LESSONS LEARNED FROM THE PLANETARY PROTECTION ACTIVITIES ON THE BEAGLE 2 SPACECRAFT

J Andy Spry
Biotechnology & Planetary Protection Group, JPL
Pasadena

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Presentation Overview

- Introduction to Beagle 2
- Beagle 2 PP approach
- AIT in the AAF
- PP beyond the AAF
- Bioload
- Lessons Learned

What to look out for:

- Where Beagle 2 approaches and methodologies might impact you at the instrument level.

- Where Beagle 2 approaches and methodologies might impact you indirectly through application to the flight system/other payload elements.

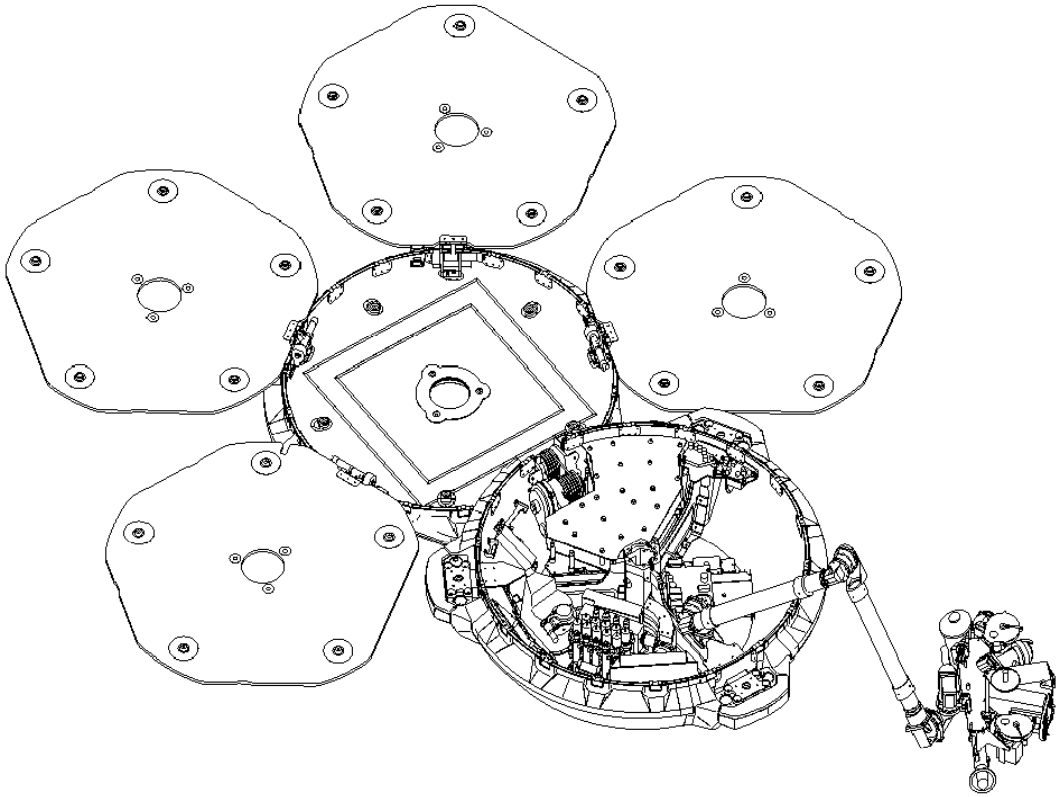
Beagle 2 Overview

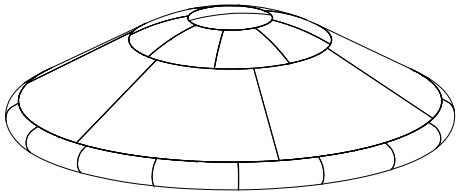
- Low mass, low cost Lander to deliver maximum science payload to the martian surface
- Science payload to include a complete geochemistry instrument suite, together with sample acquisition and geological analysis capability

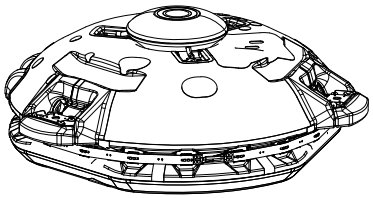
Beagle 2 Overview

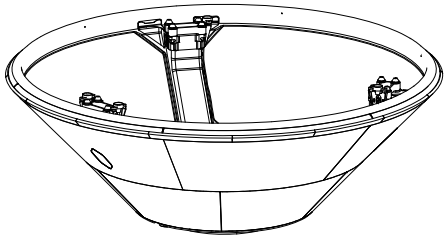
- Arising from the ESA “what next” meeting after the failure of Mars 96
- Treated as an unfunded science instrument on Mars Express
- Initial development by “in kind” contributions from Beagle 2 consortium
- “Real” funding not obtained until September 2000, less than 3 years before launch

