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Bundesanstalt für Materialforschung und -prüfung

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MONTE-CARLO-ANALYSIS OF MINIMUM BURST REQUIREMENTS FOR COMPOSITE CYLINDERS IN HYDROGEN SERVICE

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Overview

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3. Minimum burst pressure in design type testing
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5. Proof pressure during initial and re-testing
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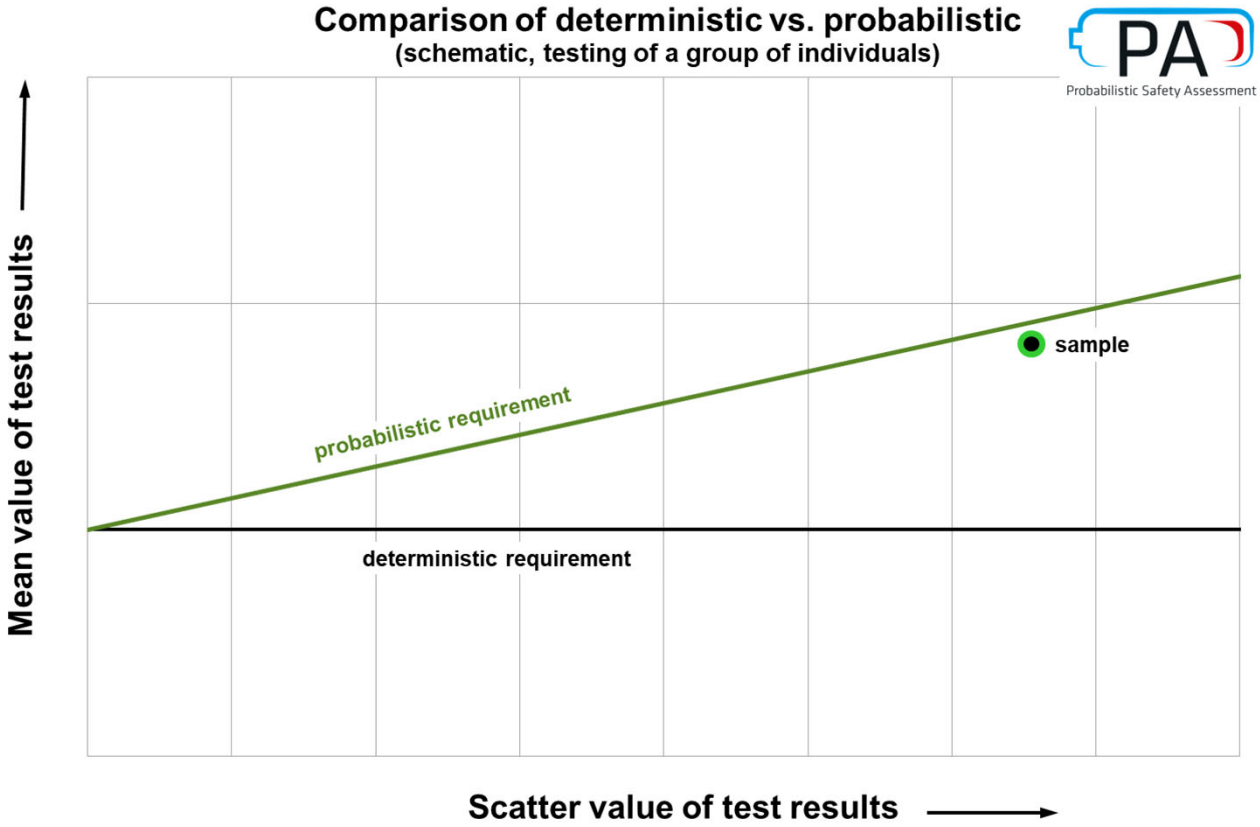
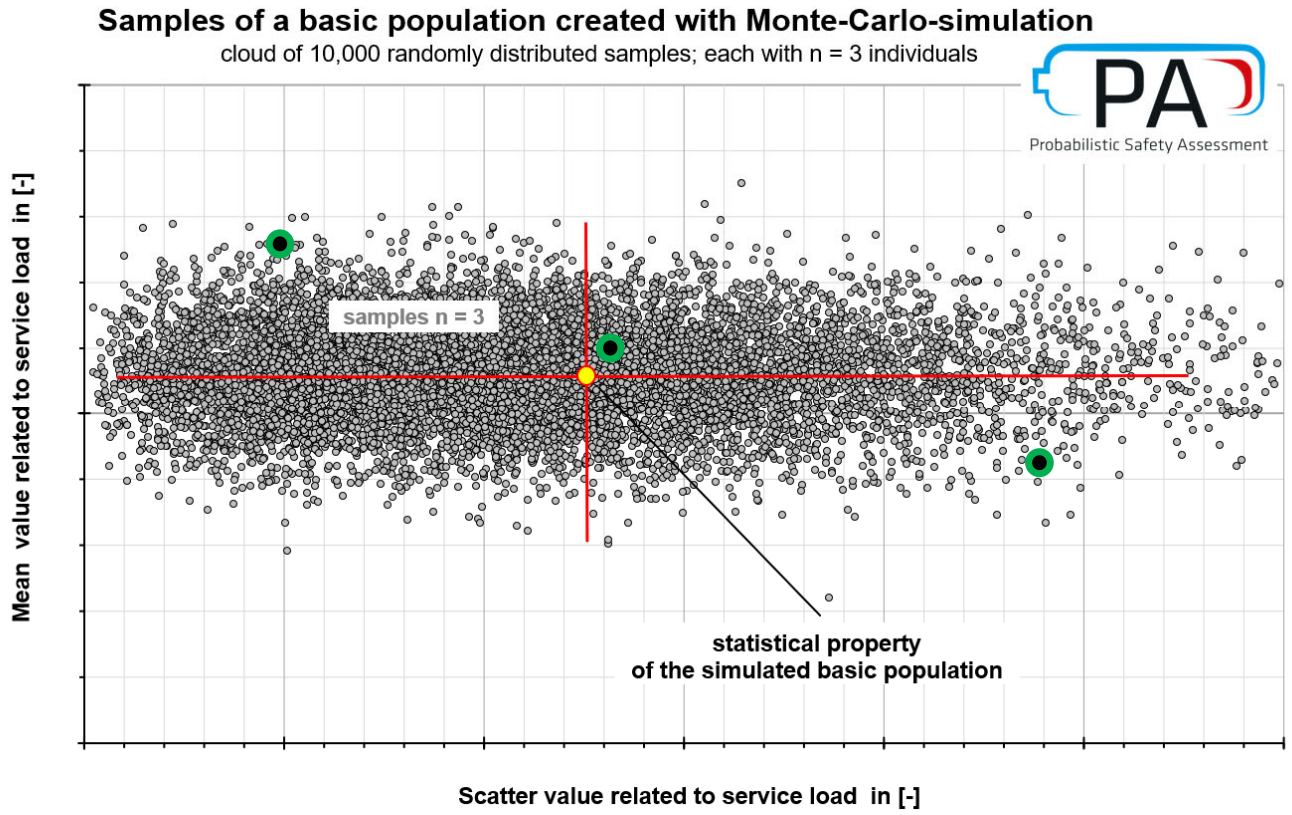
Introduction

