SPIRE & PACS Sorption Coolers FMECA

SBT internal ref : SBT/CT/2001-XX

	Name & Function	Date	Signature
Prepared	LMG Consultant		
SBT PA Check	P. Dupont – Cooler PA manager		
SPIRE Approval			
PACS Approval			
PA Approval	F. Loubere – PA manager		
Project Approval	J.L Augueres - SAp HSO project manager		
Project Approval	L. Duband - Cooler project manager		

Service des Basses Températures (SBT)
Département de Recherche Fondamentale sur la Matière Condensée (DRFMC)
COMMISSARIAT A L'ENERGIE ATOMIQUE - GRENOBLE (CEA-Grenoble)
17, rue des Martyrs 38054 GRENOBLE Cédex 9, France.

LGM CONSULTANTS

Référence : R_00.224_02
Index : D
Date : 2001-10-01

CEA

****

CRYOGENIC SORPTION COOLER

****

FMECA REPORT

Prepared by	Bruno COLLERAIS
Verified by	Michel MONTEILLARD

Resume : This document contains the FMECA report of the cryogenic sorption cooler.

REVISIONS			
REV	RAISON DE L'EVOLUTION / *CHANGE REASON*	DATE	APPROUVE / *APPROVED*
A	Creation	2001-01-25	LGM Consultants
B	Update of the document	2001-02-20	LGM Consultants
C	Integration of modifications due to the new architectural analysis	2001-06-06	LGM Consultants
D	Update of the document	2001-10-01	LGM Consultants

TABLE OF CONTENTS

1. Purpose

The cooling of the SPIRE and PACS detectors down to 300 mK will be effected by a helium three sorption cooler. This sub-Kelvin sorption cooler provides a wide range of heat lift capability at temperature below 400 mK. It relies on the capability of porous materials to adsorb or release a gas when cyclically cooled or heated. Using this physical process one can design a compressor/pump which by managing the gas pressure in a closed system, can condense liquid at some appropriate location and then perform an evaporative pumping on the liquid bath to reduce its temperature. Helium sorption refrigerators have no moving parts, are vibration less and can be designed to be self contained and compact with a high duty cycle efficiency.
The present document introduces the Failure Modes and Effects and Criticality (FMECA) analysis of the system Cryogenic Sorption Cooler (Except Electronic Part).

2. Applicable documents

	Title	Author	Reference	Date
AD1	Instrument Requirements Document	B. Swinyard	SPIRE-RAL-N-0034 Issue 1.0	23 Nov. 00
AD2	ICD Structure cooler	L. Duband & B. Winter	SPIRE-MSS-PRJ-000331	13 June 00
AD3	SPIRE & PACS sorption cooler specifications	L. Duband	SBT/CT/2000-18 Issue 2.2	23 Nov. 00
AD4	Instrument interface document – Part B - Instrument "SPIRE"	ESA	SCI-PT-IIDB/SPIRE-02124 Issue 1.0	1 Sept. 00
AD5	Instrument interface document – Part B - Instrument "PACS"	A. Heske	SCI-PT-IIDB/PACS-02126 Issue 0.5	17 July 00
AD6	Architectural Analysis Report	LGM Consultants	R_00_224_01 Index D	01 Oct. 01

3. Terms and Acronyms

AD : Applicable Document
CEA : Commissariat à l' Energie Atomique
ESA : European Spatial Agency
ETF : Environment Test Facility
EV : Evaporator
HSE : Heat Switch on Evaporator
HSP : Heat Switch on sorption Pump
MTTF : Mean Time To Failure
N/A : Not Applicable
RAL : TBD
RBD : Reliability Block Diagram
SBT : Service des Basses Températures
SCO : Sorption Cooler (full unit)
SP : Sorption Pump
SST : Support Structure
TBD : To Be Defined
TS : Thermal Shunt

4. Failure Modes, Effects and Criticality Analysis (FMECA)

4.1 General

The FMECA is based on a hardware approach from the architectural analysis previously performed (see AD6).

The component indenture level is the lowest indenture level from which the effects on the items of the upper indenture levels are determined.
The hereafter block functions are decomposed :

System functions	Function description	Components
Gas enclosure	Maintains a given volume of gas (He3)	Sorption Pump
		Pumping Line
		Evaporator
Command/Control	Establishes or interrupt thermal conduction between Cold sources and Sorption Pump or Evaporator	Heat Switch Pump
		Heat Switch Evaporator
		Connectors
		Wires
Support Structure	Mechanically interfaces the SCO with its external environment and ensures its thermal isolation	Support Structure

In order to fill in the FMECA tables, the following hypothesis have been assumed :

1. The analysed system architecture is supposed to have passed all the environmental and functional test described in chapter 4.2 LIFE PROFILE TABLE of AD6 with success, thus leading to the qualification of the architecture.
2. Each system is assumed to be manufactured, assembled and verified, according to the document : SPIRE and PACS Sorption Cooler Manufacturing, Assembly and Verification Flow Chart. Then, all potential failure that might occur due to the bad application of the manufacturing procedure mentioned above are not considered in the present FMECA report.