Beagle 2 Overview









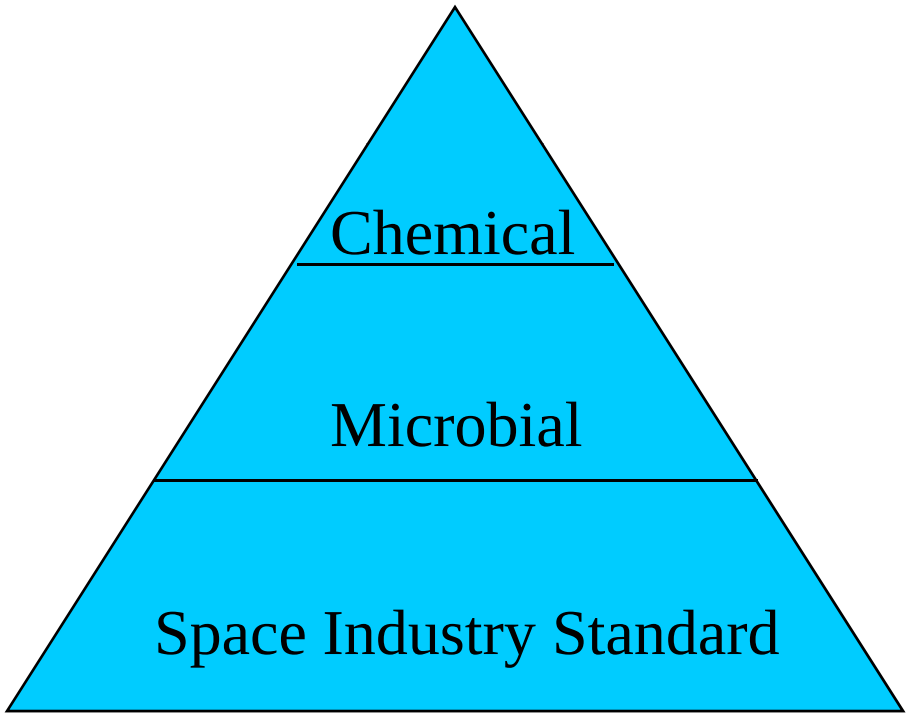
Beagle2 Planetary Protection & Sterilisation

- Critical elements of design fixed before sterilisation requirement fully understood
  - Dry heat accepted as default method from inception
  - Poor understanding of available technologies and limitations
- Key Drivers for Sterilisation Strategy
  - Cannot be baked as whole spacecraft
  - Aseptic Assembly option
  - Science drivers

Beagle2 Planetary Protection & Sterilisation

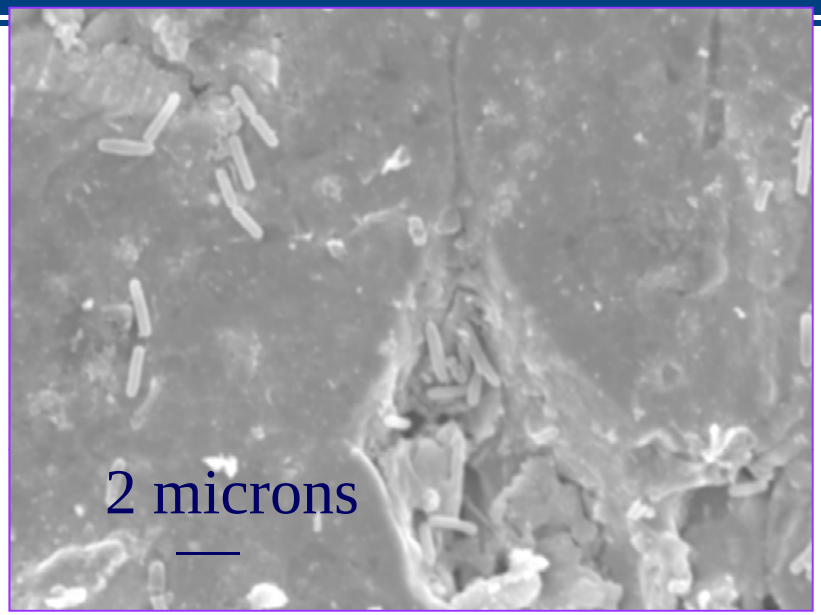
- COSPAR constraints already developed and Mission Category assigned (IVA)
- Science payload imposes additional constraints regarding organic contamination (IVA+)
- Decision to assemble to highest possible level before sterilisation (by whichever technology), then integrate aseptically

