Publication Year	2006
Acceptance in OA	2024-02-07T13:54:18Z
Title	Planck SCS PFM1 test report
Authors	MORGANTE, GIANLUCA, Pearson, David, Stassi, Patrick, TERENZI, LUCA
Handle	http://hdl.handle.net/20.500.12386/34721
Volume	PL-LFI-PST-RP-016

TITLE:

Planck SCS PFM1 Test Report

DOC. TYPE: **REPORT**

PROJECT REF.: **PL-LFI-PST-RP-016** **PAGE:** **I of IV, 29**

ISSUE/REV.: **1.0** **DATE:** **JUNE 2006**

Prepared by	**G. MORGANTE** ***INAF - IASF Bologna*** **D. PEARSON** ***JPL, Pasadena*** **P. STASSI** ***LPSC - Grenoble*** **L. TERENZI** ***INAF - IASF Bologna*** ***LFI - SCS*** ***Project System Team***	**Date:** **Signature:**	June 8th, 2006 ____________________ ____________________ ____________________ ____________________
Agreed by	**C. BUTLER** ***LFI*** ***Program Manager***	**Date:** **Signature:**	June 8th, 2006 ____________________
Approved by	**N. MANDOLESI** ***LFI*** ***Principal Investigator***	**Date:** **Signature:**	June 8th, 2006 ____________________

DISTRIBUTION LIST

Recipient	Company / Institute	E-mail address	Sent
G. CRONE	ESA – Noordwijk	Gerald.Crone@esa.int	Yes
J. MARTI-CANALES	ESA – Noordwijk	Javier.Marti.Canales@esa.int	Yes
A. HESKE	ESA – Noordwijk	Astrid.Heske@esa.int	Yes
O. PIERSANTI	ESA – Noordwijk	Osvaldo.Piersanti@esa.int	Yes
M. BRAGHIN	ESA – Noordwijk	Massimo.Braghin@esa.int	Yes
C. DAMASIO	ESA – Noordwijk	Claudio.Damasio@esa.int	Yes
J. PATTERSON	ESA – Noordwijk	Janice.Patterson@esa.int	Yes
B. GUILLAUME	ESA – Noordwijk	Bernard.Guillaume@esa.int	Yes
P. OLIVIER	ESA – Noordwijk	Pierre.Olivier@esa.int	Yes
J. RAUTAKOSKI	ESA – Noordwijk	Jan.Rautakoski@esa.int	Yes
J. TAUBER	ESA – Noordwijk	jtauber@rssd.esa.int	Yes
B. COLLAUDIN	AAS – Cannes	Bernard.Collaudin@alcatelaleniaspace.com	Yes
J.P. CHAMBELLAND	AAS – Cannes	Jean-Philippe.Chambelland@alcatelaleniaspace.com	Yes
P. ARMAND	AAS – Cannes	Pierre.Armand@alcatelaleniaspace.com	Yes
I. DOMKEN	CSL – Liege	idomken@ulg.ac.be	Yes
C. LAWRENCE	JPL – Pasadena	Charles.R.Lawrence@jpl.nasa.gov	Yes
M. FRERKING	JPL – Pasadena	Margaret.A.Frerking@jpl.nasa.gov	Yes
D. PEARSON	JPL – Pasadena	David.P.Pearson@jpl.nasa.gov	Yes
J.L. PUGET	IAS – Orsay	puget@ias.u-psud.fr	Yes
J. CHARRA	IAS – Orsay	jacques.charra@ias.u-psud.fr	Yes
J.J. FOURMOND	IAS – Orsay	Jean-Jacques.Fourmond@ias.u-psud.fr	Yes
S. VARESI	IAS – Orsay	sylvain.varesi@ias.u-psud.fr	Yes
D. SANTOS	LPSC - Grenoble	Daniel.Santos@lpsc.in2p3.fr	Yes
P. STASSI	LPSC - Grenoble	stassi@lpsc.in2p3.fr	Yes
C. VESCOVI	LPSC - Grenoble	vescovi@lpsc.in2p3.fr	Yes
F. PANCHER	LPSC - Grenoble	pancher@lpsc.in2p3.fr	Yes
O. ZIMMERMAN	LPSC - Grenoble	ozimmer@lpsc.in2p3.fr	Yes
F. MELOT	LPSC - Grenoble	frederic.melot@lpsc.in2p3.fr	Yes
E. LAGORIO	LPSC - Grenoble	lagorio@ lpsc.in2p3.fr	Yes
N. MANDOLESI	IASF – Bologna	mandolesi@iasfbo.inaf.it	Yes
C. BUTLER	IASF – Bologna	butler@iasfbo.inaf.it	Yes
LFI System PCC	IASF – Bologna	lfispcc@iasfo.inaf.it	Yes
G. MORGANTE	IASF – Bologna	morgante@iasfbo.inaf.it	Yes
L. TERENZI	IASF – Bologna	terenzi@iasfbo.inaf.it	Yes
M. BERSANELLI	UNIMI – Milano	Marco.Bersanelli@fisica.unimi.it	Yes
A. MENNELLA	UNIMI – Milano	aniello.mennella@fisica.unimi.it	Yes

CHANGE RECORD

Issue	Date	Sheet	Description of Change	Release
0.1	May 10th 2006	All	Initial Release	===
0.2	May 24th 2006	1, 22, 23	P. Stassi contribution	===
0.3	May 30th 2006	All	Including Comments	===
1.0	June 1st 2006	All	General Revision & Formatting	===

TABLE OF CONTENTS

1. Applicable and Referenced Documents

Number	**Title**
AD1	Planck PFM1 Thermal Test Specification, H-P-3-ASP-TS-0883 v. 4.0
AD2	SCS Test Requirement for Planck PFM1, H-P-3-ASP-TS-0993 v. 2.0
AD3	Planck SVM TBT Thermocouples Location, H-P-TN-AI-0117 v. 3.0
AD4	Planck Sorption Cooler ICD, PL-LFI-PST-ID-002 v. 3.1
AD5	Herschel/Planck IID-A, SCI-PT-IIDA-04624 v. 4.0
RD1	Planck SCS User Manual, PL-LFI-PST-MA-002, v.0.3
RD2	Planck Sorption Cooler Electronics User Manual, PL-MA-CRS-0036 v. 1.0
RD3	Planck SCE TC and TM Structures, TS-PSCBC-100010-LPSC, v. 7.1
RD4	Planck SCE OBSW Problem Report – SPR-PSCBC-600094-LPSC
RD5	Planck SCE S2K 2.3eP5 IEGSE USER GUIDE, UM-PSCZ-600091-LPSC v.1.1
RD6	Planck SCE FMECA, PA-PSCB-100006-ISN v. 1.5

2. Scope & Introduction

This document reports the results of SCS testing performed during the PFM1 test campaign at the CSL (Centre Spatial de Liège) facilities. Both SCS TMU's were integrated on the S/C but only the unit indicated by SCS-R, officially considered the Redundant one of the two delivered by JPL, was tested. Ground testing of the Nominal unit, FM2, will be carried out in the next PFM2 test campaign.

The test campaign spread over about 2 months, from February to March 2006. The SCS was first activated at the end of February for a warm healthcheck in order to check its functionality after shipping and then it was switched on again on March 18th 2006 for the actual cryogenic test: after a thermal vacuum healthcheck, the cooler was started and tested in all cases according to the test plan [see AD1].
This report covers tests, results and issues related to the SCS only.

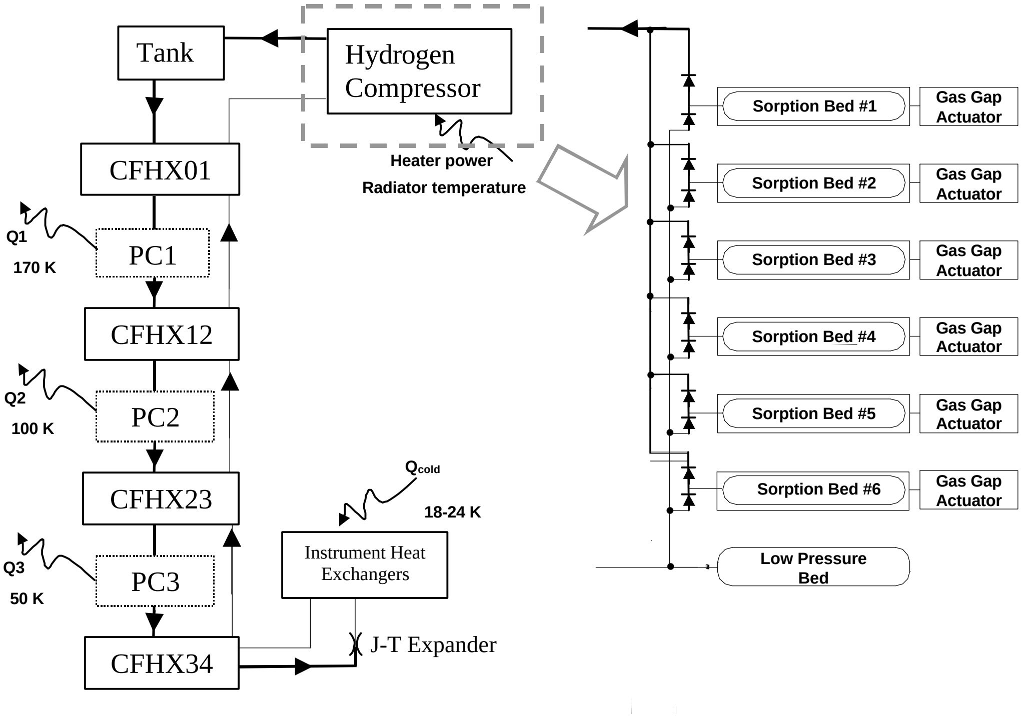


Figure 2-1. Planck Sorption Cooler Schematic

2.1. SCS General Description

The Planck Sorption Cooler uses isenthalpic (Joule-Thomson) expansion of hydrogen gas to produce approximately 1 W of heat lift at ≤19 K. A six-element sorption compressor is used to produce a pressure of 4.8MPa. The Joule-Thomson expander is chosen for a nominal mass flow rate of 6.5 mg/s. To provide the required cooling the high-pressure gas needs to be cooled to below 60 K. This is accomplished with a counter-flow, tube-in-tube heat exchanger and three pre-cooling stages nominally set at 155, 115, and 55K. With the pressure and mass flow, the temperature of the coldest pre-cooler determines the amount of cooling power while the higher temperature pre-coolers reduce the amount of heat released at the last pre-cooler. To provide independent temperatures for the two Planck instruments, two liquid-vapor heat exchangers (LVHX1 and LVHX2) are used to remove heat from the instruments. Temperature stability is obtained by maintaining the vapor pressure constant by compressor element absorption. During absorption, heat is rejected to a radiator whose temperature is crucial for determining the absorption pressure and in turn the temperature and temperature stability of the two instruments. Figure 2-1 is a schematic depiction of the cooler. A detailed description of the Sorption Cooler System can be found in RD1.

