SPIRE & PACS Sorption Coolers
SAFETY ISSUES

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Document Status

Issue	Revision	Date	Nb of pages	Modifications
0	0	04/04/2003		First draft
1	0	15/04/2003		First issue
1	1	10/07/2003		Modification of table on & 4.2.2 following ESA's comments after IHDR
1	2	15/06/2004		3D views of cooler updated

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CONTENTS

List of Acronyms

AD	Applicable Document		
CEA	Commissariat à l' Energie Atomique		
CDR	Critical Design Review	Revue de conception détaillée	RCD
CQM	Cryogenic Qualification Model		
ECSS	European Cooperation for Space Standardisation		
FIRST	Far Infrared and SubmillimetreTelescope		
FS	Flight spare		
HSO	Herschel Space Observatory		
N/A	Not Applicable		
PACS	Photoconductor. Array Camera and Spectrometer		
PFM	ProtoFlight Model		
PSS	Product Assurance Specification System		
RD	Reference Document		
SAp	Service d'Astrophysique		
SBT	Service des Basses Températures		
SCO	Sorption Cooler (full unit)		
SPIRE	Spectral & Photometric Imaging Receiver		

1 Scope of the document

This note discuss the safety issues of the SPIRE/PACS sorption coolers. It deals with the potential damages from the cooler to the user, as well as from the user to the cooler. Although the stored energy remains low, these systems are under 8 MPa when at room temperature. Safety issues related to the high pressure are discussed.

