SPIRE & PACS Sorption Coolers DEVELOPMENT PLAN

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Document Status

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2	0	23/11/2000		All document reviewed – cooler change to 6 liters unit – new reference for the document
2	1	18/01/2001		STM models added in Dev. Plan
2	2	26/03/2001		New format for doc. (PA Plan). Planning revisited + minor modifications
2	3	16/05/2001		Page 10
3	0	06/06/2001		All pages – document updated following cooler DDR
3	1	31/10/2001		Updated according to AIV plan

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CONTENTS

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List of Acronyms

AD	Applicable Document		
BV	Bureau Veritas		
CEA	Commissariat à l' Energie Atomique		
CDR	Critical Design Review	Revue de conception détaillée	RCD
CQM	Cryogenic Qualification Model		
DDR	Detailed Design Review		
EGSE	Electronic Ground Support Equipment		
EV	Evaporator		
ETF	Environmental Test Facility		
FIRST	Far Infrared and SubmillimetreTelescope		
FS	Flight spare		
HSE	Heat Switch (on evaporator)		
HSP	Heat Switch (on sorption pump)		
HIFI	Heterodyne Instrument for FIrst		
MGSE	Mechanical Ground Support Equipment		
N/A	Not Applicable		
PACS	Photoconductor. Array Camera and Spectrometer		
PFM	ProtoFlight Model		
RD	Reference Document		
RFA	Request For Approval		
S/C	SpaceCraft		
SAp	Service d'Astrophysique		
SBT	Service des Basses Températures		
SCO	Sorption Cooler (full unit)		
SP	Sorption pump		
SPIRE	Spectral & Photometric Imaging Receiver		

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1 Introduction

The Herschel/Planck mission of the ESA Horizon 2000 Science Program accommodates in the carrier option two spacecrafts for a joined launch on an ARIANE 5 launcher into a L2 orbit in 2007.
Herschel is a multi-user observatory type mission performing astronomical investigations in the infrared and submillimetre wavelength range. The Herschel payload is consisting of three instruments :

- •HIFI
- •PACS
- •SPIRE

The instruments are mounted in the Herschel payload module. The spacecraft provides the environment for astronomical observations in the infrared wavelength range from about 85 to 600 micron requiring cryogenic temperatures for the cold focal plane units.
The Spectral and Photometric Imaging Receiver (SPIRE) will cover the 200 – 670 µm spectral range using bolometric detectors, as the Photo-conductor Array Camera and Spectrometer (PACS) will cover the 60 – 210 µm spectral range.
The cooling of the detector arrays down to 300 mK will be effected by a ^{3}He sorption cooler for both instruments.

1.1 Scope of the document

This document describes the development plan of the Herschel SPIRE and PACS helium sorption coolers. This development plan is based on the applicable document referenced in § 2. This development plan does not include activities related to the drive electronic.
This document will be put under configuration at DDR

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2 Documents

2.1 Applicables documents

All Applicable Documents are listed in the AD chapter of the CIDL (HSO-SBT-LI-010).

2.2 Reference documents

	Title	Author	Reference	Date
RD1	SPIRE A Bolometer Instrument for FIRST – A proposal submitted to ESA	Various	N/A	Feb. 1998
RD2	Cooler redundancy – conclusion on what to do about it	B. Swinyard, L. Duband	SPIRE-RAL-NOT-000341	Feb. 2000

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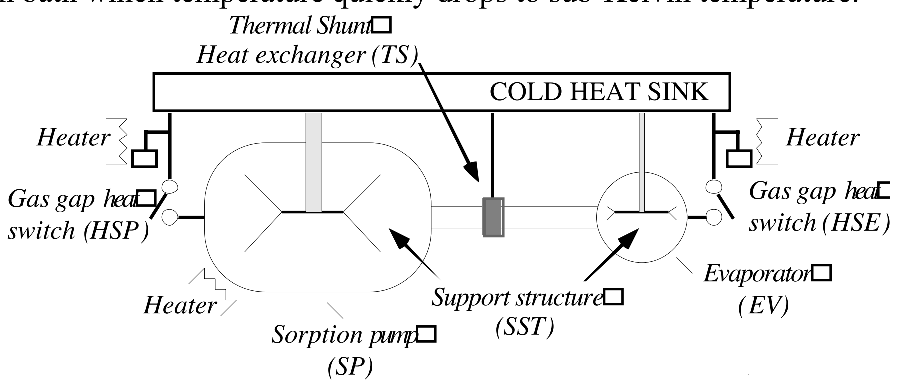
3 Description of the sorption cooler

