DE LA RECHERCHE À L'INDUSTRIE

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NDT PERFORMANCE DEMONSTRATION USING SIMULATION

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OVERVIEW

- Why using simulation for NDT performance demonstration
- NDT performance demonstration approaches
- Examples & tools for NDT performance demonstration
- Challenges

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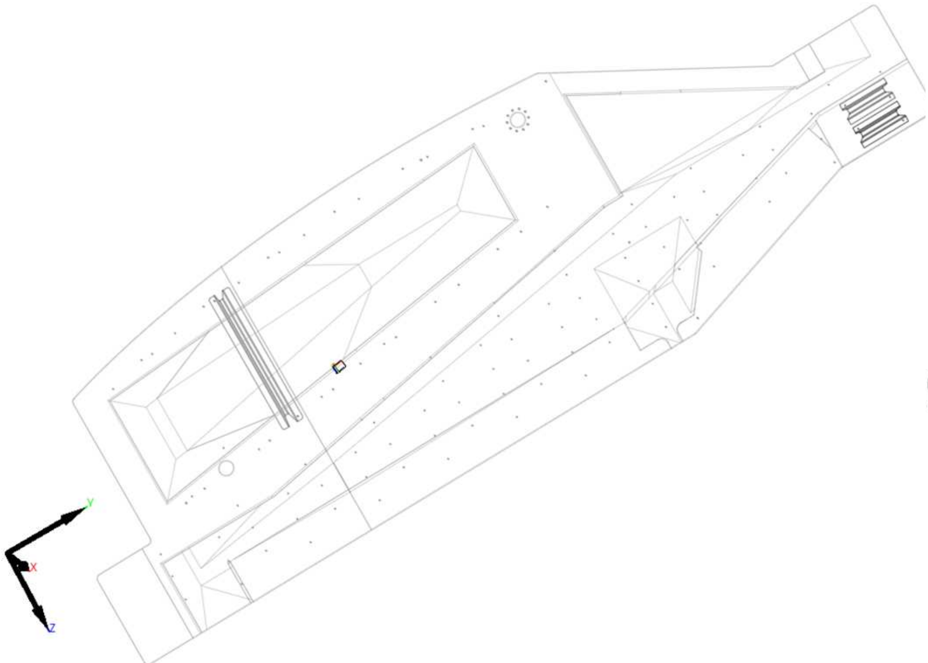
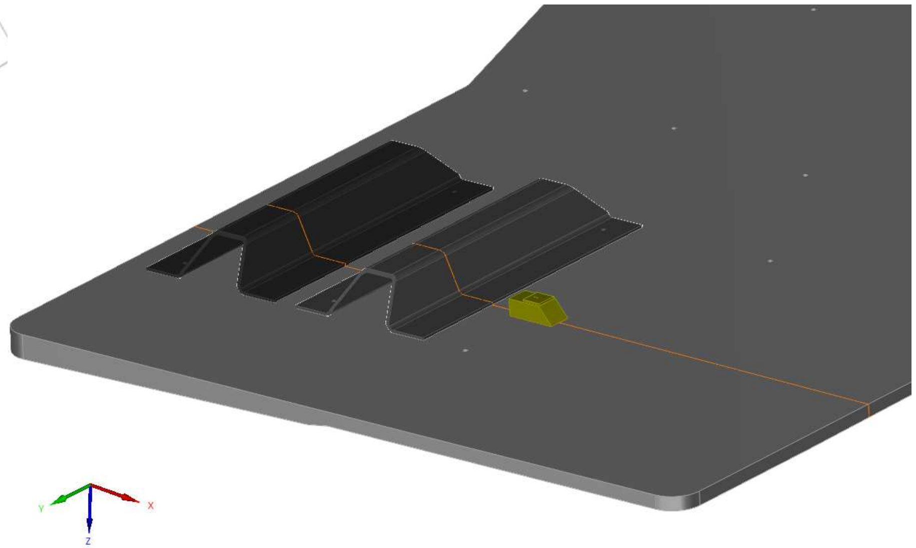
THINK NDT BEFORE IT'S TOO LATE

- Prepare NDT before parts are manufactured
- Possible use of digital mock-ups
- Evaluate changes of material, geometry
- **Early feed-back to design teams**





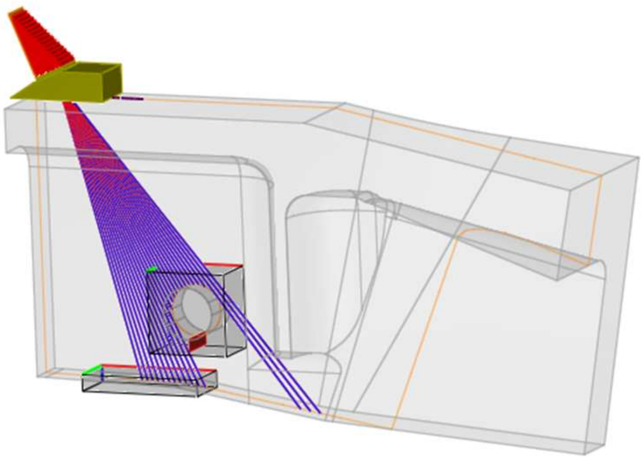
WHY USING SIMULATION FOR NDT PERFORMANCE

ANTICIPATE NEEDS

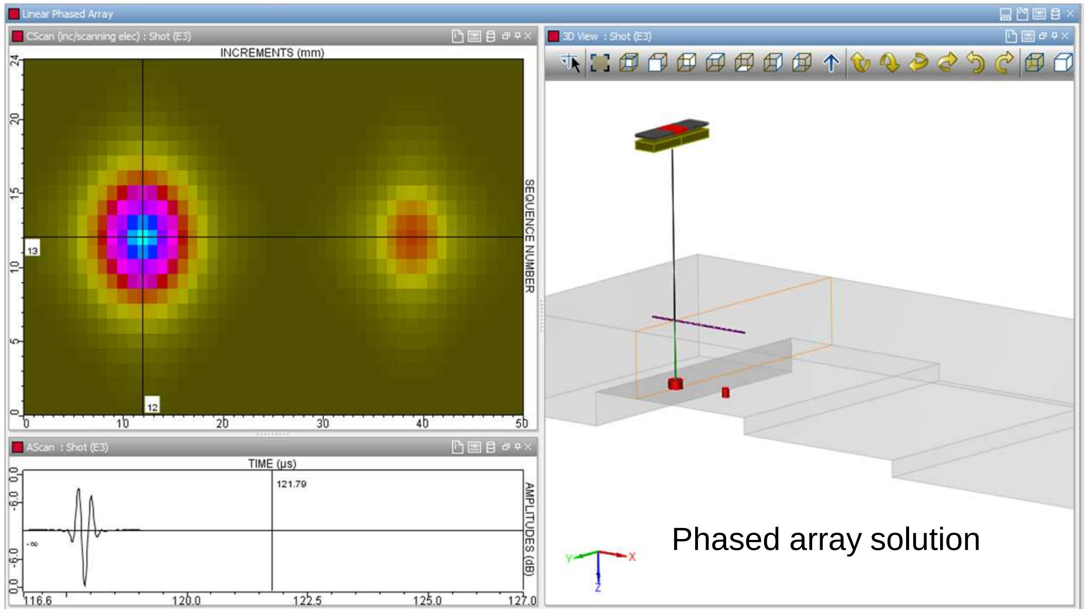
NDT often comes late in manufacturing processes.

When parts arrive it is often too late to **launch R&D or investments**.

=> Early performance evaluation can help.



Complex geometry inspection

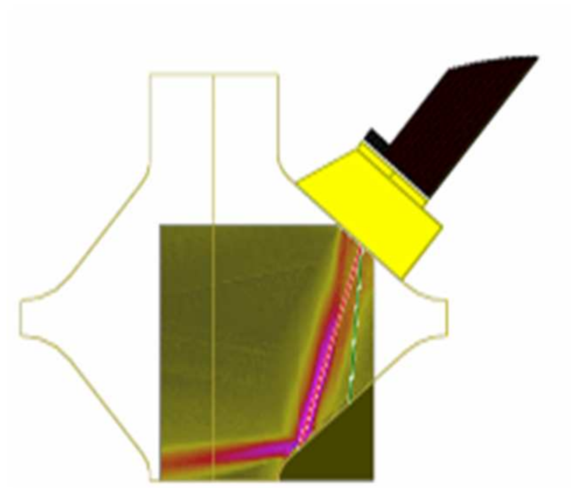


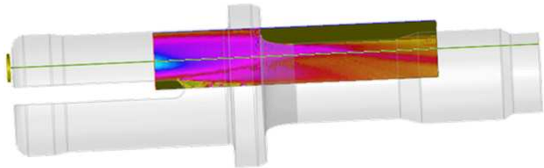
Composite parts inspection

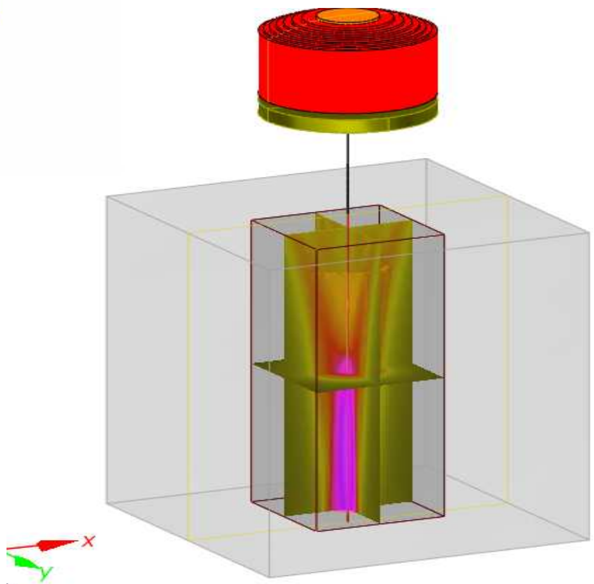
WHY USING SIMULATION FOR NDT PERFORMANCE

