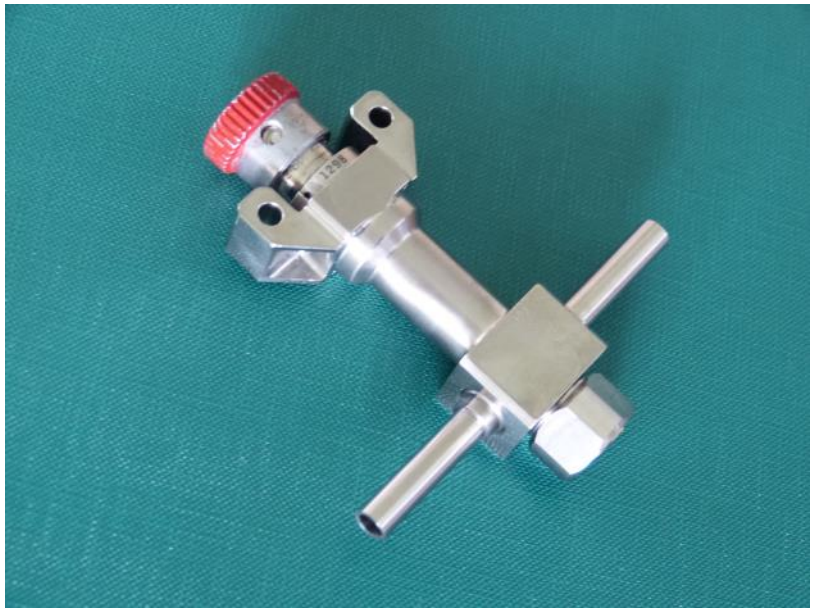
MICRO-PERFORATOR

Passivation device for Spacecraft Propulsion System



CLEAN SPACE INDUSTRIAL DAYS

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Actuators & Components - Business manager
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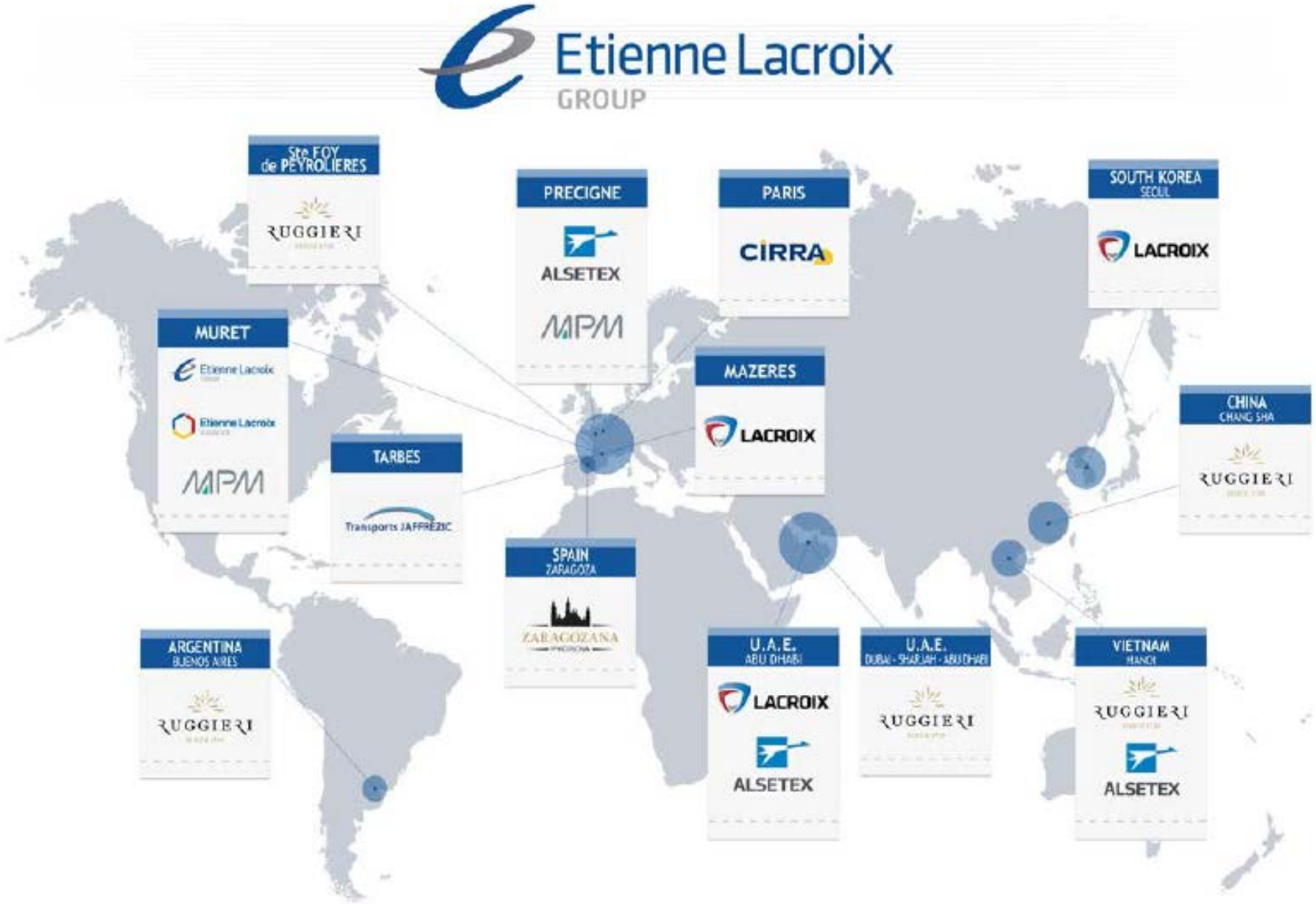
May 27, 2016

Chairman : Etienne Barès - Chief Executive Officer: Jean-Jacques Barès

OUR VOCATION

- Master industrial processes.
- Offer unique, cutting-edge and competitive solutions.
- Build a brand image on the quality, safety and reliability of our products and services.
- Maintain vigilance over the impact of our activity on the environment and ensure the continuous satisfaction of our customers, personnel, business partners and shareholders.


