POWERFUL SOLUTIONS

Design for Reliability (DfR) in the high-tech industry

Eleonora Annigoni

Reliability Specialist

Holland Innovative B.V.

Introduction

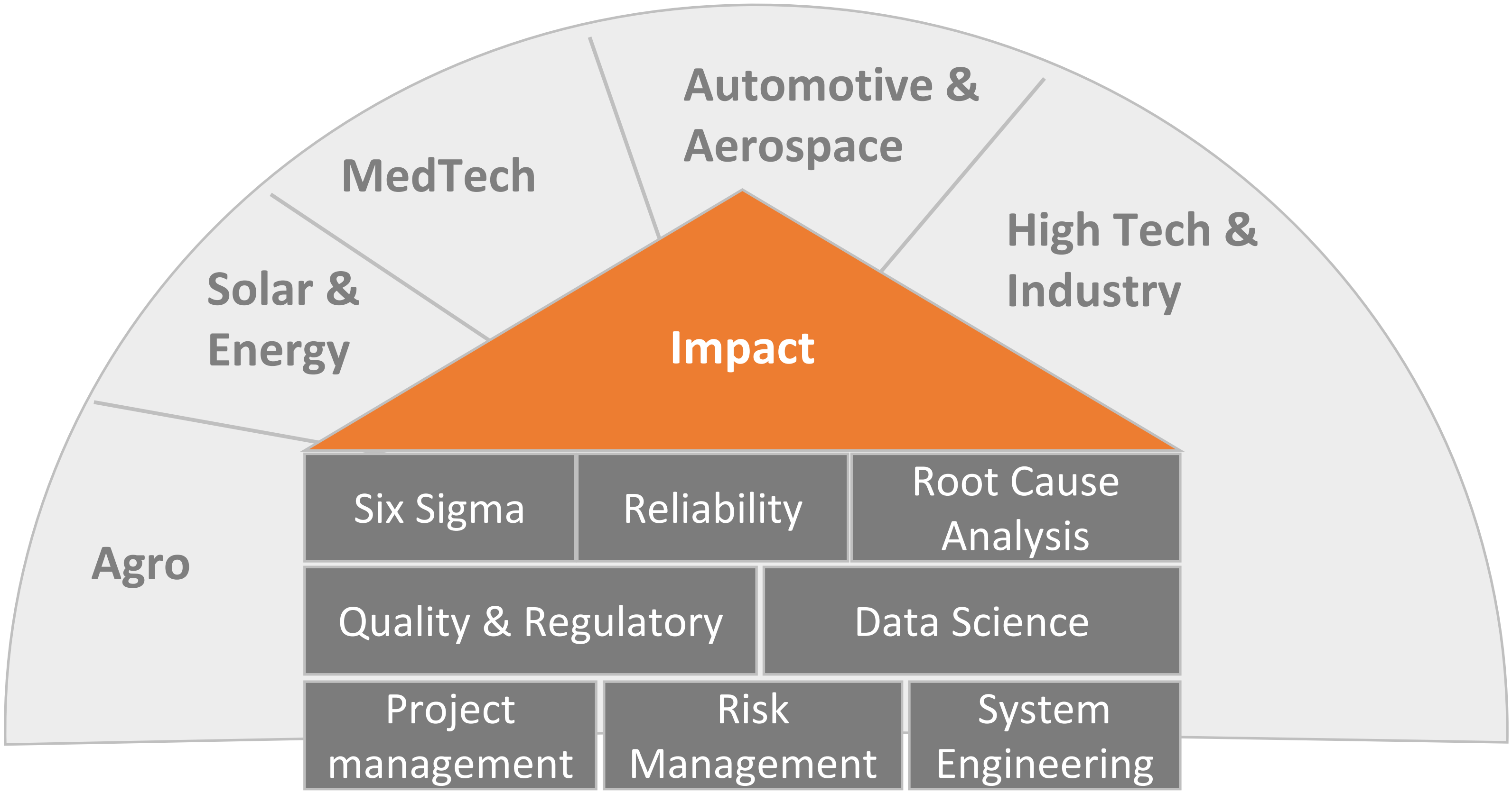
Eleonora Annigoni

Reliability Specialist

- Competencies: Reliability, Root Cause Analysis, Six Sigma
- 8-year experience in Reliability
- PhD in **Reliability of PV modules** at EPFL PV-Lab (2018)
- Experience in **high-tech industry**
  - PV → INDEOtec and CSEM (Neuchâtel), Flisom (Zurich)
  - Semiconductor equipment → ASML (the Netherlands, via Holland Innovative), ~20k employees

Competence House of HI

Solutions in product & process development, that have impact in all key markets



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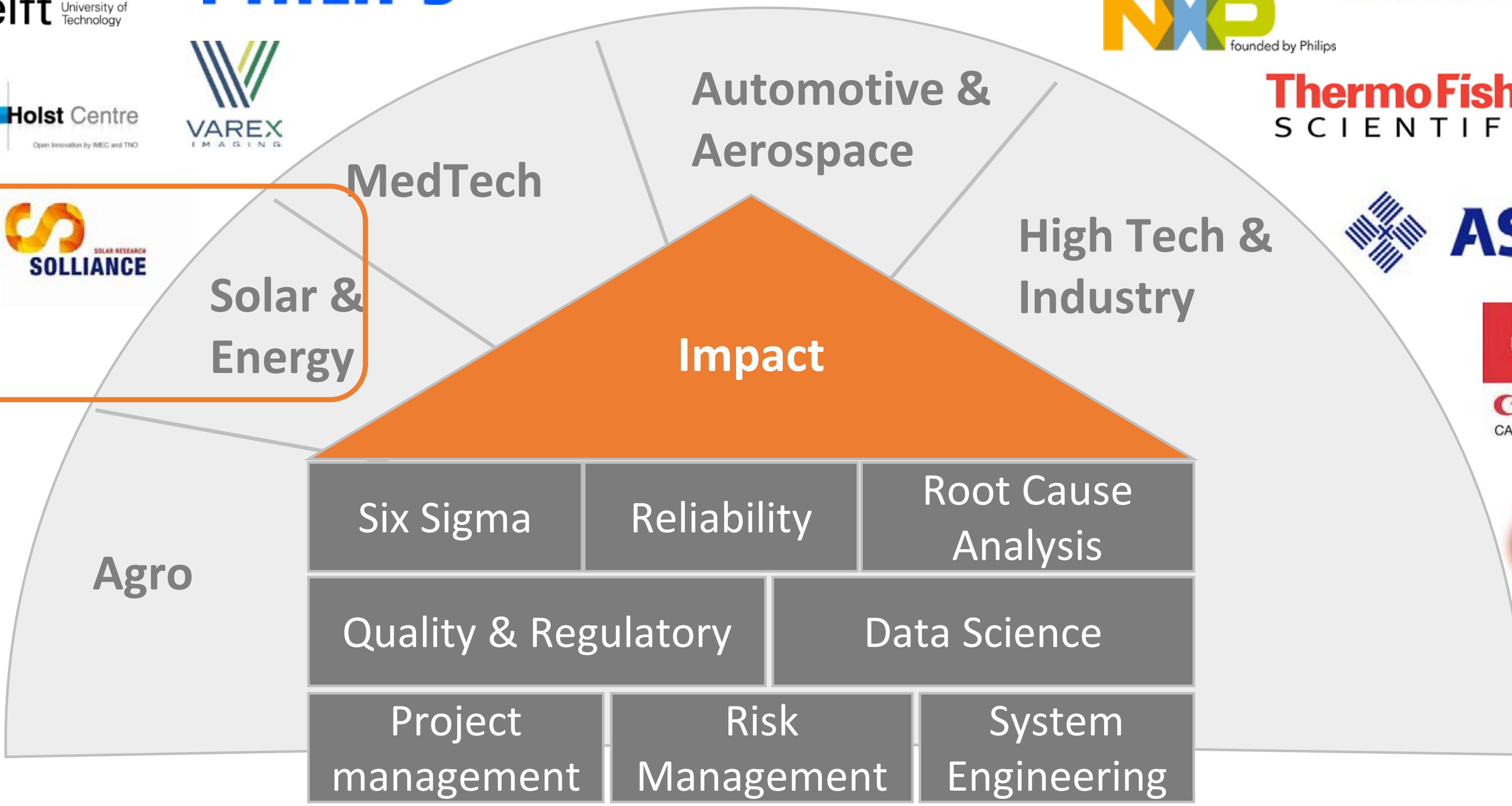


Outline

- Introduction
  - Reliability: a probabilistic discipline
  - An example: the Weibull distribution
- Reliability requirements
  - Accelerated life tests (ALT)
- Compare data
  - High-tech industry example
- Conclusions

What is Reliability ?

*The **probability***

*that a system will perform its **prescribed function***

*without **failure***

*for a certain **period of time***

*when operated correctly in a specified **environment***

*and under stated **conditions***

Why variation in Time-to-Failure?

- Because there is variation in load and strength:

  - **Variations** in production

  - **Variability** in product strength

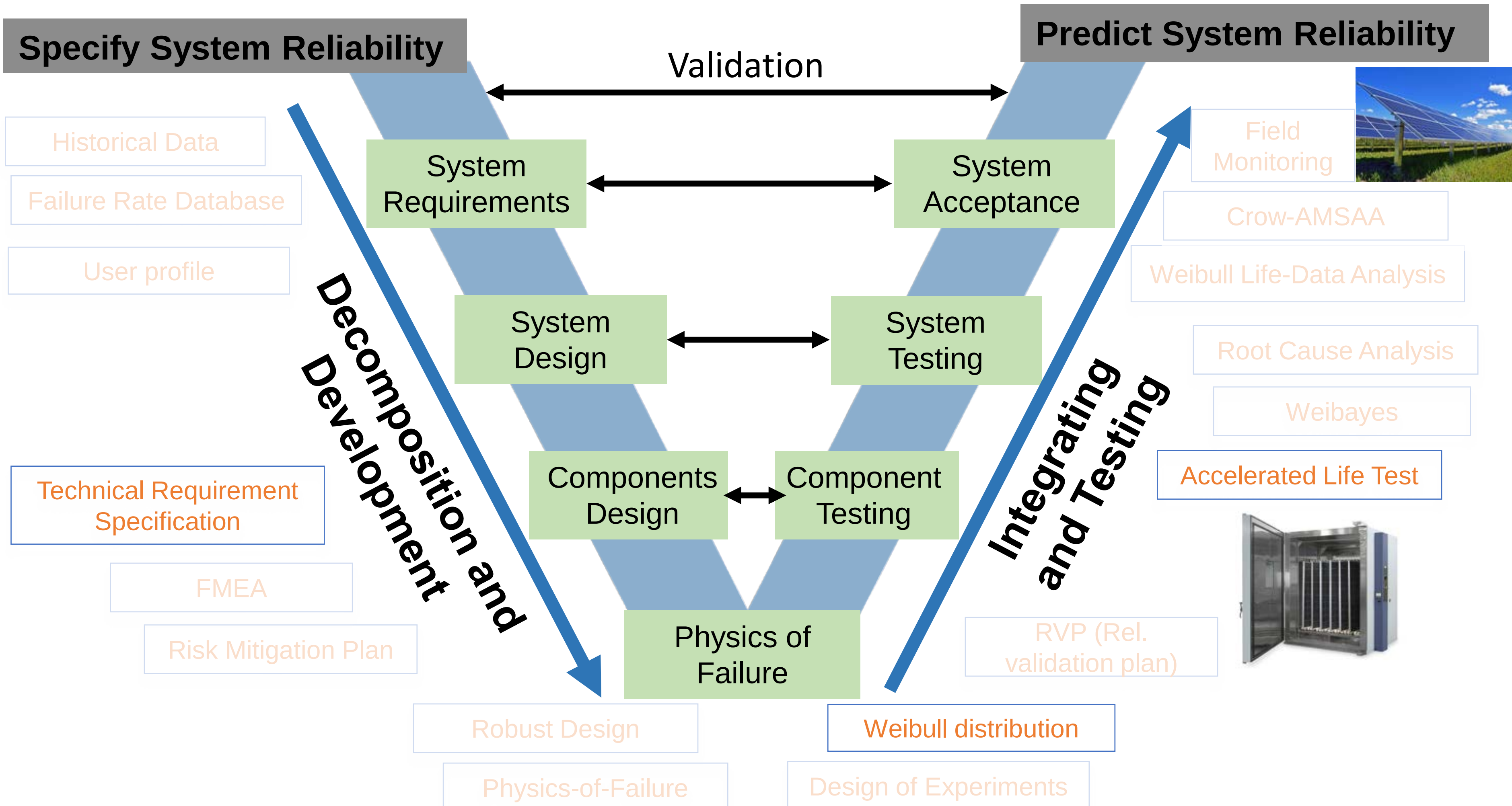
  - **Variability** of use environment

  - **Variability** of usage conditions

Probabilistic approach!

