Unit 2 CRDM Vessel Head Penetration Justification for Safe Operation

November 20, 2001

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ENCLOSURE 2

American Electric Power Meeting with Nuclear Regulatory Commission

Donald C. Cook Nuclear Plant

Unit 2 CRDM Vessel Head Penetration

Justification for Safe Operation Until January 19, 2002

Agenda

■ Introduction, Background, and Overview	Scot Greenlee
■ Deterministic Model	Warren Bamford
■ Probabilistic Risk Assessment	James Hawley
■ Inspection Plans	Daniel Garner
■ Closing Summary	Scot Greenlee

Introduction, Background, and Overview

Scot Greenlee
Director
Nuclear Technical Services Organization
American Electric Power

Background

- **October 1994 - Inspected 71 of 78 Unit 2 Penetrations**
  - Proactive response to industry issue
  - Used eddy current examination on ID
  - Three axial indications found on one penetration
  - NRC approved operation with indications until next outage
- **April 1996 - Inspected Most Susceptible Penetrations (5)**
  - No significant growth in previous indications
  - Repaired previous indications
  - No new indications
- **September 1997 to June 2000 - Extended Shutdown**

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Background

- May 2001
  - Planning begins for Unit 2 visual and NDE inspections for November 2001 outage - includes purchase of robotic repair arm
- August 3, 2001 - NRC Issues Bulletin 2001-01
  - Cook Unit 2 in Moderate Susceptibility Range
  - Previous indications require additional justification for operation past December 31, 2001
- August / September 2001
  - Forced outage - Unit 2 in cold shutdown >30 days
  - Refueling outage moved to January 19, 2002
  - Started head purchase activities

Presentation Overview

- **Cold Shutdown Period Following Bulletin Issue**
  - **No crack growth in cold shutdown**
  - **Operation to January 19, 2002, with cold shutdown period, provides less crack growth than operation to December 31, 2001, without cold shutdown**

- **Extensive Plant Specific Analyses Completed**
  - **Deterministic model conservatively shows more than 40 years to critical circumfrential crack**
  - **Probabilistic analysis shows more risk in early shutdown than operation past December 31, 2001**

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Deterministic Model of Penetration Integrity

Warren Bamford

Westinghouse

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Presentation Outline

- Background
- Stress Analysis
- Crack Growth Model
- Comparison to Babcock & Wilcox Plants
- Circumferential Crack Growth Calculations
- Results: Safety Case

Background

- Circumferential Cracking Has Been Found in Three Babcock and Wilcox Plants

- Cook Unit 2 Manufactured With Tubes From Huntington Alloys Stock

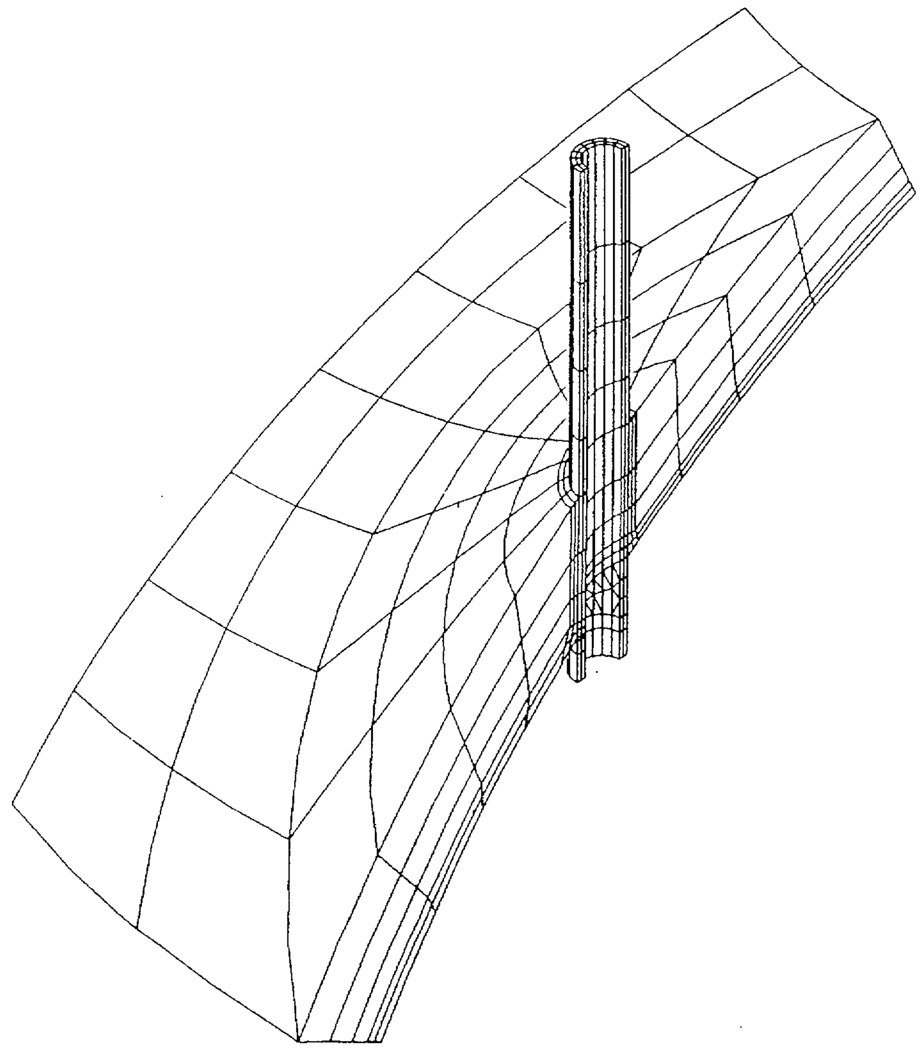
Stress Analysis Overview

- Elastic Plastic (E-P) Analysis Approach
- Model for E-P Finite Element Analysis
- Loadings
- Stress Strain Curve
- Results: Axial Stress Dominant
- Independent Confirmations
  - Framatome
  - EdF
  - CE
  - B&W

