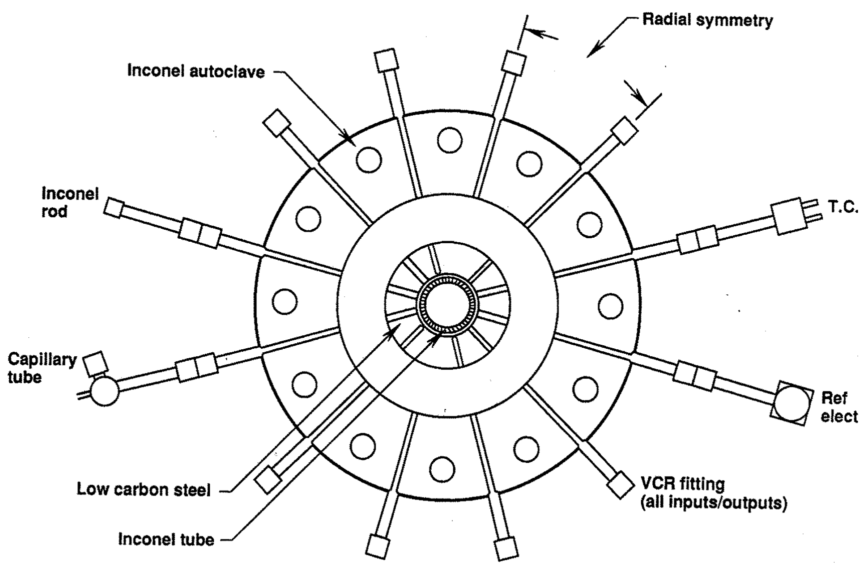
Task 2 – Test in a flowing loop to address moderate and high flow condition with ability to monitor real time corrosion rates and ECP under laminar and impact flow.

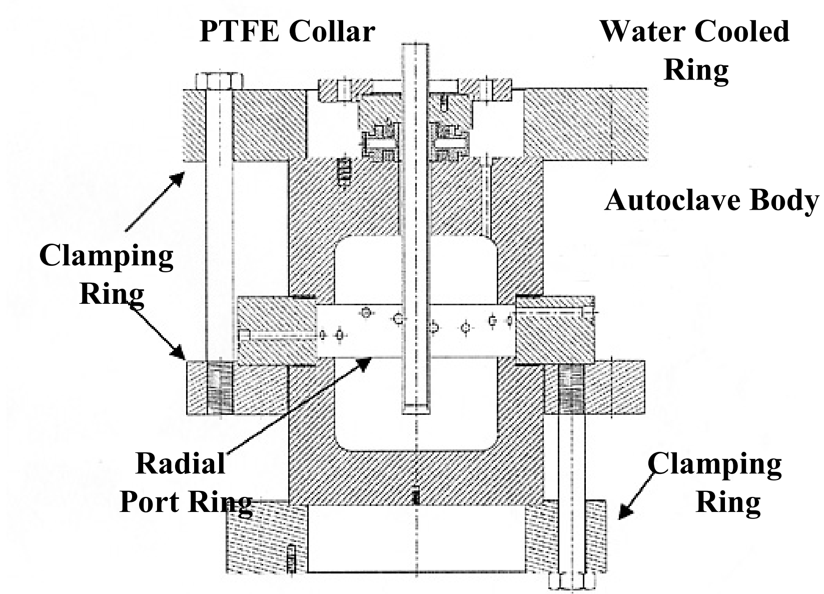
Task 3 – Separate effects tests to obtain data on corrosion rates for conditions not previously tested such as galvanic coupling and corrosion in contact with molten boric acid.

Task 4 – Full scale mockup testing to determine corrosion rates under prototypical CRDM nozzle leakage conditions including full-size nozzles, interference fits, simulated crack geometries, range of leak rates from 0.0001 to 0.3 gpm, and controlled thermal conditions.

BAC Task 1: Heated Crevice
Program Description

- *Approach*—Use modified instrumented tube/tube support plate heated crevice from EPRI/DOE hideout-SCC programs to simulate RPV/nozzle annulus

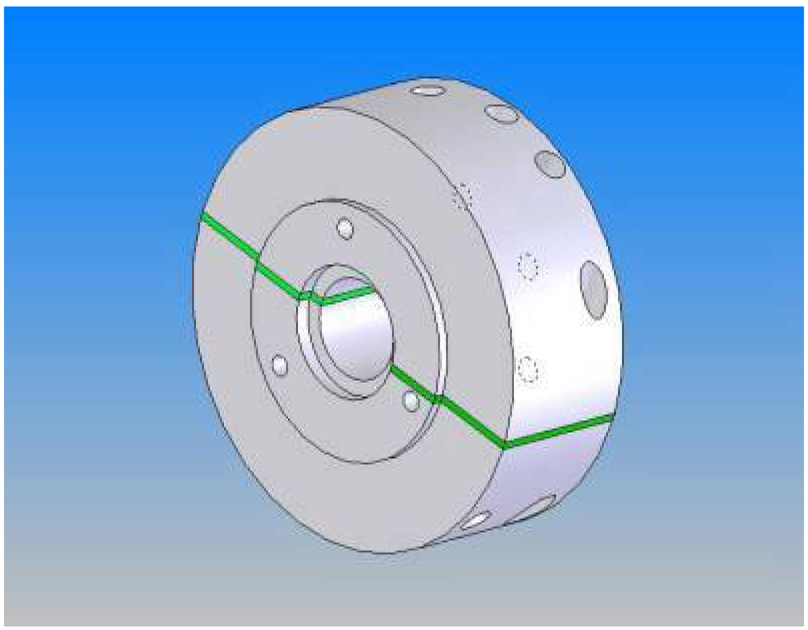




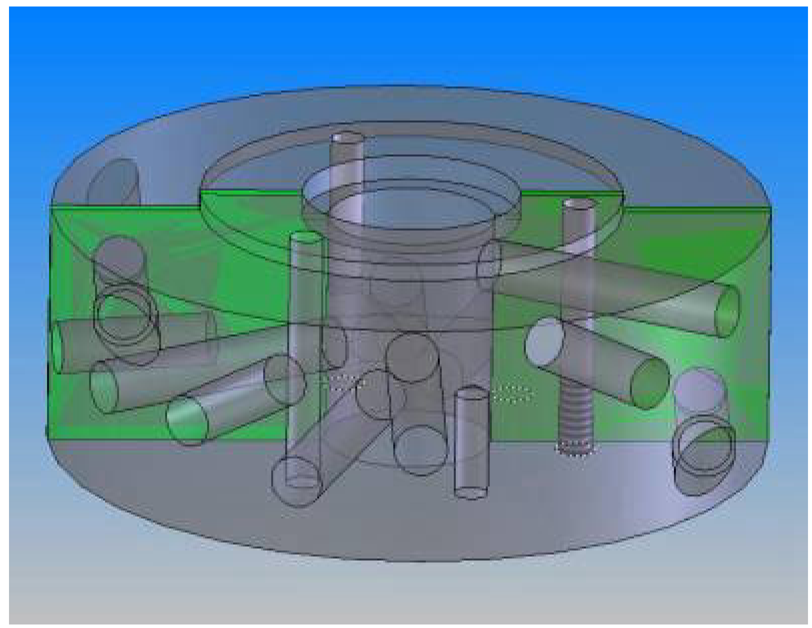
BAC Task 1: Heated Crevice
Program Description

- *Ring Construction*

Ring With Halves Separated by Teflon
Measure Electrochemical Noise Between Halves

