BAM
Bundesanstalt für Materialforschung und -prüfung

Sicherheit in Technik und Chemie

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DETERMINING PROBABILITY OF DETECTION CURVES USING EXPERIMENTAL DATA AND SIMULATION

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Overview

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2. Probability of Detection
3. Application Example: Nuclear Industry
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Introduction

Introduction

- NDT is routinely used across industries for different purposes, mainly to detect defects.
- How good is one NDT system? – The capability of the NDT system to detect a defect needs to be quantified.
- There is innate variability in the inspection process – a signal from the very same defect will vary from inspection to inspection.
- If the defect is very small, on the limits of the detection capability, this variation can mean a difference between a “hit” and a “miss”

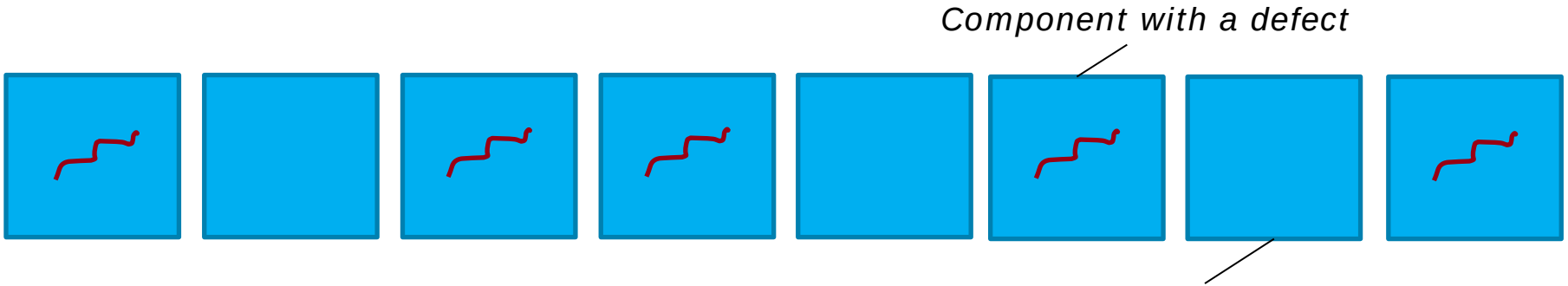
Introduction

- This was a motivation for the development of the probability of detection (POD) models in application where a missed defect can lead to catastrophic consequences
- Industries: aerospace, nuclear, railway, automotive

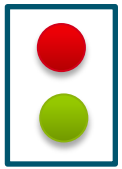
Probability of Detection (POD)

Probability of detection

- How is the probability of detection calculated?



- Simple NDT system:

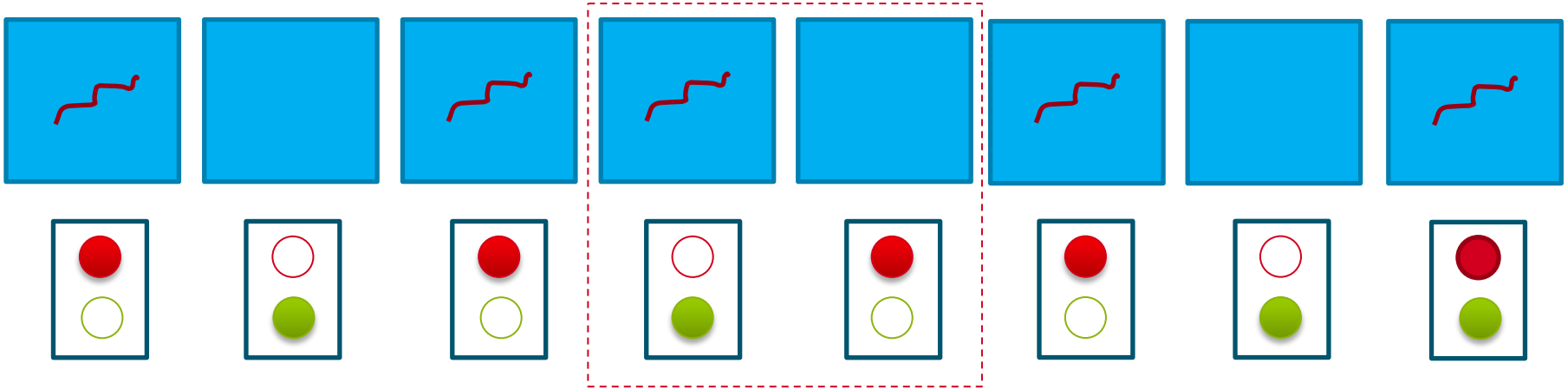


red light – there is a defect

green light – the component is defect-free.

