Report on the PACS/SPIRE ^{3}He Cooler Detailed Design Review

Bruce Swinyard
16 July 2001

SPIRE-RAL-REP-000868

1. Introduction

The Detailed Design Review for the PACS/SPIRE cooler has been held in order to fulfil the following:

1. To place the design of the cold cooler unit under configuration control at supplier (SBT Grenoble) and project level (SPIRE – RAL and PACS - SAp).
2. To have confidence that the design as presented and documented will fulfil the specifications laid upon it by the instruments
3. To close the external interfaces of the cooler with the two instruments.
4. To ensure that the cooler development plan meets the requirements for the projects
5. To ensure that the cooler PA plan meets the requirements for the projects
6. To allow release of the drawings for the manufacture of the cooler cold unit

To these ends a detailed set of documentation has been presented to the review board and a presentation of the design has been made to the board on the 17th May 2001 at CEA-SBT Grenoble.

This report will mostly follow the documentation that has been presented to the board and will make detailed comments only in the context of the documentation. These comments arise both from written submission and verbal submission and discussion at the presentation.

1.1 Review Board Members

Chair Bruce Swinyard RAL/SPIRE
Sam Heys RAL/SPIRE - Thermal
Doug Griffin RAL/SPIRE - Systems
Berend Winter MSSL/SPIRE - Structural
Jean-Louis Augeures - CEA-SAp/PACS/SPIRE - Programme
Louis Rodriguez - CEA-SAp/PACS - Detectors/Thermal
Jerome Martignac - CEA-SAp/PACS - Detectors
Chris Jewel - Estec - External expert

2. Documents Submitted

All refer to *SPIRE and PACS Sorption Coolers*

Specifications HSO-SBT-SP-001 iss 2.6 26/03/2001
Interface Control Document HSO-SBT-ICD-012 iss 0.0 10/04/2001

Development Plan HSO-SBT-PL-002 iss 2.2 26/03/2001
Product Assurance Plan HSO-SBT-PL-006 iss 0.1 27/04/2001
Configuration Item Data List HSO-SBT-LI-010 iss 0.0 27/04/2001
Hardware Tree HSO-SBT-LI-009 iss 0.0 25/04/2001
Declared Processes List HSO-SBT-LI-005 iss 0.0 25/04/2001
Declared Material List HSO-SBT-LI-004 iss 0.0 24/04/2001
MAIV Flow Chart HSO-SBT-FC-003 iss 0.0 25/04/2001

The FMECA was not provided
A Test Plan was not provided

3. Summary

A major outcome of the discussion during the review meeting was to emphasise the difference between the cooler cold unit and the overall SPIRE or PACS cooling system. The former is the SBT deliverable item and the subject of this review. The latter consists of the associated electronics and thermal hardware within the instruments and is the responsibility of the respective instrument design teams and not deliverable by SBT.

Although there are details within the Cooler documentation and assembly and test plans that need to be addressed before the SPIRE/PACS Cooler DDR is completed: it is agreed by the board that the cold unit design is compatible with the requirements of the SPIRE and PACS instruments and that the interface between the cold unit and the instruments is sufficiently well documented to allow the construction of the unit to proceed without further delay.

However there are significant issues to be addressed in the documentation for the cooler and in the definition of the cooler AIV Plan. The major outstanding issues are summarised in the following list and constitute formal Review Item Discrepancies (see table in annex 2):

1. A Cooler Electrical Specification Document must be written by SBT and agreed between SBT/SAp and RAL including a description of the cooler operation and the requirements on the on-board software.

2. A cooler EGSE has been identified as deliverable to the SPIRE project for cold testing in the absence of the SPIRE warm electronics. The specification for this unit must be included either in the test plan or in the electrical specification document.

3. The approach to cleanliness control during the cooler build and test phases need to be revisited. The proposed approach carries unacceptable risks.

