SPIRE & PACS Sorption Coolers
SPECIFICATIONS

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2	0	07/11/2000		All document reviewed – cooler change to 6 liters unit – new reference for the document
2	1	23/11/2000		Various pages. Various paragraphs will be part of the PA/QA plan and thus have been removed.
2	2	27/11/2000		Page 9
2	3	28/11/2000		Page 11 –margin added on mass budget
2	4	18/12/2000		Page 5 : AD2 modified - Page 10 : Vibration spec. Revisited
2	5	18/01/2001		Page 8 : Thermal spec. on cooler slightly revisited
2	6	26/03/2001	12	New format for doc.

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		
CVCM	Collected Volatile Condensable Material		
DML	Declared Material List		
ECSS	European Cooperation for Space Standardisation		
ETF	Environmental Test Facility		
EV	Evaporator		
FIRST	Far Infrared and SubmillimetreTelescope		
FS	Flight spare		
HSE	Heat Switch (on evaporator)		
HSP	Heat Switch (on sorption pump)		
HIFI	Heterodyne Instrument for FIrst		
MGSE	Mechanical Ground Support Equipment		
MOP	Maximum Operating Pressure		
MOS	Margin Of Safety		
MPM	Material, Processes, Mechanical Parts		
N/A	Not Applicable		
PACS	Photoconductor. Array Camera and Spectrometer		
PFM	ProtoFlight Model		
PSS	Product Assurance Specification System		
RD	Reference Document		
RFA	Request For Approval		
SCC	Stress Corrosion Cracking		
S/C	SpaceCraft		
SAp	Service d'Astrophysique		
SBT	Service des Basses Températures		
SCO	Sorption Cooler (full unit)		
SP	Sorption pump		
SPIRE	Spectral & Photometric Imaging Receiver		
SST	Support Structure		

List of Acronyms – Cont'

TML	Total Mass Loss		
TS	Thermal shunt		

1 Scope of the document

This document defines the technical requirements applied to the performances, the design and the qualification of the SPIRE and PACS coolers. It is applicable to the CQM, the PFM and the FS unless otherwise stated. The SPIRE and PACS instruments will share the same cooler design and consequently the latter will be such to be compatible with both interfaces.

2 Documents

2.1 Applicable documents

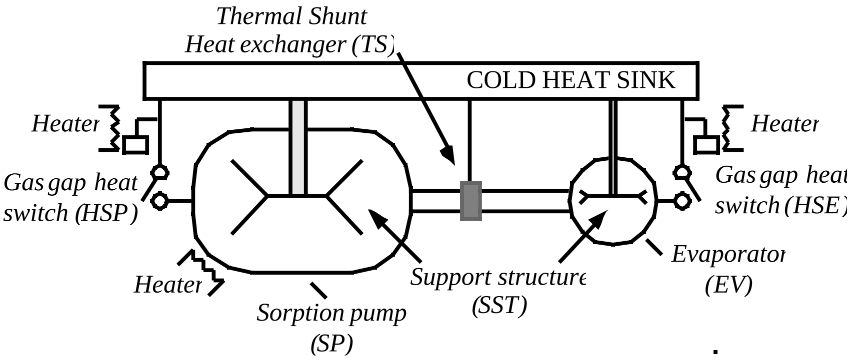
All Applicable Documents are listed in the AD chapter of the CIDL (HSO-SBT-LI-010).

3 Cooler description

3.1 General design

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.

As shown on the figure hereafter the cooler is basically made of 6 components designated as a sorption pump SP and an evaporator EV connected via a pumping line to a thermal shunt TS comprising an heat exchanger, two gas gap heat switches HSP and HSE respectively connected to the sorption pump (SP) and evaporator (EV), and finally a support structure SST. SP, EV, TS and the pumping line are assembled to form a unique component which is the actual "heart" of the cooler. This component is held within SST, which provides firm mechanical support (launch environment) while minimising any parasitic conductive load on the cooler (low temperature environment).



