50-528

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 25, 1997

LICENSEE: Arizona Public Service Company

FACILITY: Palo Verde Nuclear Generating Station

SUBJECT: SUMMARY OF MEETING HELD ON FEBRUARY 20, 1997, TO DISCUSS STEAM GENERATOR ISSUES

On February 20, 1997, the NRC staff met with representatives of Arizona Public Service Company (APS) to discuss results of the steam generator tube eddy current inspection, particularly as they relate to the issue of an appropriate cycle length for Palo Verde Unit 2. Matters discussed included structural and leakage integrity analyses supporting the operating length of Cycle 7 of Unit 2 and the Palo Verde steam generator tube degradation management program. Persons attending the meeting are listed in Attachment 1. Viewgraphs presented at the meeting are listed in Attachment 2.

The licensee gave a brief introduction describing the root cause of the dominant degradation mechanism affecting the steam generator tubes at Unit 2 (i.e., free-span, axially oriented, outside-diameter stress-corrosion cracking), along with a summary of major changes and improvements in their tube integrity program since the steam generator tube rupture in March 1993. The licensee also discussed its inspection program and the results of its structural and leakage integrity analyses for the steam generator tubes. These analyses included a condition monitoring assessment (from the as-found condition of the steam generator tubes) and an operational assessment (from the projected end-of-Cycle 7 inspection results). Much of the material presented at the meeting had previously been submitted to the staff in the Unit 2 report dated January 3, 1997.

The licensee concluded that Unit 2 could be operated until the next scheduled refueling outage at the end of Cycle 7 (approximately 16.5 months of operation) on the bases of analyses presented in the January 3, 1997, report. This report stated that the structural and leakage integrity of the Unit 2 steam generators would be maintained until the scheduled refueling at the end of Cycle 7. These analyses are similar to those used by the licensee to assess a full cycle of operation for Unit 3. This full cycle of operation for Unit 3 (approximately 15 to 16 months) ended in February 1997. Similar analyses had been used to assess the previous operating interval of 12 months (a full cycle of operation) for Unit 2.

The staff did not identify any significant concerns with the licensee's conclusion about the Unit 2 operating cycle length during the meeting; however, since the staff has not reviewed the probabilistic methodology used by the licensee in detail, the staff requested that the licensee submit the inspection results from the Unit 3 outage (which commenced in February 1997) to provide further assurance that the probabilistic methodology conservatively predicted the end-of-cycle conditions for Unit 3. Since the methodology used for Unit 2 is similar to that used for Unit 3, conservative results for Unit 3

would provide added confidence that the predictions for Unit 2 would also be conservative. The results to be submitted from the Unit 3 steam generator tube inspection outage are a comparison of the projected end-of-cycle conditions to the as-found condition.

In addition to the above, the staff observed at the end of the meeting that the licensee appeared to be relying heavily on eddy current examination results with no independent evaluation of these results (e.g., through the periodic removal of tubes, complemented by the performance of in situ pressure testing).

ORIGINAL SIGNED BY

Charles Thomas, Project Manager
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Division of Reactor Projects III/IV
Office of Nuclear Reactor Regulation

Docket Nos. STN 50-528, STN 50-529,
and STN 50-530

Attachments: 1. List of Attendees
2. Viewgraphs

cc w/atts: See next page

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Attachment 1

February 20, 1997

PVNGS Steam Generator Issues Meeting

List of Attendees

Arizona Public Service Company

Bill Ide
Phil Gray
Doug Hansen
Jo Provasoli
Rodney Wilfred
Scott Bauer
Rich Schaller
Kevin Sweeney

Aptech Engineering

Jim Begley
Brian Woodman

NRC

Ted Sullivan
Ken Karwoski
Cheryl Beardslee
Charles Thomas

Attachment 2

February 20, 1997

PVNGS Steam Generator Issues Meeting

Viewgraphs

Palo Verde Nuclear Generating Station

Unit 2 Cycle 7

Steam Generator Assessment

February 20, 1997

Agenda

- Introduction - R. Schaller
- Inspection Program - D. Hansen
- Condition Monitoring - K. Sweeney
- Operational Assessment - J. Begley
- Degradation Management - K. Sweeney
- Summary - R. Schaller

Introduction

Richard Schaller

Manager

APS Steam Generator Projects

Introduction

- Participant Introductions
- Background
  - Upper Bundle ODSCC
    - Small defects difficult to detect with standard bobbin coil
    - Distinct defect pattern (ARC)
    - First observed in U2R3 - Fall 1991
    - Led to tube rupture at end of Cycle 4 - March 14, 1993
  - APS actions
    - Root Cause Analysis
    - Inspection technology and scope improvements
    - Predictive modeling
    - Remedial actions

Introduction

- Major Changes / Improvements
  - Large scale tube pull programs
  - Extensive RPC inspection programs
  - In-situ pressure testing
  - Thermal-hydraulic modeling
  - Boric Acid Treatment
  - Thot Reduction
  - Secondary Chemistry Improvements
  - Chemical Cleaning
  - SG Modifications
  - Conservative Leak Monitoring and Response

Introduction

- Predictive Models
  - ATHOS Bounding Model
    - Theoretical Link to Corrosion
    - Empirical Validation
  - Multiple Cycle Crack Simulation Model
    - Simulates corrosion process and defect management program
      - Crack initiation
      - Crack growth
      - Crack morphology
      - Inspection and Repair
    - Model provides for Condition Monitoring Assessment
    - Projections consistent and conservative

Introduction

- PVNGS Steam Generator Status
  - Last Meeting - 9/20/95
  - No forced shutdowns since 1993
  - Unit 1 - Full Cycle Operation
    - No cycle restrictions
  - Unit 2 - Full (12 month) Cycle 6
  - Unit 3 - Full (16.5 month) Cycle 6
  - Unit 2 commenced Cycle 7 operation on 5/3/96

Inspection Program

Doug Hansen

APS Level III

PVNGS SG Inspection Program

- Purpose
  - Detect and remove from service critical tube defects
    - Conservative plugging criteria
    - All detected SCC defects plugged
- Implementation
  - State-of-the-art equipment and techniques
  - Data analyst training
  - Strong utility oversight
  - Performance demonstration and trending
  - Conservative inspection scope and expansion criteria

ECT Techniques

- APS employs "best available" techniques for PVNGS SG damage mechanisms
  - First production application of Plus Point Probe - December 1994
  - Plant specific tube pull data integrated into ECT program
- Techniques are EPRI Appendix H qualified (or equivalent) for detection
- Quantitative and qualitative data quality requirements implemented
- No sizing or threshold criteria for SCC
  - Plug on detection

ECT Analysis

- All analysts EPRI QDA qualified
  - Includes two (2) QDA's on staff
- Site Specific Performance Demonstration
  - PVNGS ECT Guidelines and Training
  - Bobbin Coil and Plus Point Practice Data
    - Supported by tube pull data
  - Examination required
- Primary/Secondary analysis teams from separate companies
- Analyst trending by APS Level III
- Resolution Analyst requirements
  - "Super Resolution"

