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International Conference on Hydrogen Safety

Sicherheit in Technik und Chemie

BAM
Bundesanstalt für Materialforschung und -prüfung

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MONTE-CARLO-ANALYSIS OF MINIMUM LOAD CYCLE REQUIREMENTS FOR COMPOSITE CYLINDERS FOR HYDROGEN

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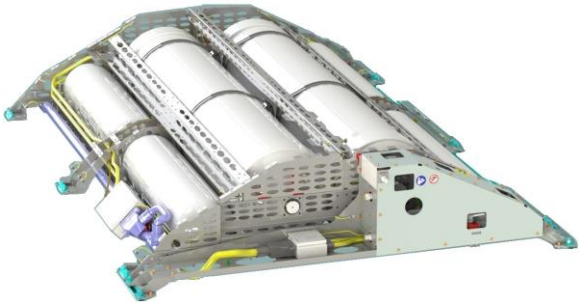
Why do we discuss safety of storage units?

1st No failures? Hydrogen storage is currently not a real safety issue.

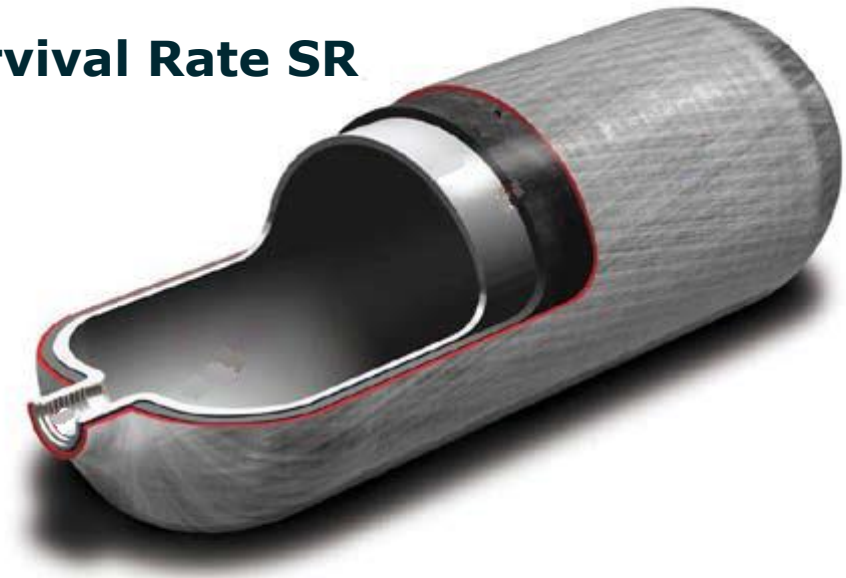


3rd How to assess the reduction of current "safety factors"?

2nd But, there is a request for weight and cost savings!

Overview

1. Principle of Monte-Carlo-Simulation for assessment of regulations
2. Acceptance Rate AR vs. Survival Rate SR
3. Safety level of regulations
   - AR of borderline SRs as benchmark
4. Summary

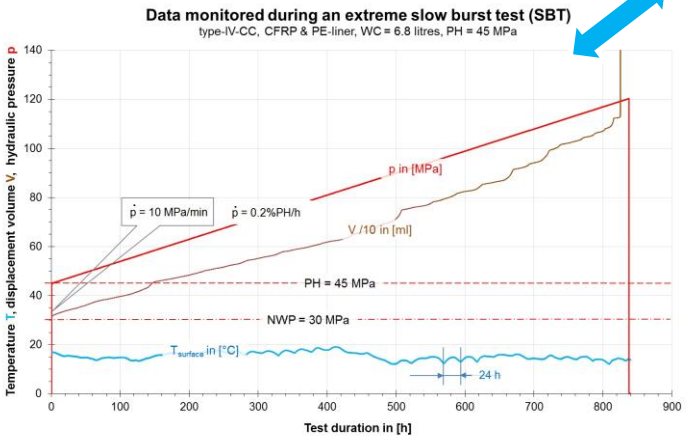


Principle of Monte-Carlo-Simulation for Assessment of Regulations

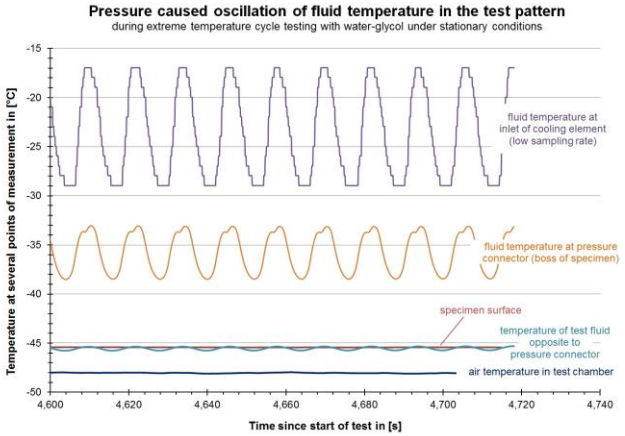
Strength is the essential safety criterion

