# Ginna Station

# CRDM Cracking Technical Evaluation

## NRC Status Update

Rockville, Maryland
December 12, 2001

Enclosure 3

**Rochester Gas & Electric Corporation**

# Ginna Station CRDM Cracking Technical Evaluation
# Agenda

| | | |
|---|---|---|
| • Overview/Background | B. Flynn | 15 minutes |
| • 1999 Inspections | A. Butcavage<br>M. Shields | 45 minutes |
| • Reactor Vessel Head Temperature | B. Flynn | 30 minutes |
| • Break | | 10 minutes |
| • Crack Growth Rate Analysis | H. Gustin, SI | 30 minutes |
| • Probabilistic Safety Assessment | M. Flaherty | 15 minutes |
| • Replacement Reactor Vessel Head | B. Flynn<br>R. Klarner, BWC | 30 minutes |
| • Summary / Conclusion | T. Marlow | 5 minutes |

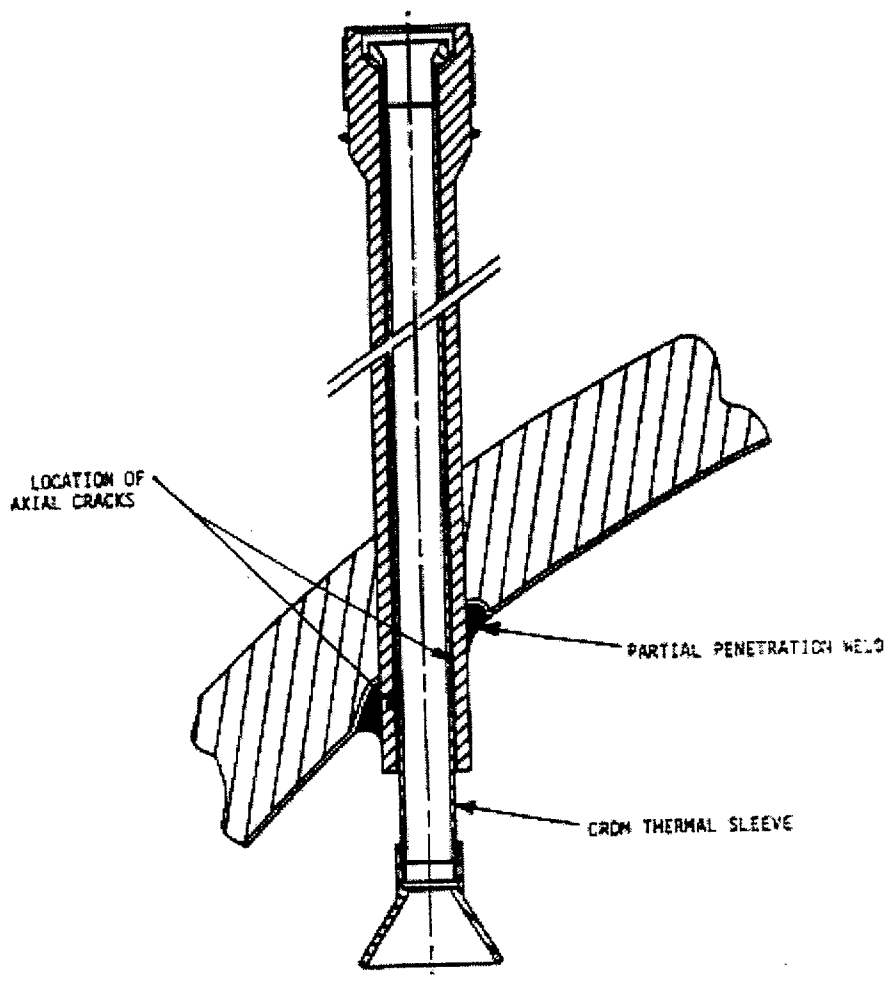
# Overview/Background

- 2-Loop Westinghouse PWR
- 490 MWe, Online December, 1969
- Reactor Vessel Manufactured by B&W
- CRDM Tube Material from Huntington

# Overview

(continued)

- Reactor Vessel Closure Head
  - 38 Penetrations in Head
    - 29 CRDM's
    - 4 Part Length CRDMs (abandoned)
    - 4 Instrumentation Ports (1 spare)
    - 1


LOCATION OF
AXIAL CRACKS
PARTIAL PENETRATION WELD
CRDM THERMAL SLEEVE

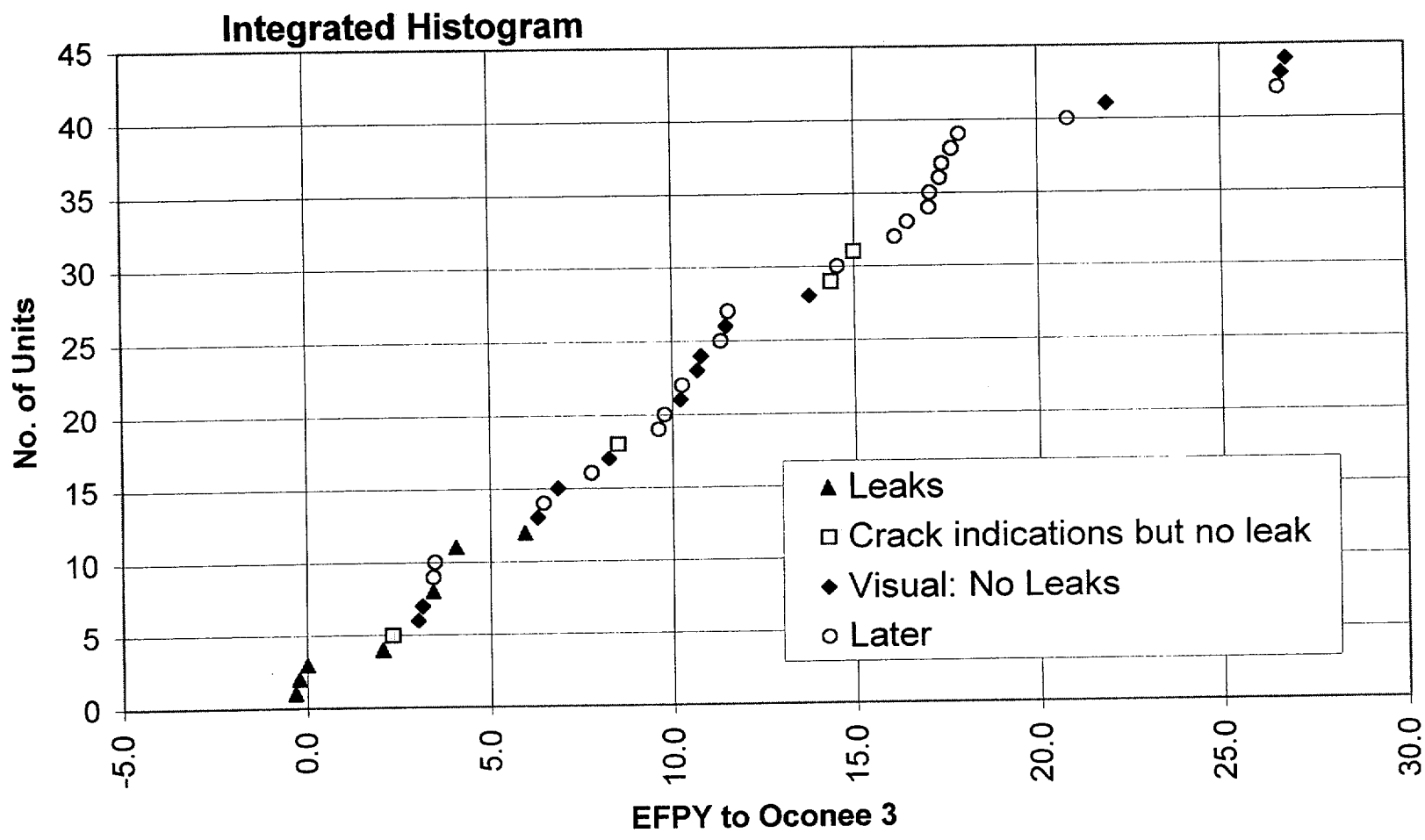
# Background

- RG&E Initially Participated in NEI AHAC Committee on Issue Starting in 1992
  - Top of Insulation Visual Inspections
  - Underhead Visual Checks Via Remote Crawler (1993)
  - Purchased As-Built Package from Manufacturer
- Following Generic Letter 97-01, RG&E volunteered for ET Penetration Inspection
  - Inspection Completed in 1999
  - All 38 Penetrations Inspected
  - Better Baseline than Effective Visual Exam
- Continued MRP Participation

# Background

(continued)

- Reactor Operating Times
  - 1999 Inspection – 22.2 EFPY's
  - December 12, 2001 – 24.7 EFPY's (2.49)
  - September 15, 2003 – 26.4 EFPY's (4.16 projected)
- Ginna Ranking in Industry Histogram (MRP-48)
  - 31st, 15.0 EFPY's (NRC Group 5 to 30 years)
  - Margin to those who have found indications


Integrated Histogram
No. of Units
45
40
35
30
25
20
15
10
5
0
-5.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
EFPY to Oconee 3
Leaks
Crack indications but no leak
Visual: No Leaks
Later