Hierarchy of Contamination Control

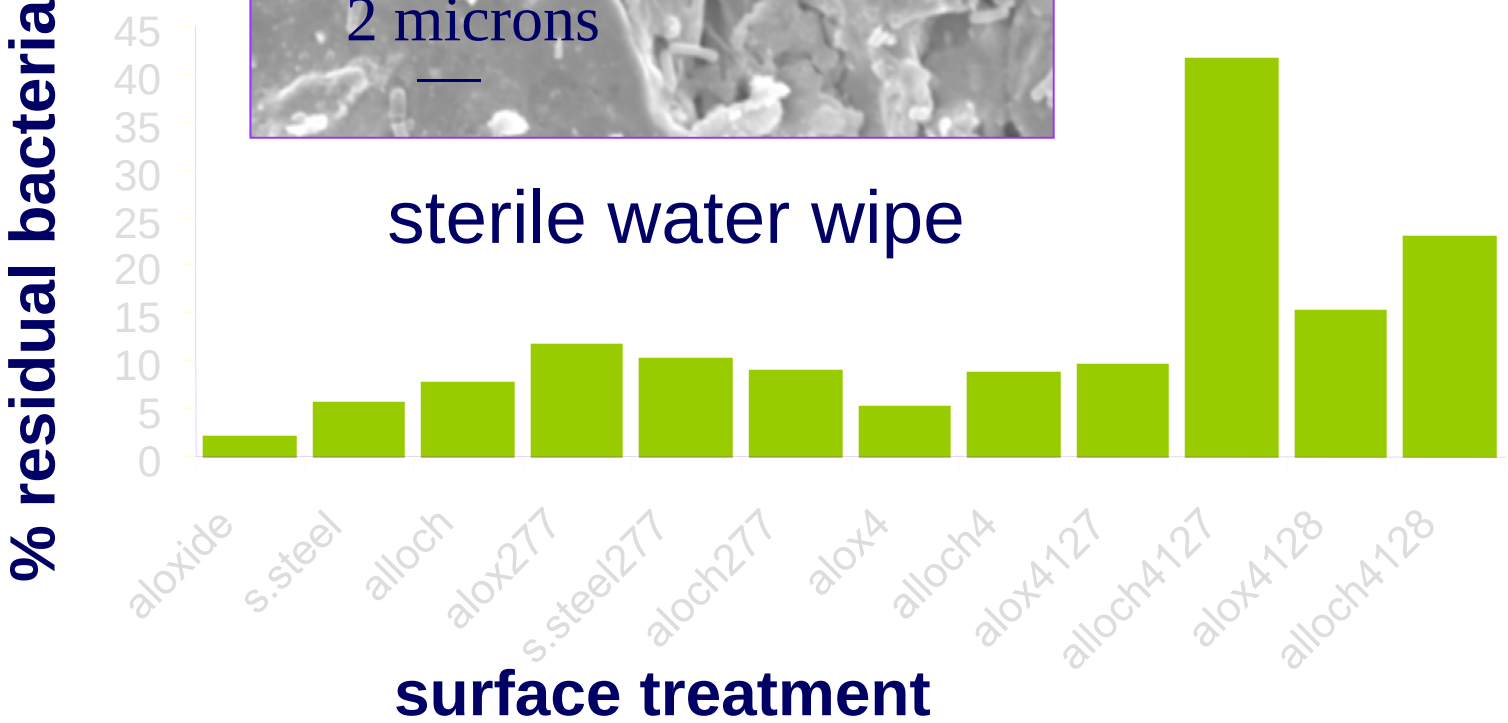


Cleanroom Requirement	Mission Category
Special Process	IVA+
Class 100	IVA
Class 100,000	III

Is sterilisation required?



Bacterial cells on a metal surface



sterile water wipe

Beagle2 Planetary Protection & Sterilisation

- AIT and sterilisation strategies iterated in parallel
  - Dry heat as default technology
  - Gas Plasma, Gamma Irradiation and IPA wipe approaches adopted for other hardware

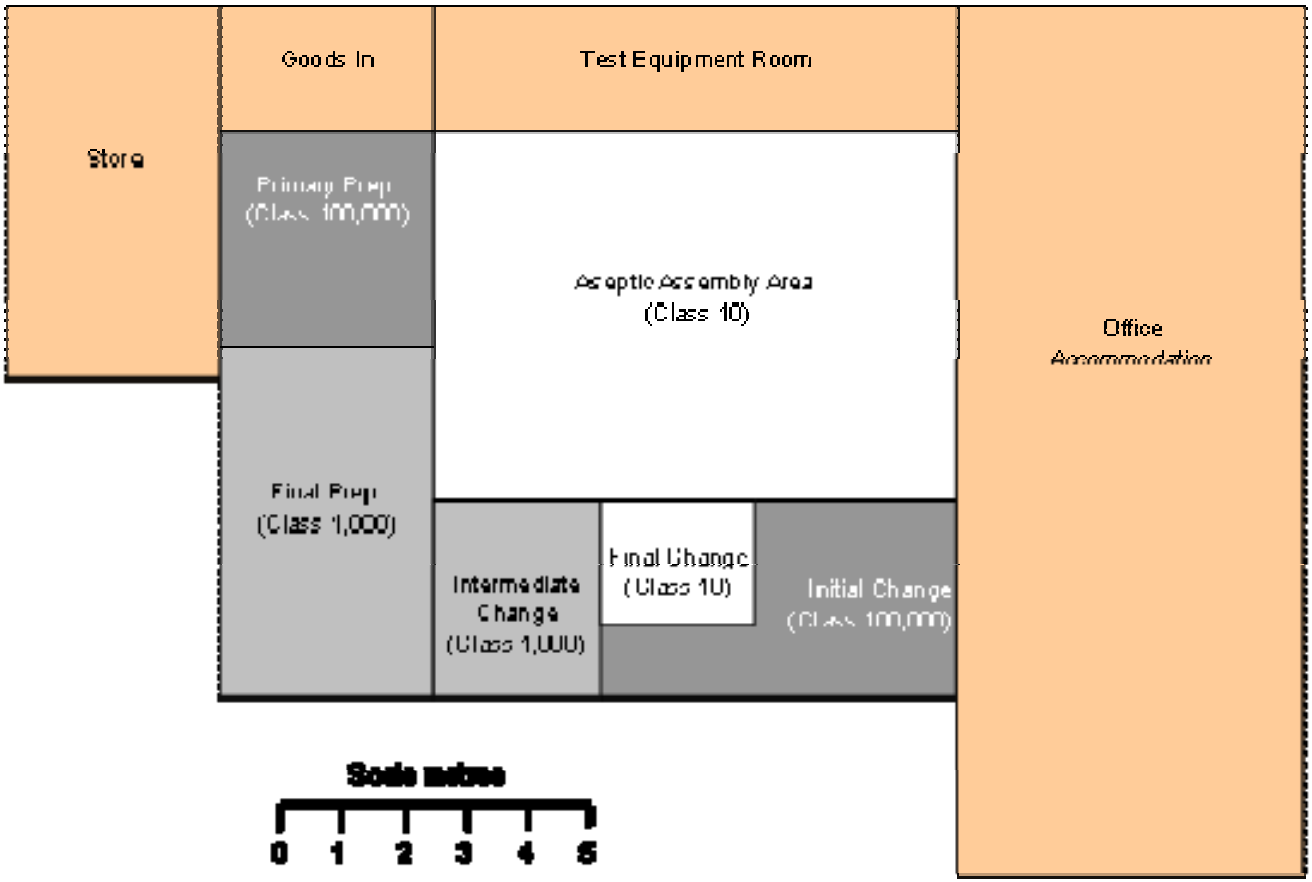
- Decision process followed to selecting alternative technology:
  - Gamma second choice – (since penetrating technology)
  - Gas plasma third choice – (since effective surface sterilisation procedure)
  - Solvent wipe a poor 4th choice