(Slow) burst test

Load cycle test



Hydraulic test methods for composite cylinders (CCs)

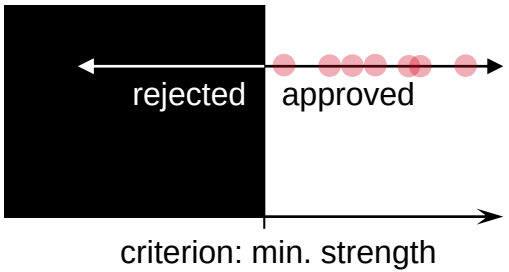


Probabilistic vs. deterministic approach

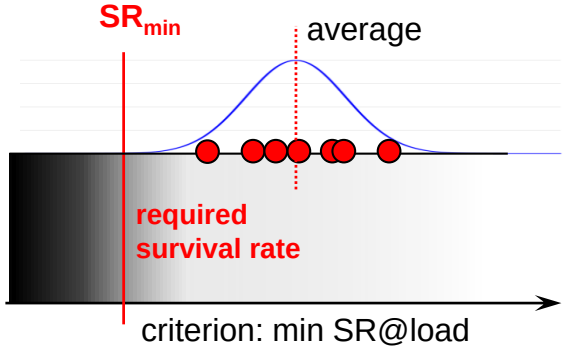
Evaluation of test results is different:

e.g. minimum strength vs. min. survival rate SR

Deterministic: simple yes/no-check



PA: quantitative property-check

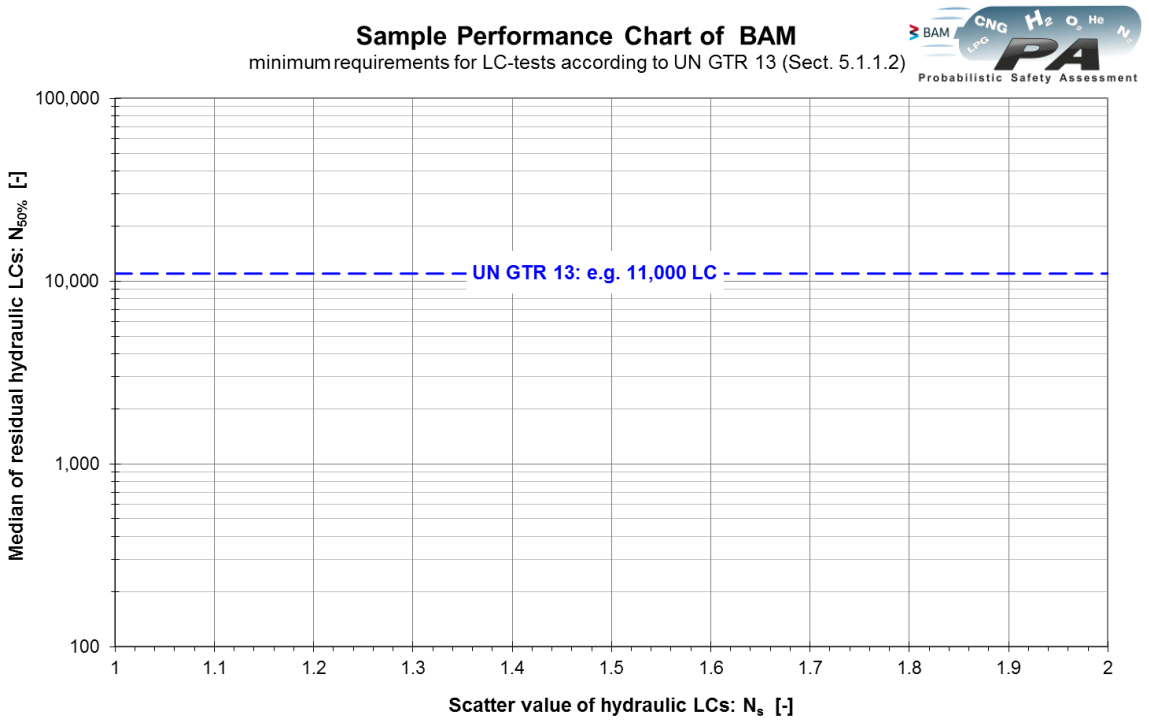


Improvement by appropriate visualisation

Usage of the

SPC
(sample
performance
chart)

