AMS-02 Thermal and Thermal Control System

AMS-02 Thermal Overview

- AMS-02 brought to ISS in shuttle payload bay
- Permanently mounted on S3, inboard, zenith site
- Payload has 2000 watts of heat dissipation
- Must meet all ISS and STS safety requirements
- Must comply with SSP 57003 (Attached Payload Interface Requirements Document) and SSP 57004 (Attached Payload Hardware Interface Control Document Template)

ISS Thermal Requirements

- SSP 57003, Attached Payload Interface Requirements Document, is the controlling document for all AMS-02 thermal requirements relating to ISS.
- Applicable sections include:

3.1.1.2.5	THERMAL EFFECTS
3.4.1.1.1	TEMPERATURE REQUIREMENT
3.4.1.1.5	THERMAL RADIATION MODELS
3.4.1.1.6	THERMAL EXCHANGE BETWEEN PAYLOADS
3.5.1.2	THERMAL ENVIRONMENT
3.7.6.2	EBCS AVIONICS PACKAGE POWER
3.7.6.3	EBCS THERMAL REQUIREMENTS

ISS Thermal Requirements

3.1.1.2.5 THERMAL EFFECTS

Attached Payload structure shall meet interface requirements when subjected to structural interface temperatures ranging from –120 degrees F to +200 degrees F when combined with static and dynamics loads.

3.4.1.1.1 TEMPERATURE REQUIREMENT

The Attached Payload to the S3 PAS and P3 UCCAS interfaces shall meet all requirements specified when the structural interface temperature is within –120 Deg. F and +200 Deg. F.

ISS Thermal Requirements

3.4.1.1.5 THERMAL RADIATION MODELS

A. Simplified thermal models of the Attached Payloads shall be provided to the ISS Program by the payload developer.

B. The Attached Payload simplified thermal models shall identify all surfaces over 10% specular and specularity values for those surfaces shall be provided.

ISS Thermal Requirements

3.4.1.1.6 THERMAL EXCHANGE BETWEEN PAYLOADS

A. Attached Payload active radiation surfaces (surfaces designed to reject heat generated by the payload) shall be oriented so that they have a cumulative view factor no greater than 0.1 to any surface of the generic attached payload operational envelope as defined in Figure 3.1.3.1.1.1-1 placed on any other S3 or P3 attach site. The view factor as used here is defined as the fraction of diffuse radiation leaving surface 1 that will fall on surface 2, such that:

$$A_1F_{1-2} = A_2F_{2-1}$$

Where A1 = area of surface 1
A2 = area of surface 2
F1-2 = view factor from surface 1 to surface 2
F2-1 = view factor from surface 2 to surface 1

B. Attached Payload surfaces with a view to other Attached Payloads shall have a specularity of 10% or less.

ISS Thermal Requirements

3.5.1.2 THERMAL ENVIRONMENT

The Attached Payload will be exposed to thermal solar constants, albedo, and earth Outgoing Long-wave Radiation (OLR) environments as defined in Table 3.5.1.2–1; a space sink temperature of 3 K; the induced thruster plume environment and induced thermal environments from vehicle(s) docking and docked with the ISS; and thermal interactions with other on-orbit segments. Induced thermal effects on Attached Payloads due to beta angle extremes, orbital altitude, and attitude variation about the ISS vehicle axes are provided in Table 3.5.1.2–2. These environments are to be used for design and analysis purposes.

ISS Thermal Requirements

TABLE 3.5.1.2–1 HOT AND COLD NATURAL THERMAL ENVIRONMENTS

Case	Solar Constant (W/m^2)	Earth Albedo	Earth Outgoing Long Wave Radiation (W/m^2)
Cold	1321	0.2	206
Hot	1423	0.4	286

TABLE 3.5.1.2–2 INDUCED THERMAL ENVIRONMENTS

Induced Environment	Assumed Parameters
Beta Angle	+/–75°
Altitude	150 nmi. to 270 nmi.
Attitude Envelope Without Orbiter(1)	Any combination of +/–15° Roll (about X axis)(2) +/–15° Yaw (about Z axis) (2) +15 to –20° Pitch (about Y axis) (2)
Attitude Envelope With Orbiter Docked to ISS(1)	Any combination of +/–15° Roll +/–15° Yaw 0 to –25° Pitch

Note(s):

1) The attitude variations include variations in the Torque Equilibrium Attitude (TEA) as well as variations in the ISS attitude from the TEA attitude, both with Orbiter docked, and without Orbiter.
2) XYZ axes refer to ISS coordinate system orientation.

ISS Thermal Requirements

3.7.6.2 EBCS AVIONICS PACKAGE POWER

A. The payload shall route the PVGF cable to the EBCS Avionics Package and provide connections as indicated in SSP 57004, Figure 3.7.2–1. The Avionics Package uses power from the PVGF and also routes payload power from the PVGF to the payload, up to 1800 Watts if necessary.

The Avionics Package will receive 30 Watts, compatible with the MSS power quality requirements specified in SSP 42004, paragraph 3.2.1.5.1, during payload berth and unberth operations.

B. The payload shall provide 2 heater busses, each capable of delivering 25 W (TBR #8), to the Avionics Package for keep–alive heater power.

ISS Thermal Requirements

3.7.6.3 EBCS THERMAL REQUIREMENTS

A. **Thermal Conductivity**
(TBD #16)

B. **EBCS Non–Operational On–Orbit**
(TBD #16)

C. **EBCS Operational On–Orbit**
(TBD #16)

STS Thermal Requirements

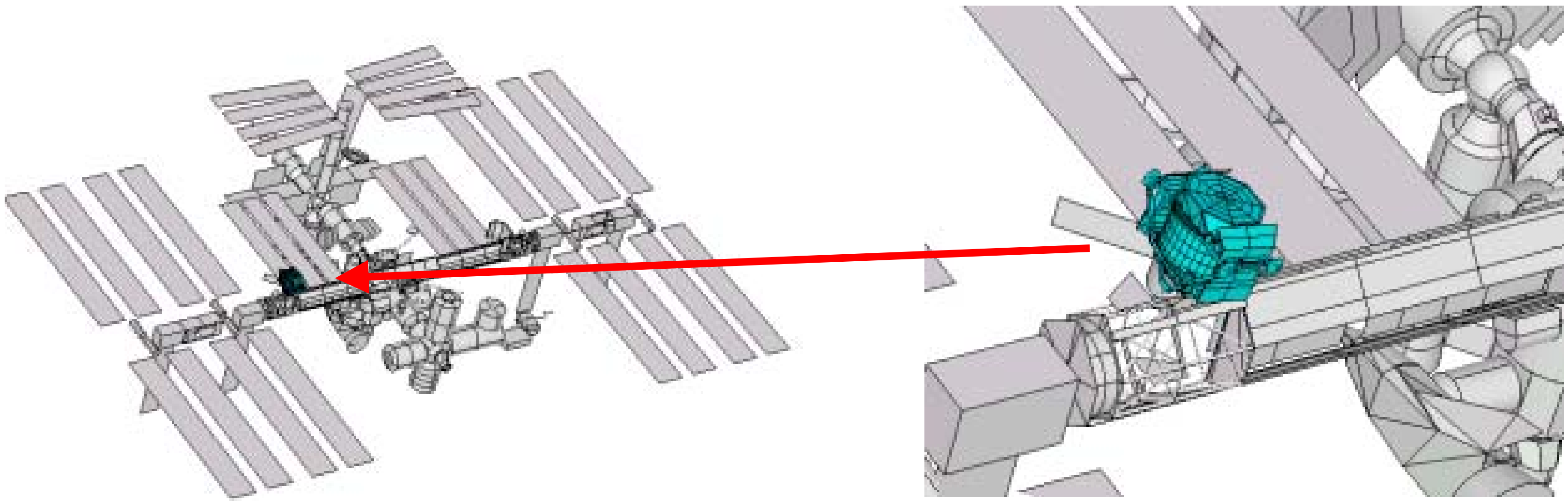
- Provide AMS-02 thermal model to STS for payload compatibility analysis. Must include temperature limits for all applicable nodes and optical properties for all external surfaces.
- Evaluation of Failed Open Vent Door case

Thermal Safety Requirements

- EVA Touch Temperature
  - Incidental contact with surfaces that exceed –180°F to +235 °F
  - Unlimited contact with surfaces that exceed –45°F to +145°F
- Failed heaters
  - Temperature predictions for thermostatically controlled surfaces assuming all heater fail "on"
- Auto-ignition
  - Verify that no surfaces can exceed +352°F while in orbiter payload bay