2 Documents

2.1 Applicable documents

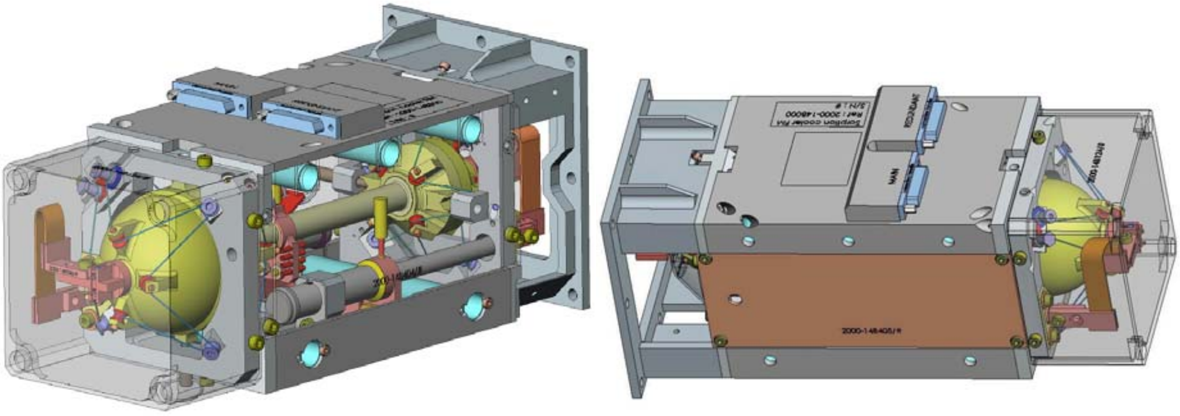
HSO-SBT-PR-025 : Test en pression

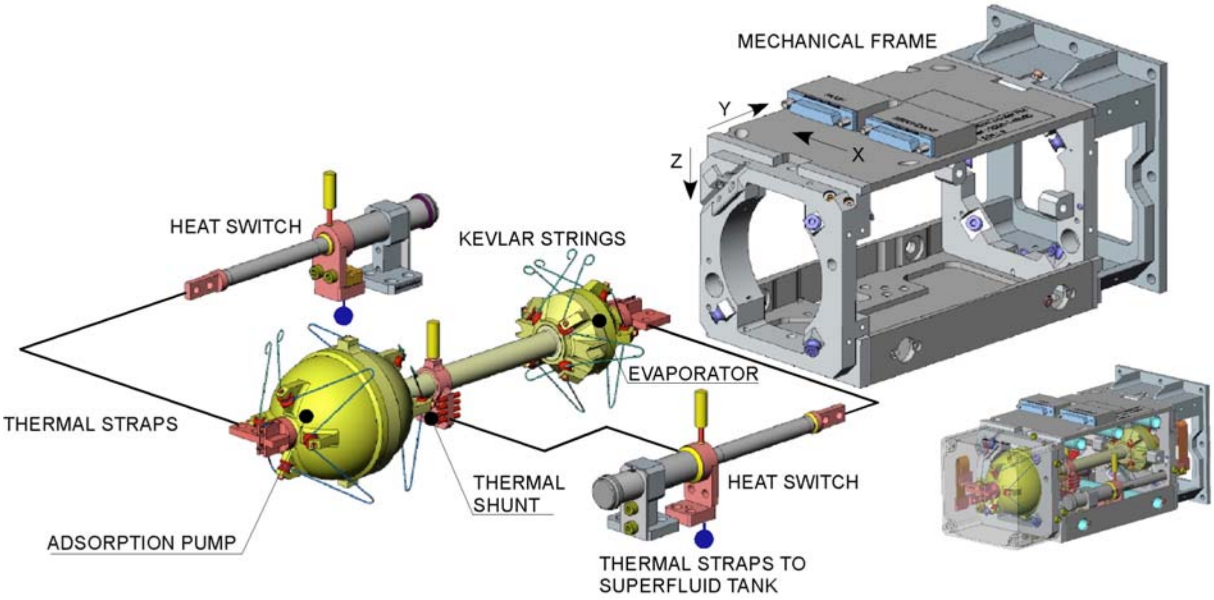
HSO-SBT-PR-027 : Handling, packing, transportation and storage manual

3 Description of sorption cooler

The cooling of the SPIRE and PACS detectors down to 300 mK will be effected by a helium three sorption cooler. This sub-Kelvin sorption cooler provides a wide range of heat lift capability at temperature below 400 mK. It relies on the capability of porous materials to adsorb or release a gas when cyclically cooled or heated. Using this physical process one can design a compressor/pump which by managing the gas pressure in a closed system, can condense liquid at some appropriate location and then perform an evaporative pumping on the liquid bath to reduce its temperature. Helium sorption refrigerators have no moving parts, are vibrationless and can be designed to be self contained and compact with a high duty cycle efficiency.

The following figure shows some 3D views of the actual cooler.





4 Potential damages to the user

4.1 Cooler manipulation

The cooler must be handled with care and using gloves to avoid any contamination to it. As described further all sensitive elements are enclosed in protective covers.
Although the cooler can be manipulated without any major risk, the external mechanical frame features some sharp edges.

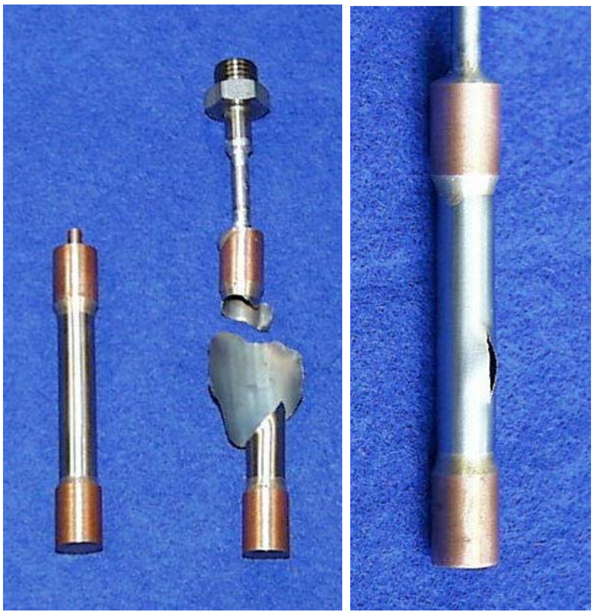
All materials used are harmless. The mechanical frame is mostly made out of Titanium Ta6V and aluminum, and include a couple of copper interfaces.
The cooler internal contains helium gas (^{3}He). Helium is an inert gas and, in case of a gas leak, the amount stored (6 liters NTP) is not significant enough to create any problem.

