SALT RSS-NIR
MID-TERM REVIEW
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THERMAL SYSTEM DESIGN

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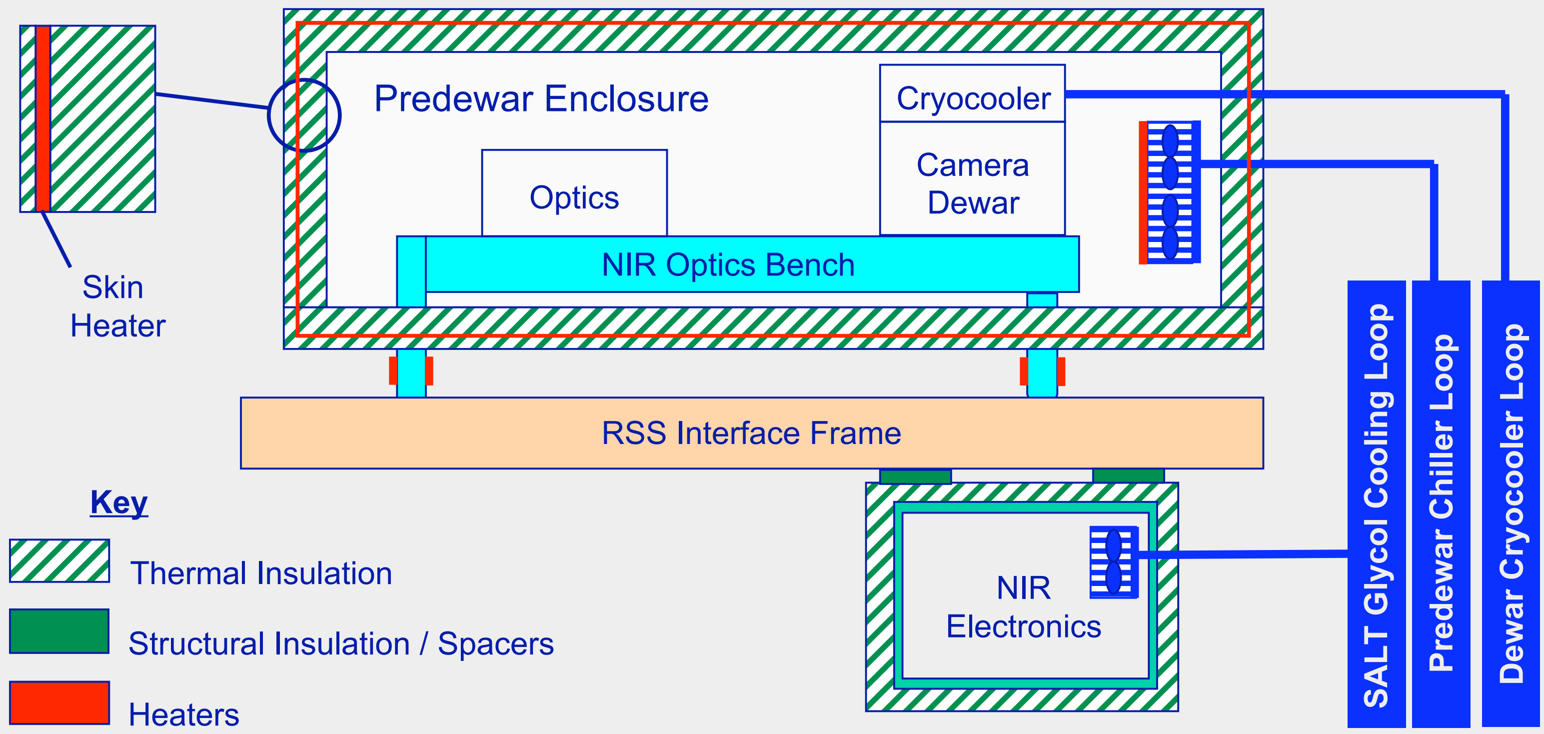
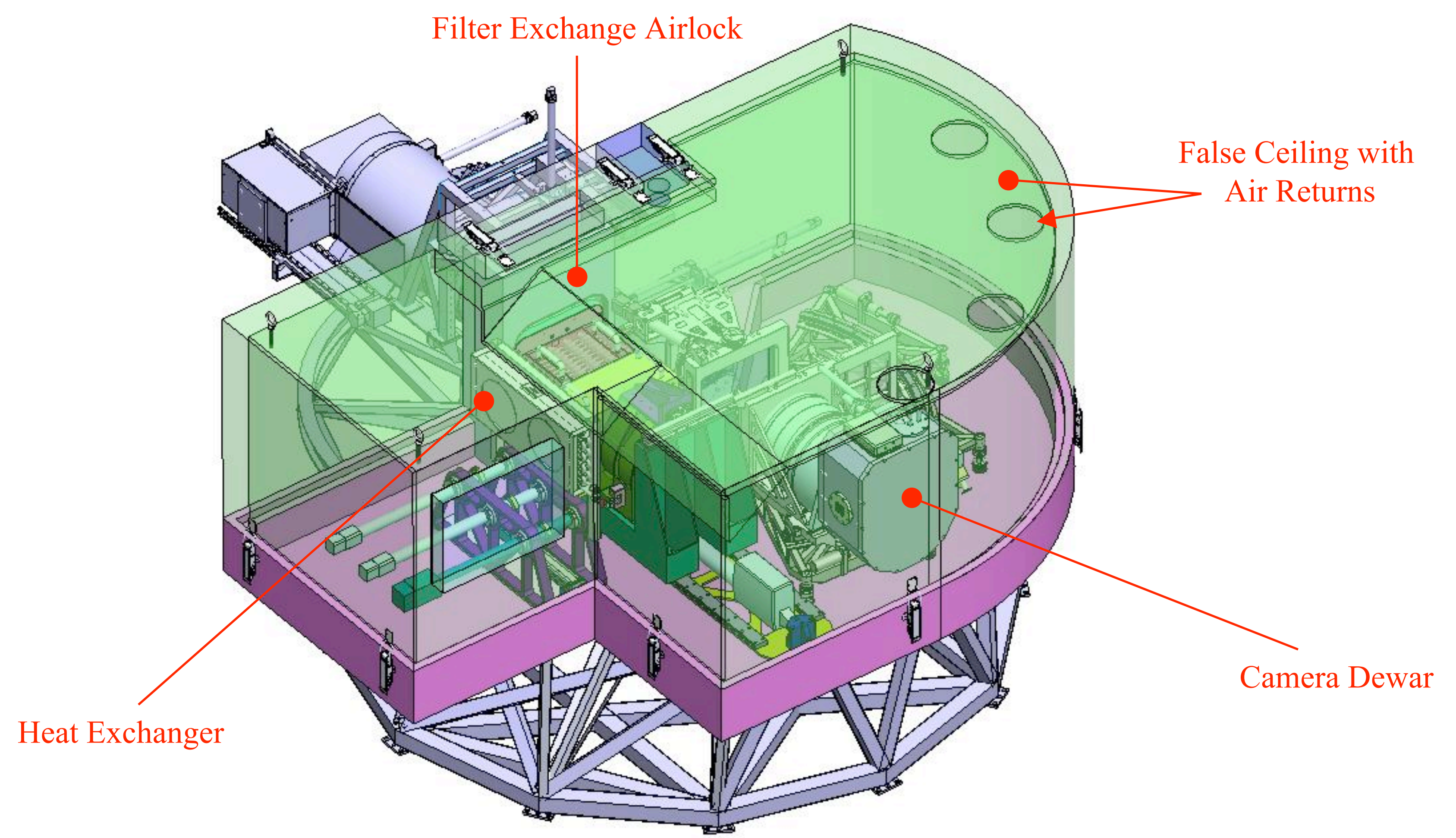
NIR THERMAL SYSTEMS