ASSUMED ISS CONFIGURATIONS

- ISS Assembly Complete (AC)
- AMS-02 attached to S3, inboard, zenith Payload site
- With and without orbiter docked to ISS
- With and without adjacent payload (outboard site)



MISSION PHASES

- Ground operations
- Transport
- Pre-launch
- Launch
- STS On-orbit
- AMS-02 Thermal Conditioning
- STS Docked to ISS
- Transfer from STS to ISS
- Nominal ISS operation

OPERATING SCENARIOS

- STS payload bay operations
- Transfer (heaters)
- Start-up Scenario (includes pre-heating, detector power up, Magnet charging, etc.)
- Nominal ISS operation (full power)
- Magnet discharging
- Keep Alive (survival power)

AMS-02 THERMAL DESIGN GOALS

- **Meet all ISS, STS, and safety requirements**
- **Maintain all experiment components and sub-detectors within specified operating and survival limits (document in AMS-02 Thermal ICD)**
- **Maximize SFHe endurance**
- **Optimize sub-detector temperatures to maximize science**

THERMAL RESPONSIBILITIES

- Lockheed Martin (LM), through the NASA-MMO, is responsible for interfaces to NASA (ISS and STS), verification of NASA requirements, and all safety related issues. LM is also providing general thermal consultation to experiment team.

- Carlo Gavazzi Space (CGS), through contract with the AMS collaboration, is responsible for integrated payload thermal design, analysis, and testing. They are also responsible for system level thermal hardware delivery and integration.

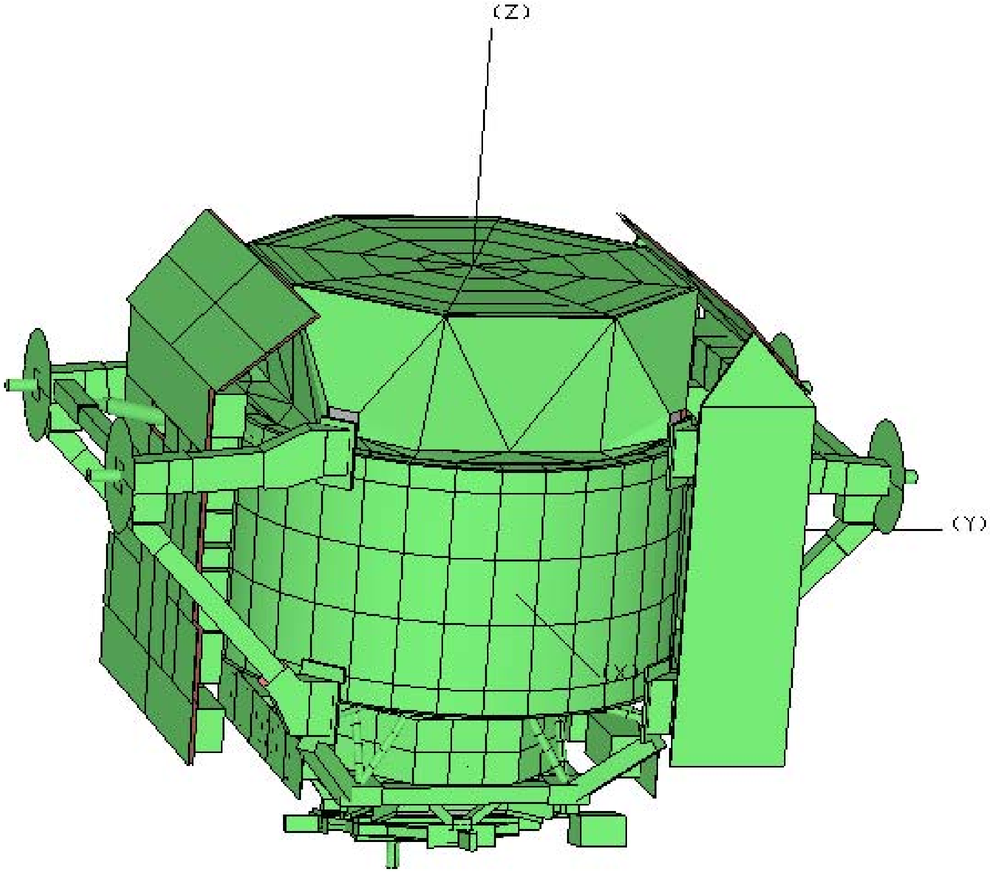
- AMS02 Sub-detector groups are responsible for their own thermal design, modeling and hardware. Sub-detector analysis is performed in conjunction with integrated thermal analysis performed by CGS.

THERMAL RESPONSIBILITIES (continued)

- **Sub-detector thermal responsibilities include:**

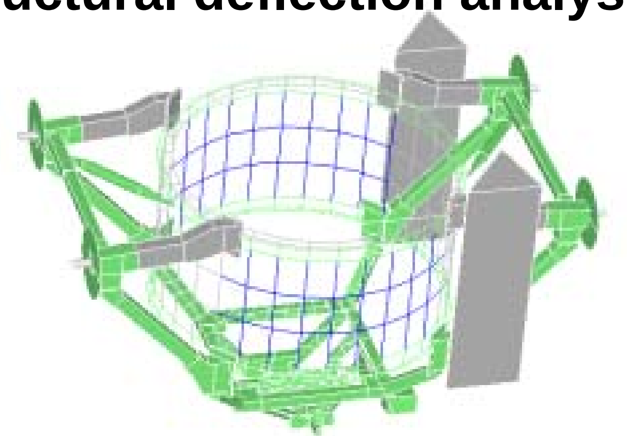
  USS02 (including ISS & STS integration hardware) – LM
  Vacuum Case –LM
  Cryo-magnet –SCL
  Cryo-coolers – MIT/GSFC
  Cryo-cooler cooling system - CGS/OHB/GSFC
  Radiators – CGS/OHB
  Electronic Crates – MIT/CGS/NSPO/CSIST
  TRD – OHB
  TOF – CGS
  Tracker – NLR/Nikhef
  ACC – RWTH
  RICH – CGS
  ECAL – CGS
  CAB – CRISA
  UPS – CSIST
  CCEB – ETH
  TRD Gas System – MIT/CGS/LM

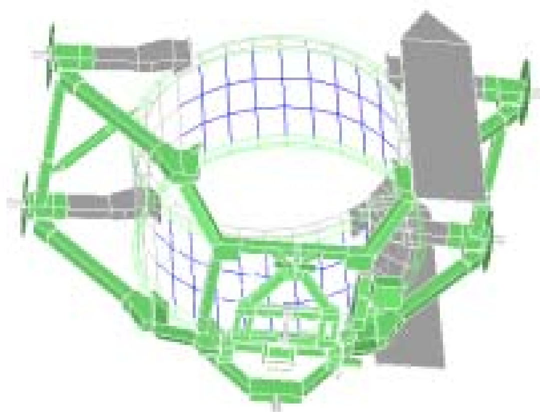
AMS-02 DESCRIPTION



USS-02

- **No heat dissipation**
- **Primarily anodized aluminum**
- **Provides structural interface to ISS, STS and AMS-02 sub-detectors**
- **Thermal blankets on joints and trunnion bridge added to help reduce gradients at TRD I/F's**
- **USS-02 temperature gradients have been considered in structural deflection analyses.**

