Reliability

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CERN, *for* internal use, 2018 @ CERN

HCCIBD reliability analyse

Failure case

Document source [*https://edms.cern.ch/document/2000852*](https://edms.cern.ch/document/2000852)

Introduction

Context for this study, goal of the work.

From end of 2017 – beginning of 2018, a sudden increase in HCCIBD units failures has occurred, each time with an internal DC-DC unit failing identically.

In June 2018, MPE contacts EPC helping with DCDC expertise.

- **Valuable competencies in EPC: electronics + reliability**
  - Power supplies: TE-EPC-LPC specialized in low power units.
  - Modelling reliability: TE-EPC used to collecting data from the field.

These DCDC units are used in the HCCIBD units, used in the BIS system.

Available Data

A very complete excel file – with *gold-type* data:

- All failures recorded carefully
  - Time to failure (included LS1 activity)
  - Failure mode (deep analyse to classify well different sorts)
- The complete population is also traced carefully
  - All operational units - still alive - data (time in operation)
- For all unit
  - Level of output current – assumed as the main stress level - recorded.

A clear *feeling* from responsible that's something goes wrong.

- With some actions already taken preventively.

Available Data: *Gold-quality data*

1. failure mode

Failure	Short	Long
0	None	CIBD est toujours en état de marche
1	Fuse HS	courant d'appel trop important, le fusible a été changé. Par contre je comptabilise jusqu'à l'échange du fusible, puis même si par la suite elle est remise en fonction elle n'apparait plus dans mon fichier (je m'arrête à la première panne).
2	Traco HS	pas d'expertise particulière à faire, je te t'en fournit par ailleurs pas avec ce type de pannes. Email exchange: il semble que le failure mode 2 n'est assurément pas le 3, meme si non connu en détail, et pouvant également renfermer plusieurs failure modes (possible).
3	Traco Erratique	c'est celles qui me posent un problème et pour lesquelles j'ai besoin d'une expertise
4	Schaffner	filtre secteur, une seule présente ce type de panne ...

2. operating conditions

Mouted On	I.op [A]	Comments
CIBF	2.4	The highest current consummed. The one showing issues 3 only.
CIBUD	0.9	
CIBUS	0.4	

3. data

CIBD ID	From (Date format OK)	To (Date format OK)	OFF during LS1 period (01/13 => 09/14) ?	Working days	Mounted on	Status	Failure
ID000210	2007-May-25	2007-Jul-18	No	54	CIBF	Fault	2
ID000386	2007-Dec-04	2008-Mar-18	No	105	CIBUS	Fault	1
ID000390	2007-Dec-04	2008-Mar-18	No	105	CIBUS	Fault	1
ID000143	2007-Aug-31	2008-Feb-28	No	181	CIBUS	Fault	2
ID000344	2007-Aug-03	2008-Mar-18	No	228	CIBUS	Fault	1
ID000201	2007-Dec-04	2008-Jul-31	No	240	CIBUS	Fault	1
ID000581	2014-Jan-23	2014-Oct-24	No	274	CIBUS	Fault	1
ID000950	2014-Jan-23	2014-Oct-24	No	274	CIBUS	Fault	1
ID000882	2017-Aug-03	2018-Jun-01	No	302	CIBUD	Operation	0
ID001103	2015-Feb-13	2016-Mar-23	No	404	CIBF	Fault	2
ID001116	2017-Apr-21	2018-Jun-01	No	406	CIBUD	Operation	0
ID000879	2012-Nov-09	2015-Aug-12	Yes	466	CIBF	Fault	
ID000739	[illegible]	2011-Feb-14	No	507			

Goal of the study

Help responsible for taking appropriate decision:

- **Based on current available data**
  - Since they are quite detailed and precise, it must be possible to extract some conclusion from them.
- **Modelling the failure modes**
  - Analysing the faulty units (DC-DC expertise), why EPC was consulted.
  - Understanding why only some families of HCCIBD were concerned.
  - Trying to estimate the level of failures in the next coming years.
- **Provide clear conclusions**
  - Chase rational conclusions from information “hidden” in available data, if possible, and extract / provide a good picture of the situation.

Context

Population of interest

Input Data (a unit = a HCCIBD)

- **845 units considered in total**
- 786 units still running, accumulated each [50; 80] kHours
- **Failure mode-1:** 039 failed units: fuse failure mode.
- **Failure mode-2:** 012 failed units mixing other failure mode (number unknown), but still assumed not to one of the detailed failure modes.
- **Failure mode-3:** 007 failed units: Erratic regulation – this failure mode is understood as appearing recently.
- **Failure mode-4:** 001 failed unit: Schaffner filter – *marginal*.
- A excel file gathers all these inputs here. EDMS N°2000850

Population considered – 2/2

Input Data

- **Consumption is depending on CIBU family where the HCCIBD module is mounted , following the table below.**

Mounted on	HCCIBD units in operation	CIBx Required Input Current [A]
CIBUS	580	0.4
CIBUD	90	0.9
CIBF	116	2.4

- **Important Note:**
  - In operation, each CIBx unit is powered by 2x HCCIBD running in a parallel configuration (still without activing sharing). HCCIBD units mounted on CIBF can then operate at only 1.2 A in best case.
  - The HCCIBD design, used in all the above families, is based on a TRACO DC-DC capable to deliver up to 5.0 A nominal.

Refresh

Reliability Analyse

Few slides to refresh Weibull curves

Weibull instant refresh in 2 slides: 1/2

Refresh

Why Weibull distribution choice:

- Five events **already** help to guess the nature of the acting process: *random-in-time* or *end-of-life*
- Cumulative distribution function curves used in reliability domain **can be well described** using **Weibull** distribution (2-parameters):
  - $F(t) = 1 - e^{-\left(\frac{t}{eta}\right)^{beta}}$
- Parameters of a Weibull curve using 2 parameters **only**, even gives some ***physical*** meaning regarding the process
  - **Beta** parameter: Shape-rate curve (its slope), its statistical nature
    - 0 < Beta < 1: **Infant** failure distribution type
    - Beta = 1 **Random-in-time** failure distribution type
    - 1 < Beta < ? **End of life** process: failure rate increasing with time.
  - **Eta** parameter: Time where 63 % of the total population is dead. Close to the Mean Time To Failure (beta = 1)

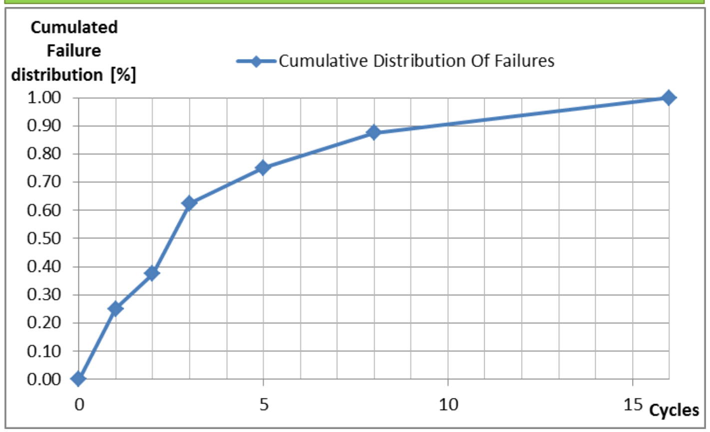
Weibull instant refresh 2/2

Refresh

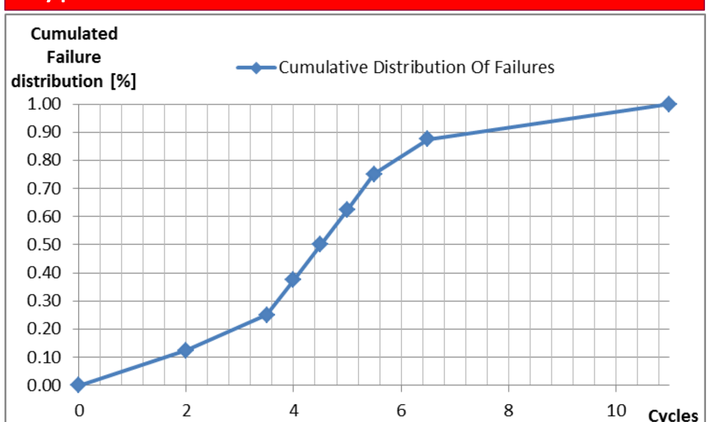
Graphical representations:

- Straight lines using specific axes, allowing to judge the fit, but also to evaluate the process.

