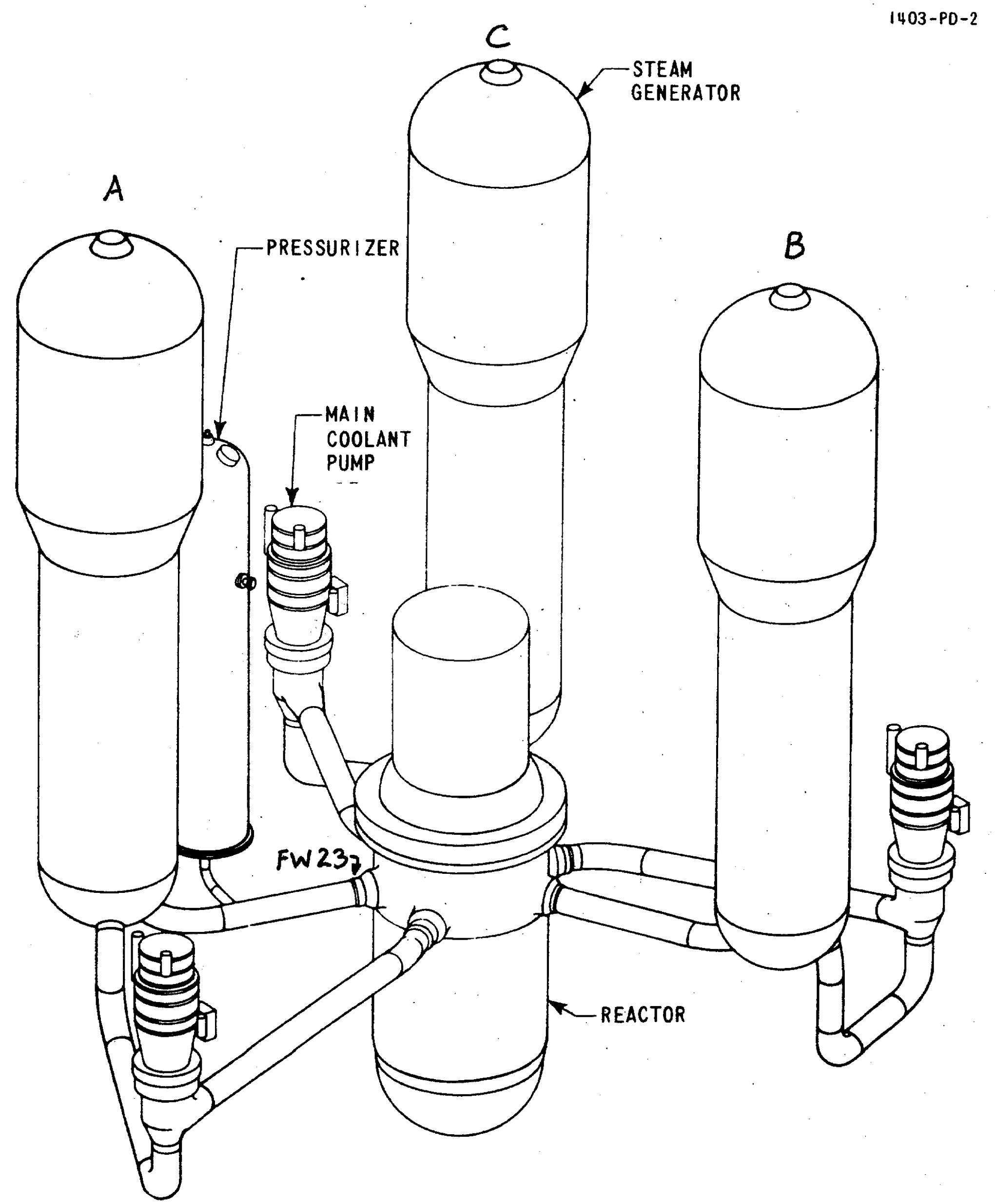
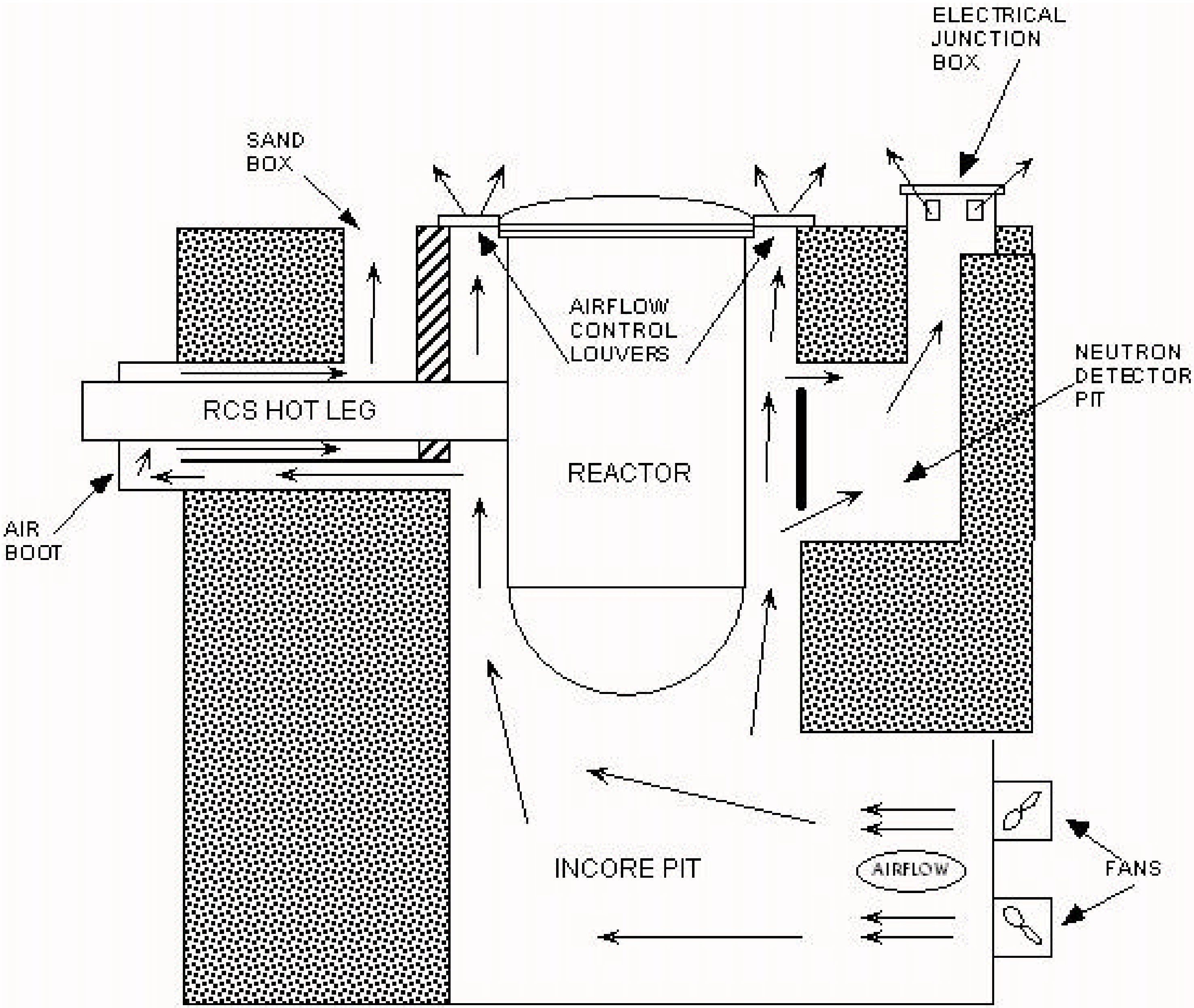
V. C. SUMMER NUCLEAR STATION
Alpha Hot Leg
Evaluation and Repair

Presented at the
V.C. Summer Nuclear Station
Jenkinsville, SC
January 18, 2001

SCE&G Agenda

- Overview & Defense in Depth - Greg Halnon
- Why We Are Safe
  – Repair of Pipe - Ron Clary
- What We Did To Ensure Safety
  – Root Cause - Gary Moffatt
  – Extent of Condition - Bob Waselus
- How Safety Margins Are Maintained
  – Future Actions - Mel Browne
- Summary - Greg Halnon


1403-PD-2
C
STEAM
GENERATOR
A
PRESSURIZER
B
MAIN
COOLANT
PUMP
FW23
REACTOR


ELECTRICAL
JUNCTION
BOX
SAND
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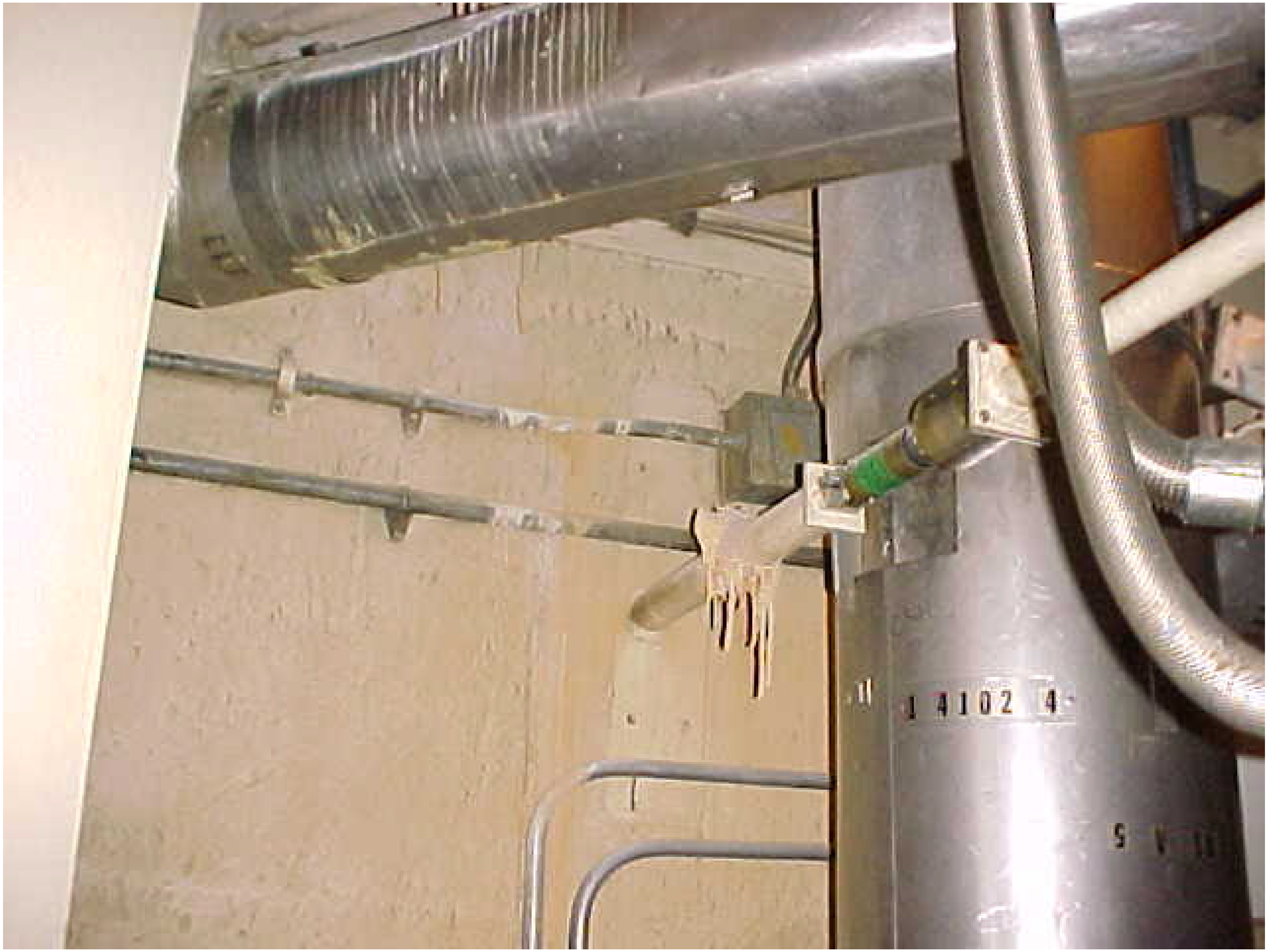
AIRFLOW
CONTROL
LOUVERS
NEUTRON
DETECTOR
PIT
RCS HOT LEG
REACTOR
AIR
BOOT
INCORE PIT
AIRFLOW
FANS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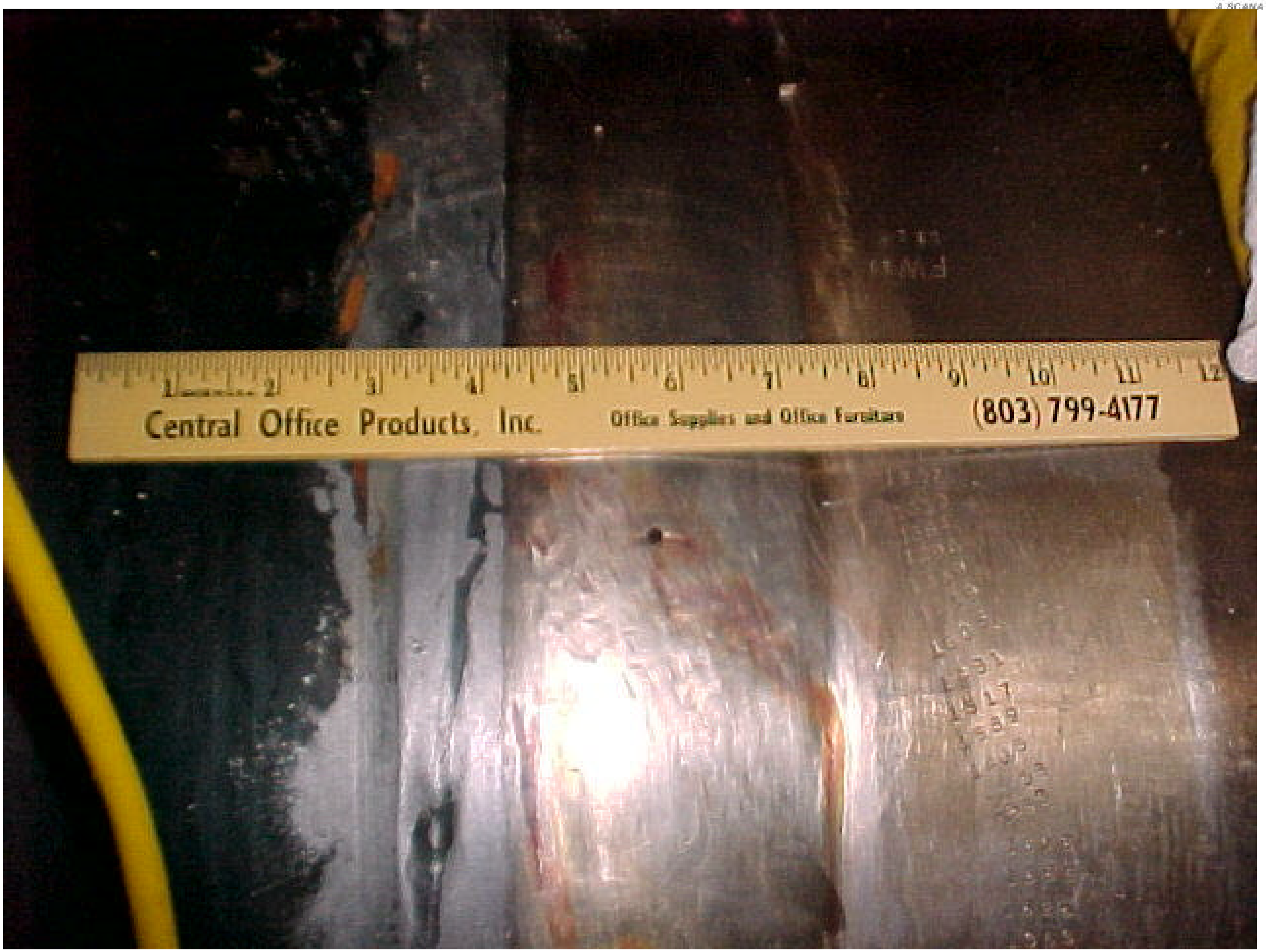
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Facts

- Leak Was Very Small
- Below the Threshold for Radiation Instrumentation to Detect
  - Fuel Had a High Level of Integrity
- No Leakage Trends Indicated This Leak Existed.
- No Effect on Operation of the Plant

Integrated Strategy

- Root Cause ⟷ Repair ⟷ Compliance
- Industry Experts Augmented VCSNS Staff
- 3rd Party Reviews Ensured:
  - Comprehensive Strategy
  - Technical Approach
  - Regulatory Compliance
- Worked in Parallel With Refueling Activities

Integrated Strategy Results

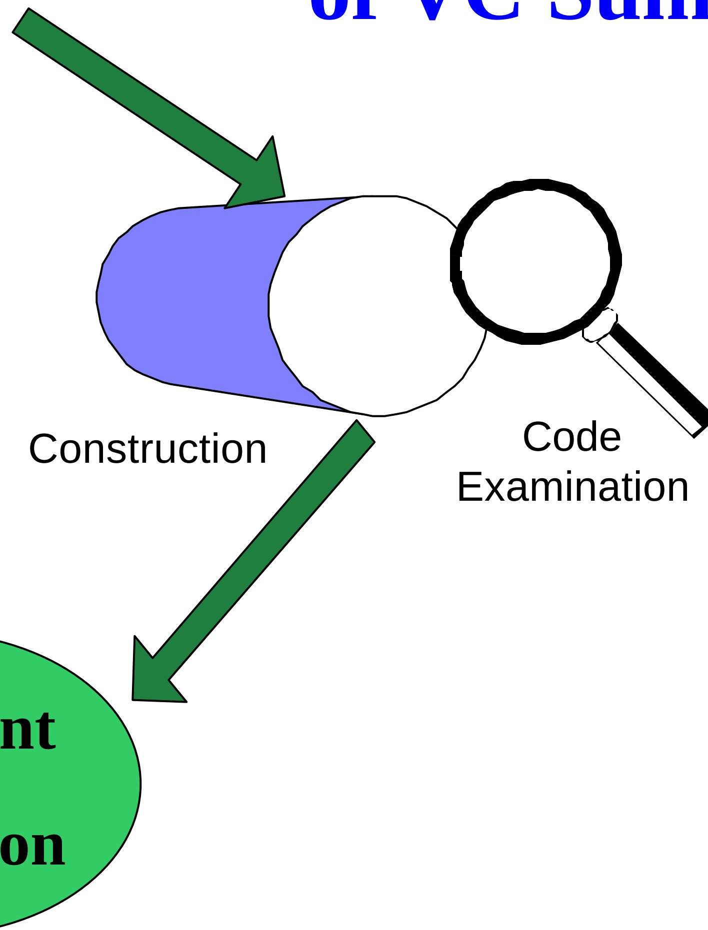
- Key Conclusions
  - Root Cause of Alpha Hot Leg Crack: PWSCC With Extensive Weld Repairs in Inconel Alloy 82/182
  - Ultrasonic Inspection Did Not See Some Eddy Current Indications In Alpha Hot Leg
    - Other Welds Contain Some Eddy Current Indications
    - Technical Evaluation To Show Acceptable Operation
  - Future Inspections In Next Two Outages And Monitoring Enhancements To Provide Further Assurance

Defense In Depth

Programs, Equipment, Structures, and Human Performance Which Provide Diverse and Redundant Levels of Assurance for Prevention of a Safety Significant Event.