Probability of detection

POD = Number of detected defects/Total number of defects = 4/5 = 80%

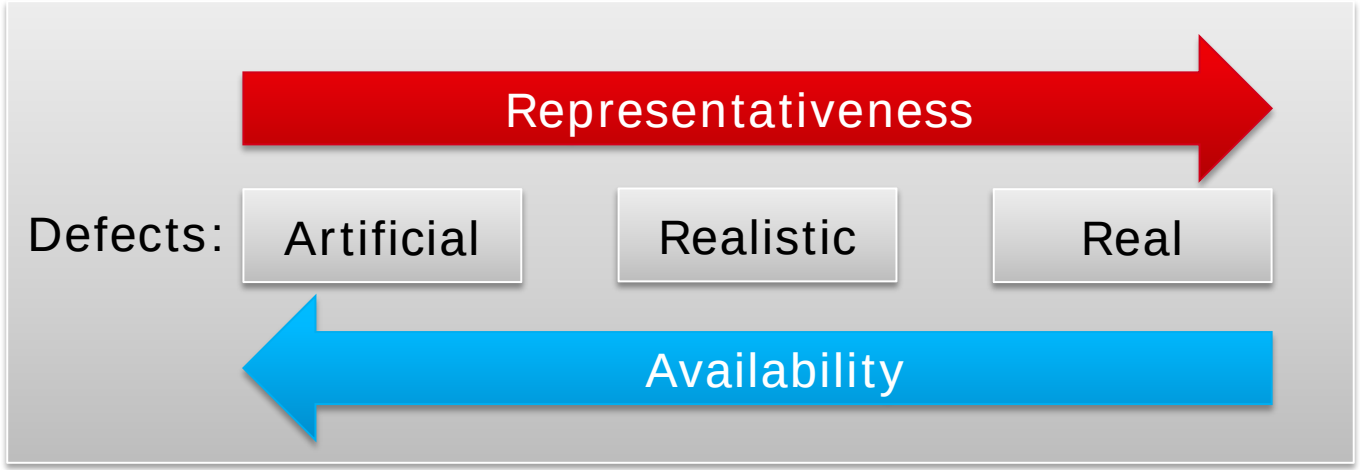


Probability of detection

- The POD is estimated by performing an experiment of number of specimens with known defects.
- These defects (sample) have to be good representative of the defects that might occur (population). The number of defects (sample size) has to be “large enough”.

Defects

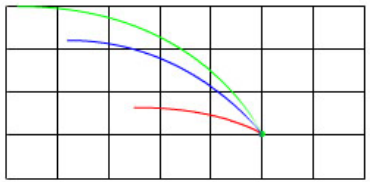
- Real defects – usually a very small number (if any) available
- Realistic defects – expensive to make
- Artificial defects – simple geometry, relatively inexpensive, but always a question how good they represent the real defects



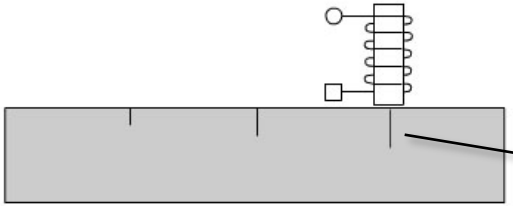
Signal-Response POD Model

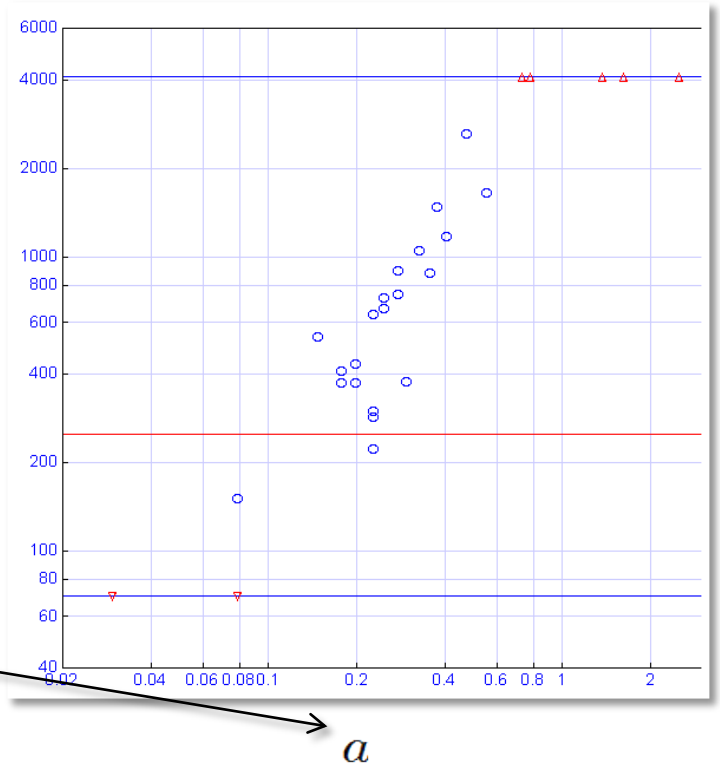
$\hat{a}$ versus a diagram

Signal, $\hat{a}$



True size, a





Alan P. Berens. NDE Reliability Data Analysis. ASM International, 17:689–701, 1989

â versus *a* diagram

Linear regression

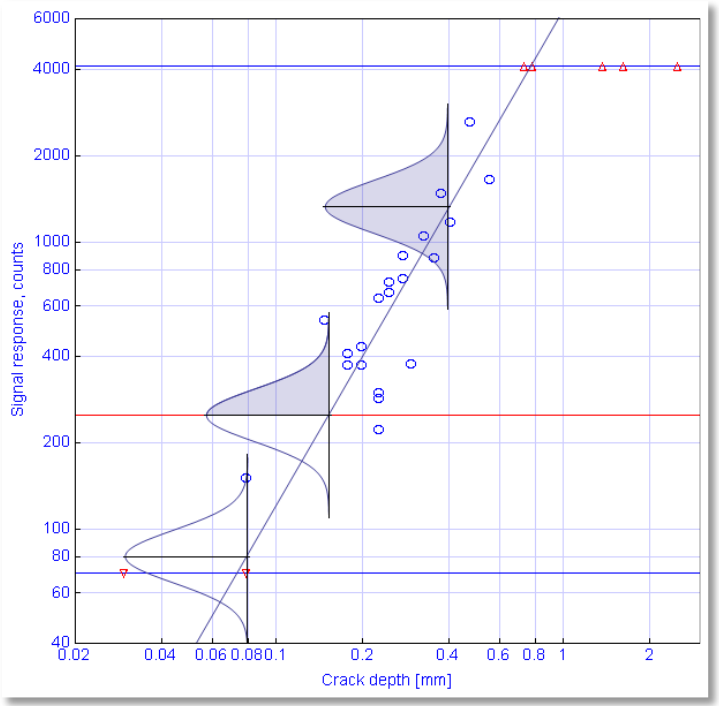
$$ln(\hat{a}) = A_0 + A_1\, ln(a) + \delta$$

Normal scatter of the data:

$$\delta \sim N(0, \sigma_\delta)$$

The threshold is set and a POD is calculated as an area below the probability density curve, above the threshold:

$$POD(a) = 1 - \Phi\left[\frac{ln(\hat{a}_{dec}) - (A_0 + A_1\, ln(a))}{\sigma_\delta}\right]$$