Heat switches are then required for operation of the cooler. The two switches are used to control the temperature gradient; during the condensation phase they are set such that the sorption pump can be heated to release the helium gas and such that liquid condensation occurs into the evaporator EV maintained as the coldest point. The liquid is held into EV by capillary attraction inside some porous material : both the surface tension and the vapour pressure provide forces that drive and hold the liquid at the coldest point. Then the switches are set such that the sorption pump is thermally grounded to the heat sink and such that the evaporator is thermally isolated. The sorption pump provides an evaporative pumping on the liquid helium bath which temperature quickly drops to sub-Kelvin temperature.

Cryogenic switches can be based upon different physical mechanisms. Gas gap heat switches have been selected as the preferred design for the present project.

Gas gap heat switch utilises concentric copper cylinders separated by a small gap which is filled with or emptied of He gas to achieve the switching action. The thermal separation between the two ends is achieved by a thin-walled tube which also provides the mechanical support. The presence or absence of gas is controlled by a miniature cryogenic adsorption pump that can be temperature regulated. Thus one of their main feature is the absence of any moving part, and consequently operation of the cooler is almost then fully controled by three heaters.

For operation in a zero-G environment two aspects are addressed: the liquid confinement and the structural strength required for the launch. The confinement within the evaporator is provided by a porous material which hold the liquid by capillary attraction, and a suspension system using Kevlar wires is designed to firmly support the refrigerator during launch while minimising the parasitic heat load on the system.

3.2 Mission profile

The following table displays the successive phases of the subsystem life under SBT responsability, that is from the end of manufacturing to the delivery to RAL. The subsequent phases are indicated for informations.

Operation	Where	What	Duration	Note
Leak tightness and Proof pressure tests	SBT	Cooler heart	1 week	
Gas gap heat switch thermal check	SBT	HSP, HSE	2 weeks	The switches are filled with 3He and then thermally checked
Thermal test program	SBT	SCO	4 weeks	Verification of cooler nominal operation – test referenced as “health check”
Transport	From SBT to ETF	SCO	4 days	
Bake out	ETF	SCO	1 week	
Transport	From ETF to SBT	SCO	4 days	
Health check	SBT	SCO	2 weeks	Performance verification
Transport	From SBT to ETF	SCO	4 days	
Vibrations tests	ETF	SCO	1 week	
Transport	From ETF to SBT	SCO	4 days	
Health check	SBT	SCO	2 weeks	Performance verification
Transport	From SBT to RAL (TBC)	SCO	4 days	
Cold vibrations test	RAL	SCO	TBD	To be clarified
Transport	From RAL (TBC) to SBT	SCO	4 days	
Health check	SBT	SCO	2 weeks	Performance verification
Cleaning / packing	TBD	SCO	1 week	
Transport	From SBT to RAL	SCO	4 days	
Delivery	RAL	SCO		
Project test plan	RAL	SCO	TBD	
Transport to ESA	RAL to ESA	SCO	TBD	
Delivery	ESA	SCO	TBD	
Satellite test	ESA	SCO	TBD	
Storage	ESA	SCO	TBD	
Launch	Kourou	SCO	TBD	
Operations	Orbit	SCO	4.2 years	
End of operation	Orbit	SCO	TBD	

4 Requirements

4.1 Functional requirements

The sorption cooler will be mounted off a 4 K plate and 1.7 K thermal paths will be provided for the heat switches and thermal shunt for the operation of the cooler. The radiative environment will be 4 K.
The recycling time shall be as short as possible, compatible with the warm heat sink heat evacuation capability. This recycling time has no real impact on the design of a cooler operated from a helium bath. It only has an impact on the recycling procedure (timing, control of heat switches, peak dissipation).
The sorption cooler should be able to operate in any orientation under 1g. However it is understood that during ground test some specific orientations shall be avoided because of potential convective effect. This constraint only applies during the recycling phase while the pump is heated to above 20 K.

A design “plug in” type shall be favored.

