PRELIMINARY -
ANALYSES STILL IN PROGRESS

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LBLOCA TUBE STRUCTURAL INTEGRITY ASSESSMENT

Determine Number of Failed Tubes and Associated Leak Area

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Lynchburg, Va.
November 9, 2004

LBLOCA Structural Integrity Assessment

- > Determine tube loads vs. tubesheet radius for projected LBLOCA tube-to-shell ΔTs of 250F to 370F.
- > Determine structural limiting circumferential flaw vs. tubesheet radius for the postulated LBLOCA loads.
- > Determine potential flaw distribution from existing plant inspection data.
- > Determine number of tubes that may potentially sever as a result of the LBLOCA loading.
- > Determine leak area associated with potentially severed tubes, tubes with projected through-wall flaws, and other potential leak paths (i.e. repair hardware).

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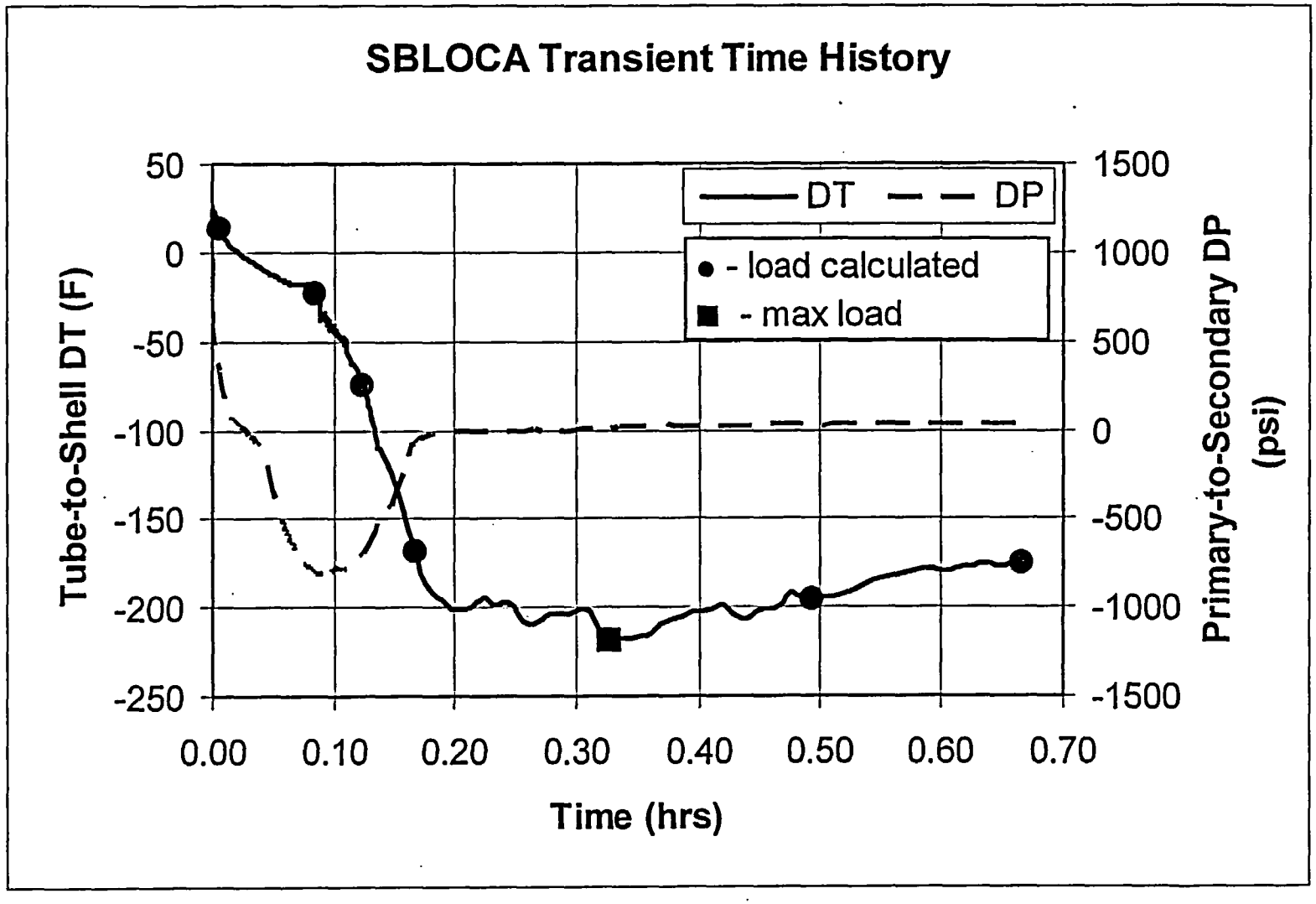
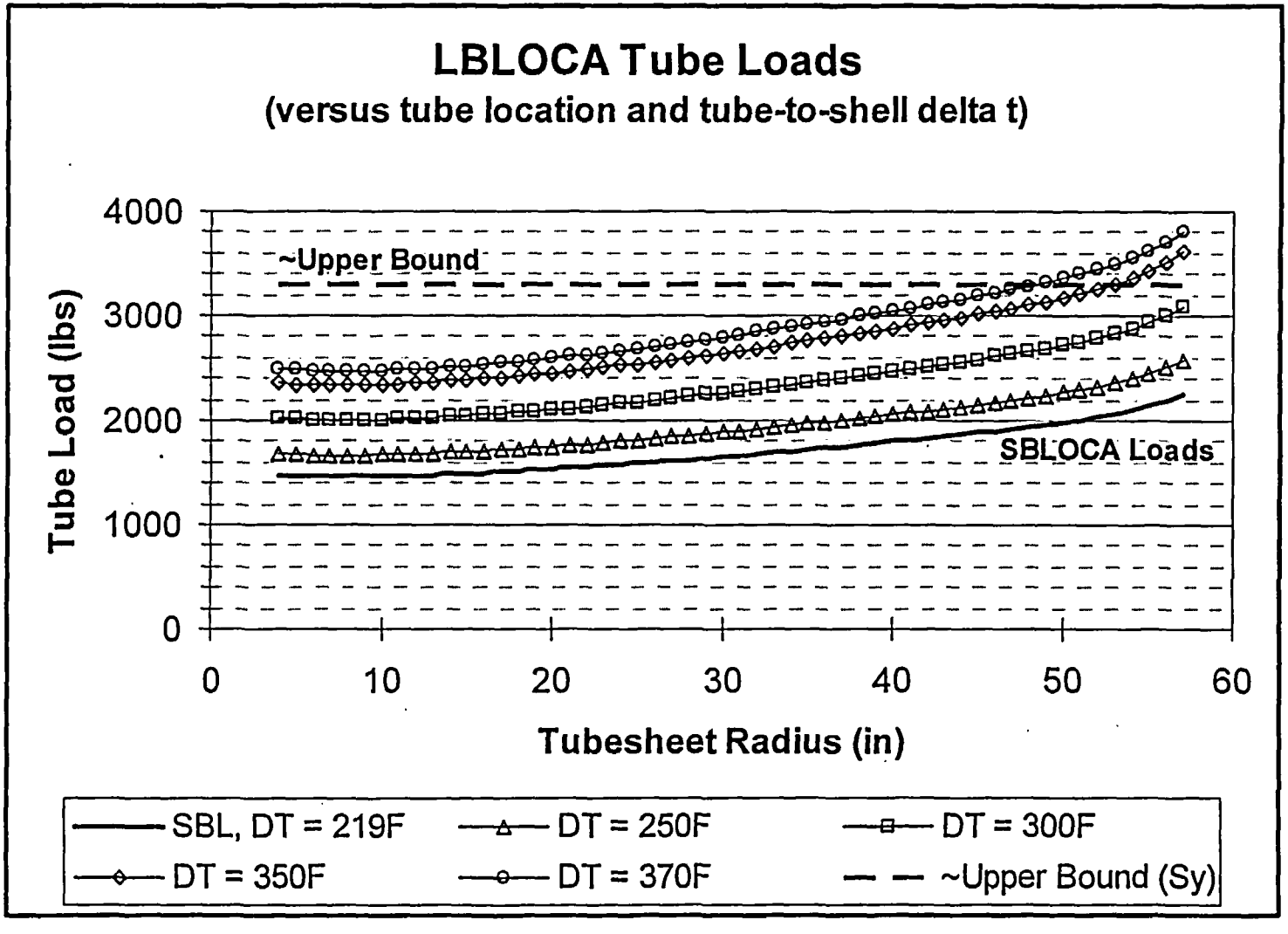
Tube Load vs. Tubesheet Radius

- The total tube load is made up of three basic parts:
  - Fabrication installed preload
  - Load due to primary-to-secondary ΔP
  - Load due to tube-to-shell ΔT
- The largest contributor to accident condition tube loads is the tube-to-shell ΔT
- LBLOCA tube loads were estimated by increasing the loads from the detailed time history analysis of the SBLOCA transient by the ratio of applicable tube-to-shell ΔTs
  - Axial loads due to preload and pressure are negligible (~60 and 10 lbs respectively).
  - The preload is constant and the pressures for the SBLOCA and LBLOCA are similar and very small.

Tube Load vs. Tubesheet Radius



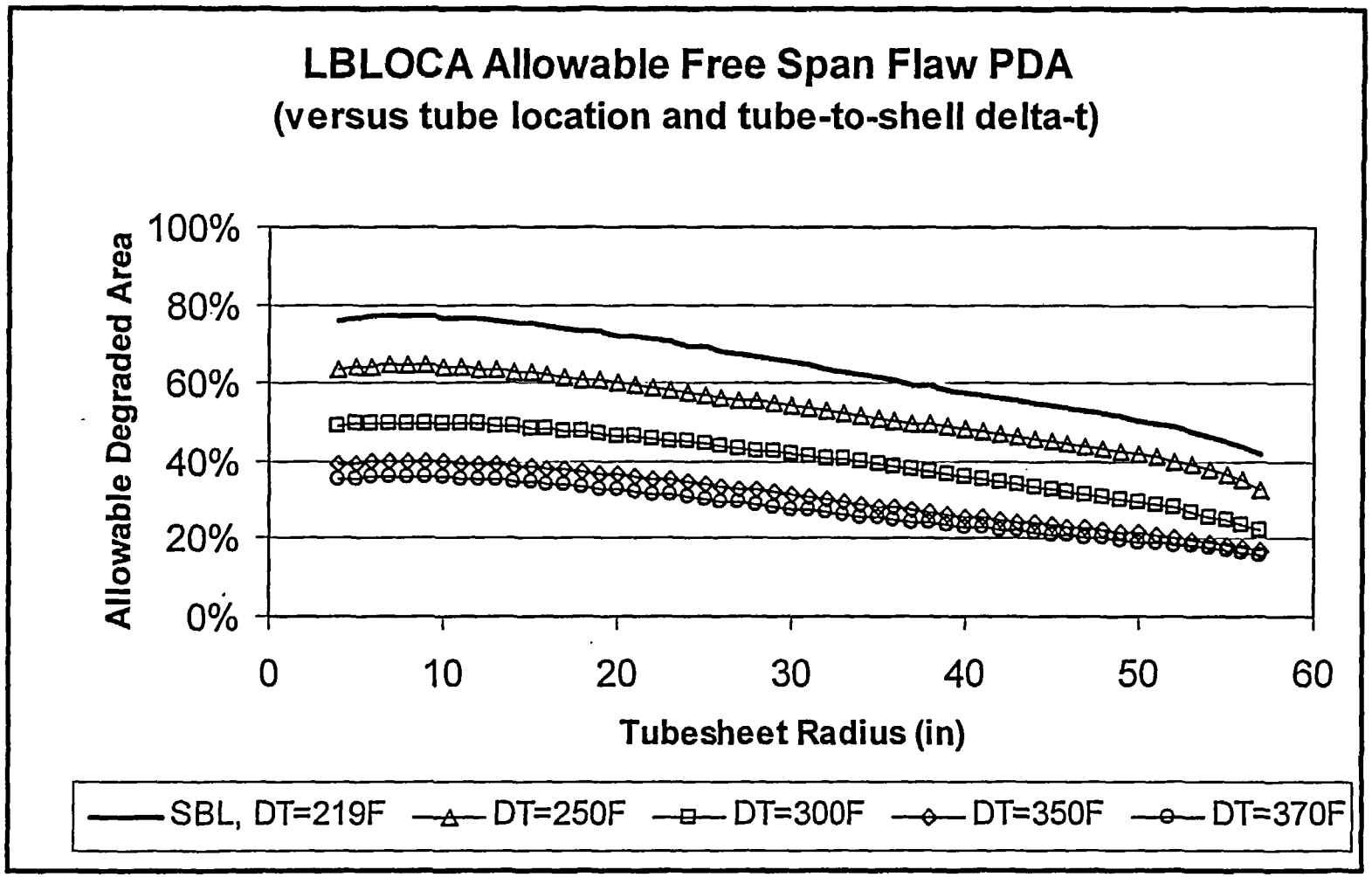
Tube Load vs. Tubesheet Radius, Results



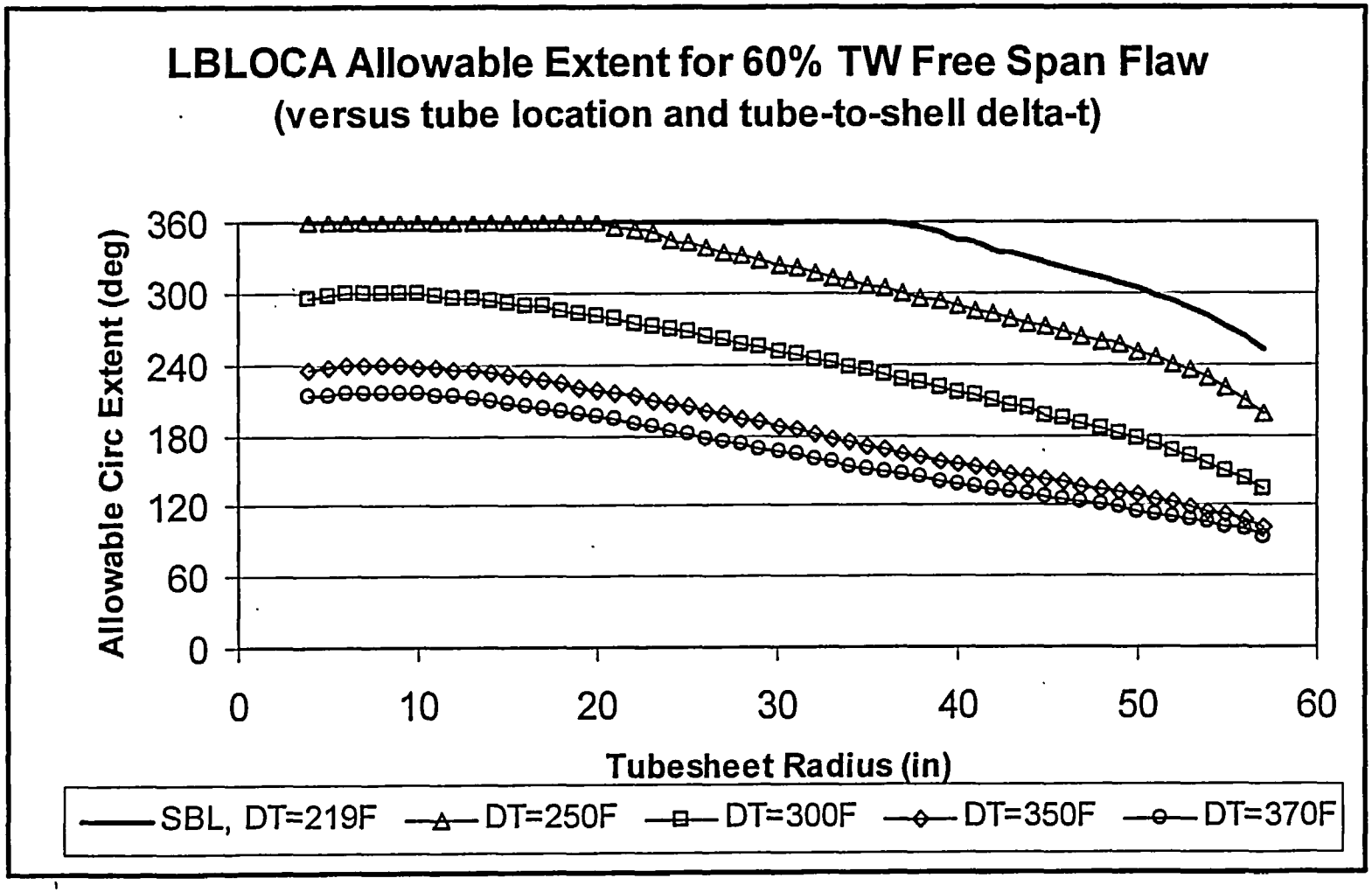
Structural Limiting Flaw vs. Tubesheet Radius

- For this assessment, the structural limit is defined as when the tube severs.
- Structural limits were determined using AREVA modified version of the EPRI Flaw Handbook equation for allowable flaw size.
  - AREVA modifications incorporate results from additional testing of tubes containing circumferential degradation.
  - Projected LBLOCA tube loads as a function of tubesheet radius and tube-to-shell ΔT were used.
- Structural limits were best estimate and based on nominal tube size and average of measured material strengths.
  - The structural limits resulting from a Condition Monitoring evaluation would be much smaller.