4. A performance characterisation test of the cooler is required by the SPIRE project before the unit is delivered. This should be identified in both the AIV plan and the schedule.

5. A comprehensive list of SPIRE deliverable items and who is responsible for them should be drawn up – this should encompass all aspects of the cooling system for SPIRE.

6. The reporting lines for PA and systems issues need to be clarified between SBT and the SPIRE and PACS project teams. This should include a documented and agreed document hierarchy for the cooler cold unit.

7. The FMECA should be submitted to ensure that the redundancy philosophy proposed is adequate.

These issues must be addressed within the context of the appropriate documents before the Cooler DDR can be considered closed. Other less urgent items are covered in the detailed comments on the individual documents.

4. Notes and Comments on Individual Documents

4.1 Design Description

This was presented as a viewgraph pack at the design review meeting. The following are notes on the presentation and issues arising from it.

The cooler design is based on experience gained from the IRTS instrument and the cooler built under an ESA TRP contract. During the TRP contract and subsequently several design issues have been addressed including:

- **The porous material** required for the confinement of the ^{3}He. This used to use silicon sponge but it is no longer available from NASA. A French supplier has now been found (Procelit). The porous material needs to be able to resist high temperature so that the cooler parts can be welded or brazed.
- The use of the **titanium alloy TiAV6** has been proven
  TiAV6 has a factor of two better thermal conductivity performance at cryogenic temperature compared to stainless steel.
- **The Kevlar suspension system** and locking mechanism has been improved, the new tensioning system uses a ratchet.
  Kevlar was chosen for the suspension system because of its excellent yield strength versus thermal insulation properties. The problem of creep with the Kevlar cord to be used has been addressed by a test programme. This has showed that, with suitable pre-conditioning, it will take 22 years to lose as much as 10% of its pre-load tension. Static tests have also been done on the size of pulley that should be used. These show that a pulley larger than 1 mm is required to maintain the UTS for Kevlar type 34 and larger than 2mm for Kevlar for type 11.
  The test programme is now moving on to do dynamic tests with a motor pulling on the Kevlar. During these tests the static tests will be done occasionally to ensure that the breaking strength has not changed.
- **The structure** design has been improved and stiffened.

- **The confinement vessel** design has been proven. The tube between the evaporator and the pump has to be straight and cannot be too long because one cannot make long sections of Ti tube. This means that there is a restriction on the ground operation of the cooler to keep the evaporator below the pump during recycling.
  The construction of the pressure vessel has changed from TIG to EB welding which is a much more reproducible process.
- **The heat switch design** has been changed to prevent the sorption pump HS turning on due to radiative load from the pump during recycling. This design change also hides the warm parts of the HS so preventing straylight from being a problem during cold operation. A snubber has been provided for the HS mini-pumps to assist with the vibration loads. The gap between the mini-pump and the snubber is 100 microns.
- **Possible failure modes** have been investigated further and a FMECA has been contracted out – this has not as yet been made available.
  Leak before burst failure is mandatory for 80 bar cooler, the major failure component in the confinement vessel is the tube. Testing on the tube design and construction has been carried out. This shows that the burst pressure for gas and water is the same but that the failure mode is slightly different. Burst pressure for Ti tube is 36 Mpa compared to a calculated value from sample testing of Ti used for the tube manufacture of 35 Mpa. This is to be compared to 8 Mpa actual operating pressure.
  The question was raised as to what happens if the sorption pump thermally shorts? This will increase the power required to turn it on and provision is required within the warm electronics to provide extra power into the sorption pump.
  The TRP cooler did fail with one of the HS in the on state. This was due to the use of a stiff copper connection rather than a braided copper type. Standardly the braided copper has been used since and there has been no repeat of the failure and the cooler has worked correctly.
  The FMECA is reported as indicating that using more switches is less reliable than using one – it is also technically not possible to mount these switches in series. So the decision has been made not to have parallel HS.
  If one Kevlar cord is broken then the resonant frequency does not change very much. However the evaporator position may change. This is an issue for PACS and they will raise a requirement on the stability of the position of the evaporator during cooldown and in the case of a broken cord.