for visualisation of
sample properties



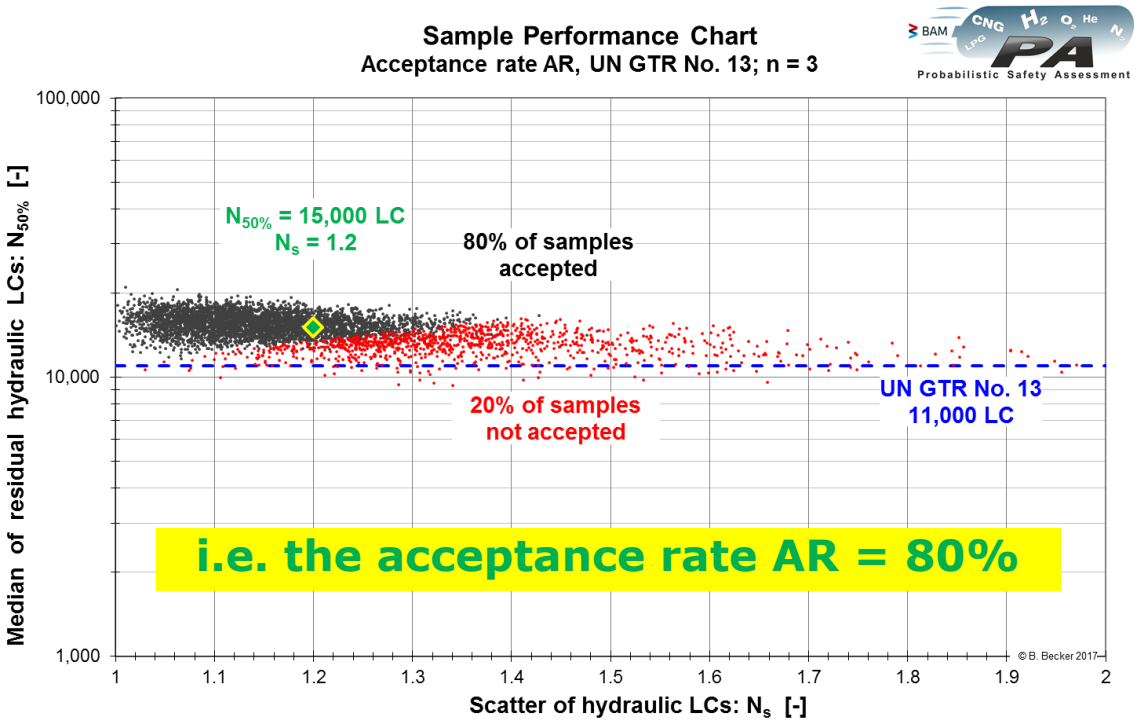
Principle of Monte-Carlo-Simulation

Simulation of a huge amount of individual test results

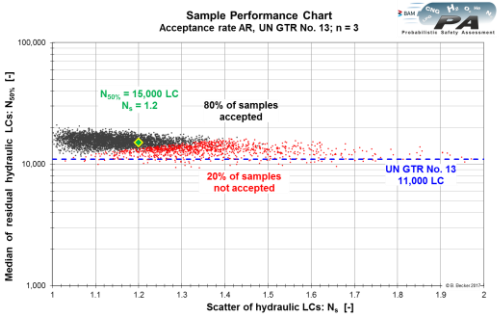
randomly collected to samples of CCs

results into a cloud

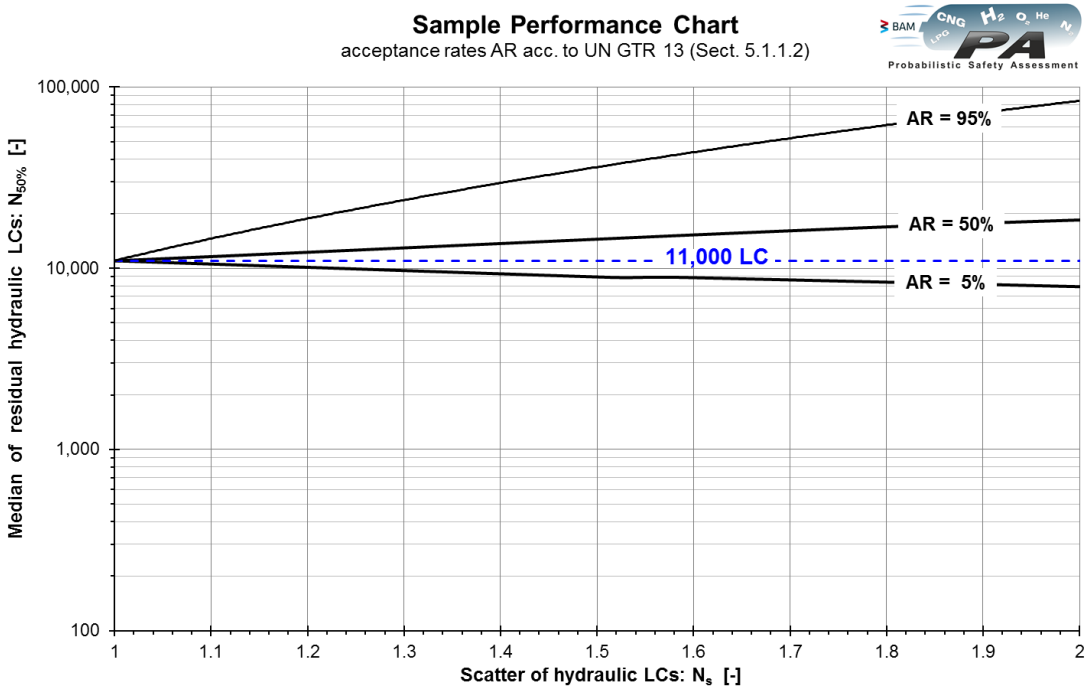
representing the determined properties of
basic population.