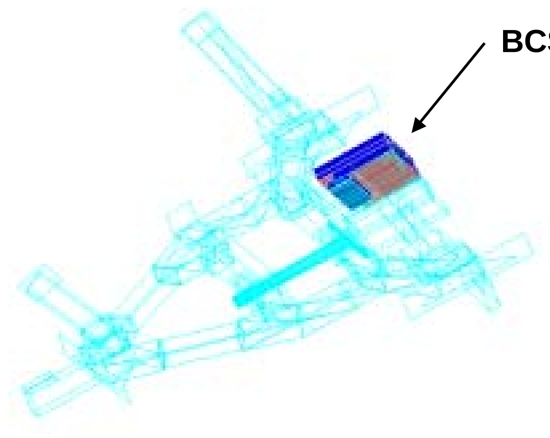


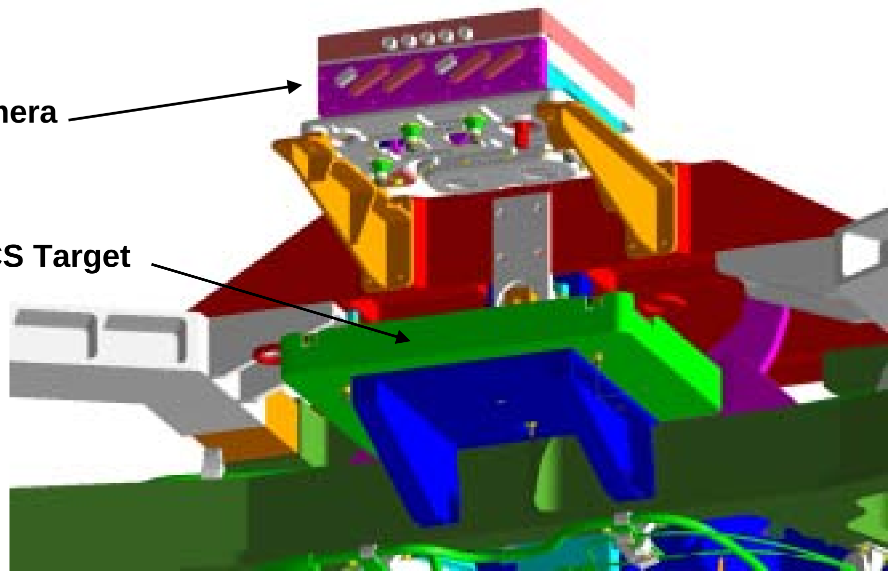


INTEGRATION HARDWARE

- **Unpowered Hardware: Power & Video Grapple Fixture (PVGF), Flight Releasable Grapple Fixture (FRGF), Umbilical Mechanism Assembly (UMA), Payload Disconnect Assembly (PDA), and EVA Connector Panel**

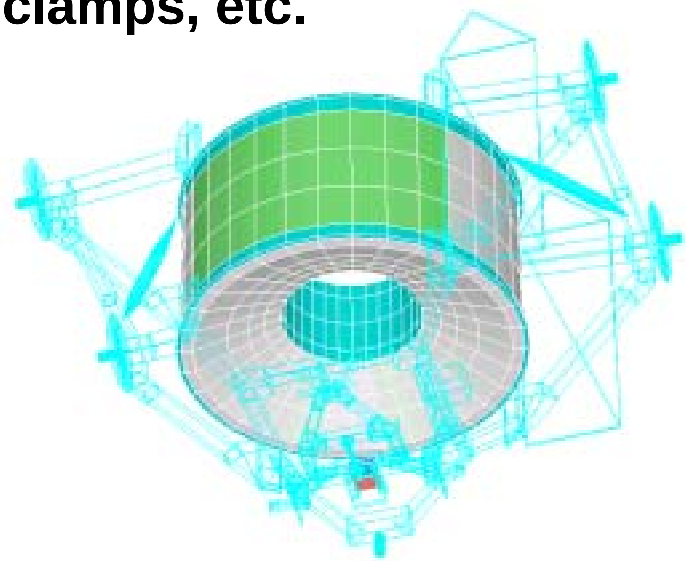
- **Berthing Camera System (BCS) will be used to berth (and unbearth) AMS-02. Camera will be power "on", whenever payload is grappled by the PVGF. Survival heaters will be activated constantly while AMS is berthed on PAS.**





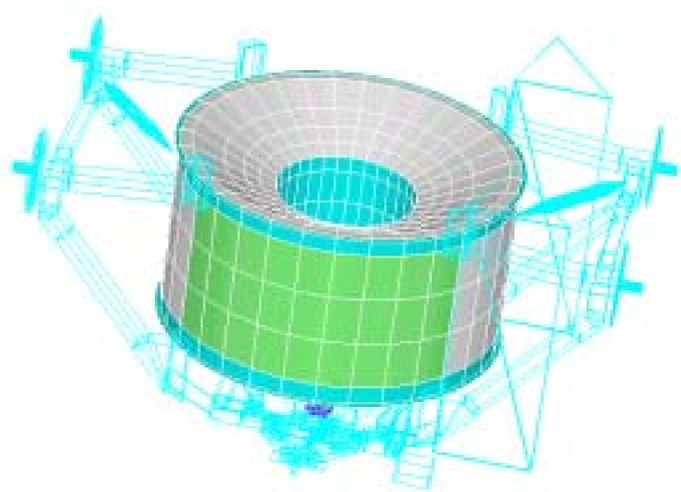
VACUUM CASE

- VC needs to be "cold as possible" to maximize SFHe endurance
- Any hardware mounted to VC with significant heat dissipation will be thermally isolated. Hardware mounted to VC include:
  - Cryo-coolers
  - ACC PM's
  - Tracker Thermal Control System (TTCS)
  - Tracker Cables
  - Star Tracker
  - Miscellaneous cables, stand-off, clamps, etc.



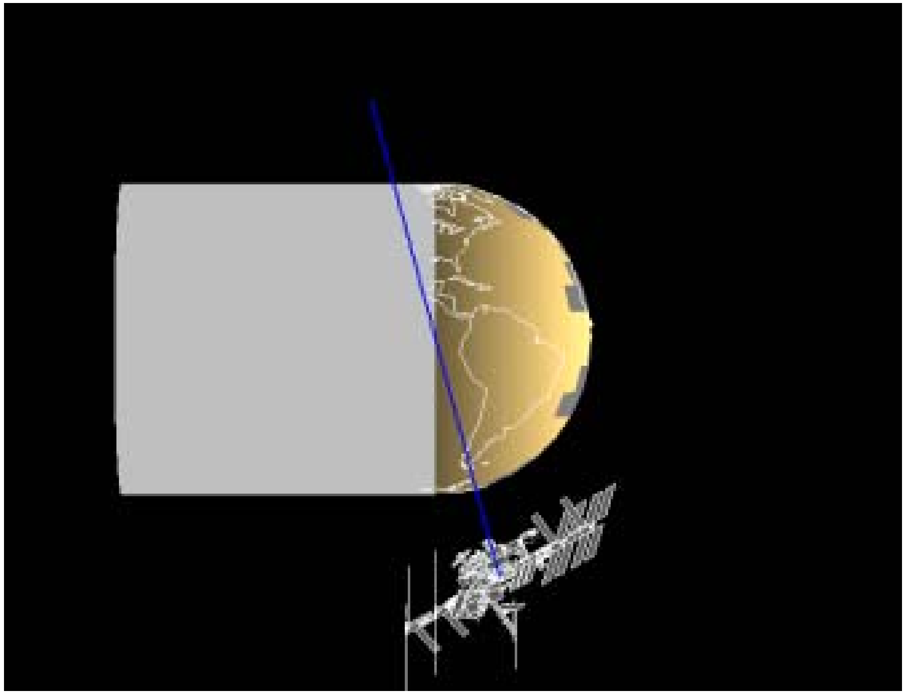
VACUUM CASE (continued)

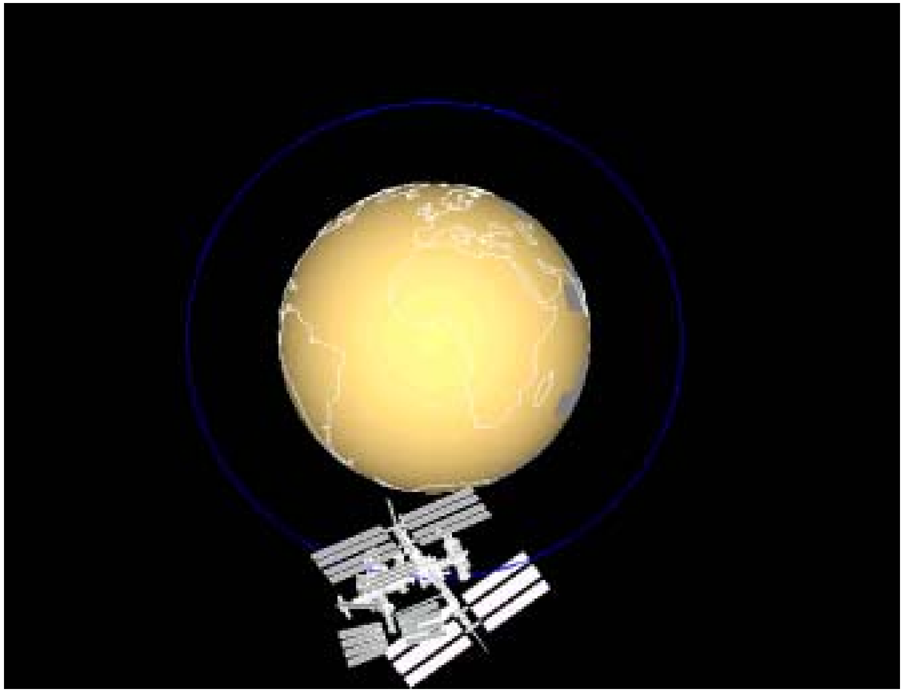
- Structural interfaces to USS-02, Tracker and ACC will also be thermally isolated.
- The VC will be covered with MLI blankets on +/- Y quadrants and silver-Teflon on +/-X quadrants. MLI blankets will also cover upper and lower conical flanges.