Etienne Lacroix
GROUP
Ste FOY de PEYROLIERES
RUGGIERI
PRECIGNE
ALSETEX
MPM
PARIS
CIRRA
SOUTH KOREA
SEOUL
LACROIX
MURET
Etienne Lacroix
Etienne Lacroix
MPM
MAZERES
LACROIX
CHINA
CHANG SHA
RUGGIERI
TARBES
Transports JAFFREZIC
SPAIN
ZARAGOZA
ZARAGOZANA
ARGENTINA
BUENOS AIRES
RUGGIERI
U.A.E.
ABU DHABI
LACROIX
ALSETEX
U.A.E.
DUBAI - SHARJAH - ABU DHABI
RUGGIERI
VIETNAM
HANOI
RUGGIERI
ALSETEX

LACROIX

Etienne Lacroix GROUP

Group Turnover: *100 M€*
Employees : *650*

DEFENCE & SPACE

LACROIX

Employees : 330

- **Self-protection**
- Training
- Civil safety & protection
- Pyrotechnic devices
- **Pyro-mechanisms**
- ILS Services

SAFETY

ALSETEX

Employees : 150

- **Law enforcement**
- Training
- Civil safety & Protection
- Pyrotechnic devices
- Pyro-mechanisms
- Training

DISPLAY AND EVENT PYROTECHNICS

RUGGIERI
SINCE 1739

Employees : 50

- Logistics
- Distribution
- Large-scale displays
- Testing laboratory
- Sourcing
- Representative network

CHAFF MATERIALS & PACKAGING

CIRRA

Employees : 20

- Chaff Materials
- Roto moulded containers
- Aluminium cases
- Foam
- Services

LOGISTICS

Etienne Lacroix LOGISTICS

Employees : 10

- Logistics
- National transport
- Safety advising
- International transport
- Storage

PLASTICS PROCESSING

MPM

Employees : 90

- Roller shutter, garage door and window accessories
- Lighting equipment accessories
- Subcontracting

LACROIX

Counter Measures: Pyrotechnic flares


AIR SELF PROTECTION


NAVAL SELF PROTECTION


LAND SELF PROTECTION

Pyro-mechanisms: 15 years Space experience


PYRO-MECANISMS

Pyrosoft

2007 (TRL9)

Cutter Balloons

2012 (TRL9)

µ-Perforator

2016 TRL7

Etienne Lacroix GROUP

SUMMARY

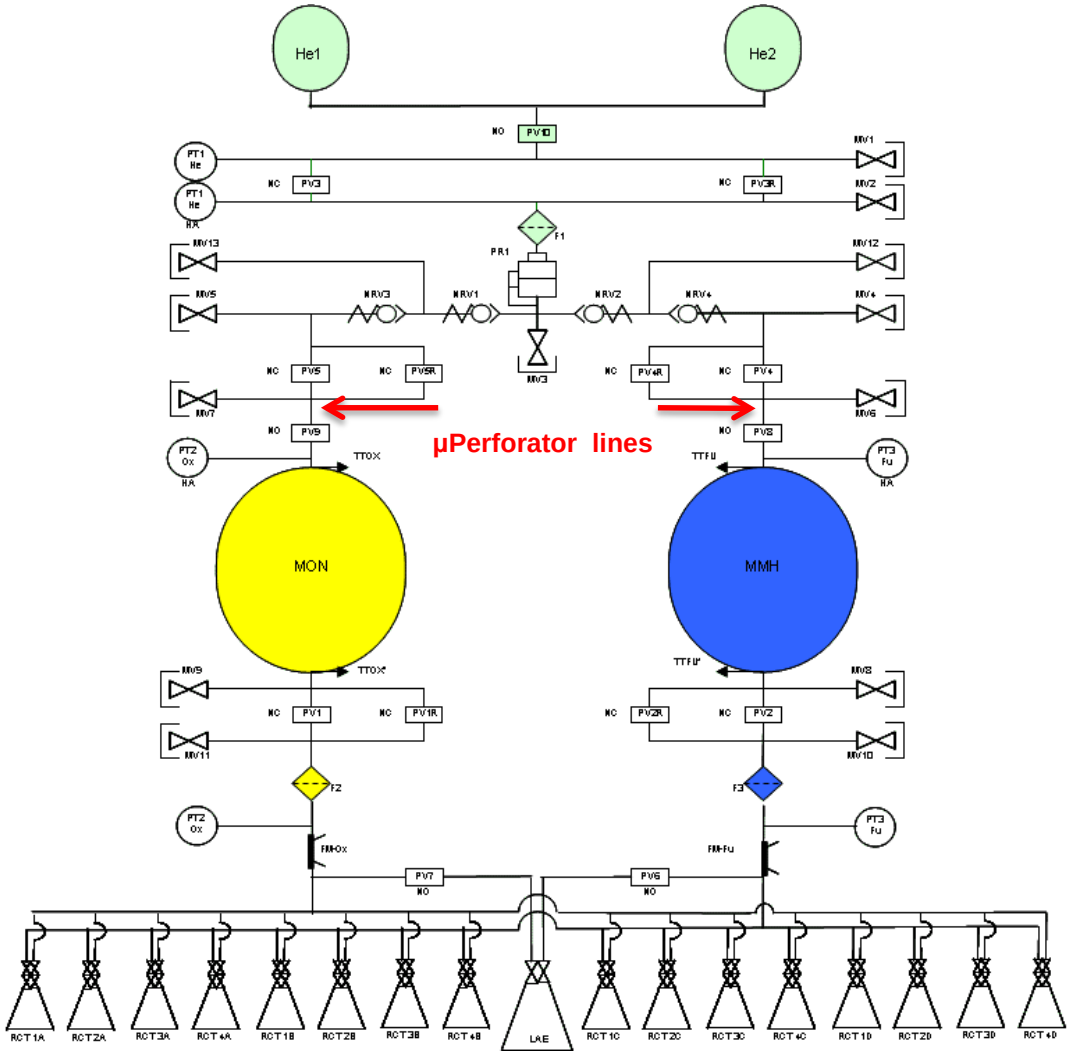
SCOPE

The French Space Act (LOS) requires the passivation of the energy sources (electrical and propulsion) of the spacecraft at the EOL. The spacecrafts launched from the Guyana Space Center shall comply with this regulation in January 2020.