U2R6 ECT Scope

- ECT Scope and Purpose
  - 100% Full Length Bobbin Coil
    - Tube condition screening
  - 100% + Point of HL TTS expansions
    - Detection of circumferential and axial SCC
    - Generic Letter 95-03
  - 5% + Point of CL TTS expansions
    - Detection of SCC defects
    - Industry experience
  - 100% + Point of Row 1 and 2 U-bends
    - PVNGS and Industry experience
  - Examine historical >20% bobbin wear
    - With +Point - determine if SCC is present
  - 100% + Point of ARC Region
  - Outside ARC Region sample
    - + Point, region verification

ECT Expansion Criteria

- Axial SCC Indications
  - + Point - Five tube buffer zone in all directions
  - + Point inspection of all bobbin indications which exceed PVNGS plugging criteria
    - Additional confirmation
  - + Point inspection of all Bobbin I-codes
- Circumferential SCC Indications
  - 100% of CL TTS expansions if one circumferential defect is identified

ECT Results - SG 2-1

Eddy Current Call	20-29%	30-39%	>40%	"I-Code"	NBI	TBP	Remarks
Wear and Small Imperfections	553	177	10	-	-	9	8 >40% 1 - BW Stay 2 > 40% also SVI
Axial Indications (SAI/MAI)	-	-	-	2	98	100	1@TSH, 1@Row 1 98 ARC
Circumferential Indications (SCI/MCI)	-	-	-	-	NA	8	All TSH
Volumetric Indications (SVI/MVI)	-	-	-		-	4	
PLI	-	-	-	1		2	01C
Total	-	-	-	-	-	123	Note 7 additional preventatively plugged at patch plate - Total plugging - 130

ECT Results - SG 2-2

Eddy Current Call	20-29%	30-39%	>40%	"I-Code"	NBI	TBP	Remarks
Wear and Small Imperfections	724	266	24	-	-	23	21 > 40% 2 - BW Stay 2 > 40% also SAI 1 > 40% - PLI
Axial Indications (SAI/MAI)	-	-	-	4	154	158	7@TSH, 1@01H 150 - ARC
Circumferential Indications (SCI/MCI)	-	-	-	-	NA	3	All TSH
Volumetric Indications (SVI/MVI)	-	-	-		- -	3	
PLI			1			1	01C
Total	-	-	-	-	-	188	1 additional tube plugged due to OBS Total plugged 189

Condition Monitoring Assessment

Kevin Sweeney
APS Steam Generator Projects

Condition Monitoring Assessment

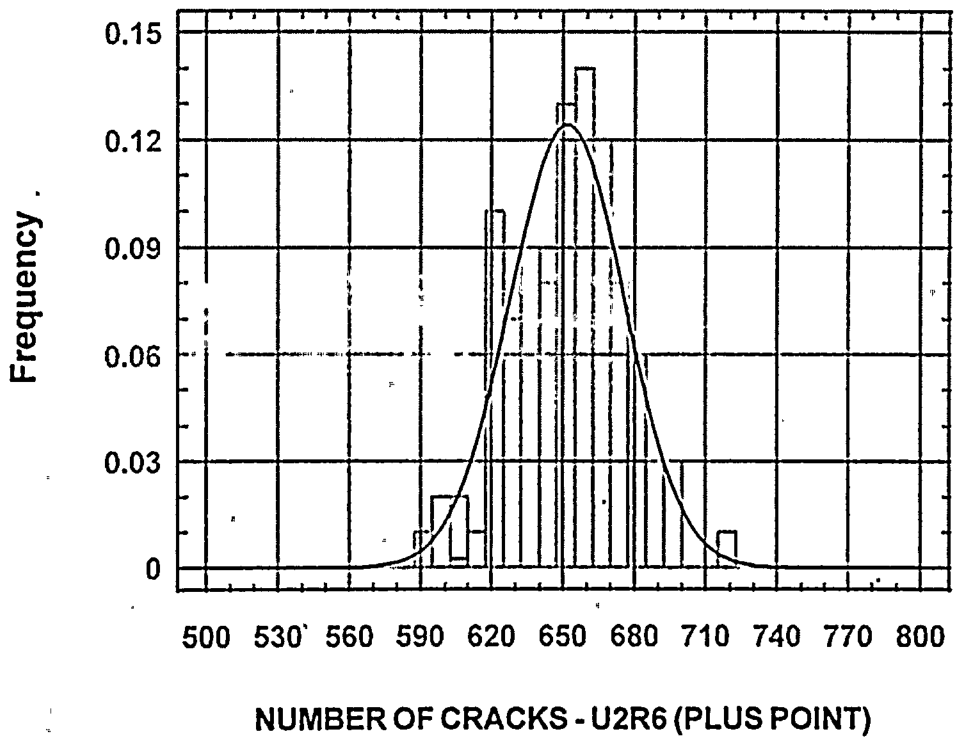
- Draft Reg Guide, Section C.3.0 states that licensees should monitor the as-found condition of SG tubing to verify compliance with performance criteria
  - Structural Integrity
  - Operational Leakage
  - Accident induced leakage
- APS approach
  - Compare measurable ECT information with EOC 6 predictions
    - Number of defects
    - Structurally significant crack length
    - MRPC voltage/depth

Condition Monitoring

- Model Description
  - APS developed means to assess steam generator tube integrity in presence of a unique stress corrosion cracking phenomena
    - Assessment required a quantitative result regarding number and size of cracks at end of operating period
    - Methodology must be benchmarked to relevant field experience
  - Basic mechanistic model preferred
    - Crack process simulated
    - Each component verifiable
  - Multiple cycle model
    - Responds to evolving conditions
  - Process has produced consistent and conservative results for PVNGS

Condition Monitoring

- Number of ARC Region cracks
  - Structural integrity analysis dependent on predicting the number of undetected and uninitiated cracks at BOC 6 that become detectable at the EOC 6