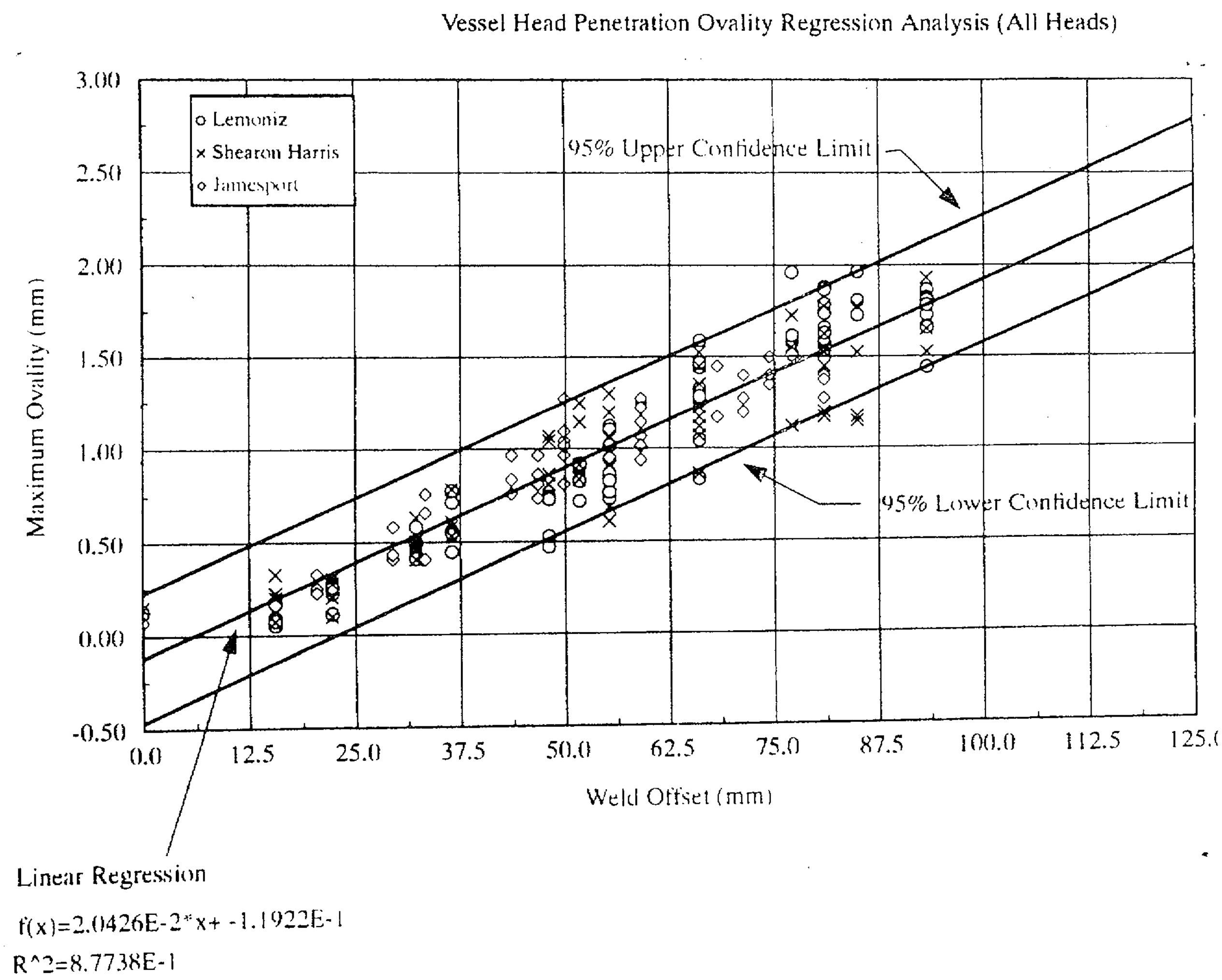
Elastic Plastic Analysis Approach

- 3-D Isoparametric Bricks and Wedges
- Model
  - Wedge of the head
  - Half a penetration
  - Takes advantage of symmetry
- Materials
  - Tube and weld: Alloy 600
  - Vessel: carbon steel
- Welding Process Model Produced Ovality - Closely Matched Field Profiles

Three-Dimensional Model of the Outermost Penetration



Vessel Head Penetration Ovality Regression Analysis (All Heads)



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Stress Analysis Results

- Highest Stresses at Outermost Penetrations
- During Operation
  - Vessel displaces radially
  - Tubes displace toward position perpendicular to head
- Gap Tends to Open Between Head and Tube
- Hoop Stress Exceeds Axial Stress Significantly on All Hill Side Locations

Stress Analysis Results

- Highest Stresses in Outermost Penetrations Are Hoop
  - On the tube ID
  - Below and near the weld
  - Corresponds to crack locations in all but the B&W Tubular Products (BWTP) penetrations

- Highest Axial Stresses Just Above and Along Plane of Weld

- Stress Analysis Consistent With No Circumferential Cracking Found in Huntington Materials

Loadings Evaluated

- Steady State - *Governing Loading*
- Hydrotest
- Operating transients
- Boltup
- Seismic
- Welding
- Interference

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Weld Model Load Sequence

- First Weld Pass
- Second Weld Pass
- Cold Hydrotest (Shop @ 3107 psi)
- Cold Hydrotest (Field @ 3107 psi)
- First Cycle of Steady State Loading / Unloading
- Second Cycle of Steady State Loading

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Stress Strain Curves

- Based on Testing Material From Outermost Penetration of Non - Irradiated Plant

- Monotonic and Cyclic Curves Obtained

- Cyclic Stress - Strain Curve Used
  - Multiple loading cycles during fabrication / service
  - Different yield strength materials converge to a single cyclic curve

