How reliable are the results of my NDT process? A scientific answer to a practical everyday question

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Abstract.
Approaches to evaluate NDT processes, like the Probability of Detection (POD), were originally developed for the aerospace. With the future challenges also other industrial sectors are seeing the advantages of introducing reliability concepts for their NDT processes. In this presentation, the needs and the basic ideas of reliability of NDT methods will be explained. It will provide the audience with the fundamentals of statistics and its connection to the physical behavior of NDT systems: How a POD evaluation is made, in general and explicitly.
The presentation will also call attention to challenges and solutions of using the POD in the field. Especially this is an important part, due to the insight into the last approaches in the scientific community, to solve typical problems in the industrial use of reliability approaches.

APPLIED VALIDATION

Probability of Detection

How reliable are the results of my NDT process?

A scientific answer to a practical everyday question.

Dr. Ing. Daniel KANZLER

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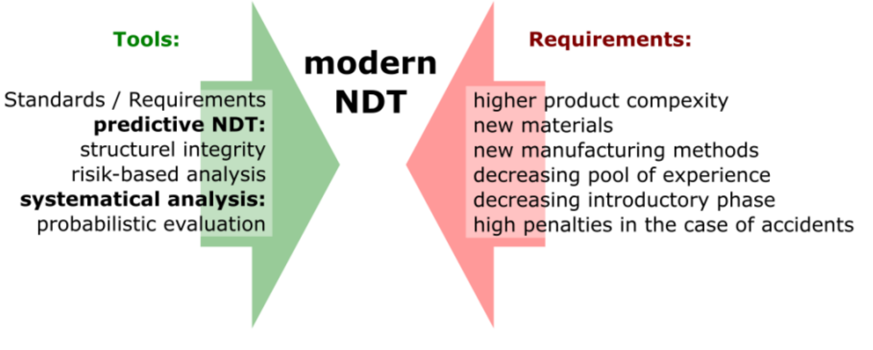
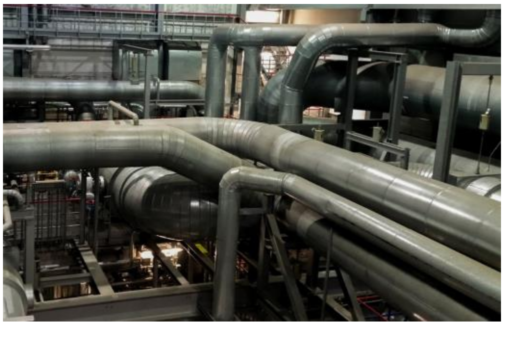
Requirements of the modern NDT situation

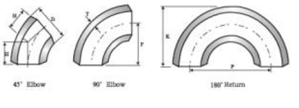


Practical use of the POD in industry

Area of Industry	Standard / Publication
Aerospace	*Airbus standard AITM 6-0014 (Probability of Detection)*
Nuclear power generation	*ASME – Code Section XI Appendix VIII "Performance Demonstration for Ultrasonic Examination Systems."*
Nuclear waste disposal	Reports about the final disposal project of SKB (e.g. R-06-08) and Posiva (e.g. WR 2013-70)
Security	Working group: Risk and security at BAM
Petrol-chemical industry	*Shell Global Solution "Use of Statistical Techniques for Sampling Inspections"*
Civil engineering	*Feistkorn et.al.: "POD and GUM Universal Methods for Making Safety Measurable"*
Railway industry	*Carboni et.al.: „Probability of Detection of Ultrasonic In-Service Inspection of Hollow Axles"*
Shipping	*Spies et.al.: „Surface, Near-Surface and Volume Inspection of Cast Components Using Complementary NDT Approaches"*

Influence of NDT on the failure rate





Typical failure rates for pipes in power plans:

10^-2 failure of a elbow pipe segment without inspection

10^-3 failure
with preservice inspection

10^-4 failure
with in-service inspection
every 10 years

There is neither a 100% detection probability nor a perfectly safe component.

How much probability is reliable?

