Calculating Inspector Probability of Detection Using Performance Demonstration Program Pass Rates

Stephen Cumblidge

NRC/PDI Meeting

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Performance Demonstration and Inspector POD

- This work calculates approximate probability of detection (POD) characteristics of inspectors in ideal conditions using the pass rates of the Performance Demonstration Initiative (PDI)
  - Statistical models were used to determine the effectiveness of the PDI tests as a screening tool
  - Possible PODs vs. Flaw depths are calculated using deterministic calculations

NRC Questions

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- How skilled are nuclear NDE inspectors in general?
- Why are requalification pass rates for IGSCC testing similar to the pass rates for the initial tests?
  - Is this a concern?
  - Why are the rates so similar?
- How well does a PDI-qualified test find a 10% through-wall flaw in a Dissimilar Metal Weld?
  - Several Flaw Evaluations for N-770-1 relief requests depend on the smallest flaw that can be reliably detected
- Why are the POD curves provided in MRP-262 not consistent with the Supplement 10 Pass Rates?

Anecdotes

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“PDI is being used by some groups as a form of training”

“Some test blocks at PDI are harder than others”

Limitations of this Work

- This work relies entirely on the pass rates for the PDI examinations described in MRP-262 and in public meetings
- There are a host of factors that produce differences between PDI results and the actual performance of NDE in the field
- This work would not have predicted the failures to find the five large axial flaws at North Anna or the laminar flaws at Diablo Canyon

Simple Inspector POD Calculations

Pass Rates at PDI

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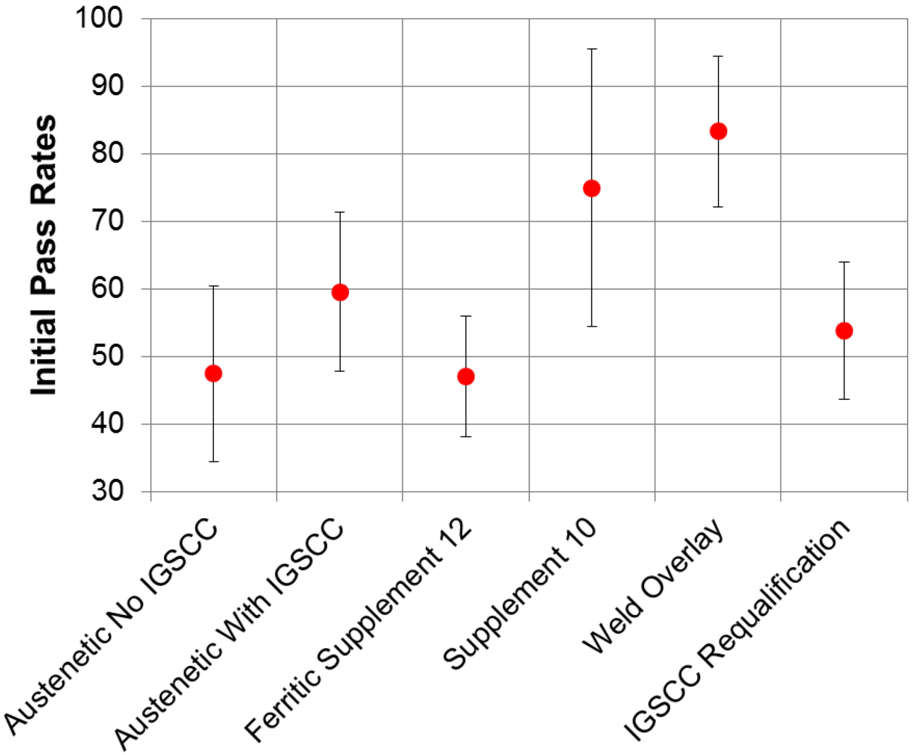
PDI Pass rates were given at the November 2012 and the June 2013 PDI meetings

Qualification	Beginning Number	Passed 1	# Round 2	Passed 2	# Round 3	Passed 3	Passed First Try	Yield
Austenetic No IGSCC	40	19	13	9	3	3	48%	78%
Austenetic With IGSCC	47	28	16	8	3	2	60%	81%
Ferritic Supplement 12	85	40	35	22	8	8	47%	82%
WOL	30	25	4	3	0	0	83%	93%
Supplement 10	12	9	3	3	0	0	75%	100%
IGSCC Requalification	65	35	29	13	3	3	54%	78%

Information From November 2012 PDI Meeting



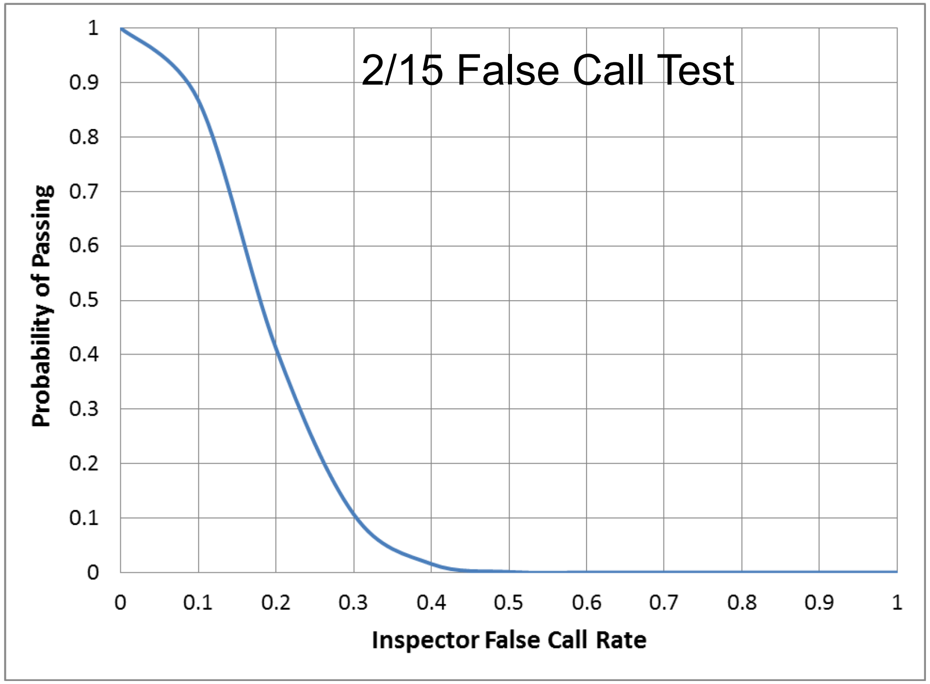
95% Upper and Lower Bounds (90% Inclusive)