Beagle2 Planetary Protection & Sterilisation

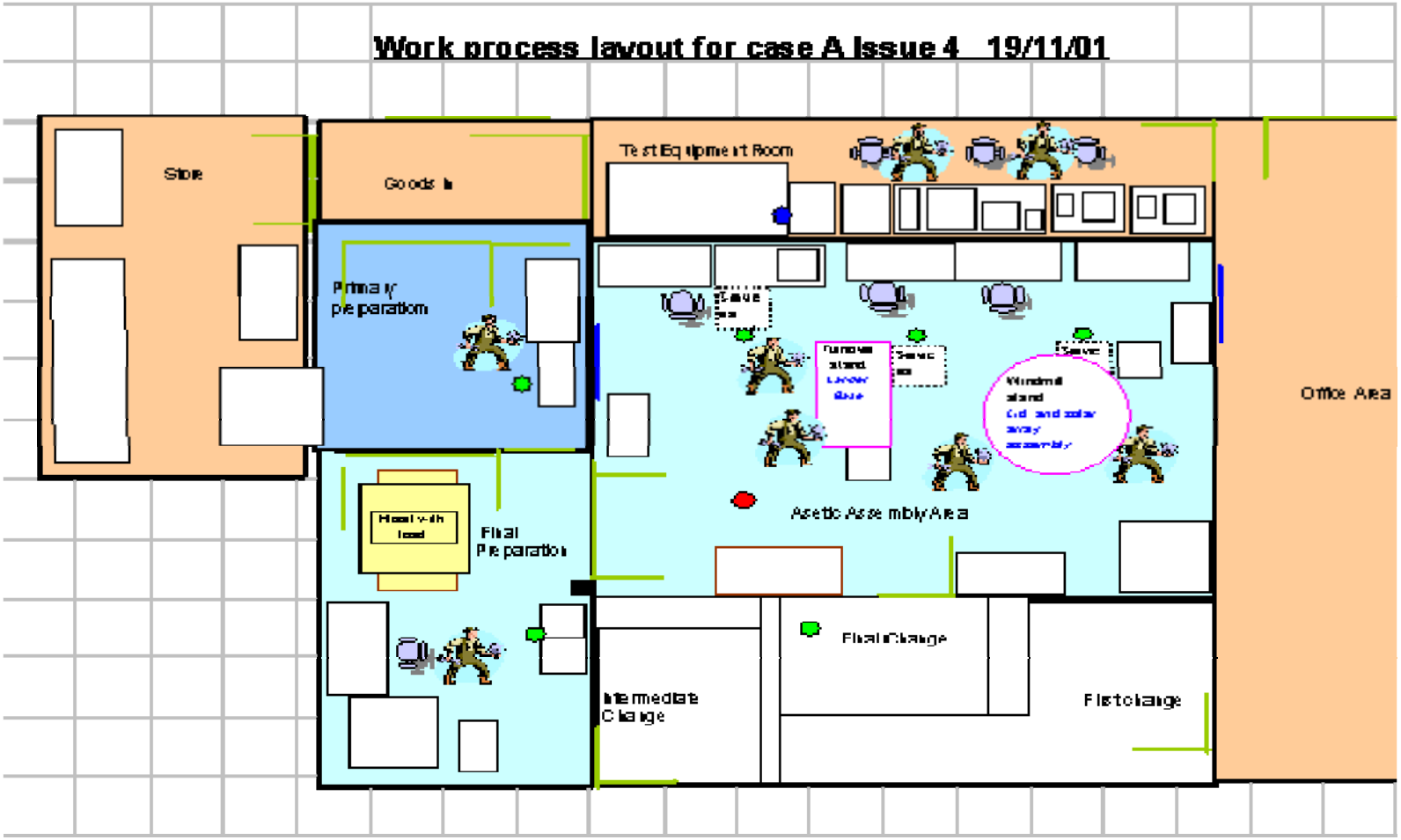
Dry Heat	Gamma	Gas Plasma	Solvent Wipe
Structure GAP Arm Solar Arrays	Parachute	Common Electronics Assy inc. Battery PAW RAT	Pyromechanisms

Beagle2 AAF

Beagle 2 Aseptic Assembly Facility Layout



Beagle2 AAF

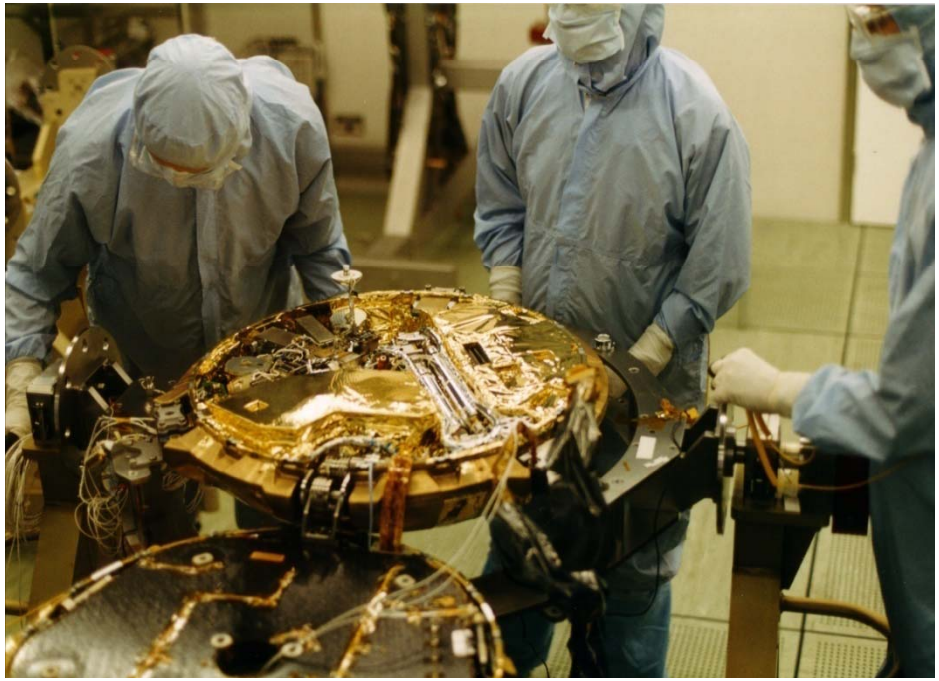

Work process layout for case A Issue 4 19/11/01
Store
Goods In
Test Equipment Room
Primary preparation
Final Preparation
Aseptic Assembly Area
Office Area
Intermediate Cleanroom
Final Cleanroom
First Cleanroom