During Construction of VC Summer

Plant Design Margins



Defense in Depth

Challenge to Safety

Safe Plant

Operation

Challenge to Safety

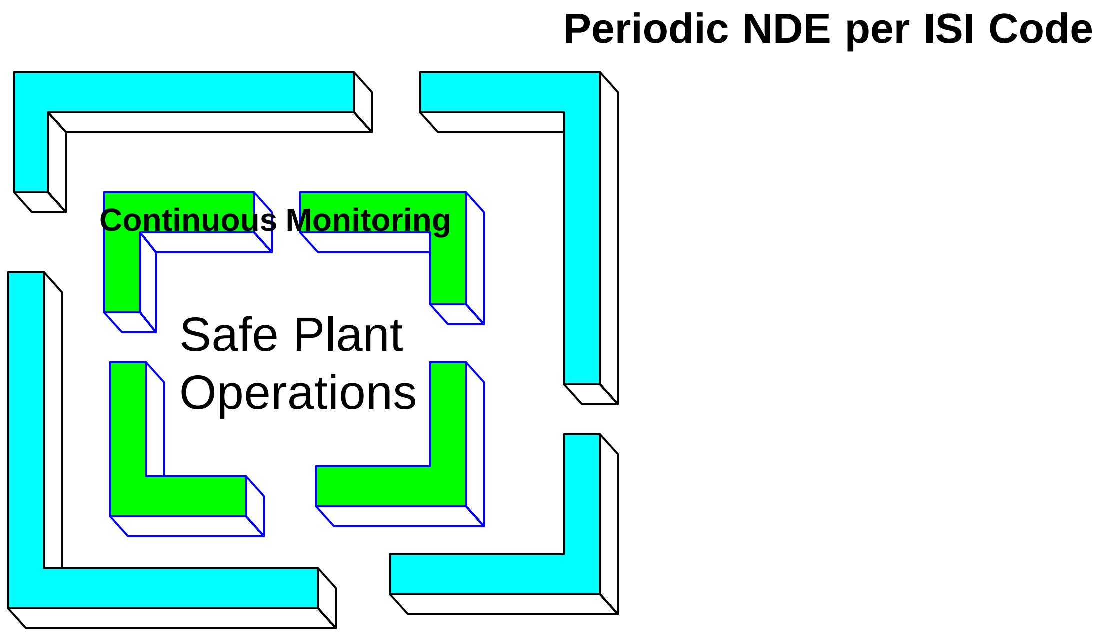
Defense in Depth

Challenge to Safety

Continuous Monitoring

Challenge to Safety

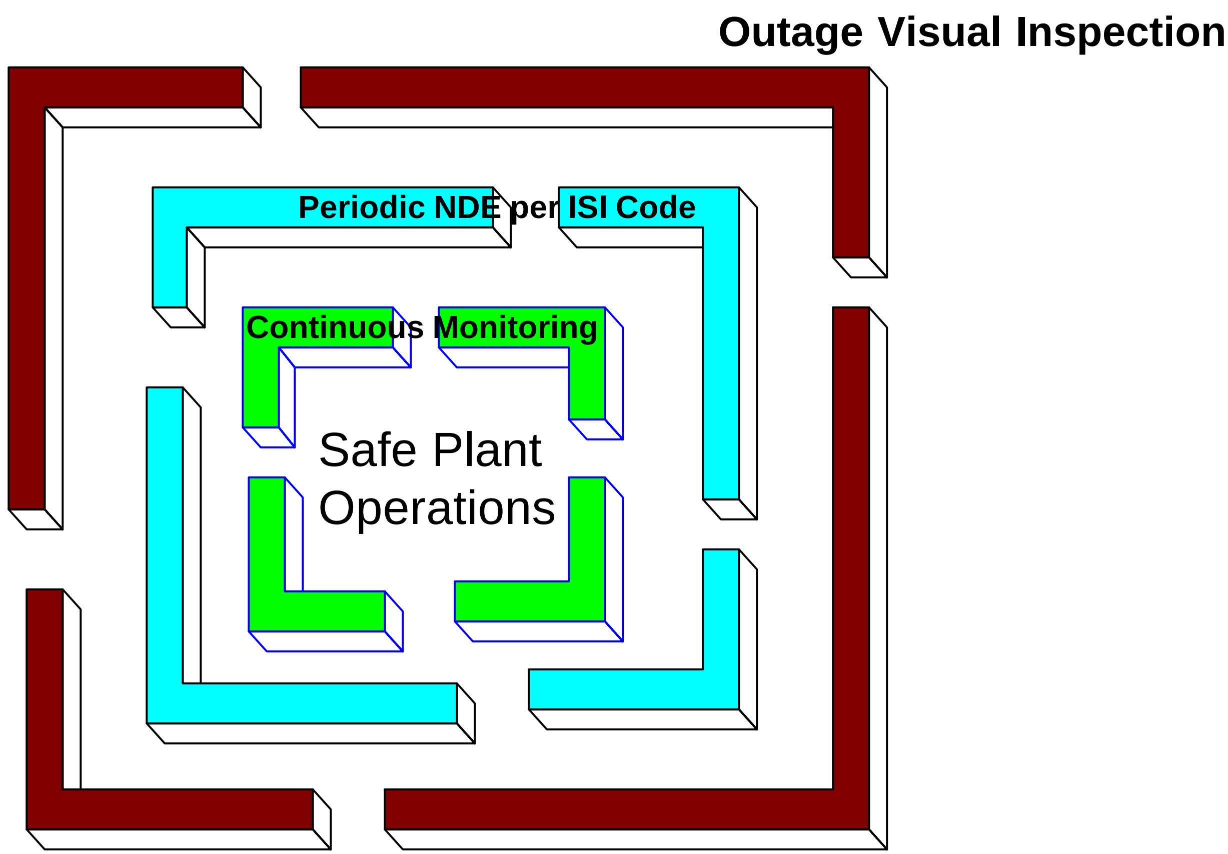
Challenge to Safety



Challenge to Safety

Defense in Depth

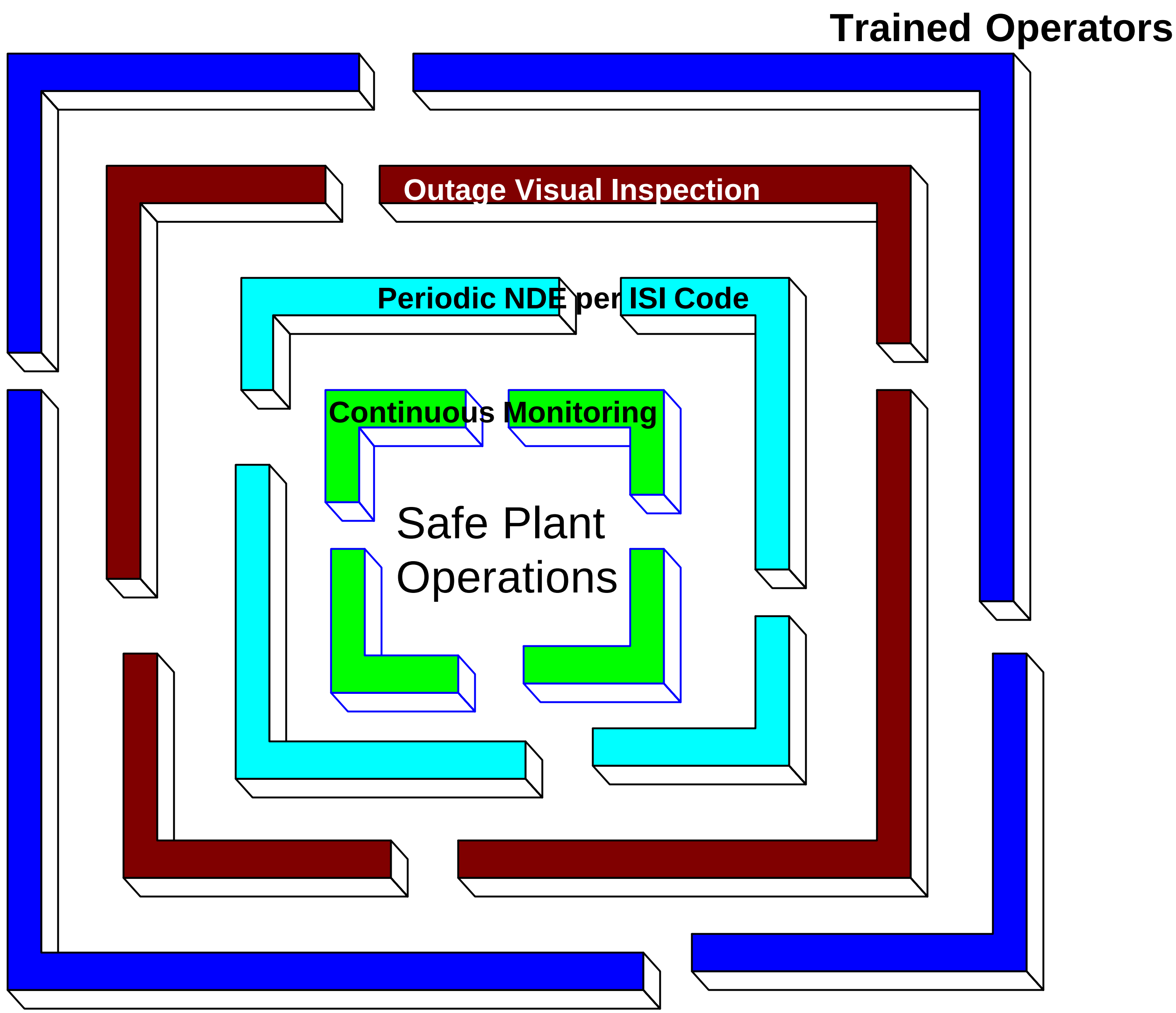
Challenge to Safety



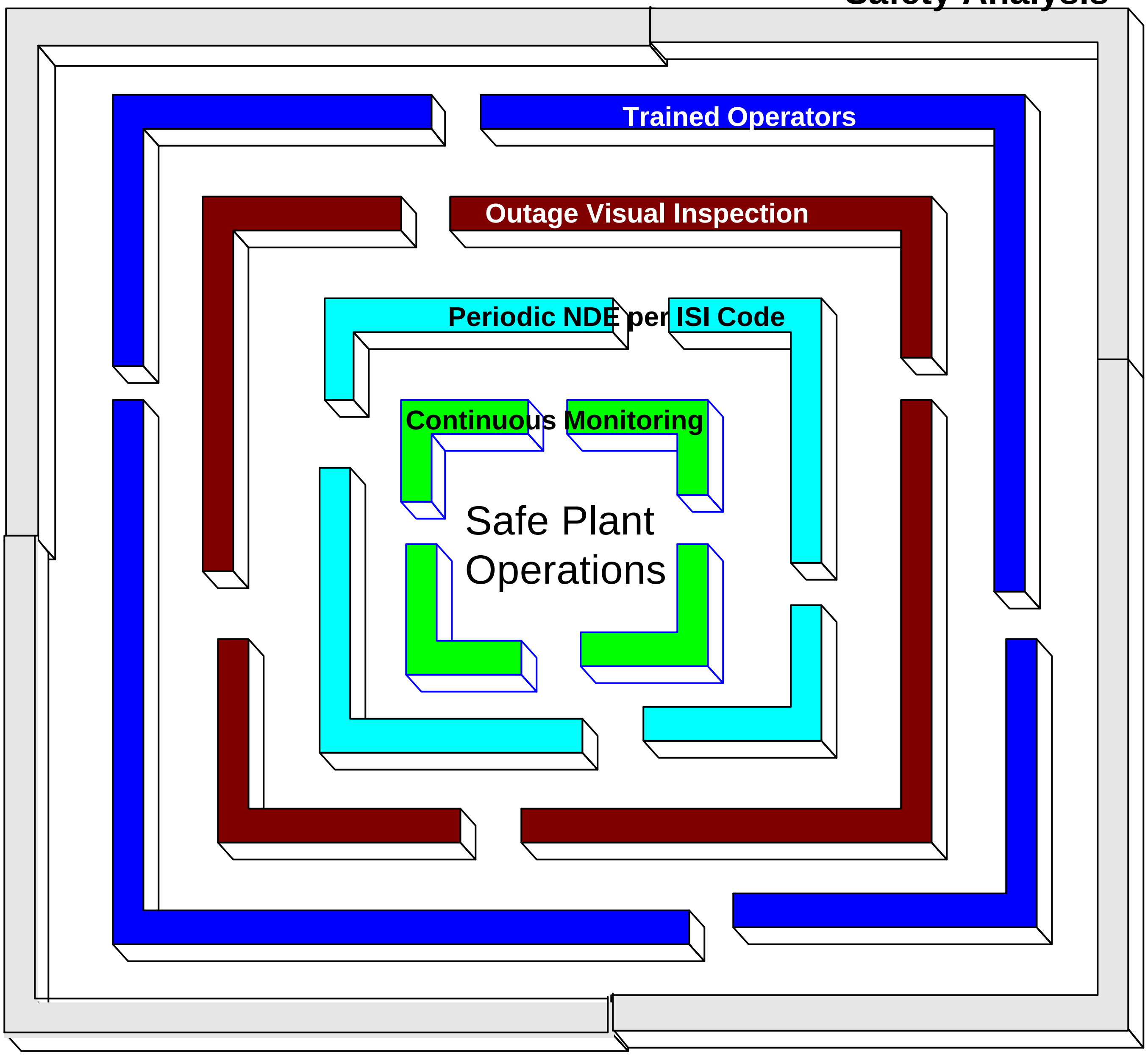
Challenge to Safety

Defense in Depth

Challenge to Safety



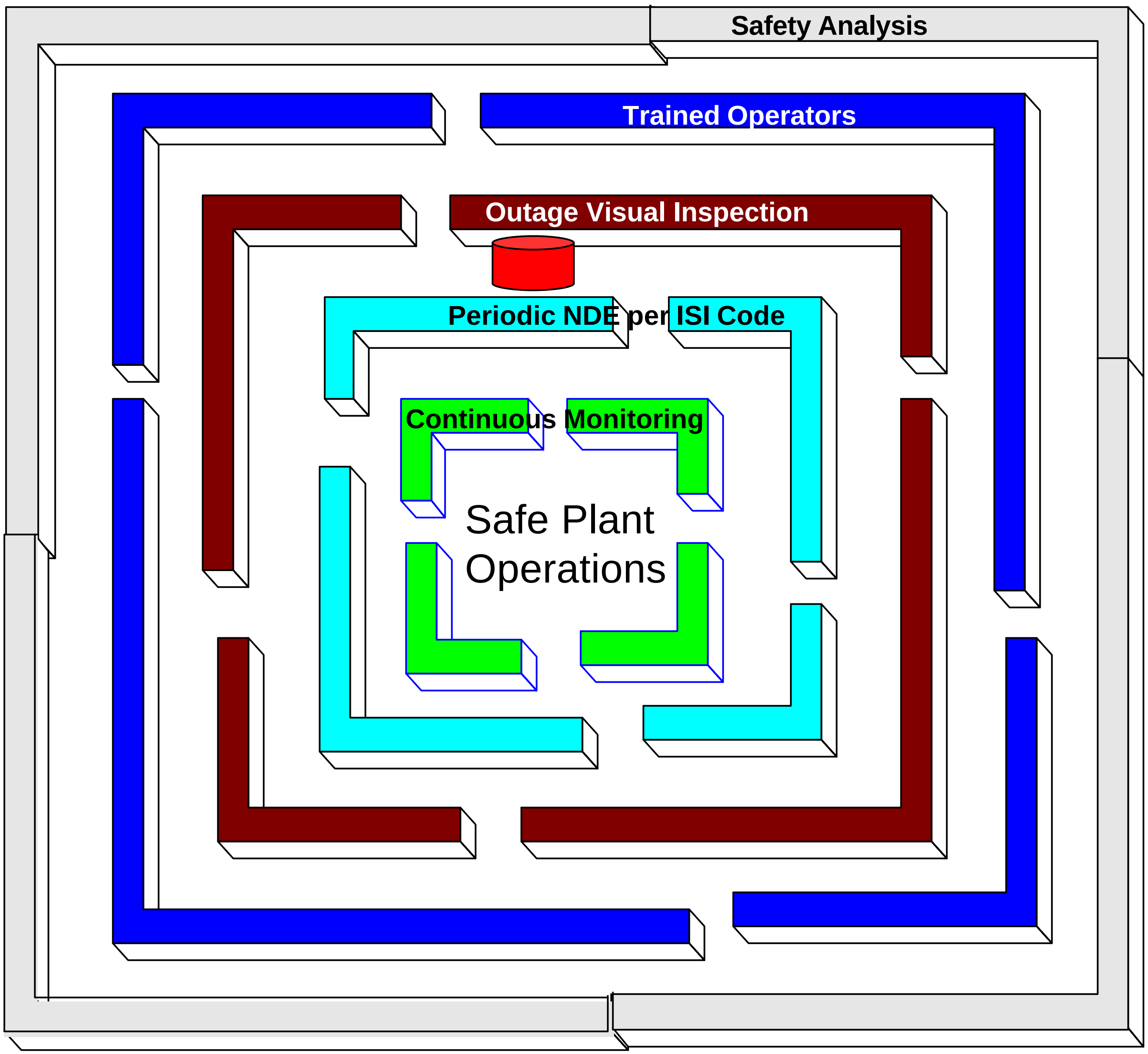
Challenge to Safety



Challenge to Safety

Challenge to Safety

Challenge to Safety



Challenge to Safety

End Point of This Effort

- Conclusion Is:
  - – Alpha Hot Leg Is Unique
  - – Commonalties in Other Welds Are Addressed
  - – Plant Is Safe for Start Up:
    - Pipe and Welds Meet Code Requirements
    - Repair Bounds Probable Failure Mechanisms
    - Extent of Condition Is Evaluated
  - – Ready for Continued Safe Operation

Why We Are Safe

Pipe Repair

Ron Clary

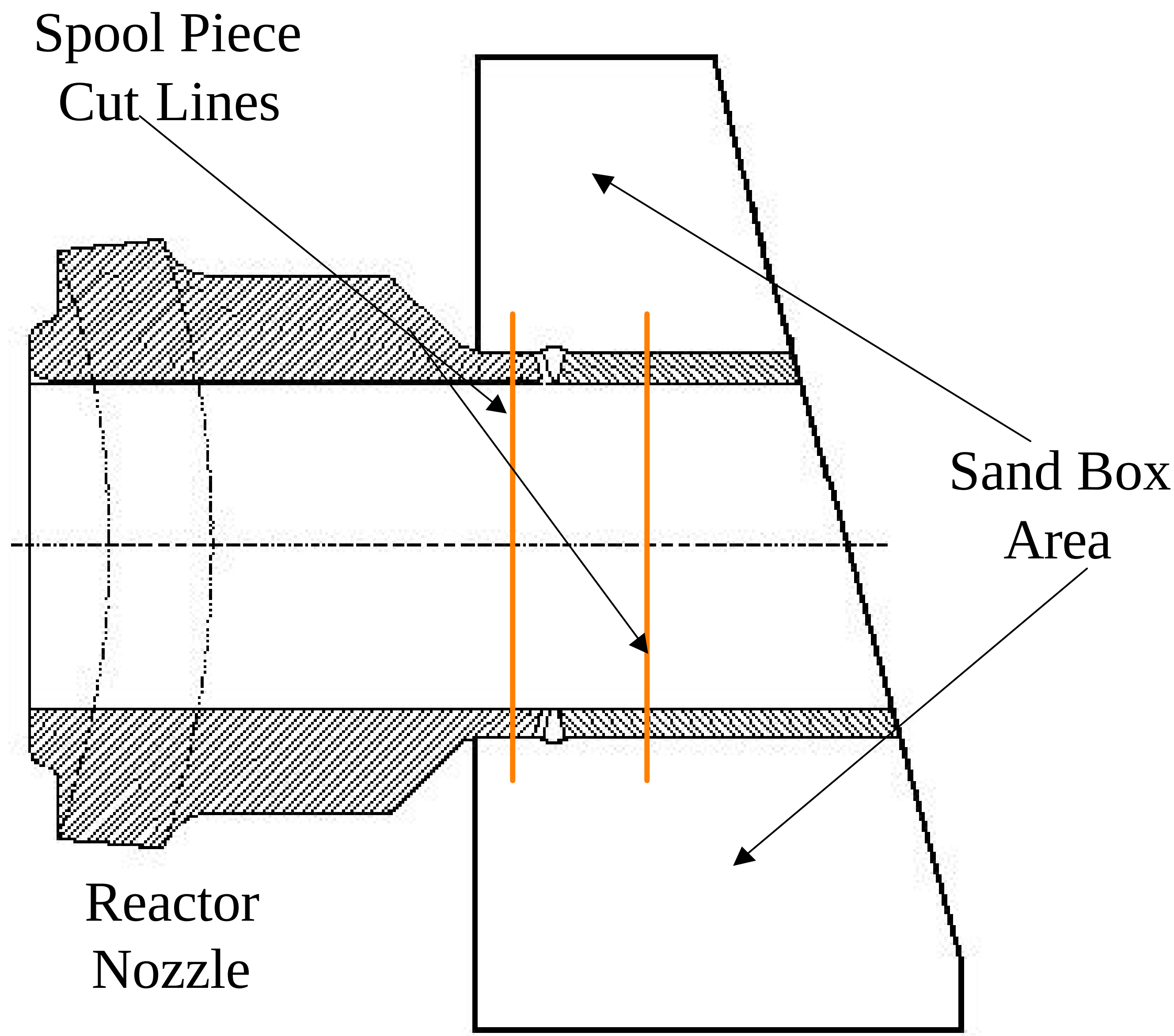
Manager, Plant Life Extension Project

Repair Strategy

- Remove Flaw
- Reduce Overall Stress in Weld
- Use Improved Materials
- Allow for Most Thorough Root Cause Evaluation

