University of Stuttgart
Germany

CERN

Quantitative reliability demonstration from production to operation on the example of the new radiation tolerant power converter controller for the Large Hadron Collider

PSAM 14

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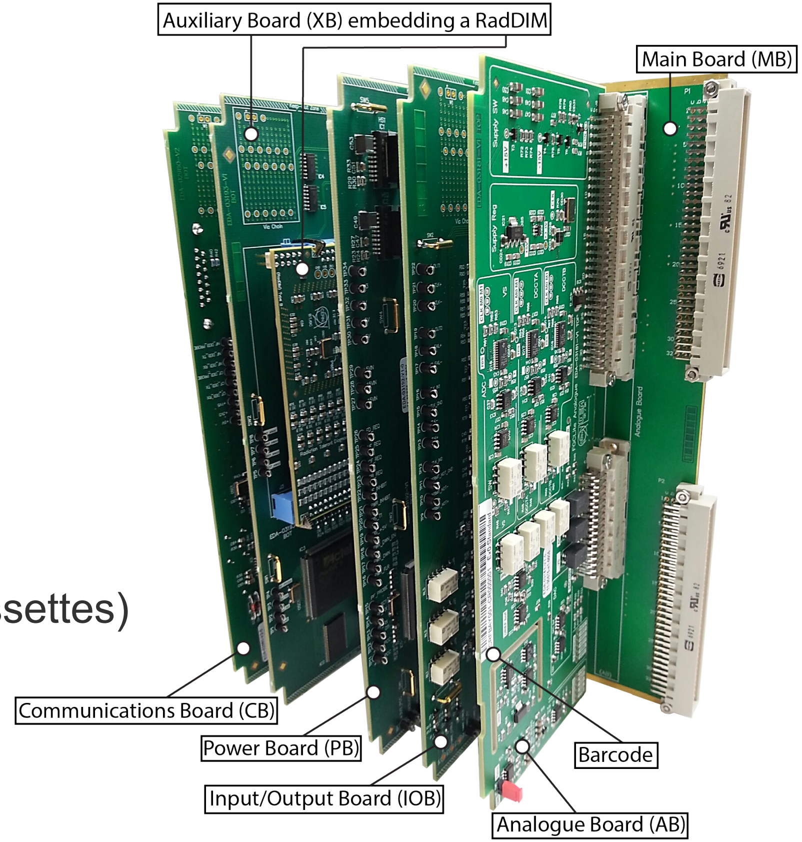
Introduction

- FGC2 → FGClite
  - Radiation tolerance (single event effects (SEE))
  - Simplified hardware - ‘lite’ FGC
  - 20 years of electrical reliability
- Specifications:
  - Maximum 10 electrical failures per year
  - Production quality: Goal < 1% failures
  - 1094 FGClite in operation + 377 spares (1471 cassettes)
  - Proven lifetime of 100k hours prior to deployment



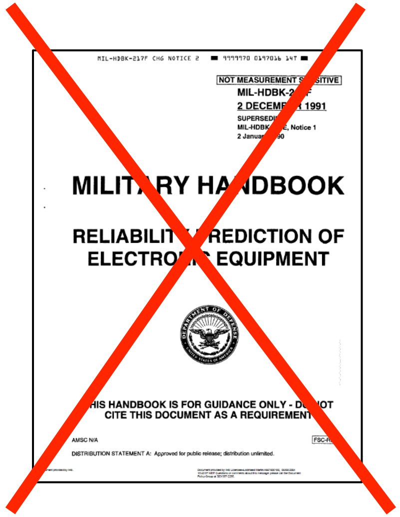
Agenda

- Introduction
- Reliability Prediction of the FGClite
- Quantitative Reliability Demonstration
  - Production Quality
  - Reception Tests
  - Field Reliability
- Conclusion and Outlook

Reliability Prediction of the FGClite

Goal:

- Prediction of the field failure rate λ of the FGClite
- Design iterations and improvements at component and system level

