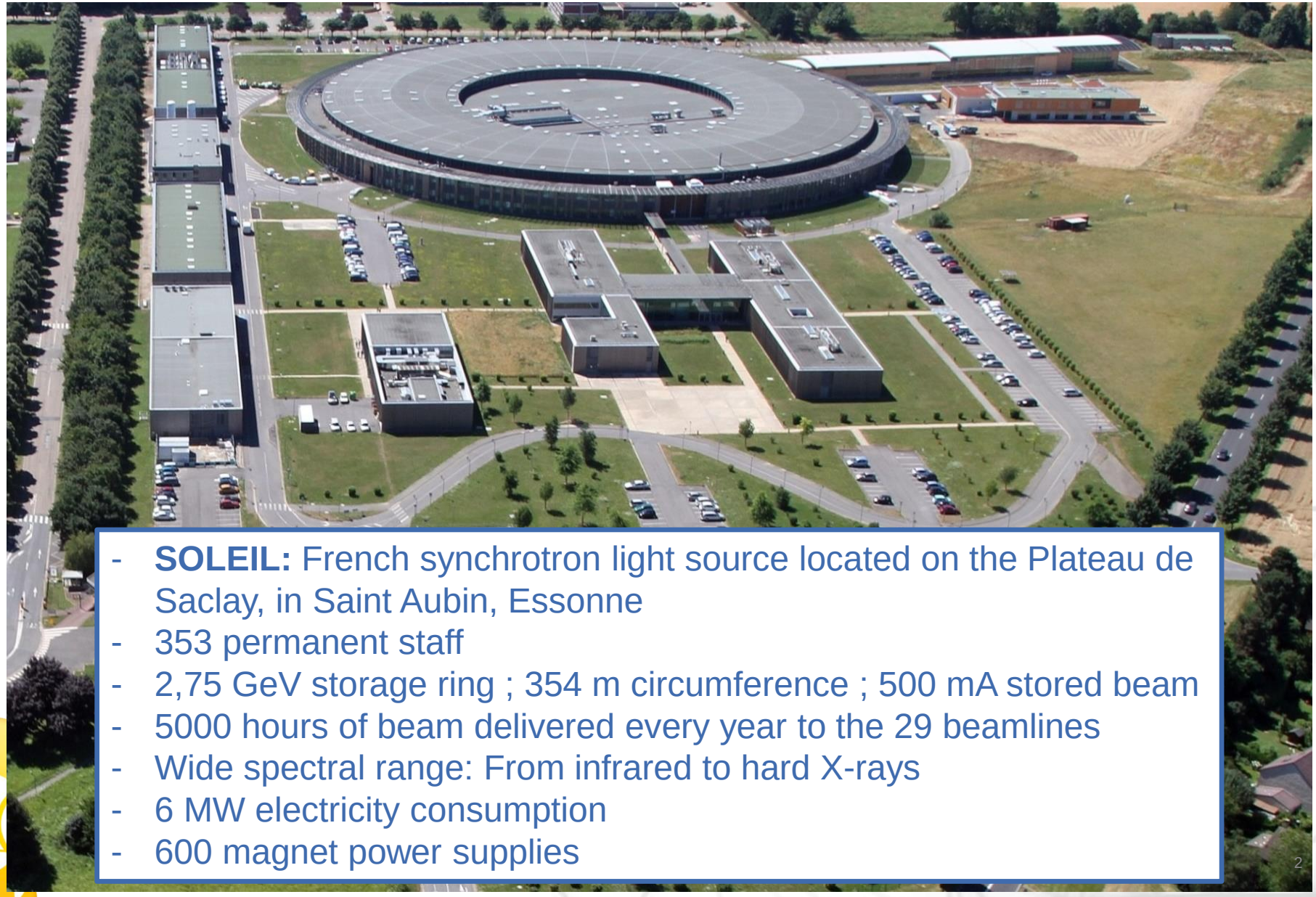
SOLEIL Power Supply Reliability

POCPA Workshop 2023

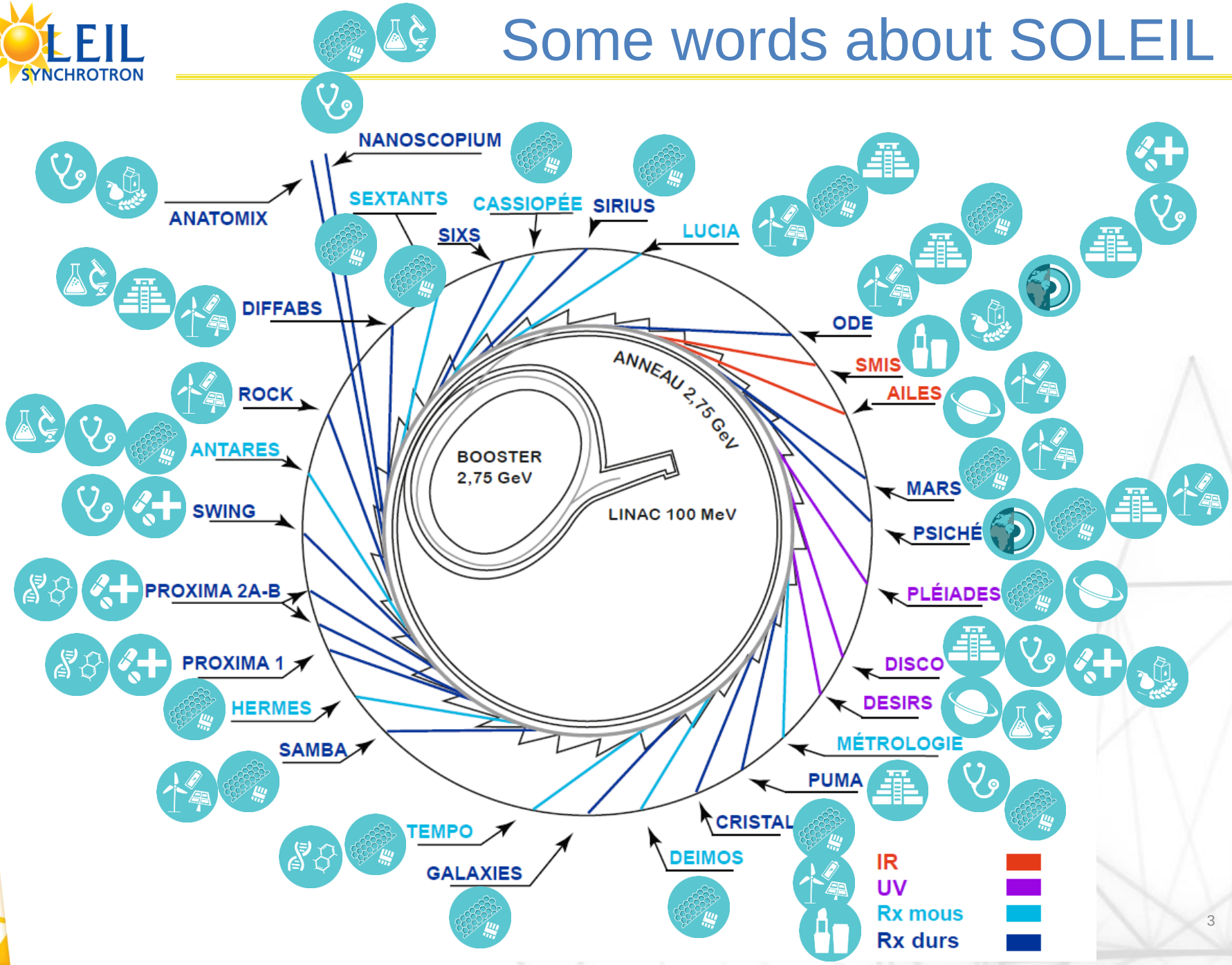
François Bouvet

Some words about SOLEIL

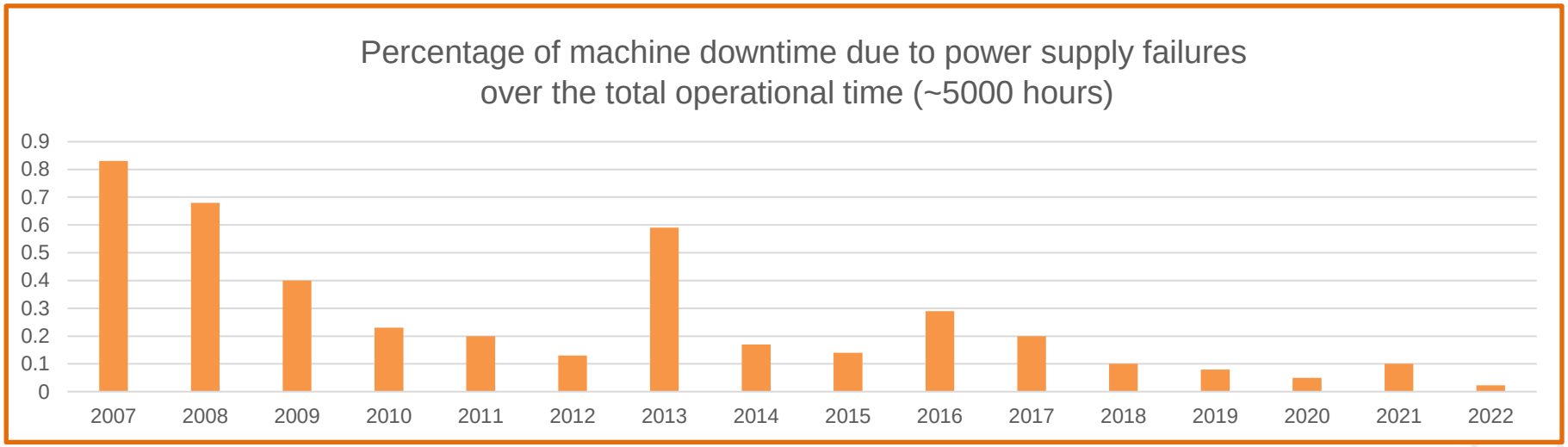


- **SOLEIL:** French synchrotron light source located on the Plateau de Saclay, in Saint Aubin, Essonne
- 353 permanent staff
- 2,75 GeV storage ring ; 354 m circumference ; 500 mA stored beam
- 5000 hours of beam delivered every year to the 29 beamlines
- Wide spectral range: From infrared to hard X-rays
- 6 MW electricity consumption
- 600 magnet power supplies