Pyrovalves could be used but the present service life (8 years) does not comply with the time of the actuation of the passivation function.

The µperforator development funded and managed by CNES Toulouse Center provides a device to the satellite Prime contractor to comply with the requirement to drain the propellant and the pressurant gases trapped in the tubing and in the propellant tanks.

µPERFORATOR APPLICATION & INTEGRATION



- Passivation of LEO/ MEO satellites:

  at the EOL, in orbit storage 10 to 15 years

- Passivation of GEO satellite :
  - Strategy 1 : at the end of LEOP
  - Strategy 2 : passivation at the EOL, in orbit storage 20 years min.

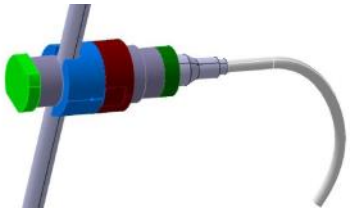
MAIN REQUIREMENTS :

- ***Reliability >0,995 @90% confidence***
- ***Service life : 28 years***
- ***Radiations : 1 Mrad***
- Low cost device
- Low mass
- Interchangeable with the Airbus D&S LAM pyrovalves : e.g.material for tubes welding, mechanical & electro- pyrotechnic interfaces
- Common design for HP (310 bar) and LP (24 bar) propulsion systems
- REACh Free energetic materials
- No sealing technology with polymer O-Ring
- Hermeticity better than 10^{-6} atm.cc.s^{-1} ΔP 1 bar He
- Exclusion of Class1 of the UN Recommandation on Transport of Dangerous Goods
- **DESIGN SHALL COMPLY WITH**:
  - ECSS E-ST-32-02C : Structural design and verification of pressurized hardware
  - ECSS-E-ST-35-06C_Rev.1: Cleanliness requirements for spacecraft propulsion hardware
  - ECSS E-ST-10-03C : Testing

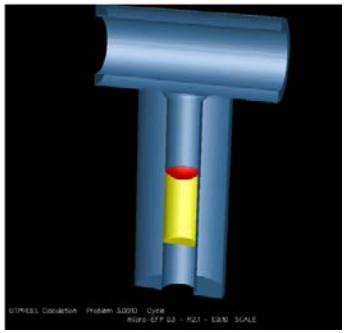
CNES PATENTED DESIGN

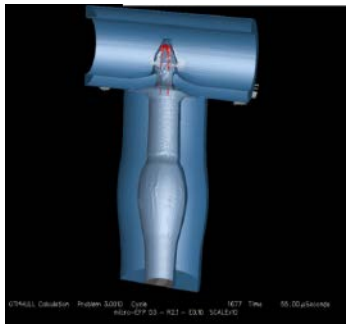
DEVELOPMENT STEPS

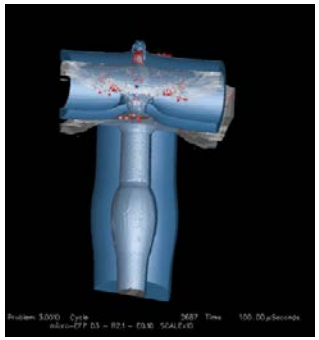
Detonation : µ Explosively Formed Projectile

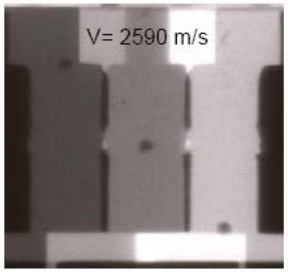


µEFP modelling 2D & 3D
*OTI*HULL software*







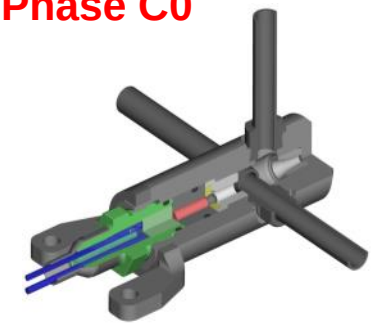


Verification of the performances on ¼ inch pipes (SST e= 0.9 mm)

High speed XRay of µEFP

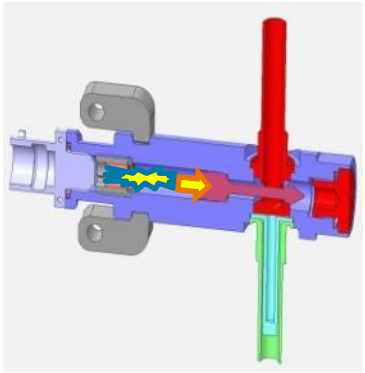
Deflagration : Projection of a steel ball

Phase C0



Phase C1 : Design modifications required by the Prime contractors

Deflagration : Projection of puncher

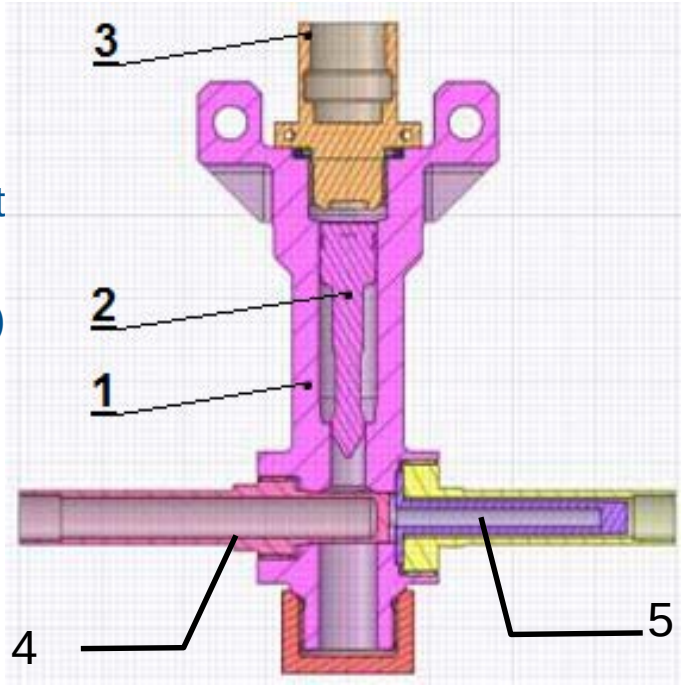


DESIGN

The passivation is achieved by the perforation of the inlet tube with a ram that creates the gas leak *(or liquid propellant leak if required).*