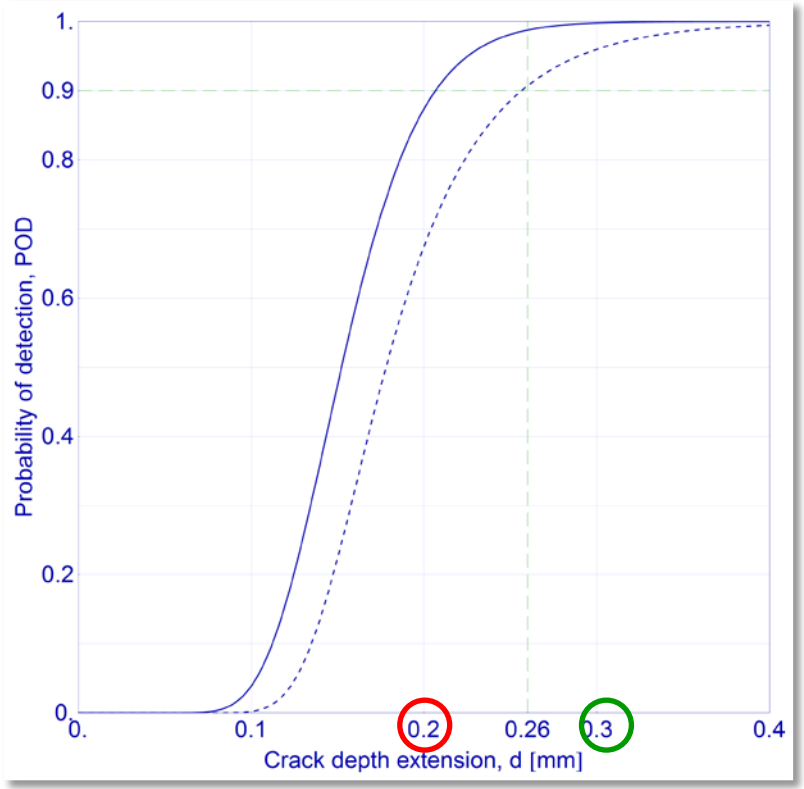
Alan P. Berens. NDE Reliability Data Analysis. ASM International, 17:689–701, 1989

POD curve
Lower 95 % confidence band; $a_{90/95}$

Confidence band reflects the sensitivity of the experiment to the number of flaws in the sample.

NDT system is *fit for purpose* if:

$$a_{\text{critical}} > a_{90/95}$$



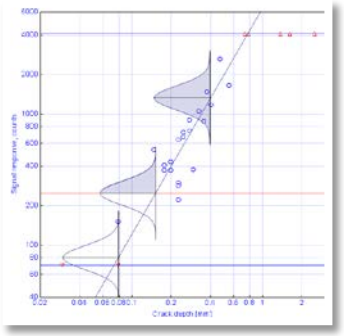
Alan P. Berens. NDE Reliability Data Analysis. ASM International, 17:689–701, 1989

Multi-parameter POD Model

Multi-parameter POD Model

- In the signal-response model, both the regression (**model**) and the **scatter** come from the observation of the experimental data

$$ln(\hat{a}) = A_0 + A_1\, ln(a) + \delta$$

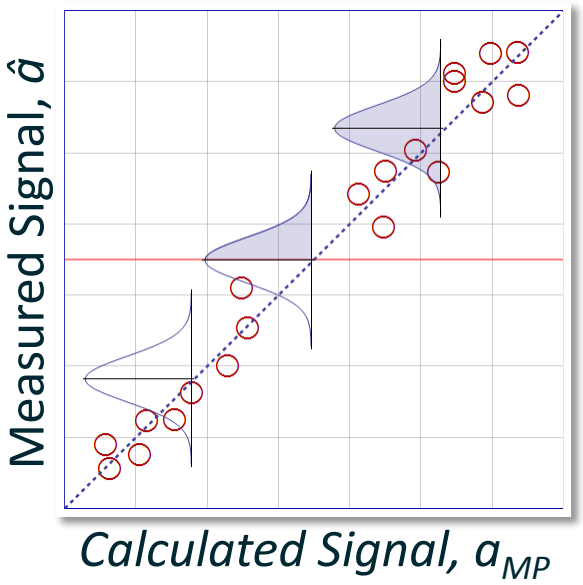


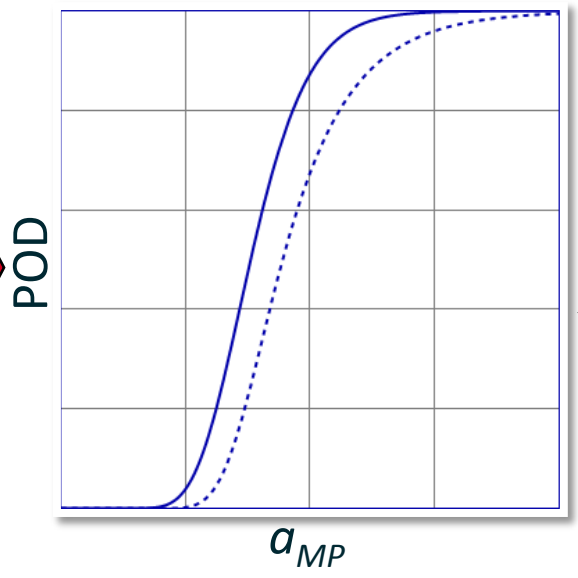
*„In the â data analysed to date, a linear relation between ln(â) and ln(a) with normally distributed deviations has proved satisfactory“**