Probability of Detection:	Meaning:
100% - Probability of Detection	Does not exist!
99% - Probability of Detection	Very high reliability (Miss: 1 von 100)
95% - Probability of Detection	High reliability (Miss: 5 von 100)
90% - Probability of Detection	Reliable ??? (Miss: 1 von 10)
50% - Probability of Detection	Coin flip

- Not every defect, which will be detected is critical
- Not every critical defect, which is not found, will lead to a failure
- In-service inspection: More times of testing will improve the detectability
  simplified example: testing a defect with 90% POD twice (independent measurement) lead to a 99 % detectability rate

29 out of 29 defects

Confidence interval of the 29 / 29 method

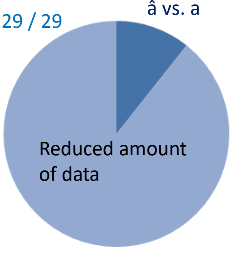
If we want to be sure about the result, we should also keep our possible error in mind: The smaller the possible error shall be the bigger will be the necessary amount of data. (error = 1 – level of significant)

90% probability of detection – 95 % confidence
29 hits out of 29 defects
45 hits out of 46 defects
59 hits out of 61 defects
73 hits out of 76 defects
85 hits out of 89 defects
98 hits out of 103 defects

Usually, we accept a 5% chance that we might be mistaken, to have the 90% probability to find the critical defect, we are searching for: 90% probability of detection with a 95% confidence interval.

High amount of data = high amount of cost. How to reduce cost?

- The theory of probability is not interested in physical and functional relationships between the signal and the defect parameter (Bury, K. V. Sons, J. W. &. *(Ed.)* Statistical Models in Applied Science *Wiley Series in Probability and Mathematical Statistics,* **1975**).
- To introduce the physical relationship of the NDT method can reduce the amount of data we need for estimating a 90% probability:
  - The 29 / 29 method needs at least 29 data for every defect size
  - The Hit/miss analysis needs at least 60 data points
  - The â vs. a analysis needs at least 40 data points
- Example from the field:
  - "29 / 29 POD (1972) from Rummel was using **328 data points"**
  - "POD (1989) from Berens was using only **35 data points"**
- The utilization of the physical principle leads to a reduction of 1/10 of the needed data points.



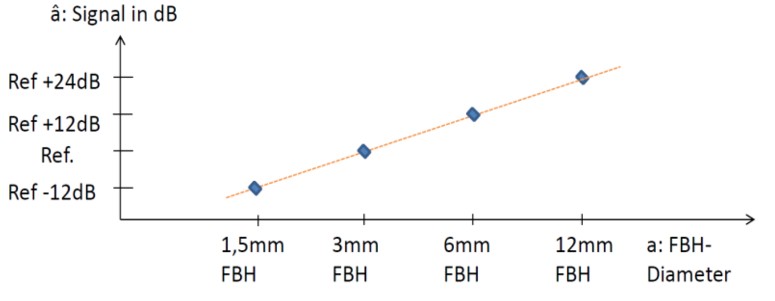
Probability of detection: â vs a

Signal response POD

Relationship between the signal and the defect parameters in UT

In the far field (4 times near the field of the probe), the signal changes as follows:

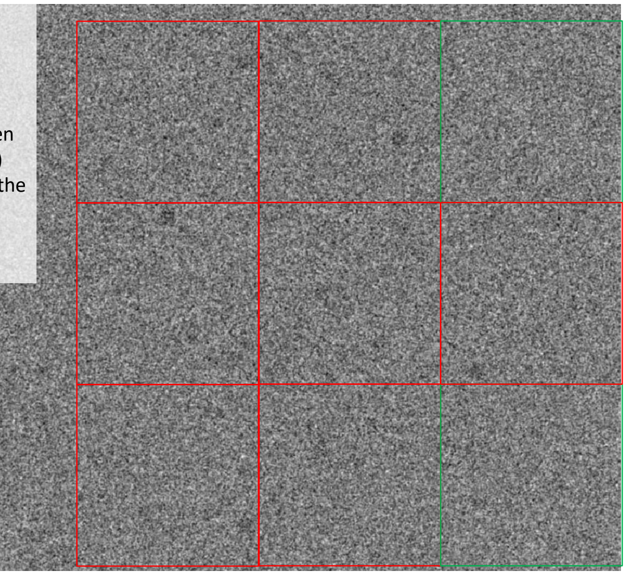
	FBH	SDH	Backwall
Twice the distance	-12 dB	-9 dB	-6dB
Twice the size (area)	+12 dB	+3 dB	0dB