The µperforator main components are:

1. A body receiving the following parts :
2. A kinetic ram designed to punch the pressurized inlet tube.
3. The electro explosive initiator (PC23-250 NSI equivalent) with integrated connection
4. The Inlet tube
5. the Outlet tube with an integrated particle filter



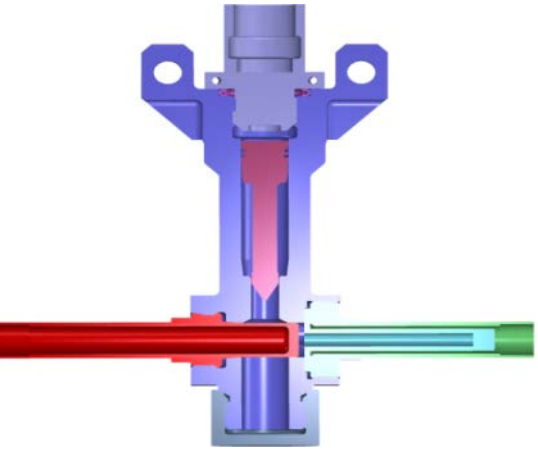
The assembly of the µperforator is performed by welding as any equipment of a propellant system.

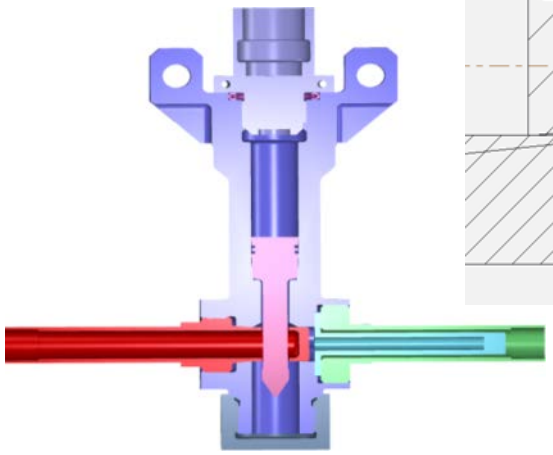
DESIGN JUSTIFICATION

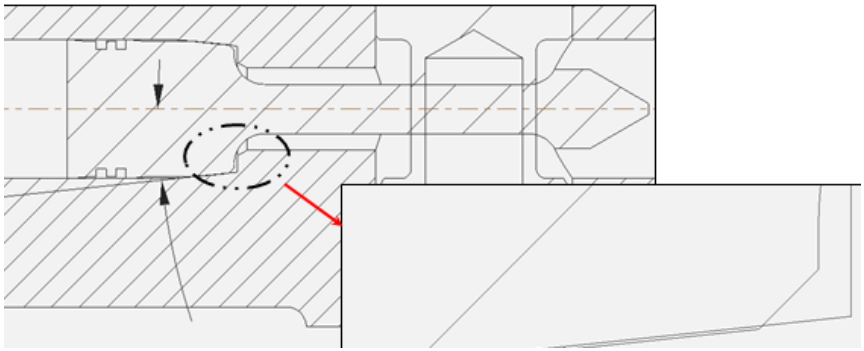
SERVICE LIFE DURATION AND RADIATIONS ENVIRONMENT : POLYMER FREE

- Initiator sealing by metallic C-Ring instead of elastomer O-ring
- Metal to metal sealing of the ram in the µperforator body before during and after firing by friction