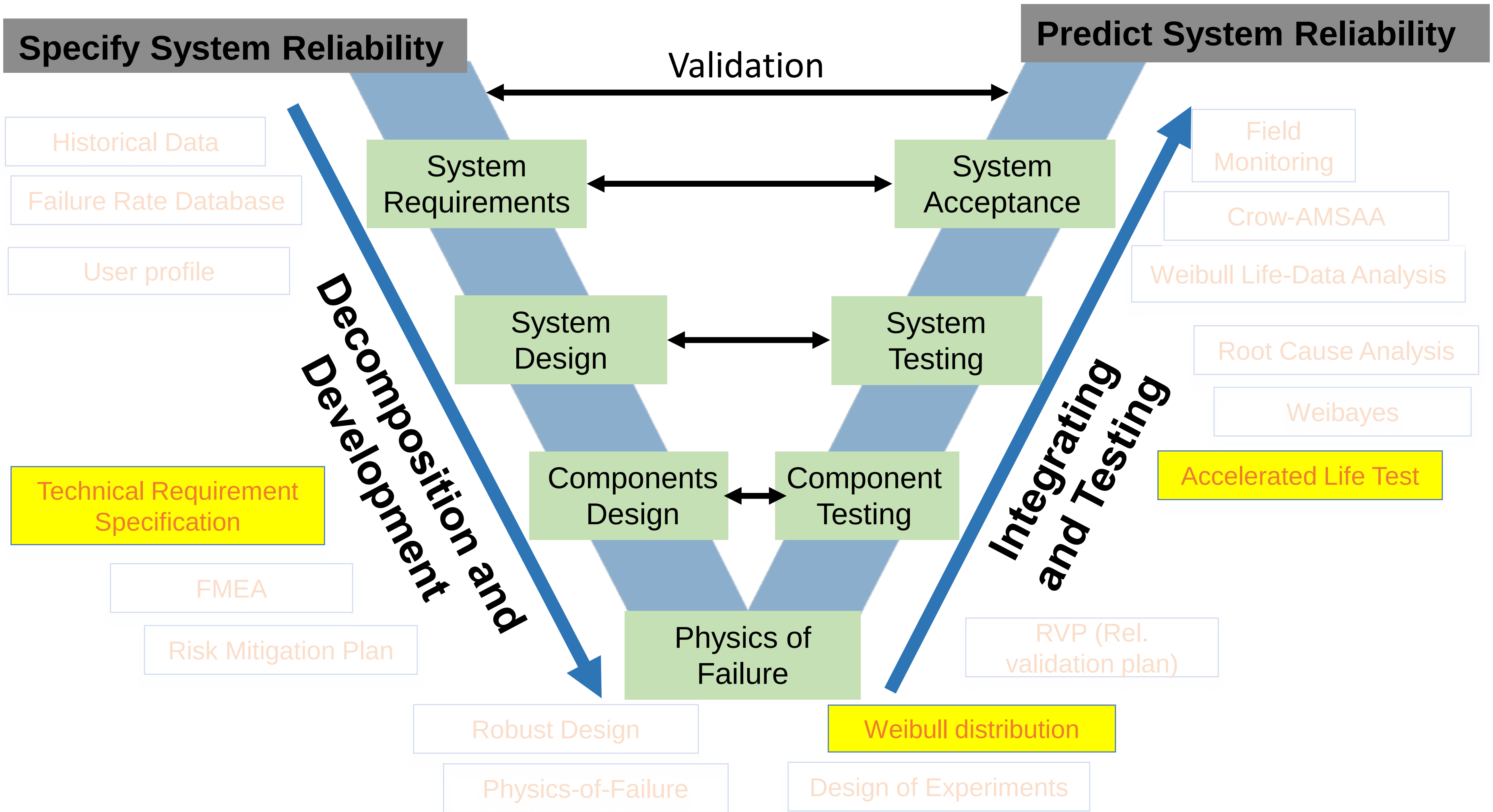
Design for Reliability
Product development process (or V Model)

Some of the tools…



Design for Reliability
Product development process (or V Model)

Some of the tools…



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Weibull distribution

- Weibull: most widely used probability distribution for Reliability.

Cumulative distribution function F(t):
Cumul. probability of failure by time t

$$F(t) = 1 - e^{-\left(\left(\frac{t}{\eta}\right)^{\beta}\right)}$$

You can use it for almost all failure modes. One tool for a lot of problems!

β: **Shape parameter**

η: **Characteristic life**

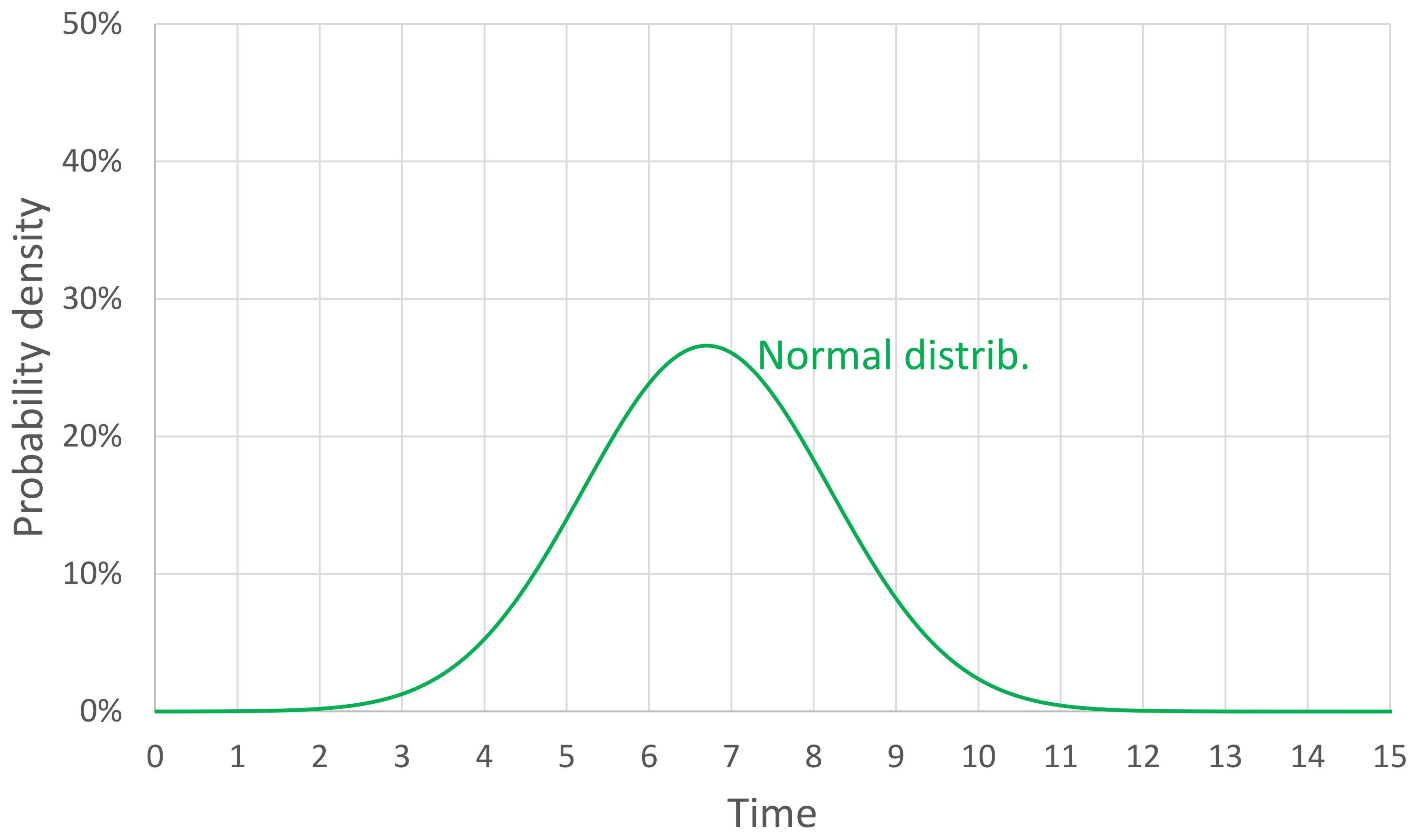
- **β ⟷ Failure mode**
  Physical interpretation:

$\beta < 1$	**Infant** mortality	→ Production problems, quality control, misassemble,...
$\beta = 1$	**Random** failures	→ Maintenance/human errors, Mother Nature,...
$\beta > 1$	**Wear out**	→ Low/High Cycle Fatigue, Corrosion, Erosion,...

- **η** = time at which 63% of units will fail

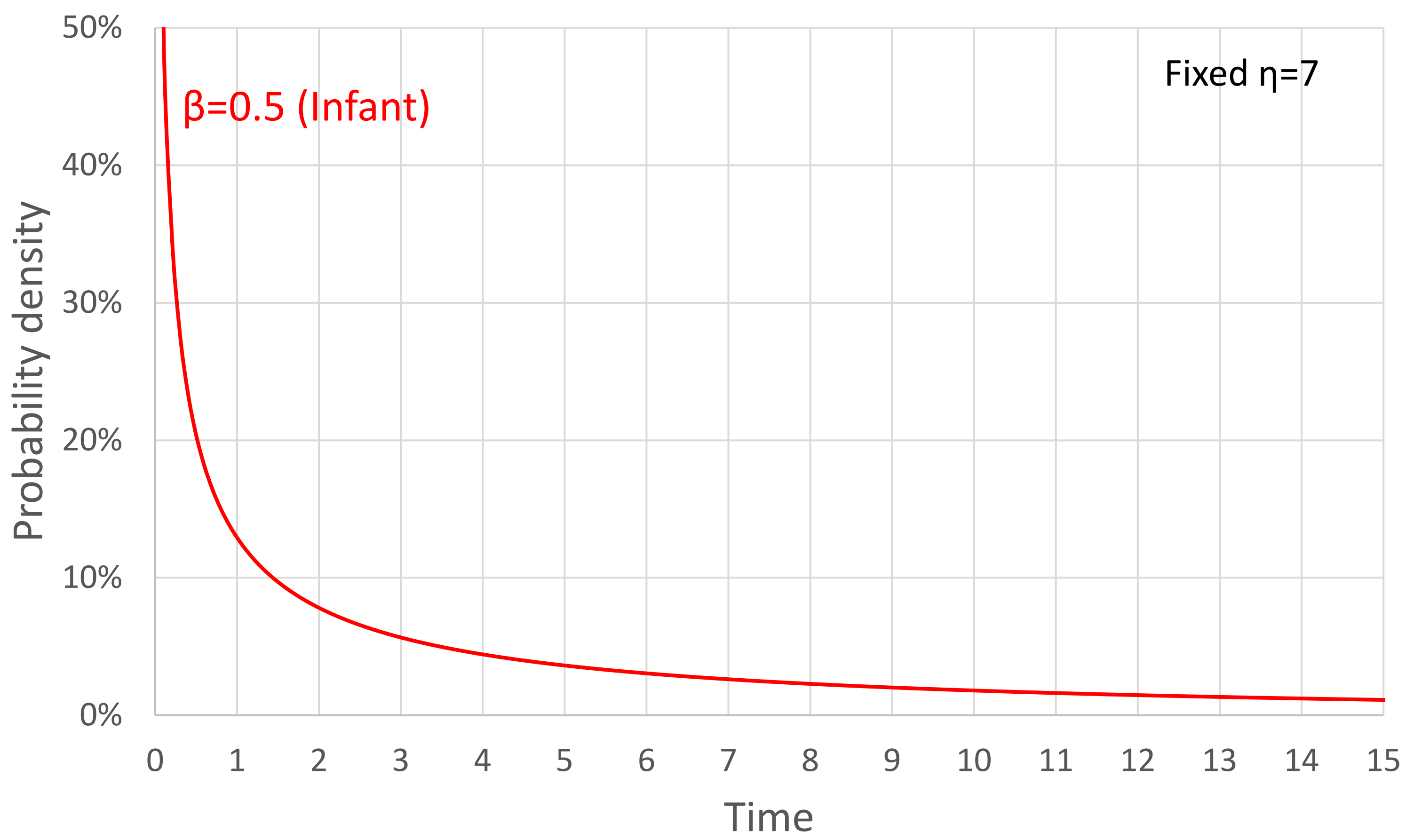
Normal distribution is always bell-shaped