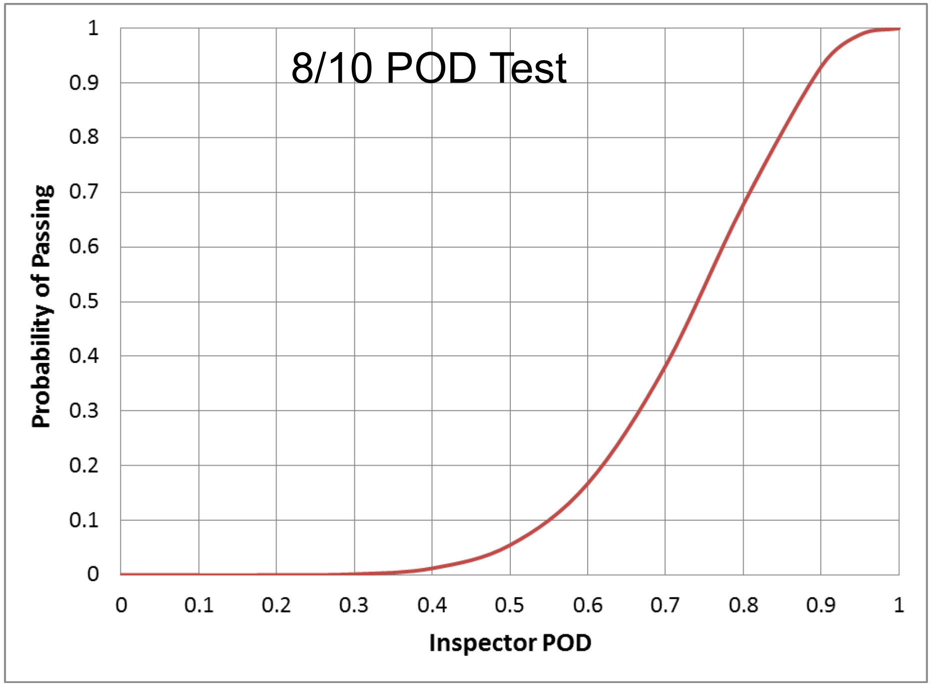
Design of Appendix VIII

- Appendix VIII uses Power Law curves to set the difficulty of the tests

$$Pwr(FCP) = \sum_{k=0}^{C_0} \left(\frac{N!}{k!(N-k)!} \right) FCP^k (1 - FCP)^{N-k}$$

$$Pwr(POD) = \sum_{k=C_1}^{M} \left(\frac{M!}{k!(M-k)!} \right) POD^k (1 - POD)^{M-k}$$

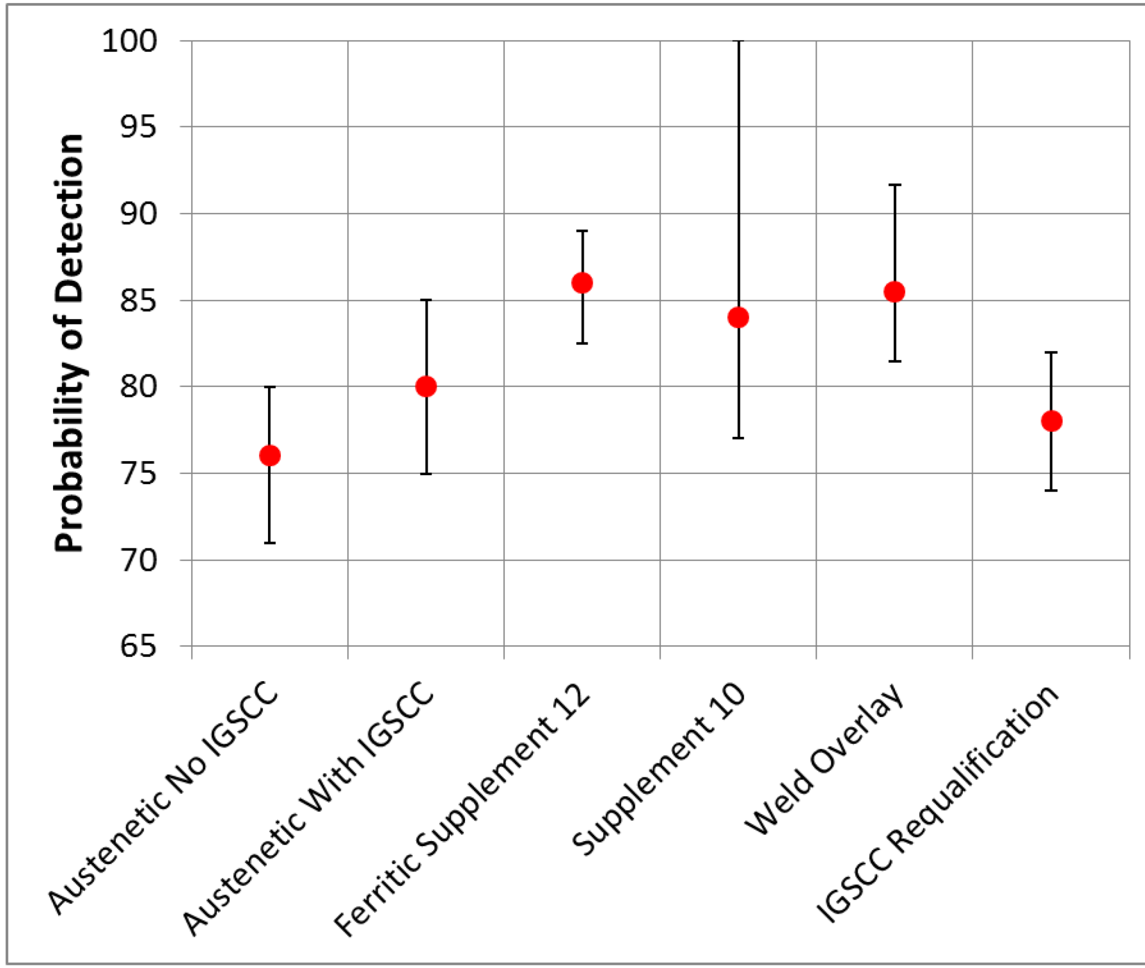




Average POD of Inspectors Who Pass PDI Testing

Pass Rates Converted to PODs using Power Law Curves

A 10% False Call Rate was assumed for Supplement 2 and 10 Examinations



95% Upper and Lower Bounds (90% Inclusive)

Skill Distributions and Pass Rates

Calculating a Pass Rate Using a POD Distribution

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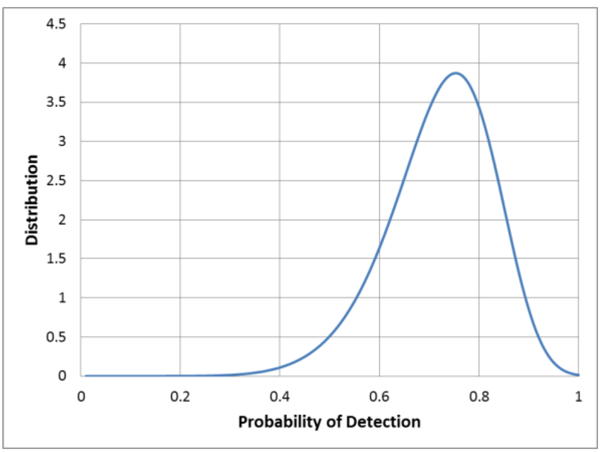
Assume an Inspector Skill Distribution, multiply by the expected pass rate for each POD, and get the probabilities of who passes and who fails

