Lunar Reconnaissance Orbiter: Lessons Learned

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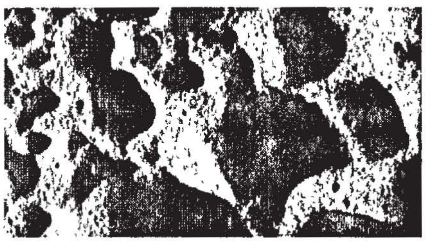
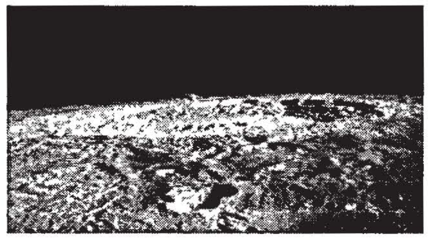
TO The Moon…

*Earth Rise, December 1968



LROC NAC Lunar North Pole July 2009
http //lroc.sese asu edu/news/?archives/71-Scanning-towards-the-north-pole html

NASA Mission:
"…to extend life to there,
To find life beyond"

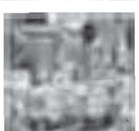


*Copernicus from Lunar Orbiter 2, November 1966, 45 km altitude

*Pictures from D Everett Systems presentation 11/08

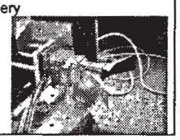
LRO Instruments

LOLA: Lunar Orbiter Laser Altimeter
- Topography
- Slopes
- Roughness



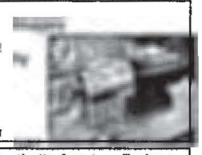
Full Orbit
Autonomous

LROC/WAC: Wide-Angle Camera
- Global Imagery
- Lighting
- Resources



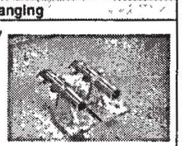
Day Side
Autonomous

LROC/NACs: Narrow-Angle Cameras
- Targeted
- Hazards
- Topograp



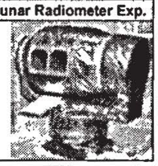
Day Side
Timeline Dr

LR: Laser Ranging
- Topography
- Gravity



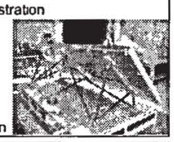
GSFC LOS
Autonomous

DLRE: Diviner Lunar Radiometer Exp.
- Temperature
- Lighting
- Hazards
- Resources



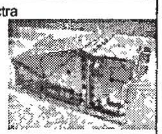
Full Orbit
Timeline Driven

Mini-RF: Synthetic Aperture Radar
- Tech Demonstration
- Resources
- Topography



Polar Regions
Timeline Driven

CRaTER: Cosmic Ray Telescope…
- Radiation Spectra
- Tissue Effects



Full Orbit
Autonomous

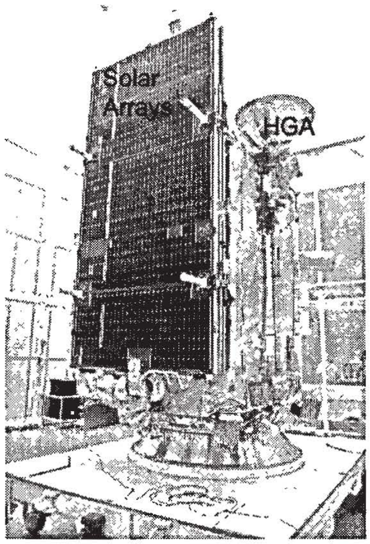
LEND: Lunar Expl. Neutron Detector
- Neutron Albedo
- Hydrogen Maps