Beagle2 AAF Issues

- Facility layout
- Flow process control – Prelim Prep, Final Prep, AAA
  - Receipt inspection
  - Sterilisation (Gas Plasma, Dry Heat)
  - Kitting (storage)
  - Assembly
  - Test
- Integration area to be spacious
- Identical area required for prep activities (man limit in integration area) For parallel working – prep or on a 2nd module / sub-assy

Beagle2 AAF Issues

- Control of kits
- Storage space, stock control, traceability
  - Full kits parts & tools
  - Identification
  - Build control (As designed/As built configuration)
- Facility costs
  - Set up costs
  - Running costs
  - Protective clothing
  - Monitoring support team
  - Monitoring equipment
  - Suppliers need to be vetted



Beagle2 AAF Issues

- Clean room operators training programme
- Microbiology workshop
- Practical training in the Aseptic Assembly Area AAA
  - Facility to be fully commissioned early and all operators to train carrying out operations in full protective clothing
  - Minimise leaning over hardware
  - Care to minimise contact with all hardware
  - Understanding of the cleaning swabbing process
  - Man limitation - max number of people in area (4)
  - Paperless (Virtual AIT – needs to be developed)
  - Buddy system – support staff adjacent to clean room

Beagle2 AAF Issues

- General Hygiene
- Infections
- Beards, Make-up etc.
- Smoking, eating
- Screening individuals to ascertain suitability
- When Not to work
  - Acute infections: Colds, Coughs, Flu
  - Skin inflammation
  - Scalp conditions
  - Cold sores
  - Ear or eye infections
- Implications of trained back-up staff to cover illness

Beagle2 AAF Issues

- ESD Compatible conductive equipment
  - Donning gloves
  - Protective suit
  - Gloves 2 pairs + Conductive finger Cots
  - Hat
  - Mask
  - Goggles
  - Footwear
  - Ground straps x2 in case of Beagle

- Dressing sequence (30 minutes)
- Reuse of suits
- Quantity of suits to support shift working 7 days a week

Beagle2 AAF Issues

- Clear working pattern to be established
- Compatible with cleanliness requirements
- Beagle 2 AIT worked 7 day week 2 x 8 hour shifts (not ideal)
- Minimise working in protective suit to 2 hours
- Ideal pattern

6.00 – 8.00	Cleaning/swabbing
8.00 – 12.00	AIT activities (2 teams – 2 hours per team)
12.00 – 14.00	Cleaning/swabbing
14.00 – 18.00	AIT activities (2 teams – 2 hours per team)

- Beagle 2 pattern

5.00 – 6.00	Cleaning/swabbing or completed previous night
6.00 – 14.00	AIT activities (1 team - long hours in clean room)
14.00 – 15.00	Cleaning/swabbing was flexible to suit operations
15.00 – 22.00	AIT activities (1 team - long hours in clean room)
22.00 – 23.00	Cleaning/swabbing was flexible to suit operations

- Activities took an experienced person 2 to 4 times longer to perform tasks in the AAA

Beagle2 AAF Issues

- Require sufficient protective clothing to support shifts 7 days a week
- Require sufficient staff to support shifts 7 days a week
  - Not all staff will be allowed to work in clean room
- Need to schedule in swabbing and cleaning operations in the AIT schedule
- Before final assembly of any item, enclosed areas will need to be cleaned and swabbed (4 hours)
- Provision needs to be made to rework areas that have failed microbiological swabs (will not know until 3 or 4 days later after swabs have been cultured)

Beagle2 AAF Issues

- MGSE
  - Specifically design for and only used in the Aseptic clean room
  - Specifically designed not to collect dust on its surfaces
  - Made of stainless steel 308 grade or Alochrom coated aluminium - considerations of dry lubricants

- Hand tools
  - Standard set of tools required – sterilised (sonically cleaned) available on a tray
    - Many sets required to support working patterns
    - All tools must be compatible (plastic handles not acceptable) with use in the aseptic facility
    - Calibration of tools to be considered (effect of sterilisation process)

Beagle2 AAF Issues

- Materials
  - Clear directive required on the sterilisation process for all materials to be used in the Aseptic clean room
    - Sterilisation method (Dry heat/Gas plasma)
    - Clear dry heat temperature and saturation times
  - All materials and adhesives that have to undergone a sterilisation process require their properties to confirmed pre/post sterilisation.
    - Adhesive tape (Kapton and double sided tape a major problem on Beagle 2)
- Simulated sterilisation cycle should be part of environmental qualification of all materials & processes

Beagle2 AIT

Monitoring Methods

- Microbial
- Particulate
- Environmental (Temperature, Relative humidity, Differential pressures)
- Visual (camera and observer)
- ElectroStatic Discharge protection
- Chemical