FUNCTIONING SEQUENCE





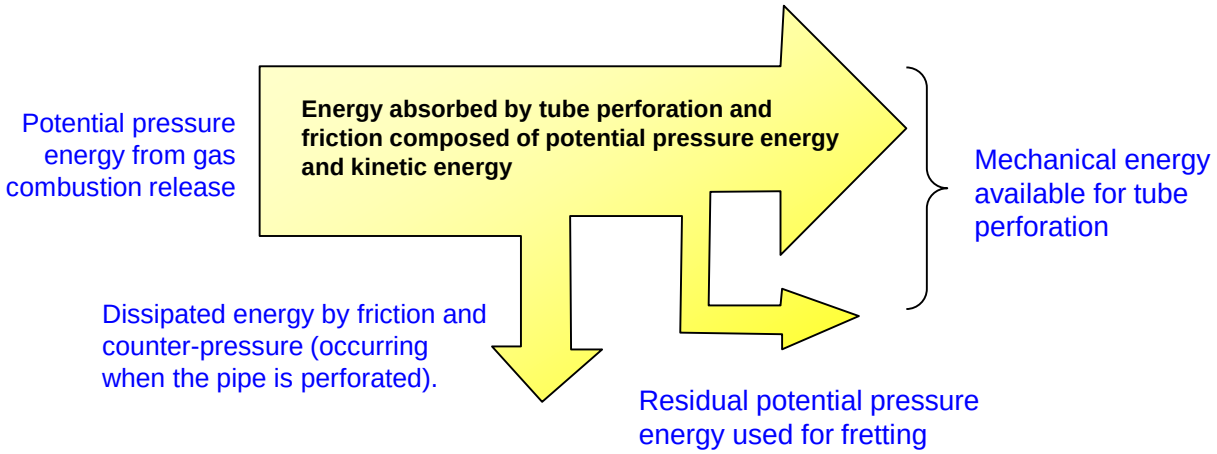


DESIGN JUSTIFICATION

ENERGY BALANCE

PC23 ENERGY MOTORIZATION VERSUS RESISTANCE FORCES

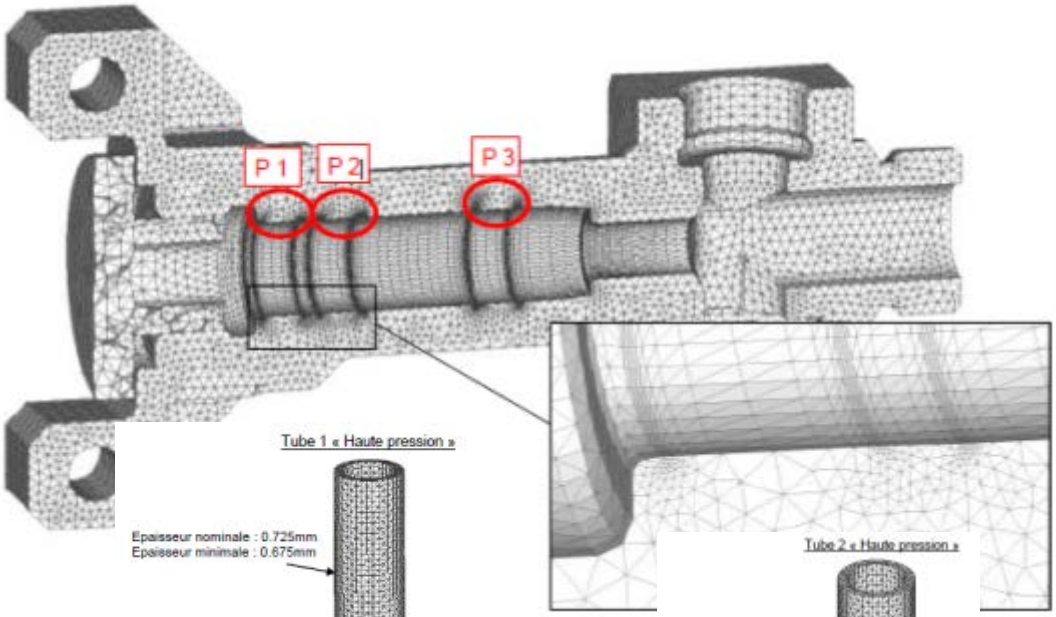
RESISTANCE ENERGY = PERFORATION + FRICTION ENERGIES

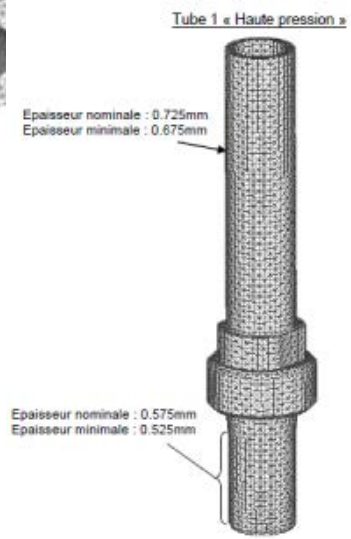


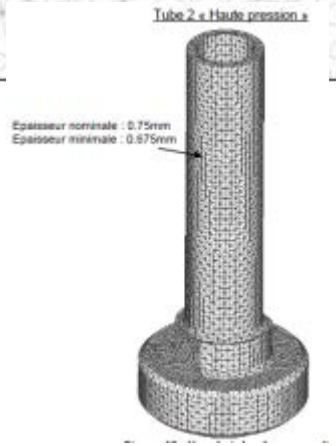
$$E_{pressure}(x) = E_c(x) + E_{perf}(x) + E_{frot}(x) + E_{ctr\,press}(x) + E_{fretting(x)}$$

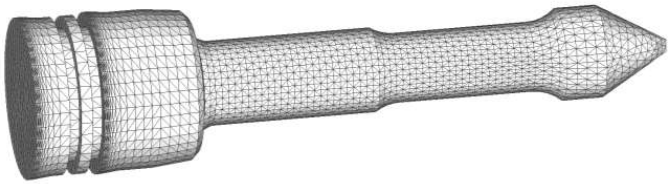
DESIGN JUSTIFICATION

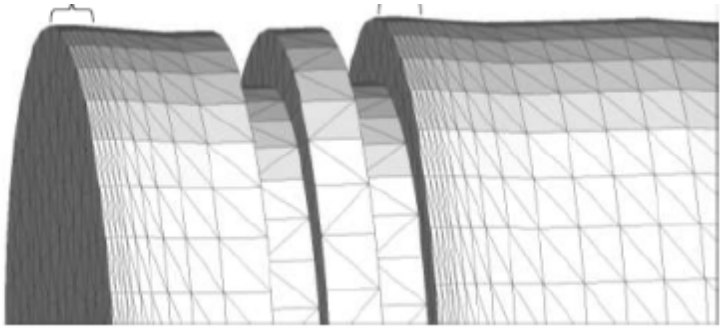
FEM of the µperforator for the mechanical and structural analysis