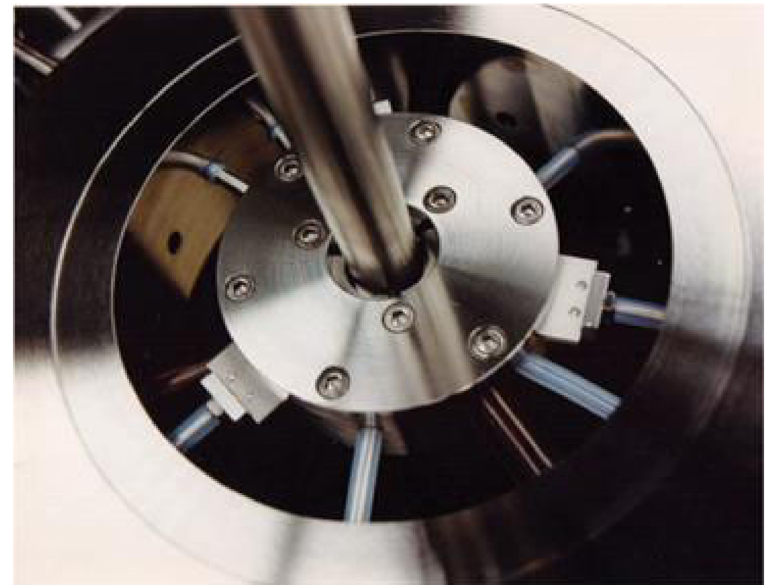


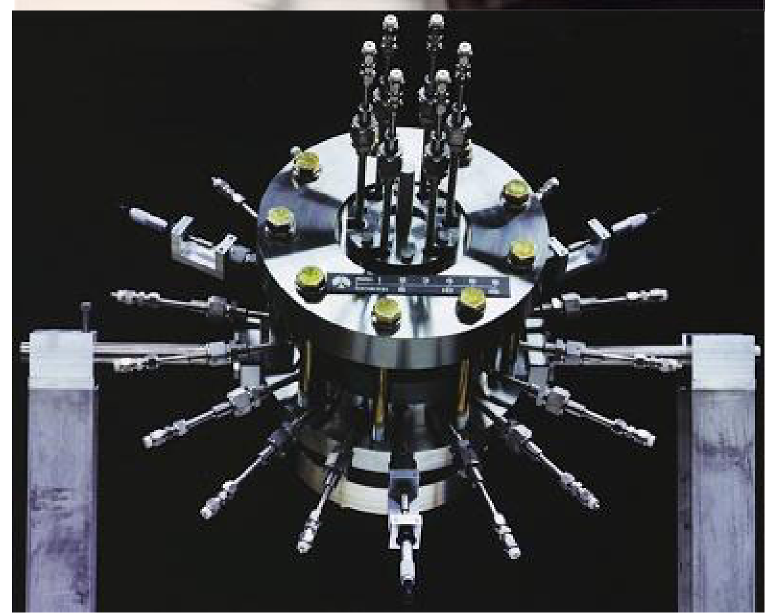
3-D View of Ring Showing Ports
Insert Electrodes for ECP, pH, Electrochemical Noise, & AC Impedance



EPRI

BAC Task 1: Heated Crevice
Program Description





- *Capabilities*
  - Bulk solution extraction for analysis (not needed)
  - Crevice solution extraction for analysis
  - ECP of carbon steel-bulk solution (NWT- Ag/AgCl)
  - ECP of carbon steel in crevice (NWT- Ag/AgCl)
  - Temperature vs. elevation in crevice (not needed)
  - Electrochemical Noise
  - Galvanic corrosion current between Alloy 600 tube and carbon steel plate
  - AC Impedance
  - pH Electrode (tungsten/tungsten oxide)
  - Raman Spectroscopy (not needed)

BAC Task 1: Heated Crevice
Program Description

- Measurements and Data Generated
  - Crevice ECP, bulk ECP, and ECP of W/W oxide electrode will be monitored continuously
  - Galvanic current will be monitored continuously except for periodic interruptions for ac impedance and electrochemical noise measurements

MEASUREMENT	REPORTABLE VALUE Inferred from Measurement
Crevice ECP	
Bulk ECP of A533 Steel	
Galvanic Current	Galvanic Corrosion Rate of A533 Steel
Electrochemical Noise	General Corrosion Rate of A533 Steel
AC Impedance	Conductivity, General Corrosion Rate
ECP of W/W oxide electrode	pH

BAC Task 1: Heated Crevice
Program Description

- Stagnant/Low Flow Rate Primary Water Conditions
  - Two primary water chemistries with RT 25 cc/kg dissolved H_2
    - 3.5 ppm Li / 2000 ppm B, simulating beginning-of-cycle primary water
    - 0.5 ppm Li / 200 ppm B, simulating end-of-cycle primary water
  - Phase 1
    - Stagnant conditions
    - Continue until steady state as indicated by galvanic current
    - At termination of each stagnant test solution will be extracted for analysis
  - Phase 2
    - Low flow rate conditions through capillary at top of crevice
    - Continue until steady state as indicated by galvanic current

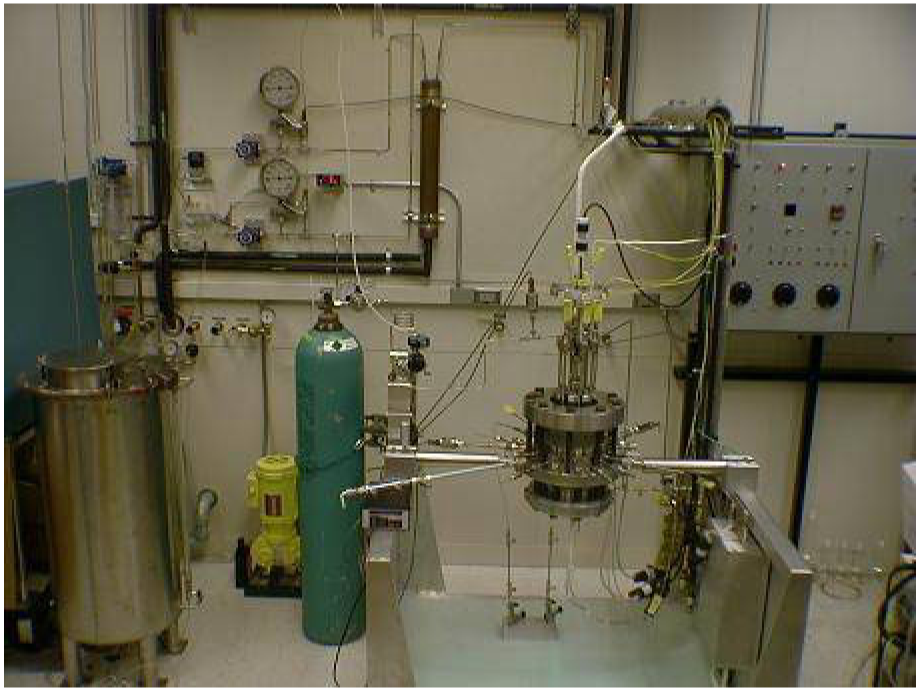
BAC Task 1: Heated Crevice
Program Description

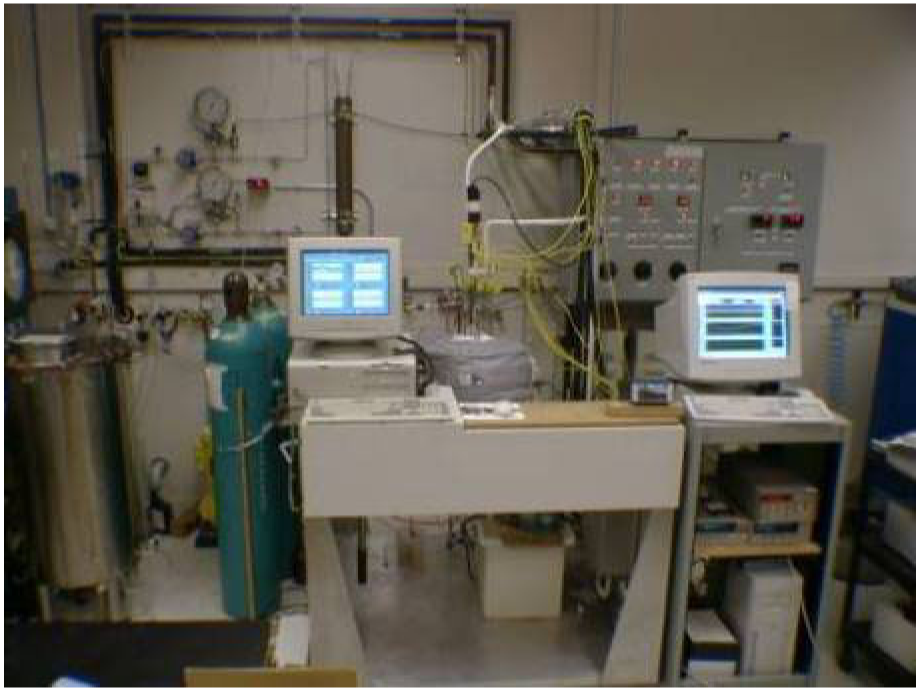
- *Planned Test Matrix*

Test Series #	Bulk Chemistry Conditions			Test Temp.	Phase 1	Phase 2
	Lithium	Boron	Gas			
1-1	0.5 ppm	200 ppm	25 cc/kg H_2	300°C	Stagnant	<0.005 gpm
1-2	0.5 ppm	200 ppm	25 cc/kg H_2	250°C	Stagnant	<0.005 gpm
1-3	0.5 ppm	200 ppm	25 cc/kg H_2	150°C	Stagnant	<0.005 gpm
2-1	3.5 ppm	2000 ppm	25 cc/kg H_2	300°C	Stagnant	<0.005 gpm
2-2	3.5 ppm	2000 ppm	25 cc/kg H_2	250°C	Stagnant	<0.005 gpm
2-3	3.5 ppm	2000 ppm	25 cc/kg H_2	150°C	Stagnant	<0.005 gpm
3-1	3.5 ppm	2000 ppm	8 ppm O_2	150°C	Stagnant	<0.005 gpm

BAC Task 1: Heated Crevice
Program Description

- *System Layout*





BAC Task 1: Heated Crevice
Current Status

- Ring assembly completed
- Trial run at 250°C in BOC chemistry (deaerated and aerated) in progress
  - Ag/AgCl reference functioning
  - Electrochemical noise (ECN) functioning
  - pH electrode being tested
  - AC impedance being tested
- First formal test planned for April 2004
- Test matrix and report planned for completion end of 2004

BAC Task 2: Impact Flow Loop
Program Description

Task 1 - Heated Crevice test device to address stagnant and low flow chemistry definition and their influence on corrosion rates.

Task 2 – Test in a flowing loop to address moderate and high flow condition with ability to monitor real time corrosion rates and ECP under laminar and impact flow.