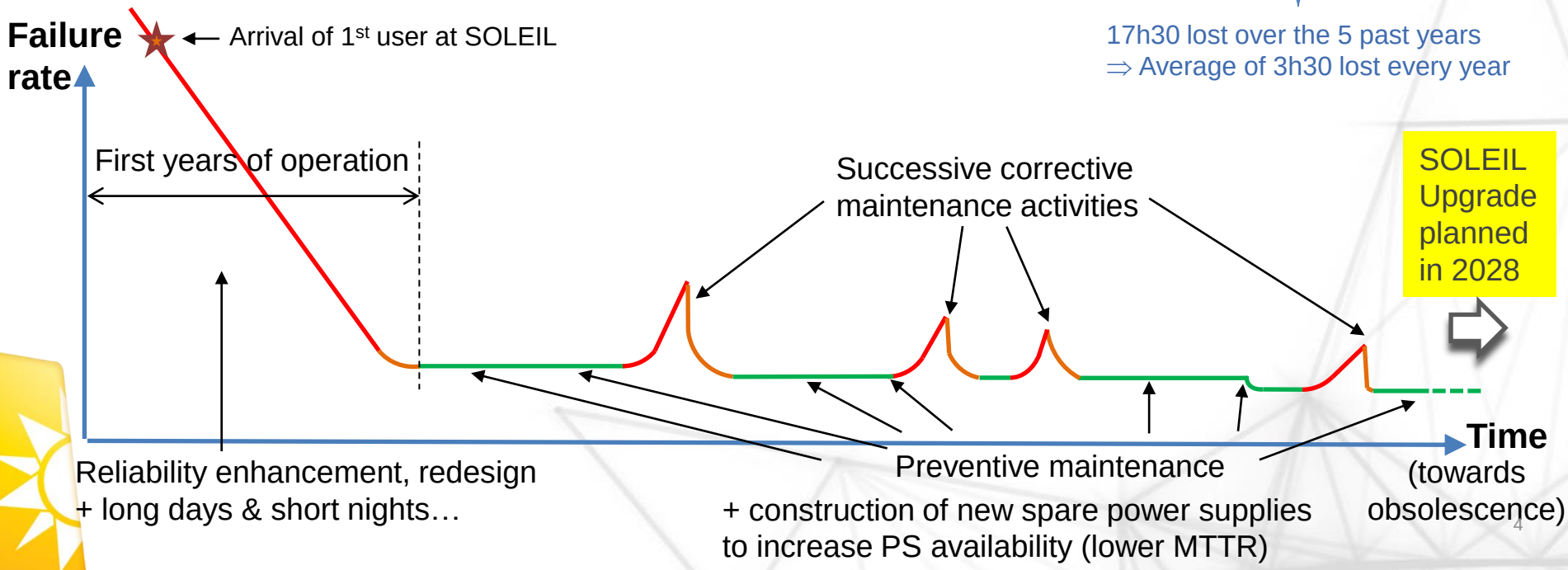
Some words about SOLEIL



Some reliability statistics



17h30 lost over the 5 past years
⇒ Average of 3h30 lost every year

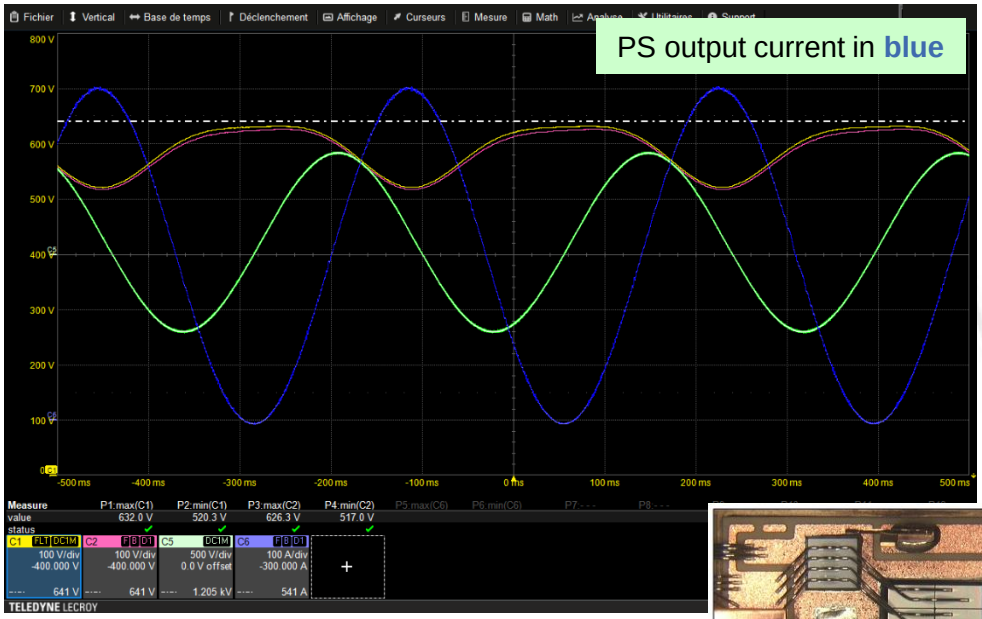


Major reliability issues

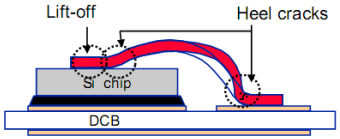
- **3Hz Booster Power supplies:** Many failures between 2007 and 2013

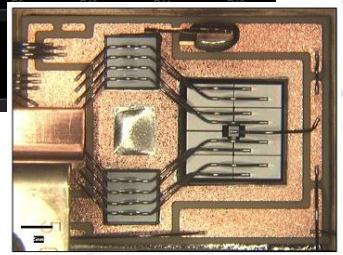
- SOLEIL Booster PS: About 10 Million 3Hz cycles every year
- High thermal stress caused by the 3Hz excursion of the IGBT chip's junction temperature ⇒ **Accelerated ageing of the IGBT modules**

Lifetime < 3 years !