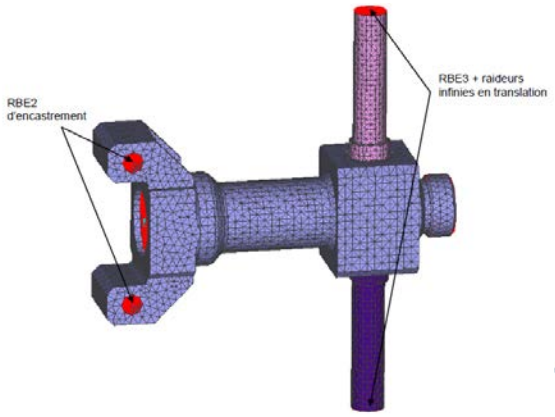








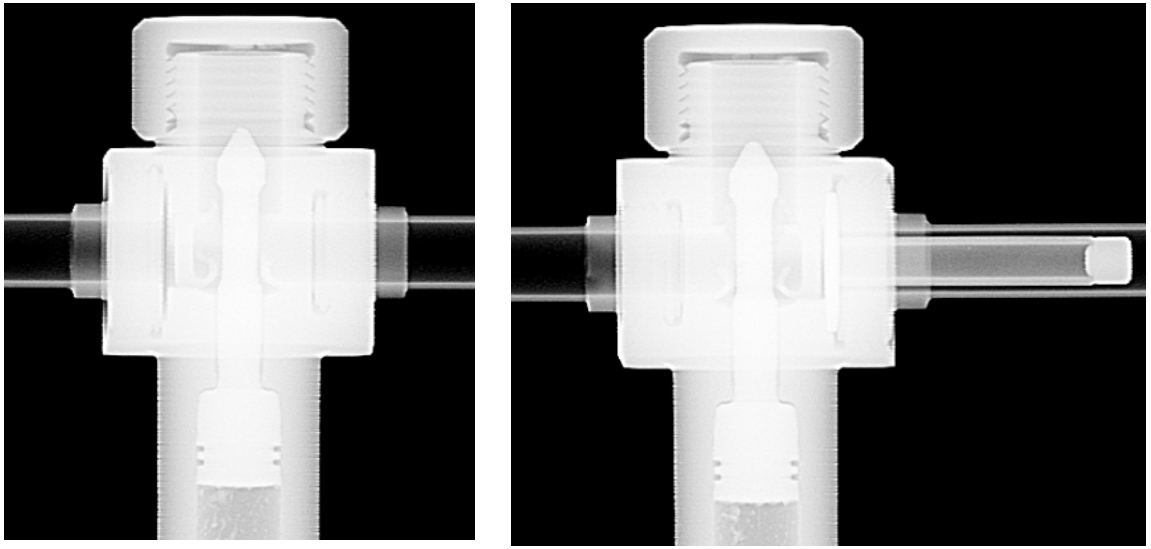




DESIGN JUSTIFICATION : INTEGRITY TESTS

120% pyro charge overload equivalent to the pyro chamber volume reduction of 20%

2 successfull tests performed at +70°C without pressure in the Inlet tube



- No damages to the µperforators
- Hermeticity requirements are fulfilled

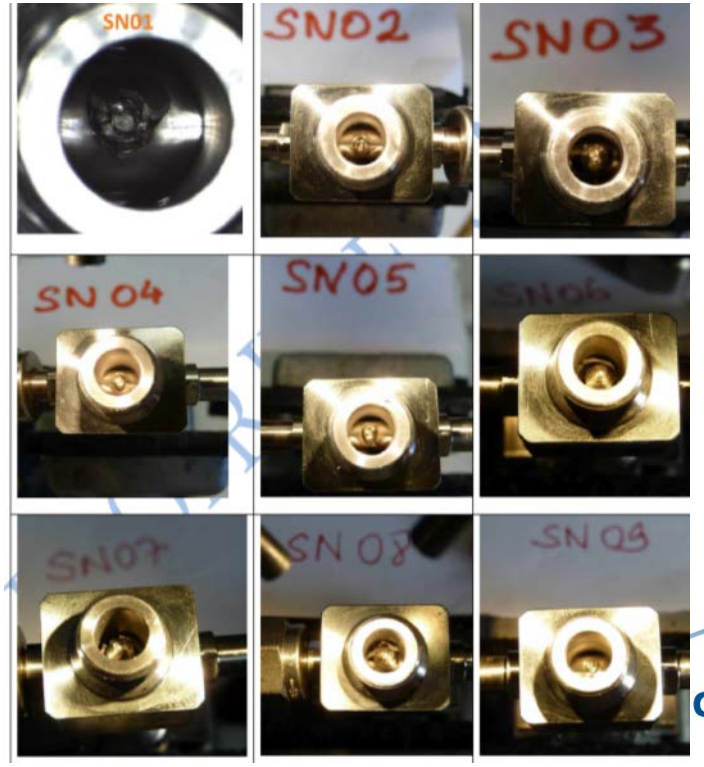
DESIGN JUSTIFICATION : RELIABILITY TESTS

RELIABILITY JUSTIFICATION : *R=0,995 for a confidence 1-α= 90%*

Application of the Severed Method of the GTPS (the French Pyrotechnics WG).

Methodology : Determination of the Km (multiplication factor applicable to the volume of the pyrotechnic chamber.

$CV_{estimated}$ =	11,82%
$CV=1,1xCV_{estimated}$	**13,0%**
R=	0,995
1- alpha =	0,9
Soit alpha =	0,1
N essais =	8
Km =	1,372



9 successfull tests (gas leak) performed at -20°C and with Inlet tubing pressurised at 310 bar (0/+10)

cnes

WORST CASE MISSION PROFILE FOR THE JUSTIFICATION OF THE SERVICE LIFETIME

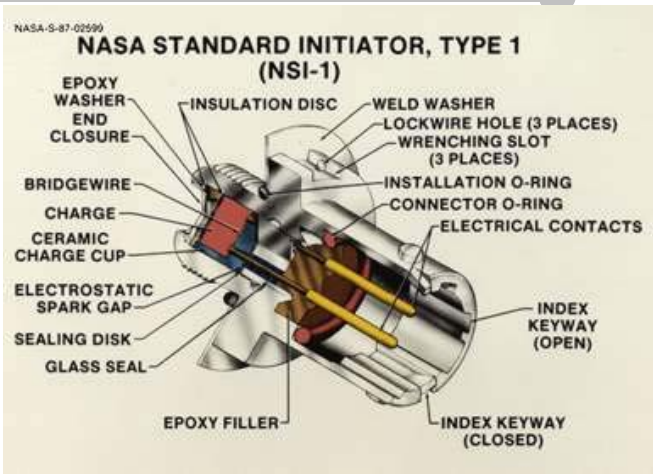
<table>
<tr><th><u>Non operating (Ground & In orbit)</u></th><th><u>Operating (In Orbit)</u></th></tr>
<tr><td colspan="2">Ground storage :
Temperatures : 27°C (*)
Duration: 5 to 8 years</td><td rowspan="4"></td></tr>
<tr><td colspan="2">In orbit storage</td></tr>
<tr><td>Temperatures :
+45°C(*)
Duration: 20 years</td><td>Radiations
1 Mrad</td></tr>
<tr><td colspan="2">EOL
Temperature : +60°C
Duration: 6 months</td></tr>
<tr><td colspan="2"></td><td>Firing temperatures: -10°C / +60°C