The cooling of the SPIRE/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 vibrationless and can be designed to be self contained and compact with a high duty cycle efficiency.

As shown on the figure hereafter the cooler is basically made of 6 components designated as a sorption pump SP and an evaporator EV connected via a pumping line to a thermal shunt TS comprising an heat exchanger, two gas gap heat switches HSP and HSE respectively connected to the sorption pump (SP) and evaporator (EV), and finally a support structure SST. SP, EV, TS and the pumping line are assembled to form a unique component which is the actual "heart" of the cooler. This component is held within SST, which provides firm mechanical support (launch environment) while minimizing any parasitic conductive load on the cooler (low temperature environment).
Heat switches are then required for operation of the cooler. The two switches are used to control the temperature gradient; during the condensation phase they are set such that the sorption pump can be heated to release the helium gas and such that liquid condensation occurs into the evaporator EV maintained as the coldest point. The liquid is held into EV by capillary attraction inside some porous material : both the surface tension and the vapor pressure provide forces that drive and hold the liquid at the coldest point. Then the switches are set such that the sorption pump is thermally grounded to the heat sink and such that the evaporator is thermally isolated. The sorption pump provides an evaporative pumping on the liquid helium bath which temperature quickly drops to sub-Kelvin temperature.



Cryogenic switches can be based upon different physical mechanisms. Gas gap heat switches have been selected as the preferred design for the present project.
Gas gap heat switch utilizes concentric copper cylinders separated by a small gap which is filled with or emptied of He gas to achieve the switching action. The thermal separation between the two ends is achieved by a thin-walled tube which also provides the mechanical

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support. The presence or absence of gas is controlled by a miniature cryogenic adsorption pump that can be temperature regulated. Thus one of their main feature is the absence of any moving part, and consequently operation of the cooler is almost then fully controlled by three heaters.

For operation in a zero-G environment two aspects are addressed: the liquid confinement and the structural strength required for the launch. The confinement within the evaporator is provided by a porous material which hold the liquid by capillary attraction, and a suspension system using Kevlar wires is designed to firmly support the refrigerator during launch while minimizing the parasitic heat load on the system.

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4 Constraints

4.1 Development constraints

4.1.1 Technical constraints

The main specifications for the sorption cooler are reported below.

- The net heat lift at 290 mK shall 10 µW at a minimum under the nominal operating conditions (1.7 K heat sink / 4 K environment).
- Inside the cooler itself the parasitic heat load to the cold tip must be minimised. As a goal it shall not exceed 12 µW under the nominal operating conditions (1.7 K / 4 K).
- The hold time shall be no less than 22 hours and shall be based on a finite number of days (a minimum of 46 hours is favored)
- The recycle time shall be no more than 2 hours
- The energy dissipated per cycle due to cooler operation shall be no more than 860 J. the 4K/1.7K thermal architecture calls for an additional contribution to the average power dissipated - this contribution (not part of the 860 J) shall not be in excess of 0.6 mW.
- The overall mass of the cooler shall be no more than 1.8 kg.
- The maximum envelope for the cooler shall be no more than 230 x 100 x 100 mm.

4.1.2 Organization

CEA-SBT is responsible for the SCO design, manufacturing, assembling, qualification and delivery (seven models). CEA-SBT designs the SCO and subcontract its manufacturing and part of its assembling to identified subcontractors. CEA-SBT contributes to the definition of the drive electronic. This drive electronic is under SAp's responsibility.
All these activities are performed in accordance with both PACS and SPIRE PA requirements.