4.2 Pressure related aspects

4.2.1 Leak before burst

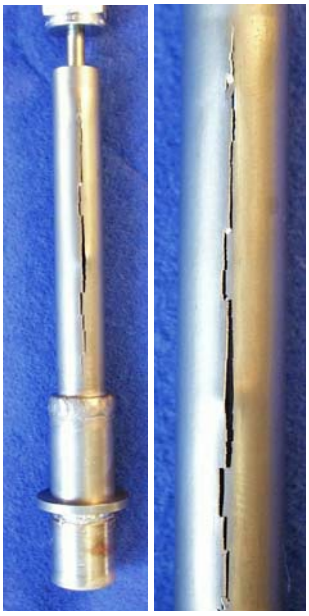
The large internal pressure required for efficient operation of the cooler, as well as for size purpose, certainly calls for an appropriate design. The design has been performed so that the pumping line, ie the thin walled tubing, is the weakest mechanical part of the cooler with respect to the internal pressure. The margin of safety on all other components are significantly higher than that of the tube.
Experimental pressure tests performed with water on pieces of tubing show that when the internal pressure reaches the bursting pressure the tube opens up along its length, and the internal fluid or gas quickly leaks to the outside, leading to leak before burst type behavior.
In a previous ESA contract a test piece representative of the pumping line has been manufactured and tested to demonstrate this behavior. A schematic of this piece is shown below.

The calculated burst pressure of this piece was 35 MPa (350 bars) and consequently the pressure test could only be safely performed with a water pump. Thus prior to testing this piece, a couple of stainless steel samples (smaller diameter and wall thicknesses) were also manufactured to check for any difference in behavior between water and gaz pressure test and additionnaly any difference in behavior between stainless steel and titanium.
The results are displayed on the following figures.



With gaz *With water*

Stainless steel sample



With water

Titanium sample

For all the tests the failure appears as expected in the middle of the tube, along its length; with gaz, as gas is exhausted and because of the remaining internal pressure the crack propagates toward the copper brazed end, which in the case of the small stainless tube is then teared up. The tube does not break apart and no "flying" pieces are seen – with water the failure is "clean": basically the same (middle of tube, along its length), but since the pressure is almost instantly released, the crack does not propagate.

The experimental bursting pressure for the titanium sample was found to be 36 MPa, consistent with the calculated 35 MPa.

In this case the visual aspect is quite different from stainless steel and is probably due to the difference in ductility : the breaking elongation for stainless steel can reach values higher than 60% as for Ta6V it remains below 15%. In any case the failure appears in the middle of the tube and then propagate along its length.

We believe these tests have demonstrated the tube failure at the burst pressure is of the “leak before burst” type. Consequently if the tube is designed to be the weakest point in the system with regards to internal pressure the cooler can be qualified as a leak before burst device.

In addition as described further, the cooler internal (components under pressure) are fully enclosed to further increase the safety aspects.

4.2.2 Proof pressure testing

Obviously the real coolers are not tested to failure. However to provide confidence on the quality of the tubes and on all of the soldering, each cooler is proof pressure tested under helium at 20 MPa (200 bars) – twice the maximum operating pressure (MOP).

The maximum operating pressure is defined as the maximum pressure the cooler will ever reach in its lifetime. This maximum pressure occurs during the bake out process at 80°C. Consequently the cooler has been designed with an operating pressure of 8 MPa at ambient (20°C), leading to 10 MPa at 80°C. all structural elements have been designed accordingly. The table below displays the stress at the MOP and the margin of safety (MOS). The MOS is defined as :

$$MOS = \frac{max\ allowable\ stress}{applied\ stress} - 1$$

The maximum allowable stress is taken as the elastic limit.