Task 3 – Separate effects tests to obtain data on corrosion rates for conditions not previously tested such as galvanic coupling and corrosion in contact with molten boric acid.

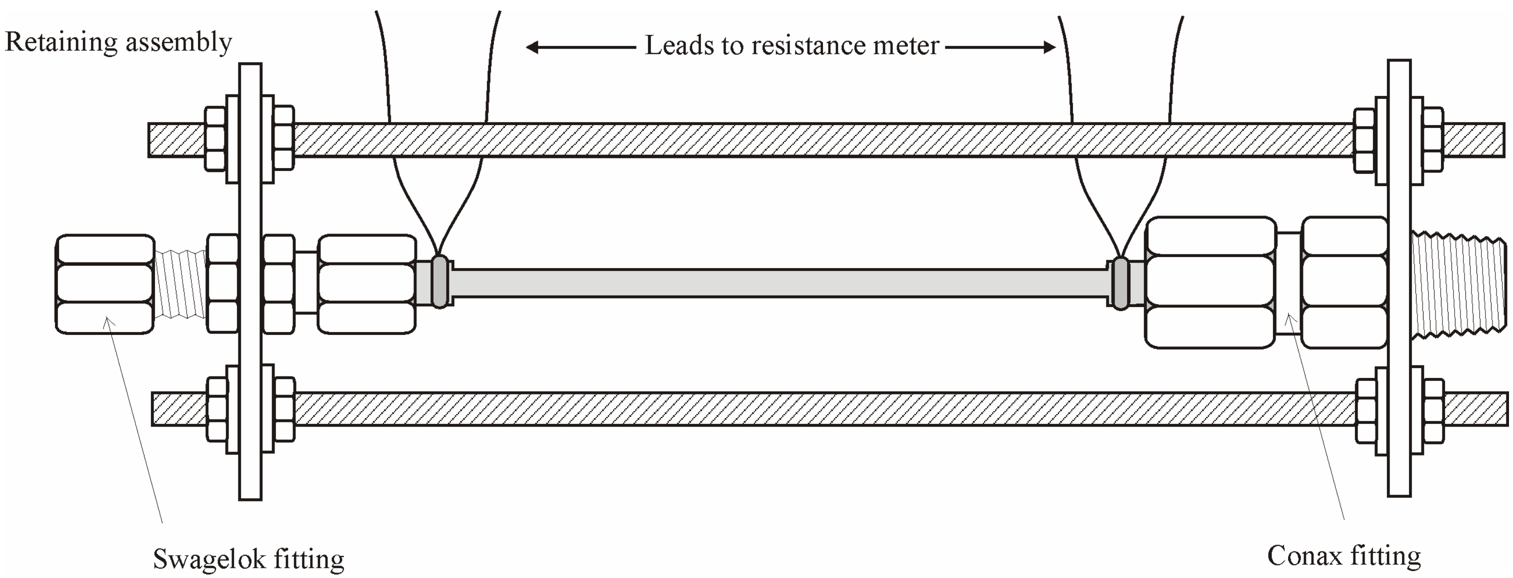
Task 4 – Full scale mockup testing to determine corrosion rates under prototypical CRDM nozzle leakage conditions including full-size nozzles, interference fits, simulated crack geometries, range of leak rates from 0.0001 to 0.3 gpm, and controlled thermal conditions.

BAC Task 2: Impact Flow Loop
Program Description

- Main Test Characteristics
  - Loop tests
  - Perpendicular jet impacting
  - Rectangular coupons
  - 18 runs; each 1 wk
  - pH 6.9, 7.15, and 7.4 primary water
  - Electrical resistivity and ECP monitoring
  - Profile, metallography, SEM, EDX, and Auger characterization

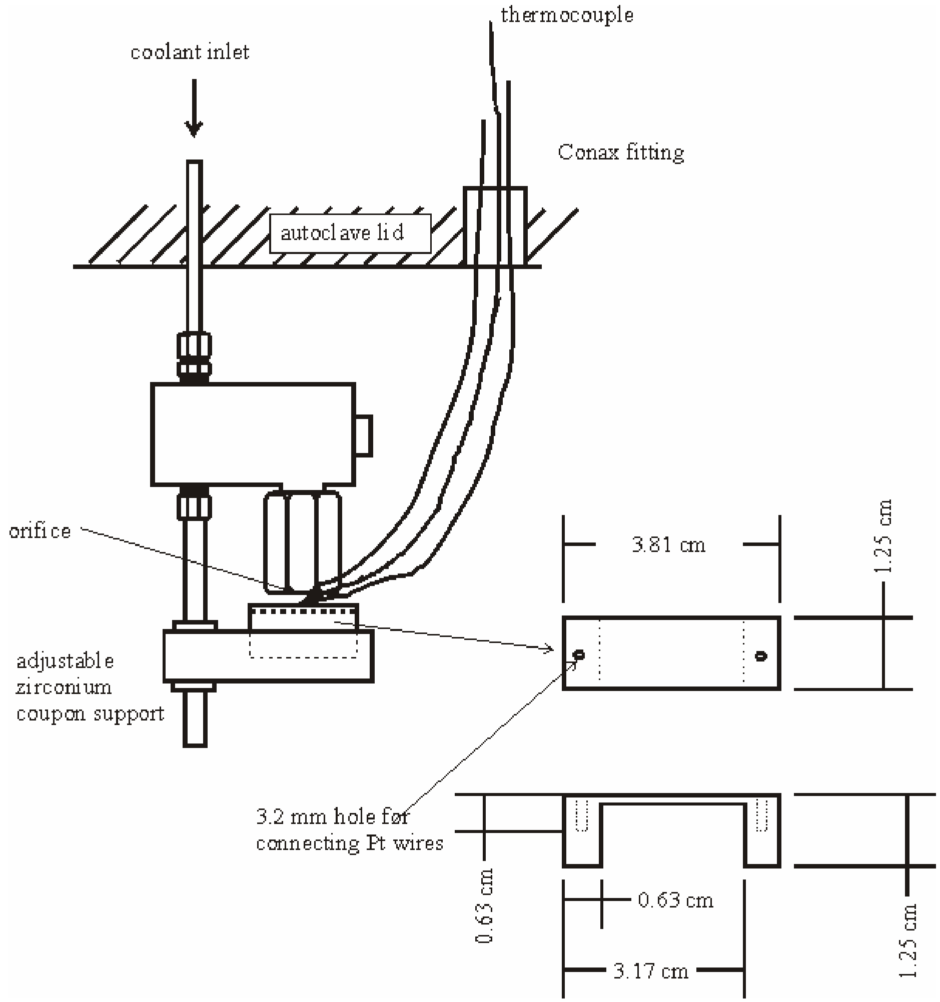
BAC Task 2: Impact Flow Loop
Program Description

- *Corrosion Probe Development at UNB*—Resistance probe for sensitive measurement of corrosion rate in flowing, high-temperature water



BAC Task 2: Impact Flow Loop
Program Description

- *Jet Impingement Apparatus Developed for BAC Testing*



BAC Task 2: Impact Flow Loop
Program Description

Experimental Plan—Test Matrix

$pH_{300°C}$	$[H_3BO_3]$ ppm as B	[LiOH] ppm as Li	Flow rate - ml/min (gal/min)					
			50 (0.013)	125 (0.033)	200 (0.053)	275 (0.073)	350 (0.092)	425 (0.112)
6.9	1500	2.66	**1**	**2**	**3**	**4**	**5**	**6**
7.4	100	1.12	**7**	**8**	**9**	**10**	**11**	**12**
7.15	850	2.66	**13**	**14**	**15**	**16**	**17**	**18**
Orifice size required for 2250 psi pressure drop (mm)			0.091	0.144	0.183	0.213	0.240	0.265

- Total of 18 runs, each of 1 week duration.
- For each test, the parameters to be controlled and measured are:
  - pH (boron and lithium)
  - coolant oxygen concentration
  - temperature
  - pressure
  - flow rate
  - coupon resistance
    - thickness
    - corrosion rate
  - electrochemical corrosion potential