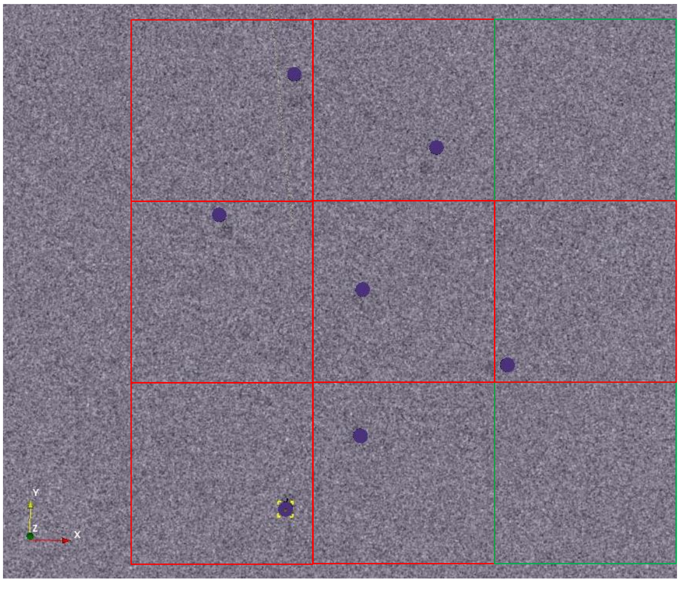
Do we find every defect?

Same defects – different finding probability

Not all defects (even with the same size) can be found with the same probability

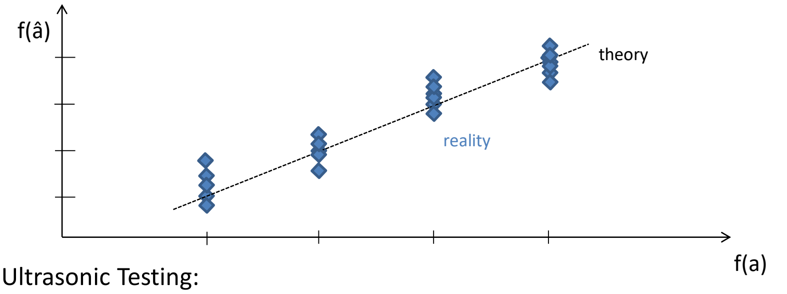


Do we find all defects, which we should find?



POD – measurements with fluctuations

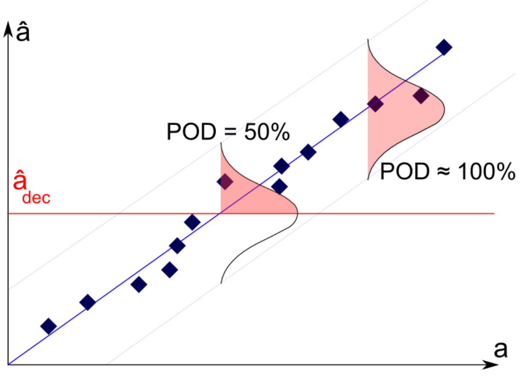
We don‘t measure the same contrast every time.
Theory vs. Reality!



Ultrasonic Testing:
a: area perpendicular to the sound beam
â: maximum echo height (SNR)

Statistics provides models to describe the fluctuations!

