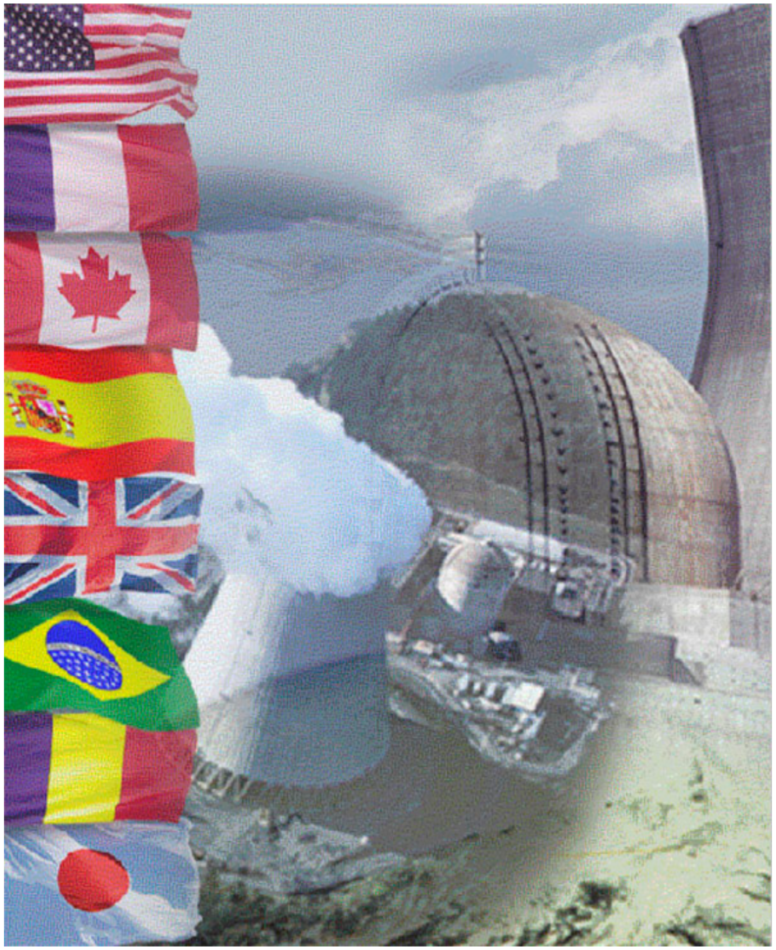

Bottom Mounted Nozzle Strategic Plan: Industry Update

Craig Harrington, TXU Power
Co-chair, MRP Alloy 600 ITG

Dave Bajumpaa, Dominion Millstone
Chair, WOG Analysis Subcommittee

Glenn White, Dominion Engineering

NRC Meeting
September 29, 2005

Sept 29 Meeting Agenda

- Background
- Integrated Industry Inspection Plan
- NDE Demonstration Program
- BMN Repair Attributes
- Safety Assessment Results
- BMN Management Plan Development
- Wrap Up

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Background

- Industry activities initiated in 1998 to evaluate the consequences of degradation of bottom mounted nozzles via PWSCC
- First field event – staining (no leak) on the Davis-Besse vessel which led to associated FANP Preliminary Safety Concern (mid-2002)
- STP discovery of boric acid crystal deposits on April 12, 2003 accelerated the concern
- EPRI MRP issued letter requesting each site to complete bare metal visual inspection of RV lower head (June 2003)
- NRC issued Generic Letter 2003-02 requesting information on site plans

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Background
BMN Strategic Plan

- Coordinate activities through EPRI MRP, WOG/CEOG and B&WOG
  - NDE Demonstration Program
    - MRP Alloy 600 ITG
  - BMN Assessment Plan
    - B&WOG, WOG, and MRP Alloy 600 ITG
  - Integrated Industry Inspection Plan
    - MRP and PWR Owners
  - BMN Repairs
    - MRP Alloy 600 ITG

Background
Previous NRC Meetings

- November 25, 2003 Meeting
  - B&WOG LOCA Evaluation Results
  - WOG Operability Assessment Results
  - MRP Visual Examination Recommendations
  - NDE Demonstration Program Status
  - Safety Assessment Plans
  - Industry Integrated Inspection Plan Status
  - BMN Repair Criteria Development
- July 19, 2004 Conference Call
  - BMN NDE Demonstration Program Status
  - BMN Safety Assessment Plan
  - Integrated Inspection Plan
    - Planned Inspections
    - Callaway BMN Inspection Results
  - BMN Strategic Plan Status

Integrated Industry Inspection Plan

Integrated Industry Inspection Plan

- Interim plan until the long term BMN management plan is available
- Purpose
  - Initiate voluntary volumetric inspections
  - Perform BMV baseline inspection of fleet
  - Gather data to determine extent of plant condition (short term)
  - Use inspection data gathered as input to BMN management plan (long term)

Integrated Industry Inspection Plan Volumetric Inspections

- Multiple plant inspections beginning in Spring 2004
- Goal: Broad cross section of plants
  - No susceptibility ranking for initial choices
  - 10-year Vessel Examination Schedules
- Monitor results based on NSSS vendor, plant design, date of commercial operation

Integrated Industry Inspection Plan

- **Potential** Inspection Methods:
  - BMV of lower vessel head
  - UT/ECT of nozzle
  - Enhanced visual of J-groove weld
  - ECT of J-groove weld
- Inspection results are reviewed as available to determine if a susceptibility model could/should be developed

Domestic Inspection Results

- 10 plants have inspected the Alloy 600 bottom mounted nozzle base material
  - Primarily with ultrasonic methods
- The NDE methods used were demonstrated in the MRP Alloy 600 BMN blind demonstration program.
- No indications of service-induced degradation or leakage were identified
  - except for two nozzles at STP-1

Tabulated Domestic BMN Inspection Results

NSSS Design	# BMNs	BMV	Volumetric
B&W *	364	364	0
W 2-Loop *	216	216	0
W 3-Loop	650	600	198
W 4-Loop	1682	1682	403
CE 80	183	183	0
TOTAL	3095	3045	601

* Capability was not successfully demonstrated to the satisfaction of the utility (false positives)

Foreign Inspection Results (EdF Experience)

- *EdF BMN PWSCC Monitoring Program*
  - Twelve lead units were selected based on: repairs, severe bending, or poor material properties
  - Inspect one or two units per year
  - BMN inspection methods employed include:
    - Video inspection before and after the hydro test
    - Volumetric inspection is performed using UT probes.
      - Probes include ET coils
    - Inspect the base material of the tube only

Foreign Inspection Results

EdF PWRs - total of 797 BMNs out of the 2893 total in their 54 units
- ID ET only revealed scratches
- The UT inspection sometimes exhibits some weld defects especially at the uphill position, base metal inclusions or OD grinding marks
- No cracking due to PWSCC

Japan PWRs – 4 plants inspected
- No findings except for one scratch

Belgium PWRs – 2 plants inspected
- No findings

Sweden PWRs – 1 plant inspected
- No findings

BMN NDE Demonstration Program

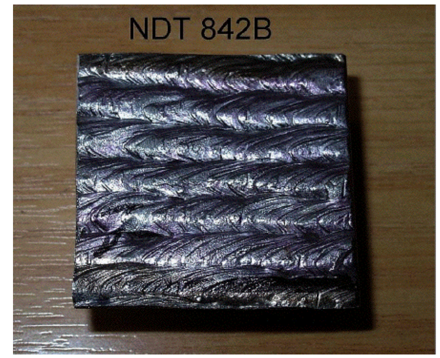
BMN NDE Demonstration Program

- Purpose: Demonstrate NDE technologies and techniques to effectively inspect BMNs
- BMN NDE mockup design criteria is similar to recommendations for upper head mockups
  - Demonstrate basic flaw detection and sizing capability
  - Assume PWSCC is the operative damage mechanism
  - Include axial, circumferential flaw orientations, OD and ID of tube
  - Include weld flaws

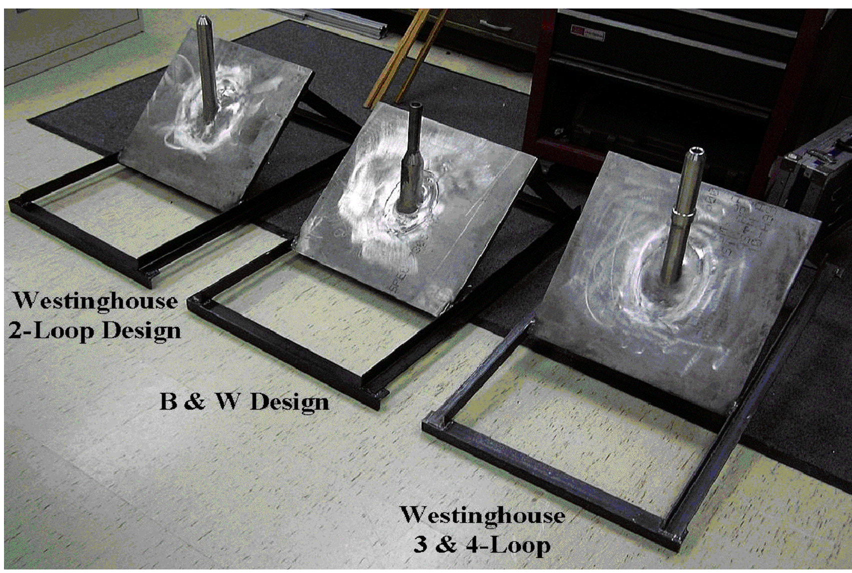
BMN Practice Mockups (Non-Blind)

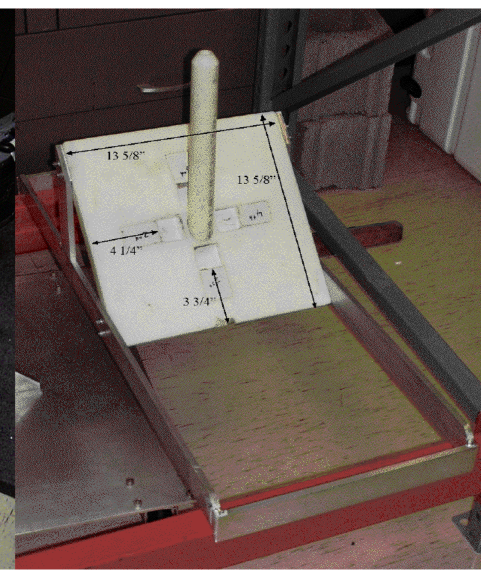
- 4 Practice Mockups
  - 2 Westinghouse 3/4-Loop
  - 2 B&W Designs
    - Tube Only
    - Tube w/repair weld
- Made available in 2003

BMN Blind Demonstration Mockups



- 7 Mockups for Volumetric and Surface Inspection
  - 6 Full-Scale Mockups
    - 2 Westinghouse 2-Loop Design
    - 2 B&W Design
    - 2 Westinghouse 3/4-Loop Design
  - 1 Mockup with coupons containing Lab-grown SCC





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Status of Demonstrations

- Demonstrations to-date
  – WesDyne
  – AREVA
  – Other inspection vendors have been invited to participate
- Techniques Demonstrated
  – Used currently available technology (best effort)
  – UT of nozzle base material (TOFD)
  – ECT of ID surface of nozzle base material
- No successful demonstrations on ECT of J-groove weld surfaces
  – Delivery system and probe design limitations
  – Will not be requested in future demonstrations due to the minimal cost benefit

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Status of Demonstrations (cont'd)

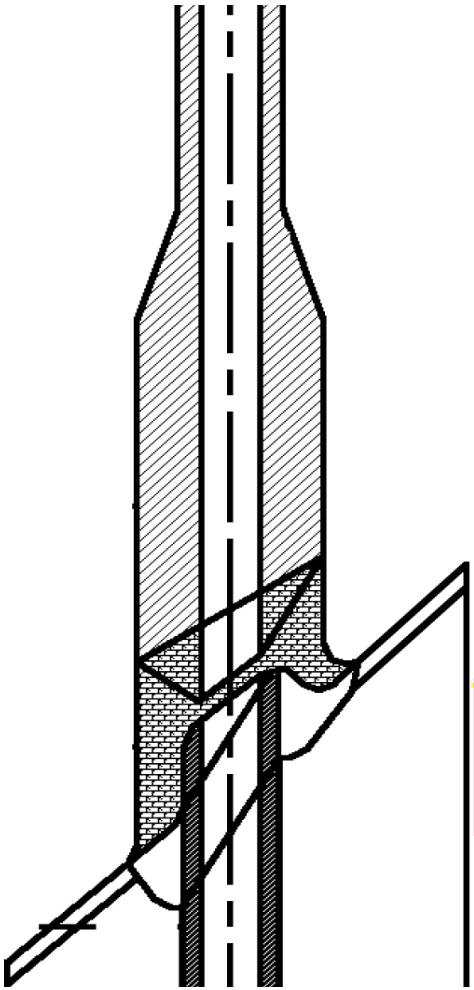
- UT Demonstration Results
  - Westinghouse 3-Loop/4-Loop design
    - 10 to 100% TW detected, none missed, no false calls
  - Westinghouse 2-Loop design
    - 5 to 100% TW detected, 23% TW missed, 1 false call
  - B&W design
    - 11 to 73% TW detected, 9 to 100% TW missed
    - False calls on UT of nozzle base material
    - Due to geometry of repair configurations, UT inspections did not cover 100% of targeted inspection area
      - BMN Management Plan will address this inspection limitation for B&W plants

