United States Nuclear Regulatory Commission

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Non-Destructive Examination Research Program

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Nuclear Regulatory Research

- Provides independent technical bases for regulatory actions
  - Improved inspection & condition-monitoring techniques
  - Advanced analytical & modeling techniques
  - Independent data & evaluations
- Stimulates & leads international nuclear safety research activities

Historical Overview of NRC Research on NDE

- Need to quantify NDE reliability
  - To support fracture mechanics analyses
  - To establish baseline for later improvements
- Desire to improve inspection capability and NDE requirements (ASNT, ASME Code)
- Round robin tests to evaluate techniques, instrumentation, inspectors
  - PISC –I, -II, -III
  - PD-by-analysis vs. PD-by-lab tests
  - Formation of Industry PDI
- Statistical techniques developed

NRC Research to Improve Piping NDE

- 1970's – NDE guided by ASME BPVC Sec. XI (In-Service Inspection)
- 1975 – IGSCC of 4" diam. piping forced inspections of stainless steel piping in all US BWR's
- 1978 – NRC began a program on NDE reliability at Pacific Northwest National Laboratory (PNNL)
  - Data needed for fracture mechanics analyses
  - Results of parametric studies on NDE published 1981 (NUREG/CR-1696)
  - 1977-80's – NUREG-0313 (rev.1&2) provided guidelines to address IGSCC in BWR piping and maintain integrity
  - NRC recommended capability demonstration tests, required in Bulletin 82-03, Bulletin 83-02

PNNL Round Robin Tests

- 3 Round robin test programs in 1980's
  - PIRR, MRR, PISC
- Objectives
  - Quantify NDE performance, reliability (POD)
  - Identify NDE techniques, procedures & methods for more reliable inspections
- Results
  - Demonstrated effectiveness of improved training, periodic re-training for inspectors
  - NRC recommended performance demonstration (PD) approach that was incorporated into ASME Code Sec. XI Appx. VII and VIII
  - Industry formed PDI to implement Code PD requirements

Performance Demonstration Initiative

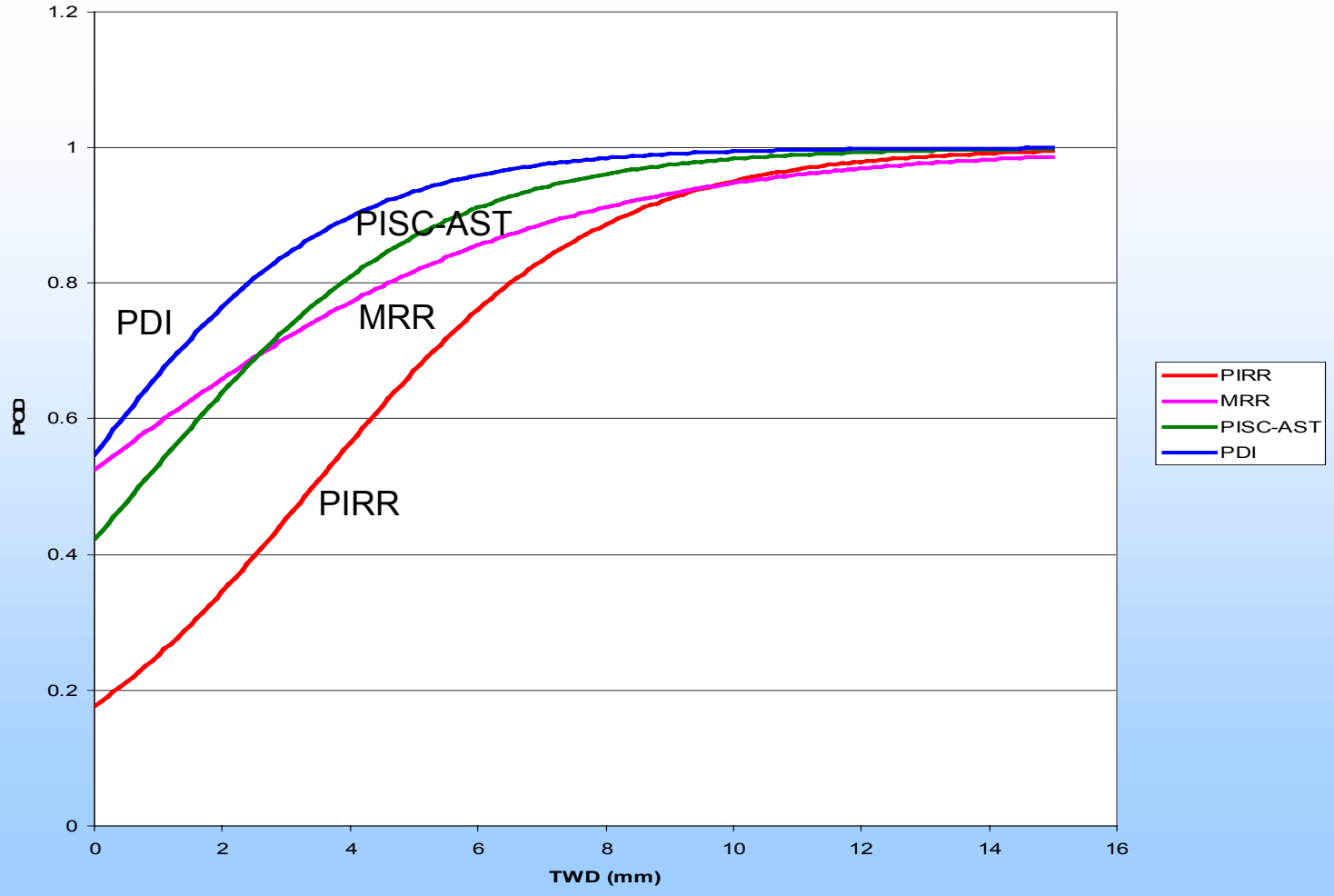
- EPRI-administered program to qualify inspectors and NDE procedures, est. in 1991 and ongoing
- Variety of pipe sizes and materials
- Detection and sizing tested separately
- Large number of inspectors tested have produced more aggregated data than any of the round robin tests
- Objectives
  - Uniform implementation
  - High level of credibility
  - Minimized costs through shared resources