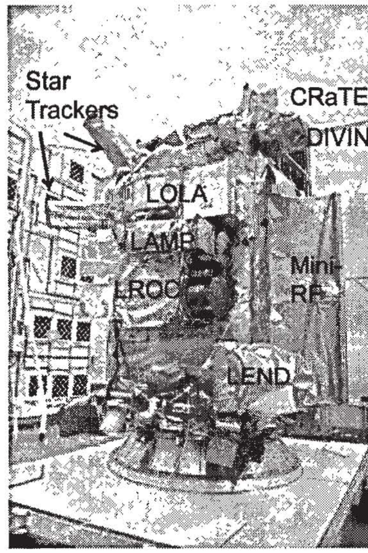
Full Orbit
Autonomous

LAMP: Lyman-Alpha Mapping Project
- Water-Frost
- PSR Maps

Night Side
Autonomous

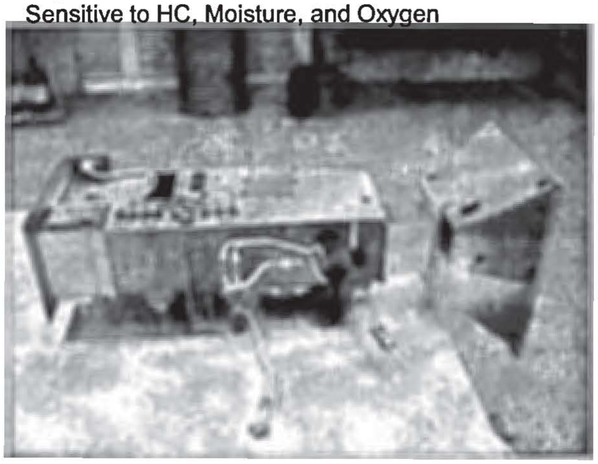
LRO Orbiter





LAMP Requirements

Lyman-Alpha Instrument with most contamination critical requirements: Internal Surface Cleanliness 400 A/20
Sensitive to HC, Moisture, and Oxygen

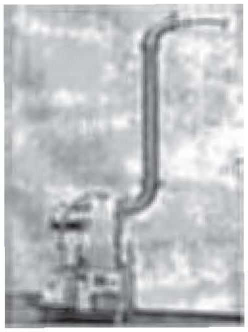


•LAMP internal molecular requirements were exceeded upon delivery to GSFC.
NVR swab yielded Level C.
•LAMP chose to not re-clean their instrument and take the risk because internal witness plates performed at expected levels.
LL: Ensure risks are discussed and agreed upon with other teams prior to Integration

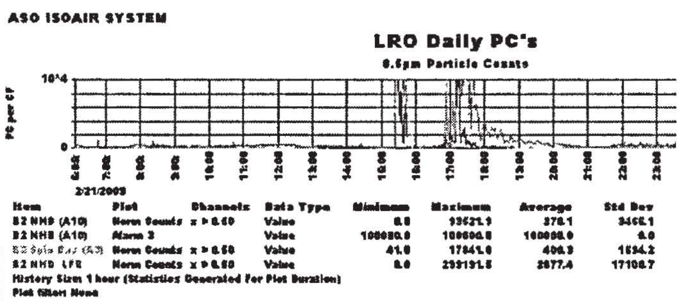
LAMP Vacuum Pump

Vacuum Ion Pump: "cleanroom approved" leaked small particles within cleanroom. PC picked up 300k 0.5um particles. Exceeding 10k room levels. Analysis indicated aerosolized oil (fluid loss).
Action taken was to run vacuum line and exhaust outside of cleanroom.

LL: Molecular contamination can show up as particulate. Plan ahead to remove pumps and exhaust from cleanrooms.



LAMP MGSE



Star Tracker Requirements

LRO External Cleanliness Level Requirements for Sub-systems upon delivery to I&T was 450 A/2.

- Star Trackers failed NVR Levels twice at Level C, B.
- Star Trackers were wrapped in pink polyester
- NVR FTIR data showed polyesters consistent with pink poly
- Star Trackers failed NVR levels for both LRO and SDO projects.
- Final cleaning and inspections eradicated NVR level failures.

LL: Even though pink poly has been on a "do not use" list, vendors are still using it.