Display of probabilistic and deterministic requirements with test results



The sample performance chart SPC of BAM

Visualisation of statistical behaviour

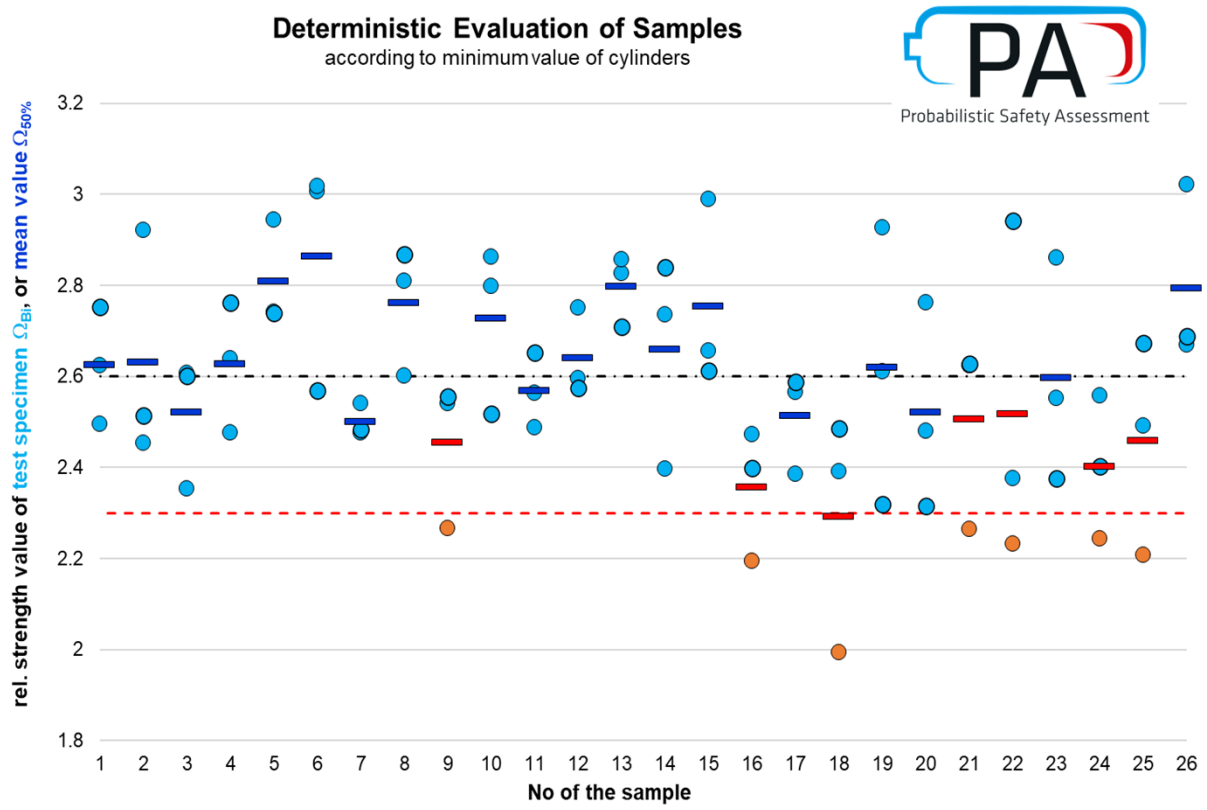


The Monte-Carlo-experiment is helpful for the simulation and visualization of strength properties – as far as the data base is sufficient for describing reality.

Displayed here is the sample performance chart SPC of BAM.