BAC Task 2: Impact Flow Loop
Program Description

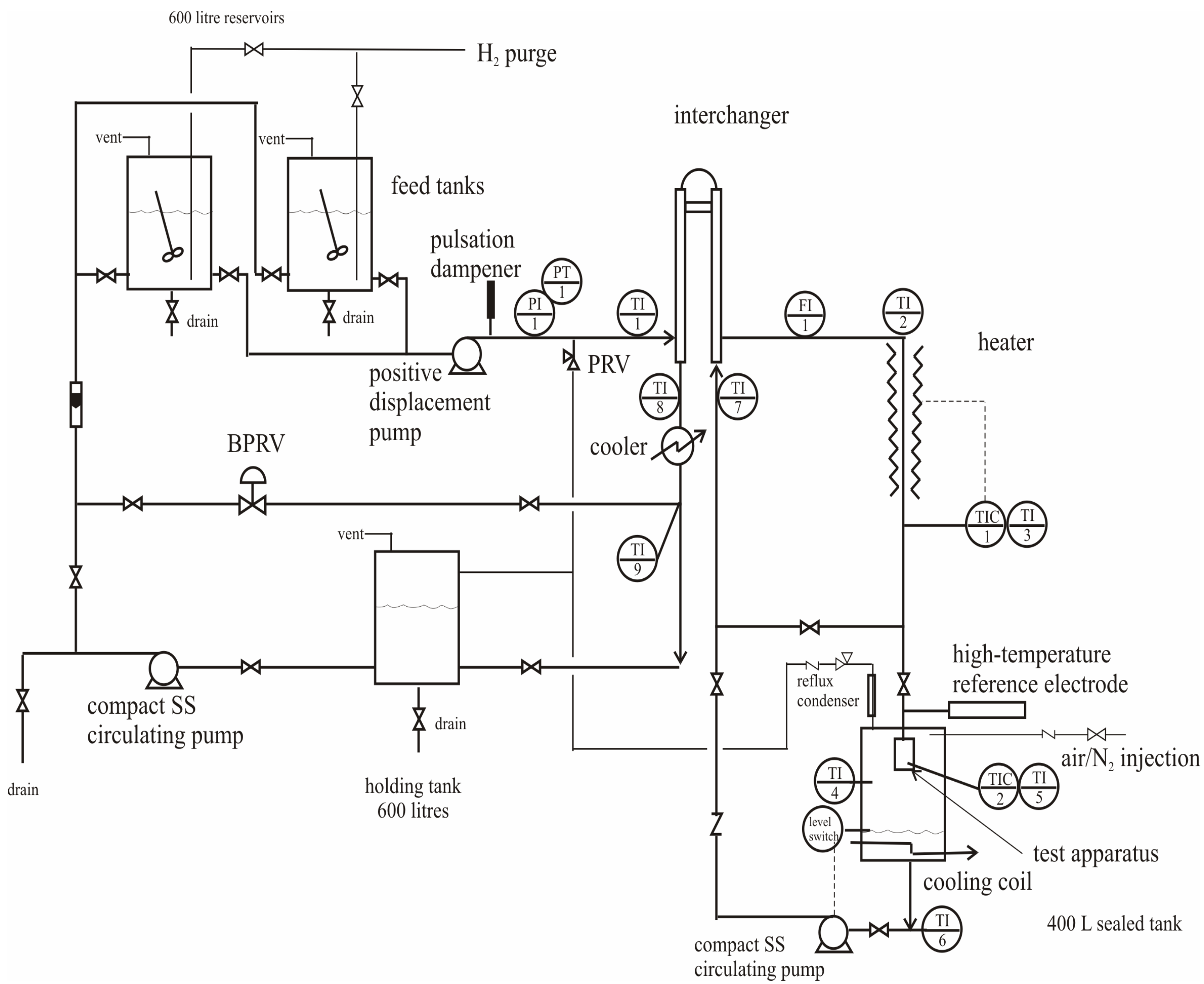
- Experimental Plan—Further Details
  - Orifice size will be changed as indicated in the test matrix to maintain ~2250 psi at the given flow rate
  - The intermediate pH runs (the last set in the test matrix) may be altered to examine other parameters at the most aggressive chemistry condition found in the first two sets. Could include:
    - orifice-to-coupon spacing (mimicking variations in cavity size)
    - autoclave temperature (mimicking cooling of the RVH)
    - coupon geometry, etc.
  - After testing is completed, should be able to generate a matrix of RV steel corrosion rates and ECP as a function of:
    - flow rate
    - operating chemistry (B, Li)

BAC Task 2: Impact Flow Loop
Program Description

- Test Challenges
  - *Solidification of boric acid in the autoclave*
    The final design of the autoclave addresses this concern.
    - The test apparatus is contained in a 100 gallon, sealed stainless steel tank.
    - A cooling coil is inserted into the bottom of the test tank to condense the steam with the condensate subsequently pumped to the holding tank.
  - *Heating of the test coupon*
    The test apparatus incorporates heating of the specimen in order to impose a heat flux on the test sample.
    - The coupon support is a heated zirconia block, which contains a standard 1 kW cartridge heater.
    - Heat transfer calculations have been performed to predict the coupon temperature as a function of power input.

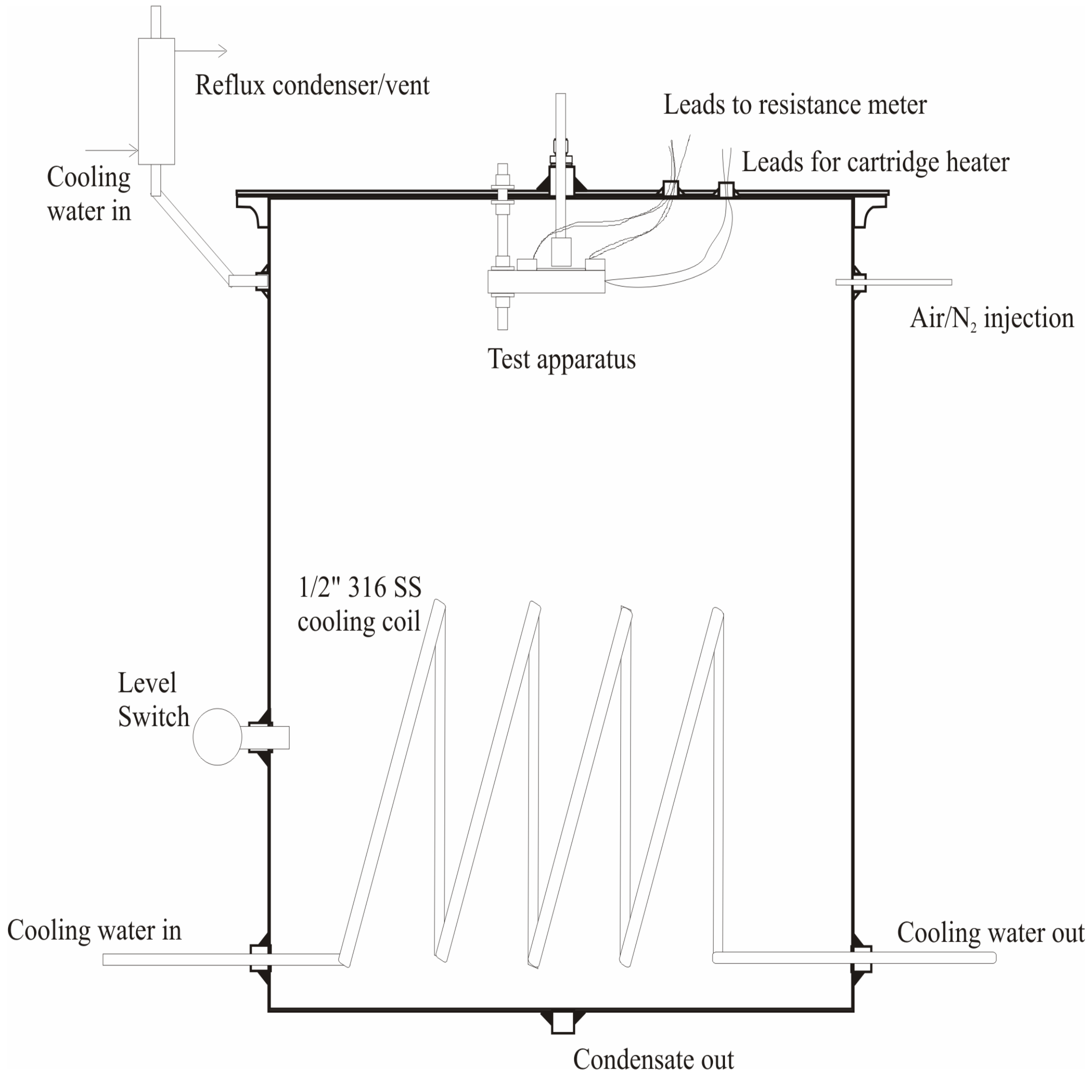
BAC Task 2: Impact Flow Loop
Program Description

- *Test Loop*



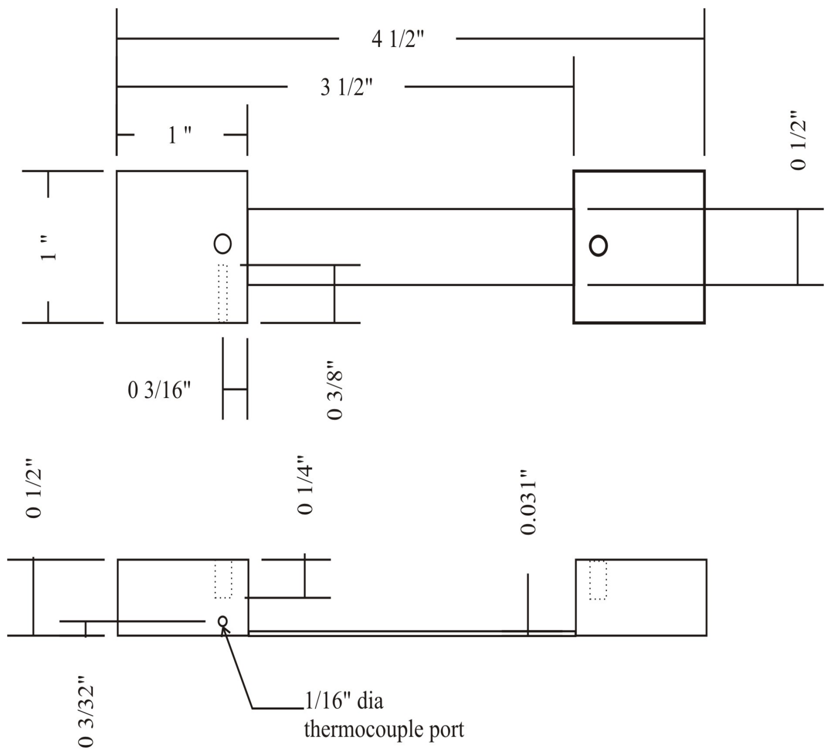
BAC Task 2: Impact Flow Loop
Program Description