Microbial Monitoring Methods

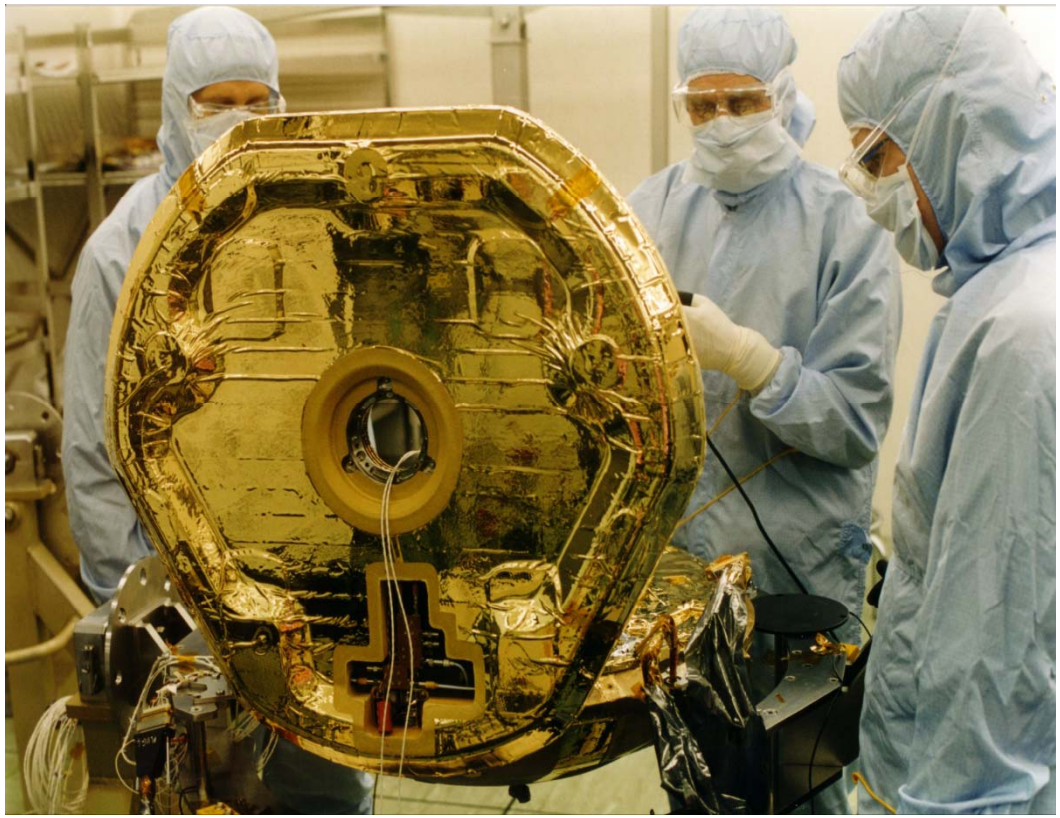
- Analysed blind by RSSL, an independent external laboratory accredited to ISO9001 and UKAS standards.
- Assay methodologies are based on NASA-derived protocols from NPG5340.1D
- Methods include:
    - Settle Plates
    - Contact Plates
    - Active air sampling
    - Active surface sampling (swabbing/witness plates)

Beagle2 Aseptic Facility

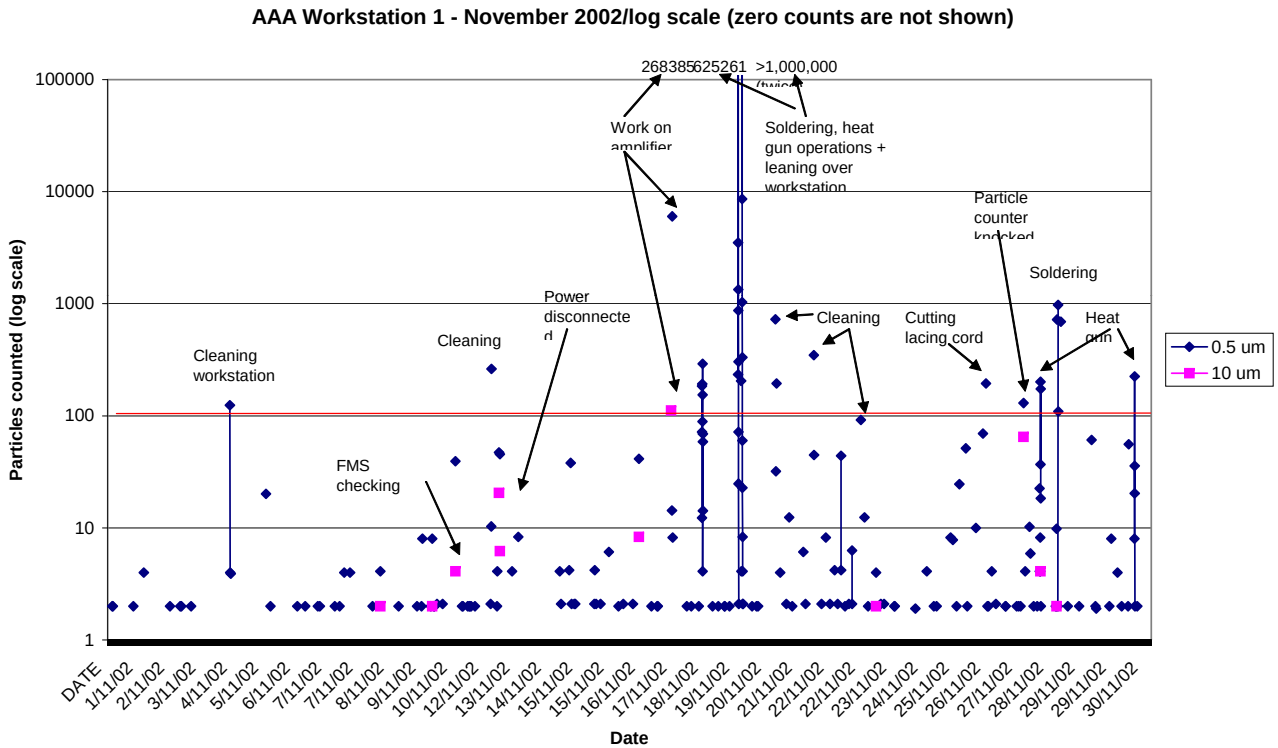
- Microbial Monitoring of facility for:
  - Bacteria
  - Fungus and Yeasts
  - “Exotics” - thermophiles, psychrophiles, anaerobes, xerophiles, acidophiles, alkylophiles, halophiles, sulphur reducing bacteria