Potential of Monte-Carlo-simulation

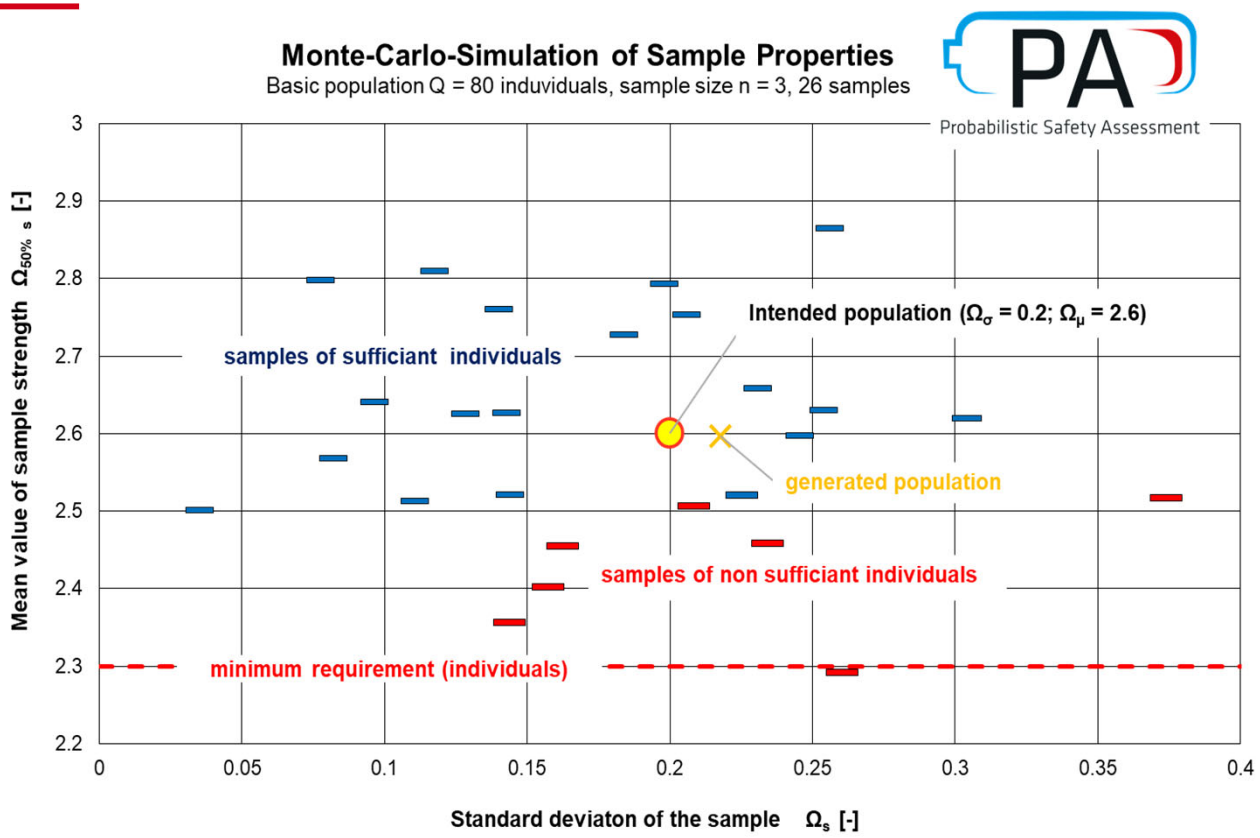
How Monte-Carlo-simulation “MCS” works



The generated properties of individuals in each sample (here 3) can be checked against a minimum requirement, which allows to count how many batches would not pass.