- Three primary thermal systems: Predewar, Dewar, and Electronics
  - NIR instrument in insulated predewar enclosure, chiller in igloo under mirror
  - Camera dewar has a dedicated cryocooler; compressor in igloo under mirror
  - NIR electronics enclosure cooled with SALT facility glycol cooling loop

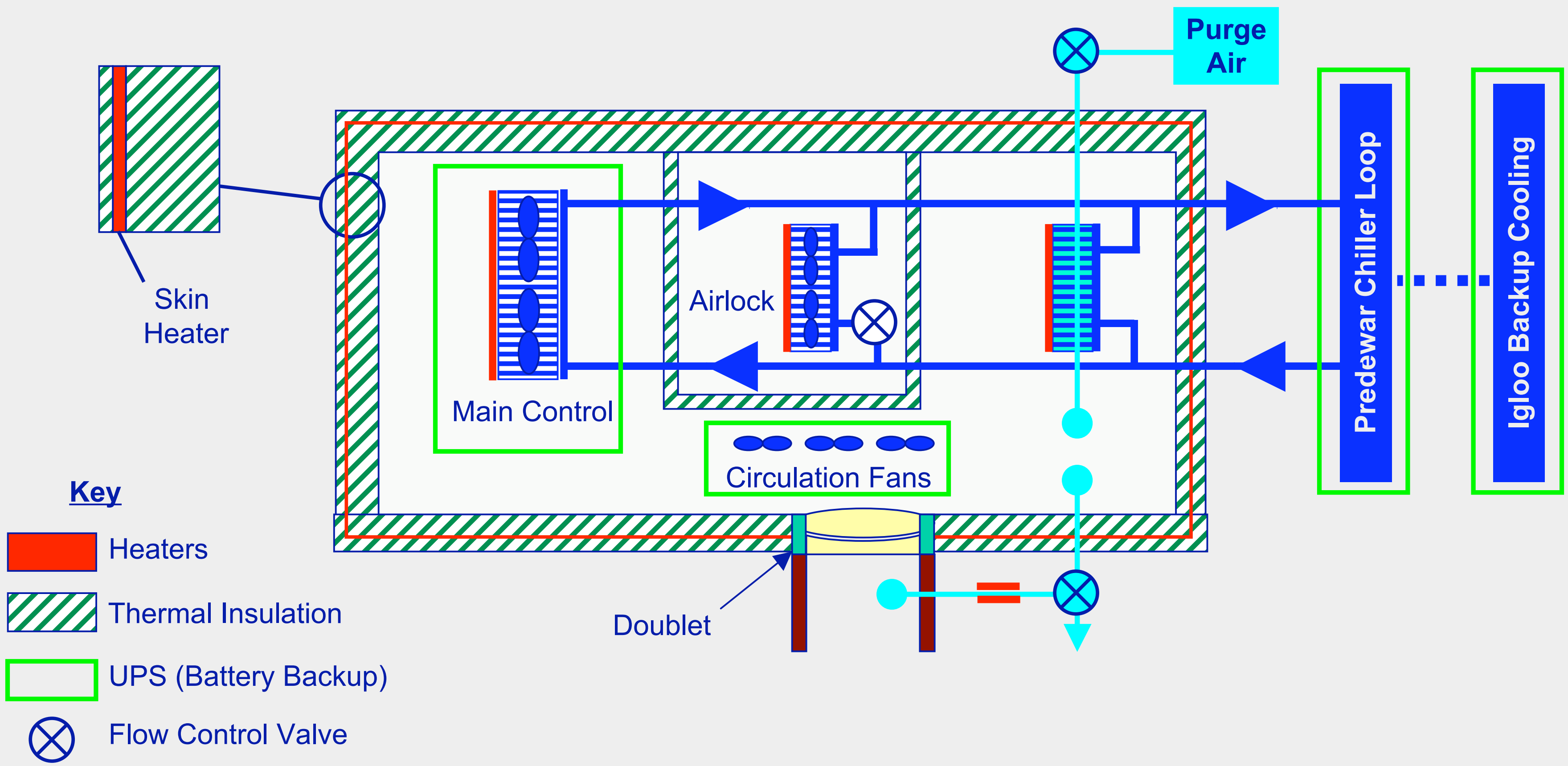


PREDEWAR ENCLOSURE



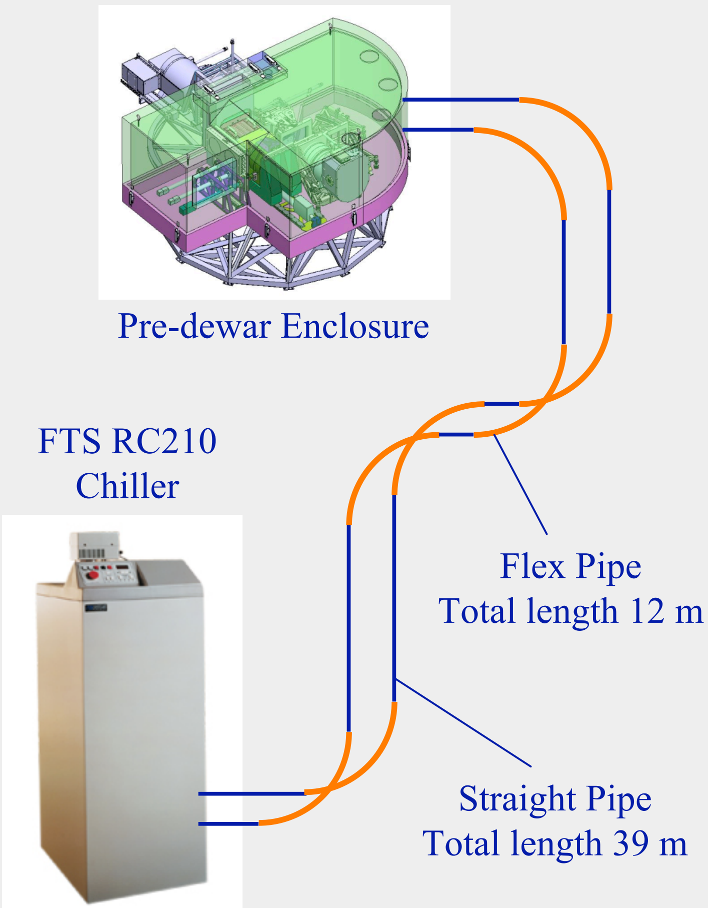
PREDEWAR SCHEMATIC

- Four predewar thermal systems: Main Control, Skin Heat, Purge Air, Airlock
- Local penetration and multizone skin heaters utilize "One-Wire" control
- Chiller, Main Control, and circulation fans on UPS



PREDEWAR CHILLER

- Enclosure Chiller Schematic



- Steady State Heat Loads (W)