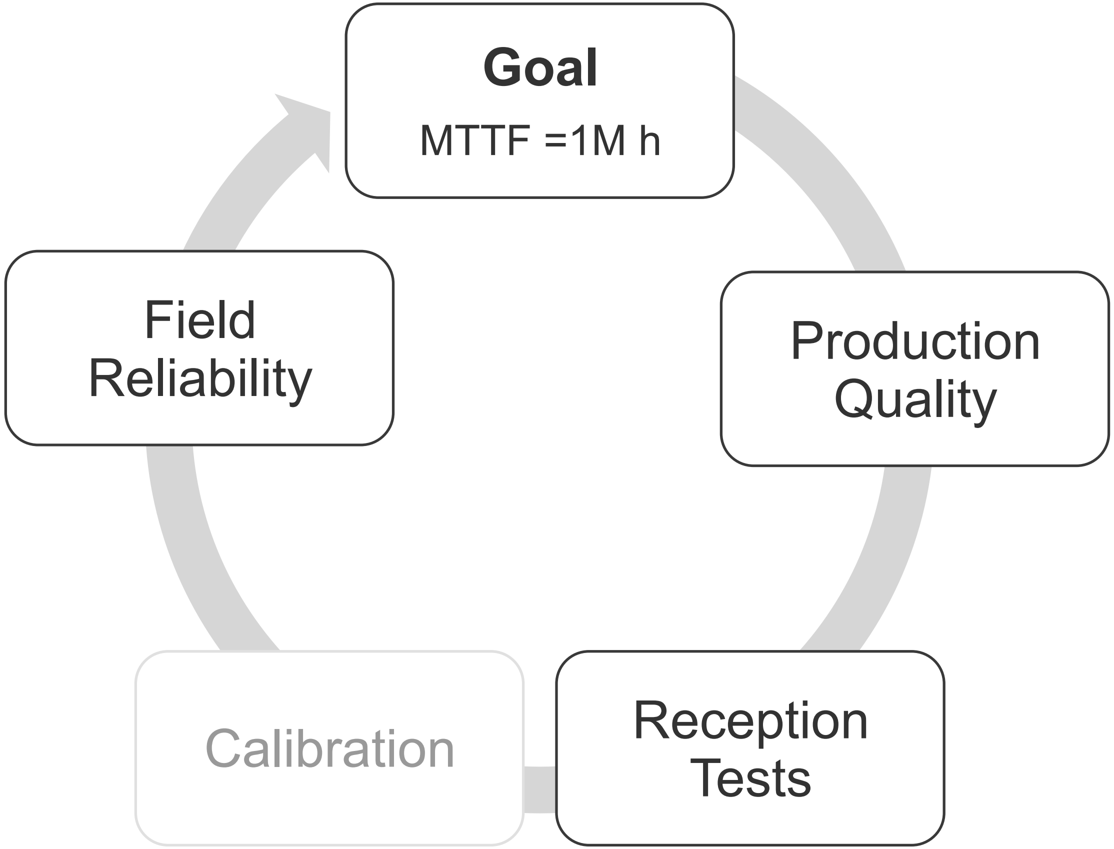


Standard/Method	Last update
MIL-HDBK-217F Notice 2	1995
FIDES Guide	2009
217Plus™:2015	2015
Bellcore/Telcordia SR-332 Issue 4	2016

System	MTTF Prediction [h]	Field MTTF [h]	Magnitude
FGC2	104K	1.1M	x10.6
FGCLITE	198K	unknown	unknown