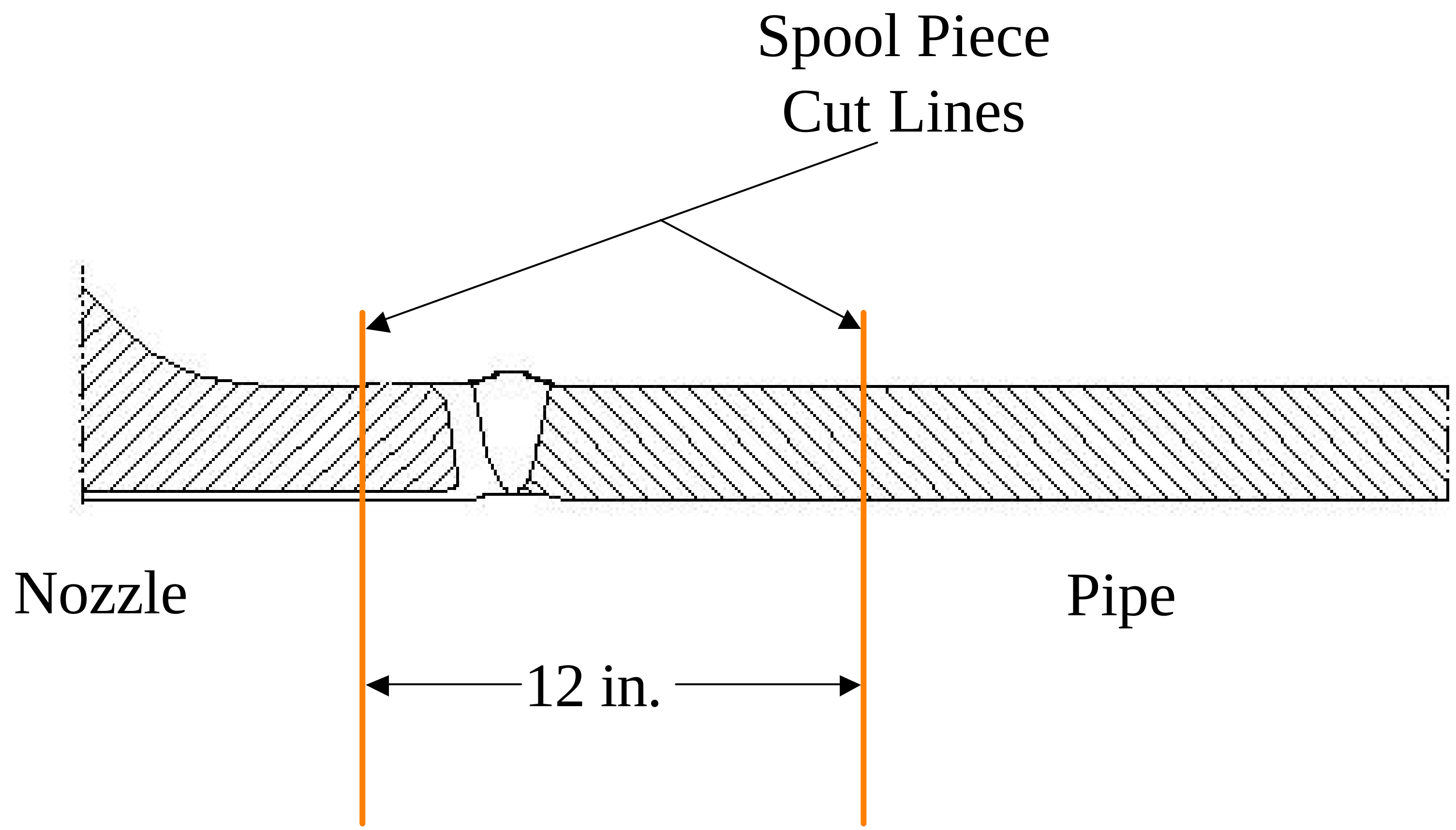
Spool Piece Repair

- Remove Section of Pipe Including Original Weld
- Create Two New Welds
- Narrow Groove Weld Design
  - Entire Weld Made Externally from Inside to Outside
  - Reduces ID Tensile Stresses
- Challenges
  - Limited Space for Repair Tooling & Personnel
  - Long Repair Process
  - Radiation Exposures


Spool Piece
Cut Lines
Sand Box
Area
Reactor
Nozzle

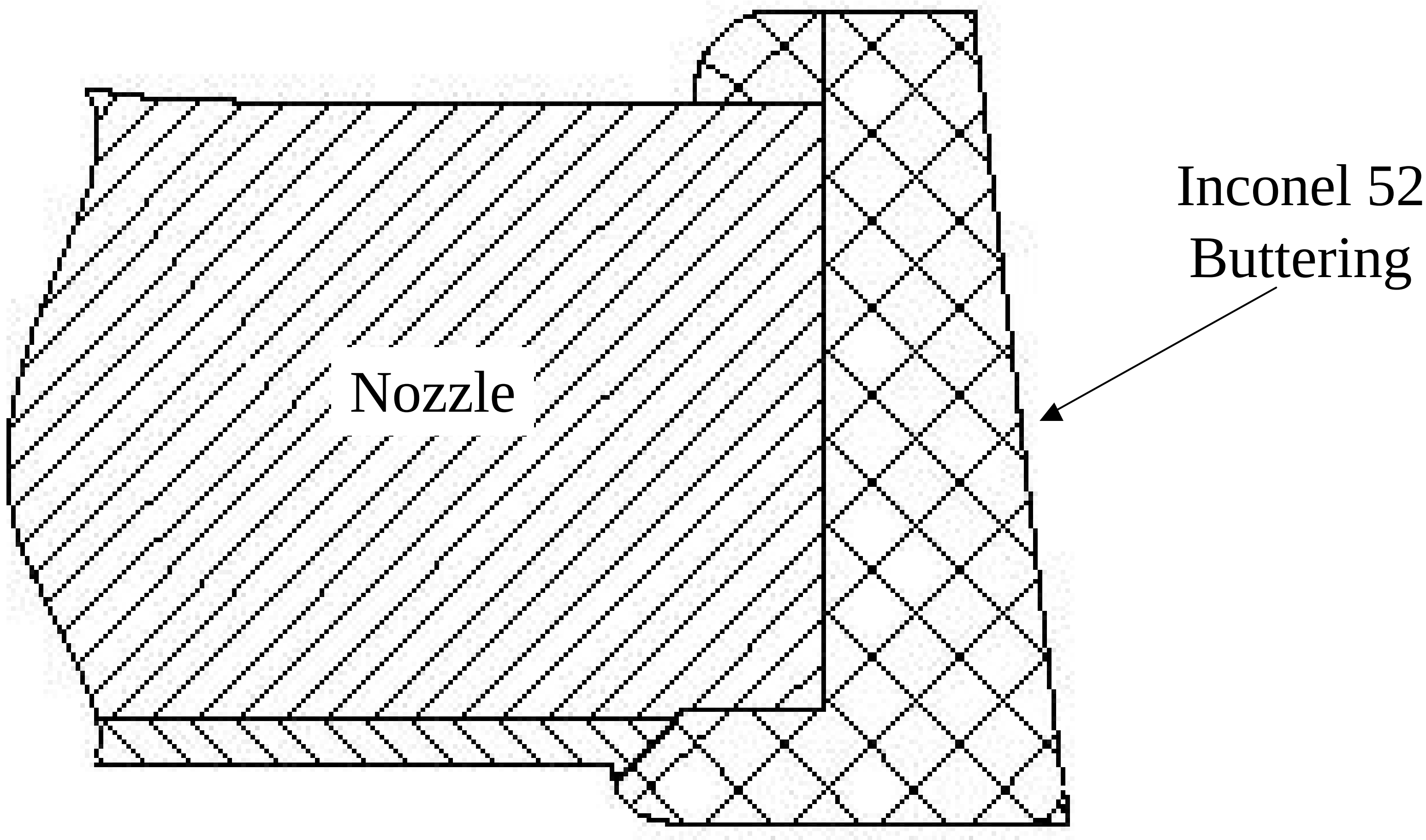
STEP 1 - SPOOL PIECE REMOVAL

- Sever Reactor Vessel Nozzle to Ensure All of Flaw Was Removed
- Sever Pipe About 12 Inches Away From Nozzle Cut
- Remove Section of Pipe to Send Offsite for Evaluation


Spool Piece
Cut Lines
Nozzle
Pipe
12 in.

STEP 2 - PREPARE NOZZLE

- Preheat the Nozzle
- Deposit New Inconel 52 Material (Buttering) on Nozzle Face Using Temperbead Process

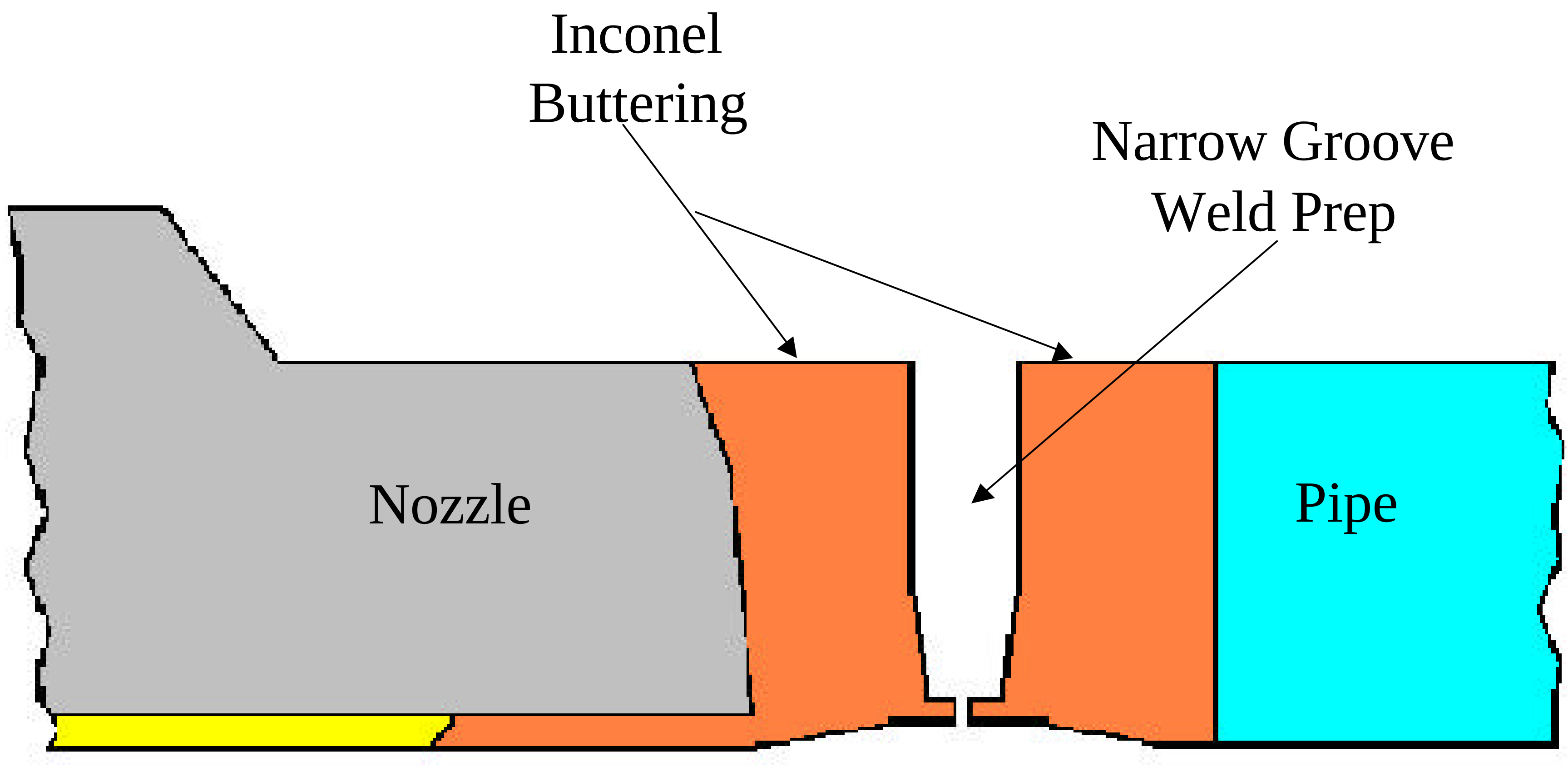

Inconel 52
Buttering
Nozzle

STEP 3 - PREPARE NEW SPOOL PIECE

- Apply Inconel 52 Butter to One End
- Cut to Measured Length

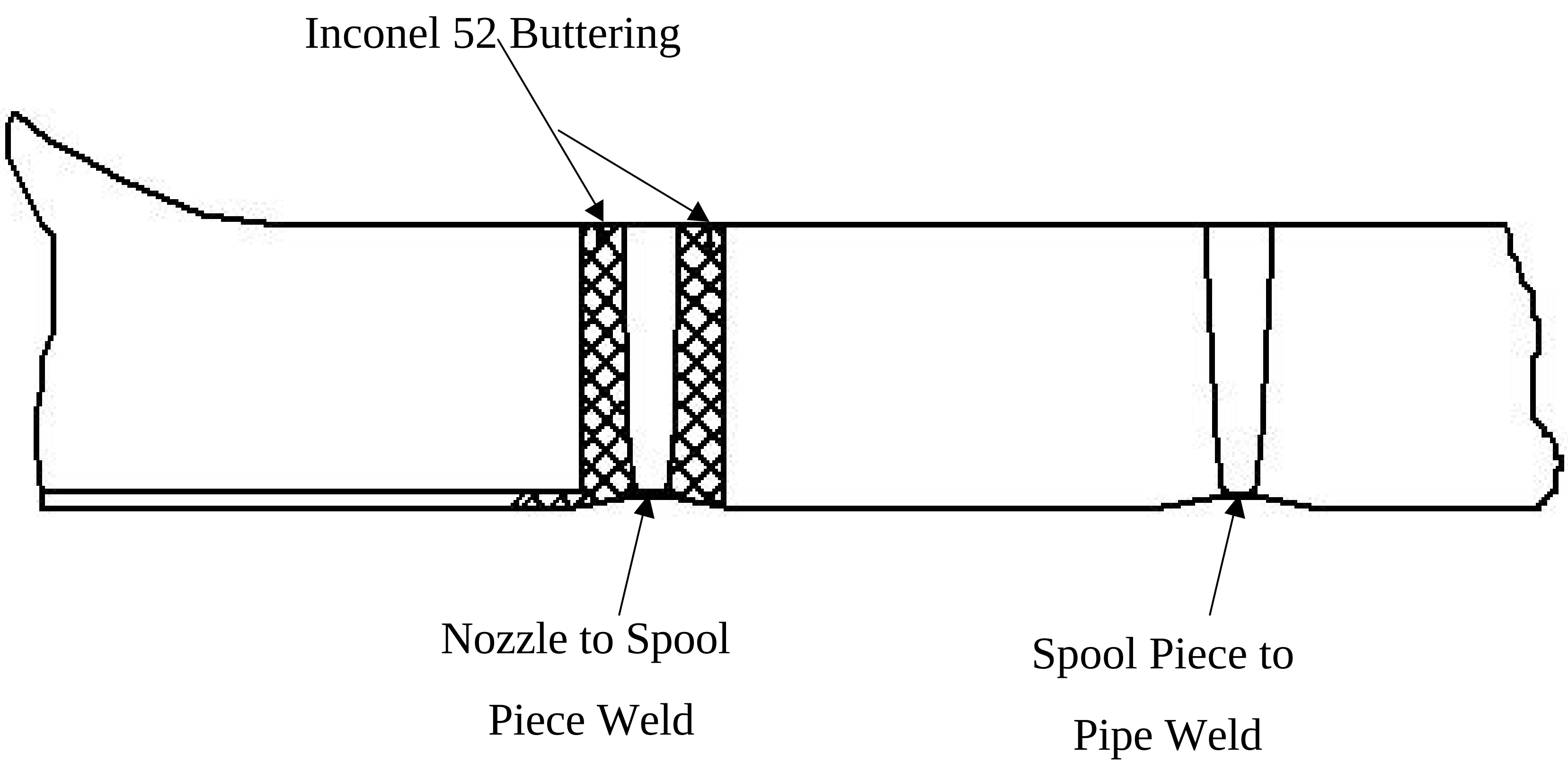
STEP 4 - MACHINE WELD PREPS

- Buttered Nozzle
- Existing Pipe
- Both Ends of New Replacement Spool Piece


Inconel
Buttering
Narrow Groove
Weld Prep
Nozzle
Pipe

<u>STEP 5</u> - INSTALL REPLACEMENT SPOOL PIECE

- Install New Spool Piece Into Open Section of Pipe
- Progressively Weld Both Spool Piece Welds Externally From ID to OD


Inconel 52 Buttering
Nozzle to Spool
Piece Weld
Spool Piece to
Pipe Weld

Code Applicability

- ASME Section III
- ASME Section XI
  - ASME Section XI Code Case N432 - Machine GTAW Temperbead
- NRC Approved Relief Request for Inconel 52 Material
- Regulatory Guides
  - RG 1.31 - Control Of Stainless Steel Welding
  - RG 1.44 - Control Of The Use Of Sensitized Stainless Steel

Final Inspections & Examinations

- Volumetric Examination of New Welds
  - Radiograph
  - Ultrasonic
- Surface Examination of New Welds
  - Liquid Penetrant
- Visual Leakage Inspection at System Pressure

End Point of This Effort

- Conclusion Is:
  - Alpha Hot Leg Is Unique
  - Commonalties in Other Welds Are Addressed
  - Plant Is Safe for Start Up:
    - √Pipe and Welds Meet Code Requirements
    - Repair Bounds Probable Failure Mechanisms
    - Extent of Condition Is Evaluated
  - Ready for Continued Safe Operation

What We Did To Ensure Safety

Root Cause

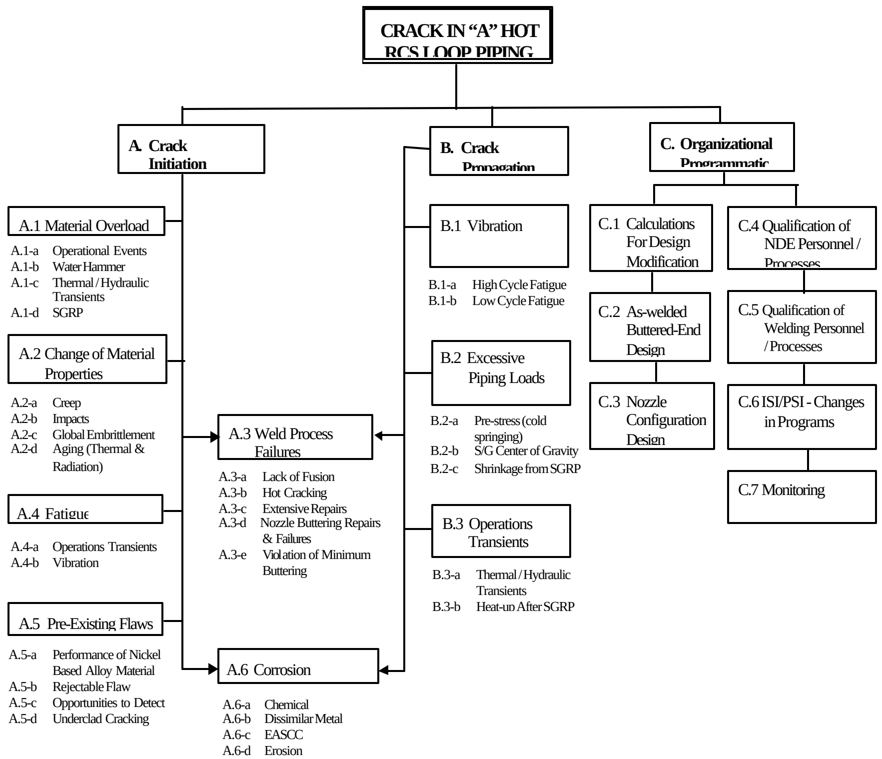
Gary Moffatt

Manager, Design Engineering

Alpha Hot Leg Root Cause

- Root Cause Team: 10 People / Technically Diverse Backgrounds
- Root Cause Problem Statement: Determine Why the Through Wall Crack Occurred
- Evaluation Technique:
  - Define Possible Failure Modes
  - Gather Evidence