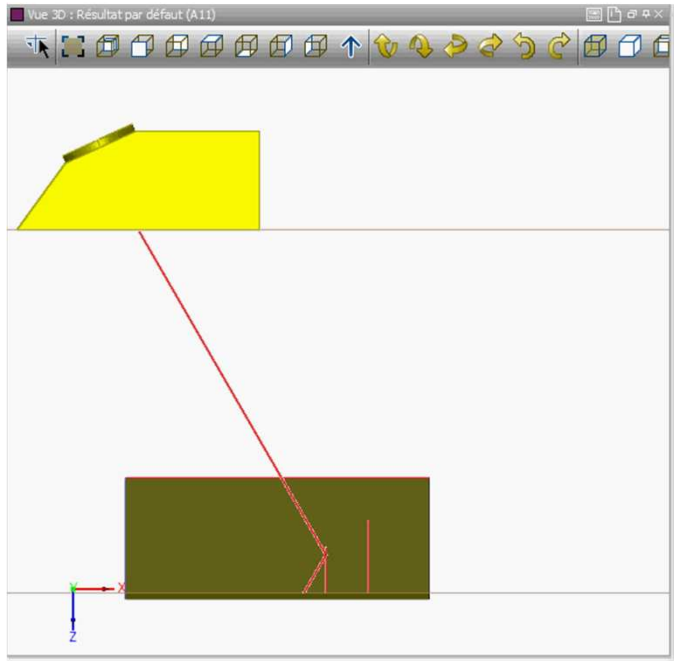
UNDERSTAND NDT PROCESS BEHAVIOUR

Propagation behaviour







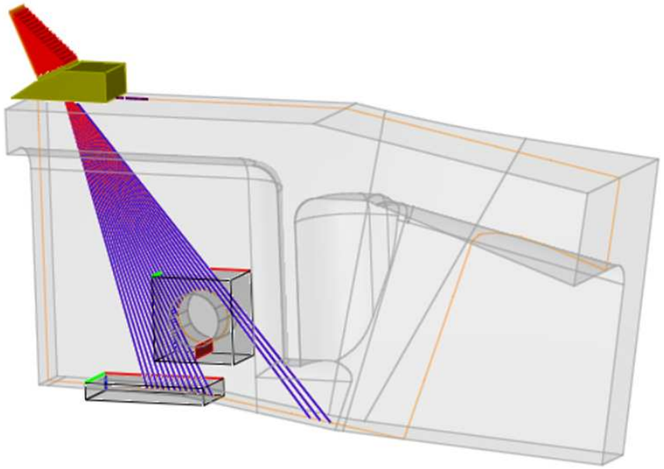


REDUCE COSTS

- Samples

Coupons

= $, €



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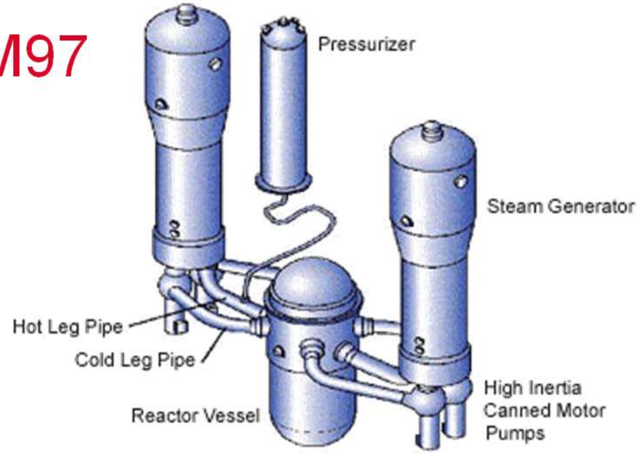
NDT PERFORMANCE DEMONSTRATION

DEMONSTRATIONS OF PERFORMANCES

- NUCLEAR QUALIFICATION RSEM97
  - Comprehensive NDT
  - Deterministic proof: worst case



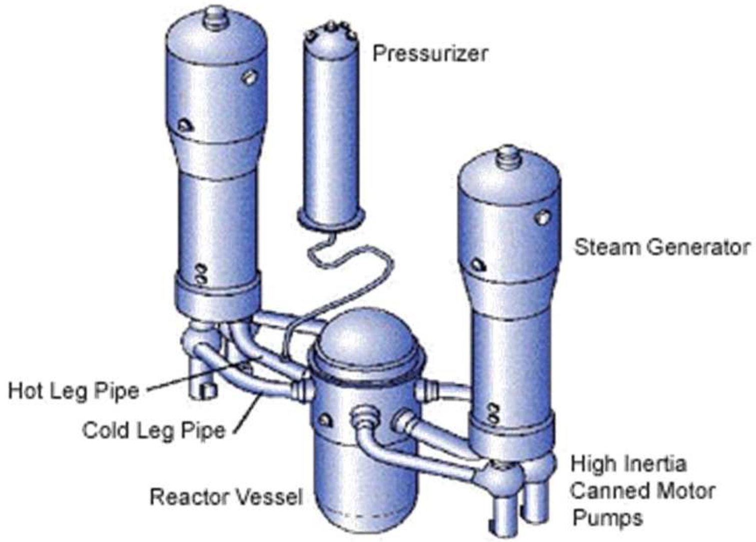
- PROBABILITY OF DETECTION (POD)
  - Intensive NDT
  - Statistical analysis

NDT PERFORMANCE DEMONSTRATION

NUCLEAR QUALIFICATION (France RSEM97)
EDF philosophy (ENIQ based)

➡ Demonstrate the ability for a process to detect and/or characterize flaws of a given size in a given component taking into account environment.

- Comprehensive study
- Includes worst case
- Every defect must be detected



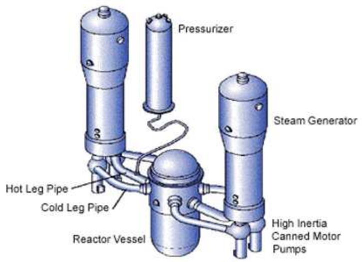
PROBABILITY OF DETECTION (POD)

Damage tolerance design rules impose production of POD values as input for maintenance interval justification

➡ Quantify the ability of a process, implemented in operational conditions, to detect flaws of different sizes.

- Intensive NDT
- Statistical analysis
- Defects are detected with a given POD and given confidence

ANALYSIS OF PARAMETERS VARIABILITY ON NDT RESULT



List influent parameters (explicitly)
- nominal value
- range of variation [min; max]

For each parameter, quantify influence on inspection result and demonstrate that the targeted defects are still detected.

➡ **Deterministic approach**

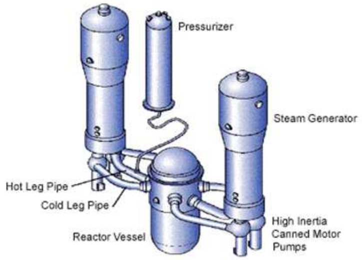
Realize NDT according to the procedure under evaluation:
Influent parameters are integrated implicitly.

Global analysis of influence of parameters by statistical estimation.

➡ **Probabilistic approach**

NDT PERFORMANCE DEMONSTRATION

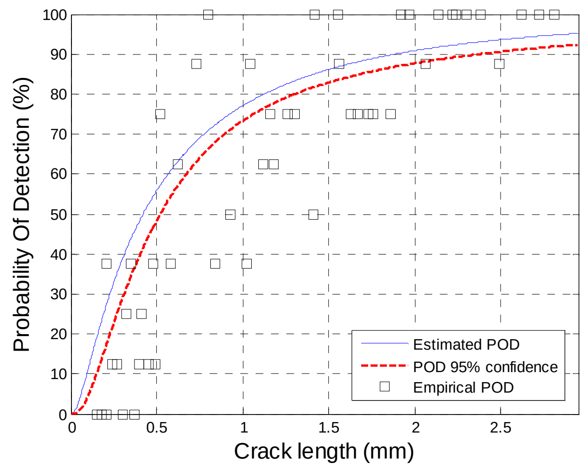
OUTPUT OF NDT PERFORMANCE DEMONSTRATION



The NDT procedure allows sure detection of flaws of size a within the specified range of application.

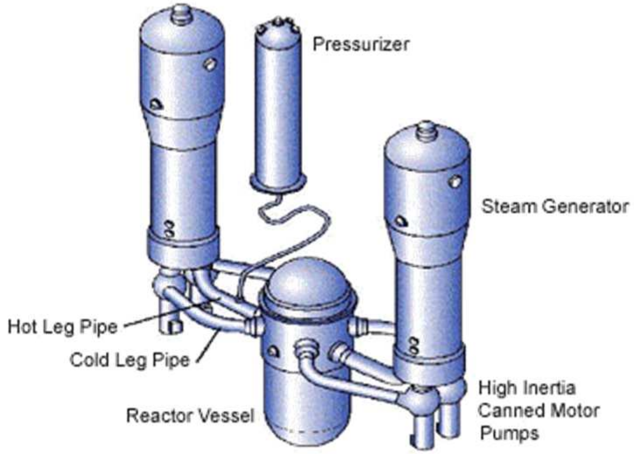
The probability of missing a defect is not considered.

The NDT procedure allows detection of flaws of size a with a probability p.



NDT PERFORMANCE DEMONSTRATION

NUCLEAR & AERONAUTICS: WHAT IN COMMON?