Reliability >0,995@90% confidence</td></tr>
</table>

(*) mean values

The servive life of the µperforator is the one of the PC23 initiator (manufacturer Chemring Energetic Devices)

THE PC23 INITIATOR SERVICE LIFE



PC23 - NSI commercial equivalent User's Guide:

Recommended firing current pulse: 5A for 10ms

STORAGE LIFE

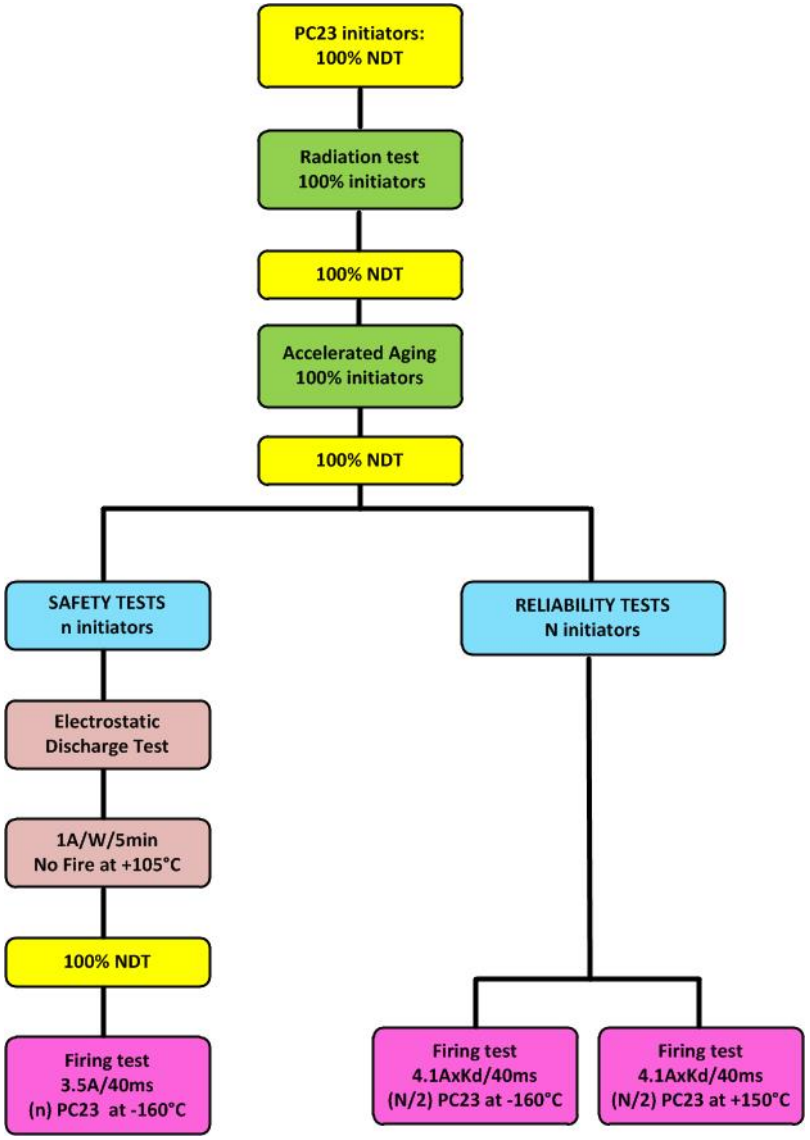
The initiator has a minimum storage life of 10 years when temperatures are maintained within a

Additional information, for a CNES Satellite mission : "*Given that CED's PC23 initiator has been aged at 71°C for a period of 94 days and that the items provided to CNES are and have been stored by CNES at a maximum temperature of 27°C a shelf life of 13 years can be supported by the analysis indicated above.*

In providing this analysis, CED provides no warranty nor will incur any liability for any product utilized by a customer or a customer's end user utilized beyond the period where CED has successfully demonstrated age life extension through formal successful testing."

A SERVICE LIFE EXTENSION PROGRAMME IS REQUIRED

SERVICE LIFE EXTENSION of the PC 23



CNES PyroLab : PC23 : Lot 13-41432
Mfg date : 05/2000 – Qty : 18

Non Destructive Tests

- Bridgewire resistance measurement
- Insulation resistance measurement
- Thermal response test
- Leak test < 10^{-6} atm.cc/s ΔP 1 bar of He

Firing tests:

- Reliability justification : *R=0,999 for a confidence of 1-α= 90%*

Application of the Severed Method of the GTPS

Input :
PC23 Coefficient of variation Cv: 6%
Number of successfull tests : 10 tests
then Kd = 1,17 and the Severed Firing Current to apply is 3,5A

SERVICE LIFE EXTENSION of the PC 23

RADIATIONS TESTS

TEST CONDITIONS

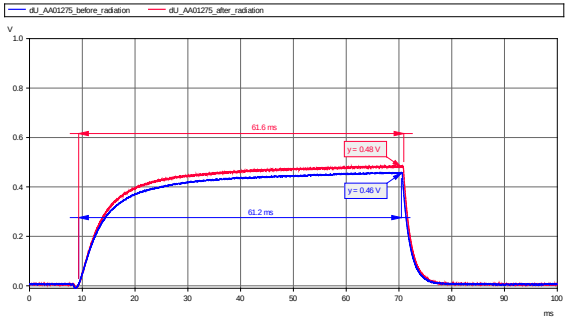
Radiation source : ^{60}Co
Wave length : Gamma Ray bands: 1.17MeV and 1.33MeV
Dose rate: 1500 rad/h - Temperature: 20°C
Exposure time: 03/29/2016 to 04/27/2016
Total ionizing dose [krad]: 1052

Bridgewire Test

Insulation Test

Thermal Response Test

Example TRT before & after irradiation



NO SIGNIFICANT CHANGES OF THE ELECTRICAL AND THERMAL RESPONSE PRPERTIES OF THE PC23s AFTER RADIATIONS

PC23 SERVICE LIFE EXTENSION

ACCELERATED AGING ACCORDING TO THE ARRHENIUS METHOD

» Accelerating factor AF = $\frac{k_1}{k_2} = \left(\frac{e^{\frac{Ea}{R T_2}}}{e^{\frac{Ea}{R T_1}}} \right)$ with T1: Mission temp. & T2 : Aging test temp.