4.2 Specification Document.

No formal RIDs are raised on this document, although the requirement for an electrical specification document is raised as an issue here. The following points should be addressed in a future version.

Page 5 Section 3.2 (table)
Clarification is still required on the need for cold vibration and at what temperature. The statement from Chris Jewel at the review was that Estec will not insist on cold vibration but it must be shown that there will not be a problem cold by analysis. The possibility exists of “cold qualification” on the STM or CQM unit within the SPIRE structure.

Page 6. Section 4.1.1
All specifications should be numbered for reference in other documents (test plans etc)
It is decided that the 10 uK/rt(Hz) specification applies to the cooling system as a whole and will be placed onto the temperature control specification within the detector sub-system specification document.
The drift specification for 0.1 mk/hour should have a time period associated with it. This will be specified by PACS and SPIRE system teams.

Page 7 Section 4.2.3
In the table the regulated state is definitely using the pump in the text below both pump and heat switch are mentioned as possibilities. We need some urgent attention as to how these modes will work; what requirements they place on the electronics and on board software and what the thermal dissipation will be to the He tank for these modes - all this is required to be placed in a "Cooler Electrical Specification" document.

Page 7 Section 4.2.5
Monitoring the temp. "absolute accuracy will be 0.5% of the measured temperature at operating temperature"

Page 7 Section 4.3.1
What do we write for the specification for the fact that level1 may not be at 4.2 K – specified performance at a number of interface

Page 8 Section 4.3.2.1
The limit loads for the sub-system do not appear in AD2 (The IID-B) but in the SPIRE (and presumably PACS) structure interface document which should be an AD for this document and the ICD (SPIRE-MSS-PRJ-000617)

Page 8/9 Section 4.3.2.3
The shock loads do not apply to focal plane units within Herschel.

Page 9 Section 4.4.4
Remove statement on mass from specification document this should appear in the interface control document and drawings only.

P11 Section 4.5.2
The cooler unit interfaces with SPIRE are definitely NOT in AD2 - see comment above.

4.3 Interface Control Document

Significant RIDs are raised in the context of this document (see summary and list in annex 2). The following additional comments apply.

Page 1 Section 1

The cooler operational interfaces such as thermal dissipation in different cooler states; required currents into heaters to get the cooler into different states; required voltages/currents for the thermistors etc need to be specified – either here or in an Electrical Specification Document.

Page 2 Section 2
SPIRE Structure ICD is not in the AD list - SPIRE Thermal Configuration Control Document is not in AD list - SPIRE DRCU ICD and Spec Docs are not in AD list - all of these should be

Page 3 Section 3 and rest of document
References to temperature levels should always be to Level 0 and Level 1. References to "4 K level" and "He Tank" through out this and other documents are misleading as the temperatures of Level 0 and Level 1 can and will vary depending on the instrument operational state.

Page 4 Section 4
Mass+uncertainty and C.o.G+uncertainty should appear on the drawing. The eigenfrequency should also be quoted somewhere in the document

Page 6 Section 4.3
Typo - "Nw" inst. "Nm"

Page 9 Section 5.1
The interface definition is not complete. The cooler is mounted from the SPIRE/PACS structure which are held at Level 1 of the cryostat - this may be anywhere from <4 K to as much as 6 K. Also there must be requirements on the temperature at the end of the Level 0 strap. What are the limits on these temperatures for correct cooler operation in terms of hold-time and lift versus mounting temperature?

Page 9 Section 5.2.1
These tables aren't readily translatable into an interface definition. It would be more concise to give required values for the interface conductivities.

Page10 Section 6
The electrical interfaces for such things as maximum allowed voltages/currents; required current stability/control in each operating mode; maximum inrush current; speed of switch on etc should be placed in a separate drive electronics requirements specification document.