Probability density function = Prob of failure at time t



Weibull fits a wide range of shapes

Probability density function = Prob of failure at time t



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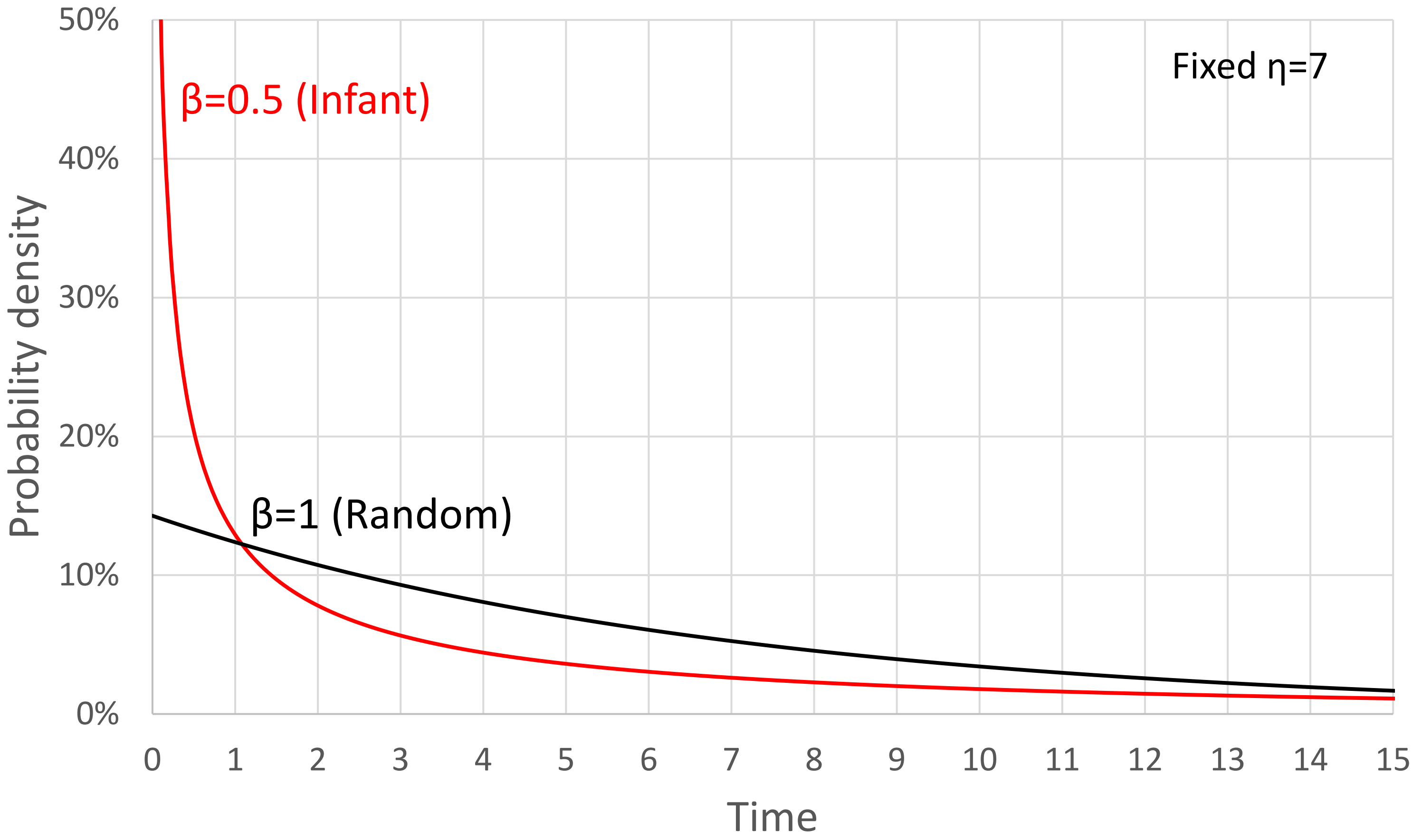
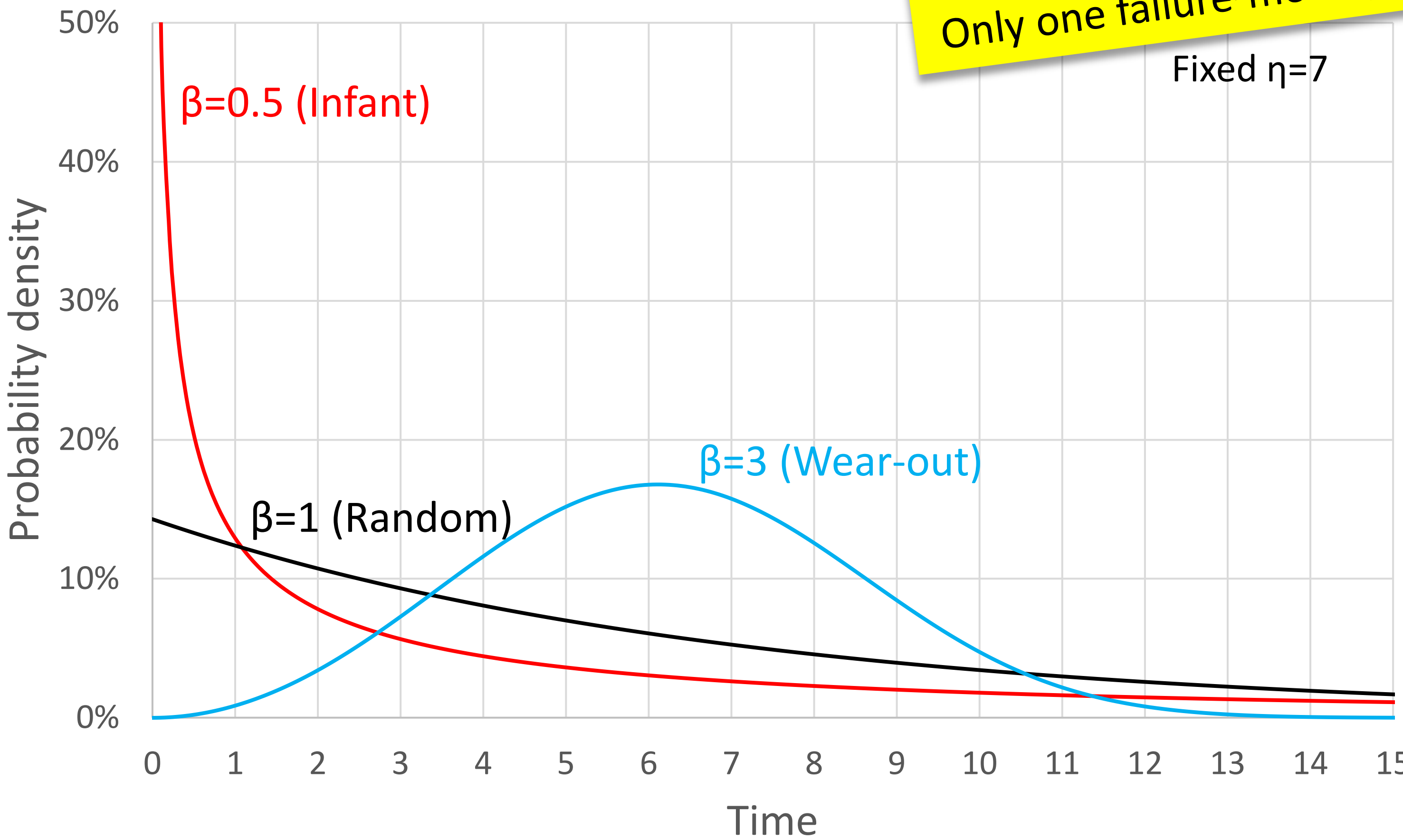


Weibull fits a wide range of shapes

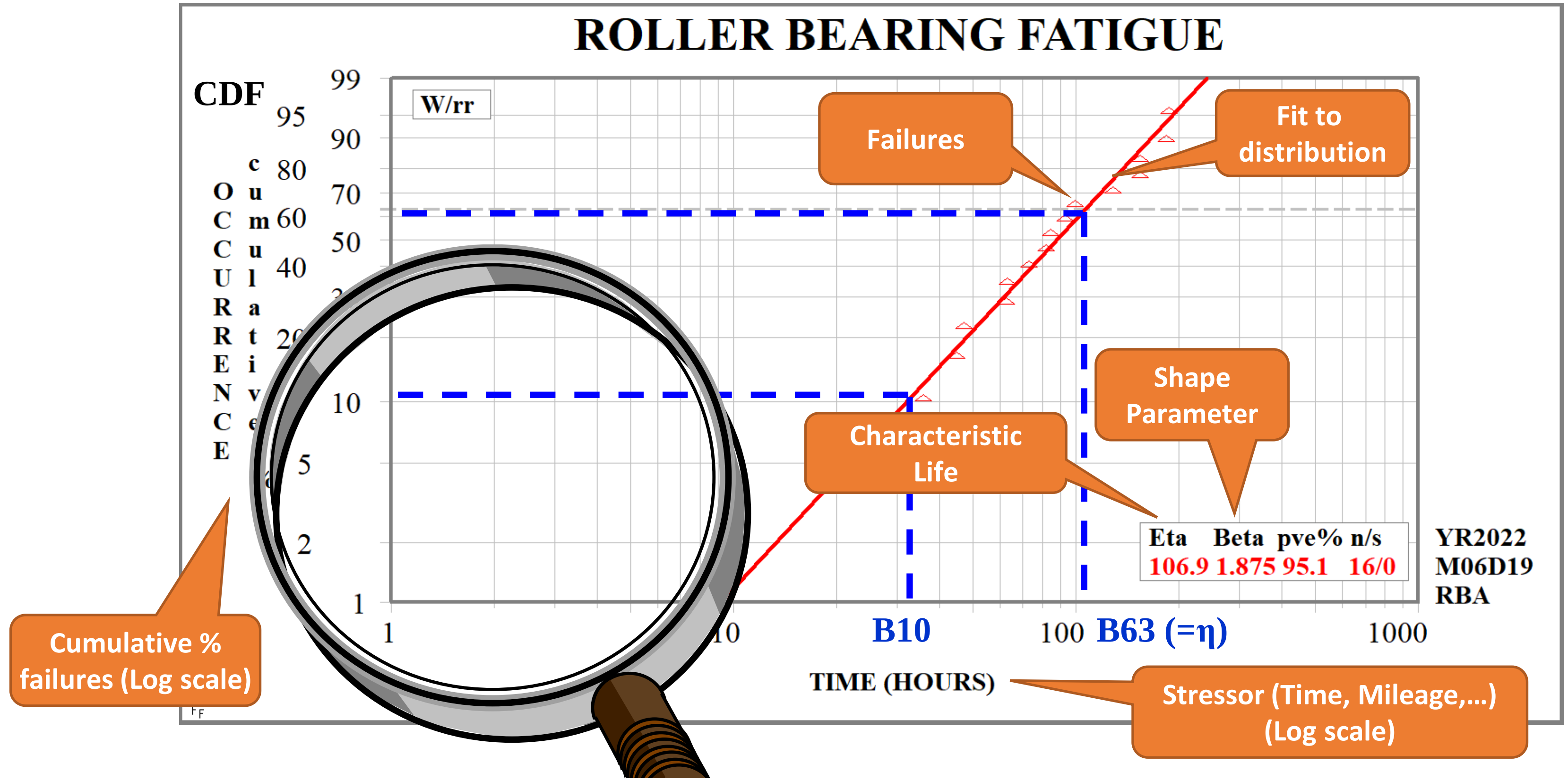
Probability density function = Prob of failure at time t