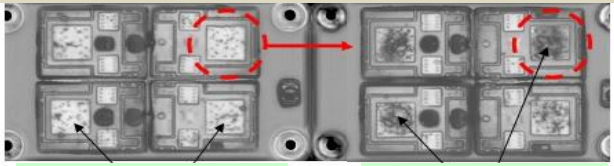


Bonding wire pull test on IGBT chip





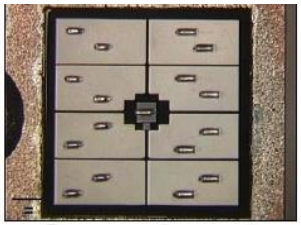
Delamination of chip – substrate layer

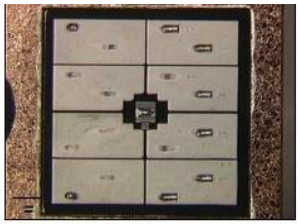


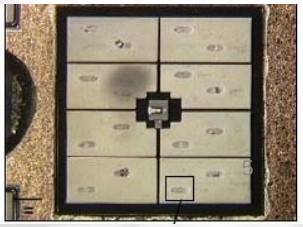
New module — 25 Million cycles

Puces IGBT — Evolution de la brasure

New module	5 Million cycles	25 Million cycles
REF	SN003	SN010
(Wedge arraché : 0/64)	(Wedges arrachés : 43/64)	(Wedges arrachés : 60/64)

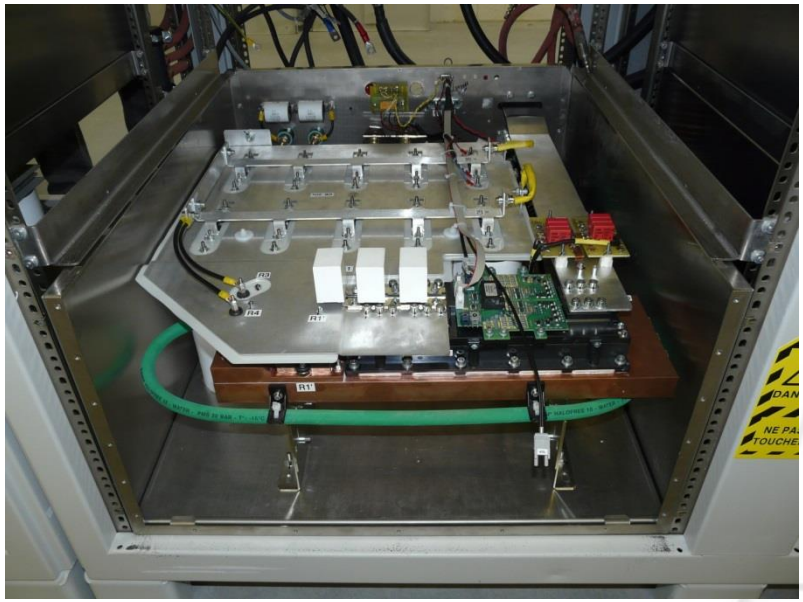




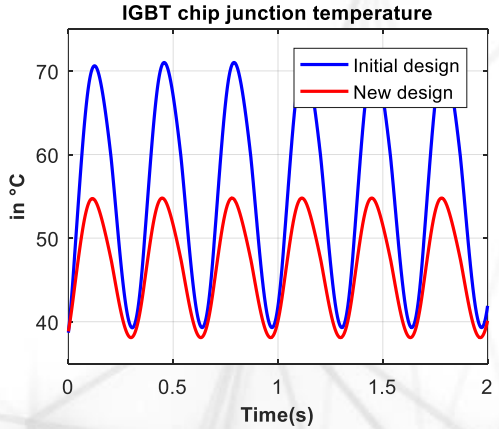


Major reliability issues

- **3Hz Booster Power supplies:** Complete redesign of the power crates in 2013



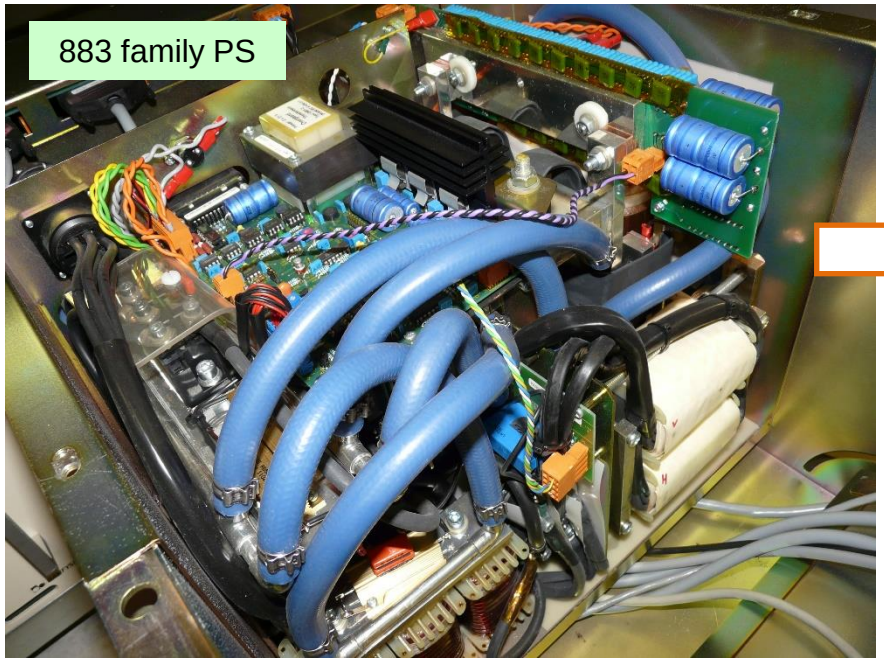
New crates based on 1200V / 2500A IGBT modules with high thermal / power cycling capability
Calculation of IGBT junction temperature excursion: ~17°C
Estimation of the IGBT cycling capability: > 200 Million
No failure since 2014

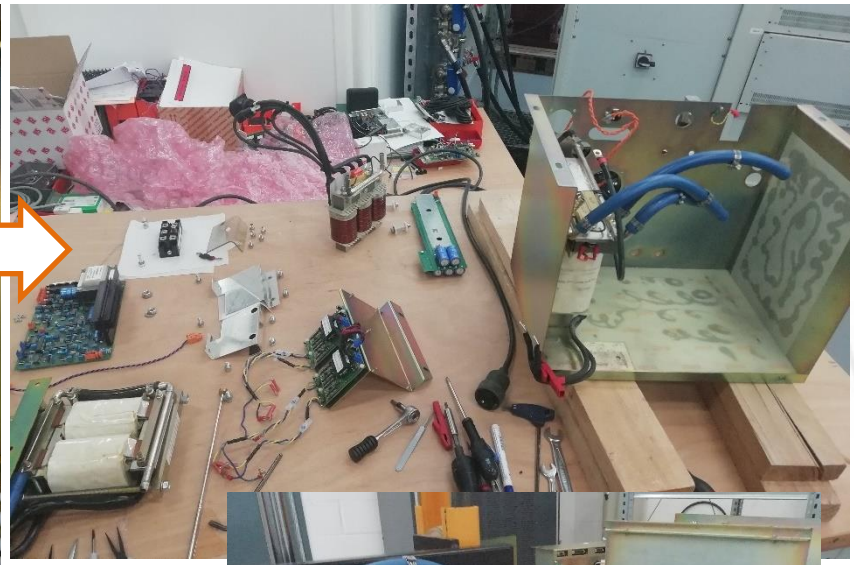


Cycle counters are now implemented on our 3Hz power supplies, to accurately follow the lifetime