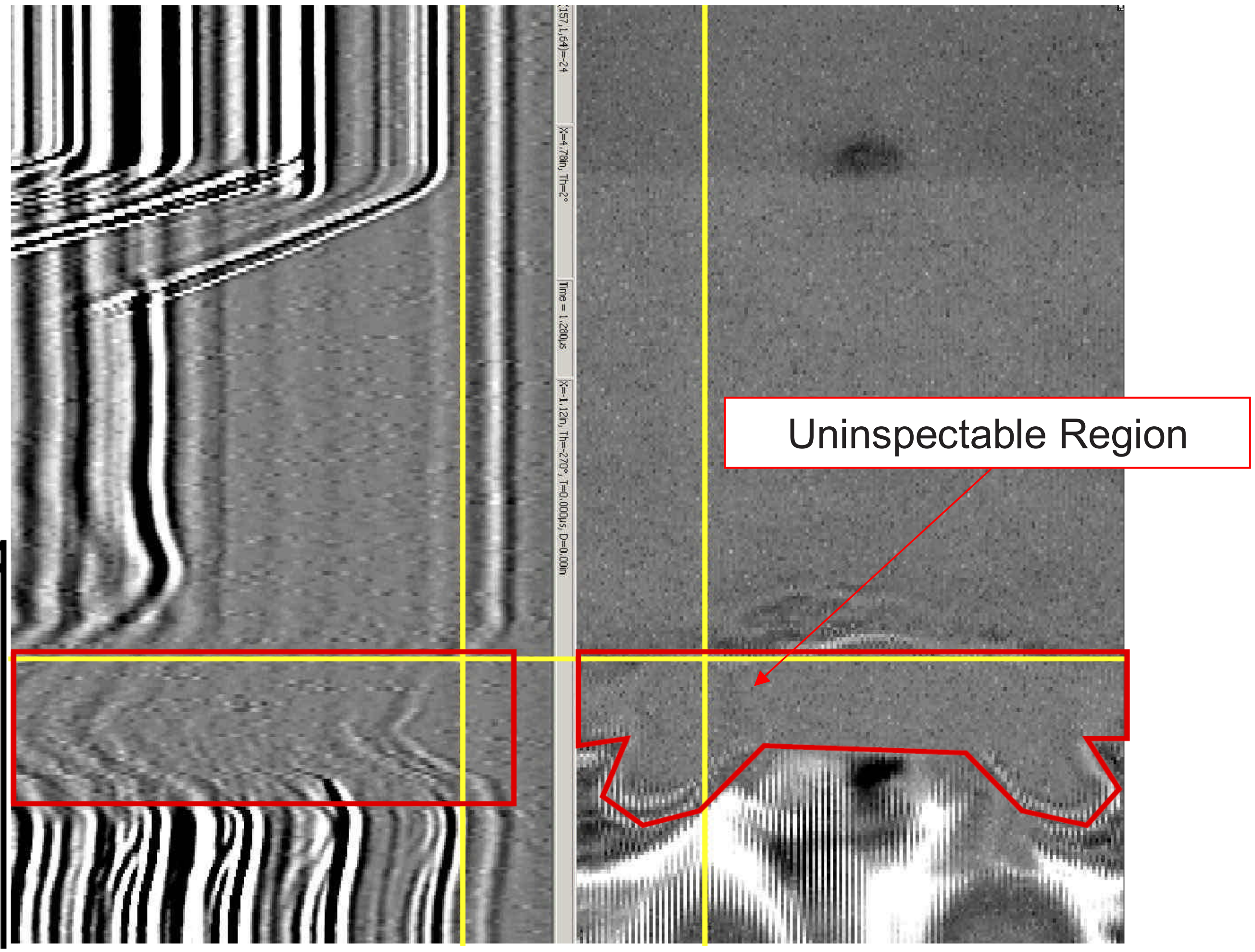
B&W BMN Uninspectable Region

TOFD UT

B-Scan

C-Scan





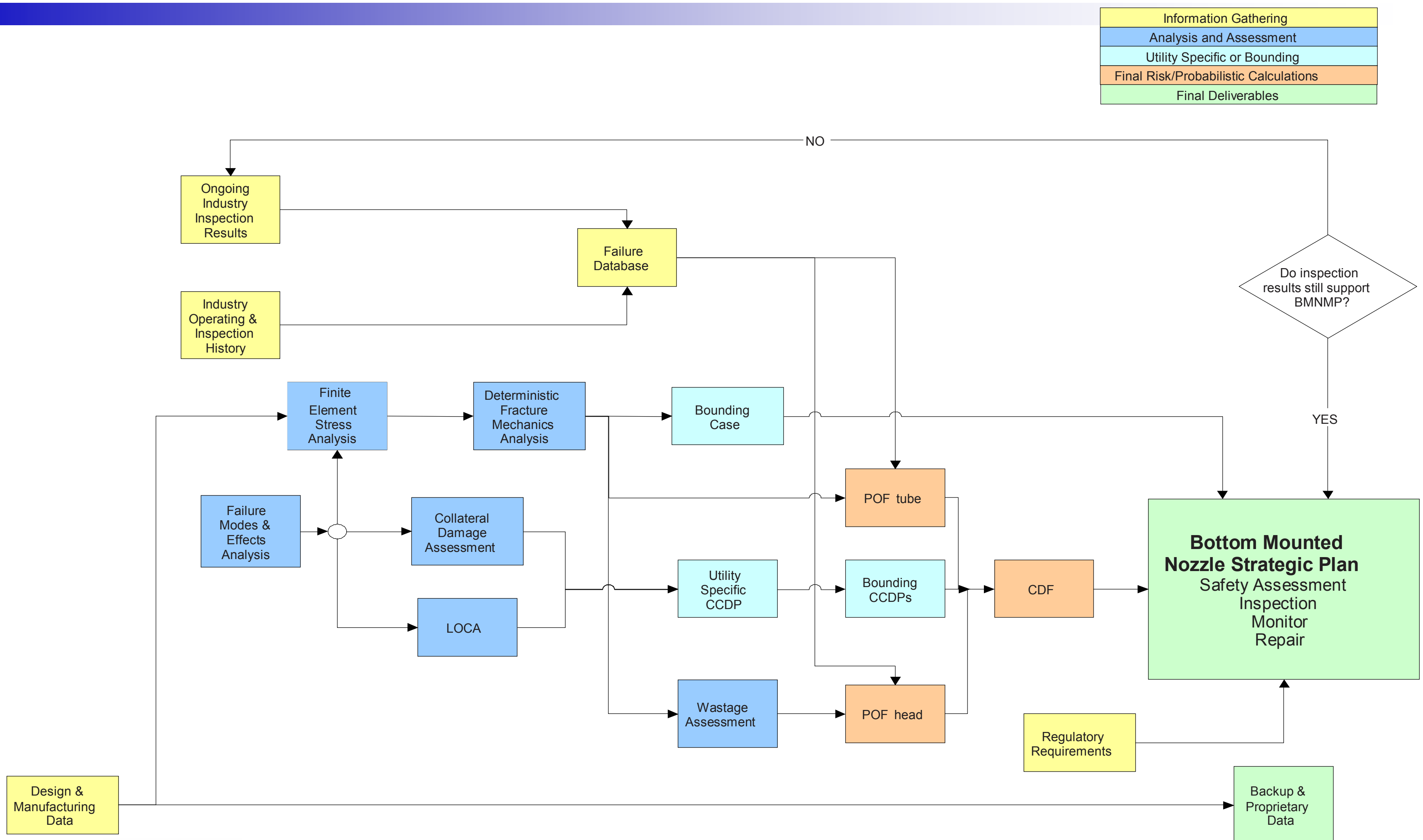
BMN Repair Attributes

Bottom Mounted Nozzle Repair Attributes

- Defined the attributes of an ideal repair
- Evaluated the current repair options with respect to ideal attributes
- Discussed the various strengths and areas for improvement of each repair technique available
- Individual utilities to determine the preferred repair techniques for their unique location

Safety Assessment of Potential Cracking in BMN

Bottom Mounted Nozzle Issue Management



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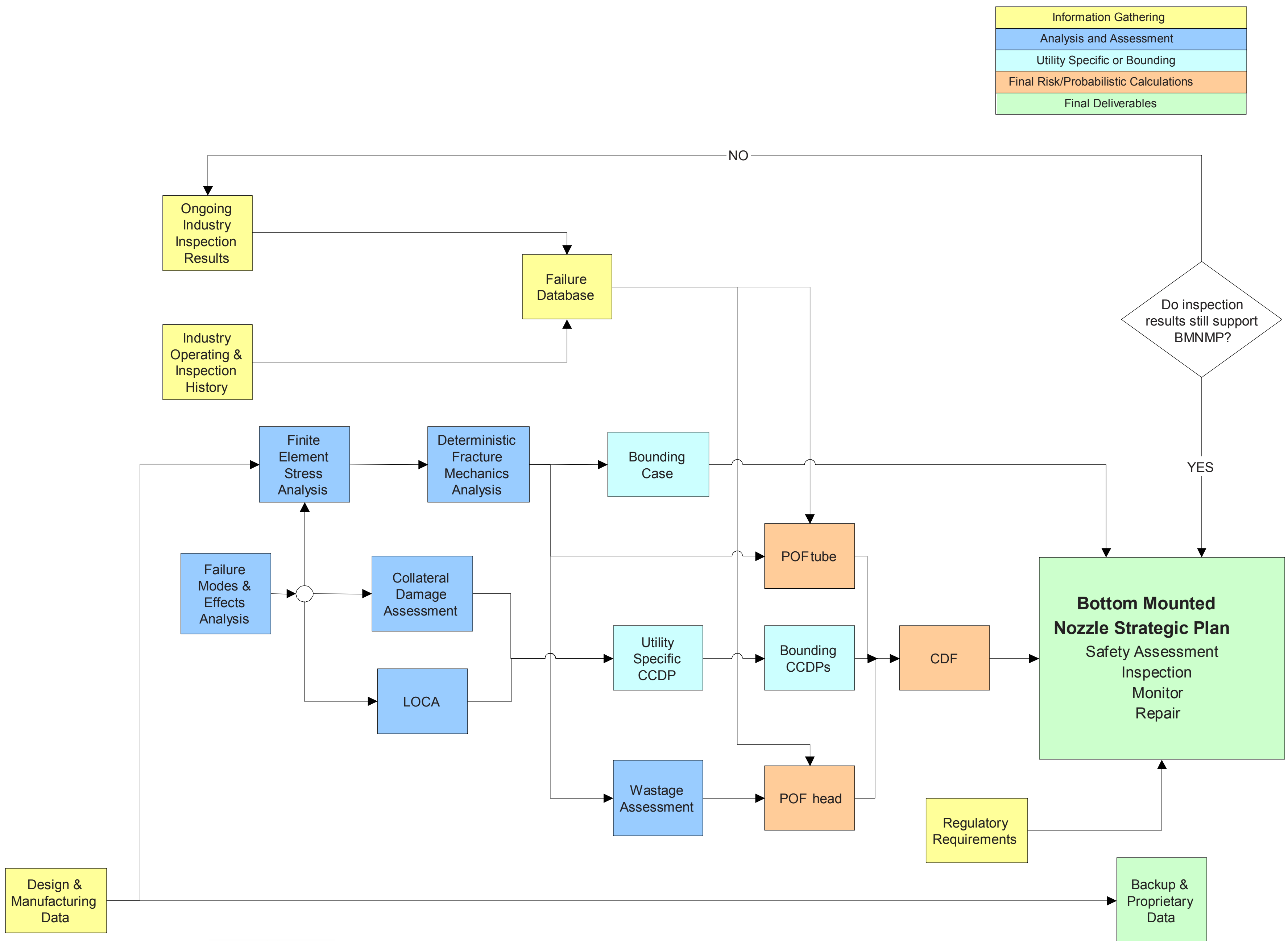
Safety Assessment Presentation Outline

- Materials and Fabrication Records
- FMEA
- WOG/B&WOG
  - Deterministic Fracture Mechanics
  - LOCA Analysis
  - Probabilistic Risk Assessment
- Collateral Damage Assessment
- Wastage Evaluation