» The ZPP pyrotechnic composition is a very stable

» Energy of activation: Ea (ZPP) >>140kJ /mole

» The accelerated aging temperature may be increased to +80°C or more

Mission (Temp. °C)	Mission (days)	Test +80°C (days)
27	2920	0,6
45	7300	38,5
60	183	10,4
	Test duration (days)	49,6

Accelerated aging tests at CED Torrance T0= Mid June – Firing tests : Sept.

Objective : CED's commitment for a 28 years service life for the PC23 initiator.

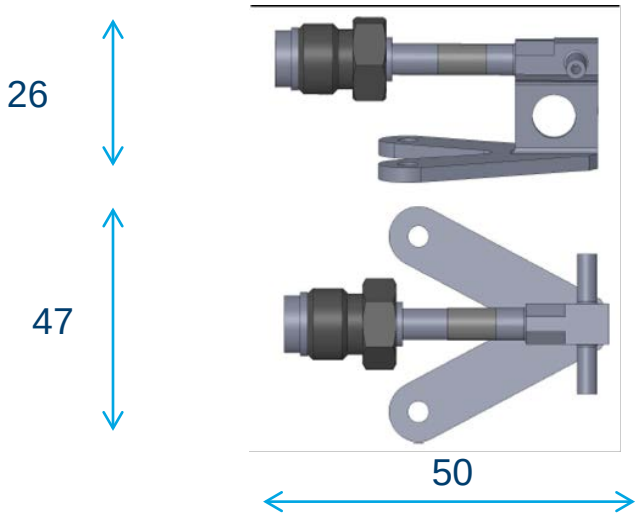
QUALIFICATION TEST SEQUENCE APPLICABLE ON 6 DEVICES

Physical inspections
Cleanliness and dryness
Proof pressure
Electrical tests (grounding, insulation …)
X-Ray
Leakage (internal and external)
Vibration tests (resonance search, sinus, resonance search, random, resonance search)
Shock (3 shocks) per axis as defined in ECSS
Thermal Cycling (-20°C/+70°C) including high and low temperature leak check
Leakage test - X-Ray inspection - Electrical test
µPerforator actuation (-20°C/ambiant /+70°C) - Functioning time, generated shocks
External leakage

ZERO FORCE DEVICE

TO PREVENT TORQUE EFFECT ON THE SATELLITE WHEN GASES ARE VENTED A « ZERO FORCE » DEVICE IS TO BE INSTALLED

The GOD (GAS OPPOSITE DRAIN) has been designed and qualified in the frame of the Microscope satellite.



	Passivation pressure 345 bar	Passivation pressure 10 bar
Force (µN)	350	5
Torque (µN x m)	50	25

MILESTONES

SUCCESSFULLY COMPLETED :

- **End of Phase C1-Design KP with Prime contactors : Dec. 2015**
- **CDR : May 12th , 2016**
- **CDR Board : May 26th, 2016**

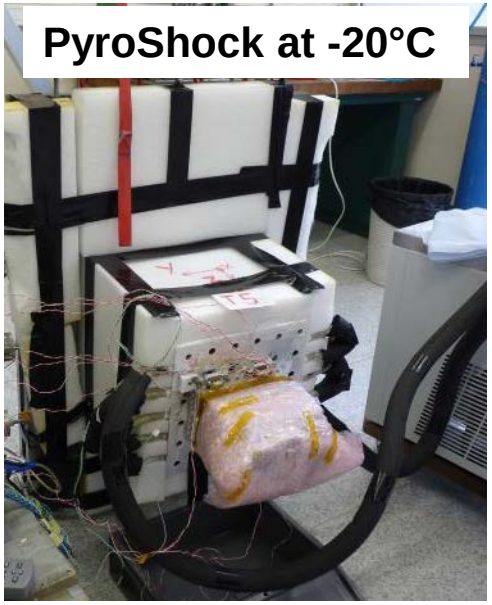
IN PROGRESS

- Processes Qualification and Material & Process Control Board : CW 23 to 25
- 6 QM assembly : CW 26
- Qualification tests : CW 27 to 28
- Qualification review : Sept. 2016 (CW37)

CONCLUSION

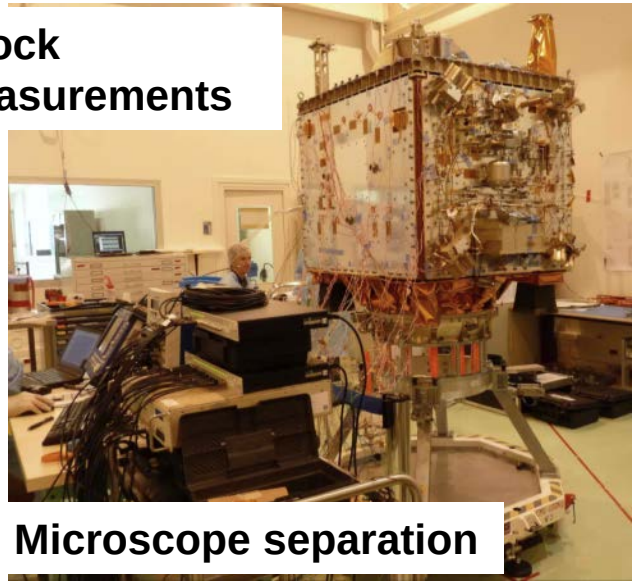
- Service Life up to 28 years: demonstration in progress
- Modular Integration & compatible Pyro-valve brackets
- Low mass (<95g)
- Flight Models available in September 2016
- Cost effective

THE CNES PYROLAB


PyroShock at -20°C


Balloon separator test
6mm ICE/ -110°C

Shock measurements


Microscope separation


2 TVC chambers

THANK YOU FOR YOUR ATTENTION

ANY QUESTIONS?