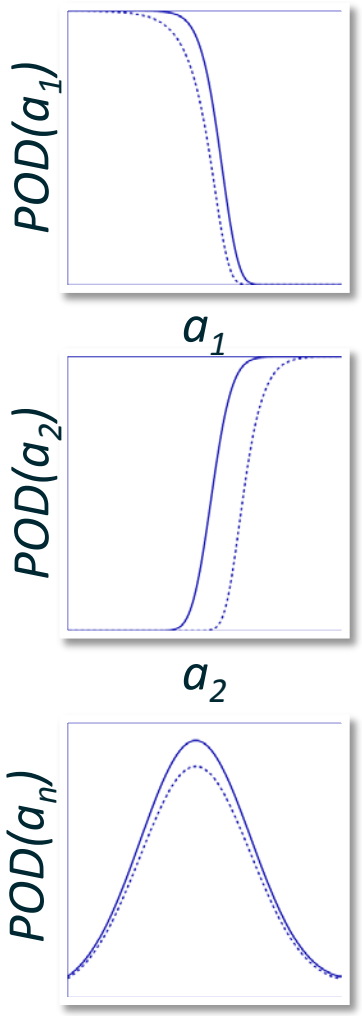
**Alan P. Berens. NDE Reliability Data Analysis. ASM International, 17:689–701, 1989*

Multi-parameter POD Model

$$POD(a_{MP}) = 1 - \Phi\left[\frac{\hat{a}_{dec} - (B_0 + B_1\, a)}{\sigma_{\delta_{MP}}}\right]$$





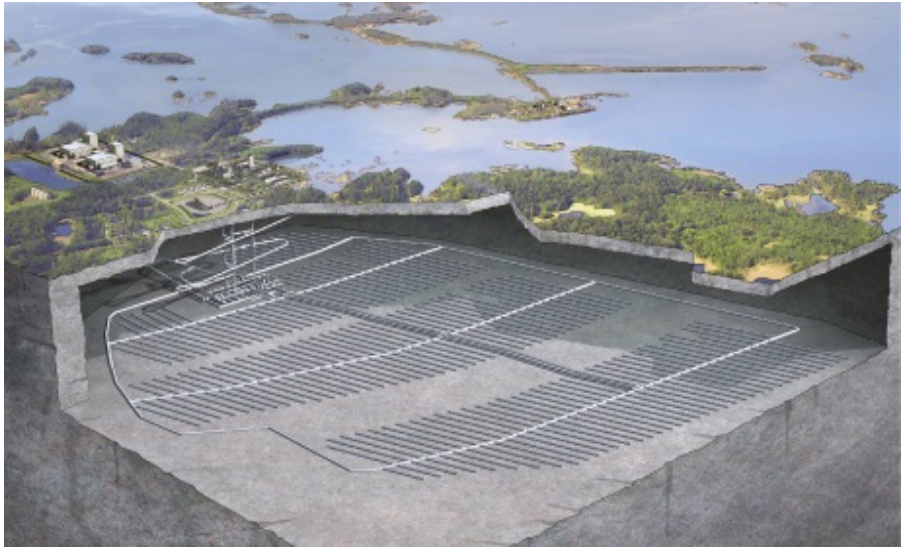


$$a_{MP} = f(a_1, a_2, \ldots a_n)$$

Application example: nuclear industry

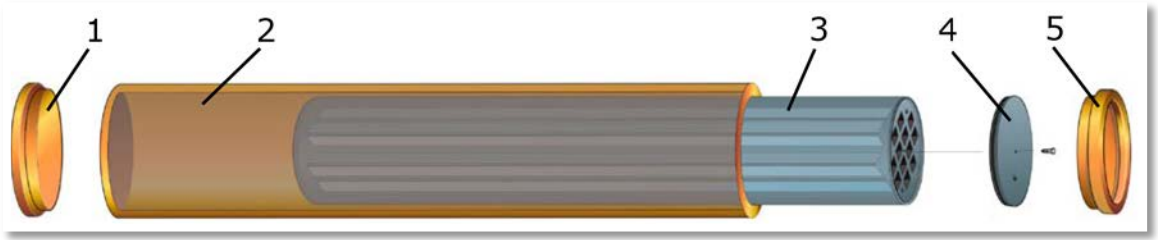
Project: Final repository of the spent nuclear fuel

- Sweden and Finland are building a final repository for the nuclear waste.
- It takes about 1 million years for radioactivity of the spent nuclear fuel to come to the levels of naturally occurring radioactivity.
- No contact between the spent nuclear fuel and the environment should occur during that time.
- Long-term safety is based on the multiple barriers principle, both natural and technical.



Canister

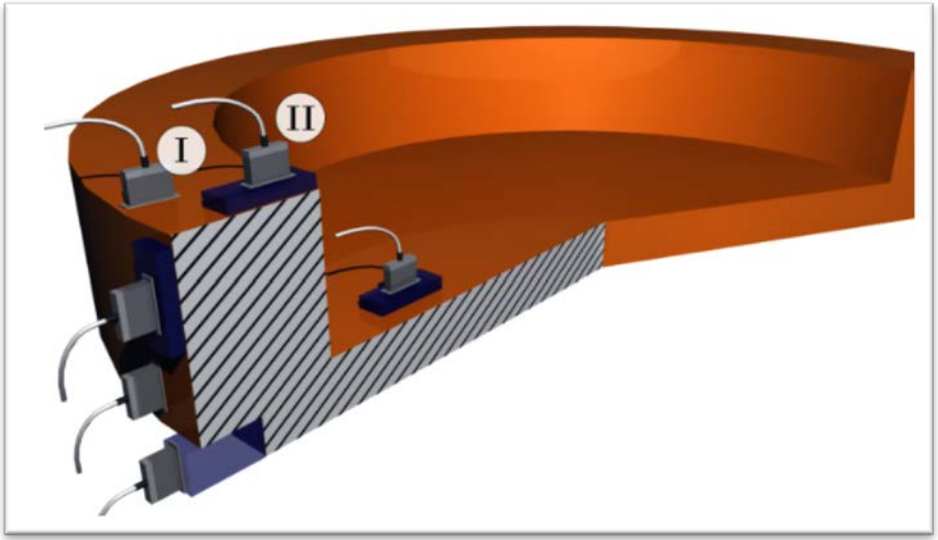
- Canister is the most important technical barrier
- It consist of the cast iron insert and the copper shielding
- Before the deposition in the repository, 100% of the volume of each canister has to be inspected with the NDT