2.1.1. Planck Sorption Compressor

The “engine” of the cryocooler is the sorption compressor. It serves two main functions: 1) production of high-pressure hydrogen gas flow at ~4.8 MPa; and 2) to maintain a stable gas recovery rate, which keeps the return pressure, and thus the liquid temperature, constant. This is done by the use of compressor elements (or “beds”) whose principle of operation is based on the properties of a unique sorption material that is able to absorb large amounts of hydrogen isothermally at relatively constant pressure and to desorb high-pressure hydrogen when heated to around 200 C. Heating of the sorbent material is accomplished by electrical resistance heaters while the cooling is achieved by thermally connecting the compressor element to a radiator sized to reject the cooler input power at 270 K ±10 K. Six compressor elements are required for the compressor to operate cyclically. At any moment one bed is releasing gas (desorption) at 5 MPa, three are absorbing gas to maintain the vapour pressure constant, while the other two beds are being heated and cooled in preparation for desorption and absorption respectively. The ability of the compressor to maintain the vapour pressure of the liquid constant is determined by the absorption properties of the sorbent material. As a compressor element fills with hydrogen, the pressure will rise slightly and this is the main source of temperature fluctuations at the LVHX’s. The cycle time of the compressor is 667 seconds and is determined by the cooler requirements and the 60-second spin cycle of the Planck spacecraft.

As each compressor element undergoes the cyclic heating and cooling, a gas-gap heat switch is used to couple or decouple the compressor element to the radiator depending on its state. The heat switches use a sorbent material that when heated releases gas to turn the switch “ON” and when cooled reabsorbs the gas to isolate the element. During the heat-up and desorption cycles the heat switch is “OFF”, while during the cooldown and absorption cycles the heat switches are “ON”.

The compressor also includes four 1-liter tanks on the high-pressure side (HPST). These tanks serve as a gas ballast to smooth mass flow variations due to the desorbing compressor elements. On the low pressure side of the compressor is a low pressure storage bed (LPSB) that stores hydrogen gas when the cryocooler is not operating to keep the system pressure below 1 Bar. Additionally, the LPSB stores gas that is evolved as the cooler ages. Two heaters are mounted to the LPSB. One is used in nominal operation to control the gas concentration in the compressor elements, while the second is used when the cooler is started to move gas from the LPSB to the HPST. Check valves direct flow out of the compressor elements into the HPST and control flow from the low pressure manifold and the LPSB back into the absorbing beds.

2.1.2. Piping Assembly and Cold End (PACE)

The Piping Assembly and Cold End comprise the two main parts of the PACE. The piping assembly consists of a tube-in-tube heat exchanger and three pre-cooler interfaces. This assembly serves to pre-cool the high-pressure gas stream to below 60 K to produce the required cooling power. The three pre-coolers in flight will attach to V-groove radiator panels with nominal temperatures of 155 K (PC1), 110 K (PC2), and 55 K (PC3). For PC3, three stages are implemented to distribute the heat into the radiator panel.

A carbon cold trap is also located on the coldest radiator to remove condensable contaminants from the high pressure gas stream. As shown in Figure 2-2, the Cold End as the second assembly, consists of the Joule-Thomson (JT) expander, two liquid-vapour heat exchangers, and an assembly (formerly known as LR3), to heat balance the Cold End.

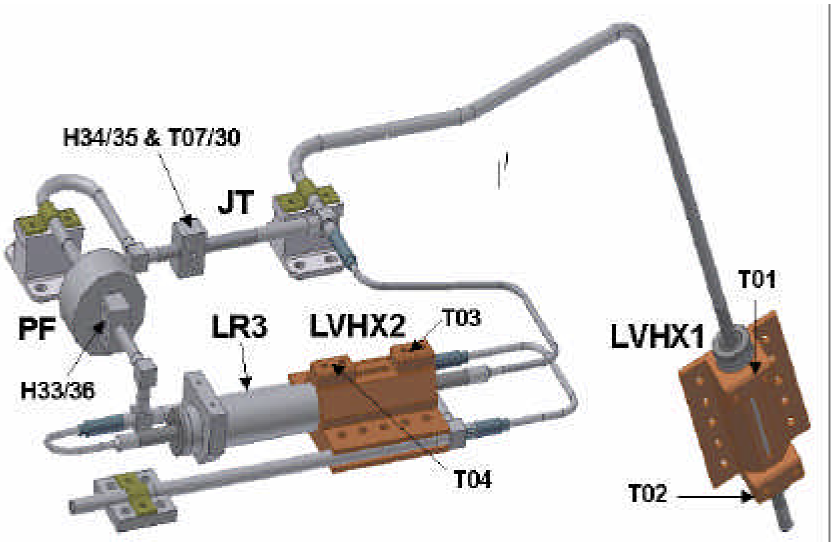


Figure 2-2 Schematic of Cold End.

The JT expander is selected to produce a flow of 6.5 mg/s +/- 5% for an input pressure of 4.8 MPa. The first liquid-vapour heat exchanger, LVHX1, attaches to the HFI instrument. It is designed to provide a temperature lower than 19 K with 190 mW of cooling power. The second LVHX, attaches to the LFI instrument to provide a temperature less than 22.5 K and 646 mW of cooling power. At the interface of LVHX2 and LFI, a copper block is designated as the Temperature Stabilization Assembly (TSA). Two stainless steel strips are sandwiched in between to define the conductance between the TSA and LVHX2. This arrangement allows active temperature control at the interface using a PID algorithm. 150 mW is allocated for the TSA for implementation of this temperature control scheme. In addition, the high-pressure gas stream exchanges heat with LVHX2 to pre-cool the gas and maintain its temperature constant before passing through the JT expander. Other elements of the cold-end include a tube-in-tube heat exchanger that joins the last pre-cooler to the cold-end, and a particle filter that protects the JT expander.

2.1.3. SCS sensors

The TMU include T and P sensors, used to monitor and control the SCS, can be summarized in the following tables.

T sensors

Item	Location	Nominal (K)	Resolution requested for specified Range				Type
			Range I (K)	Resolution I (K)	Range II (K)	Resolution II (K)	
T1	LR1	18	16-25	0.010	20-80	1	CERNOX
T2	LR1	18	16-25	0.010	20-80	1	CERNOX
T3	LR2	20	16-25	0.010	20-80	1	CERNOX
T4	LR2	20	16-25	0.010	20-80	1	CERNOX
T5	LR3	20	16-24	0.004			CERNOX
T6	LR3	20	16-24	0.004			CERNOX
T7	JT	20	16-25	0.010	20-150	1	CERNOX
T8	PC3C	55	40-80	0.1	80-330	2	CERNOX
T9	PC3B	70	40-80	0.1	80-330	2	CERNOX
T10	PC3A	80	40-80	0.1	80-330	2	CERNOX
T11	PC2	100	80-150	0.1	150-330	2	CERNOX
T12	PC1	160	140-190	0.1	190-330	2	CERNOX
T13	HPST1	300	220-320	0.040			PRT
T14	HPST2	300	220-320	0.040			PRT
T15	Shell CE1	270	220-350	0.040			PRT
T16	Shell CE2	270	220-350	0.040			PRT
T17	LPSB	300	220-320	0.040			PRT
T18	LPSB	300	220-320	0.040			PRT
T19							
T20	CE1	40	0 - 275	0.3	275-425	1	KTC
T21	CE2	40	0 - 275	0.3	275-425	1	KTC
T22	CE3	40	0 - 275	0.3	275-425	1	KTC
T23	CE4	40	0 - 275	0.3	275-425	1	KTC
T24	CE5	40	0 - 275	0.3	275-425	1	KTC
T25	CE6	40	0 - 275	0.3	275-425	1	KTC
T26	Shell CE3	270	220-350	0.040			PRT
T27	Shell CE4	270	220-350	0.040			PRT
T28	Shell CE5	270	220-350	0.040			PRT
T29	Shell CE6	270	220-350	0.040			PRT
T30	JT	20	16-25	0.010	20-150	1	CERNOX

P Sensors

Name	Location	Nominal (bar)	Range (bar)	Resolution (bar)	Resolution (mV)	Accuracy (bar)	Input (Vdc)	Return (Vdc)
P1	CE1	50	0 – 67	0.07	5	0.3 FSR	28	0 – 5
P2	CE2	50	0 – 67	0.07	5	0.3 FSR	28	0 – 5
P3	CE3	50	0 – 67	0.07	5	0.3 FSR	28	0 – 5
P4	CE4	50	0 – 67	0.07	5	0.3 FSR	28	0 – 5
P5	CE5	50	0 – 67	0.07	5	0.3 FSR	28	0 – 5
P6	CE6	50	0 – 67	0.07	5	0.3 FSR	28	0 – 5
P7	HPST	50	0 – 67	0.07	5	0.3 FSR	28	0 – 5
P8	LPSB	0.5	0 – 3.4	0.01	14	0.02	28	0 – 5

Another set of important sensing lines is acquired by the electronics in order to monitor power used or dissipated and to check the SCE box operating temperatures. These extra values are:

SCE sensors

Channel	Type	Range
28V	Internal voltage	26 to 29 V
+12V	Internal voltage	11 to 13.1 V
VCC	Internal voltage	5 to 5.2 V
+15V	Internal voltage	14 to 17.3 V
-15V	Internal voltage	-14 to -17.3 V
31V	Internal voltage	29.9 to 35.7 V
SCE_T(1)	Internal T Readout Module	-24 to +85 C
SCE_T(2)	Internal T Power Module	-24 to +85 C
SCE_T(3)	Internal T Digital Module	-24 to +85 C
SENSE_LPSB	Heater Current	0 to 0.96 A
SENSE_LR3N	Heater Current	0 to 0.80 A
SENSE_LR3R	Heater Current	0 to 0.80 A
GG_CE(1)	Heater Current	0 to 1.84 A
GG_CE(2)	Heater Current	0 to 1.84 A
GG_CE(3)	Heater Current	0 to 1.84 A
GG_CE(4)	Heater Current	0 to 1.84 A
GG_CE(5)	Heater Current	0 to 1.84 A
GG_CE(6)	Heater Current	0 to 1.84 A

2.1.4. The Sorption Cooler Electronics (SCE)

The SCE (nominal or redundant) is the electronics unit operating the SCS (nominal or redundant). The purpose of the SCE is to:

- Drive the sorption cooler by

  - switching control for the sorption bed heaters
  - switching control to the heat switches
  - timing signals for the switching
  - controlling of power to the compressor elements in the “desorbing” state
  - controlling the T (PID) of the Temperature Stabilization Assembly (TSA) in the SCCE.
- Detect abnormal situations and react if a problem is detected in order to ensure the sorption cooler and its environment health. This is done by reading temperature and pressure sensors values from the sorption cooler.
- Read temperature, voltage and intensity sensors from sorption cooler electronic.
- Receive commands from CDMU sent by users from ground
- Send housekeeping data to CDMU that will be transmitted to ground by telemetry.

Block Diagram of the Sorption Cooler Subsystem (SCS)Figure 2-3 shows the SCE Nominal and Redundant in the S/C environment.

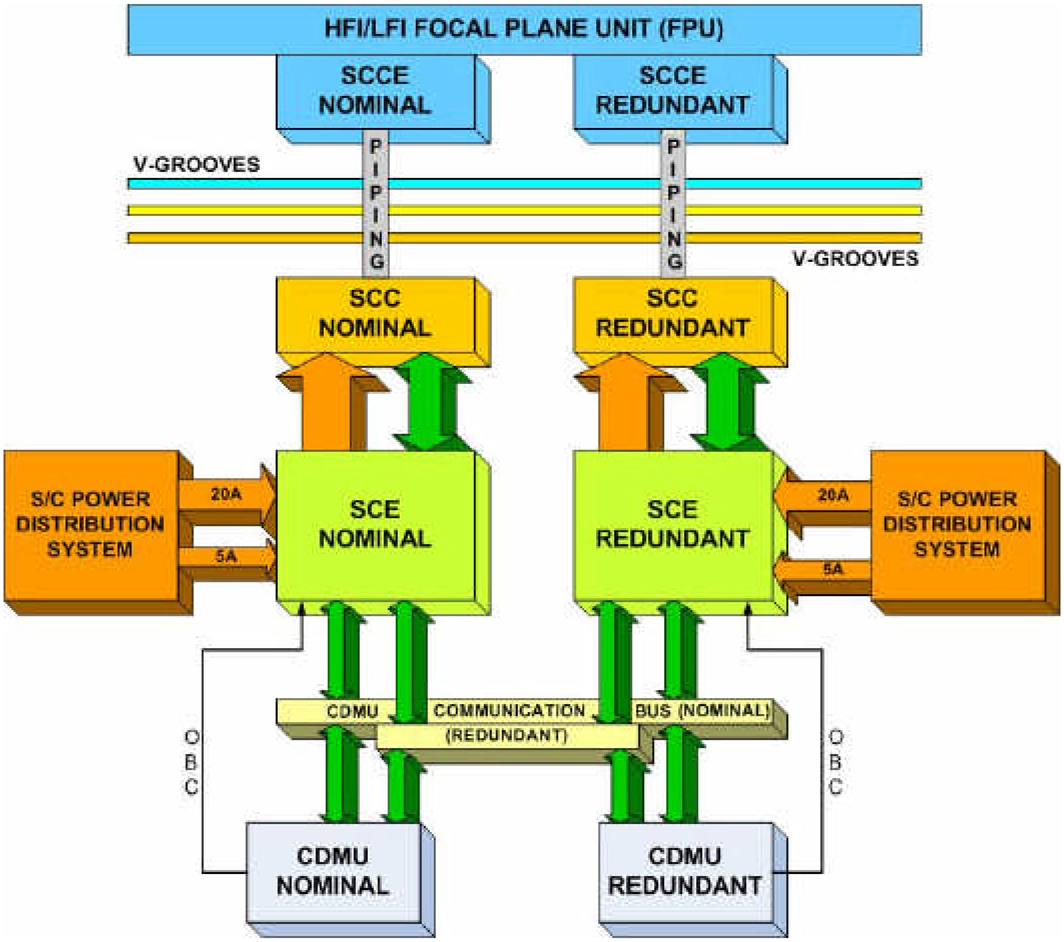


Figure 2-3 Block Diagram of the Sorption Cooler Subsystem (SCS)

The Figure 2-3 shows the interface relationships between the SCE and the other parts of the SCS, together with the top-level redundancy concept of the SCS itself:
The nominal SCE is active while the other one is in “not-operating redundancy state”. The selection of the working SCE is made by the S/C by selecting the appropriate 28 V lines.
The interface with the spacecraft will be able to handle a baseline data rate of 2 kbit/s and will be compliant with the MIL-STD-1553B standard, with the SCE acting as a remote terminal and the CDMS as the bus controller.
The SCE subsystem will include DC/DC converters with a nominal input DC voltage of 28 V and +5V, +15V, –15V and 31V or +12V.
The SCE will also contain ADCs and Multiplexer components allowing the read data from the sensors (voltage, current, temperature and pressure). The interface to the heaters will be realized with DAC’s components and power MOS radiations tolerant transistors.
Data communication interface will be implemented following the MIL-STD 1553B standard, through one nominal and one redundant transformer in the long stub configuration.
The specifications and detailed descriptions of the SCE SW and HW can be found in RD1 and RD2.

2.2. SCS requirements

TMU Spec	Requirement Value
Cold End Temperature	**17.5 K < LVHX1 < 19.02 K** **17.5 K < LVHX2 < 22.50 K**
Cooling Power	**Cooling power @ LVHX1 > 190 mW** **Cooling power @ LVHX2 > 646 mW** **TSA dissipation = 150 mW** **Total Cooling Power > 986 mW**
Input Power	**TMU Input power < 426 W @ BOL**
Cold End Temperature Fluctuations	**?T @ LVHX1 < 450 mK** **?T @ LVHX2 < 100 mK**

Table 2-1. Primary verification criteria for SCS TMU performance

In Table 2-1 are summarized the SCS requirements: they are the primary reference values to evaluate the cooler performance.

3. Test configuration

The PFM1 test configuration is derived from the PFM one (see AD1 and AD2) with some main differences.

The main FM subsystems are:

- Structural elements
- Thermal Control elements
- PCS, CDMS, TT&C and ACMS equipments mainly located on (-Y/+Z) and -Y panels
- SVM harness
- Propulsion except tanks
- Both SCS TMU's (N and R)
- VGroove 1 (with extensions as a thermal shield between SVM and telescope dummy)
- VGroove 2 and 3 (without extensions)

Main differences with Flight configuration are:

- Special configuration of PPLM:
    - FM cryo-structure to support PACE
    - Telescope dummy to simulate telescope cryo-structure and the PCE/FPU I/F
    - PACE environment (control of conductive and radiative parasitics)
    - PC3C thermal control (through a thermal strap to a cold point) to simulate different cold I/F conditions
    - PC1 (VG1)

- Use of MTD's instead of Instruments Warm Units
- Use of a CQM SCE-R instead of a FM one.

- The mechanical SVM configuration is very similar to the flight one except for:

    - No RCS tanks and supports are present
    - Solar array replaced by a STM with heaters to simulate solar load
    - Some subsystems are replaced by MTD's

A specific orientation is required for this test: both the heat pipes and the SCS compressor have horizontality requirements (see RD1).

For a detailed description of the Test configuration refer to AD1.
For a detailed description of Test Technical Description see AD2.
For a detailed description of SVM Test Thermal Instrumentation see AD3.

Figure 3-1 shows the configuration of EGSE (see RD5) used to operate the spacecraft and for performance testing during the PFM test campaign #1.

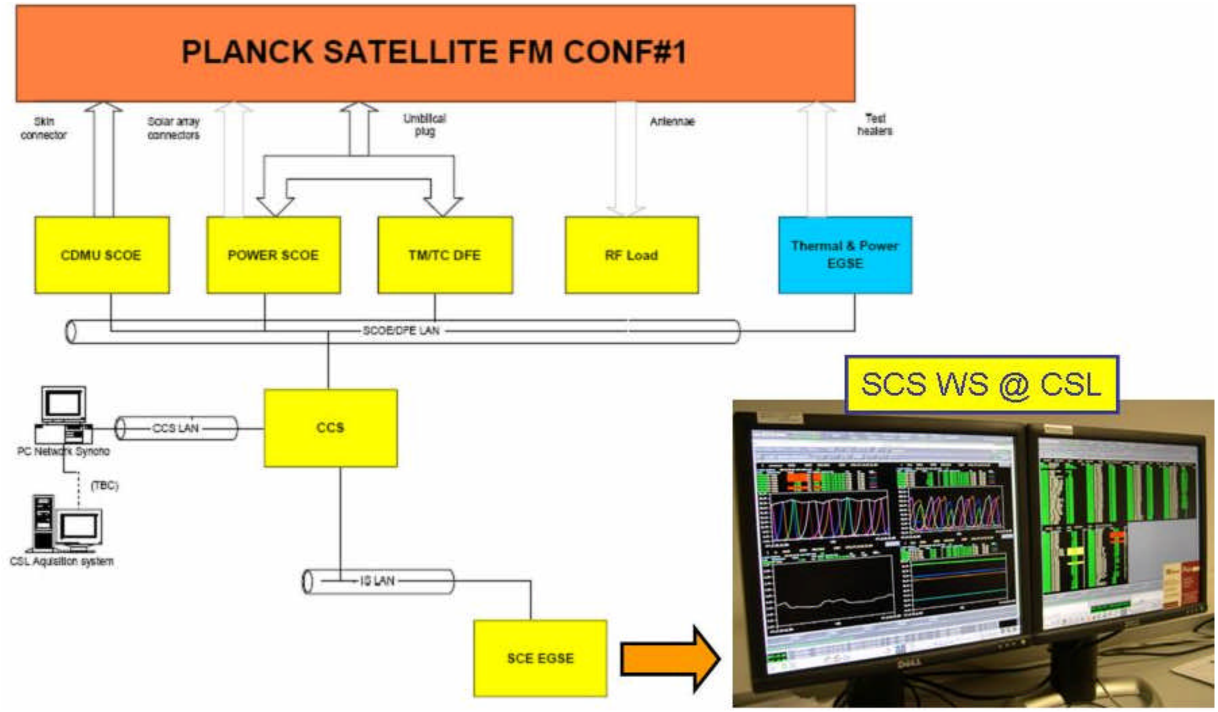


Figure 3-1 ***Configuration of spacecraft EGSE for PFM1***

The CCS is the system controlling the sequencing of the test and required while the experiment (SCE in this case) EGSE in only limited to monitoring the status of the cooler and the procedures of the test.