4.4 Development Plan

RIDs are raised in the context of this document: a compliance matrix between tests and specifications must be presented in this document and a separate performance test plan must be established.

Page 6 Section 4.2
For the record the following points were raised at the review.

Materials availability (including ^{3}He) status was reported as follows:

Ti – have enough
^{3}He – have 100 liters need 30 liters comes from U.S.
Order copper soon (not a problem)
Have 12 km kevlar
Have charcoal
Have porcelit
Need to get heaters and thermometers for flight

There will not be a problem with the Kevlar losing tension as long as the correct procedures are followed (see above)

Page 9 Section 5.2.3
Both a warm and cold "Health Check" should be identified as separate tests.

Page 10 Section 5.3
Wrong AD in table? These do not refer to the IID-B. The table only appears to refer to qualification and interface verification.
A compliance matrix between numbered specifications in the specification document and referenced test procedures should be presented.
A set of performance verification tests must also be established to characterise the performance of the cooler before delivery to the instruments. A test plan covering this must be written.

Page 11 Section 5.5
Additionally to the equipment listed here, they is an issue as to how the drive electronics will get to be integrated with the cooler. The SPIRE CQM cooler will arrive at RAL under present plans without drive electronics. There needs to be identified some EGSE for the drive electronics. The situation for PACS is different as the cooler is delivered to SAp and they have to integrate electronics and cooler before delivery.

Page 12 Appendix A is not in the document - presumably the milestone list or schedule?

4.5 PA Plan

Two major issues need to be clarified in the context of this document that were raised and discussed at the review.

General:
It is not at all clear how to go into configuration control because of the difference between the approach on the two project and who is in charge of the PA plan. Who does the SBT PA report to who approves the documents etc? SBT will provide a document list with suggested names for signature as responsible person from each project.

Page 11 Section 6.3
The statement is made "not assembled in a clean room". Neither PACS nor SPIRE project teams like the idea of having a fully assembled unit cleaned at the end of the integration and test programme. Rather they would prefer to have the procedures carried out under clean conditions and exposure to non-clean conditions logged to ensure the unit is kept within its contamination budget.

4.6 Materials List

Page 10 Item 19-1
Type of varnish not identified

4.7 Process List

Two general points were addressed at the review:
The assembly of the Kevlar suspension system could be added as a process.

The control of processes carried out by sub-contractors. The sub-contractors for the cooler manufacture will not always deliver process descriptions for commercial reasons, but all work is delivered with a certificate of conformity.

5. Matters Arising not covered in the documentation

5.1 Temperature Control

A study is required on the feasibility of focal plane temperature regulation for both SPIRE and PACS focal planes.

- SBT will provide basic information (possible regulation modes and respective performances).
- Regulation to be specified at system level by SPIRE and PACS.

5.2 Harness

SAp wish to have a central procurement of the internal harness for the SPIRE cold sub-systems – they are willing to pay but do not want to take responsibility for the procurement and specification. This issue will be discussed by the SPIRE project team.

5.3 Provision of Flight Spare

A single dedicated flight spare unit is to be built under present plans, however SPIRE requires a delivery of a working and flight worthy flight spare unit for inclusion in the flight spare instrument. The CQM units provided for SPIRE (at least) will anyway be refurbished into flight worthy condition. Whether the dedicated flight spare unit is required under these circumstances is TBD. A note is being prepared by Lionel on this subject.

Annex 1: Meeting Agenda

Start 9:00 a.m.

9:00 Welcome and aims of the meeting - Bruce Swinyard

9:15 Main specifications from SPIRE/PACS - 20 minutes + questions

9:45 Heritage from ESA TRP - 15 minutes

10:00 Evolution from ESA TRP - 15 minutes

10:15 Pause de Cafe

10:30 Presentation of current design - 30 minutes plus questions and clarifications

11:15 Presentation and discussion of all interfaces - Lionel - 15 minutes
Berend - 5 minutes
+ Questions and Clarification

11:45 Expected performance - 30 minutes plus questions and clarification

12:30 Dejeuner

13:30 Ground support equipment - 15 minutes (?)