Major reliability issues

- **DANFYSIK power supplies: A continuous nightmare…**

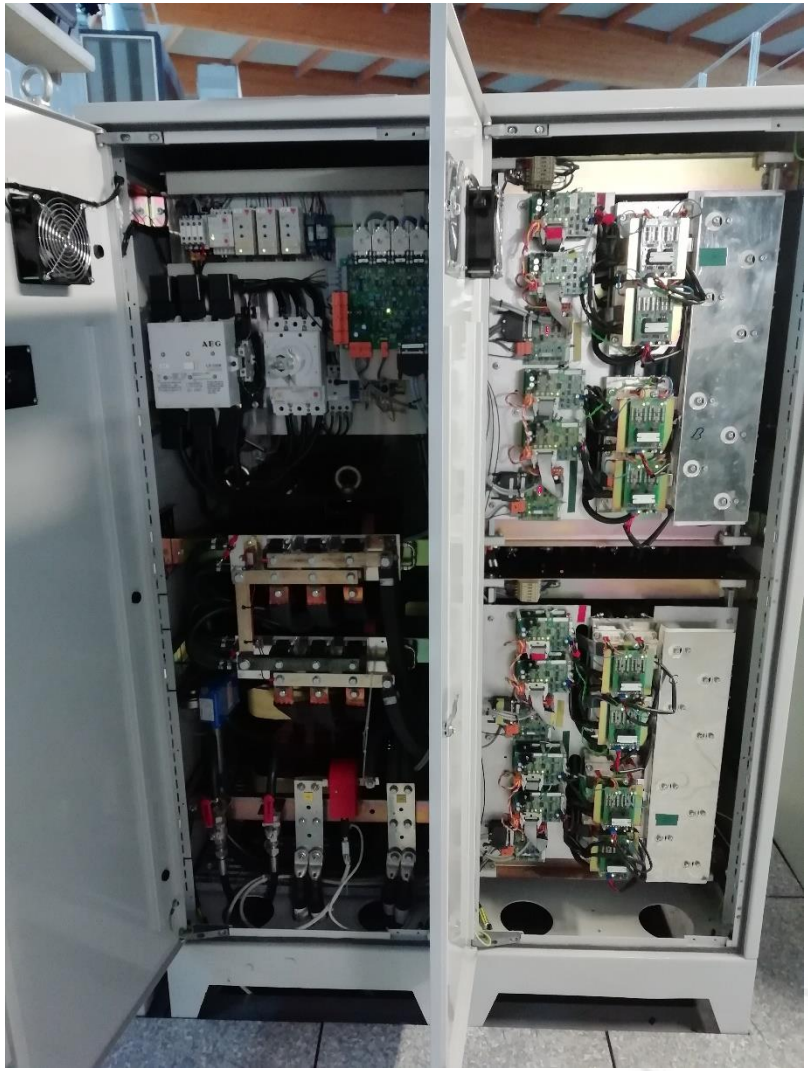




- Too compact
- Too complex
- Poor diagnostics (many interlocks in series ⇒ Identification of faulty element is difficult)
- DANFYSIK support: Ineffective (+ unaffordable)

Major reliability issues

- **DANFYSIK power supplies: Overview since September 2022…**



- **Many failures with the 859 family PS**
- Luckily, we only have 6 of these PS, which power electromagnetic undulators feeding the beamlines
- 9 (!) cards changed since September 2022
- Fortunately, nearly no impact on the beamlines, but many hours of investigation to solve all the problems

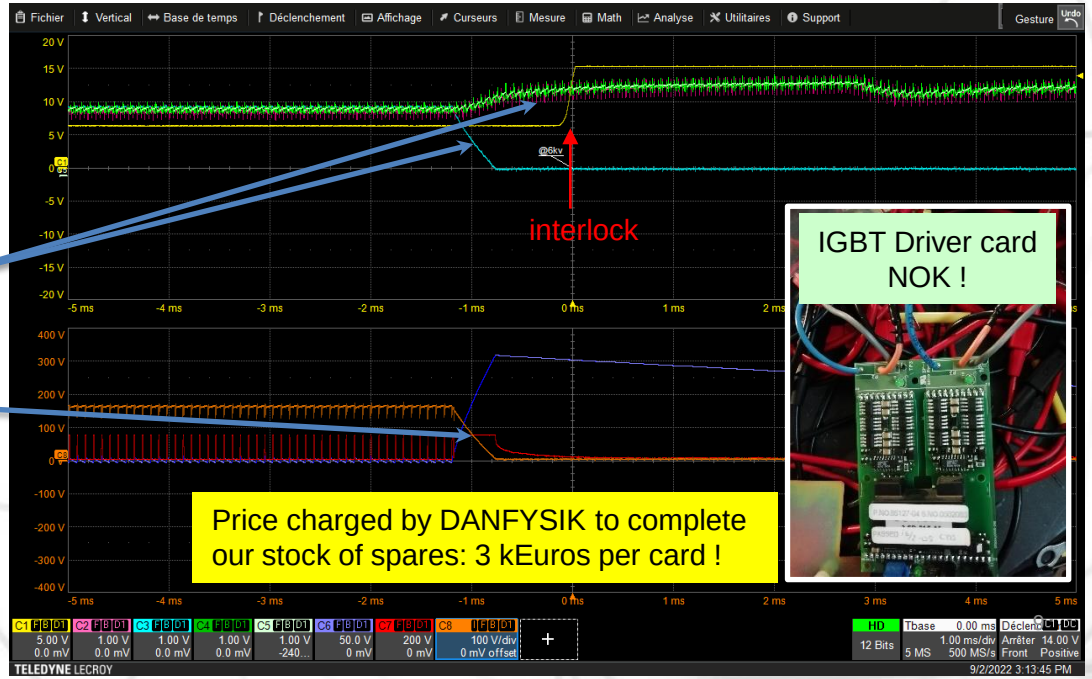
Major reliability issues

- **DANFYSIK power supplies: Some failures examples…**
  - September 2022: **Sporadic "DC Overload" Faults**
  - The "DC Overload" fault is a sum of many interlocks:
    - Overcurrent at the output of one of the 16 (!) IGBT legs
    - Overcurrent at the output of the power supply
    - Malfunction of one the 16 PCMPMW cards
    - Malfunction of one of the 4 PCMINT cards
    - All these interlocks are serialized on the FQDRINT and REGULATION MODULES SMD cards and are finally transmitted to the CONTROL BOARD for processing
  - Where to start when the fault is not permanent ? Here, time and energy are requested…

After many hours…

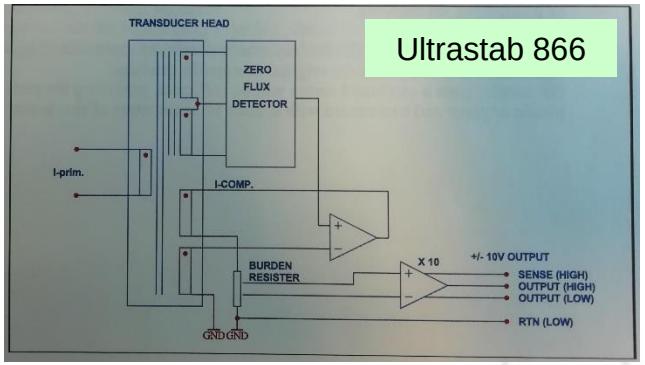
Output current of the IGBT legs

One IGBT is set and maintained OFF shortly before the interlock

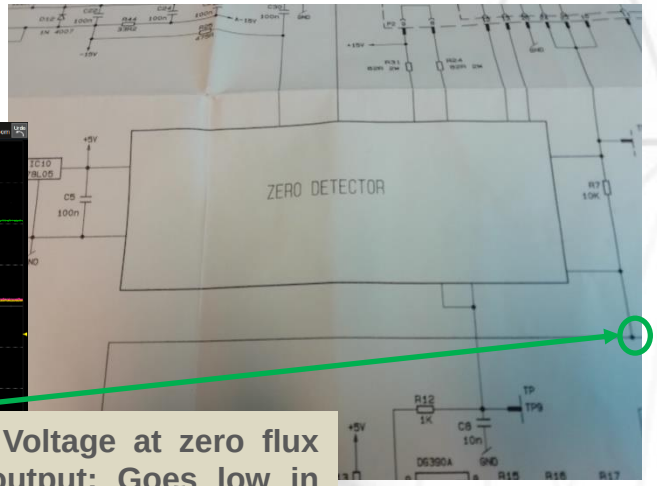


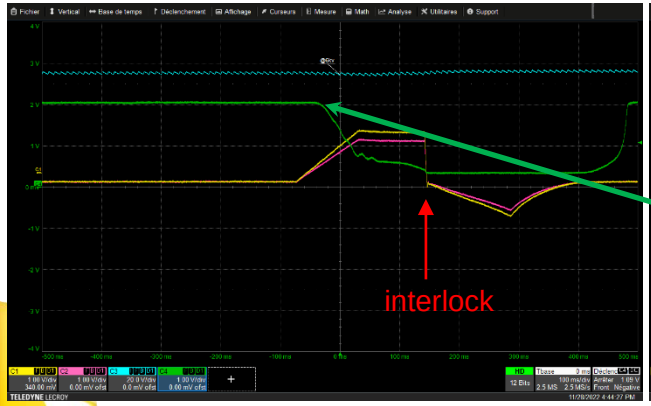
Major reliability issues

- **DANFYSIK power supplies: Some failures examples…**
  - November 2022: **“OCP” Fault** : Indicates a saturation of the DCCT zero detector cores (compensating winding of the DCCT is unable to cancel the ampere turns of the primary current)
  - Phenomena only for negative currents, above a certain level of current
  - Check of DCCT auxiliary power supplies: OK
  - Replacement of DCCT head: No improvement
  - Replacement of DCCT card: ⇨ No improvement