The PFM1 data analysis and test evaluation is performed with the help of the results of all previous ground test campaign carried out at JPL. For this reason it is important here to underline the main differences between the PFM1 configuration and the JPL ground test set-up. The three major differences are:

- Warm radiator (at JPL there was no common radiator for all beds)
- PC3A&B warmer than PC3C (at JPL they were both at the same T of the last one, PC3C, like in flight)
- Cooler Monitoring through Scos2000 and cooler control “flight like” (ground EGSE)

Another important difference with previous tests for functional and performance evaluation is given by the fact that the TSA cannot be used, and tested, due to issues with the software version: it was not possible to patch it before the test campaign. For the same reason the cold processes of the health-check procedure could not be tested.

3.1. Test Objectives

The main goals of the PFM#1 test campaign are:

Functional validation of the Sorption Cooler Redundant Unit (SCS-R) on the S/C with flight representative interfaces (Warm Radiator 260-280 K; VGroove 3 45-60 K) according to the following table

Test	Description	PC3C T (K)	SCC Radiator T(K)		
			Cold	**Ref**	**Hot**
Cold SCC Thermal Balance	WR starts at 262K and floats up to the balance T given by SCC dissipation. Average T ~270.5K	45	**DONE**		
Reference SCC Thermal Balance	WR is controlled at 282K by SCC Panel heaters. Average T ~282.6K	60		**DONE**	
Hot SCC Thermal Balance	WR starts at 282K and floats up to the balance T given by SCC dissipation. Average T ~276.9K	60			**DONE**
Functional **Regeneration**	Functional Test of Regeneration Procedure (not actual process)	NA	**DONE**		
Cold Reference SCC Thermal Balance	WR is controlled at 262K by SCC Panel heaters. Average T ~264K but very unstable	45	**DONE** **?**		

A green box means "Test Successful"

- For each test case the LVHX's T and their fluctuations were observed
- A thermal load on cold end representing the nominal heat lift due to HFI and LFI dissipation was applied. A dedicated measurement was performed to estimate the SCS R cooling power
- For each test case the SCS total input power was recorded
- The presence of the second flight unit (SCS-N) ensured representativity of the mutual influence between both TMU's, if any
- A functional test of the regeneration sequence (no actual regeneration is obtained) was performed on the SCS-R

1. Perform a thermal balance of the SVM

   - validation of the SVM thermal mathematical model (TMM) in steady state and in transient conditions

   - validation of the SVM thermal control S/S design and thermal performances:
     - units temperature level
     - units temperature stability
     - SVM heating power

- validation of the SVM thermal control flight hardware:
  - MLI assembly
  - heaters and thermistors location and set up

2. SCS Warm Radiator Performance

- validation of the SCS assembly thermal mathematical model (TMM) in steady state and in transient conditions

- validation of the SCS assembly thermal control design and thermal performances:
  - bed temperature level
  - bed temperature fluctuation
  - SCS heating power

- validation of the SCS thermal control flight hardware:
  - heat pipe assembly
  - heaters and thermistors location and set up

Only the first (1) of the above listed points will be evaluated in this report, the other two will be addressed in AAS Test Reports.

3.2. Test History

The PFM1 cold testing of SCS-R unit started on Saturday March 18th 2006 and was completed by Sunday March the 26th. A summary of the testing sequence is showed in the following Table.

Test Time	Case performed
March 18th 12.30 UTC	SCS Healthcheck
March 18th 16.30 UTC	SCS Start-up
March 20th 09.00 UTC	Cold SCC Thermal Balance
March 22nd 10.00 UTC	Reference SCC Thermal Balance
March 24th 10.00 UTC	Hot SCC Thermal Balance
March 25th 11.00 UTC	Regeneration Functional Test
March 25th 23.30 UTC	Cold Ref. SCC Thermal Balance

Table 3-1 PFM1 time sequence

4. Test Results

4.1. Healthcheck

Before starting the SCS a Warm Healthcheck process in thermal-vacuum was performed to check that the system was in the nominal status. Basically this procedure activates in steps each heater of the TMU and checks the response of the T and P sensors involved by that specific heater. The process is referred as “Warm Healthcheck” because for on-board software issues it was not safe to activate the Cold End (SCCE) heaters. For this reason, the SCCE check was skipped.
The whole process can be shown in Figure 4-1 where the upper section of the graph shows the LPSB temperature behaviour while the lower section illustrates the compressor elements temperature and pressure.

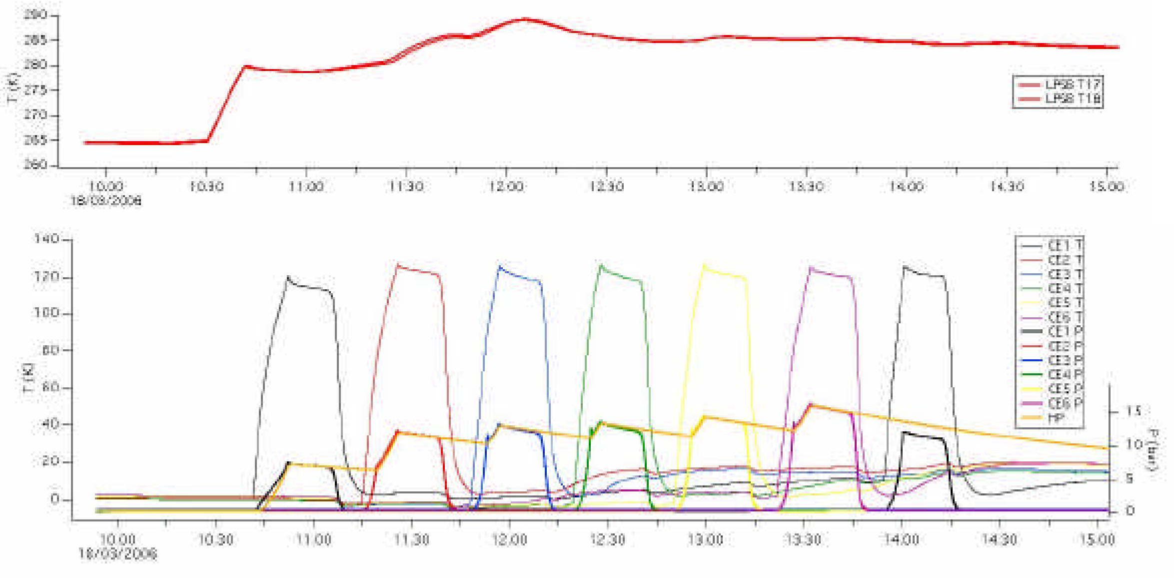


Figure 4-1 Healthcheck procedure: LPSB test (upper), Beds T and P (Lower)

The results of the Healthcheck process were fully compliant to the nominal status required to operate the SCS: For this reason, it was then decided to start the Sorption Cooler.

4.2. Phase 2-002 SCS Cooldown

The SCS was started at 16.30 of March the 18th: first LH_2 was produced 40 hrs later (at 8.30 of March 20th), the system entered Nominal Operations about one hour later (9.30).
The whole cool down process is shown in Figure 4-2

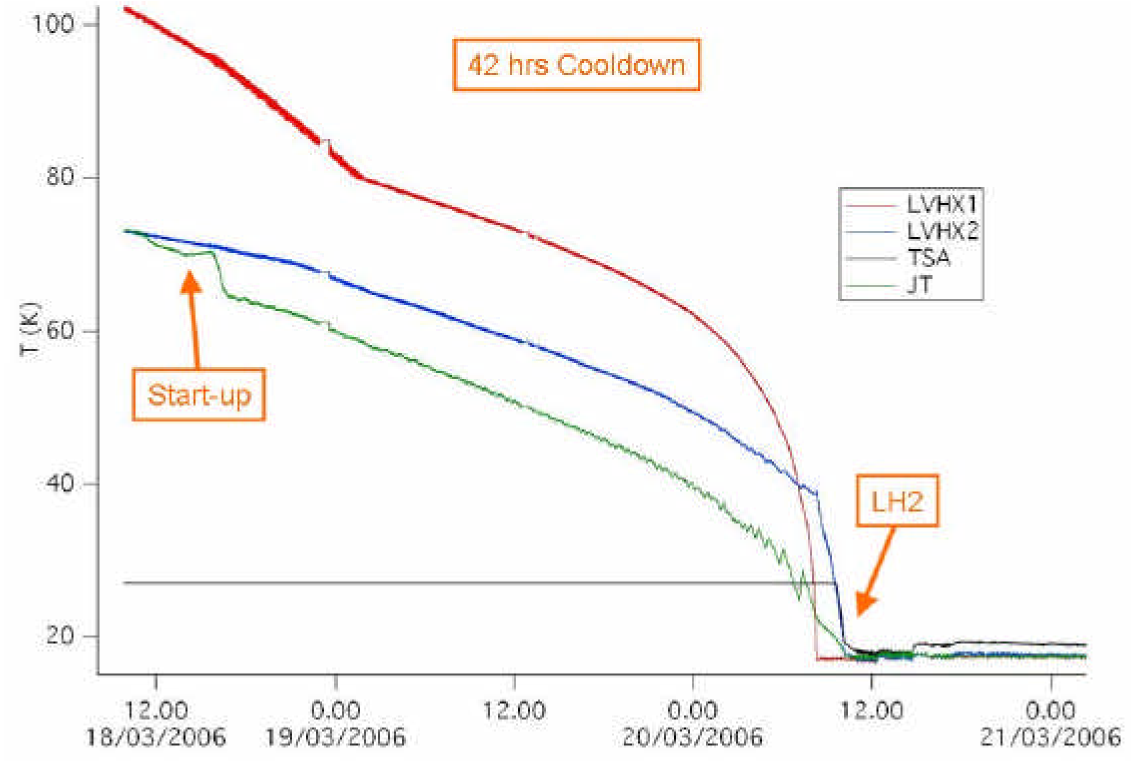


Figure 4-2 Cooldown of the SCS cold-end. Total time from SCS start-up to the production of liquid was 40 hours.