13:45 AIV Plan - 15 minutes + questions and clarification

14:00 Planning - 20 minutes plus questions and clarification

14:30 PA Plan - 15 minutes

14:15 Final questions from the board/floor

15:00 Pause de The

If possible/optional 15:15 tour of the lab - 45 minutes

16:00 Board plus key SBT people get together and immediate feedback

16:30 End

Annex 2: RIDs

Spacecraft/Project	Herschel	**Document No**	TBA
Instrument	SPIRE	**Organisation**	CEA-SBT

Document Title	Cooler Electrical Specification Document (TBW)

Action

A Cooler Electrical Specification Document must be written by SBT and agreed between SBT/SAp and RAL including a description of the cooler operation and the requirements on the on-board software

Source of Action	Cooler Detailed Design Review 17 May 2001

Closure Comments

A Cooler Electrical Specification document has been drafted by SBT and will be issued on October 8th 2001 (draft available on demand). This document will encompass:

- the specification of the input and output channels (temperature, heaters).
- the definition of all the modes supported by the cryocooler and their interconnection.
- all the necessary informations to operate the cryocooler in the various mode (including the possible regulation modes(*)) as well as the way to pass from one mode to another (including failure detection, possible recovery actions).

(*) details on the various regulation capability including pro and cons analysis will be addressed in a separate document.

Most of the information required by SAp to develop the cooler driving electronics have been already given to SAp via e-mail, live or on the phone discussions.

Initiator	BMS	**Actionee**	Lionel Duband
Date Raised	15/5/2001	**Due Date**	10/9/2001

RID Signatures and Closure Date required

Project Manager	**Date**	**PA Manager**	**Date**

RID Number: HR-SP-SBT-RID- 002

Spacecraft/Project	Herschel	**Document No**	TBA
Instrument	SPIRE	**Organisation**	CEA-SBT
Document Title	Cooler Electrical Specification Document (TBW)		

Action

A cooler EGSE has been identified as deliverable to the SPIRE project for cold testing in the absence of the SPIRE warm electronics. The specification for this unit must be included either in the test plan or in the electrical specification document.

Source of Action	Cooler Detailed Design Review 17 May 2001

Closure Comments

A dedicated EGSE to drive the cooler for cold testing does not prove to be necessary. In fact, during these test phases, the cooler can be operated using standard lab current supplies and a temperature measurement bridge. This is in fact how SBT operates the cryocooler during test phases.

The list and specification of the necessary lab devices as well as an operator manual covering the various operation phases will be issued.

Initiator	BMS	**Actionee**	Lionel Duband
Date Raised	15/5/2001	**Due Date**	10/9/2001

RID Signatures and Closure Date required

Project Manager	**Date**	**PA Manager**	**Date**

Spacecraft/Project	Herschel	**Document No**	HSO-SBT-PL-006 iss 0.1
Instrument	SPIRE	**Organisation**	CEA-SBT
Document Title	Cooler PA Plan		

Action

The approach to cleanliness control during the cooler build and test phases need to be revisited. The proposed approach carries unacceptable risks.

Source of Action	Cooler Detailed Design Review 17 May 2001

Closure Comments

The approach has been revisited and CEA-SBT is currently evaluating the implantation of a complete clean room.

However SBT is still awaiting for cleanliness specifications both from SPIRE and PACS; these specifications are needed urgently for SBT to make a decision on the clean room specification as well as on the cleanliness philosophy.