4.2 Description of FMECA Columns

The columns of the FMEA are described in the following table :

Block ref.	Reference of the concerned block function
Functional block	The name of the functional block
Location	The location of the concerned component
Mission phase	The phase of the mission when the failure occurs
Failure Mode	The Failure modes of the component
Cause	The component failure mode cause
Primary failure effect	The failure effect at the technical function level
System failure Effect	The effect of the failure at the SCO level
G	The gravity of the system failure effect (from the gravity matrix)
D	The detectability of the failure
O	The probability of occurrence of the failure (from the occurrence matrix)
C	The criticality of the failure (from the criticality matrix)
Preventive action	The action to provide to prevent failure
Criticality after application of corrective action	The value of the criticality of the failure, once the potential corrective action will be applied to the system (manufacturing or testing)
Remarks	Remarks

4.3 System effects list

The failure effects at the system level that have been identified through the application of the FMECA process are the following :

Line N°	***Failure effect on system designation***
1	No effect
2	Loss of system functionality
3	System efficiency reduction

4.4 Detectability

The detectability column has been completed according to the fact that the considered failure is able to be detected by one of the test to which the system will be submitted before launching or not.
Detectability of a failure that might occur after launch has no importance because there will be no way after launch to fix this failure.
The detectability matrix is consecutively presented in the hereafter table :

Detectability	Signification
0	Failure is detected in functional tests and efficiency measurements phases
1	Failure is not detected

4.5 System failure effect gravity

This column contains an evaluation of the gravity of each system failure effect, dedicated to allow the failure criticality for the system.

Gravity	*Signification*
0	No effect
1	Minor
2	Major
3	Catastrophic

The meaning of these different gravity parameters have to be understood in the following way with regards to the function realised by the Sorption Cooler :

No effect signify that the effect engendered by the considered failure is negligible and has no impact neither on the efficiency of the system, nor on the mission life duration.

Minor signifies that the effect engendered by the considered failure can affect, either the efficiency of the system which might then only be able to cool down the instruments at a temperature a bit higher than the 300 mK expected leading to a lower sensitivity of the detectors, either the mission life duration which would be shortened by a factor of maximum 20%.

Major signifies that the effect engendered by the considered failure would affect the efficiency of the system or the mission life duration in such a way that it would be unacceptable (abortion of the mission).

Catastrophic signifies that the effect engendered by the considered failure would affect the integrity of the spacecraft.

4.6 Occurrence rate matrix

This matrix is indicating the probability of occurrence of the considered component failure mode.

Failure sensitivity :	
1	Very Improbable : Failure rate (FR) < 10^{-9} /hour
2	Possible : 10^{-9}<FR<10^{-8}
3	Probable :10^{-8}<FR<10^{-7}
4	Very Probable : 10^{-7}<FR<10^{-6}

Based on the hypothesis mentioned in § 4.1 of this document, it has been considered the following :

1. Concerning all structural mechanical components of the system, like those of the Support Structure, screws, pulleys, etc, the probability of occurrence associated to their main failure mode which is “break” is assumed to be highly improbable which means much lower than 10-9/hour.
2. Concerning electronics components such as thermometers, heaters, wires and connectors, a dimensioning hypothesis has been taken, that is their failure modes have been considered possible (<10-8)
3. Concerning all the weldings and solderings of mechanical parts of the system, it is assumed that, known that the system is supposed to have passed all the environmental test with success, which then lead to the assembly process qualification, the probability of occurrence of a failure on these elements is very improbable.
4. Concerning the Kevlar cord, by lack of information and test results at the time this document is written, a conservative hypothesis has been taken, that is the probability of occurrence of its failure modes is considered to be Probable.

4.7 Criticality matrix

The criticality associated to a failure mode of a component is given by the value of the gravity, the probability of occurrence and the testability of the failure mode.
This parameter allows to identify the failure modes of the system which are unacceptable and need that some actions might be taken in order to reduce their criticality to an acceptable level. (which is the main objective of a FMECA process).
In the present analysis, it has been considered the following :

1. Criticality associated to a given failure mode is equal to the product of its gravity and probability of occurrence if necessary multiplied by two in the case where this failure mode would not be detectable before launch
2. Criticality values equal or greater than 4 are considered to be unacceptable and necessitates that a corrective action should be applied to the system.

5. Synthesis

The analysis of the FMECA tables which are presented in annex A of the present document shows that, excepted for the Kevlar cord, the proposed architecture of the system does not present any weakness necessitating to apply modifications.
Effectively, the tables does not show any failure mode criticality above the fixed threshold of "4" which points out that no particular improvement need to be considered.