- Used Cyclic Curve for One Half the Life of Penetration

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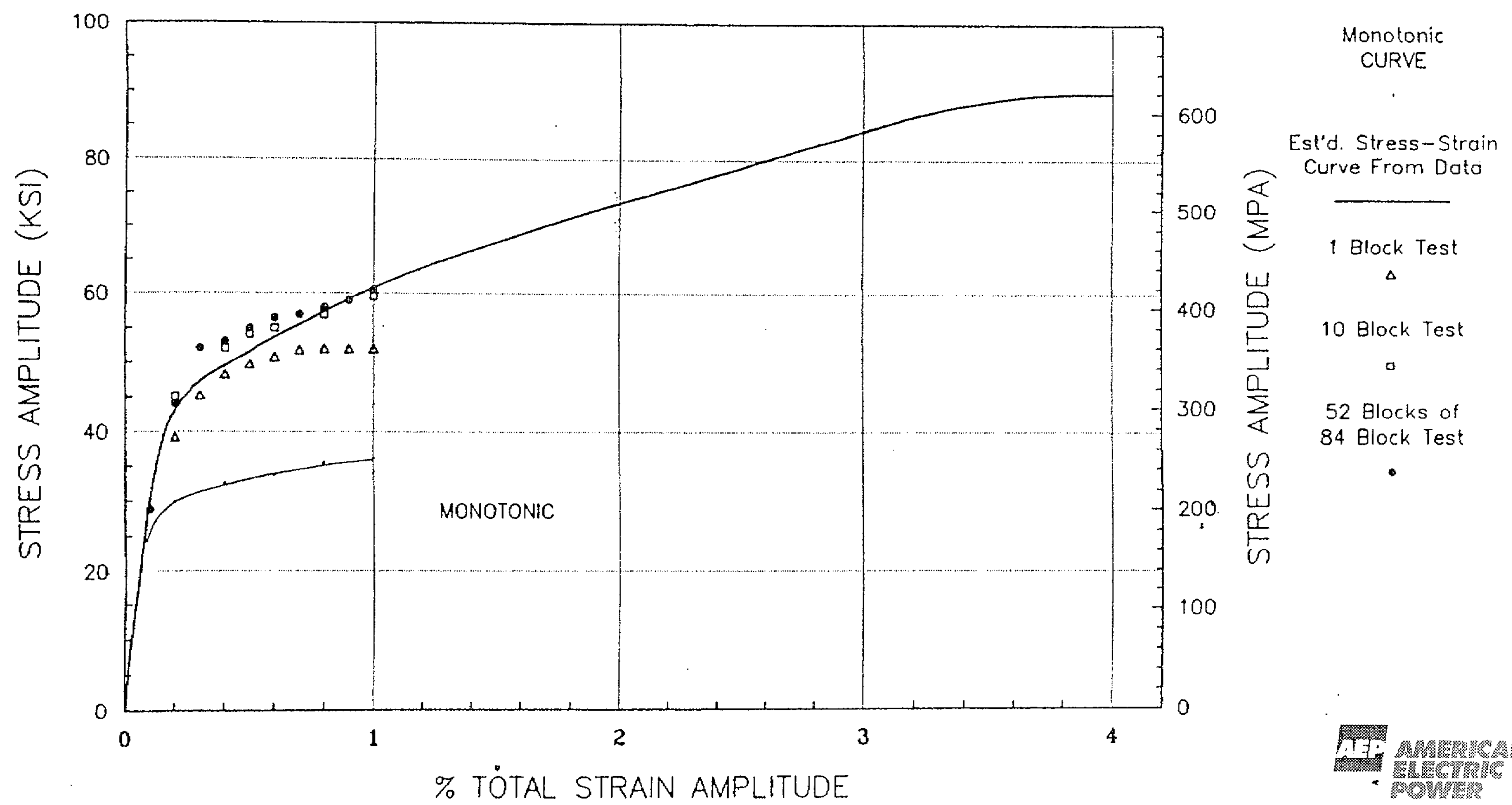
Cyclic Stress - Strain Curve and Test Data

ALLOY 600 HEAD PENETRATION MATERIAL
@ 600 °F(316 °C)
CYCLIC STRESS-STRAIN CURVE AND TEST DATA



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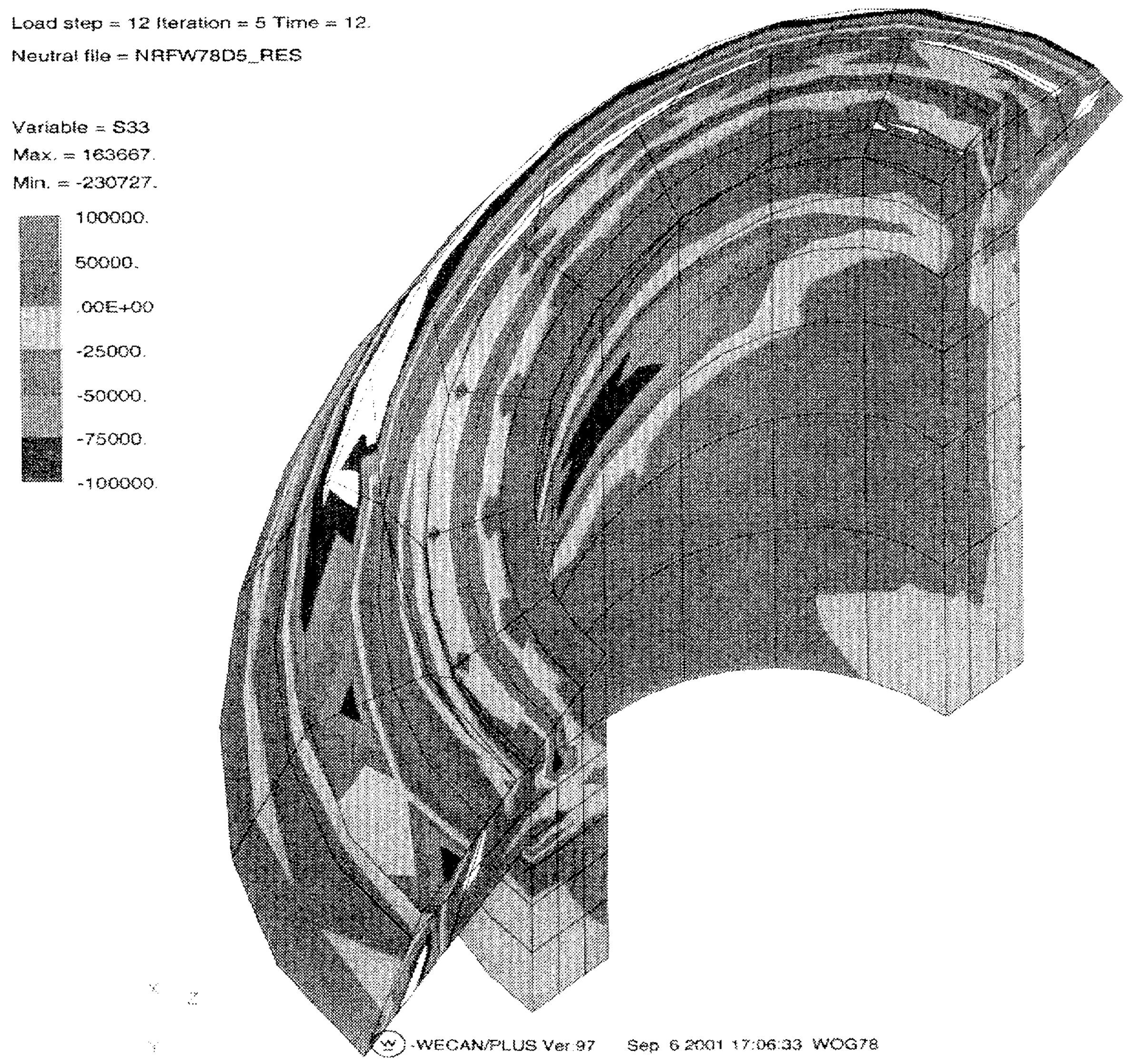
Axial Stresses in CRDM Above Weld Region