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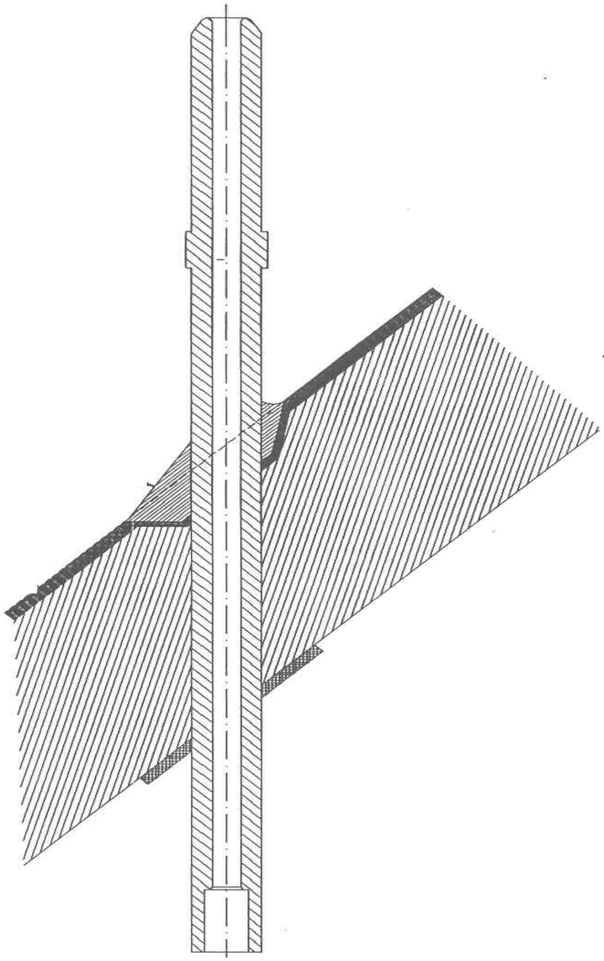
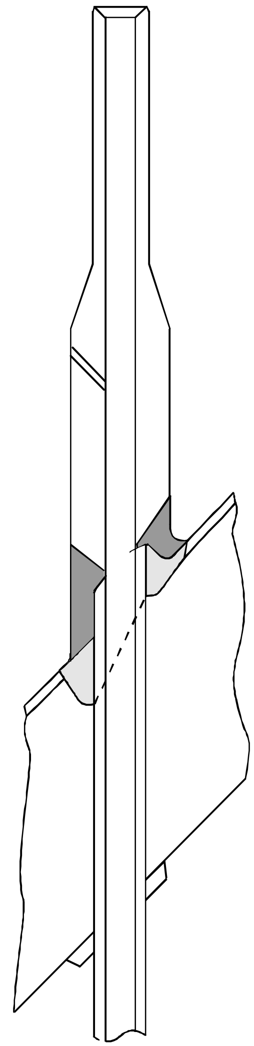
Materials and Fabrication Records

- Critical information collected and documented:
  - Outline drawings including bill of materials and configuration
  - Material certifications including heat numbers, chemistry, and mechanical properties (where available)
  - Fabrication sequence and applicable welding processes, and BMN guide tube design (where available)
- Benefits
  - Input to Safety Assessment analyses
  - Preparation for inspections and repairs – unit specific variations
  - Validation of mock-ups
  - As-fabricated information available for future analyses

Geometry: Westinghouse Design vs. B&W Design



Representative W Design

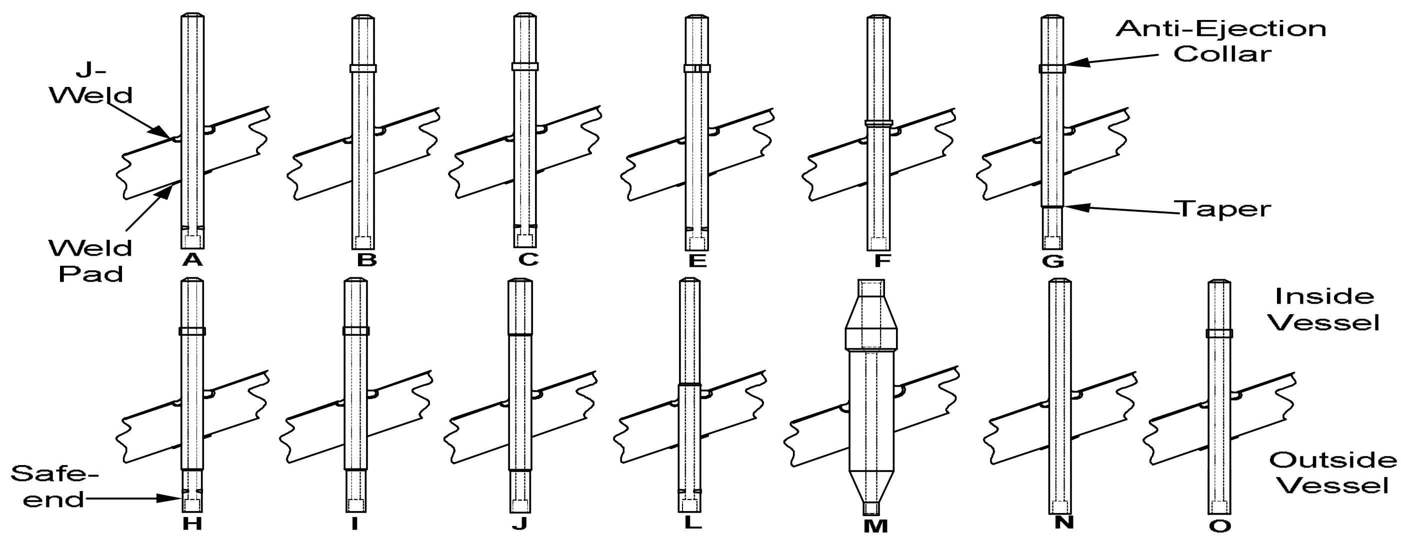


B&W Design

Variety of Westinghouse BMNs

Penetration Features		A	B	C	E	F	G	H	I	J	L	M	N	O
		Tube Configurations												
Main Tube of Uniform Diameter		●	●	●	●	●							●	●
Reduced-Diameter at Top End											●	●		
Reduced-Diameter at Bottom End							●	●	●	●		●		
Anti-ejection Feature	Machined Collar, Short		●	●			●	●	●					●
	Welded Inset Collar, 2-Piece, Short				●									
	Machined Collar, Tapered End, Short					●								
	Machined Collar, Long									●				
	Machined Collar, Tapered End, Long											●		
Safe-End		●		●	●			●			●			
Weld Deposit (Weld Pad)		●		●	●	●	●	●			●		●	●
Number of Plants*		9	1	4	1	2	2	6	14	1	7	3	2	2

* Each plant can contain more than one style

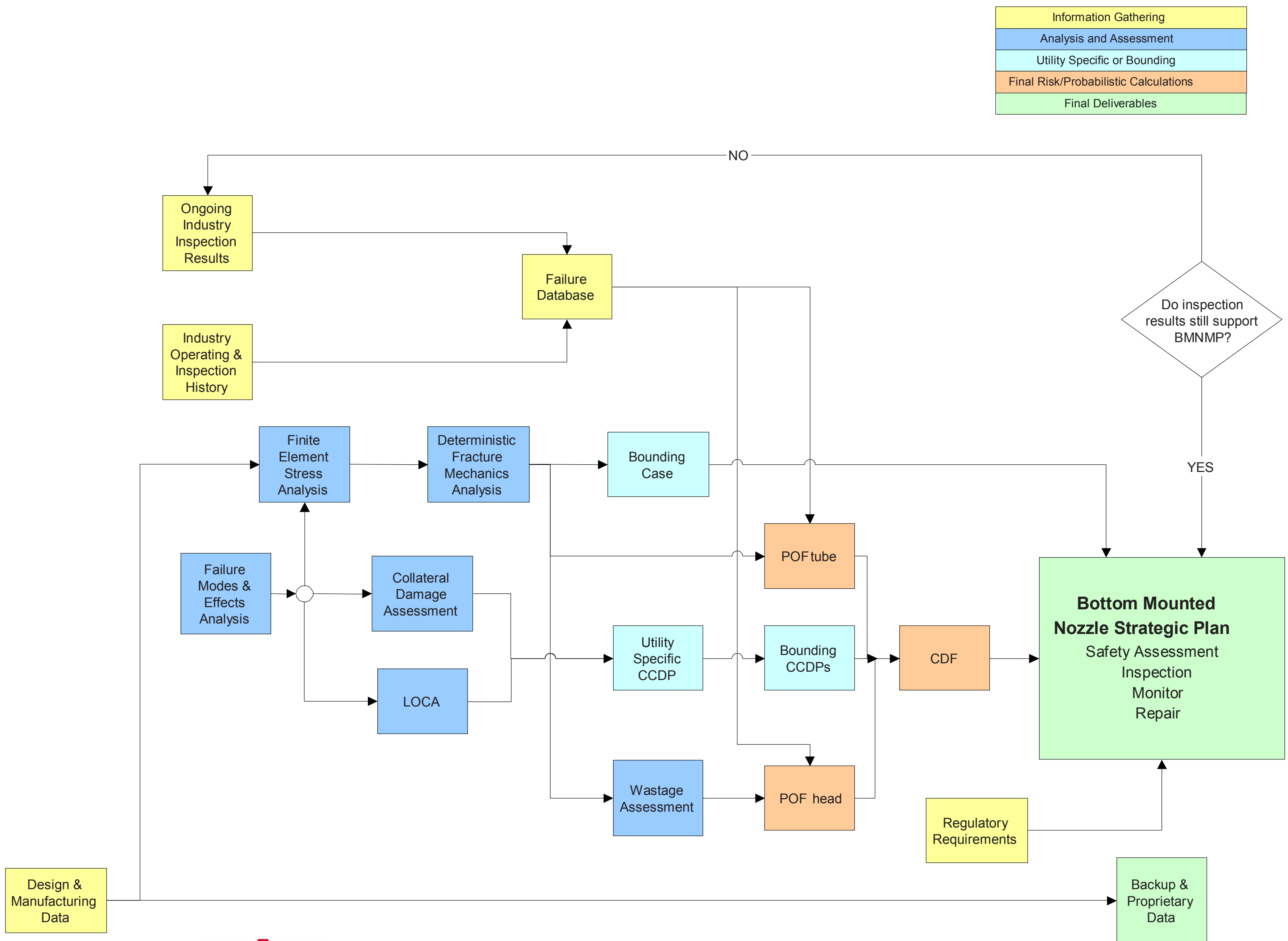


Geometry Comparison

	Tube OD	Tube Thickness	J – Groove Weld Length Parameter
B&W	1.03 in. (original) 2.0 in. (modified)	0.21 in. (original) 0.69 in. (modified)	1.10 in.
CE	3.0 in.	1.125 in.	1.99 in.
Westinghouse	1.5 in.	0.45 – 0.587 in.	0.58 – 1.67 in.

WOG and B&WOG Safety Assessment Analysis

Dave Bajumpaa, Dominion Millstone



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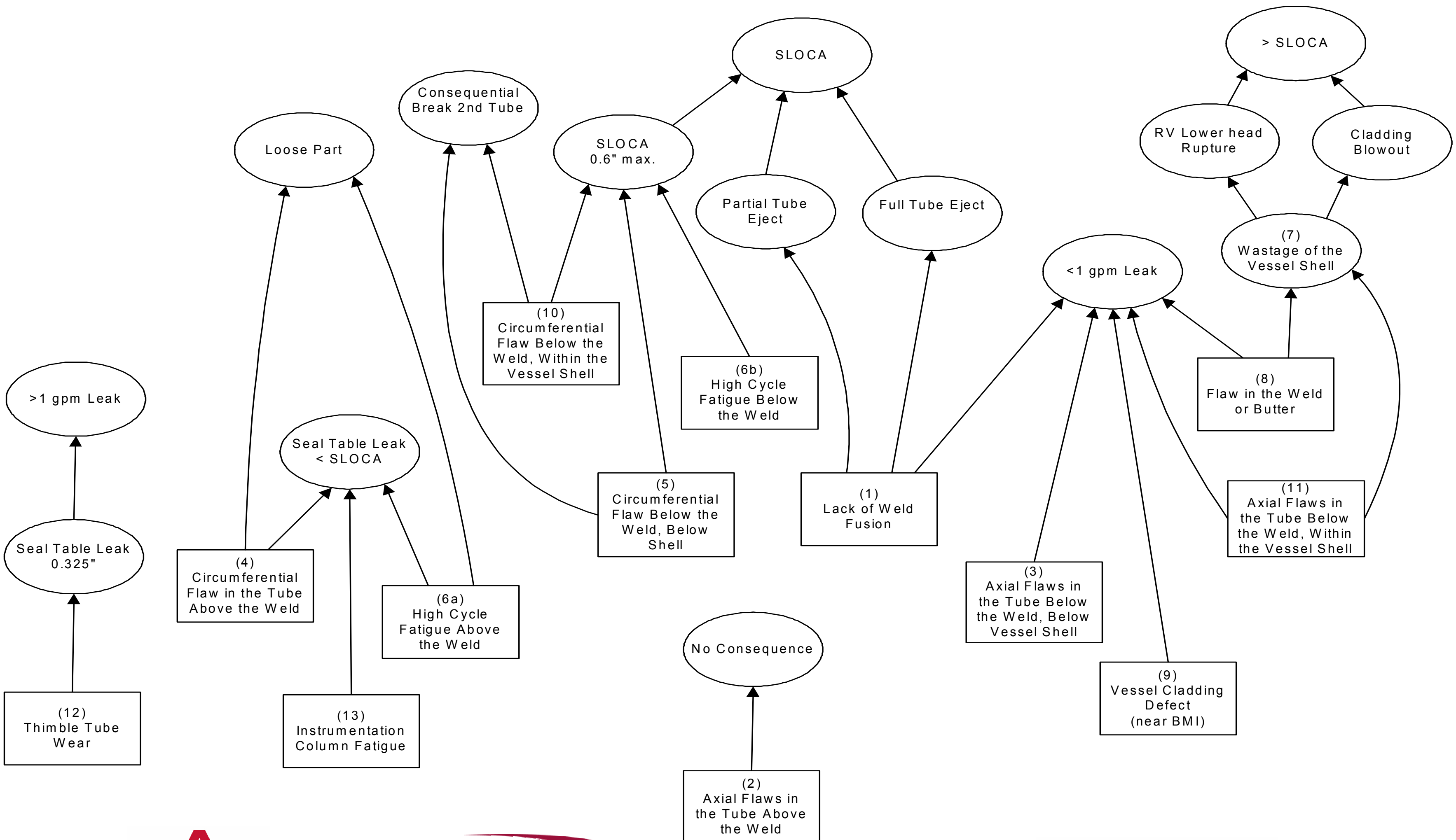
Failure Modes & Effects Analysis (FMEA)