Linear â vs. a graph: decision threshold

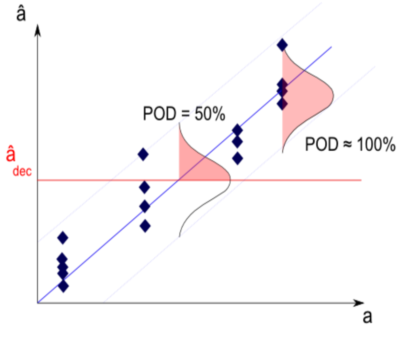


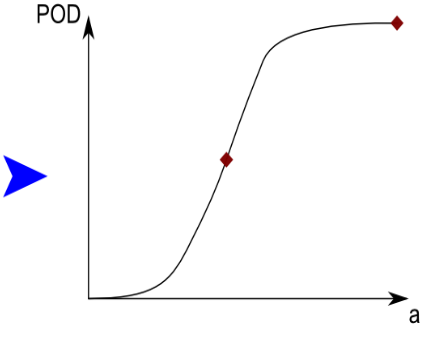
- The decision threshold is a part of the testing procedure: It often depends on the detectable contrast, the noise, etc..
- The probability of detection correlates with the area **under the distribution above the decision threshold** for each parameter size a.

POD from the linear â vs. a graph to the POD curve

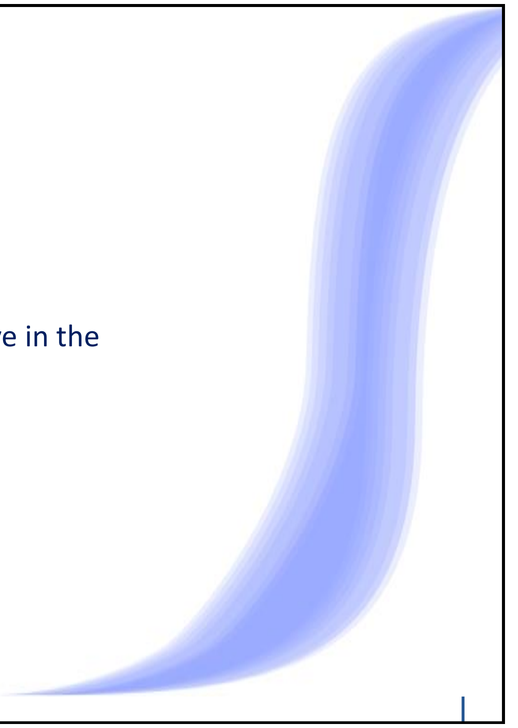
Linear â vs. a graph

POD curve



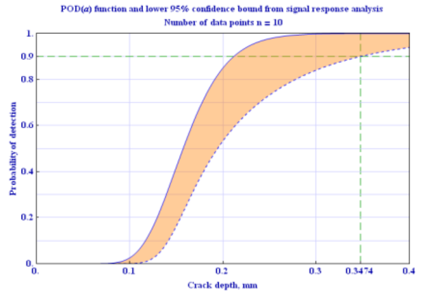


How much confidence do I have in the POD result?

