TITLE: # Planck Sorption Cooler Inflight Prediction Report

DOC. TYPE: Report

PROJECT REF.: PL-LFI-PST-RP-042 **PAGE:** I of III, 13

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CHANGE RECORD

Issue	Date	Sheet	Description of Change	Release
1.0	Aug 2008	All	First Issue of the Document	===

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1 INTRODUCTION AND SCOPE

The scope of this document is to show the predictions of inflight performance of the Sorption Cooler subsystem as a consequence of analysis, the Subsystem Testing and Unit testing, and the Planck System Level Thermal Vacuum, Thermal Balance, and Cryogenic verification campaigns. These predictions will be compared with those in Section 4.7 of (AD1) as required by ESA to demonstrate that the Sorption Cooler will operate as expected in the mission.

2 APPLICABLE DOCUMENTS

[AD 1] Planck Sorption Cooler ICD, PL-LFI-PST-ID-002, Is.3.1, 20/7/04. Annex of the LFI IID-B, SCI-PT-IIDB-LFI-04142, Is.3.1, 20/7/04

[AD 2] Planck Instrument Flight Acceptance Review (IFAR) Procedure, SCI-PT-51537, Is.1/Rev1, 9/6/08

3 The Requirements on the SCS from Section 4.7 of AD (1)

In this section the requirements given in the Planck Sorption Cooler ICD, PL-LFI-PST-ID-002, Is.3.1, 20/7/04, Section 4.7 are reproduced.

3.1 COOLING REQUIREMENTS (AD1, SEC. 4.7.1)

Table 4.7-1 Total Cooling Requirements

	Power (mW)
HFI 18K	190
LFI 20K	796
TOTAL	986

3.2 COOLING POWER CAPABILITY (AD1, SEC. 4.7.2)

(Accounts for parasitics from active and redundant coolers)

(For a TMU Total Input Power of ≤ 470 W*)

Cryogenic Heat Load		Operating Point
LVHX1	**LVHX2**	**Temperatures of TMU heat transfer components (LVHX1, LVHX2, PC3, PC2, PC1, SCC)**
≥190 mW	≥796 (1) mW	Maximum Flight Allowable Temperatures, Operating, per 4.3.1.1 and 4.3.1.2

(1) Accounts for 150 mW allocated and agreed to by LFI, to implement PID at LVHX2 interface per TSA (near LVHX2) to a < 100 mK fluctuation level. This 150 mW are assuming a spacecraft radiator temperature stability of 6K; 2K; 1K (see 5.9.3.1)

3.3 TEMPERATURE STABILITY (AD1, SEC. 4.7.3)

Interface	**Temperature[2] Fluctuation** (maximum – minimum), **Over TMU Operating Period[1]** ***(@ ≤ 470 W TMU Input Power)***
LVHX1	≤0.45 K
LVHX2	≤0.1 K

Notes: 1. TMU Operating Period defined in 4.3.2

(2) Temperature is measured on LVHX1 and LVHX2, and reported for the condition of zero attached thermal mass. These fluctuations are assuming a spacecraft radiator temperature stability of 6K; 2K; 1K (see 5.9.3.1)

3.4 LIFETIME (AD1, SEC. 4.7.4)

The SCS shall be capable of operating 6 months before launch (3 months at JPL + 3 months for Europeans operations) and 18 months on-orbit.

The requirement above is applicable to a single Sorption Cooler (either the nominal or redundant) of the Sorption Cooler Subsystem.
Note that this requirement has been the subject of a Request for Waver that has been accepted by both LFI, HFI and by ESA Project. PL_LFI_JPL_RFD_010 entitled Planck SCS TMU limited life and post regeneration power. The acceptance of the request for waver allows the life of a sorption cooler to be extended by regeneration of its hydride beds in orbit. The RFW is attached as Annex-1.

3.5 RELEVANT EXTRA INFORMATION FROM AD1

The requirements reproduced in Secs. 3.1 to 3.4 quote other sections of AD1 for further information, and these sections of AD1 are reproduced below for completeness.

3.5.1 Interface Temperatures to Ensure Cooling Capability(Sec. 4.3 of AD1)

4.3.1.1 HFI Cooling Requirements

The table gives the estimated HFI cooling requirements at 18K +1.02K/–0.5K, including all parasitics and 4K cooler pre-cooling. Margins originating from precooling temperature less than 60K, will be discussed jointly by JPL and the two instruments teams and managed by the LFI Project Manager.