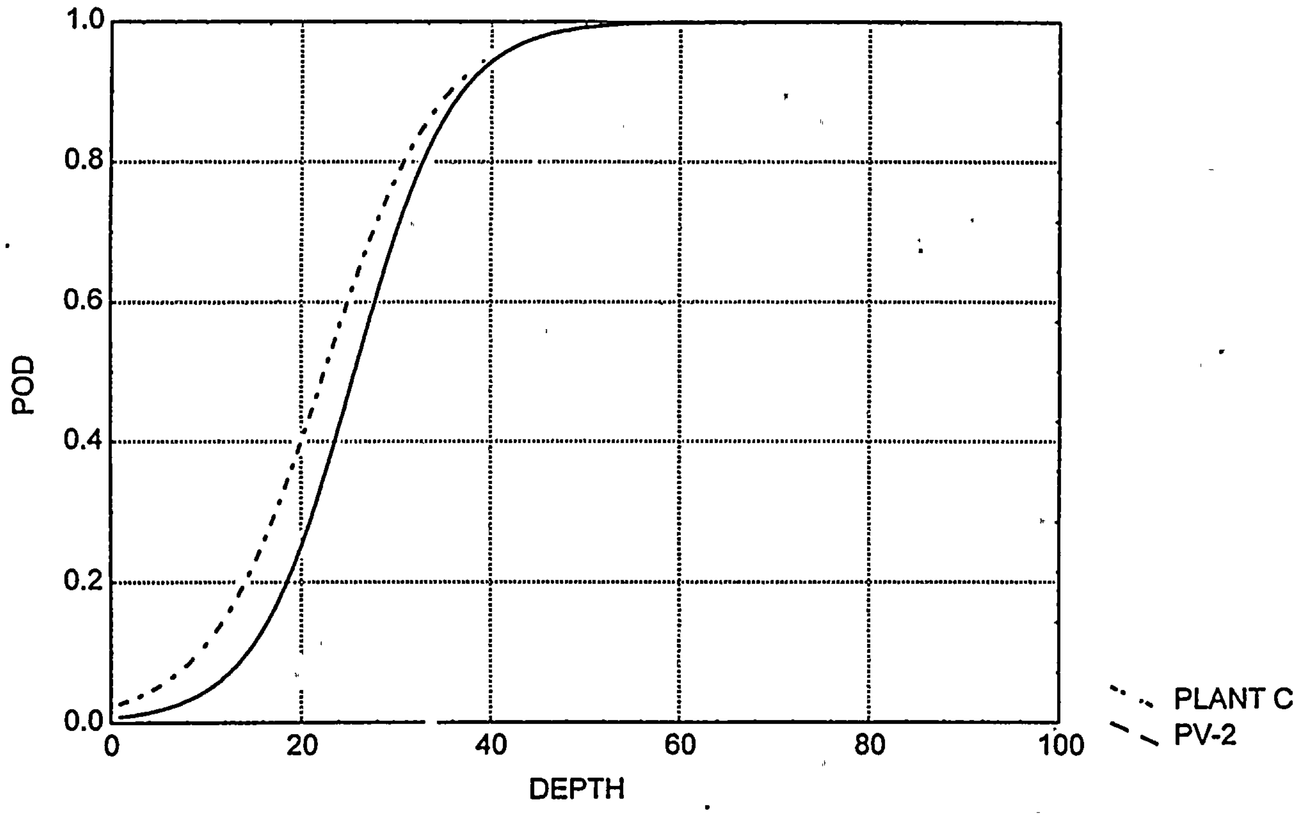


Cracks detected U2R6 = 286

Assessment

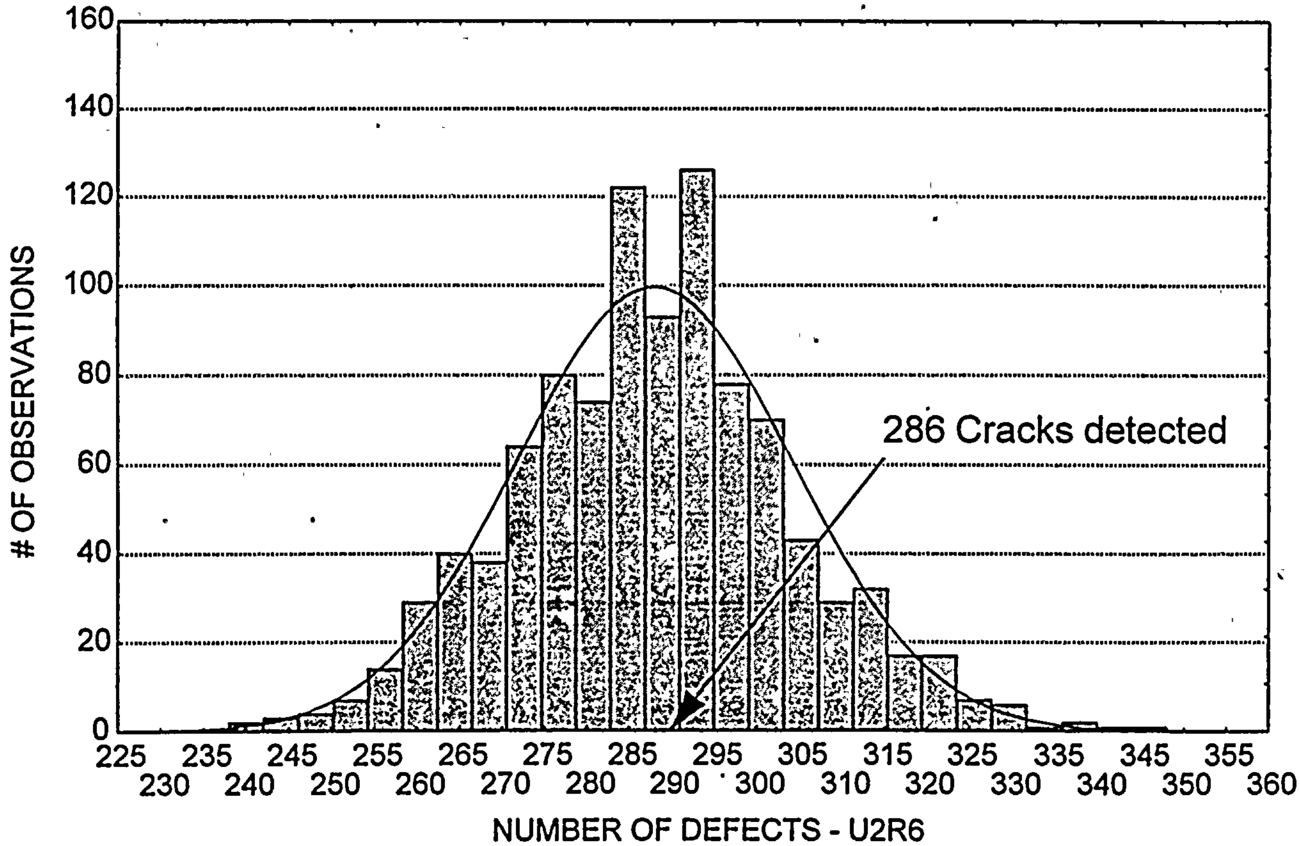
- ➤ Projection clearly conservative
- ➤ APS/APTECH assessed over-estimate
  - – POD effects
    - Simulated vs Actual
  - – Multi-population effects
  - – "Shutdown" of initiation process
  - – Growth rate reduction
- ➤ Assessment indicated strong correlation with growth rate reduction
  - – Attributed to remedial measures employed at PVNGS
    - Chemical cleaning
    - Thot reduction
    - Secondary Chemistry improvements

Plus Point POD



Comparison of Simulated Plus Point POD with Recent Tube Pull Data for Upper Bundle Freespan ODSCC