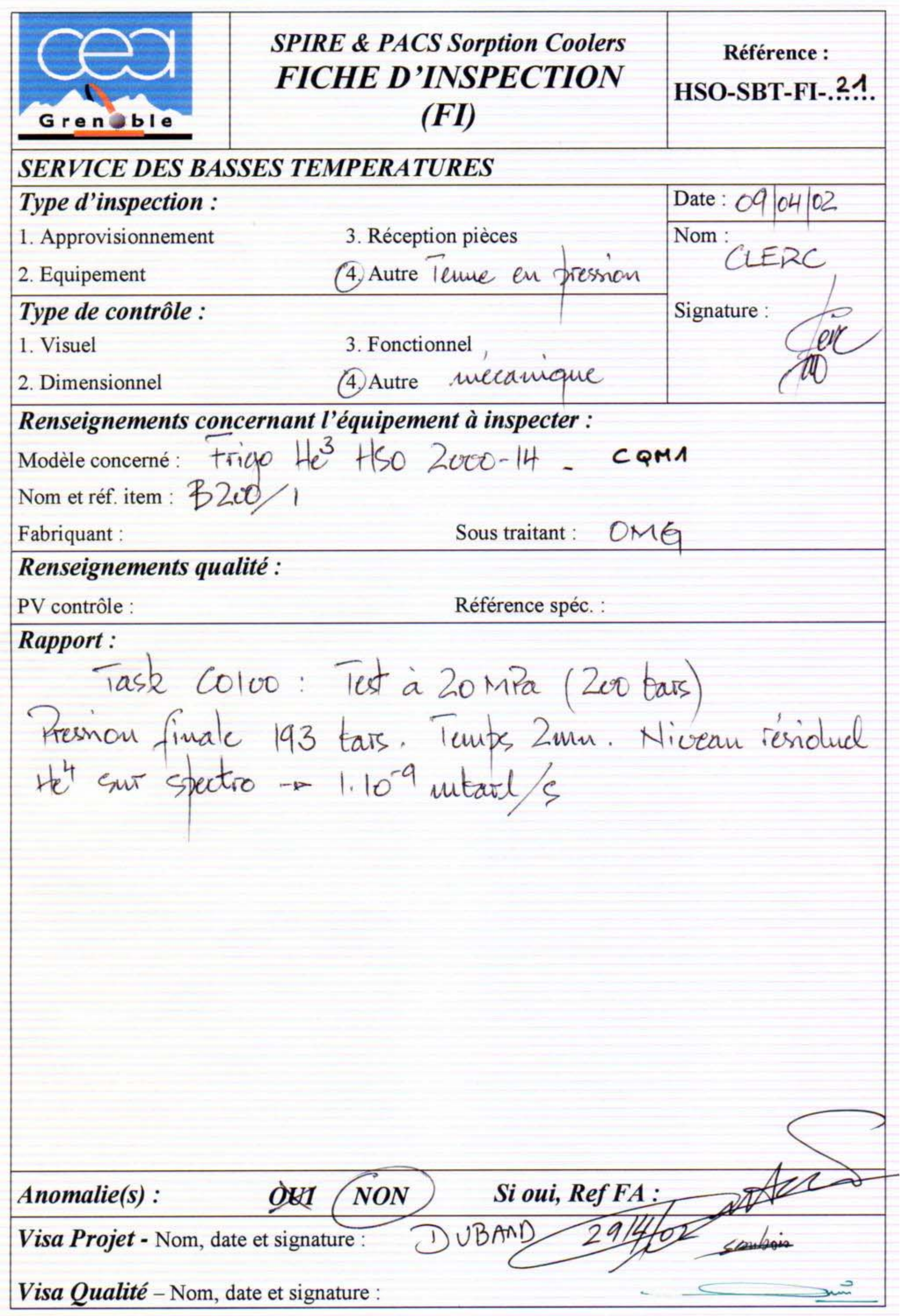
	Stress at MOP (MPa)	MOS
Pumping line	250	2.2
Evaporator	77	9.4
Sorption pump	125	5.4

(Note : titanium Ta6V, actual measurements – elastic limit : 798 MPa – ultimate strength : 875 MPa)

The table hereafter displays the burst pressure and margins with regards to the maximum operating pressure.