Considering the Kevlar cord which is known since the beginning of this project to be the weak point of the Sorption Cooler (not because one might think that there is a high risk of failure on this particular component but just because of the lack of field experience of this material at such temperatures for a long period of time), specific actions are already engaged in order to demonstrate, either its compliance with the requirements of the system for the whole life mission duration, either the necessity to find how the suspension system should be modified in order to reach an acceptable criticality level.

ANNEX A

FMECA TABLES

Block ref.	Functional block	Part	Location	Failure mode	Cause	Primary failure effect	System failure effect	D	G	O	C	Corrective action	Criticity after corrective action	Remarks
100	Gas Enclosure	1/2 male pump	sorption pump	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	1/2 female pump	sorption pump	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Pulleys and pulley screws	sorption pump	break	part failure	Gas enclosure badly maintained	probable destruction of the system leading to the loss of system functionality	0	2	1	2	N/A		Not applicable
100	Gas Enclosure	Charcoal casing	sorption pump	break	part failure	Unability to transmit cooling and/or heating to the charcoal pellets	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Active charcoal pellets	sorption pump	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
100	Gas Enclosure	Stycast glue	sorption pump	loss of gluing properties	part failure	Unability to transmit cooling and/or heating to the charcoal pellets	Loss of system functionality	1	2	1	2	N/A		
100	Gas Enclosure	Grid mesh	sorption pump	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
100	Gas Enclosure	Grid ring	sorption pump	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
100	Gas Enclosure	Pump cold tip	sorption pump	break	part failure	Unability to transmit cooling and/or heating to the charcoal pellets	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Heater	sorption pump	open circuit	part failure	Loss of SP heating capability on one channel	Loss of system redundancy	0	1	2	2	N/A		Heaters are redounded on the SP.
100	Gas Enclosure	Thermometer	sorption pump	open circuit	part failure	Loss of SP temperature measurement capability on one channel	Loss of system redundancy	0	1	2	2	N/A		Thermometers are redounded on the SP.
100	Gas Enclosure	External shape weld (Electron beam weld)	sorption pump	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas	Pumping line	sorption pump	Loss of	part	Gas leakage	Loss of system	0	2	1	2	N/A		

Block ref.	Functional block	Part	Location	Failure mode	Cause	Primary failure effect	System failure effect	D	G	O	C	Corrective action	Criticity after corrective action	Remarks
	Enclosure	weld (Electron beam weld)		hermeticity	failure		functionality							
100	Gas Enclosure	SP Heat exchanger solder	sorption pump	break	part failure	Unability to transmit cooling and/or heating to the charcoal pellets	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Evaporator tube	Pumping line	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Pump outgoing tube	Pumping line	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Sleeve	Pumping line	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		Not applicable
100	Gas Enclosure	Shunt	Pumping line	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Filling pipe	Pumping line	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Thermometers	Pumping line	open circuit	part failure	Loss of pumping line shunt temperature measurement on one channel	No effect	0	0	2	0	N/A		The shunt thermometer has no effective rôle in the regulation of the system (there is no heater associated to this thermometer) and moreover, the shunt thermometer is redounded
100	Gas Enclosure	Shunt weld	Pumping line	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Filling pipe weld	Pumping line	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	1/2 female evaporator	Evaporator	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	1/2 male evaporator	Evaporator	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Pulleys and pulley screws	Evaporator	break	part failure	Gas enclosure badly maintained	probable destruction of the system leading to the loss of system functionality	0	2	1	2	N/A		Not applicable
100	Gas	1/2 female cup	Evaporator	No failure	N/A	N/A	N/A	0	0	0	0	N/A		

Block ref.	Functional block	Part	Location	Failure mode	Cause	Primary failure effect	System failure effect	D	G	O	C	Corrective action	Criticity after corrective action	Remarks
	Enclosure	evaporator		mode identified										
100	Gas Enclosure	1/2 male cup evaporator	Evaporator	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
100	Gas Enclosure	Procelit (foam)	Evaporator	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
100	Gas Enclosure	Evaporator cold tip	Evaporator	Break	part failure	Loss of the ability to transmit the cooling to the instrumens	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Thermometer	Evaporator	open circuit	part failure	Loss of EV temperature measurement on one channel	Loss of system redundancy	0	1	2	2	N/A		Thermometers are redounded on the EV.
100	Gas Enclosure	External shape weld	Evaporator	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	Pumping line weld	Evaporator	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
100	Gas Enclosure	EV cold tip solder	Evaporator	break	part failure	Loss of the ability to transmit the cooling to the instrumens	Loss of system functionality	0	2	1	2	N/A		
200	Command / Control system	Mini pump	HSP/HSE	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
200	Command / Control system	Active charcoal parts	HSP/HSE	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
200	Command / Control system	Mini pump cap	HSP/HSE	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
200	Command / Control system	Mini pump tube	HSP/HSE	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
200	Command / Control system	Pumping line weld	HSP/HSE	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
200	Command /	Glue	HSP/HSE	loss of gluing	part	Unability to transmit	Loss of system	0	2	1	2	N/A		