# Ginna 1999 Inspection

Al Butcavage
Mike Shields

Rochester Gas & Electric Corporation

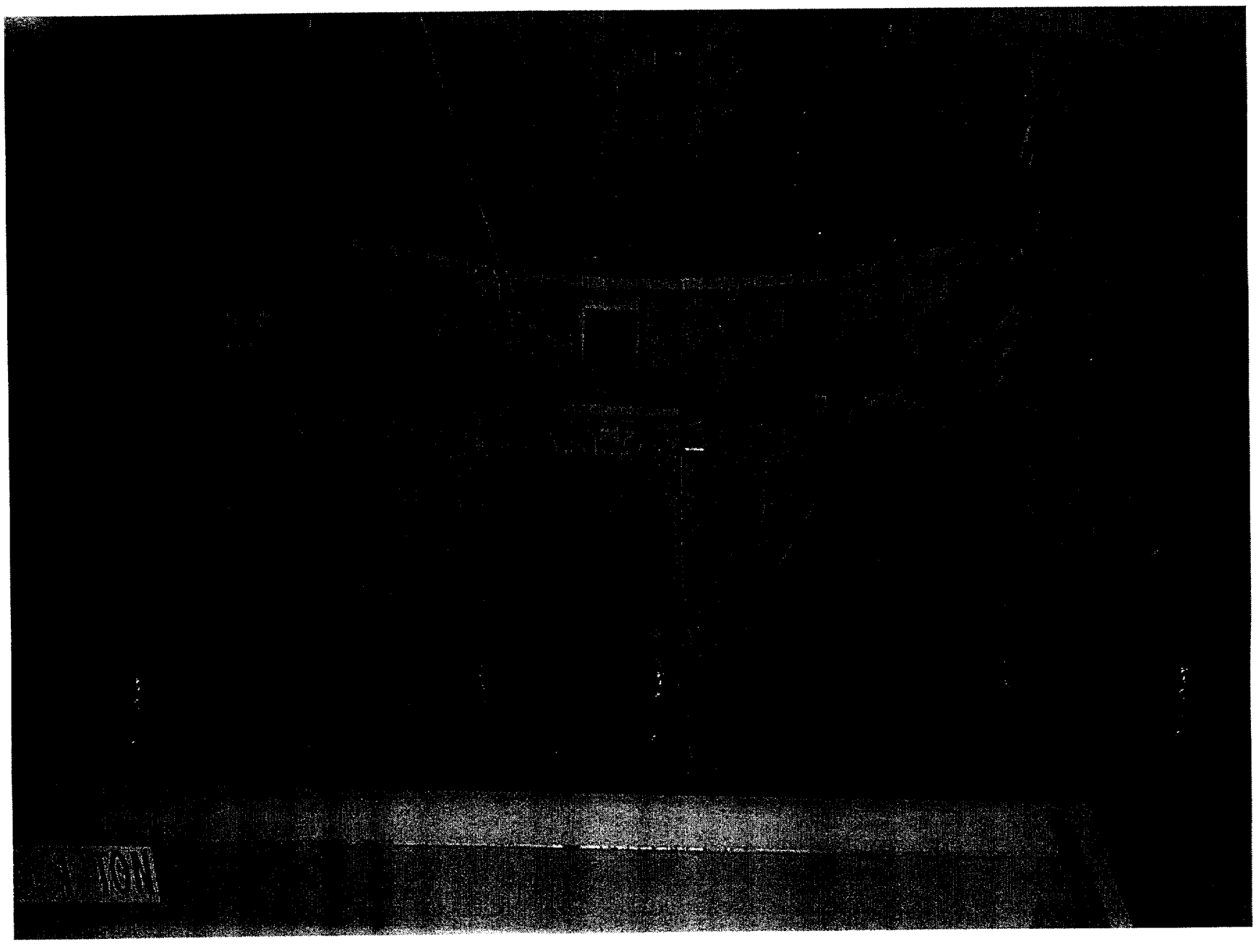
# Ginna 1999 Inspection

- Purpose
  - GL 97-01 Issues
  - Primarily looking for Axial Indications
  - Equally Sensitive to Axial and Circumferential Indications
  - All nozzles not just CRDMs

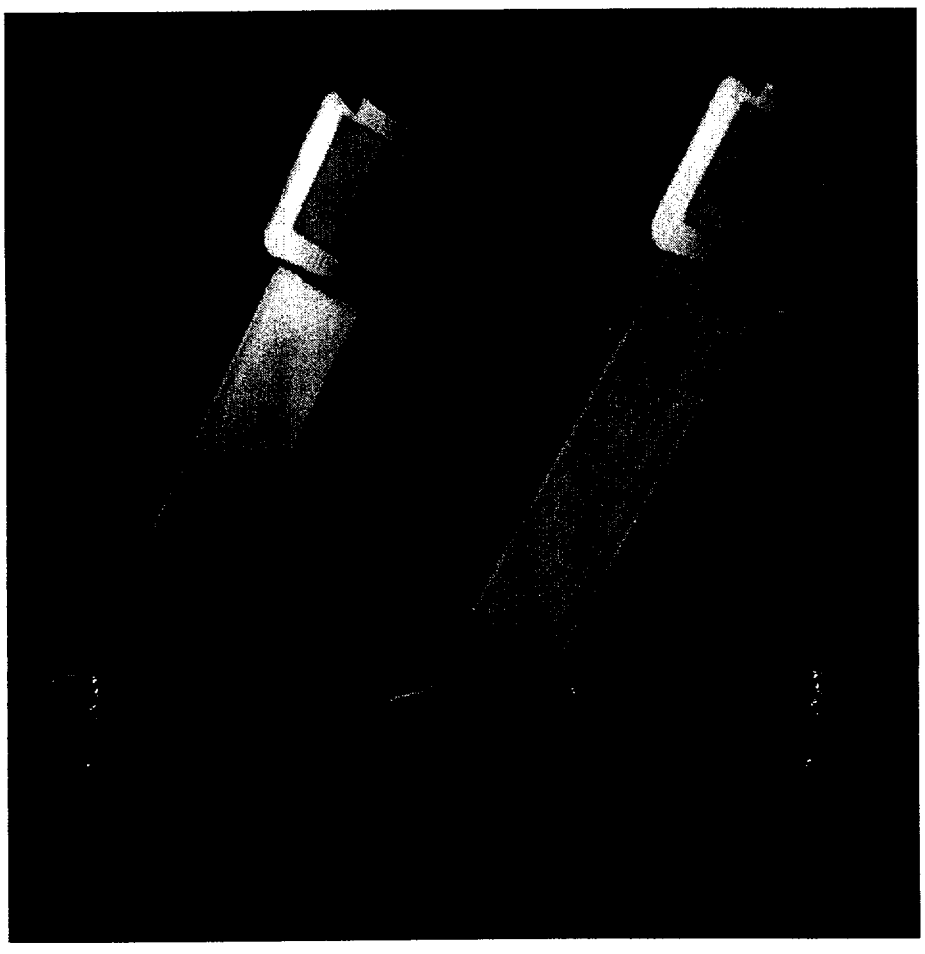
# Ginna 1999 Inspection

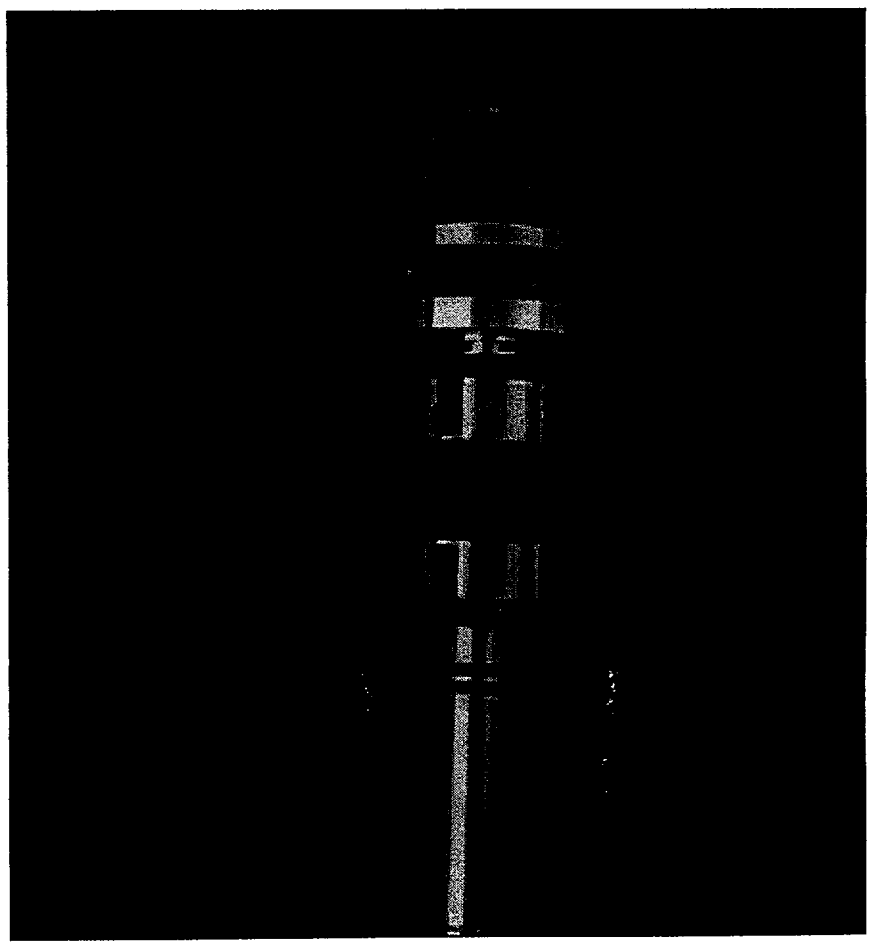
- 3 Vendors Considered
- FTI Selected
  - Experience in European Plants
  - Equipment matched our expertise (Zetec)
  - Vendor agreed to additional EPRI Blind Tests
  - Viable Repair Technique
- Method
  - Blade/Rotating Probes
  - ET Used for Detection
  - UT Used for Sizing

