Photometer Calibrator (SCAL)

Subsystem Specification Document

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List of Acronyms

Term	Meaning	Term	Meaning
AD	Applicable Document	IR	Infrared
ADC	Analogue to Digital Converter	IRD	Instrument Requirements Document
AIV	Assembly, Integration and Verification	IRTS	Infrared Telescope in Space
AME	Absolute Measurement Error	ISM	Interstellar Medium
AOCS	Attitude and Orbit Control System	JFET	Junction Field Effect Transistor
APART	Arizona's Program for the Analysis of Radiation Transfer	ISO	Infrared Space Observatory
APE	Absolute Pointing Error	LCL	Latching Current Limiter
ASAP	Advanced Systems Analysis Program	LIA	Lock-In Amplifier
ATC	Astronomy Technology Centre, Edinburgh	LVDT	Linear Variable Differential Transformer
AVM	Avionics Model	LWS	Long Wave Spectrometer (an instrument used on ISO)
BDA	Bolometer Detector Array	MAC	Multi Axis Controller
BFL	Back Focal Length	MAIV	Manufacturing, Assembly, Integration and Verification
BRO	Breault Research Organization	MCU	Mechanism Control Unit = HSMCU
BSM	Beam Steering Mirror	MGSE	Mechanical Ground Support Equipment
CBB	Cryogenic Black Body	M-P	Martin-Puplett
CDF	Cardiff, Department of Physics & Astronomy	NEP	Noise Equivalent Power
CDMS	Command and Data Management System	NTD	Neutron Transmutation Doped
CDMU	Command and Data Management Unit	OBS	On-Board Software
CDR	Critical Design Review	OGSE	Optical Ground Support Equipment
CEA	Commissariat a l'Energie Atomique	OMD	Observing Modes Document
CMOS	Complimentary Metal Oxide Silicon	OPD	Optical Path Difference
CoG	Centre of Gravity	PACS	Photodetector Array Camera and Spectrometer
CPU	Central Processing Unit	PCAL	Photometer Calibration source
CQM	Cryogenic Qualification Model	PFM	Proto-Flight Model
CVV	Cryostat Vacuum Vessel	PID	Proportional, Integral and Differential (used in the context of feedback control loop architecture)
DAC	Digital to Analogue Converter	PLW	Photometer, Long Wavelength
DAQ	Data Acquisition	PMW	Photometer, Medium Wavelength
DCU	Detector Control Unit = HSDCU	POF	Photometer Observatory Function
DDR	Detailed Design Review	PROM	Programmable Read Only Memory
DM	Development Model	PSW	Photometer, Short Wavelength
DPU	Digital Processing Unit = HSDPU	PUS	Packet Utilisation Standard
DSP	Digital Signal Processor	RAL	Rutherford Appleton Laboratory,
DQE	Detective Quantum Efficiency	RD	Reference Document
EDAC	Error Detection and Correction	RMS	Root Mean Squared
EGSE	Electrical Ground Support Equipment	SCAL	Spectrometer Calibration Source
EM	Engineering Model	SCUBA	Submillimetre Common User Bolometer Array
EMC	Electro-magnetic Compatibility	SED	Spectral Energy Distribution
EMI	Electro-magnetic Interference	SMEC	Spectrometer Mechanics
ESA	European Space Agency	SMPS	Switch Mode Power Supply
FCU	FCU Control Unit = HSFCU	SOB	SPIRE Optical Bench
FIR	Far Infrared	SOF	Spectrometer Observatory Function
FIRST	Far Infra-Red and Submillimetre Telescope	SPIRE	Spectral and Photometric Imaging Receiver
FOV	Field of View	SRAM	Static Random Access Memory
F-P	Fabry-Perot	SSSD	SubSystem Specification Document
FPGA	Field Programmable Gate Array	STP	Standard Temperature and Pressure
FPU	Focal Plane Unit	SVM	Service Module
FS	Flight Spare	TBC	To Be Confirmed
FTS	Fourier Transform Spectrometer	TBD	To Be Determined
FWHM	Full Width Half maximum	TC	Telecommand
GSFC	Goddard Space Flight Center	URD	User Requirements Document
HK	House Keeping	UV	Ultra Violet
HOB	Herschel Optical Bench	WE	Warm Electronics
HPDU	Herschel Power Distribution Unit	ZPD	Zero Path Difference
HSDCU	Herschel-SPIRE Detector Control Unit		
HSDPU	Herschel-SPIRE Digital Processing Unit		
HSFCU	Herschel-SPIRE FPU Control Unit		
HSO	Herschel Space Observatory		
IF	Interface		
IID-A	Instrument Interface Document - Part A		
IID-B	Instrument Interface Document - Part B		
IMF	Initial Mass Function		

Table of Contents

1. Scope

This specification defines the requirements and specifications applied to the performance, design, qualification and interfaces of the SPIRE Spectrometer Calibrator (SCAL) subsystem. It is applicable to the STM, the CQM, the PFM and the FS as described in this document.