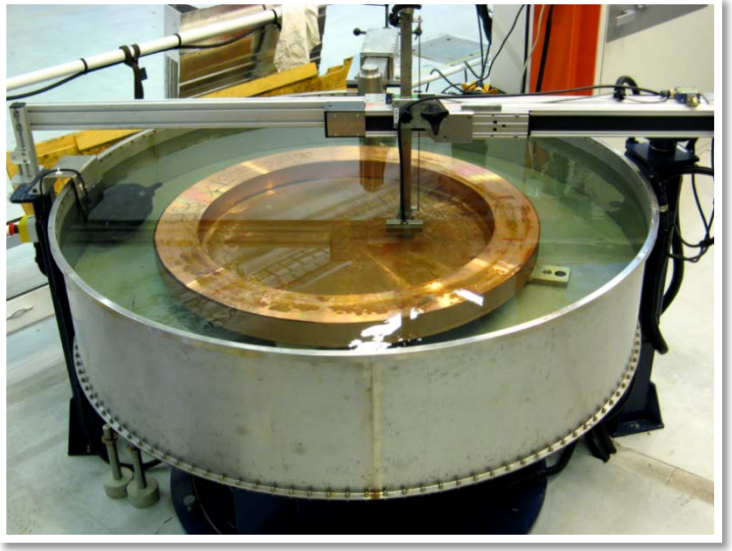


1. Copper base 2. Copper tube 3. Cast iron insert 4. Steel lid 5. Copper lid

NDT of the canister

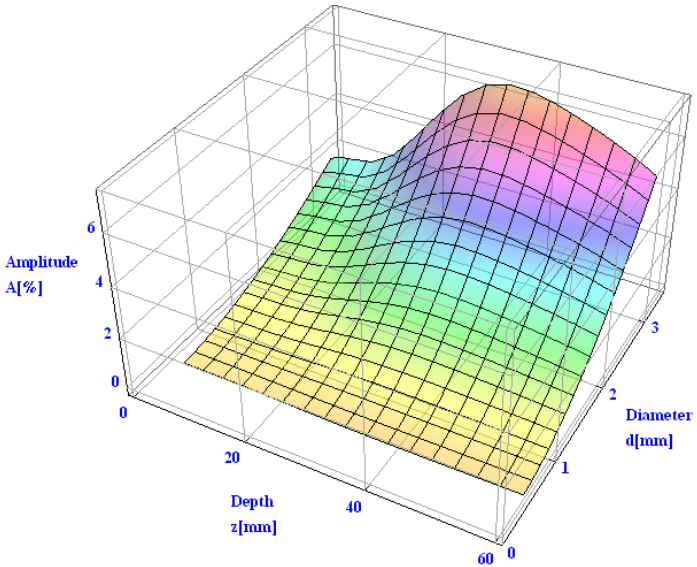
- For the inspection of canister, several NDT techniques are being developed
- Ultrasonic inspection of the copper lid with a phased array probe(s) is shown here