	Burst Pressure (MPa)	MOP (MPa)	Margin
Pumping line	35	10	3.5
Evaporator	113	10	11.3
Sorption pump	70	10	7

During the proof pressure test, the helium leak rate is recorded. The results of each proof pressure test are reported on an inspection sheet (FI) as shown hereafter (FI for SPIRE and PACS CQM units).



SPIRE & PACS Sorption Coolers
FICHE D'INSPECTION (FI)

Référence : **HSO-SBT-FI-21**

SERVICE DES BASSES TEMPERATURES

Type d'inspection :

1. Approvisionnement
2. Equipement
3. Réception pièces
[✓ 4. Autre] Tenue en pression

Date : 09/04/02
Nom : CLERC
Signature :

Type de contrôle :

1. Visuel
2. Dimensionnel
3. Fonctionnel
[✓ 4. Autre] mécanique

Renseignements concernant l'équipement à inspecter :

Modèle concerné : Frigo He^3 HSO 2000-14 - CQM1
Nom et réf. item : B200/1
Fabriquant :
Sous traitant : OMG

Renseignements qualité :

PV contrôle :
Référence spéc. :

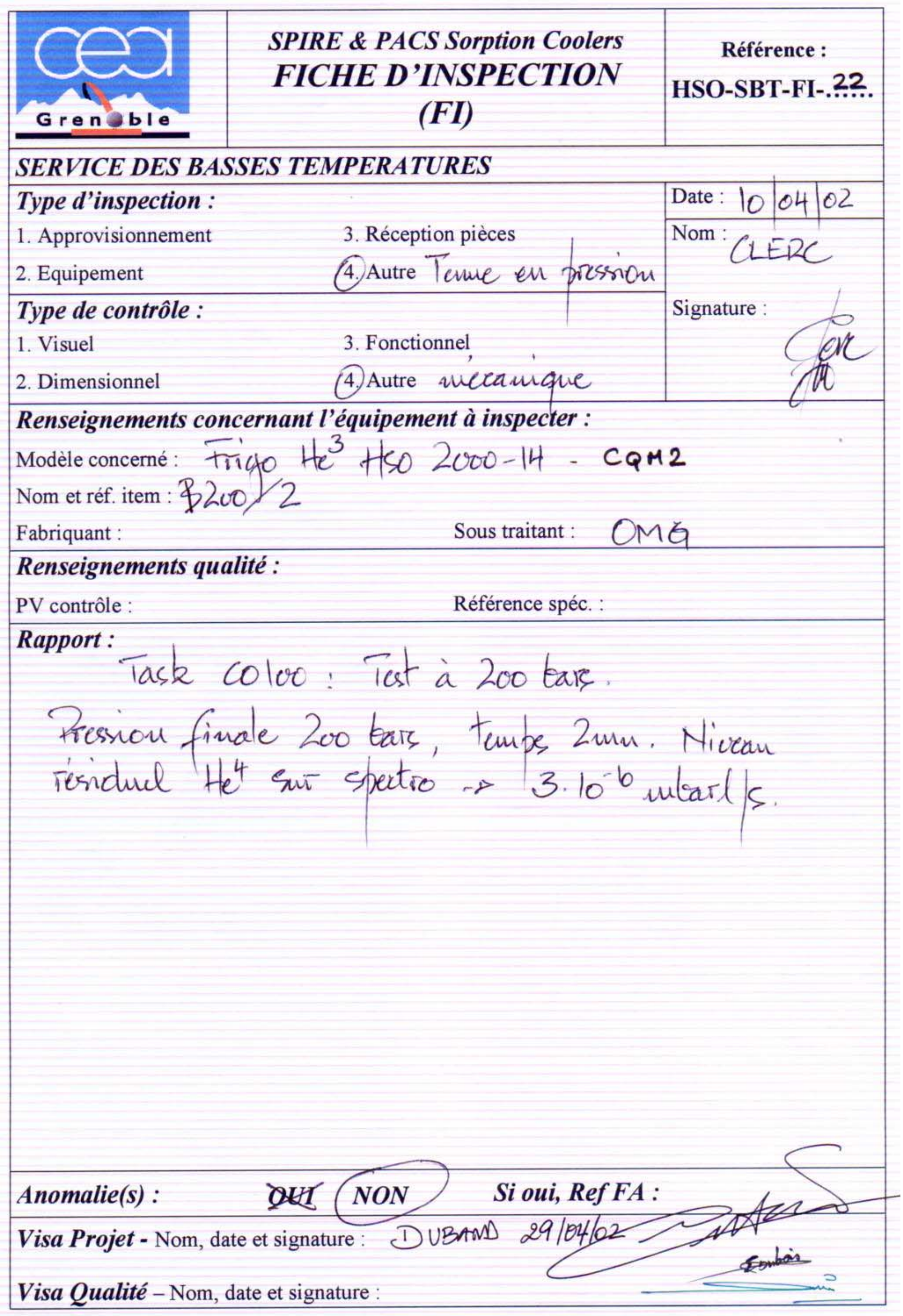
Rapport :