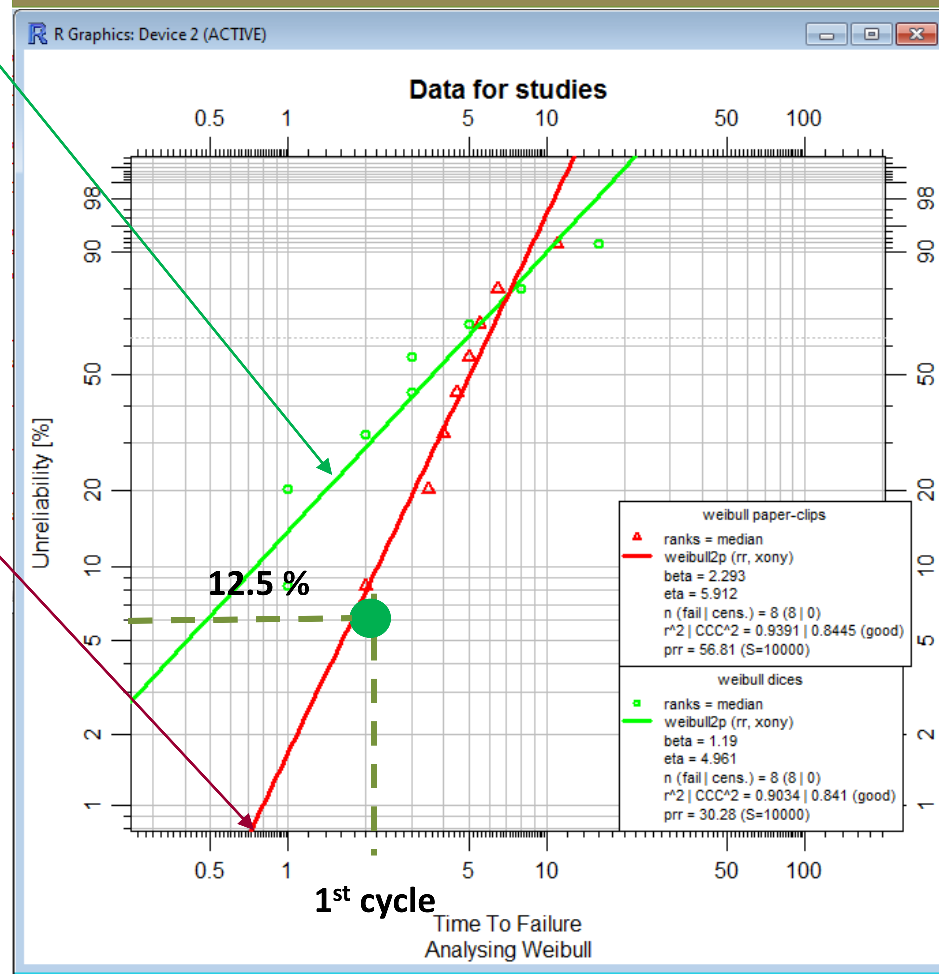
Typical cumulative **random** distribution



Typical cumulative **"end of life"** distribution

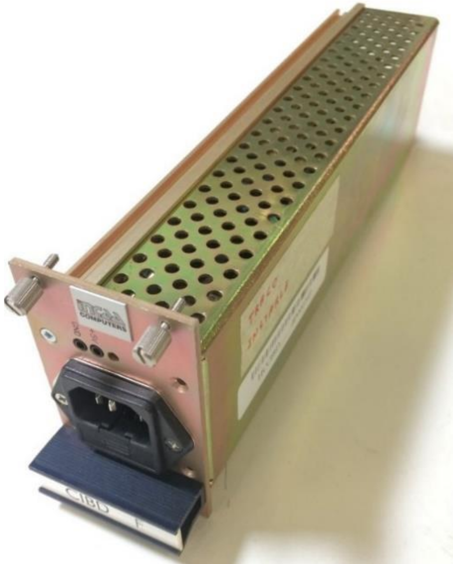


All Weibull distribution (2-par) are easily readable straight lines



HCCIBD Failure analyse

*Observations at the **HCCIBD** level unit.*



CIBD: Failure rough analyse

Input Data – HCCIBD level

- **All CIBx units considered, i.e. 845 units in total considered. 58 millions hours of running time accumulated in total.**
- **59 failures of different types accumulated on units running, for most of them, for more than 10 years.**
  - 19 units involving Traco unit reliability (Traco HS + Traco Reg.Erratic)
  - 39 units involving Fuse issue, not impacting directly Traco reliability.
  - 01 unit involving the Shaffner issue, not impacting Traco reliability.
- **Let's focus on HCCIBD unit: (all type of above fault considered)**
  - $MTBF_{HCCIBD}$ = 58 145 000 / 59 = 1 Millions of Hours…over ≈ 10 years
  - It is the figure *we should care*, since we certainly promised a given failure rate **forever**, or at least up to the LHC end of life.
  - The concept of end of life is not clearly applicable to the system we deliver at CERN, and we must stay in the central bath curve part, and that, even if the system is made of limited life time components…