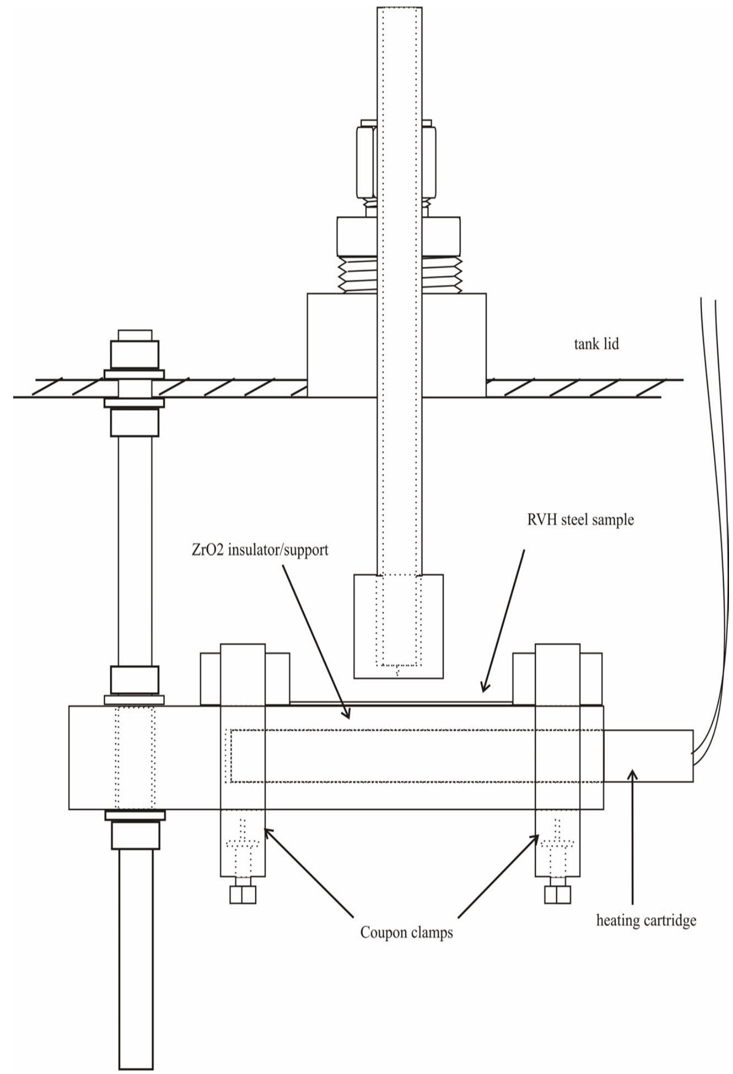
- *Test Tank*



BAC Task 2: Impact Flow Loop
Program Description

- *Coupon Geometry and Heating*





BAC Task 2: Impact Flow Loop
Current Status

- All components have arrived except the coupon support/heating block and low alloy steel samples
- Loop modifications have been completed
- Loop commissioning is in progress
- The first experiment is scheduled for mid-April
- Completion of test program including final report planned for end 2004

BAC Task 3: Separate Effects Testing
Program Description

Task 1 - Heated Crevice test device to address stagnant and low flow chemistry definition and their influence on corrosion rates.

Task 2 – Test in a flowing loop to address moderate and high flow condition with ability to monitor real time corrosion rates and ECP under laminar and impact flow.

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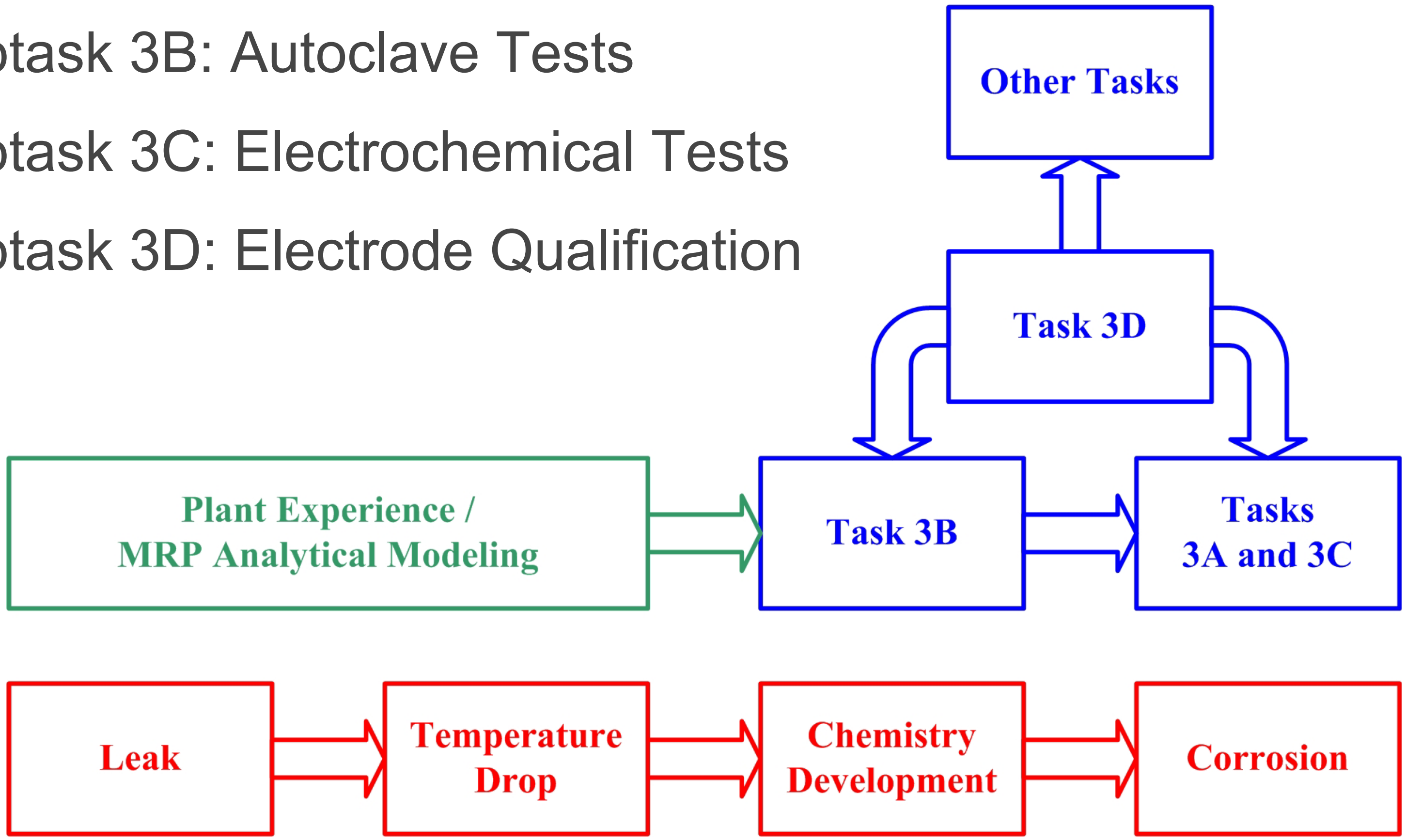
BAC Task 3: Separate Effects Testing
Task Structure

- Subtask 3A: Immersion Tests
- Subtask 3B: Autoclave Tests
- Subtask 3C: Electrochemical Tests
- Subtask 3D: Electrode Qualification



BAC Task 3: Separate Effects Testing
Task 3A: Immersion Tests

- Description:
  Immersion tests in concentrated boric acid solutions and molten boric acid at a range of temperatures and pressures. Test specimens to include bare metal specimens, creviced specimens, and galvanically coupled specimens
- Areas Addressed:
  - Corrosion rates and location for low alloy steel in a concentrated boric acid solution or molten boric acid environment
  - Galvanic corrosion behavior in these environments
  - Crevice corrosion behavior in these environments
  - Effect of moisture content on the corrosivity of molten boric acid

BAC Task 3: Separate Effects Testing
Task 3A: Immersion Tests
Experimental Setup Tested Successfully

