SERVICE DES BASSES TEMPERATURES

FIRST / SPIRE

SPIRE SORPTION COOLER SPECIFICATIONS

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Département de Recherche Fondamentale sur la Matière Condensée
Service des Basses Températures

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1 Scope of the document

This document defines the technical requirements applied to the performances, the design and the qualification of the SPIRE cooler. It is applicable to the CQM, the PFM and the FS unless otherwise stated.

2 Documents

2.1 Applicable documents

	Title	Author	Reference	Date
AD1	Instrument Requirements Document	B. Swinyard	SPIRE-RAL-PRJ-000034 Issue 0.20	15 sept 99

2.2 Glossary

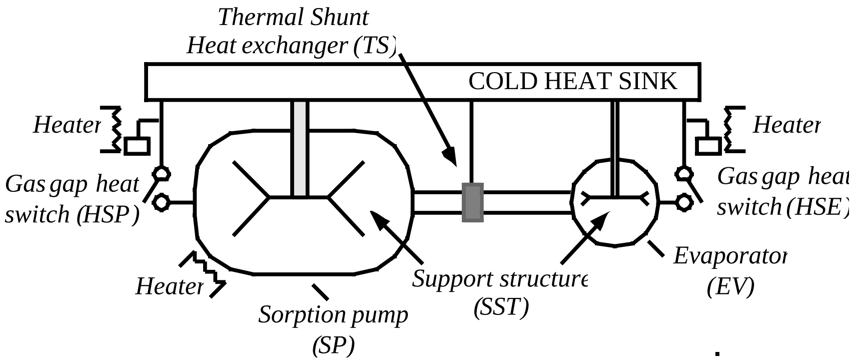
AD	Applicable Document
CEA	Commissariat à l' Energie Atomique
CDR	Critical Design Review
CQM	Cryogenic Qualification Model
EV	Evaporator
FS	Flight spare
HSE	Heat Switch on Evaporator
HSP	Heat Switch on sorption Pump
MGSE	Mechanical Ground Support Equipment
N/A	Not Applicable
PFM	ProtoFlight Model
RFA	Request For Approval
S/C	SpaceCraft
SCO	Sorption Cooler
SP	Sorption pump

3 Cooler description

3.1 General design

The cooling of the SPIRE 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

To be completed

3.3 Product tree

The hardware and software items to be produced during the development and test of the sorption cooler are detailed in the following table. Unless otherwise specified the following list applies to the CQM, PFM and FS models.

Product Item	Descriptor	Number	Function/description	Resp.
Sorption pump, pumping line and evaporator set	SP, EV	1	Provide subKelvin cooling capacity	CEA-SBT
Gas gap heat switch (sorption pump : one – evaporator : one)	HSP, HSE	2	Make and break thermal contact with 1.8 K heat sink	CEA-SBT
Support structure		1	Firmly support the cooler while providing good thermal isolation	CEA-SBT
Cooler heaters		6	Provide heating power	CEA-SBT
Cooler thermometers		8	Temperature measurement	CEA-SBT
Test cryostat		1[*]	Permit thermal characterization of cooler in various orientation	CEA-SBT
Mounting tools		1	Mounting of the cooler in the support structure	CEA-SBT
Verification tools		1	Verify Kevlar support structure nominal tension	CEA-SBT
Cooler container		1	Ground Transportation of full cooler	CEA-SBT
Performance software model		1 [*]	Predict the cooler thermal performance	CEA-SBT
Cooler User Manual		1	Description of principle of operation.	CEA-SBT

[*] : common to all models, i.e. only one unit to supply. Possibly two test cryostat will be required.

To be completed

4 Requirements

4.1 Functional requirements

The sorption cooler will be mounted off a 4 K plate and 1.8 K thermal paths will be provided for the heat switches 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 Performance requirements

The following list of requirements are defined in AD1.