Task C0100 : Test à 20 MPa (200 bars)
Pression finale 193 bars. Temps 2mn. Niveau résiduel He^4 sur spectro → 1.10^{-9} mbarl/s

Anomalie(s) : ~~OUI~~ [✓ NON] ***Si oui, Ref FA :***

Visa Projet - Nom, date et signature : DUBAND 29/4/02

Visa Qualité – Nom, date et signature :



SPIRE & PACS Sorption Coolers
FICHE D'INSPECTION (FI)

Référence :
HSO-SBT-FI-22

SERVICE DES BASSES TEMPERATURES

Type d'inspection :
1. Approvisionnement
2. Equipement
3. Réception pièces
[✓ 4.] Autre Tenue en pression

Type de contrôle :
1. Visuel
2. Dimensionnel
3. Fonctionnel
[✓ 4.] Autre mécanique

Date : 10/04/02
Nom : CLERC
Signature :

Renseignements concernant l'équipement à inspecter :
Modèle concerné : Frigo He^3 HSO 2000-14 - CQM2
Nom et réf. item : B200/2
Fabriquant :
Sous traitant : OMG

Renseignements qualité :
PV contrôle :
Référence spéc. :

Rapport :
Task C0100 : Test à 200 bars.
Pression finale 200 bars, temps 2mn. Niveau résiduel He^4 sur spectro -> 3.10^{-6} mbarl/s.

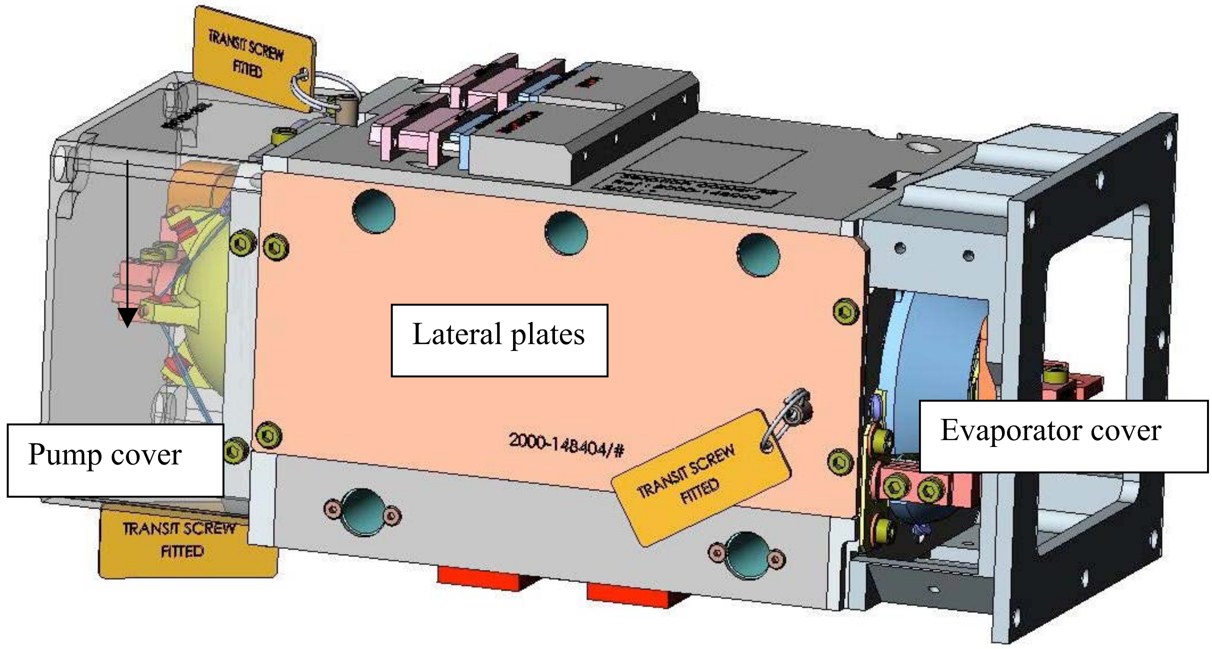
Anomalie(s) : ~~***OUI***~~ [✓ ***NON***] ***Si oui, Ref FA :***