The FPU dummy cooled by the SCS is not representative of flight conditions in mass: only 5 Kg of Al instead of about 27. During the CQM test campaign, the cooldown time for a 27 Kg mass was about 75 hrs and the cooldown was somewhat faster than modelling would indicate. For the PFM1 testing the cooldown was much longer than the modelling would predict. It is not clear why there is such a large discrepancy. Inputs from Alcatel will be needed.

4.3. Phase 2-005 Cold SCC Thermal Balance

The Cold SCC Thermal Balance Test started at about 9 AM on 20 March 2006. The warm radiator temperature was about 270 K for this case (see Table 4.1)and the lookup table (LUT) was for a 262 K radiator and was not re-tuned due to test time limitations.

4.3.1. Temperature and temperature fluctuations

Temperature and temperature fluctuations are shown for two different time periods in Figures 4-3 and 4-4. Figure 4.3 shows two regimes of fluctuation behavior. On the left, the temperature fluctuation levels are about 216 and 206 mK for LVHX1 and LVHX2 for the period from 6 AM until 7:45 AM. At around 7:45 AM, a transition to much higher levels of fluctuation on the two LVHX's then occurs.

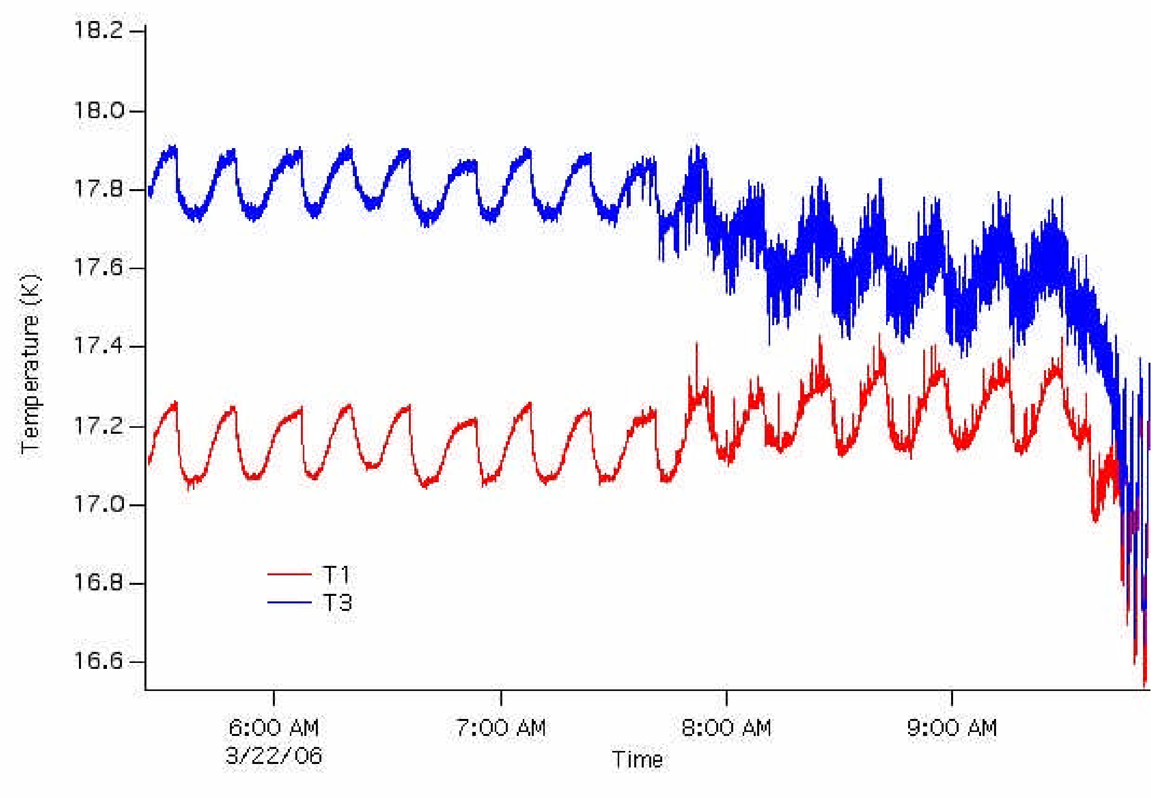


Figure 4-3 Cold Case Balanced-Unbalanced Cold End transition. Note the two regimes of temperature fluctuations.

This behavior is well understood and was observed during the CSL CQM testing (see JPL D-34632 section 2.5). Briefly, the cold-end, prior to 7:45 AM, is in a balanced state where the production of trap-and-plug events is suppressed by the liquid interface being drawn into the LVHX2 body. In contrast, the increased fluctuations are due to trap-and-plug events as the liquid interface moves into the counter-flow heat exchanger just past the LVHX2 body. These trap-and-plug events are believed to be an artefact of the 1-g environment. Consequently, the temperature fluctuation behaviour prior to 7:45 AM will be more representative of that expected in flight.

Figure 4-4 shows additional temperature fluctuation data, with the levels being 418 and 652 for LVHX1 and LVHX2 respectively. The system is clearly in the trap-and-plug flow condition. The fluctuation requirement of 450 mK is only satisfied for LVHX1, but there is no requirement on the LVHX2 fluctuations, only on the TSA interface, which was not implemented for this testing. High fluctuation levels on LVHX2 are consistent with the testing results at JPL.

For all cases the nominal heat loads of 190 mW (LVHX1), 650 mW (LVHX2), and 150 mW (TSA), for a total of 990 mW, were applied.

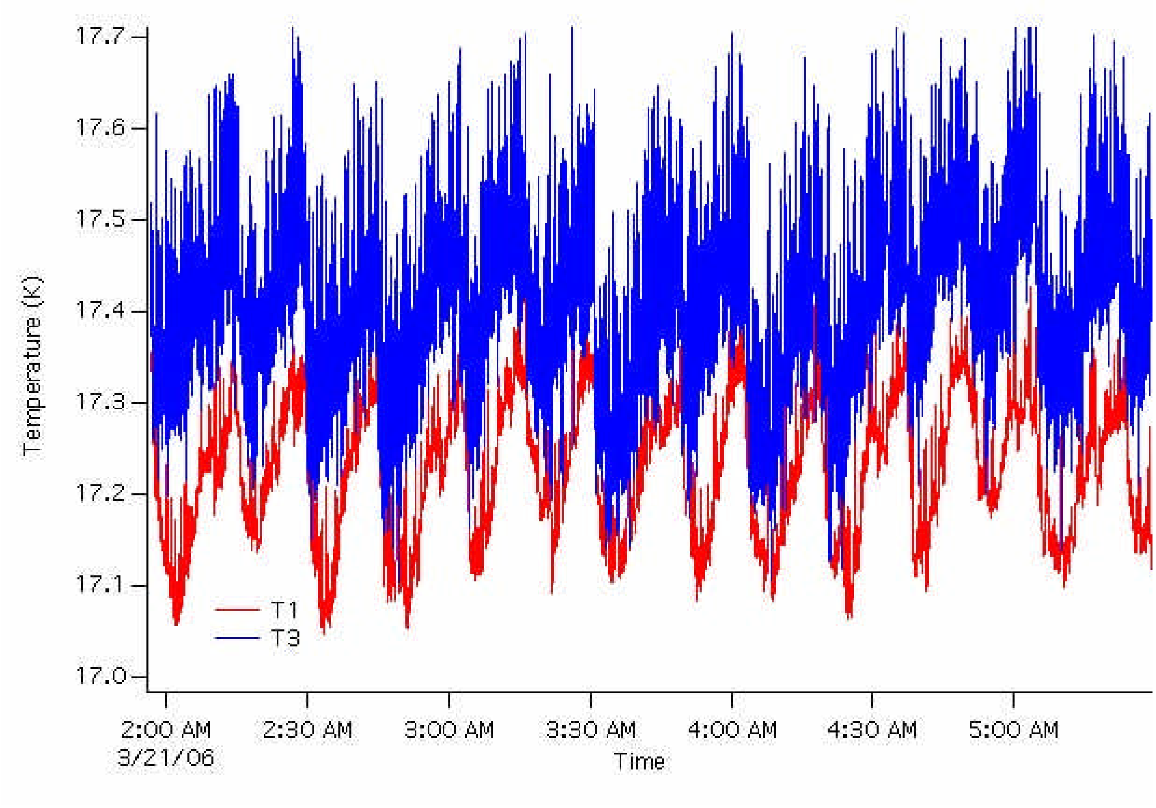


Figure 4-4 Typical trap-and-plug flow conditions

4.3.2. Cooling Power

The cooling power was measured twice for this case, at around 9 AM on the 21st and later the night of the 21st and 22nd. For the first case, the measurement was not completed due to problems with the sorption cooler electronics (SCE). The final measurement was 1150 mW. This measurement is problematic because pre-coolers 3A&B are at about 75 K, while PC3C is at 45 K. Because the PC3 pre-cooler system is designed to remove the gas-stream heat when all three pre-coolers are at the same temperature i.e. between 45 and 60 K, the elevated temperatures of PC3A&B will decrease the cooling capacity of the SCS. A thirty-node finite element program was used to estimate the reduction in the cooling power, with the result being about 150 mW. which is consistent with the measured value of 1150 mW. Cooling power at a final exit temperature of 45 K is not a performance issue, as the SCS will have as excess of 1 W if run at the full operational pressure. The measurement at a 60 K final pre-cooling temperature is more indicative of the SCS performance. At a PC3C temperature of 60 K, the effect of the elevated PC3A&B temperatures will be reduced to about 50 mW and the cooler margin is minimal. These results will be discussed when the Reference case is considered.