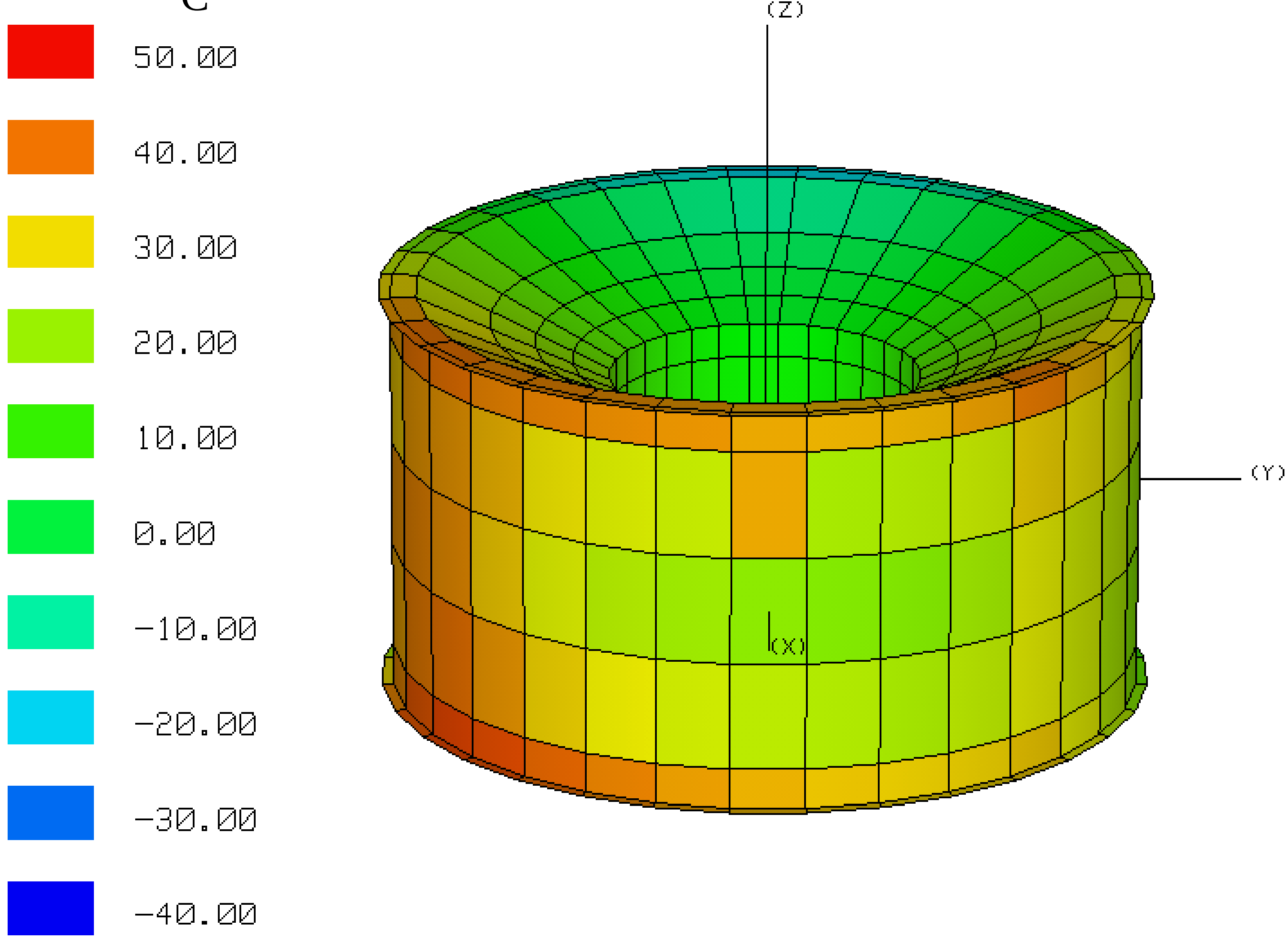
VACUUM CASE GRADIENTS

- Vacuum case temperature gradients have been considered in structural deflection analyses.
- Worst case gradients occur at beta=+75, YPR=-15,-20,-15