HFI Cooling Requirements (at 60K environment)

	Power (mW)
18K cooling	190

4.3.1.2 LFI Cooling Requirements

The table gives the estimated LFI Cooling requirements, including HFI parasitics intercepted at a temperature of 20K (+2.5K/-2.5K). Margins originating from precooling temperatures less than 60K, will be discussed jointly by JPL and the two instrument teams and managed by the LFI Project Manager.

LFI Cooling Requirements (at 60K environment)

	Power (mW)
20K cooling (including TSA)	796

3.5.2 Effect of Warm Radiator Temperature on the Cooling capability (from Sec 5.9.3.1 of AD1)

5.9.3.1 Radiator Temperature Stability

In addition to holding the average interface temperature within the range specified in Table 5.7.3, the radiator interface will also maintain the following levels of temperature stability peak to peak under the absorbing compressor elements adjacent to the cooling compressor element (at outer shell interface on top of the heat-pipes) :

- First adjacent element: 8.4 K
- Next adjacent element: 5.2 K
- Next most adjacent element: 5.2 K

[Note: For example, in the case where the 6 elements of the operating cooler of Figure 5.9.3-2 are performing the following (Table 4.4.1-1) functions,

- Element 1 (Heatup)
- Element 2 (Desorbing)
- Element 3 (Cooling)
- Element 4 (Absorbing)
- Element 5 (Absorbing)
- Element 6 (Absorbing),

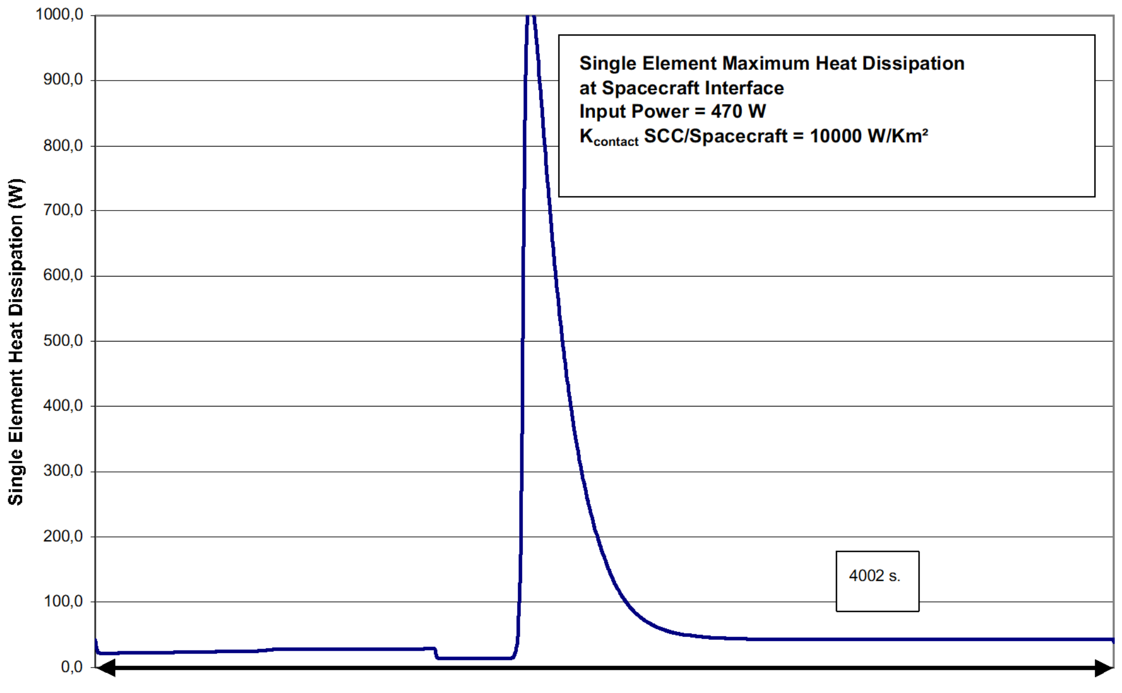

Fig. 5.9.3-2 Variation of the heat loading at the Radiator Interface (single bed)

Of course, the element operation sequence is cyclic, and the spatial location of the cooling element and adjacent elements will shift with the cycle period identified in section 4.3.2.