BAC Task 3: Separate Effects Testing

Task 3A: Immersion Tests

Initial Test Plan

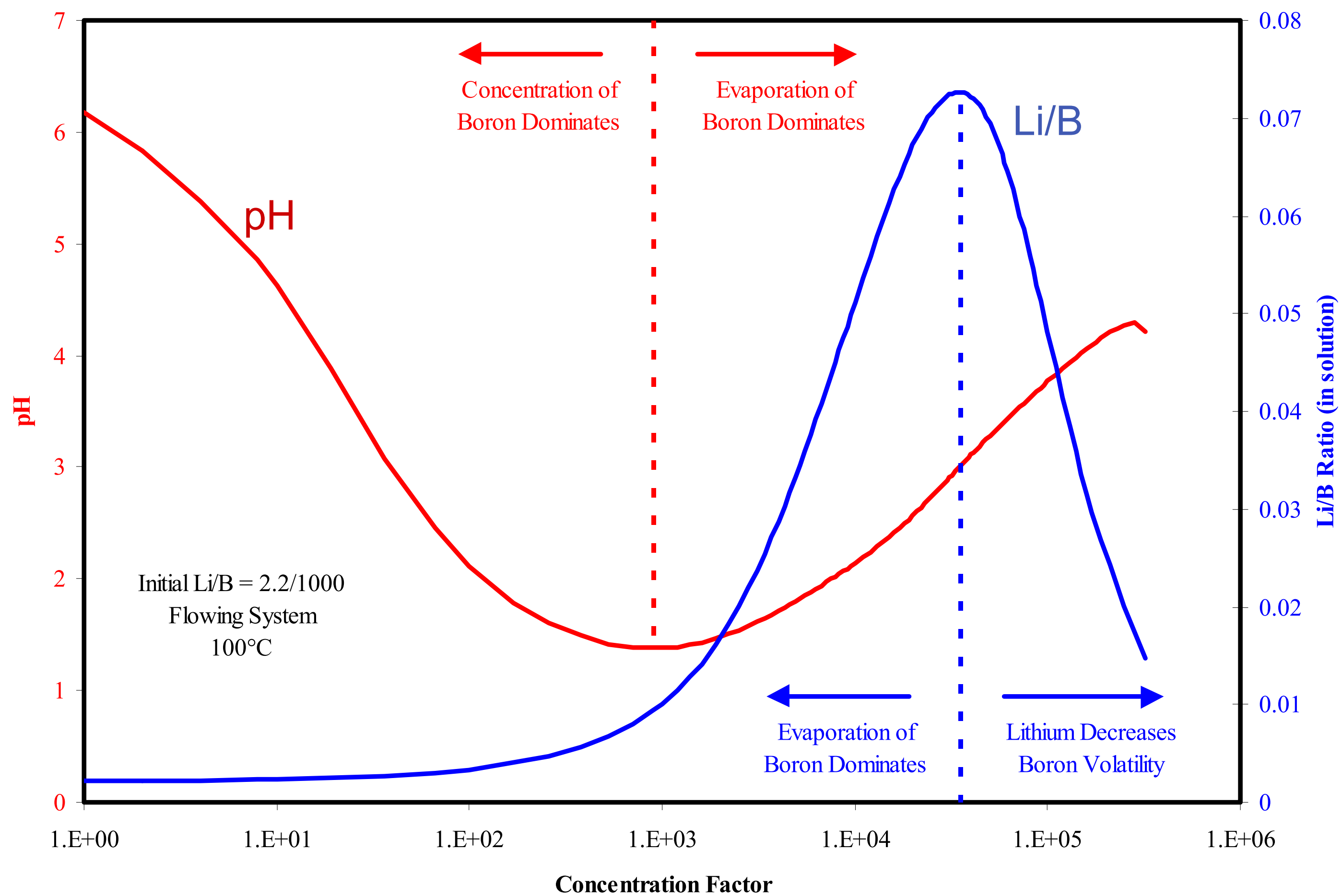
Test #	Temperature °C	[H_3BO_3]		[$LiOH\text{-}H_2O$]	
		g/kg_{water}	basis	g/kg_{water}	basis
1	100	11.4	2000 ppm B	0	Li/B = 0
2	100	1000	50:50 slurry	0	Li/B = 0
3	100	9000	10% water	0	Li/B = 0
4	100	11.4	2000 ppm B	0.024	Li/B = 0.002
5	100	1000	50:50 slurry	2.13	Li/B = 0.002
6	100	9000	10% water	19.54	Li/B = 0.002
7	100	11.4	2000 ppm B	0.607	Li/B = 0.05
8	100	1000	50:50 slurry	56.22	Li/B = 0.05
9	100	9000	10% water	919.5	Li/B = 0.05
10	200	11.4	2000 ppm B	0	Li/B = 0
11	200	1000	50:50 slurry	0	Li/B = 0
12	200	9000	10% water	0	Li/B = 0
13	200	11.4	2000 ppm B	0.024	Li/B = 0.002
14	200	1000	50:50 slurry	2.13	Li/B = 0.002
15	200	9000	10% water	19.54	Li/B = 0.002
16	200	11.4	2000 ppm B	0.607	Li/B = 0.05
17	200	1000	50:50 slurry	56.22	Li/B = 0.05
18	200	9000	10% water	919.5	Li/B = 0.05
19	315	11.4	2000 ppm B	0	Li/B = 0
20	315	1000	50:50 slurry	0	Li/B = 0
21	315	9000	10% water	0	Li/B = 0
22	315	11.4	2000 ppm B	0.024	Li/B = 0.002
23	315	1000	50:50 slurry	2.13	Li/B = 0.002
24	315	9000	10% water	19.54	Li/B = 0.002
25	315	11.4	2000 ppm B	0.607	Li/B = 0.05
26	315	1000	50:50 slurry	56.22	Li/B = 0.05
27	315	9000	10% water	919.5	Li/B = 0.05

BAC Task 3: Separate Effects Testing
Task 3B: Autoclave Chemistry Tests

- Description:
  Autoclave tests to determine chemistry under a range of temperature, pressure, and concentration conditions in which a boric acid solution is concentrated by steaming
- Areas Addressed:
  - Basic data needed to assess various corrosion mechanisms
  - Conductivity of concentrated boric acid solutions and molten boric acid
  - Effect of large local cooling on annulus chemistry (e.g., pH)
  - Time scale for dehydration of molten boric acid
  - Time scale for development of pH, conductivity, etc.

BAC Task 3: Separate Effects Testing
Task 3B: Autoclave Chemistry Tests

- *EPRI MULTEQ Predictions for pH in a Flowing System at 100°C*

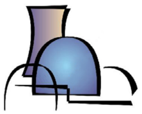


BAC Task 3: Separate Effects Testing
Task 3C: Electrochemical Tests

- Description:
  Autoclave tests to determine the corrosion rates of low alloy steel materials as a function of the electrochemical potential for the range of conditions identified in the chemistry tests

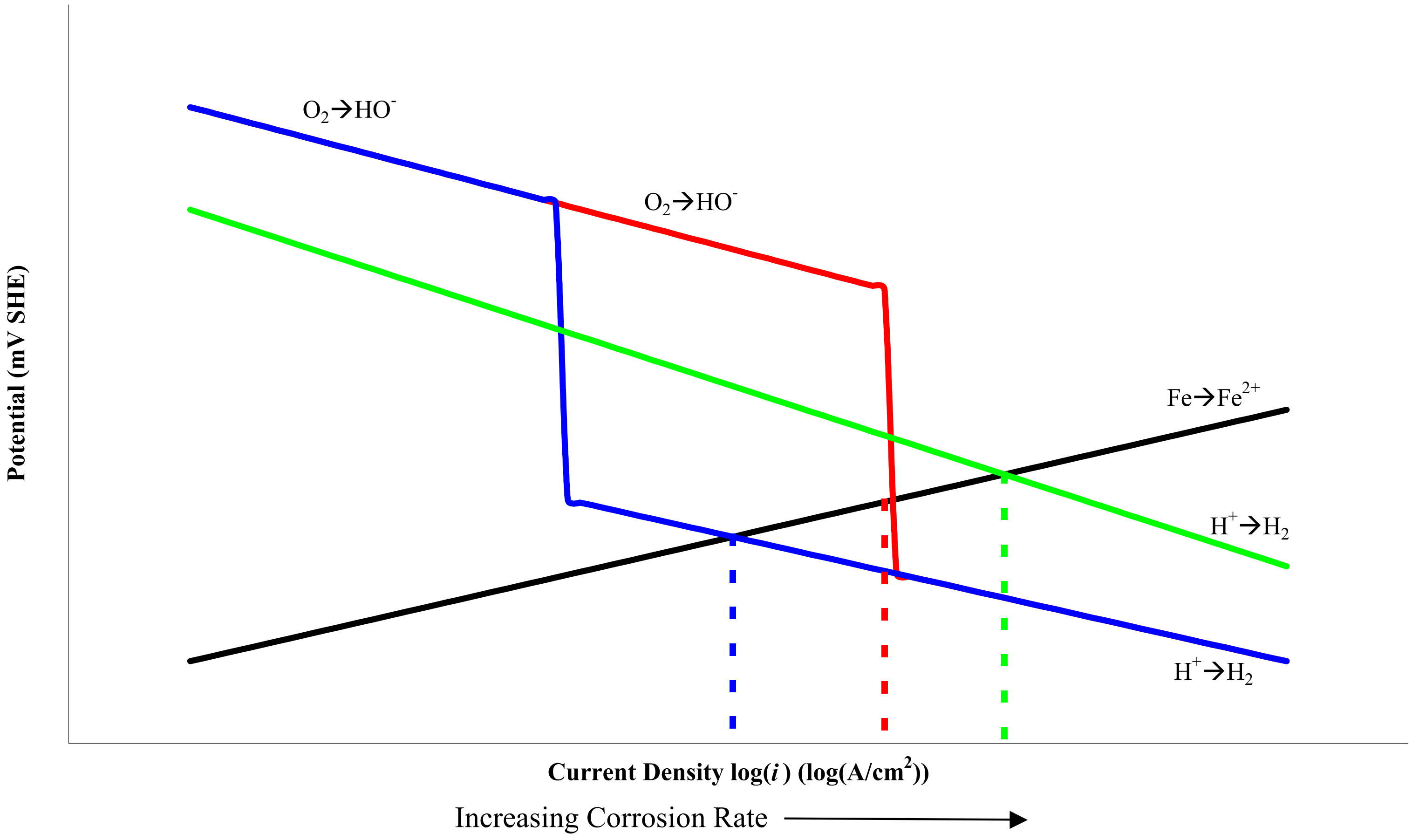
- Areas Addressed:
  - Provides theoretical basis for generalizing results
  - Anodic electrochemical polarization curves for low alloy steel in concentrated boric acid environments
  - Cathodic electrochemical polarization curves for Alloy 600 in concentrated boric acid environments