26 samples:
7 failed, 19 passed,
acceptance rate = 70%

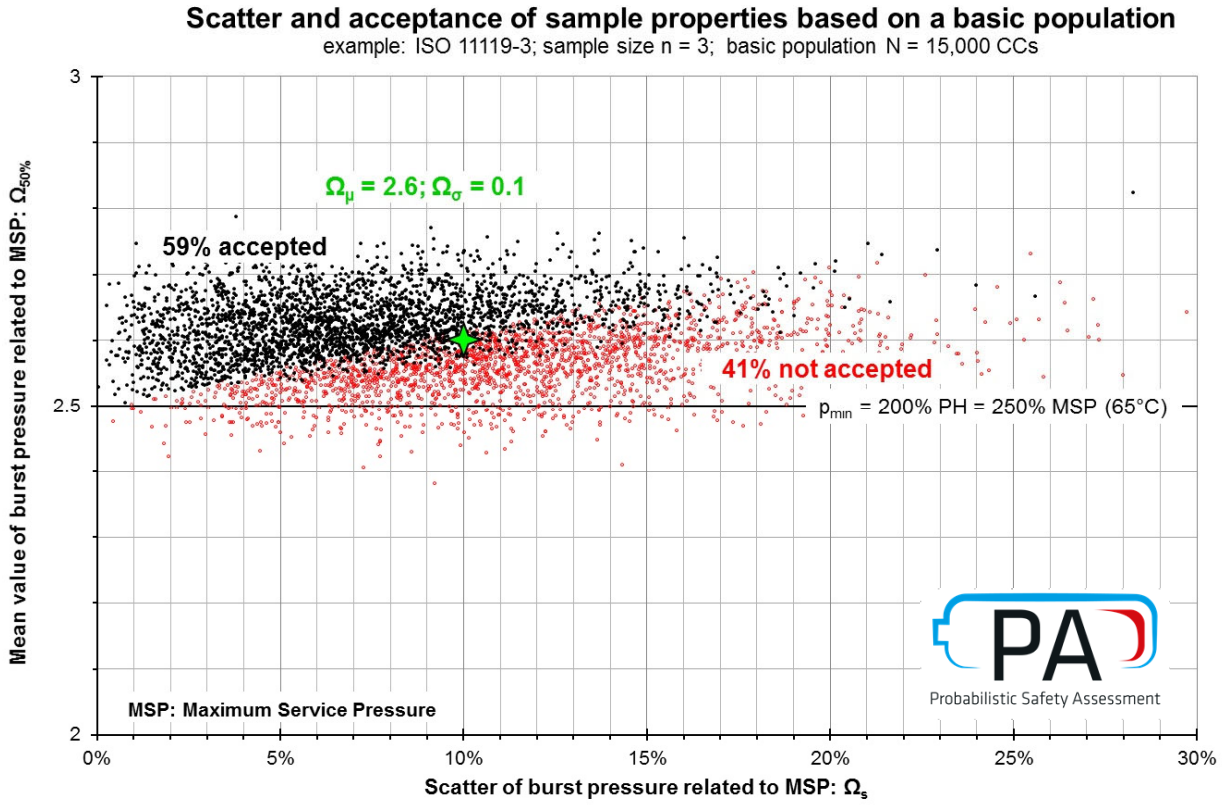
How the sample evaluation works



The information about passing the minimum requirement and the mean strength of the batch links the two different worlds of deterministic and probabilistic.

This enables to calculate the likelihood for passing a legal requirement and the probability of failure under normal load.

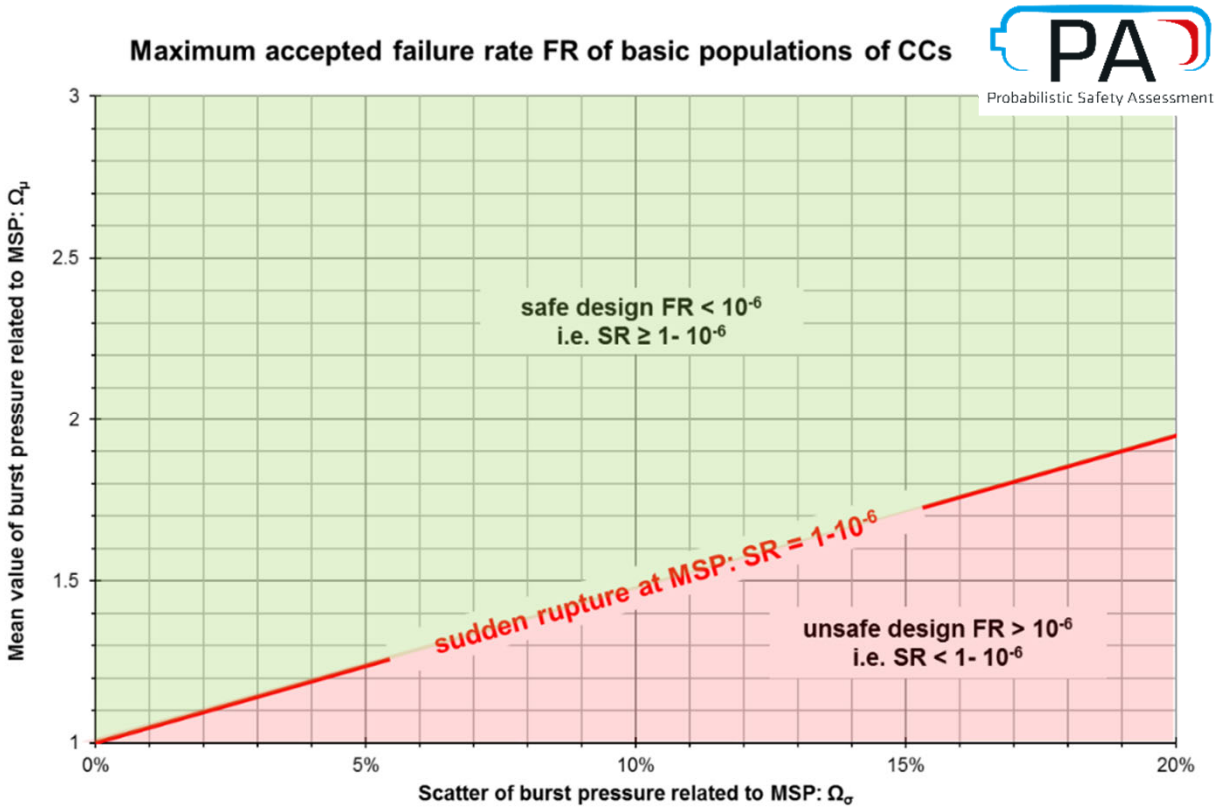
Simulation of a larger population



When you ask for a minimum burst pressure on the basis of a small amount of CPVs to be tested there is always a high influence of chance in the test result.