Block ref.	Functional block	Part	Location	Failure mode	Cause	Primary failure effect	System failure effect	D	G	O	C	Corrective action	Criticity after corrective action	Remarks
	Control system			properties	failure	cooling and/or heating to the charcoal pellets	functionality							
200	Command / Control system	Heater	HSP/HSE	open circuit	part failure	Loss of HSP or HSE mini pump heating capability on one channel	Loss of system redundancy	0	1	2	2	N/A		Heaters are redounded on the HSP/HSE.
200	Command / Control system	Thermometer	HSP/HSE	open circuit	part failure	Loss of HSP or HSE temperature measurement on one channel	Loss of system redundancy	0	1	2	2	N/A		Thermometers are redounded on the HSP/HSE.
200	Command / Control system	Thermal shunt	HSP/HSE	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
200	Command / Control system	Filling pipe	HSP/HSE	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
200	Command / Control system	Filling pipe weld	HSP/HSE	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
200	Command / Control system	Copper braid	HSP/HSE	No failure mode identified		N/A	N/A	0	0	0	0	N/A		
200	Command / Control system	Copper switch head	HSP/HSE	No failure mode identified		N/A	N/A	0	0	0	0	N/A		
200	Command / Control system	Thermal shunt weld	HSP/HSE	Loss of hermeticity	part failure	Gas leakage	Loss of system functionality	0	2	1	2	N/A		
200	Command / Control system	Connectors	Lower plate	open circuit	part failure	Loss of one command/control channel	Loss of system redundancy	0	1	2	2	N/A		Loss of system redundancy
200	Command / Control system	Wires	N/A	Open circuit	part failure	Loss of one heater or thermometer functionality on one channel	Loss of system redundancy	0	1	2	2	N/A		Loss of system redundancy
200	Command / Control system	Anti-vibration interface	HSP	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		

Block ref.	Functional block	Part	Location	Failure mode	Cause	Primary failure effect	System failure effect	D	G	O	C	Corrective action	Criticity after corrective action	Remarks
200	Command / Control system	Anti-vibration interface screw	HSP/HSE	Break	part failure	Loss of one of the two screws maintaining the anti vibration interface	No effect	0	1	1	1	N/A		All mechanical elements fixations are redounded with two screws
300	Support Structure	End plate	Support structure	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
300	Support Structure	Lower plate	Support structure	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
300	Support Structure	Upper plate	Support structure	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
300	Support Structure	Lateral plate	Support structure	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
300	Support Structure	Lateral plate mounting side	Support structure	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
300	Support Structure	Evaporator bracket	Support structure	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
300	Support Structure	Pump bracket	Support structure	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		
300	Support Structure	Pulleys screws	Support structure	Break	part failure	Gas enclosure badly maintained	probable destruction of the system leading to the loss of system functionality	0	2	1	2	N/A		
300	Support Structure	Perforated pulleys screws	Support structure	Break	part failure	Gas enclosure badly maintained	probable destruction of the system leading to the loss of system functionality	0	2	1	2	N/A		
300	Support Structure	Ratchet wheel	Support structure	Break	part failure	Gas enclosure badly maintained	probable destruction of the system leading to the loss of system functionality	0	2	1	2	N/A		
300	Support	Tensioning	Support	Break	part	Gas enclosure badly	probable destruction	0	2	1	2	N/A		

Block ref.	Functional block	Part	Location	Failure mode	Cause	Primary failure effect	System failure effect	D	G	O	C	Corrective action	Criticity after corrective action	Remarks
	Structure	pulleys	structure		failure	maintained	of the system leading to the loss of system functionality							
300	Support Structure	Pawl	Support structure	Break	part failure	Gas enclosure badly maintained	probable destruction of the system leading to the loss of system functionality	0	2	1	2	N/A		
300	Support Structure	Kevlar cord	Support structure	Break	part failure	Gas enclosure badly maintained	probable destruction of the system leading to the loss of system functionality	0	2	2	4	Vibration test might be performed in order to verify the influence of the rupture of one of the four Kevlar cords	TBD	
				Lengthening	part ageing	Gas enclosure badly maintained	probable destruction of the system leading to the loss of system functionality	1	2	2	8	A tool must be designed to be able to measure the tension of each portion of the Kevlar cord	TBD	
300	Support Structure	Centering screws	Support structure	No failure mode identified	N/A	N/A	N/A	0	0	0	0	N/A		