CIBD: Failure Mode-1: Fuse 1/4

HCCIBD level

Failure Mode-1 : Fuse

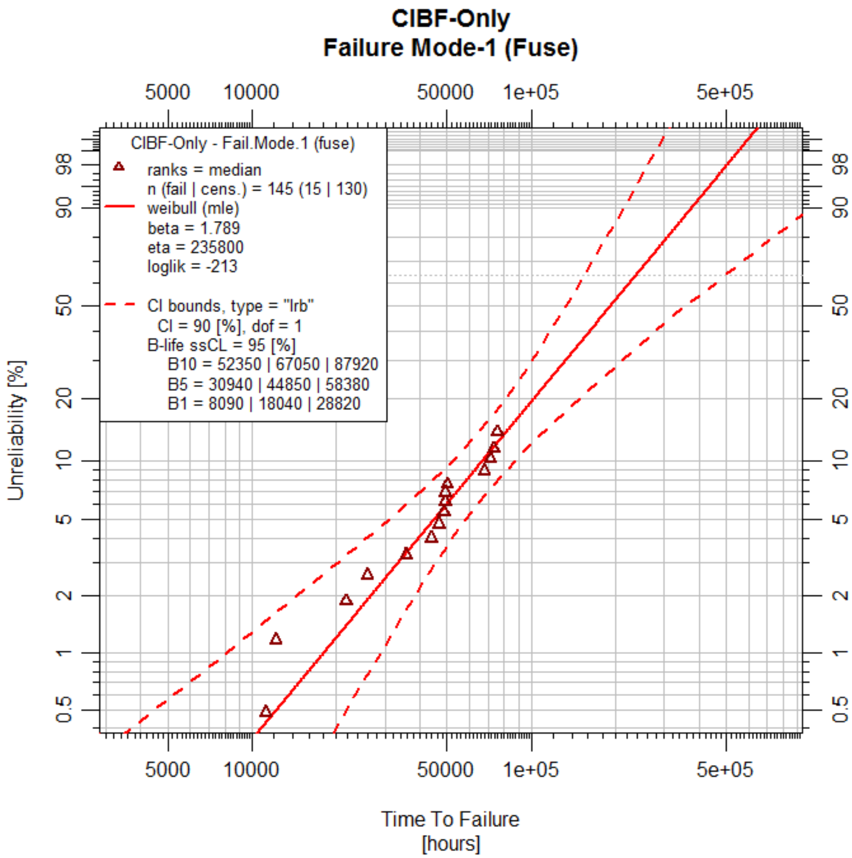
Input Data

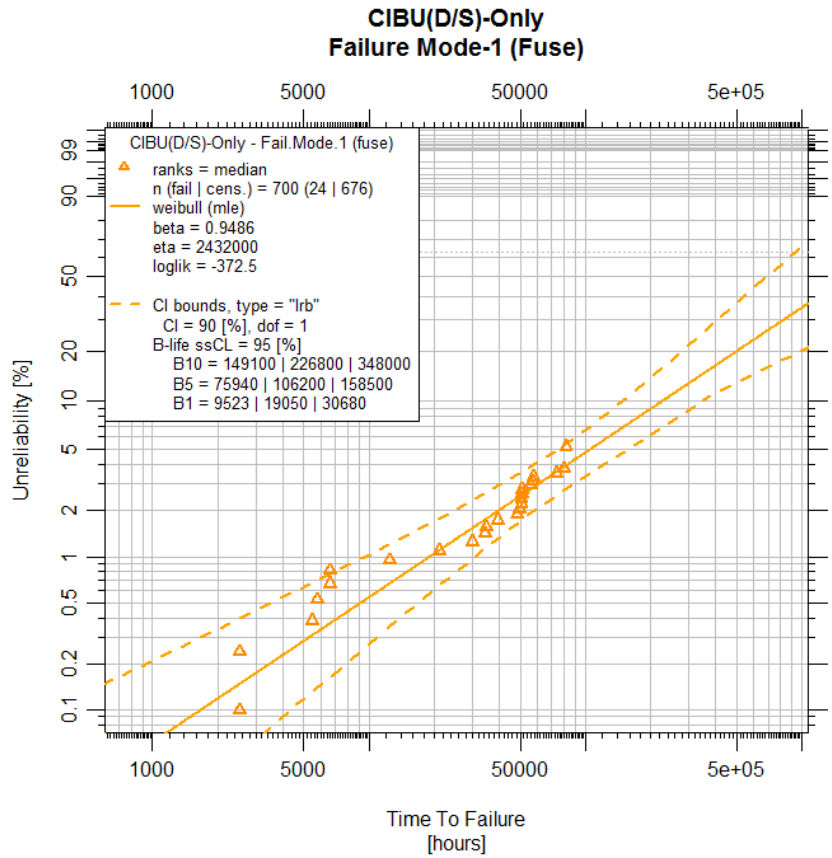
- **All units considered, then CIBF compared to others.**
- **845 (806+39) units in total considered (all types)**
- **039 failures of Fuse Failure type.**
  - 15/39 on CIBF (145 units in total) 15/145 = 10 %
  - 02/39 on CIBUD (095 units in total) 02/095 = 02 %
  - 22/39 on CIBUS (605 units in total) 22/605 = 03 %

CIBD: Failure Mode-1: Fuse 2/4

This failure mode seems rather random, CIBF more stress

- **CIBF - only**: beta=1.78, eta=0 235 800 hours = **009 825** days
- **CIBU+CIBD**: beta=0.95, eta=2 432 000 hours = 101 333 days

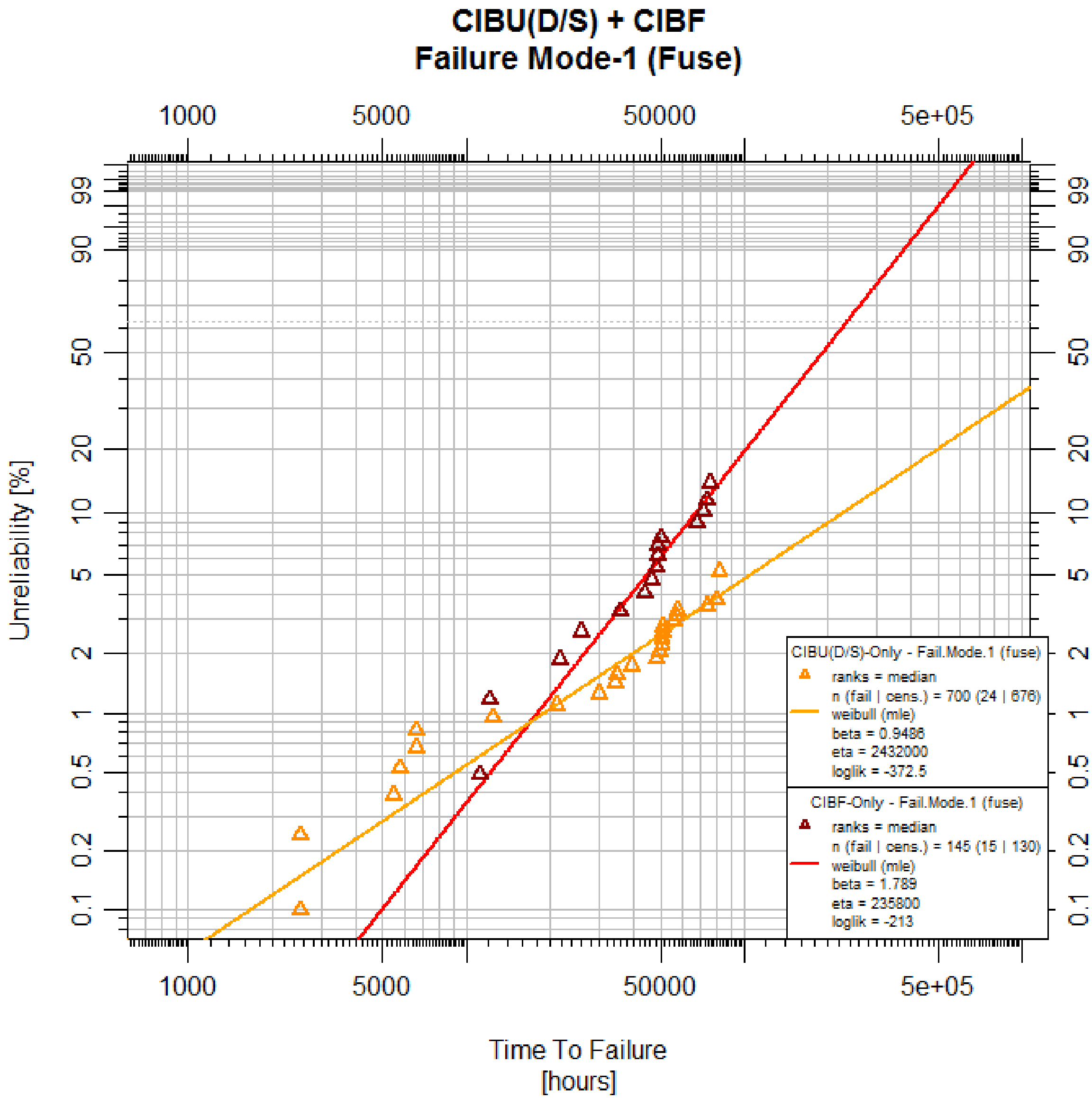




Graph 1+2

CIBD: Failure Mode-1: Fuse 3/3

CIBF versus CIBU(D/S) regarding Failure Mode 1 (Fuse)



Traco level

Traco TXL 025-05S Failure analyse

*Modeling & understanding failure mode from the **Traco** unit.*

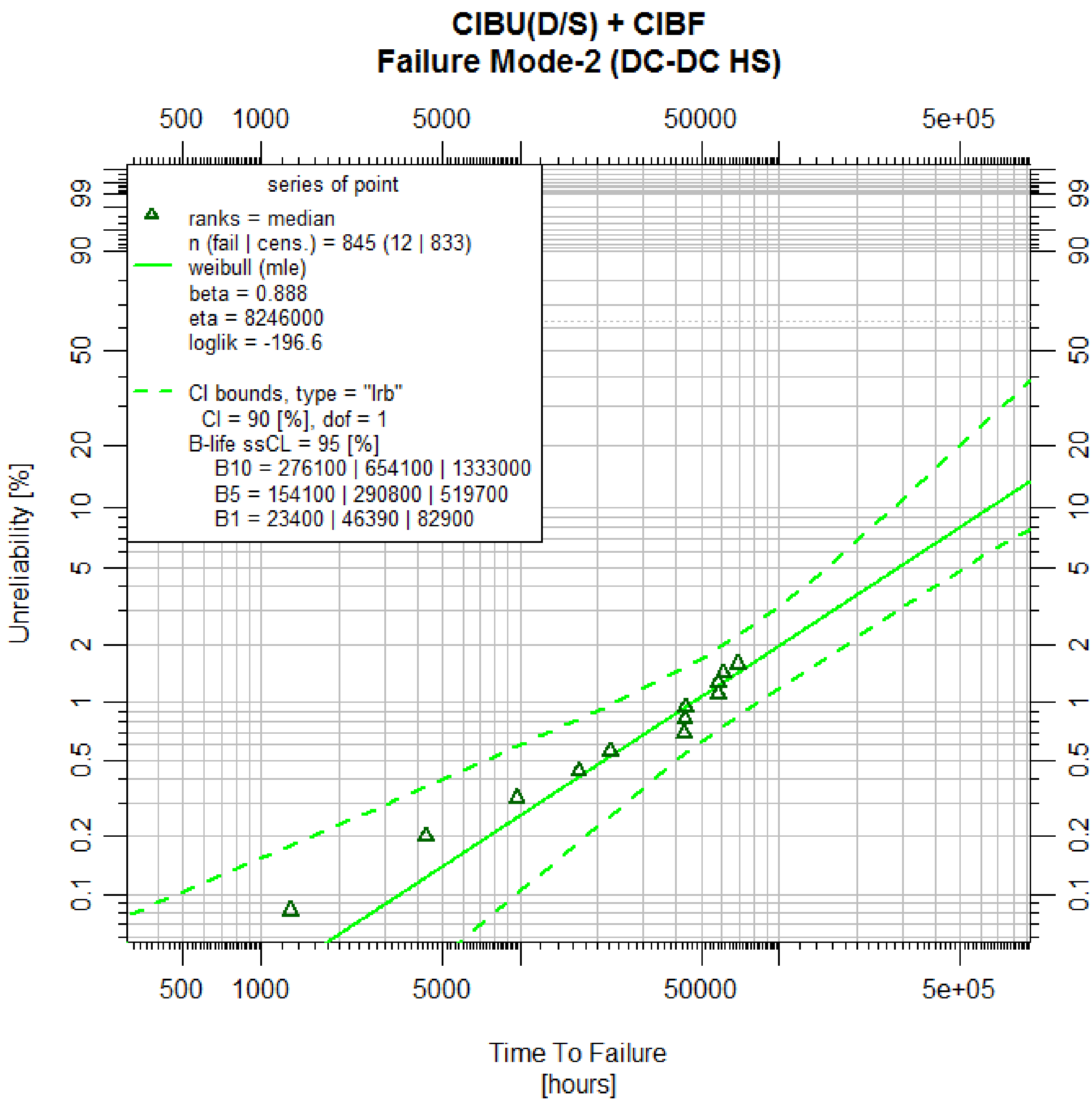
Input Data – Traco level: ref TXL 025-05S