Policies and Procedures in the AAF

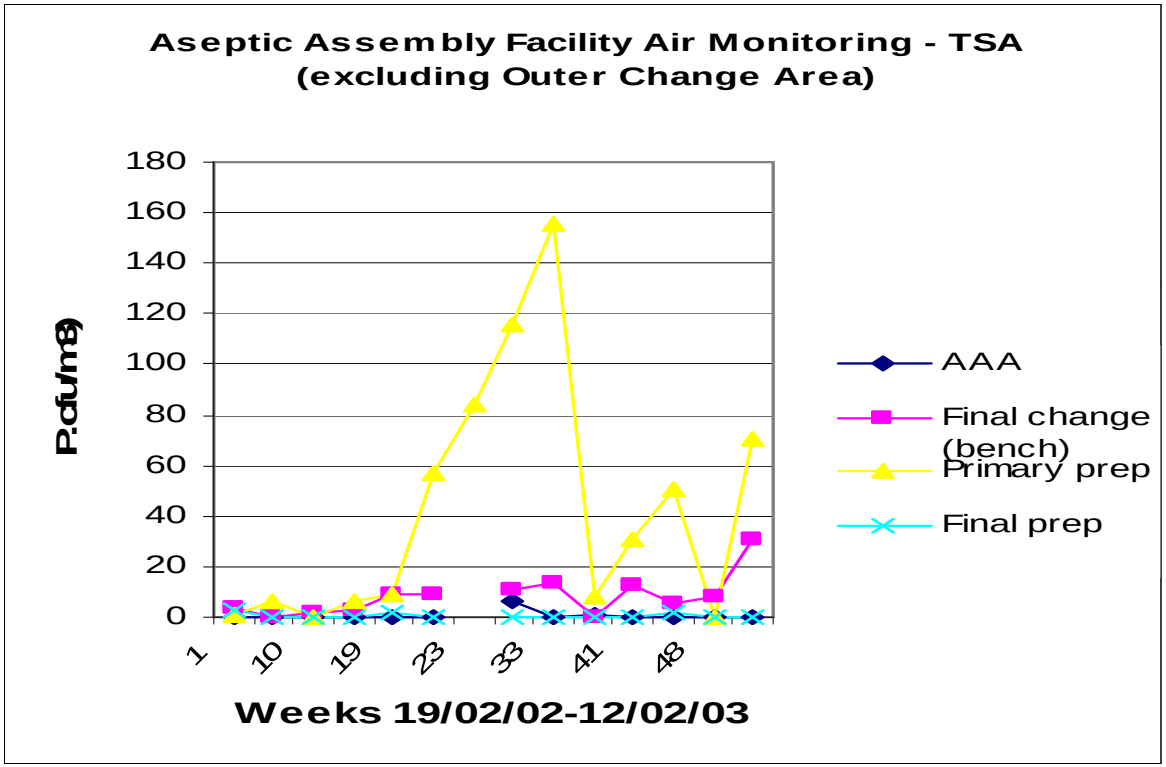
- Training/Occupational Health
- Apparel
- Access/People Flow
- Material/Tool Flow
- Cleaning - AAF
- Cleaning - Hardware
- Sterilisation



Beagle2 AAF Performance



Beagle2 AAF Performance



MEx/Beagle 2 Launch Campaign pre-Baikonur

- At class 100
  - Completion of Beagle in UK Feb 2003
- Closed probe then protected from recontamination by HEPA filter
- At class 100,000
  - Fit check with MEx at Toulouse
  - Disassemble and ship MEx and Beagle 2 to Baikonur April 2003

MEx/Beagle 2 Launch Campaign at Baikonur

- At Class 100,000
  - Reassemble MEx and Beagle 2
  - Integrate with Fregat upper stage and fairing
- Uncontrolled environment (Fairing under +ve pressure with filtered air at Class 100,000)
  - Integrate with rocket motor
  - Launch

Estimation of Bioload

- Based on:
  - Direct sampling pre-sterilisation
  - NASA NPG8020.12B assumptions for inaccessible areas
  - Reduction due to sterilisation processing

    (10^{-4} for heat; 10^{-6} for gamma & HPGP; 10^{-2} for IPA wipe)
  - Pre-emptive cleaning of high risk areas
  - Direct/parametric confirmation that recontamination had not occurred
  - Last measurement before closure carried forward

    (77 different sampling locations)

Spacecraft Bioload - The “Log Book”

- Electronic Spreadsheet format
- A “Working Document”
- Bioload by Sub-assembly (highest build level at which components are sterilised)
- Processes and assumptions detailed to estimate bioload
- Final bioload for each sub assembly
- Assumption: bioload will not be added to during build, or if it is, it will be captured and recorded