Adaptations of ASTM G5/G59/G96/G102



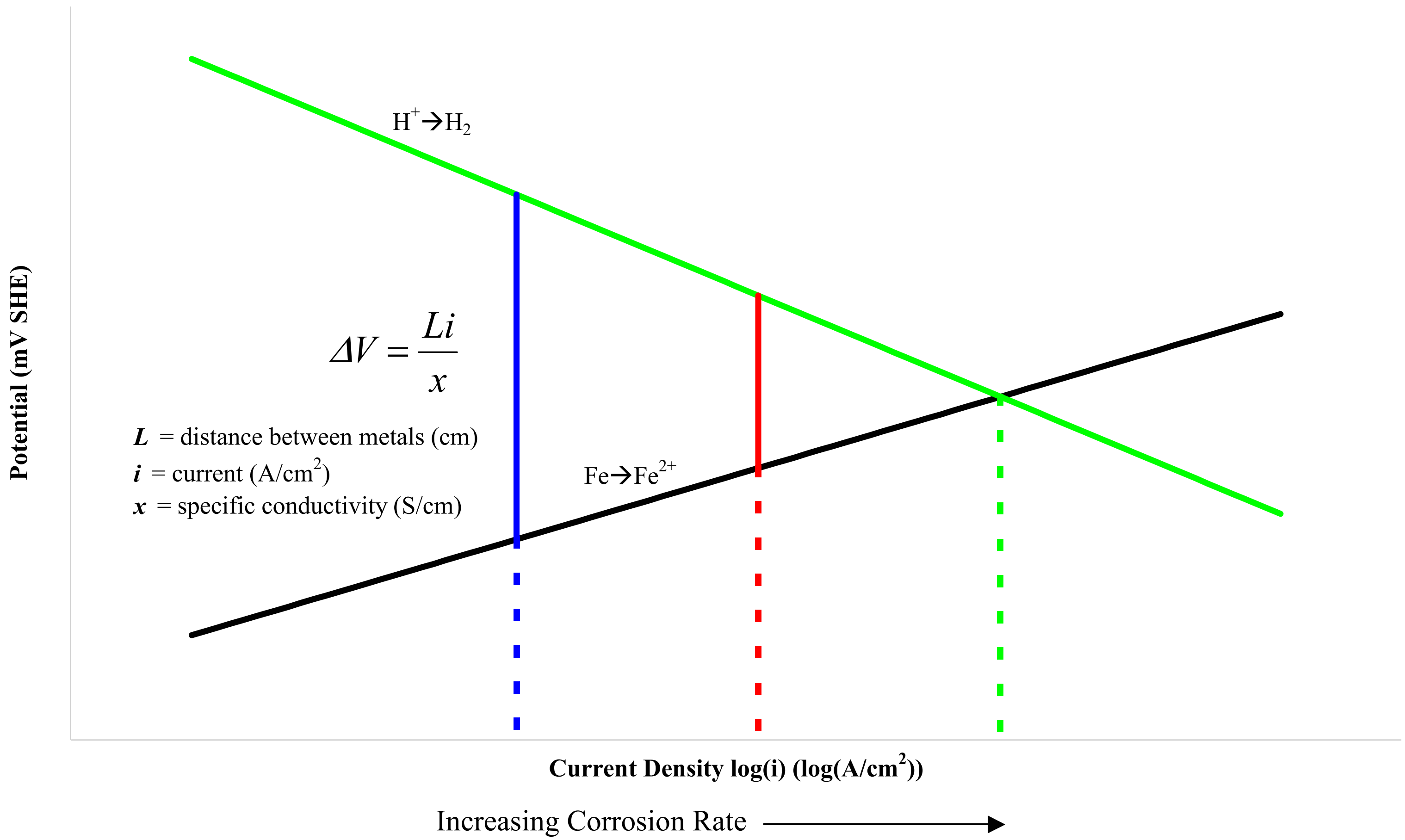
BAC Task 3: Separate Effects Testing
Task 3C: Electrochemical Tests

- *Galvanic Corrosion Electrochemistry for a Non-Passivating Metal*



BAC Task 3: Separate Effects Testing
Task 3C: Electrochemical Tests

- *IR Drop Effect*



BAC Task 3: Separate Effects Testing
Task 3D: Electrode Qualification

- Description:
  Qualification of electrochemical reference and pH electrodes for characterization of concentrated boric acid solutions
- Areas Addressed:
  - Required to obtain accurate characterization of solution conditions
  - Allows comparison and generalization of specific corrosion testing results
  - Required if detailed corrosion modeling (FEA) is to be performed

BAC Task 3: Separate Effects Testing
Current Status

- Task 3A: Immersion Tests
  - Preliminary test completed to test procedures
  - Initial test plan approved and equipment procured
  - Tests ready to go upon receipt of corrosion coupons
- Task 3B: Autoclave Chemistry Tests
  - Test plan to be completed after results of Tasks A and D become available
- Task 3C: Electrochemical Tests
  - Preliminary test design work in progress
  - Test plan to be completed after results of Tasks A and D become available
- Task 3D: Electrode Qualification
  - Electrode designs identified
  - Qualification tests underway

BAC Task 4: Full Scale Mockup Tests
Program Description

Task 1 - Heated Crevice test device to address stagnant and low flow chemistry definition and their influence on corrosion rates.

Task 2 – Test in a flowing loop to address moderate and high flow condition with ability to monitor real time corrosion rates and ECP under laminar and impact flow.

Task 3 – Separate effects tests to obtain data on corrosion rates for conditions not previously tested such as galvanic coupling and corrosion in contact with molten boric acid.

Task 4 – Full scale mockup testing to determine corrosion rates under prototypical CRDM nozzle leakage conditions including full-size nozzles, interference fits, simulated crack geometries, range of leak rates from 0.0001 to 0.3 gpm, and controlled thermal conditions.

BAC Task 4: Full Scale Mockup Tests
Program Description

- Main Test Characteristics
  – Full size CRDM nozzle geometry
  – Design team collaboration
  – HIP'd EDM slit 0.25, 0.75, and 1.23" long
  – 550–600°F
  – Use Existing BAC test facility
  – A range of nozzle fits
  – Leak rates from 0.0001 to 0.3 gpm
  – UT monitoring of wastage during test
  – Leak rate vs. crack geometry
  – Extent of cooling
  – Sensitivity of visual inspection

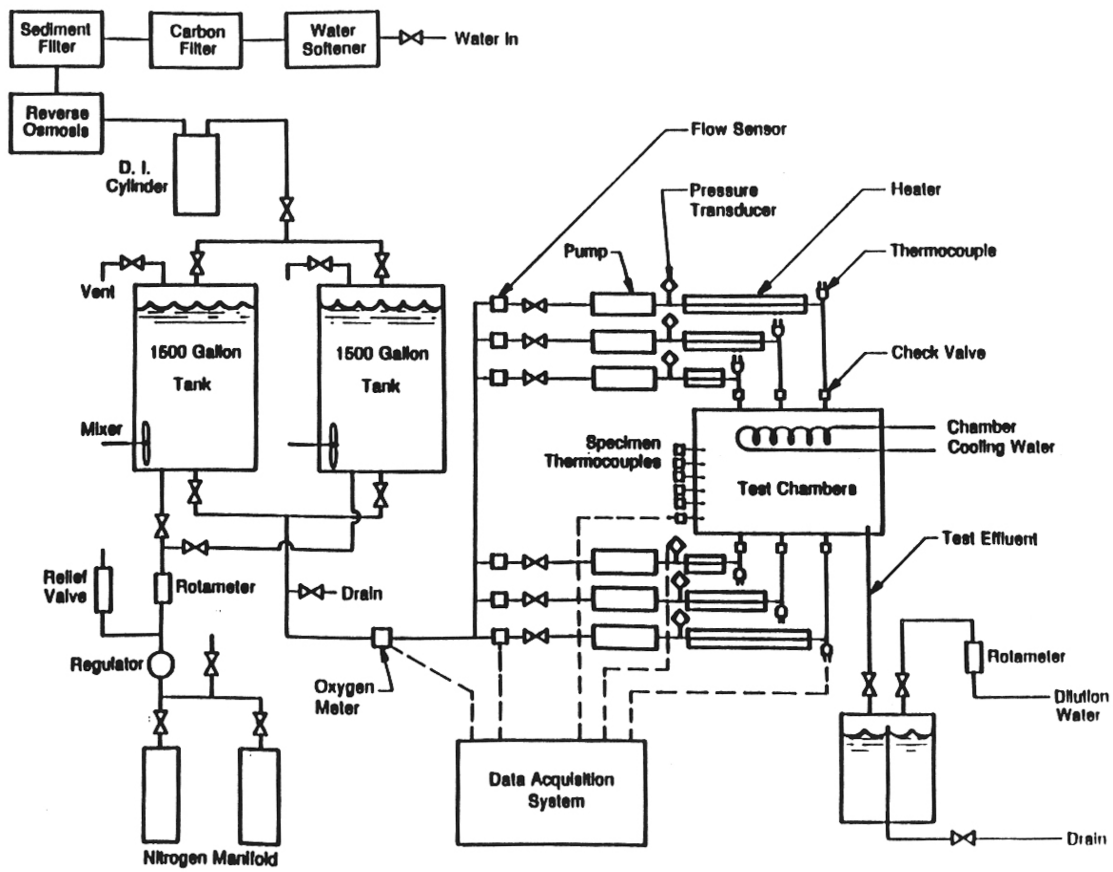
BAC Task 4: Full Scale Mockup Tests
Program Description