Structural Limiting Flaw vs. Tubesheet Radius, Results



Structural Limiting Flaw vs. Tubesheet Radius, Results

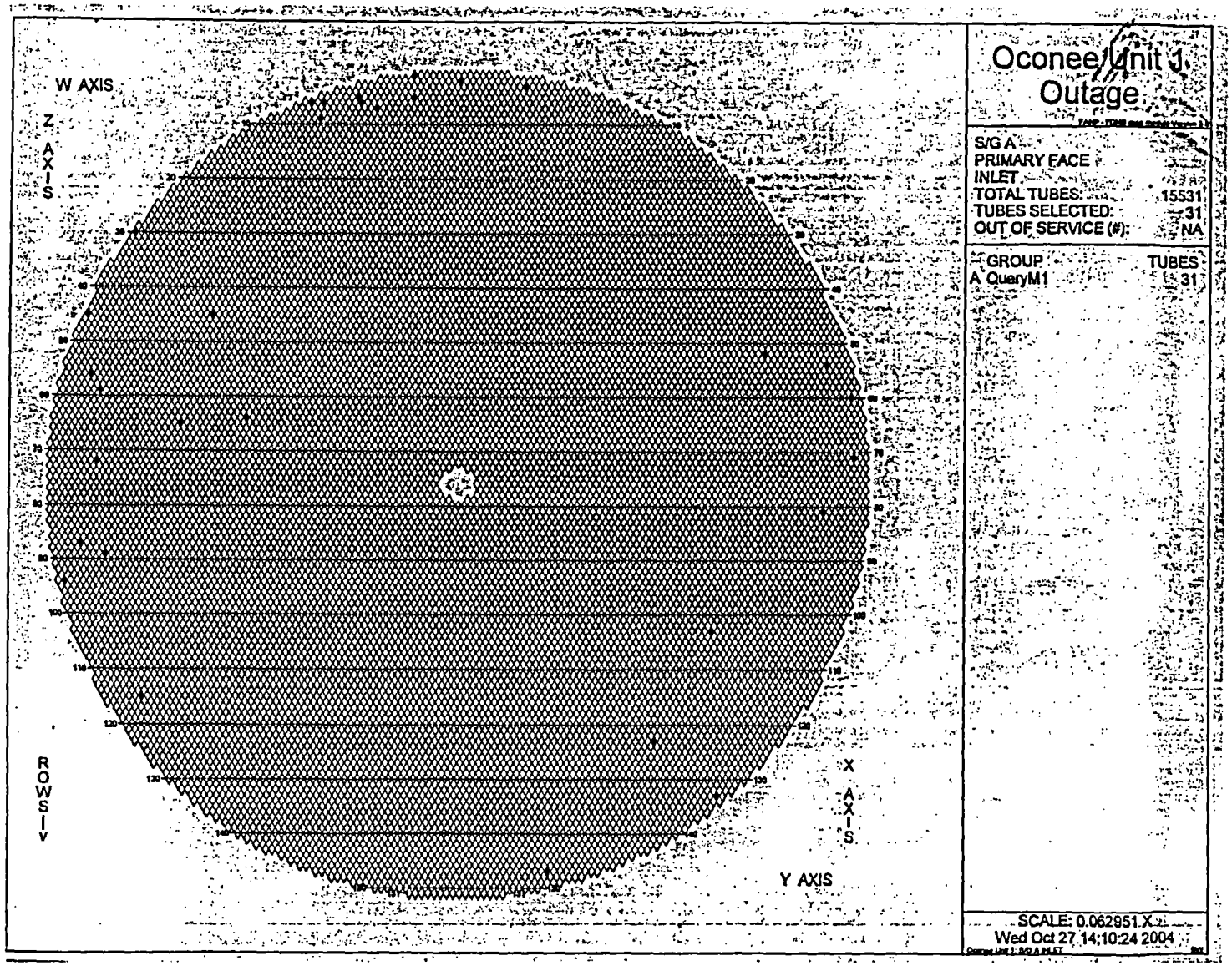


Potential Flaw Distribution vs. Tubesheet Radius

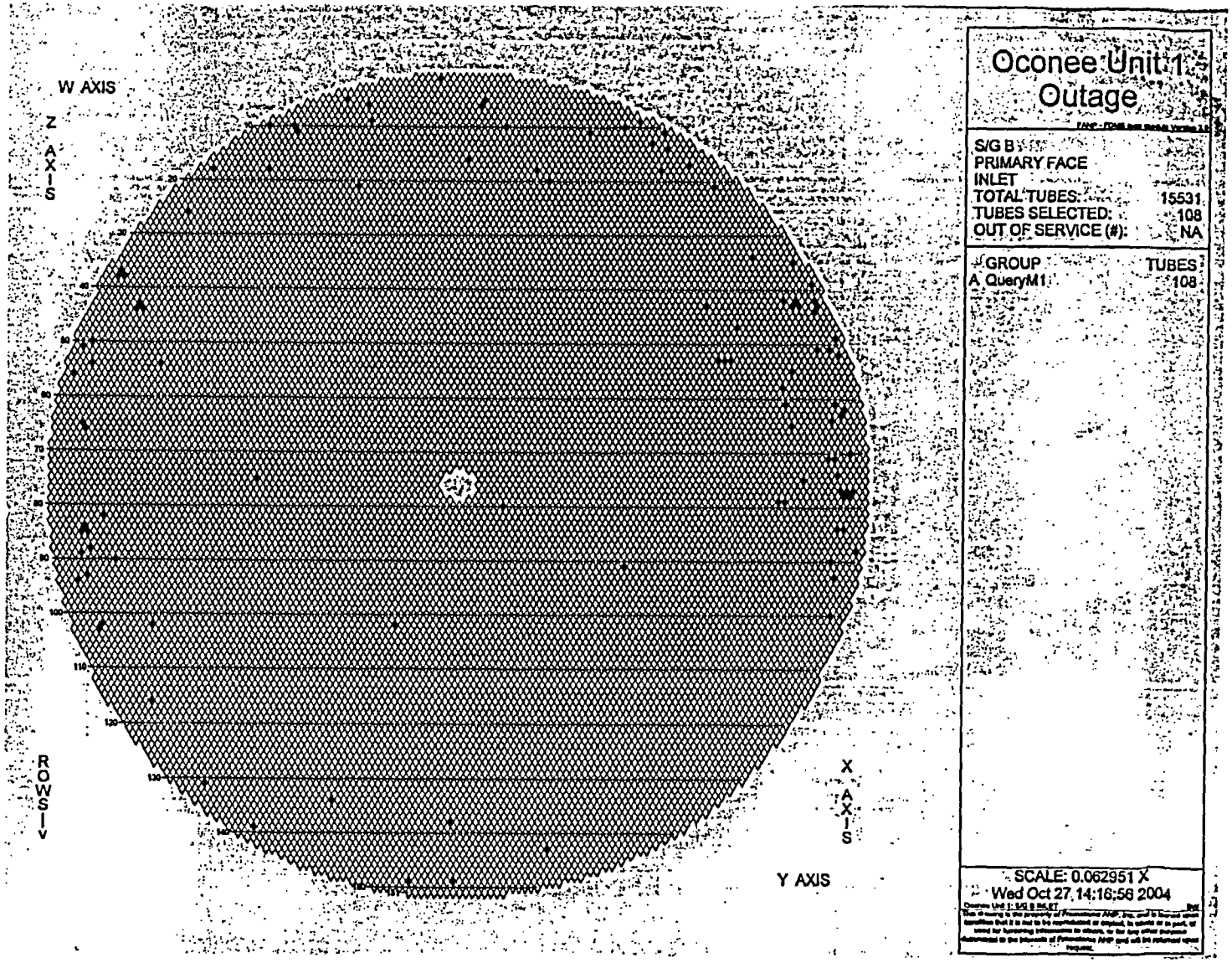
> Existing plant inspection data was used to project potential future circumferential degradation.

- History shows the size (depth and extent) of detected flaws is relatively constant from outage to outage and plant to plant.
- The number of detected flaws increases from outage to outage.
- The number of critical flaws is not cumulative because tubes with detected indications are plugged each outage.
- Due to small ΔP, failure of axial degradation is not a concern.
- Due to difference in tube loads between SGs, only the limiting SG need be considered.
- Plants with replacement steam generators or generators that are scheduled for replacement in near future (i.e. Oconee-1,2,3 and ANO-1) need not be considered since the Alloy 690 tubing has not been shown susceptible to significant forms of degradation.

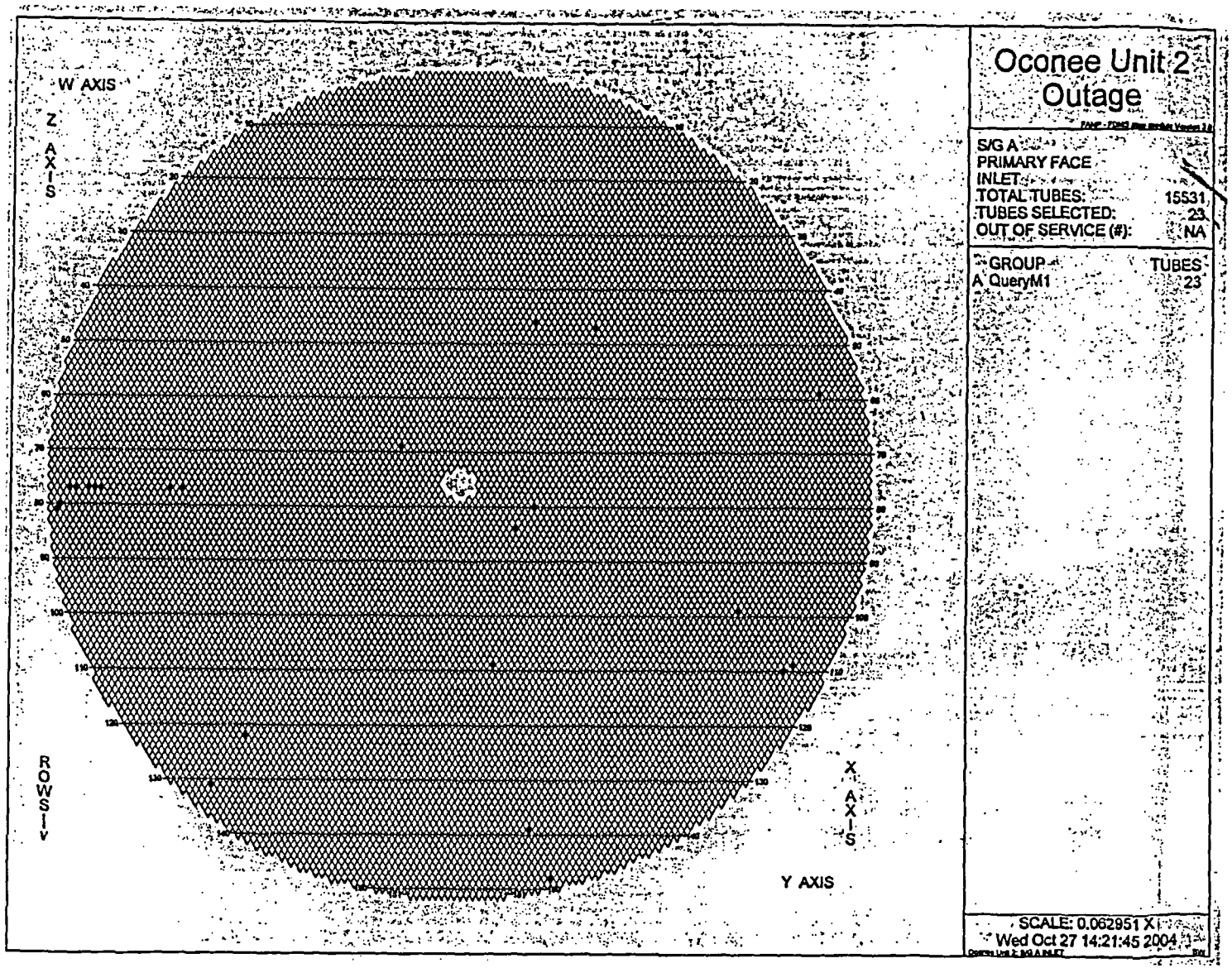
Radial Distribution of Flaws



Radial Distribution of Flaws



Radial Distribution of Flaws



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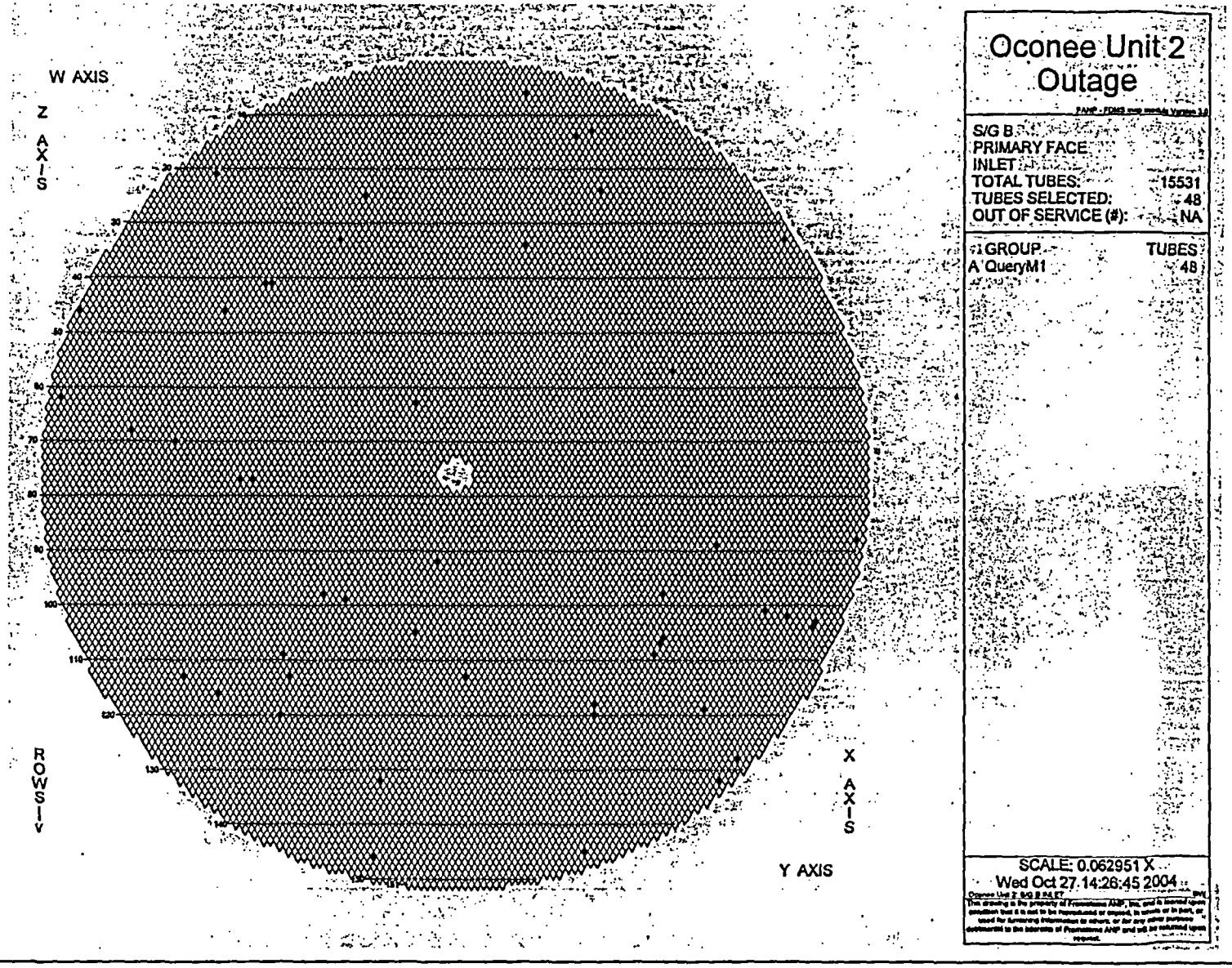
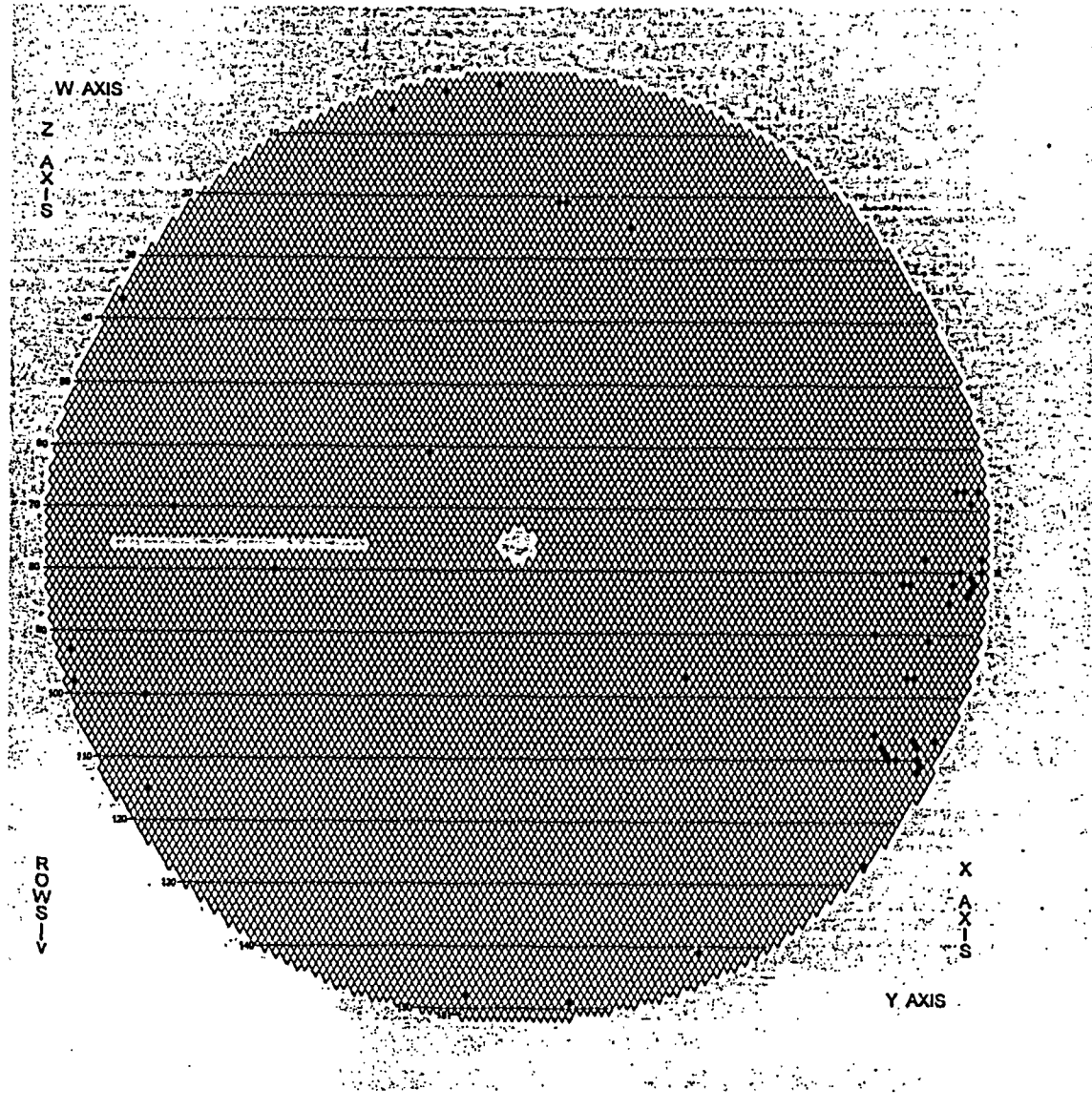