- **All CIBx units considered, i.e. 845 units in total considered. 58 millions hours of running time accumulated in total.**
- **Let's focus on the Traco unit (not considering then fuse fault)**
  - Traco MTBF = 58 145 000 / 19 = 3 Millions of Hours... over ≈ 10 years
  - Please note: Manufacturer *should disagree* with this, preferring:
    - Only 5 units failed during *the* 3 years of warranty (see datasheet), leading to a real MTBF of ≈ 21 Millions / 5, then ≈ 4.2 Millions of hours, which is a lot better than the 250 000 hours (failure rate 4E-6) given by manufacturer.
- **Concerns comes clearly from distribution on one failure mode**
  - Fail. mode-2 | 12 units: "std fault" seems randomly distrib.
  - Fail. mode-3 | 07 units: erratic reg. seems of wear out type.
    - *No failures up to 50 000 hours, 7 in the 20 000 hours after. Failure rate is clearly increasing with time! Still, note that a failure rate of 4E-6 (from manufacturer MTBF) leads to 28 fail/years (with 826 units in operation).*

Input Data

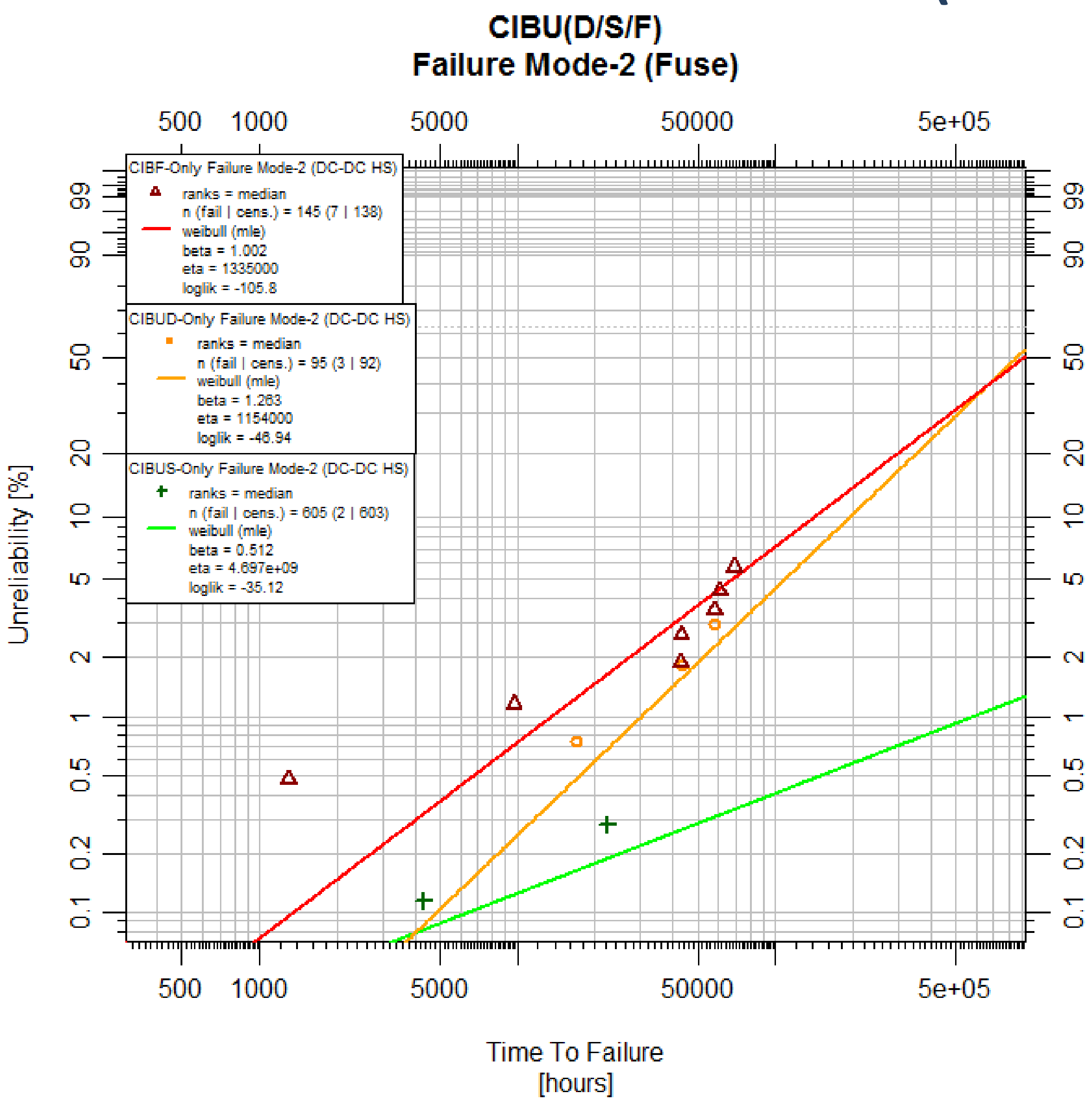
- All **units** considered, then CIBF compared to others.
- 845 (833+12) units in total considered (all types)
- 012 failures of (DCDC HS/Dead).
  - 7/12 on CIBF (145 units in total) 7/145 = 4.8 %
  - 3/12 on CIBUD (095 units in total) 3/095 = 3.1 %
  - 2/12 on CIBUS (605 units in total) 2/605 = 0.3 %
  - Fail time: 1.296, 4.344, 9.696, 16.824, 22.248, 43.128, 43.248, 43.464, 58.032, 58.248, 61.176, 69.360
- This failure mode is not diagnosed in detail (dead unit, not analysed nor repaired), and is considered different from others failure mode identified.

CIBD: Failure Mode-2: Dead Unit – 2/4



Graph 4

CIBF vs CIBUD vs CIBUS on Failure Mode 2 (Dead Unit)



CIBD: Failure Mode-2: Dead Unit – 4/4

Failure Mode-2 discussions

- **The output current and/or the operating temperature seems to generate more failure, in a consistent way.**
- **Note that only 2 events were considered for CIBUS, resulting in pretty weak distribution prediction.**
- **Still the failure mode is considered as:**
  - Not severe: very high eta value > 1 Millions of hours.
  - Not alarming: beta of less than 1.2 ≈ almost random.