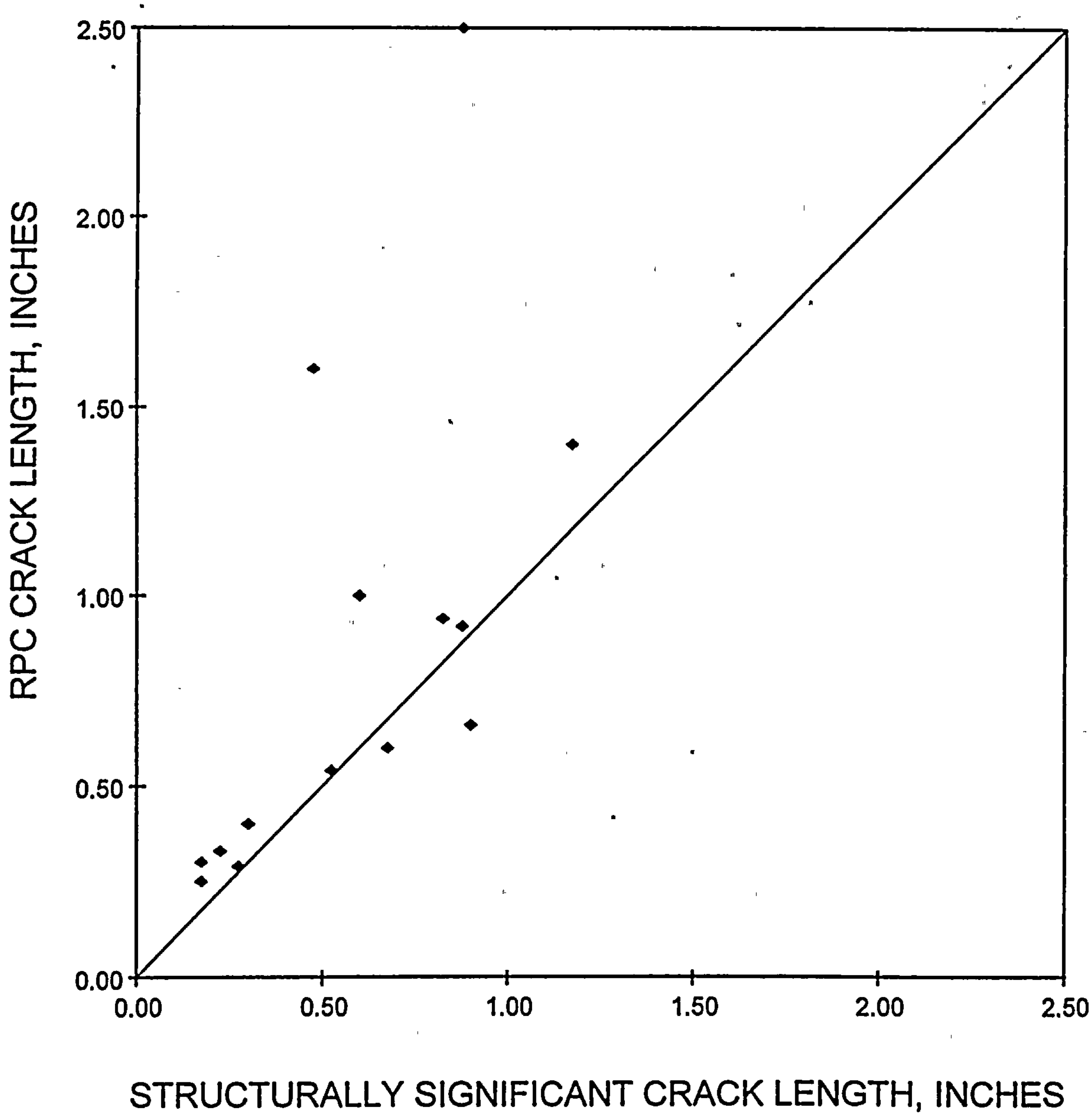
Crack Benchmark
Cycle 6 Growth Rates



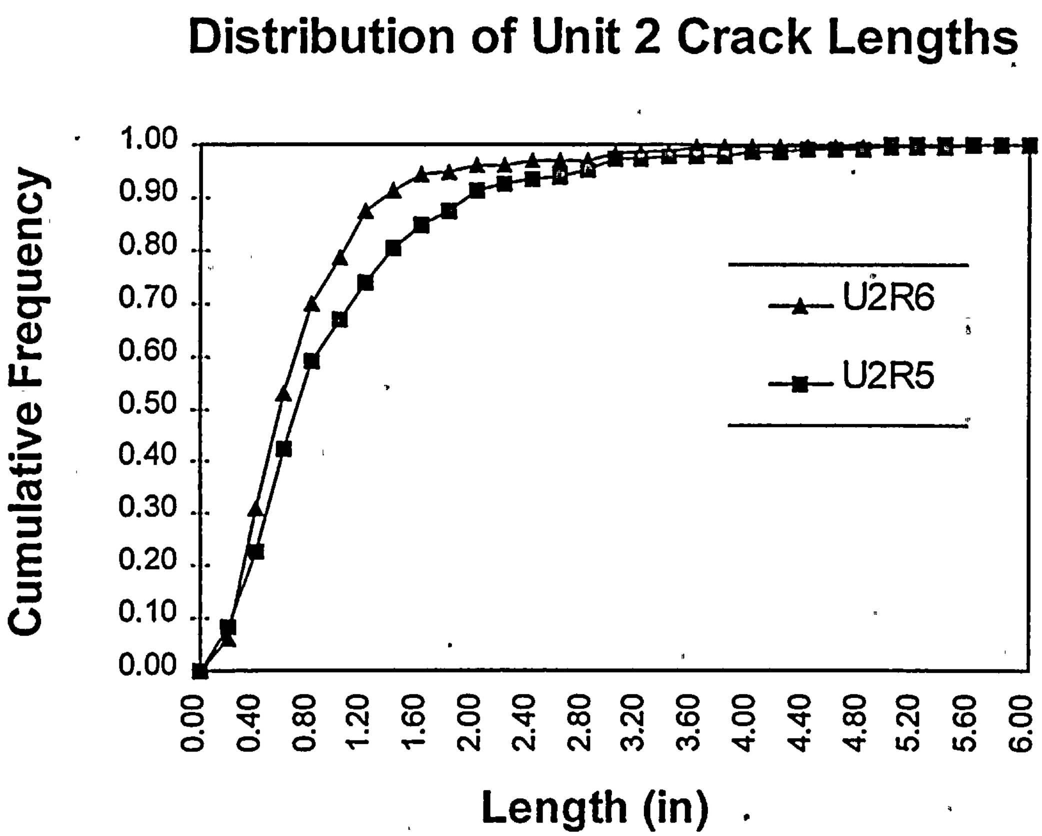
Crack Length

- Crack Length Distribution
  - Not a projection
  - Little change from cycle to cycle, unit to unit
  - Input distribution to structural limit simulation
- Probe Characteristics
  - From tube pull data, APS found that 0.115 coil detected length was a reasonable estimate of structurally significant crack length
  - Plus Point Impact
    - Plus Point lengths overly conservative
- Assessment
  - Compare crack length distributions