Radial Distribution of Flaws



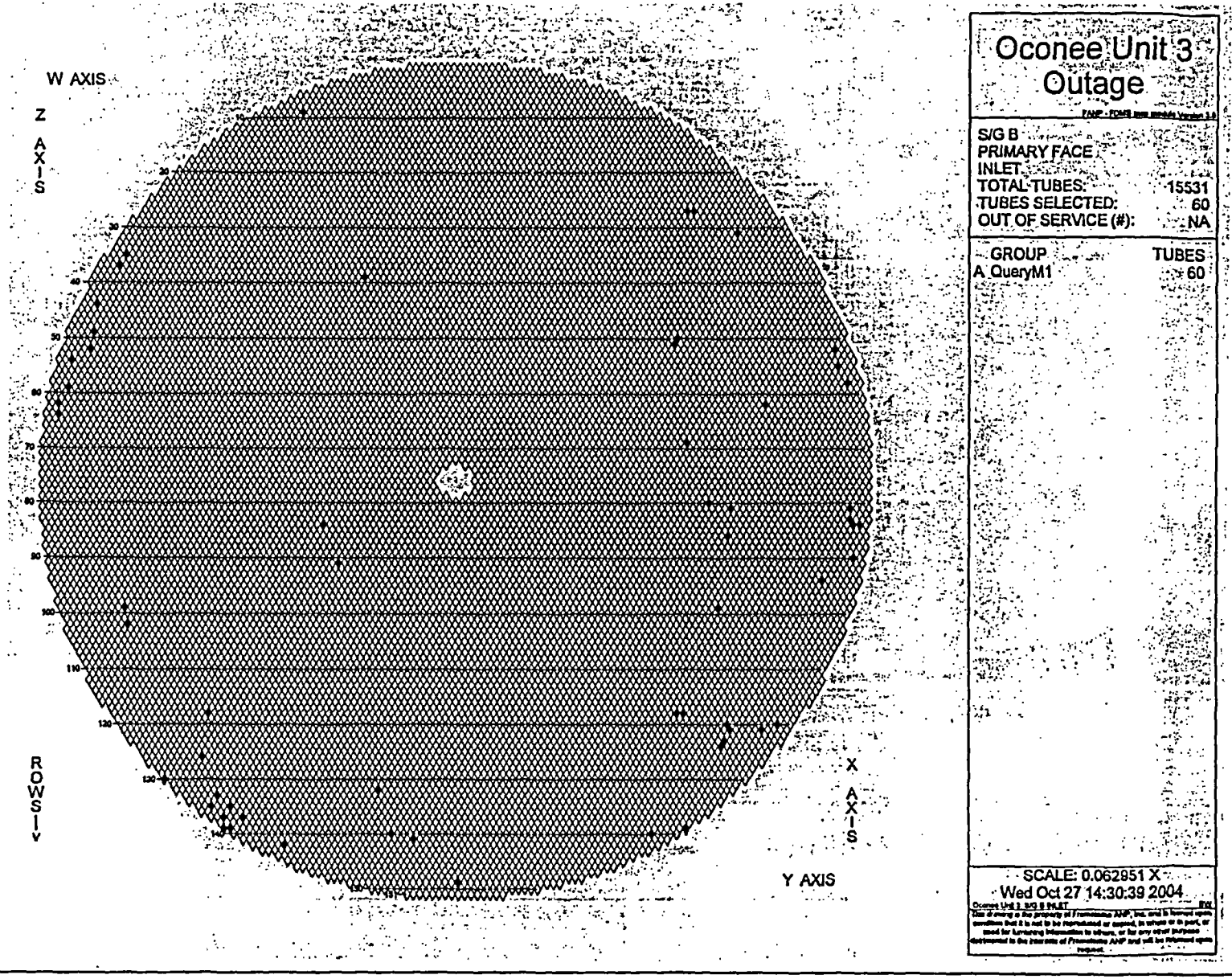
Oconee Unit 3
Outage

S/G A	
PRIMARY FACE	
INLET	
TOTAL TUBES:	15459
TUBES SELECTED:	50
OUT OF SERVICE (#):	NA

GROUP	TUBES
A QueryM1	50

SCALE: 0.062951 X
Wed Oct 27,14:28:29 2004

Radial Distribution of Flaws



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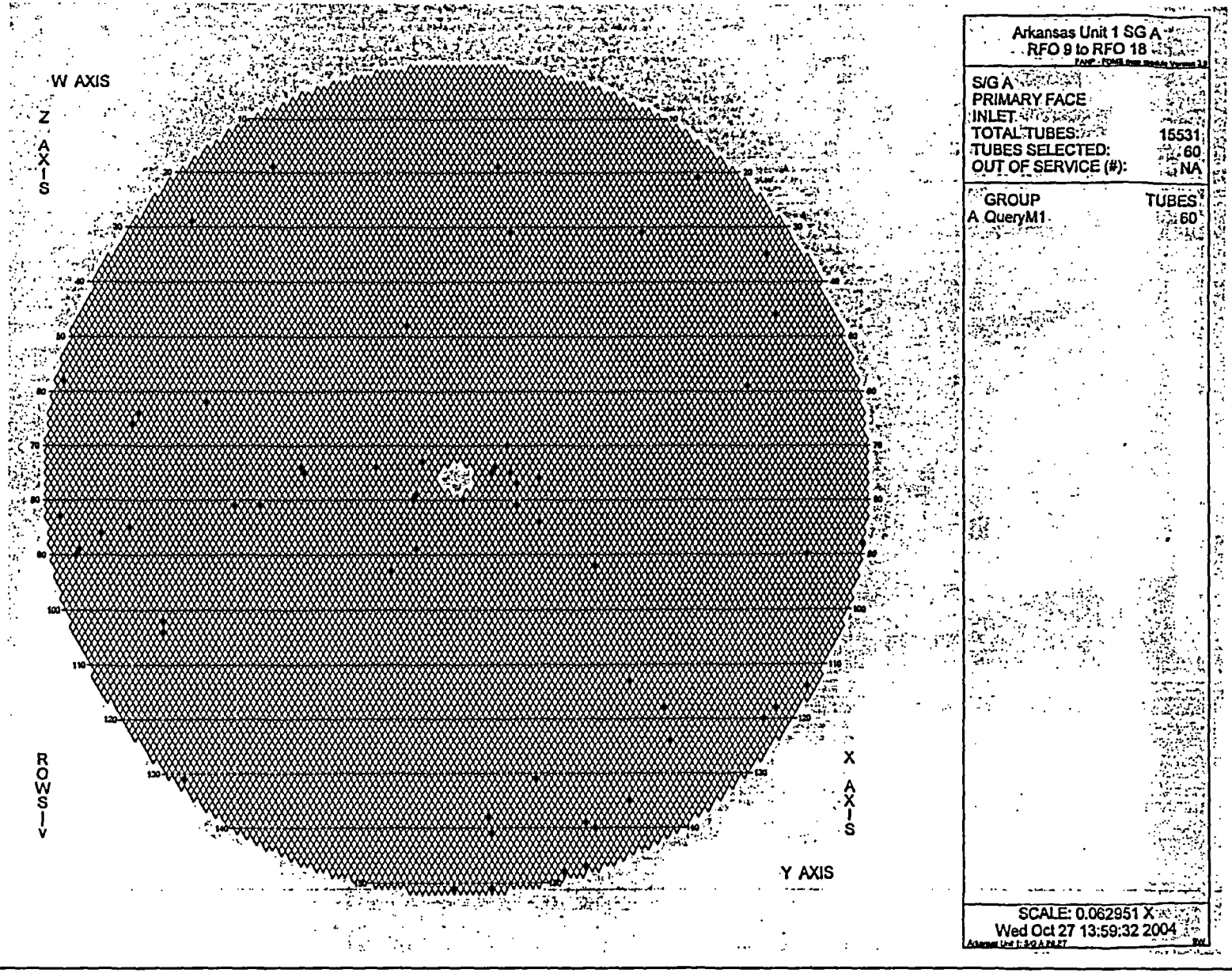

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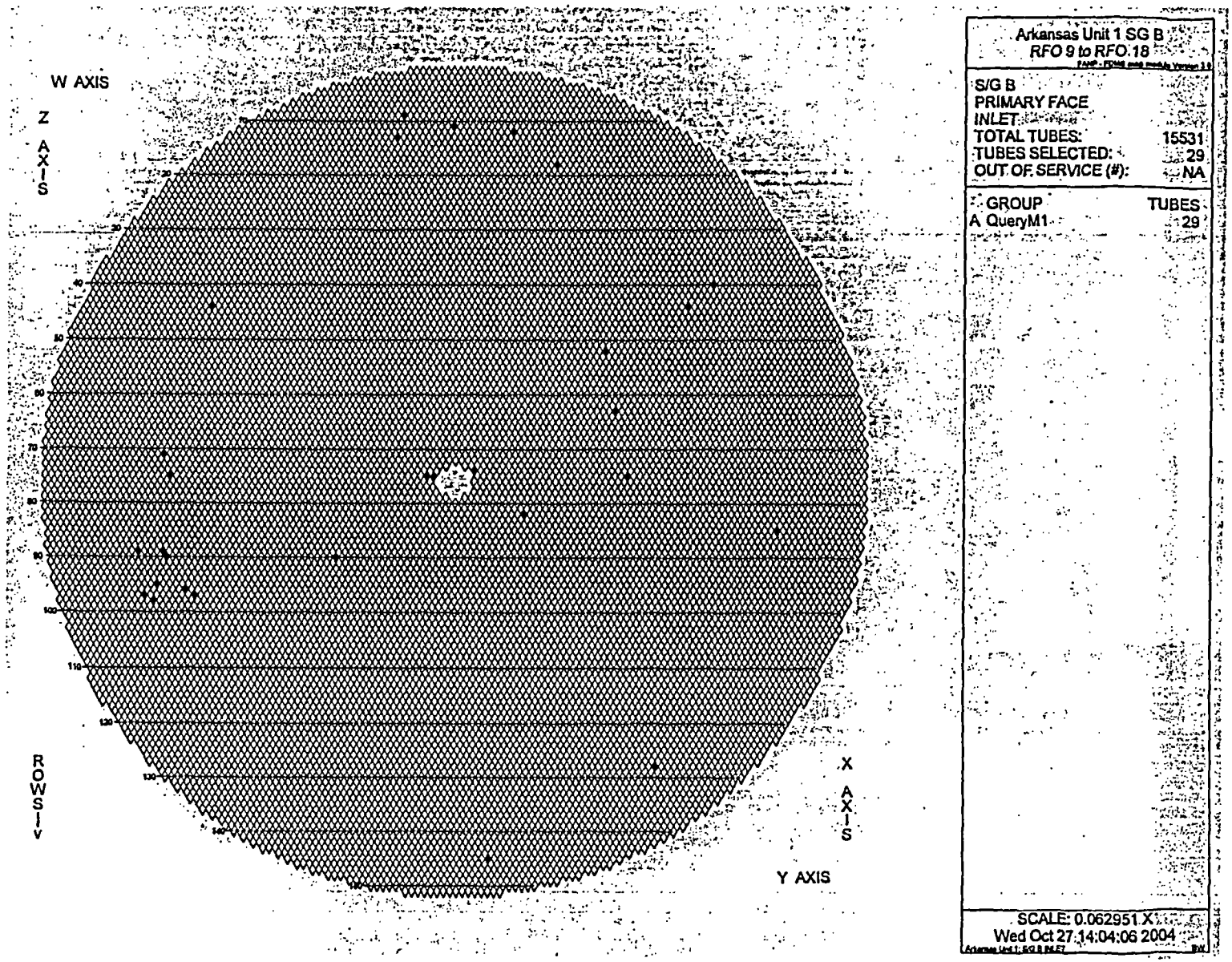