The assumptions taken on the radiator temperature stability to evaluate the temperature stability at HFI and LFI cold end interfaces were optimistic wrt the actual radiator design. Therefore, the impact on HFI and LFI will be :

- HFI : added temperature fluctuation : +160 mK (see 4.7.3)
- LFI : added required power for the TSA : + 53 mW (see paragraph 4.7.2)

4 Best Estimate of Heat Loads on LVHX1 and LVHX2

LFI	Current Estimates values in mW	Comments	HFI	Current Estimates values in mW	Comments
70-44-30 GHz FEMs	344,8	Based on measured dissipation values for each of the 11 FEM			
44 WG's Including Upper and Lower Supports	227,0	Derived from RAA Thermal Model			
LFI Harness	8,0	Estimate for the LFI Cyroharness			
Radiant	2,0	Derived from RAA Thermal Model			
LFI Struts	23,0	Derived from RAA Thermal Model			
PID in SCS for LFI	150,0	Agreed dissipation between LFI and JPL with no consideration of a lower performance radiator			
LFI Total	**754,8**	**Compare to the requirement with a 60K interface of 798 mW**	**HFI Total**	**190,0**	**Allocation to HFI**
Heater added to LFI FPU	20,0	Load is on LVHX2. Heaters required to ensure telescope outgassing products do not condense on LFI/HFI. The maximum parasitic load of 20 mW from the sum of two heaters (nominal and redundant			
Thermal blanket added to LFI FPU against stray-light	40,0	Load is on LVHX2.This blanket is in the configuration but heat load is understood to be a worst case.			
Total Load on LVHX2	**814,8**	**See conditions in text below table**	**Total Load on LVHX1**	**190,0**	

Table 4.1 Best Estimates of Heat Loads on the Cold Ends of an operating Sorption Cooler with an interface temperature of 60K

In Table 4.1 is given the breakdown of the actual best estimates of the heat loads on an operating cooler sorption cooler assuming a 60 K interface temperature. Note that while LFI would be inside the heat loads agreed for the design of the Sorption Cooler, the actual heat load on LVHS2 is higher because of the System Level needs that became visible late in the development program.

These extra heat loads are on LVHX2 and are:-

- 20mW of parasitic heat load due to the need of the system to add heaters to the LFI FPU to ensure that during the out-gassing activity on the telescope LFI and HFI remain at temperatures high enough to exclude the possibility of condensation of the out-gassing products occurring on their surfaces
- 40mW of parasitic heat load derived from an extra thermal blanket that has been attached to LFI to eliminate stray-light. The need for this addition was agreed between both LFI and HFI.

Thus the heat load on LVHX2 exceeds the requirement by 19mW which, depending on the actual performance of the warm radiator could be further increased by 53mW (see Sec. 3.5.2) through increased dissipation of the TSA, to 72mW.

5 SCS Performances

5.1 PERFORMANCE SUMMARY

The following SCS performances have been evaluated at the end of the integration and test campaign of the Planck Satellite.

Performance Parameter	BOL		EOL	
	WR T (K)	PC3C T (K)	WR T (K)	PC3C T (K)
	270	47	273	48
LVHX1 T (K)	17.1 K		17.5	
LVHX1 ΔT (K)	0.45 K		0.45 K	
TSA T (K)	18.6 K		18.6 K	
TSA ΔT (K)	0.1 K		0.1 K	
Heat Lift (W)	1.050 W		1.050	
Input Power (W)	305 W (TMU)		470 W (TMU)	
Cycle Time	1050 s		525 s	

Table 5-1 SCS Performance Summary

5.2 LIFETIME PERFORMANCE

Based on the results of the PFM2 testing results the estimated lifetime for the two SCS systems are:

Nominal (FM2)	15.5 months
Redudant (FM1)	13.5 months

6 Conclusions

The results of the SCS TV/TB Test Campaigns (PFM1 and PFM2) show that SCS N & R performances are in agreement with requirements.

Only exceptions concern Cold End T fluctuations that are exceeded due to gravitational orientation as was expected according to JPL document D-46302, 01/06/2008, “Planck Sorption Cooler Two-Phase Flow Summary”.