RPC Crack Length



RPC Crack Length Comparison



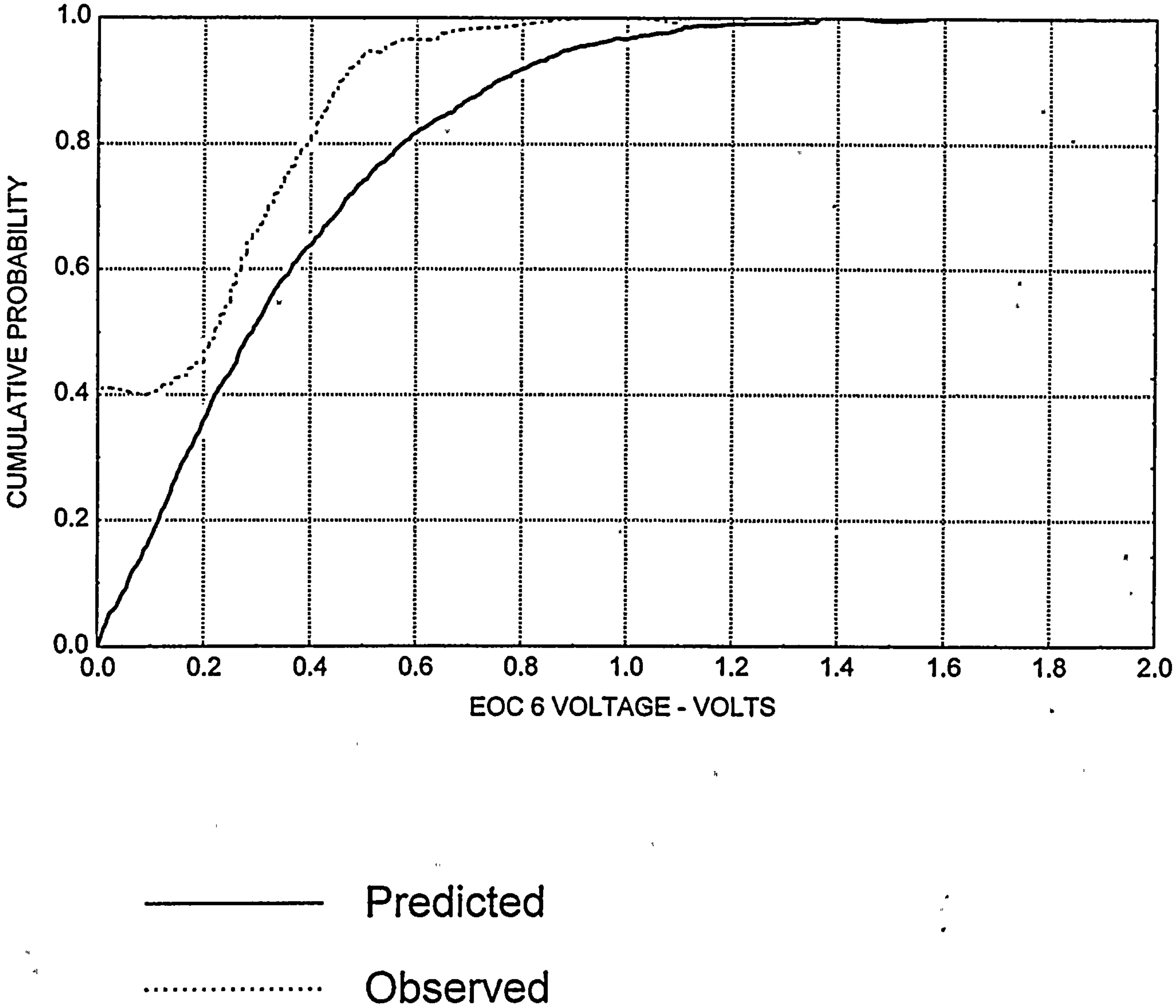
Voltage/Depth

- No validated sizing technique
  - Plug on detection
- PVNGS Voltage-to-depth correlation developed from tube pulls
  - 31 tubes removed from Unit 2and 3
  - 0.115 pancake coil voltage
  - Correlation has been consistent for monitoring growth rather than absolute depth
  - Supported by In-situ testing
- Sizing Checkpoints
  - In-situ test candidate > 2 volts
  - Exceedance criteria > 2.25 volts
- Largest defect in U2R6 - 1.23 volts

Voltage/Depth

- Model predicted no through-wall leakers
  - Through-wall defect an indicator of severity
  - No indication of leakage
- Predicted vs observed voltages
  - Measurable ECT parameter for condition monitoring
  - Observed results bounded by model predictions

Voltage Distribution EOC 6



Condition Monitoring Summary

- As-found condition of Unit 2 steam generators satisfies all structural and leakage performance criteria
- Condition monitoring performed on measurable inspection criteria
- Modeling techniques provide consistent and conservative results for all PVNGS units

Operational Assessment

Dr. Jim Begley
APTECH

Probabilistic Methodology

- Four major elements modeled
  - Crack initiation
  - Crack propagation
  - Crack detection
  - Structural limit evaluation
- All elements have significant variational as well as deterministic components
- Solution requires advanced probabilistic methodology
- Monte Carlo simulation
  - Analog process-deterministic simulation with variation
  - Major components modeled with distributions

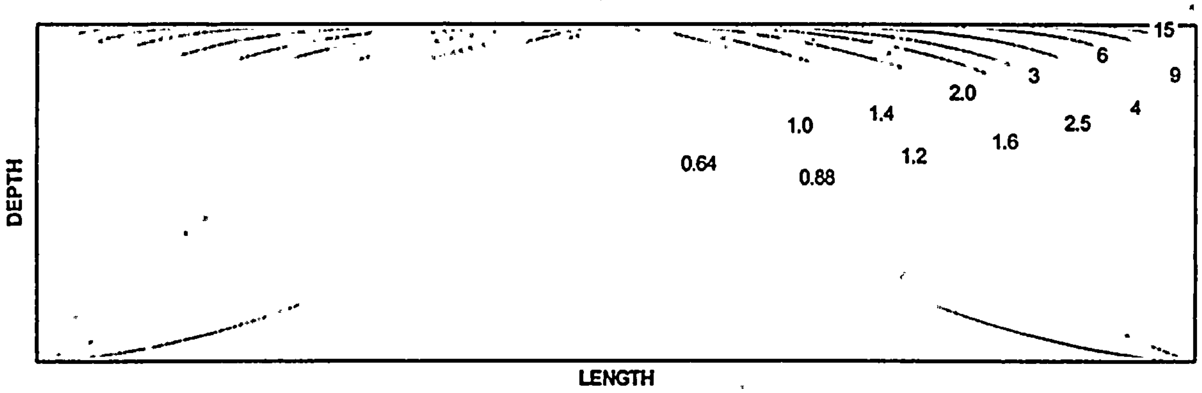
Simulation Process

- Each major component describable by appropriate probability distribution function (pdf)
- Crack initiation - Weibull
- Crack propagation rate - Log-normal
- Crack detection - Sigmoidal or ramp
- Tube structural limits - Output pdf from simulation involving:
  - As-built material mechanical properties
  - Crack length pdf
  - Burst pressure correlation
    - Modified Framatome correlation