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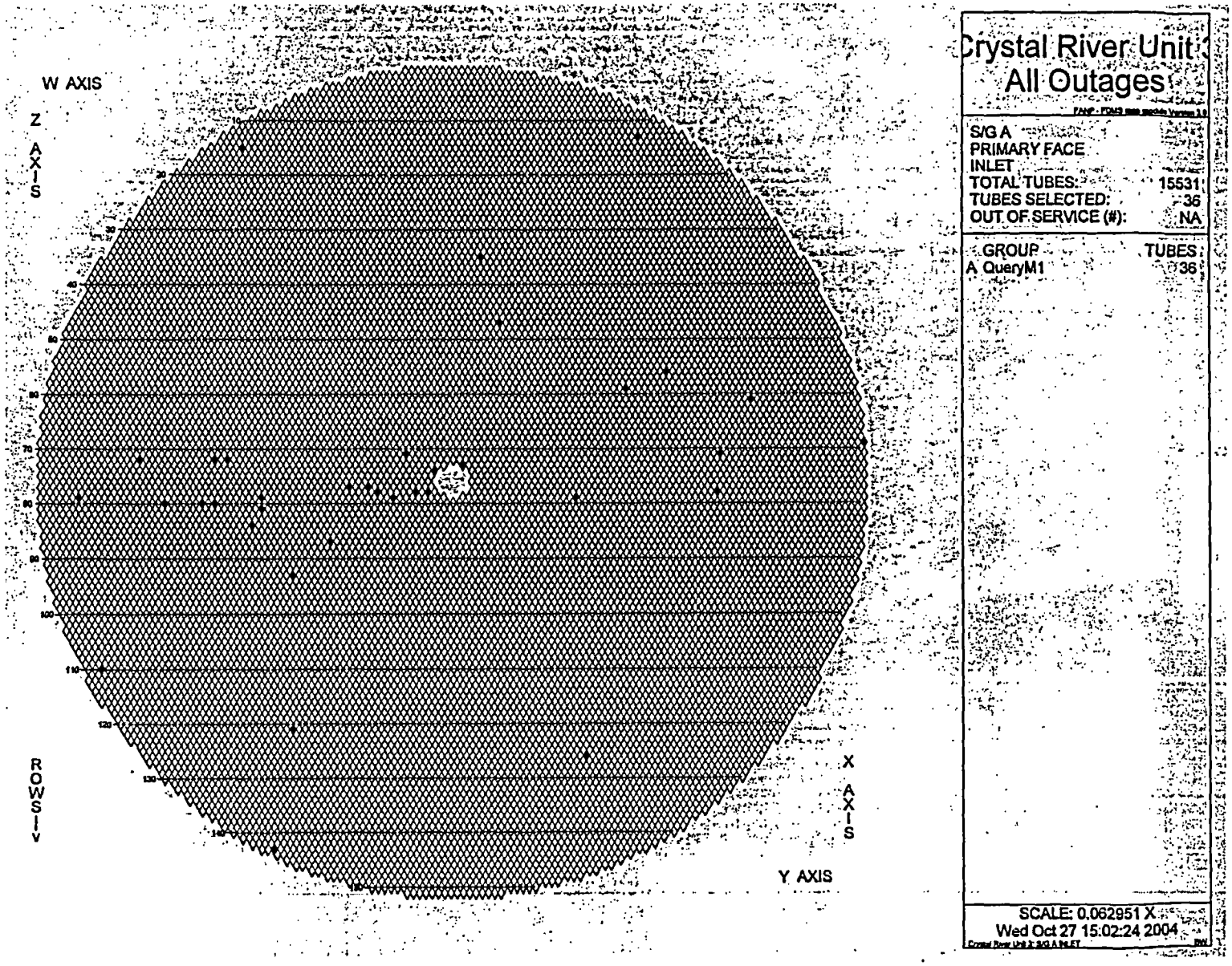

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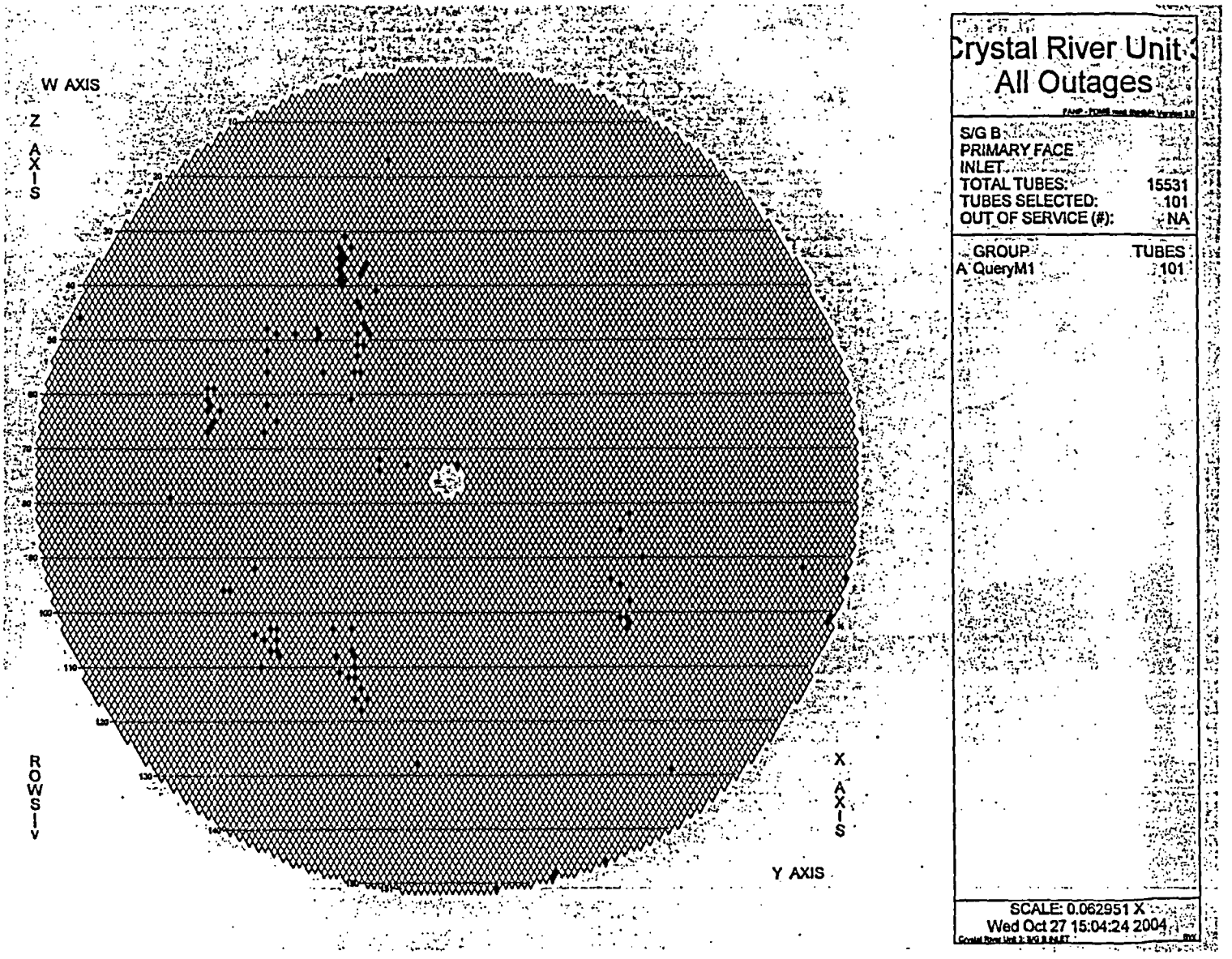

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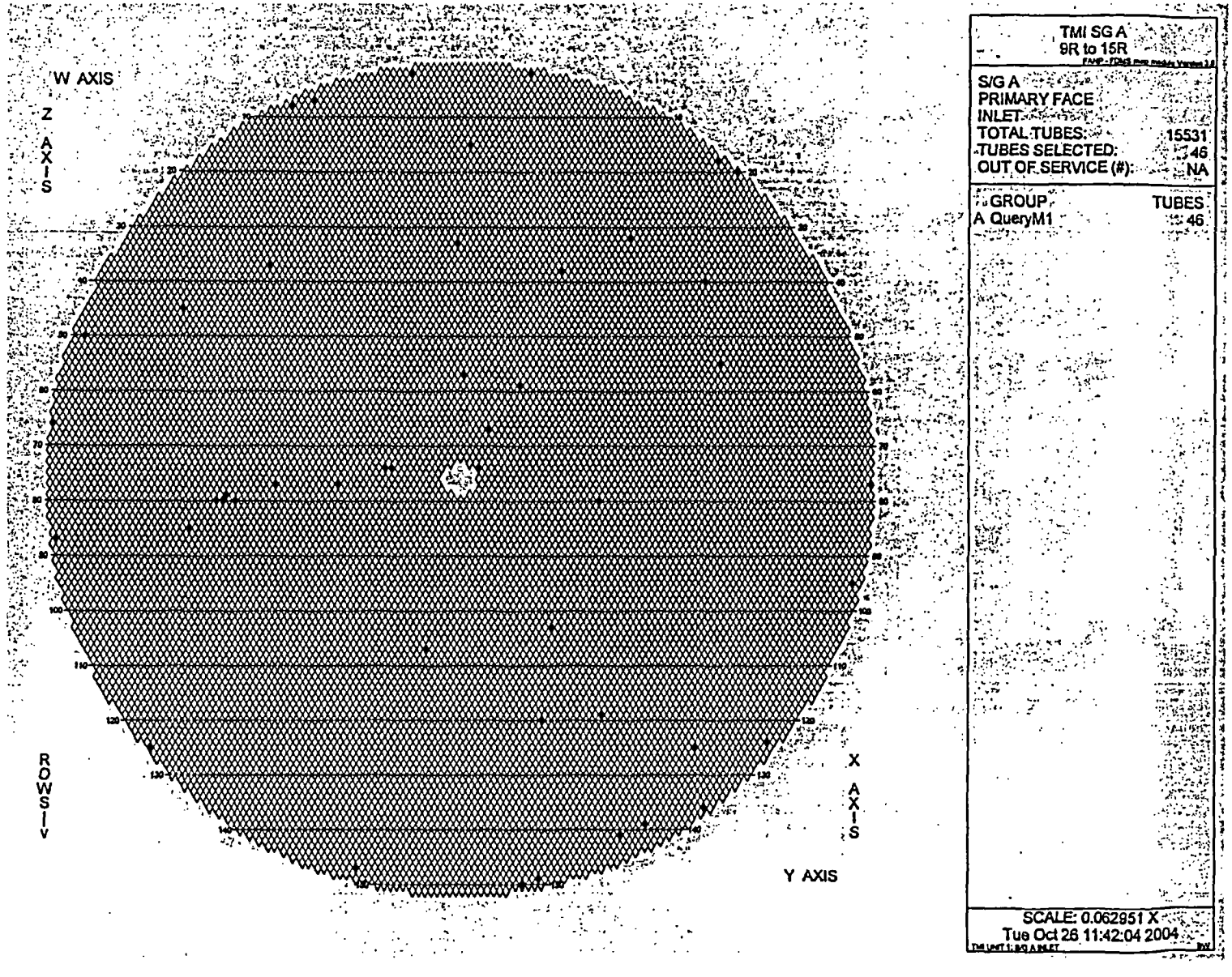

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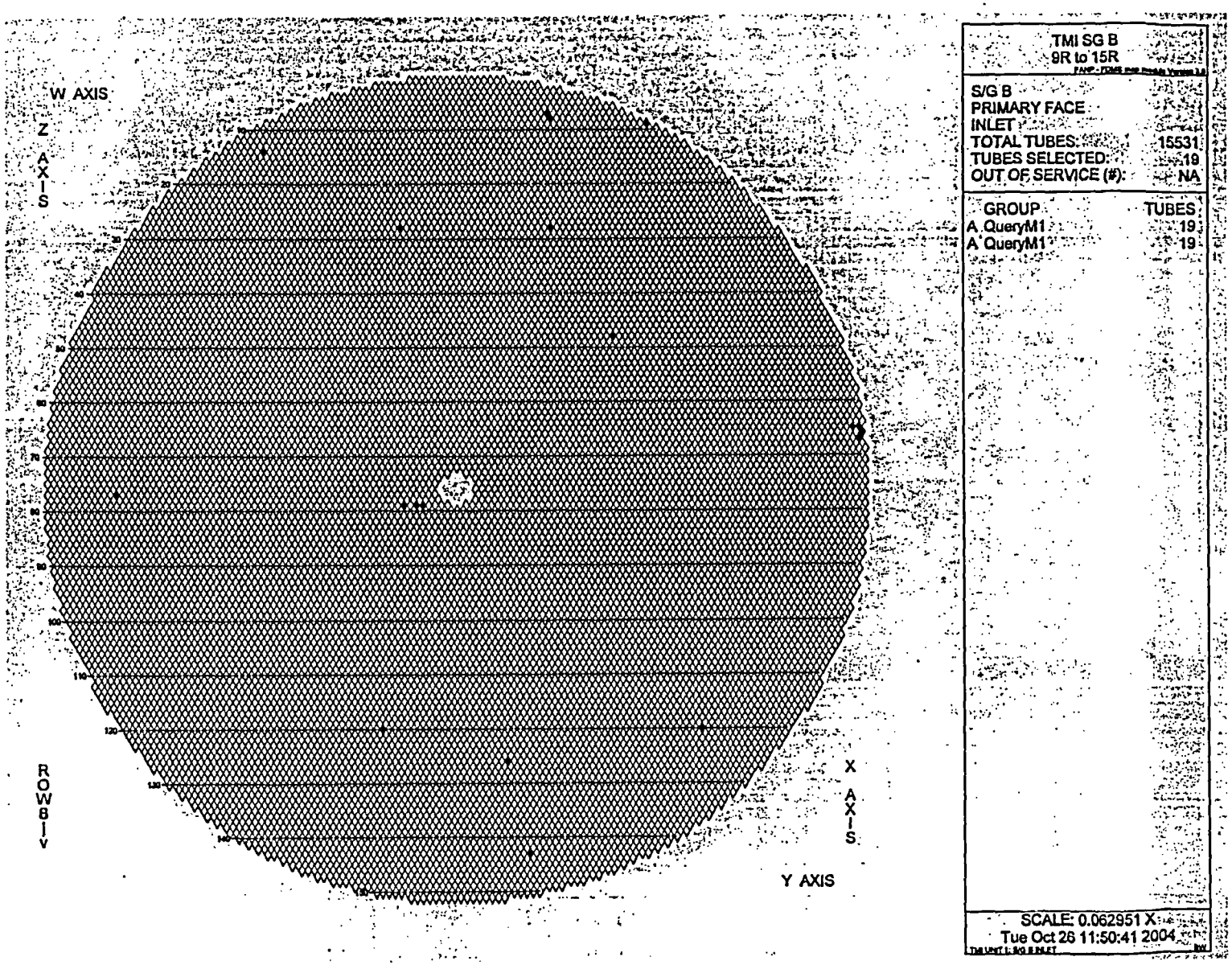