2. Documents

2.1. Applicable documents

All applicable documents are listed in the AD chapter of the CIDL (HSO-CDF-LI-029).

3. Subsystem Description

3.1. General overview

PCAL is an electrically heated thermal source of submillimetre radiation the purpose of which is to provide a repeatable signal for monitoring of health and responsivity of the SPIRE photometer detectors. It is not required to provide absolute calibration or uniform illumination of the array, although it may be used as part of the overall calibration scheme in flight.

PCAL will be located at the position of a hole in the centre of the Beam Steering Mirror (BSM), which is at a pupil image. Although PCAL is optimised for the photometer, it can also be viewed by the FTS detector arrays. The thermal source will be positioned behind the mirror with a light pipe connecting the aperture in the mirror to a cavity in which the source is mounted, as shown in Figure 1. The BSM will be switched off when PCAL is operating, and some clearance will be needed to ensure the BSM does not foul on the light pipe when chopping. The location of PCAL and the BSM in the photometer opto-mechanical layout is shown in Figure 2

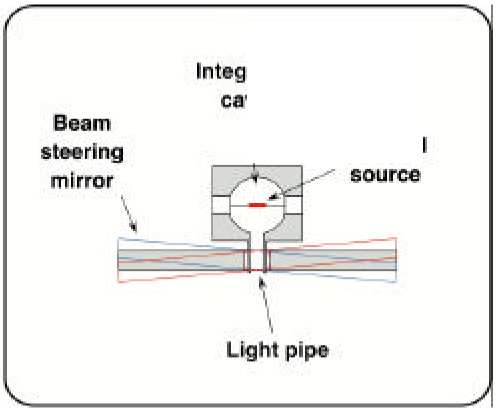

Figure 1: Conceptual design of PCAL

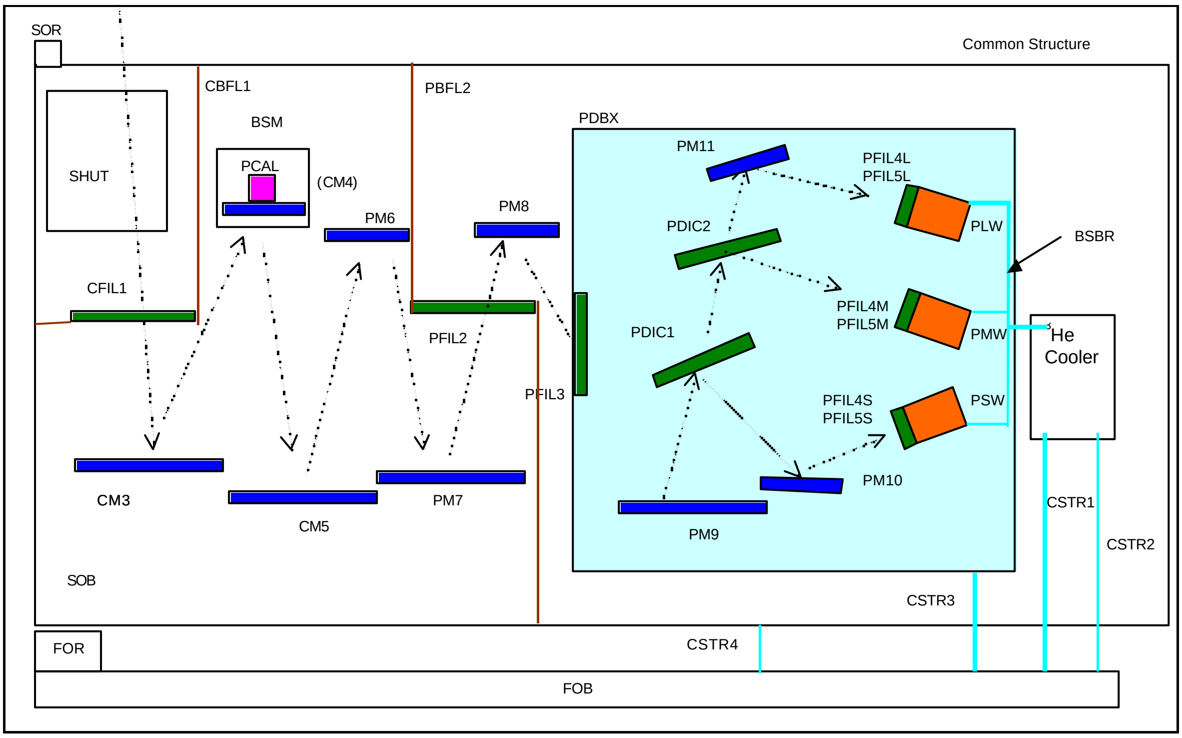

Figure 2: Location of the BSM and PCAL in the SPIRE FPU

4. PCAL requirements

The following tables summarise the PCAL performance and system requirements, as stated in the SPIRE Instrument Requirements Document, taking into account the changes requested by Cardiff (July 25 2001) and the response of the SPIRE Instrument Scientist (e-mail, August 30 2001). Each requirement is discussed individually below.

PCAL Performance Requirements		
Requirement ID	**Description**	**Value**
IRD-CALP-R01	Nominal operating output	Equivalent to εT = 40 K for 200 < λ < 700 μm
IRD-CALP-R02	Operating temperature range	Commandable in 256 steps with at least 124 steps covering the range from zero output to εT = 40 K
IRD-CALP-R03	Pupil obscuration	The outside envelope of the calibrator housing shall not foul on any part of the BSM for any angular position that the BSM may attain in operation or under vibration.
IRD-CALP-R04	Time constant	In response to a step change in applied electrical power, the 90% settling time of the radiant power output shall be less than 350 ms (requirement); 70 ms (goal)
IRD-CALP-R05	Repeatability	RMS better than 1% over 20 operations equi-spaced over a period of 12 hours, with uniform base temperature and drive current. An operation is here defined as an appropriate standard sequence of On/Off excitation cycles.
IRD-CALP-R06	Operation	Nominally once per hour for no more than 10 seconds