# Ginna 1999 Inspection

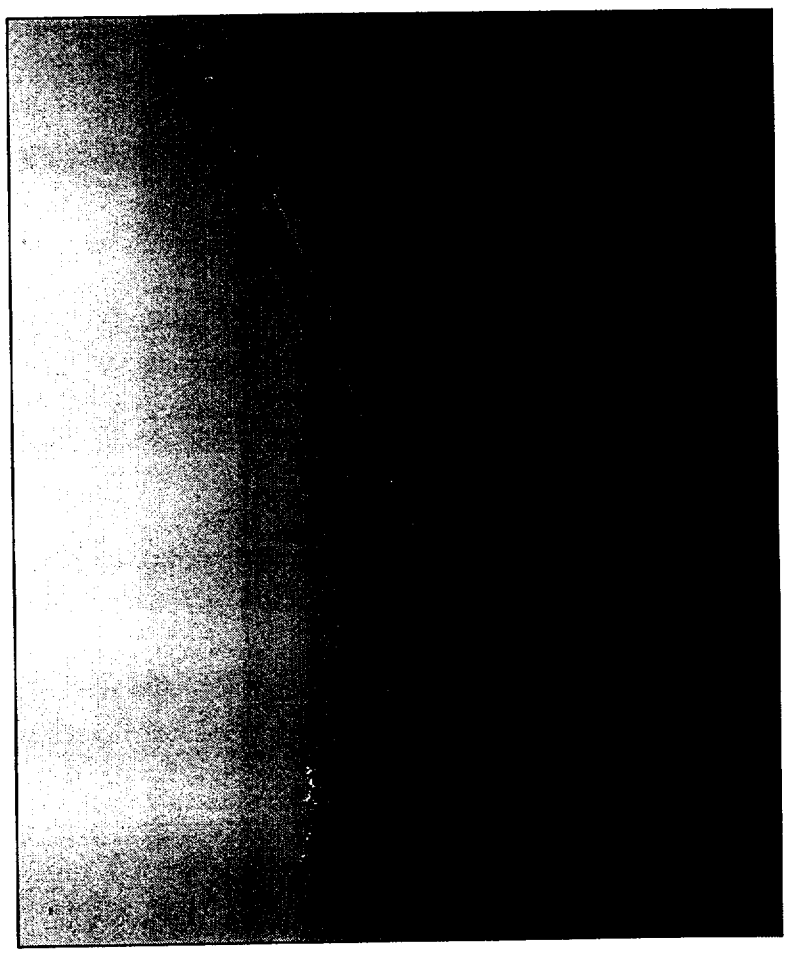


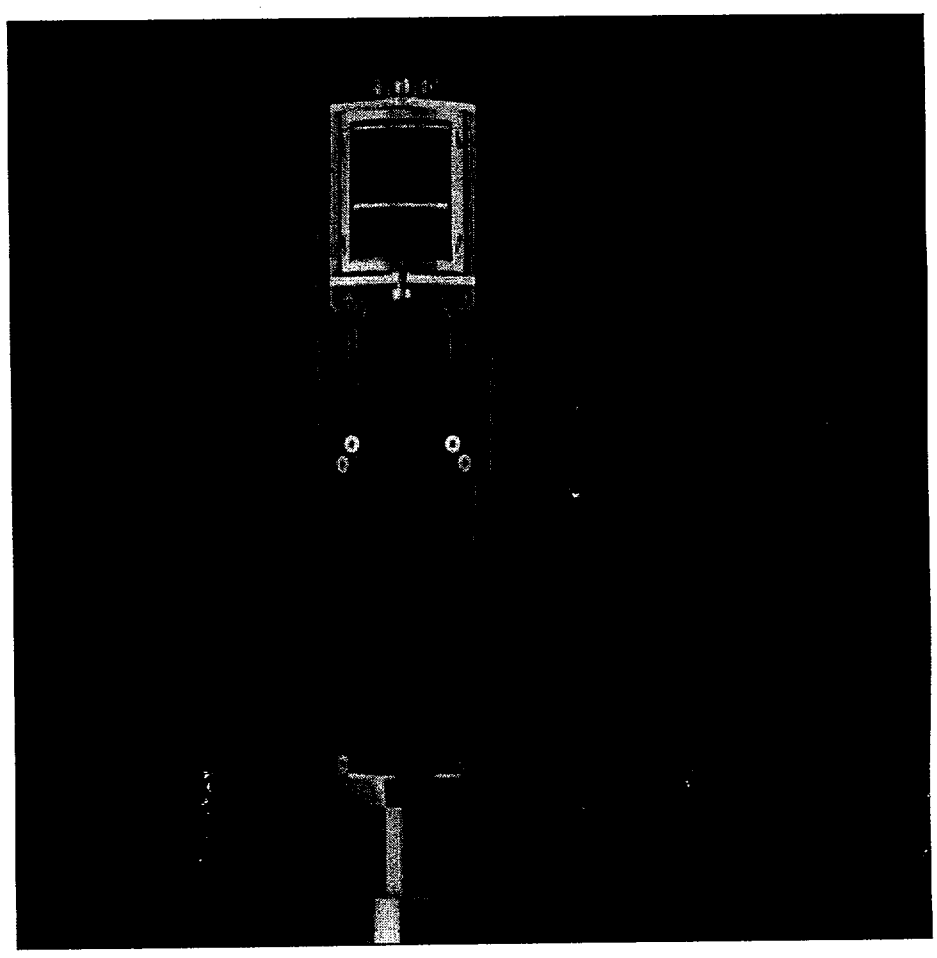
# Typical Blade & Rotating Eddy Current Probes





# Typical Blade & Rotating Ultrasonic Probes





# Ginna 1999 Inspection

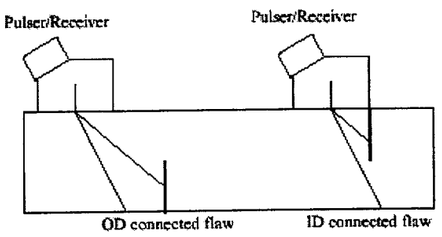
- EPRI Blind Performance Test
  - ET/UT Qualifications
    - Axial
    - Circumferential
    - Off Axis
    - Clustered
    - Single
    - Branched
  - Equally sensitive to I.D. or O.D. circumferential or axial throughwall cracks
  - Results Detect-Size-Locate (EPRI Report TR-106260)
    - Successful in all areas

# Ginna 1999 Inspection

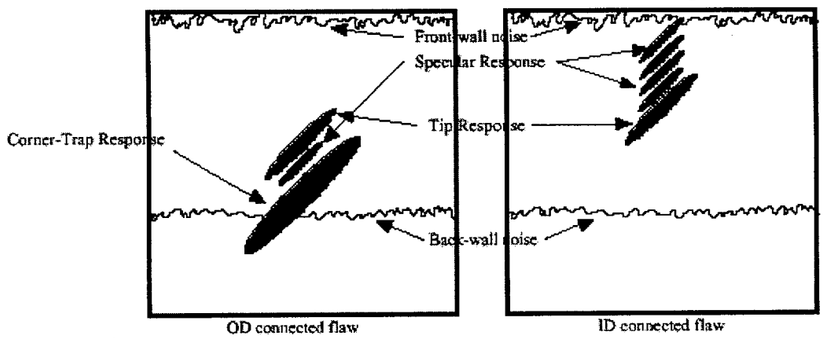
- Results
  - RG&E NDE Level III Online Review of 100% of ET and UT Data
  - The required nozzle inspection area was ±2" from weld
  - 93% of surface area covered
  - 1 nozzle (#13) with ET shallow indications
    - Shallow "craze" ID indications ≈ 5% of area
    - Random in HAZ
    - Sized with UT
    - 2 probes mid surface, near surface
    - Indications below minimum detection of UT probes (< 0.8 mm)