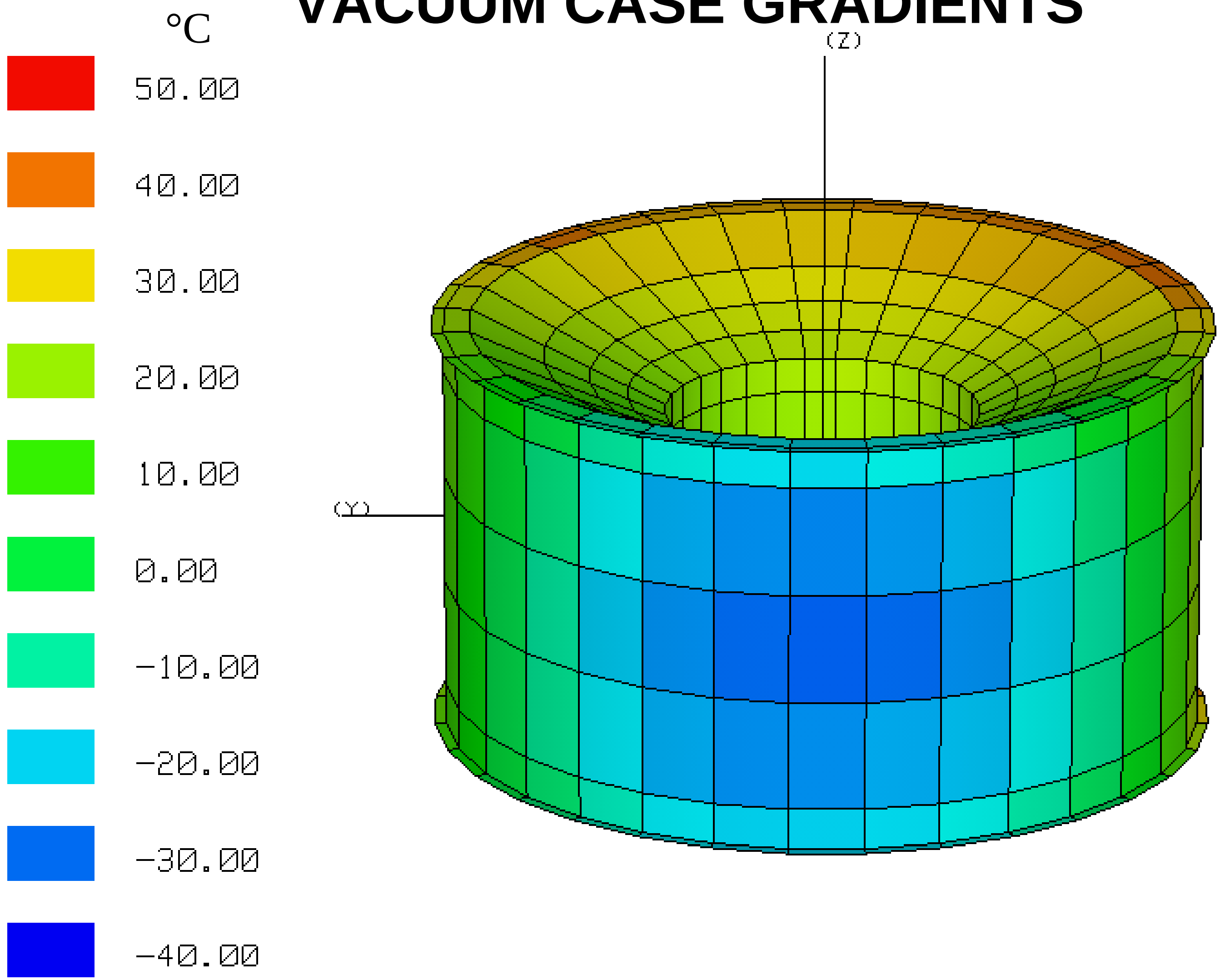


VACUUM CASE GRADIENTS



Vacuum Case Maximum Delta T
B=+75, YPR=-15,-20,-15

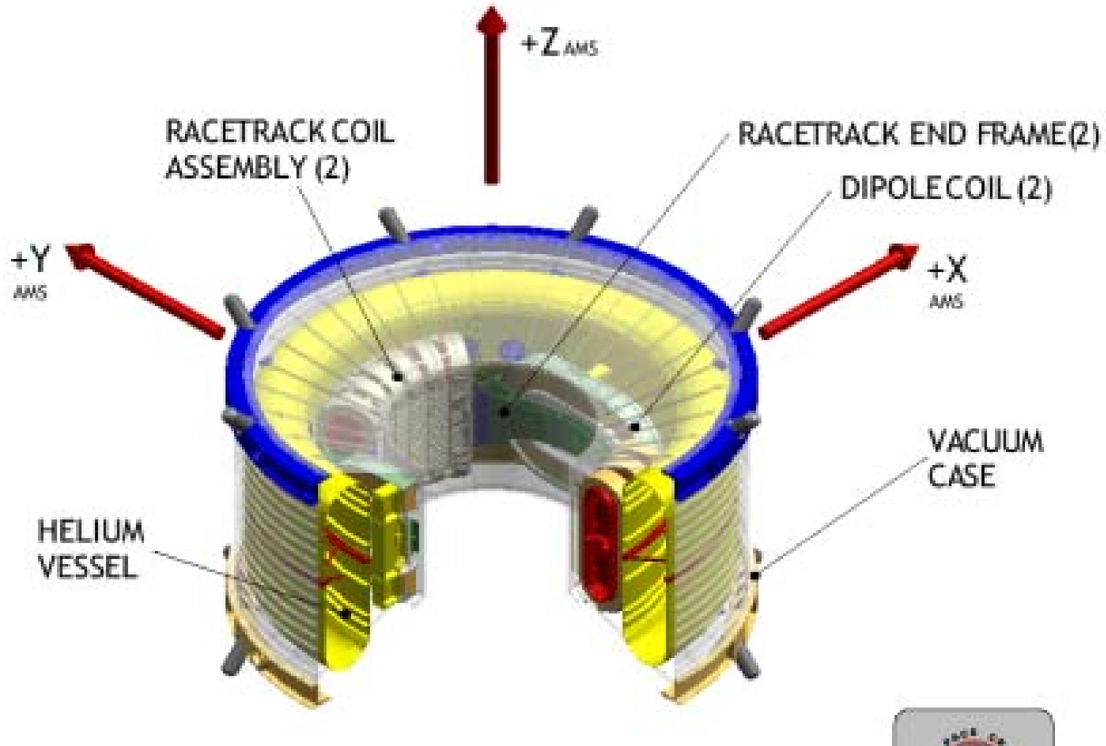
VACUUM CASE GRADIENTS



Vacuum Case Maximum Delta T
B=+75, YPR=-15,-20,-15

MAGNET

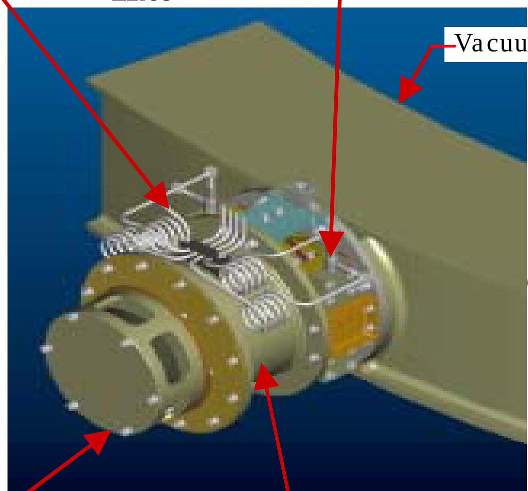
- **By design magnet Cold Mass has minimal effect on VC temperature and is not included in thermal model. VC temperature, however, does play a significant role in heat leak into cold mass and therefore needs to be as cold as possible.**

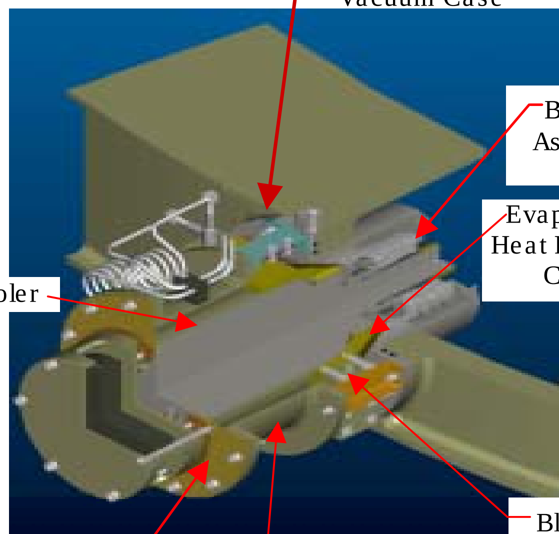


AMS-02 SUPERCONDUCTING MAGNET

Cryo-coolers

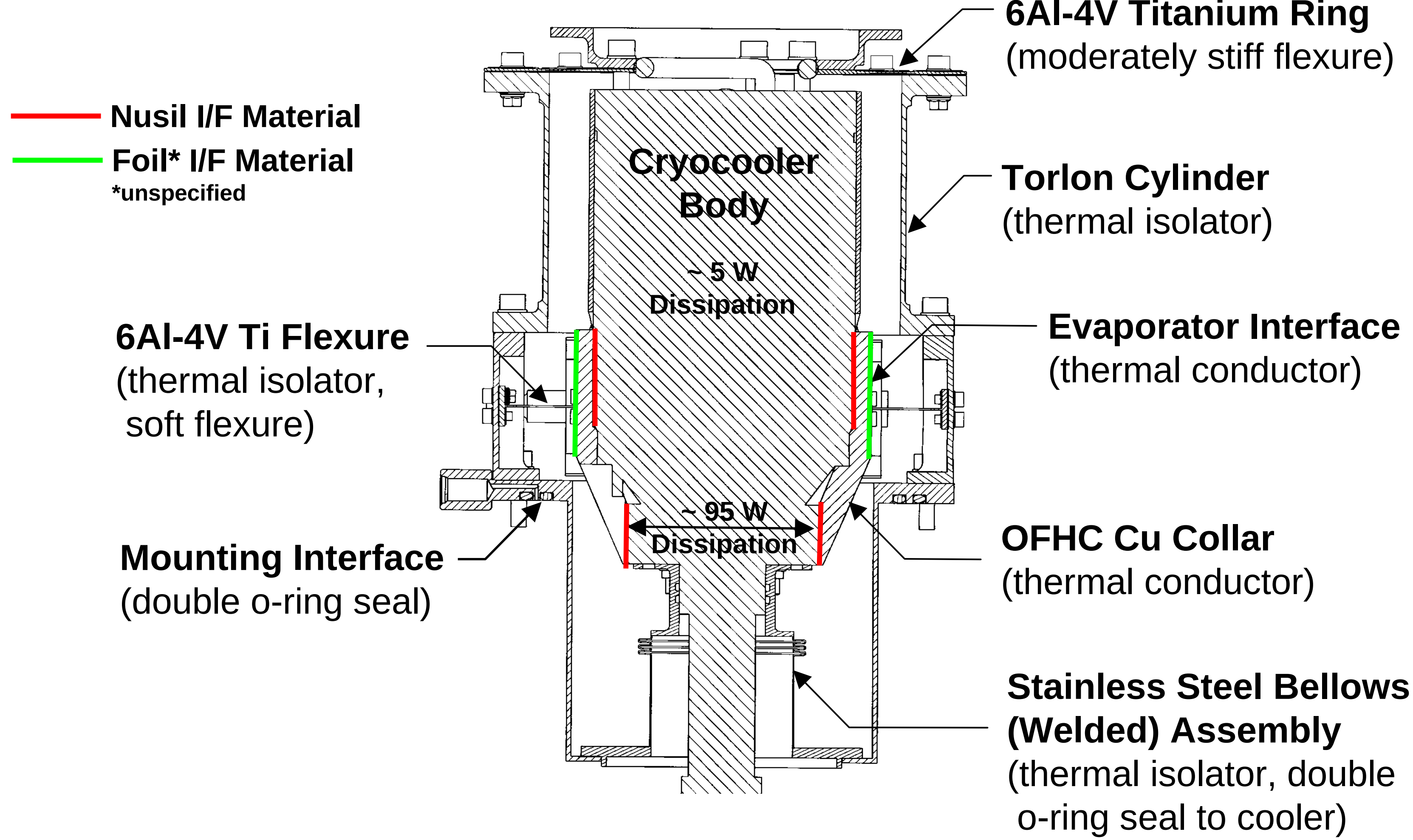
- **Cryo-coolers are used to cool the outer Vapor cooled shield to ~70K**
- **Cryo-coolers need to dissipate a significant amount of heat (100W x 4 units = 400W or 150W x 3 units = 450W), while maintaining heat rejection collar temperatures between –10°C and +10°C (design goal for optimum performance).**