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4.2 Risk analysis

The risk analysis hereafter only refer to this development plan not being completed.

Risk	Impact	Preventive action	Note
Major failure during assembling process	Development plan must be updated. Delivery dates are delayed by TBD months	None	This type of failure can only occurs on the sorption pump + evaporator + heat switches. Consequently only part of the cooler would have to be re-manufactured.
Availability of ^{3}He gas	Idem as above	Required amount of 3He gas has already been supplied	
Major failure during prequalification tests (proof pressure test, etc..)	Idem as above	Leak before burst and ultimate pressure tests will be performed on samples.	Idem as above
Failure of test cryostat	TBD	Two tests cryostat are supplied	
Unavailability of main test team member	None	Other group members are involved in the project.	One person is identified as responsible for the test plan, but other group members are involved to a level such they can replace the missing person.
Qualification failure	Development plan must be updated. Delivery dates are delayed by TBD months	None	

4.3 Redundancy

Some redundancy aspects have been specifically covered in RD2. The conclusion of this document indicate that :

- it is not possible to have complete insurance against the random mechanical failure of the cooler pressure vessel or mechanical support – this must be achieved by design and test.

- The wiring and electronics might be made fully redundant.

In order to get the necessary inputs for a final decision on the best redundancy scheme, a reliability study will be performed (scheduled in Mid 2001).
A FMEA will be performed in order to take all the risks reduction actions.

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5 Work description

5.1 Task plan

The general plan is defined through the following table; the tasks are listed chronologically. Parallel tasks are grouped under the same sequence number.

Sequence	Task n°	Task Name	Performed by
All		PA follow up throughout activities	BV + CEA-SBT
All		Project management	CEA-SBT
1	1.1	Technical requirements	CEA-SBT
	1.2	Overall design	CEA-SBT
	1.3	Detailed design	CEA-SBT
	1.4	Test plan and test set-up design	CEA-SBT
2	2	DDR – Design approval	
3	3.1	Cooler manufacturing and assembling	TBD
	3.2	Test set up manufacturing	TBD
	3.3	Test predictions	CEA-SBT
	3.4	Manufacturing progress meeting	
4	4	Test readiness review and approval	
5	5	Pre qualification test	CEA-SBT
6	6	Thermal test program – first set	CEA-SBT
7	7	Environmental test program (Vibration)	ETF
8	8	Thermal test program – second set	CEA-SBT
9	9	Environmental test program (bake out)	SBT
10	10	Thermal test program – third set	CEA-SBT
11	11	Delivery preparation	TBD
12	12	Delivery	CEA-SBT

The tasks 3 to 10 are repeated for the 2 CQM, 2 PFM and 1 FS models. The 2 STM model are manufactured, assembled, vibration tested and delivered.
In between each model an additional task references as " Correction of design and correction approval if needed" may be performed.

5.2 Development and model philosophy

The model philosophy is compliant with the SPIRE/PACS projects requirements.

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5.2.1 Preliminary design

The overall design of the sorption cooler takes advantage of the know-how of CEA-SBT in sorption cooling technologies. This design benefits the design heritage of the orbital sorption cooler which successfully flew in April 1995 on board the Infrared Telescope in Space.

Moreover as part of the ESA Technology Research Program (TRP) CEA-SBT was awarded a contract which purpose was to bring the existing sorption cooler technology to a level compatible with space missions. This work has been completed in fall 2000. A ^{3}He sorption cooler prototype, which initial specifications were closed to that of the SPIRE cooler (as of 1998), has been designed, manufactured, and has successfully undergone the test program.
This prototype design has been substantially improved and features our latest advances. The design of the SPIRE/PACS cooler is very similar and has been further refined based on the obtained results.
The thermal performance are evaluated using a software tool developed at CEA-SBT. This software has been already used in the design of various sorption coolers and has proven to be a very useful tool. It continues to evolve as more experimental data are made available.
The sorption cooler uses a suspension system utilizing Kevlar wires to firmly support the cooler during launch while minimizing the parasitic heat load on the system during cold operation. A mathematical model has been developed to predict the resonant frequencies. In addition a full finite elements modelisation has been done on the present prototype cooler to further confirm the mechanical behavior.