Postulated distribution of inspectors with different skill levels



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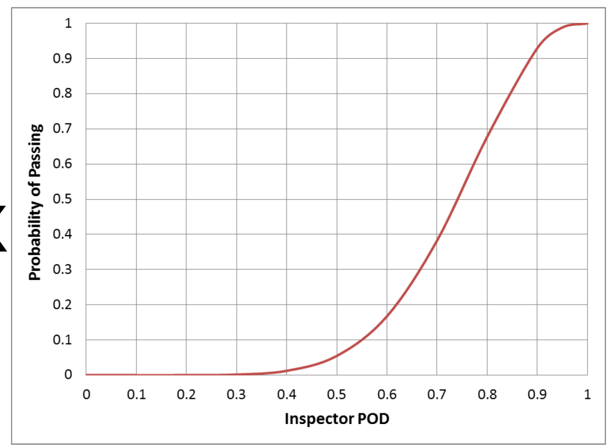
Power Law Curve



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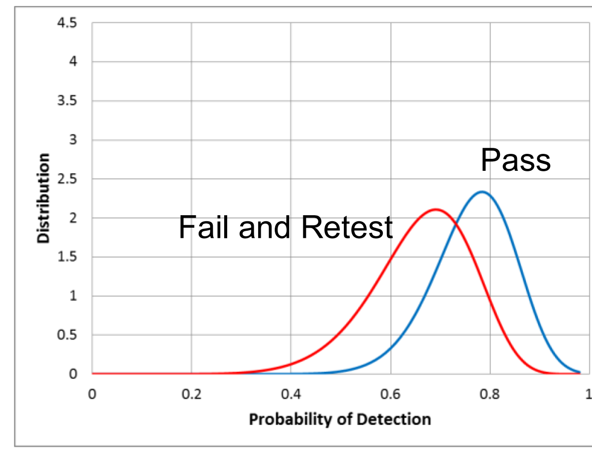
Pass and Fail Distributions



The "Failed" inspectors are sent back through for a total of three possible tests

Postulated Distributions are chosen to produce ≈50% initial pass rates and 80% Total Yields after three tries

Case 1- A Mix of Skilled Inspectors and Inspectors in Training

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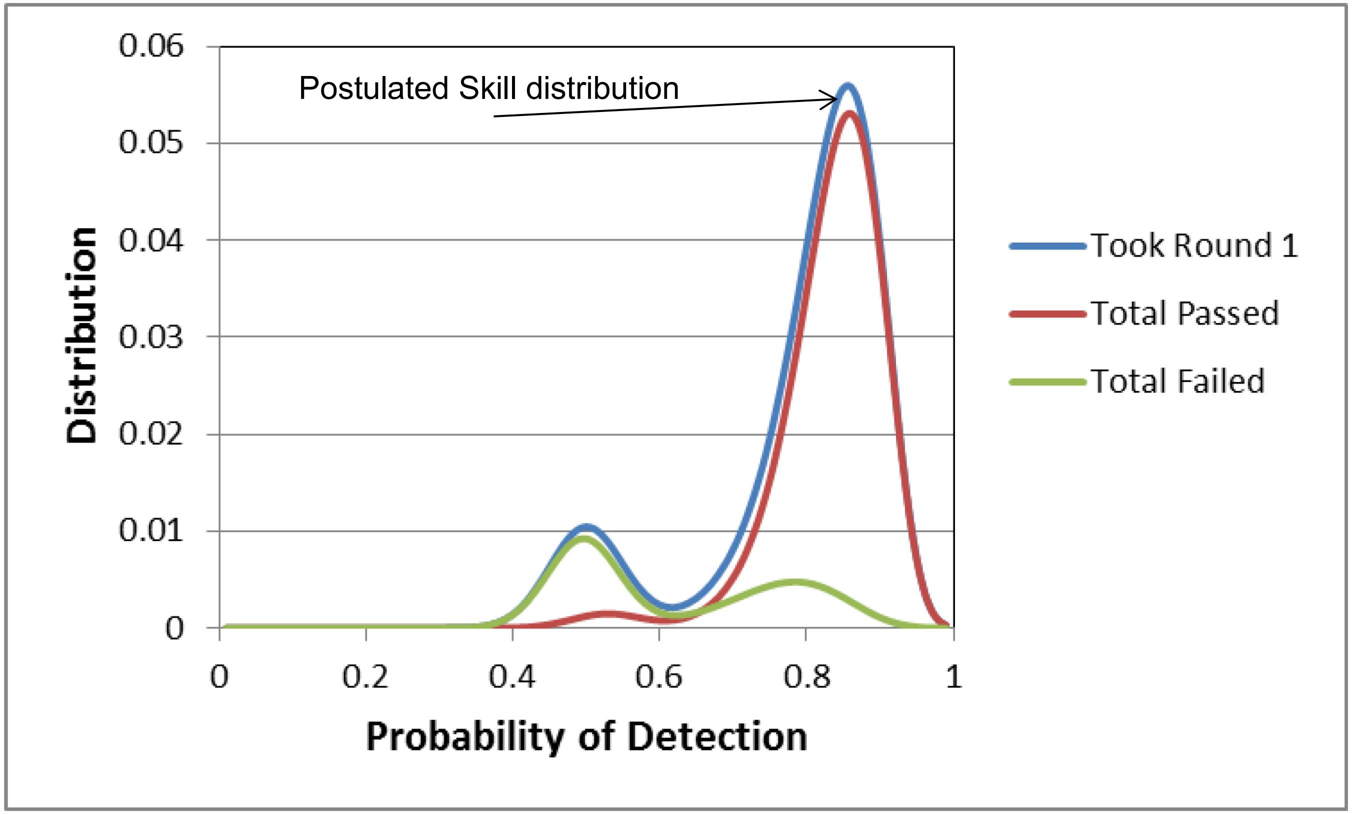
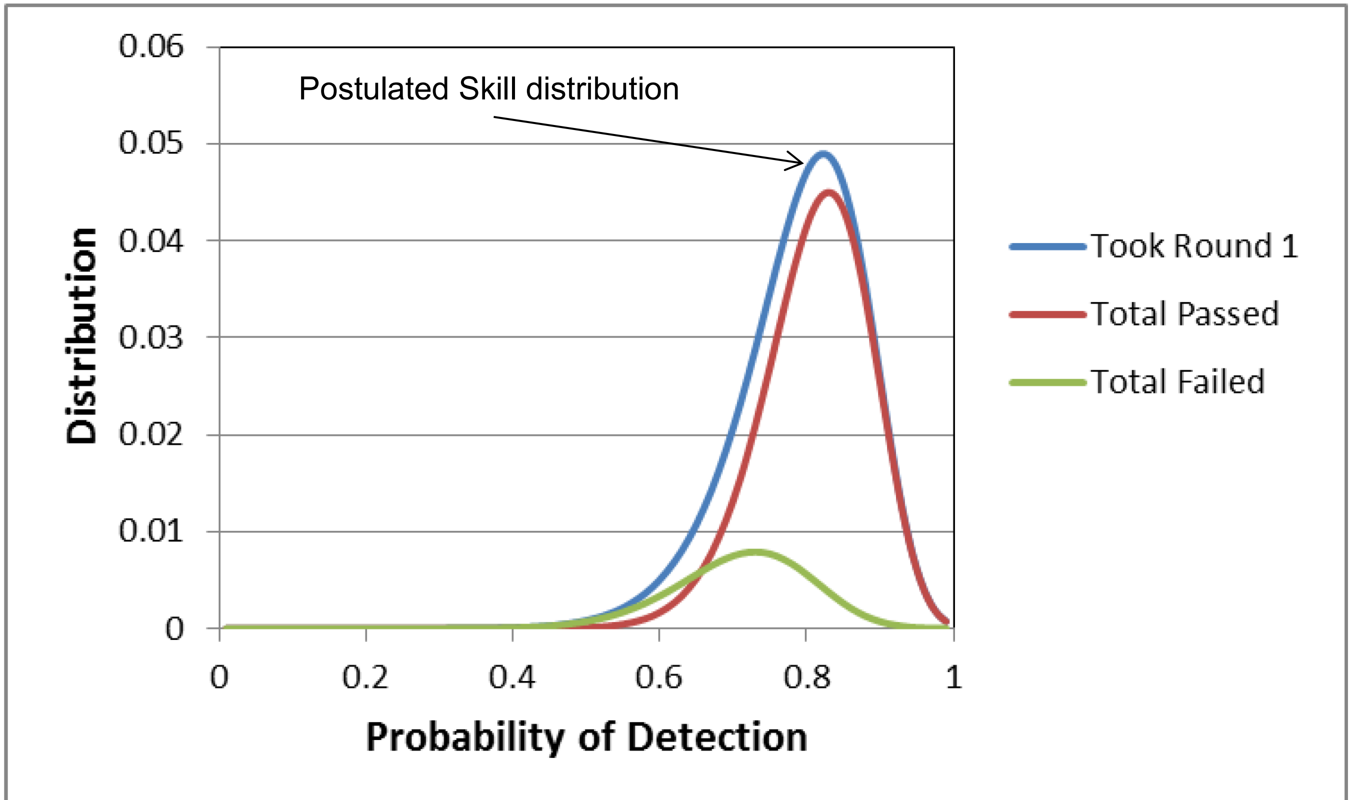