4.3.3. Input Power

Input power applied was 297 W, well below the beginning of life requirement of 426 W. An additional 10 W reduction would result if the SCS were tuned properly due to the elevated warm radiator temperature.

4.3.4. Cold SCC Thermal Balance Test Results Summary

TMU Spec	Cold Case Results	Requirement Value
Cold End Temperature	1st case 17.15 K 2nd case 17.24 K	17.5 K < LVHX1 < 19.02 K 17.5 K < LVHX2 < 22.50 K
Cooling Power	1150 ± 50 mW	Cooling power @ LVHX1 > 190 mW Cooling power @ LVHX2 > 646 mW
Input Power	297 W	TMU Input power < 426 W @ BOL
Cold End Temperature Fluctuations	1st case 216 mK 2nd case 418 mK	?T @ LVHX1 < 450 mK ?T @ LVHX2 < 100 mK

Table 4-1 Cold Case results summary

4.4. Phase 2-005.2 Reference SCC Thermal Balance

The warm radiator was changed to provide an average value of the compressor element shells of 282.65 K at about 10 AM on March 22, with a minimum value of 280 K. This was done to approximate the JPL test case. The PC3C temperature was changed to 60 K. The system became fairly stable at about 6 PM that evening.

4.4.1. Temperature and temperature fluctuations

Two periods of relative stability were observed for this case. These two periods are summarized in Table 4-2. The average temperature for these two periods was ~ 18.45 K; this compares to a value of 18.63 measured during the JPL flight acceptance testing. For the first stable period, the LVHX1 temperature fluctuations of 497 mK exceed the requirement of

450 mK. In this regime the system is in the trap-and-plug regime discussed above. The second stable period exhibits fluctuations for a balanced condition of about 380 mK. At JPL the measured value was 442 mK, which was for the unbalanced regime. During both periods the nominal heat loads of 190 mW (LVHX1), 650 mW (LVHX2), and 150 mW (TSA), for a total of 990 mW, were applied.

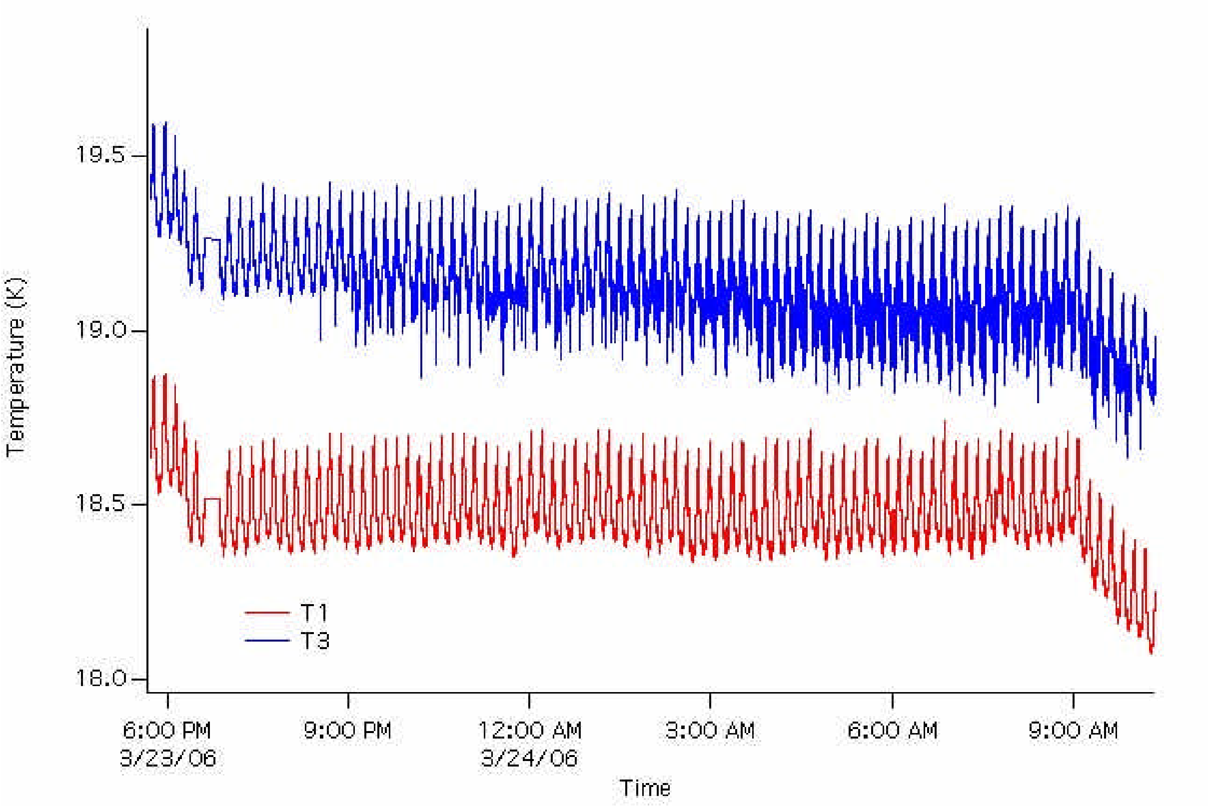


Figure 4-5 Reference Case LVHX's temperature value and stability

4.4.2. Cooling Power

The cooling power was measured between 7 AM and 1 PM on 23 March. The value measured was 1050 mW. This value compares well with the calculated value for the operating condition. Again, PC3&B were at an elevated temperature of 75 K. Modelling estimates a reduction of 50 mW for this case. Thus 1100 mW is available; 110 mW above the requirement. In addition, the TSA typically needed only 100 mW to control the TSA stage, which provides some additional margin. These measurements are consistent with those measured at JPL.

4.4.3. Input Power

Input power applied was 387 W, well below the beginning of life requirement of 426 W. This is the same input power used for the JPL flight acceptance testing.

4.4.4. Reference SCC Thermal Balance Test Results Summary

TMU Spec	Reference Case Results	Requirement Value
Cold End Temperature	**1st case 18.43** **2nd case 18.48**	**17.5 K < LVHX1 < 19.02 K** **17.5 K < LVHX2 < 22.50 K**
Cooling Power	**1050 ± 50 mW**	**Cooling power @ LVHX1 > 190 mW** **Cooling power @ LVHX2 > 646 mW**
Input Power	**387 W**	**TMU Input power < 426 W @ BOL**
Cold End Temperature Fluctuations	**1st case 497 mK** **2nd case 380 mK**	**?T @ LVHX1 < 450 mK** **?T @ LVHX2 < 100 mK**

Table 4-2 Reference Case results summary

4.5. Phase 2-006 Hot SCC Thermal Balance

The warm radiator was changed to provide an average value of the compressor element shells of 277 K at about 10 AM on March 24, with a minimum value of 274.2 K. The heatup power was changed from 170 W to 240 W in order to approximate the end-of-life power. The PC3C temperature remained at 60 K. Because the LUT was for a 280 K radiator several changes had to be made before the SCS transitioned into normal operating mode. The system did not become stable until about 3 AM on 25 March.

4.5.1. Temperature and temperature fluctuations

For the stable period, from 3 AM to 9 AM on 25 March, LVHX1 had an average temperature of 18 K. The fluctuations were 307 mK on LVHX1 while they were 325 on LVHX2. The system was balance during this period. This fluctuation behavior is shown in Figure 4.6. Temperature and fluctuations values are summarized in Table 4-3.