# Ginna 1999 Inspection

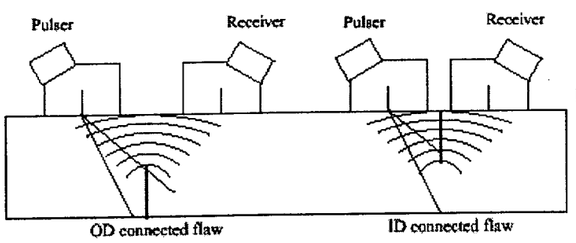
**Pulse-Echo Backscatter UT Technique**



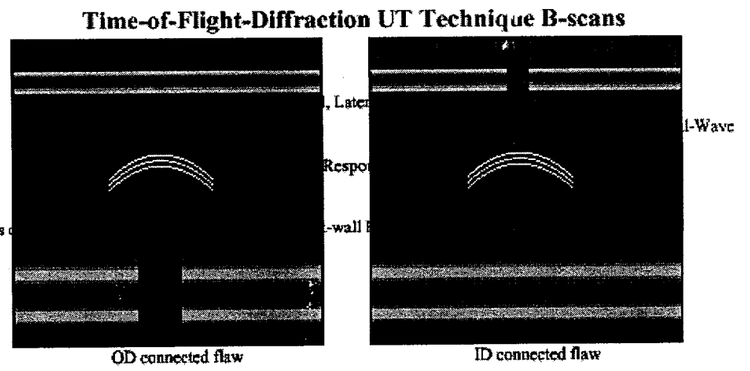

**Pulse-Echo Backscatter UT Technique B-scans w/angle correction**




**Time-of-Flight-Diffraction UT Technique**



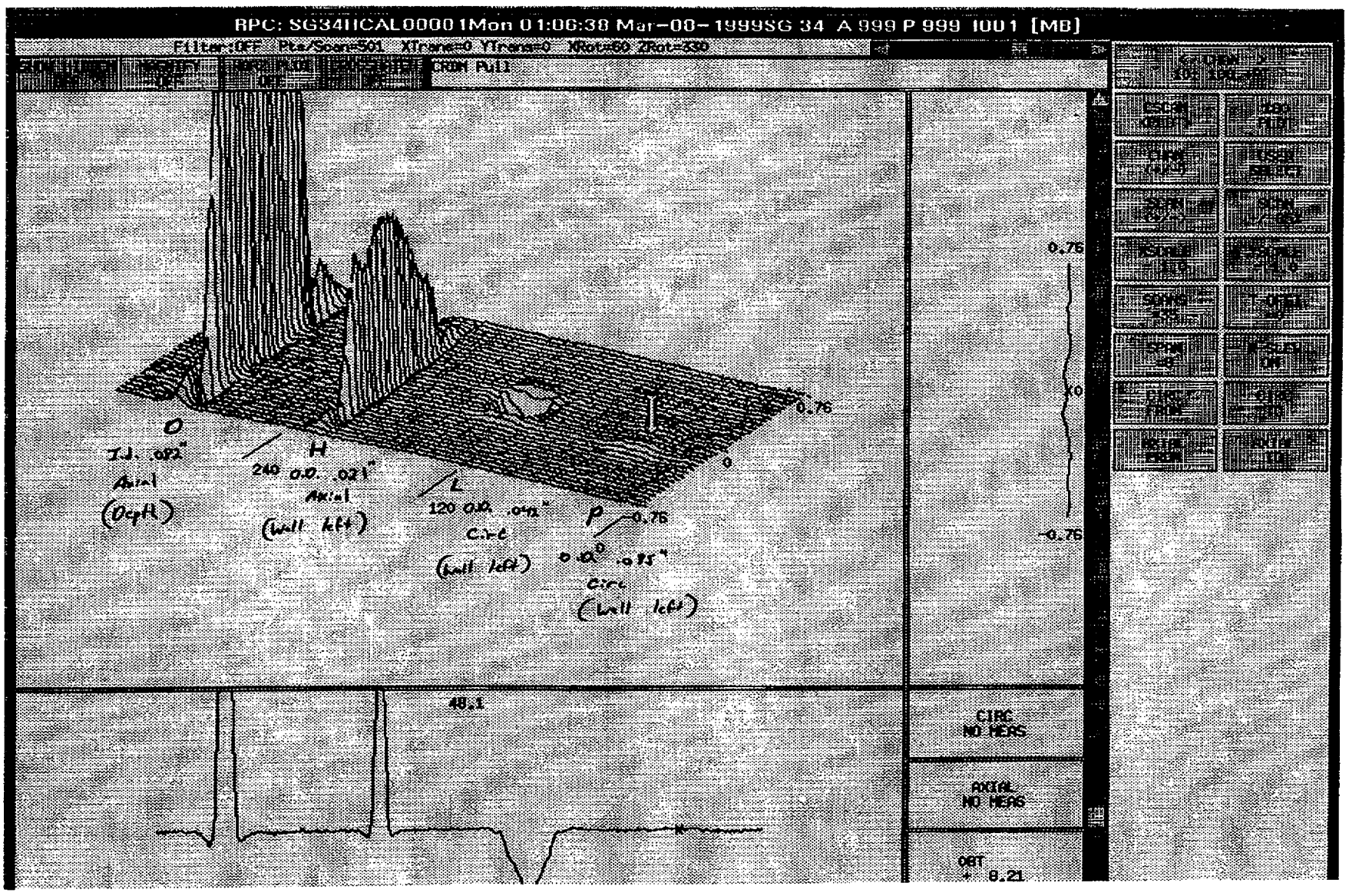

**Time-of-Flight-Diffraction UT Technique B-scans**



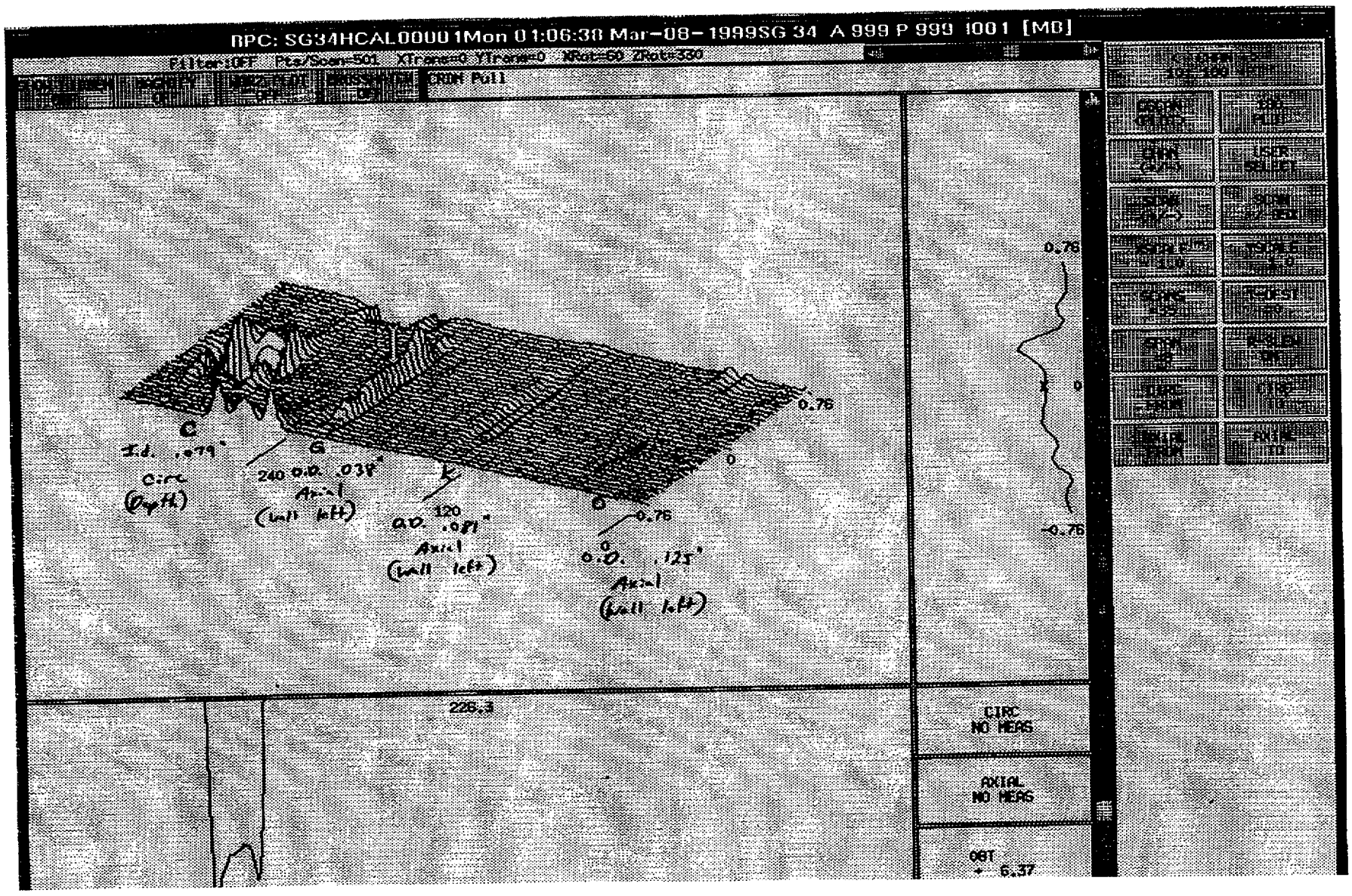
# Ginna 1999 Inspection

- Post Oconee Review
  - Vendor Review of UT Data (#13)
    - No change in conclusions
  - RG&E Level 3 Review of ET Data
    - Mockup contained O.D. initiated Axial and Circumferential flaws and were detected at .042" subsurface
    - ASME Section XI considers eddy current for S/G a volumetric inspection for tube wall up to .050"
    - Data review included lower frequency deeper inspection approach
    - No change to original report