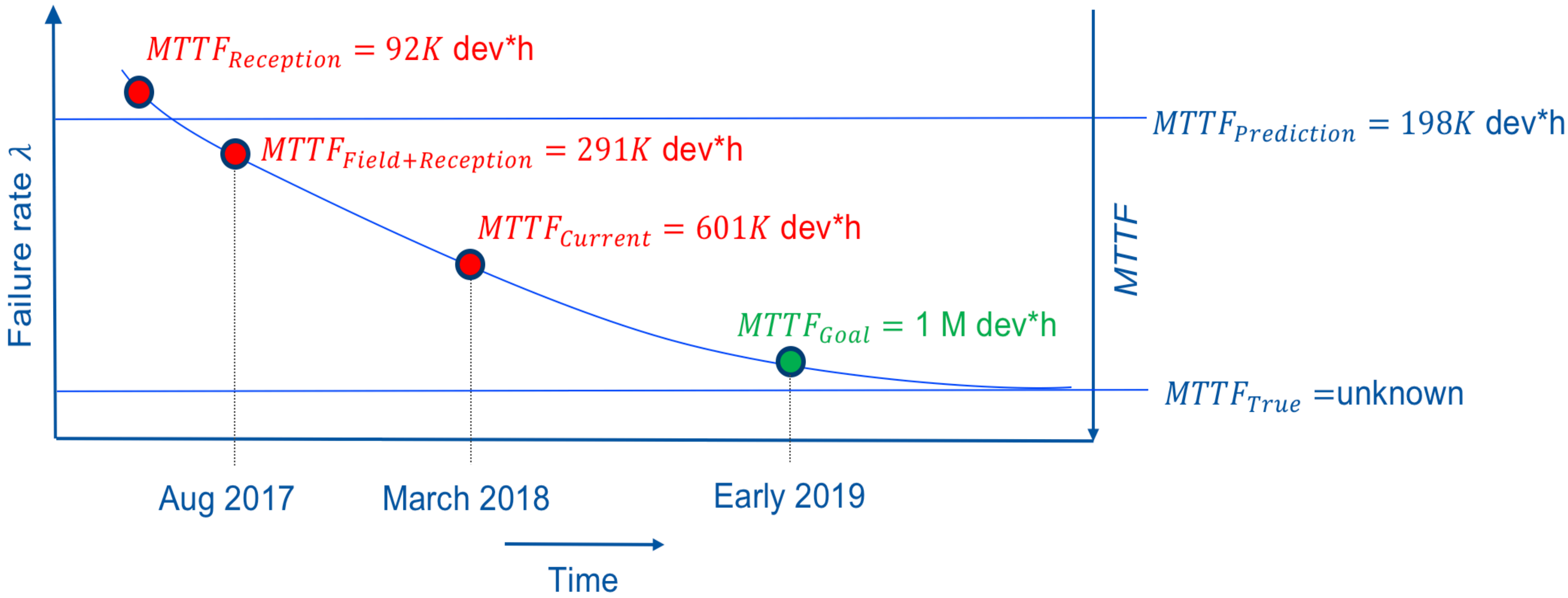
Quantitative Reliability Demonstration

Overview



Quantitative Reliability Demonstration

Overview



Quantitative Reliability Demonstration

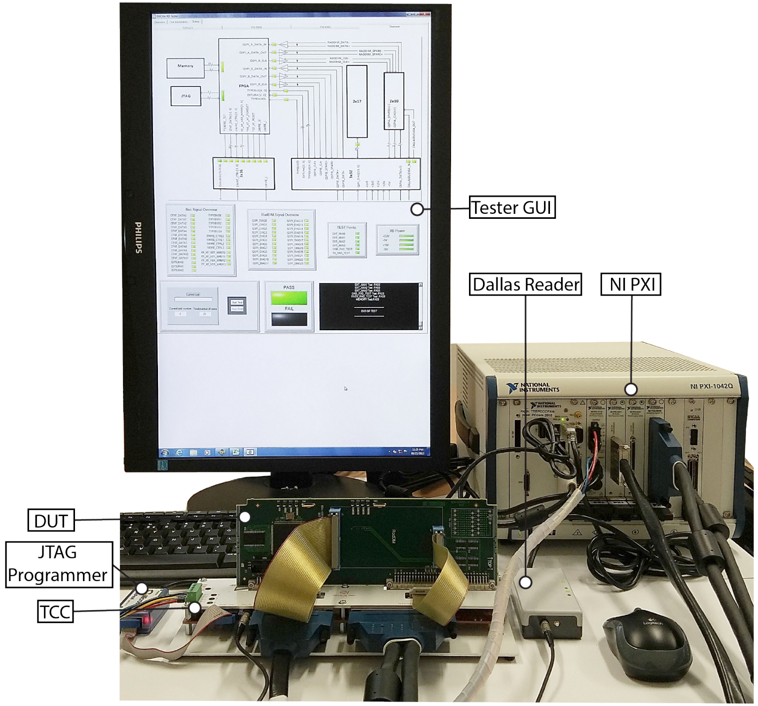
Production Quality

Goal:

- < 1% faulty boards
- Discover production flaws
- Guarantee enough functional boards for FGClite

Approach:

- Functional tests based on the NI PXI test platform
- 100% of the population is tested
- Assumption: Failures are binomially distributed
- Repairs conform to IPC Class 3 standard



Quantitative Reliability Demonstration

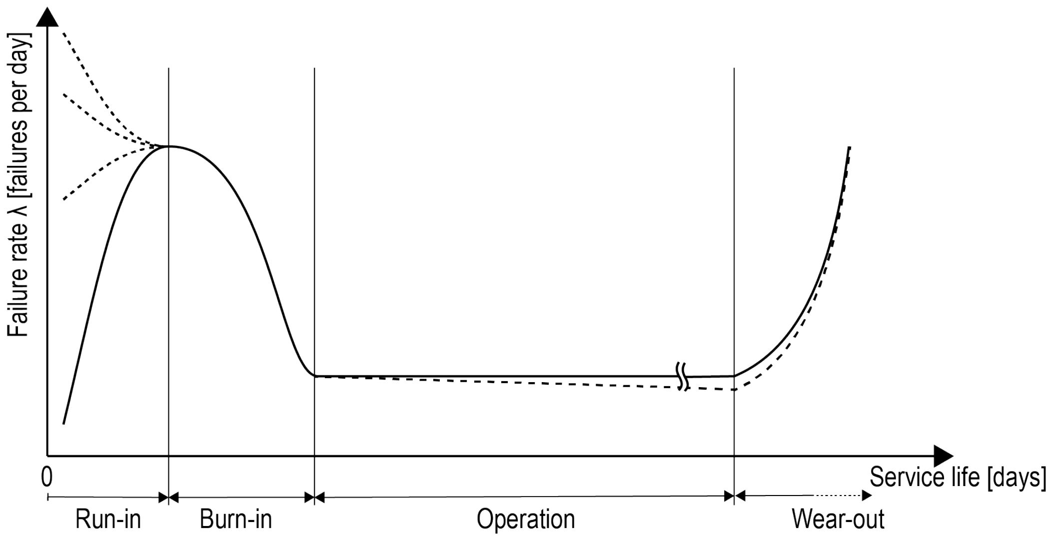
Production Quality

Board	Produced and tested until August 2017	No. of failures until August 2017	Probability of failure (failed/ tested)	Prediction made in February 2017
AB	1481	62	4.19%	$52 \leq r \leq 82$
CB	1534	20	1.30%	$13 \leq r \leq 30$
PB	1550	19	1.23%	$10 \leq r \leq 26$
MB	1498	5	0.33%	$4 \leq r \leq 16$
IOB	1472	4	0.27%	$2 \leq r \leq 12$
XB	1506	4	0.27%	$2 \leq r \leq 9$

Quantitative Reliability Demonstration

Reception Tests

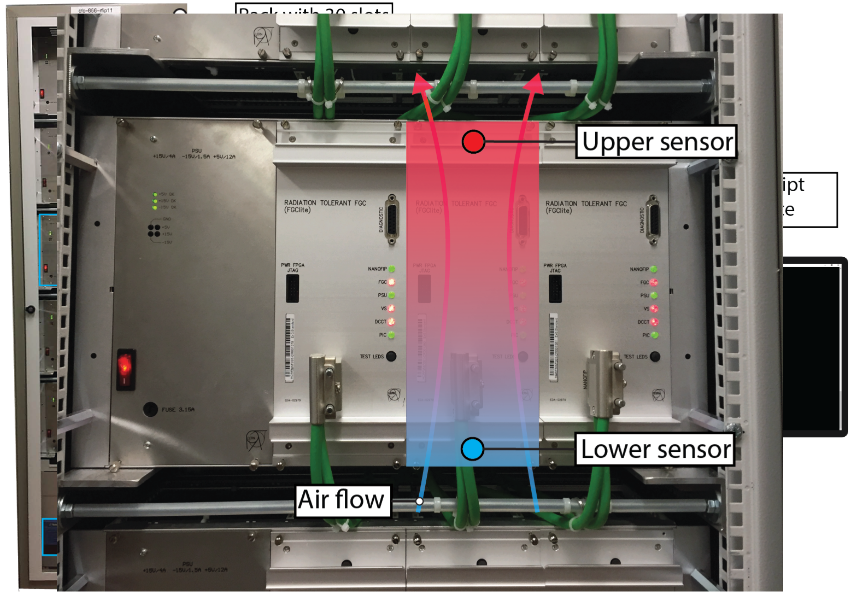
- Goal:
  - Lower no. of early failures in the field
  - Design validation prior to deployment
  - Proof of min. MTTF=100K hours (95% CL)