CIBD: Failure Mode-3: Regulation – 1/12

Failure Mode-3: Regulation

Traco level

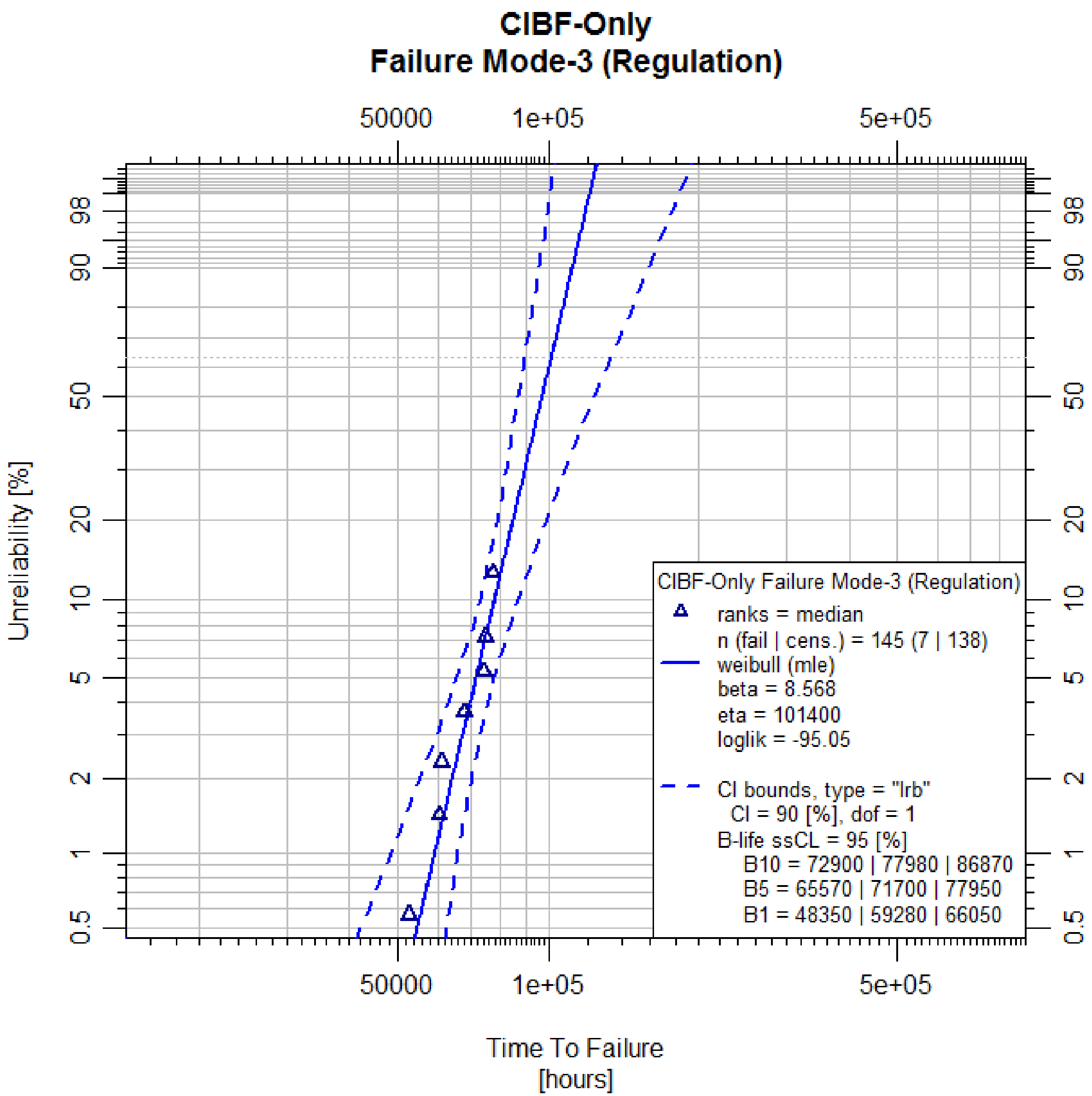
Input Data

- CIBF **units** only considered (CIBD = 2.4 A output), since thi failure mode is only encountered on these units & seems likely due to higher operation T°C (at 1st glance).
- 145 (138+007) units in total considered (all CIBF)
- 007 failures of (regulation erratic type).
  - Fail time: 52704, 60456, 61176, 67752, 74232, 75000, 77448
- 022 suspended units, failed for other reason / failure mode.
- 116 units still running, accumulated each [50; 80] kHours

CIBD: Failure Mode-3: Regulation – 2/12

Traco level

Failure Mode-3: Regulation



Graph 6

Failure Mode-3 discussions

- **The fit is relatively good, with already seven points available.**
- **A beta of 8.6 is very high, still *moderated* by a high eta value.**
- **Based on the projection**
  - 90% units would have been failed before 120 000 hours, which is around Mid-2023, for many of the considered units.
  - Number of failures expected in coming year (+7 000 hours) would have been of 6-8 more units, without having replacing all units).
    - Note: this is a rough estimation, since all the starting dates are not equal, and the calculation is then very rough.
    - Even if the number of failures would have not been dramatically high - let’s compare it with the manufacturer failure rate deduced from MTBF - what is clearly annoying is that the failure rate initially *experienced* up to now will increase, with higher risk of dramatic simultaneous failure, since entering the bath curve end-increasing part.

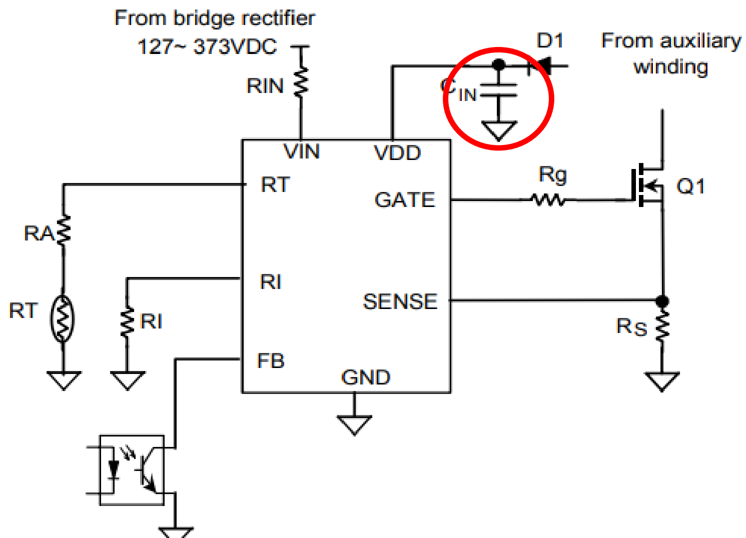
Failure Mode-3 analyse: root cause

- A full report exists here:EDMS N° 2004847, written by **Raul Bianchi** (te-epc-lpc).
  - Converter topology : Flyback converter
  - Two PCB versions exist, quite different (complicating the analyse!!).
    - The "old" PCB up to serial number #10091004
    - The "new" PCB from serial number #10126225.

Old		New	
			

Failure Mode-3 analyse: root cause

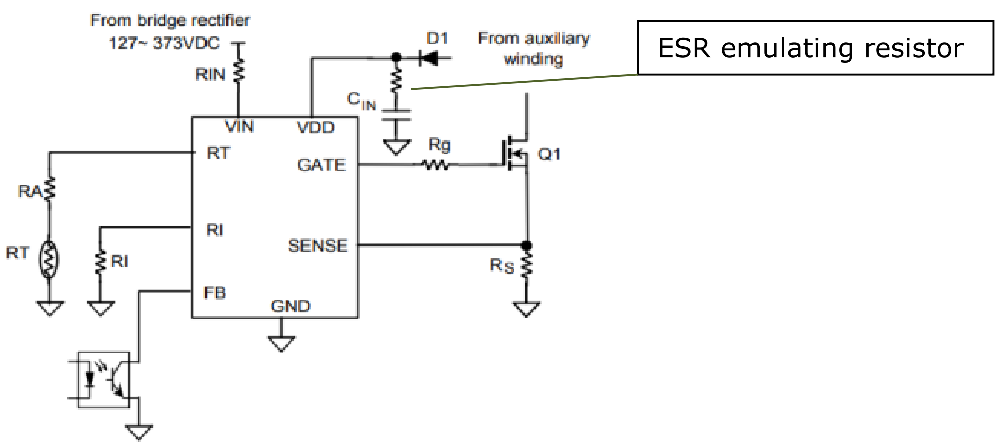
- The reason of the fault is the degradation of the C8 electrolyti capacitor of 10uF 35V. The capacitor C8 found dead is a general-purpose grade electrolytic capacitor 10uF 35V

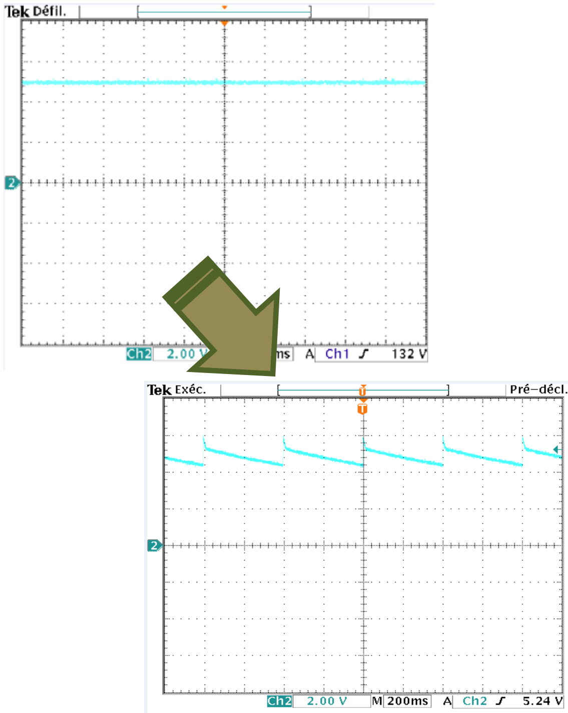


- Two brands has been identified for C8: Pce-TUM & YellowStone, with max T°C of 85°C for *Yellowstone*, and 105°C for *Pce-TUM*..
- This capacitor is used to power the PWM, its operating current not highly depending on the DCDC output current (quick eval).