IRD-CALP-R07	Frequency	Continuously or pseudo continuously variable between 0 and 2 Hz.

PCAL System Requirements		
Requirement ID	**Description**	**Value**
IRD-CALP-R08	Interface	The calibrator will be integrated into the BSM

IRD-CALP-R09	Volume envelope	This shall be compatible with the space available within the BSM enclosure as described in the BSM SSSD.
IRD-CALP-R10	Thermal isolation	The temperature of the PCAL housing shall rise by no more than 1 K over the temperature of the BSM structure after 10 seconds when the calibrator is operated unmodulated at nominal power output.
IRD-CALP-R11	Operating temperature	4 K
IRD-CALP-R12	Cold power dissipation	Calibrator power dissipation in the FPU when operating continuously at nominal radiant output shall be less than 4 mW (requirement); 2 mW (goal)
IRD-CALP-R13	Warm power dissipation	Removed – IRD issue 1.0
IRD-CALP-R14	Operating voltage	Less than 28 V at input power level of 5 mW
IRD-CALP-R15	Redundancy	Cold redundancy for the thermal source
IRD-CALP-R16	Number of operations	The calibration source shall be capable of up to 300,000 operational cycles at the nominal electrical power.

4.1. *Discussion of PCAL requirements*

4.1.1. CALP-R01-R02 (operating output and range)

During the life of the instrument, the responsivity of the detectors could change for various reasons. For example, responsivity is a strongly dependent on the overall background power level on the detector. This will be different during for different situations:

- instrument-level testing in the SPIRE AIV facility;
- spacecraft-level testing in the Herschel cryostat;
- in-flight operation (during which the thermal radiation level may vary depending on telescope temperature and source brightness).

There may also be variations due to ageing or other changes in FPU component properties.

So, at suitable times, is will be important to monitor the detectors' optical responsivities. A practical way to do this is to illuminate the detectors with a repeatable thermal source, so that the output signals are proportional to the optical responsivities.

To facilitate rapid characterisation of the SPIRE detectors, it is required that PCAL provide a high instantaneous S/N. As viewed by the detectors, PCAL is a grey body emitter with a certain area, emissivity (ε), and temperature (T). The requirement of $\varepsilon T > 40$ K is designed to ensure a S/N of at least 500 in all bands. The SPIRE photometric model (see Appendix A for the latest version) computes the required effective temperature (εT) for the emitting area assuming nominal instrument and detector parameters. The requirement is set by the 250 μm band. For a 1-mm aperture, a minimum S/N of 500 is achieved with $\varepsilon T = 29$ K (circular area) or 26 K (square area).