Cryo-cooler Mounting

- **Cryo-cooler brackets provided isolation between cooler and VC support ring.**

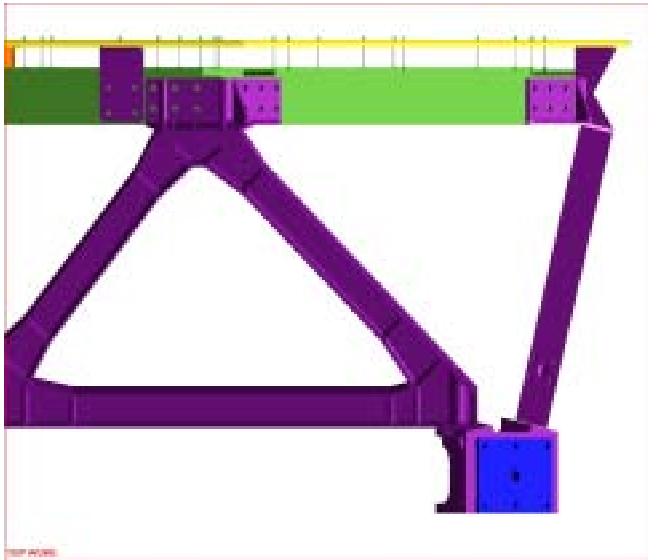


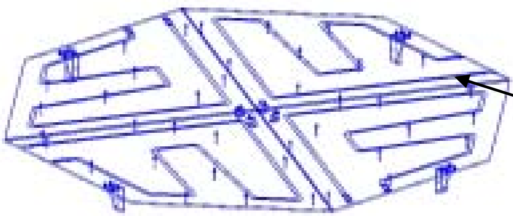
Cryo-Cooler Cooling - Loop Heat Pipe

- **Loop Heat Pipes (LHP) collect heat at each cryo-cooler and dissipate it by a direct flow zenith-mounted radiator.**
- **LHP built by TAIS/Moscow will be similar to one successfully demonstrated on orbit as part of COM2PLEX (STS-107).**
- **Ammonia working fluid with a Nickel wick.**
- **Stainless steel tubing (3mm) transitions to aluminum tubing in the radiator via a bi-metallic solder joint.**

Cryo-cooler Cooling – Zenith Radiator

- **Zenith radiator mounted on Upper TRD honeycomb plate.**
- **Thermal isolation provided by small support pins and a radiation barrier.**

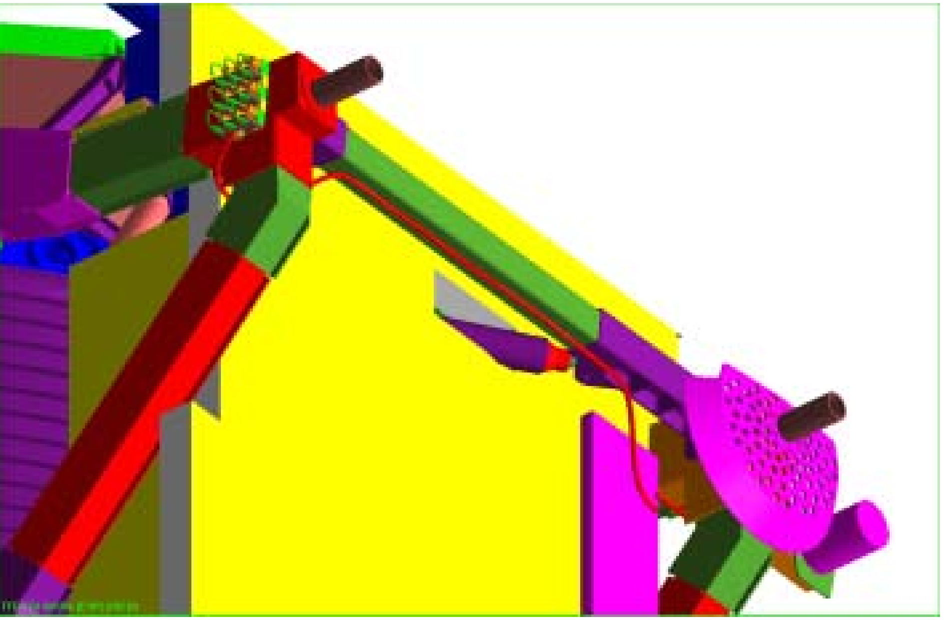


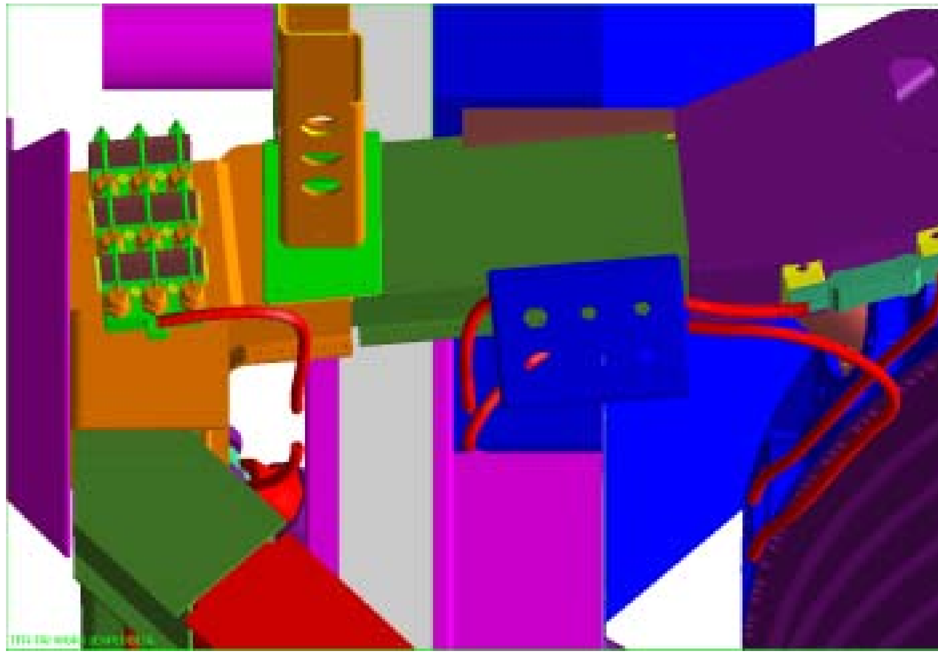


Tube Lay-Out
(3 mm OD)