Model Improvements/Validation

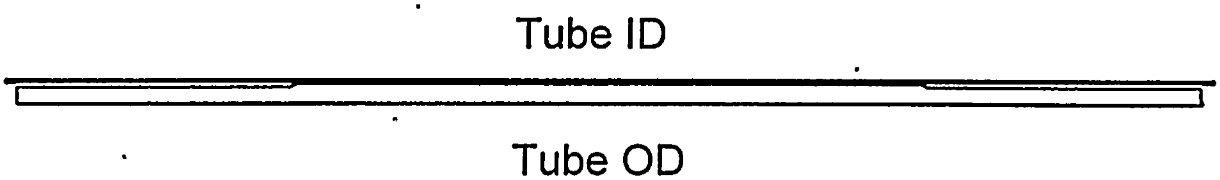
- Form Factor
  - Crack morphology effects
- Crack Growth Rates
  - Direct Sampling
  - Variational cycle to cycle
- Benchmarking - voltage
  - Measurable ECT parameter
  - Assessment of measurement errors

Form Factor



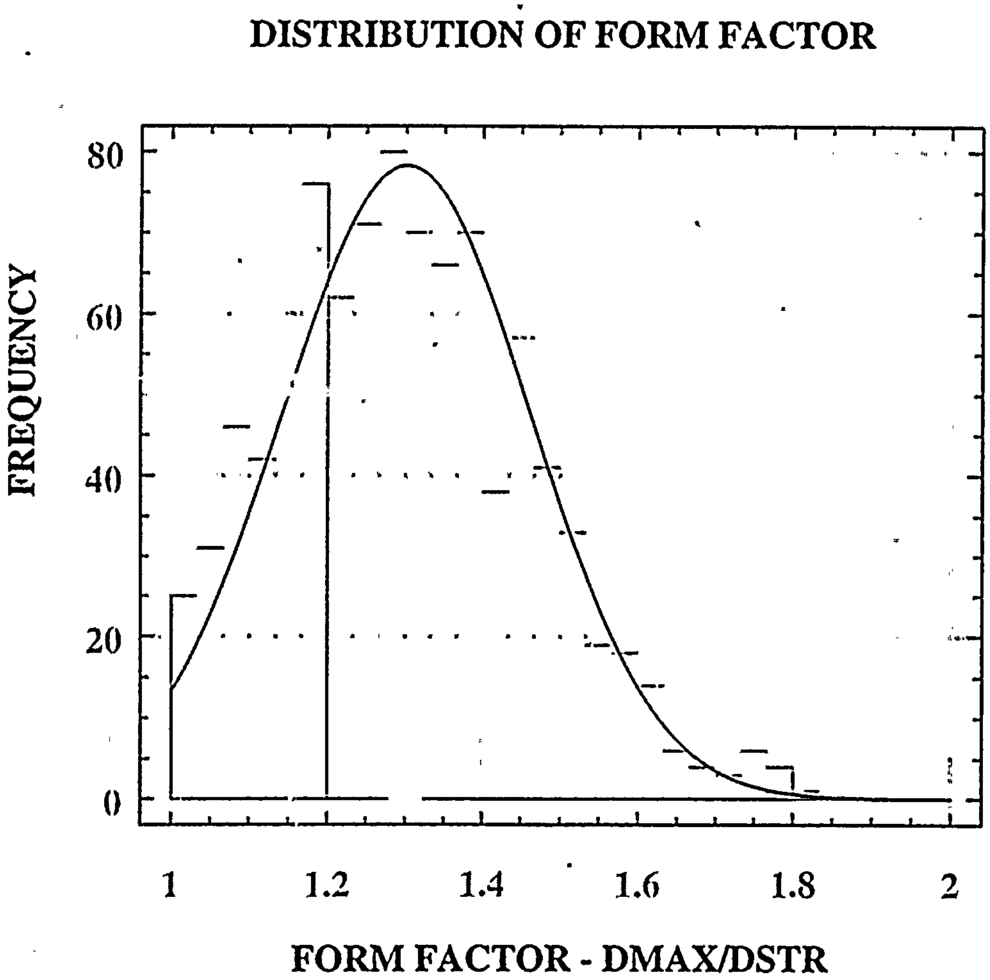
Spectrum of Axial Crack Profiles

Form Factor



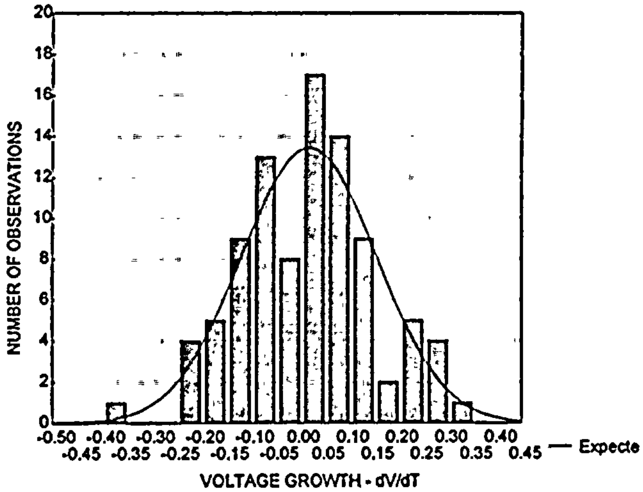
Cusp-Like Crack Profile Drawn to Scale

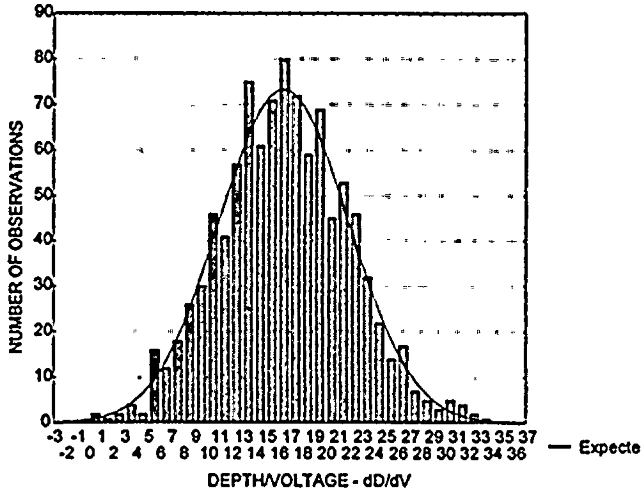
Form Factor

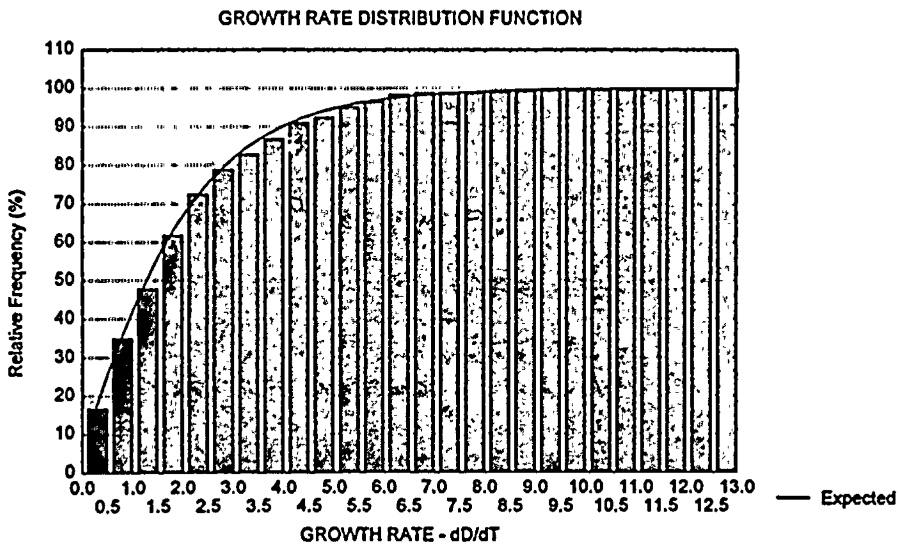


DISTRIBUTION OF FORM FACTOR
FREQUENCY
80
60
40
20
0
1
1.2
1.4
1.6
1.8
2
FORM FACTOR - DMAX/DSTR

Crack Growth Rate

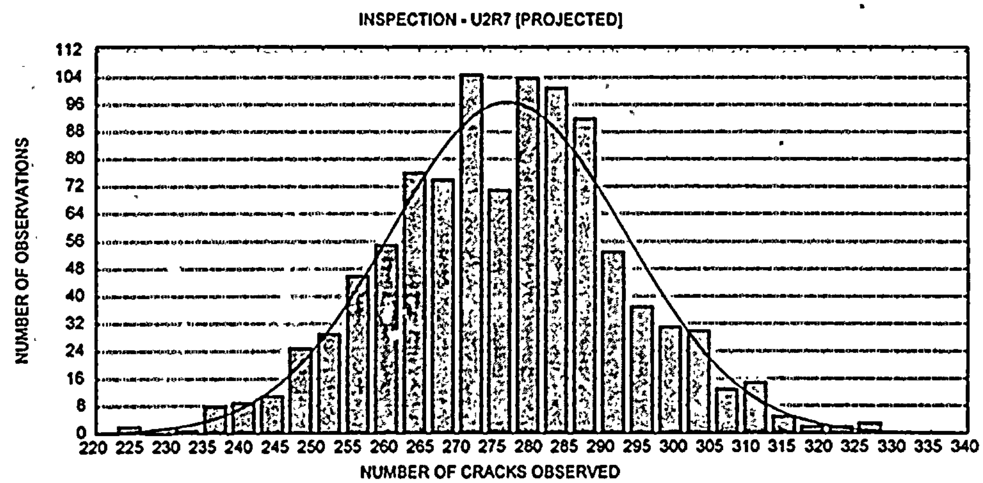


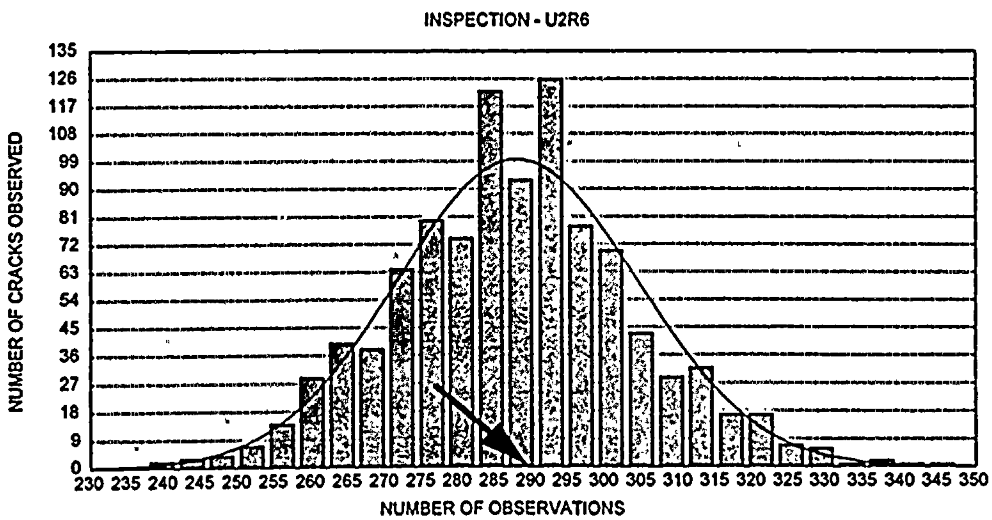




Results

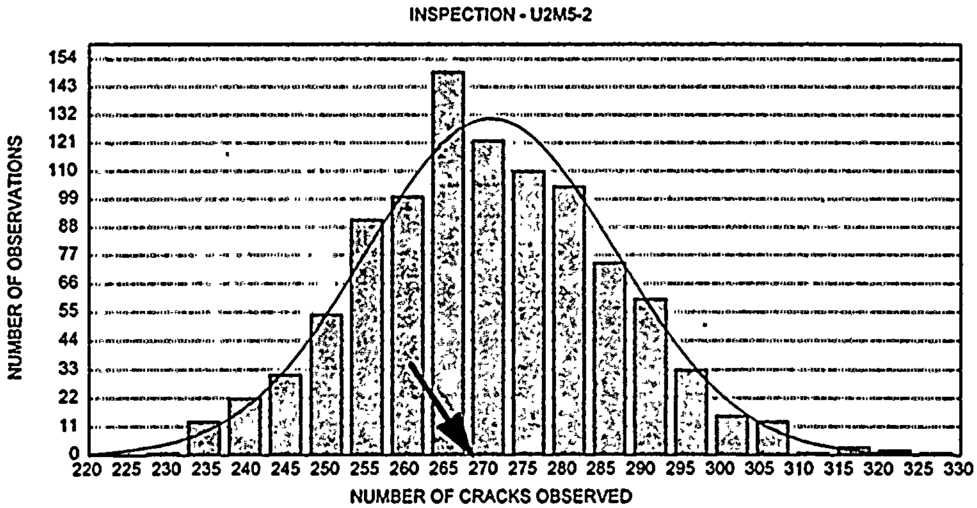
➢ Projections and Benchmarks

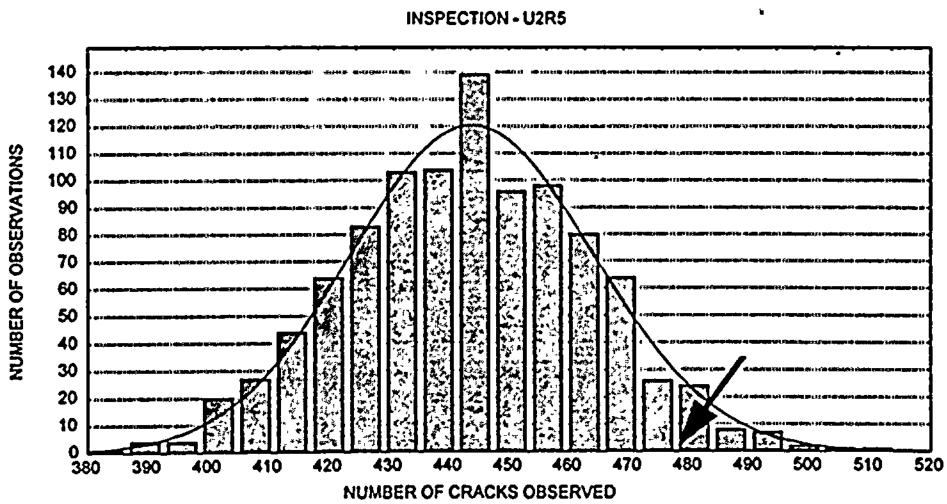




Results

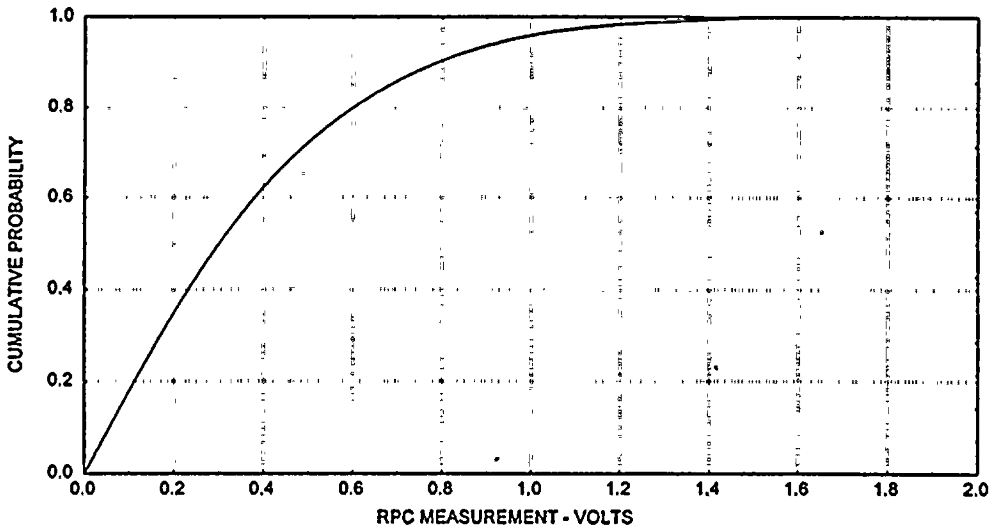
➢ Projections and Benchmarks



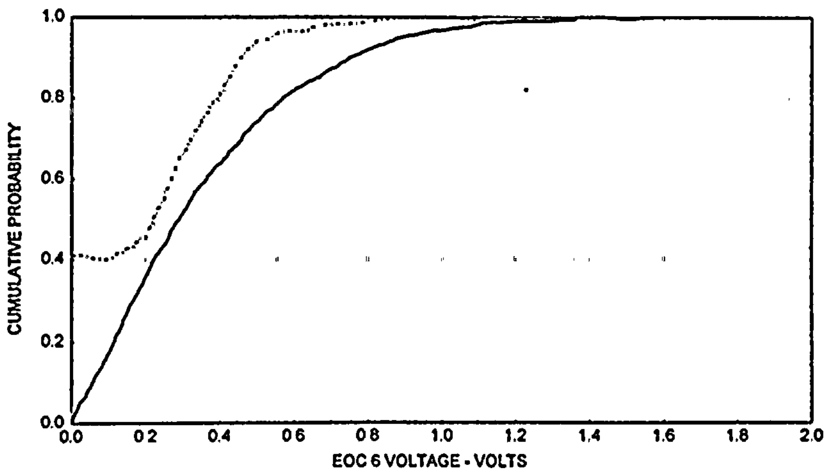


EOC Voltage Projection

EOC 7 Voltage Projection



EOC 6 Voltage Projection



Results

- Structural Integrity
  - Performance Criteria
    - Conditional Probability of tube rupture at MSLB < 10^{-2}
    - Low probability of Reg Guide 1.121 exceedance
  - Results - 16.5 month run time
    - Upper 95% confidence for MSLB - 3×10^{-4}
    - Reg Guide exceedance - 4×10^{-4}
- Leakage Integrity
  - Chance of leaking ARC region crack at normal operation or MSLB - 4×10^{-5}