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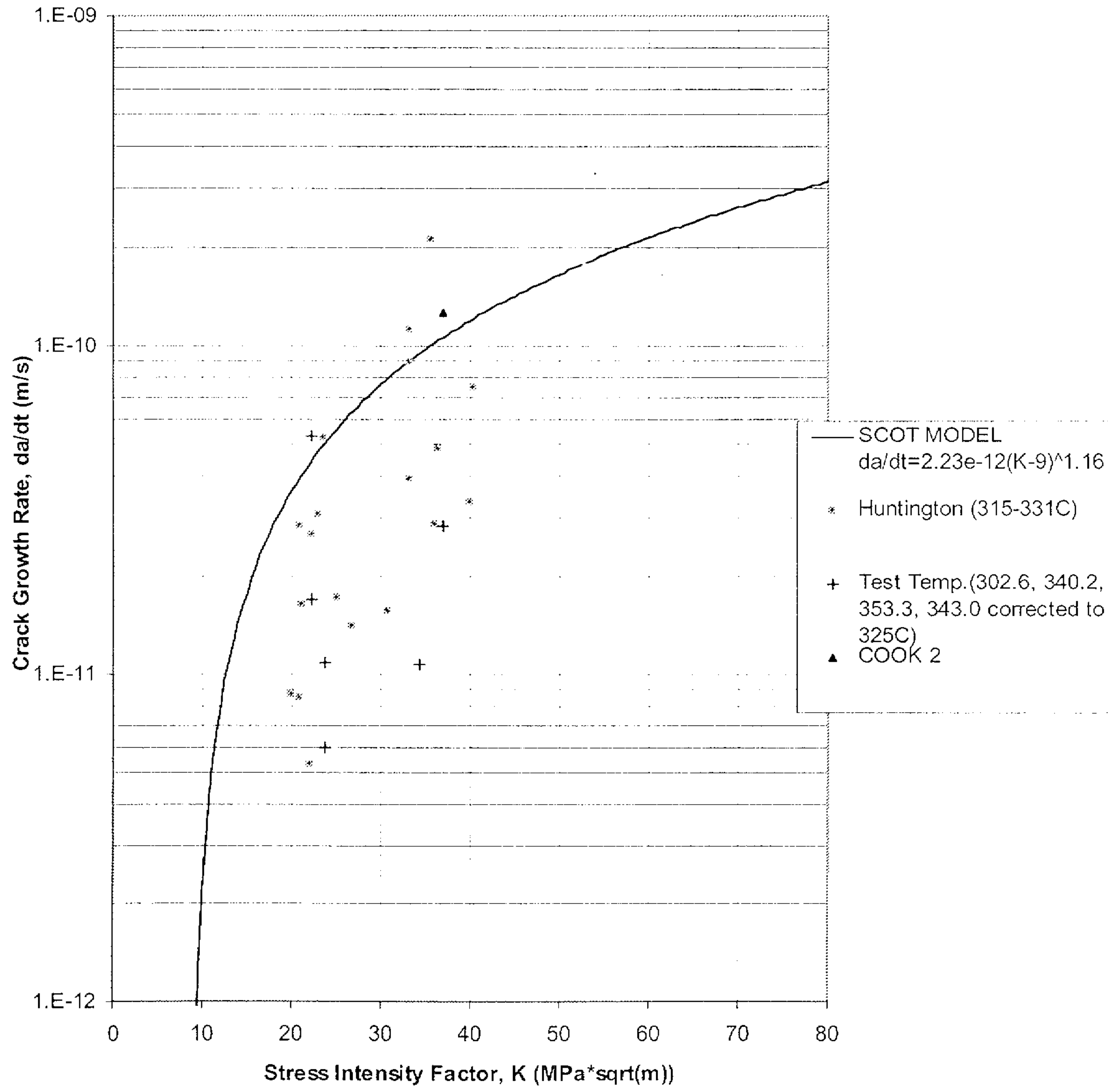
Crack Growth Model Overview

- Development of Scott Model
- Independent Confirmation
- Available Test Data
- DC Cook ISI Confirmation
- MRP Recommendations
- Comparison With NRC Model of November Report
- Temperature Correction

Crack Propagation

- Mechanism Is Primary Water SCC
- Key Variables
  - Temperature
  - Applied Stress Intensity Factor
- Temperature Effect Modeled on Observed Cracking in Alloy 600
- Base Crack Growth Rate of Scott Modified to Account for Temperature Effects
- Results to Be Discussed
  - Propagation through wall
  - Propagation along circumference of penetration

Crack Growth Data 325C, Huntington Heats



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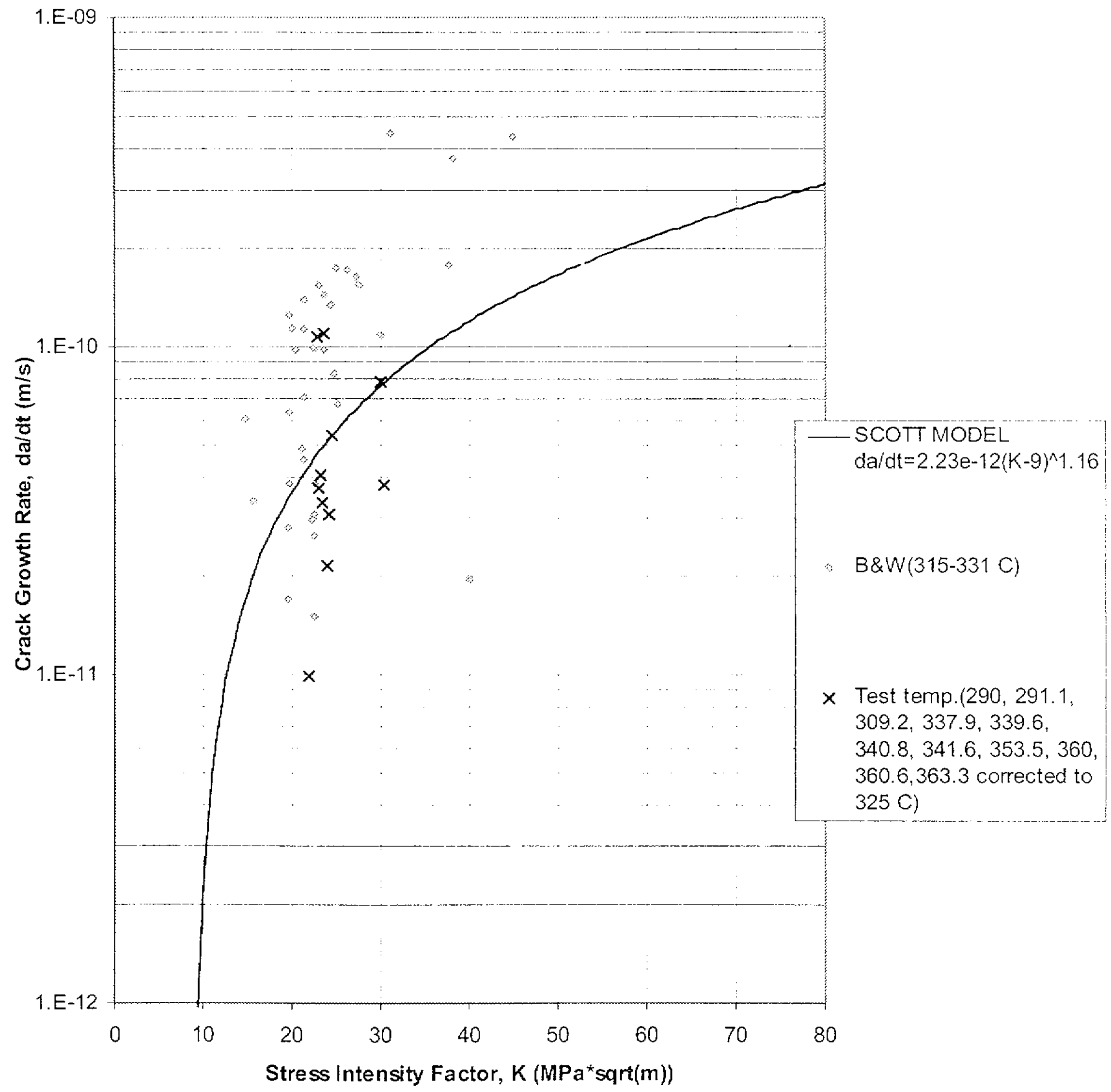
Comparison to Babcock and Wilcox Plants