# Ginna 1999 Inspection



# Ginna 1999 Inspection



# Reactor Vessel Head Temperature

**Brian Flynn**

**Rochester Gas & Electric Corporation**

# Ginna Reactor Vessel Head Temperature

- CRDM Cracking Susceptibility and Growth Very Temperature Dependent
  - 2.25 EFPY at 580°F = 1.0 EFPY at 600°F
- Westinghouse Reactor Vessel Internals Design Provides Some Upper Head Cooling
- Two-loop Plants Inherently Cooler Upper Heads
- Temperature Utilized in MRP Ranking Conservatively Chosen

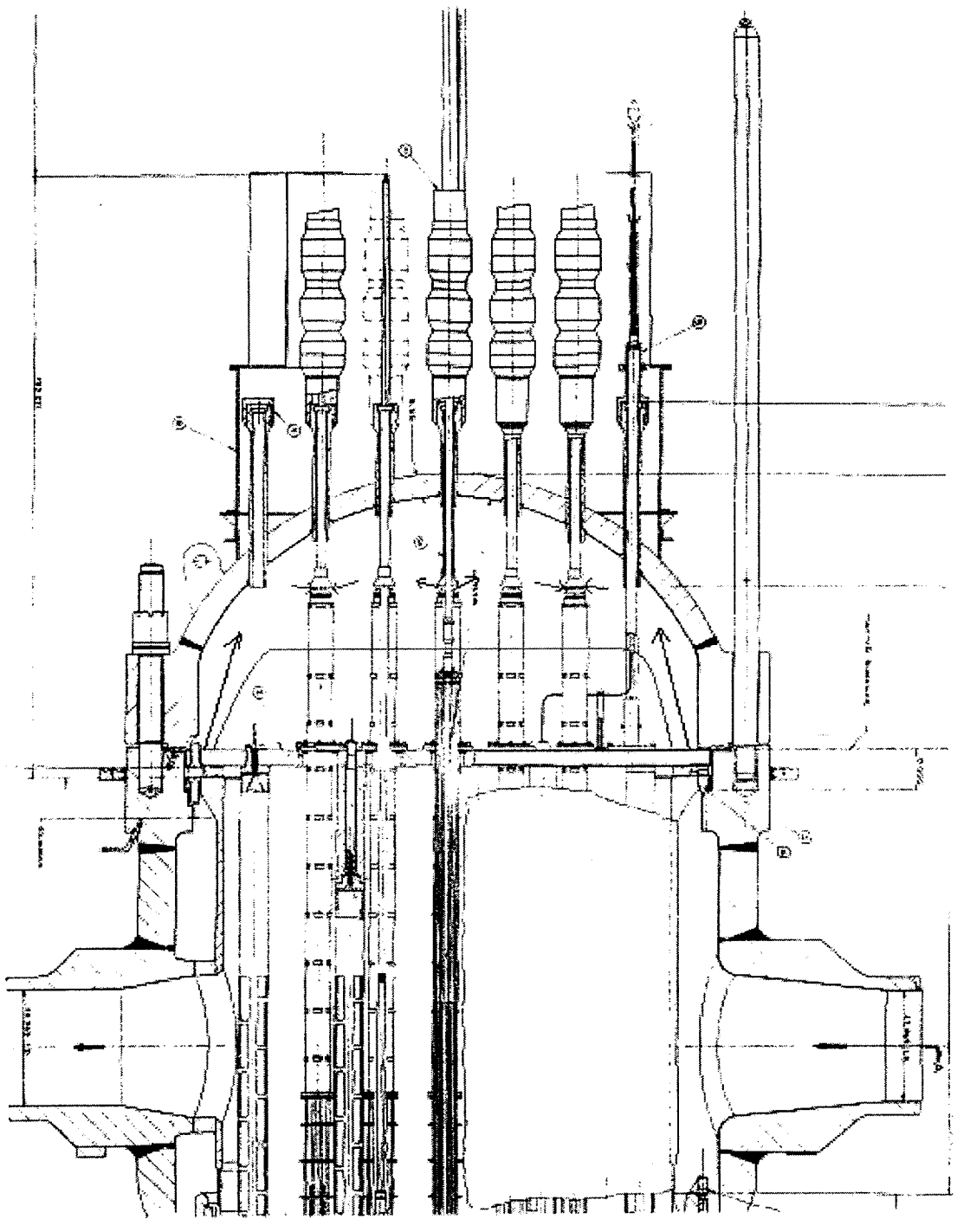
# Ginna Reactor Vessel Head Temperature Operating Conditions

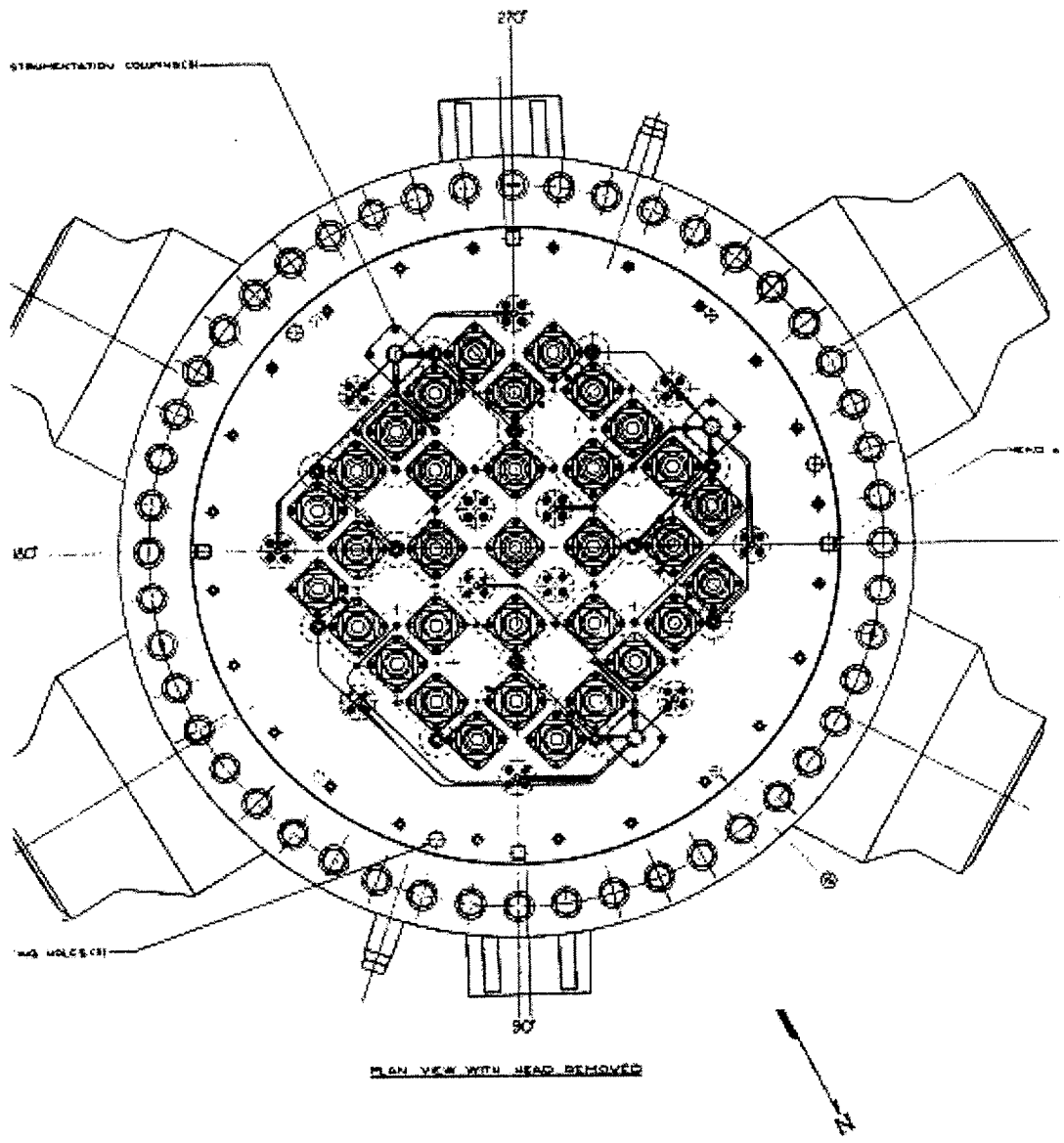
- 100% Power Operation

  Tcold = 532.6° F
  Tavg = 561° F
  Thot = 589.5° F

  Upper Head Bypass Flow ≈ 550 gpm (0.29%)

- Operation Since 1999 Inspections
  - 2.49 EFPY
  - 4.16 EFPY prior to proposed replacement