Both approach

- Require production of a large number of data (samples and NDT)
- Include sources of variability in the NDT results (implicitly or explicitly)

➡ **Simulation can help in producing data for NDT performance demonstration**

NDT PERFORMANCE DEMO. USING SIMULATION

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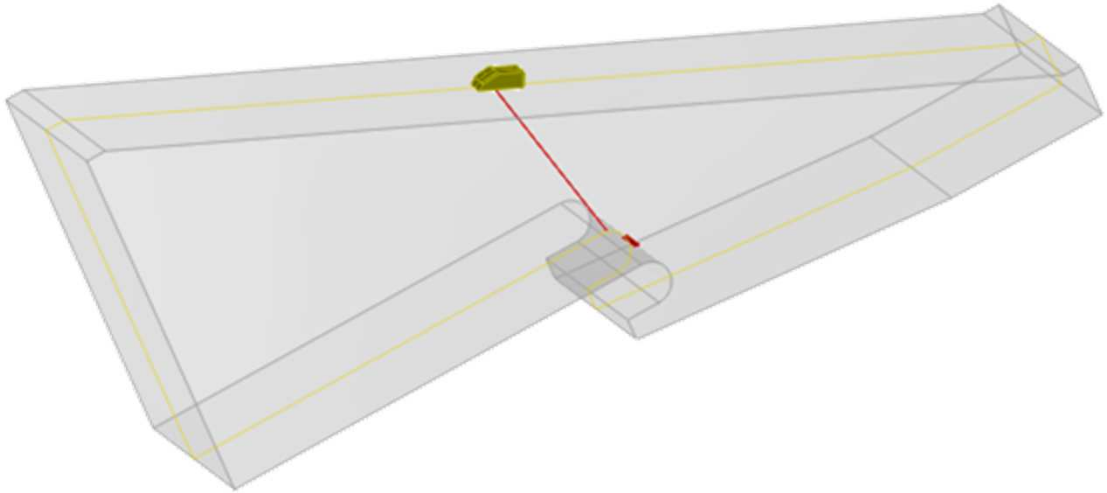
EXAMPLE OF PERFORMANCE DEMONSTRATION

DETERMINISTIC ANALYSIS

Example: UT of Thermal Sleeve of Steam Generator

- Bring elements for Technical Justification in Qualification Dossier
- Reduce the number of mock-ups or their complexity

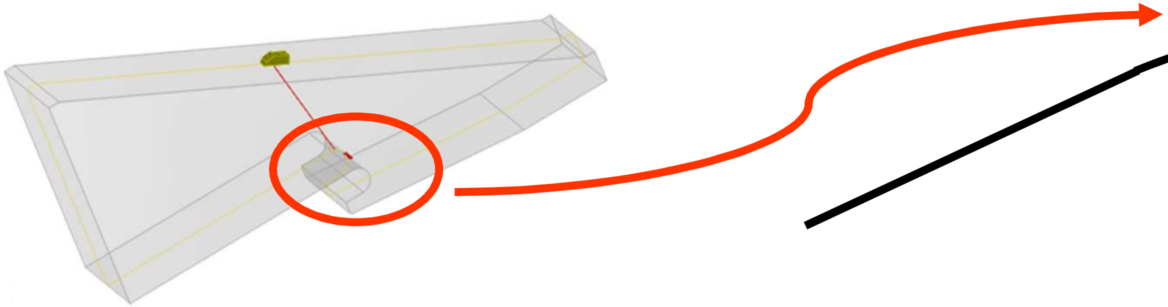


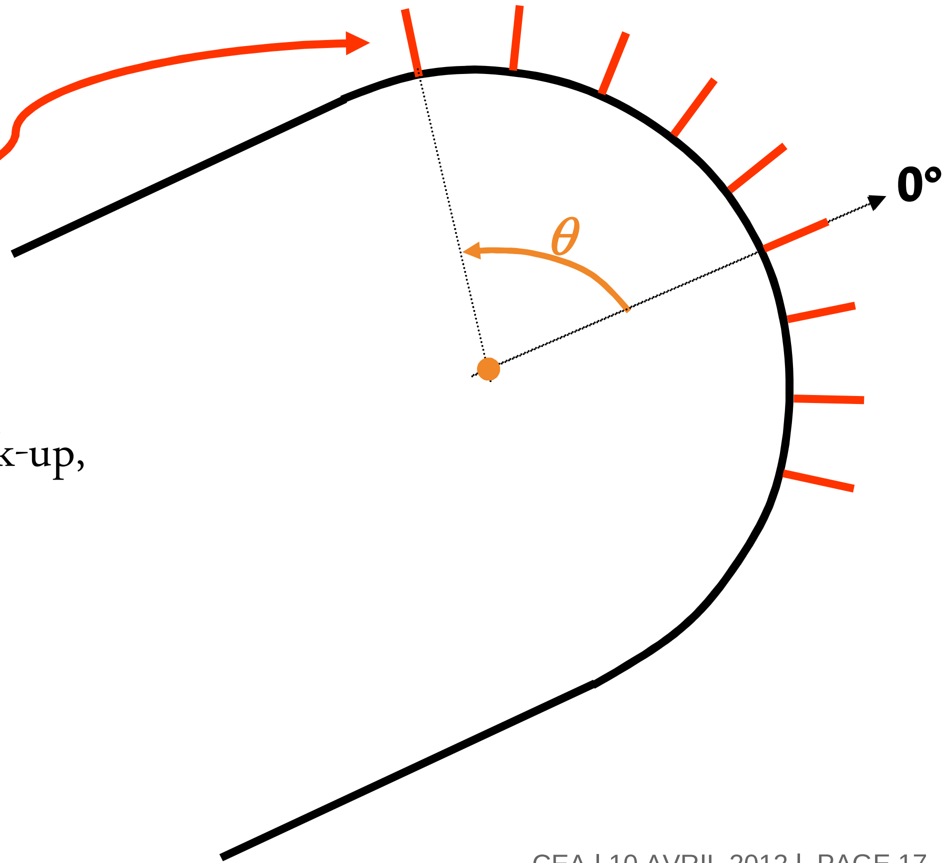
EXAMPLE OF PERFORMANCE DEMONSTRATION

DETERMINISTIC ANALYSIS

Example: UT of Thermal Sleeve of Steam Generator

- What is the response if the defect takes different positions around the sleeve?





Some positions can be studied with a mock-up,

But the variation will not be linear…

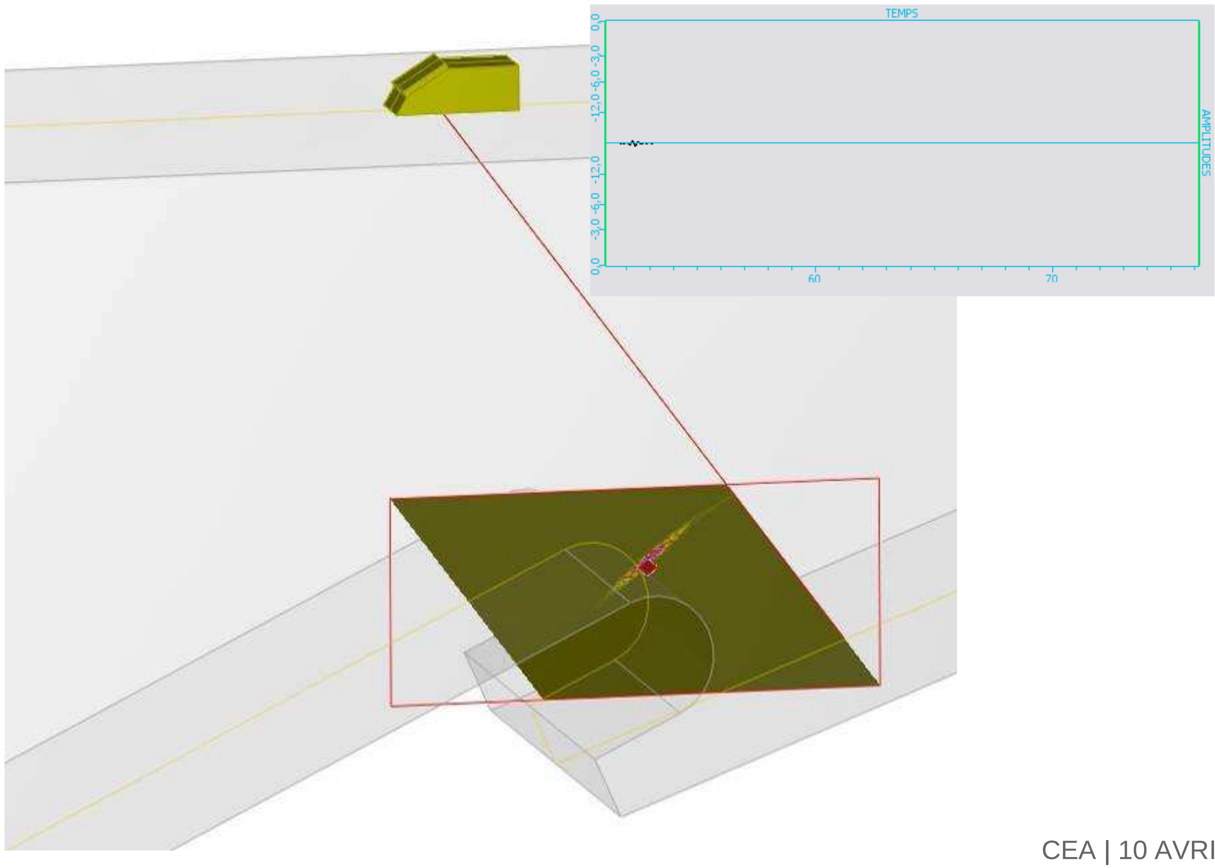
How choosing positions?