Acceptance Rate AR of tests acc. GTR 13 depends on the scatter of the basic population



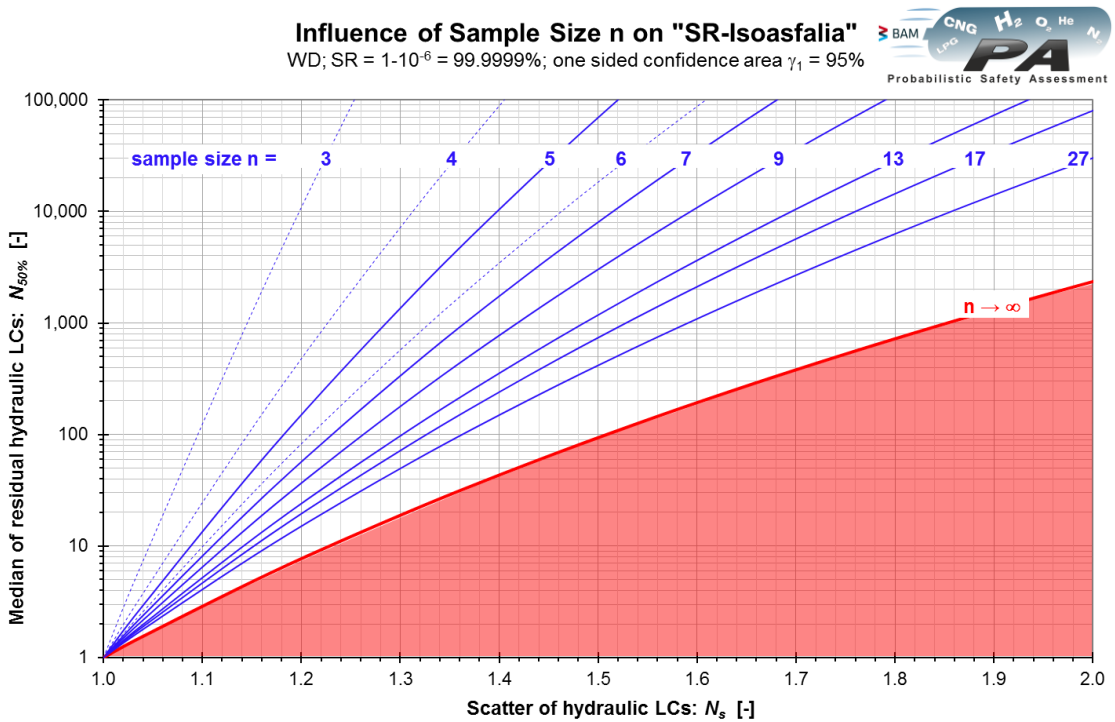
Systematic analysis of AR of basic populations



Acceptance Rate AR
vs.
Survival Rate SR

Acceptance rate AR acc. BAM-PA is constant

The requirements of the PA depend on scatter and sample size and reflect already uncertainties of basic populations by considering the confidence level.