Silicones, Silicones, Silicones

Nusil Controlled Volatility (CV) 2946: Silicone Bonding Agent
Contact Transfer was the main issue. NVR foils in curing tests showed no silicones
Application **Mitigation Techniques** on Flight H/W:

- Disposable Garments
- Glove Change-out
- Restricted Activity
- Separate trash cans used/bags removed from cleanroom
- CC person present

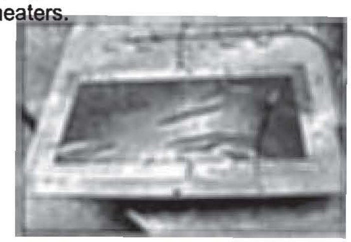
Testing post cure showed no contact transfer

Tayco Heaters:
Acrylic adhesive but Pressure Sensitive Adhesive (PSA) slip agents contained silicones
Cleaning would not remove silicones. Too late to change heaters.
Application **Mitigation Techniques**:

- Clean front side with Hexane
- Use tweezers
- Change-out gloves

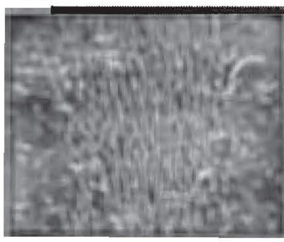
Kapton Tape:
Analex screens tape for silicones
Check labels for Analex testing

Green Flashbreaker Tape: Acrylic Adhesive
TML 1.02 CVCM 0.25
Difficult to remove and not flight approved



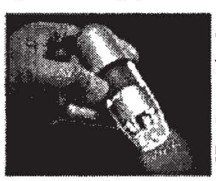
Tayco produced Kapton Heaters

Solar Array Gimbal Radiator Micro-Cracking



Ag/FEP micro-cracks (~10x mag.)

IFM

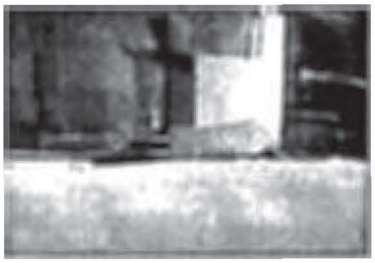


Dino-Lite

- Thermal coating Silver Teflon (Ag/FEP) micro-cracks affect thermal alpha properties as adhesive bleeds through the cracks; UV light photo-polymerizes and blackens the adhesive.
- Micro-cracks found on substrate are typical for bended applications.
- Infinity Microscope (IFM) analyses found little micro-cracks.
- Affect of UV radiation on thermal properties was ascertained on a sample.

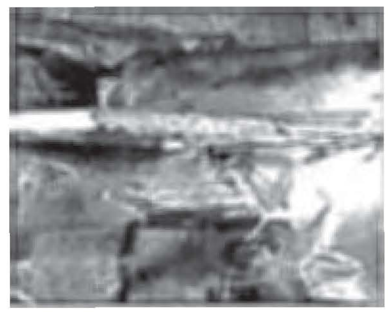
LL: Beneficial uses of IFM and Dino-Lite in the field to check for microscopic damage.

LOLA Radiator NS43C



LOLA's NS43C coated Radiator had damaged coating on outer edges Thermal ascertained a touch-up was aesthetically needed and not performance driven.

- The touch-up job performed at ASO on the Orbiter caused continuous flaking noted on the surrounding MLI.
- Initial cleaning of the coating did not eliminate the flaking. Continued cleaning kept pulling coating. Cleaned to original coating levels.
- LL: No last minute aesthetic touch ups; Potential contamination risk from particle generation/flaking.