(green cross = real properties of the basic population; accepted samples of this population are black; rejected samples are red)

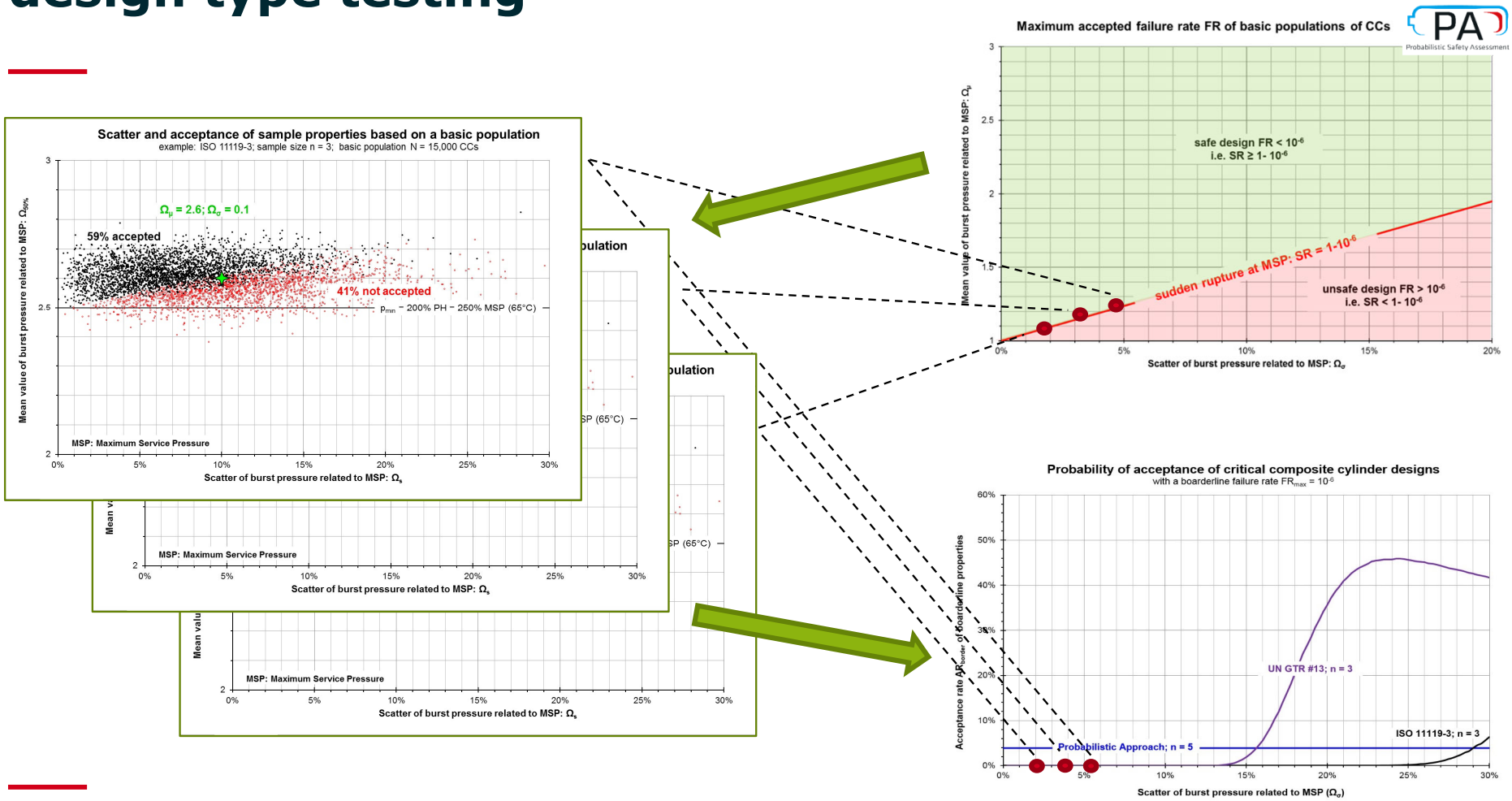
The probabilistic safety criterion



When the data are verified the sample properties (either tested or simulated) need to get checked against the minimum requirement (e.g. 1 of 1 Mio), which depends on the pressure-volume-product (pV).

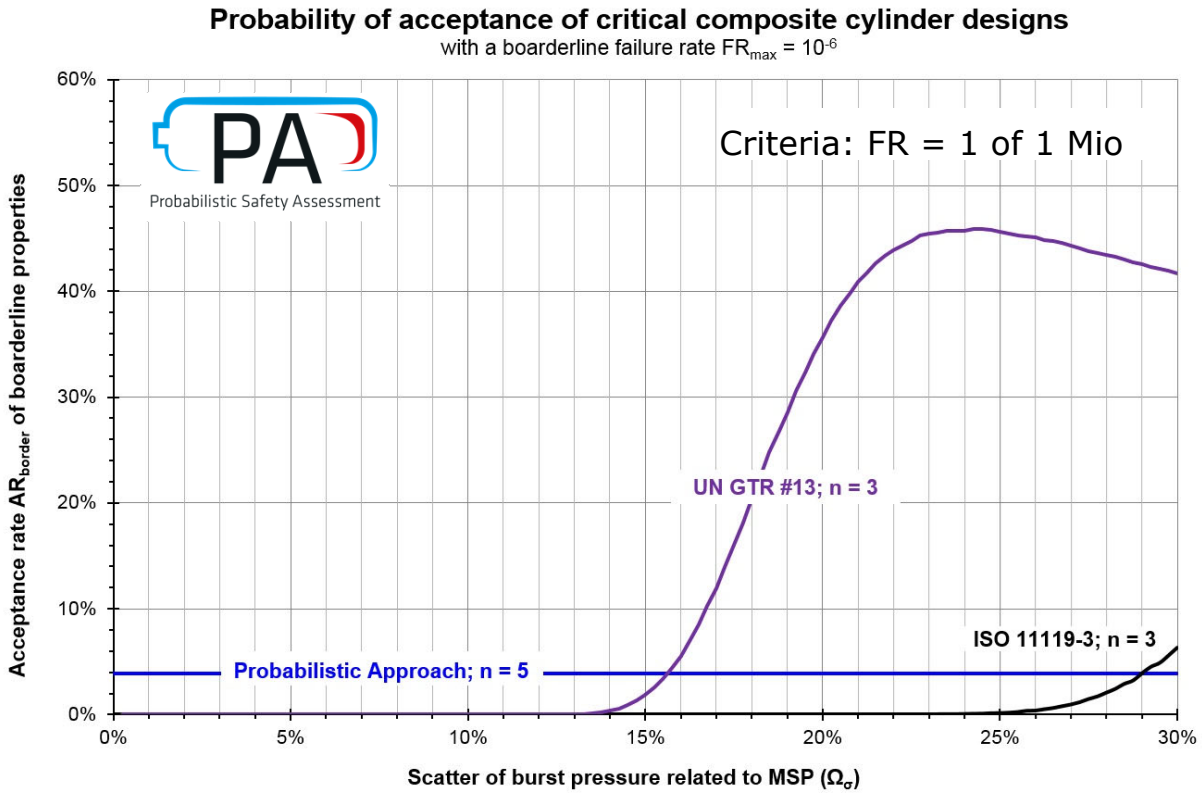
For the TAHYA-design $2 \cdot 10^{-7}$ (1 of 5 Mio) has been determined.