Quantitative Reliability Demonstration

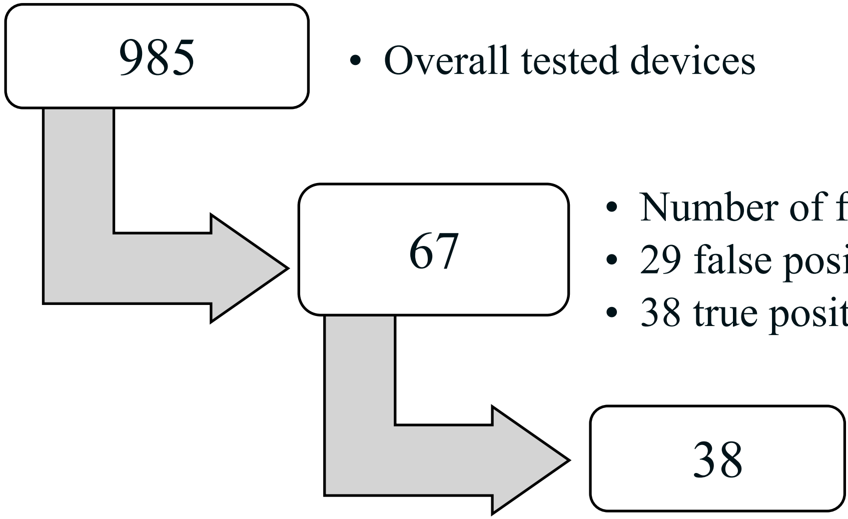
Reception Tests

- Goal:
  - Lower no. of early failures in the field
  - Design validation prior to deployment
  - Proof of min. MTTF=100K hours (95% CL)
- Approach:
  - Validate test equipment: 4 Racks
    - 2x Run-in: 36°C (required min. 30°C)
    - 2x Burn-in: 55°C (required min. 50°C → FGC2 cracks in vias)
  - Assess each failure mode (systematic/non-systematic)
    - Failure analysis strategy
  - Temperature of each FGClite is being tracked



Quantitative Reliability Demonstration

Reception Tests



- Overall tested devices

- Number of failed devices
- 29 false positives (retested: passed)
- 38 true positives

- 20 from run-in/burn-in
- 18 from calibration

- Improved overall reliability→ Preventive FPGA firmware Update
- MTTF=**92K** dev*h (95% confidence interval)

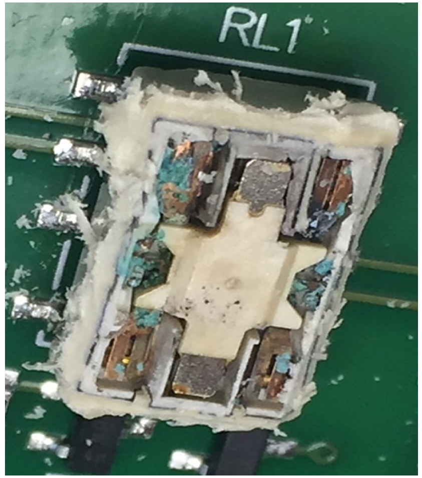
Quantitative Reliability Demonstration

Field Reliability

10 real failures (+8 false positives=18 total)			
Quantity	Malfunction	Repair	Comments
3	ADC gain error too high	On-going (HPM)	Failed after several months in operation
2	1-Wire	1x Replace oxidized relay RL1 1x On-going	Failed after several weeks in operation
1	No connection to device after reprogramming attempt	On-going	Reprogramming attempt in laboratory failed as well
1	JTAG connector	Resolder connector	-
1	NANOFIP connector	Replace connector	Pin was not broken in the laboratory tests
1	Mainboard connector	Replace connector	-
1	Missing LED lenses	Mount missing lenses on front panel	-