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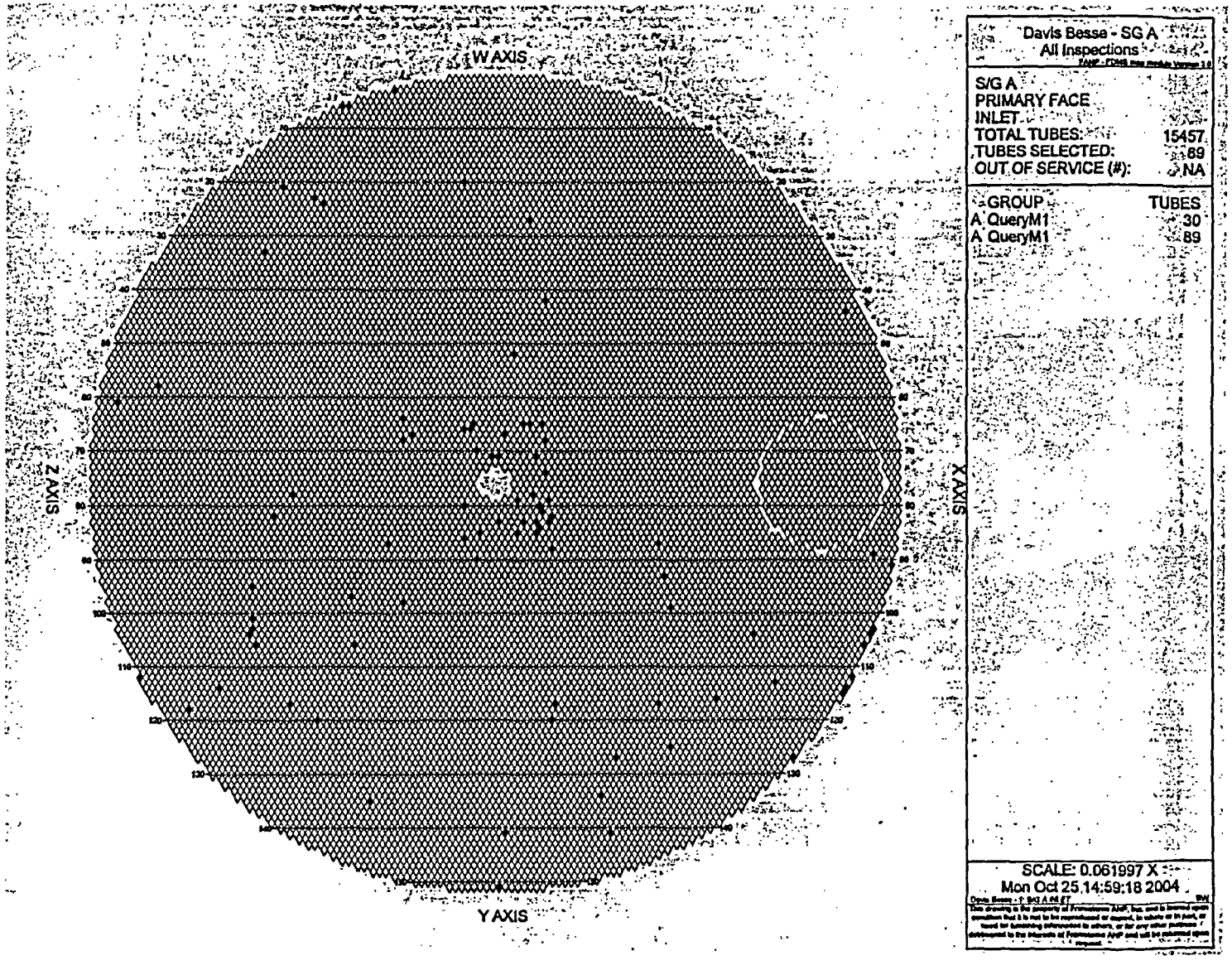
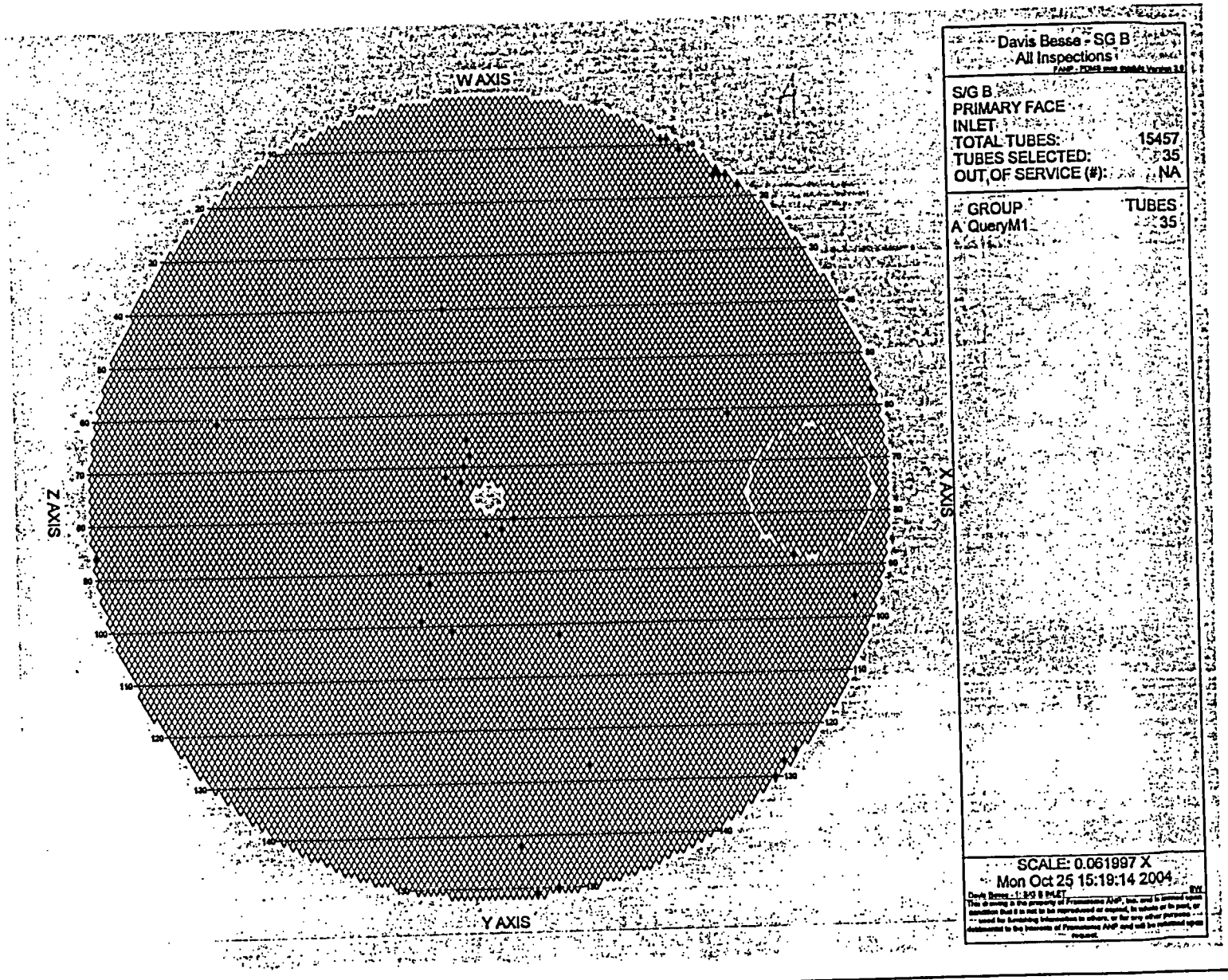
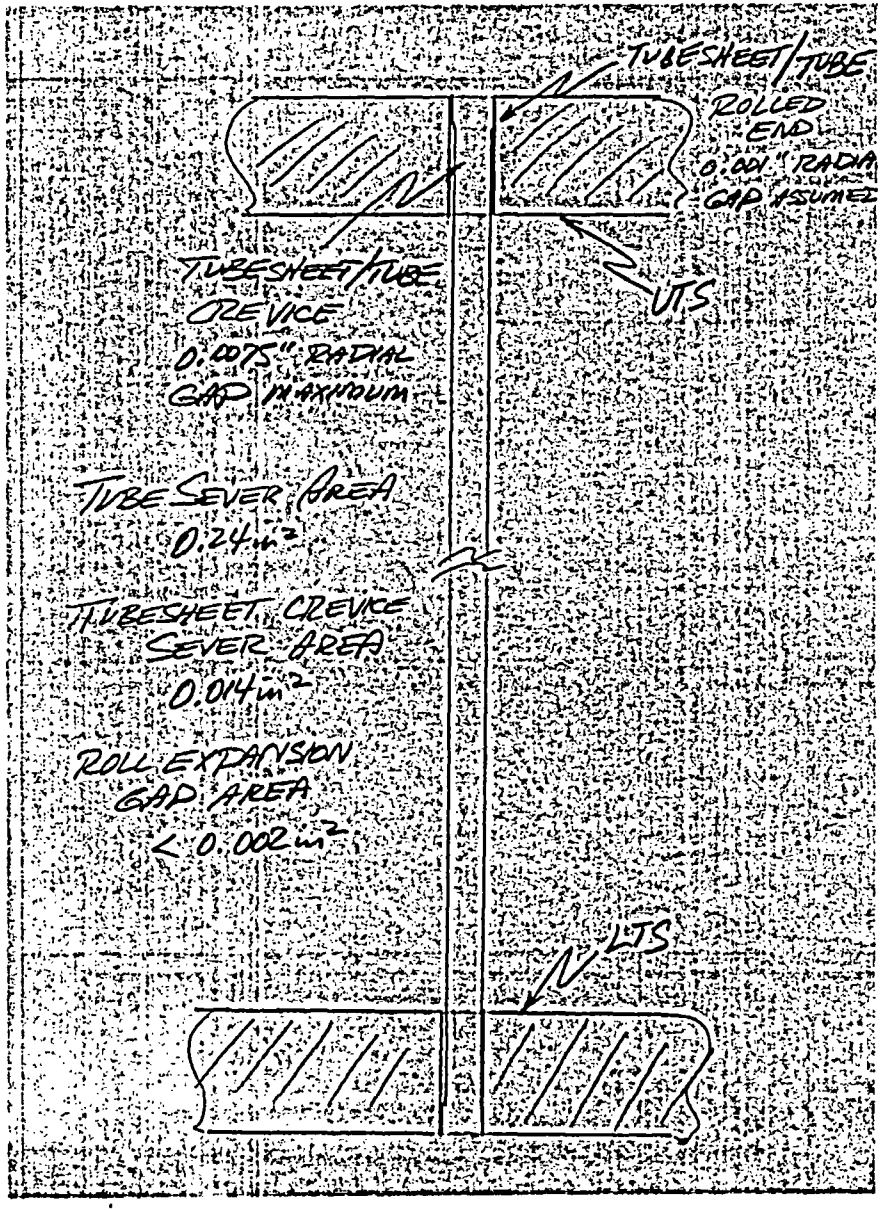


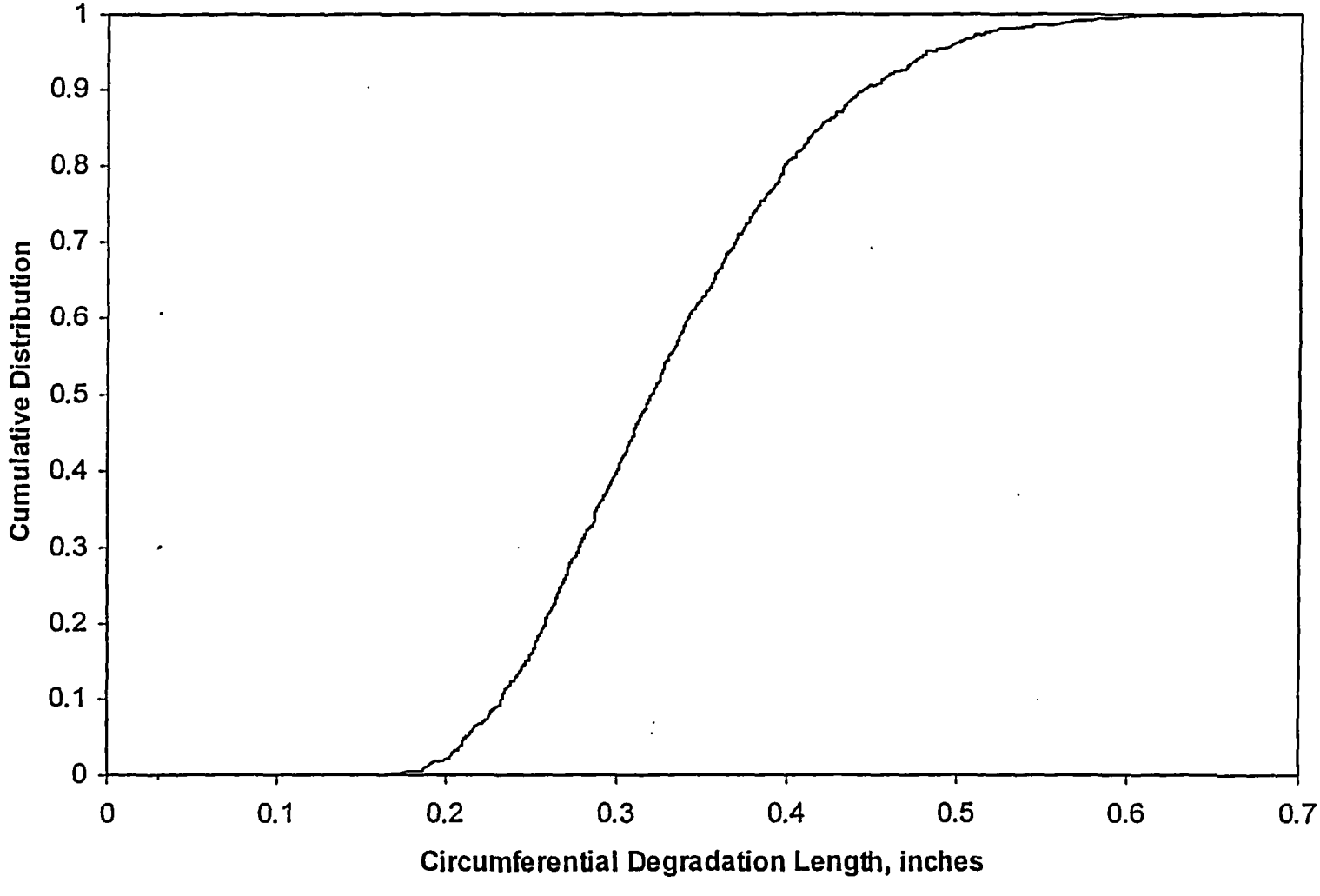
Radial Distribution of Flaws



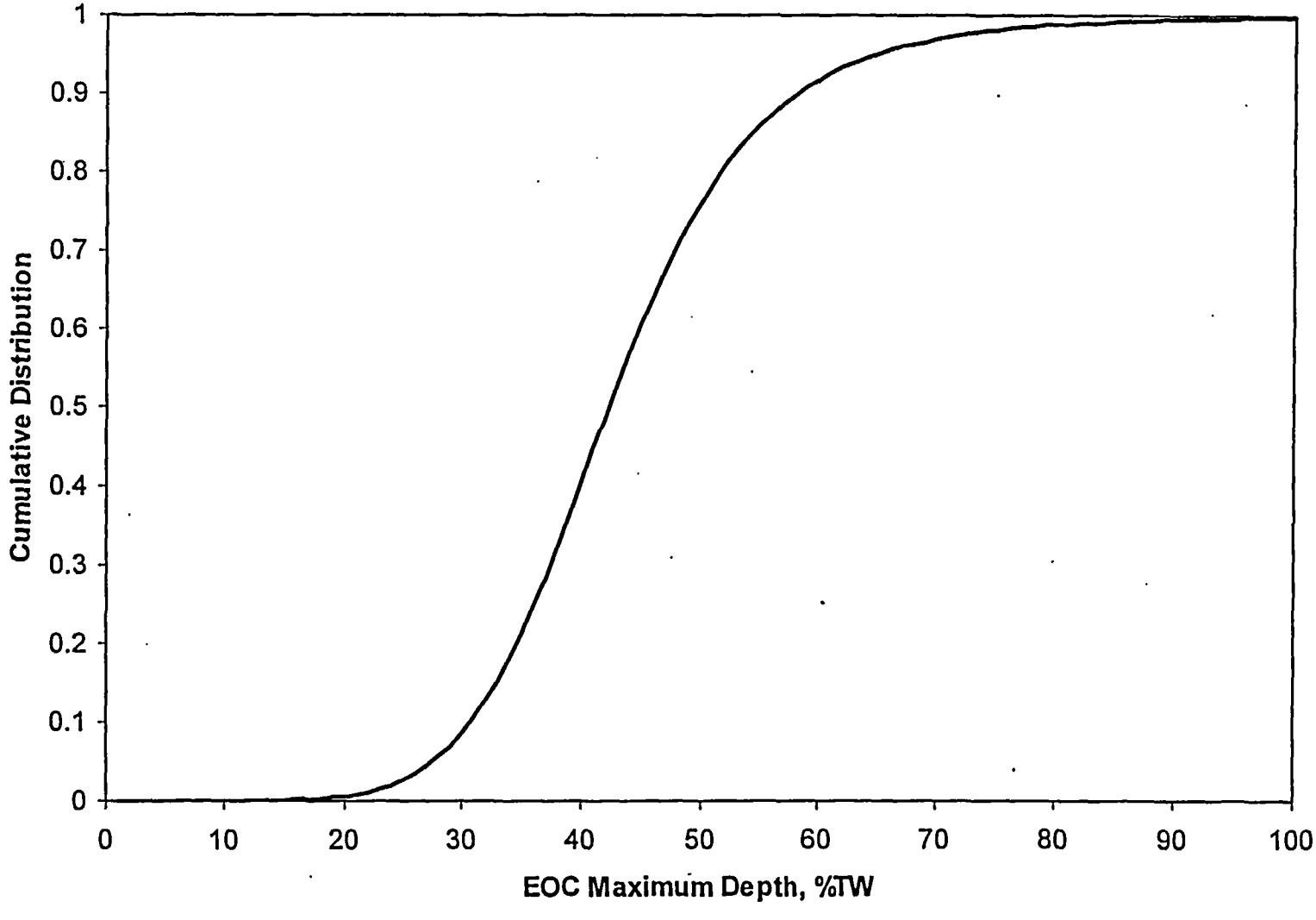
Axial Locations of Flaws



EOC Distribution of Circumferential Degradation Lengths



EOC Distribution of Maximum Depths



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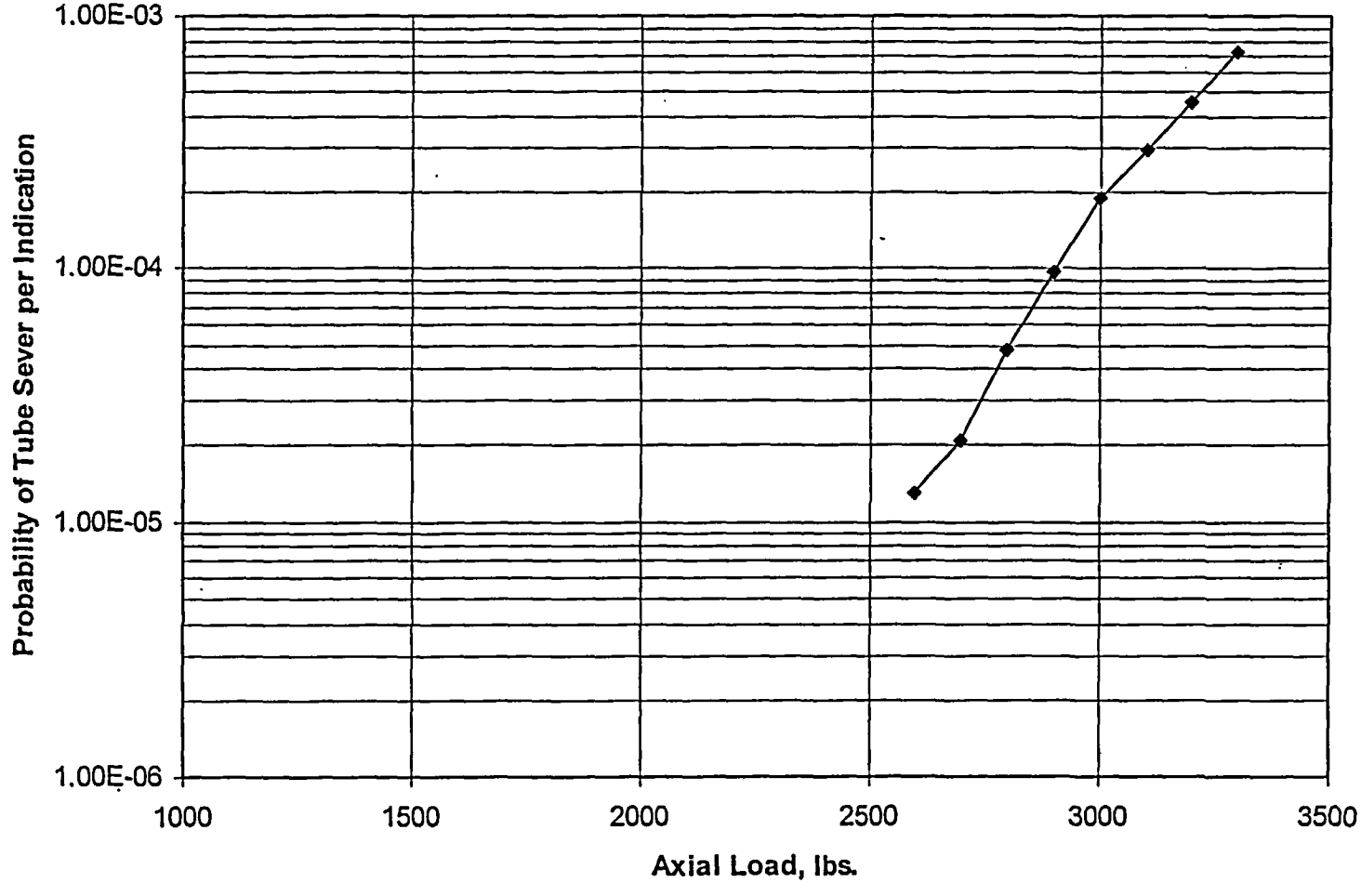
Structural Integrity of Circumferential Flaws

> A PROBABILISTIC ANALYSIS OF FREESPAN TUBE SEVERS WAS PERFORMED.