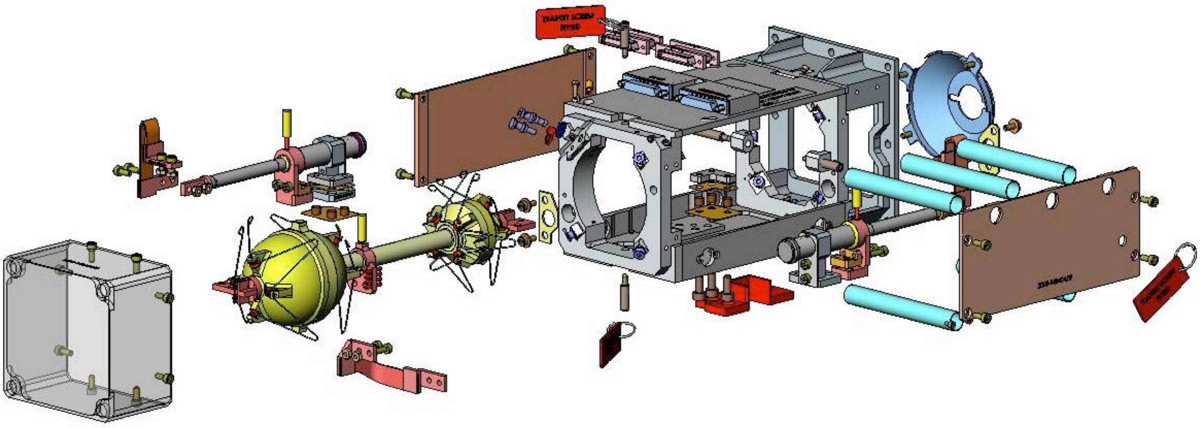
Visa Projet - Nom, date et signature : DUBAND 29/04/02

Visa Qualité – Nom, date et signature :

5 Potential damages to the cooler

The cooler sensitive parts are mainly the thin wall titanium tubes as well as an original suspension system using Kevlar strings. Whenever possible the cooler internal area is protected by covers to prevent any damages. Seen from the outside the cooler is pretty much a closed box with limited access to any internal parts and no access to sensitive parts (see figure below). The dismounting of any covers or plates is prohibited by non authorized staff.