Using Simulated Bimodal Distribution

Initial Pass Rate:	49%
Yield after three tries:	79%
Average POD of All:	79%
Average POD of Passed:	83%

The test appears to weed out poor inspectors while allowing skilled inspectors to pass, as designed

Case 2- Skilled Inspectors Only



Using Simulated Weibull Distribution

Initial Pass Rate:	49%
Yield after three tries:	82%
Average POD of All:	79%
Average POD of Passed:	81%

Discussion

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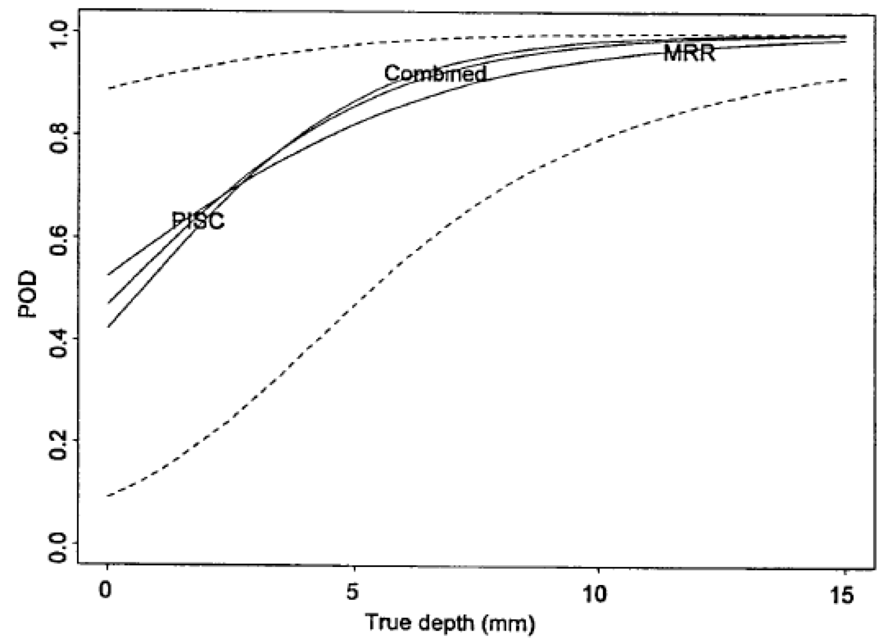
- If a mixed group of inspectors are tested, mostly only the skilled inspectors will pass
  - If a large number of unskilled people were taking the test, the pass rates would be significantly lower
- If a group of only skilled inspectors is tested, the skill distribution does not change greatly
  - The requalification rates for a skilled group may therefore not be very different than the initial pass rates
- Appendix VIII and PDI appear to work well as a screening test

Pass Rates and POD vs. Flaw Depth

POD vs. Flaw Depth

- Deep flaws are generally considered easier to detect during ultrasonic testing than very shallow flaws
- Appendix VIII describes the required flaw depth distribution, so this work will focus on POD vs. flaw depth
- Depth is certainly not the only factor



From NUREG/CR-6795

PISC- Programme for the Inspection of Steel Components

MRR- Mini Round Robin

PIRR- Piping Inspection Round Robin

Appendix VIII and Flaw Depths and Lengths

- The flaw depths in the tests were designed to be evenly distributed
- No flaw length requirements for specimens are described in Appendix VIII
- The effects of the flaw depth distribution on the difficulty of the test was not discussed in "NUREG/CR 7165 "The Technical Basis Supporting ASME Code, Section XI, Appendix VIII: Performance Demonstration for Ultrasonic Examination Systems"