The thermal performance are verified by test. The on orbit performance (liquid confinement) are validated by operating the cooler in various orientation, in particular upside down, during the low temperature phase.
A vibration test is performed to verify the mechanical behavior; this vibration test includes a low level sine sweep to check the resonant frequencies.

5.2.2 Procurements of long delay cryogenic components

Once the preliminary design has been validated by the PDR, the procurement for long delay cryogenic components is initiated if money is available. These components include mostly space qualified thermometers, heaters and connectors.

5.2.3 Detailed design and CQM/STM manufacture

The detailed design encompasses all the functions. The design is verified by more detailed modelisation where necessary, in particular a numerical modelisation of the mechanical characteristics is performed. This detailed design benefits from the outcome of the ESA TRP contract.
The detailed design is presented at the Detailed Design Review. The DDR must have been held before the CQM/STM manufacture can be initiated.
A test program is produced which contains the tests sequence to be performed on the sorption cooler (to the exception of the STM) which contributes, together with analysis and other verification methods, to qualification.
This test program covers the functional performance and environmental tests required to provide confidence in the ability of the cooler to meet the specified requirements.

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Performance measurements will be made before and after the environmental tests, designed to detect changes in performance parameters which may indicate a potential failure.
A test cryostat that can be operated in any orientation between –90° and +90° to enable testing of the cooler in a wide range of orientation will be developed. It is indicated that CEA-SBT has already developed such cryostats and possesses this know-how.
The environmental tests will be performed at ETF.

The CQM cooler includes all the functions of the flight design and undergoes the full test program. All external components (thermometers, heaters, etc…) are not of flight grade.
The CQM cooler shall permit to validate all modifications implemented in the design at the outcome of the TRP contract.
A test referenced as the "Health Check" is established. This test allows to verify nominal operation of the cooler from a mechanical, leaktightness and thermal point of view. It includes a verification of various components (thermometers, heaters, Kevlar cords). This health check will be performed whenever necessary to check for the integrity of the cooler.

The STM cooler is mechanically representative (all interfaces) but does not feature any thermal capability. The cooler heart is replaced by a component comprising two aluminum spheres joined by a tube. The spheres feature all the relevant mechanical aspects (pulleys, design angles, moment of inertia, etc…). The evaporator sphere features the nominal interface to the 300 mK detectors strap. The heat switches are replaced by two pieces providing the mechanical interfaces to the 1.7 K strap.
The STM unit is used to address mechanical and integration problems only. It will undergo a vibration test prior to delivery to the instruments.
At SBT level the STM cooler shall permit to validate the mechanical design of the suspension structure.

5.2.4 Flight design modifications and PFM/FS manufacture

Following the CQM/STM qualification program, some modifications may have to be implemented in the design.
If the changes are major and require further thermal experimental validation CEA-SBT will use for this purpose a simple development model prototype developed in the framework of the ESA TRP contract.
Otherwise the changes are implemented in the flight design, and the SCO PFM and SCO FS are manufactured and assembled at the same time.
They both undergo the full test program successively, PFM first.

5.3 Verification plan

The STM, CQM, PFM and FS coolers are designed based on our mechanical and low temperature know how and manufactured and assembled by qualified and skilled subcontractors and CEA-SBT.
All precautions are taken to guarantee successful devices and the coolers are controlled at various step during their fabrication.
The table hereafter is a "summarized" verification matrix in which for each relevant specification or requirement is indicated whether it is verified by analysis, design, test and/or

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inspection. A more detailed matrix with reference to each single specification/requirement is provided in the AIV plan (HSO-SBT-PL-0013).
These verifications apply to all models (to the exception of the STM).
The column "§ Spec." refers to the related paragraph in the document "SPIRE & PACS Sorption Cooler Specifications", ref. HSO-SBT-SP-001.