270°
180°
90°
PLAN VIEW WITH HEAD REMOVED

| | 1 | 2 | 3 | 4 | 5 | | 560<br>27 | | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | | | | | | | | | | | | | |
| B | | | | | 583<br>50 | | 580<br>48 | | | | | | |
| C | | | 551<br>18 | | | 597<br>64 | | 596<br>63 | | | 549<br>16 | | |
| D | | 553<br>20 | | | 596<br>63 | | | | | | | 561<br>28 | |
| E | | | | 594<br>61 | | 597<br>64 | | | | 596<br>63 | | | |
| | | | | | | | | 589<br>56 | | | | | |
| | 579<br>46 | 585<br>52 | | 580<br>47 | | | 594<br>61 | | | | | 585<br>52 | |
| | | | | | | 592<br>59 | | | 596<br>63 | 598<br>66 | 598<br>65 | | 548<br>15 |
| I | | 562<br>29 | | 592<br>59 | | | 593<br>60 | | | 580<br>47 | | | |
| J | | | | | | 606<br>73 | | 606<br>73 | 597<br>64 | | | | |
| K | | | 564<br>31 | | | | | | | | 550<br>17 | | |
| L | | | | | | | 575<br>42 | | | 558<br>26 | | | |
| M | | | | | | 548<br>15 | | | | | | | |

TEMP DT

TRAIN A

# Determining Upper Head Temperature

- WCAP - 9404 "Study of Reactor Vessel Upper Head Region Fluid Temperature", 1978
  - Analytical Modeling
  - 1/5 Scale Tests
  - In Plant Instrumentation, 5 plants installed new thermocouples
    - Ginna was 2-Loop Plant
    - Farley Under Construction, Enhanced Instrumentation

- Results
  - Analytical Model Closely Matched Scaled Tests
  - Temperatures Measured at Farley Match "Momentum Controlled" Flow Pattern
  - Two-Loop Plant Lowest Predicted Temperature
    - Low Differential Pressure in Outlet Plenum
  - Tmax in head in lower region

# Ginna Upper Head Temperature Results

- Ginna Utilized Temperature Representative of Tmax in Upper Head Region
  - Average of 3 Upper Head Thermocouples 580.2° F
- Westinghouse Model Predicts Bulk Fluid Average 577.5° F
- Region of CRDM Welds Expected to be Lower
  - Particularly in Region of Outer Penetrations

# Allowable Flaw Size and Flaw Growth Calculations

Hal Gustin

December 12, 2001

Structural Integrity Associates

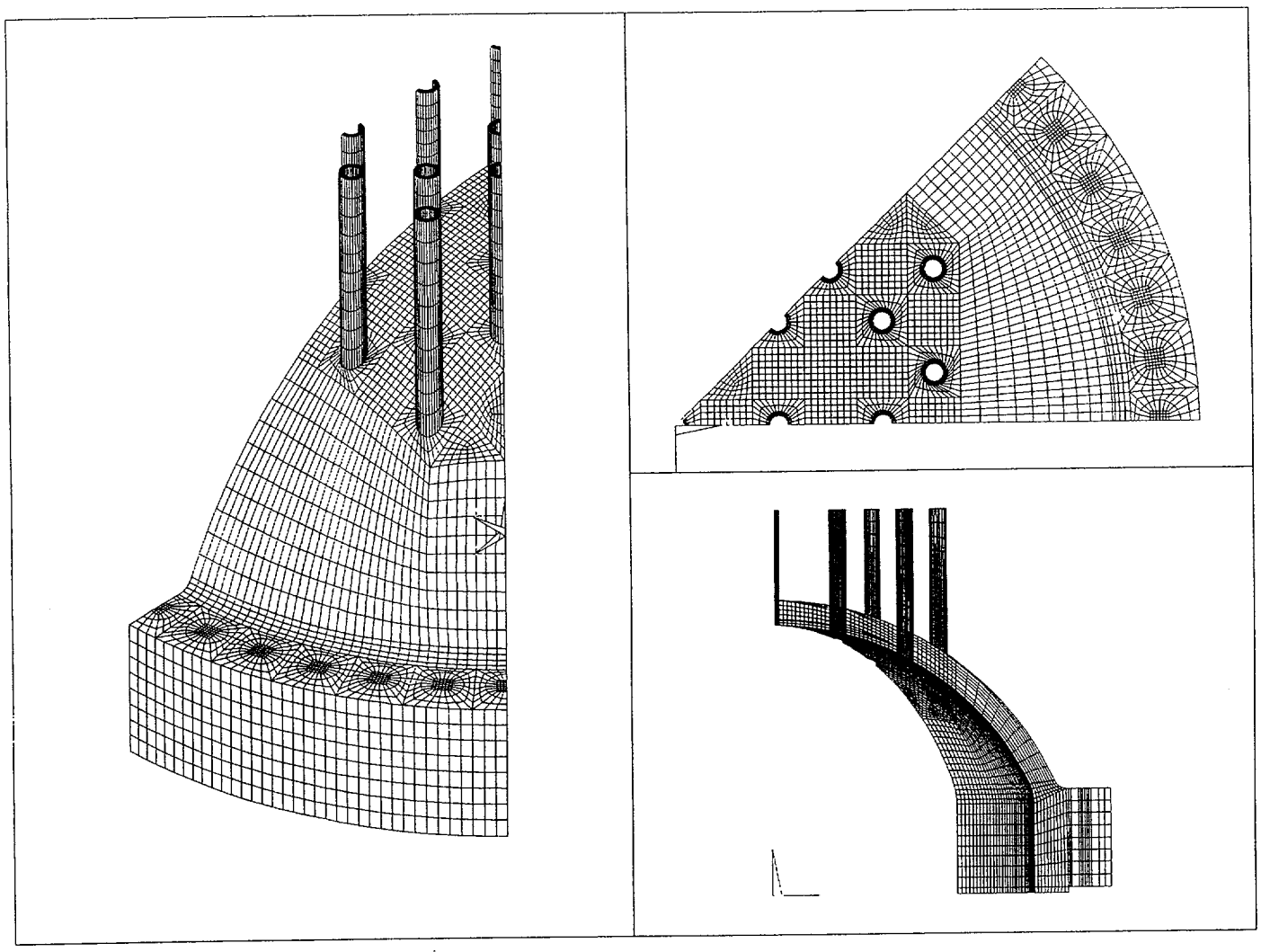
# GINNA ANALYTICAL PROGRAM

- Determine maximum gap sizes for linear elastic fracture mechanics evaluations
- Determine critical/allowable circumferential through-wall flaw length for nozzle
- Perform linear elastic fracture mechanics analyses for representative set of nozzles for various flaw lengths
- Develop crack growth law by adjusting MRP 95% confidence crack growth rate to Ginna temperature (580° F)
- Determine time to reach allowable flaw length from hypothetical "large" through-wall circumferential flaw in nozzle

# MAXIMUM GAP SIZES - GINNA

- Finite element analysis of 45° of top head with nozzles
  - Symmetric boundary conditions
  - Gap elements between nozzles and head
- Loading conditions
  - Normal operating pressure
  - Normal operating temperature
  - Closure bolt loads
  - Gasket/spring loads
  - Initial 0.00 inch clearance between nozzles and head
- Maximum gap openings determined

# GINNA FINITE ELEMENT MODEL



Structural Integrity Associates

PRS-01-060/4

# CRITICAL/ALLOWABLE FLAW LENGTH - GINNA

- **Equation 5.1 of MRP-44 utilized:**

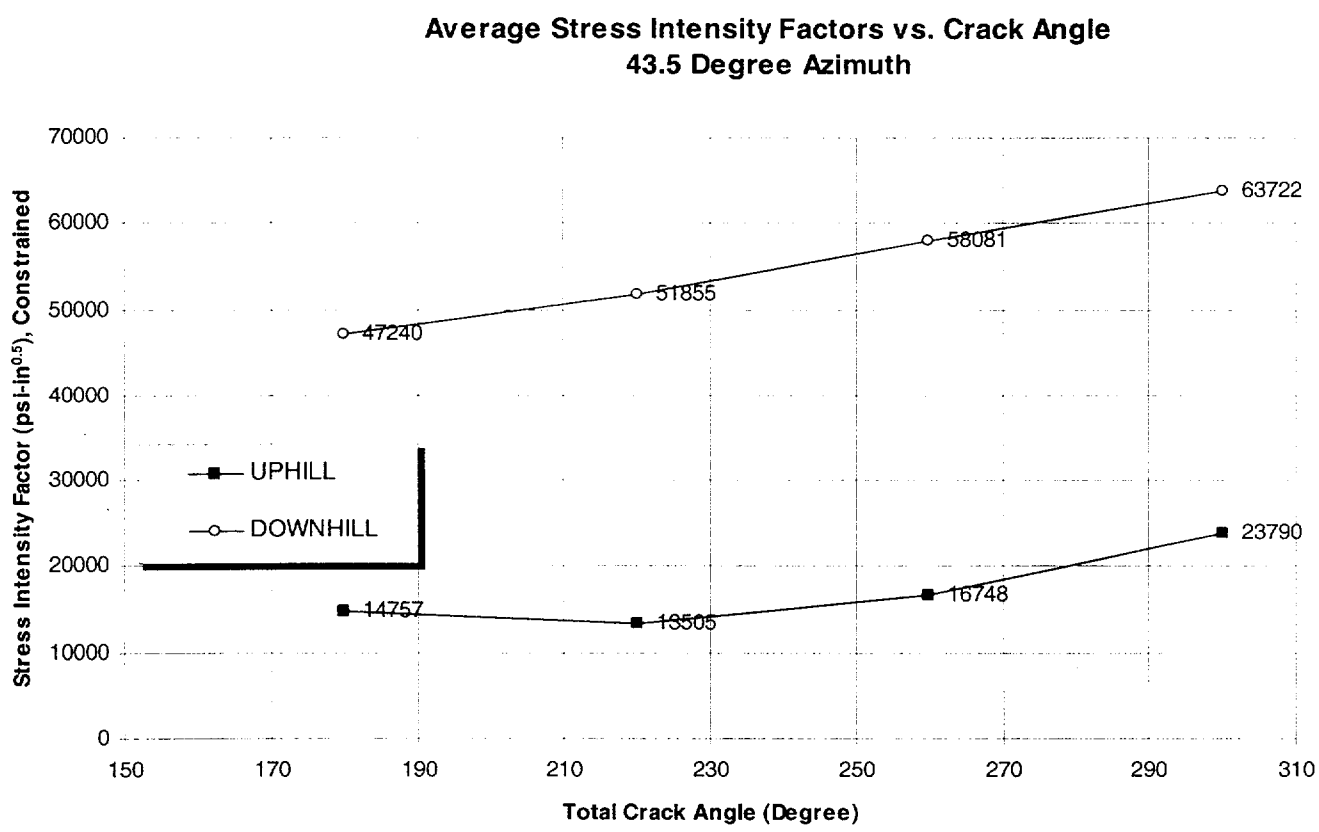
$$P = \frac{\sigma_{flow}}{FS}\left[\frac{A_{wall}\left(1-\frac{\theta}{360}\right)}{A_{bore} + A_{wall}\left(\frac{\theta}{360}\right)}\right]$$