- Team included W, AREVA, and utility representatives
- BMN subcomponents defined for consideration (BMN penetration tube, J-groove weld, thimble tube, etc.)
- List of failure mechanisms defined (fatigue, PWSCC, vibration, etc.)
- Failure modes considered (J-groove weld/lack of fusion, BMN penetration/axial flaw above the weld, etc.)
- Failure effects identified (crack, leak, loose part, jet impingement, etc.)
- Failure dispositioned based upon detectability (actionable, not-actionable)
- Output of BMN FMEA provided input required to address failure mechanisms and locations where an inspection program should focus

FMEA



SLOCA
> SLOCA
Consequential Break 2nd Tube
Loose Part
SLOCA 0.6" max.
RV Lower head Rupture
Cladding Blowout
Partial Tube Eject
Full Tube Eject
(7) Wastage of the Vessel Shell
<1 gpm Leak
(10) Circumferential Flaw Below the Weld, Within the Vessel Shell
(6b) High Cycle Fatigue Below the Weld
(8) Flaw in the Weld or Butter
>1 gpm Leak
Seal Table Leak < SLOCA
(5) Circumferential Flaw Below the Weld, Below Shell
(1) Lack of Weld Fusion
(11) Axial Flaws in the Tube Below the Weld, Within the Vessel Shell
Seal Table Leak 0.325"
(4) Circumferential Flaw in the Tube Above the Weld
(6a) High Cycle Fatigue Above the Weld
(3) Axial Flaws in the Tube Below the Weld, Below Vessel Shell
No Consequence
(9) Vessel Cladding Defect (near BMI)
(12) Thimble Tube Wear
(13) Instrumentation Column Fatigue
(2) Axial Flaws in the Tube Above the Weld

FMEA: Failure Modes Examined

- Axial and Circumferential flaws in the BMN tube above the J-groove weld
- Axial and Circumferential flaws in the BMN tube at or below the J-groove weld
  - within the wall thickness of the reactor vessel
  - outside the reactor vessel
- Vessel cladding defects
- Wastage (consequence of other failure modes)
- Lack of fusion in the tube to bottom vessel shell weld region
- Flaws in the J-groove weld or butter
- BMN penetration wear from the thimble tube or ICDA
- Instrumentation column or instrumentation guide tube fatigue
- Flow induced and RCP vibration on J-groove weld/BMN penetration

- Ejection of BMN due to complete lack of fusion not considered credible

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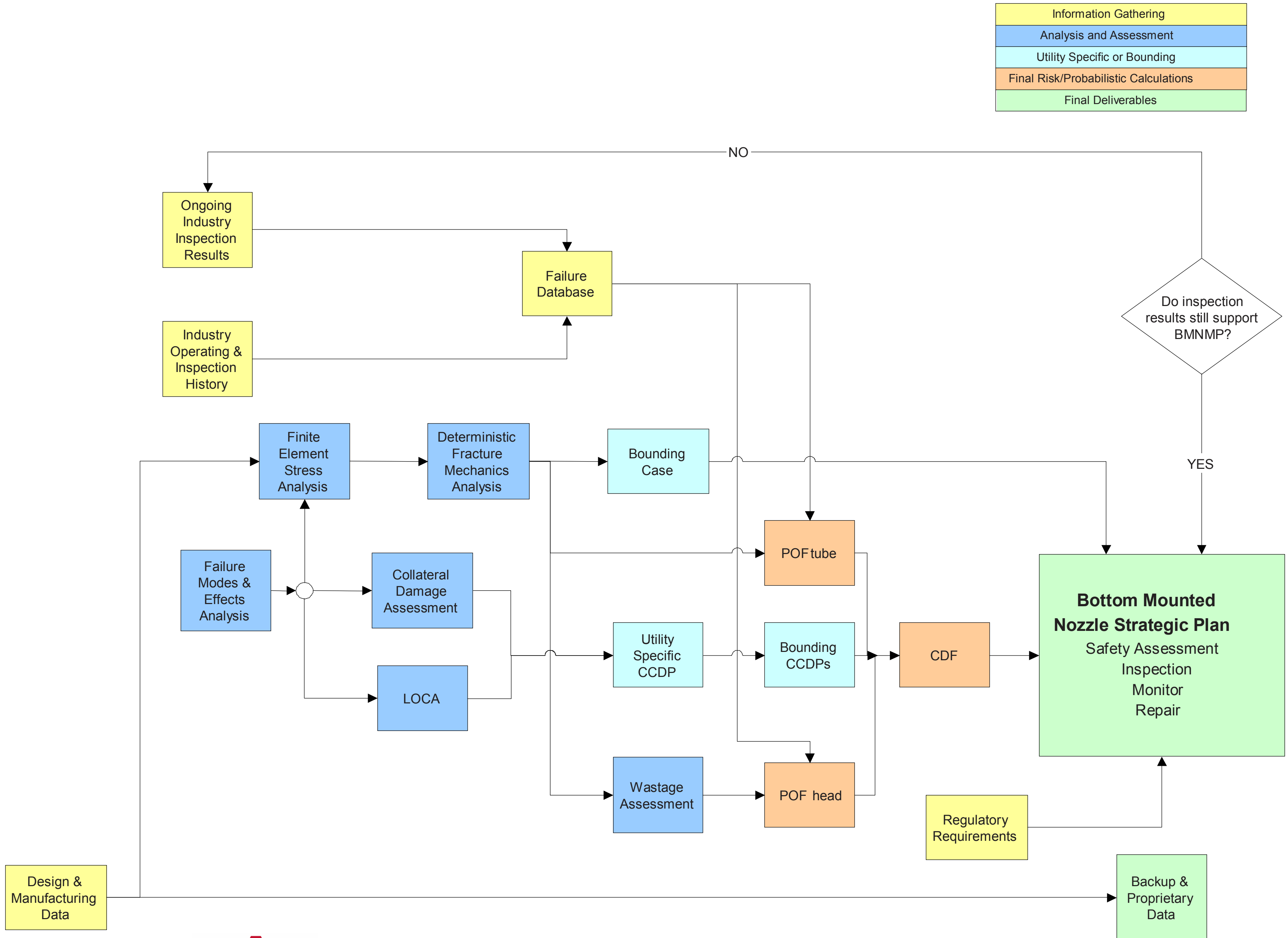

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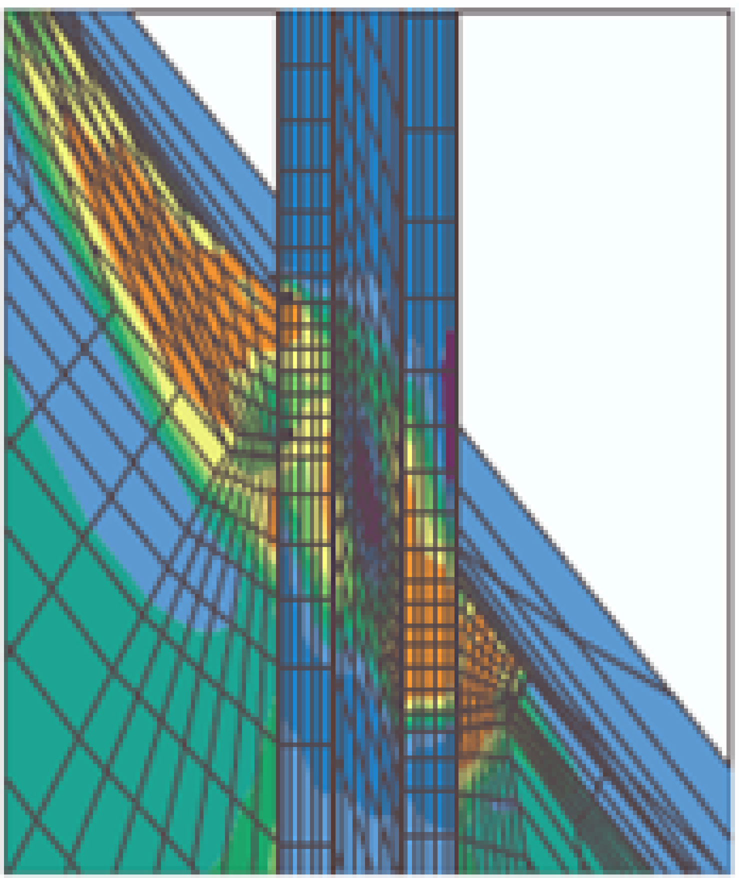
Deterministic Fracture Mechanics Process Overview

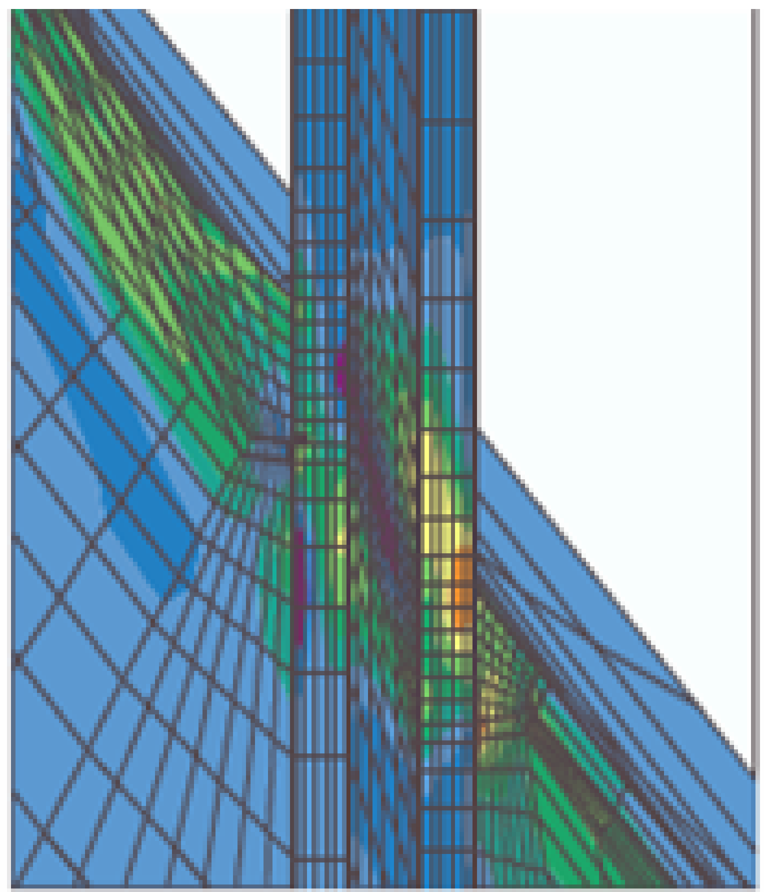
- 3-D Elastic Plastic FEA completed on five bounding geometries
  - 1 CE
  - 3 Westinghouse
  - 1 B&W
- Obtained stresses and selected flaw locations to be analyzed
- Evaluated crack growth mechanisms
  - Considered PWSCC, Fatigue Crack Growth
- Fracture mechanics methodology
  - Calculated acceptable flaw sizes
  - Evaluated part through-wall flaw growth
  - Evaluated through-wall flaw growth

Finite Element Analysis

Hoop Stresses



Axial Stresses



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Finite Element Analysis Key Results

- High stresses are localized around the area of the J-groove weld
- If a flaw were to initiate, it is expected to be axial in nature due to the hoop stresses
- An axial flaw is not expected to propagate to critical flaw sizes

Critical Flaw Size – Axial Crack

- Critical Thru-Wall Flaw Length
  - CE plant: 34.2”
  - W plants : 13.2”
  - B&W plants: 4.77”

- Differences in flaw length are primarily due to nozzle dimensions

- No credit taken for structural reinforcement of the bore

Geometry Comparison

	Tube OD	Tube Thickness	J – Groove Weld Length Parameter
B&W	1.03 in. (original) 2.0 in. (modified)	0.21 in. (original) 0.69 in. (modified)	1.10 in.
CE	3.0 in.	1.125 in.	1.99 in.
Westinghouse	1.5 in.	0.45 – 0.587 in.	0.58 – 1.67 in.