		Verification method			
§ Spec	**Heading**	**Analysis**	**Design**	**Test**	**Inspection**
4.1	***Functional requirements***	X	X	X	
4.2	***Operational requirements***				
4.2.1	Safety	X		X	
4.2.2	Lifetime	X	X		
4.2.3	Operating modes		X	X	
4.2.4	Commands	X		X	
4.2.5	Monitoring	X		X	
4.3	***Environmental requirements***				
4.3.1	Thermal environment		X	X	
4.3.2	***Mechanical environment***				
4.3.2.1	Limit loads and launch levels	X	X	X	X
4.3.2.2	Orbit		X	X	
4.3.2.3	Ground		X	X	
4.3.3	***Electrical environment***		X		
4.3.4	***Radiation environment***		X		
4.4	***Design & construction requirements***				
4.4.1	Interchangeability		X		
4.4.2	Control electronics	Under responsibility of SAp			
4.4.3.1	Maximum operating pressure		X		
4.4.3.2	Proof pressure and Burst pressure	X	X	X	
4.4.4	Mass		X		
4.4.5	Size		X		
4.4.6	Mechanical stiffness requirement	X	X	X	
4.4.7.1	Design margin – Structural	X	X	X	
4.4.8 4.4.8.5	Parts, Material and processes Cleanliness	X	X	 X	X
4.5	***Interface requirements***				
4.5.1	Thermal interface to detector		X	X	
4.5.2	Mechanical interface to the heat sink		X		
4.5.3	Thermal interface to the heat sink		X	X	
4.5.4	Electrical interface		X	X	
4.6	Logistic requirements		X		X

5.4 Product Assurance

Product Assurance will cover the overall duration of the project, from design phase upon delivery to higher level. The PA plan is presented in the document untitled "Product Assurance Plan" Ref. HSO-SBT-PL-006.

All PA tasks will be carried out in accordance with PACS and SPIRE PA requirements. The main activities are summarized hereafter :

- definition of the PA plan
- definition of the cleanliness plan

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- configuration control and management of the documentation
- product/quality assurance during the definition phases by document writing, verification and updating (PA plan ; Parts, Material and Processes list, EEE Parts List ; FMEA ;...)
- product assurance during the manufacturing phases by inspections, controls and by document writing, verification and updating (Cleaning procedures ; Processes procedures ; Assembly Procedures ; Inspection and Control reports ;...)
- product/quality assurance during the verifications and tests phases by inspections, controls and by document writing, verification and updating (procedures ; Cleanliness Reports ;...)
- Non Conformance system management during all the phases (Non Conformance Reports, Request for Waiver, Request for Approval)
- Management of the coolers data packages

5.5 Ground associated equipment

The main ground equipment to be developed and required for the coolers qualification at SBT level is a test cryostat. This test cryostat shall provide temperature down to 1.8 K. Its autonomy at 1.8 K shall be at least 48 hours in normal orientation (see hereafter). One particular feature is the capability of this cryostat to be operated tilted to any angle between –90° and +90°. When tilted the 48 hours requirement does not apply.
This feature allows to mount the coolers such they can be thermally tested during the low temperature phase in almost all orientations, i.e. rightside-up, horizontal and upside down.
CEA-SBT has developed similar cryostat in the past.

All other EGSE at SBT level are standard laboratory equipment (power supplies, temperature bridges, computer, etc…).

5.6 Man power

The project team includes engineers and technicians from CEA-SBT with the necessary experience. This team is supported by specialists when appropriate. Although most of the thermal tests can be carried out by one person, other group members are involved to a level such they could perform the tests. The project manager and PA manager are responsible for the implementation of the complete manufacturing, assembling, and qualification program.

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6 Development calendar

Item	Action	Date
Detailed design	Production of 3D drawings	Winter 2000 – Spring 2001
CQM&STM	Manufacture	Summer – Fall 2001
STM	Vibration test	Winter 2001
STM	Delivery	Winter 2001
CQM	Assembling	Fall 2001
CQM	Qualification (test program)	Winter 2001-2002
CQM	Delivery	Spring 2002
PFM & FS	Manufacture	Spring 2002
PFM & FS	Assembling	Summer 2002
PFM	Qualification (test program)	Fall 2002
PFM	Delivery	Winter 2002
FS	Qualification (test program)	Spring 2003
FS	Delivery	Summer 2003

Note : Potential modifications to be implemented in PFM and FS at completion of the qualification program might require some delay. In this case this calendar will need to be revisited.
The detailed planning for the CQM and STM coolers is given in appendix A.