Design of Detection Test Blocks

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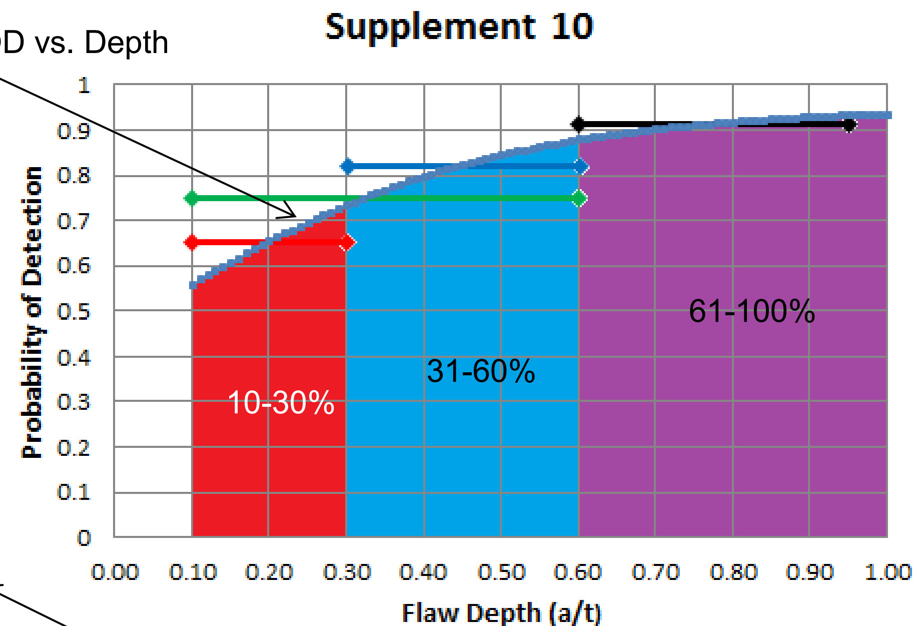
- Appendix VIII Supplement 2 has the following stipulations on detection sample design:
  - 33% of the flaws need to be from 5-30%
  - 33% of the flaws need to be from 31-100%
    - A test block with six 5% deep flaws and four 31% deep flaws is allowed
    - A test block with four 30% deep flaws and six 99% deep flaws would also be allowed
- Appendix VIII Supplement 10 has the following stipulations on detection sample design:
  - 20% of the flaws need to be from 10-30%
  - 20% of the flaws need to be from 31-60%
  - 20% of the flaws need to be from 61-100%
  - 75% of the flaws need to be from 10-60%
    - A test block with six 10% deep, two 31% deep and two 61% deep flaws is allowed
    - A test block with two 30% deep, six 60% deep and two 99% deep flaws would also be allowed

Calculating Pass Rates Using POD vs. Depth

The POD for each depth category is calculated by integrating under the POD curve over the depth range

This assumes an even distribution of flaws across the flaw ranges



Flaw Number	Flaw Depths	POD	POM
1	10-30%	0.652058	0.347942
2	10-30%	0.652058	0.347942
3	31-60%	0.820871	0.179129
4	31-60%	0.820871	0.179129
5	61-100%	0.913523	0.086477
6	61-100%	0.913523	0.086477
7	10-60%	0.751360	0.248640
8	10-60%	0.751360	0.248640
9	10-60%	0.751360	0.248640
10	10-60%	0.751360	0.248640

POM= 1-POD

Calculation Method

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Flaw Number	Flaw Depths	POD	POM
1	10-30%	0.652058	0.347942
2	10-30%	0.652058	0.347942
3	31-60%	0.820871	0.179129
4	31-60%	0.820871	0.179129
5	61-100%	0.913523	0.086477
6	61-100%	0.913523	0.086477
7	10-60%	0.751360	0.248640
8	10-60%	0.751360	0.248640
9	10-60%	0.751360	0.248640
10	10-60%	0.751360	0.248640

The probability of passing an 10/10, a 9/10, and an 8/10 test are calculated

These values are summed

The Pass Rate is modified by a false call rate

POD1 x POD2 * POD3 * etc.

POM1 x POD2 x POD3 x etc.

POD1 x POM2 x POD3 x etc.

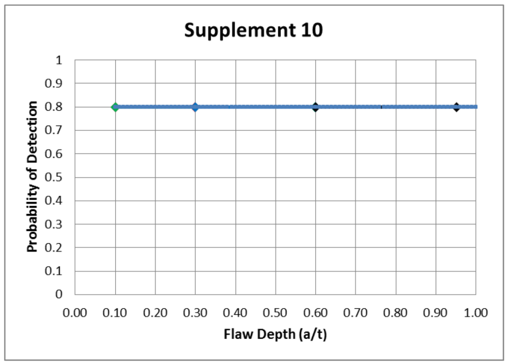
Probability of 10 out of 10		0.07619969
Probability of 9 out of 10	Miss Flaw	
	1	0.04066053
	2	0.04066053
	3	0.01662821
	4	0.01662821
	5	0.00721327
	6	0.00721327
	7	0.02521604
	8	0.02521604
	9	0.02521604
	10	0.02521604
	Sum	0.22986818

POM1 x POM2 x POD3 x POD4 x etc.

POD1 x POM2 x POM3 x POD4 x etc.

		Miss Flaw								
Probability of 8 out of 10	And	1	2	3	4	5	6	7	8	9
	2	0.02169666								
	3	0.0088729	0.008873							
	4	0.0088729	0.008873	0.003629						
	5	0.00384904	0.003849	0.001574	0.001574					
	6	0.00384904	0.003849	0.001574	0.001574	0.000683				
	7	0.01345541	0.013455	0.005503	0.005503	0.002387	0.002387			
	8	0.01345541	0.013455	0.005503	0.005503	0.002387	0.002387	0.008345		
	9	0.01345541	0.013455	0.005503	0.005503	0.002387	0.002387	0.008345	0.008345	
	10	0.01345541	0.013455	0.005503	0.005503	0.002387	0.002387	0.008345	0.008345	0.008345
	Sum	0.10096215	0.079265	0.028787	0.025159	0.010231	0.009548	0.025034	0.016689	0.008345