Enclosure walls	360
Structural penetrations	50
Electrical feedthroughs	10
Doublet window	10
Exchanger & circulation fans	180
Instrument dissipation	20
Fluid pipe heat loss	20
Total Heat to be Removed from Fluid by Chiller	560
Chiller Capacity	1000

PREDEWAR HEAT LOADS

- Predewar enclosure requirements:
  - Maintain a nominal instrument temperature of -40°C in ambient temperatures ranging from -10° to + 25°C, with up to 75 kph steady winds and 90 kph gusts
  - Maintain all external surfaces within 2°C of ambient temperature to prevent condensation and thermal plumes
  - The enclosure interior and contents shall be isothermal (+/- 5°C) and stable (+/- 1°C, max. rate 0.1°C/hr)
- Enclosure heat load through walls: 360 W
  - Enclosure covers entire instrument including dewar – area 9.2 m^2
  - Assumes outside air at 25°C, inside air at -45°C to hold instrument at -40°C
- Other heat loads:
  - Structural instrument mounting penetrations: 50 W
  - Average internal instrument power dissipation expected to be below 20 W
  - Electrical feedthroughs (estimate based on 40 22-AWG wires): 10 W
  - Heat load through doublet window (conduction/convection/radiation): 10 W
  - Air circulation and heat exchanger fans: 180 W
  - Losses from chiller coolant lines to ambient: 20 W
- Total steady state enclosure heat removal required: 560 W

PREDEWAR COOLING

- Predewar enclosure cooling provided by FTS RC210 recirculating chiller
  - Chiller is located in an igloo (insulated box) under the telescope mirror
    - Produces up to 2 kW of heat load to be removed from igloo by SALT glycol system
    - Chiller is available with air or water cooling options; choice depends on emergency power loss scheme to protect doublet
  - Coupled to a Lytron ES071 fluid-air heat exchanger mounted in the enclosure
- Enclosure chiller fluid pumping requirements:
  - Vacuum insulated fluid lines follow cabling route from enclosure to chiller
  - Space available in cable wraps limits flex pipe size – 6.4 mm ID/30 mm OD
  - Larger pipe used in straight sections to reduce head loss - 13mm ID/51 mm OD
  - Due to head loss in small flex lines need low viscosity heat transfer fluid – selected Fluorinert FC-87
  - Exchanger and lines have 1 MPa (150 psi) max pressure; other losses estimated at 0.35 MPa (50 psi) due to pumping height, and 0.1 MPa (15 psi) in heat exchanger
  - Designing to 0.69 MPa (100 psi) for safety margin, flow rate is limited to 3.8 l/min (1 gpm) – this results in 5°C fluid temp rise with 560 W heat removal
  - Chiller pump provides 6 gpm at 22 psi; boost pump is needed due to high pressure

ENCLOSURE DESIGN

- Chiller heat removal capacity:
  - Nominal predewar air temp must be ~7°C below desired instrument temp due to air coupling resistance to instrument (5°C) and air temp rise (2°C)
  - Chiller temp 5°C below predewar air temp due to fluid temp rise → -52°C
  - The RC210 chiller provides up to 1000 W cooling at -50°C, 880 W at -60°C
    - Sufficient for steady state 560 W cooling required, and for instrument cooldown
- Fans circulate air inside enclosure for temperature uniformity
  - Enclosure air will be circulated over the heat exchanger, then past a 500 W heater for precise temperature control
  - Exchanger fans provide 450 cfm; additional fans for temperature uniformity
  - False enclosure ceiling provides air returns for better air circulation
- To prevent condensation issues:
  - Enclosure purged with dry air prior to and during cooling
    - Dry air dew point to be -57°C (5°C less than chiller fluid temp at exchanger inlet)
    - Purge air cooled to predewar temp with small heat exchanger using chiller fluid
      - Can serve as "touch up" or backup purge air dryer
    - Purge air provides slight positive pressure (<3.5 kPa, 0.5 psi) inside enclosure
  - Outer enclosure heated to maintain exterior temps within 2°C of ambient; thin insulation over heated skin needed for temperature uniformity and control
  - Localized heating will be used as needed at penetrations and feedthroughs