To provide margin in the event of degraded instrument performance, it is appropriate to allow for a factor two on the final temperature achieved at the maximum allowed power. If a 1-mm square emitting area can be used (which at the time of writing is believed to be feasible) then the desired temperature is about 53 K with an input power of 4 mW: this has therefore been adopted as the goal for PCAL.

The PCAL electronics are required to supply the electrical power in 256 discrete steps under command from the DPU, allowing any desired kind of modulation between different temperatures.

4.1.2. CALP-R03 (pupil obscuration)

The SPIRE optics are designed to form a pupil image of the telescope secondary on the BSM (M4). The BSM is uniformly illuminated by an astronomical source and the telescope central obscuration is reproduced proportionally. This unused free circular area is chosen as a good place where place the calibration source. The size of the hole in the BSM is dictated by the optical design rather than the calibrator, and is assumed here to be 2.8 mm (TBC). The PCAL mechanical envelope should be such that it cannot foul on the BSM in any position of the mirror, with a suitable margin of safety. The necessary clearance will be specified in the Calibrators Interface Control Document.

4.1.3. CALP-R04 (time constant)

The warm-up and cool-down of a calibrator do not necessarily follow a single-time constant curve. The speed of response is therefore specified in the form of the 90% settling time (for a single time constant system the 90% settling time is 2.3τ where τ is the time constant). The nominal chopping frequency for point source or jiggle-map mode is 2 Hz, and it is desirable (but not essential) to operate the calibrator at a similar frequency. The goal is based on a 2-Hz excitation with the requirement based on a slower excitation frequency of 0.5 Hz.

Figure 3 shows the single-time-constant response to a 2-Hz square wave excitation with the goal time constant (30 ms) and a 0.5-Hz excitation with the required time constant (150 ms).

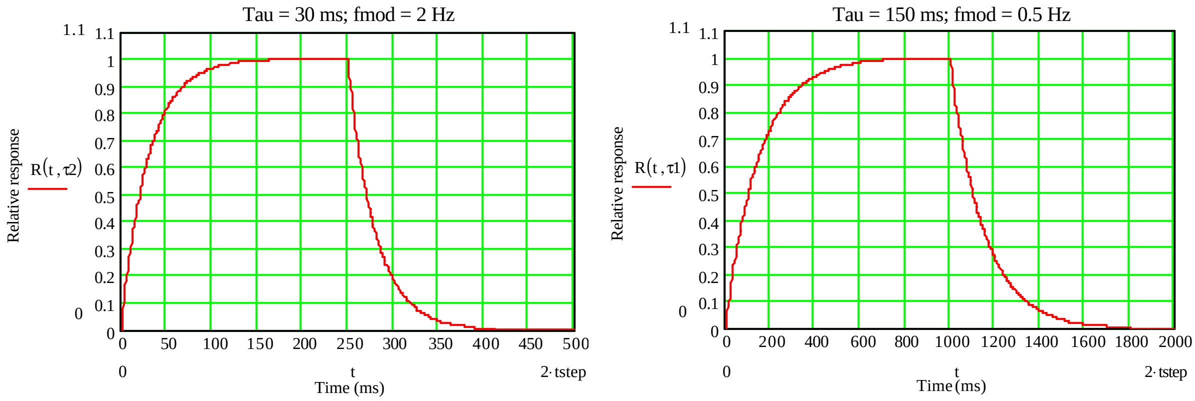

Figure 3: Single-time constant system response for (t = 30 ms; f_{chop} = 2 Hz) and (t = 150 ms; f_{chop} = 0.5 Hz)

4.1.4. CALP-R05 (repeatability and drift)

This repeatability requirement is dictated by the fact that the calibration accuracy of the relative detector responsivities cannot be any better than the repeatability of the calibrator radiant output.

A calibrator efficiency drift less than 10% over the mission lifetime means that only occasional re-calibration of the detectors with respect to astronomical sources will be necessary, and ensures that the S/N and operational levels will not change greatly over the course of the mission.