Root Cause Failure Modes

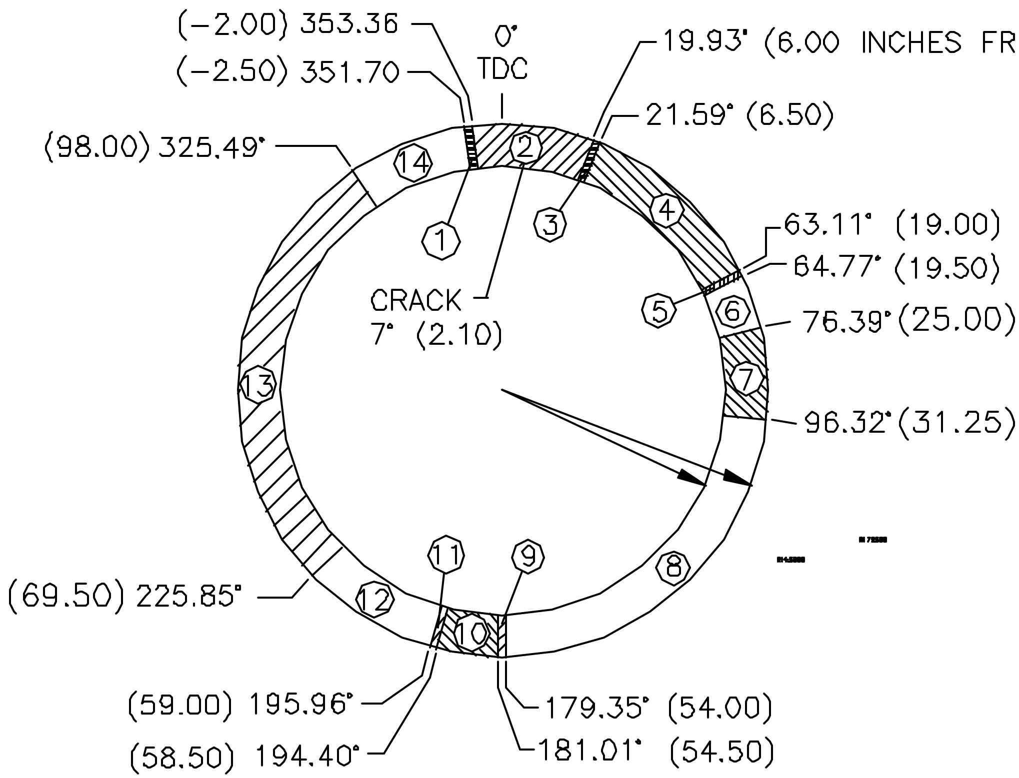


- 30 Failure Modes
- 7 Org / Programatic
- 5 Supported Failure Modes
- 4 Org / Programatic Contributing Factors.

Root Cause Conclusions

- The Through Wall Crack in the Alpha Hot Leg Occurred Due To:
  - Primary Water Stress Corrosion Cracking
  - High Residual Stresses From Original Welding / Fabrication

Marking Sectioning Locations



SAMPLE LEGEND

1. Mettalography/Wet Chemistry
2. Metallography/Fractography/Chemistry
3. Metallography/Microprobe Chemistry
4. ECT/Metallography
5. PT/SEM/Metallography
6. Spare
7. ECT/SEM/Metallography
   Circumferential EC Indication
8. Spare
9. Metallography
10. Surface Exam (LOM/SEM/PITS)
11. Wet Chemistry
12. Spare
13. ECT/SEM/Mettalography
14. Spare

NOTE: VIEWED LOOKING INTO THE PIPE FROM VESSEL

CRACK LOCATION IS 7° (2.10) FROM TDC

Revised per Marked-Up print Nov. 24, 2000/JAH

WESTINGHOUSE ELECTRIC CORPORATION
SPARTANBURG SERVICE CENTER

TITLE: VC SUMMER ALPHA LOOP
NOZZLE WELD INVESTIGATION

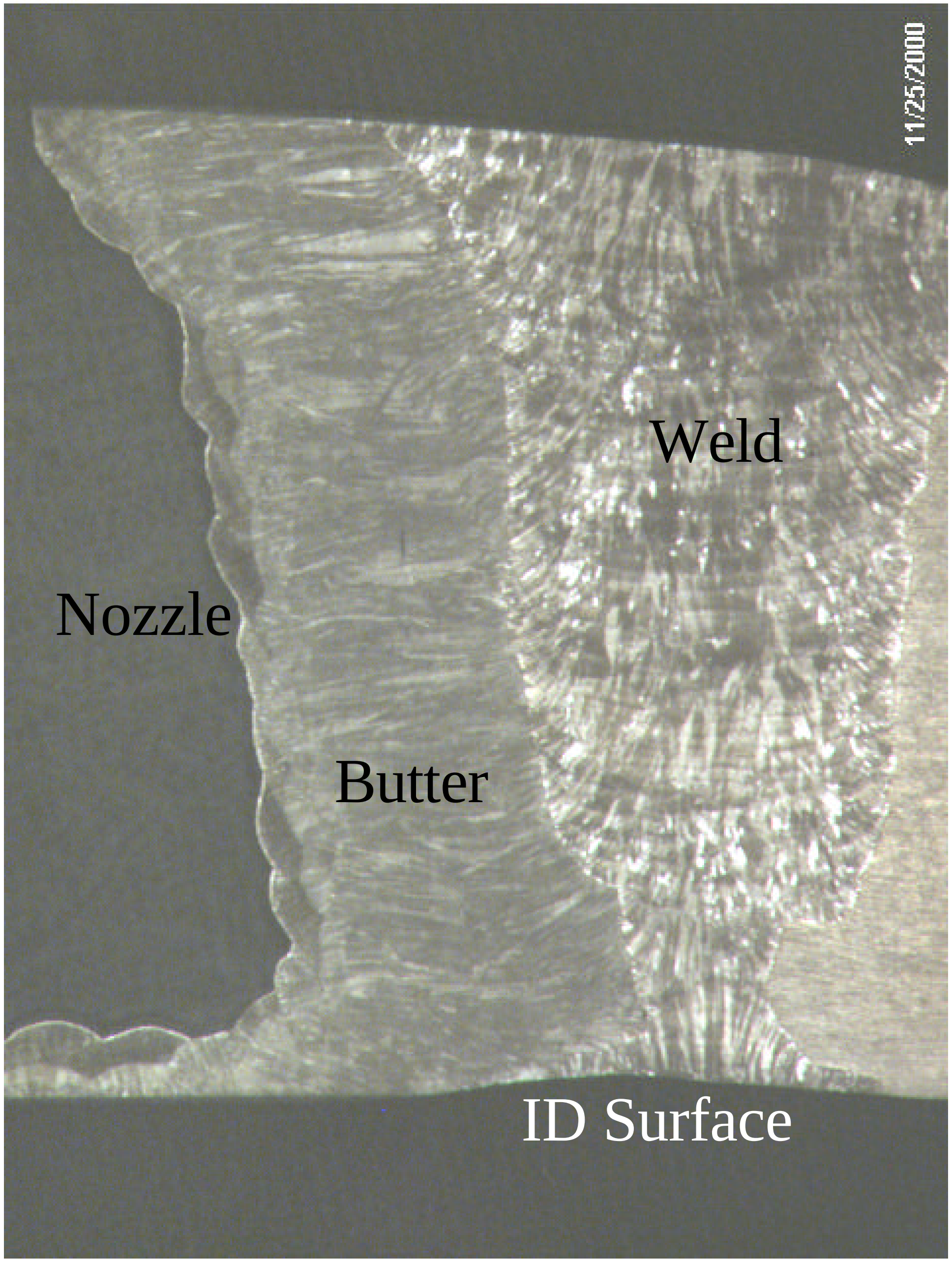
DRAWN BY	DATE	SCALE	REV	SHEET OF
B HOWARD	11-21-00	NTS	0	1 OF 1

Sectioning Layout of the Weld Spool Piece

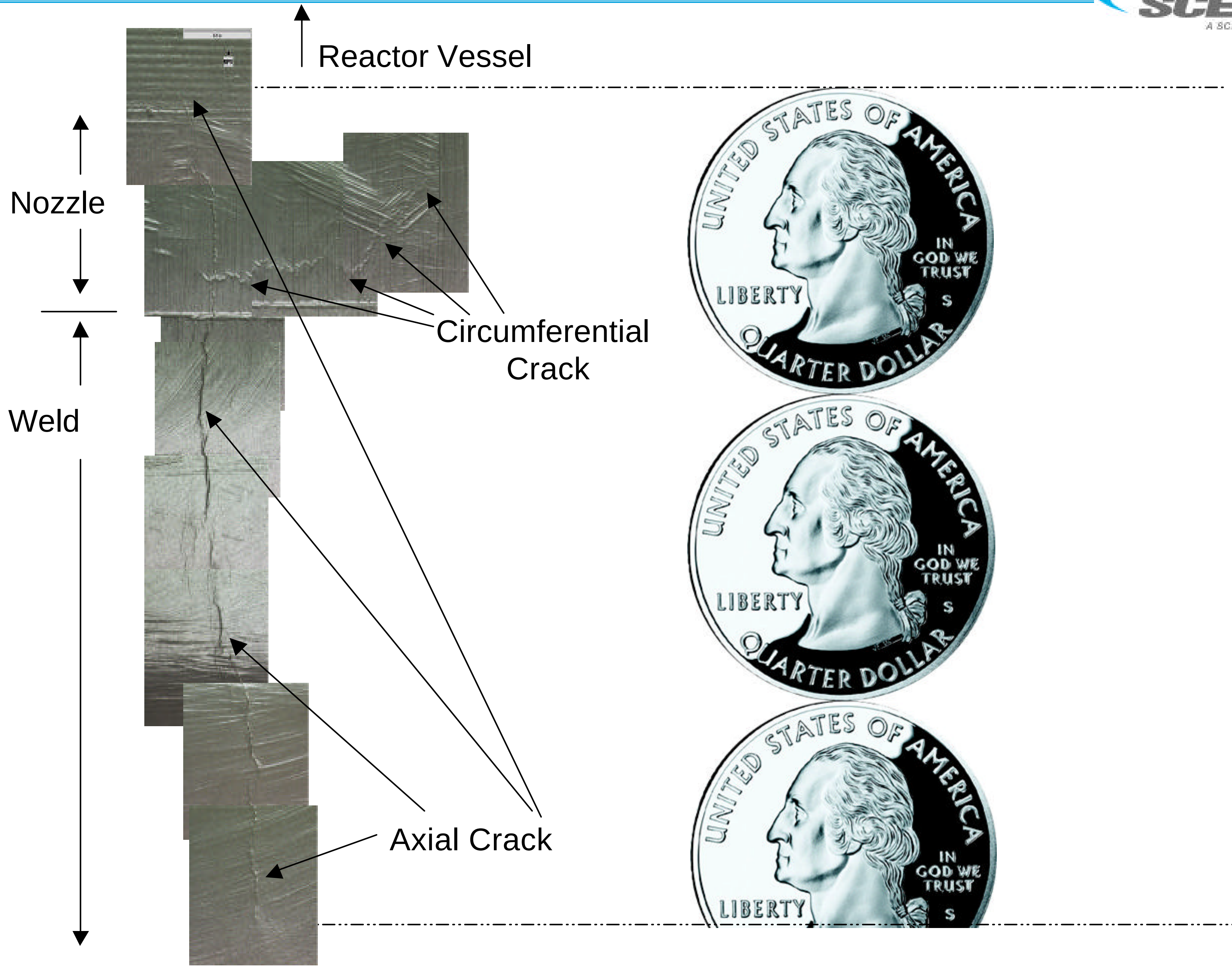
Layout of the Sectioned Pieces

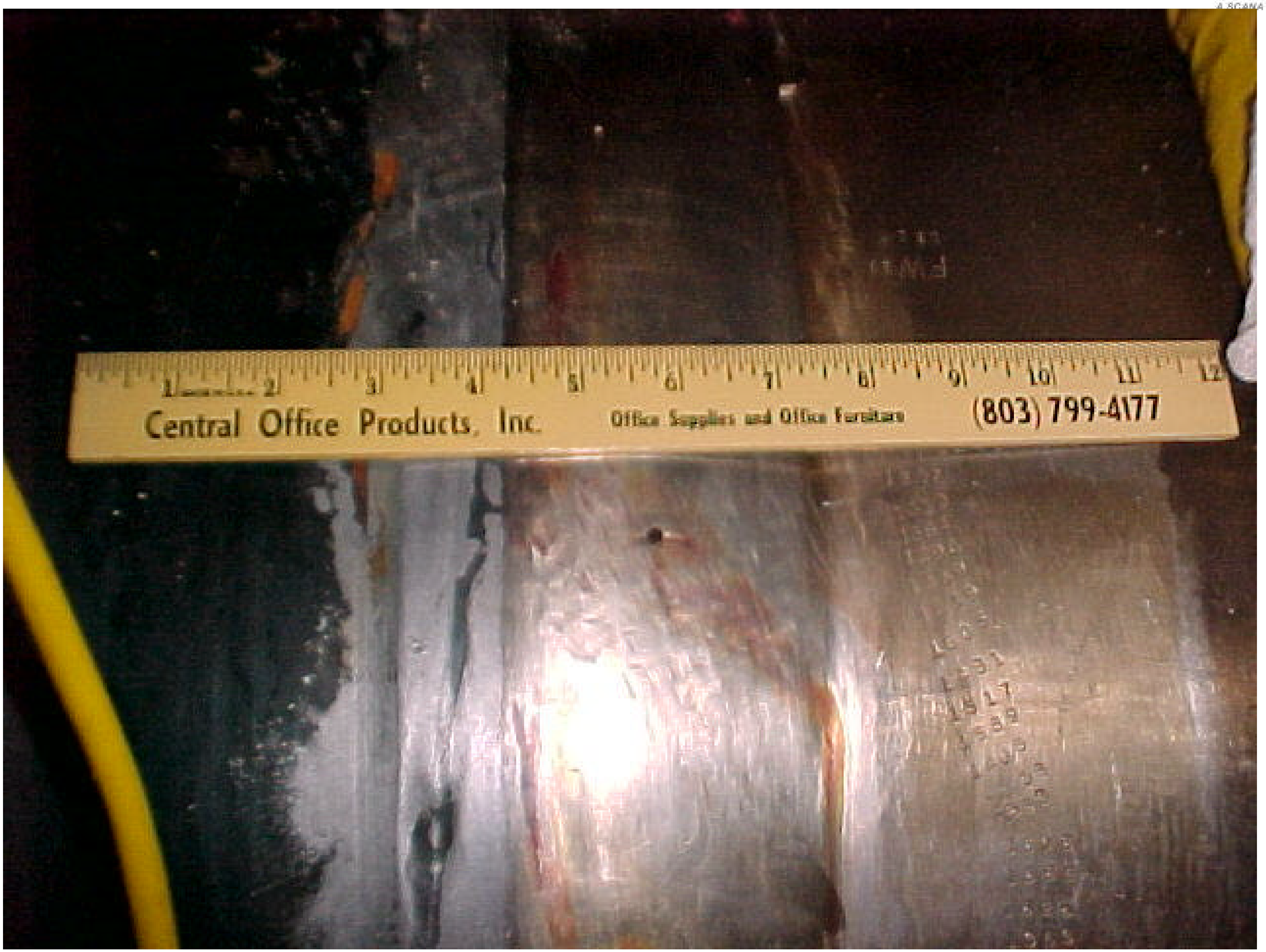
Metallurgical Analyses

- Surface Examinations
- Ultrasonic Non Destructive Testing
- Surface Examinations
- Ultrasonic Non-destructive Testing (UT)
- Eddy Current Non-destructive Testing (ECT)
- Metallographic Examinations
- Fractographic Examinations
  - Optical & Scanning Electron Microscopy (SEM)
- Chemistry Evaluations
  - Energy Dispersive X-ray Analysis
  - Microprobe Analysis
- Micro Hardness Measurements
- Local Residual Stress Measurements



Cross Section of Weld & Butter


Reactor Vessel
Nozzle
Weld
Circumferential Crack
Axial Crack
UNITED STATES OF AMERICA
IN GOD WE TRUST
LIBERTY
S
QUARTER DOLLAR


1 2 3 4 5 6 7 8 9 10 11 12
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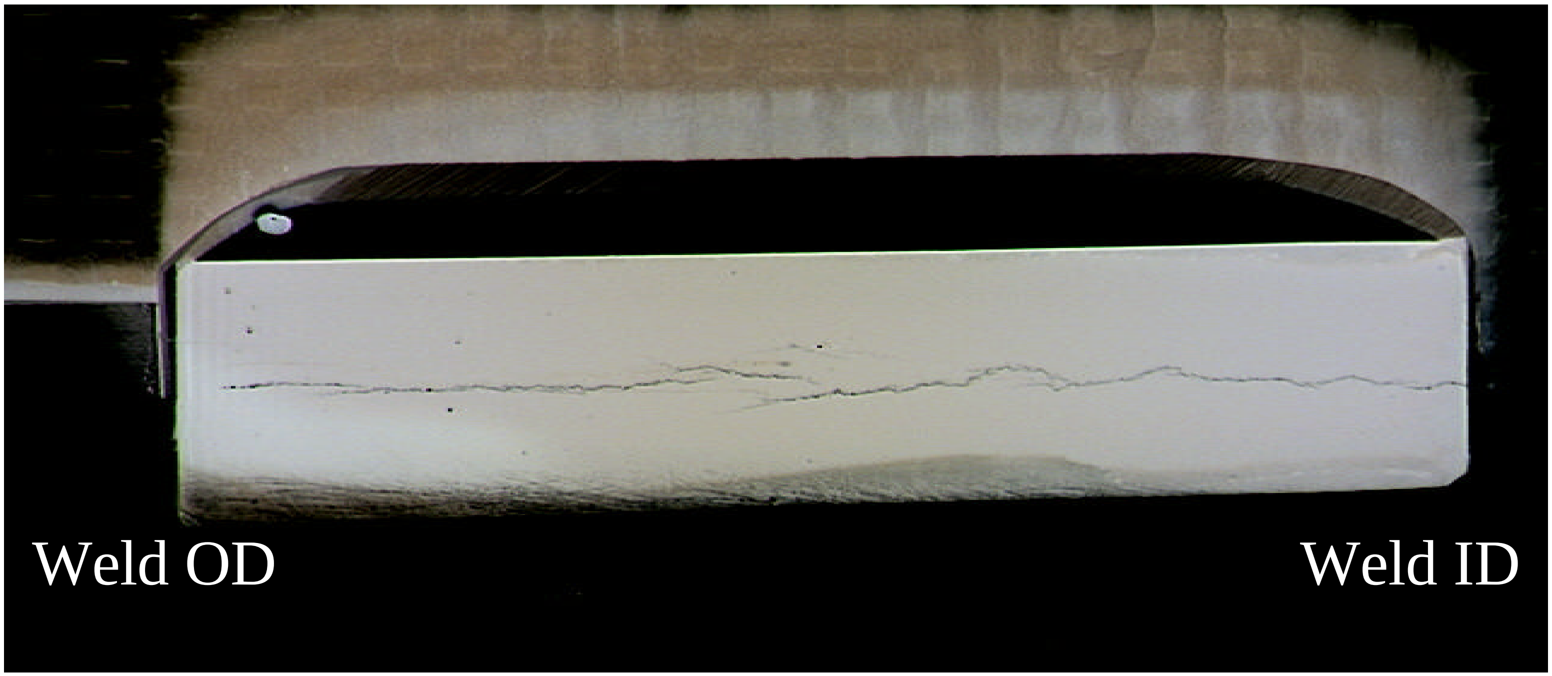
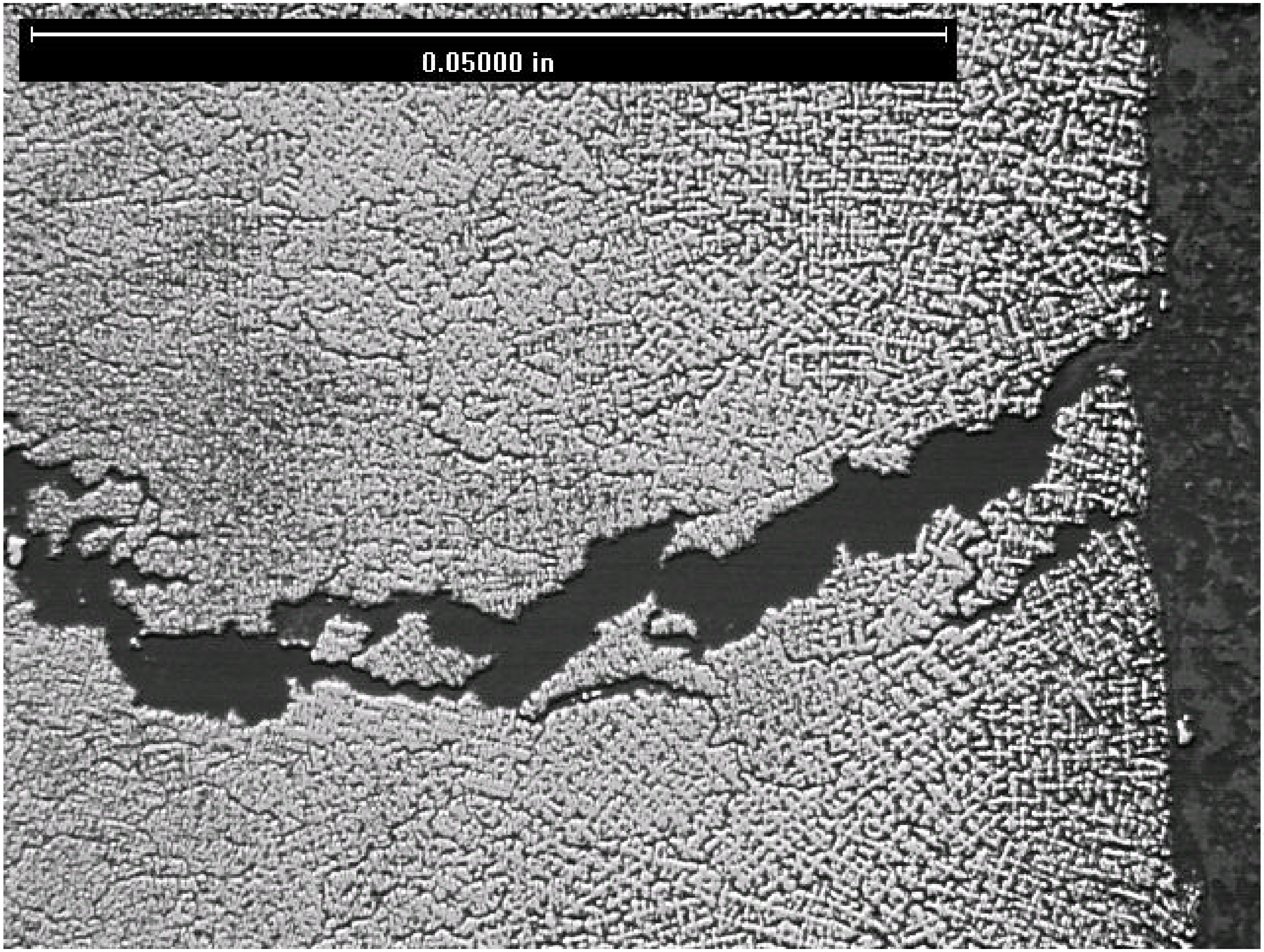
Cross Section of Weld Showing Crack