Critical Flaw Size - Circumferential Crack

- Critical Thru-Wall Flaw Size
  - CE plant: 323º
  - W plant : 320º
  - B&W plant: 339º

Summary of Deterministic Fracture Mechanics Analysis – W/CE

- Postulate undetected flaw (inside surface circ flaw, 0.062 inch long, Aspect Ratio = 3)
  - Flaw growth to through-wall (leakage)
    - CE: 35+ EFPY
    - W: 12.3 EFPY
  - Through-wall flaw growth to critical length
    - CE: 13.8 EFPY
    - W: 7.8 EFPY
  - Total time from initial flaw size to critical length
    - CE: 48.8+ EFPY
    - W: 20.1 EFPY

Summary of Deterministic Fracture Mechanics Analysis – B&W

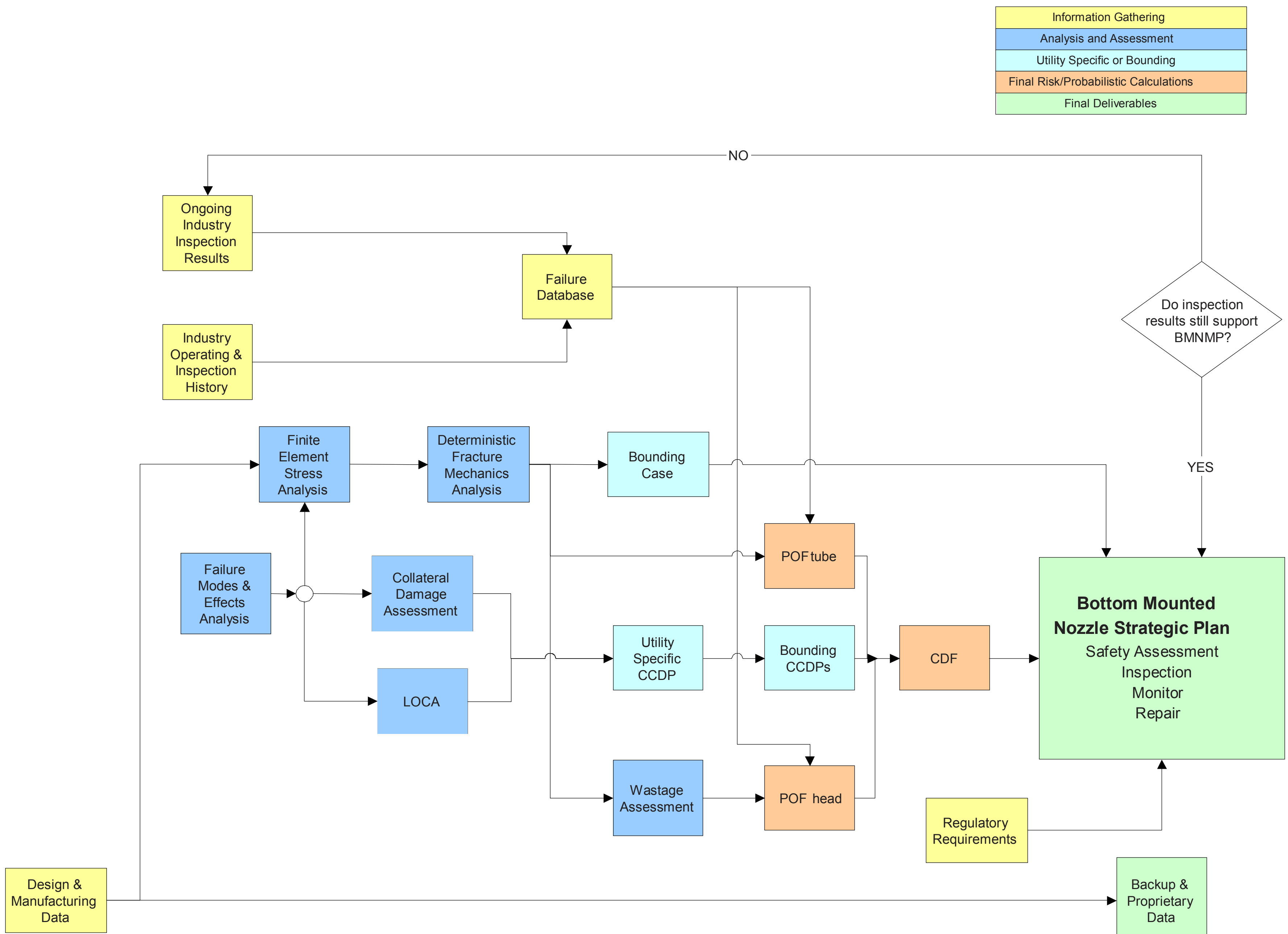
- Postulate undetected 0.023 inch deep by 0.2 inch long flaw
  - Flaw growth to through-wall (leakage)
    - Circ: Inside surface flaws on uphill side limiting for leakage
      - Uphill: 15.3 EFPY to grow through thickness
      - Downhill: 20.1 EFPY to grow through thickness
  - Through-wall growth to critical length
    - Circ: Uphill

      18.6 EFPY to grow to critical flaw size

      33.9 EFPY total time to critical flaw
    - Circ: Downhill

      5.0 EFPY to grow to critical flaw size

      25.1 EFPY total time to critical flaw



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LOCA Analysis

- Small break LOCA Analyses performed for each plant type
  - 2 B&W plant types (Lowered Loop and Raised Loop)
  - 7 W/CE plant types (2, 3, 4 loop, High Pressure (HP) & Low Pressure (LP) ECCS; CE)
- Methodology used:
  - B&WOG work completed using Appendix K
  - WOG work completed using Appendix K with the following realistic assumptions (typically used to support PRA):
    - ANS-5.1 1979 decay heat with 2σ uncertainty
    - Fauske HEM Break Flow Model
    - Credit for the steam generator power operated relief valves
    - Only one train of ECCS Injection is available
    - Operator induced cooldown of the RCS at 45 minutes into the transient consistent with emergency operating procedure guidance

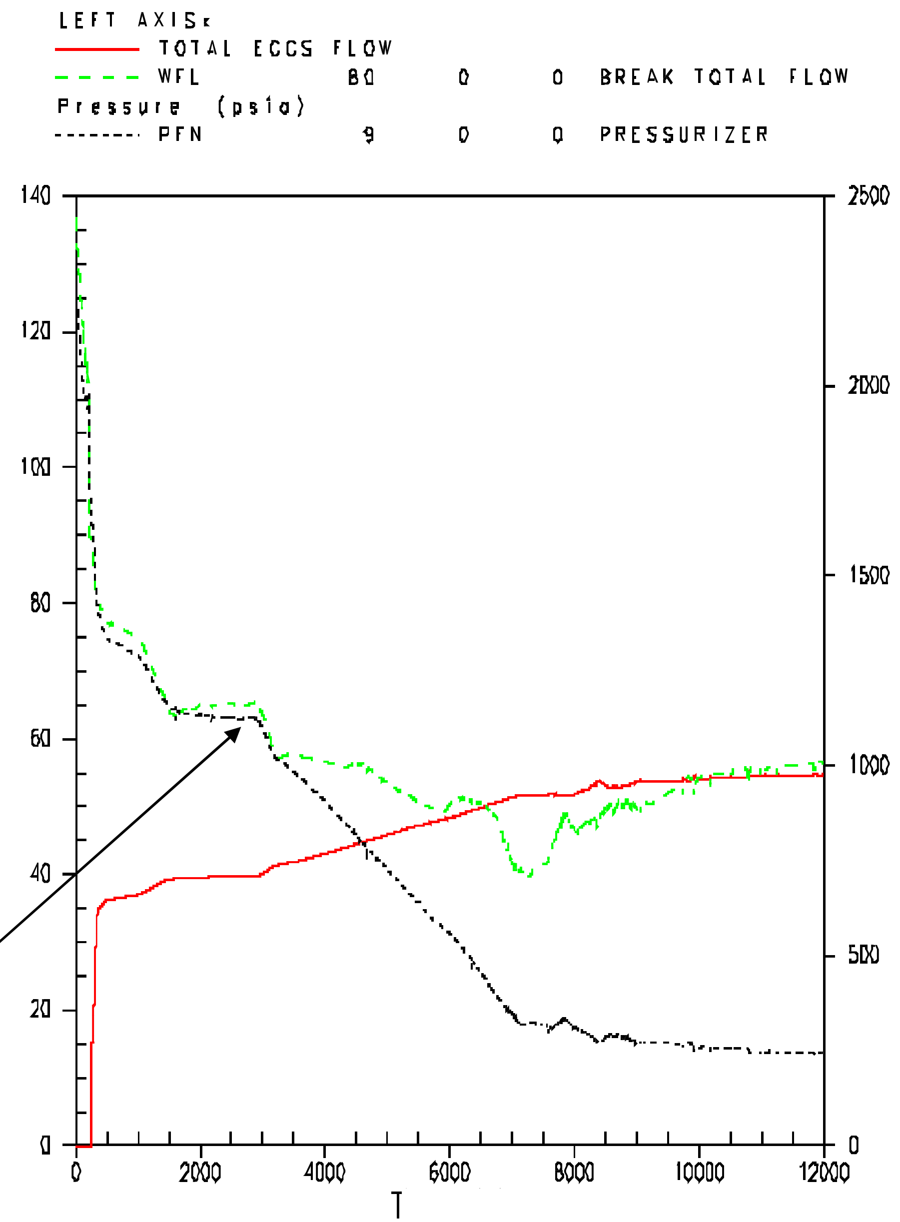
LOCA Analysis (cont'd)

- Breaks analyzed:
  - B&WOG considered break sizes of the inside diameter and the outside diameter (1.03" equivalent diameter with the incore detector ejected)
  - WOG evaluated each plant type to determine equivalent break size that can be mitigated with the ECCS with operator action
    - Results range from 1" to 1.3" diameter
    - Core uncovery used as acceptance criteria
- Results used to estimate plant-specific CCDPs for BMN break

WOG Small Break LOCA Analyses Plant Groupings

4-Loop (HP)	3-Loop (HP)	2-Loop	CE System 80
Braidwood 1&2	VC Summer	Ginna	Palo Verde 1,2 & 3
Byron 1&2	Shearon Harris	Point Beach 1&2	
Callaway	Farley 1&2	Prairie Island 1&2	
Comanche Peak 1&2	North Anna 1&2	Kewaunee	
DC Cook 1&2			
Diablo Canyon 1&2	**3-Loop (LP)**		
McGuire 1&2	Beaver Valley 1&2		
Salem 1&2	Surry 1&2		
Seabrook	Robinson		
Sequoyah	Turkey Point 3&4		
Vogtle 1&2			
Wolf Creek			
Watts Bar			
4-Loop (LP)			
Indian Point 2&3			
4-Loop (NEW)			
South Texas 1&2			

WOG Representative BMN LOCA Transient



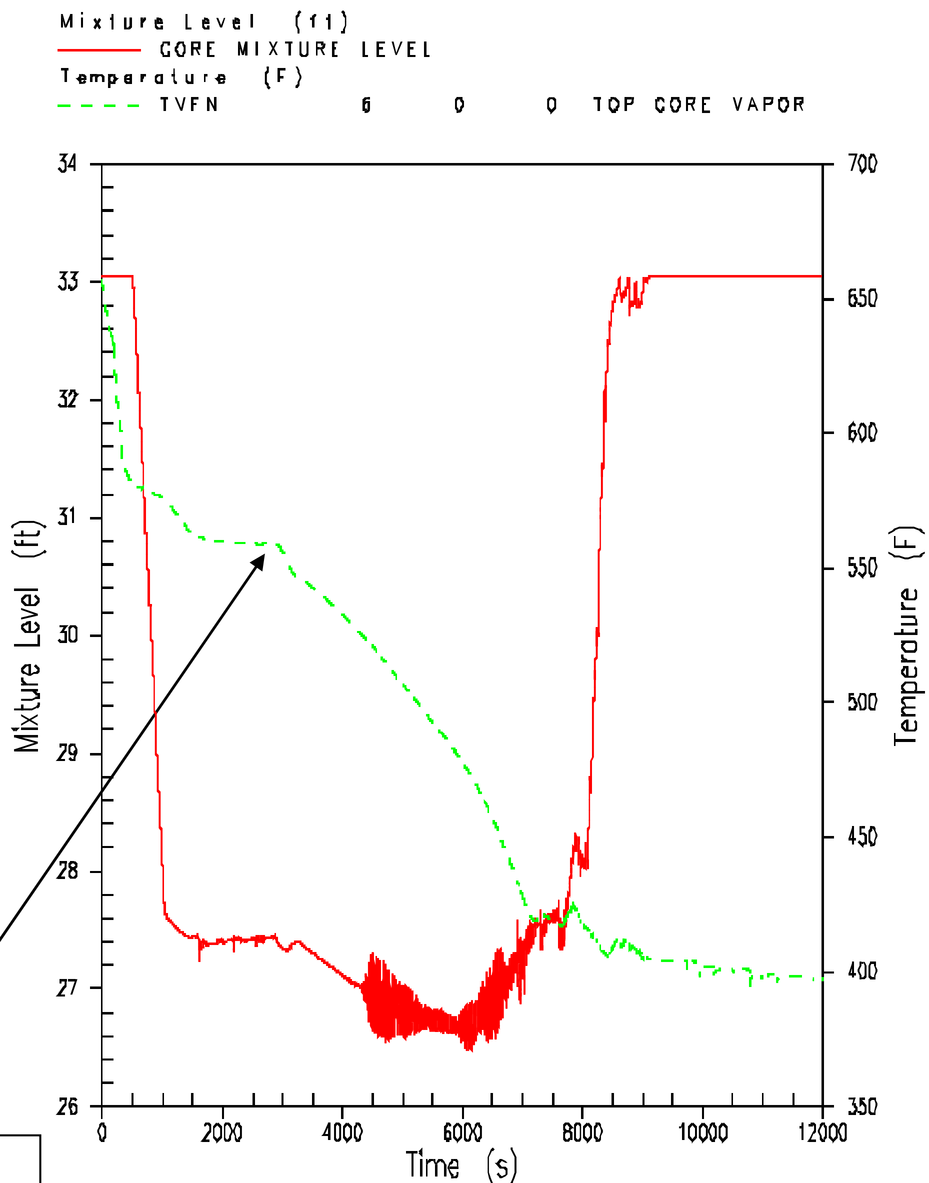
ECCS Flow
lbm/sec

Pressure
psia

Time
sec

Operator action to cooldown at 2,700 sec.