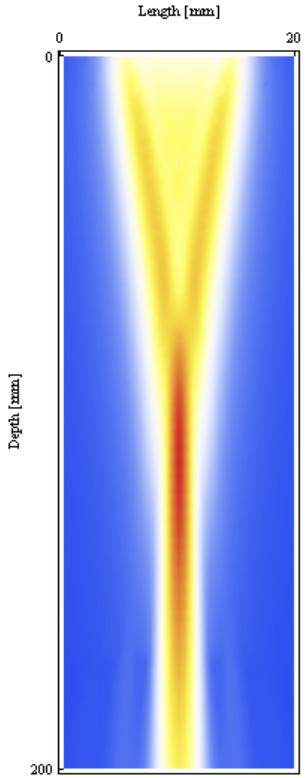




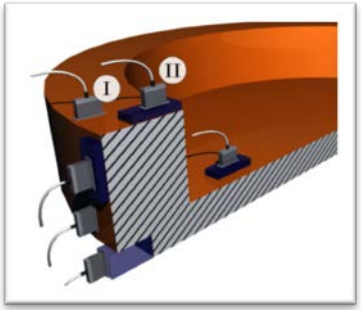
Simulation of the NDT

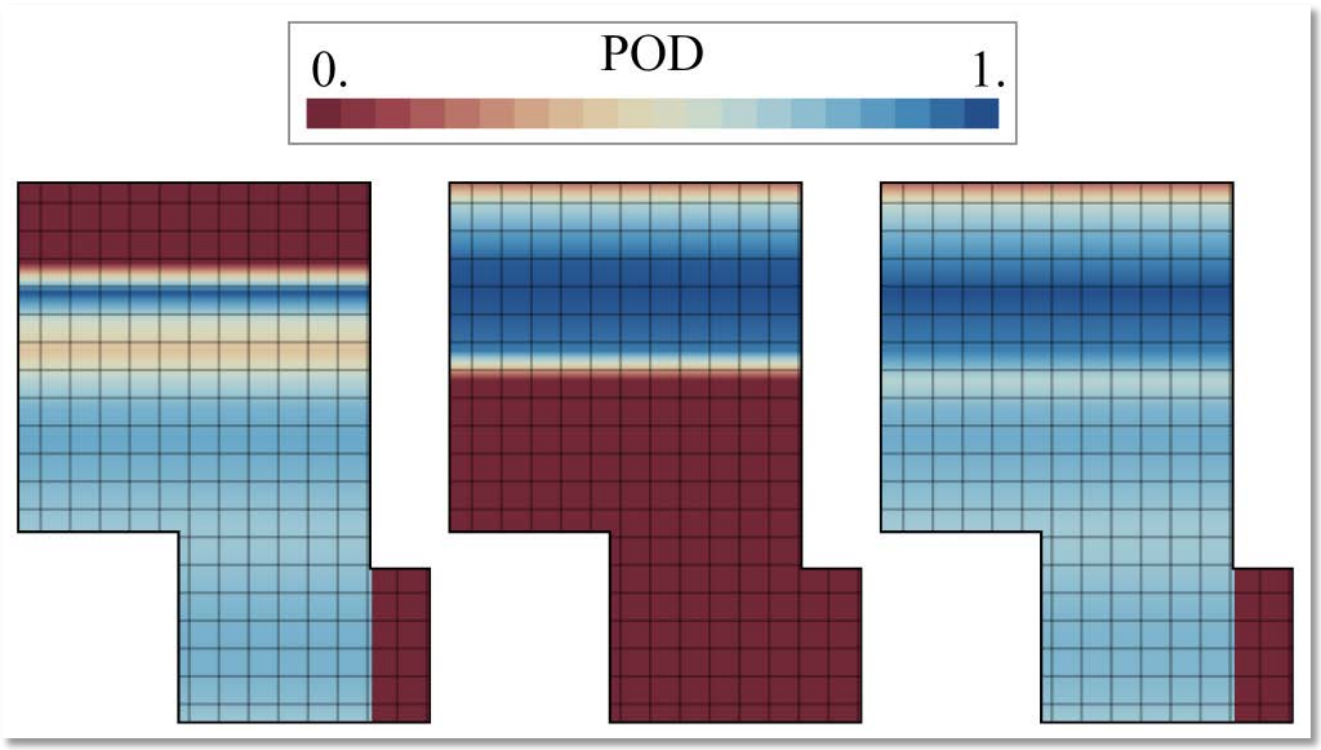
- Software used for the phased array ultrasonic simulation developed in BAM





Probability of detection data fusion

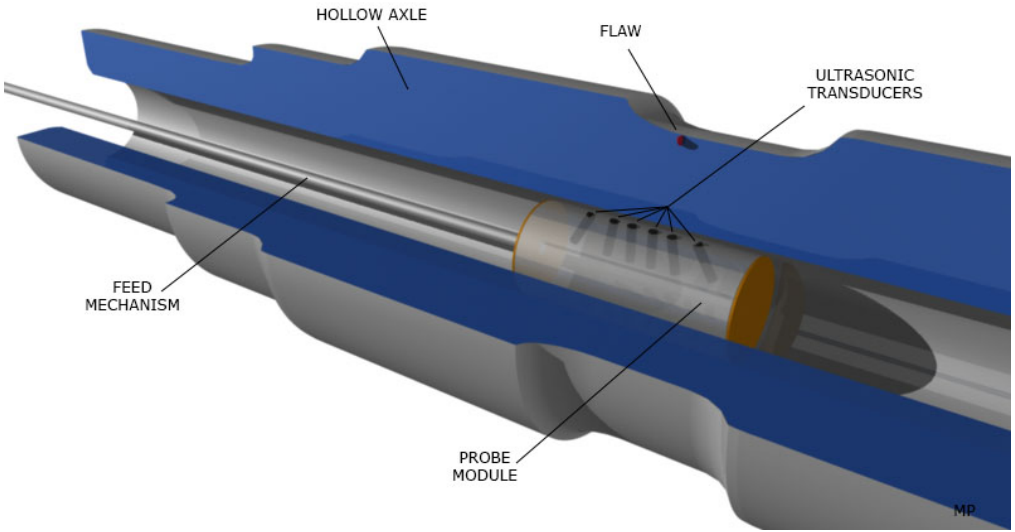




Application example: railway industry

Project: Ultrasonic inspection of the hollow railway axles

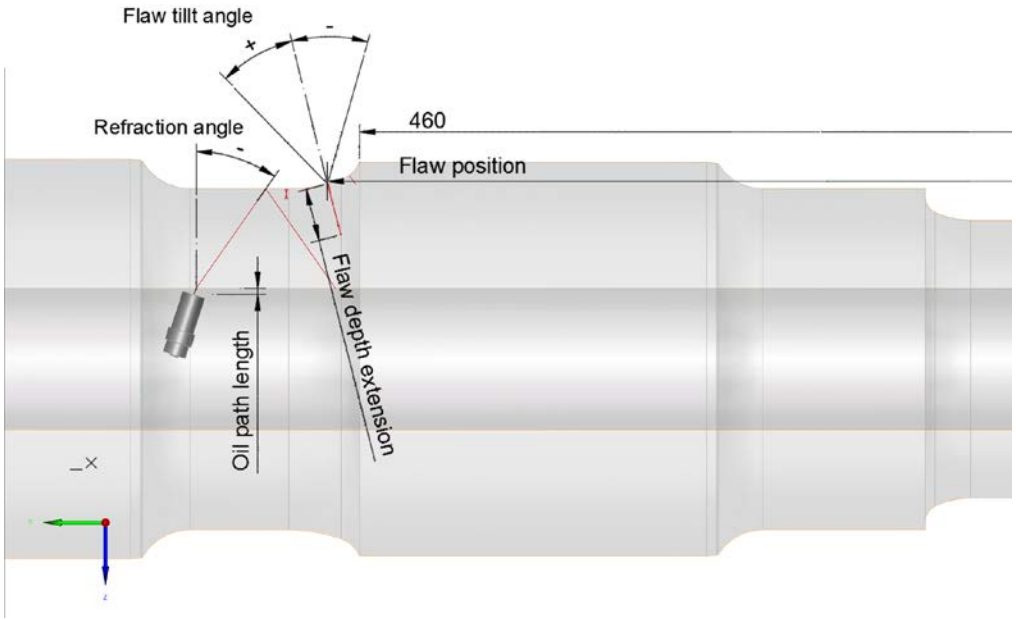
- Reliability of the automated ultrasonic inspection system used to inspect hollow railway axles needs to be determined
- Axles are inspected from the bore surface
- Ultrasonic transducers are located in the probe module
- The aim is to detect cracks on the outer surface of the axle