Metallography Results of Axial Crack (7^0)

Looking From the Nozzle Towards the Pipe.



Metallography of Through Wall Crack at the ID Surface (7°)
Magnified 50x

Metallurgical Test Results

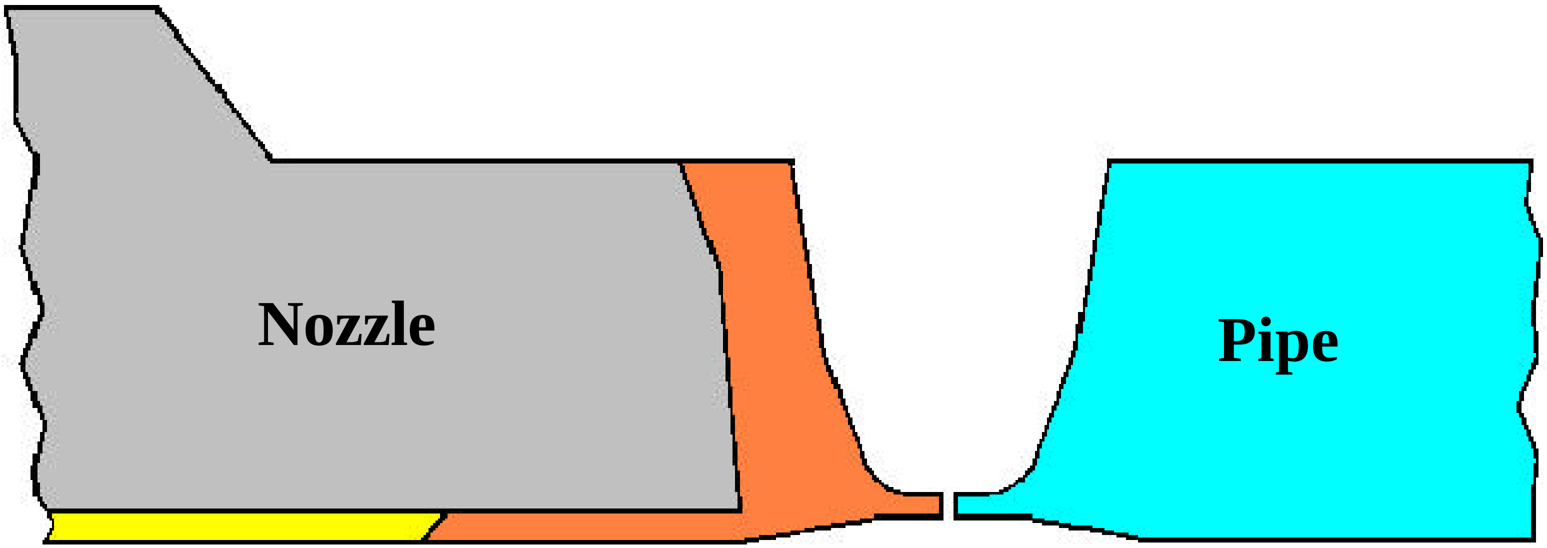
- Some ET Indications Confirmed -- PWSCC Cracks Following Interdendritic Morphology.
- Some ET Indications Were Not Cracks
- Axial Through Wall Crack - Multiple Initiation Sites.
- Axial Crack Contained Within Weld, Butter, HAZ.
- Circumferential Crack Contained in Cladding.

Primary Water Stress Corrosion Cracking

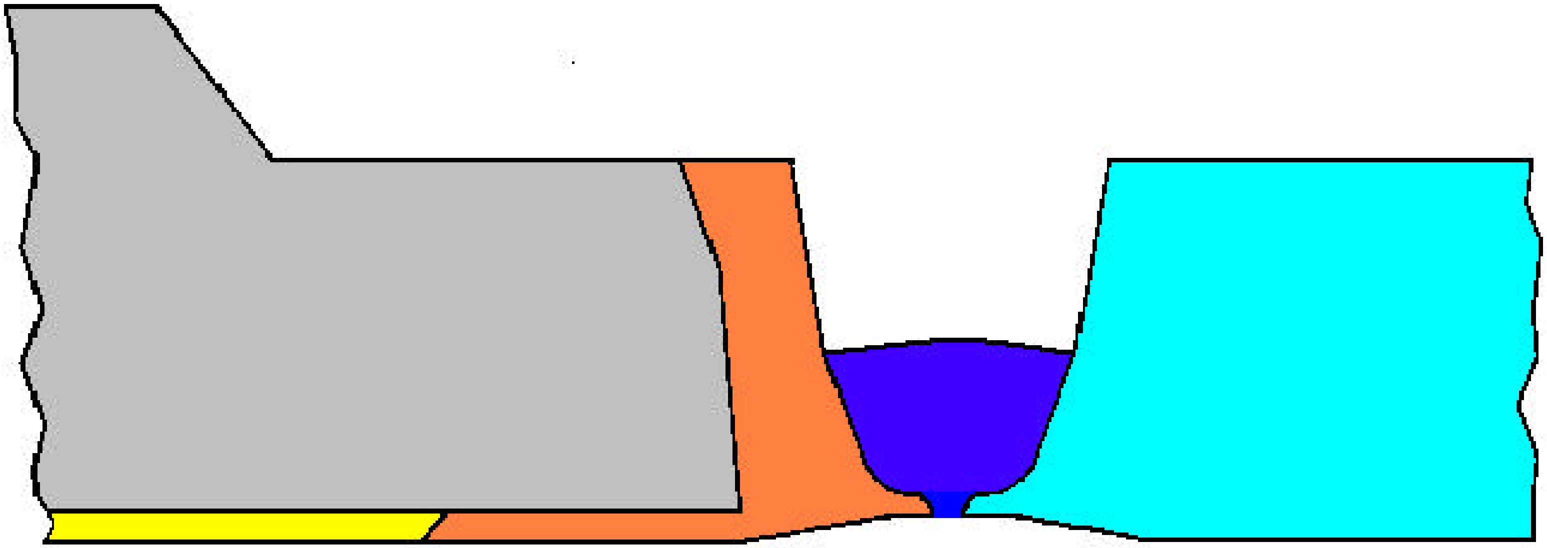
√ Environment

√ Susceptible Material

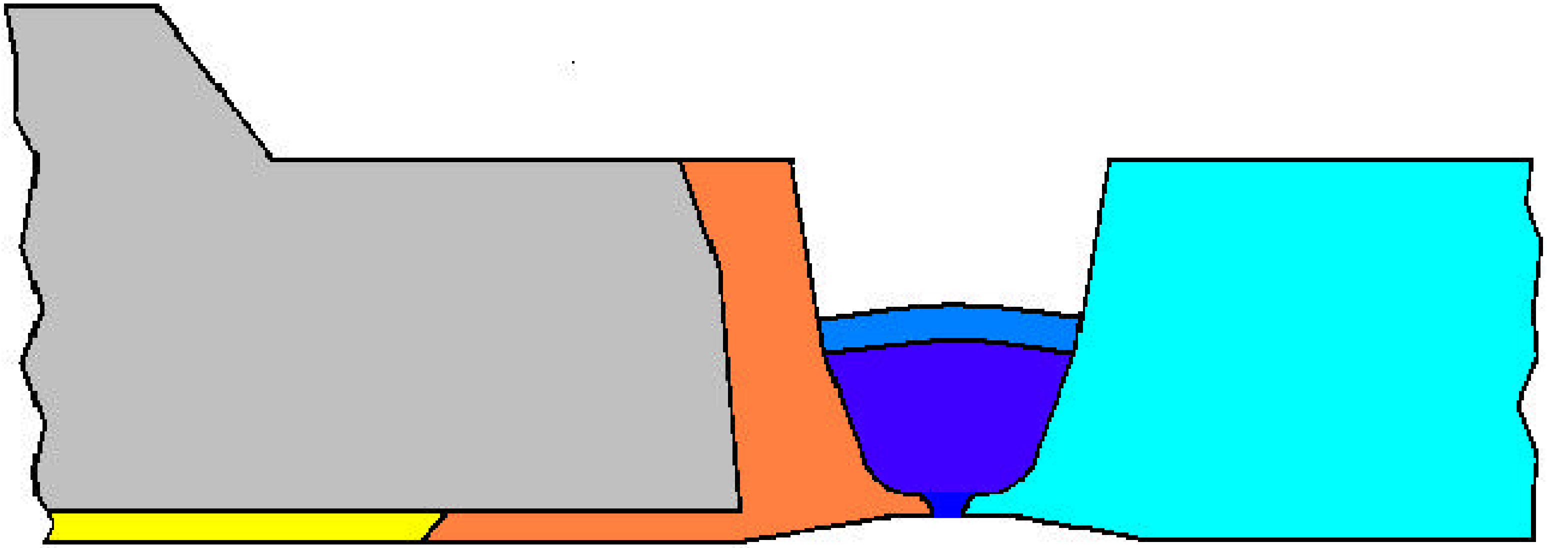
- High Stresses



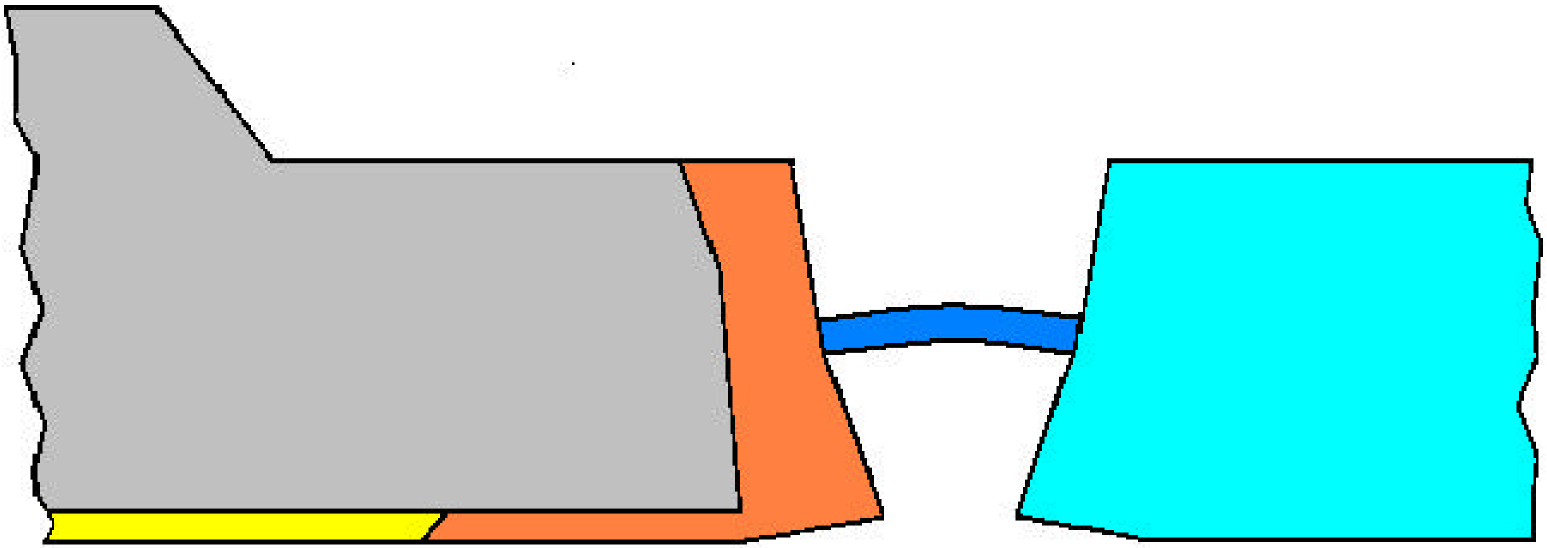
This is the start of the original weld. It was designed to be filled from the ID out toward the OD



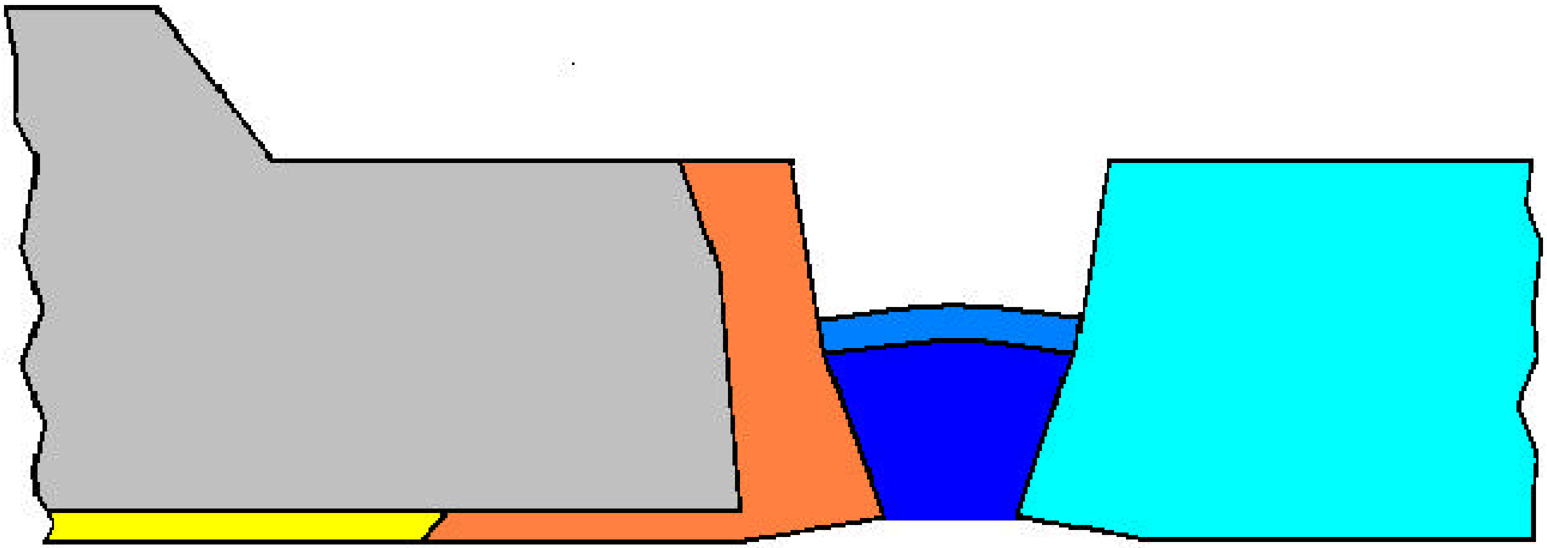
The first pass was made per design but rejected



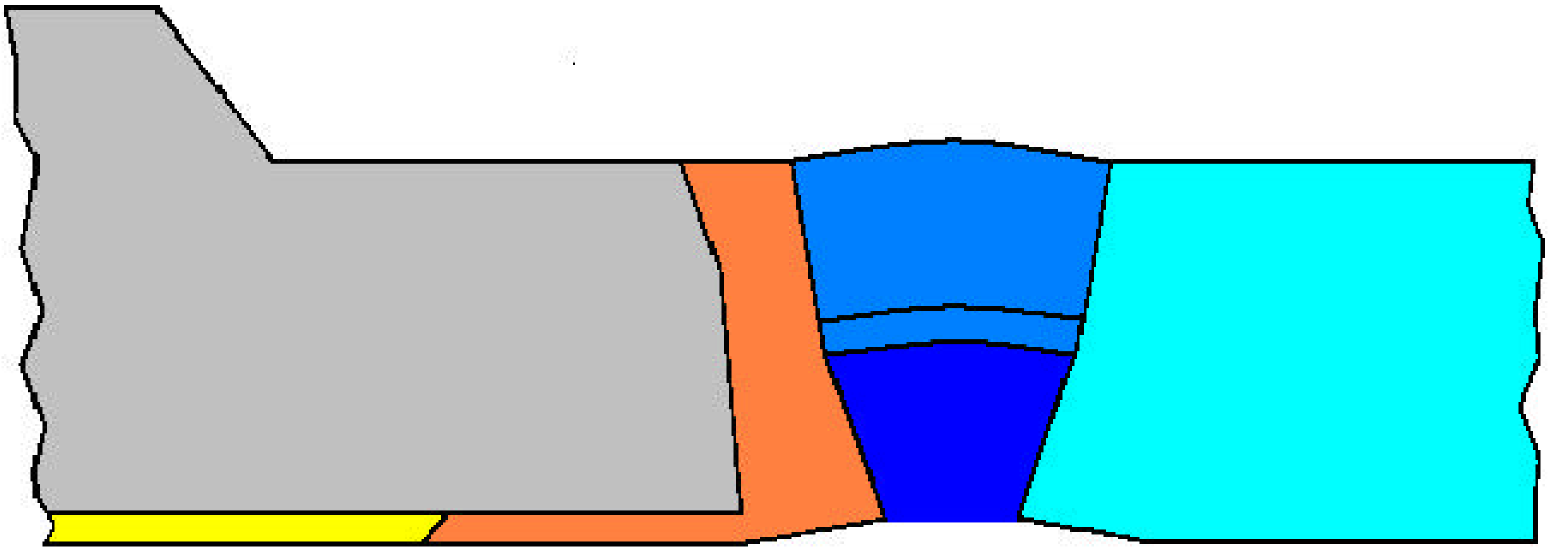
A bridge was laid in to stabilize the pipe