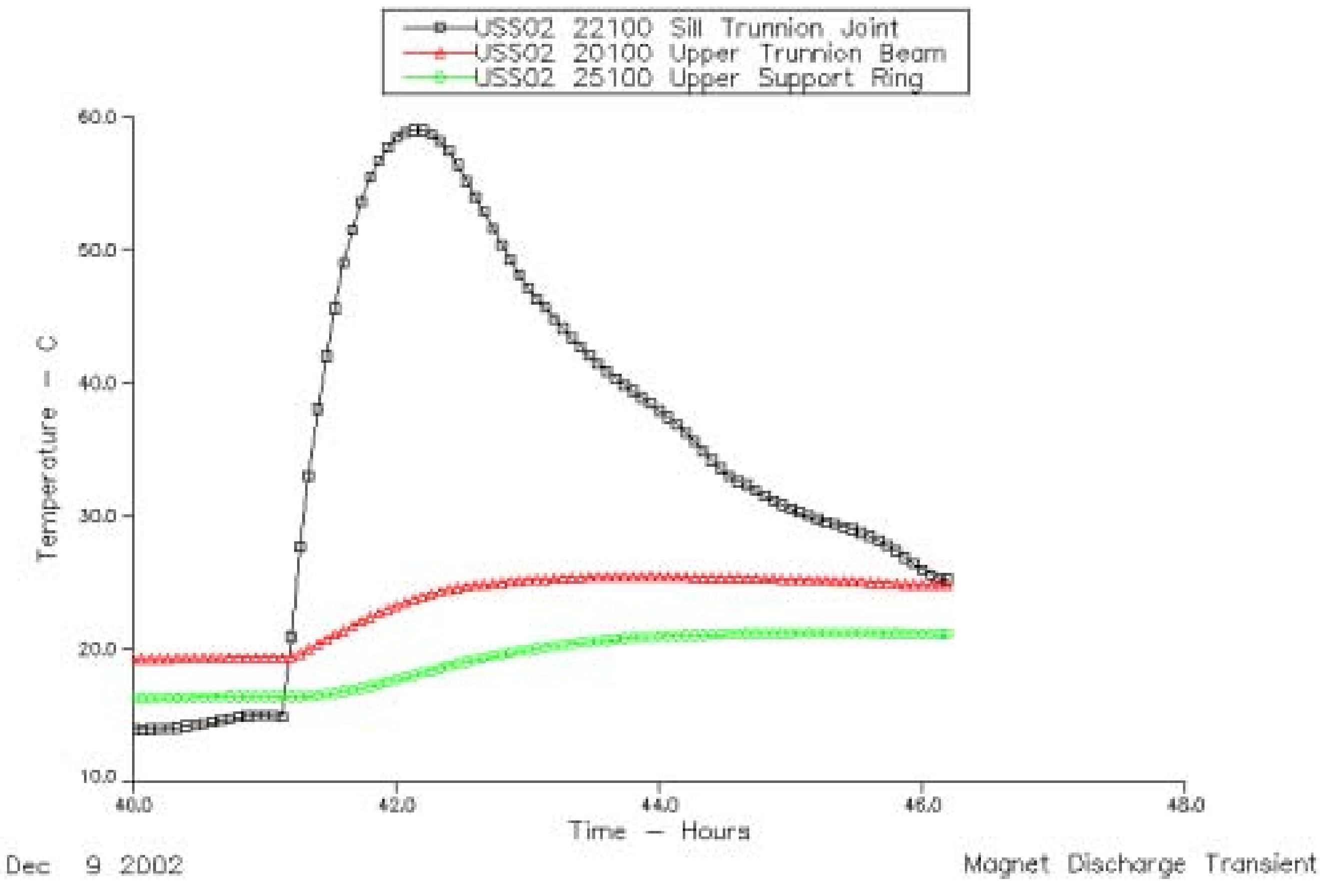
Cryo-Magnet Dump Rectifiers

- **Need to dissipate a significant amount of heat (5MJ over 2hr) when magnet is discharged. Sunk to USS-02 sill joints.**





SILL JOINT TEMPERATURES (MAGNET DISCHARGE)

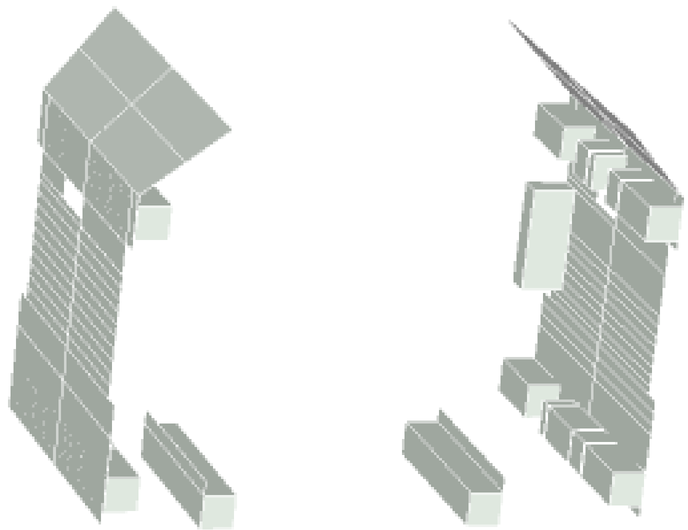


ELECTRONIC CRATES

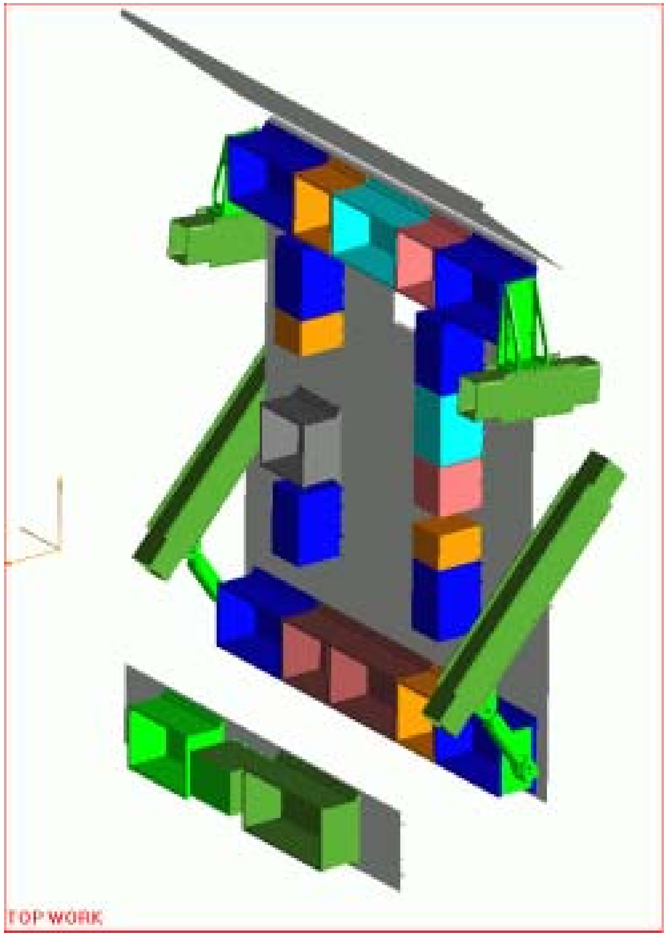
- **Majority of all heat dissipation (1500 W)**

- **With some exceptions, typical thermal limits are:**
  -20°C to +50°C (operating)
  -40°C to +80°C (non-operating).

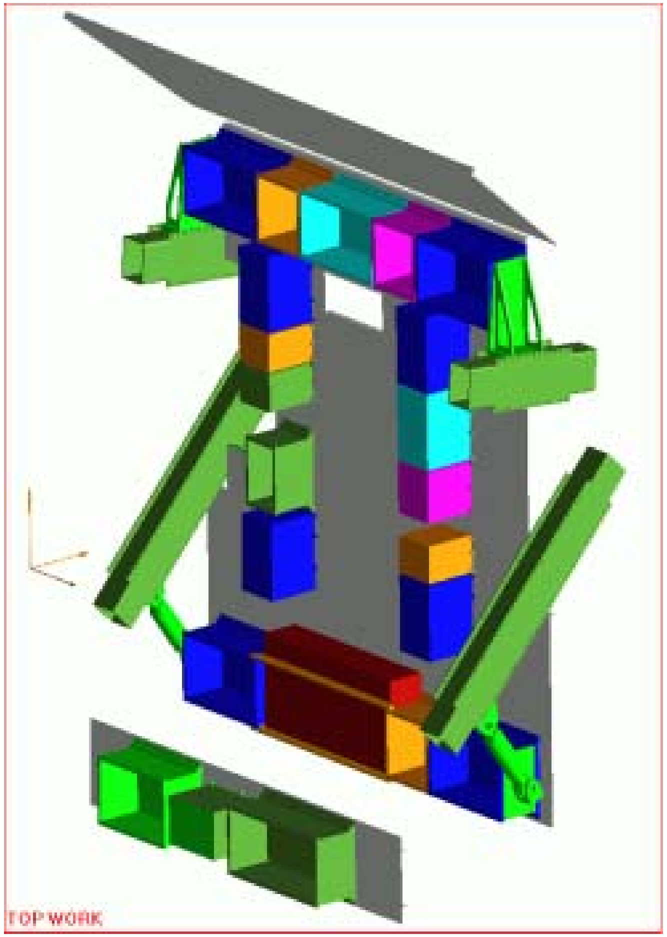
- **MLI blankets will cover +/-X crate sides and some other surfaces with view to VC.**