4.1.1 Thermal performance requirements

- The net heat lift at 290 mK shall 10 µW at a minimum
- Inside the cooler itself the parasitic heat load to the cold tip must be minimised. As a goal it shall not exceed 12 µW under the nominal operating conditions (1.7 K / 4 K - AD1).
- It is desirable to be able to vary the detectors temperature up to 320 mK. Electronic control shall be provided to perform this task in the flight electronic
- The temperature of the evaporator cold tip should not drift by more than 0.1 mK/h under active temperature control
- The temperature fluctuations at the evaporator cold tip shall be no more than 10 $\mu K/Hz^{0.5}$ in a frequency band from 0.1-10 Hz
- The hold time shall be no less than 22 hours and shall be based on a finite number of days (a minimum of 46 hours is favoured)
- The recycle time shall be no more than 2 hours
- The energy dissipated per cycle due to cooler operation shall be no more than 860 J. the 4K/1.7K thermal architecture calls for an additionnal contribution to the average power dissipated - this contribution (not part of the 860 J) shall not be in excess of 0.6 mW

4.2 Operational requirements

4.2.1 Safety

The structural failure mode shall be leak-before-burst.

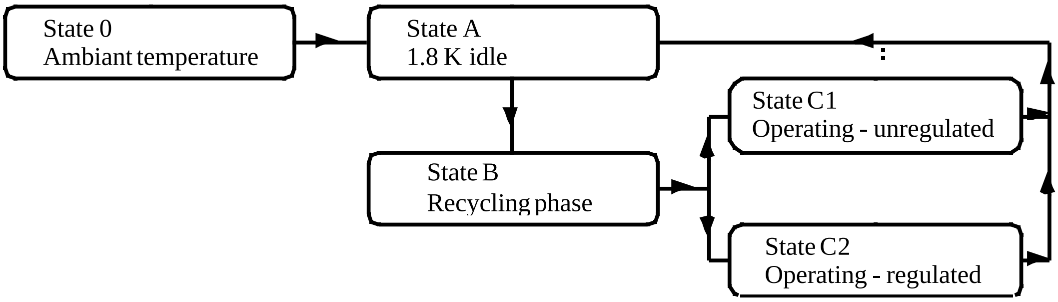
4.2.2 Lifetime

The lifetime of the sorption coolers shall be at least 5 years in orbit of continuous operation / recycling, and 5 years on ground.

4.2.3 Operating modes

The table hereafter summarizes the cooler various states, as the following schematic displays the links between the different states.

State	Description
0 (300 K)	cooler is at ambient temperature (300 K) – this state is only pertinent during ground tests - no functions possible
A – 1.8 K idle	The cooler is in standby mode, ready for recycling. All switches are in the OFF position. No power is dissipated by the cooler neither any current or voltage are required.
B - Recycling	This is the most complex state of the cooler; it comprises sequences of heating and cooling.
C - Operating	This state corresponds to the low temperature phase when the cooler is operating at sub Kelvin temperature. Two sub state can be defined (see below)
C1 - unregulated	No active control of the operating temperature is performed and the ultimate temperature is a function of the thermal environment (load, parasitic, etc…)
C1 – regulated	The evaporator is regulated at some desired temperature. This temperature regulation is achieved by adjusting the pumping speed of the sorption pump via a regulation of its temperature



4.2.4 Commands

The control electronics shall not only be able to perform a full recycling of the sorption cooler, but also shall be able to control the temperature of the evaporator at a desired value in a range [0.29 – 0.4 K] either by controlling the temperature of the pump (and consequently of the pumping speed), or by directly controlling the temperature of the evaporator via direct applied power. The nominal method will be selected at a later stage.

4.2.5 Monitoring

The absolute accuracy on the measurement of the evaporator temperature shall be better than 0.5% at the operating temperature. The absolute accuracy on the measurement of the pump temperature shall be better than 5% at the operating temperature.

4.3 Environmental requirements

4.3.1 Thermal environment

The thermal environment of the electronic unit is not specified here. For the cooler, the following shall apply.