EXAMPLE OF PERFORMANCE DEMONSTRATION

DETERMINISTIC ANALYSIS

Example: UT of Thermal Sleeve of Steam Generator

- What is the response if the defect takes different positions around the sleeve?



EXAMPLE OF PERFORMANCE DEMONSTRATION

DETERMINISTIC ANALYSIS

Example: UT of Thermal Sleeve of Steam Generator

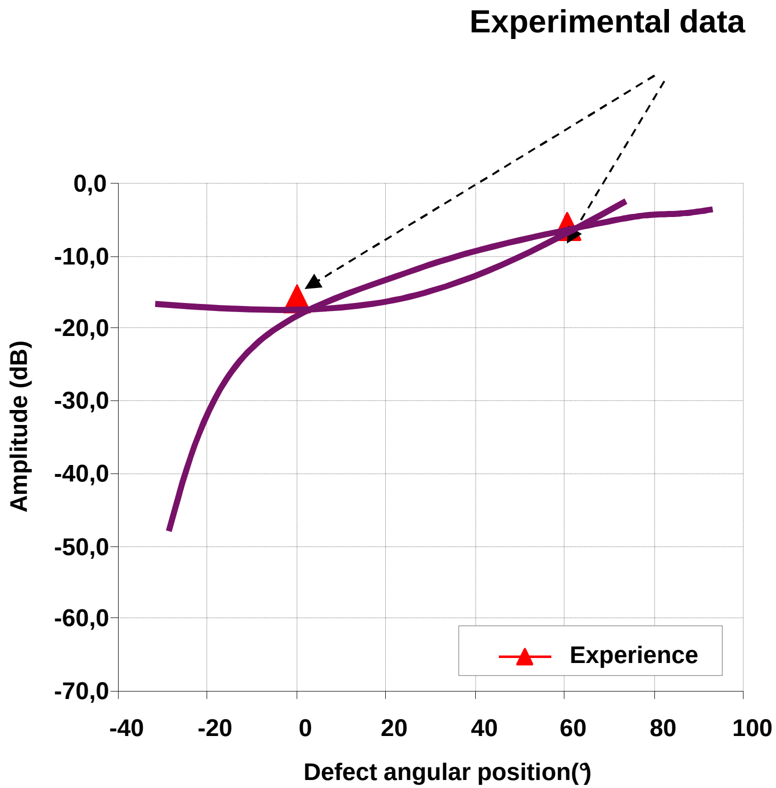
- What is the response if the defect takes different positions around the sleeve?

=> Make one mock-up with 2 defects at different positions and get the experimental amplitudes

Then what is amplitude for other positions?

Guess?
Other mock-ups?

Or…



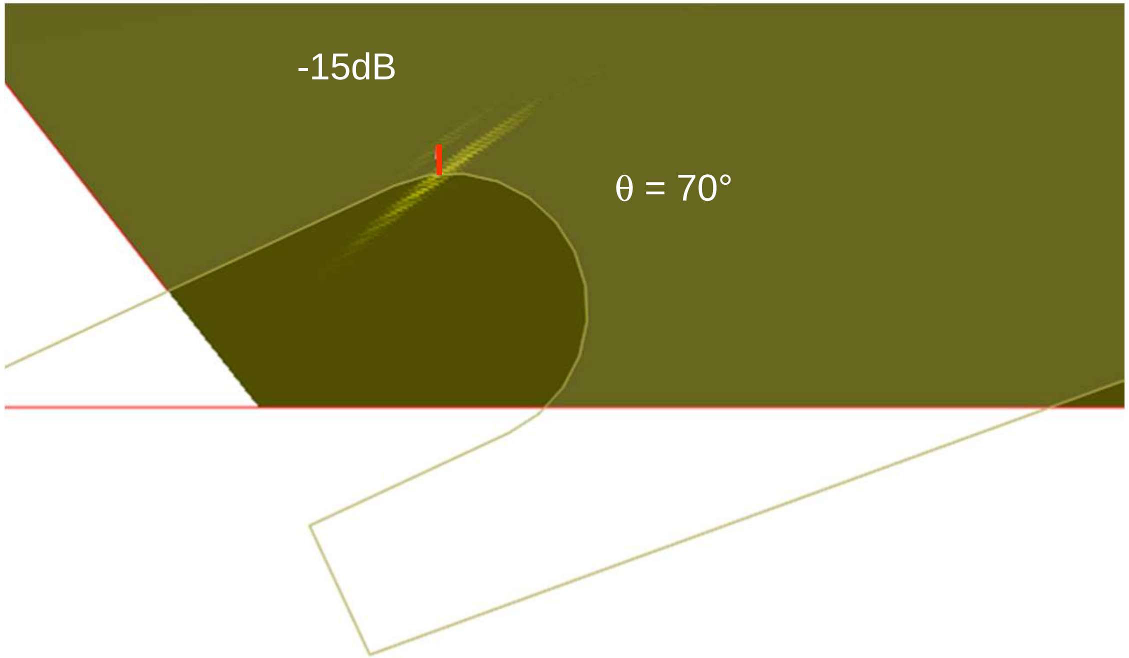
EXAMPLE OF PERFORMANCE DEMONSTRATION

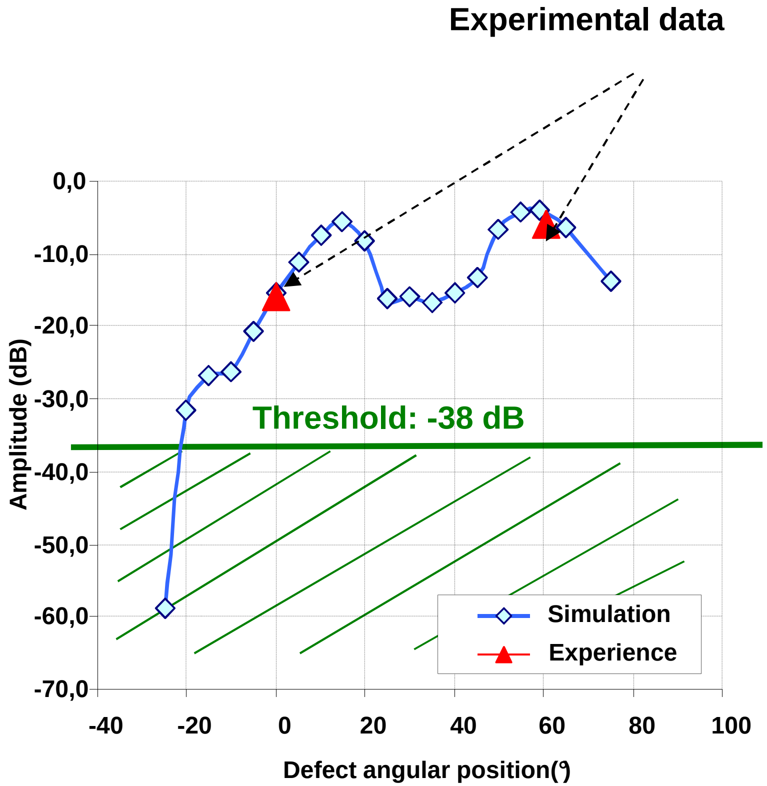
DETERMINISTIC ANALYSIS

Example: UT of Thermal Sleeve of Steam Generator

- What is the response if the defect takes different positions around the sleeve?

=> Complete the data set by using simulation!

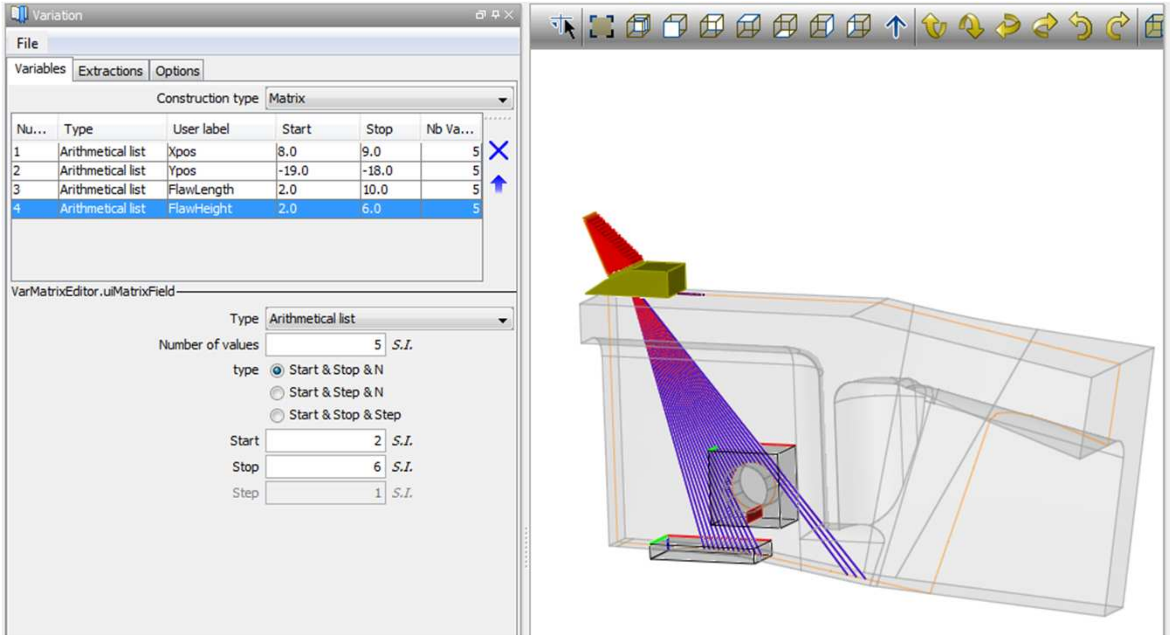




VARIATION SCENARIOS

Tools to achieve deterministic variation analysis

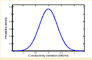
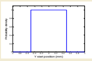
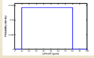
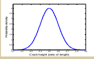
1. List influent parameters and give a range of variation [min;max]
2. Compute NDT response for each combination of parameters
3. Draw resulting curves