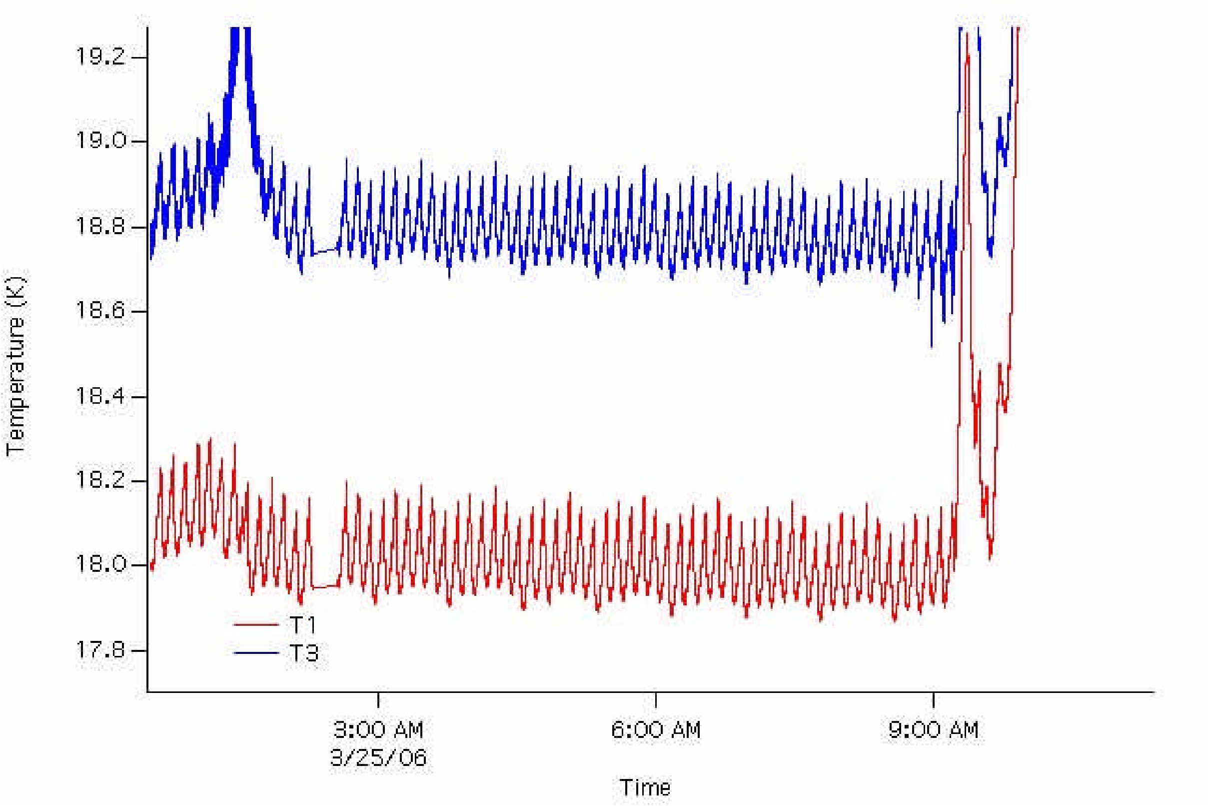


Figure 4-6 Hot Case LVHX's temperature value and stability

4.5.2. Cooling Power

The cooling power was measured between 12 AM and 1:30 AM on 25 March. The value measured was again 1050 mW. This value compares well with the calculated value for the operating condition and with the value measured for the reference case of section 4.4.2 (the two cases, to first order, should be identical). Again, PC3&B were at an elevated temperature of 75 K. Modelling gives a reduction of 50 mW for a 60 K PC3C. Thus 1100 mW is available; 110 mW above the requirement. In addition, the TSA typically needed only 100 mW to control the TSA stage, which provides some additional margin.

4.5.3. Input Power

Input power applied was 460 W. This is 10 W less than the maximum power allocated to the sorption cooler. The performance of the SCS at nearly the EOL power indicates that the radiator will perform well over the cooler lifetime.

4.5.4. Hot SCC Thermal Balance Test Results Summary

TMU Spec	Hot Case Results	Requirement Value
Cold End Temperature	**18.0**	**17.5 K < LVHX1 < 19.02 K** **17.5 K < LVHX2 < 22.50 K**
Cooling Power	**1050 ± 50 mW**	**Cooling power @ LVHX1 > 190 mW** **Cooling power @ LVHX2 > 646 mW**
Input Power	**460 W**	**TMU Input power < 426 W @ BOL**
Cold End Temperature Fluctuations	**307 mK**	**?T @ LVHX1 < 450 mK** **?T @ LVHX2 < 100 mK**

Table 4-3 hot Case results summary

4.6. Phase 2-007 Functional Regeneration

The SCS was shutdown at 9 AM on 25 March to perform the functional regeneration procedure. The procedure performed properly, as can be seen in Figure 4-7, but start-up problem of the cooler were encountered after the completion of the regeneration procedure. This was due to the state of the cooler after the regeneration. During this procedure the LPSB became full of gas, which led to an elevated temperature. The safety limits on this temperature would not allow the cooler to start properly. Changes to these limits will be made for so that this problem does not occur again.

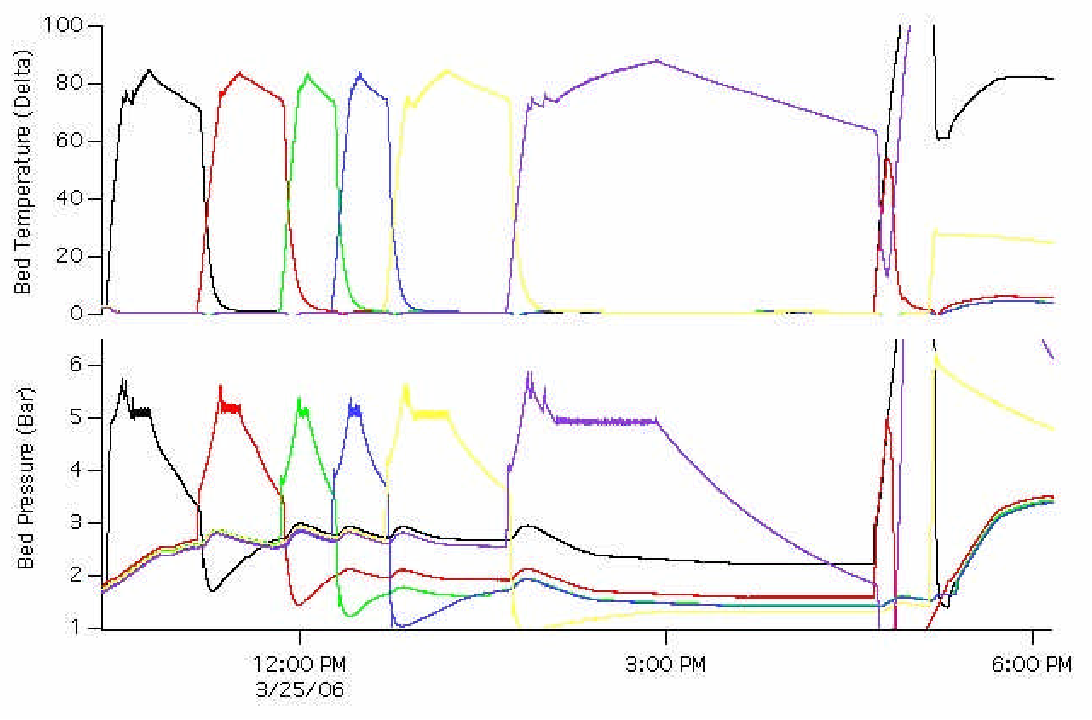


Figure 4-7 Regeneration Functional Test process

4.7. Phase 2-002 Cold reference SCC Thermal Balance

An additional case was attempted the night of 25-26 March. What was planned was to run a 45 K PC3C and a 260 K warm radiator. Due to the problems discussed above and problems with the telemetry from the CCS the cooler could not be started until about 12 AM that night. In addition, the warm radiator was only lowered to the correct temperature at about 4:30 AM, and was only able to run for 2.5 hours. Thus the SCS was not stable and the average LVHX1 temperature only reached 16.96 K. See Figure 4-8. Temperature fluctuation levels were 458 mK on LVHX1.

The LUT table used for this case, and thus the Input power applied, was the same as for the Cold Reference Case, Section 4-3.

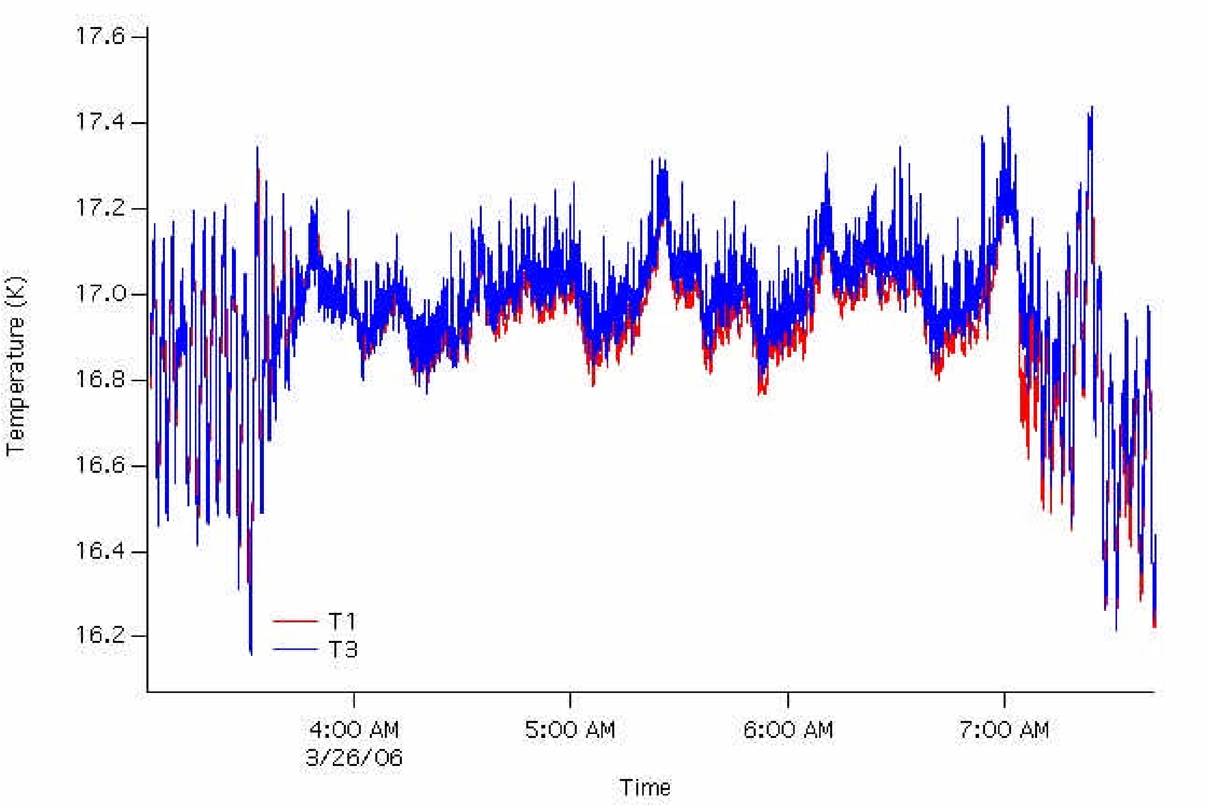


Figure 4-8 Cold Reference Case unstable conditions

4.8. Warm Radiator Issues

One of the important testing goals was to quantify the effect of the warm radiator on the cold-end fluctuations. Testing at JPL was performed on an interface that did not simulate the actual flight radiator. The interface at JPL consisted of thermally isolated chiller plates while for the actual flight radiator, all six of the compressor elements are thermally coupled through the warm radiator. Thus the mutual interaction between the six compressor elements was not accounted for in the JPL testing. JPL, through modelling, quantified the actual effect of the radiator fluctuations on the cold-end temperatures. Table 4-4 summarizes the observed temperature fluctuations of the compressor elements for each of the three main tests. The largest fluctuations occur after a compressor element begins its cooldown cycle, thus the listed levels are for the three absorption beds. These levels, using the JPL modelling, increase the fluctuation levels above the required 450 mK to 545 mK for the reference case, 536 mK for the hot case, and 542 mK for the cold case. In contrast, the actual values measured during the PFM1 testing are below 500 mK for all test cases In summary, radiator fluctuation are greater than those required by JPL to meet its cold-end temperature fluctuation requirement of 450 mK, but the actual measured values meet these requirements for all test cases but two.