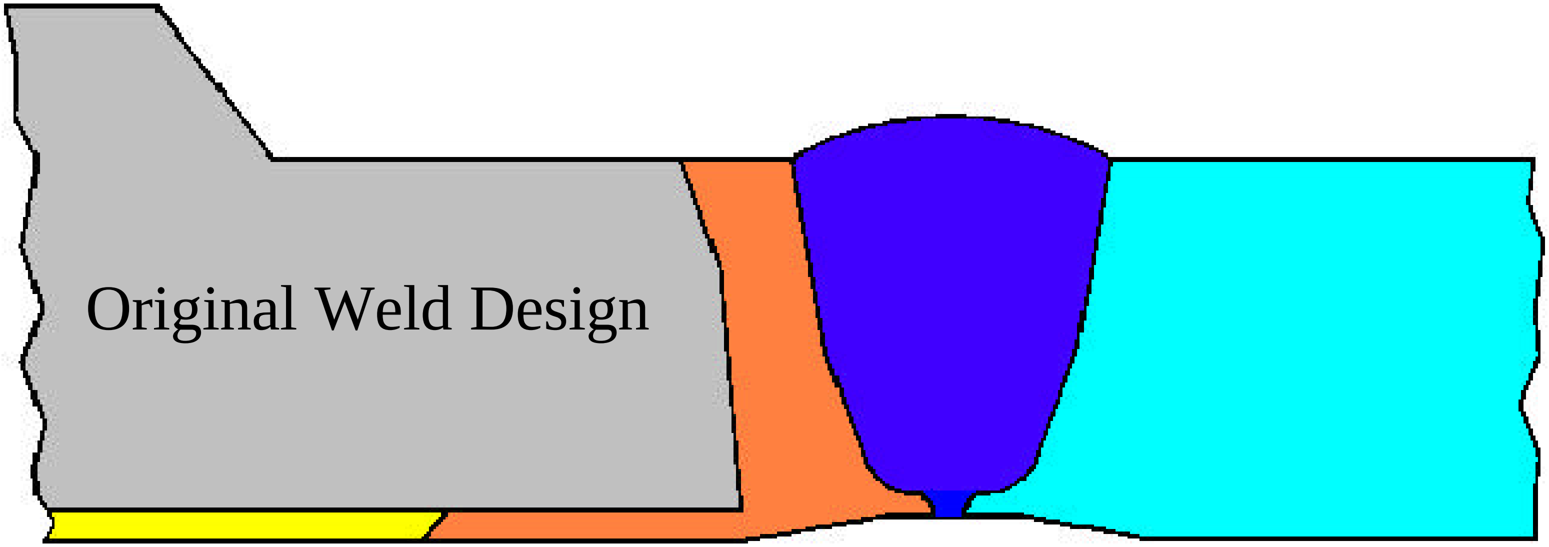
The rejected area was removed

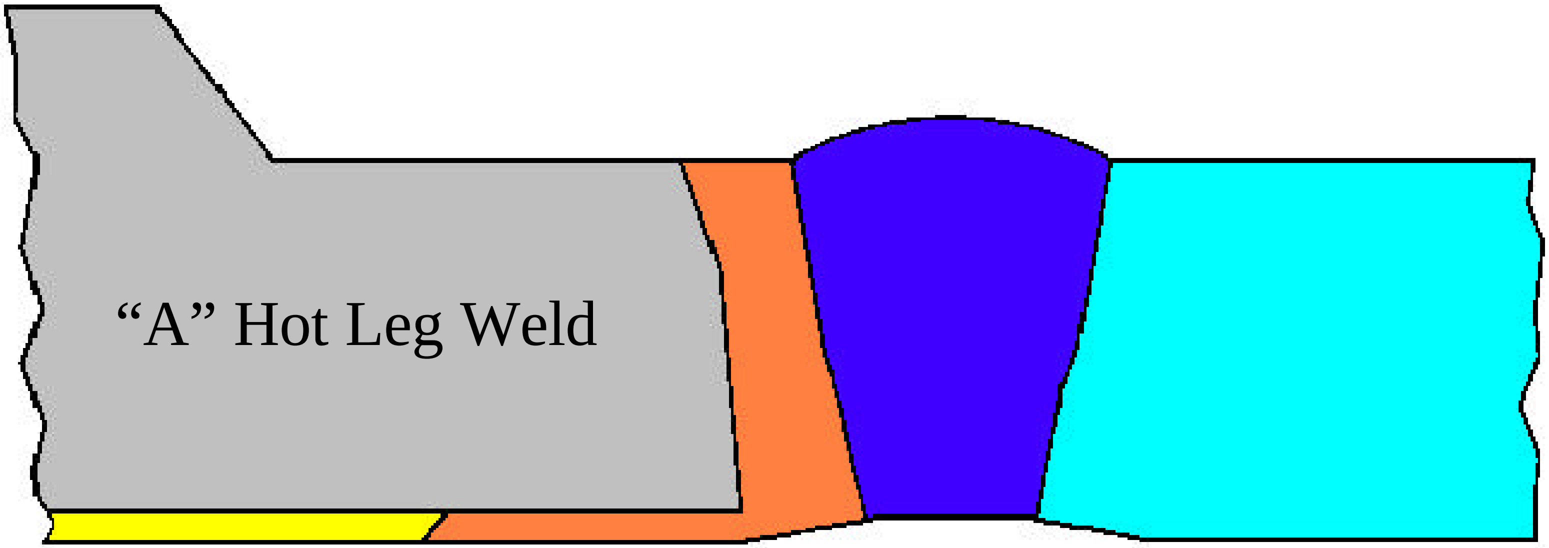


Weld was reapplied from the bridge to the ID

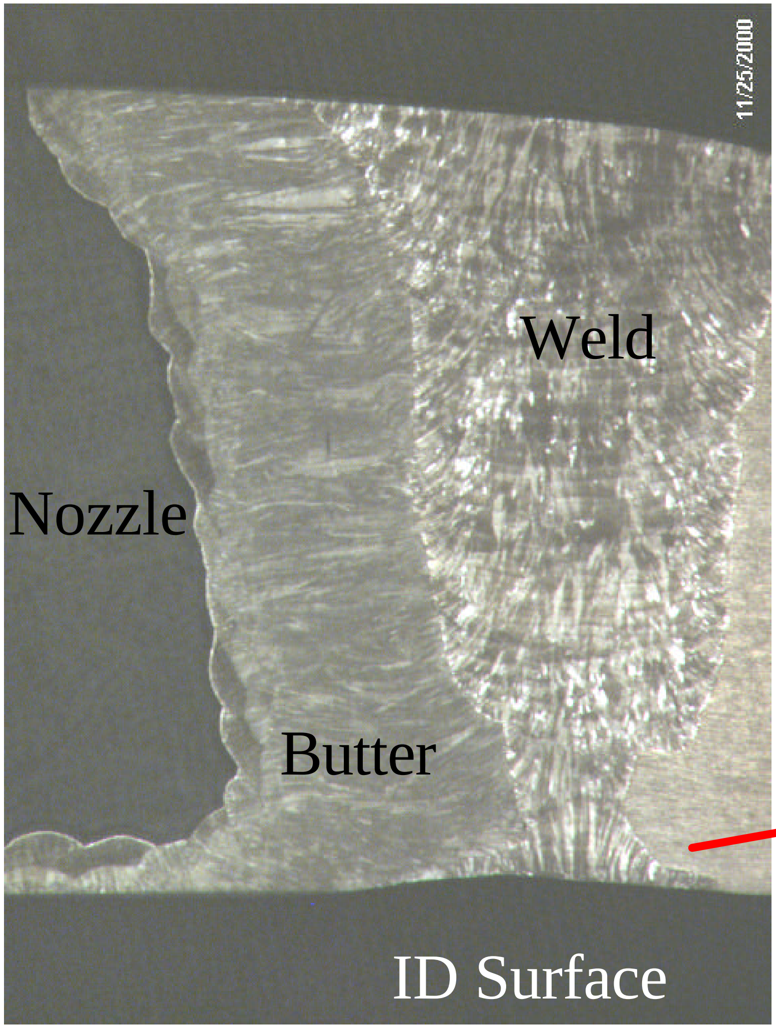


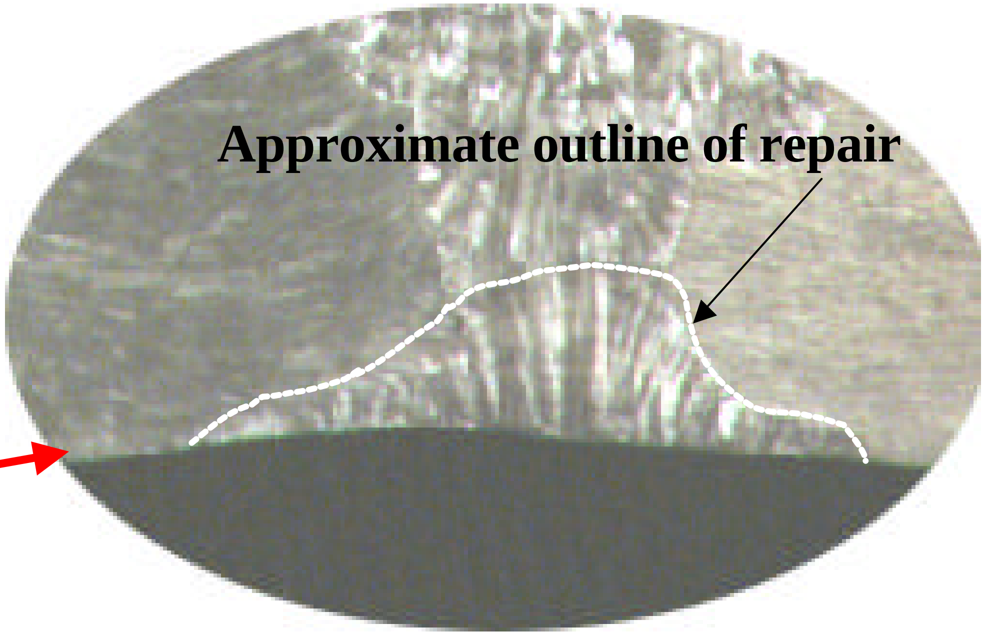
The weld was then completed from the bridge to the OD


Original Weld Design


"A" Hot Leg Weld

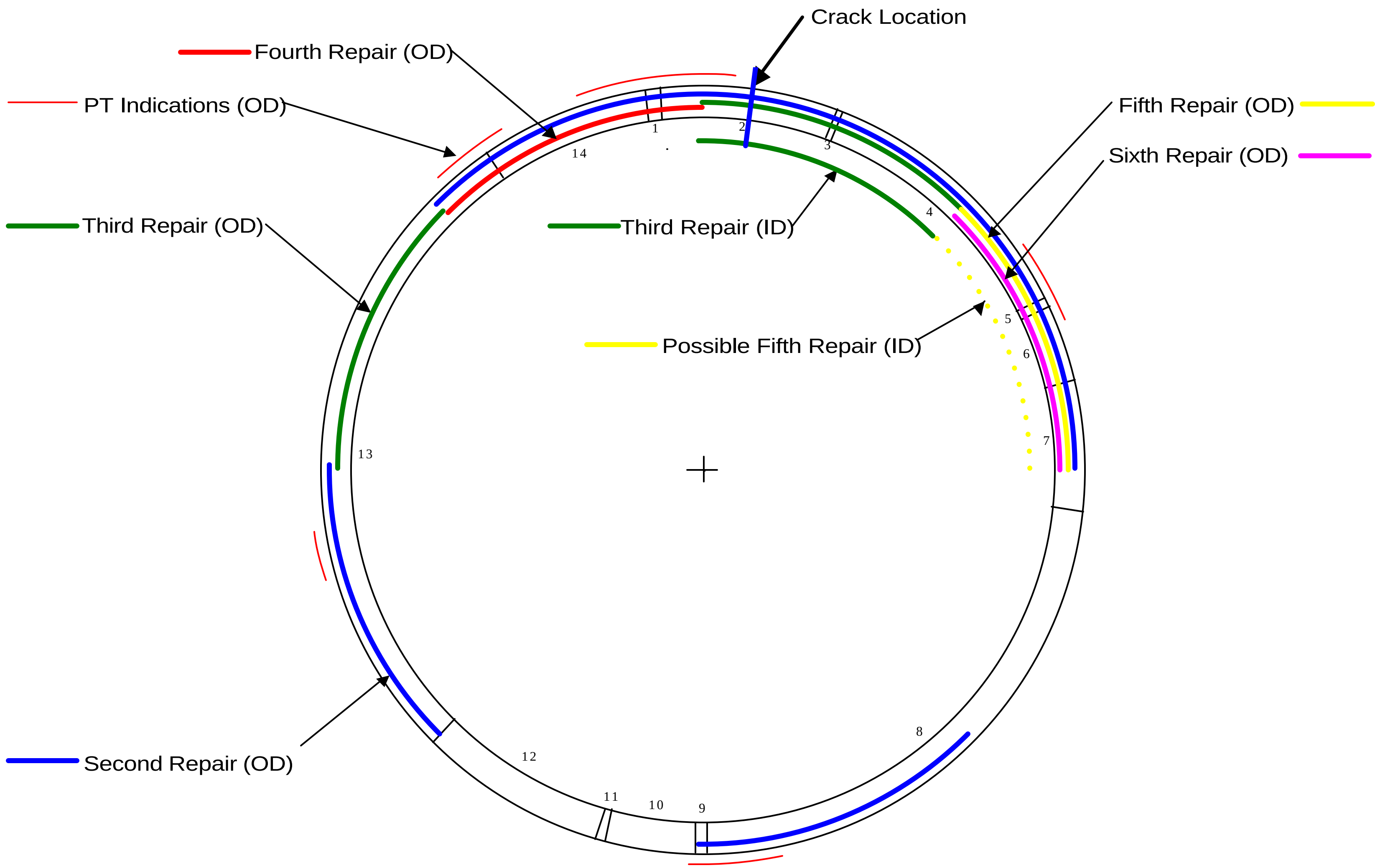
Cross Section of Weld/Butter





VC Summer "A" Hot Leg Reactor Nozzle to Pipe Weld Spool Piece

(Looking OUT from the RV Centerline)



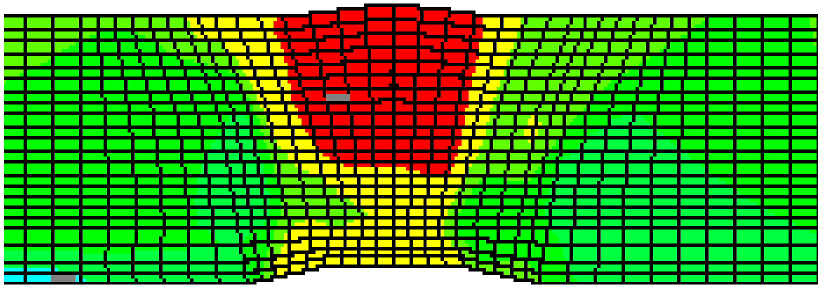
EPRI Typical Weld Finite Element Analysis Result

VC Summer Nozzle

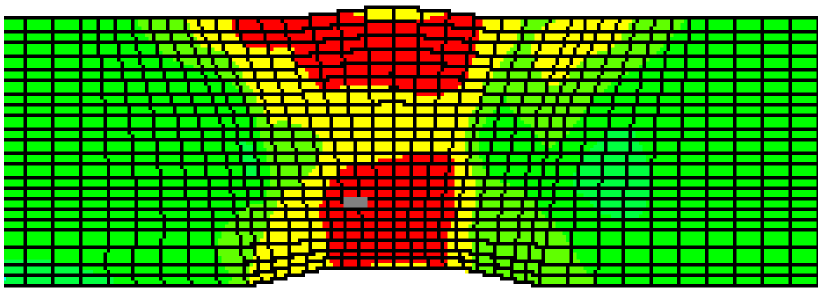
Stresses

- As Designed

- ID Welded First



- ID Welded Last



Primary Water Stress Corrosion Cracking

- √ Environment
- √ Susceptible Material
- √ High Stresses

Repair Has Addressed Root Cause Issues

Issue	Resolution
• Inconel 182 / 82	• Used Inconel 52
• Construction Weld Process High Residual Stresses	• Narrow Groove Weld Design, Welded ID to OD, Reduced ID Tensile Stresses

End Point of This Effort

- Conclusion Is:
  - √ Alpha Hot Leg Is Unique
  - – Commonalties in Other Welds Are Addressed
  - – Plant Is Safe for Start Up:
    - √ Pipe and Welds Meet Code Requirements
    - √ Repair Bounds Probable Failure Mechanisms
    - • Extent of Condition Is Evaluated
  - – Ready for Continued Safe Operation

Break

What We Did To Ensure Safety

Extent of Condition

Bob Waselus

Acting GM ,Strategic Planning

ASME Code Testing (NDE)

- 1993 ISI (UT) Showed No Reportable Indications
- 2000 UT Reported 1 Rejectable Flaw in the Alpha Hot Leg.
- The Other 5 Legs Had No Reportable Indication

Complimentary NDE

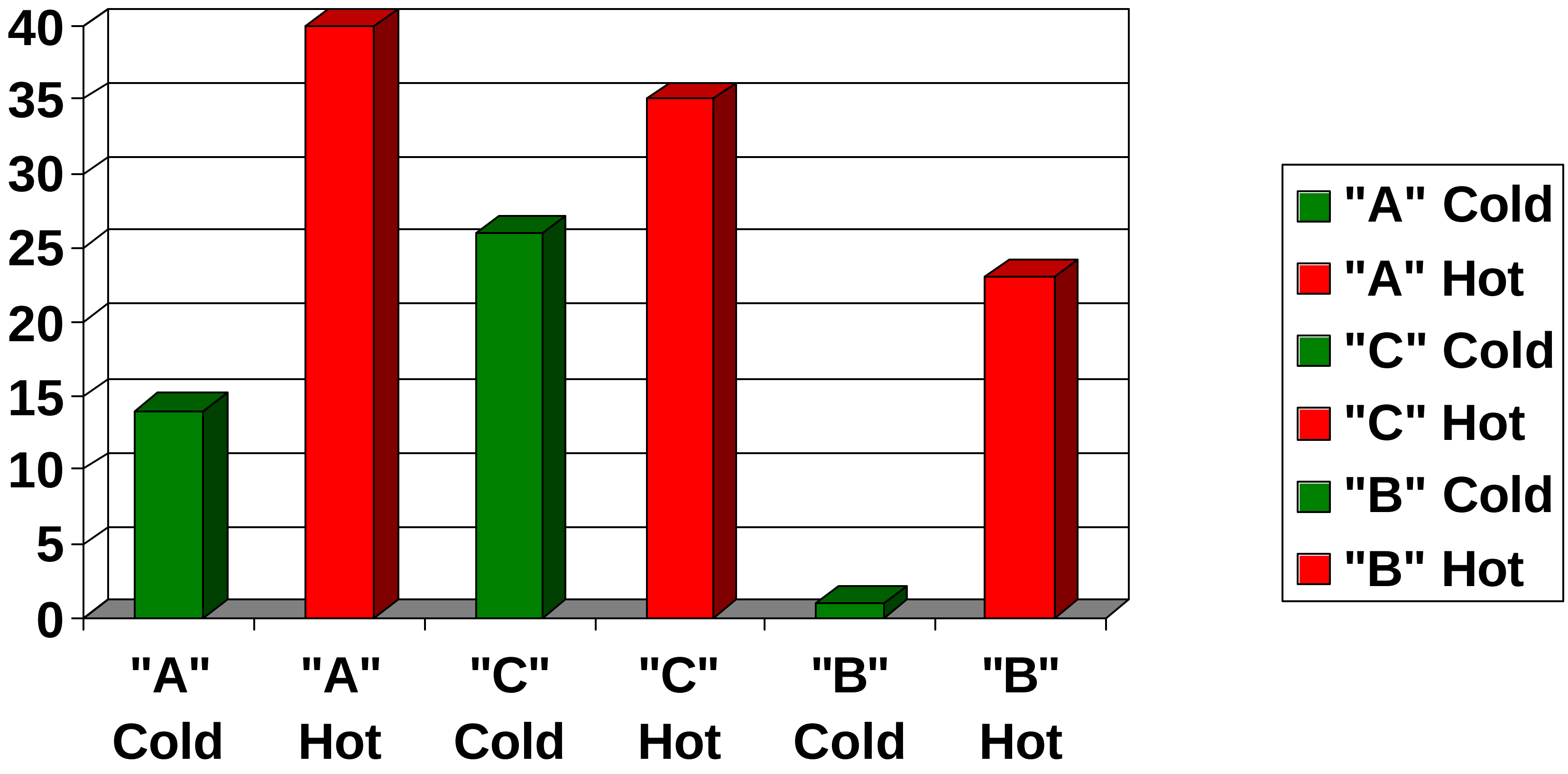
- Eddy Current (ET)
  - First Time Used for This Application in This Country
  - No Pretest Acceptance Standard nor Sizing Capability Were Set Due to the Research Nature
  - On Site Demo to Show Ability to Detect Surface Indications Under Ideal Conditions

Complimentary NDE

- Why Eddy Current Was Performed:
  - We Recognized and Discussed Before Starting the Risk of Not Being Able to Fully Explain Our Findings and That This Was Research
  - Assist in Developing a Full Picture of the Condition of the Welds to Understand the Extent of the Condition.
  - To Build on Experience From European Application of ET
  - We Believed It Was the Right Thing to Do.