Challenges

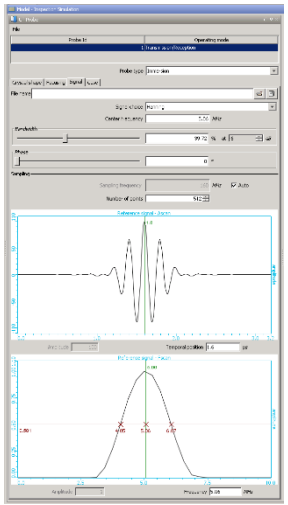
Several factors influence the POD:

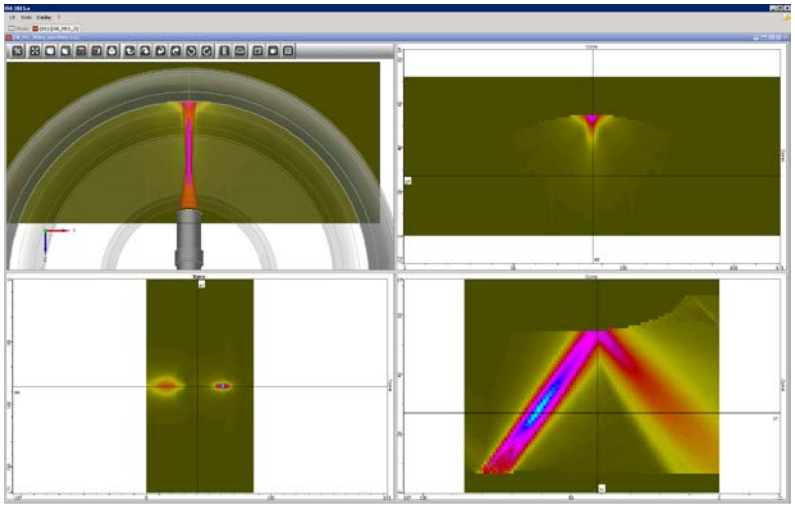
- crack size,
- crack orientation,
- crack position
- crack shape
- axle geometry

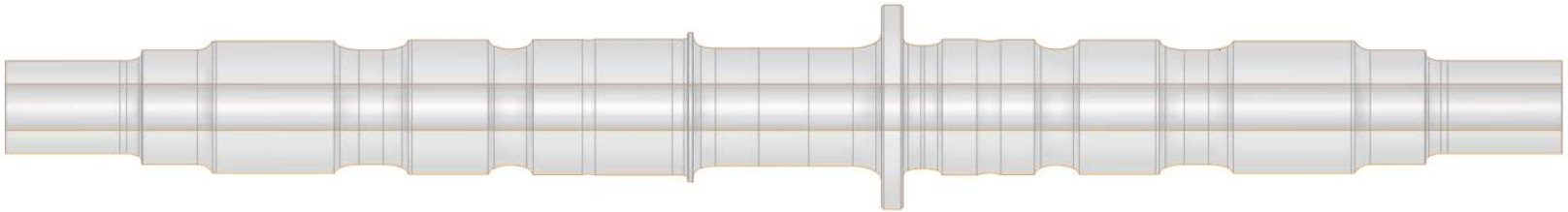


Simulation of the NDT

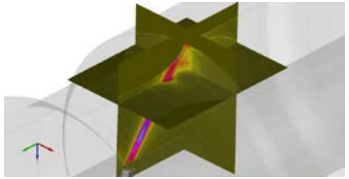
- Simulation with CIVA 2015 (11.1)
- Calculation with 5 MHz transducers generating ±37° and ±70° transversal waves in the axle.