Procedure and Personnel Qualification

- Two stage qualification developed in cooperation with PNNL
- Procedure qualification demonstrates that procedure is capable of detecting flaws
  - Requires a large number of samples with varied size, location, geometry, material
  - 100% detection required on up to 50 samples
- Personnel qualification demonstrates that individual is capable of applying the procedure
  - 10-15 samples
  - 80% detection required, with limited false calls

Comparison of Detection Data

Probability of Detection (POD) vs. Flaw Size (through wall dimension)

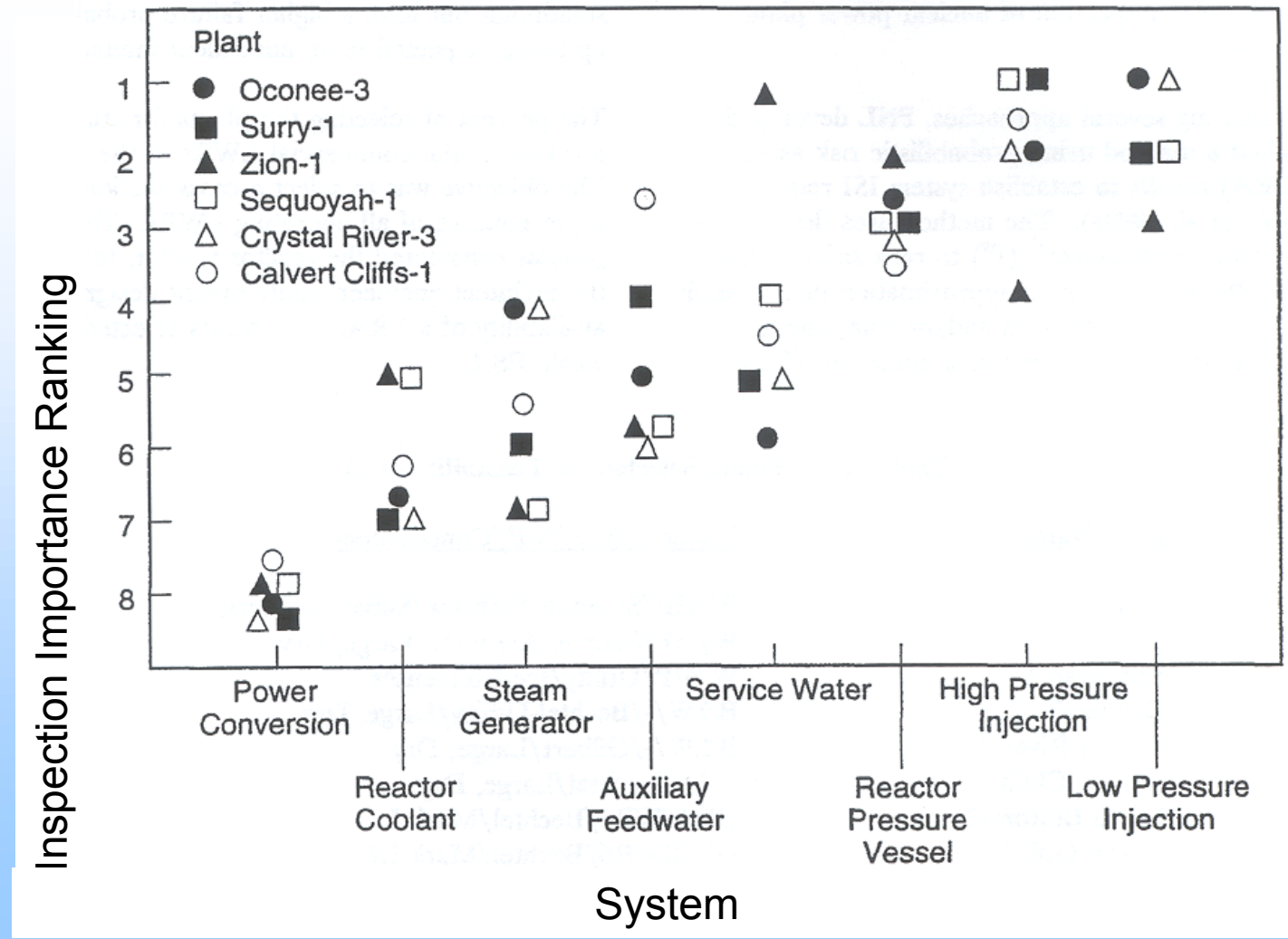


Risk Informed In-Service Inspection

- Developed methodology to identify and prioritize plant passive components most relevant to safety for inspection
- Modified probabilistic risk assessment (PRA)
- Determined failure probability of components
  - By probabilistic fracture mechanics and expert elicitation
  - Considering inspection reliability and degradation mechanisms
- Evaluated 8 plants (6 PWRs, 2 BWRs) to assess generic applicability of methodology and ranking of systems
- Applied to Surry-1 to validate methodology
- First application of risk informed regulatory requirements at NRC
  - RG 1.178 Guidance on risk informed inspection for piping