| | | | |
|---|---|---|---|
| where: | P | = | maximum normal operating pressure acting on the nozzle bore and crack face |
| | $\sigma_{flow}$ | = | flow stress |
| | $A_{bore}$ | = | cross-sectional area of the nozzle bore |
| | $A_{wall}$ | = | cross-sectional area of the nozzle |
| | $\theta$ | = | circumferential angle of the allowable through-wall flaw |
| | FS | = | factor-of-safety = 3.0 for allowable flaw size |

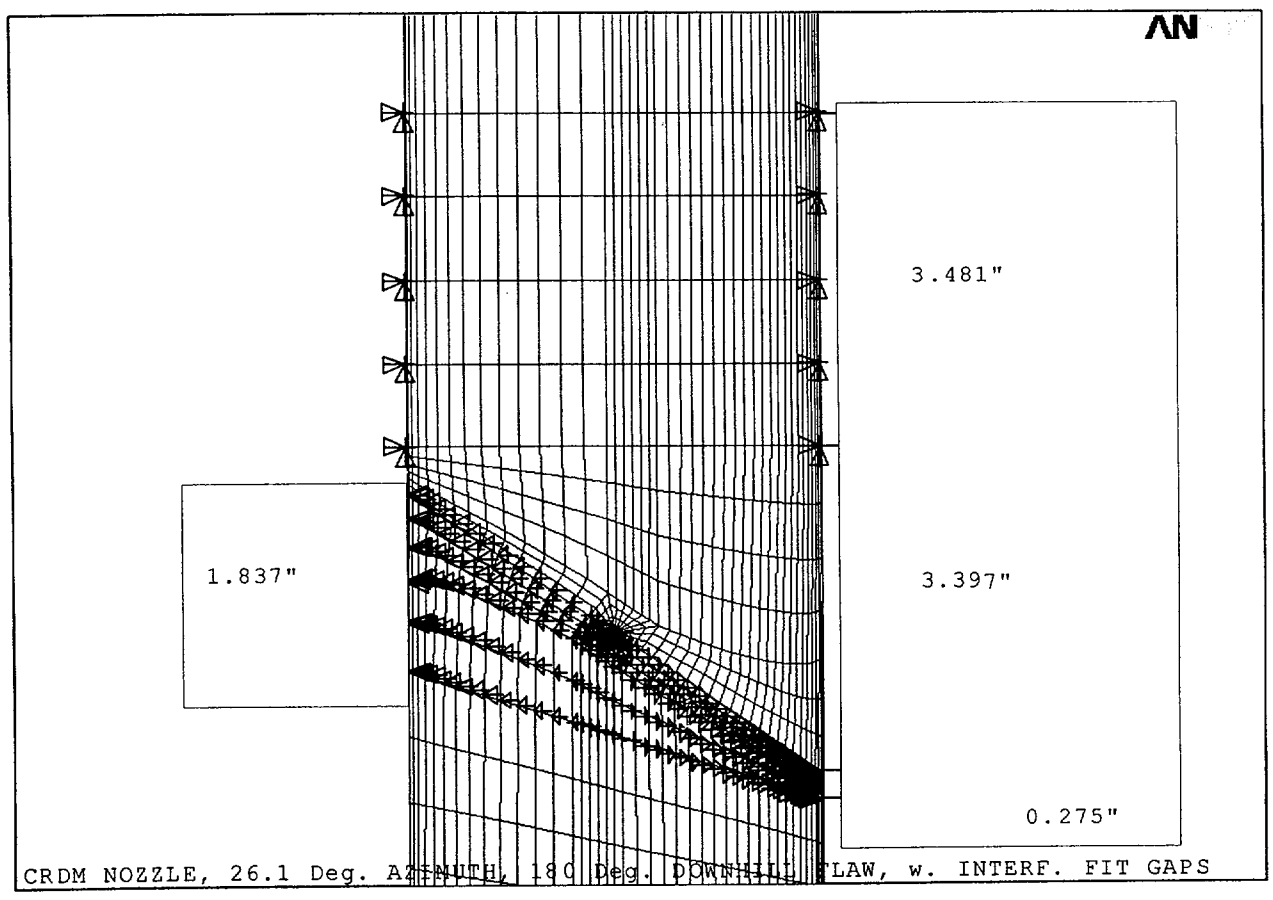
- **For Ginna, the allowable through wall flaw length is 300°, with the critical flaw length equal to 338°**

# GINNA FLAW EVALUATION

- Three-dimensional finite element model developed for nozzles
  - Solid elements
  - Crack face above weld modeled with coupled double nodes
  - Circumferential through-wall flaw modeled by releasing nodes
  - Weld location modeled with radial restraint
  - Gap elements used on crack face (crack closure)
  - Gap elements used along nozzle interface with vessel
- Load combination
  - Normal operating pressure
  - Normal operating temperature
  - Weld residual stress
  - Max. gap values from gap analysis
- Loads applied as pressure on crack face
- Stress intensity factor (K) calculation performed for various flaw lengths


Average Stress Intensity Factors vs. Crack Angle
43.5 Degree Azimuth
Stress Intensity Factor (psi-in^0.5), Constrained
70000
60000
50000
40000
30000
20000
10000
0
150
170
190
210
230
250
270
290
310
Total Crack Angle (Degree)
UPHILL
DOWNHILL
47240
51855
58081
63722
14757
13505
16748
23790

# SAMPLE FINITE ELEMENT MODEL BOUNDARY CONDITIONS




Structural Integrity Associates

# GINNA CRACK GROWTH LAW

- Crack growth law developed:

$$da/dt = 5.17 \times 10^{-7} (K-8.188)^{1.11} \text{ inch/hour}$$

- Based upon MRP 95% confidence crack growth rate, adjusted for Ginna head temperature of 580°F

# TIME TO REACH ALLOWABLE FLAW SIZE - EXAMPLE

- Assume the previously presented crack growth law
- Assume that the limiting location has an average applied K of about 55 ksi-(in)$^{0.5}$ between 90° and 300°
- Two cases
  - 90° circumferential through-wall flaw in the nozzle
  - 180° circumferential through-wall flaw in the nozzle
- Time to grow from an assumed flaw in the nozzle to the allowable flaw size of 300° is:
  - 9 years for Case 1
  - 5.3 years for Case 2

# SUMMARY

- Finite element model consistent with industry standards
- Conservative inputs and assumptions
  - Head temperatures
  - Nozzle gaps
  - Assume initial hypothetical 90° and 180 degree throughwall crack
- Time to grow to allowable flaw size is significantly beyond 2003 RFO

# Probabilistic Safety Assessment

**M. Flaherty**

**Rochester Gas & Electric Corporation**

# Ginna Mitigation Design Insights

- Previous presentations demonstrate low risk of a LOCA
- Medium LOCA CCDP - 2.252E-03
  - Dominate Risk Scenarios
    - 53% - Operators Fail to Transfer to Recirc
    - 12% - RWST Suction Failures for RHR
    - 7% - Test and Maintenance of RHR, SI, CCW
    - 5% - CCFs of SI System
    - 5% - CCFs of RHR System (includes CCW)
    - 3% - Throttling Position of CCW Valves

# Ginna Mitigation Design Insights

- Two Human Events Contribute 56%
  - Transfer to sump recirculation
    - Operators will be trained on this first cycle following startup from 2002 RFO
  - Throttling position of CCW valves for RHR HXs
    - Procedurally specified activity (hardened step)
    - Position verified every 31 days

# Ginna Mitigation Design Insights

- Test and Maintenance Activities Contribute 7%
  - RHR and SI are "green" indicators
  - Actual maintenance unavailabilities very low
    - RHR – 91 hours in 2000 (38 hrs in 2001 to date)
    - SI – 29 hours in 2000 (21 hrs in 2001 to date)