Analysis of minimum burst pressure required for design type testing



Minimum burst pressure in design type testing

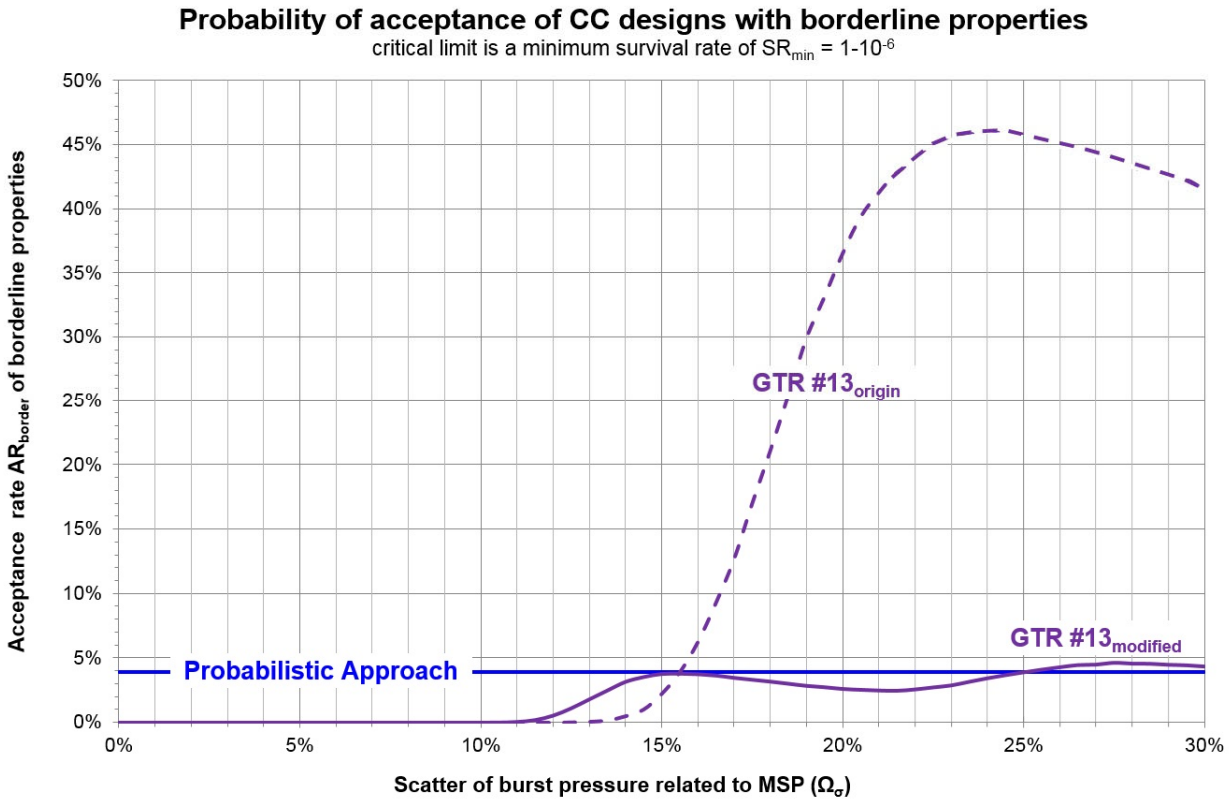
Probability of acceptance of critical designs



Monte-Carlo analysis of the probability accepting insufficient populations in accordance with current. This level should not go above 5%.

The minimum value has a direct influence on the critical level of production scatter.

MCS-optimization of burst requirements



Three measures are necessary for achieving the intended acceptance rate AR for borderline populations of max. 5%.

5% uncertainty equals the confidence level of a probabilistic approach.

Measures for improvement

1. Increase the number of burst tests for approval from 3 to 5 pressure vessels.

   This creates a higher confidence in test results.