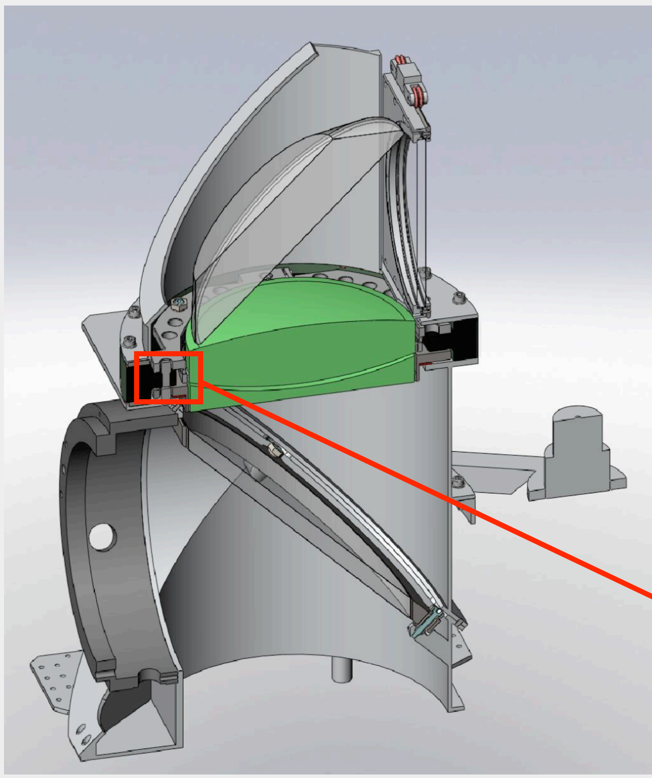
ENCLOSURE DESIGN

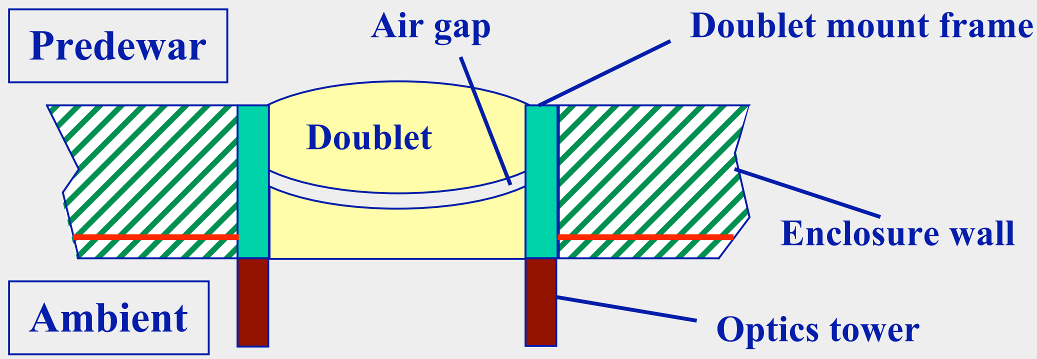
- Enclosure material is Divinycell H60, sandwiching 0.5 mm heated aluminum skin
  - Divinycell outer thickness 5 mm, inner 45 mm on enclosure bottom, 60 mm top and sides
  - 0.5 mm fiberglass on inner and outer surfaces for encapsulation and rigidity
- Filter exchange airlock allows filter changes during the day
  - Small liquid-air heat exchanger with fan uses small amount of chiller fluid to cool airlock; integral heater provides rate control and warmup
  - Airlock is purged with ambient dry air for 1 to 2 hours prior to cooling, until dew point is 5°C below predewar temp
  - Cooldown time ~4 hours at -50°C chiller fluid temp
  - Faster cooldown can be achieved by opening door to predewar when filters are close to predewar temp
  - Warmup time can be faster, may be limited by filter glass thermal stresses
  - Investigating ways to reduce filter cooldown time to allow for two filter exchanges during the day
- During use the airlock will add up to 30 W heat load to the predewar
  - Will not significantly disturb predewar stability; not active when observing

DOUBLET DESIGN

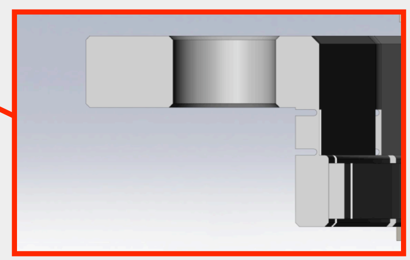
The doublet serves as the window through the enclosure wall

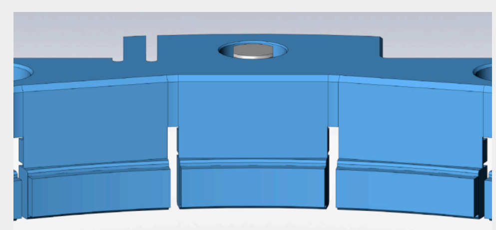
- The region below the doublet will be purged to prevent condensation
- The inner doublet lens is CaF2, outer lens is fused silica
- Cold air blown on CaF2 inner surface to reduce temperature for background IR
- CaF2 is relatively fragile; worst case optical element for thermal gradient stresses