CALP-R05 is in need of further clarification:

Comment from Instrument Scientist: *"What does an "operation" consist of? The requirement is on both the repeatability over the short term - i.e. rms of 1% over 20 >cycles< on/off within one calibration operation; and the long term drift 10% over the mission. Perhaps we should have a medium term - i.e. within 12 or 24 hours - requirement as well?"*

Cardiff Team response: *The function of the calibrator is to provide a series of signals at nominal one-hour intervals which are repeatable to the desired level. There should be no requirement on the repeatability of the individual ON-OFF cycles within an hourly operation. Due to short-term localise heating effects, this may be difficult to achieve, and in any case is unnecessary: provided the overall result (e.g., as represented by the integrated signal over 10 seconds) is repeatable hour-to-hour, then the relative calibration requiremetn is met. We therefore recommend that the wording of CALP-R05 as above be adopted.*

4.1.5. CALP-R06 (operation)

The envisaged mode of operation will involve PCAL being driven according to a pre-set sequence of output levels over a period of around 10 seconds. The interval between such operations will depend on the overall stability of the instrument and its environment, but is expected to be at least one hour.

4.1.6. CALP-R07 (frequency)

This requirement follows from the required chopping frequency of the BSM. (This is essentially a requirement on the PCAL drive electronics and the On-Board Software.)

4.1.7. CALP-R8-R9 (interface and volume envelope)

PCAL will be integrated into the BSM structure, and so must be compatible with the available space.

4.1.8. CALP-R10 (thermal isolation)

The Cardiff team had originally requested that this requirement be deleted as it is effectively a requirement on the BSM structure. When PCAL is switched on, almost all of the electrical power will be conducted to the BSM mounting (only a tiny fraction is actually radiated by the device). The rise in temperature of the BSM environment must be small to avoid changes in the radiated power by the BSM structure affecting the overall sensitivity of the system. The BSM mounting and FPU structure must thus be designed to be able to conduct efficiently this power into the Herschel cryostat 4-K strap.

The wording in the table above is proposed by the Cardiff team, in response to the following comment from the Instrument Scientist: *IRD-CALP-10 - there is such a requirement on the BSM - this is supposed to constrain the design of PCAL to prevent its case heating up - if the better way to express this is through the thermal impedance to the case then o.k.*

4.1.9. CALP-R11 (operating temperature)

The nominal temperature of the PCAL housing is the same of the BSM structure, that is 4 K. In practice this temperature could rise by one or two degrees depending on the total power dissipation of the SPIRE FPU. This will have no significant impact on the operation of PCAL.

4.1.10. CALP-R12 (cold power dissipation)

PCAL will be in the ON condition for only about 5 seconds every hour. Allowing for the maximum dissipation of 4 mW, during this period, the time-averaged dissipation of PCAL will be less than 6 μW, which is negligible compared to other contributions from the FPU. However, to prevent local transient heating of the BSM environment during and after PCAL operation, it is desirable to keep the power dissipation as low as possible.

This requirement as proposed here is still under consideration by the SPIRE Project Team.

4.1.11. CALP-R14 (operating voltage)

This requirement is dictated by maximum voltage that the warm electronics can provide.

4.1.12. CALP-R15 (cold redundancy)

The Cardiff Team had requested that cold redundancy be a goal rather that a requirement on the grounds that loss of PCAL would not severely compromise SPIRE science, and that implementing cold redundancy would complicate the design of PCAL or require a much larger radiating area than is necessary to meet the photometric requirement or available given the size of the hole in the BSM.

This request was not accepted by the SPIRE Instrument Scientist, with the following comments: *We have prime and redundant electronics sides - and they must be isolated from each other and therefore drive cold redundant systems in the FPU. I also don't agree that loss of the calibrator will have minimal scientific impact. This will only be true when we have established that the performance of the instrument is as it was on the ground or what the difference is with what we did on the ground. The only sure fire way of doing this is by carrying a ground reference source into flight - PCAL is it for the photometer. We don't need to go overboard but cold redundancy is mandatory as far as I am concerned.*

Cardiff Team Response: *The basic design presented here does not have cold redundancy. However, we indicate conceptually how the design might be modified in order to implement it. We propose that this issue be considered and a decision made at the DDR.*

4.1.13. CALP-R16 (number of operations)

In order to define the life-test requirement for PCAL, it is necessary to specify the number of operations that PCAL must be able to tolerate. This is derived using the following conservative assumptions:

Mission operational lifetime:	4.5 years
Fraction of lifetime for which SPIRE operates:	33%
Fraction of SPIRE time for which PCAL used:	100% *
Number of operational hours per day:	21
Frequency with which PCAL sequence is carried out:	Once per hour
Duration of each sequence:	10 seconds
Modulation frequency during the sequence:	2 Hz
Margin factor (and allowing for ground operation):	1.5

* This assumes that PCAL will also be used during spectrometer operation. This results in a larger number of operations than previously estimated when operation was envisaged only during photometer time.