2. Require a scatter value of ±5% BP_O instead of ±10% BP_O at given BP_{min}

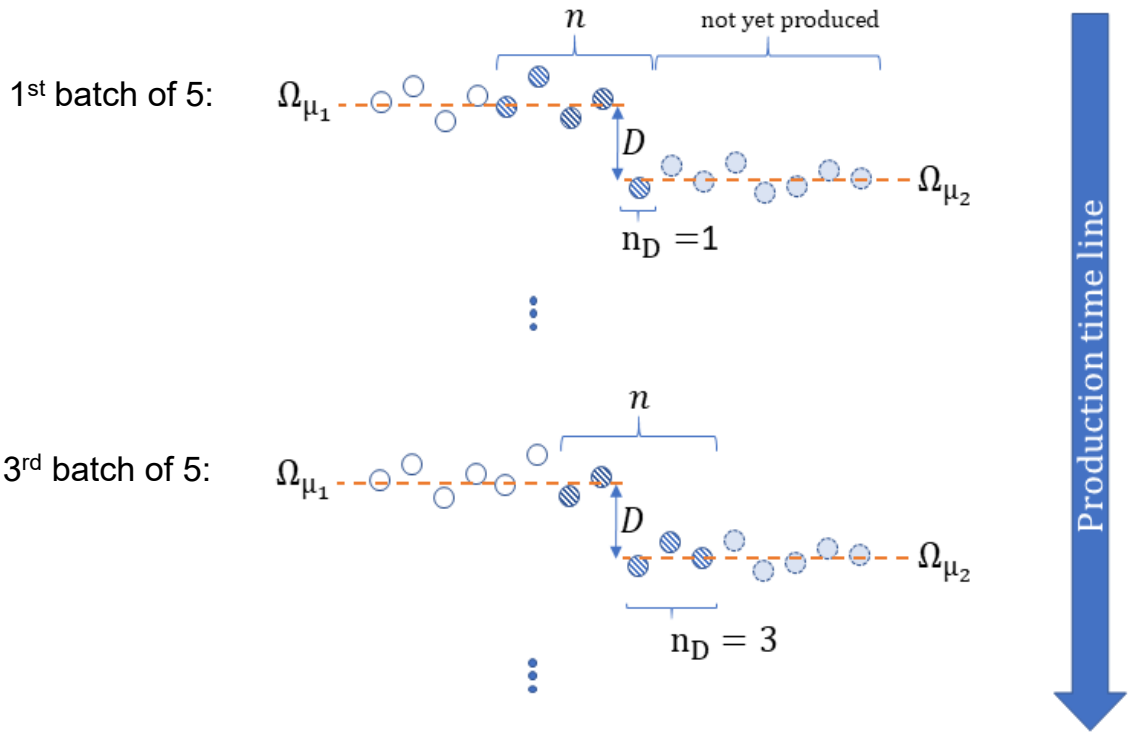
   This prevents the acceptance of designs with too high scatter in production.

3. If $BP_O \geq 2.75$ NWP an increased scatter value of ±7% BP_O is acceptable

   This enables the approval of designs with a higher production scatter.

Minimum burst pressure in batch testing

Minimum burst pressure requirement in batch testing



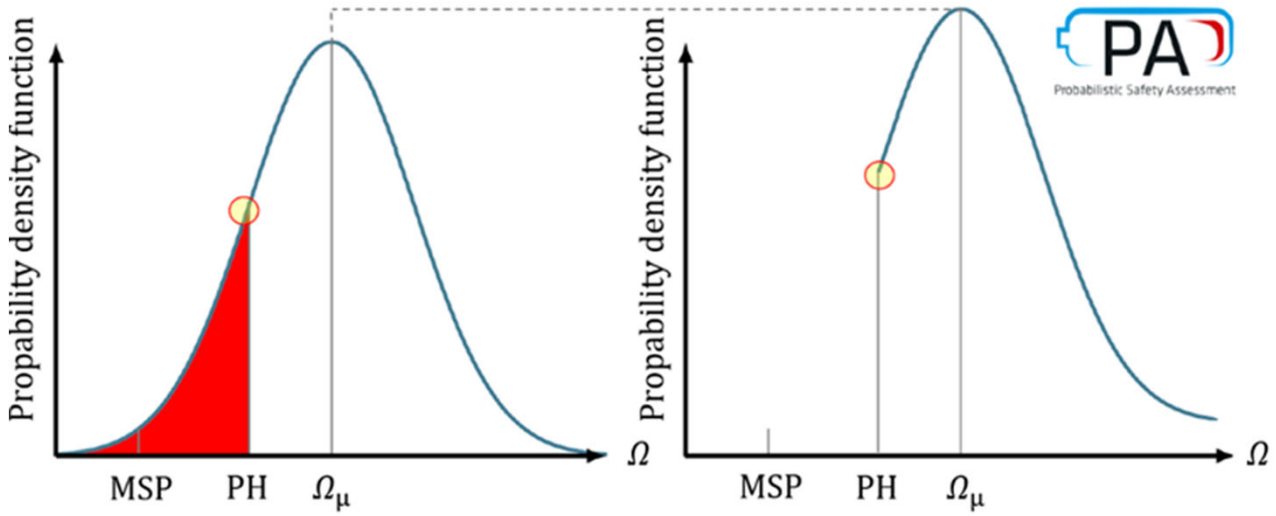
Batch tests target on general faults and not on defective individuals.

With changes of the evaluation process of data the efficiency of the mandatory destructive tests can be increased significantly.

1. $BP > BP_{min} = 2\ NWP$
2. $BP_{50\%}\ (\text{of last } 10) > 0.9\ BP_O$

Proof pressure during initial and re-testing

Proof testing to a pressure above maximum service pressure



Proof testing sorts the weakest units (red) out and cuts the distribution at the test pressure (density curve). For the moment none can fail at service pressure (MSP), which is a load lower than test pressure (PH).