- Basis = Multi Cycle Monte Carlo Model Results Which Includes Simulation of: Flaw Initiation, Flaw Shape, Growth in Depth and Length, NDE Inspection. Detected and Undetected Flaw Populations Considered.
- EOC Distributions of Flaw Depth and Flaw Length After Multiple Cycles of Operation Become Relatively Stable.
- Depth Distribution Becomes Equivalent to Eddy Current Probability of Detection Curve
- Number of Indications Follows Weibull Distribution
- Probability of Tube Sever Can Be Calculated from Length and Depth Distributions and Number of Indications
- Probability of Freespan Tube Sever for Maximum Axial Load of 3300 lbs. is 0.000722 per Detected EOC Indication

Probability of Freespan Tube Sever Results

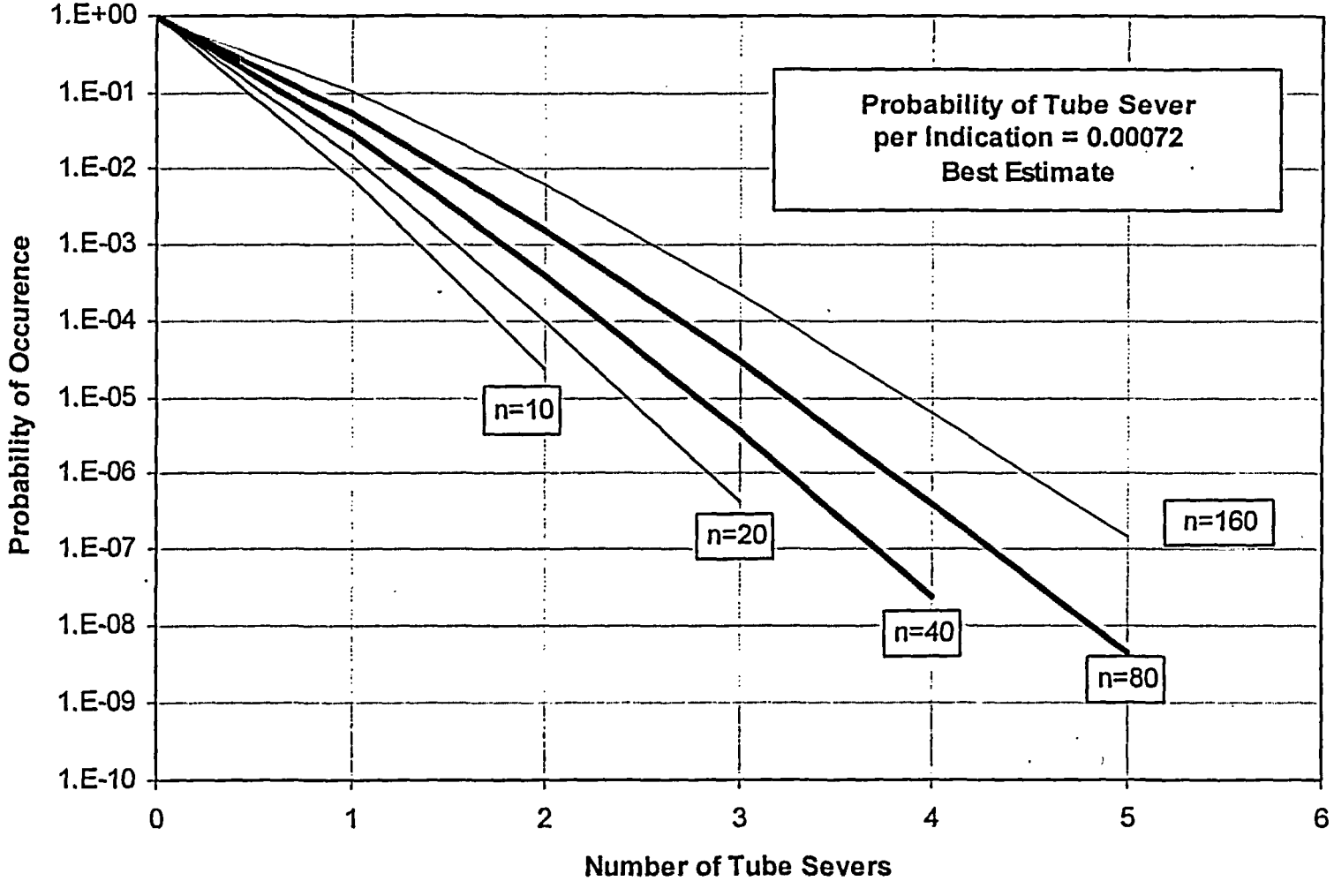


Probability of Multiple Tube Severs

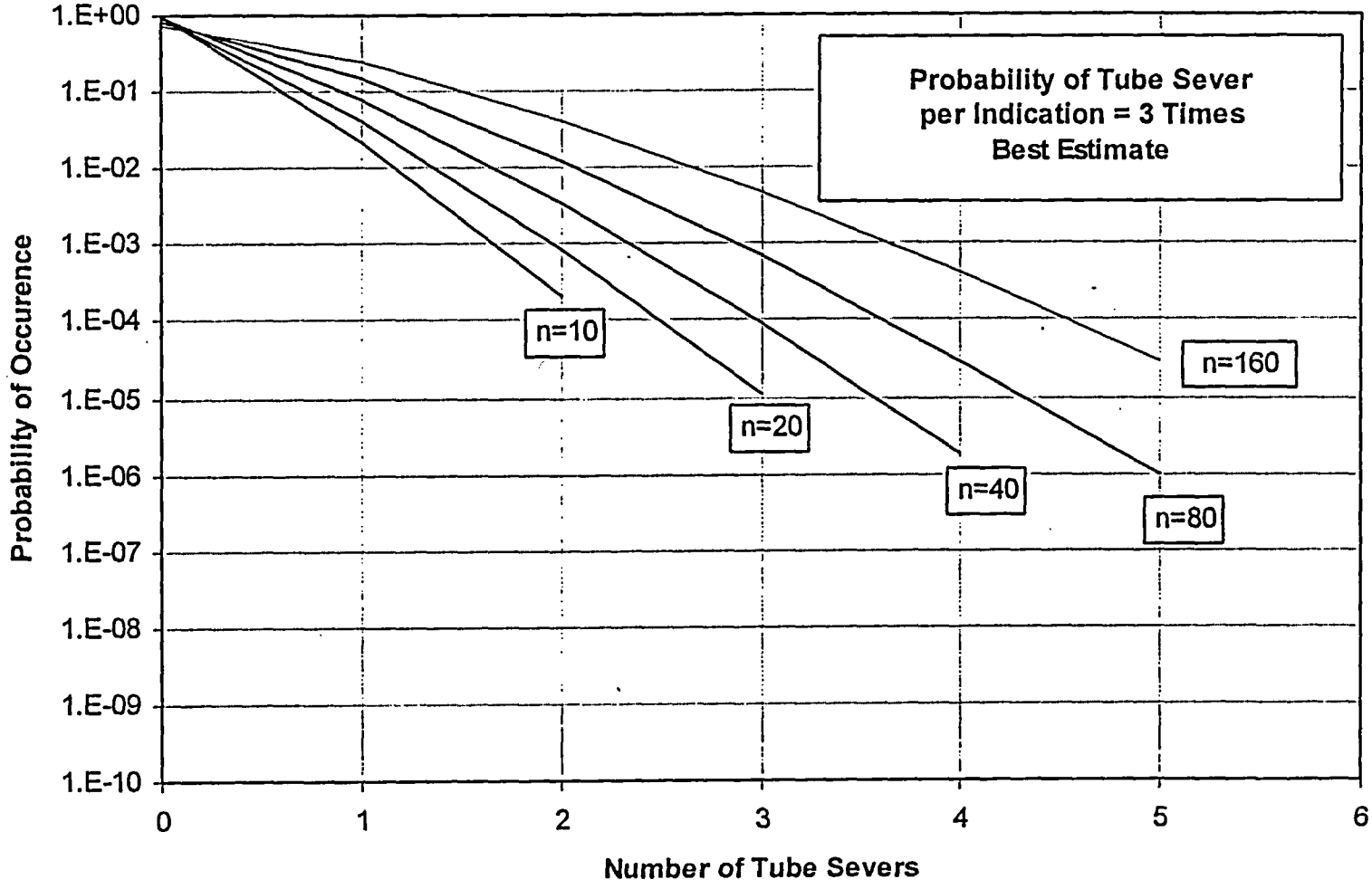
- P(x) = Probability of Exactly "x" Tube Severs for "n" Indications
- p = Probability of a Tube Sever per Indication

$$P(x) = \frac{n!}{x! \bullet (n-x)!} \bullet p^{x} \bullet (1-p)^{(n-x)}$$

Best Estimate of Multiple Tube Severs



Probability of Tube Sever per Indication Increased by a Factor of 3

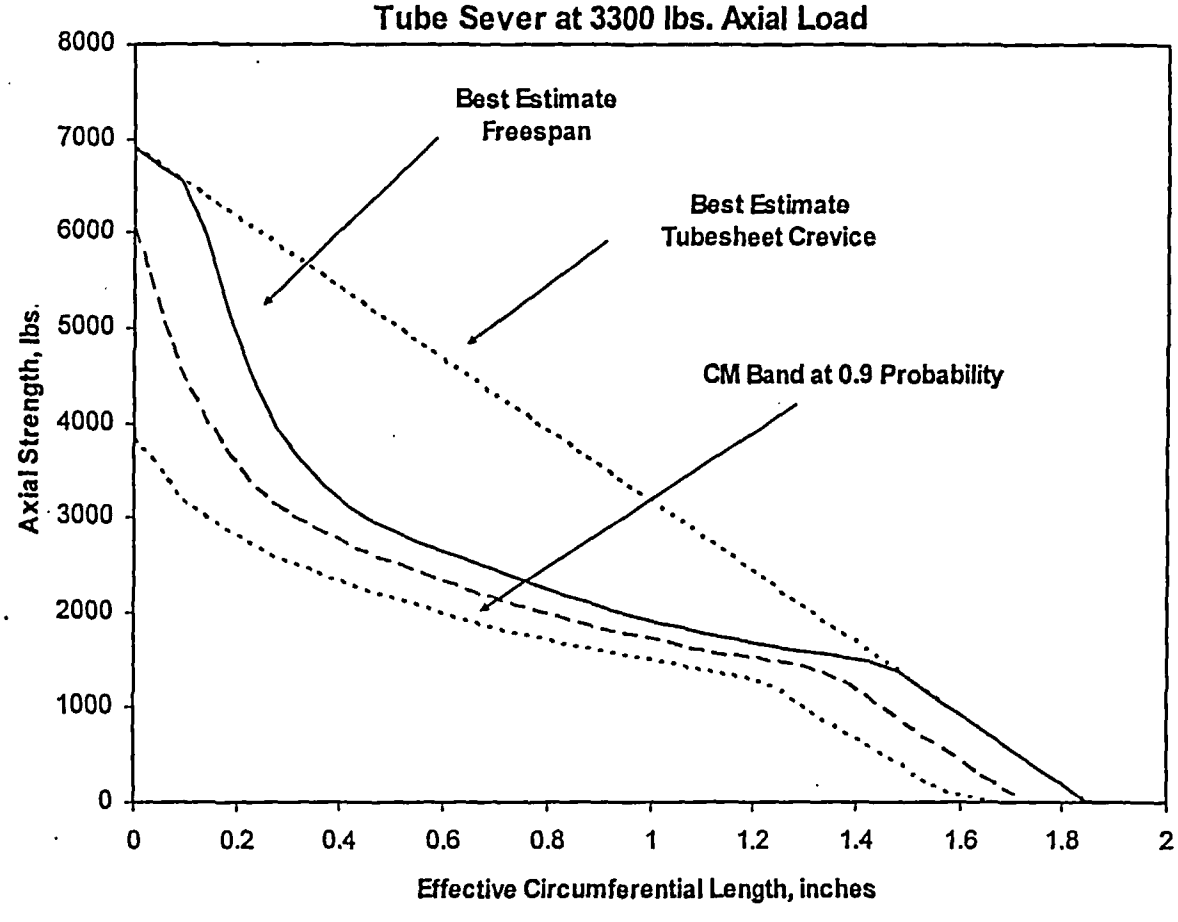


Leakage Areas Associated with Flaw Type

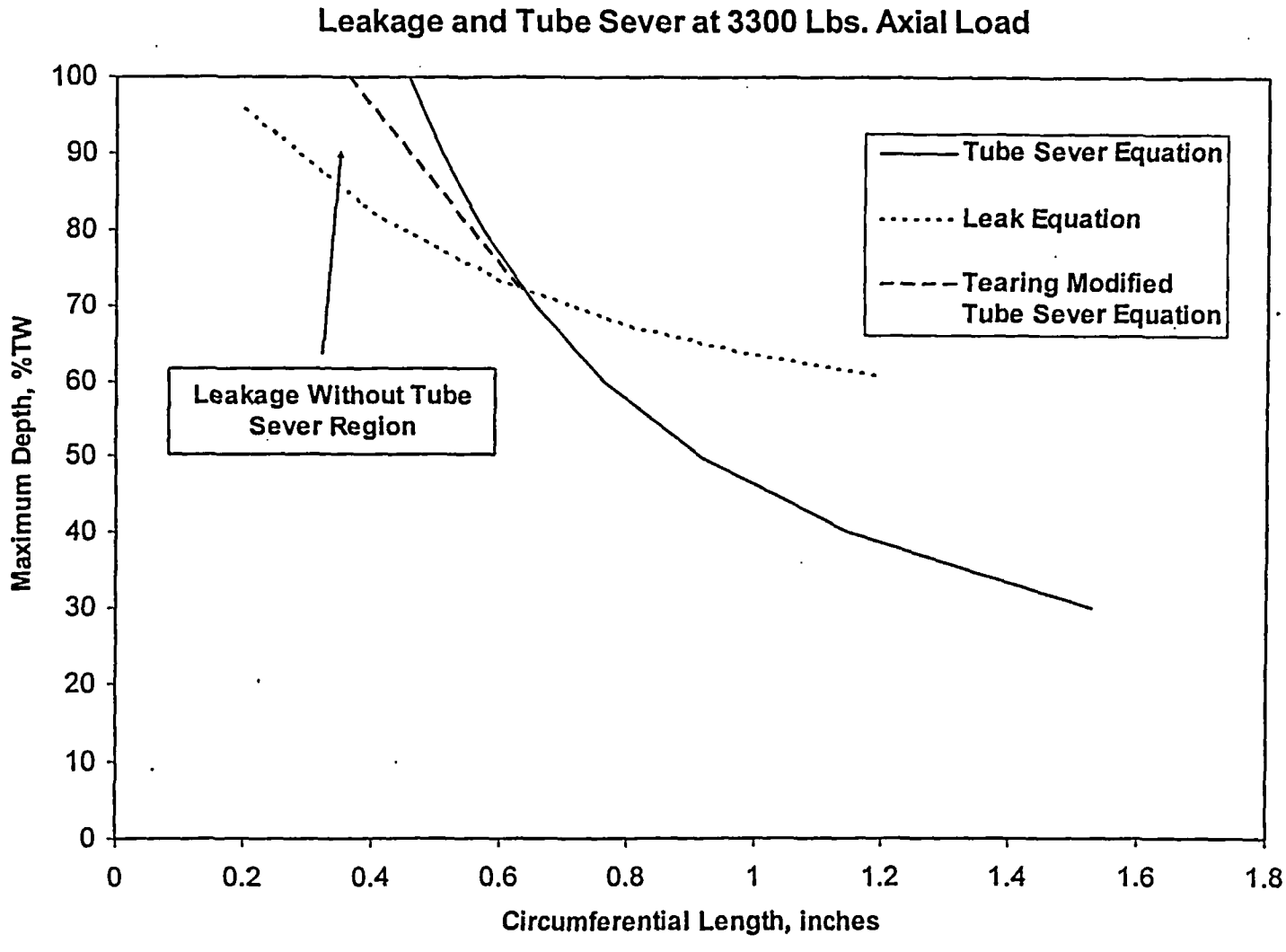
- > Freespan Tube Sever = 0.24 in.^{2}
- > Tubesheet Crevice Tube Sever = 0.014 in.^{2}
- > Pop-Through of Freespan Flaw Without Tube Sever = 0.014 in.^{2}
- > Tube End Circumferential Crack = < 0.002 in.^{2}