NUREG/CR-6151

Inspection Importance Ranking for Various PWR Systems Based on CDF



NUREG/CR-6151

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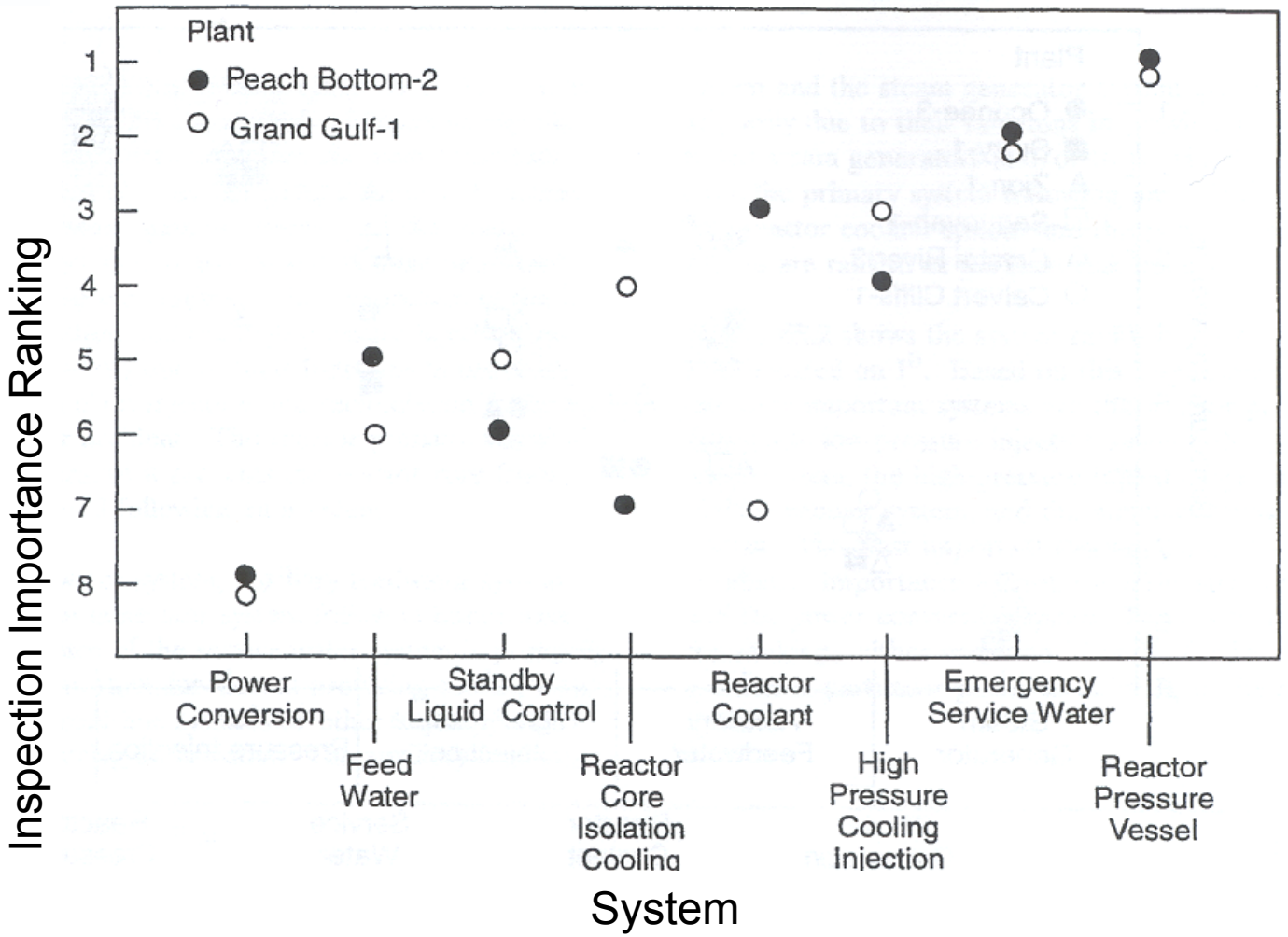