These assumptions result in a total number of cycles of 300,000. A continuous accelerated life test with 2-Hz modulation frequency will achieve this total number of cycles in approximately 48 hours.

4.2. Interface requirements

4.2.1. Mechanical interface

PCAL is mounted off the BSM structure via three 4-40UNC bolts on a 33 mm PCD. All bolt holes in this interface will be fitted with locking inserts.

4.2.2. Thermal interface

The main thermal interface will be the mechanical interface described above. However, provision could be made for the placement of a thermal strap from the PCAL body direct to the SOB in the event that the thermal impedance of the main mechanical interface is too great.

4.2.3. Electrical interface

All wiring necessary for the operation of PCAL shall be designed to minimise any possible thermal effects on PCAL and on the heatsink.

4.3. Logistics requirements

PCAL will be delivered to ATC in a nitrogen-purged box for storage. We require that this box be not opened unless the cleanliness of the environment is class 100,000 or better. For the purposes of integration to the BSM, or for extended periods of storage in an unprotected/unpackaged state, we require that the cleanliness of the environment is class 10,000 or better. We assume there will be no need to disassemble PCAL once delivered to ATC. If that need arises, members from Cardiff must be present.

4.4. Environmental requirements

4.4.1. Thermal environment

The design of PCAL shall be compatible with a 72 hour bake-out at 80°C.
Limits on the storage and handling temperature and humidity are as follows:-

- Storage and handling temperature – short duration <80°C,
  Continuous limit <50°C
- Humidity - <50%

4.4.2. Mechanical environment

PCAL will be designed to withstand >100g static loads in X, Y and Z directions.

4.4.3. Electrical environment

PCAL shall not generate any electrical noise in the vicinity of the detectors, nor shall it be sensitive to emitted radiation. PCAL shall not remain charged or be subject to electrical discharges.

4.4.4. Radiation environment

PCAL shall not be sensitive to ionising radiation.

4.5. Design requirements

4.5.1. Mass

The overall mass of PCAL shall be no more than 50g.

4.5.2. Structural

All structural elements shall be designed to exhibit a positive margin of safety (MOS) with respect to yield and ultimate loads. The margin of safety is defined as the ratio of the allowable loads (or stresses) to the applied load (stress):-

$$MOS = \frac{AllowableLoad(stress)}{AppliedLoad(stress)} - 1$$

Unless otherwise stated for all other requirements in this specification, a margin of at least 20% shall be included in the design. Allowable stresses shall be derived from MIL-HDBK-5. Other sources shall be subject to SPIRE PA manager approval.

4.5.3. Parts, materials & processes

4.5.3.1. General

The workmanship and materials used shall be, or shall be shown to be compatible in any future build, of a standard consistent with flight hardware.
The number of materials, mechanical parts types, and processes shall be minimized. Materials and mechanical parts that have been successfully used in similar space applications shall be preferred. Standard processes or known processes previously used in space applications shall be preferred.
Material justification shall prove the hardware structural integrity during the design life.

4.5.3.2. Magnetic materials

PCAL shall not use magnetic materials.

4.5.3.3. Fungus nutrient materials

Materials shall not support bacterial of fungal growth, and shall be sterilisable without any deterioration of their properties.

4.5.3.4. Flammable, toxic and unstable materials

Flammable, toxic and unstable materials shall not be used.

4.5.3.5. Cleanliness

PCAL shall be class 100 compatible following FED-STD-209-F.

4.5.3.6. Finish

Surface finish shall prevent deterioration from exposure to the environment. Aluminium surfaces shall be treated for corrosion protection coating. Thermal interfaces shall be gold plated.

4.5.3.7. Outgassing

Outgassing of the external surfaces of PCAL shall demonstrate a Total Mass Loss (TML) <1%, and a Collected Volatile Condesable Material (CVCM) <0.1%. PSS-01-702 shall be used as a guideline.

4.5.3.8. Susceptibility to stress corrosion

Metallic materials shall have high resistance to Stress Corrosion Cracking (SCC) and shall be chosen from table 1 of PSS-01-736. Materials and welds that are not listed, or whose SCC resistance is not known, shall be tested according to PSS-01-737.

4.5.3.9. Limited lifetime materials

All materials with limited-life characteristics shall be subject to lot/batch acceptance tests, to be agreed with the PA manager, and shall have their date of manufacture and shelf-life expiry date marked on each lot/batch.