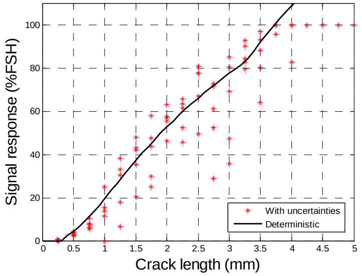
POD ANALYSIS

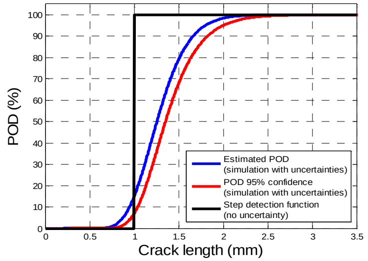
Apply specific variation scenario to produce POD curves

Input parameters:

- Part
  - Dimensions
  - Conductivity 
- Probe
  - Dimensions
  - Number of turns
  - Frequency
- Inspection
  - Start scan position 
  - Scan increment
  - Lift-off 
- Flaw
  - Shape
  - Length
  - Height 
  - Width

CIVA NDE

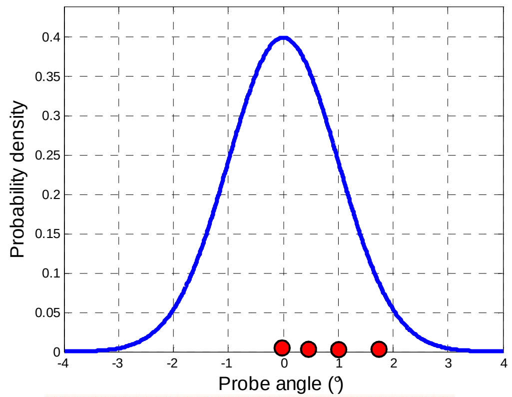




Explicit influent parameters description needed for POD using simulation

TOOLS FOR PERFORMANCE DEMONSTRATION

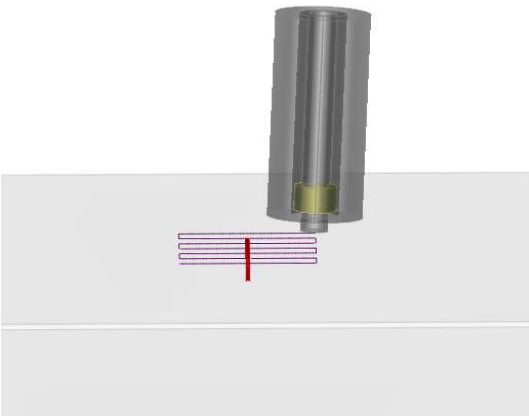
POD simulation by uncertainties propagation

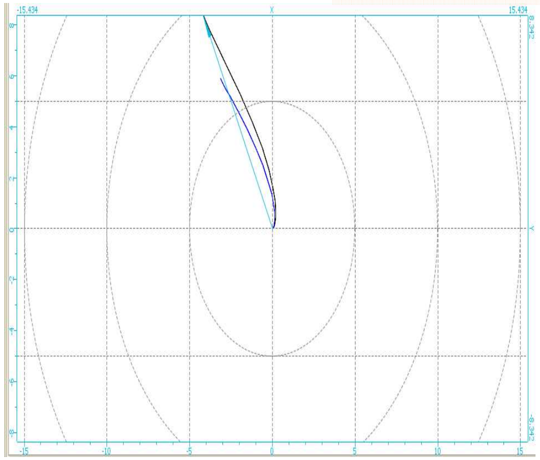


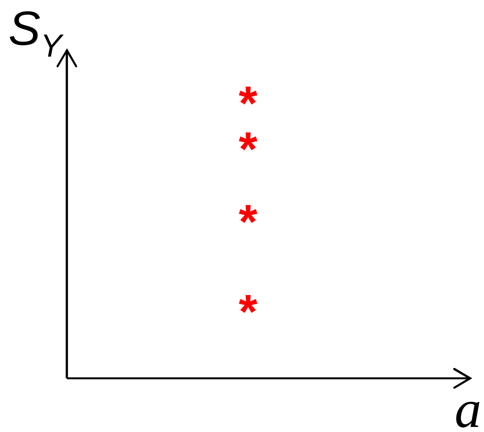
Input parameter values are picked up « randomly » following the probability density function

Input: uncertainty

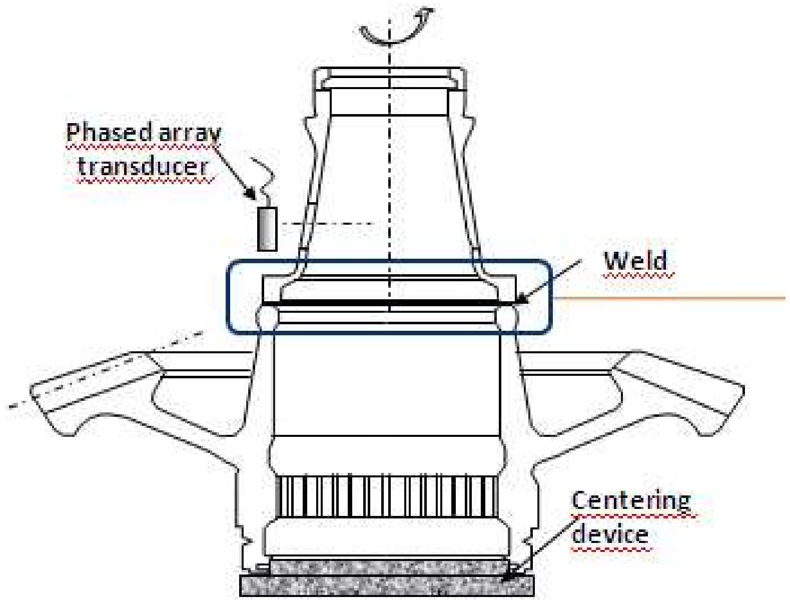
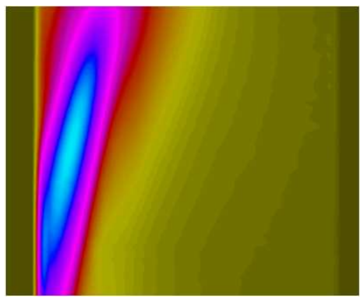
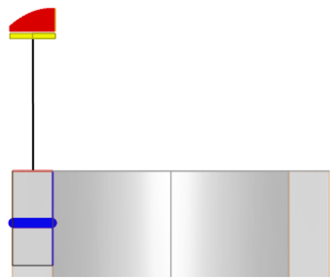
Output: variability



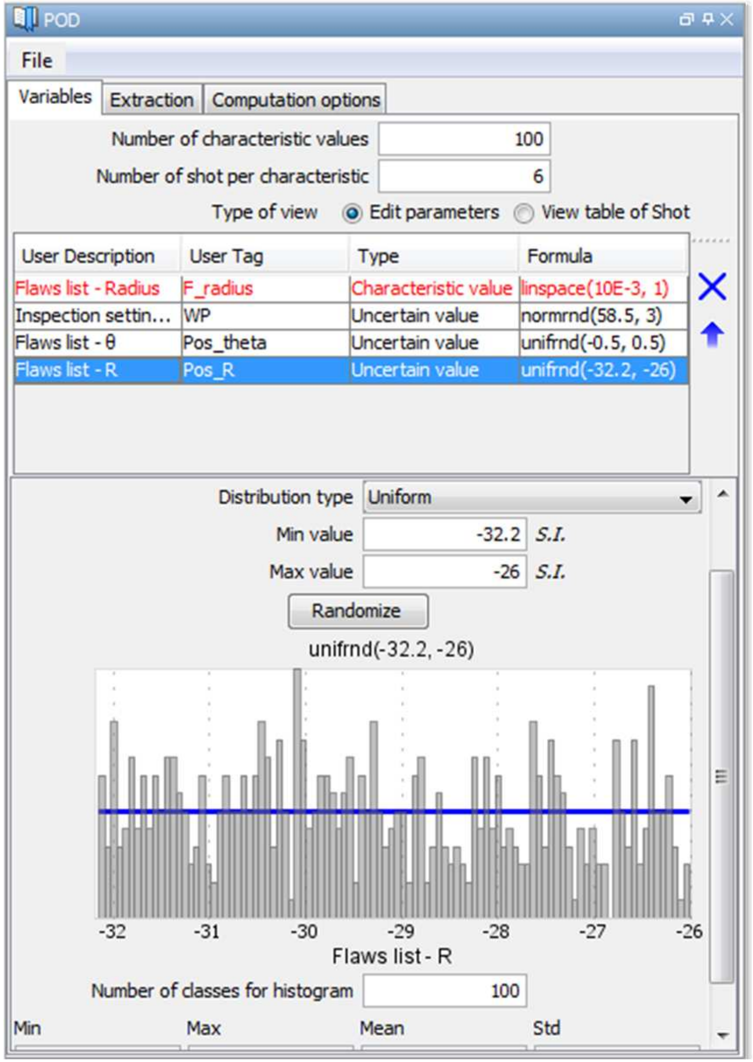


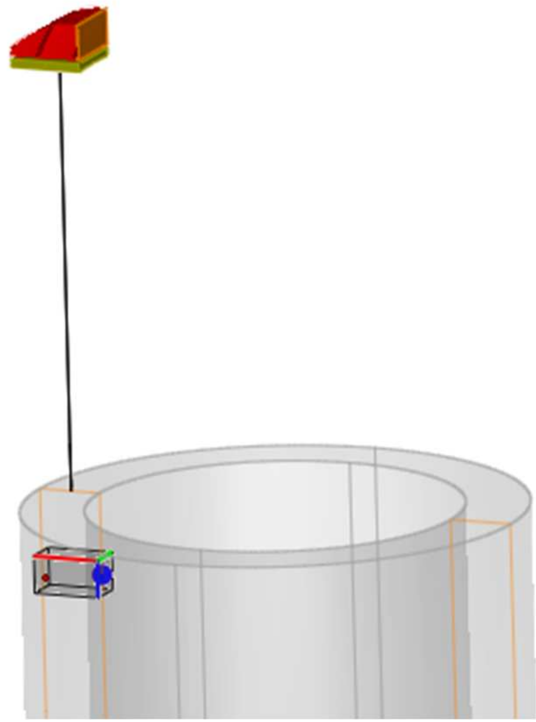


AUTOMATED PHASED ARRAY INSPECTION OF ELECTRON BEAM WELDING (STEEL)