# Ginna Mitigation Design Insights

- Operators Sensitive to RCS Leakage
  - Containment particulate monitor (R-11)
    - Sensitivity to detect 0.013 gpm leak in 1 hour
    - Required operable in MODES 1 - 4 due to LBB
    - If inoperable, perform grab sample every 12 hours
      - More restrictive than Standard ITS
    - Successfully detected letdown line vent leak in 1998
      - Estimated to be 0.05 - 0.1 gpm
  - RCS leakage reviewed daily at morning meeting
    - Both upward and downward trends are discussed

# PSA SUMMARY

- Ginna 1999 Inspection and Analyses
  - Low likelihood of occurrence
- If Event Were to Occur
  - Implementing steps to manage risk through training and operator awareness

# Replacement Reactor Vessel Head

B. Flynn
R. Klarner

# REPLACEMENT REACTOR VESSEL HEAD
# GINNA TIMELINE

- Spring/Summer 2001 Evaluated Options
- August 2001 Decision to Replace
  - Improve joint design and material
  - Improved insulation design for inspection
  - Address other design improvements
- September 2001 Issued Specification
- November 2001 Awarded Contract to BWC
  - Delivery August 2003

# *Schedule*

- Head forging Purchase Order issued 12/01
- Tubing Purchase Order issued 1/02
- Award installation contract - 1/02
- Spring 2002 RFO
  - Optical templating of existing Ginna head
  - Containment laydown for changeout
  - Rigging evaluation
  - Evaluate dose projections

# R. G. & E Ginna

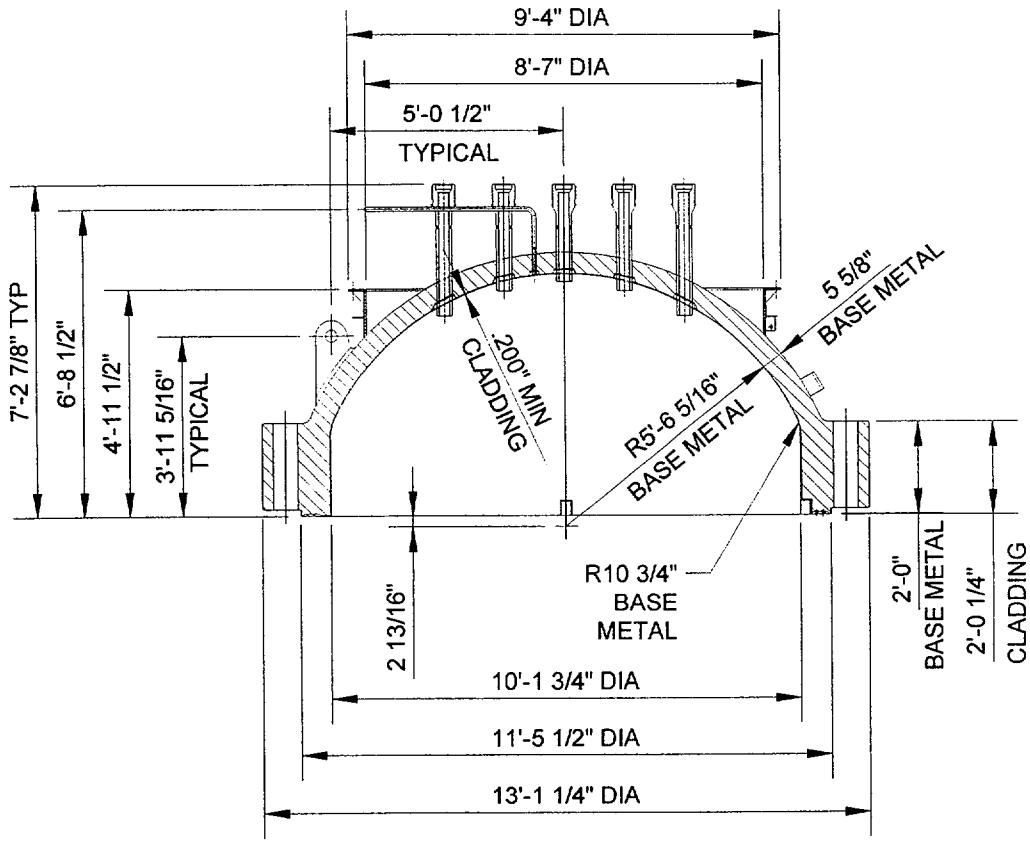
# RVC Head Replacement

## Presentation by
## Babcock & Wilcox Canada

**December 12, 2001**

Babcock & Wilcox Canada

# Ginna Replacement Head




SECTION A-A

SEE PLAN VIEW FOR TRUE ORIENTATIONS
SCALE: 1/4"= 1'-0"

Form, Fit and Function
Replacement

Dec. 12, 2001.2

# Replacement RVCH Design Features

- Maximize the PWSCC integrity of CRDM guide tubes:
  - Using Alloy 690 TT materials with ESR (double melt to enhance purity and microstructure)
  - Electropolishing of guide tubes and welds to remove the cold-work surfaces induced by machining/grinding operation
  - Minimum weld volume permitted by ASME code
  - Automatic weld process to perform the "J-groove" weld
  - Weld configuration qualified by mockup testing and Finite Element Analysis to minimize residual stress in the weld joint
- Use of a single piece forged head minimizes risk of welding distortion, and eliminates potential ISI of head welds.
- Additional proprietary design features to facilitate inspections.

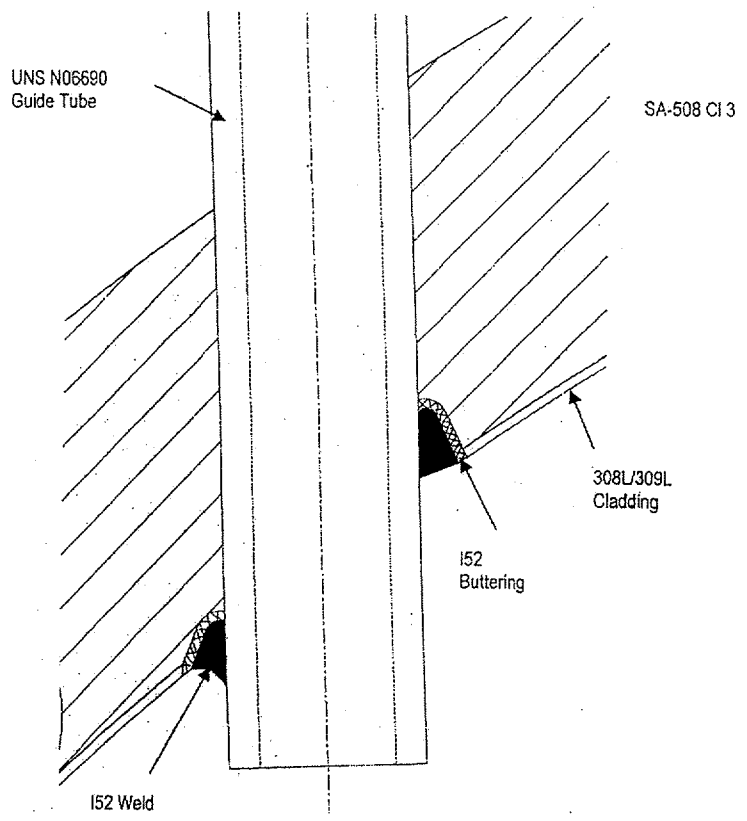
# Materials

## Reactor Pressure Vessel (RPV) Head - Materials of Construction

| | Original RPV Head (ORPVH) | Replacement RPV Head (RRPVH) |
|---|---|---|
| Head | SA-336 / SA-302 Grade B | SA-508 Cl 3 |
| Cladding | 18-8 Stainless Steel | ER308L/ER309L |
| CRDM Guide Tubes | SB-167 Inconel 600 | SB-167 Inconel 690 |
| CRDM/Head Weld | Inconel 600 | Inconel 690 (I-52) |
| CRDM Flange | SA-182 Tp 304 | SA-182 Gr. F316LN |

# CRDM Nozzle Installation Sequence

- Control of cold work and residual stresses during all stages of CRDM assembly and fabrication
  - Head procured with post weld heat treated cladding
  - Machined 'J' groove over-layed with I-52 (GTAW) using a deep bore automated welding system.
  - Pockets are then machined and holes for the guide tubes are drilled.



# CRDM Nozzle Installation Sequence
*(Continued)*

- Post weld heat treatment of head and overlayed 'J' groove
- Machine "guide tube" hole with interference fit
- Machine guide tube with controlled finishing pass, both ID and OD surfaces
- Electropolish guide tube on ID
- Shrink fit guide tube
- I-52 partial penetration welding of guide tube to overlayed 'J' groove weld prep by GTAW process with deep bore automated welding system
- Blend grind final attachment weld profile
- Electropolish attachment weld and OD region of guide tubes

# SUMMARY

- 1999 Ginna Inspection is a Good Baseline
  - Cracks detectable before throughwall
- Ginna head temperatures are significantly lower than plants which have seen cracking
- Low PSA impact with selected course of action
- Replacing Reactor Vessel Head is best technical approach to this issue
  - design enhancements
  - material
  - inspectability

# CONCLUSION

- Final Response to Bulletin 2001-01 Will Be Consistent with Technical Analysis Presented Here
  - Alternative evaluations justify no safety issues with our plans to not inspect in 2002
  - Current OE Supports our Conclusions
  - Proactive Head Replacement 2003