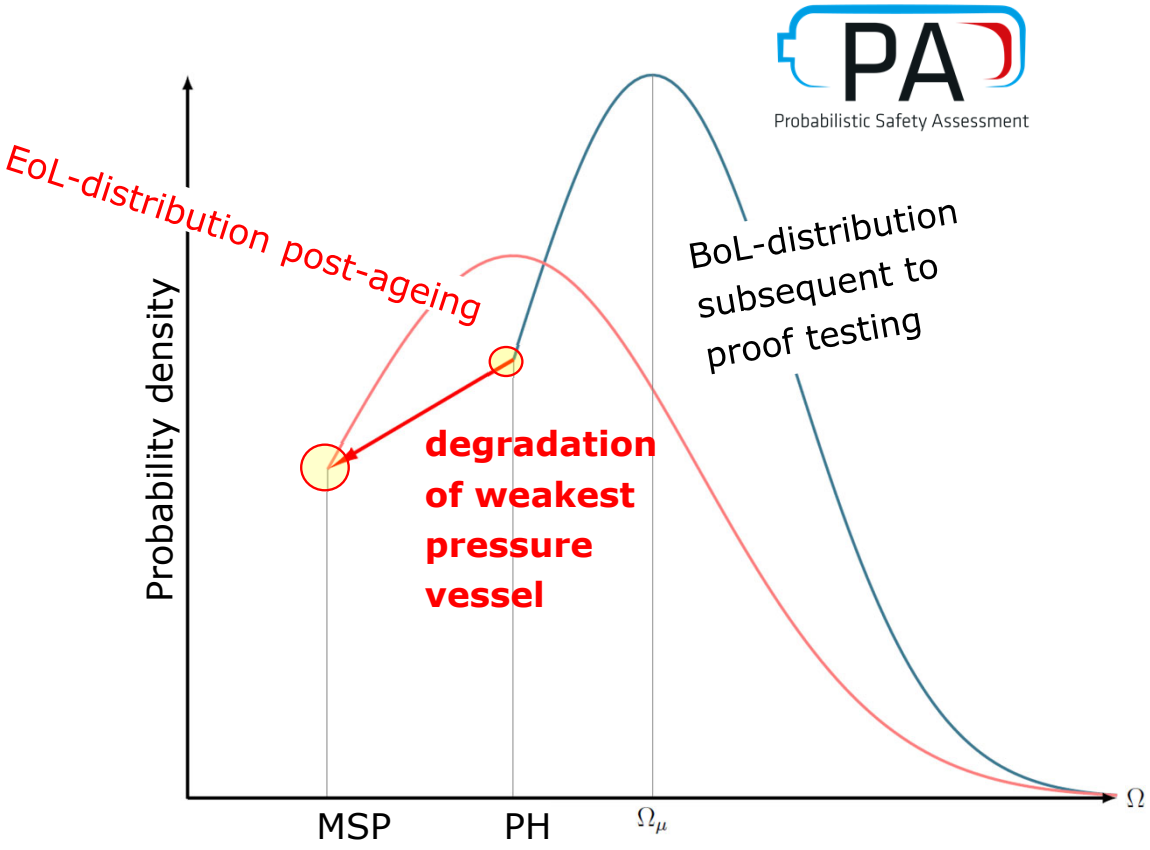
The proof testing of each individual is relevant for initial testing and for re-testing (except automotive onboard storage)

Proof testing and degradation

Due to degradation each individual of the remaining population will lose strength.

The question is just: “when will the first individual become critical?”

What is the period that the weakest need for going below MSP?



Summary

Summary and outlook

1. A quasi-static loading is part of four mandatory test procedures: design type, batch, initial proof and re-testing.
2. Monte-Carlo-simulation enables to check the effect of minimum requirements in approval regulations and standards.
3. Requirements for design type and batch testing can and should get optimized by MCS with a significant effect on safety at begin of life (BoL) and indirectly for safety at end of life (EoL).

Due to ageing and degradation, safety assessment and MCS must focus on the reliability level at end of life (EoL-safey).

Since ageing effects are not sufficiently experienced we will improve our understanding of service degradation by destructive testing, NDT and structural health monitoring.

Acknowledgement

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Thank you for your attention!

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References

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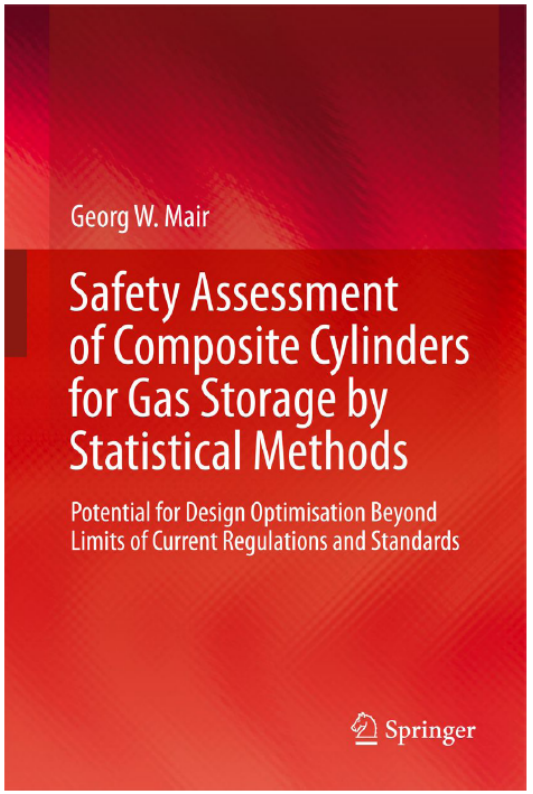

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