ANNEX-1 PL-LFI-JPL-RFD-010

Request for Deviation

1 PROGRAM : Herschel-Planck
Plance SCS TMU

3 DOC.: PL-LFI-JPL-RFD-010
ISSUE / REV.: 1/1
DATE: 10 October 2006 PAGE 1 OF

4 TITLE : Planck SCS TMU Limited Life and Post-Regeneration Power Increase

5 OTHER SYSTEMS/CI'S AFFECTED ☒ YES ☐ NO

6 RECURRING DEVIATION ☒YES ☐ NO

7 BASELINE AFFECTED

8 CONTROLLED DOCUMENTS/SPEC AFFECTED

SPEC/DOC. NUMBER	ISSUE/ REV.	DATE	TITLE	APPL. PARAGRAPH
PL-LFI-PST-ID-002	3.1	20Jul04	Plancl Sorption Cooler ICD	4.32

9 EFFECT ON COST/PRICE
None – reflects as-built config

10 EFFECT ON DELIVERY SCHEDULE
IF APPROVED None
IF DISAPPROVED Delay

11 QTY

12 EFFECT ON :
LOGISTICS ☒ SUPPORT ☐
I/F ☐ PERFORMANCE ☒

13 DESCRIPTION

As documented in PL-LFI-JPL-NCR-001, the lifetime of the Planck Sorption Cooler Compressor Element hydride is less than the required 2 years. The impact of shorter hydride life is gradual degradation of cooler performance, resulting in failure to meet heat lift specifications at the nominal input power and maximum specified V-groove 3 radiator temperatures at the end of mission life (836 mW heat lift, with 470W power input, and 60K precooler temperature).

As described in NCR-001, the planned technique for recovery of cooler lifetime has heretofore been regeneration, wherein the hydride temperature would be elevated for several hours. Unfortunately, regeneration testing on the FM2 TMU, conducted in June 2005, showed that the process results in an increase in nominal cooler operating power, as documented in PL-LFI-JPL-NCR-003. Additional testing on a spare compressor element / gas gap heat switch in July 2005 further verified and quantified the post-regeneration power increase.

Required cooling, at worst case thermal interfaces, cannot be provided within allocated power, for required lifetime, with redundancy.

cont.sheets ☐

14 JUSTIFICATION / REASON

The lifetime limitation is a function of hydride chemical degradation. While the effects of this degradation can in fact be "reset" through the regeneration process, it comes at the price of increased cooler operating power, due to the production of methane within gas gap heat switches and an attendant increase in off-state thermal conductance.

cont.sheets ☐

15 ORIGINATOR: COMPANY JPL NAME David Pearson SIGNATURE Dave Pearson 10/18/2006

16 APPROVAL NEED DATE: 27 October 2006

17

SUBCONTR.	System Manager Dave Pearson Date: Oct 16, 2006	☒ a ☐ d ☐ c	PA Manager J – Lee Date: 10/16/06	☒ a ☐ d ☐ c	Program Manager [signature] Date: 10/16/06	☒ approved ☐ disappr. ☐ cond.appr.
....	System Manager Date:	☐ a ☐ d ☐ c	PA Manager Date:	☐ a ☐ d ☐ c	Program Manager Date:	☐ approved ☐ disappr. ☐ cond.appr.
PRIME	System Manager Date:	☐ a ☐ d ☐ c	PA Manager Date:	☐ a ☐ d ☐ c	Program Manager Date:	☐ approved ☐ disappr. ☐ cond.appr.
CUSTOMER	System Manager Date:	☐ a ☐ d ☐ c	PA Manager Date:	☐ a ☐ d ☐ c	Program Manager Date:	☐ approved ☐ disappr. ☐ cond.appr.

1 PROGRAM :	2 **Request for Deviation**	3 DOC.: ISSUE / REV.: DATE: PAGE 2 OF

13 DESCRIPTION
14 JUSTIFICATION / REASON

It is the intent of this RFD to integrate the two JPL NCRs, PL-LFI-JPL-NCR-001 and PL-LFI-NCR-003, since the actions necessary to close them are related. PL-LFI-JPL-NCR-001 is concerned with the lifetime requirement for each sorption cooler not being met, while PL-LFI-NCR-003 concerns the gas-gap contamination due to the regeneration process, which was intended to alleviate the problem assocaiated with PL-LFI-JPL-NCR-001. JPL has stated that with the two sorption coolers the mission requirements can be met, but the process of regeneration must be a part of the spacecraft capability as some mission scenarios will require it. JPL will provide support to develop optimized sorption cooler operations to maximize cooler lifetime . This support will be given through the entire mission operations. The work will be done under the supervision of Gianluca Morante.