- **B&W Plants Use BWTP Tubes**
- **BWTP Tubes Are Different From Huntington Alloy Tubes**
  - Lower grain boundary carbide coverage leads to shorter initiation times for BWTP heats
  - PWSCC crack growth rates are 2-3 times faster for BWTP heats
  - Majority of BWTP tubes were roto-straightened
    - » High hardness on the OD
    - » Higher PWSCC susceptibility on the OD
- **Cook Unit 2 Uses Huntington Alloy Tubes**

Crack Growth Data 325C, B&W Tubular Products Heats



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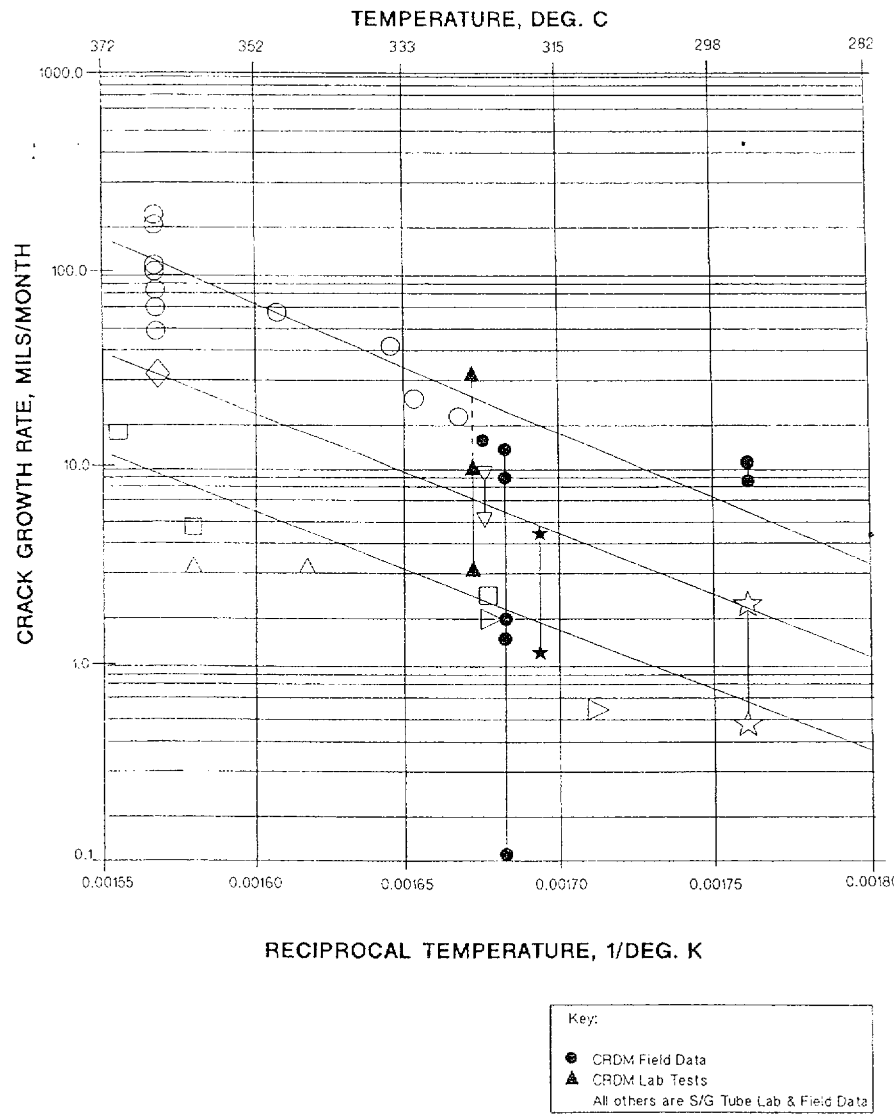
Summary of Crack Growth Temperature Effects



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Crack Growth Calculations For Circumferential Flaws

- **Development of a Leak Path**
- **OD Initiation and Growth Toward the ID**
- **Circumferential Growth to Failure**

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Development of a Leak Path

- Three Possible Paths
  - ID above weld
  - OD up past weld
  - Through the weld

- ID Above Weld Is Preferred Path For All Except B&W Plants

- Cook Unit 2 ID Verified Flaw Free in 1994, Except One Penetration - Repaired in 1996

OD Initiation and Growth Toward ID

- Assume Leakage Occurs by Any of Three Paths
- Nine Circumferential Locations Studied
- Only Uppermost Hillside Location Had Stresses Leading to Through - Wall Penetration
- Compressive Stresses Lead to Relatively Slow Growth
- Raju and Newman Stress Intensity Factor Used
- Through - Wall Growth Would Take About 24 Years

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Circumferential Growth to Failure