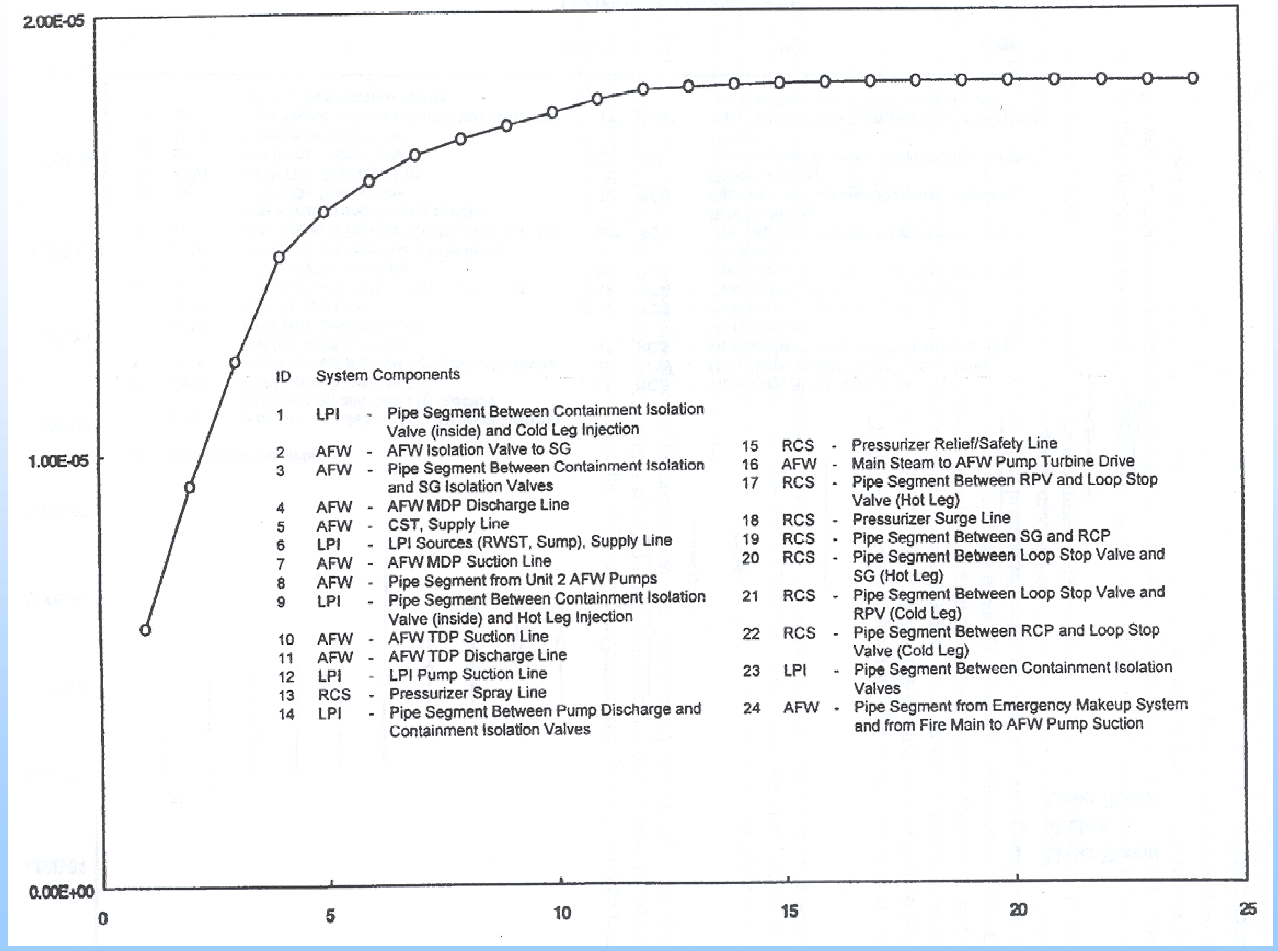
NUREG/CR-6181 Rev. 1 (1997)

Risk Contribution of Surry-1 Components to CDF

- Determine component failure probability using expert elicitation
- Define direct & indirect failure consequences
  - Disable a single component, train or mitigating system
  - Disable multiple components, trains or mitigating systems
  - Cause an initiating event such as a LOCA or reactor trip
  - Cause any combination of the above
- Calculate component failure contribution to CDF