  - No schematic available of the zero detector circuitry ⇨





In green: Voltage at zero flux detector output: Goes low in case of saturation

In yellow + red: Output current/voltage (opposite sign)

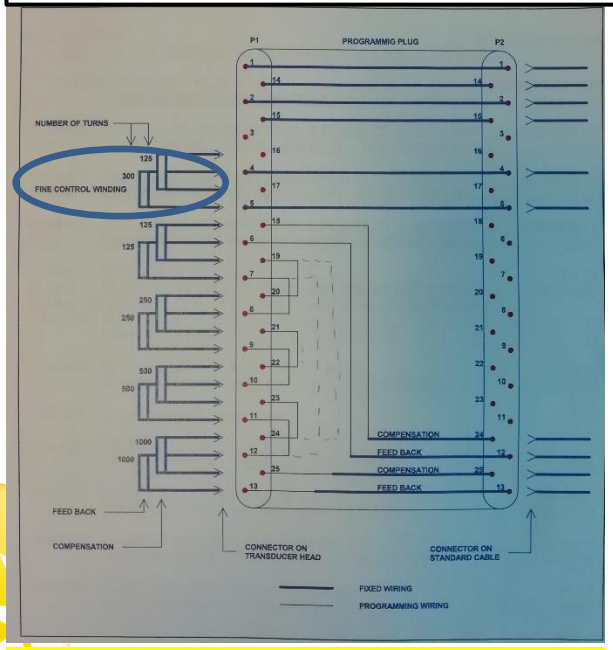
Major reliability issues

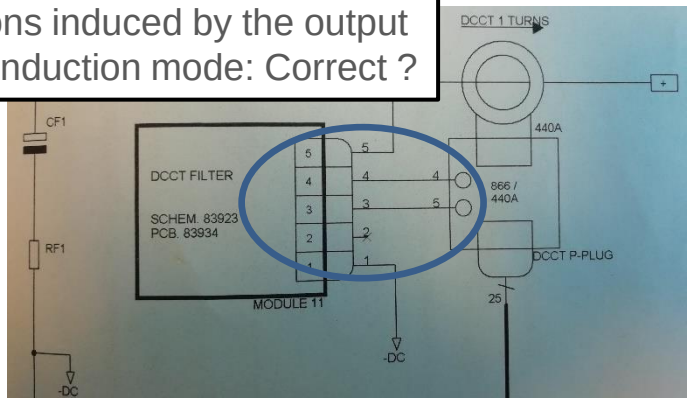
- **DANFYSIK power supplies: Some failures examples…**
  - November 2022: **“OCP” Fault**
  - Decision to replace the DCCT (head + electronic card) with another DCCT reference integrating the electronics (including zero flux detector circuitry)

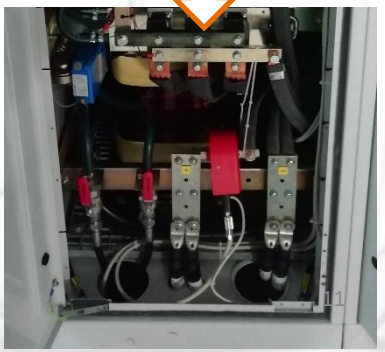
⇒ No improvement ; Worse: Huge output voltage oscillations, but only for low output current

⇒ These power supplies cannot operate without the “Fine control winding” of the DCCT connected to the PS output potentials ⇒ ????

Seems to compensate the oscillations induced by the output stage operation in discontinuous conduction mode: Correct ?





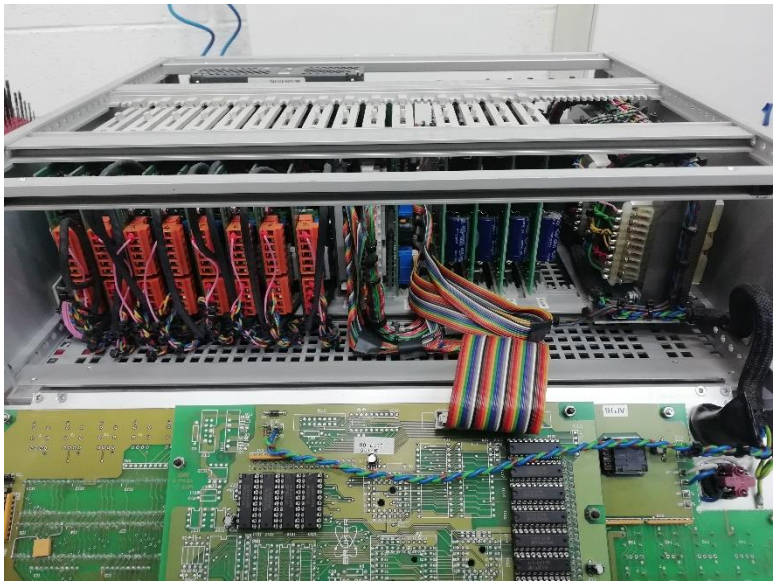


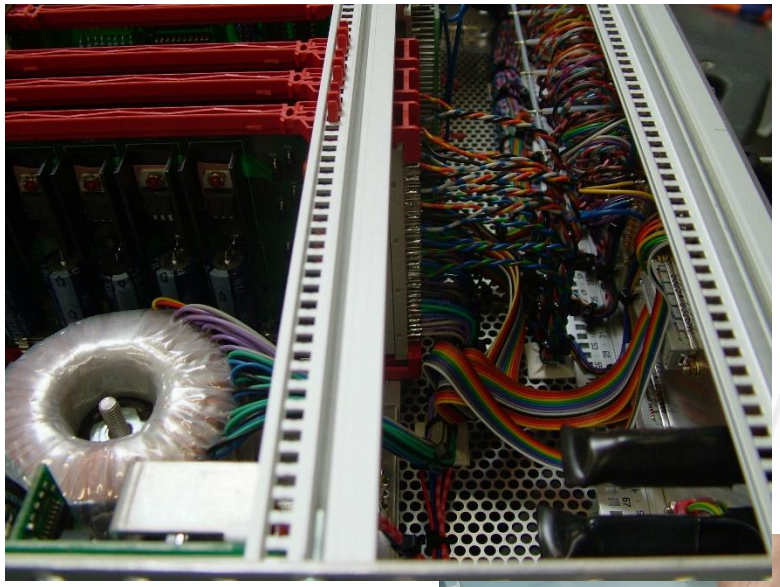
- General observation: DCCT head close to PS output inductors deep inside the rack
- **Problem solved by moving the DCCT head at the bottom of the rack, far from the initial location**
- Current ripple in the output filter inductors is OK: Emergence of this saturation of the DCCT (only for negative currents, after 15 years of operation) remains a mystery… Any ideas ?

Many other problems in 2023…
Situation is now stabilized (until when ?)

Major reliability issues

- **Short focus on wiring/electrical connections**





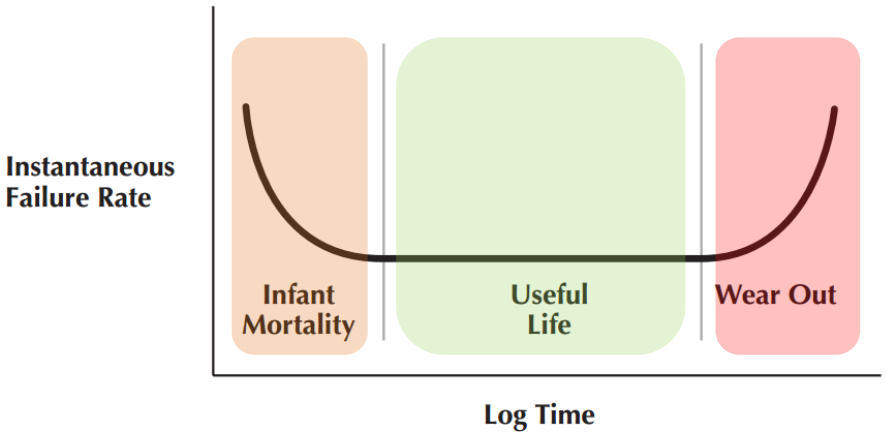
- No backplane cards in some of our power supply crates + lots of cabling/electrical connections
- **After 17 years of operation, reliability issues begin to appear**

⇒ **Such kind of design will be avoided for SOLEIL Upgrade**

PS Reliability: Which strategy for SOLEIL II ?