Failure Mode-3 analyse: root cause

- **A deeper analyse and test shows that the degradation of the capacitor is related to its increasing E.S.R, and not directly to its capacitance value.**
  - Converter works fine with a brand new 4.7 µF (ESR of 5.5 Ω @ 120 Hz).
  - Converter malfunctions with C8 showing a E.S.R higher than 250 Ω.





Failure Mode-3 analyse: root cause

- Results obtained on five **faulty** DC-DC units.

Traco SN	CIBx ID	Type	Traco Fail. Mode	C8 Manuf	C8 Value [uF] @ 120Hz *(New: < 10)*	C8 ESR [Ω] @120Hz *(New: < 10)*	C8 ESR [Ω] @100kHz *(New: < 5)*
06433368	ID000769	CIBF	3	Pce-TUM	4.81	368	241
07140429	ID000714	CIBF	3	YellowStone	1.75	4 180	2 190
06332692	ID000647	CIBF	3	Pce-TUM	6	260	156
04178030	?	?	3	Pce-TUM	2.2	3 220	1 411
07222482	?	?	3	YellowStone	4.9	595	382

10 uF   10 Ω   5 Ω

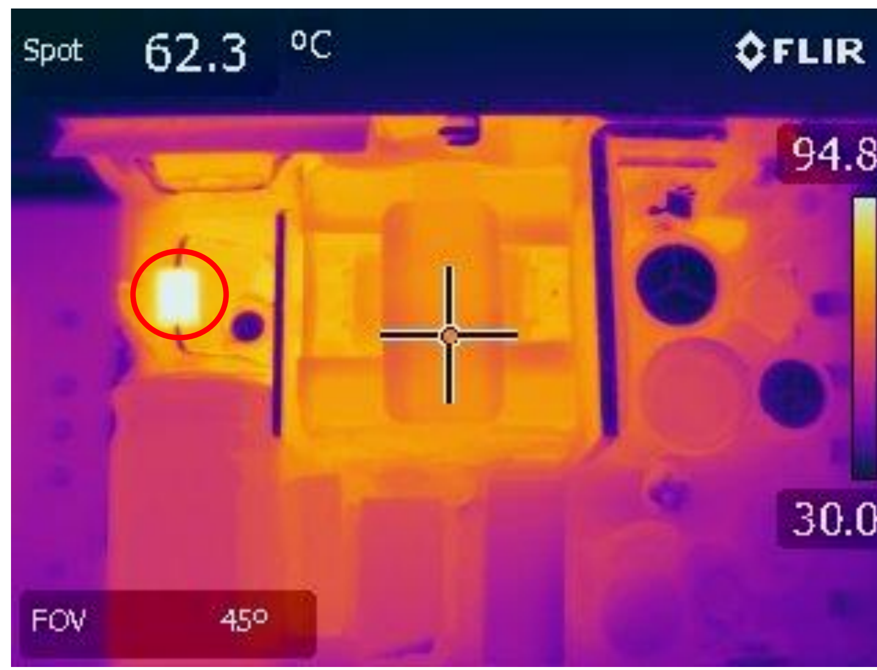
CIBD: Failure Mode-3: Regulation – 8/12

Traco level

Failure Mode-3: Regulation

IR Thermal inspection

- C8 (old PCB version) is very close to a Transient Voltage Suppressor (D2), which becomes hotter with output current, heating C8.



CIBD: Failure Mode-3: Regulation – 9/12

Traco level

Failure Mode-3: Regulation

IR Thermal inspection

- Temperature of capacitor is affected by TVS.
- It is assumed the current ripple in C8 is not depending on the output current, and not *self* participating to C8 temperature elevation.

Output current [A]	Hall Ambient [°C]	CIBx Internal Ambient [°C]	CIBx Isolation Diode D1 [°C]	TRACO C8 Capacitor [°C]	TRACO D2 TVS Diode [°C]	TRACO Power MosFet H1 [°C]	TRACO Sec. Diodes D7 [°C]
0.4	25.7	28.7	32.2	39.4	42.8	34.6	35.4
0.9	25.8	30.9	38.7	49.3	57.1	41.9	42.9
2.4	25.9	35.6	54.2	70.2	94.2	57.2	60.3

(at 1.2 A, C8 temperature is deduced to be around 53 °C)

CIBD: Failure Mode-3: Regulation – 10/12

Failure Mode-3: Regulation

Traco level

Extrapolation on Traco DC-DC lifetime for CIBUD/S units

- **For units mounted on CIBUD/S units, 670 units are considered, and accumulating, at 2018-June:**
  -]80 000; 82 000] hours for 260 units
  -]78 000; 80 000] hours for 220 units
  - <78 000 hours for 190 units (many less than 73 000 hours).
  - *All in one , the population of 480 units, having collecting around 80 000 hours of operating time has to be studied in detail, since the one which will suffer first from this aging failure mode.*

CIBD: Failure Mode-3: Regulation – 11/12

- ***It is very hazardous to deduce the lifetime on CIBUD/S units, with reference to CIBF events & its population, indeed:***
- **What we know**
  - It is almost certain the 480 *old (from the 670)* units will "soon" suffered from the discovered failure mode (erratic regulation).
  - We know that up to now, NO fail.-mode-3 happened on the 480 units.
- **What we can feel *- not able to clearly quantify it -***
  - Temperature plays a role for sure, but in which manner & impact?
  - If temperature obviously impacts the *eta* parameter, is *beta* one the same, on lower level of stress?! *It sounds it should be only lower…*
- **What we don't know *- and we have to live with -***
  - A doubt exists on which PCB version all the installed units use.
  - Level of operating current is not well known (sharing or not) on any operating units. (It could be 1.2 A on some, and up to 2.4 A on others).

CIBD: Failure Mode-3: Regulation – 12/12

Traco level

Failure Mode-3: Regulation

- **Assumptions**
  - Even if operating conditions are not the same, the **8.6 beta** value is considered as a **worst case**, and is kept even with lower stress level.
- **Calculation**
  - It is possible (*Weibayes*) to calculate the **eta value is 164 000 hours** for the CIBUD/S *limit* Weibull distribution, @ 90% confidence.
- **Result & conclusion:**
  - Such a distribution applied to 480 units only (oldest) result in:
    - First failure of mode 3 could appear around 80 000 hours (it could then normally happen in 2018). Also, five failures could be expected before 100 000 hours of operation, 100 000 hours mean is around Mid 2021.
    - This level of failures, (this is a **worst case**) can be expected

LS3

Year	2018	2019	2020	2021	2022	2023	2024
Failures / year	≈ 1	≈ 2	≈ 3	≈ 5	≈ 8	≈ 13	≈ 20
Cumulative	≈ 1	≈ 2	≈ 5	≈ 9	≈ 18	≈ 30	≈ 50

Annex 3

Conclusions

Conclusions

Failure mode analyse

- **Failure mode 3 is quite severe, with a very high beta value, but still to be moderated by the high value of eta.**
  - Situation is quite clear on CIBF units, with actions already taken (replacement of all units, justified by the analyse *at posteriori*).
  - Important unknown parameters (PCB version, level of sharing, brand capacitor: 85-105 °C) gives some doubt on the result of the analyse.
  - Still, on CIBUD/S oldest units (480/670), calculations with some assumptions seems to indicate a worst case scenario would lead to around 30 units dying from now up to LS3.
  - A predictive maintenance, with no action on the 670 units on CIBUD/S up to LS3, could be compatible with results of the analyse.
- **Others failure mode are quite “natural” and non alarming. They are deeply correlated with level of output current or/and operating temperature.**