NUREG/CR-6181 Rev. 1

Cumulative Risk Contribution of Surry-1 Components to CDF



Cumulative Risk Contribution

Component Identification

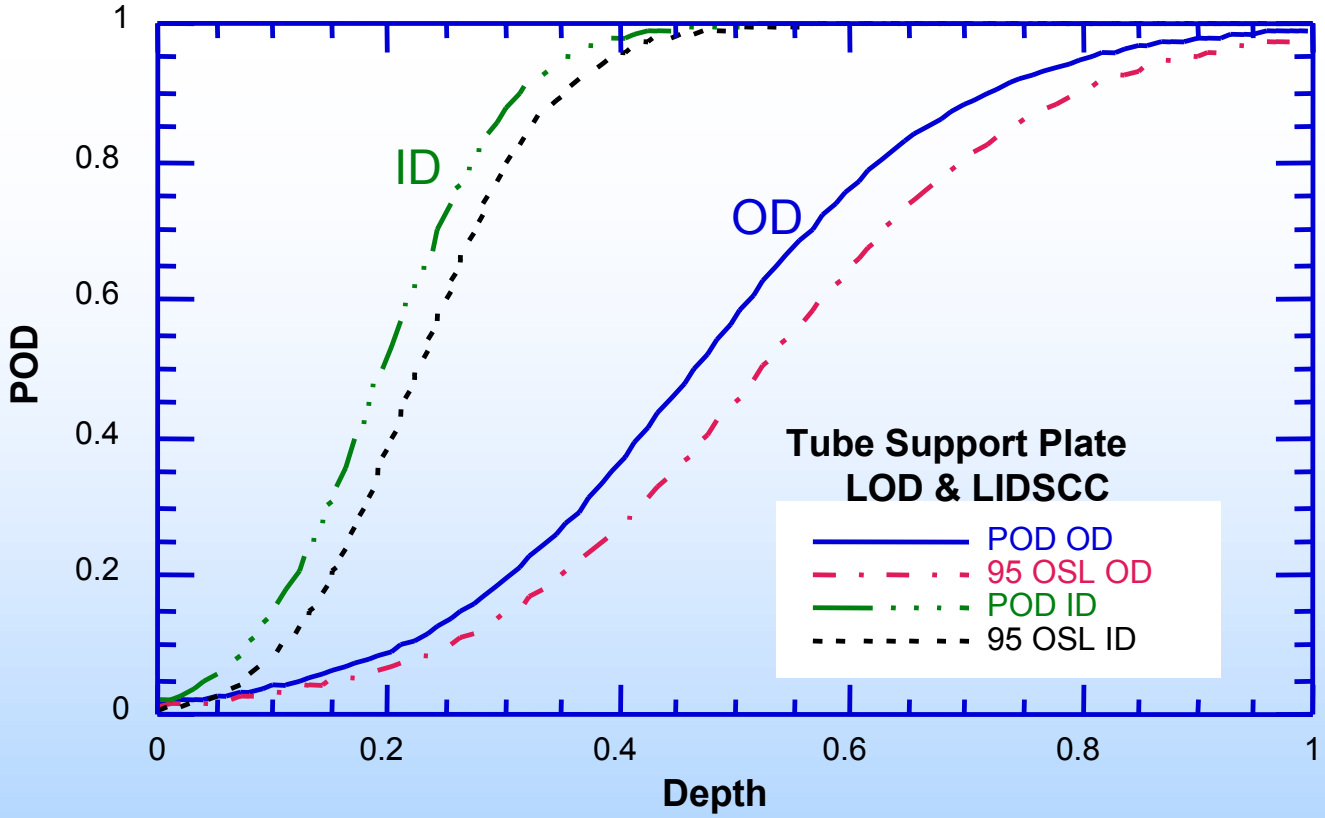
Current NDE Research

- NDE round robin on ISI of steam generators
- Dissimilar metal welds
- Cast austenitic stainless steels
- NDE for PWSCC
- Vessel head penetrations

ANL/NRC Steam Generator Mock-up for Eddy Current Tests

- Contains realistic laboratory grown flaws and SG conditions
- Round robin to evaluate and quantify inspection reliability of currently practiced NDE methods
  - POD
  - Sizing accuracy
  - Function of flaw size, type, location