- **Propagation Follows the Top of the Weld**
- **Stress Decreases as the Flaw Propagates**
  - Nominal axial residual stresses
  - Displacement - induced stresses
- **Stress Intensity Factor Determined from Finite Element Modeling Accounts for These Factors**
- **Results Obtained for Two Crack Growth Models**
  - Scott Model
  - NRC Model

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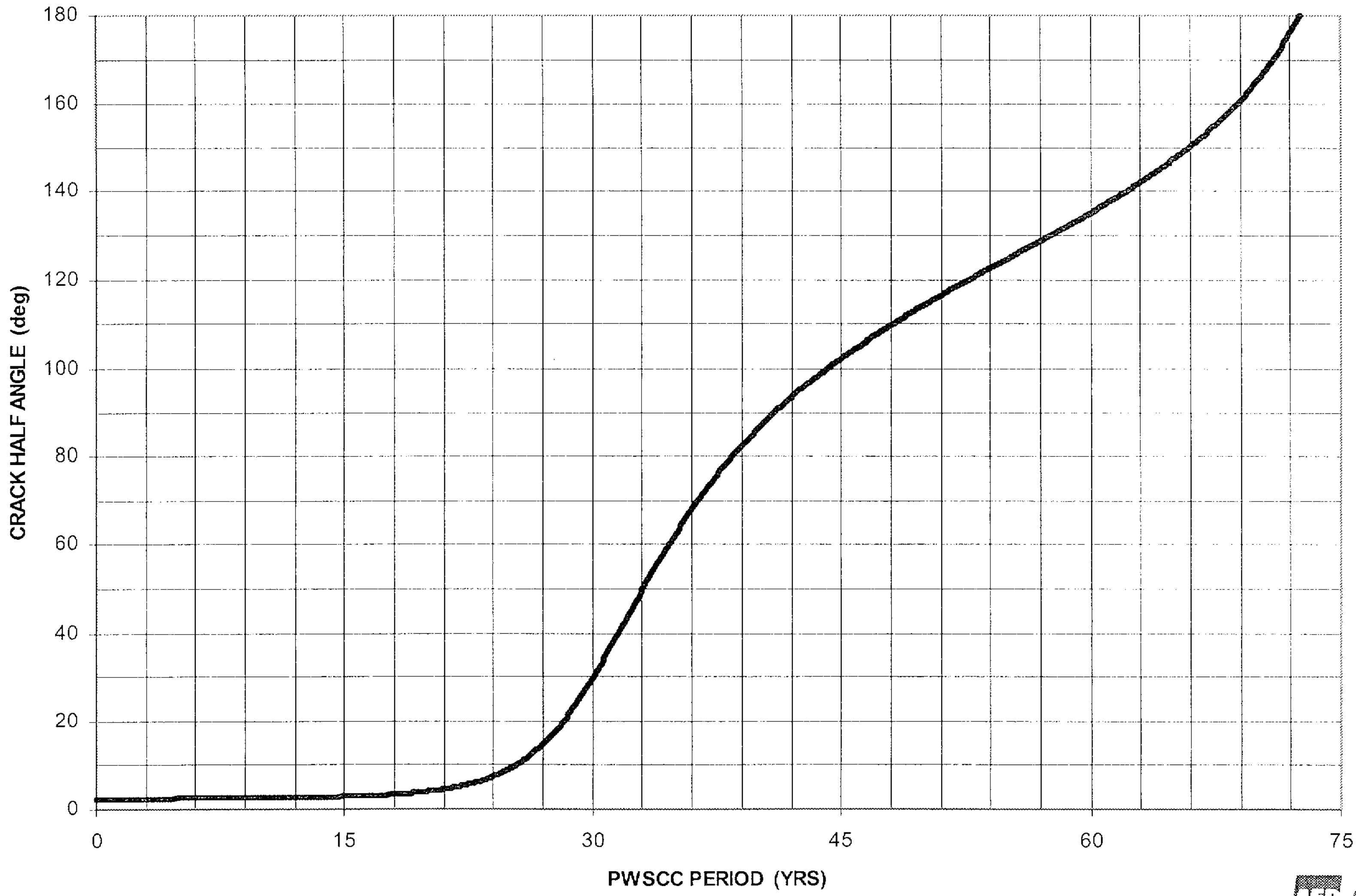
Scott Crack Growth Model

- Assume Through-wall Circumferential Flaw
  - Occurred just after the Cook inspection in fall 1994
  - Length of 10 percent of circumference
- Over 40 Years Required to Grow Flaw to Unacceptable Length
- Cook Unit 2 Will Have Less Than 4 EFPY of Operation From 1994 Inspection to January 19, 2002
- Any Circumferential Flaw Occurring in 1994 Would Still Be at Acceptable Level

Scott Crack Growth Model



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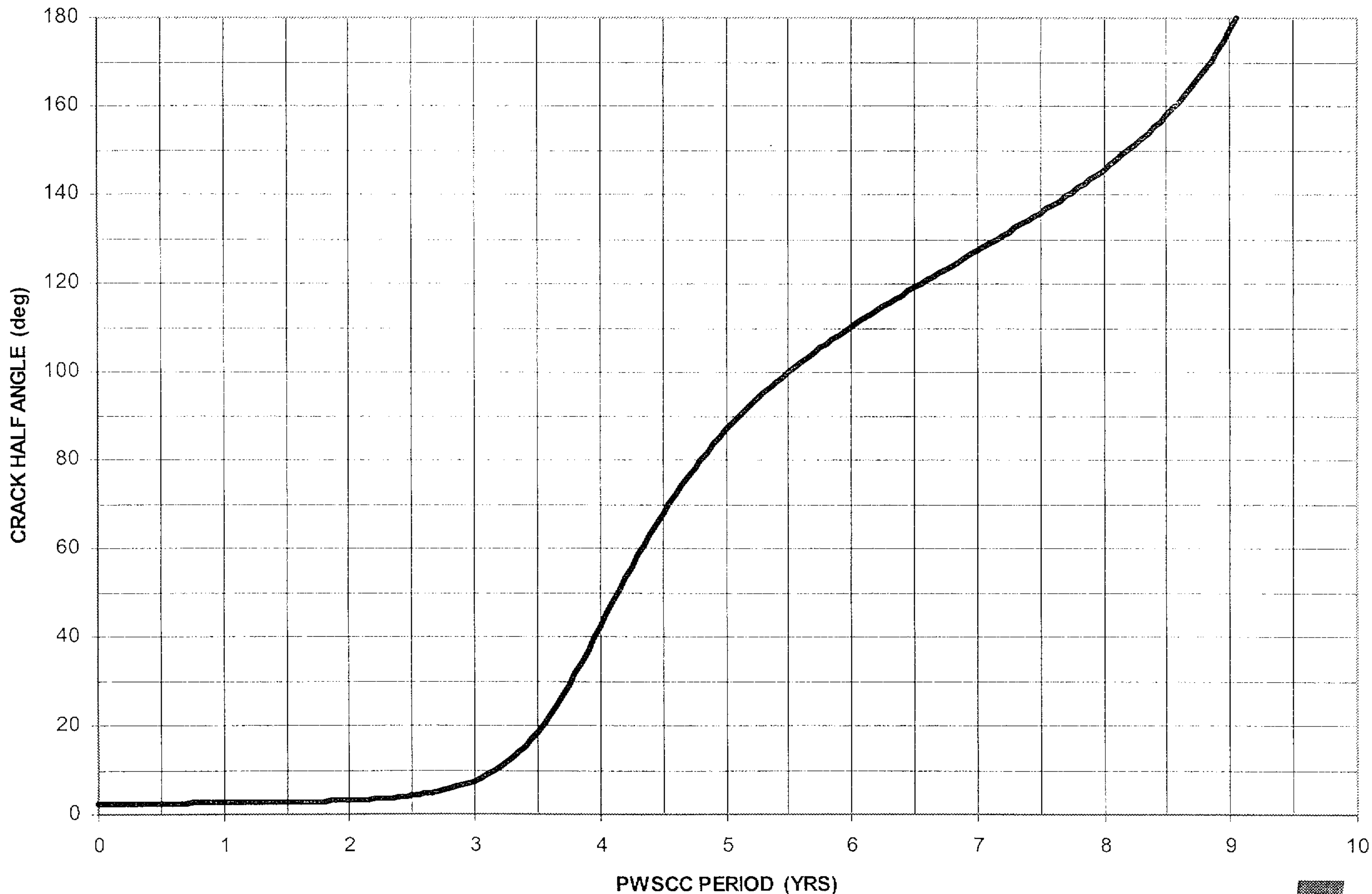
NRC Crack Growth Model