Calculation Check



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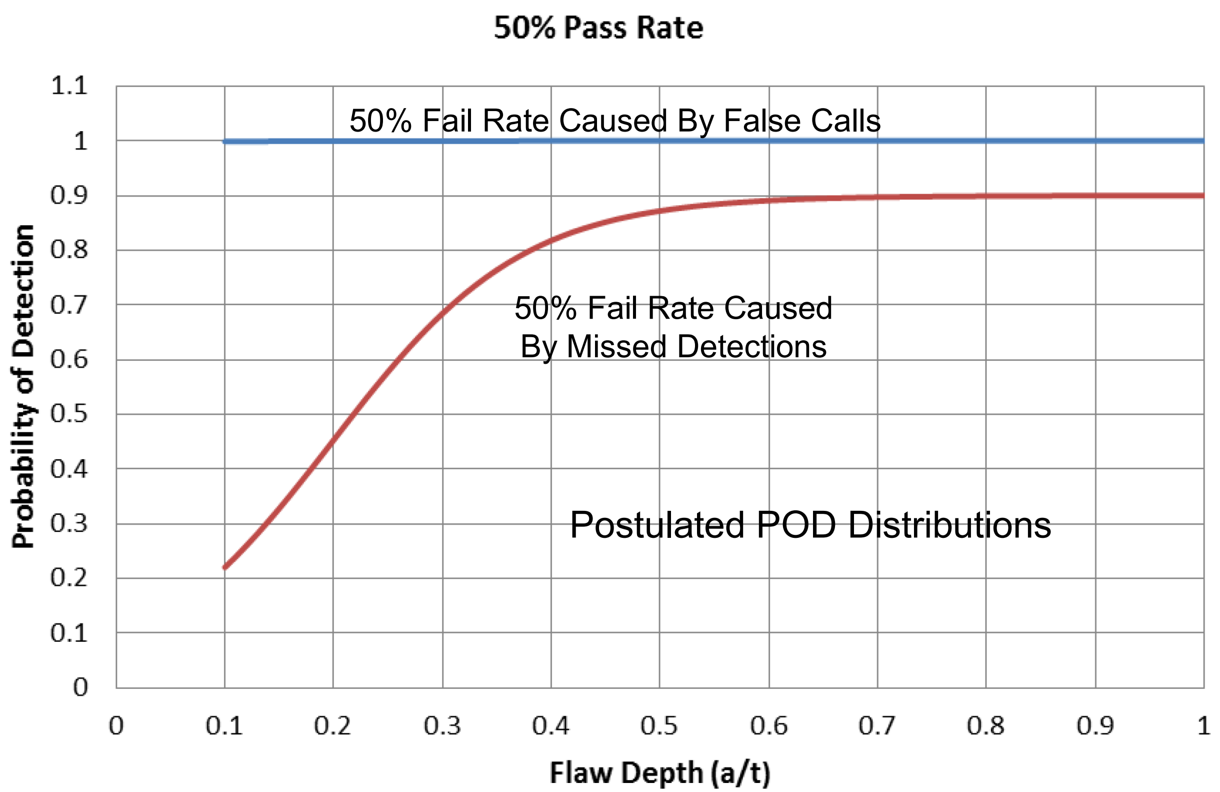
Probability of										
10 out of 10		0.07619969								
Probability of	Miss Flaw									
9 out of 10	1	0.04066053								
	2	0.04066053								
	3	0.01662821								
	4	0.01662821								
	5	0.00721327								
	6	0.00721327								
	7	0.02521604								
	8	0.02521604								
	9	0.02521604								
	10	0.02521604								
	Sum	0.22986818								
		Miss Flaw								
Probability of	And	1	2	3	4	5	6	7	8	9
8 out of 10	2	0.02169666								
	3	0.0088729	0.008873							
	4	0.0088729	0.008873	0.003629						
	5	0.00384904	0.003849	0.001574	0.001574					
	6	0.00384904	0.003849	0.001574	0.001574	0.000683				
	7	0.01345541	0.013455	0.005503	0.005503	0.002387	0.002387			
	8	0.01345541	0.013455	0.005503	0.005503	0.002387	0.002387	0.008345		
	9	0.01345541	0.013455	0.005503	0.005503	0.002387	0.002387	0.008345	0.008345	
	10	0.01345541	0.013455	0.005503	0.005503	0.002387	0.002387	0.008345	0.008345	0.008345
	Sum	0.10096215	0.079265	0.028787	0.025159	0.010231	0.009548	0.025034	0.016689	0.008345

$$= \quad Pwr(POD) = \sum_{k=C_1}^{M} \left(\frac{M!}{k!(M-k)!} \right) POD^{k} (1 - POD)^{M-k}$$

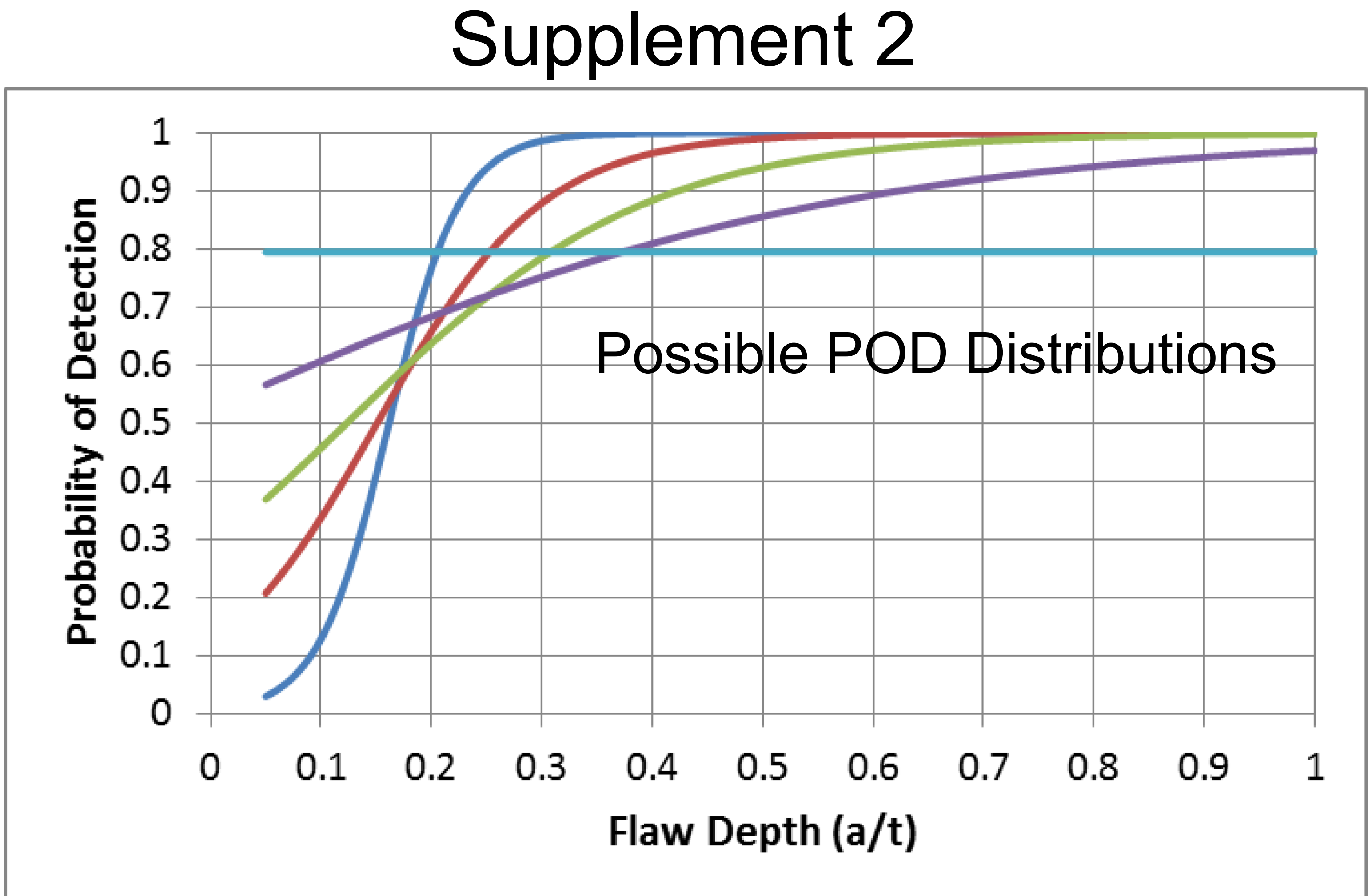
- For a constant POD (no depth dependence), the spreadsheet calculation needs to produce the same result as the power law calculations
- This was checked against several PODs, and the spreadsheet calculation does indeed match the power law calculation
- For Example, a POD of 0.8 yields a pass rate of 0.6778 from both methods for an 8/10 detection test