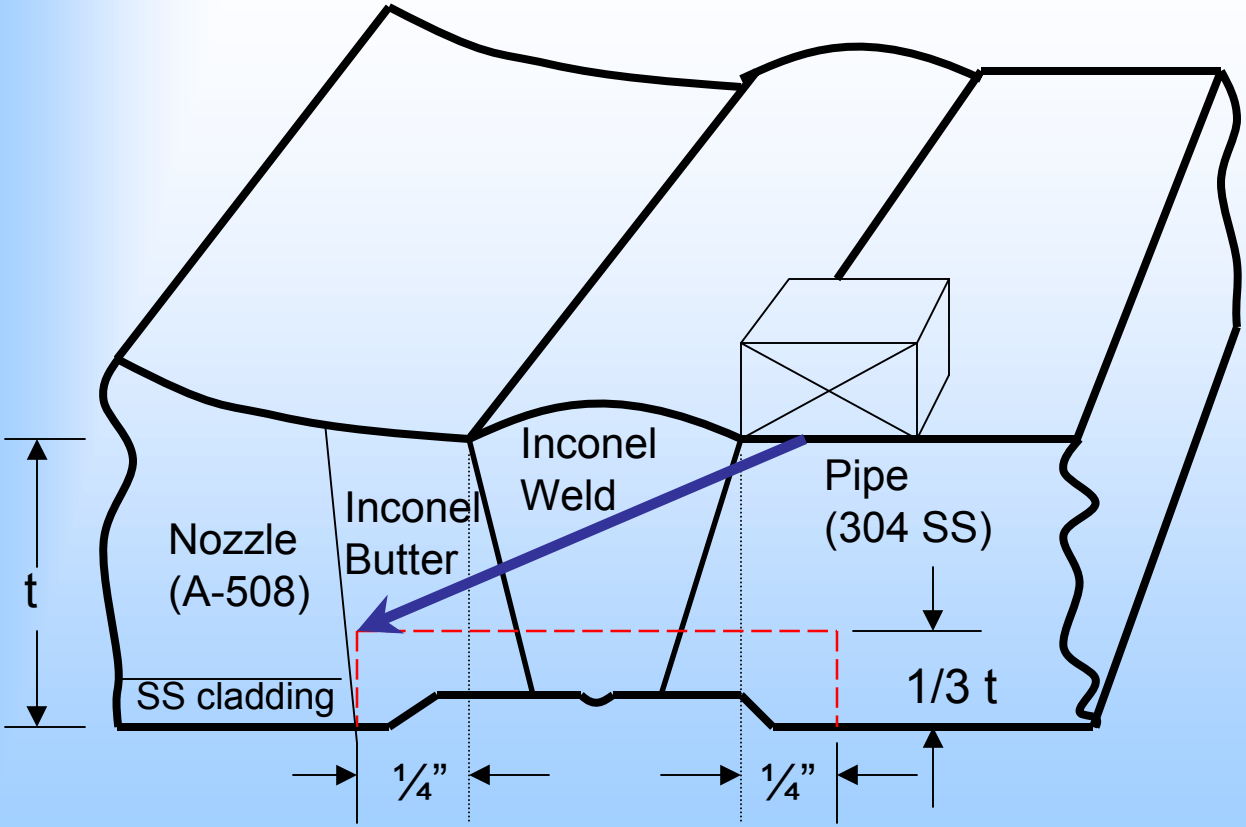
Eddy Current (ET) Round Robin



Bobbin Coil Probability of Detection for TSP data as a function of maximum depth (as fraction through-wall) for Longitudinal Stress Corrosion Cracking using maximum likelihood fit and 95% One-Sided Limits