→ Proven MTTF=601K dev*h

- 10 real failures:
  - **6 in operation**
  - 4 sorted out during installation



Quantitative Reliability Demonstration

Field Reliability

- Goal: 1,000,000 dev*h (95% confidence interval)
  - 10 electrical failures per year
  - 200 failures in 20 years
- Available no. of spares: 344
- Currently proven MTTF=601K dev*h (March 2018)

  → needed spares for MTTF=601K dev*h: 378 (Poisson Distribution)
- Data from operation indicates a shape parameter **β of 0.85**

Conclusion and Outlook

Reliability prediction:

- Use of newer prediction methods (217Plus is used at CERN (BE))

Production Quality:

- The whole population of devices is to be screened prior to deployment

Reception tests:

- Can lead to preventive firmware updates that improve the overall reliability
- Lowers the failure rate prior to operation
- If overall $\beta<1$ → emphasis on reception tests in order to guarantee high reliability
- The assumption of a constant failure is sufficiently good and on the safe side, as the actual shape parameter for electronics seems to be less than 1

Field data:

- Continuous monitoring of failure rate and MTTF, respectively
- Proven 1M dev*h in early 2019

Thank you!

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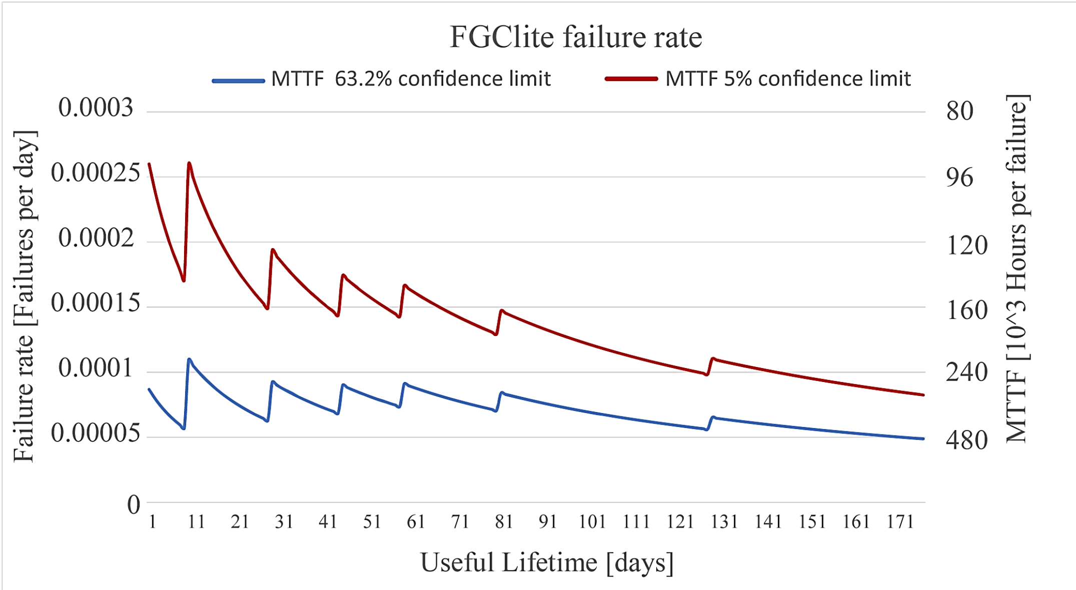
BACKUP

Field reliability

- Each spike → Failure
- Curve approaches true mean lifetime of the population

→‘Law of large numbers’