Effects of Failures Because of False Calls



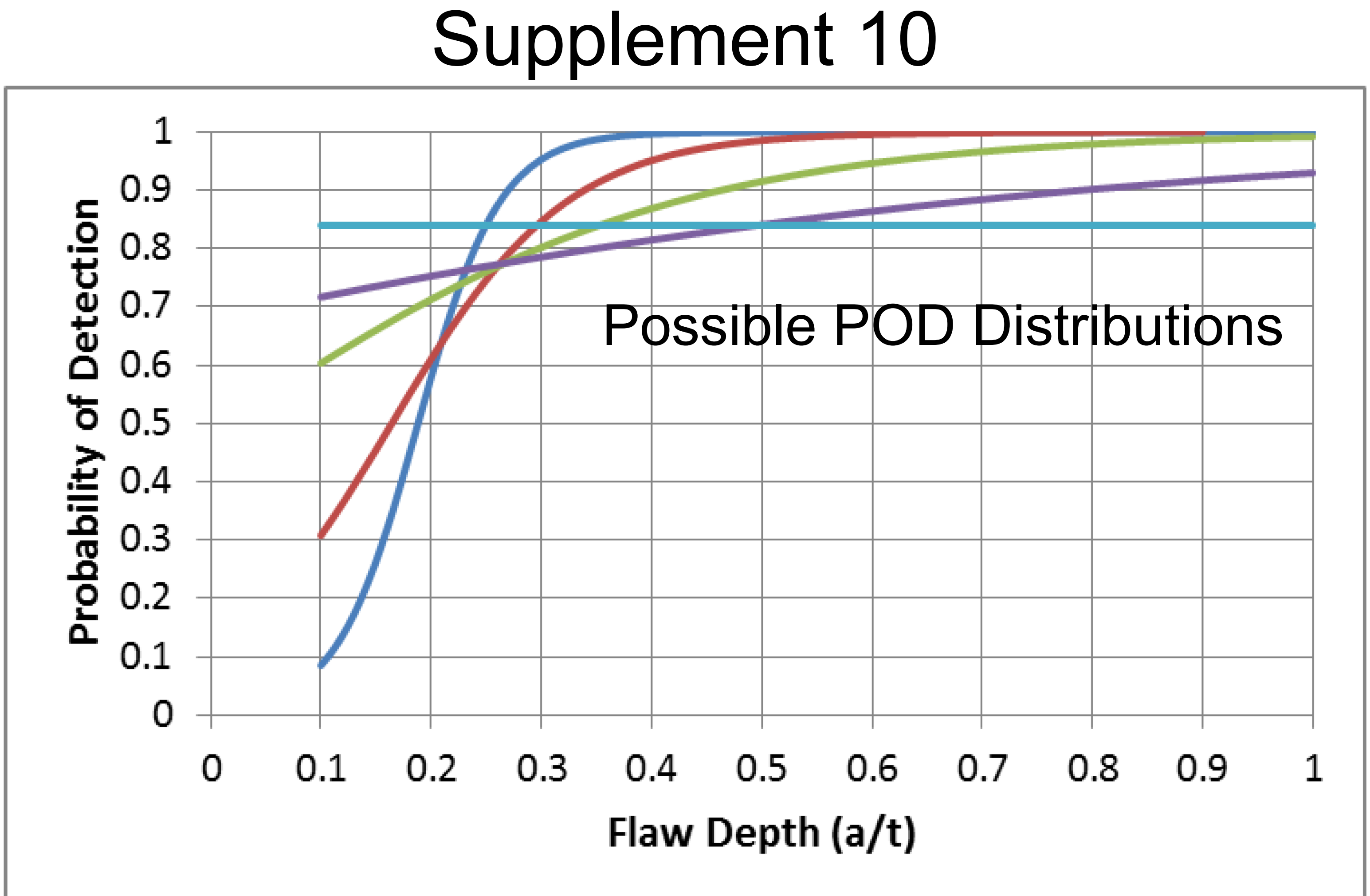
Based on the data supplied by EPRI at previous PDI Meeting and MRP-262 a 10% FCR was used

55% Pass Rates For Supplement 2



These distributions assume a 10% FCP

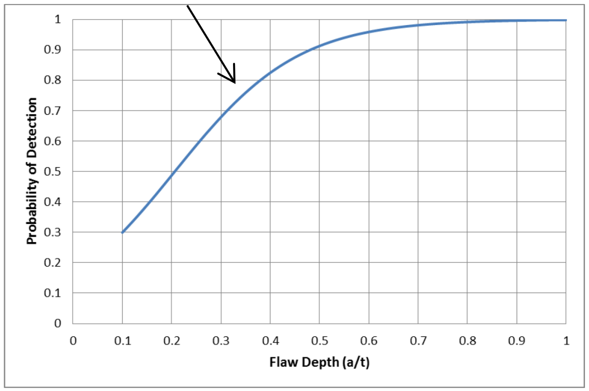
75% Pass Rate for Supplement 10



These distributions assume a 10% FCP

Effects of Test Block Variability

Postulated POD vs. Depth



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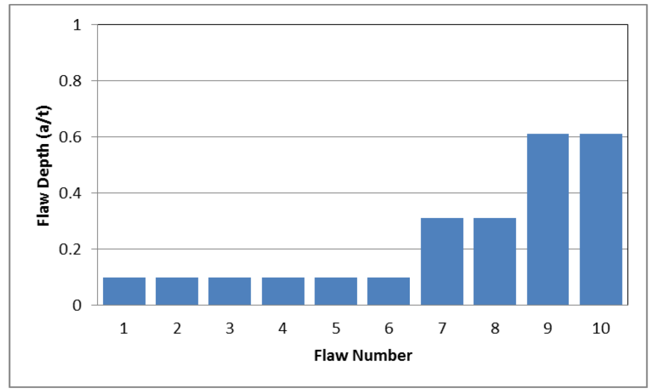
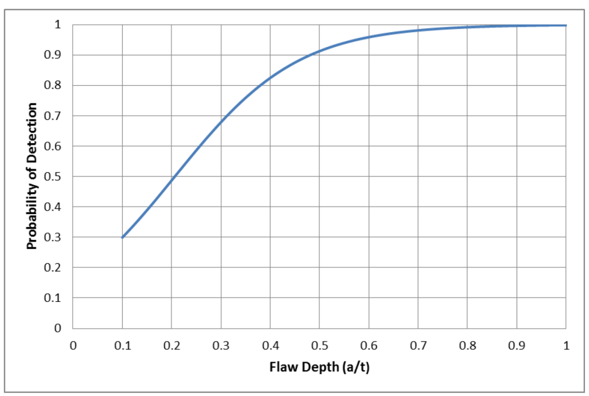


= 3%



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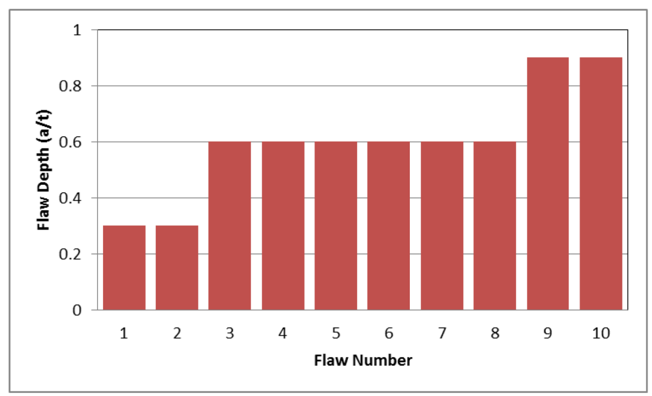

= 96%

If POD is strongly affected by flaw depth, one can influence the outcome of a test by selecting easy or difficult test blocks

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MRP-262 Analysis

MRP-262 PODs vs. Pass Rates

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- MRP-262 Revision 1 describes the average POD for PDI inspections of circumferential flaws in dissimilar metal welds as being between 94-100%
- The high PODs are based on many inspections and have been verified by independent review
- The POD curves showed a small dependence on flaw depth
- The false call rates ranged from 2-16%
- These high PODs are not consistent with the 75% pass rates at PDI and are more consistent with 95% or better pass rates
- Why is there a difference?