Chosen strategy to enhance equipment reliability:

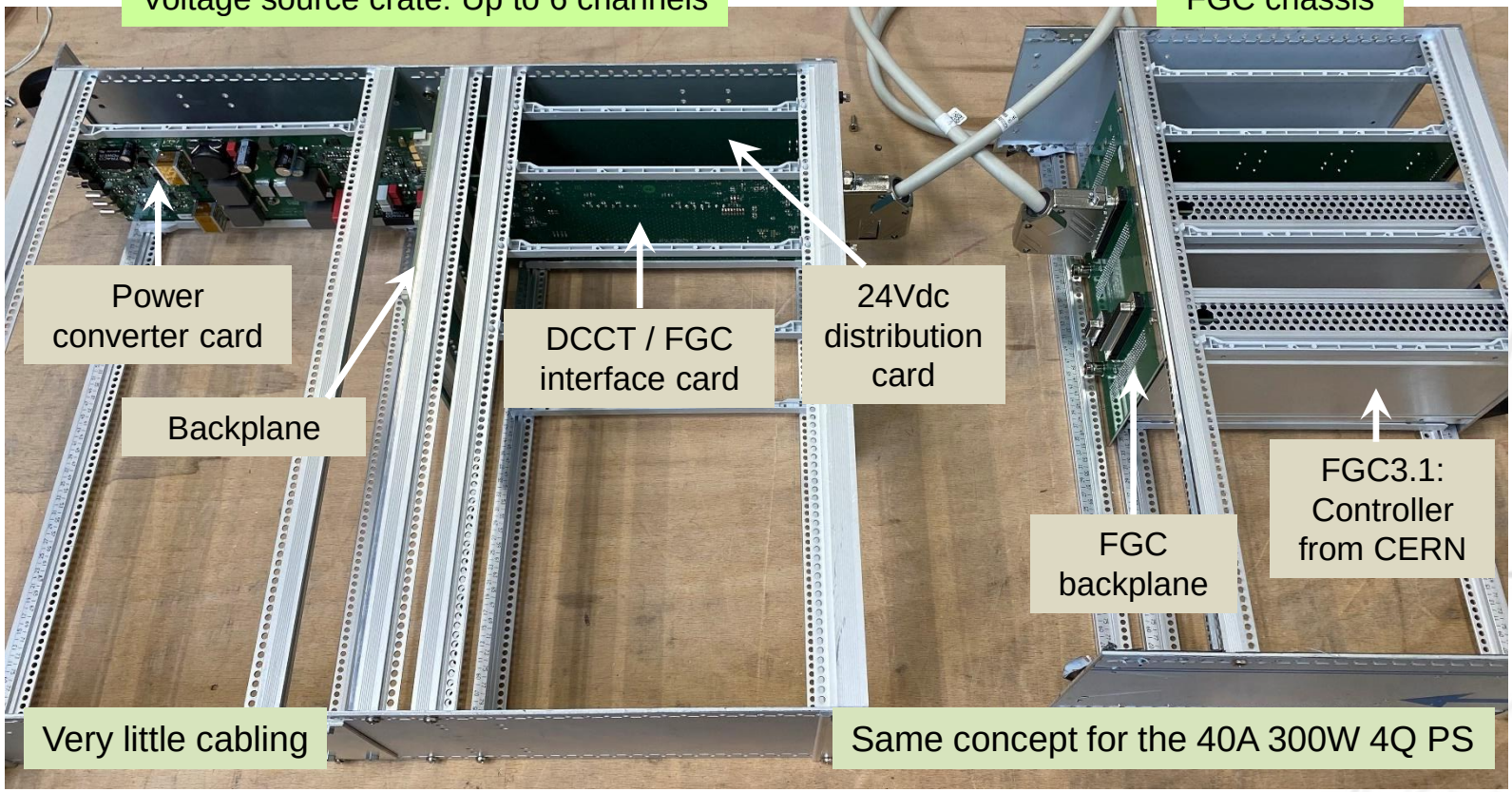
- Careful design
- Predict useful life failure rate ⇒ Software to calculate MTBF: iQT ITEM Software
- Improve overall robustness and lifetime
  - ⇒ HALT (Highly Accelerated Life Tests) on developed prototypes: More on this in the next slides
  - ⇒ Before the dark period in 2028: Tests of power supply prototypes on the existing machine under normal operating conditions to detect any potential anomaly
- High quality production: Pre-selection of suitable suppliers
- Remove infant mortality: Burn-in tests on all equipment prior to installation

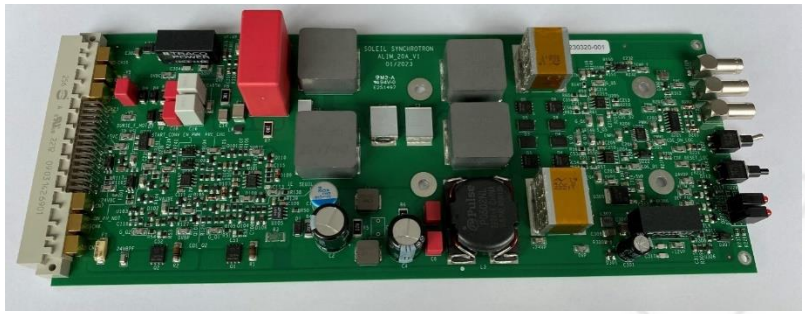


Purchase of climatic chamber

PS Reliability: Which strategy for SOLEIL II ?

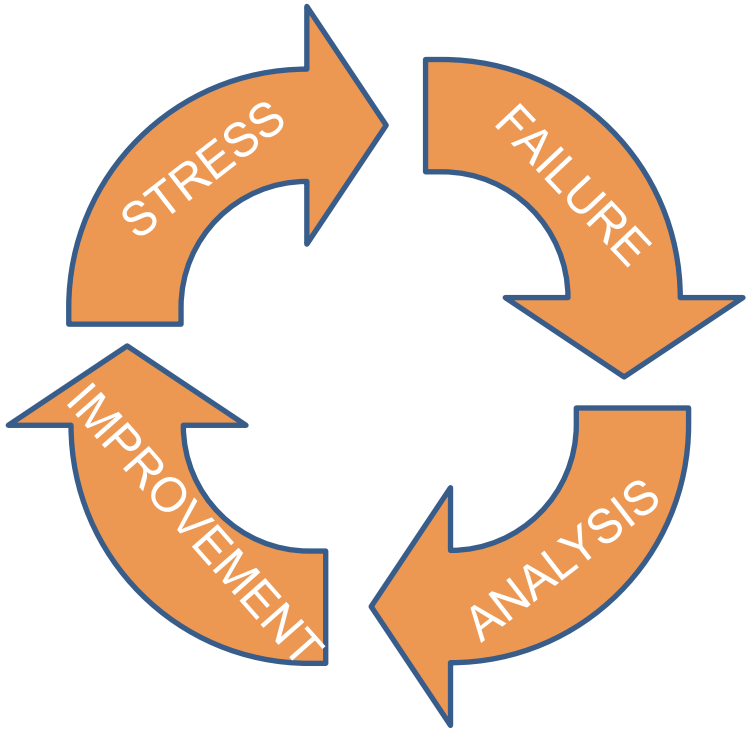
20A 100W 4Q power supply prototype for SOLEIL II:





PS Reliability: Which strategy for SOLEIL II ?