NOTE:
Only one failure-mode per Weibull



Weibull Plot

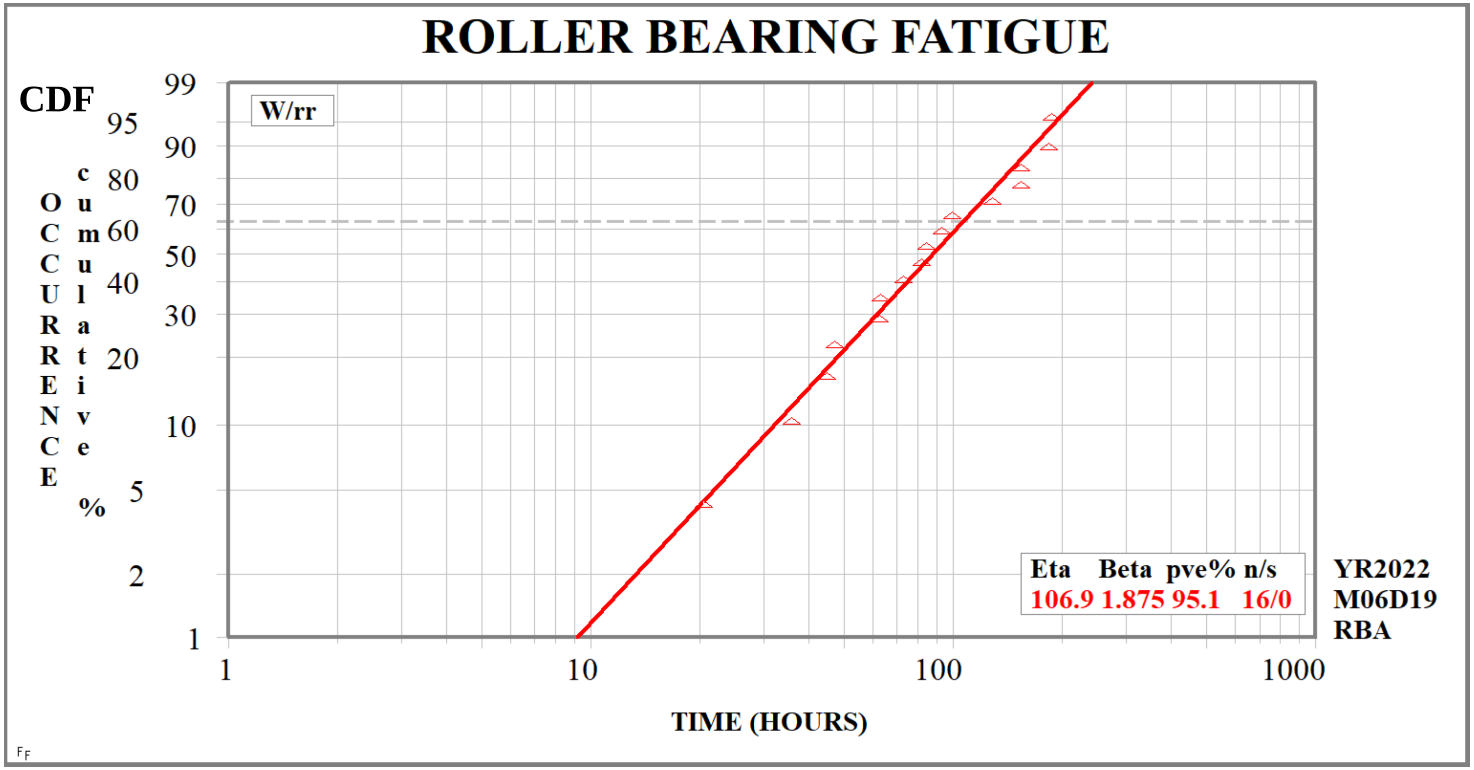
Cumulative distribution function (CDF) = Cumulative prob of failure *by* time t



Plot modified from R. Abernethy, "The New Weibull Handbook"

Weibull Plot

Cumulative distribution function (CDF) = Cumulative prob of failure *by* time t



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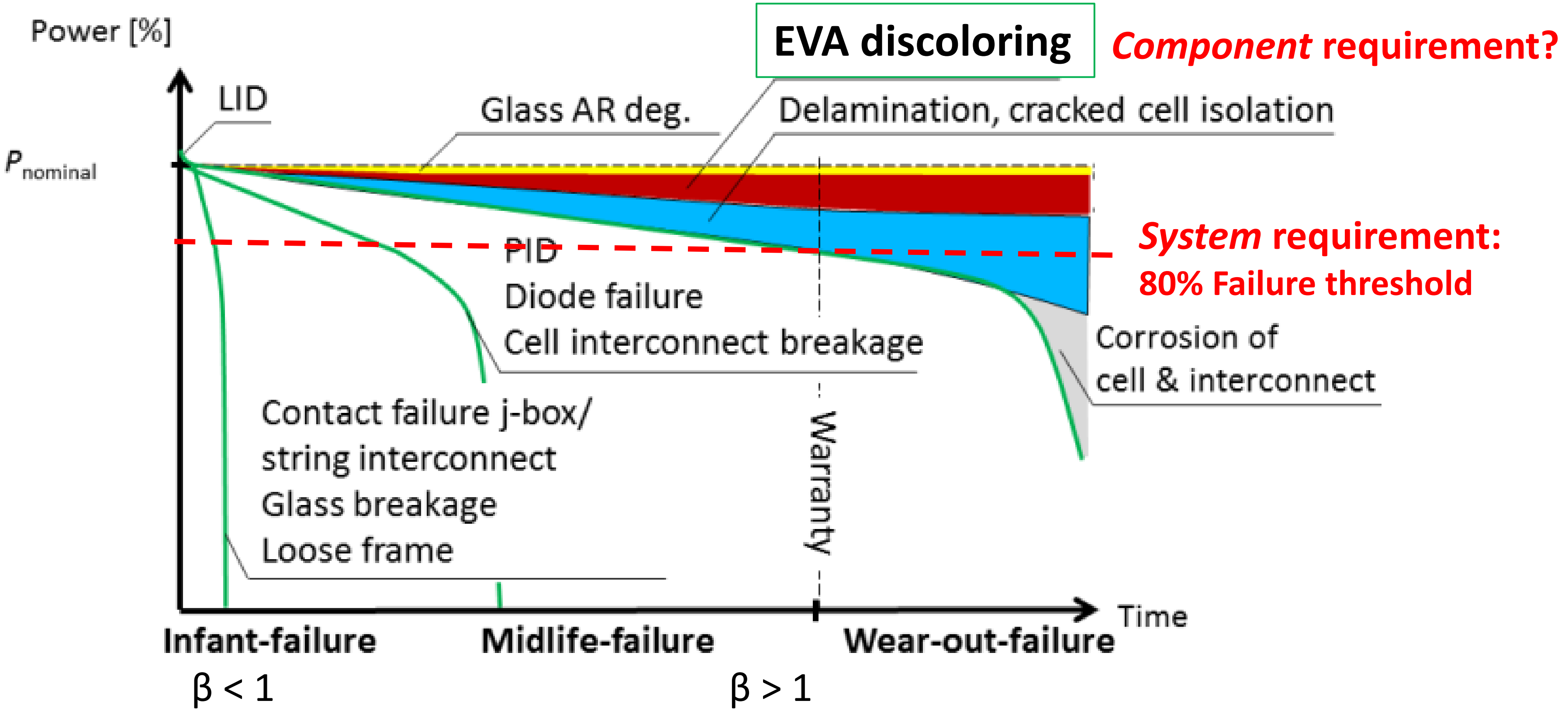
Every component needs a requirement



IEA "Review of Failures of Photovoltaic Modules" (2014), modified.

Question

What Reliability Requirement is there for EVA discoloring?

TISO 10kW PV plant in Ticino (CH) after 35 yrs of operation:
Annigoni, E., Virtuani, A., Caccivio M., et al, “35 years of photovoltaics: Analysis of the TISO-10-kW solar plant, lessons learnt in safety and performance” Parts 1 & 2, PiP, 2019

Reliability requirement

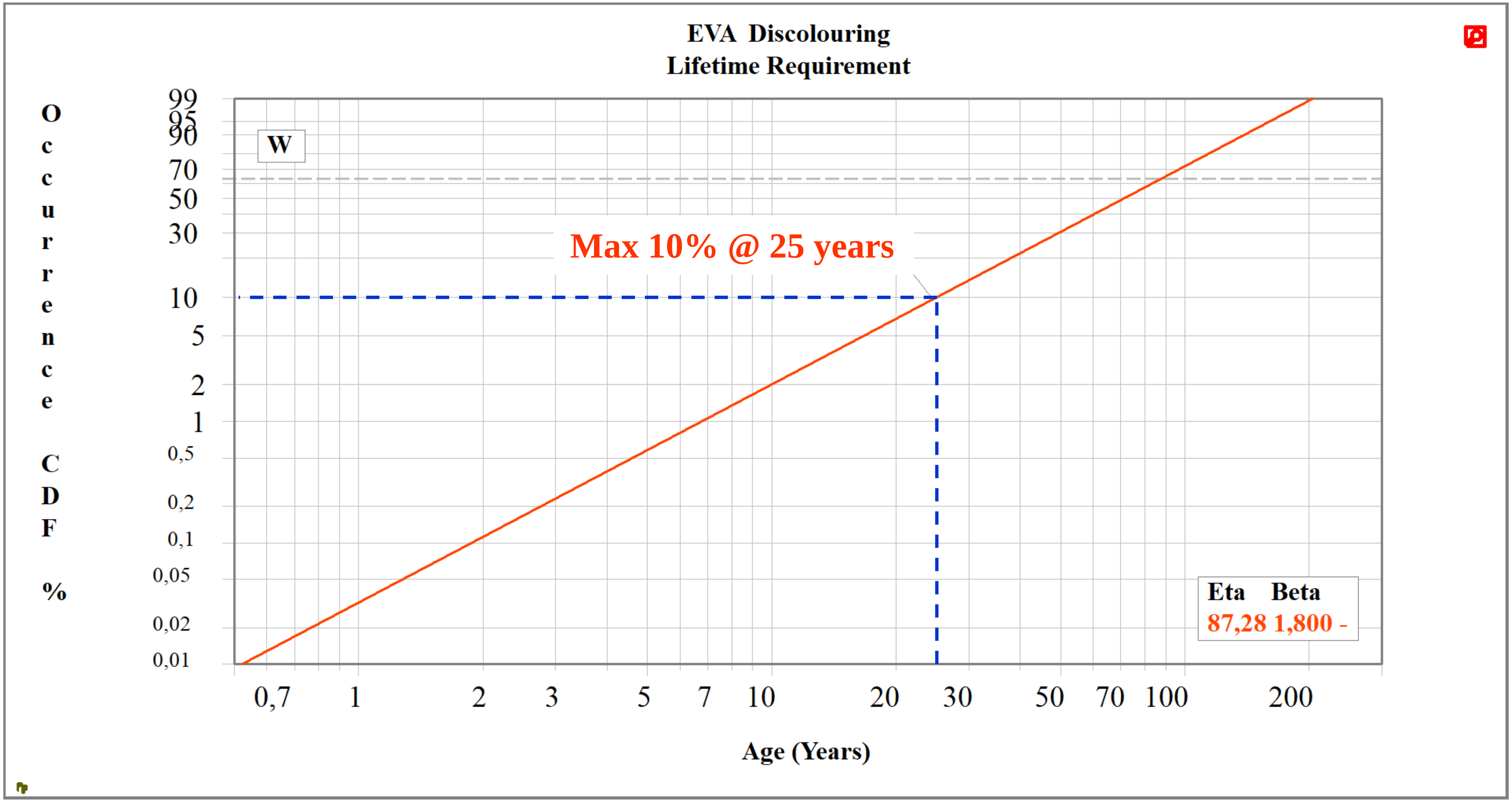
- Product: EVA
- Function: Encapsulate the cells while letting light through
- Failure mode: EVA discoloring
- Failure criterion: Optical transmittance < threshold value
- Max % failures allowed: 10% of modules failed due to EVA discoloring during 25 yrs