Reference from AD1	Description
Performance Requirements	
IRD-COOL-R01	The coolers shall be able to cool and maintain at 300 mK the detector assembly
IRD-COOL-R02	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
IRD-COOL-R04	The temperature drift of the evaporator cold tip shall be no more than 10 mK/h
IRD-COOL-R05	The temperature fluctuations at the evaporator cold tip shall be no more than 150 $nK.Hz^{0.5}$ in a frequency band from 0.1-100 Hz
IRD-COOL-R06	The system low frequency temperature stability with active temperature control shall be TBD nK at 0.015 Hz at a maximum power dissipation of TBD µW
IRD-COOL-R07	The heat lift at 300 mK shall 10 µW at a minimum
IRD-COOL-R08	The hold time shall be no less than 46 hours
IRD-COOL-R09	The recycle time shall be no more than 2 hours
System Requirements	
IRD-COOL-R10	The mechanical interface is with the instrument 4 K structure
IRD-COOL-R11	The thermal interfaces are with the 1.8 K pumped helium bath (FIRST cryostat)
IRD-COOL-R12	The thermal load onto the cryostat during cold operation shall be no more than 1.2 mW.
IRD-COOL-R13	The energy dissipated per cycle due to cooler operation shall be no more than 860 J. the 4K/1.8K thermal architecture calls for an additionnal contribution to the average power dissipated - this contribution shall not be in excess of 0.4 mW
IRD-COOL-R14	The overall mass of the cooler shall be no more than 1 kg (this number will be revisited once the mounting interfaces are clearly defined)
IRD-COOL-R15	The maximum envelope for the cooler shall be no more than 200 x 100 x 100 mm
IRD-COOL-R16	The preferred orientation is with the axis pump-evaporator along the S/C Y axis, with the evaporator at the Y end – TBC
IRD-COOL-R17	It is desirable to increase all heaters resistances (currently 402 ohms), so the resistance of the cryoharness can also be increased. The maximum voltage available is 28 volts.

4.2 Operational requirements

4.2.1 Safety

The structural failure mode shall be leak-before-burst.
For handling or transportation, the coolers shall be equipped with protection caps

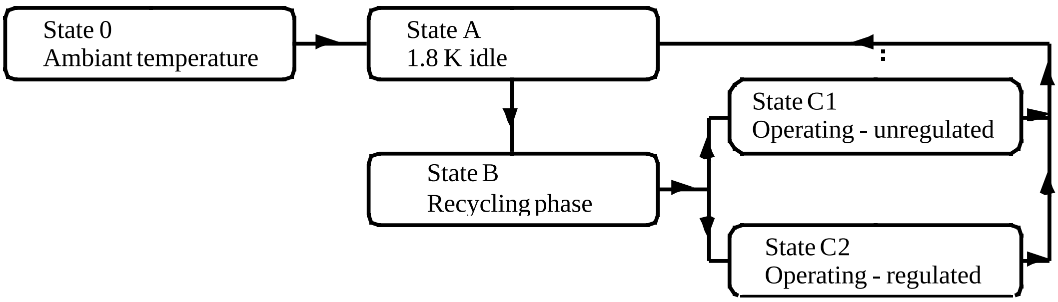
4.2.2 Lifetime

The lifetime of the sorption coolers shall be at least 5 years in orbit of continuous operation / recycling, and 3 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 as described below
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] by controlling the temperature of the pump (and consequently of the pumping speed)..

4.2.5 Monitoring

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

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 : never exceeds 80°C - Less than TBD %
Test or orbit	The heat sink used to operate the cooler will be a pumped helium cryostat. The cooler will 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

The sorption cooler shall be designed for 15g limit loads acting simultaneously in 3 orthogonal directions.

Vibration - sinusoidal / random
Qualification levels. (data from ISO instruments requirements).

Vibration type	Axis of application	Frequency range (Hz)	Power spectral density	Level
Sinusoidal sweep vibration	X, Y, and Z	5-23 23-100	N/A	±11mm peak ±22.5g peak
Random	X, Y, and Z	20-150 150-300 300-600 600-2000	+6db/oct 0.09g^2/Hz -9db/oct -3db/oct	Overall equivalent: 6g RMS

For sinus vibrations, the sweep rate is 2 oct/mn
Acceptance levels are divided by a factor 1.5, and sweep rate shall be 4 oct/mn

Random vibrations shall be applied 2 mn per axis
Acceptance levels can be divided by 2.25, and duration 1mn 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

N/A

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.