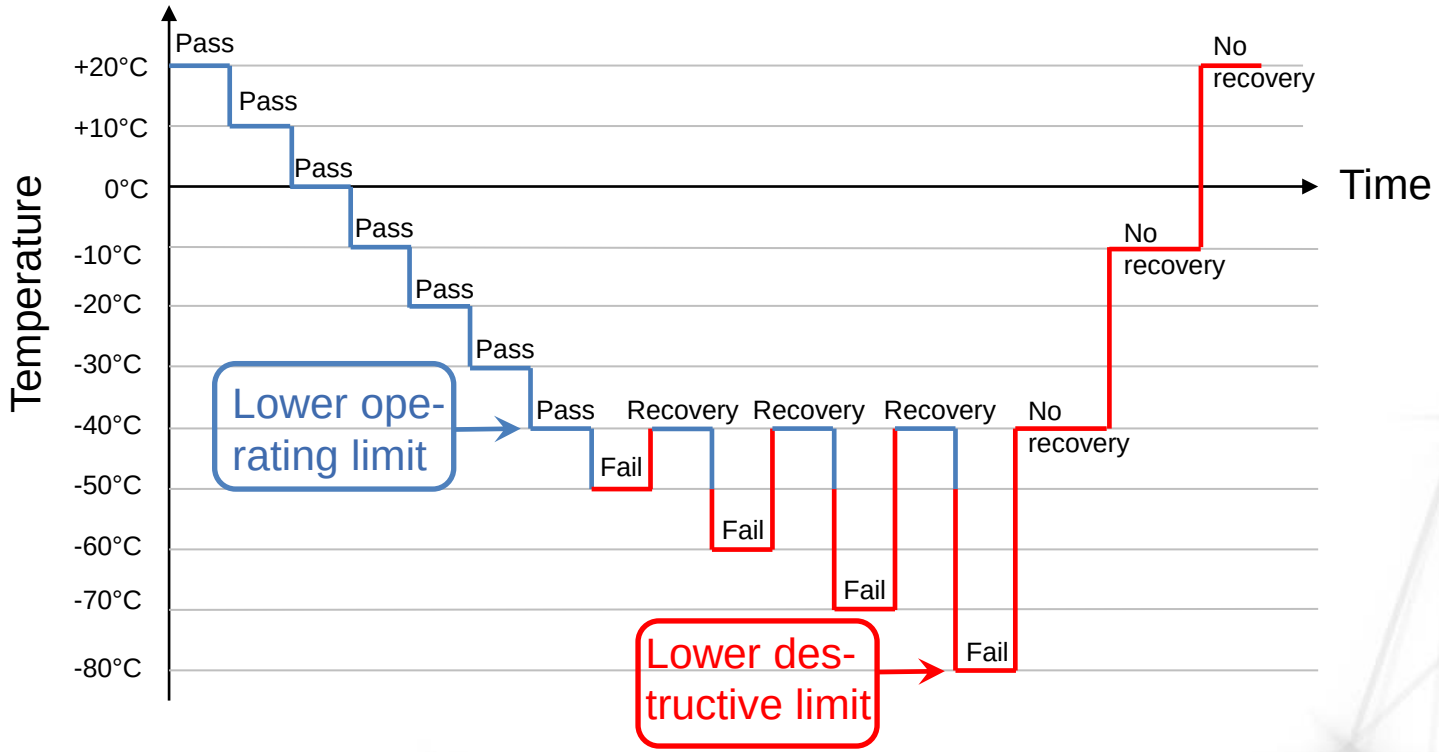
- **Focus on the HALT methodology:**
  - **Highly Accelerated Life Test**
  - Goal: Enhance product reliability by identifying design defects & weaknesses (R&D phase)
  - **Principle:**



  - No pre-established environmental stress limits: The robustness of the product determines the limits which can be significantly beyond those expected during normal use
  - Thermal + mechanical stresses are applied until failure / destruction
  - HALT gives you: Operating limits + destructive limits of the product
  - Analysis of the failures allows you to build the robustness of your product

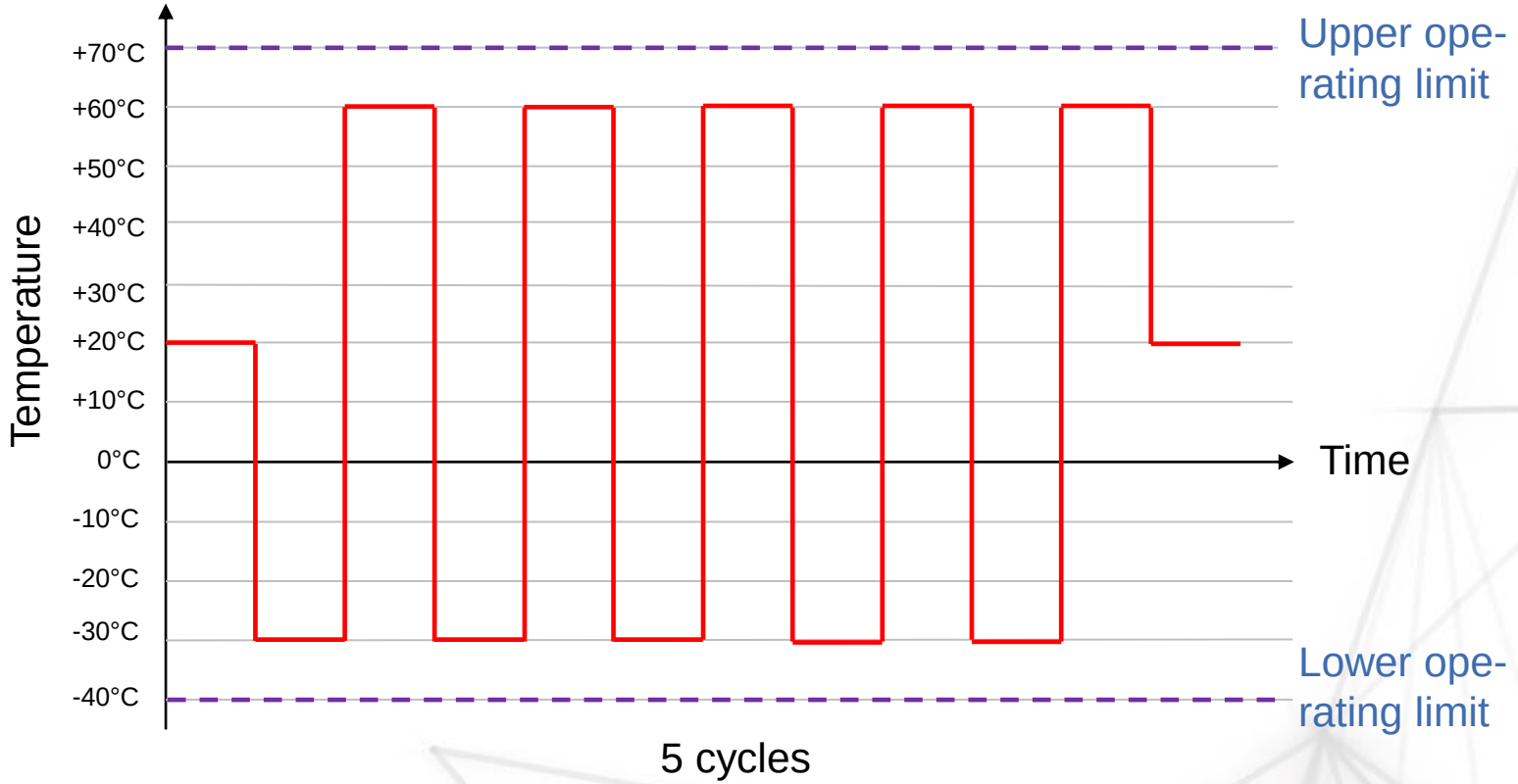
PS Reliability: Which strategy for SOLEIL II ?