What We Found

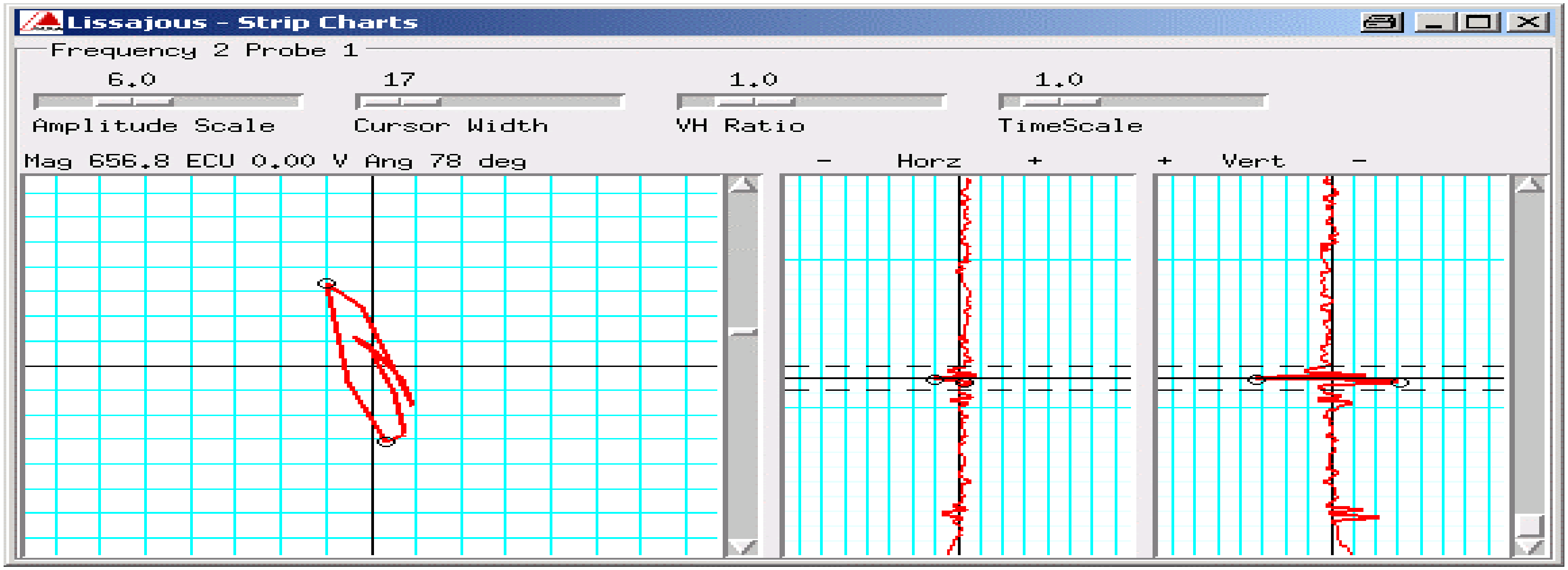
ET Identified 139 Indications in the Nozzle to Pipe Connections



ET Analysis

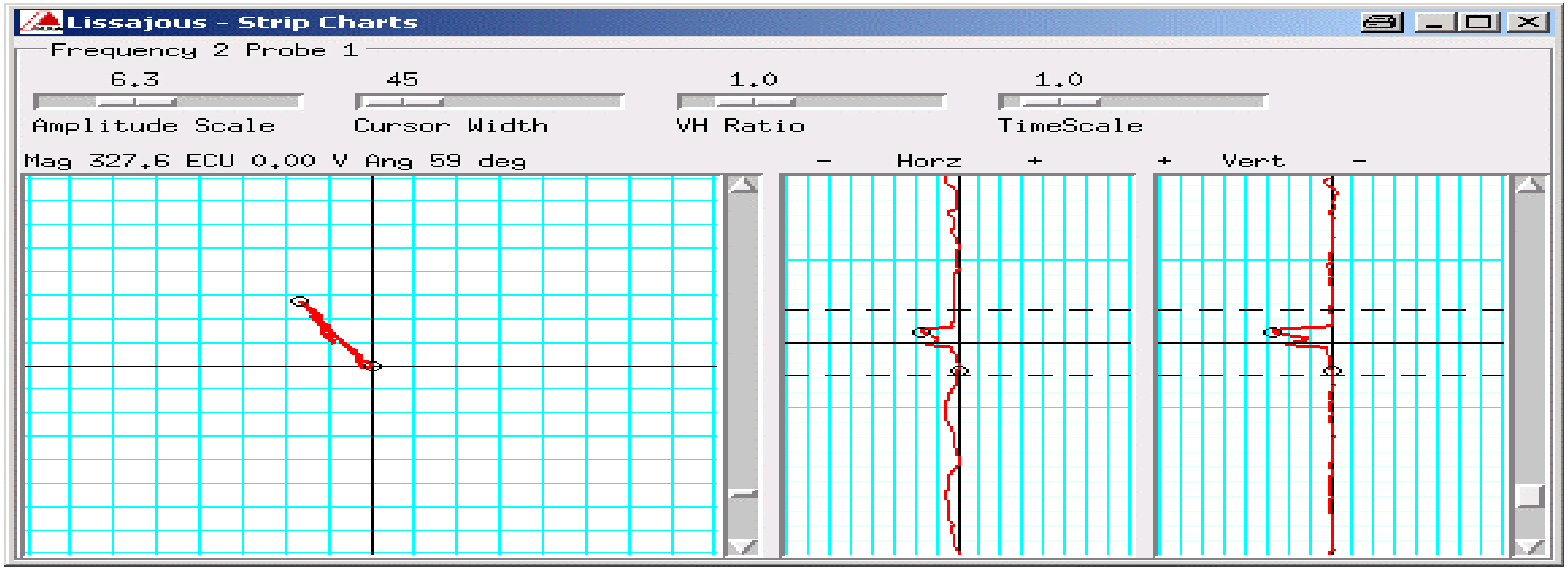
- Preliminary Screening/Grouping of Raw Data.
  - Single Hit Indications
    - 0.125 Indexing
  - Non Quantifiable Indications (NQI)
    - Detected Only With Primary Probe
    - Different Signal Characteristics From Valid Indication

2001 ET Results



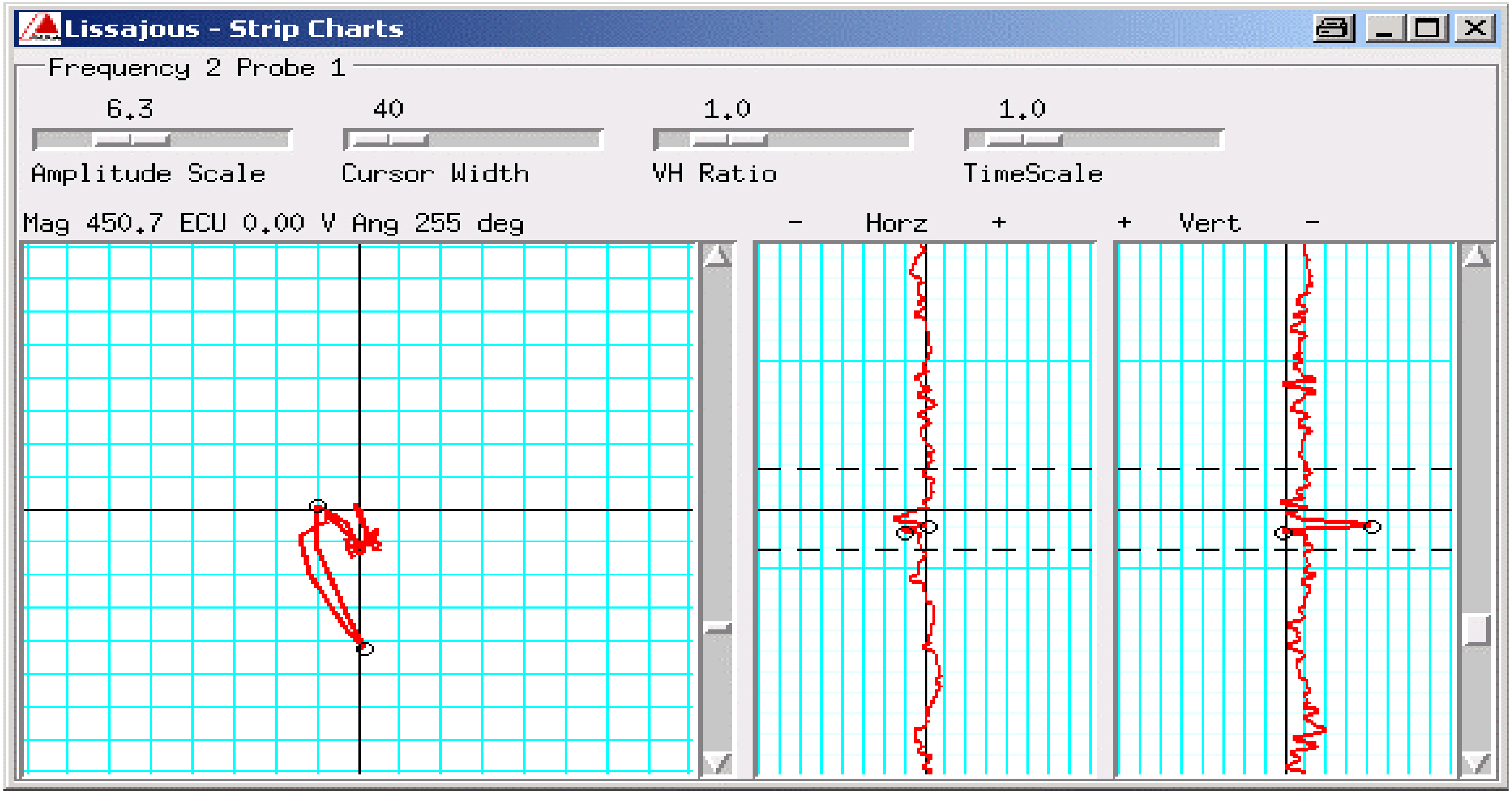
Lissajous from NQI l Indication in Nozzle N-95

2001 ET Results



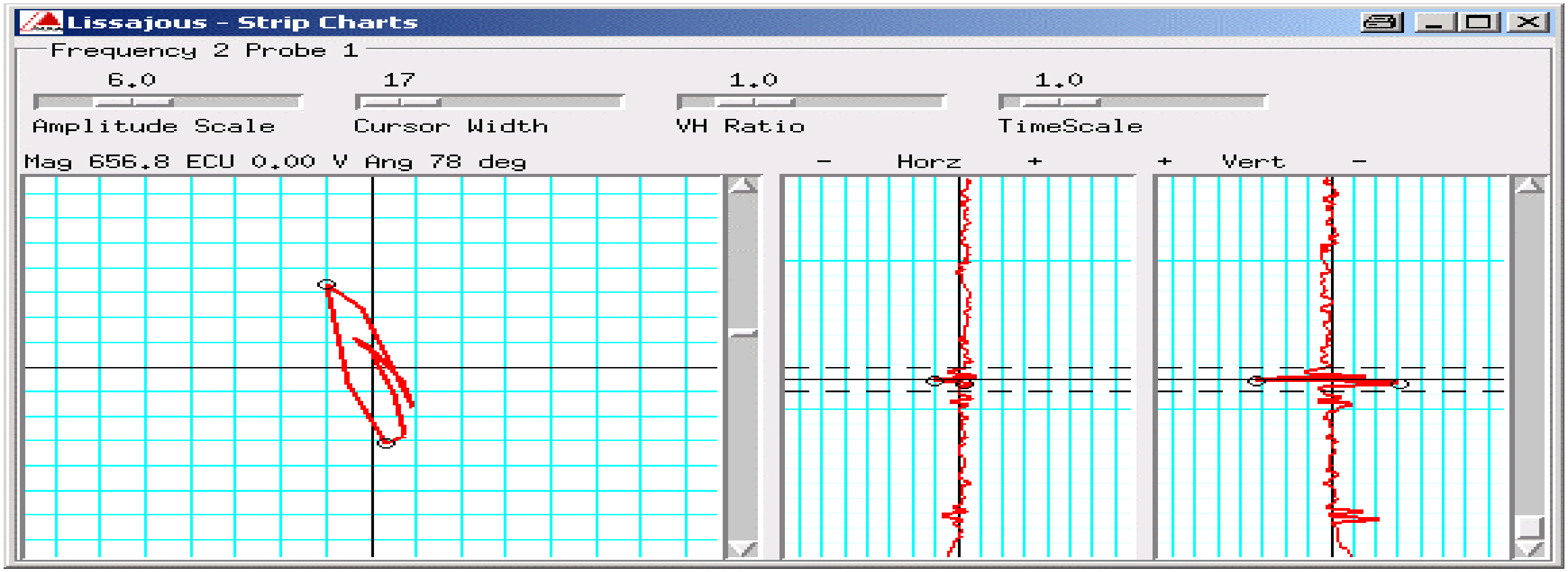
Lissajous from Circumferential Indication in Nozzle N-335
(Axial: 125.00; Circ.: 326 deg. Actual)

2001 ET Results



Lissajous from Axial Indication in Nozzle N-145
(Axial: 121.375; Circ.: 282 deg. Actual)