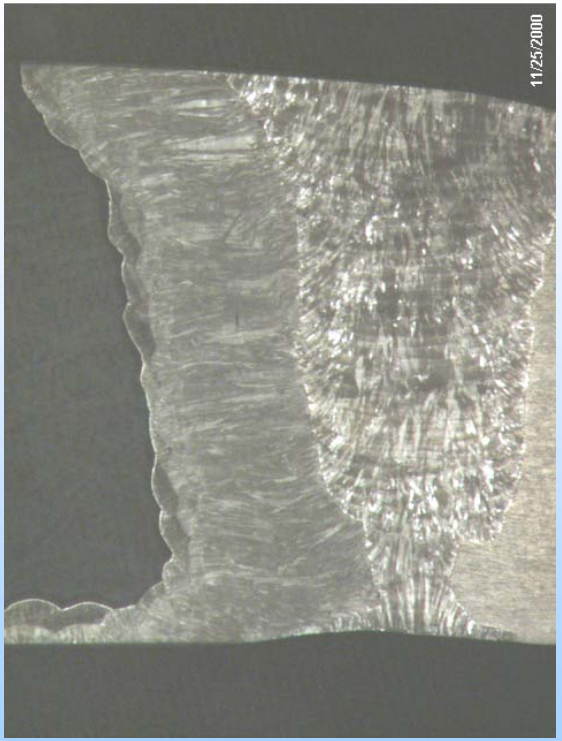
UT Challenges in Dissimilar Metal Welds

Typical Geometry Challenges



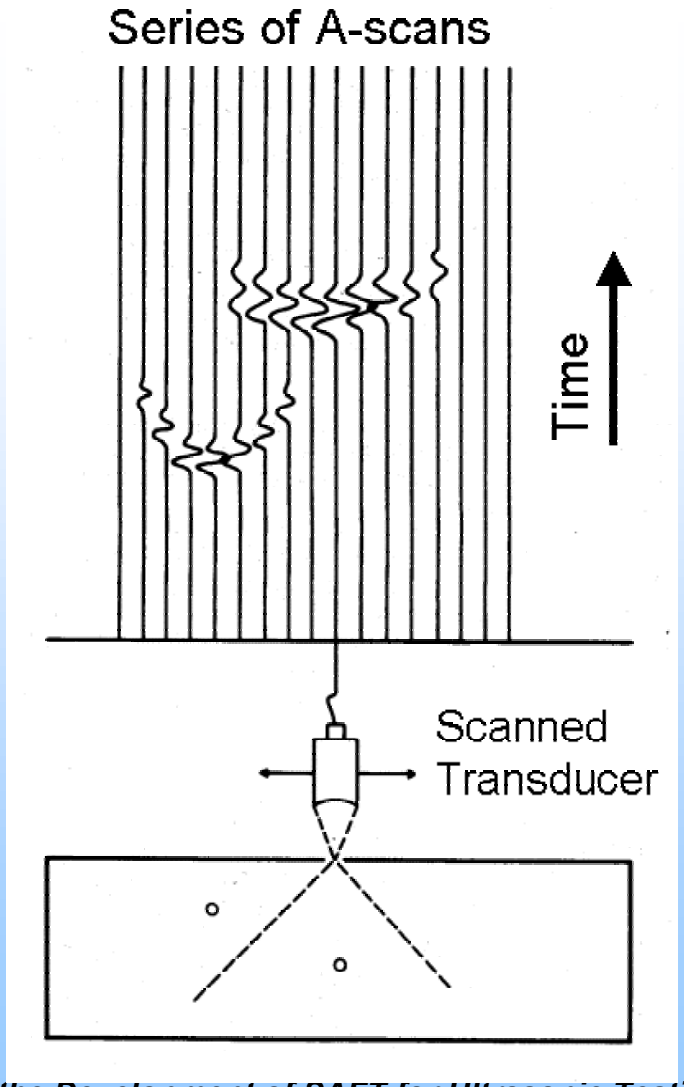
Typical Code Volume

Typical Micro-structural Challenges



Synthetic Aperture Focusing Technique (SAFT-UT)

- Technique uses a diverging ultrasonic beam
- Echoes from point source fall on a hyperbola as transducer is scanned
- Hyperbola is a function of depth and beam angle
- Data is time shifted to finite depths through the thickness and averaged to construct a focused image



Normal Beam SAFT from NUREG/CR-3625: ***Review & Discussion of the Development of SAFT for Ultrasonic Testing****, 1984*

SAFT-UT Applications

- Develop fabrication flaw density distributions for fracture mechanics
  - Reactor pressure vessels
  - Primary loop piping
- Evaluate low frequency SAFT-UT for coarse grained materials
  - Primary loop cast SS
  - Primary loop wrought SS far-side of weld
- Better detect and characterize SCC due to improved resolution; differentiate from geometry

NRC Research Initiatives on PWSCC

- Quantify reliability of NDE systems, identify most capable techniques
  - Vendors have current equipment capabilities but not qualified inspection methods
- Develop international cooperative project with objectives:
  - Compile a knowledge base on Inconel cracking
  - Evaluate methods of flaw simulation
  - Identify NDE methods to adequately detect, size and characterize tight cracks such as PWSCC through round robin tests

