Key Cryogenic Requirements

- Cryogens: < 1.85 K superfluid He
- Instrument temperature: < 3.0 K at interfaces
- Bath temperature regulation: < 30 mK
- Controlled by the Attitude and Translation Control (ATC) subsystem which uses vent gas for throttling
- Pumps: Alignment: 10-3 mPa in 10-6 mPa
- Main tank ground hold (< 1.9 K) > 10 days (106 days achieved)
- Flight lifetime: 16.5 months or more (17.3 months achieved)
- Calorimetric liquid He mass measurement to within 1% (calculated end-of-life prediction: 6%)
- Steady-state field/gyro-trapped flux < 9 μG (0.05 μGauss uniform field equivalent trapped field)
- Superconducting Pb-foil shield < 6.5 K to end of mission (< 6.5 K maintained over critical region)
- External ac magnetic field attenuation factor <= 2x10^-12 (~2.5x10^-12)
- Ability to perform flux flush (heat Nb components of the science instrument above Tc) and low temperature bakeout to achieve pressure < 2x10^-10 torr in probe (< 10^-10 torr)

Unique Aspect of GP-B Cryogenic System

The requirement of an ultra-low magnetic field region for the science instrument is satisfied by means of an expanded superconducting Pb-foil shield lining the interior of the dewar well. Once installed, it must be maintained in a superconducting state until the end of the science mission. This requirement must be satisfied even during the insertion and cooling of the room-temperature cryostat probe with its 38 kg science instrument.

Features of Cryogenic System

- GP-B dewar is one of several superconductive cryogenic systems containing ~337 kg (2320 l) of 1.8 K helium at launch (95% full)
- Dimensions: 2.15 m diameter x 3.03 m height
- Lightest flight He dewar for its capacity: dry weight: 800 kg (2.4:1)

Ultra-Low Magnetic Field Shield Installation

- The flight shield had an internal field < 5 μGauss in the gyro region. Installation of the return increased the magnetic field to 0.07 μGauss.
- Leak bag retainer mechanically protects and thermally isolates shield from probe and shields to liquid He in main tank.
- On-orbit ac shielding factor was 2.5 x 10^-12. (Includes the additional shielding of the science instrument)

Probe Insertion

- Warm probe cooled by insertion into dewar well
- Well maintained with liquid He by internal transfer from main tank
- Purged artwork used to avoid air contamination of dewar well
- Cool-down rate limited to reduce thermal stress and improve efficiency (~15 hour)
- Exchange gas used to cool 38 kg science instrument

Launch Preparations at Vandenberg AFB

- Final preparations performed on NASA’s hazardous processing facility (HPF)
- Condition main tank
- Install solar arrays

Flight Thermal Operations: Low Temp. Bakeout

Results of Bakeout

- Residual He gas remaining in the probe after gyro spin-up could produce excessive damping torques. A modified bakeout of cold surfaces in the probe while the probe is vented to space will greatly reduce the amount of weakly bound adsorbed gas.
- Effectiveness of the bakeout is substantially improved by the addition of a sintered Ti cryopump (located forward of the telescope) that adsorbs 2.0 x 10^17 molecules area.

End of Life Prediction

- EOL prediction needed when to switch to calibration phase without prematurely terminating Science
- Calorimetric method: Heat Pulse Meter (HPM)
- Determine liquid mass by measuring temperature rise as a result of a known heat input under the condition of a constant vent rate
- Heat input chosen to achieve 10 mW/min
- EOL prediction independent of scale factor error
- Used only 6 times because of risk and system disturbance
- Integration of vent flowrate measurements
- Useful for daily trending
- EOL prediction sensitive to scale factor error
- ATC flow rate estimated from thruster nozzle pressures
- Predicted EOL on 9/1/05 based on last HPM measurements (5/29) for a lifetime of 16.3 mo.
- Actual EOL: 9/29/05 for a lifetime of 17.2 months
- Lifetime corresponds to 744 mgs or 112 mW average heat rate
- Major source of error in EOL prediction is uncertainty in modeling response of vapor
- Assuming vapor in equilibrium with liquid underpredicts lifetime
- Ignoring vapor overpredicts lifetime

Flight Results

- Uniform field equivalent of flux trapped in gyro motors as measured by readout 50/12/04 after thermal cycle.
- Gyro 1: 15,800 yr
- Gyro 2: 14,700 yr
- Gyro 3: 7,000 yr
- Upper limit on gas pressure: ~10^-12 Pa (~10^-14 torr)
- Effectiveness of the bakeout is substantially improved by the addition of a sintered Ti cryopump (located forward of the telescope) that adsorbs 2.0 x 10^17 molecules area.
- All key cryogenic requirements met
- Dewar and its superconducting shield kept cold > 6 years
- Required removing guard tank vent line blockages on several occasions without warming shield
- Utilized computer-triggered commercial alarm system and surveillance of data fed to web site
- Sensors: Cheap, out-of-limit data or by watchdog timer in case of computer malfunction
- In case of critical operations, 24/7 on-site monitoring was maintained
- Guard tank (GT) is a valuable asset in the pre-launch environment where it provides a long main tank hold time, eliminating the need to service a sub-atmospheric main tank on the Mobile Service Tower
- GT: vent lines in isolation valve could have prevented vent line blockages
- GT heater should be used to reach ~50 K to clear line blockages if necessary (GP-B dewar had this ability)
- Dewar vacuum hold time was excellent: indefinite with the well evacuated and ~3 months with He in the system
- Lifetime prediction: Although a superfluid He reservoir is an ideal system for calometric mass gauging, accuracy is limited by uncertainty in the reservoir of the vapor phase

Conclusions

- Dewar gas remaining in the probe after gyro spin-up could produce excessive damping torques. A modified bakeout of cold surfaces in the probe while the probe is vented to space will greatly reduce the amount of weakly bound adsorbed gas.
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