- Assume Through-wall Circumferential Flaw
  - Occurred just after the Cook inspection in fall 1994
  - Length of 10 percent of circumference
- Over 5 Years Required to Grow Flaw to Unacceptable Length
- Cook Unit 2 Will Have Less Than 4 EFPY of Operation From 1994 Inspection to January 19, 2002
- Any Circumferential Flaw Occurring in 1994 Would Still Be at Acceptable Level

NRC Crack Growth Model



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Probabilistic Risk Assessment

James Hawley
Supervisor
Probabilistic Risk Assessment
American Electric Power

RISK ASSESSMENT

- NRC Requested Justification for Operation Past December 31, 2001
- Risk Assessment Complements Deterministic Assessment
- Looks at Operation Past December 31, 2001 From Incremental Perspective (Incremental Core Damage Probability – ICDP)
- Comparison Made to Unplanned Outage Risk

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RISK INPUTS

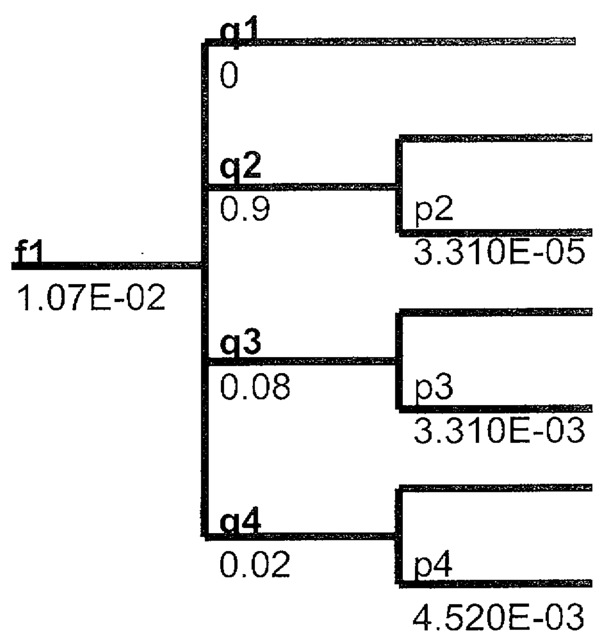
- Leak Frequency: Based on Statistical Analysis of Industry Data

- Four Types of Leaks / LOCAs: Seepage, Leak, Small LOCA, Medium LOCA
  - Fractions conservatively chosen as 0, 0.9, 0.08 & 0.02 based on Engineering Judgement
  - Industry data for fractions: 0.965 (28/29), 0.035 (1/29), 0, 0

- Conditional Core Damage Probability (CCDP)
  - From recently updated / WOG certified PRA model

CDF Risk Assessment Model Event Tree

Leak Freq.	Type of Leak or LOCA	Conditional core damage Probability	Sequence	End State	Frequency
			1	OK- seepage	
			2	OK - leak	
			3	CD - leak	3.20E-07
			4	OK - small LOCA	
			5	CD - small LOCA	2.83E-06
			6	OK - Medium LOCA	
			7	CD - Medium LOCA	9.67E-07
				Total CDF =	4.14E-06



ICDP for 19 DAYS = 4.14E-06 X 19/365 = 2.16E-07

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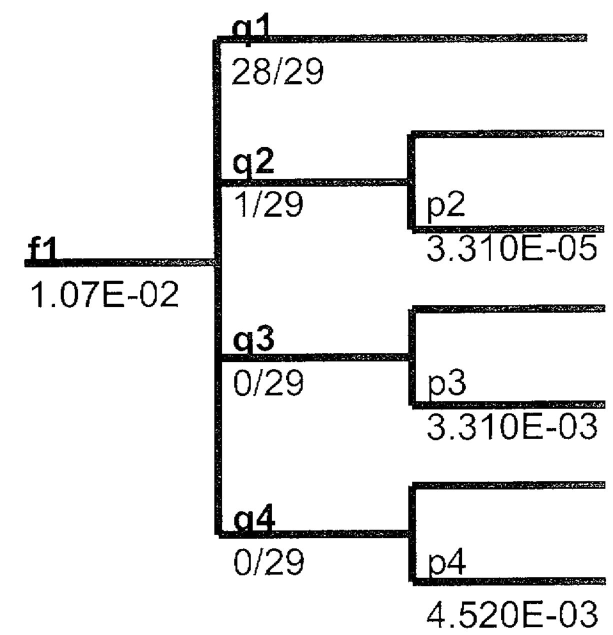
CDF Risk Assessment Model Event Tree Using Leak Inspection Data Results