Reference Case			
Cooldown Bed	*1st*	*2nd*	*3rd*
Bed 1	6.2	5.2	3.9
Bed 2	6.2	5.4	4.3
Bed 3	5.7	4.6	3.3
Bed 4	5.4	4.5	3.4
Bed 5	6.1	4.9	3.7
Bed 6	6.1	5	3.4
Average	**5.95**	**4.93**	**3.67**
Hot (High Power) Case			
Cooldown Bed	*1st*	*2nd*	*3rd*
Bed 1	5.6	5	3.8
Bed 2	5.3	4.7	4.1
Bed 3	5.2	4.3	3.2
Bed 4	4.9	4.2	3.4
Bed 5	5.7	4.6	3.7
Bed 6	5.5	4.6	3.2
Average	**5.37**	**4.57**	**3.57**
Cold Case			
Cooldown Bed	*1st*	*2nd*	*3rd*
Bed 1	5.3	4.9	4.3
Bed 2	5.5	4.7	4.6
Bed 3	5	4.7	3.7
Bed 4	4.8	4.3	4.2
Bed 5	5.4	4.3	4
Bed 6	5.1	4.5	3.7
Average	**5.18**	**4.57**	**4.08**

Table 4-4 Measured T gradient across SCS beds

4.9. Sorption Cooler Electronics Performance

The Sorption cooler electronics behaviour was conforming to the specification and requirements, the measurement ranges and resolution was as good as expected. Only one SW problem was reported, concerning the automatic detection of Gas Gap Actuators heaters failures during Run mode. This problem is described in the next paragraph and in the Software Problem Report SPR-600094-LPSC (RD4). However, all planned PFM1 test phases could be safely completed by disabling the “Bad Heater Detection” feature.

For the future, the check of the Gas Gap Actuators current in comparison with their states will be executed in a secure way (e.g. triple voting) before concluding on an error. This new way of performing the check will be implemented on every tests of the FDIR.
This modification will be implemented in the next ASW version, uploaded in the next delivered SCE model (FM).

5. Contingencies

This paragraph reports the problems encountered during PFM1 campaign. They can be summarized as follows:

a) The cooldown time for the sorption was longer than expected. At this point it is not understood why. This discrepancy will be worked with the Alcatel team, as the cooldown time depends on the testing conditions controlled by Alcatel.

b) Before the start of SCS operations a serious power outage occurred. The non-break circuit did not activate with the result of a total power loss to the spacecraft. The non-break unit was substituted and the test campaign could be restarted without further power problems. The power loss did not cause any damage to the SCS hardware. An assessment of this failure has to be provided by AAS.

c) At the beginning of the SCS testing, during Phase 2-002, two occurrences (one in Start-up process, one in Normal) of bad bed detection and removal were reported. The TM(3,25) shows that time to time, in a random way, there is a discrepancy between the Gas-Gap Actuators state and their current, observed at cooler cycle phase transition time. Some of these discrepancies are detected by the “Bad Heater Detection” procedure (internal FDIR, see RD6) and then trig the Off Normal Mode (5 or 4 beds).

d) A small discrepancy with the SCS bed 6 heaters resistance value was noticed. The voltage loss across the cabling was not properly input in the LUT with the result of a slightly lower estimation of the actual power provided to the Bed. This will be corrected in the next update of the LUT’s.

e) An abnormal temperature gradient between the TMU interface with LFI and the FPU dummy was measured. An extra and unexpected thermal resistance of about 4K/W was observed across the interface. Possible explanations were focusing on the combination of several phenomena such as the “alodination”(?) of the FPU, the torque applied to the interface, a mismatch in the machining of both side of the interface (roughness, planarity etc.). Following the analysis of this problem, discussions and possible actions are already being taken on the LFI side to ensure the best thermal contact across the I/F.

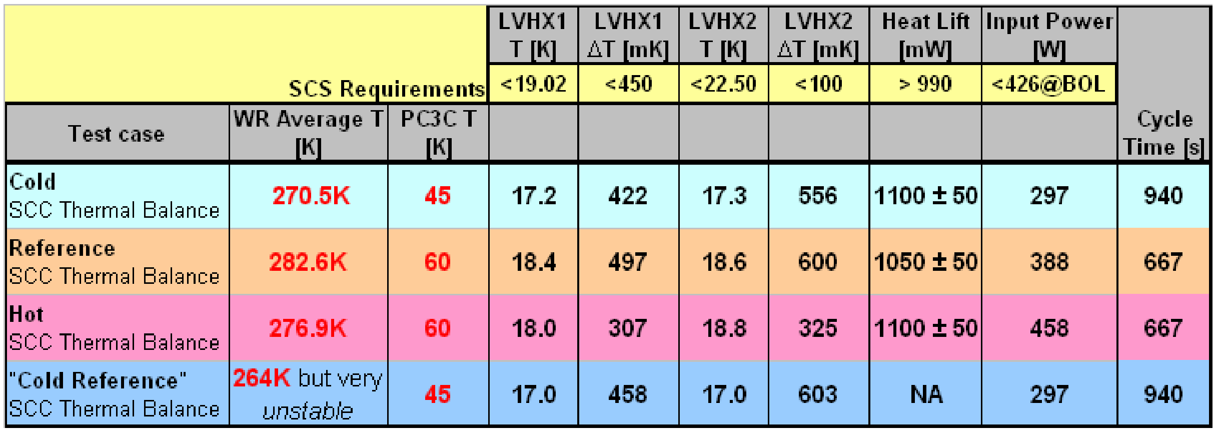
f) After the regeneration functional test, problems were encountered in re-starting the SCS. This was due to the re-distribution of the hydrogen gas during this procedure. This problem will be alleviated by changing the temperature safety limit on the LPSB. Doing this will not expose the hardware to any risk.

6. Summary & Conclusions

In summary the PFM1 test campaign confirmed the functionality of the SCS at hardware, software and operating level: the SCS performed as expected and, in few cases, even better. Parameters like Cold End temperatures and fluctuations, heat lift, input power were in most cases compliant to the requirements and comparable to previous ground tests, as it is shown in Table 6.1.

Test Results Summary

In the following Table all the relevant results of PFM1 Test are reported, in comparison with their requirements:



			LVHX1 T [K]	LVHX1 ΔT [mK]	LVHX2 T [K]	LVHX2 ΔT [mK]	Heat Lift [mW]	Input Power [W]	
		SCS Requirements	<19.02	<450	<22.50	<100	> 990	<426@BOL	
Test case	WR Average T [K]	PC3C T [K]							Cycle Time [s]
Cold SCC Thermal Balance	270.5K	45	17.2	422	17.3	556	1100 ± 50	297	940
Reference SCC Thermal Balance	282.6K	60	18.4	497	18.6	600	1050 ± 50	388	667
Hot SCC Thermal Balance	276.9K	60	18.0	307	18.8	325	1100 ± 50	458	667
"Cold Reference" SCC Thermal Balance	264K but very *unstable*	45	17.0	458	17.0	603	NA	297	940

Table 6-1

Warm radiator

The performance of the Warm Radiator, even if not compliant to the requirements in terms of T fluctuations, did not have the expected negative impact on the Cold End T fluctuations that remained in the range of all previous JPL ground tests.

2nd TMU effects

One of the secondary tasks of the Test Campaign was to observe possible influence of the non-operating cooler on the working one. A negative effect was presumed based on the idea that the operating TMU could induce condensation on the gas present in the Cold End of the non operating unit: this would have resulted in a reduced heat lift of the working cooler. No measurable effects were noticed: this could allow to conclude that the influence, if any, is negligible.

SCS Instrument Team Ground Segment Verification

The PFM1 Test Campaign validated also part of the "ground segment flow" of the SCS control and operations. This campaign was a test bench of the SCS Instrument Team capabilities of:

- operating the cooler in terms of LUT parameters and procedures
- monitoring the SCS through the SCOS2K-based workstation (see next paragraph).

Both the parameter values and the procedures used ensured a correct and robust control of the system ensuring compliancy to the functionality and performance requirements. As an example, changing the thermal interfaces (Warm Radiator and/or VGroove 3) set point, the cooler was able to produce the required heat lift by adjusting input power and cycle time, while maintaining the other requirements. The Test confirmed the importance of proper filling of the LUT's: great care must be used in the definition, input and check of the stored values.

SCOS2000 EGSE

PFM1 Test was the first time the SCS was monitored through a SCOS2000-based EGSE. The interaction between the operator and the system through the SCS Work Station was satisfactory and no major issues or difficulties were reported. Few minor discrepancies or comments can be notified:

- Some soft and hard limits should be fine tuned to be more conforming to the actual ranges of an operating SCS.
- TC acknowledgment communication to the SCS Work Station was missing. This lack caused some uncertainty in the operator knowledge of the cooler status in real time. TC acknowledgment must be sent to the SCS Work Station in the next ground testing phases and during flight operations.
- The SCS Scos2000 Data Base should be extended to include parameters from the S/C. The knowledge of sensors and powers in various subsystems of the satellite is important information for the interpretation of the SCS data. This should be possible in the next ground testing phases and during flight operations.

The PFM1 Test Campaign provided a lot of useful information in terms of facilities and logistics: these inputs will be taken into account for the organization of the next thermal vacuum test PFM2 and, in general, of the SCS Instrument Team.
Test results or indications will be considered and included in the editing of next issues of the main documents such as SCS User Manual and Operation Plan, or in the refinement of operating procedures and LUT's of both SCS units.