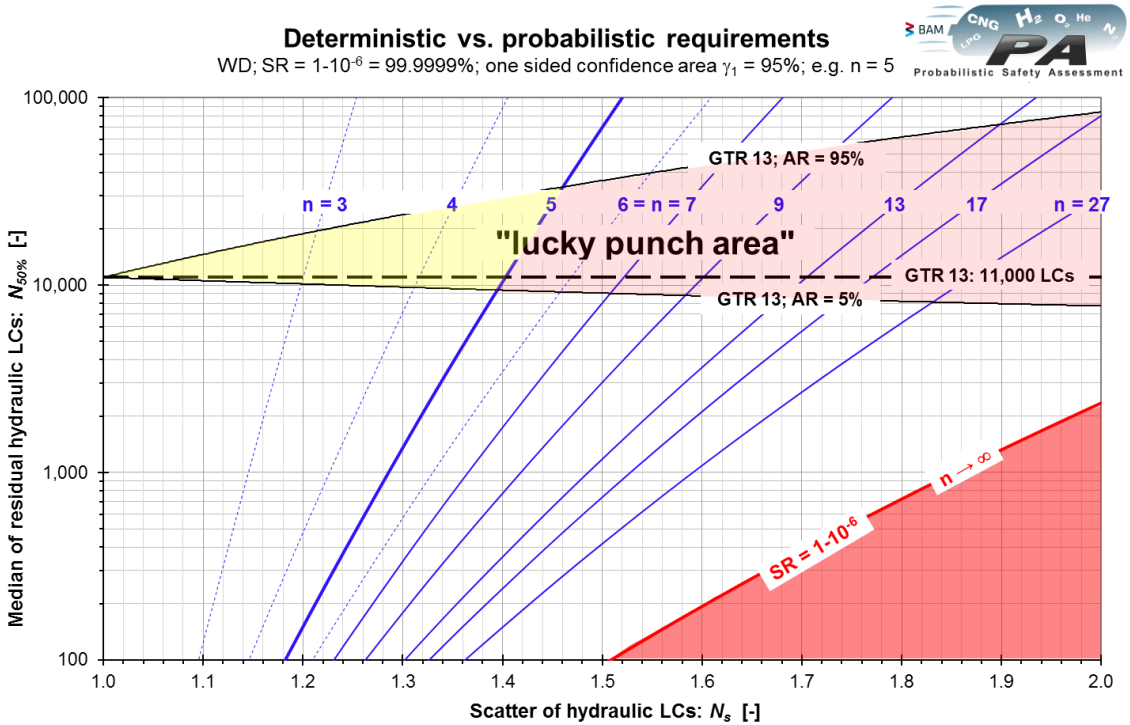


The area of a “lucky punch”

An approval below an AR of 95% is possible.

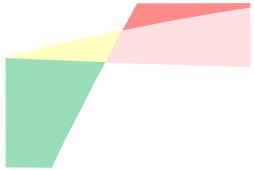
In case of n=5 the yellow area would be SAFE;

the light red area NOT!



Comparison of deterministic and PA shows different results of safety assessment

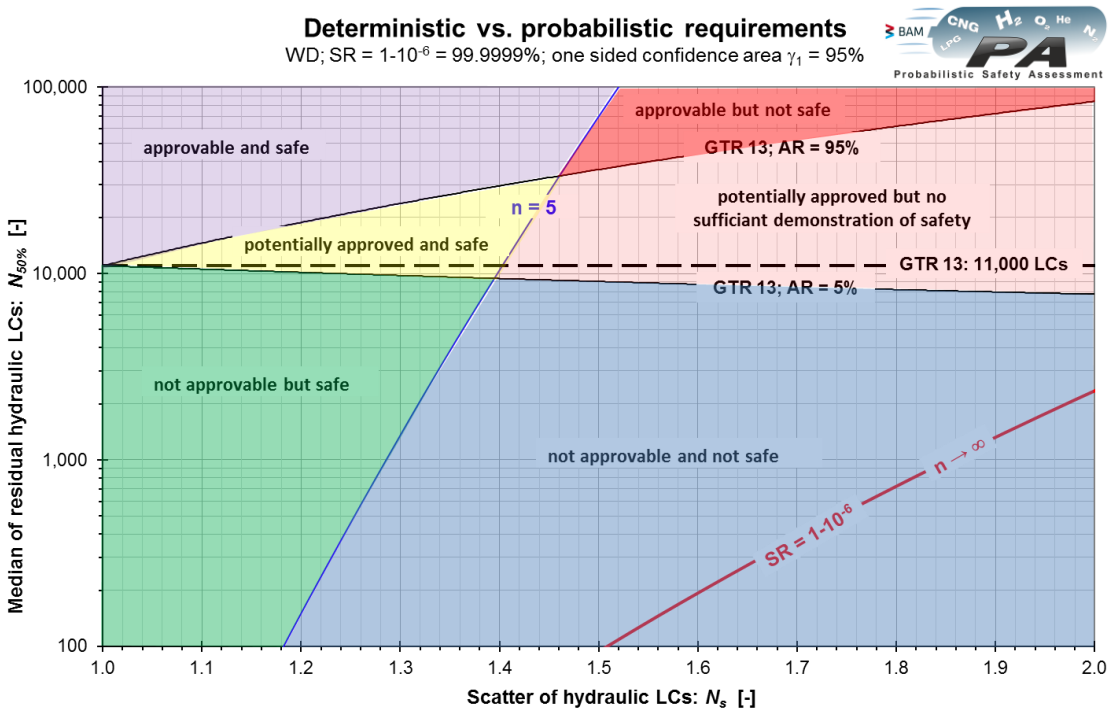
There are 4 areas of contradiction:



Just 2 areas indicate identical results:

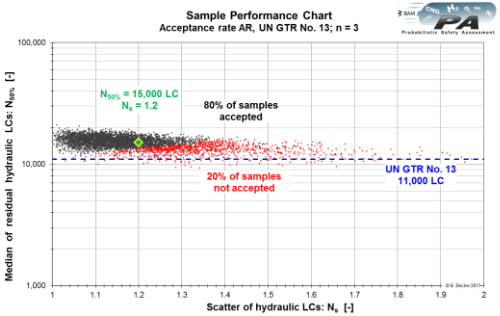
Yes!

No!

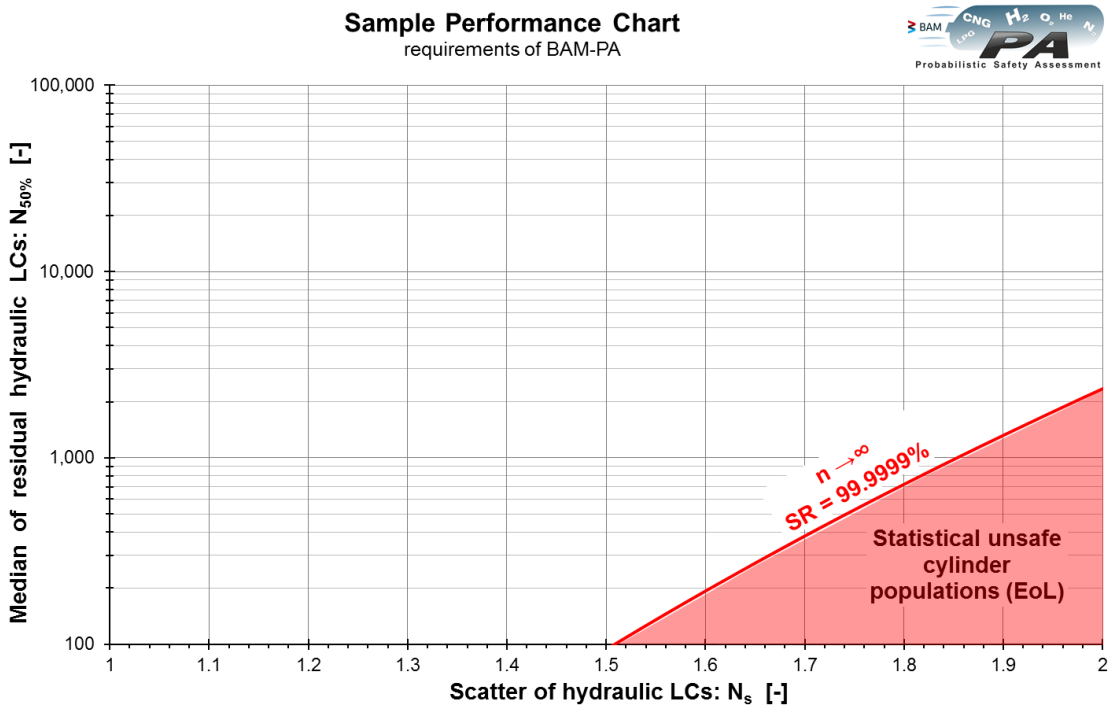


Safety level of regulations - acceptance of borderline SRs as benchmark

Analysis of borderline properties



Systematic analysis of AR of borderline basic populations

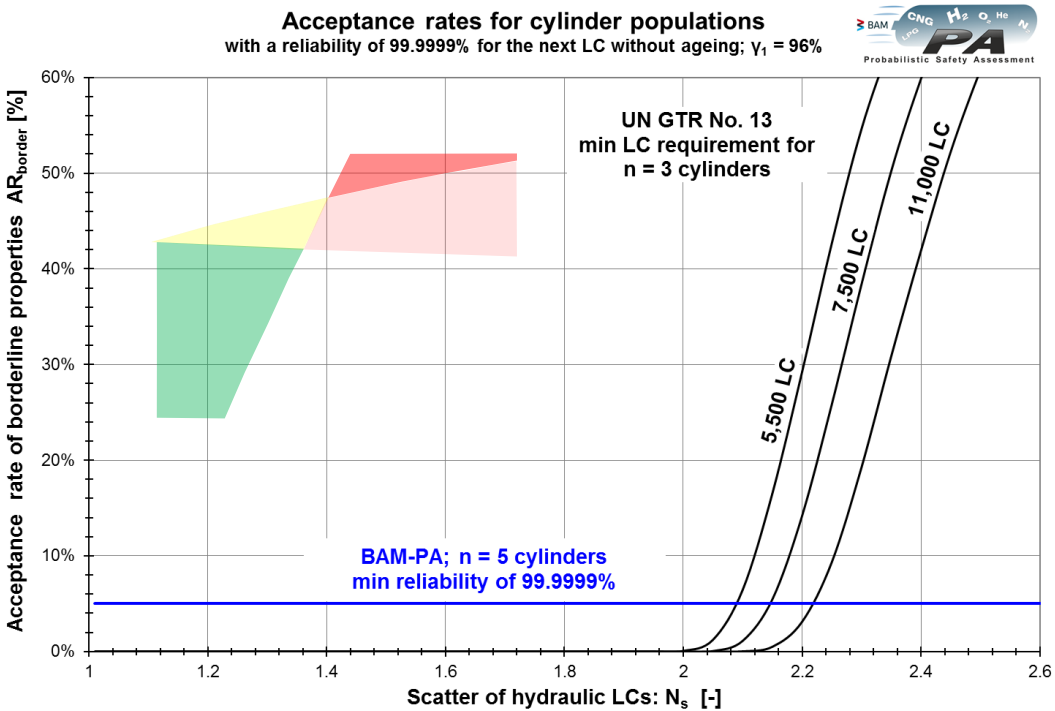


The Monte-Carlo-simulation enables …