There is more…:

- For stated conditions (load profile, usage, environment)
- Proven with certain confidence level
- Customer perception…

Hypothetical values

Reliability requirement



Hypothetical values

Main reliability testing types

Test for Failure

To find a.s.a.p. the different failure modes of the component/system

- HALT – Highly Accelerated Life (Limit) Testing
- FMVT® – Failure Mode Validation Test
- MEOST – Multiple Environment Overload Stress Test
- Step Stress testing

Find the Failure

Test for Life (Reliability)

To determine life or verify if the component/system operates **according to prescribed Reliability requirements**

- LT – Life Testing
- ALT – Accelerated Life Testing
- Fully Censored testing
- DVT – Design Validation Testing
- Step Stress Testing

Prove and Quantify Reliability

Main reliability testing types

Test for Failure

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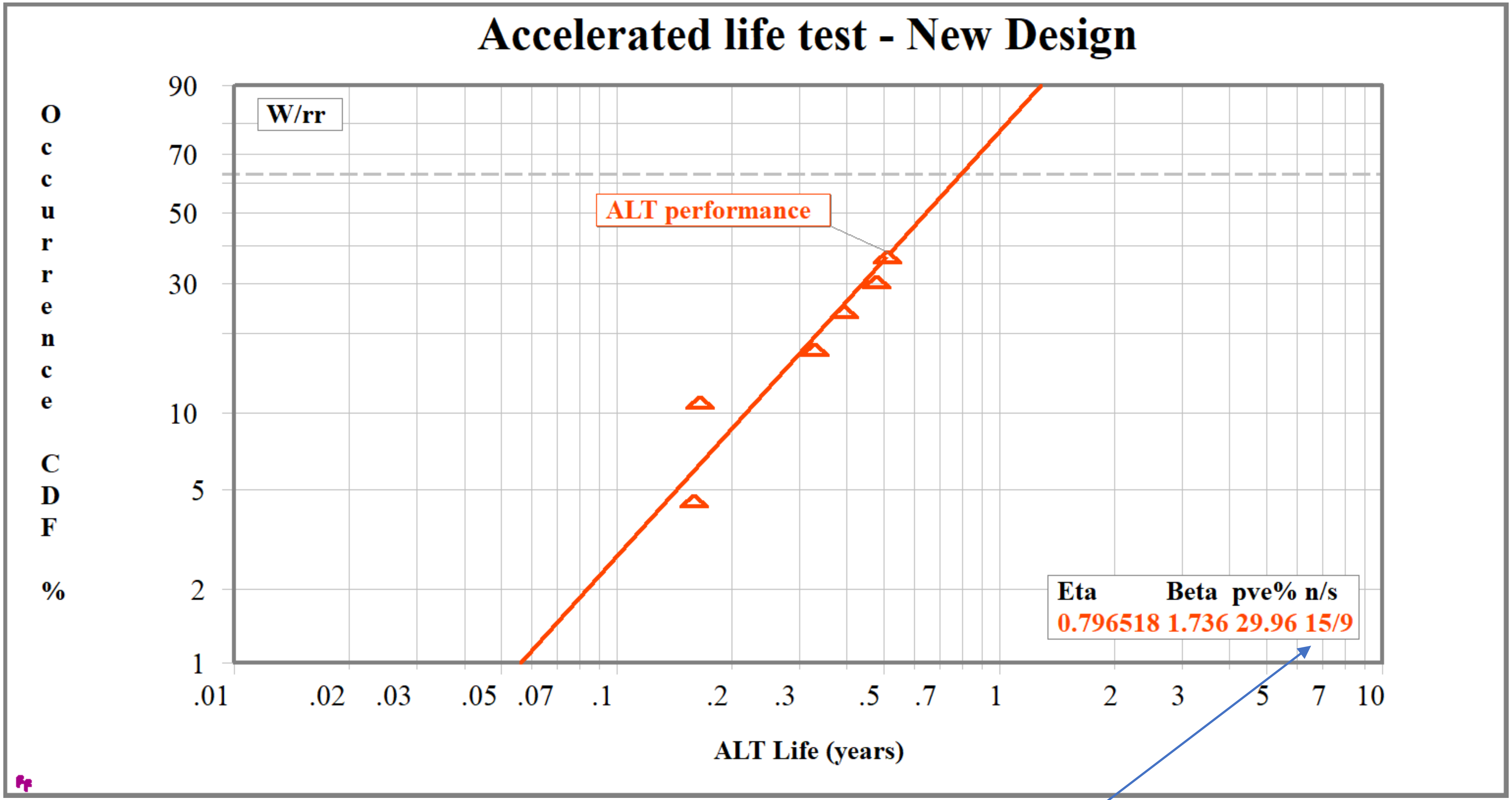
Prove and Quantify Reliability

New EVA design – ALT (T + UV)

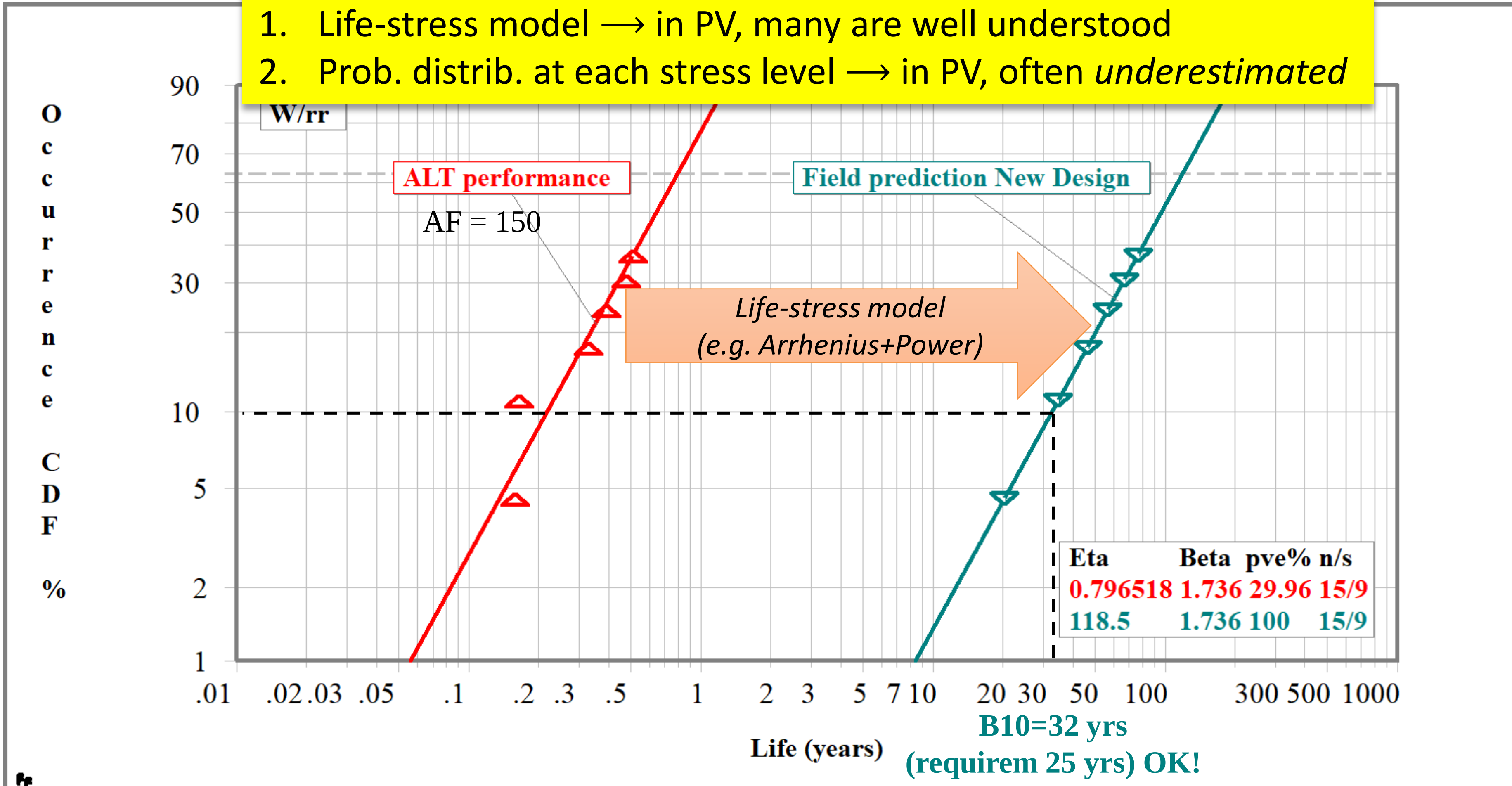


Hypothetical values

n = number of samples tested
s = number of suspensions (i.e. survivors)