- Model benchmarked against previous outage results
- Independent assessment in agreement

Degradation Management

Kevin Sweeney

Steam Generator Projects

PVNGS
Degradation Management

- Program developed following the discovery of ARC Region ODSCC
- Program consistent with the draft SG Rule
  - Preventative measures to reduce degradation
    - Chemical cleaning
    - Thot reduction
    - Secondary chemistry improvements
    - SG modifications
  - Comprehensive ISI program
    - Use of Plus Point since 1994
    - Supported by tube pull data
  - Conservative plugging program
    - Plug SCC defects on detection
    - Critical wear mechanisms plugged at 20%

Plug Results

Plugging results bounded by preoutage projections

Damage Mechanism	Plug Projection	Plug Actual
Arc Region	515	248
Circumferential Cracks	45	11
Axial Cracks Lower Bundle	25	9
Other (Wear, PLP)	90	44
Preventative Plugging		7
Total	675	319

Plugging totals
SG 22 - 1379 or 12.5%
SG 21 - 550 or 5.0%

PVNGS Degradation Management

- Prescriptive measures
  - Conservative leakage monitoring
    - More conservative than EPRI
    - Limits on RCS activity
  - Operator training
    - Response to tube leakage and rupture events
  - Consistent and conservative analysis techniques
    - Demonstrated via condition monitoring and benchmarking
  - Active industry role
    - CEOG
    - EPRI/NEI Rulemaking response
    - Technology Transfer Program with EdF
    - INPO Evaluation participants

Program Application

- Program works and is evolutionary
  - ISI program adjustments
    - Integration of PVNGS inspection results
    - Industry integration
  - Leakage monitoring
    - Heightened awareness
    - Leakage response
  - Analysis Improvements
  - Self Assessment

ARC Region Scope Verification

- APS active in following recent CE plant observations of freespan cracking
  - CEOG activities
  - ECT Program best indicator of the validity of T/H models
- PVNGS ARC Region Verification
  - Location of defects consistent through twelve (12) PVNGS inspections
  - Outside ARC sample program employed
  - Buffer zone program
  - 100% Bobbin Coil exam employed
    - Bobbin POD adequate for problem defects
    - All I-codes are re-examined with Plus Point
    - Bobbin wear calls examined
- Program works
  - Led to expanding standard extent to 07H & second VS

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Summary

Richard Schaller
Manager
APS Steam Generator Projects

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Summary

- High confidence that structural and leakage integrity for Unit 2 Cycle 7 will be maintained
  - U2R6 results bounded by EOC 6 predictions
  - Analysis indicates reduction in corrosion rates
  - Operational Assessment performance criteria satisfied
- PVNGS SG Degradation Management provides defense-in-depth
- Full cycle operation justified for Cycle 7