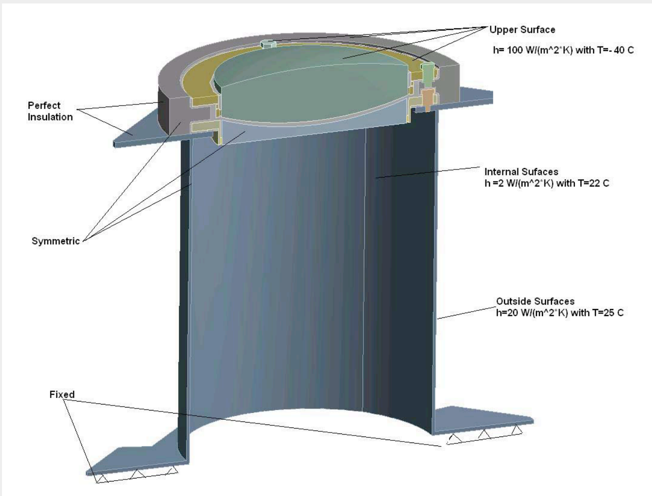


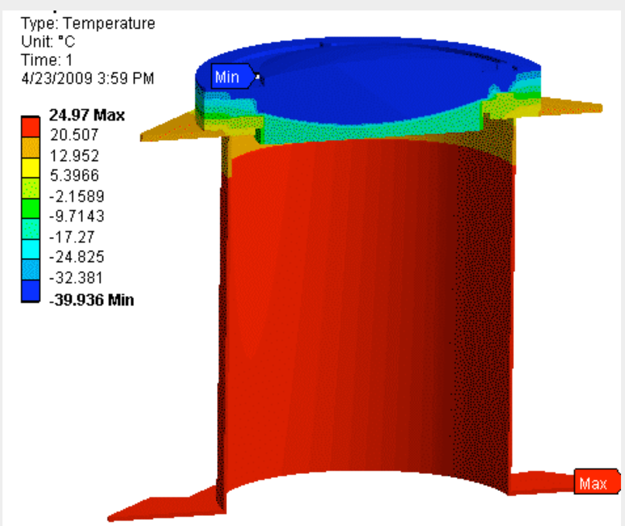
- The inner lens is adhesive mounted to a support ring with flexures to minimize stress





DOUBLET DESIGN

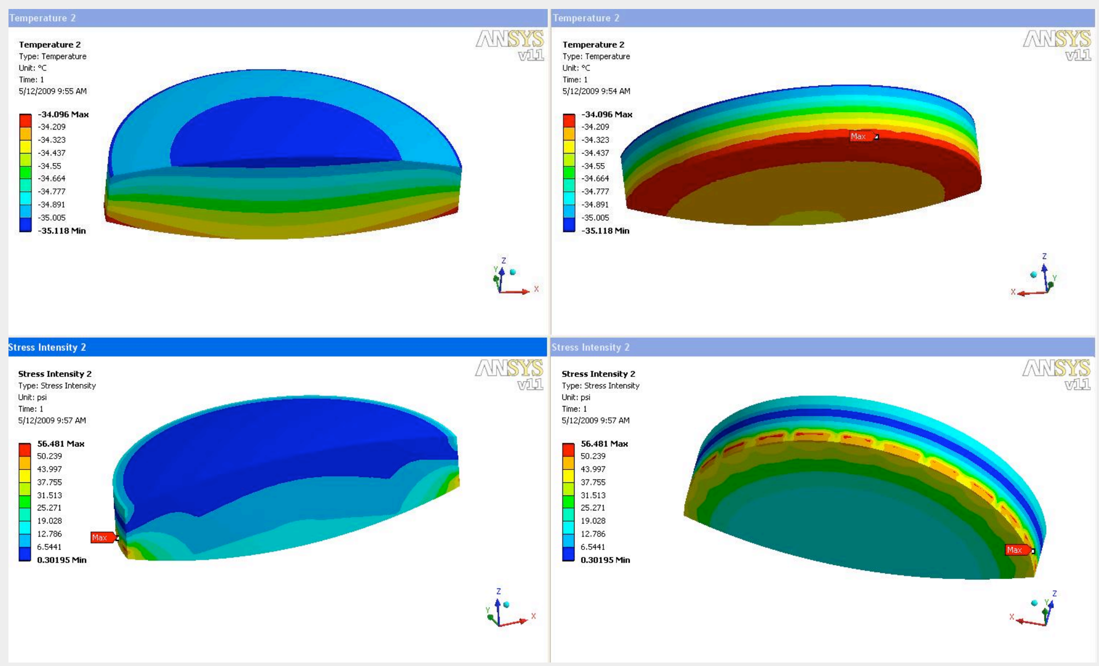




- Determined probability of CaF2 failure based on relationship from Vukobratovich:

$$PF = 1 - \exp\{-(\sigma / \sigma_o)^m\}$$

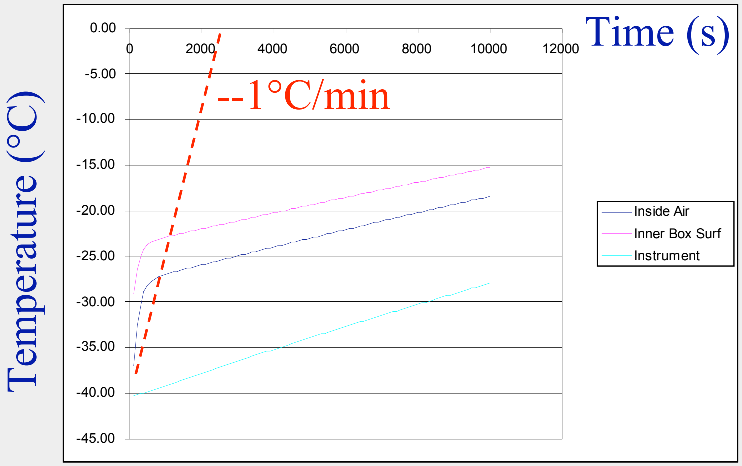
- For 0.1% failure, stress limit is 0.5 MPa
- Analysis results used to optimize mounting; current result is 0.39 MPa steady state
- Conservative; Corning datasheet failure stress is 19 MPa rough, 138 MPa polished and annealed