- **Focus on the HALT methodology:**
  - **Example: Step by step temperature decrease**



- **Focus on the HALT methodology:**

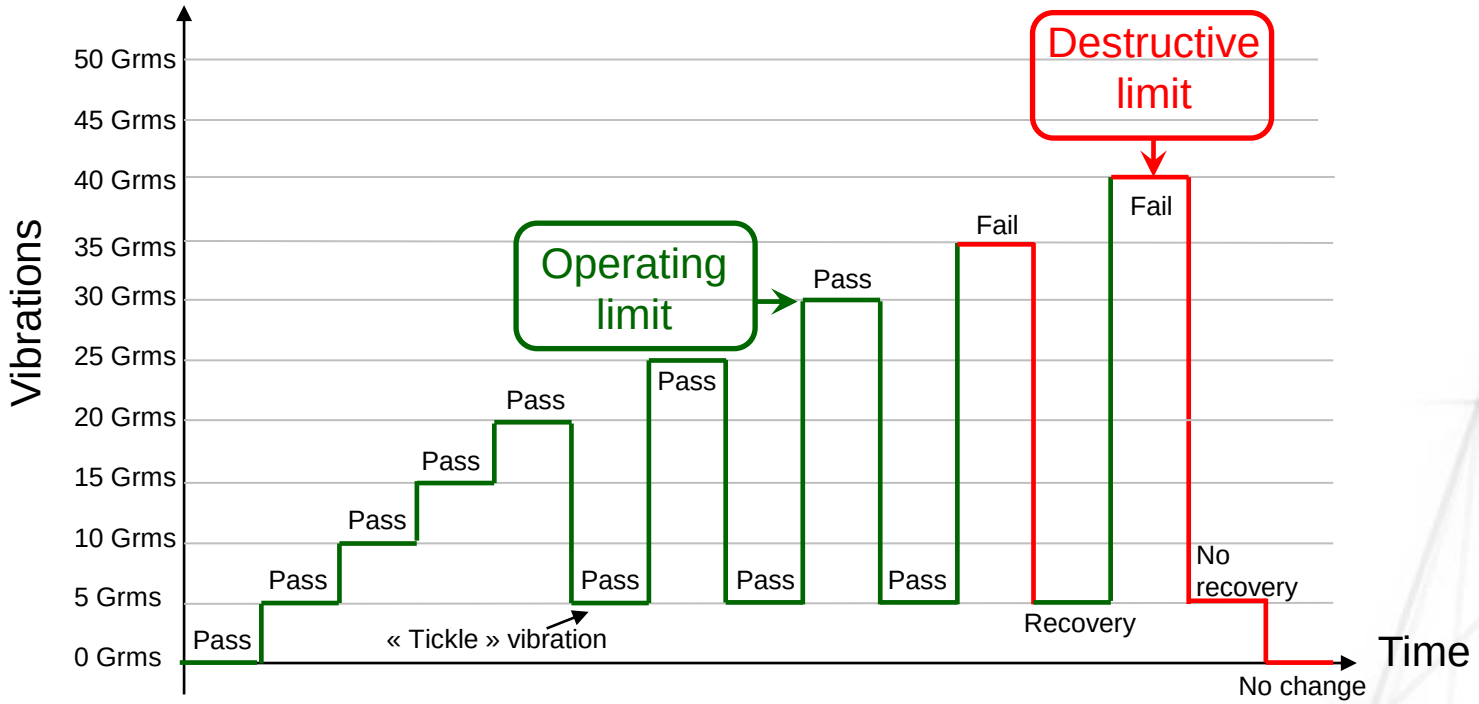
  - **Example: Rapid temperature variations (min. 45°C/min, up to 60°C/min)**



PS Reliability: Which strategy for SOLEIL II ?

- **Focus on the HALT methodology:**

  - **Example: Step by step "Grms" vibration level increase**

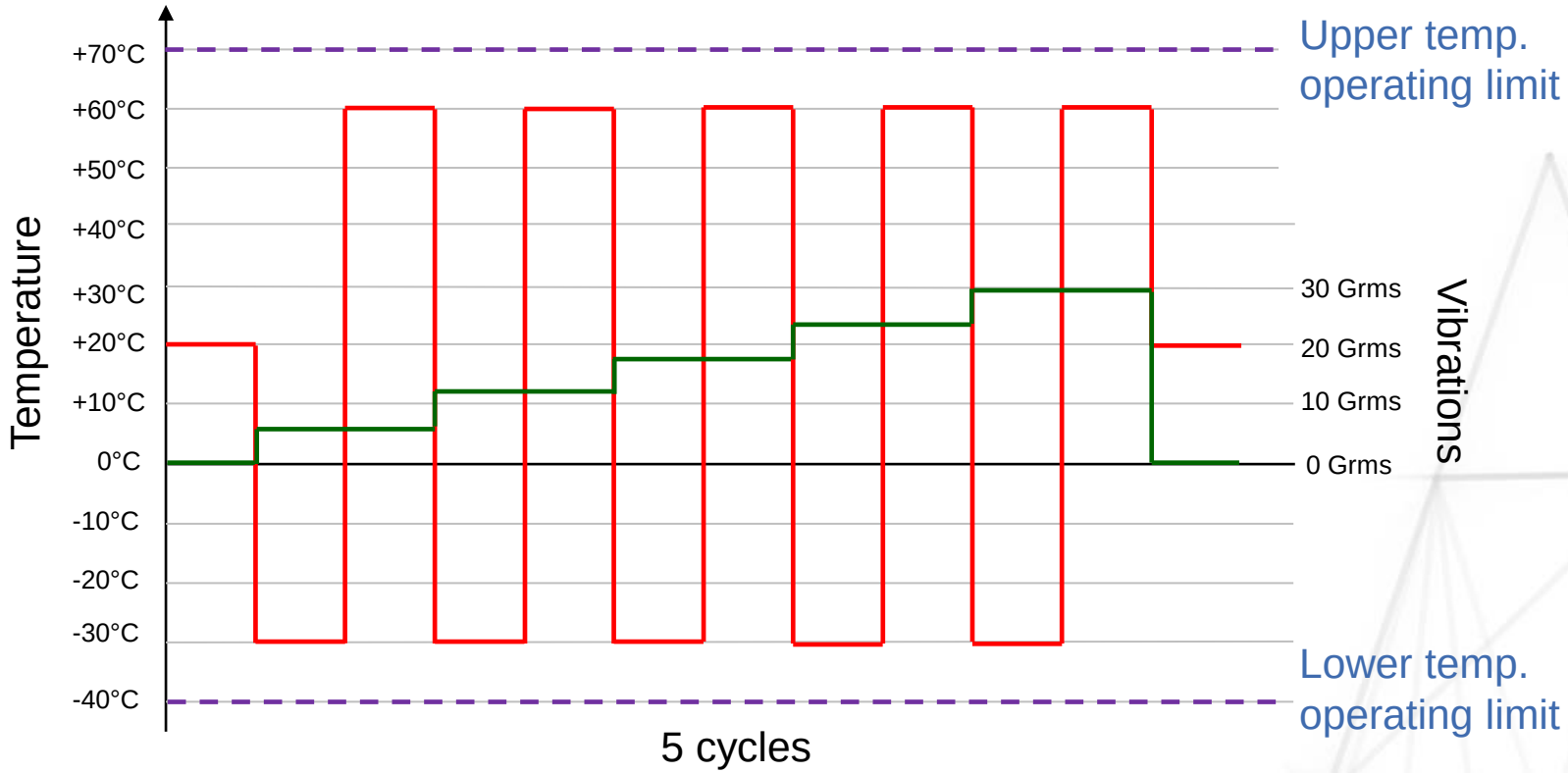


Pseudo-random vibrations 0 to 10 kHz on the 3 axes

PS Reliability: Which strategy for SOLEIL II ?

- **Focus on the HALT methodology:**

  - **Example: Combined test RTV & vibration**



HALT in short = CRASH TEST: Purpose is **not to simulate** an environment to check the proper functioning of an equipment, but **to stimulate a product** in order to know its limits + determine the root causes of all failures and corrective actions **to resolve the weak points** in the design (iterative process)
⇒ HALT is about to start on the developed prototypes for SOLEIL II

Conclusion

- **Power converter operation:** Availability is crucial [A = MTBF/(MTBF+MTTR)]
- First years of operation of SOLEIL have been difficult: High failure rate
- Still some difficulties today (mainly with DANFYSIK systems)
- Design & construction of most of the existing power supplies completely outsourced
- Since 2007: A lot of redesign + maintenance operations + PS monitoring enhancement, before reaching good operation statistics

- **Different approach for SOLEIL II:**
  - Most power supplies designed in-house
  - Single controller for all the PS: FGC controller from CERN, with extensive self-diagnostic
  - Set up of a strategy to enhance reliability from the prototyping phase (⇒ high MTBF)
  - Ease of repair / maintenance (⇒ low MTTR)

Thank you for your attention