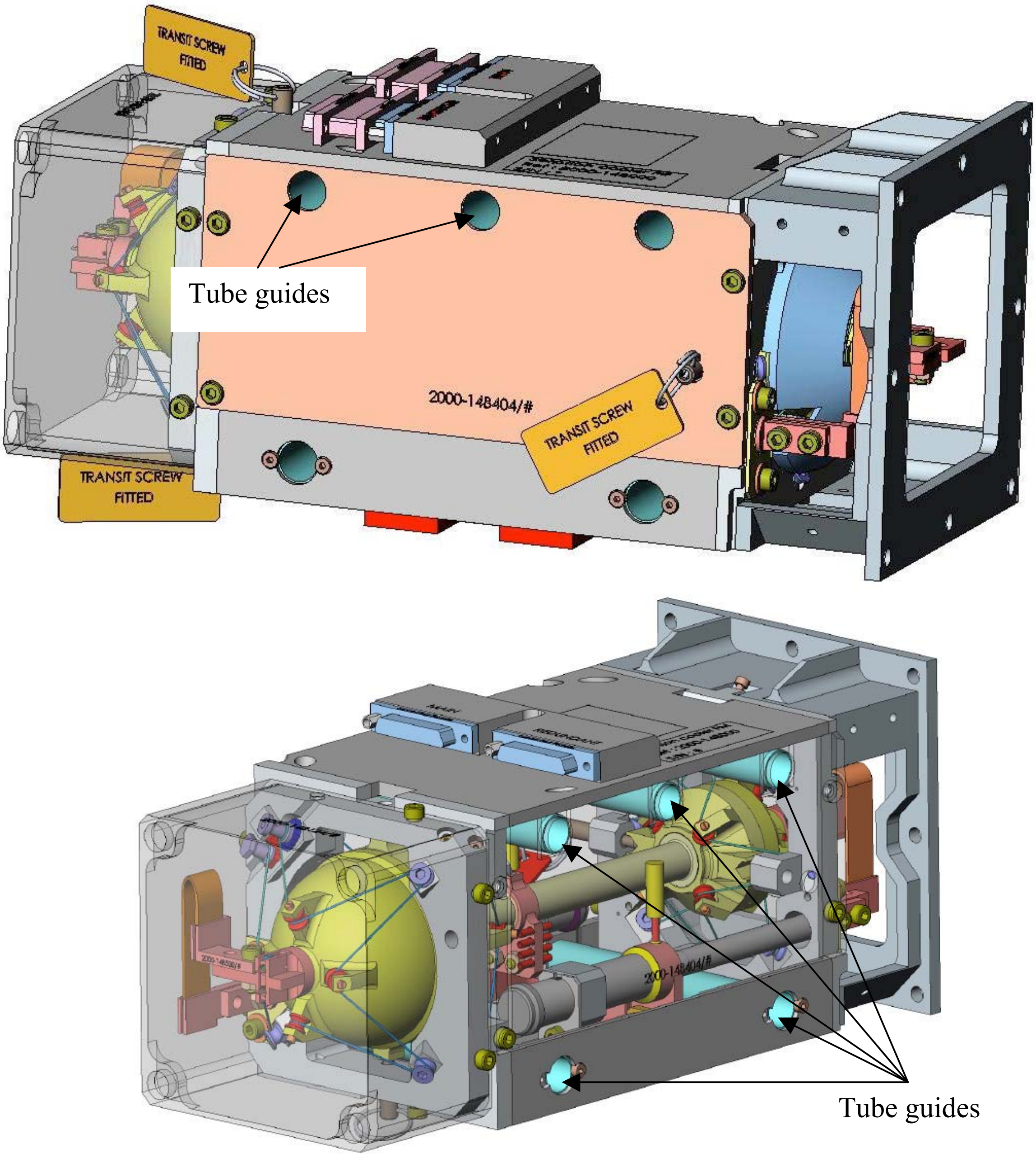


3D exploded view showing the protective covers, lateral plates and guiding tubes for the screws (PACS interface)

5.1 Internal access to the cooler

As much as possible the internal access to the cooler has been restrained and is limited to the mounting interfaces operation, which only concerns the mounting within the PACS instrument.

Within the PACS instrument, the cooler is mounted on the side via 5 screws. These screws are inserted inside the structural box, and to prevent any damage to any internal component as well as to ease the screw mounting, aluminum tubes have been included in the design as guides for the screws and tool (see previous figure and below).



Side view of unit – 5 through holes for PACS mounting
(Lateral plate removed – tube guides are visible)

6 On orbit configuration

Once in orbit the cooler is thermally connected to a superfluid helium tank. The internal pressure of the cooler is then limited to values lower than typically 0.1 MPa (1 bar). Note that this is also the case whenever the cooler is cooled to below roughly 10 K.
Consequently the cooler is not anymore a pressure vessel once cold.