WOG Representative BMN LOCA Transient



Mixture Level
ft

Temperature
(F)

Time
sec

Operator action to cooldown at 2,700 sec.

WOG Small Break LOCA Results

Summary of Thermal Hydraulic Analyses							
Plant Group	**W 4-Loop (HP)**	**W 4-Loop (LP)**	**W 4-Loop (New)**	**W 3-Loop (HP)**	**W 3-Loop (LP)**	**W 2-Loop**	**CE System 80**
Equivalent Break Size (inches in diameter)	1.25	1.25	1.0	1.1	1.0	1.0	1.3

B&WOG LOCA Analysis Results

- AREVA performed two small break LOCA analyses for B&W 177 Fuel Assembly (FA) plants:
  - Lowered Loop (ONS-1, ONS-2, ONS-3, CR-3, TMI-1, and ANO-1)
  - Raised-Loop (Davis-Besse)
- Each plant type was evaluated for a break area of:
  - The inside diameter of the BMN tube with the incore detector ejected (0.0021 ft^2)
  - The reactor vessel BMN bore diameter with the incore detector ejected and nozzle not obstructing the break flow area (0.0060 ft^2)
- Work completed using an Appendix K methodology

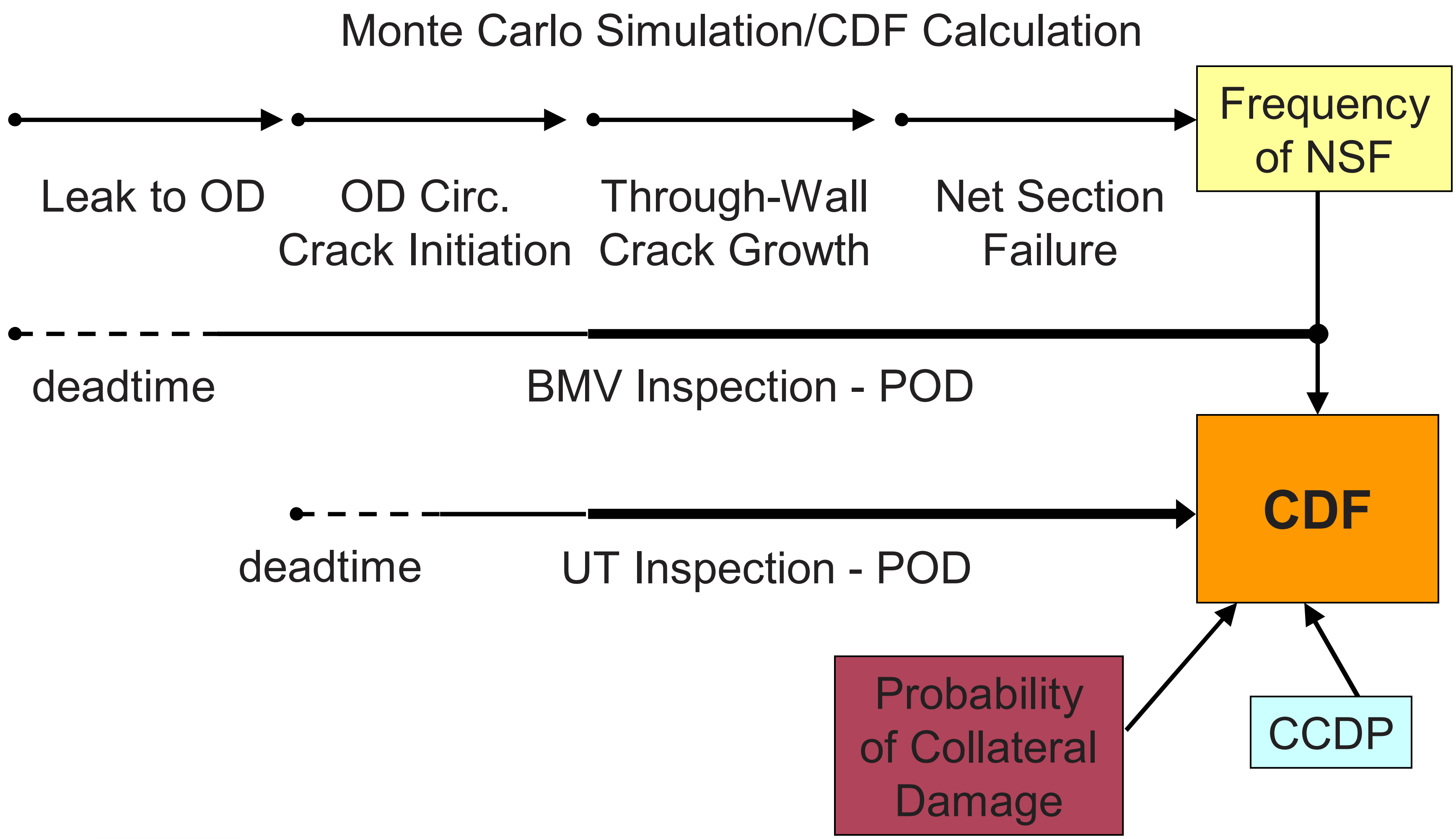
B&WOG LOCA Analysis Conclusions

- Generic 0.0021-ft^2 break
  - No core uncovering for either plant design
  - Minimum RCS level remained within the hot legs
- Generic 0.0060-ft^2 break
  - 177 FA raised loop plant
    - No core uncovering
    - Minimum RV level was ~2 ft above top of the heated core region
  - 177 FA lowered loop plants
    - Some core uncovering
    - Bounding peak cladding temperature (PCT) of 1346°F
      - 10 CFR 50.46 criteria for PCT is 2200°F
    - Minimum RV level was ~4 ft below the top of the heated core region

B&WOG LOCA Evaluation Conclusions (cont'd)

- Operator initiated steam generator cooldown improves ECCS delivery. SG depressurization also creates primary side condensate that augments the HPI flow. These contributions increase the minimum core mixture level (decrease PCT) for the largest bottom mounted nozzle break.
- Any break of a single bottom mounted nozzle at any B&W operating (177 FA) plant would be mitigated by the ECCS systems and allow for safe shutdown preventing fuel damage.

Timeline of Progression of Crack from Initiation to Core Damage for an OD-initiated flaw



Change in Core Damage Frequency

- B&WOG and WOG performed independent PFM analyses of BMNs for various plant types
  - B&W plant
  - W 2, 3, and 4-loop plus CE System 80
- Resulting failure probabilities used in conjunction with CCDPs to determine ΔCDF for BMN LOCA:

$$\Delta CDF = CCDP \times \boxed{\text{Frequency of NSF}}$$

WOG PFM Approach

- Used Westinghouse PFM methodology previously reviewed and approved by NRC
  - Growth of existing circ. flaw for piping RI-ISI
  - Initiation and Growth of axial flaw for top head nozzles
  - Use stress intensity factor (SIF) correlation with a/t and break lengths from WOG Structural Integrity Evaluation

WOG PFM Approach (cont'd)

- Changes made to methodology specifically for BMN evaluations
  - Benchmarked for small axial flaw leak at STP Unit 1
  - Initial length to depth ratios uniformly sampled from 2, 3, 6, 10, and 20
  - SIFs and critical crack sizes taken directly from deterministic analyses
  - Flaw initiation time not considered since fabrication flaw conservatively assumed
  - Effects of Inspections not specifically considered – frequency of NSF conservatively bounded by 1 GPM leak detection case
- Additional Sensitivity Studies completed to quantify
  - The effects of increasing probability of fabrication flaw
  - The effects of PWSCC initiation with time
  - The effects of volumetric inspections

B&WOG PFM Approach

- Used top head Weibull distribution of time to cracking or leakage, corrected to BMN operating temperature
- Performed Monte Carlo simulation of:
  - Time to leak or crack
  - Through wall crack growth
  - Net section failure of nozzle
  - BMV inspection – POD
  - UT inspection – POD
- Inspection periodicity varied to examine inspection strategies
- Sensitivity studies were completed on a variety of modeling parameters

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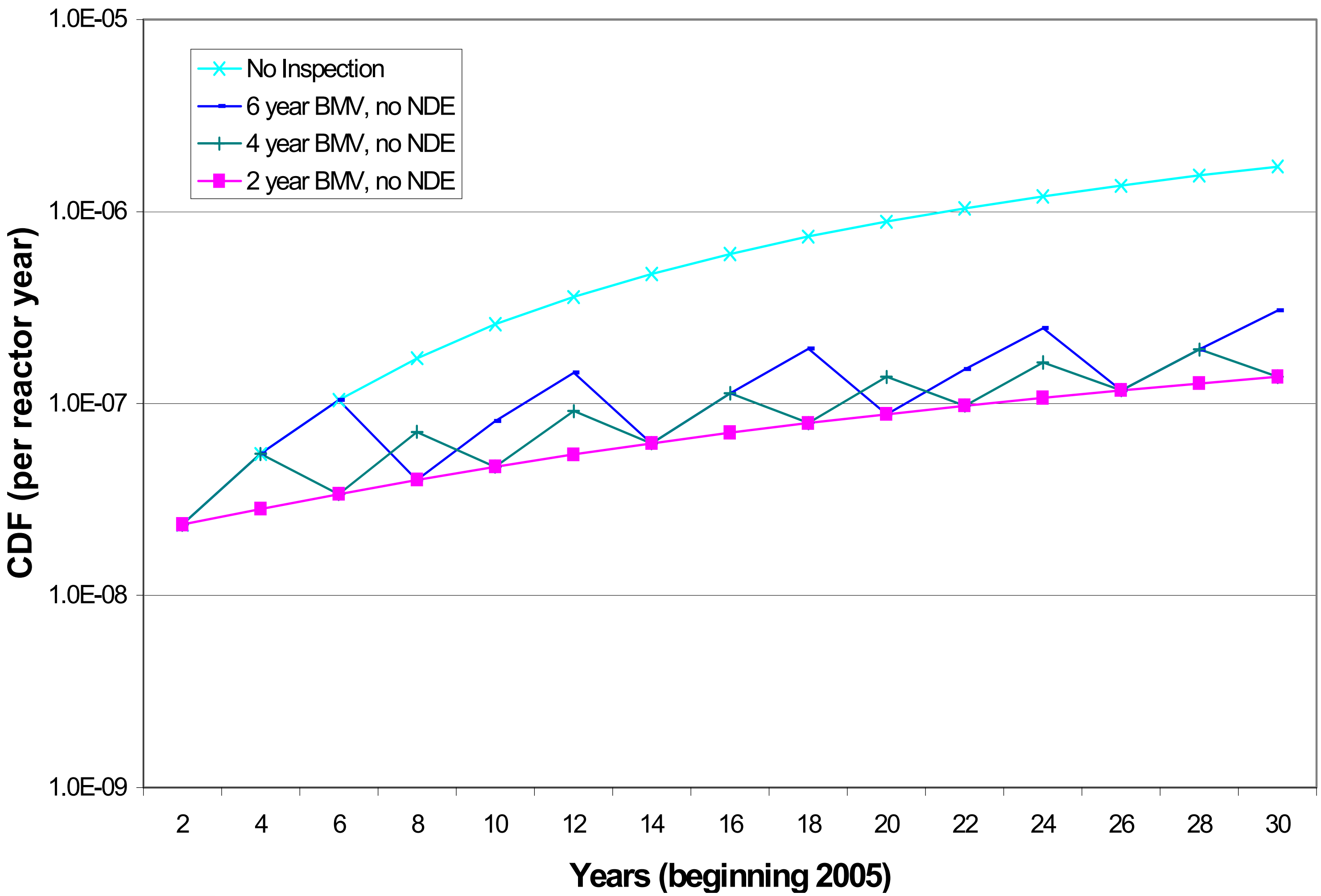
WOG Risk Evaluation Results

Summary of Risk Calculations				
Calculated Values for BMI LOCA	**Westinghouse Generic 2-Loop**	**Westinghouse Generic 3-Loop**	**Westinghouse Generic 4-Loop**	**CE – Palo Verde**
BMI CCDP	1.91E-02	2.62E-02	3.82E-02	3.82E-02
BMI IE (/yr)	6.08E-07[(2)]	6.08E-07[(2)]	6.08E-07[(2)]	1.93E-07
ΔCDF[(1)] (/yr)	1.16E-08	1.59E-08	2.32E-08	7.37E-09