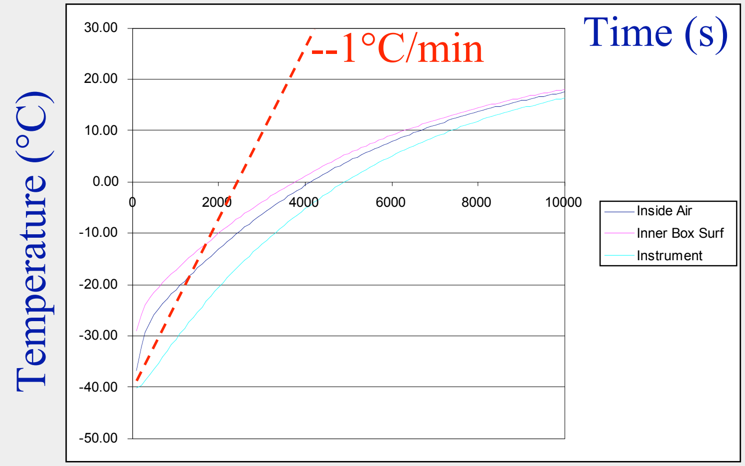
DOUBLET DESIGN

- In event of predewar chiller power loss, enclosure will rise to ambient temperature
- With inside air temp rise of 1°C/min lens stress is 1 MPa, for 0.8% chance of failure
- Estimated rate of predewar air temperature change:

100% Instrument mass well coupled to air



10% Instrument mass well coupled to air



- Based on this estimate, thermal coupling of instrument to enclosure is not sufficient to keep air temp rise below 1°C/min, especially during initial period
- Two hours of emergency backup power for the exchanger fans & chiller is recommended, to bring the instrument temperature up in a controlled manner and minimize the risk of lens breakage
  - Assuming main facility glycol loop is down also, need alternate means of removing chiller heat from the igloo, such as open loop water supply or forced air ventilation of igloo

OTHER THERMAL ASPECTS

Electronics Box:

- The instrument electronics will be housed inside a thermally insulated aluminum box that is mounted to the RSS Interface Frame
  - Heat removed with liquid-air heat exchanger to SALT glycol cooling loop
  - Appropriate conductive coupling and internal fans will minimize "hot spots" within the box

Cryogenic Dewar

- The cryogenic dewar for the camera will be cooled to 120 K by a Polycold PCC (aka Cryotiger) cooling system
- The air-cooled compressor unit will be located in the igloo below the mirror, and produces 500W nominal / 800W peak heat load that will be removed from the igloo using the SALT glycol cooling loop
- The supply lines run 2-3°C above ambient, and the return lines 2-4°C below ambient, so little or no insulation will be needed on the lines
- Flexible lines inside predewar must be vacuum insulated or heated to prevent refrigerant condensation

COOLED SLITMASK

- At this time cooled slitmasks are not being pursued due to science/budget tradeoffs, but viable options exist for future incorporation if desired
- To reduce background IR, investigated five concepts to cool the slitmasks:
  1. Cool mask with forced air blown over entire mask surface
  2. Cool mask using jet impingement at discrete locations; conduction across mask
  3. Mask frame conductively coupled to glycol cooled TEC with contact conduction
  4. TECs installed in corners of mask frame, air cooled from bottom
  5. Cold air circulated through passages in masks via couplings
- All concepts warm and cool in use position to avoid difficult purge of mask transfer and storage areas
- Concepts # 1 & 2 ruled out due to condensation risk from unconfined cold air
- Analysis of gradients and cooling time verified feasibility of remaining concepts
- Based on tradeoff analysis conductively cooled frame (concept #3) chosen
  - Key advantages include:
    - Significantly lower dry air flow rate required – purge only
    - Higher TEC power possible due to glycol cooling loop vs. air
    - Less complex control system
    - No excess air movement near mask
  - For multi-slit masks use high conductivity material; if not viable use conducting bars