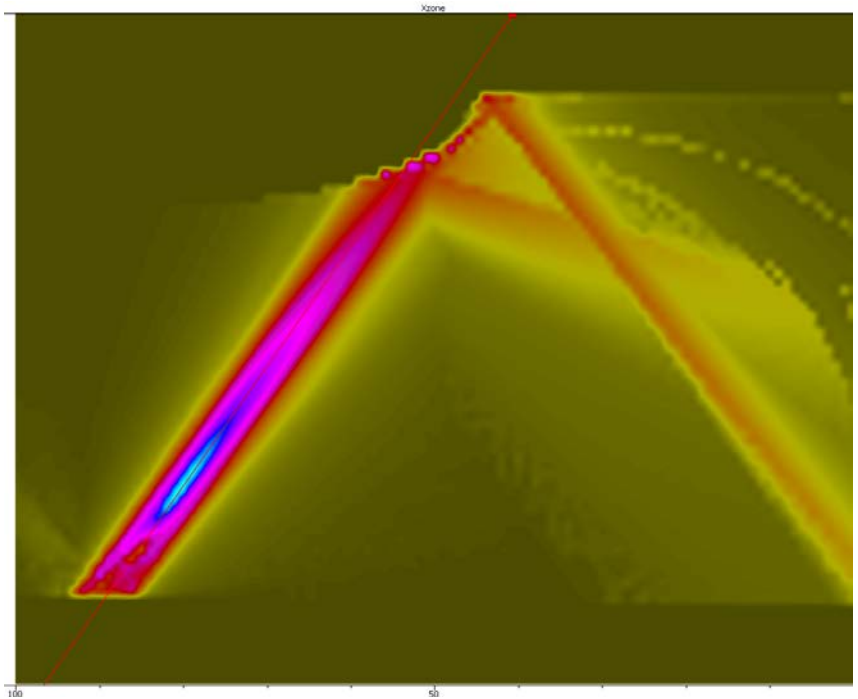


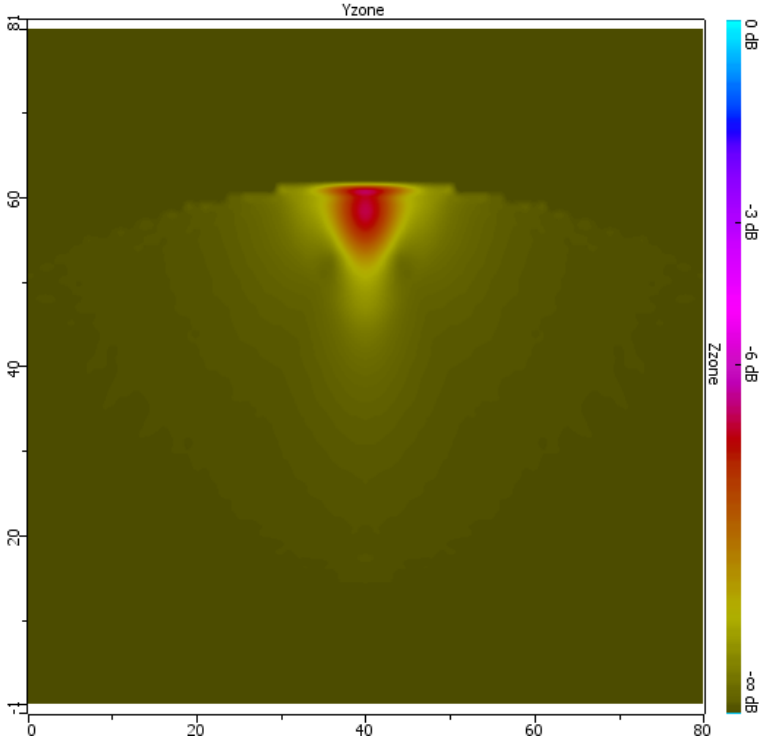




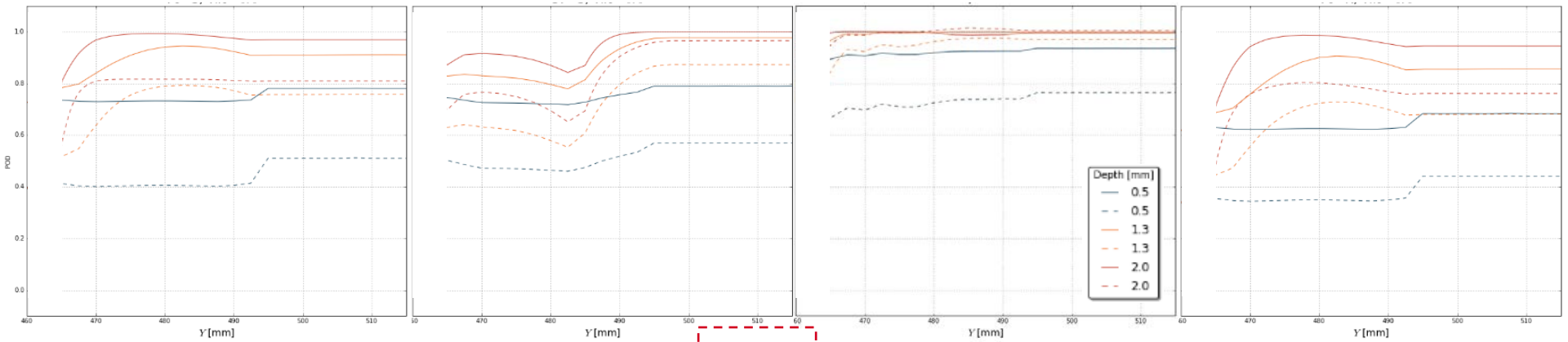
Simulation of the NDT

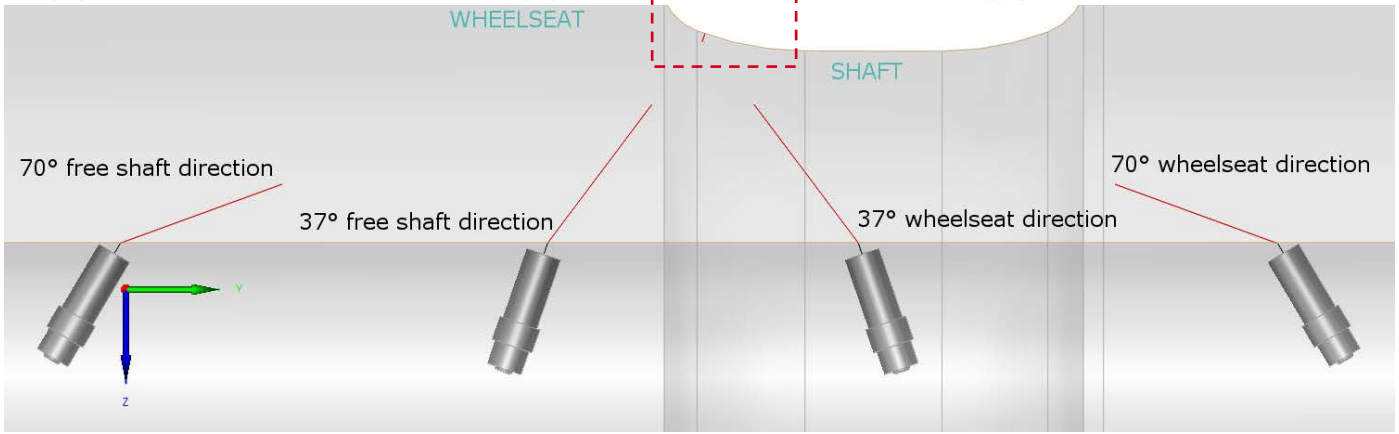






Probability of detection





Conslusions

Conclusions

- In application where a missed flaw can lead to catastrophic consequences, it is necessary to estimate the reliability of the NDT system´used for the inspection
- With the increase of complexity of the inspection task, the complexity of the reliability analysis is also increasing.
- The POD is estimated on the samples containing known defects. The sample has to be large enough and a good representative of the population. The process is expensive and time consuming.
- The use of simulation of the NDT provides better understanding of the inspection task and reduces the time and the cost of the reliability analysis.