New EVA design – Prediction

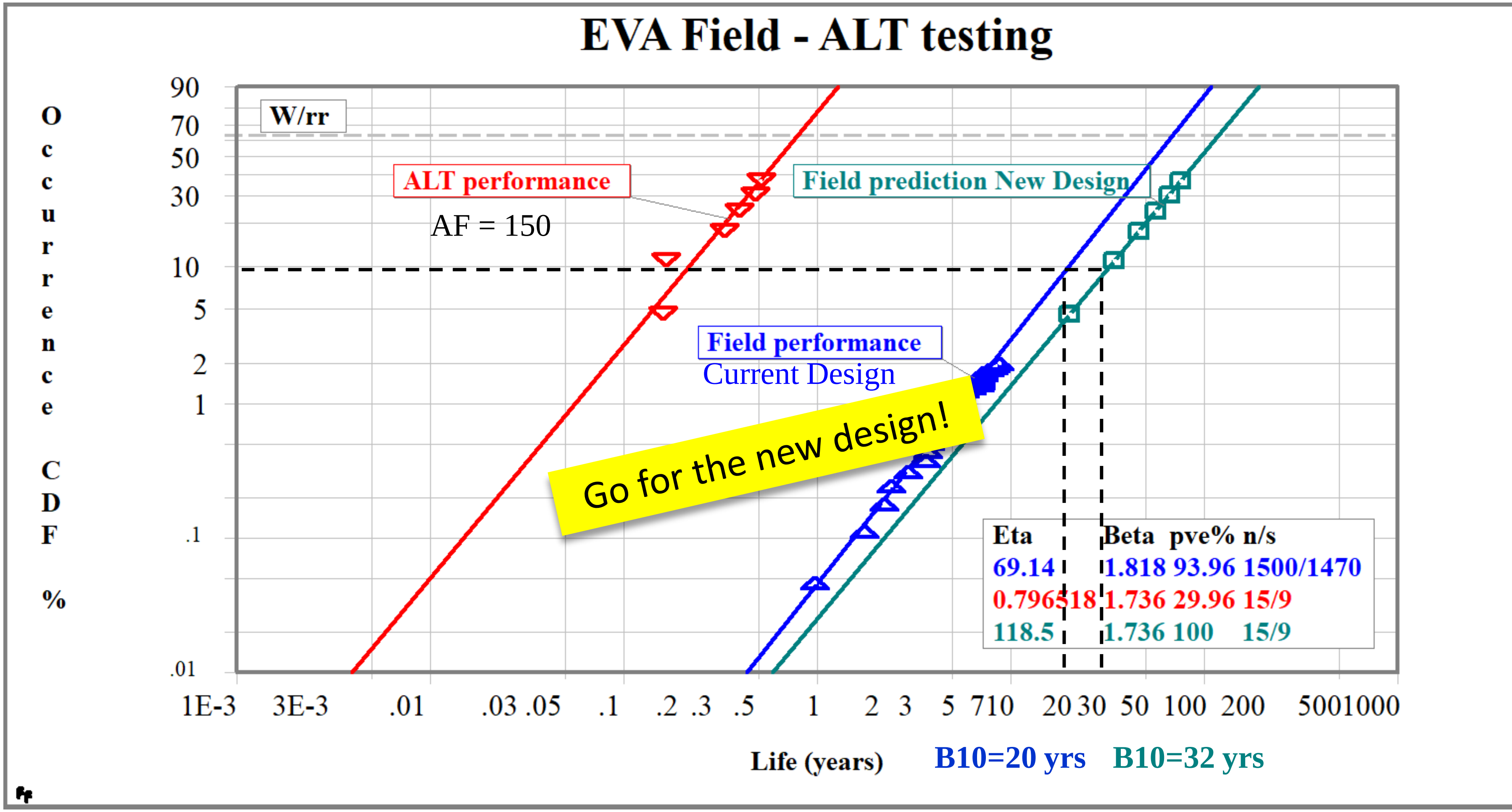
ALT requires 2 models
1. Life-stress model ⟶ in PV, many are well understood
2. Prob. distrib. at each stress level ⟶ in PV, often *underestimated*



AF = Acceleration factor

Hypothetical values

New *vs* Current design in the field



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Hypothetical values

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Compare data

2 sets are to be compared, e.g. from:

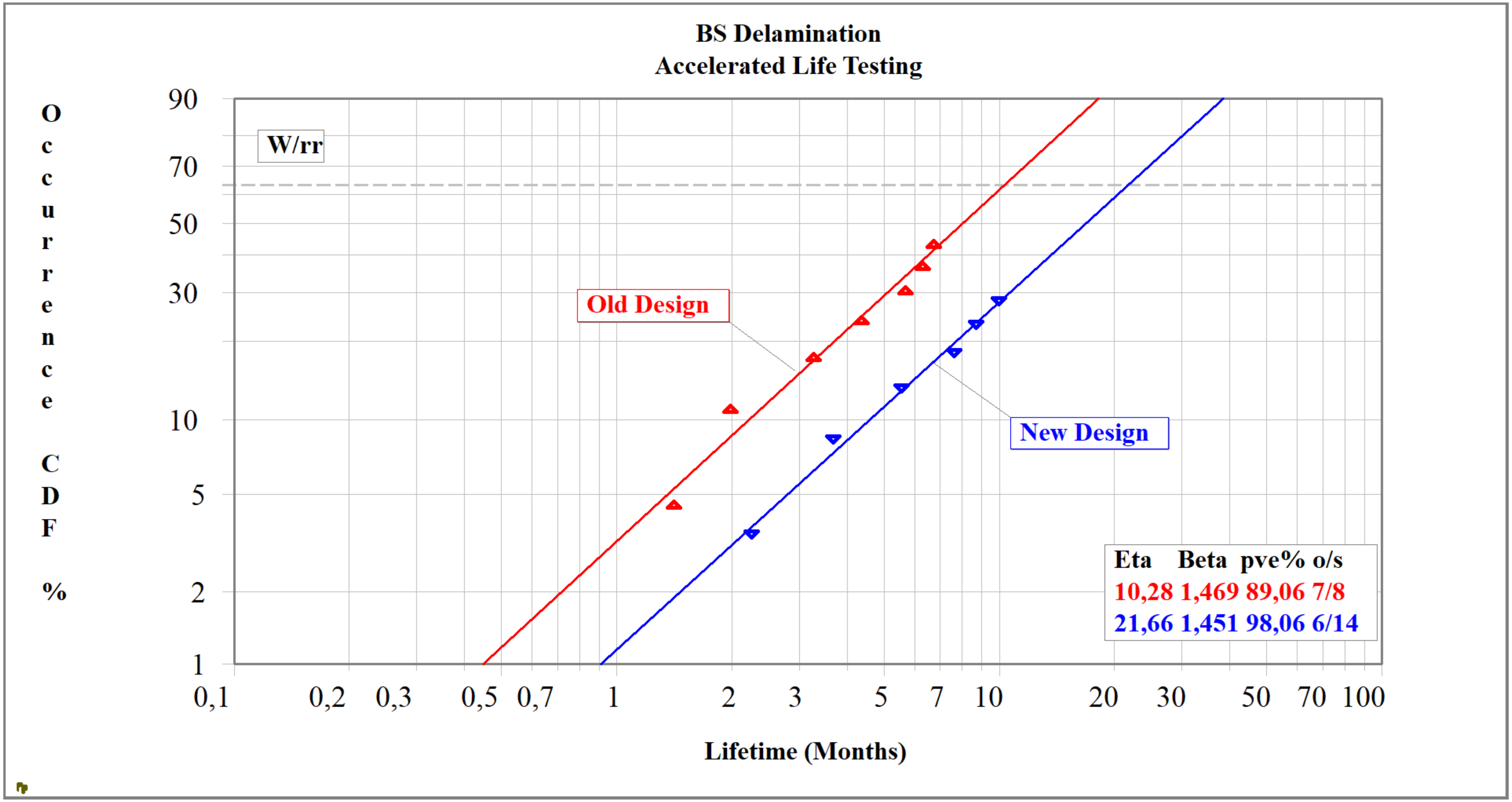
- New *vs* Old Design (e.g. new BOM)
- Geographic locations
- Product Usage
- Production lots
- Vendors

New *vs* Old Design (e.g. new BS)

Production lots

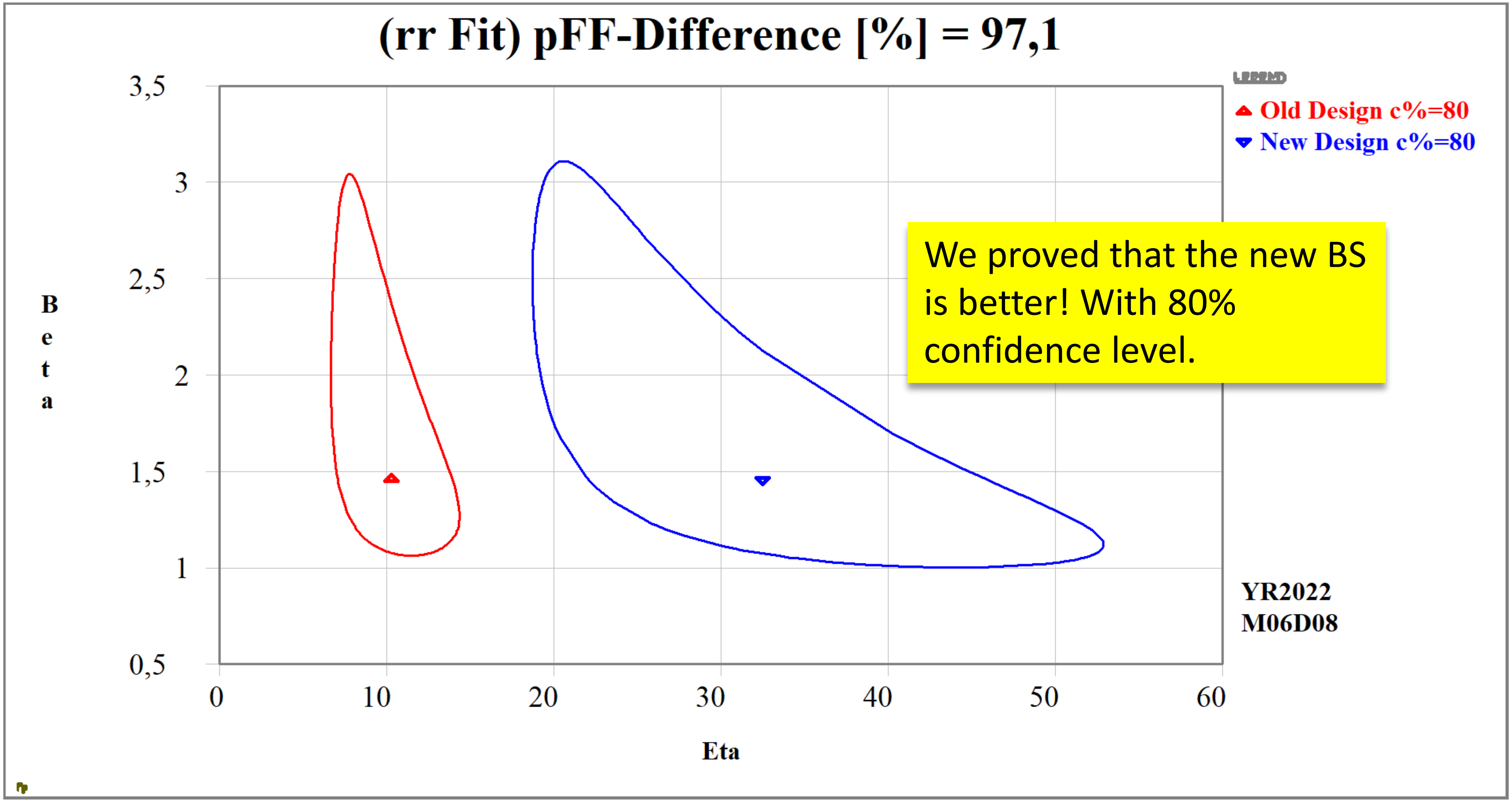
Geographic locations

Is your new BS better than the old one?