Benchmarking With Past Inspection Results

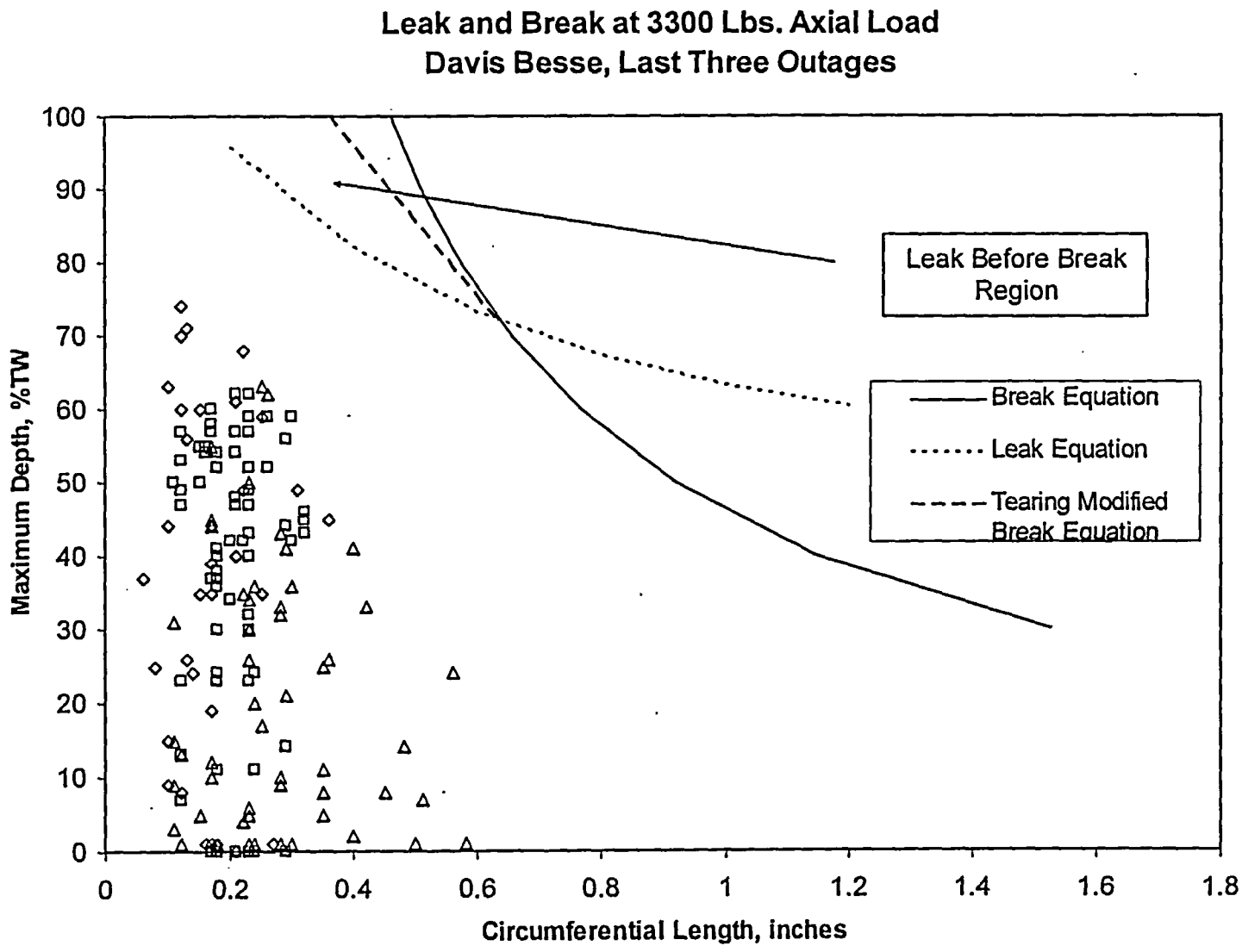
> Tube Sever is Only Expected for Indications Close to Best Estimate (50/50) Curve



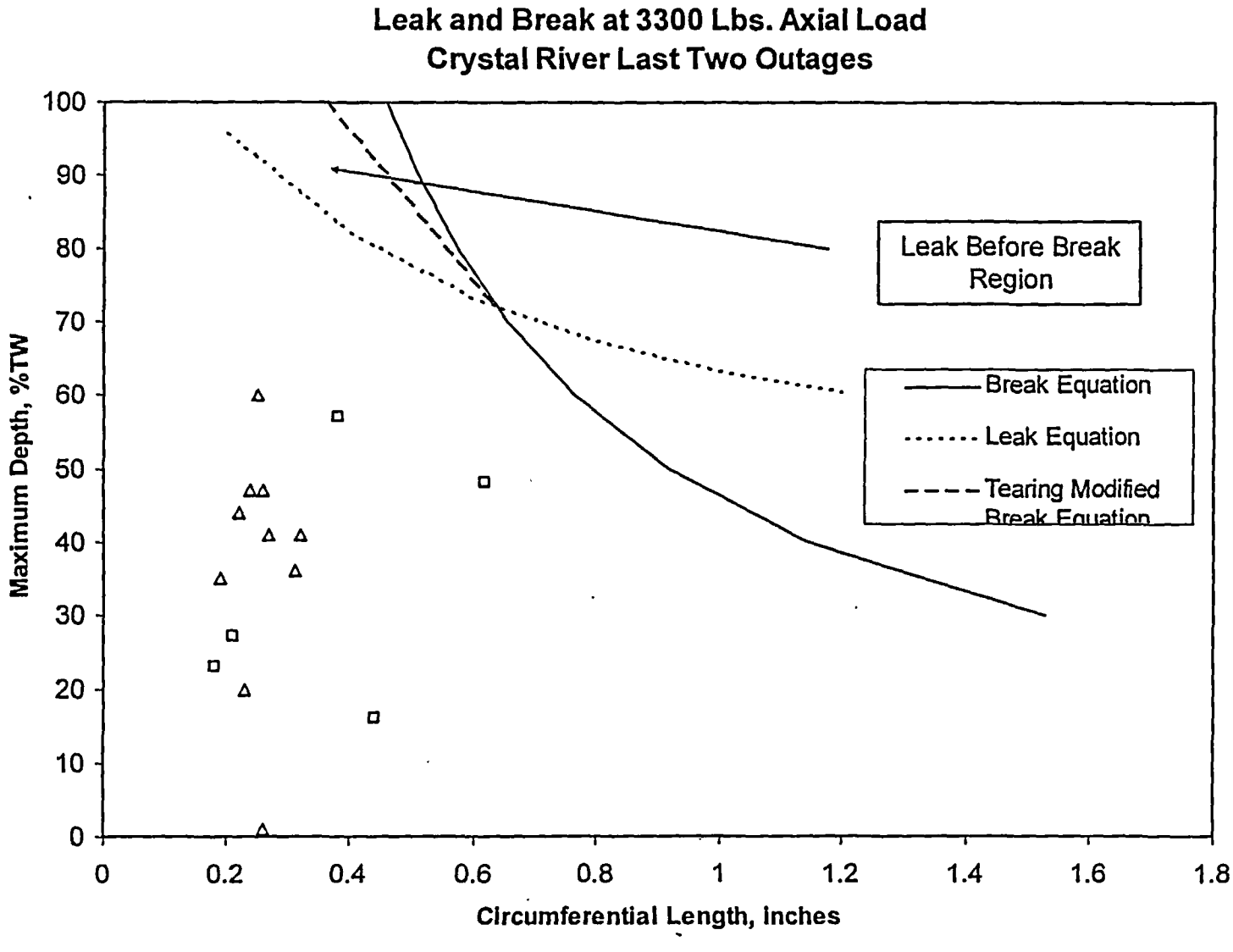
Benchmarking, cont.



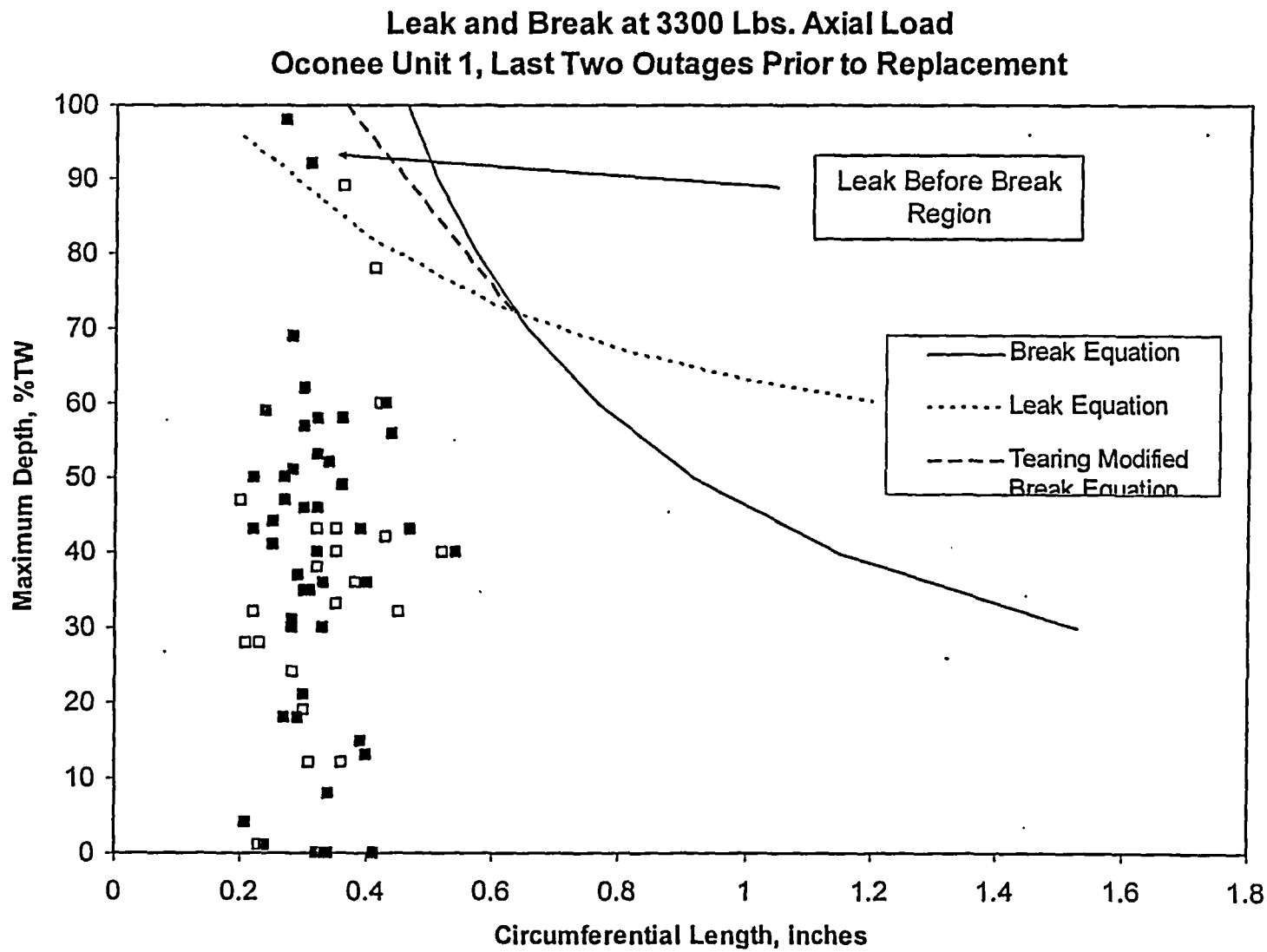
Benchmarking, cont.



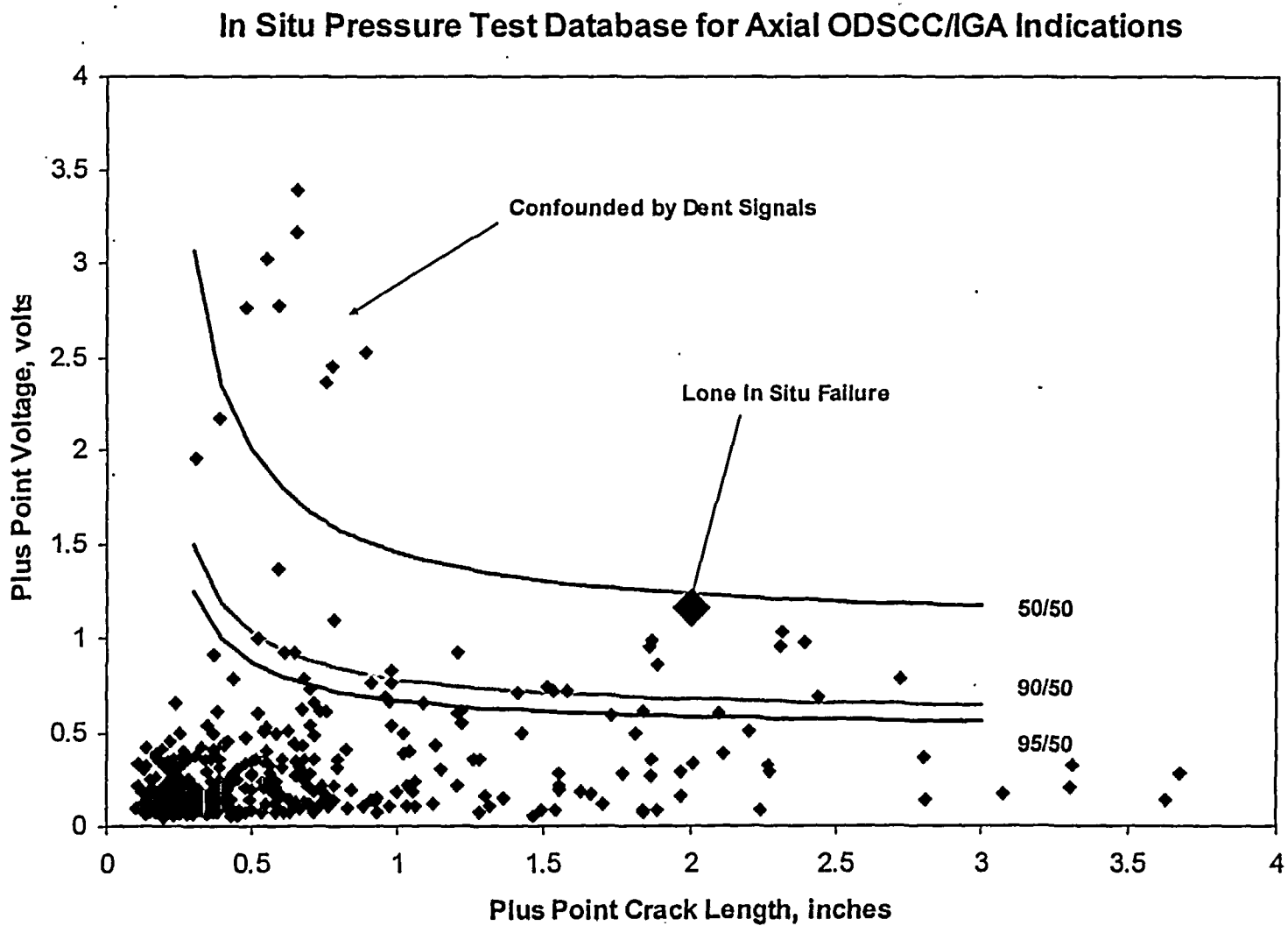
Benchmarking, cont.