Field reliability

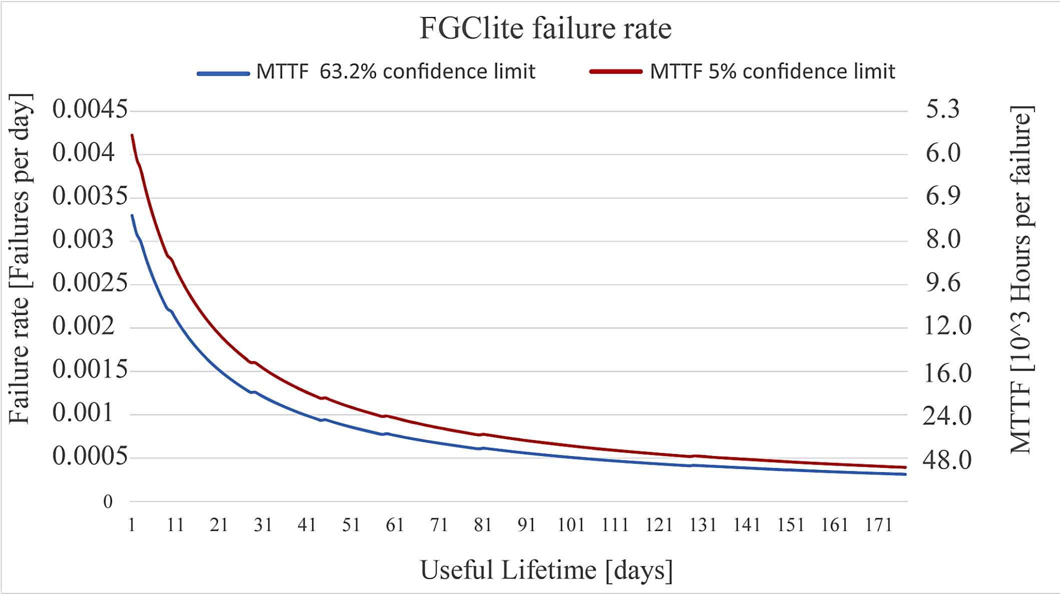
- Each spike → Failure
- Curve approaches true mean lifetime of the population

→'Law of large numbers'

Without reception tests:

- Higher failure rate, lower MTTF
- First half of the bathtub curve
- Proven MTTF=60K dev*h

  instead 601K dev*h (in Aug 2017)

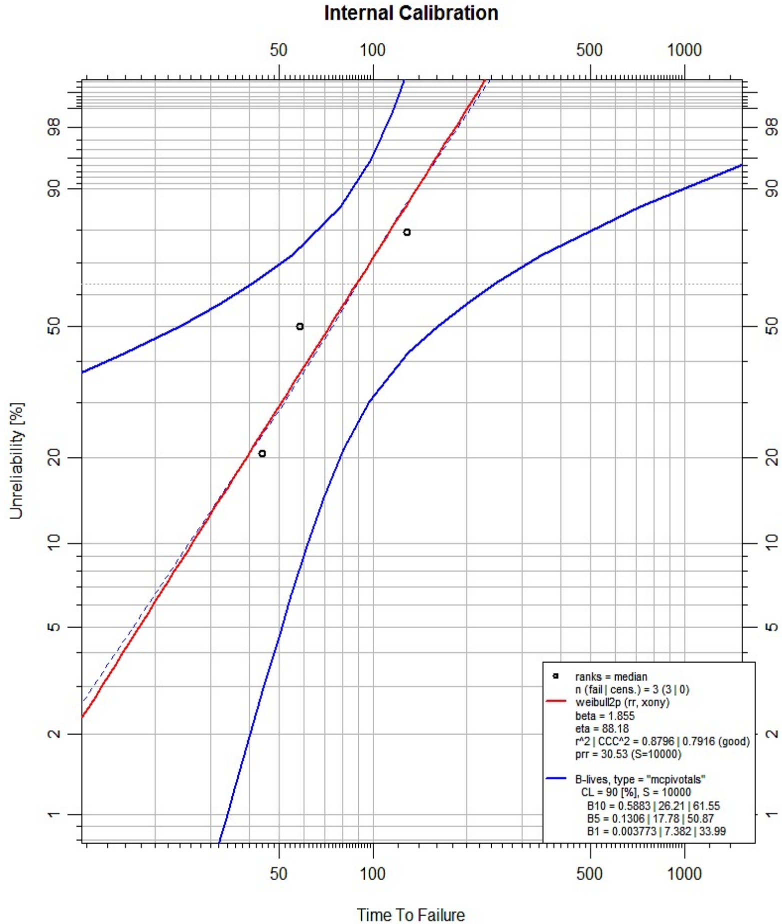


Field reliability

- Issue: Unknown failure mechanism
- $\beta = 1.885$ → early wear-out
- Not enough data for conclusive analysis