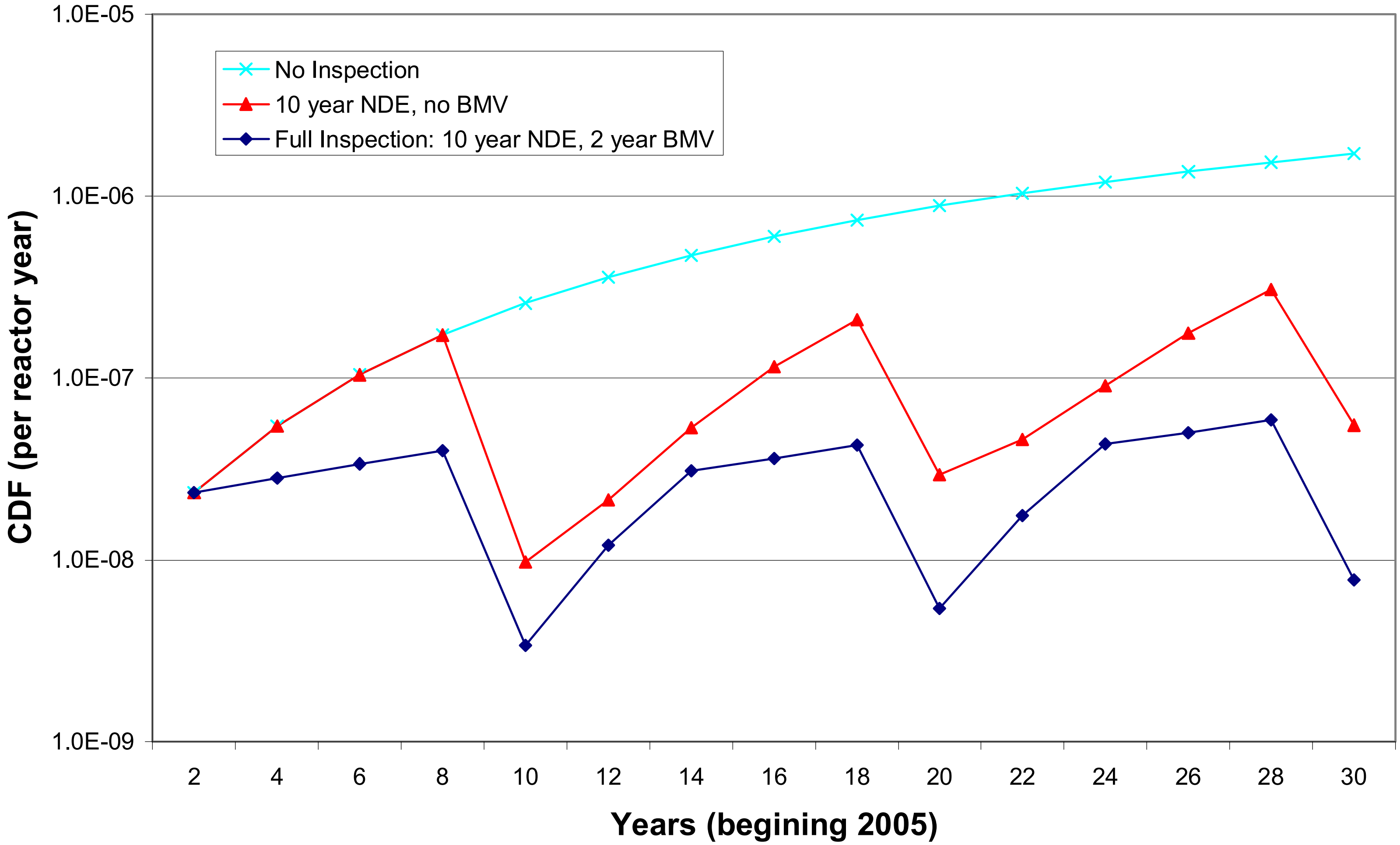
Notes:

1. ΔCDF (BMI LOCA) = BMI CCDP * BMI IE
2. The BMI IE frequency used for Generic Westinghouse plants is the IE frequency calculated for plants with the same BMI geometry and maximum stresses as ST1 since this value bounds all Westinghouse plant designs.

B&WOG CDF Due to BMN LOCA Inspection Sensitivity for BMVs



B&WOG CDF Due to BMN LOCA Inspection Sensitivity for UT +/- BMVs



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Summary WOG Risk Assessment

- Integrity Evaluations for 3 W Plants and 1 CE Plant completed
- PFM Evaluation completed
- LOCA evaluations completed for input to CCDP
- CCDP calculations completed
- Change in CDF for new BMN event is negligible (< 1E-06)
- Safety Assessment Results will be factored into inspection guidelines

Summary B&WOG Risk Assessment

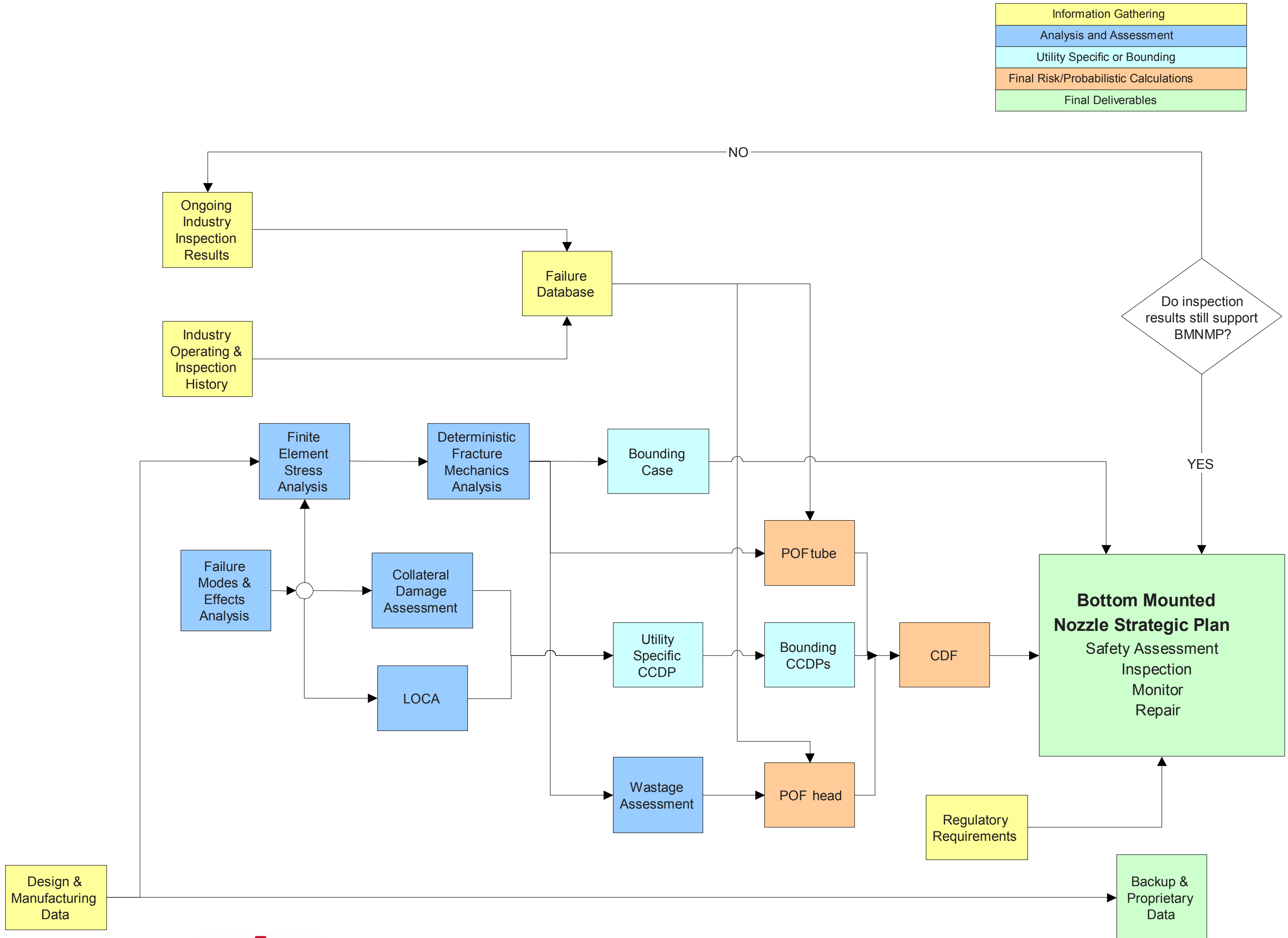
- Results based on ID and OD circumferential flaws, and assumption that CRDM experience is applicable for BMNs
- Risk assessment which considers B&W plant-specific circumstances and age-related degradation has been completed
- Change in CDF for new BMN event is negligible (< 1E-06) provided that periodic inspections are performed

B&WOG Collateral Damage Assessment

- Prepared a deterministic collateral damage assessment that calculated loads on nearby BMNs due to failure of a single BMN considering:
  - Asymmetric cavity pressure effects
  - Pipe whip
  - Direct jet impingement
  - RV insulation frame movement
- The critical circ. flaw size of an adjacent flawed nozzle at the inside surface of the RV is 110 degrees
- Results were used in a probabilistic assessment of BMN collateral damage
- Probabilistic assessment shows that BMN collateral damage is not a significant contributor to CDF

BMN Wastage Evaluation

Glenn White, Dominion Engineering



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Westinghouse

Bottom Head Wastage Evaluation
Background and Status

- Utilized top head wastage evaluations as a starting point
- Reviewed relevant plant experience for inverted nozzles
- The probabilistic model was extended to the entire head including modeling of leak initiation based on a Weibull distribution fit to small-bore J-groove nozzle data
- Draft Report in final review, plan to publish end of October

Wastage Process Modeling
Probabilistic Model Description

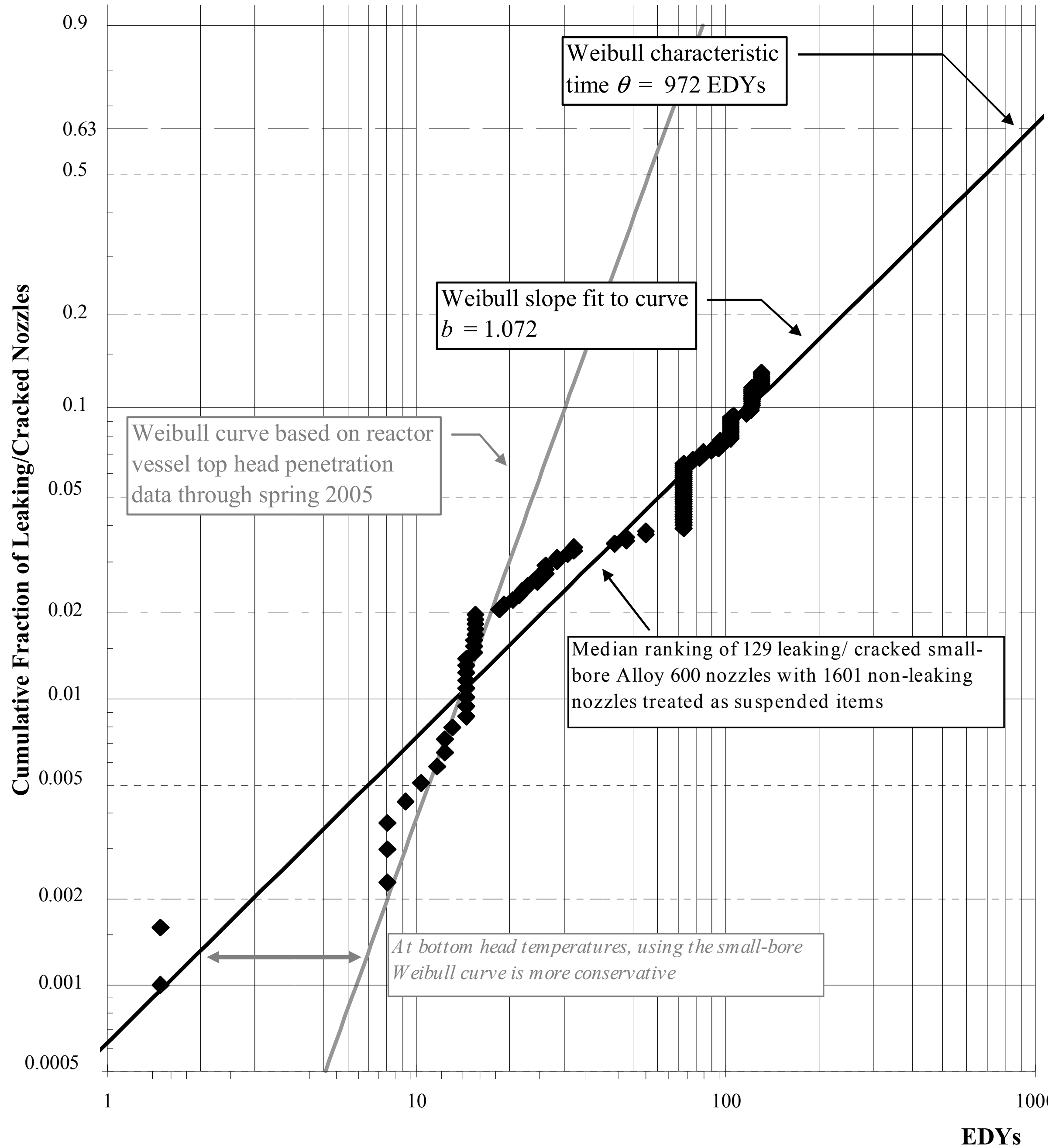
- The probabilistic model includes the following steps :
  – Possibility of initiation of a leak in any BMN
  – Growth of axial nozzle crack
  – Increase in leak rate with distance below bottom of weld
  – Wastage rate as function of leak rate
  – Conservatively assumed area of unsupported cladding based on integrated wastage rate over time
  – POD of BMV examination to detect deposits
  – Detection via unidentified leak rate > 1.0 gpm
- 58 nozzles all with the same susceptibility to leakage based on common T_{cold} temperature
- 2 & 1.5 year cycle with capacity factor of 0.97 assumed