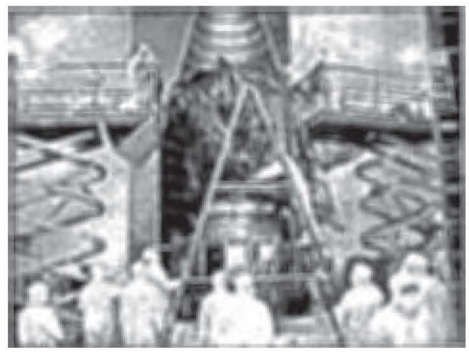


LRO Bagging Lessons

- Contamination concerns required bagging the spacecraft for I&T testing
- Access to the lift points became a significant concern
  - Lift points were well within bagged volume
  - Necessitated cutting large holes in bag for lifting operations
    - Sometimes jeopardizing the mechanical integrity of the bag
  - LL: Consider bagging needs when designing lift points on contamination sensitive payloads
- Bagging during installation into the GSFC SES thermal vacuum chamber was required
  - SDO experience showed significant buildup of particles on their bag
  - Use of a thermal vacuum fixture surrounding the observatory made bag removal a challenge. Less than 1 ft clearance in some areas
  - Bag design provided by Joe Hammerbacher was removed with no issues
    - Bag incorporated modular pieces that could be removed separately
    - Bag removal incorporated the use of parachute cords to gain access

LRO Bagging Lessons - ASO

- Bag removal prior to encapsulation was performed in the middle of the night to limit the exposure of the observatory to contaminants
  - Removal of the bag was again challenging due to the stack of two payloads
  - Access was very limited due to risk of contact with either payload or the stand on which the fairing would be placed
- Scheme was designed again using parachute cord to lift the bag vertically off the spacecraft
- There were many meetings to address concerns about removing the bag with the limitations
- Bag removal occurred with minimal difficulties in less than 1 hour



White House Cleanroom

- With space limited at GSFC, LRO was to be housed in brand new 100k facility known as the "white house"
  - LRO cleanroom requirement was class 10K cleanroom
- A class10k Laminar Flow Enclosure (LFE) was designed to house LRO in order to meet cleanliness requirements within available facilities
  - *LFE is a laminar flow tent with no roof, HEPA/ULPA – carbon filtration(supply and return), with sufficient air flow to meet class 10k cleanliness levels*
  - A similar LFE was successfully used by STEREO at ASO
  - The LFE provided significantly cleaner air cleanliness than the facility itself
  - The STEREO LFE was again used when LRO was transported to ASO
- The time frame for LFE design, fabrication and installation was less than three months
- LL: The small room used as a garment change room for the "white house" became an issue during LRO processing
  - Small size limited personnel entry rates, cause delays on entry
  - Small size created contamination risks due to lack of space for necessary garmenting and waste removal

LFE Lesson Learned

•LL: The use of the LFE provided a safe contamination environment for the LRO I&T program where no other facility was available and at significantly less time and cost than a new facility

•LL: The motors used in this LFE to drive the fans were very loud however, and exceeded OSHA decibel exposure limits.

- •The fan speeds were reduced to meet OSHA sound limits with minimal air flow impact. Laminar flow was maintained
- •Despite the reduction, crane operations required the fans to be shut off due to the noise impact on lift safety

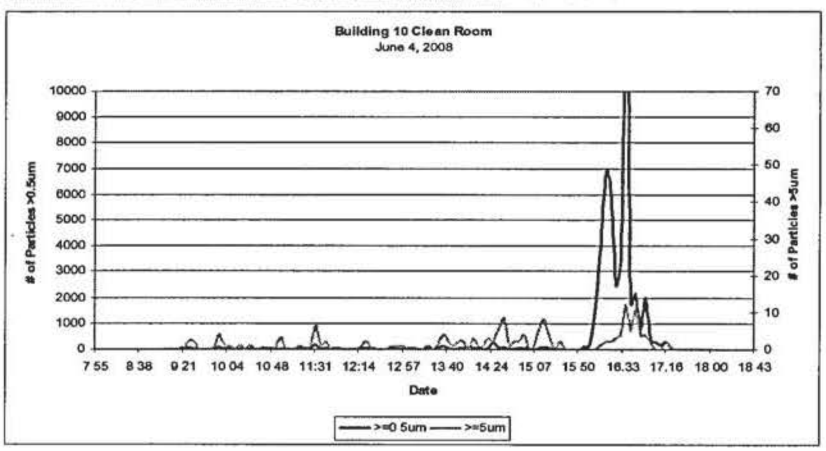
•LL: The tent modular design allowed flexibility in tent entry, however, entrance into the tent for large items such as LRO still required removing the return wall