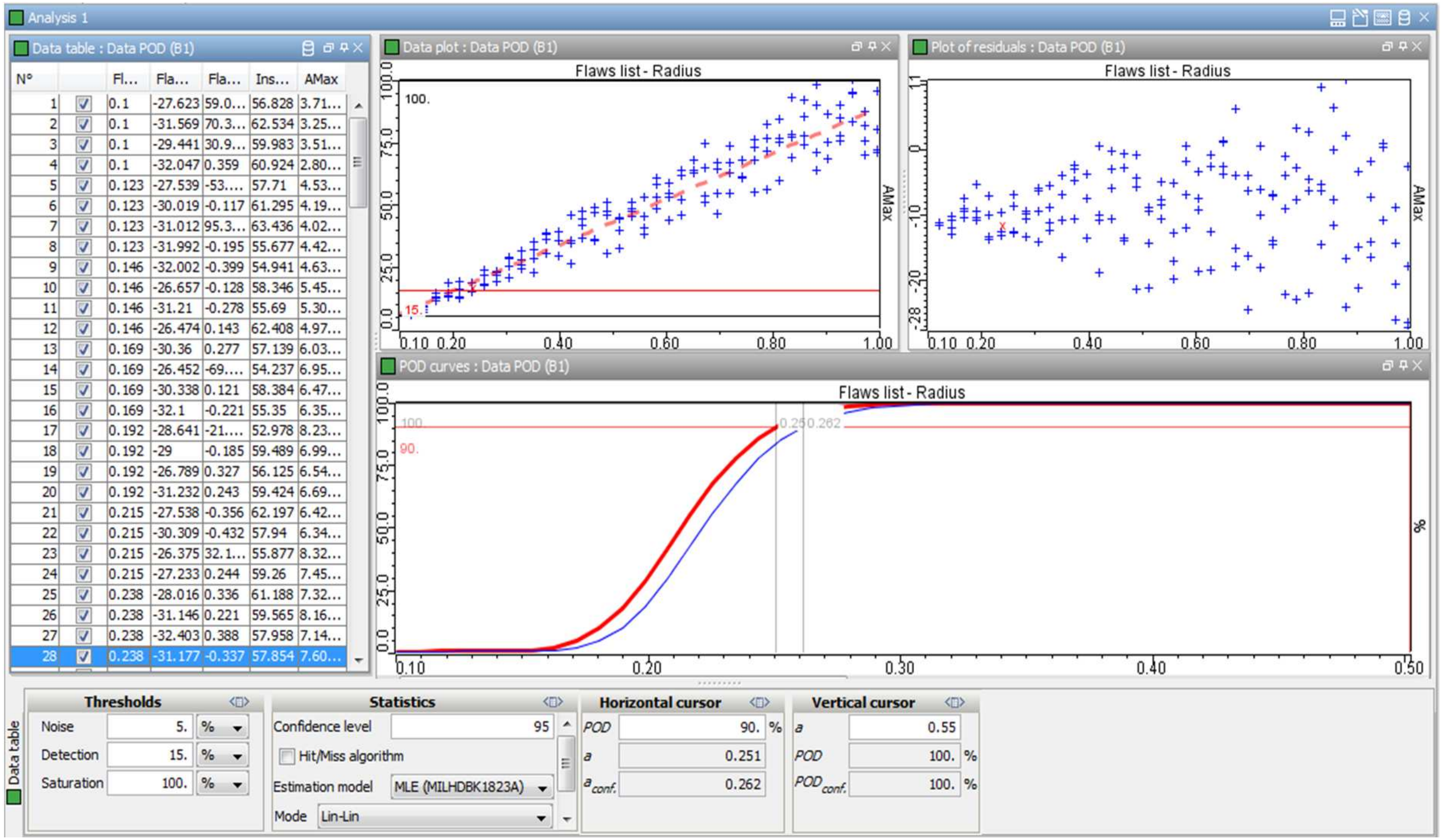
Part	NDT
 **Material:** Steel **Electron Beam Welding** **Geometry:** Locally flat areas **Defects:** Voids	**Configuration:** Phased array UT Multi-points focusing along the weld (0.2 mm pitch) 0.2 mm increment on external radius   **Probe:** Linear array 32 elements, pitch 0.3 mm, 10 MHz central frequency **Conditions:** In-plant (automated rotation)

POD simulation: probabilistic variation scenario





POD Analysis



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CHALLENGES IN PERFORMANCE DEMONSTRATION

ZONE COVERAGE FOR COMPLEX PARTS

How to ensure zone coverage of areas to be inspected, with a specified sensitivity?

POD WITH CONFIDENCE

How to provide simulated POD with confidence?

ZONE COVERAGE (SENSITIVITY)

Context:

Inspection of a part with a complex geometry

Objective:

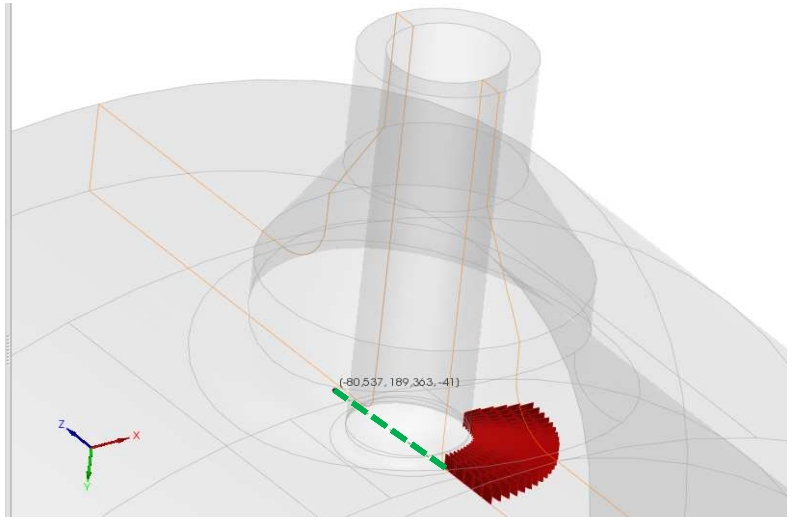
For a given zone, ensure that the probe allows detection of a given defect located somewhere in the zone.

Simulation can help, providing tools to

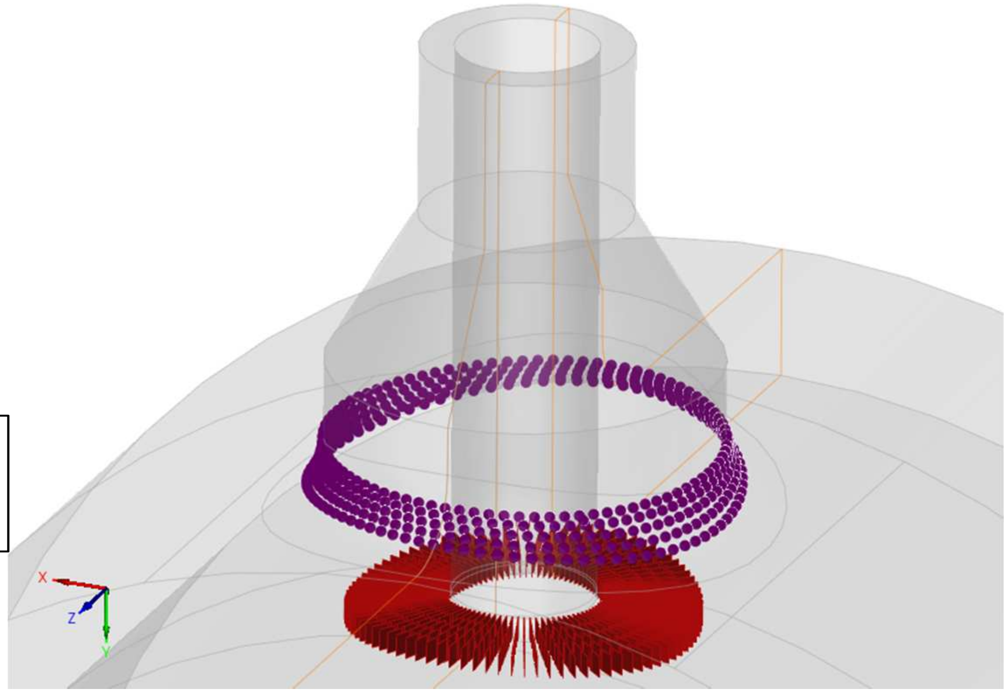
- Define the appropriate probe trajectory
- Determine the appropriate delay laws associated to the computed trajectory
- Evaluate the sensitivity of the inspection everywhere in the inspected zone