Wastage Process Modeling
Probabilistic Model Description (cont'd)

- The wide bounds in the statistical inputs are designed to capture the process uncertainties
- The statistically distributed inputs include:
  - Weibull scaling time and slope
  - Crack growth rate (same MRP-55 inputs as for top head)
  - Leak rate as function of crack size
  - Wastage rate as function of leak rate
  - BMV POD
- Nozzles found to be leaking are assumed to be repaired and not subject to leakage again

Wastage Process Modeling

Small-Bore Nozzle Weibull



Supporting Calculations
Maximum Cladding Unsupported Area

- Maximum allowable wastage based on ORNL cladding burst test results and modeling (see figure)
- Key input values
  - Critical Pressure = 2.5 ksi
  - t_{clad} = 5/32“
  - Crack depth = 0.125 t_{clad}
- Maximum allowable wastage area is equivalent to 6.0-inch diameter circle from ORNL testing

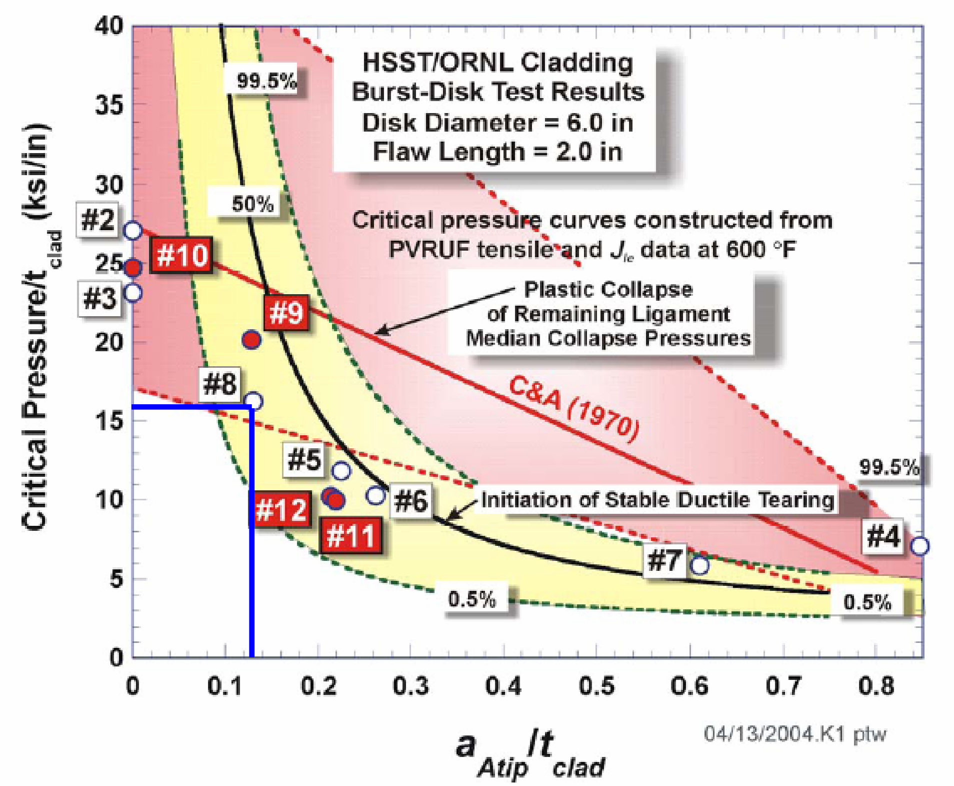
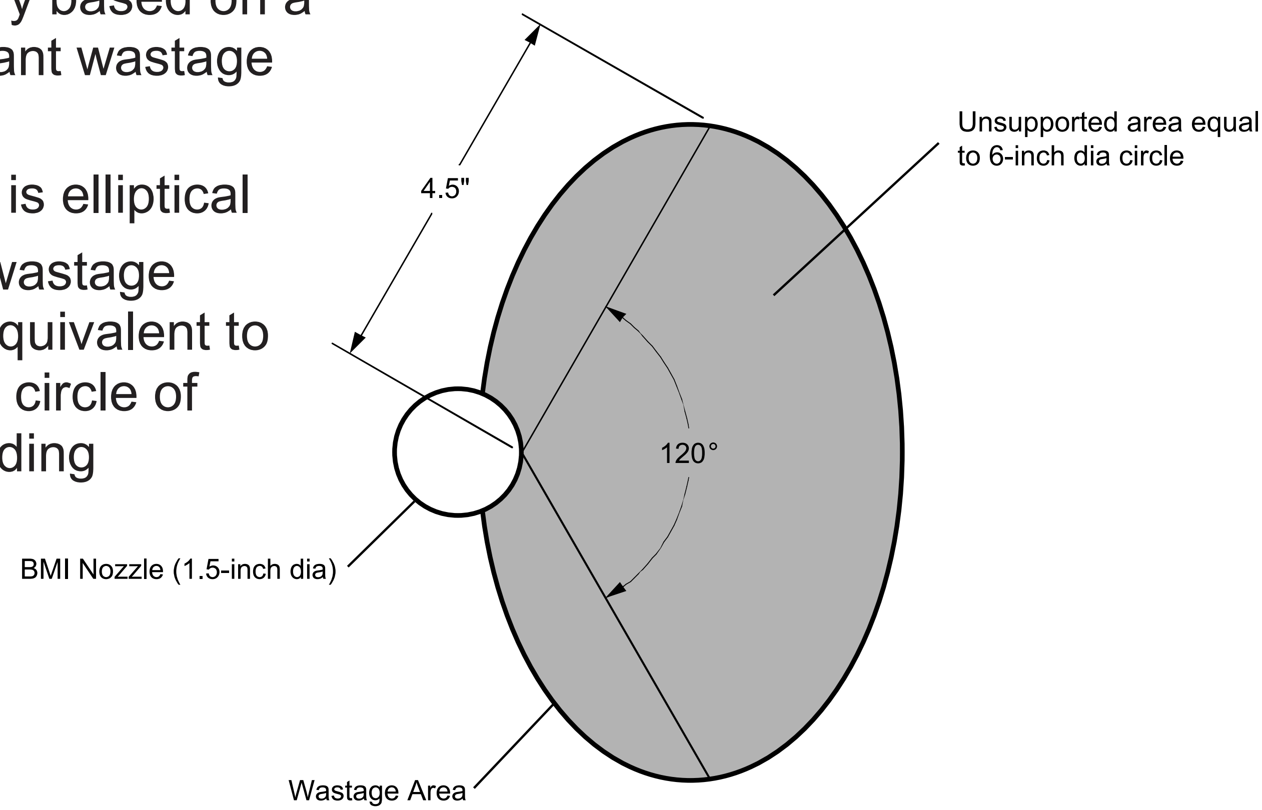


Fig. 7.7. Comparisons of failure pressure versus crack depth, both normalized by clad thickness, for the Phase 1 (open symbols) and Phase 2 (filled symbols) test series consisting of CB 9 through CB 12; test CB 13 was terminated prior to failure. The test results are compared with predictions for ductile tearing initiation (based on Weibull statistical distribution derived from PVRUF J_{Ic} PCCVN data) and predictions of plastic collapse of the remaining ligament using a statistical model of PVRUF plastic-flow tensile properties.

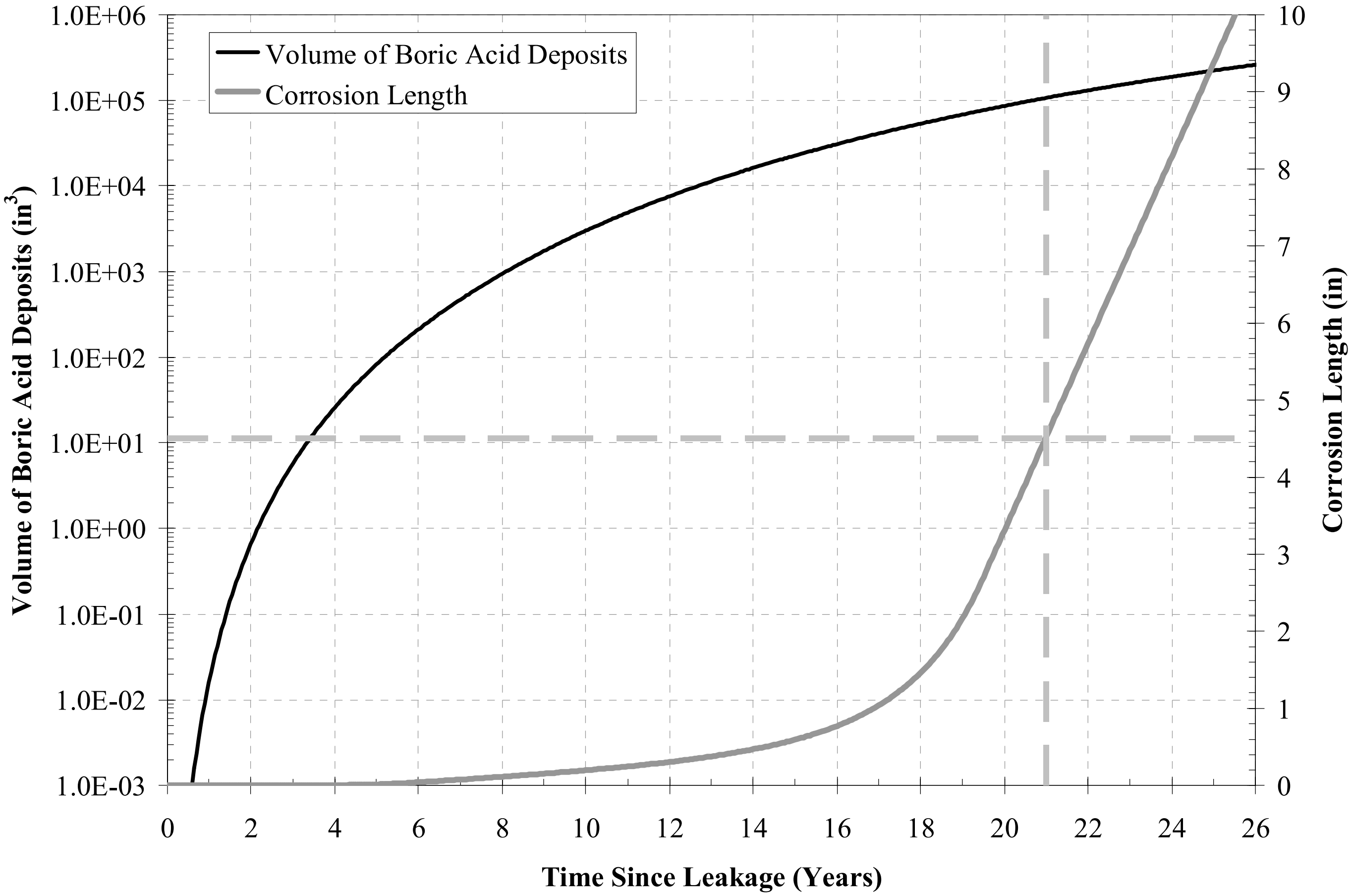
Supporting Calculations
Maximum Linear Wastage Length

- Wastage geometry based on a 120° arc of constant wastage length
- Overall geometry is elliptical
- Maximum linear wastage length of 4.5" is equivalent to 6.0-inch diameter circle of unsupported cladding



Deterministic Evaluation

Large Volume of Deposits Precedes Significant Wastage



Based on deterministic MRP-55 CGR equation

Wastage Process Modeling
Probabilistic Model Conclusions

- Significant time (> 15 years) is required for leakage to increase to point that rapid wastage may occur
  - > 20 years to cladding failure
  - Significant deposits available for detection <<15 years
- The model does not take credit for surface/volumetric NDE
- Sensitivity cases have been completed to check robustness of the results
- Results indicate periodic visual examinations provide assurance that structurally significant wastage of the low-alloy steel head material will not occur
- Wastage results will be incorporated into the BMN Management Plan

BMN Management Plan

Craig Harrington, TXU Power

BMN Management Plan Development

- OG Safety Assessment documents are complete
- MRP Wastage Assessment will be finalized by end of October
- Review and assess the results and decide how the BMN degradation management plan will be developed (November and December)
- Start writing the BMN degradation management plan in January 2006
- Final Guideline expected to contain "Mandatory" elements

WRAP UP SLIDE

- Questions and comments
- Future NRC meetings