Parameter	Value
Ground and Launch	The sorption coolers shall be compatible with a 72 hours bake out at 80° C.
- Storage and handling temperature *- Humidity*	- Lower limit : N/A - Higher limit (short duration) : never exceeds 80°C – Continuous temperature limit : 60°C - Less than 50% (TBC)
Test or orbit	The heat sink used to operate the cooler will be a pumped helium cryostat. The cooler will be mechanically mounted off a 4 K plate. The radiative environment will be 4 K.

4.3.2 Mechanical environment

4.3.2.1 Limit loads and Launch levels

All listed values are excluding a qualification factor of 1.5, and are based on the specifications given in AD2. The sorption cooler shall be designed for the following quasi-static loads.

Levels	**Case 1**	**Case 2**	**Case 3**
X direction	25 g	-	-
Y direction	-	14 g	-
Z direction	-	-	14 g

The sinusoidal and random vibration levels are displayed in the following table.

Vibration type	Axis of application	Frequency range (Hz)	Power spectral density	Level
Sinusoidal sweep vibration	X, Y, and Z	5 - 27	N/A	22 mm (peak-peak)
		27 - 110		26 g
		110 – 1000		0.2 g
Random	X, Y, and Z	5-150	+6db Hz	Overall equivalent:
		150-700	1.44 g^2/Hz	45g RMS
		700-2000	-3db Hz	

For sinus vibrations, the sweep rate is 2 oct/mn

Random vibrations shall be applied 2.5 mn per axis

It is important to notice that the launch will be done with the coolers at the temperature of the cold heat sink, i.e. below 5 K, and consequently with no internal pressure. Consequently if the vibration tests are performed at room temperature, the effect of temperature on the results shall be addressed by analysis (mechanical and thermal properties of materials, support structure behavior).

4.3.2.2 Acoustic noise

TBD

4.3.2.3 Shock Handling loads

The sorption cooler shall be able to survive without any performance degradation a shock spectrum in each direction of the three orthogonal axes equivalent to a half sine pulse of

0.5ms duration and 200g (0 to peak) amplitude. These levels are provisional and might revisited.

4.3.2.4 Orbit.

The performances of the sorption cooler shall not change during and after attitude motion (rotation) and orbit correction (delta V).

4.3.2.5 Ground

The sorption cooler shall be compatible with normal transportation and qualification / acceptance tests of the spacecraft.

4.3.3 Electrical environment

As a design goal, the sorption cooler (and especially the temperature and heater control and monitoring) shall not generate any electrical noise in the vicinity of the detector, nor being sensitive to emitted radiation.
The sorption cooler shall not remain charged or be subject to electrical discharges.

4.3.4 Radiation environment

The sorption cooler shall not be sensitive to radiations.

4.4 Design and construction requirements

4.4.1 Interchangeability

The sorption cooler is made of the “cooler heart” itself (sorption pump - pumping line – evaporator), two heat switches and a support structure. It is desirable the design shall be made such that each of these components shall be easily interchangeable.

4.4.2 Control electronics

Not specified here (separate item).

4.4.3 Pressure

4.4.3.1 Maximum operating pressure

The maximum operating pressure (MOP) shall be lower than 100 bars absolute (at 80°C).

4.4.3.2 Proof pressure and Burst pressure

The sorption cooler shall be able to meet all the requirements of this specification after having been subjected to an internal pressure of 1.5 times the MOP, at ambient conditions.

The sorption cooler shall be able to withstand an internal pressure of 2.0 times the MOP at ambient conditions during 2 minutes, without any rupture or failure of the components.

4.4.4 Mass

The overall mass of the cooler shall be no more than 1.4 kg ± 20% – This number will be revisited if necessary.

4.4.5 Size

The maximum envelope for the cooler shall be no more than 230 x 100 x 100 mm.

4.4.6 Mechanical stiffness requirement

The first eigenfrequency of the sorption cooler shall be larger than 120Hz.