ZONE COVERAGE (SENSITIVITY)

First step: Definition of the zone to be inspected and defect type to be detected

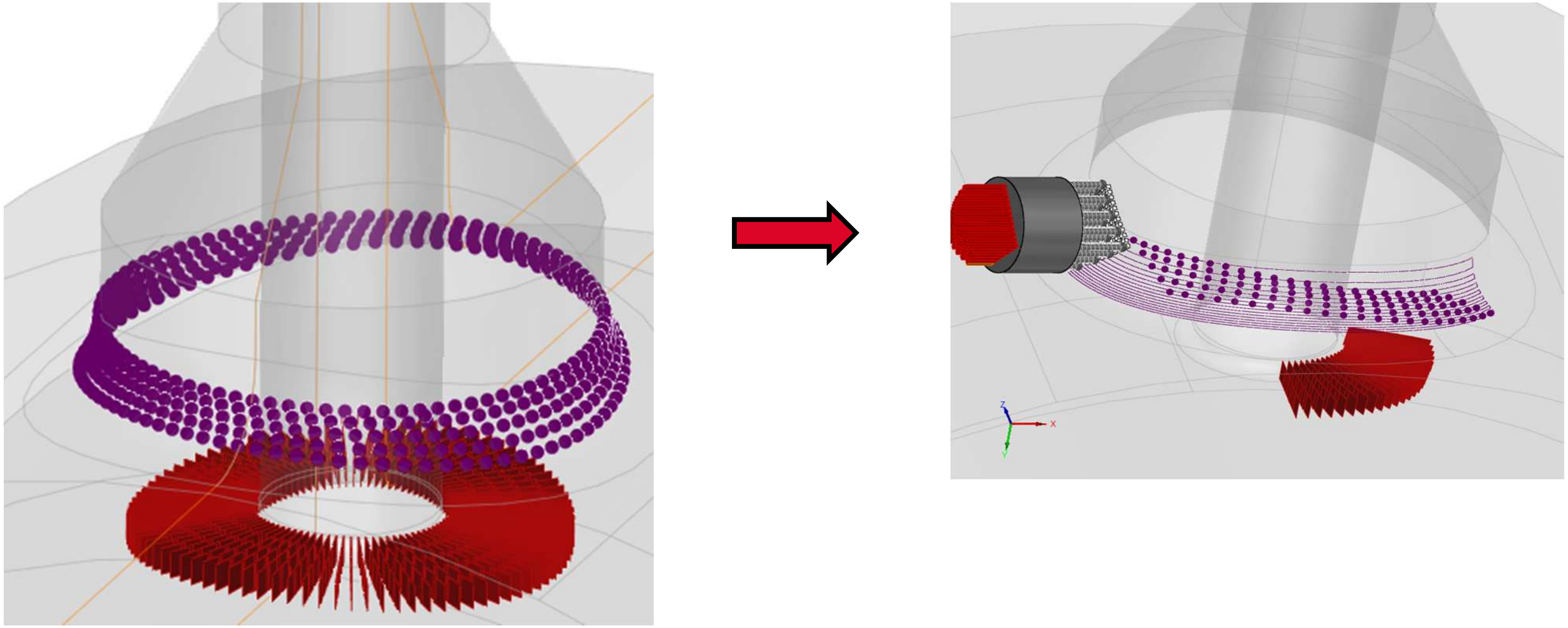


Computation of optimal probe positions and corresponding optimal delay laws



ZONE COVERAGE (SENSITIVITY)

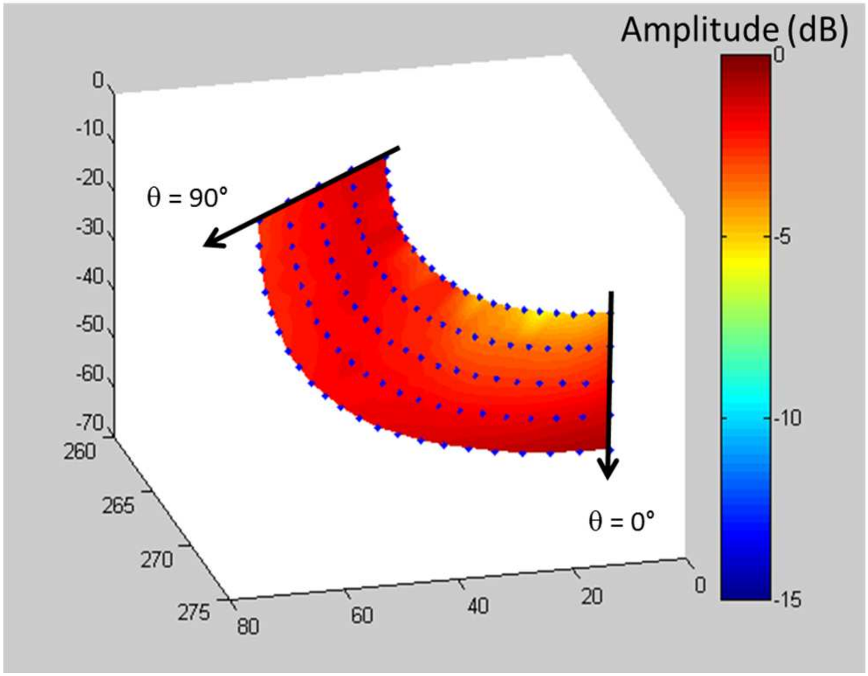
Second step: Determination of the appropriate probe trajectory

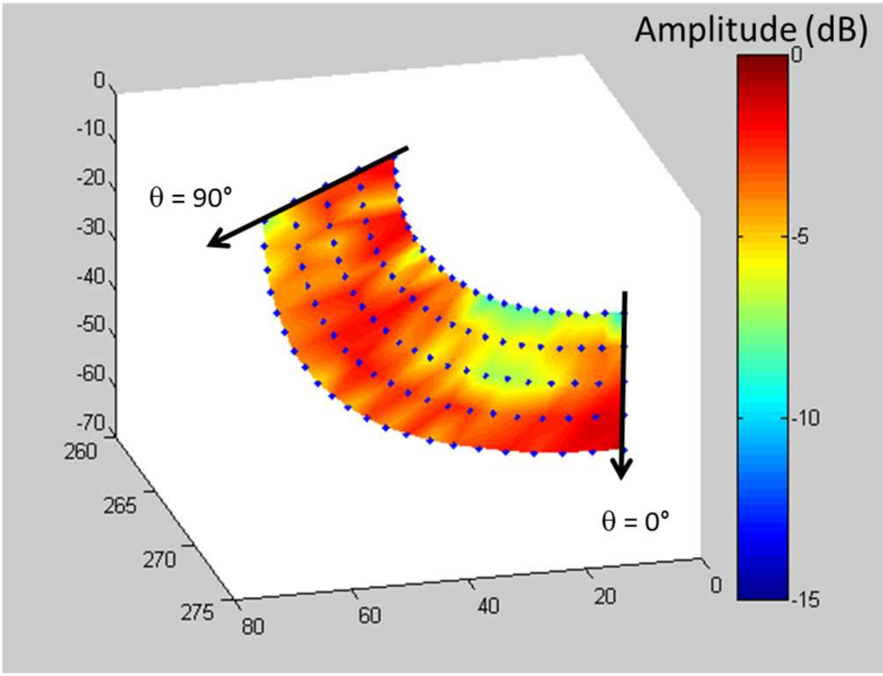


- The cloud formed by the optimal probe positions may be difficult to describe with a parametric trajectory (such as those used by a robot for instance)
- Necessary to simplify the problem

ZONE COVERAGE (SENSITIVITY)

Third step: Computation of sensitivity maps





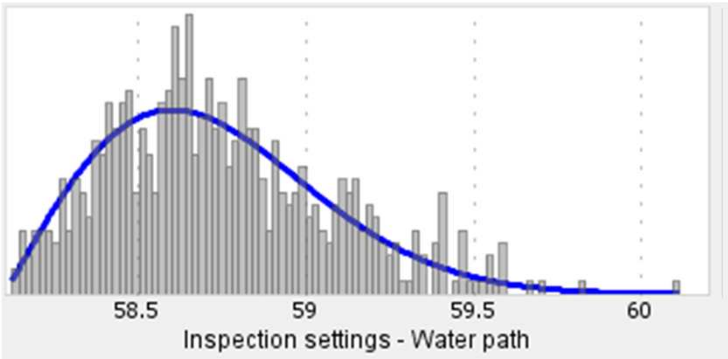
- Using the cloud of optimal probe positions
- After simplification, using a parametric probe trajectory

Further works:

- Propose GUI for the 3 step process
- Sensitivity maps in 3D views, projected onto the specimen

CONFIDENCE IN POD ESTIMATION WITH SIMULATION

- **Difficult point**: fill in the uncertain parameters description in input



?