Initiator	BMS	**Actionee**	Lionel Duband
Date Raised	15/5/2001	**Due Date**	10/9/2001
RID Signatures and Closure Date required			
Project Manager	**Date**	**PA Manager**	**Date**

RID Number: **HR-SP-SBT-RID- 004**

Spacecraft/Project	Herschel	**Document No**	TBA
Instrument	SPIRE	**Organisation**	CEA-SBT
Document Title	Cooler AIV Plan		

Action

A performance characterisation test of the cooler is required by the SPIRE project before the unit is delivered. This should be identified in both the AIV plan and the schedule.

Source of Action	Cooler Detailed Design Review 17 May 2001

Closure Comments

A dedicated performance test has been added in the Cooler MAIV Plan. This test will be carried out before delivery of each cooler model.

Initiator	BMS	**Actionee**	Lionel Duband
Date Raised	15/5/2001	**Due Date**	10/9/2001

RID Signatures and Closure Date required

Project Manager	**Date**	**PA Manager**	**Date**

Spacecraft/Project	Herschel	**Document No**	HSO-SBT-PL-002 iss 2.2
Instrument	SPIRE	**Organisation**	CEA-SBT
Document Title	Development Plan		

Action

A comprehensive list of SPIRE deliverable items and who is responsible for them should be drawn up – this should encompass all aspects of the cooling system for SPIRE.

Source of Action	Cooler Detailed Design Review 17 May 2001

Closure Comments

For each instrument (SPIRE and PACS), CEA-SBT will manufacture and deliver the following models:

- 1 Structural Model.
- 1 CQM, 1 FM and 1 FS (TBC) each including: a structural box (SBT), a cooler "heart" (SBT), 2 heat switches (SBT), heaters (SBT (CQM), SAp (FM, FS)), thermometers (SBT (CQM), SAp (FM, FS))
- 1 carrying case.

For SPIRE, SBT will deliver the Cooler models to RAL for integration on the instrument.
For PACS, SBT will deliver the Cooler models to SAp for integration on the Photometer detector focal plane.

The driving electronics is provided by SAp as part of the DRCU for SPIRE and BOLC for PACS.

Initiator	BMS	**Actionee**	Lionel Duband
Date Raised	15/5/2001	**Due Date**	10/9/2001

RID Signatures and Closure Date required

Project Manager	**Date**	**PA Manager**	**Date**

RID Number: **HR-SP-SBT-RID- 006**

Spacecraft/Project	Herschel	**Document No**	TBA
Instrument	SPIRE	**Organisation**	CEA-SBT
Document Title	Cooler Management Plan		

Action

The reporting lines for PA and systems issues need to be clarified between SBT and the SPIRE and PACS project teams. This should include a documented and agreed document hierarchy for the cooler cold unit.

Source of Action	Cooler Detailed Design Review 17 May 2001

Closure Comments

Each of the documents issued by SBT will be formally approved by the SAp HSO project manager and the SAp PA manager.

For SPIRE SBT will continue working as in the past : each document will be issued directly by SBT to the project but the SAp Project Manager will then produce an official letter asking the SPIRE Project to approve the document. The SAp Project manager will keep record of the issued documentation and of the approval by the SPIRE Project..

Initiator	BMS	**Actionee**	Lionel Duband
Date Raised	15/5/2001	**Due Date**	10/9/2001

RID Signatures and Closure Date required

Project Manager	**Date**	**PA Manager**	**Date**

RID Number: **HR-SP-SBT-RID- 006**

Spacecraft/Project	Herschel	**Document No**	TBA
Instrument	SPIRE	**Organisation**	CEA-SBT
Document Title	Cooler FMECA		

Action

The FMECA should be submitted to ensure that the redundancy philosophy proposed is adequate.

Source of Action	Cooler Detailed Design Review 17 May 2001

Closure Comments

The new FMECA version is almost available and will be sent no later than Sept. 30th, 2001

Initiator	BMS	**Actionee**	Lionel Duband
Date Raised	15/5/2001	**Due Date**	10/9/2001

RID Signatures and Closure Date required

Project Manager	**Date**	**PA Manager**	**Date**