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```
library(WeibullR); data1 <-
wblr(data.frame(time=c(11184,12168,21672,25848,35712,43752,46584,48552,49128,49128,50088,67848,71448,73632,75624,1296,9696,24624,29616,43128,43248,52704,53304,53304,53304,53304,5330
4,53304,55824,56616,56616,56760,56760,56760,56760,58248,60456,61176,61176,61392,61392,61392,61392,61392,61728,61728,61728,62472,62472,62472,62472,62472,62472,62472,62472,62472,6247
2,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62520,62520,62520,63144,63336,67752,67752,67752,67752,69360,74232,74232,74232,74232,74232,74232,74232,7423
2,74232,74952,74952,74952,74952,74952,74952,74976,74976,75000,75000,75000,75312,75312,75312,75312,75312,75312,75312,75312,77448,77448,77448,77448,77448,77448,77448,7744
8,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,83784),event=c(1,
1,1,1,1,1,1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)),col="darkred",pch=2,lwd=2,label="CIBF-Only - Fail.Mode.1 (fuse)");
data1 <- wblr.conf(wblr.fit(data1,col="red",lty=1,lwd=2,method.fit="mle"),lty=2,lwd=2,col="red",method.conf="lrb");
plot.wblr(list(data1),legend.text.size=0.8,legend.position="topleft",main="CIBF-Only\nFailure Mode-1 (Fuse)",sub="[hours]")
```

```
library(WeibullR); data2 <-
wblr(data.frame(time=c(2520,2520,5472,5760,6576,6576,12528,21072,30192,34512,34800,39576,48576,49656,50712,50712,50760,50832,55848,57288,57696,73920,79464,81312,4344,7248,9744,16824
,21480,22248,28752,28752,28752,28752,28776,28776,28776,28776,28776,28776,28776,28800,28800,28800,28800,28800,28824,28824,28824,28824,28824,28824,28824,28824
,28824,28824,28824,28824,28824,28824,28824,28824,28896,28896,28896,28896,28896,28920,28920,28920,28920,28944,28944,28944,28944,29280,30432,30456,30456,38160,38160,43464,44160
,46800,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600
,48600,50040,50040,50040,50040,50040,50040,50040,50040,50040,50040,50040,50040,50040,50040,50040,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096
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,53304,58032,61392,61392,61392,61392,62472,62520,63336,63336,63336,63336,63336,63336,63336,65184,65184,65184,65568,67944,69360,72552,72552,72552,73560,73800,76080,76080,76584
,76584,76584,76584,77112,77760,77832,77832,77832,77832,78960,78984,78984,78984,78984,78984,78984,78984,62952,78984,78984,78984,78984,78984,78984,78984,79008,79008,79008,79008,79008
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,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,80016,80016,80016,80016,80016,80016,80016,80016,80016
,80016,80016,80016,80016,80016,80016,80016,80016,80016,80016,80016,80016,80016,80016,80016,80016,80016,80832,80832,80856,80856,81048,81048,81048,81048,81048,81048,81048,81048,81048
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,81312,81312,81312,81312,81312,81312,81336,81336,81336,81336,81336,81336,81696,81696,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888
,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81960,81960,81960,81960,81960,81960,81960,81960
,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,83640,90288),event=c(1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)),,col="darkorange
",pch=2,lwd=2,label="CIBU(D/S)-Only - Fail.Mode.1 (fuse)");
data2 <- wblr.conf(wblr.fit(data2,col="orange",lty=1,lwd=2,method.fit="mle"),lty=2,lwd=2,col="orange",method.conf="lrb");
plot.wblr(list(data2),legend.text.size=0.8,legend.position="topleft",main="CIBU(D/S)-Only\nFailure Mode-1 (Fuse)",sub="[hours]")
```

Graph 1+2

Annex


```
library(WeibullR); data1 <-
wblr(data.frame(time=c(11184,12168,21672,25848,35712,43752,46584,48552,49128,49128,50088,67848,71448,73632,75624,1296,9696,24624,29616,43128,43248,52704,53304,53304,53304,53304,53304,53304,5582
4,56616,56616,56760,56760,56760,56760,58248,60456,61176,61176,61392,61392,61392,61392,61392,61728,61728,61728,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,
62472,62472,62472,62472,62472,62472,62472,62472,62520,62520,62520,63144,63336,67752,67752,67752,67752,69360,74232,74232,74232,74232,74232,74232,74232,74232,74232,74952,74952,74952,74952,74952,7
4952,74952,74976,74976,75000,75000,75000,75312,75312,75312,75312,75312,75312,75312,75312,75312,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77
448,77448,77448,77448,77448,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,83784),event=c(1,1,1,1,1,1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)),col="darkred",pch=2,lw
d=2,label="CIBF-Only - Fail.Mode.1 (fuse)");
data1 <- wblr.fit(data1,col="red",lty=1,lwd=2,method.fit="mle");
plot.wblr(list(data1),legend.text.size=0.8,legend.position="topleft",main="CIBF-Only\nFailure Mode-1 (Fuse)",sub="[hours]")
```

```
library(WeibullR); data2 <-
wblr(data.frame(time=c(2520,2520,5472,5760,6576,6576,12528,21072,30192,34512,34800,39576,48576,49656,50712,50712,50760,50832,55848,57288,57696,73920,79464,81312,4344,7248,9744,16824,21480,22248,
28752,28752,28752,28752,28776,28776,28776,28776,28776,28776,28776,28776,28776,28800,28800,28800,28800,28800,28824,28824,28824,28824,28824,28824,28824,28824,28824,28824,28824,28824,28824,2
8824,28824,28824,28824,28896,28896,28896,28896,28896,28896,28920,28920,28920,28920,28944,28944,28944,28944,29280,30432,30456,30456,38160,38160,43464,44160,46800,48600,48600,48600,48600,48600,48
600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,50040,50040,50040,50040,50040,50040,50040,500
40,50040,50040,50040,50040,50040,50040,50040,50040,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,5109
6,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51240,53304,53304,53304,53304,53304,53304,53304,53304,58032,61392,61392,61392,61392,62472,62520,63336,63336,63336,63336,63336,
63336,63336,63336,65184,65184,65184,65568,67944,69360,72552,72552,72552,73560,73800,76080,76080,76584,76584,76584,76584,77112,77760,77832,77832,77832,77832,78960,78984,78984,78984,78984,78984,7
8984,78984,62952,78984,78984,78984,78984,78984,78984,78984,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79
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04,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,7910
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776,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,80016,80016,80016,80016,80016,80016,80016,80016,80016,800
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81888,81888,81888,81888,81888,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,83640,90288),event=c(1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1
,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)),,col="darkorange",pch=2,lwd=2,label="CIBU(
D/S)-Only - Fail.Mode.1 (fuse)");
data2 <- wblr.fit(data2,col="orange",lty=1,lwd=2,method.fit="mle");
plot.wblr(list(data2),legend.text.size=0.8,legend.position="topleft",main="CIBU(D/S)-Only\nFailure Mode-1 (Fuse)",sub="[hours]")
```

```
plot.wblr(list(data1,data2),legend.text.size=0.6,main="CIBU(D/S) + CIBF\nFailure Mode-1 (Fuse)",sub="[hours] ")
```

Graph 3

Annex

```
library(WeibullR); data2 <-
wblr(data.frame(time=c(1296,9696,43128,43248,58248,61176,69360,11184,12168,21672,25848,35712,43752,46584,48552,49128,49128,50088,67848,71448,73632,75624,24624,29616,52704,53304,53304,53304,53304,53304,53304,5
5824,56616,56616,56760,60456,56760,61176,56760,56760,61392,61392,61392,61392,61392,61728,61728,61728,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,6247
2,62472,62472,62472,62472,62520,62520,62520,63144,67752,63336,67752,67752,67752,74232,74232,74232,74232,74232,74232,74232,74232,74952,74952,74952,74952,74952,74952,74976,74976,75000,75000,75000,7
5312,75312,75312,75312,75312,75312,75312,75312,75312,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77496,77496,77496,77496,7749
6,77496,77496,77496,77496,77496,77496,77496,77496,77496,83784),event=c(1,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)),col="darkred",pch=2,lwd=2,label="CIBF-Only Failure Mode-2 (DC-DC HS)");
data2 <- wblr.fit(data2,col="red",lty=1,lwd=2,method.fit="mle");
plot.wblr(list(data2),legend.text.size=0.8,legend.position="topleft",main="CIBF-Only\nFailure Mode-2 (DC-DC HS)",sub="[hours]")
```