Hypothetical values

Confidence Level



Hypothetical values

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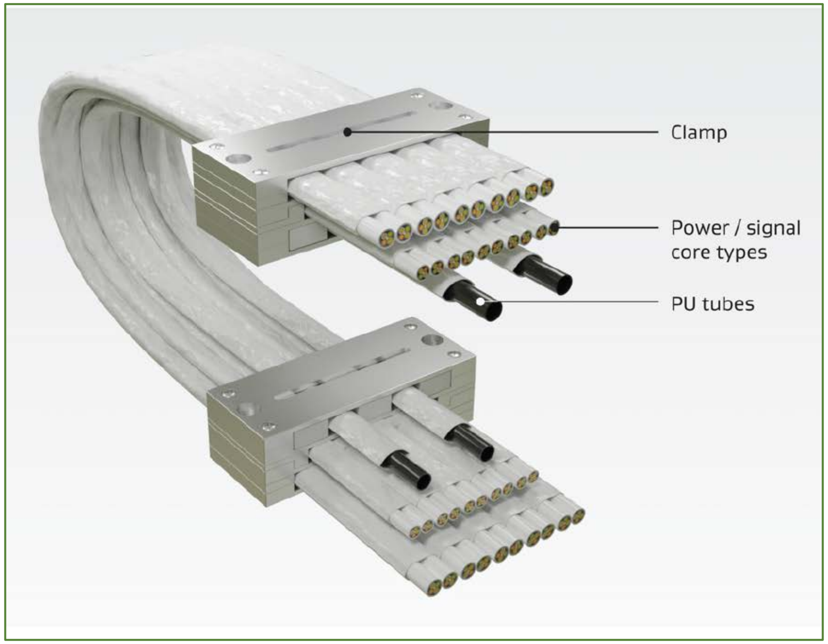
Weibull Analysis of Power Cables
Old Design versus New Design

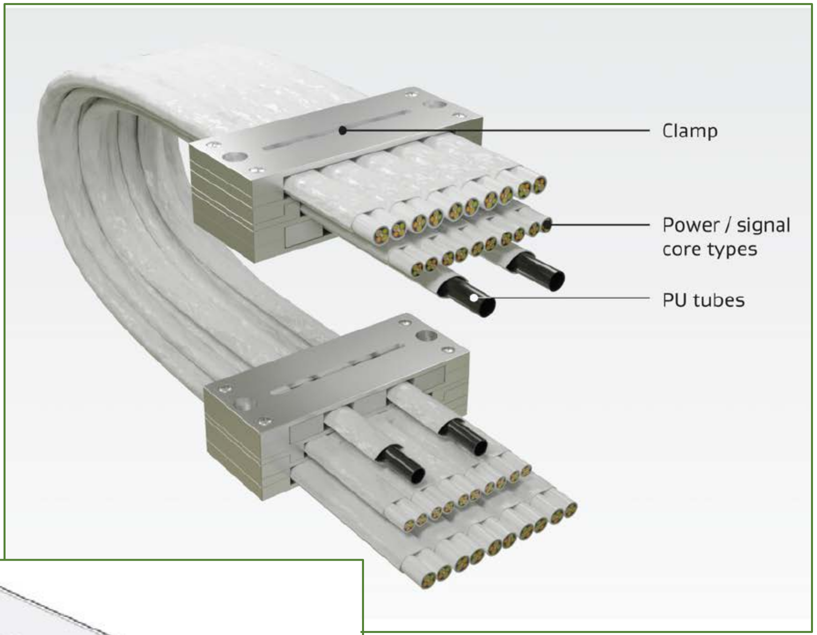


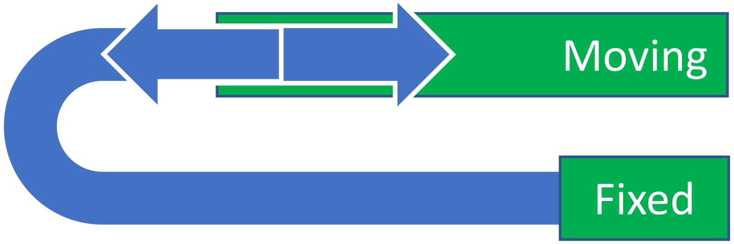
Elly van den Bliek

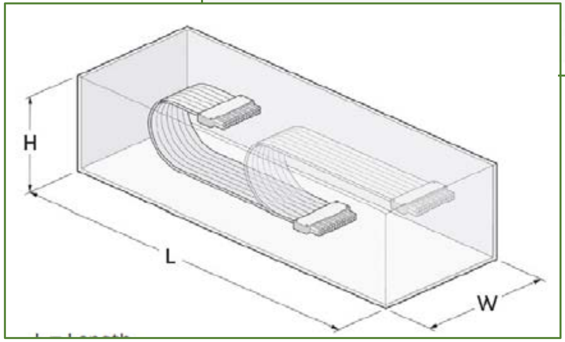
Sr. Reliability & Functional Safety Specialist

Power cable and usage

- Power cable, flex-type, flat cable
- Cable load:
  - Strokes (counted in cycles), in linear motion, with fixed bend radius
  - One cable end is fixed, other cable end moves along horizontal axis
  - Number of cycles relevant
  - Forces not relevant







Power cables – Reliability requirement

- Max 6% failed @ 50 kcycles
  - Statements with 50% CL
- Design life = 50 kcycles
- Failure mechanism: Expected general wear, Weibull β ~ 2 – 2.5… ⟶ Let products & data speak!
- Failure criterion: No power through cable

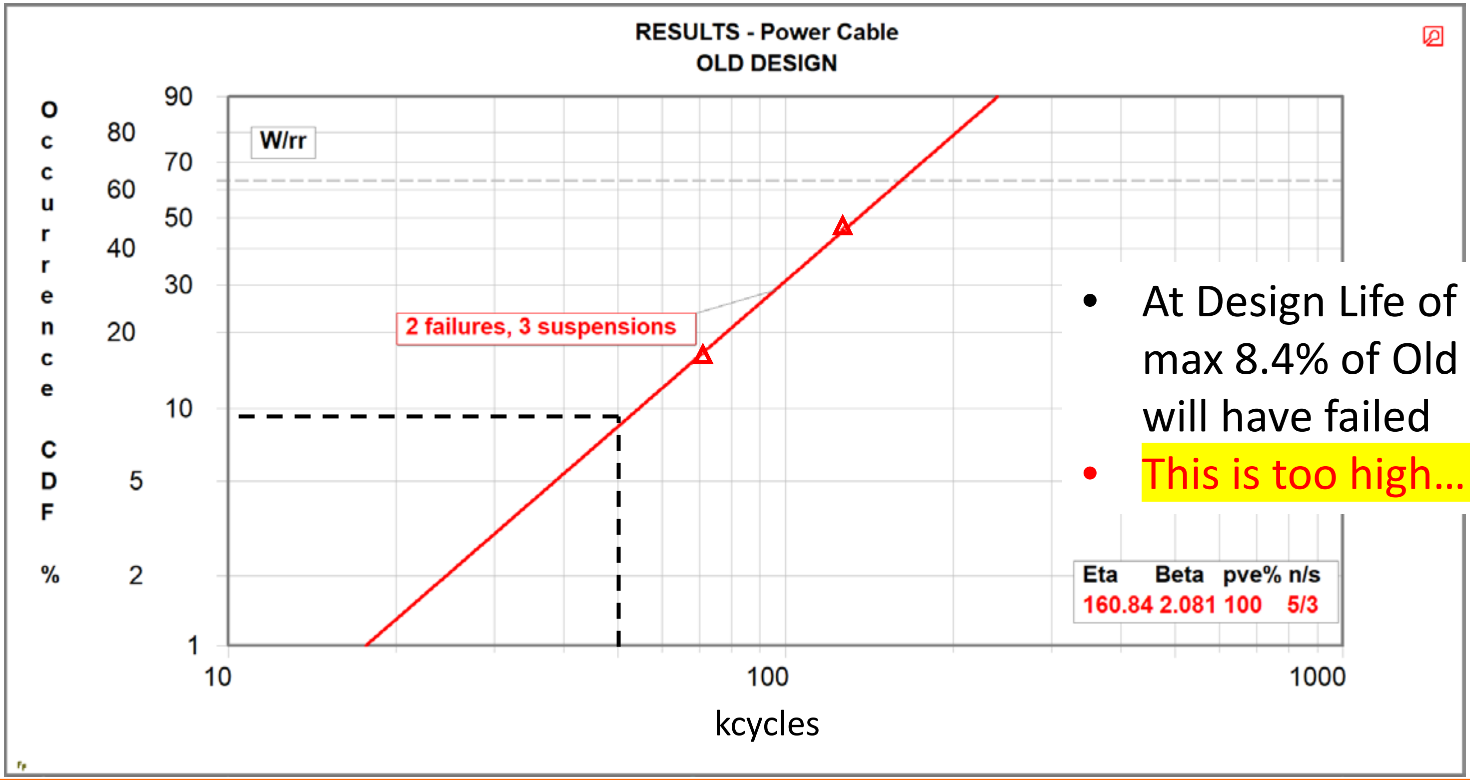
Proved by ALT

- Set up as 0-failure test but failures occurred
- 3 test rigs, where power cables can be replaced with new cables upon failure.

Old Design Power cables

- Old Design: 3 tested
- During test, 2 failed and replaced by new cables
- Failures at 71 kcycles and 128 kcycles
- Suspensions (i.e. survivors) of 47, 100, and 129 kcycles

- Resulting Weibull β ~ 2.1
- Fits with expected failure mechanism of general wear
- Wear observed on failed Power cables

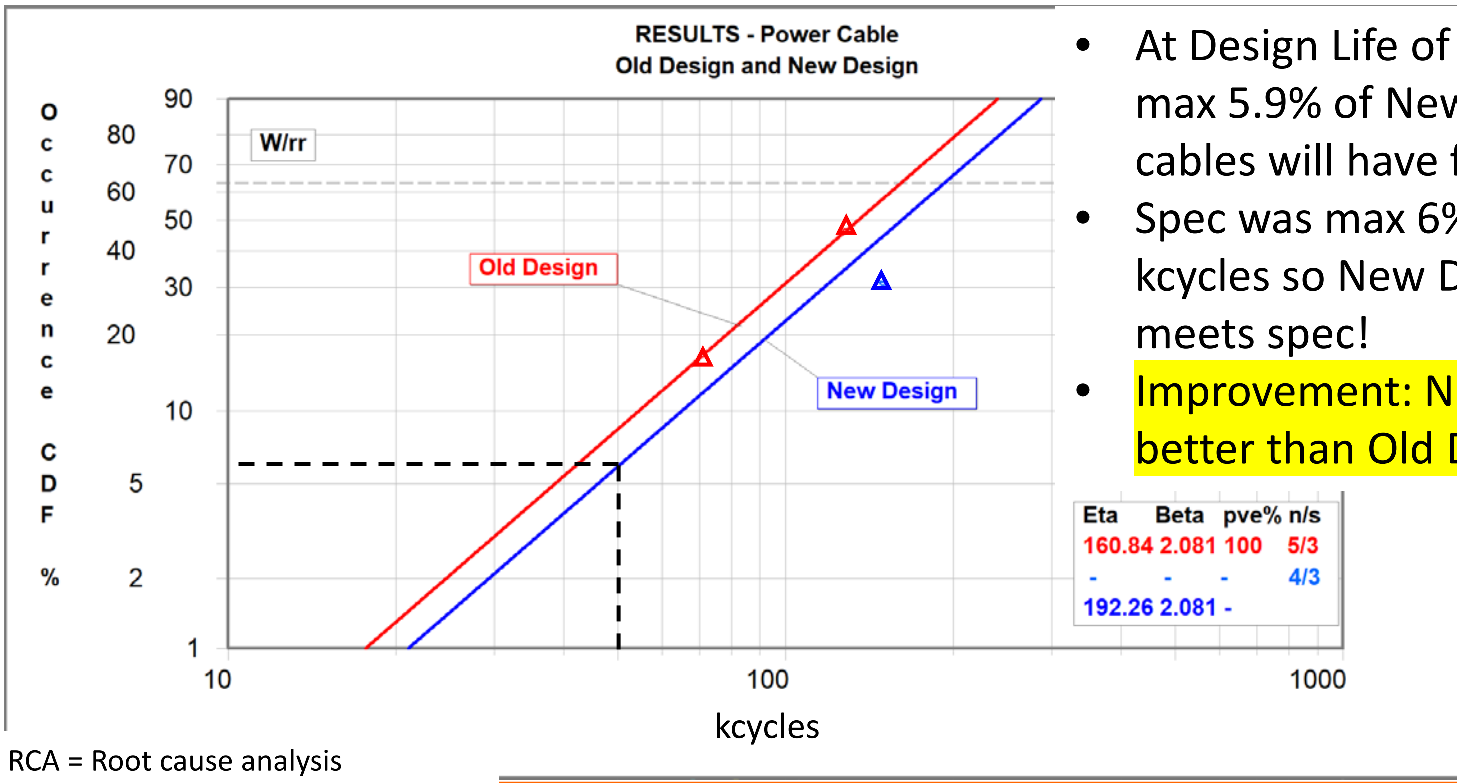


- At Design Life of 50 kcycles, max 8.4% of Old Design cables will have failed
- This is too high… re-design!