- **What influence on POD result?**

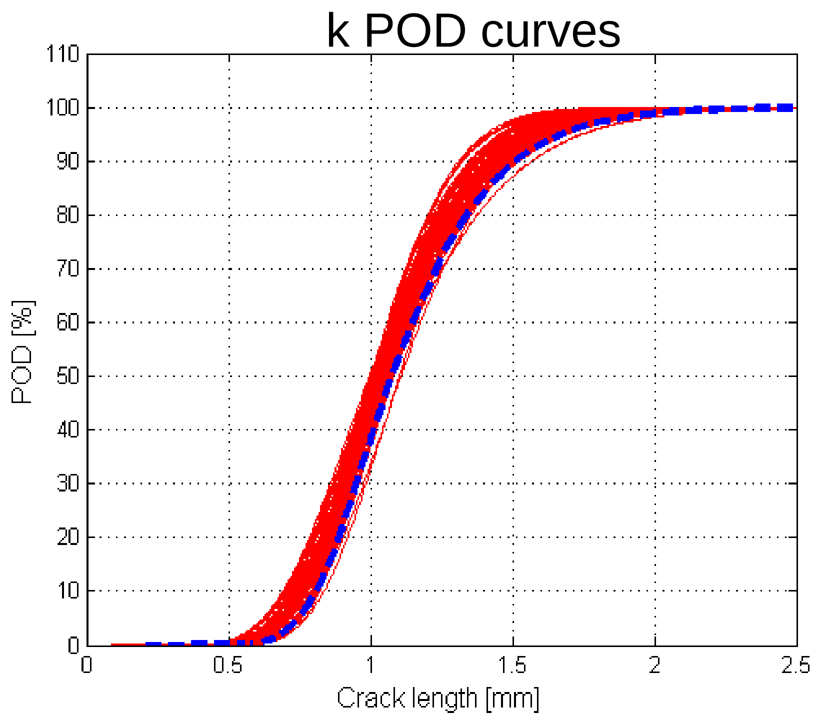
CONFIDENCE IN POD ESTIMATION WITH SIMULATION

- One POD scenario is:
  1. Define uncertain parameters
  2. Calculate POD curve

POD scenario	Scan position		Crack height		Probe angle	
	Uniform		Gaussian		Gaussian	
	Min	Max	μ	σ	μ	σ
1	-0.5	0.5	0.5L	0.12 L	0	1.0
2	-0.5	0.5	0.5L	0.09 L	0	0.9
3	-0.5	0.5	0.5L	0.11 L	0	[illegible]
…	…	…	…	…	…	…
k	-0.5	0.5	0.5L	0.17 L	0	1.2

Sure

Not sure



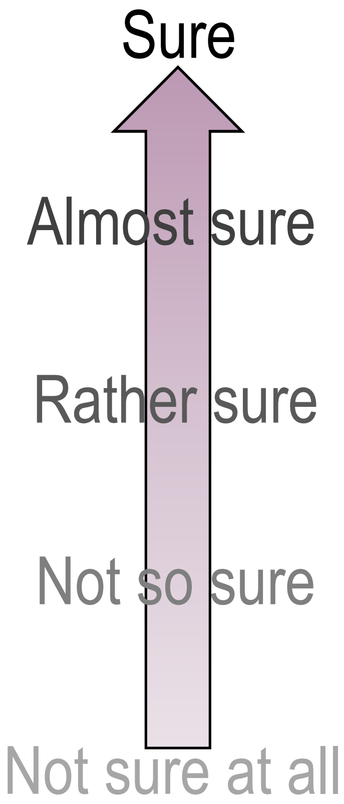
- <u>Confidence approach</u>: **calculate a beam of scenarios and use the scattering on the POD curves to estimate a confidence**

CONFIDENCE IN POD ESTIMATION WITH SIMULATION

CERTAINTY INDEX DEFINITION

Applies on the probability distribution parameters

- **Index 5**
  No uncertainty on the distribution parameter
- **Index 4**
  The distribution parameter follows a gaussian law with
  (μ=GV*, σ=20% GV)
- **Index 3**
  The distribution parameter follows a gaussian law with
  (μ=GV, σ=50% GV)
- **Index 2**
  The distribution parameter follows a gaussian law with
  (μ=GV, σ=100% GV)
- **Index 1**
  The distribution parameter follows a uniform law with
  (min=GV-3*GV, max=GV+3GV)



* GV stands for « guessed value »

CONFIDENCE IN POD ESTIMATION WITH SIMULATION

The 95% lower confidence POD curve is the curve which leaves on the left 95% of the « POD curves » of the beam.

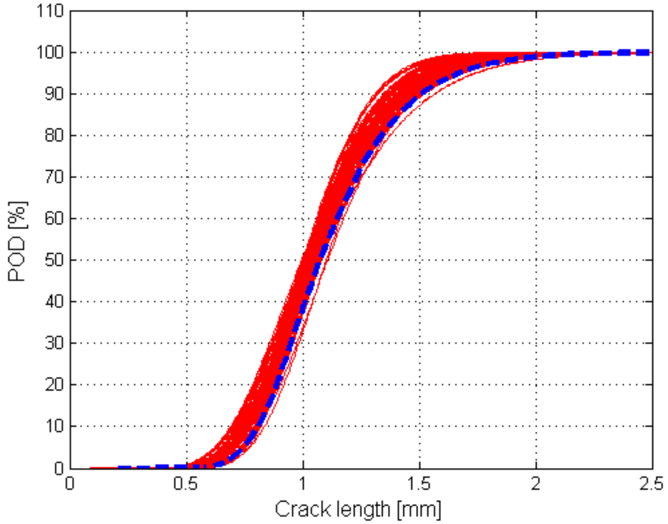
In practice the POD curve with confidence can be built pointwize, looping on POD values :

For *p* in [0.01;0.99]

- **Find the POD curve leaving 95 % of the curves on the left at ordinate p**
- **Pick-up the corresponding flaw size a_p**

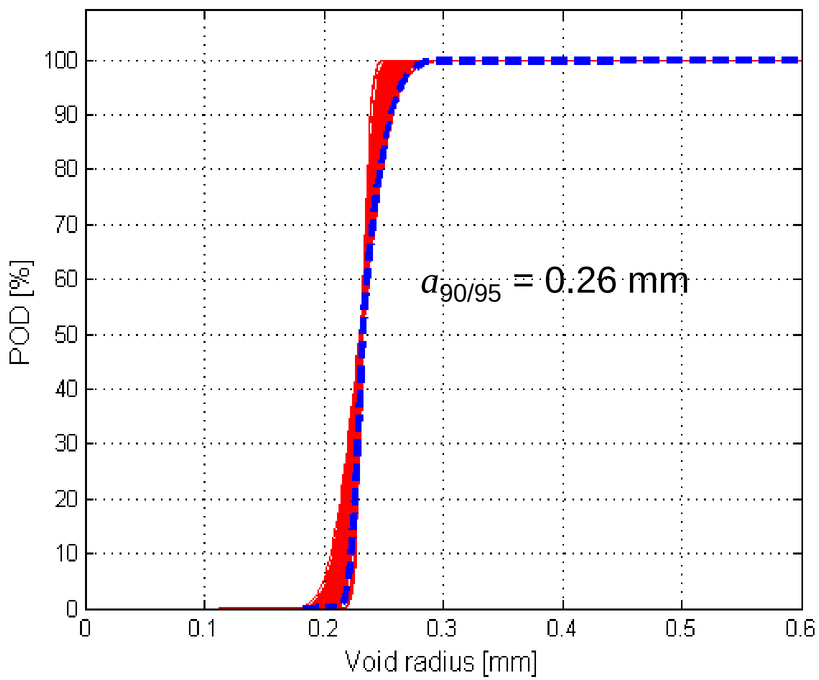
End

The POD curve with confidence is the set of points (a_p, p).

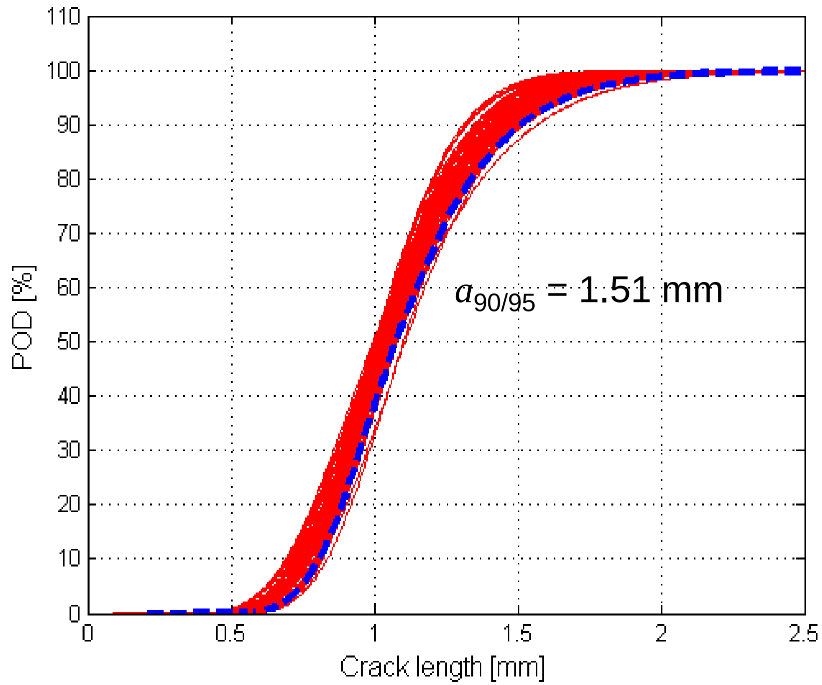


CONFIDENCE IN POD ESTIMATION WITH SIMULATION

Automated Phased Array UT of EBWeld



Manual HFET of fatigue cracks on Ti



⇨ The more the NDT process is mastered and repeatable, the better the confidence.

SUMMARY

- Simulation can help in making performance demonstrations
- Variation tools allow for deterministic performance analysis
- Probabilistic variation tools allow for POD evaluation
- Zone coverage tools allows design of NDT including a target of sensitivity

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