```
library(WeibullR); data3 <-
wblr(data.frame(time=c(16824,43464,58032,7248,9744,61392,61392,61392,61392,62520,63336,63336,63336,63336,63336,63336,63336,63336,67944,69360,78984,78984,78984,79008,79008,79008,79008,79008,79008,79008,7
9008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,34800,48576,81048,81048,81048,81048,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,8188
8,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81888,81960,81960,90288),event=c(1,1,1,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)),col="darkorange",pch=1,lwd=2,label="CIBUD-Only Failure Mode-2 (DC-DC HS)");
data3 <- wblr.fit(data3,col="orange",lty=1,lwd=2,method.fit="mle");
plot.wblr(list(data3),legend.text.size=0.8,legend.position="topleft",main="CIBUD-Only\nFailure Mode-2 (DC-DC HS)",sub="[hours]")
```

```
library(WeibullR); data4 <-
wblr(data.frame(time=c(4344,22248,21480,28752,28752,28752,28752,28776,28776,28776,28776,28776,28776,28776,28776,28800,28800,28800,28800,28800,28800,28824,28824,28824,28824,28824,28824,28824,28824,28824,
28824,28824,28824,28824,28824,28824,28824,28824,28896,28896,28896,28896,28896,28920,28920,28920,28920,28944,28944,28944,28944,29280,30432,30456,30456,38160,38160,44160,46800,48600,48600,48600,48600,486
00,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,48600,50040,50040,50040,50040,50040,50040,50040,50040,50040,
50040,50040,50040,50040,50040,50040,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,51096,510
96,51096,51096,51096,51096,51096,51096,51240,53304,53304,53304,53304,53304,53304,53304,62472,65184,65184,65184,65568,72552,72552,72552,73560,73800,76080,76080,76584,76584,76584,76584,77112,77760,
77832,77832,77832,77832,78960,78984,78984,78984,78984,62952,78984,78984,78984,78984,78984,78984,78984,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,79008,790
08,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,
79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79104,79272,79272,79272,79272,79272,79272,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,797
04,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79704,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,
79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,79776,797
76,79776,79776,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,79824,80016,80016,80016,80016,80016,80016,80016,80016,80016,80016,
80016,80016,80016,2520,2520,5472,5760,80016,6576,80016,80016,80016,80016,80016,80016,80016,80016,80016,80016,80016,80832,80832,80856,80856,81048,81048,81048,81048,81048,81048,81048,81048,81048,81
048,81048,81048,81048,81048,81048,81048,81048,81048,81048,81048,81048,81048,81168,81168,81168,81168,81168,81192,81192,81192,81192,81192,81192,81192,81192,81192,81192,81192,81192,81192,81192,6576,
12528,21072,30192,34512,39576,49656,50712,50712,81192,81192,81192,81192,81192,81192,81192,81192,81192,50760,50832,55848,81192,81192,81192,81192,81192,81192,81192,81192,81192,81192,81192,81192,81192,811
92,81192,81192,81216,81216,81216,57288,81216,81216,81216,81216,57696,73920,81216,81216,81216,81216,81216,81216,81216,81216,81264,81288,81288,81288,81288,81288,81288,81288,81288,81288,81288,81288,
81288,81288,81288,81288,81288,81288,81288,81288,81288,81288,81288,81288,81288,81288,81288,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,813
12,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81312,81336,81336,81336,81336,81336,81696,
81696,79464,81312,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,81960,83640),event=c(1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)),col="darkgreen",pch=3,lwd=2,label="CIBUS-Only Failure Mode-2 (DC-DC HS)");
data4 <- wblr.fit(data4,col="green",lty=1,lwd=2,method.fit="mle");
plot.wblr(list(data4),legend.text.size=0.8,legend.position="topleft",main="CIBUS-Only\nFailure Mode-2 (DC-DC HS)",sub="[hours]");
```

```
plot.wblr(list(data4,data3,data2),legend.text.size=0.6,legend.position="topleft", legend.inset=c(0,.37),main="CIBU(D/S/F)\nFailure Mode-2 (Fuse)",sub="[hours]");
```

Graph 5

Annex

```
library(WeibullR); data2 <-
wblr(data.frame(time=c(52704,60456,61176,67752,74232,75000,77448,1296,9696,11184,12168,21672,24624,25848,29616,35712,43128,43248,43752,46584,48552,49128,49128,50088,53304,53304,53304,53304,5330
4,53304,55824,56616,56616,56760,56760,56760,56760,58248,61176,61392,61392,61392,61392,61392,61728,61728,61728,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,62472,
62472,62472,62472,62472,62472,62472,62472,62472,62520,62520,62520,63144,63336,67752,67752,67752,67848,69360,71448,73632,74232,74232,74232,74232,74232,74232,74232,74232,74952,74952,74952,74952,7
4952,74952,74952,74976,74976,75000,75000,75312,75312,75312,75312,75312,75312,75312,75312,75312,75624,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77448,77
448,77448,77448,77448,77448,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,77496,83784),event=c(1,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)),col="darkblue",pch=2,l
wd=2,label="CIBF-Only Failure Mode-3 (Regulation)");
data2 <- wblr.conf(wblr.fit(data2,col="blue",lty=1,lwd=2,method.fit="mle"),lty=2,lwd=2,col="blue",method.conf="lrb");
plot.wblr(list(data2),legend.text.size=0.8,main="CIBF-Only\nFailure Mode-3 (Regulation)",sub="[hours]")
```

Calcul of Traco -3 years MTBF.

- **Calculate the number of units operating in the 3 years duration.**
  - 782 units without issues for 3-years Σ.hours = 20 550 960 hours
  - 021 units operating less than 3 years Σ.hours = 251 400 hours
    - 004 units in operation (installed in 2018)
    - 017 units in Fault
      - 005 units in failure-mode-2
- **MTBF = (20 550 960 + 251 400) / 5 = 4.16 Millions of hours**
- **Note:**
  - 3 years = 26 280 hours.

Expected number of failed units vs Traco data

- **MTBF.Traco = 250 000 hours**
- **826 units in operation accumulating 7 235 760 hours in one year**
- **Number of expected failure per year = 7 235 760 / 250 000 = 28**

- **Note:**
  - 3 years = 26 280 hours, 1 year = 8 760 hours

Population & Observations for up to 6 different tests

Total Nb of Units Being tested		[ ]	480	
Test 1	Test 1: Nb Units Being tested (N1)	[ ]	260	*Enter total number of units for this test*
	Test 1: Test Duration on N1 Units (Duration.1)	[hours]	81 000	*Enter total number of hours units were under test* — *or* 3375 days = 108.9 months = 9.1 years
Test 2	Test 1: Nb Units Being tested (N2)		220	*Enter total number of units for this test*
	Test 1: Test Duration on N1 Units (Duration.2)	[hours]	79 000	*Enter total number of hours units were under test* — *or* 3292 days = 106.2 months = 8.8 years
Test 3	Test 1: Nb Units Being tested (N3)			*Enter total number of units for this test*
	Test 1: Test Duration on N1 Units (Duration.3)	[hours]		*Enter total number of hours units were under test* — *or* 0 days = 0 months = 0 years
Test 4	Test 1: Nb Units Being tested (N4)	[ ]		*Enter total number of units for this test*
	Test 1: Test Duration on N1 Units (Duration.4)	[hours]		*Enter total number of hours units were under test* — *or* 0 days = 0 months = 0 years
Test 5	Test 1: Nb Units Being tested (N5)			*Enter total number of units for this test*
	Test 1: Test Duration on N1 Units (Duration.5)	[hours]		*Enter total number of hours units were under test* — *or* 0 days = 0 months = 0 years
Test 6	Test 1: Nb Units Being tested (N6)			*Enter total number of units for this test*
	Test 1: Test Duration on N1 Units (Duration.6)	[hours]		*Enter total number of hours units were under test* — *or* 0 days = 0 months = 0 years
Beta		[ ]	8.6	*Enter known or assumed beta of population distribution failure*
Confidence level			0.9	*Enter confidence level for lower bound (eta and MTBF)*

Deduced Results in case of 0 failure encountered (weibayse analyse)

eta	[hours]	164 274	*or* 6845 days = 220.8 months = 18.4 years
MTBF	[hours]	155 237	*or* 6468 days = 208.7 months = 17.4 years
eta(lower.bound) @ 90 % >	[hours]	149 091	*or* 6212 days = 200.4 months = 16.7 years
MTBF(lower.bound) @ 90 % >	[hours]	140 889	*or* 5870 days = 189.4 months = 15.8 years

Testing 480 units during different tests without any failure observed demonstrates @ 90 %
the reliability of the population is better than:
failure distribution of characteristic life of 149091 hours providing failure distribution beta =8.6

Annex 3