… to visualise how scatter of basic population influences passing approval requirements:

LC-tests acc. GTR 13

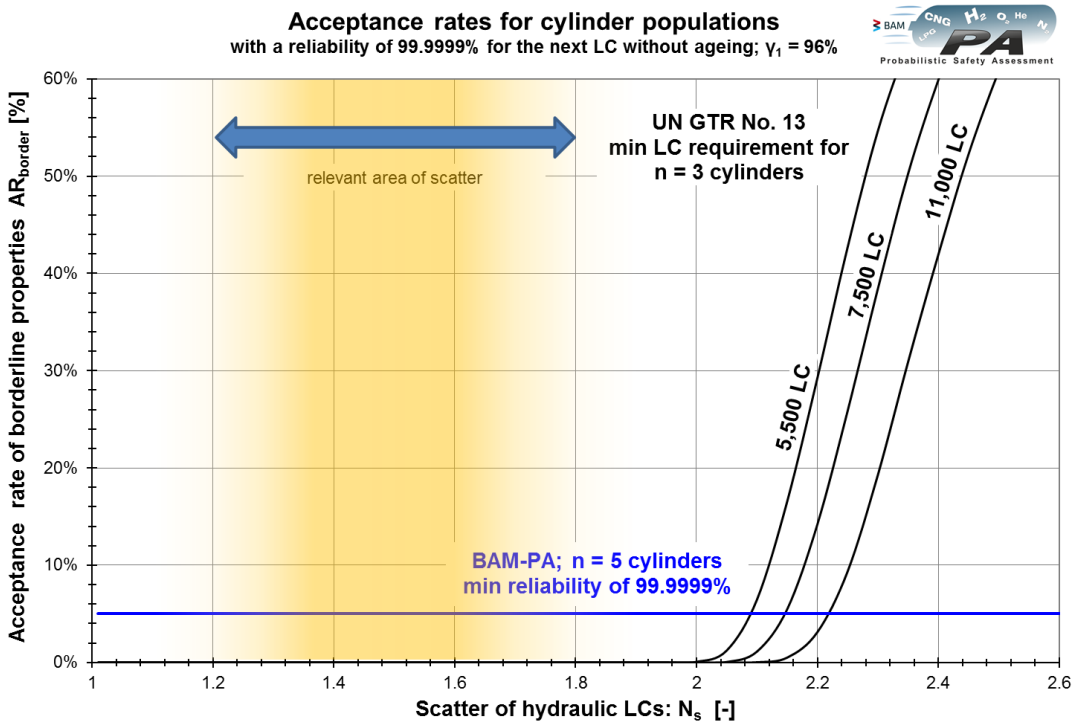
PA shows the reliability level directly!



The Monte-Carlo-simulation provides data …

… which show an non critical behaviour for the whole range of scatter of new CCs with respect to the next load cycle.