4.4.7 Design Margin

4.4.7.1 Structural

All structural elements shall be designed to exhibit a positive margin of safety (MOS) with respect to yield and ultimate loads. The margin of safety is defined as the ratio of the allowable loads (or stress) to the applied load (stress when applicable):

$$MOS = \frac{\text{Allowable load (stress)}}{\text{Applied load (stress)}} - 1$$

Unless otherwise stated for all other requirements in this specification a margin of at least 10% shall be taken in the design.

Allowable stresses shall be derived from MIL-HDBK-5. Other sources shall be subject to the PA manager approval

4.4.8 Parts, Material and Processes

4.4.8.1 General

The workmanship and materials used shall be, or shall be shown to be compatible in any future build, of a standard consistent with flight hardware.

The number of materials, mechanical parts types, and processes shall be minimized. Materials and mechanical parts that have been successfully used in similar space applications shall be preferred. Standard processes or known processes previously used in space applications shall be preferred.

Material justification shall prove the hardware structural integrity during the design life.

4.4.8.2 Magnetic materials

The sorption cooler shall not use magnetic materials. The magnetic field measures at 50mm of the unit shall be lower than 0.1 Gauss.

4.4.8.3 Fungus Nutrient materials

Materials shall not support bacterial or fungus growth, and shall be sterilisable without any deterioration of their properties.

4.4.8.4 Flammable, toxic and unstable materials

Flammable, toxic and unstable materials shall not be used unless they are confined.

4.4.8.5 Cleanliness

The cooler shall be class 100 compatible following FED-STD-209-F.

4.4.8.6 Finish

Surface finish shall prevent deterioration from exposure to the environment. Aluminum surfaces shall be treated for corrosion protection coating. Mechanical parts made of stainless steel shall be passivated. Copper thermal interfaces shall be gold plated.

4.4.8.7 Outgassing

Outgassing internal to the sorption cooler (excluding helium) and any subsequent internal vacuum bake-out, shall be compatible with the design life of the cooler.
Outgassing of the external surfaces of the cooler shall demonstrate a Total Mass Loss (TML) <1%, and a Collected Volatile Condensable Material (CVCM) < 0.1%.PSS-01-702 shall be used as a guideline.

4.4.8.8 Susceptibility to stress corrosion

Metallic materials selected shall have high resistance to Stress Corrosion Cracking (SCC) and shall be chosen from table 1 of PSS-01-736. Metallic materials and welds that are not listed in PSS-01-736 or whose SCC resistance is not known, shall be tested according to PSS-01-737.

4.4.8.9 Limited lifetime materials

All materials with limited-life characteristics shall be subject to lot/ batch acceptance tests, to be agreed with the PA manager, and shall have their date of manufacture and shelf-life expiration date marked on each lot/ batch.

4.5 Interface requirements

4.5.1 Thermal interface to the detector.

Gold coated copper plate with two 3.2 mm diameter through holes.

4.5.2 Mechanical interface to the heat sink

The cooler mechanical interfaces must be compatible with both instruments SPIRE and PACS interfaces. The mechanical interfaces are with the instrument 4 K structures. These interfaces are described in AD2 and AD3. For SPIRE the cooler is mounted vertically and the interface is a square 100 x 100 mm with 8 holes 5.3 mm diameter equally spaced (one per corners plus one per side). For PACS the cooler is mounted on the side via 5 holes 5.3 mm diameter (these interfaces will be revisited if necessary).

4.5.3 Thermal interface to the heat sink

The thermal interfaces are with the 1.8 K pumped helium bath (FIRST cryostat). The thermal interface to the heat sink is provided by two copper straps, one for the evaporator heat switch and thermal shunt, and one for the sorption pump heat switch. These strap are out of the scope of these specifications.

4.5.4 Electrical interface

Any electrical wiring necessary for the operation of the cooler shall be designed in order to minimize any possible thermal effect on the cooler itself and on the heat sink.

4.6 Logistic requirements

The sorption cooler shall be compatible with normal transportation.
The coolers shall be equipped for safe handling or transportation.
The storage and handling temperature must never exceed 80°C.