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.

4.3.5 Optical environment
N/A

4.4 Design and construction requirements

4.4.1 Interchangeability
The sorption cooler are made of the "cooler" 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 Mechanical strength requirements
The sorption cooler shall withstand the environment it will encounter during its lifetime without degradation of performances. For the design limit loads specified in §4.3.2, the following factors shall be applied :

- Qualification factor 1.5
- Yield factor 1.1
- Ultimate factor 1.25

The following specific factors apply on identified components:
Cables: Ultimate stress factor of safety: 3.

4.4.5 Fatigue life and fracture control

Fatigue life analysis shall be based on a scatter factor of 4. It is expected the leak before burst failure mode will be fulfil by the tube itself and not by a burst disk. Water burst tests will be performed on 3 samples to demonstrate the leak before burst crack shape and pressure.

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 TBD approval

4.4.7.2 Thermal

The effect of a change of 20% on the heat sink temperature shall be evaluated. In any case the sorption cooler thermal performance shall remain within 50% of the specified requirements.

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 Materials, Processes and Mechanical parts (MPM) approval and listing

All MPM meeting the requirements of this document shall be approved by submitting to TBD the Declared Materials List. If these requirements are not met, a RFA shall be submitted to TBD.
A Declared Materials List (DML) shall be drawn up, according to the requirements of ECSS-Q-70 § 3.1.3. The format of PSS-01-700, issue 2, Annex B, is a suitable example. Materials with limited-life characteristics and non-metallic materials shall be highlighted.
Mechanical parts shall be included in the DML as a separate group.
Process details shall also be included in the DML for the appropriate material. Critical processes shall be highlighted.

4.4.8.3 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.

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

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

4.4.8.6 Cleanliness
The cooler shall be class 100 compatible following FED-STD-209-F. The electronic unit shall be class 100 000 compatible following same standard.

4.4.8.7 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.

4.4.8.8 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.

4.4.8.9 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.

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

4.4.8.11 Processes
The use of existing ESA documents shall be maximized. In particular the following documents shall be consulted:

- PSS-01-708 for soldering
- PSS-01-726 for crimping
- PSS-01-728 for repair and modification of PCB's
- PSS-01-738 for surface-mounting technology PCB's

Critical processes shall be identified and reported to TBD through a critical process list or the DML. Any process that involves critical or catastrophic hazards shall be identified as critical.

4.5 Interface requirements

4.5.1 Thermal interface to the detector.
Gold coated copper plate with two 4.2 mm diameter through holes. (This is yet to be defined. TBD)

4.5.2 Mechanical interface to the heat sink
(This is yet to be defined. TBD)

4.5.3 Thermal interface to the heat sink
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 and are under TBD responsibilities. TBD.

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.
For handling or transportation, the coolers shall be equipped with protection caps.
The storage and handling temperature must never exceed 80°C.

4.7 Verification requirements

4.7.1 General
Requirement verification shall be performed (in particular, the qualification process) according to the requirements of ECSS-Q-20 § 4.6

4.7.2 Verification methods
A verification plan shall be proposed and shall define how all given requirements will be verified. The verification can be done by test, analysis and review of design (similarities) or inspection.
A special chapter of the verification plan shall cover the pre-qualification testing. It shall define the:
- Type of test to be performed
- Level of test parameters
- Test article
- Test equipment and set up
- Step by step procedure
- Pass/ fail criteria and test requirements

4.7.3 Verification matrix
A verification matrix shall be established as part of the verification plan with rational as to various parameter are verified by analysis, review of design, inspection, similarity with other models or by testing.

4.7.4 Test responsibility
Responsibilities for the execution of the tests shall be defined.

4.7.5 Rejection and retest
The local project manager shall, as part of his test / verification plan and procedures clearly define rejection / acceptance criteria in compliance with the objective of the test and define conditions when a retest may be acceptable.

4.7.6 Test Report
The local project manager shall prepare reports to document the tests performed. Test reports shall include, in addition to the test data records and a summary of the test results, a conclusion stating the extent to which compliance with the relevant requirement(s) has been demonstrated, and what actions are recommended to overcome areas of non-compliance.