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7 Description of deliverables

7.1 Deliverable model

Model	Flight representativity	Difference with flight	Deliverables
CQM	Not 100%	Thermometers and heaters equivalent functionally and fit, but not of flight grade	2
PFM	100%	None	2
FS	100%	None	1

7.2 Associated equipment

Specific tools are provided with each coolers – these include mounting and tension verification tools.

7.3 Associated documentation

Each model will be delivered with its acceptance data package. This data package includes the following :

- certificate of conformance for the cooler
- log book
- test report
- user manual
- etc…

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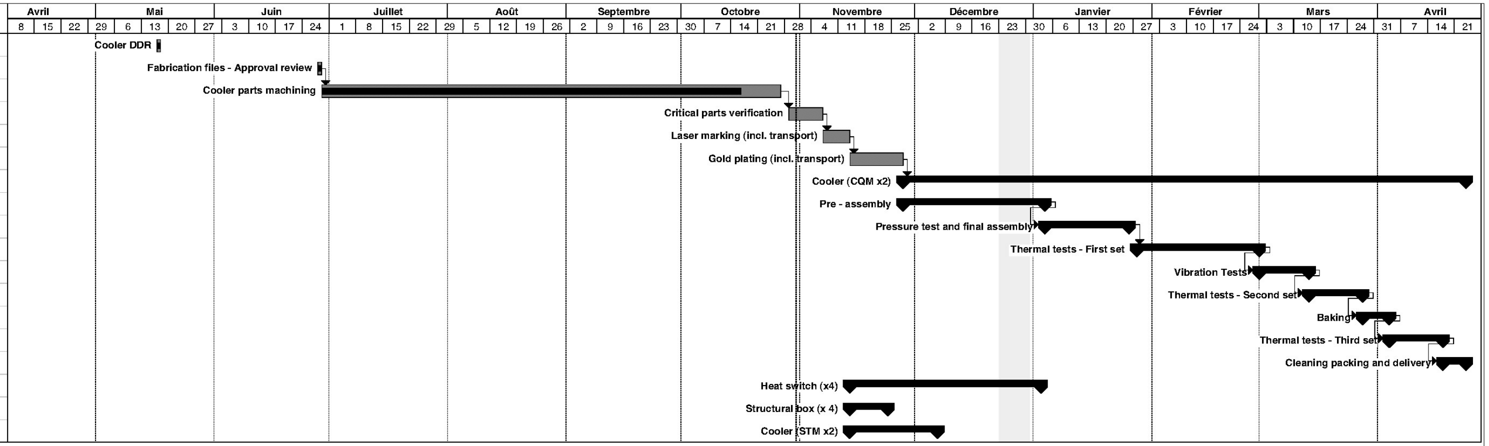
Appendix A

Planning as of October 31st 2001

N°	Nom de la tâche	Durée
1	Cooler DDR	1j
2	Fabrication files - Approval review	1j
3	Cooler parts machining	17s
4	Critical parts verification	1s
5	Laser marking (incl. transport)	1s
6	Gold plating (incl. transport)	2s
7	**Cooler (CQM x2)**	**100j**
8	**Pre - assembly**	**22j**
25	**Pressure test and final assen**	**16j**
39	**Thermal tests - First set**	**24j**
50	**Vibration Tests**	**9j**
55	**Thermal tests - Second set**	**10j**
58	**Baking**	**5j**
62	**Thermal tests - Third set**	**10j**
66	**Cleaning packing and deliver**	**4j**
71	**Heat switch (x4)**	**31j**
91	**Structural box (x 4)**	**8j**
97	**Cooler (STM x2)**	**17j**



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