Destructive Analysis of Field Cracks in CRDM Penetrations

- North Anna Unit 2 CRDMs containing PWSCC cracks
- Joint program with EPRI/MRP
- 7 nozzles flame cut from head – Shipped to PNNL
- Being decontaminated for study – Note extreme care being taken to keep cracks pristine
- ISI vendors to conduct NDE inspections
- Will provide an assessment of what was and was not detected and how accurately characterized
- Destructive validation and study of cracking process planned

Nuclear Safety and Component Reliability Engineering Research Facility

- Energy Northwest cancelled plant: WNP-1
  - 1260MW PWR, Babcock & Wilcox design
  - Plant never operated, components uncontaminated
  - Typical of 1970's design and construction
  - Plant is well preserved in desert environment
- PNNL is pursuing a long term lease to access the WNP-1 site

Potential Uses of WNP-1 Facility

- Technology transition of NDE programs from R&D to field application
- Characteristic fabrication flaw population in RPV, vessel penetrations, internals, piping, etc.
- Reduced need for mockups for research programs, remote tooling development, etc.
- Containment integrity issues
- Personnel training
  - NDE
  - Emergency response
  - Physical security

Future NDT Issues

- Aging management
  - License extension, component life prediction
- Advanced reactors
  - Reduced access for inspection, extended intervals
  - Online monitoring
- Emerging NDT technologies
- Emerging degradation mechanisms