New Design Power cables

- New Design: 3 tested
- During test, 1 failed
- Failure at 149 kcycles
- Suspensions of 62, 110, and 160 kcycles

- Assume failure is due to same failure mechanism as Old design – confirmed by RCA* on failed cable
- Plot *Weibayes*** with same Weibull β ~ 2.1



- At Design Life of 50 kcycles, max 5.9% of New Design cables will have failed
- Spec was max 6% @ 50 kcycles so New Design meets spec!
- Improvement: New Design better than Old Design

* RCA = Root cause analysis
** Weibayes is a Weibull with known β

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Conclusions

Thank you for your attention!

Eleonora Annigoni

Reliability and Root Cause Analysis Specialist

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Competences and Projects

https://www.holland-innovative.nl/

Trainings

https://www.holland-innovative.nl/academy/

Some literature references in next slide!

Literature

- **Abernethy R., “The New Weibull Handbook, Reliability and Statistical Analysis for Predicting Life, Safety, Supportability, Risk, Cost and Warranty Claims”**
- O’Connor, P.D.T., “Practical Reliability Engineering”, John Wiley and Sons, New York, 2002
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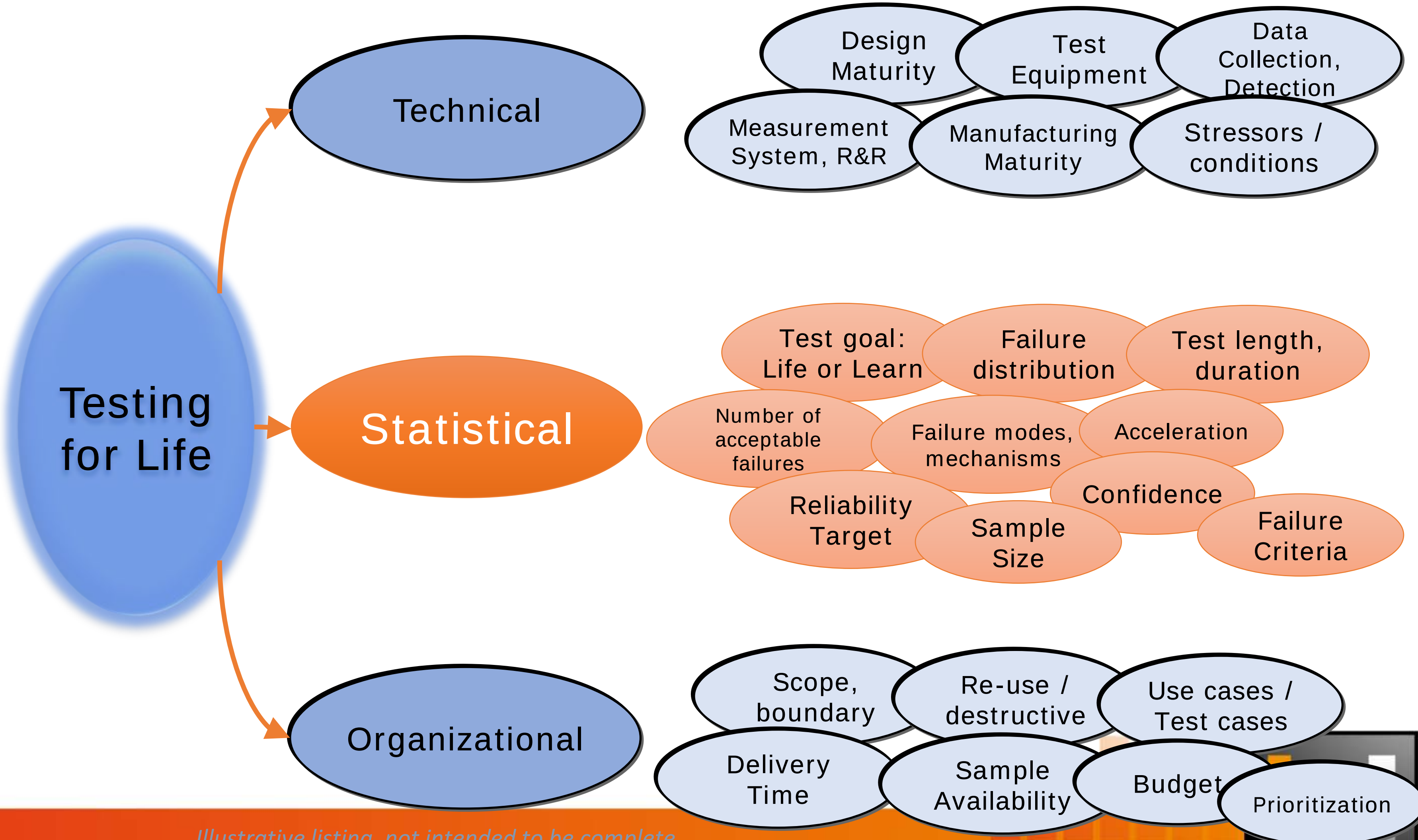
- Nelson, Wayne B., “Accelerated Testing: Statistical Models, Test Plans, and Data Analysis”, Wiley Series in Probability and Statistics, 2004, ISBN: 978-0-471-69736-7

Extra

Drivers in Testing for Life

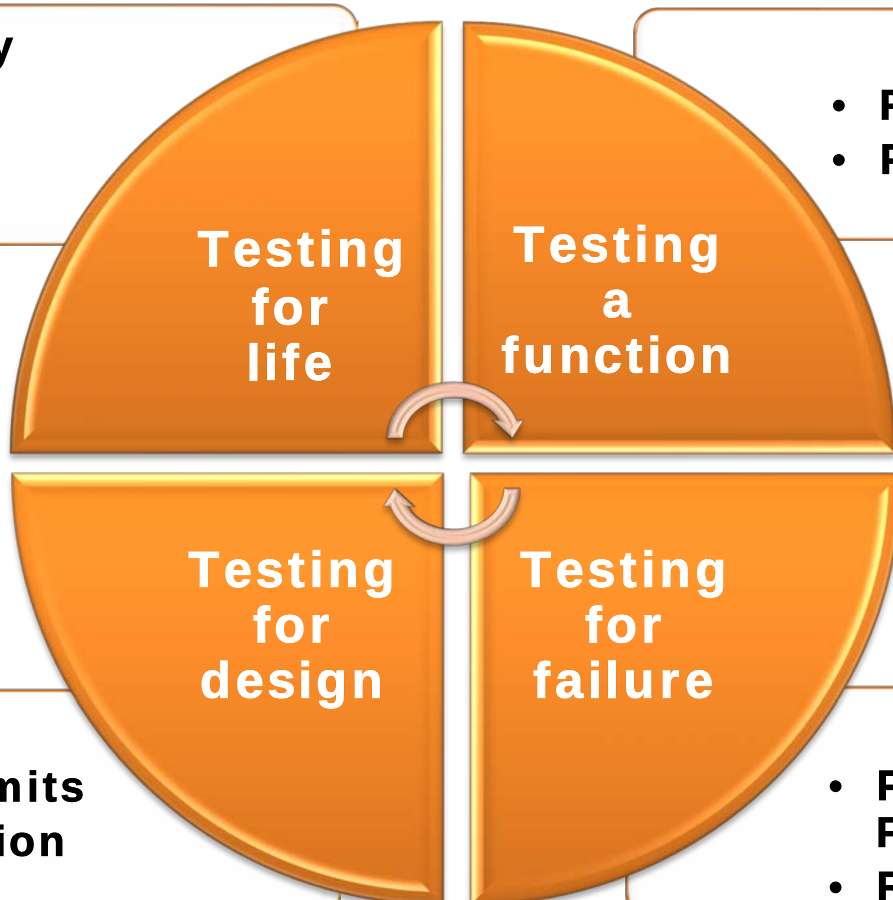


Illustrative listing, not intended to be complete

Reliability Testing - Types

- Reliability Validation
- System Prediction

- Function
- Performance



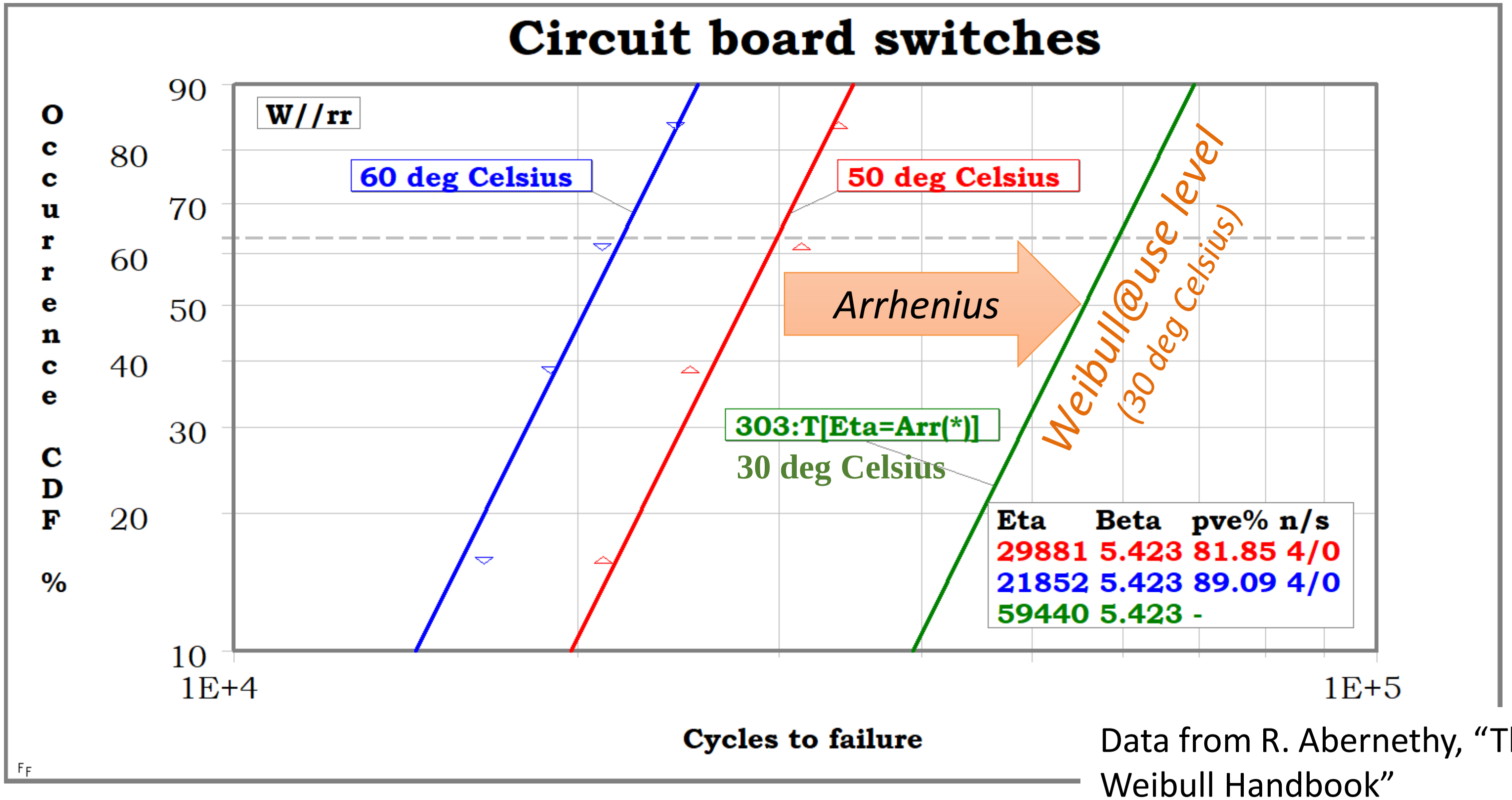
- Design Limits
- Optimization

- Physics of Failure
- Robustness

ALT requires 2 models

1. Probability distribution: at *each* stress level tested

2. Life-stress model (e.g. Arrhenius) ⇒ extrapolation of prob. distr. at any stress level



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Old *vs* New design