Leak Freq.	Type of Leak or LOCA	Conditional core damage Probability	Sequence	End State	Frequency
			1	OK- seepage	
			2	OK - leak	
			3	CD - leak	1.22E-08
			4	OK - small LOCA	
			5	CD - small LOCA	0.00E+00
			6	OK - Medium LOCA	
			7	CD - Medium LOCA	0.00E+00
				Total CDF =	1.22E-08



ICDP for 19 DAYS = 1.22E-08 X 19/365 = 6.35E-10

RISK RESULTS

- Risk of Operating 19 Days Past 12/31/01 = 2.16 E-07

- Risk of One Unplanned Day in Mode 5 is 6.1E-08
  - Based on Shutdown Safety Monitor Model

- Four Extra Days In Mode 5 Causes Increase In Overall Plant Risk

Cook Unit 2 Inspection Plans

Daniel Garner
Project Manager
American Electric Power

Inspection Plans

- **Visual Examination**
  - 100% effective visual examination using robotic crawler
  - Evaluating qualified visual examination

- **Eddy Current / Ultrasonic Exam**
  - All J-groove welds and outside diameter metal of interest for all CRDMs and thermocouples
  - Inside diameter of most susceptible penetrations - (19)
  - Inside diameter for seven part length rod locations

Susceptibility Summary

- WCAP 14907 (Not Docketed) Prepared in 1997 for Cook Units
- Each Penetration Analyzed for Probability of Achieving 75% Through Wall Cracks
- Data Provided at 10 EFPY Intervals
- Cook 2 Is at ~15 EFPY - Linear Interpolation Used Between 10 and 20 EFPY

Probabilities of Reaching 75% Through Wall Cracks

Penetration	15 Years
76-78	49.5
75	49.2
66-68	40.3
74	36.6
62	36.2
69-71, 73	34.9
63, 65	27.8
64	22.3
72	19.8
56	17.5
58	17.2
53	12.9
42, 44	11.5
43, 45-48	11.1

Penetration	15 Years
38-41	9.7
61	8.0
60	6.9
50, 51	5.3
54, 55, 57, 59	4.7
49	3.9
23, 24	3.2
27, 28	3.1
52	3.0
32	3.0
31, 33	1.6
30, 34-37	1.3
25, 26	1.2
22	0.8

Penetration	15 Years
29	0.7
17	0.7
10, 11, 12	0.7
13	0.6
18-21	0.5
14, 16	0.5
8	0.5
7	0.5
15	0.4
9	0.1
6	0.1
2, 3, 4, 5	0.1
1	0.0

Most Susceptible Locations

Part Length Rod Locations

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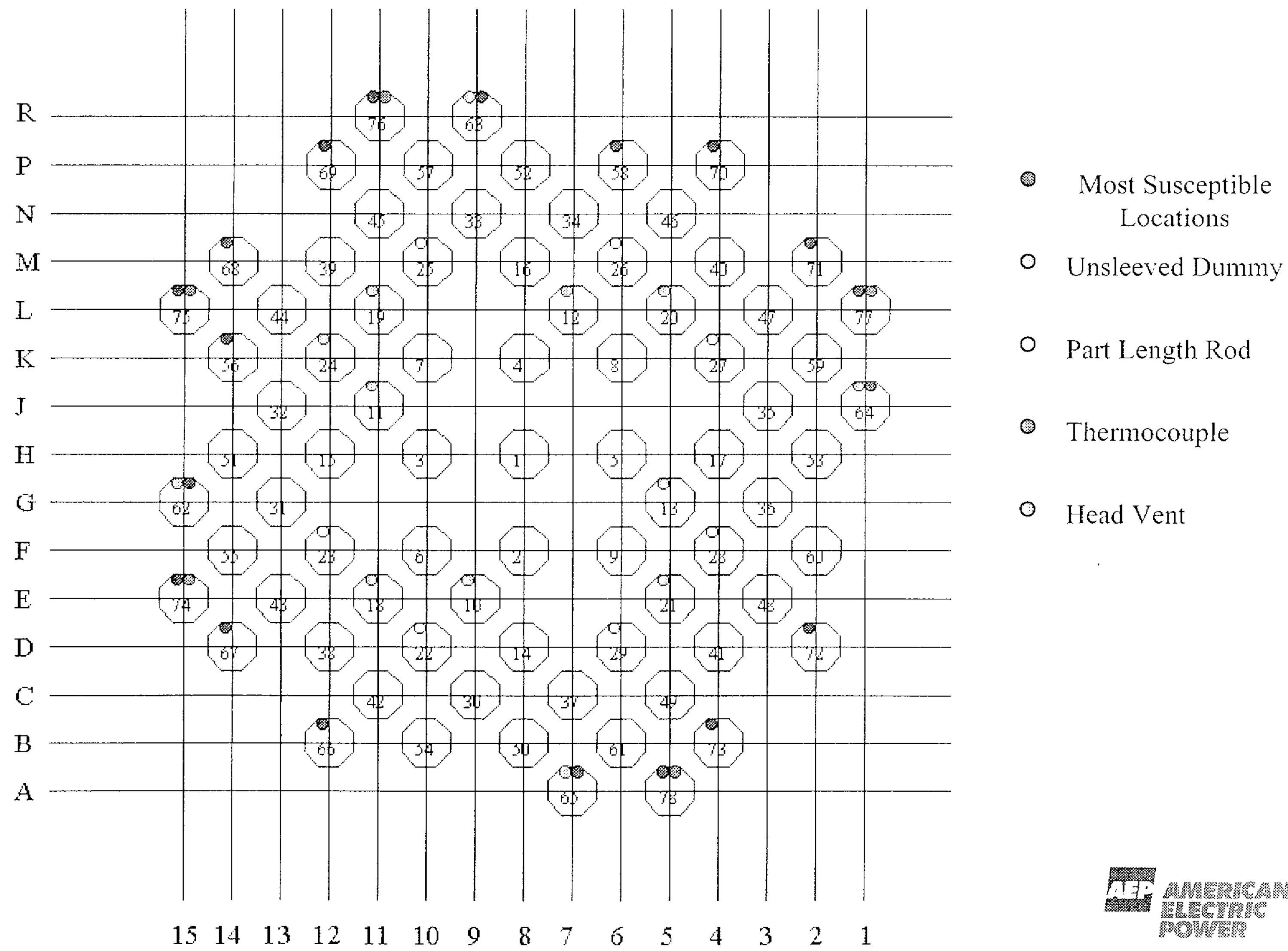
UNIT 2 REACTOR VESSEL HEAD PENETRATION MAP



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Closing Summary

Scot Greenlee
Director
Nuclear Technical Services Organization
American Electric Power

Closing Summary

Based on Conservative Analysis

Cook Unit 2 Is Safe to Operate Until January 19, 2002