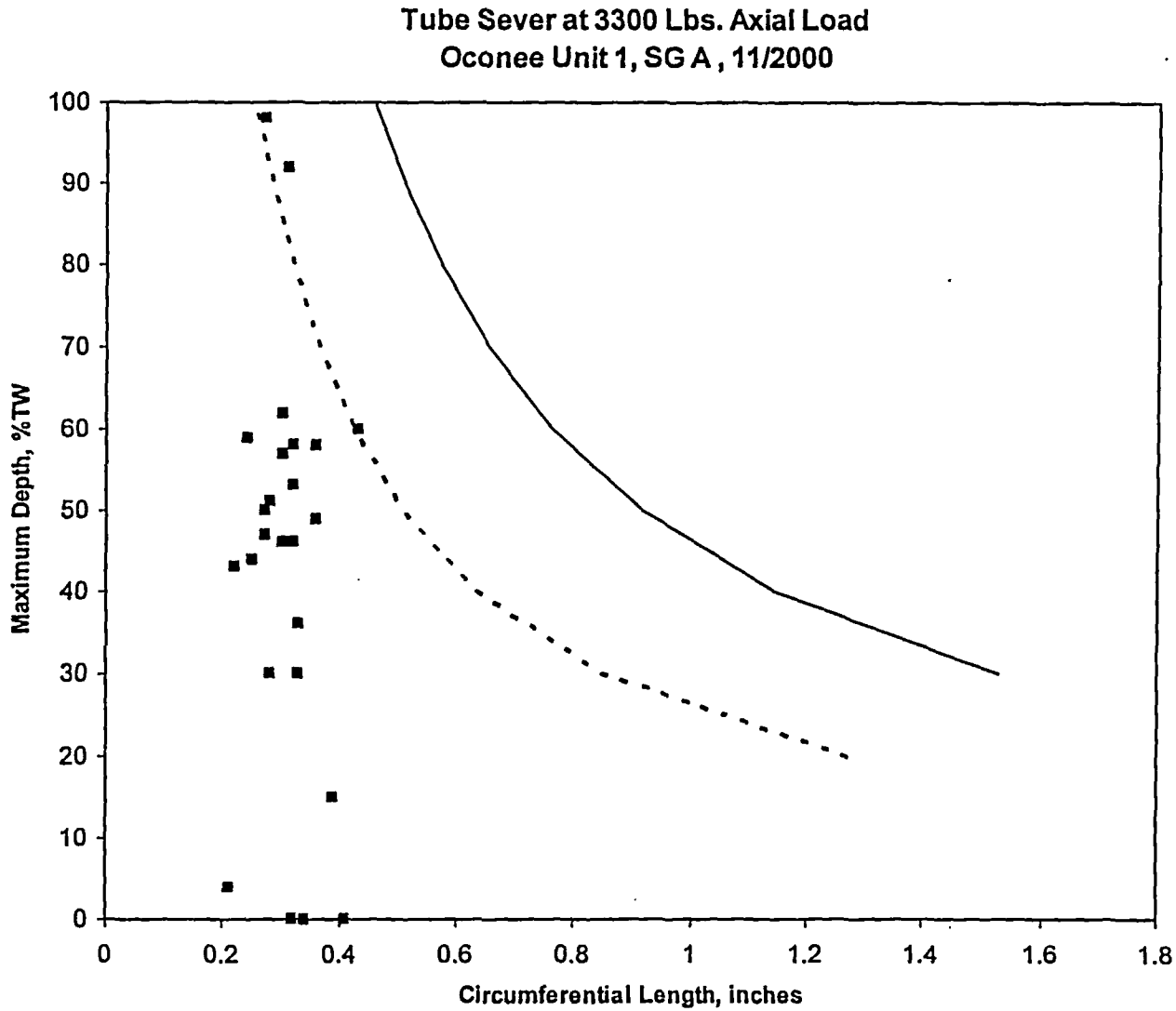
Benchmarking, cont.



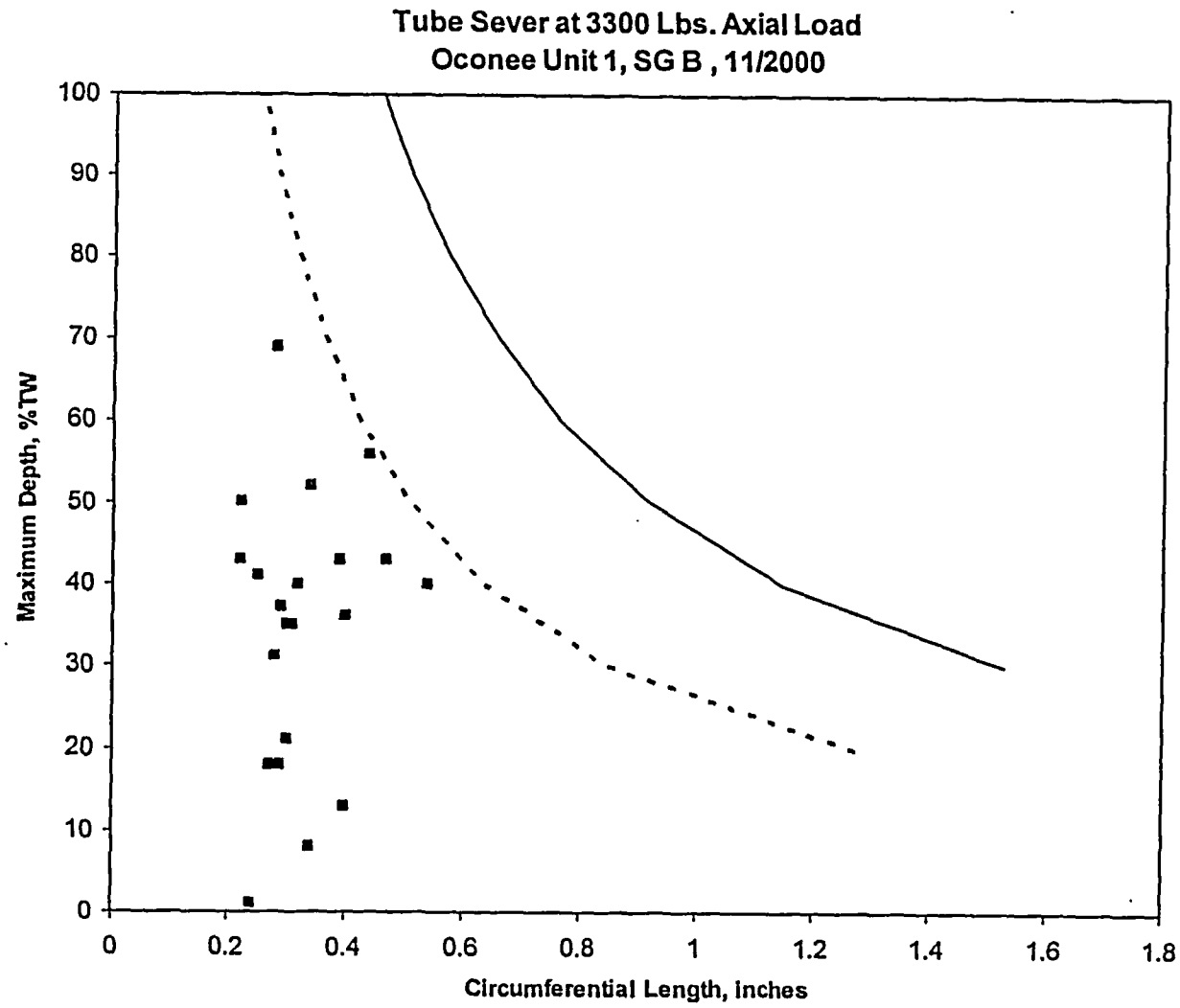
In Situ Pressure Test Results for Axial ODSCC



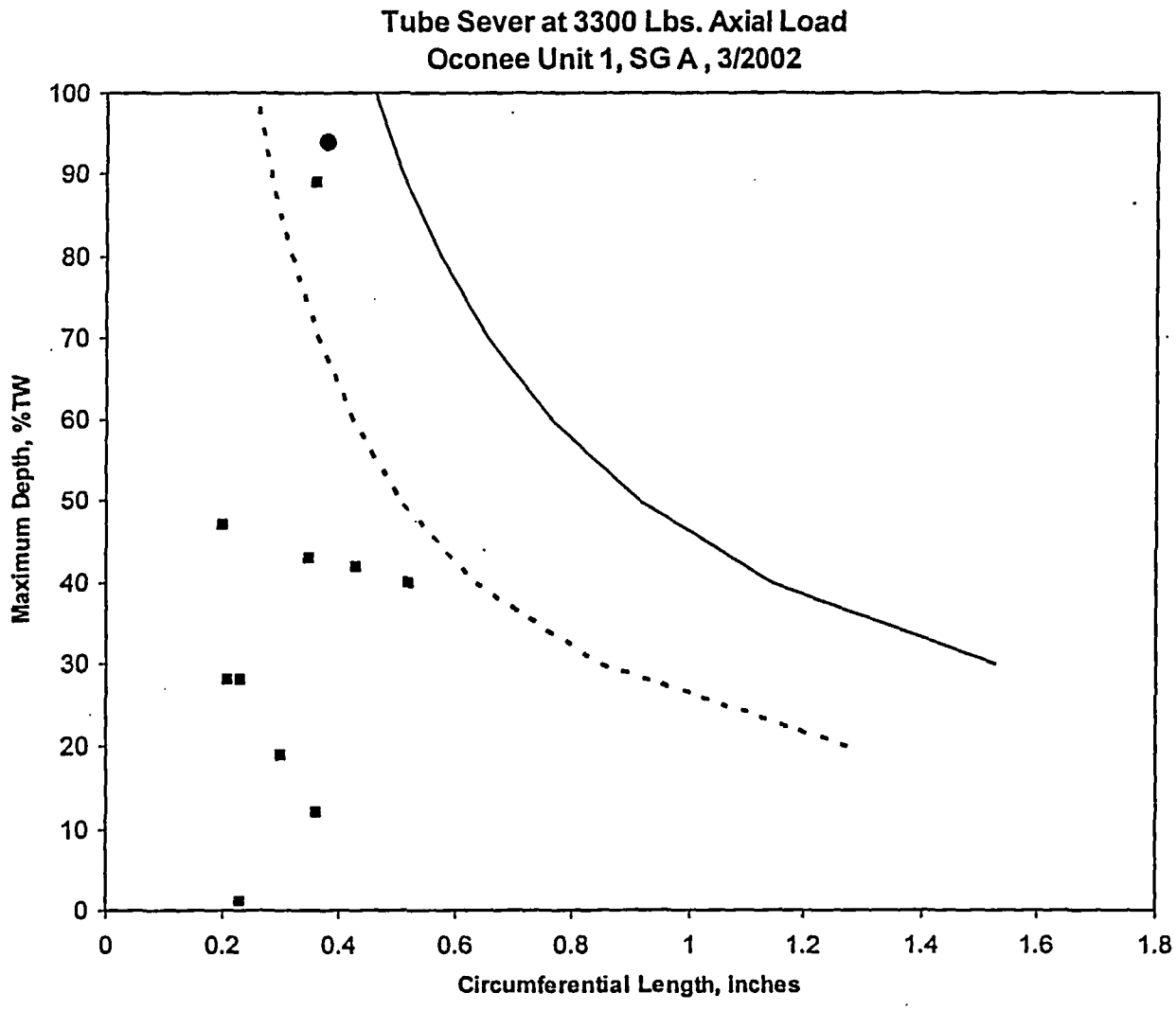
SG Tube Integrity
Condition Monitoring Perspective



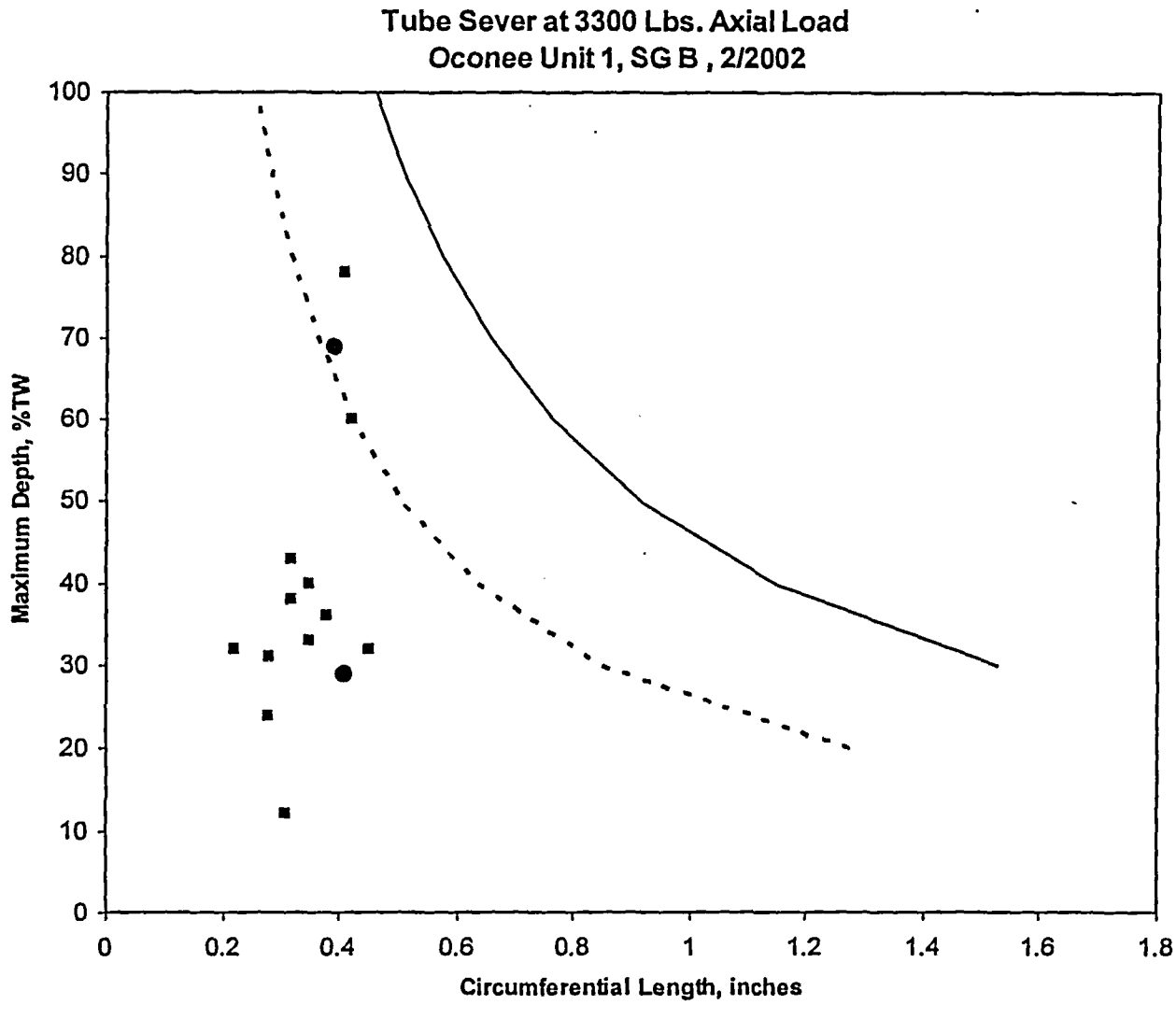
Condition Monitoring, cont.



Condition Monitoring, cont.



Condition Monitoring, cont.



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In Situ Axial Force Testing

- > Applying Very High (3300 lbs.) Axial Loads in Periphery Tubes is Highly Problematic
  - Small Bowl to Tubesheet Face Distance and A Large Axial Force Probe Length Makes Probe Insertion an Issue
- > Extra Axial Force Must be Applied to Compress Tube Region Below Flaw
- > If Buckling Occurs Applied Force is Grossly Underestimated
- > Potential to get In Situ Test Axial Load Cable Stuck in Tube

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Summary

- LBLOCA tube loads, allowable flaw sizes, and potential for severing tubes are significantly affected by tube-to-shell ΔT and tube location within the bundle (tubesheet radius).
- The projected number of in service circumferential flaws at periphery tube locations for at risk SGs is approximately 60.
- The probability of having a tube sever at the maximum periphery loads is 7.2E-4 per detected indication.
- For the worst case SG just prior to replacement, it is projected that 1 tube will sever as a result of a LBLOCA event with a probability of 0.04.

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Summary, cont.

- The leakage associated with SG repair products (plugs, sleeves, ARC), tubesheet crevice flaws and pop through of flaws in the free span is a small fraction of a tube sever.
- The limiting projected leakage area associated with one tube sever is 0.24 in^2.
- Including a LBLOCA event as a level D accident in Condition Monitoring tube integrity evaluations would impose severe In Situ testing requirements with unwarranted dose and outage schedule penalties.