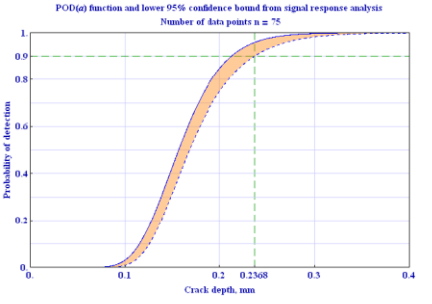


Amount of data and the confidence band

10 data points

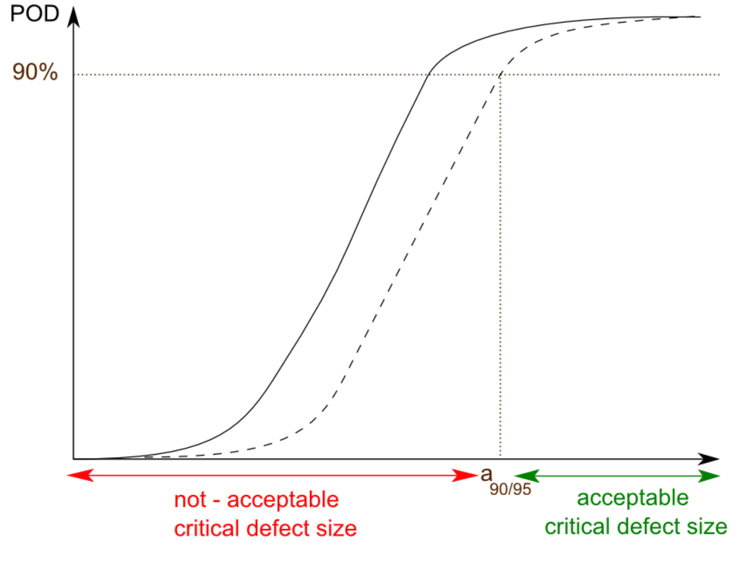


75 data points

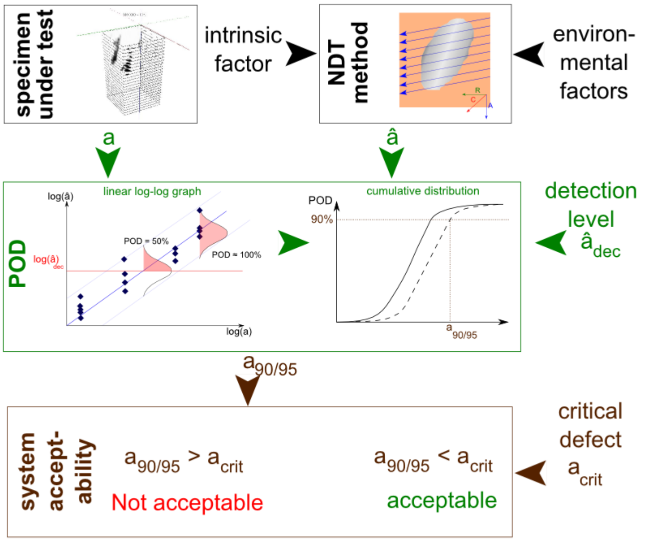


- The confidence band gets smaller as the amount of data increases
- As the amount of data increases, the parameters are closer to reality
- In the original POD: At least 40 data points for â vs a!

What are we doing with the result of the POD?



Summary: POD in radiographic testing



Why a program is not the answer!

Requirements for a useful signal response POD

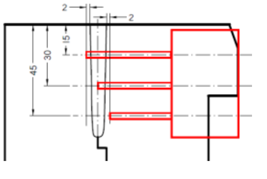
There are four requirements, which should be checked and discussed:

1. Linearity between the defect parameter and the indication signal. (Transformation e.g. with a logarithmic model is possible).
2. The fluctuation of the data points around the (linear) regression curve should be homogeneous (homoscedasiticity).
3. The data points from the experiments should be independent of each other.
4. The fluctuation of the data points can be approximated with a normal distribution.

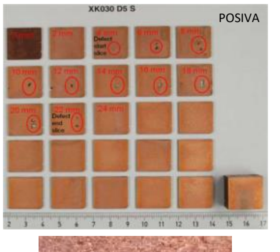
Department of Defense Handbook: MIL-HDBK-1823 (2009) G3.2

Aim: Testing as realistic as possible

- Artificial defects – according to the EN & ASTM standards



- Realistic welding defects (in this work. real defects)



- Production of the disposal canisters for the use in the final disposal (after 2020)

SKB Müller et al 2006

A few comments: Design of Experiments:

In the Design of Experiments (DoE) defect parameters, testing condition and used amount of data will be defined. Therefore:

- A deep **physical and material-relevant knowledge** is required for the evaluation of an NDT method.
- The DoE helps to ensure the correct NDT situation, considering **relevant parameters** (z.B. Greco-Latin-Square).
- The **requirements of the POD** are not fulfilled every time. The advice of statisticians might be helpful.

DoE reduces the number of experiments concerning necessary combination of variables in different levels.

For further information:

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