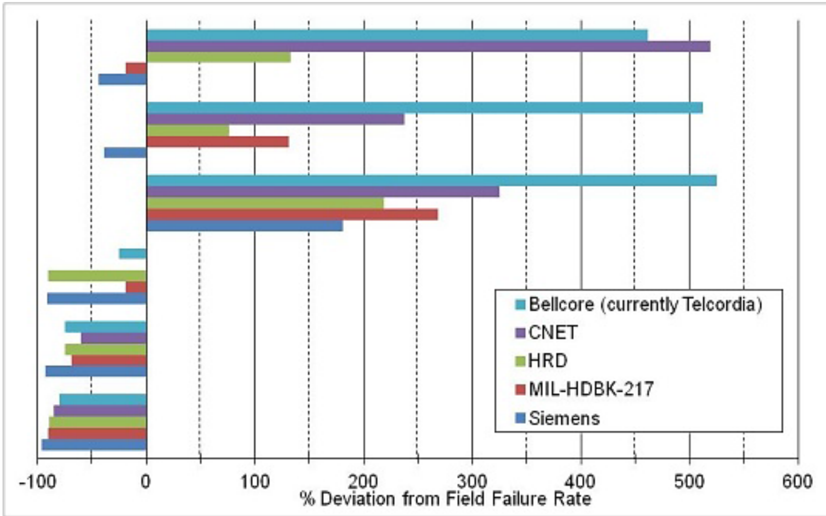
  (min. 5 needed)
- 225 days until all devices with the same failure mode fail (50% confidence)

Useful lifetime [days]	Temperature [K]	What failed?
44	303.15	Internal calibration
58		
128		



Reliability Prediction of the FGClite

- Critical Examination:
  - Statistical uncertainty not known (point estimates)
  - Predictions can be too optimistic as well as too pessimistic
  - **No way to assess results prospectively**
- Conclusion:
  - Do not use MIL-HDBK-217F
  - 217Plus or FIDES recommended
  - Design should be conform to industrial standards



Reliability Basics

- **Reliability *R***: $R(t) = 1 - F(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}} = e^{-(\lambda \cdot t)^{\beta}}$

Electronics: Constant failure rate (exponentially distributed)

Mean Time To Failure: $\mathrm{E}_{\mathrm{Exp.-Distr.}}(\mathrm{X}) = \boldsymbol{MTTF} = \frac{1}{\lambda} = \eta$ (non-repairable)

Estimation of η: $\eta \approx \eta_{MLE} = \left[\sum_{i=1}^{N} \frac{{t_i}^{\beta}}{r}\right]^{\frac{1}{\beta}} = \sum_{i=1}^{N} \frac{t_i}{r}$

$$MTTF = E(X) = \int_{0}^{\infty} R(t)dt = \eta \cdot \Gamma\left(1 + \frac{1}{\beta}\right) + \gamma$$

Parameter	Meaning
F	Unreliability [0,1]
η	Characteristic lifetime
β	Weibull shape parameter
t	Lifetime, no. Of cycles
r	No. of failures
N	No. of devices

Reliability Basics

- **Confidence Bounds**: Chi-Square distribution (proven *MTTF*)

$$\eta_C = \left[\frac{2 \cdot \sum_{i=1}^{N} t_i{}^{\beta}}{\chi^2(C;2r+2)}\right]^{\frac{1}{\beta}}$$

Accelerated Life Testing:

- Arrhenius equation: $AF_T = e^{\left[\frac{E_a}{k} \cdot \left(\frac{1}{T_U} - \frac{1}{T_{AF}}\right)\right]}$

E_a	Activation energy in electron volts [eV]
k	Boltzmann's constant $(8.617 \cdot 10^{-5}\ [eV/K])$
T_U	junction temperature at normal use conditions
T_{AF}	junction temperature at accelerated conditions
AF_T	Acceleration factor