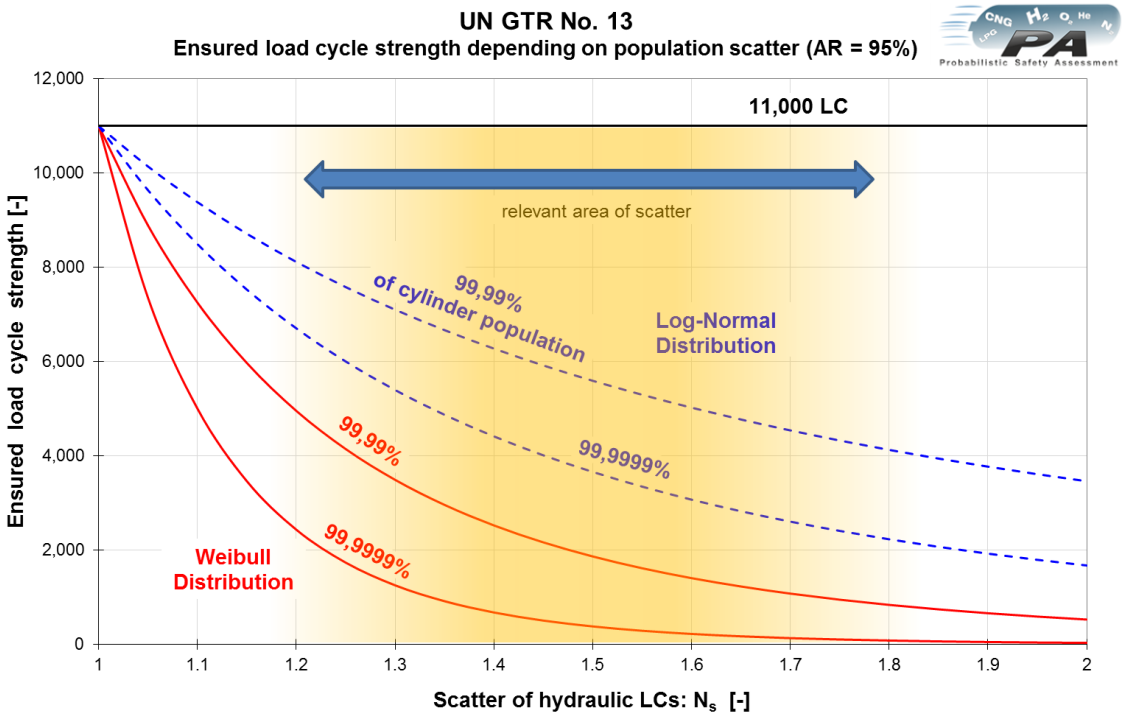
I.e. the remaining range for acceptable degradation depends on scatter.



The acceptable degradation in terms of LCs in case of confirmed 11,000 LCs

The amount of LCs to failure confirmed at the relevant survival rate varies enormously.

The degradation from filling cycles related to hydraulic or gaseous LCs is not considered so far.



Summary

Summary

- The visualisation of deterministic and probabilistic criteria in the sample performance chart “BAM-SPC” shows contradictions in safety assessment.
- In deterministic world a high acceptance rate is the basis for each successful approval.
- But real safety means sufficient strength properties of the whole population at end of life; i.e. very low failure rates.
- Monte-Carlo-Simulation provides information about the rates of accepting borderline populations acc. to a criterion of a RCS.

Recommendation for validation of requirements in RC&S:
When approval criteria are in discussion check the outcome by using Monte-Carlo-simulations!

References

– since ICHS 2015 I‘ve published both books mentioned there

1. Aufl. 2016,
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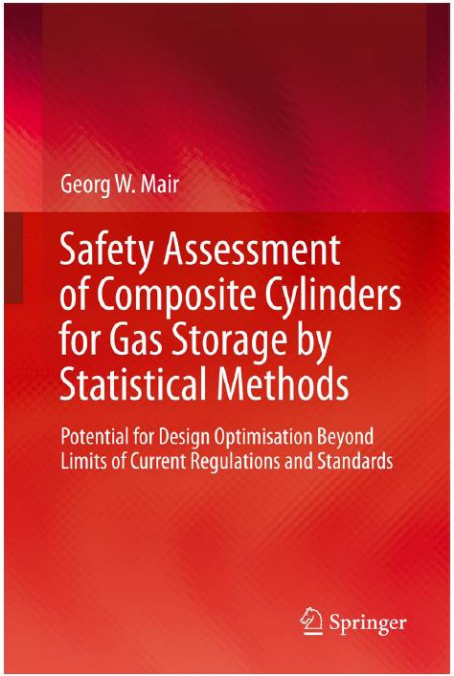

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