- •Removal of the wall required power to be cut off to the return wall
- •Power supply design required shutting down the supply wall as well if the return wall power was disabled

•LL: The independent power for the LFE enabled the tent to continue to operate even if the White House facility failed

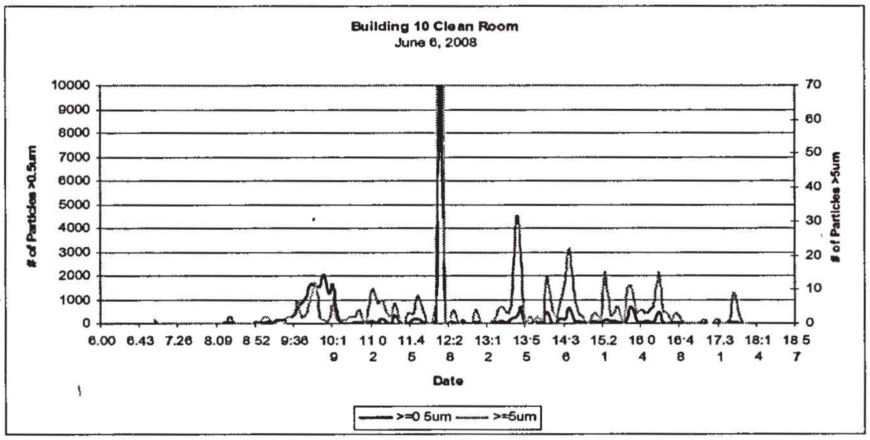
- •The LFE does not have an independent HVAC system, so humidity and temperature control is lost with failure of the room HVAC system
- •LRO temperature and humidity limits were occasionally exceeded in LFE

LFE Particle Data During Power Off



•Fans shut down from 16:02-17:22. Return wall was opened and ARONSON table brought into the room. 0.5μ counts rose to 13,703 (10K limit is 10,000 0.5μ particles.) *(Used from Joe Hammerbacher - SGT)*

LFE Particle Data During Power Off



•Fans were shut down around 11:50-12:20. The LRO spacecraft was rotated on the ARONSON table. 0.5µ particle counts rose to 10,659 *(Used from Joe Hammerbacher - SGT)*

OSR Contamination

•A blue cloth material provided by the vendor was required to protect the OSRs from scratches

•This cloth turned out to be a significant contamination source

•Particulate: Cut edges created significant particles and fibers

- •Folding and "hemming" the edges reduced particulate contamination but did not eliminate these fibers

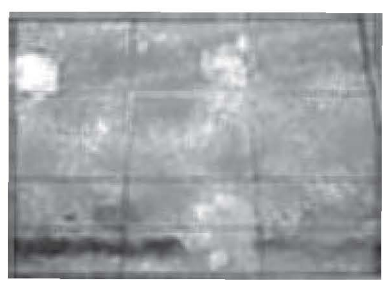
•Molecular: Testing of the cloth revealed methyl silicone contamination in an IPA rinse (release agent used on the threads of the cloth?)

•After final cleaning of the OSRs at ASO, spotting and smearing on the OSRs was noted

- •Gentle swab cleaning of each individual OSR was necessary to remove visible contamination

•LL: Less contaminating alternative methods/materials should be used to protect OSRs

- •Material standoffs, hard covers, other materials should be considered



Fairing Clean Tents

- The LRO observatory was transported to the launch pad already encapsulated per normal Atlas procedures
- At the launch complex, the payload area of the Vertical Integration Facility (VIF) is not a cleanroom
- Access into the fairing was required by ULA and the LCROSS project from both the mission unique doors as well as the boatail doors.
    - Full garmenting was required for this access
    - Exposure of cleanroom garments to the "unclean" area was not acceptable
- Two mission unique door tents and four boatail door tents were designed and fabricated
    - The mission unique tents included a separate garmenting area, the bowtail tents did not
    - The requirements for all tents was class 100K, however the goal for the mission unique tents was a 10K environment
    - All tents were operated well below the class 10K goal as measured by particle counter data monitored during activity within the tents