MRP-262 Compared to Calculations

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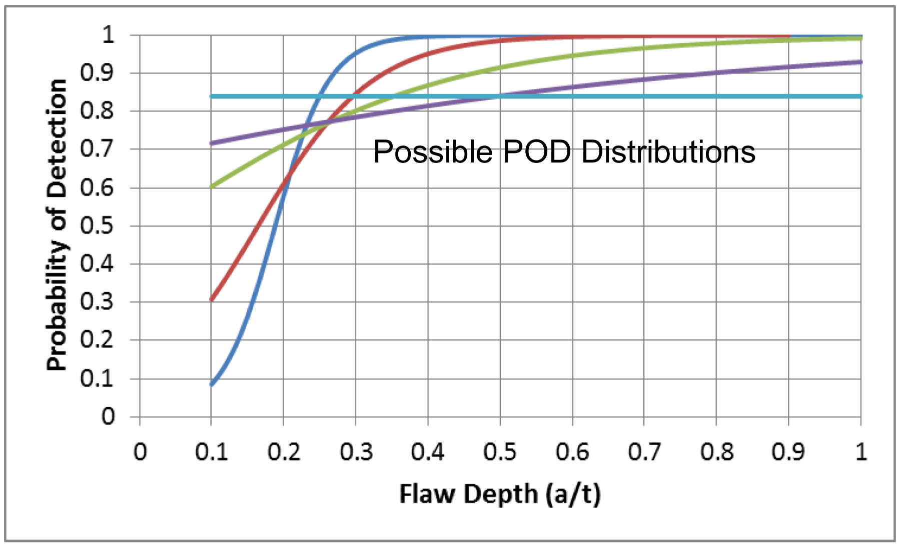
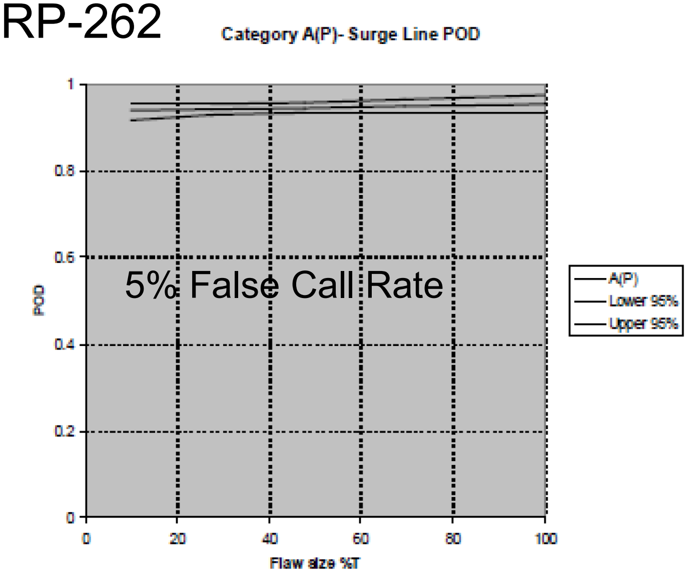
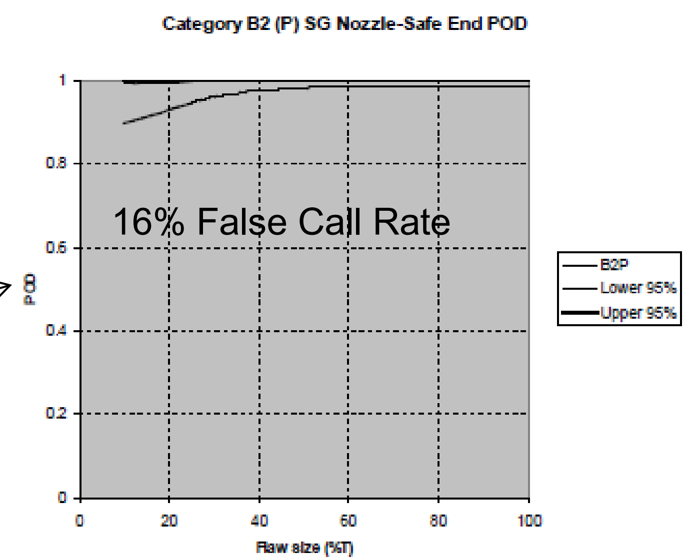
Supplement 10



MRP-262





From MRP-262 Materials Reliability Program: Development of Probability of Detection Curves for Ultrasonic Examination of Dissimilar Metal Welds (MRP-262, Revision 1) Typical PWR Leak-Before-Break Line Locations

MRP-262 Analysis

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- The high POD for circumferential flaws appears to be valid based on independent review
  - The 10% Circumferential flaws are apparently large enough to be in the "Plateau" of the POD vs. depth curve
- The large difference between the POD expected based on pass rates and the given POD is most likely caused by the exclusion of axial flaws
  - The MRP-262 results exclude axial flaws, which make up 30%-70% of the flaws in the test specimens
  - This suggests that the axial flaws have a ≈65-75% POD in these tests (Assuming 50% Axial flaws)

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Have We Answered Any Questions?

NRC Questions Revisited

- How skilled are the inspectors in general?
  - PODs under ideal conditions appear to be fairly high (≈75-85%)
- Why are requalification pass rates for IGSCC testing similar to the initial tests?
  - This appears to be a result of the difficulty of the test and the skill distribution of the inspectors

NRC Questions Revisited

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- How well does a PDI-qualified test find a 10% through-wall flaw?
  - This question cannot be answered by this type of analysis
  - For circumferential flaws the MRP-262 data is likely accurate
  - For axial flaws not enough information is publically available
- Why are the POD curves provided in MRP-262 not consistent with the Supplement 10 Pass Rates?
  - This is likely caused by reduced detection of axial flaws which were not included in MRP-262 Analysis

Anecdotes

- "Unqualified people are sent to PDI as a form of training"
  - Unless their skills improve during testing, they are unlikely to pass via luck
- "Some test blocks at PDI are harder than others"
  - This is likely true

Path Forward

- The following information would be useful in improving the statistical analysis
  - The failure rate caused only by false calls for each test category
  - Axial Flaw Information For Supplement 10 Tests
    - Percentage of axial flaws in Supplement 10 tests
    - Size Distribution for axial flaws in Supplement 10 tests
  - The flaw depth distribution for each test
  - An analysis of the pass rates by test block
- The effects of training, initial and ongoing, are unknown