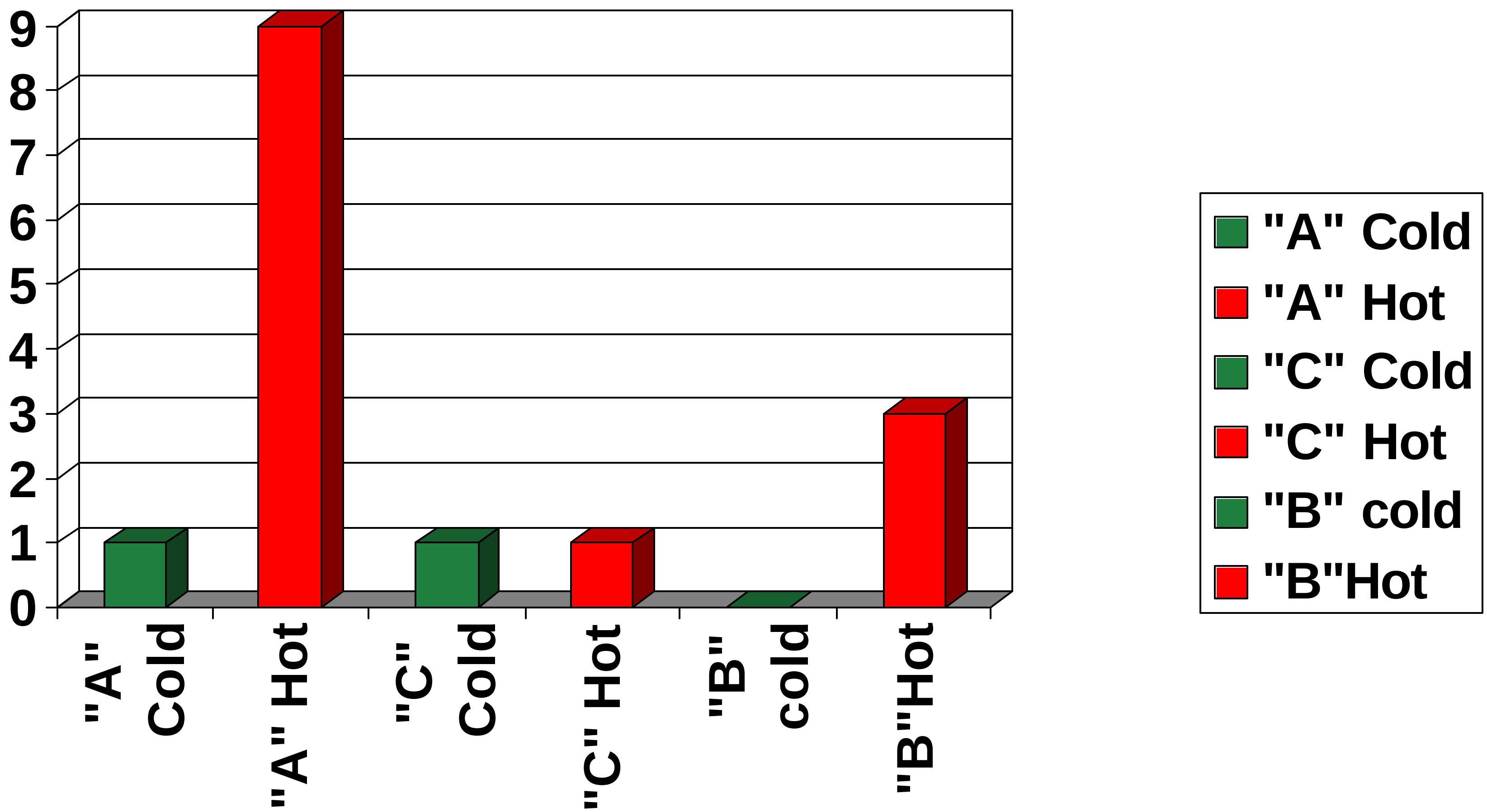
2001 ET Results



Lissajous from NQI l Indication in Nozzle N-95

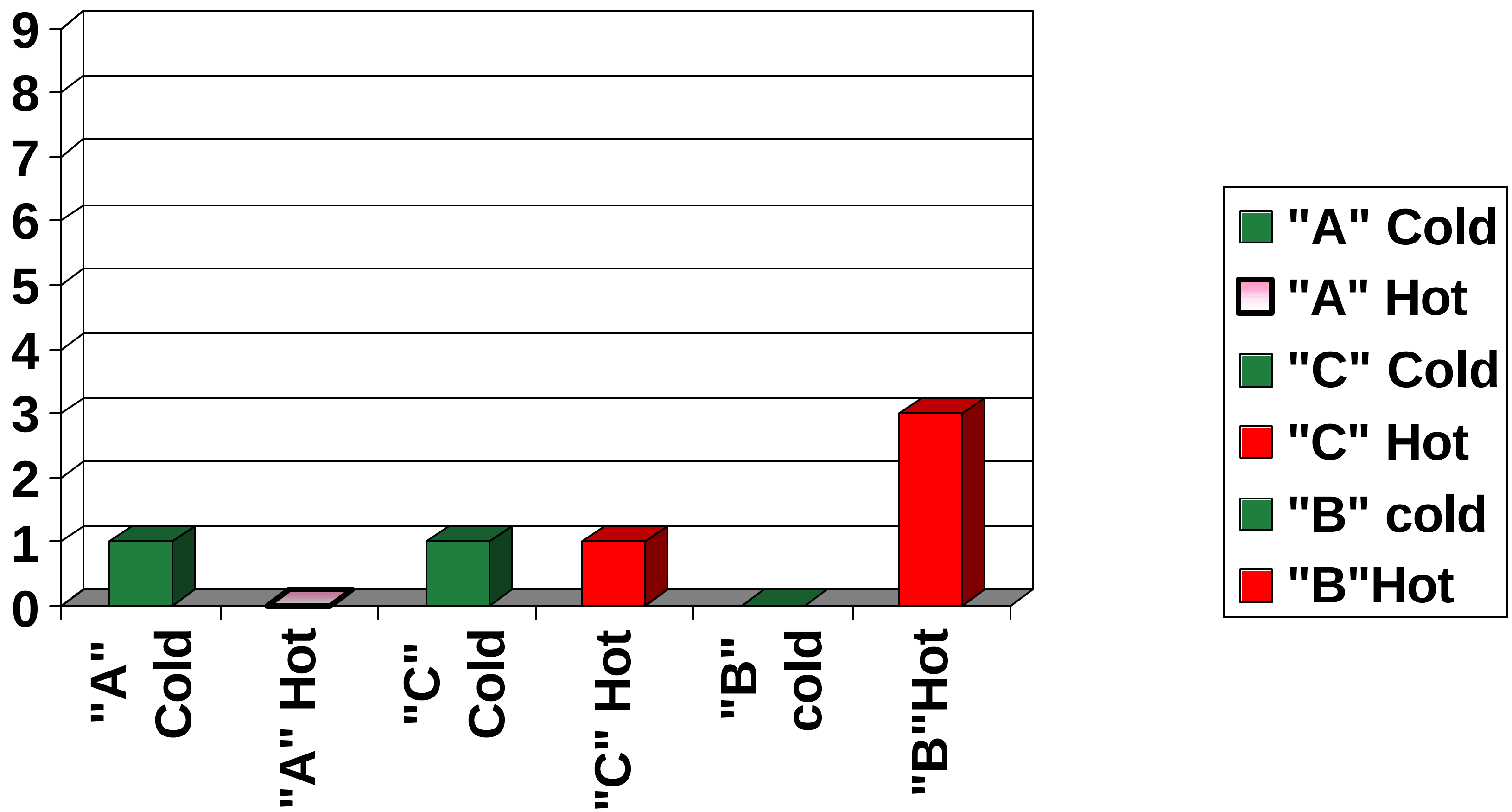
Results

15 Relevant Indications



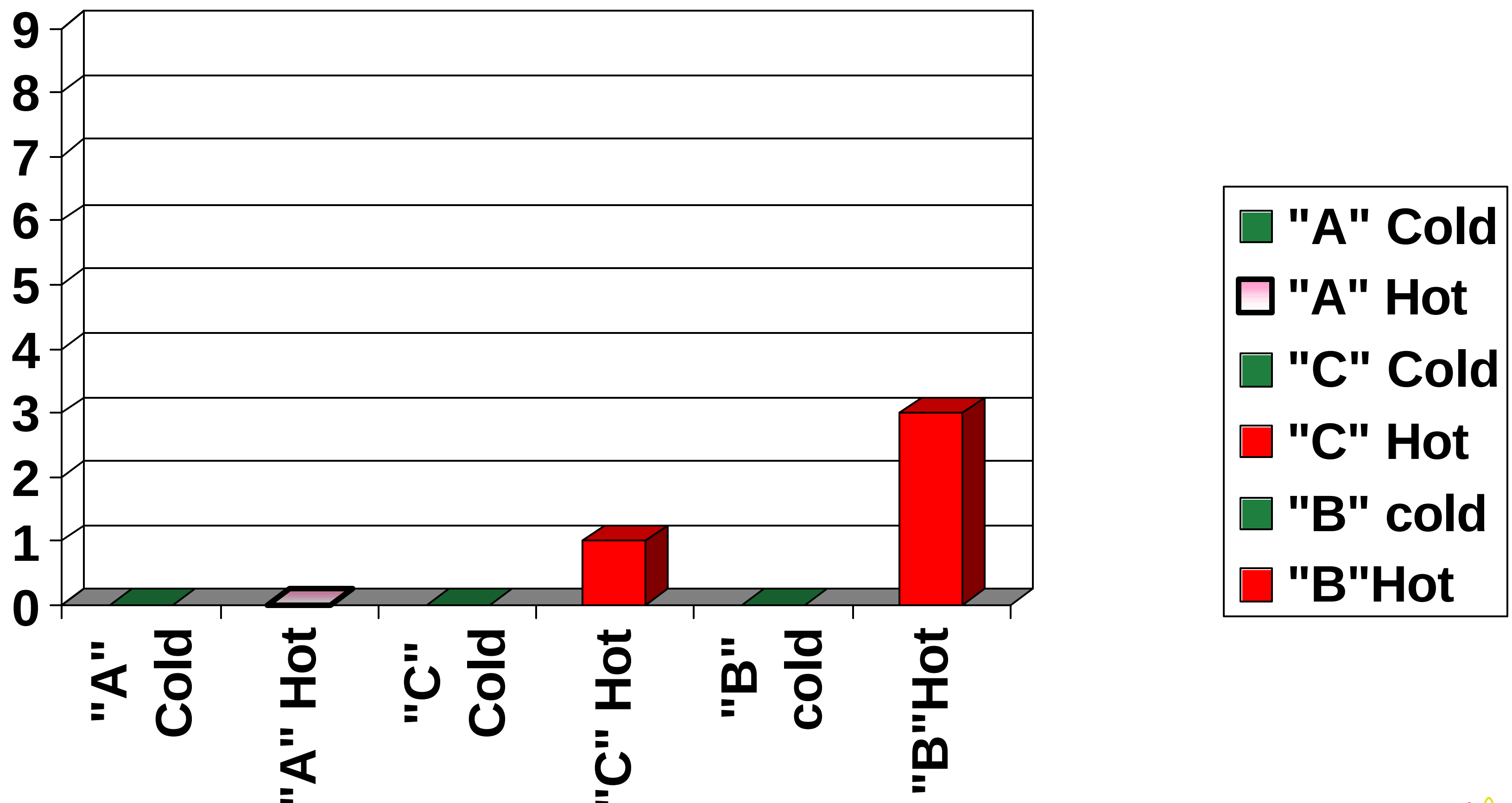
Spool Piece Removal

6 Relevant Indications



Cold Leg Temperature

4 Relevant Indications



ET Analysis

- ET Indications of Interest Are Greater Than 1/4 Inch in Length
- These Indications "Bound" the Smaller Indications in the Nozzles.
- 8 of the 9 Indications in Alpha Hot Leg Were Measured for Crack Length and Then Destructively Examined to Determine the Depth of the Crack.
- The 9th Indication (309 Degree, Axial) Was Preserved for Future Investigations/use.

ET Analysis

- The Aspect Ratio (AR) Was Determined by Dividing the Hot Cell As Measured Length by the As Measured Depth.
- Metallurgical Examination
  - ET "Overcalls" Small Indications (1/2 Inch or Less)
  - ET "Undercalls" Large Indications (1/2 Inch or Greater)
  - False Call Subsurface Iron/Titanium Inclusion
- ET Provides Length Only.

Indications in V. C. Summer RV Nozzle to Pipe Weld Regions

Loop	Leg	Circ. Location/ Orientation	Length (Eddy Current)	Length/Depth* (as measured)	Aspect Ratio
A	Hot (N25)	10 deg/axial	1.75	2.5/2.5	1.0
		11-14/circ	1.0	1.6/0.2	8.0
		12/axial	0.5	0.5/0.2	
		250/axial	>0.5	.750/.615	1.2
		252/axial	0.5	.350/.132	2.7
		255/axial	0.4	.275/.129	2.1
		260/circ	0.25	inclusion	None
		265/axial	0.6	.200/.090	2.2
		309/axial	0.25	Not measured	Not measured
C	Cold (N95)	200 / circ.	0.5		
C	**Hot (N145)**	**309/circ.**	**0.5**		
B	Cold (N215)		No indications		
B	**Hot (N265)**	**35/circ.**	**0.6**		
		200.8/axial	**0.25**		
		348/axial	**0.25**		
A	Cold (N335)	326 / circ.			

*Verified by destructive examination.

Extent of Condition Evaluation

- Determine Flaw Shape
- Know Maximum Allowable Flaw Size
- Crack Growth Rate
- Calculate Safe Conservative Time to Reach Allowable Flaw Size.

Flaw Shape Determinations

- ET Results Are Length Only
- Flaw Depth Was Determined From Destructive Examination of Alpha Hot Leg Indications
- Axial Flaws
  - 4 Flaws Measured
  - Average AR Is 1.8 (will use 2.0)
  - This Matches Observations at European Plant

Flaw Shape Determinations

- Circumferential Flaws
  - No Hot Cell Measurements Available to Apply
  - Axial AR Used Was 2.0
  - The Average Measured AR for Short Axial Flaws Is < 3.0
  - **The ASME Reference Flaw Shape AR Is 6.0**

Allowable Flaw Size

- Determined per ASME Section XI, IWB 3640
- Allowable Depths Determined for Axial Flaws and Circumferential Flaws
- The Maximum Allowable Flaw Size per Section XI is 75 Percent of the Wall Thickness

Crack Growth Calculations

- Fatigue Crack Growth - Very Small Predicted Growth, Even for 40 Years
- Stress Corrosion Crack Growth - Dominant Mode of Growth

Stress Corrosion Crack Growth

- Two Year EPRI Program Completed - 1998 & 1999
- 17 Specimens Tested From Three Welds
- Reference Law Developed by Westinghouse and Published As an EPRI Report, June 2000
- Calculations Completed For:
  - Axial and Circumferential Flaws
  - Several Flaw Shapes
  - Hot Leg and Cold Leg Locations

Conservative Operation Time

- Flaw Lengths Taken Directly From Eddy Current Indications for Other Legs
  - Axial: 0.25 Inches
  - Circumferential: 0.55 Inches (Avg.)
- Axial Flaws
  - AR = 2.0
  - Depth = 0.117 in.
- Circumferential Flaw
  - AR = 6.0
  - Depth = 0.09 in.

Conservative Operation Time

- Axial Flaw
  - **Allowable Service: 3.2 Years**
- Circumferential Flaw
  - (AR = 2.0) - Allowable Service = 14 Years
  - (AR = 3.0) - Allowable Service = 8.4 Years
  - **(AR = 6.0) - Allowable Service = 3.4 Years**
- Cold Leg Indications
  - Crack Growth Rate Is a Factor of 10 Slower, Due to Lower Temperature
  - Hot Leg Results Will Be Governing
  - Safe Operation Time at Least 25 Years

Conclusions

- ASME Section XI Evaluation Shows Acceptable Depths for Both Axial and Circumferential Flaws Are 75 Percent of the Wall Thickness
- Allowable Service Times Were Conservatively Determined Using Crack Growth Data Obtained Recently
- All Service Times Exceed 3.2 Years

However:

Using Additional Conservative Assumptions

- Assume AR of 1.0
- Assume ET Undercalls Large Cracks by 60%
- Apply To Longest Axial Indication (0.25")
- Time to Reach 75% Through Wall Would Be 1.9 Years.
- 1.9 Years Conservative Operation Baseline

End Point of This Effort

- Conclusion Is:
  - √Alpha Hot Leg Is Unique
  - √Commonalties in Other Welds Are Addressed
  - Plant Is Safe for Start Up:
    - √Pipe and Welds Meet Code Requirements
    - √Repair Bounds Probable Failure Mechanisms
    - √Extent of Condition Is Evaluated
  - Ready for Continued Safe Operation

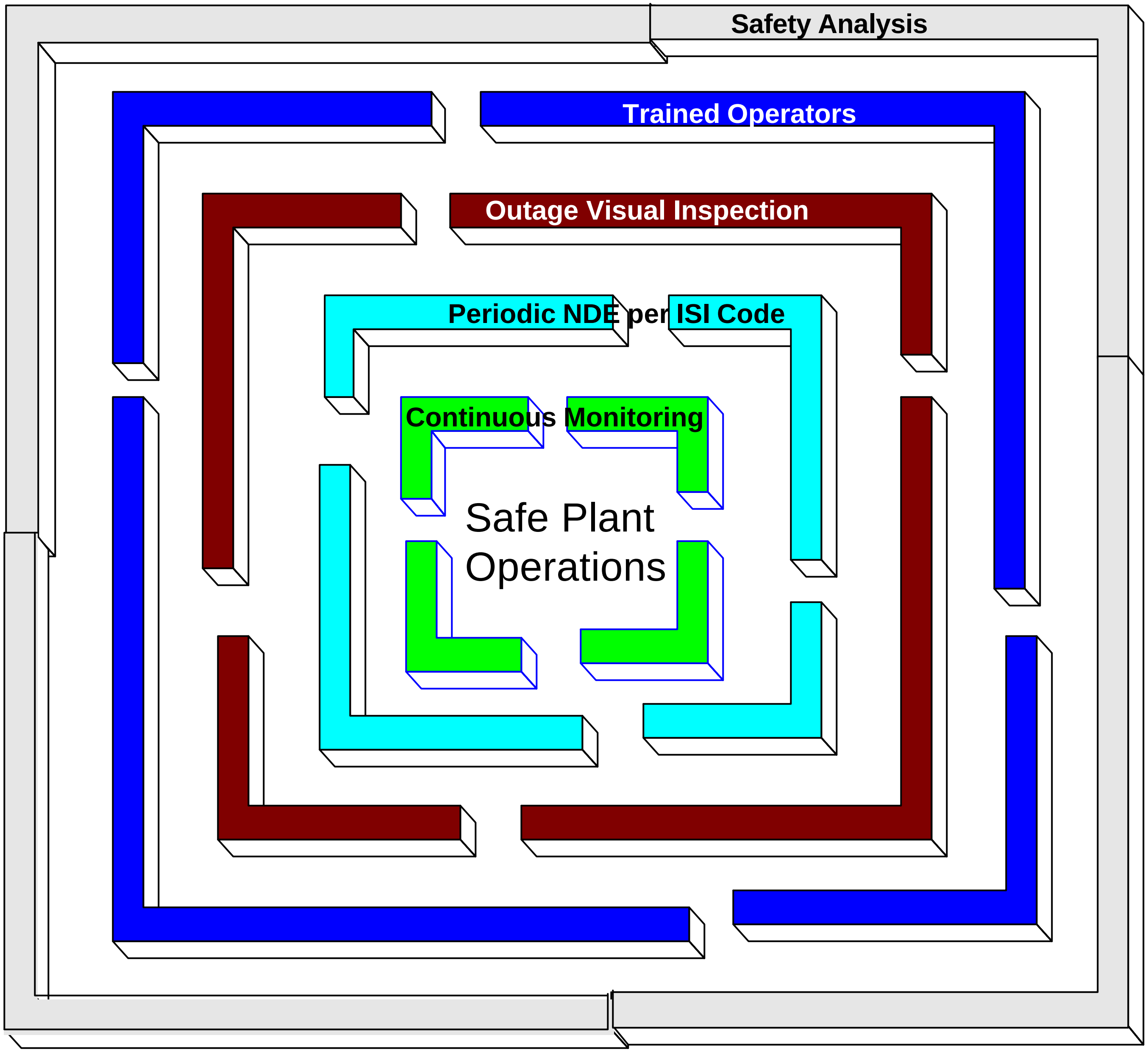
How Safety Margins Are Maintained

Future Actions

Mel Browne

Manager Nuclear Licensing

Challenge to Safety



Challenge to Safety

Future Actions

What Else Can We Do to Provide Additional Confidence in Future Operation?

Leakage Detection Program

- Leakage Detection Program Meets Current Standards
- Noble Gas Sampling of Reactor Bldg.
- Water Balance Inventory
- Computer Generated Warning Alarm
- Apply Lessons Learned to Visual Inspection Procedures

Refuel 13 Inspections

- Operating Interval of 15 Months
- Visual Inspections
- Perform Non-Destructive Exams
  - Potentially Susceptible Nozzles
  - Best Available Ultrasonic Tools & Techniques
  - Other Inspections Based on Industry Initiative
- Inform NRC of Results

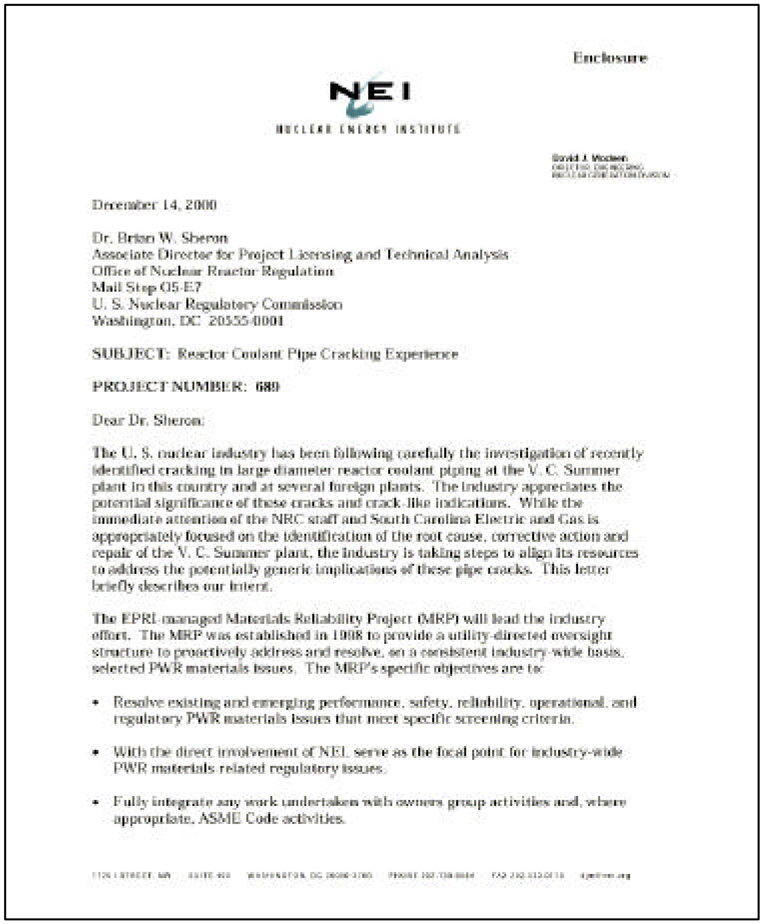
Refuel 14 Inspections

- Operating Interval of ~16 Months
- Repeat Inspections & Expand Scope
  - Visual Inspections
  - Include All Other Reactor Vessel Nozzles
  - Best Available Ultrasonic Tools & Techniques
  - Other Inspections Based on Industry Initiative
- Support or Refute Assumptions
- Inform NRC of Results

Generic Issues

- Potentially Broader Issue?
  - V. C. Summer
  - International Experience
- Industry Response
  - NEI Letter
  - Materials Reliability Project

Generic Implications



Enclosure

NEI

NUCLEAR ENERGY INSTITUTE

December 14, 2000

Dr. Brian W. Sheron
Associate Director for Project Licensing and Technical Analysis
Office of Nuclear Reactor Regulation
Mail Stop O5-E7
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: Reactor Coolant Pipe Cracking Experience

PROJECT NUMBER: 689

Dear Dr. Sheron:

The U. S. nuclear industry has been following carefully the investigation of recently identified cracking in large diameter reactor coolant piping at the V. C. Summer plant in this country and at several foreign plants. The industry appreciates the potential significance of these cracks and crack-like indications. While the immediate attention of the NRC staff and South Carolina Electric and Gas is appropriately focused on the identification of the root cause, corrective action and repair of the V. C. Summer plant, the industry is taking steps to align its resources to address the potentially generic implications of these pipe cracks. This letter briefly describes our intent.

The EPRI-managed Materials Reliability Project (MRP) will lead the industry effort. The MRP was established in 1998 to provide a utility-directed oversight structure to proactively address and resolve, on a consistent industry-wide basis, selected PWR materials issues. The MRP's specific objectives are to:

- Resolve existing and emerging performance, safety, reliability, operational, and regulatory PWR materials issues that meet specific screening criteria.
- With the direct involvement of NEI, serve as the focal point for industry-wide PWR materials-related regulatory issues.
- Fully integrate any work undertaken with owners group activities and, where appropriate, ASME Code activities.

- MRP Action Plan
  - Define Potential Generic Implications
  - Develop Action Plan
  - Obtain NRC Feedback
  - Obtain Approval
  - Advise NRC
- VCSNS Participating Fully

Summary and Questions

Greg Halnon

General Manager Engineering Services

End Point of This Effort

- Conclusion Is:
  - √Alpha Hot Leg Is Unique
  - √Commonalties in Other Welds Are Addressed
  - √Plant Is Safe for Start Up:
    - √Pipe and Welds Meet Code Requirements
    - √Repair Bounds Probable Failure Mechanisms
    - √Extent of Condition Is Evaluated
  - √Ready for Continued Safe Operation