Fairing Clean Tents

- LL: The operation of these tents exceeded expectations and enabled the protection of the contamination sensitivities required by LRO
    - Future use of this design is recommended where contamination sensitivity is required
    - These tents exceeded all expectations on cleanliness operations
    - Provision for clean room garment use for these tents should be clearly worked out prior to operations

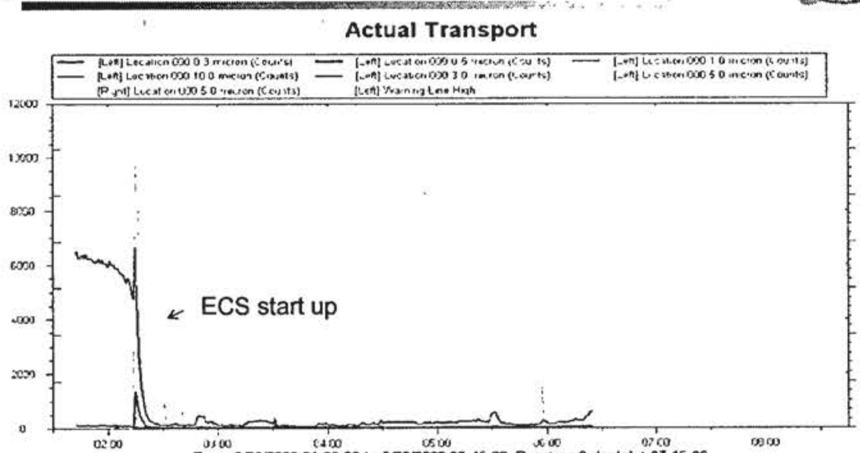
Boatail Door Clean Tent

LRO Fairing Transport from ASO to VIF

- Particle counts were taken within the actual fairing and not just at the air supply
  - Believe this is the first data of this type for this fairing
- Wireless capability provided real time monitoring and saving of the data
  - RF activity was approved for use by ULA , KSC and GSFC safety
- Battery change out was required on a 4 hour basis
  - Safety also approved use of battery system on transporter
  - Transport stop points provided battery change points (5 minutes to change)
- Counts show clean air after ECS system settled

Particle Counter Lighthouse's SOLAIR 3100+ used to monitor fairing air during transport

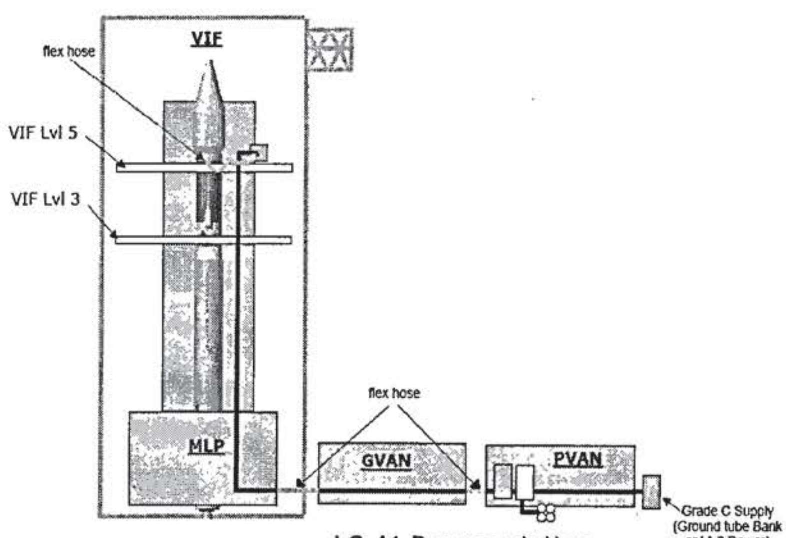
LRO Fairing Transport from ASO to VIF



- Counts show fairing interior met cleanliness requirements after ECS system settled
- New RF capability provided this information/analysis prior to fairing hoist into VIF
- Fairing environment meets cleanliness, caution should be used on ECS startup