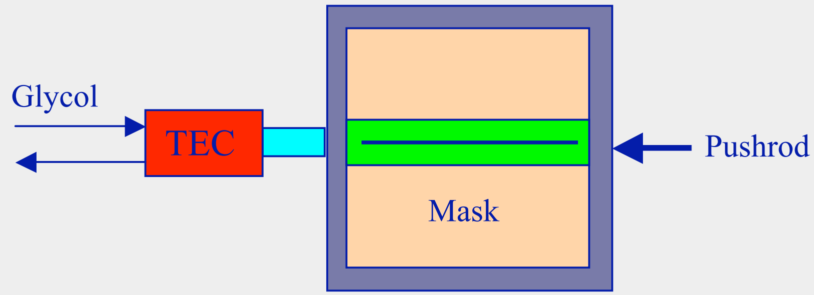
COOLED SLITMASK

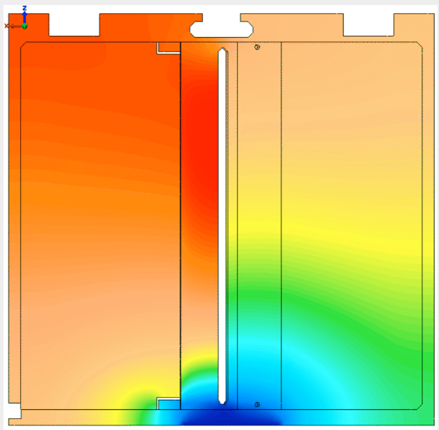
Cooled Slitmask Tradeoff Matrix

Concept	Advantages	Disadvantages	Status
1. Cool mask using cold air blown over mask with fan/blower	•Uses existing masks	•Surrounding area exposed to low temps with potential for condensation •High velocity air required •High dT to cooling air required •Low temp on field lens surface	•Not viable with reasonable fan/blower sizing
2. Cool mask using air jet cooling of frame	•May be able to use existing masks	•Surrounding area exposed to low temps with potential for condensation	•High risk due to condensation potential unless cold air is contained
3. TECs mounted in mask frame, cooling top of mask & slit Hot side of TEC on bottom, air jet cooling from enclosure	•Low risk electrical connections •TEC cooling air can end up near ambient and provide purge (if separate TEC added)	•Inefficient; must remove 4x cooling power from hot side •May require separate TEC to chill TEC cooling air •Possible gradient to 'free' side of long slit •Large amount of TEC cooling/purge air (42 lpm/1.5cfm) circulating around	•Verified jet cooling feasibility •Need FEA to verify gradients, determine if baffles and/or insulation needed
4. Cold air through passages in mask frame and/or baffle	•Cooling air contained & separate from purge air •Can warm waste cooling air for purge	•Fabrication of air passages may be difficult •Possible gradient to 'free' side of long slit •Need sliding air couplings to masks w\o alignment affect	•Need FEA to verify gradients, determine extent of passages needed, determine if baffles and/or insulation needed
5. Mask frame leading edge coupled to glycol cooled TEC (cylinder pressure or separate clamp)	•Only purge air required •May be able to use existing masks	•Potential gradients •Potential thermal coupling degradation •Potential mask / TEC coupling alignment issues	•Need FEA to verify gradients & determine if baffles, insulation, or new frames needed

COOLED SLITMASK

- Concept #3: Glycol cooled TEC, mask frame pushed into contact with TEC coupler or possibly clamped

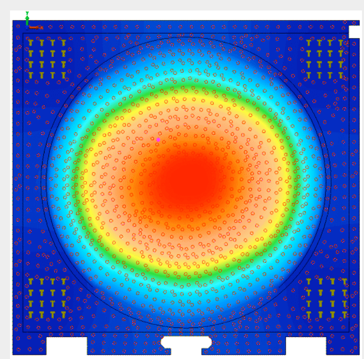


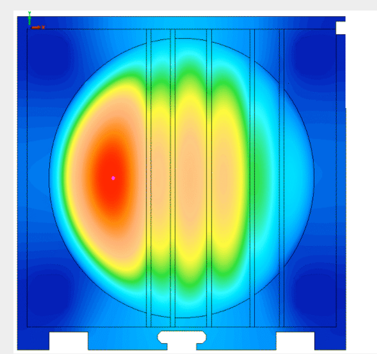


Analysis Results:

- Maximum allowable gradient for slit distortion is 4°C
- With copper frame, beam, and 2mm thick copper baffles coupled to free side of slit, and heat pipes ΔT is 1.5°C
- Worst case cooldown time 10 minutes; nominally under 6 minutes

- Current multi-slit masks have low CTE for low distortion, but low conductivity limits cooling, ΔT=20°C
- High conductivity carbon fiber ΔT=5°C
- Conductive bars provide backup option





FUTURE ACTIONS

The following actions will be taken as the design matures:

- Detailed design and analysis of doublet mounting for thermal stresses
- FEA on other lower risk optical elements
- Refine all instrument power estimates and temperature requirements
- Detail design and thermal analysis of enclosure including structural penetrations, feedthroughs, and other penetrations
- Design and analysis of electronics enclosure
- Design and analysis of filter/grating exchange box
  - Attempt to achieve two filter exchanges per day