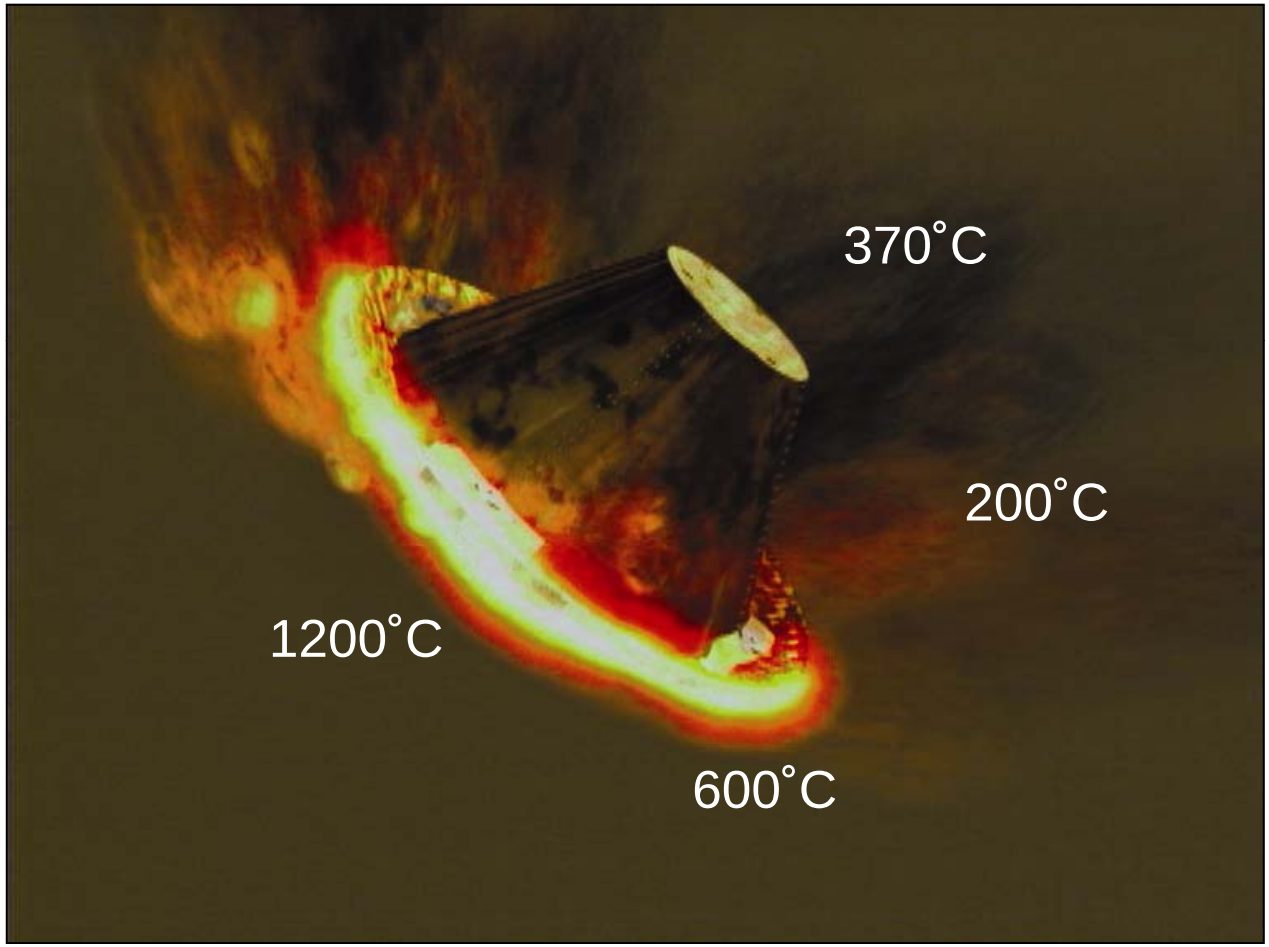
Estimation of Bioload

- Issues:
  - For Beagle 2, obtaining sufficient area for sampling was difficult (to obtain stats.)
  - Resampling frequency
- Treatment of Results:
  - Analysis based on mean +3 sigma burden as per NASA practice
  - Most results negative, therefore necessary to “group and add one” to gain estimate
- Estimate is therefore conservative:

Beagle 2 Planetary Protection Pre-launch Report

	COSPAR Requirement (at launch)	Beagle 2 Status (at launch)
Surface Bioburden	**max. 3 x 10^5 spores**	**2.3 x 10^4 spores**
Total Bioburden	**max. 5 x 10^5spores**	**1.01 x 10^5 spores**
Bioburden Density	**max. 300 spores/m^2**	**20.6 spores/m^2**

Sterile or not ?



Fate of Beagle 2 hardware

- MLI – decomposes on atmospheric entry
- Thermal Protection: 500°C not achieved across the whole surface
- Account for contaminant organisms to the surface
- Estimated 77 spores on the back cover at the time of atmospheric entry

Summary & Conclusions

- End to end PP of whole spacecraft from component level until launch needs to be developed, agreed and followed through
- Training in PP issues for design and AIT staff is of valuable benefit in integrating engineering with the PP function
- Rehearse activities at Qualification Model stage, outside the critical path for flight hardware delivery. This has a number of benefits:
  - i) it enables an understanding of cleanroom performance with respect to PP implementation and the AIT requirement
  - ii) it will also identify teething problems for new facilities/novel processes
  - iii) it will speed up procedures and processes on the flight hardware, which will most likely be at the schedule-critical phase of the project

Summary & Conclusions

- Involve Planetary Protection early in mission concept design
- Labelling and stock control systems for sterilised hardware, compatible with cleanroom operations, need to be set up and maintained.
- The QA/PA interface and processes need to be agreed early in any facility/AIT design process, in order to allow sign off to proceed without undue risk of contaminating the spacecraft.
- For tools with moving parts which are to be baked and/or repeatedly cleaned with IPA, dry lubricant coating (WS_2/MbS_2) can be utilised
- From a PP re-work (risk management) perspective, fixings and connectors are preferred to adhesive bonding and soldering.

Summary & Conclusions

- Solvent/cleaning agent control is an important issue. Biocides need to be used in cleanroom cleaning. Standard cleanroom detergents contain aggressive chemicals which cannot come into contact with spacecraft systems. IPA or ethanol are acceptable in most space hardware environments
- Where access is restricted, quality communication systems are important to facilitate the task in hand. Avoid spurious blanket constraints in the use of optical/RF/IR IT/comms equipment as these technologies have great potential in easing cleanroom working For any new facility, care needs to be taken in the fit-out at a detailed level, since most cleanroom contractors/suppliers will not be familiar with the combined needs of facilities requiring sterility, cleanliness and ESD control.

Conclusions and Lessons Learnt - Strategy

- Dry heat sterilisation is problematic for “modern” spacecraft – sterilisation strategies need to be agreed early in the project
- It is possible to aseptically assemble small spacecraft and/or sub-assemblies
- Monitoring using classical microbiology is slow, adding risk to the project
- Classical pharmaceutical industry models for monitoring cleanroom operations do transfer
- Whilst current methodologies do work, updating application knowledge of sterilisation and microbiology would ease the implementation of Planetary Protection

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