Other Lessons

- •ULA reluctant to accept IEST particle counting for Level 450 Cleanliness Requirements
  - •Cleanliness in the fairing verified by 450 PAC equivalent
  - •Cleanliness easily met LRO requirements
- •Instrument teams familiarity with cleanliness requirements and procedures was sometimes more limited than indicated
  - •More assistance was required than originally anticipated
- •Creation of a Purge Engineer position within the contamination group for this project was a dramatic benefit
  - •Timely access to someone familiar with, and able to make changes to the LRO purge system
  - •Greater understanding of the needs both of the purge system and the spacecraft
  - •Greater flexibility in purge system tweaking and alteration to meet changing needs, particularly at the launch site



LC-41 Representation
Note: Drawing NTS

Launch Site Purge Problems

- Gas sampling from the tube bank passed, but sampling downstream at the PLF (Payload Fairing) failed
  - H_2O levels were not meeting instrument specification
- Purge suitcase located in the PVAN (van allocated for S/C GSE)
  - Upstream of 300+ft of Stainless Steel tubing
  - SS flex hoses braided over PTFE teflon lines used at several locations along the 300+ft
    - 50-75ft worth of flex hose
    - Permeability of PTFE was seen as the likely cause for high moisture content
- LRO/CC considered the installation of an additional Aeronex purifier on the Atlas MLP (Moveable Launch Platform) Mast the best way forward
  - To be installed in-line downstream of the ULA particle 5µm filter ~300ft downstream of the PVAN
  - The closest location you can get to the PLF interface

Aeronex Purifier

- Entregris Aeronex purifier CE-100KF-I-4R used to purify GN_2 gas to 99.999999% purity
  - Removes O_2, H_2, CO, CO_2, and H_2O to sub ppb (part-per-billion)
- Selected for its oxygen removal capability
  - Oxidation sensitivity to mirror coatings inside the LAMP instrument
  - Part of the 'Inert' gas series which uses a nickel oxide catalyst which reacts to remove the oxygen and other contaminates
- Previously used on New Horizons for the ALICE instrument
  - ALICE is heritage Lyman-Alpha UV instrument for LAMP

Purifier Installation Obstacles

- Short turn around time on flight configuration request
  - Large amounts of paper work and trails for such a change
- "Spontaneously combustible" label identified on the purifier raised concerns and resistance
  - Passive purifier not identified on the MSPSP
  - Several ERBs (Engineering Review Boards) were conducted to justify its implementation and address any potential safety concerns
  - Study by manufacturer showed any hazards to be limited to flowing incorrect gas through the purifier
    - In the extreme scenario where air was flowed through an 'inert' purifier at a maximum rated flow rate showed an very high heat up of the cartridge but no combustion occurred *(Exposure of Nickel Based Inert Gas Purifiers to Air, Don Alvarez, Jr., Joshua Cook, Jeffrey J. Spiegelman, AERONEX, INC.)*
  - Time constraints and reluctance led to a compromise to use a non-reactive version which would purify the high moisture content found in the lines

Lessons Learned

- Conduct sampling as soon as possible
  - Need tube bank ordered and in place
  - Keep parties involved aware of any potential contingencies
- Work early with LVC (Launch vehicle Contractor) to strive to get the purge system set-up as downstream as possible
  - Atlas V Vertical Integration Facility (VIF) level 5 is a very active area post PLF mate
- Don't rely on heritage and contractually delivered items when it comes to safety
  - Identify all components *(including passive GSE components)* to safety along with their MSDS
    - Ensure its documented on the MSPSP for any potential launch site issues
  - Consider safety hazards based on the location of possible use