- Test Parameters for Possible Investigation

– Leak rates	0.0001, 0.001, 0.01, 0.10, and 0.30 gpm
– Crack lengths	0.25, 0.75, and 1.25 inch
– Crack geometry	Simulated through-wall axial PWSCC crack
– Nozzle fits	0.001” interference to 0.010” diametral clearance
– Counterbore	No counterbore to 0.005” radial counterbore
– Pre-existing cavity	No cavity, volume of 1-10 in3
– Temperature	550°F to 600°F (before cooling)
– Insulation	Direct contact and stand-off

BAC Task 4: Full Scale Mockup Tests
Program Description

- *Test Facility (Design for Previous 1996–97 Testing)*

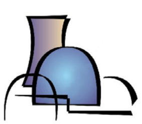


BAC Task 4: Full Scale Mockup Tests
Program Description

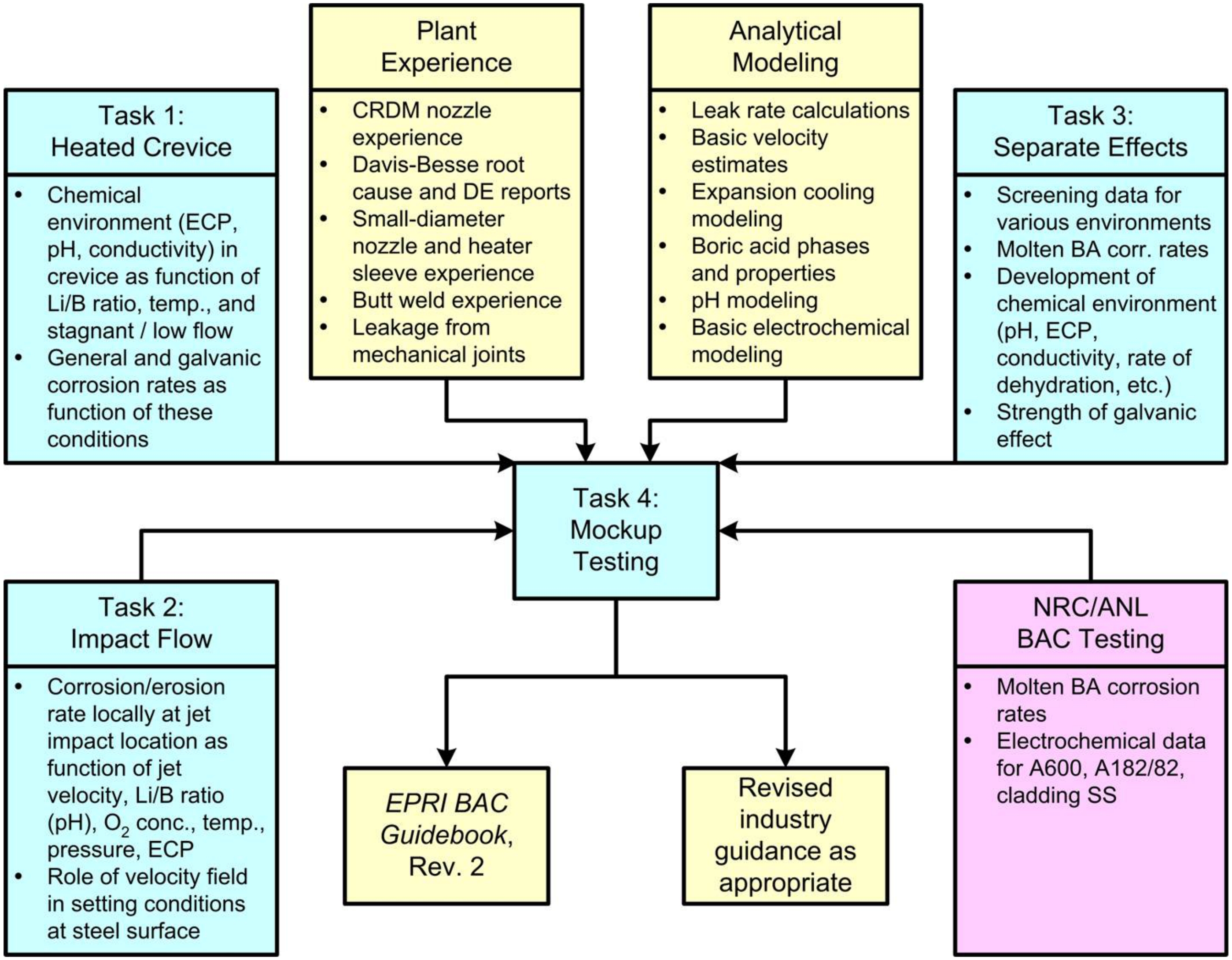
- Planned Test Section Configuration
  - Goal is to select test specimen that
    - Represents prototypical conditions
    - Is easy to fabricate and of relatively low cost
    - Is of a size that would support about five simultaneous tests
  - Key features
    - Actual Alloy 600 CRDM nozzle dimensions
    - Modular design with bolted connections and gasket seals
    - Crack simulated by EDM slit subjected to Hot Isostatic Press (HIP) method to produce near prototypical crack exit velocities
    - Carbon steel rings to simulate head
      - Large enough to simulate thermal conditions for wastage up to about ½-1" depth
    - Controlled leak rates
    - Volume of fluid under pressure kept low by use of sealed leakage annulus

BAC Task 4: Full Scale Mockup Tests
Program Description

- Previous MRP Analytical Modeling (Since 2002)
  - Short-term confirmation of plant experience that large wastage cavities are unlikely for small leak rates
  - Inputs to probabilistic wastage model presented in MRP safety assessment for reactor vessel closure heads (MRP-110, currently under final MRP review)
  - Help define needs for additional BAC test data
- Analytical Modeling Input to Mockup Testing
  - Leak rate calculations, expansion cooling modeling, boric acid phases and properties, pH, and electrochemistry
  - Establish the thermal boundary conditions for simulating plant conditions (placement and power for heaters, insulation design, and TC locations)
  - Determine simulated crack parameters for achieving desired leak rates
  - Help establish the adaptive test matrix
  - Support data interpretation and application



BAC Task 4: Full Scale Mockup Tests
Program Description



BAC Task 4: Full Scale Mockup Tests
Program Description

- Questions Addressed
  - The minimum leak rate at which high corrosion rates may occur
  - The role of steam cutting and two phase jet impingement erosion
  - The role of flow effects on the rate of corrosion and the shape of the developing cavity
  - The relationship between crack/annulus geometry and leak rate
  - The minimum leak rate leading to pooling / turbulent wetting of liquid on the head top surface
  - The fraction of released boron that is transported to a remote location as opposed to forming deposits locally
  - The sensitivity of visual inspections
  - The effect of the initial nozzle fit
  - The effect of the insulation configuration
  - The effect of pre-existing boron deposits on the head top surface.

BAC Task 4: Full Scale Mockup Tests
Current Status

- Preliminary tasks have been completed
  - Conceptual design of modular mockup
  - Preliminary test matrix
  - List of planned loop improvements
  - Basic thermal and analytical modeling work (previous MRP task)

BAC Task 4: Full Scale Mockup Tests
Current Status

- Main effort will begin early 2005 when results of Tasks 1, 2, and 3 and the NRC/ANL work are available
  - *Additional analytical modeling work*
    Additional thermal and chemical modeling of annulus/cavity environment as function of leak rate, etc.
  - *Preparation of detailed test plan*
    Refinement of mockup design and test matrix based on other tasks and analytical modeling
  - *Testing and analysis of results*
    An adaptive test matrix whereby on-line measurements are used to improve the remaining matrix
- Program including final reported expected by end of 2006