ELECTRONIC CRATES



RAM

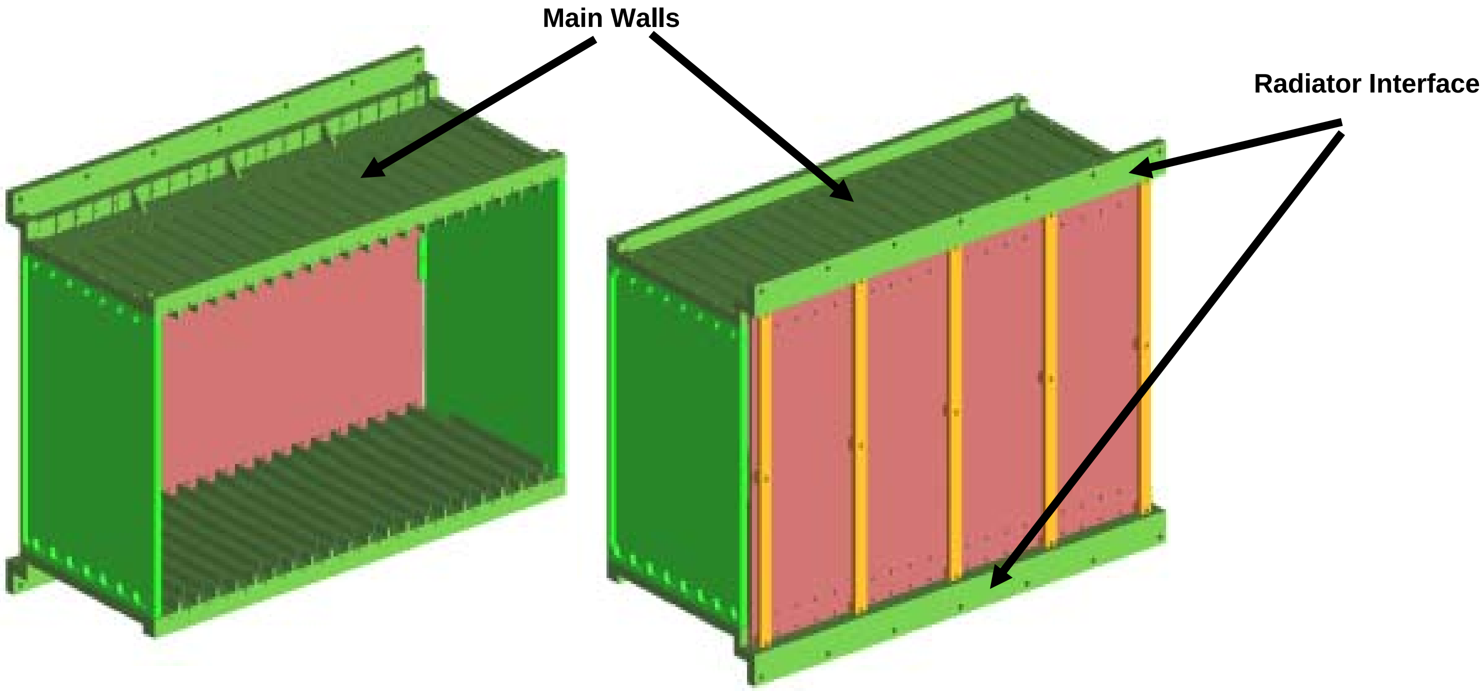


WAKE

□

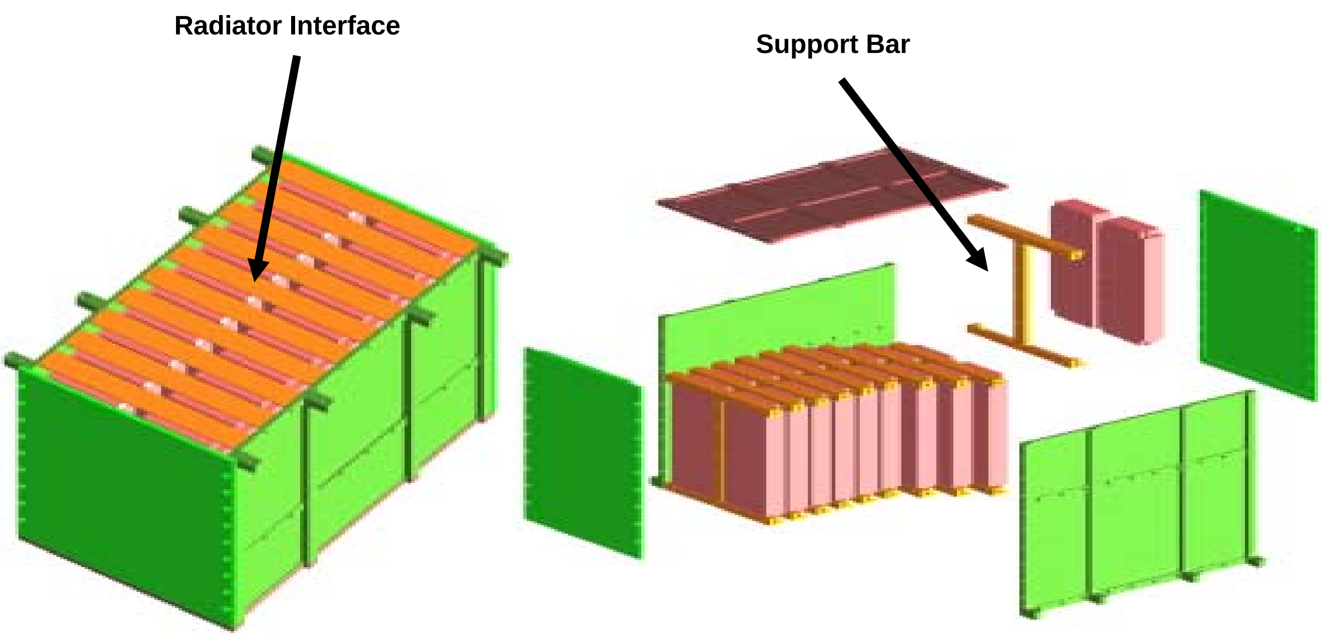
ELECTRONIC CRATES

- **Crates are designed to dissipate heat from main walls directly attached to radiators.**



XPD's (POWER DISTRIBUTION UNITS)

- **XPD's dissipate heat to radiators via "double T" shaped support bars.**



TRD

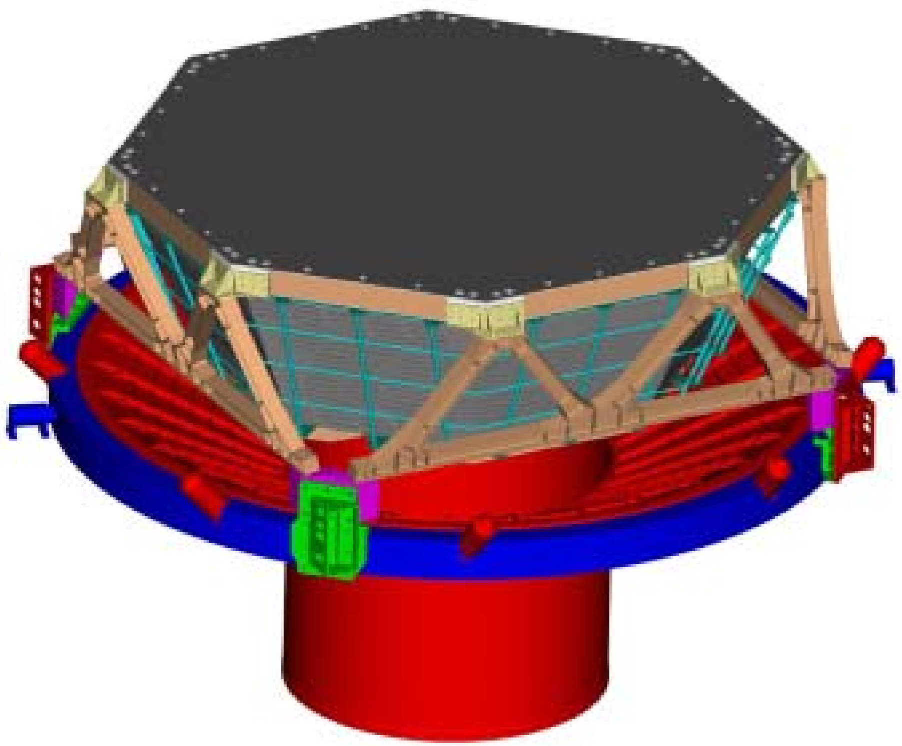
- **Minimal heat dissipation (20W on periphery)**
- **Strict thermal requirements:**

  -5°C to +25°C operating, -20°C to +40°C non-operating

  +/-1°C over an orbit

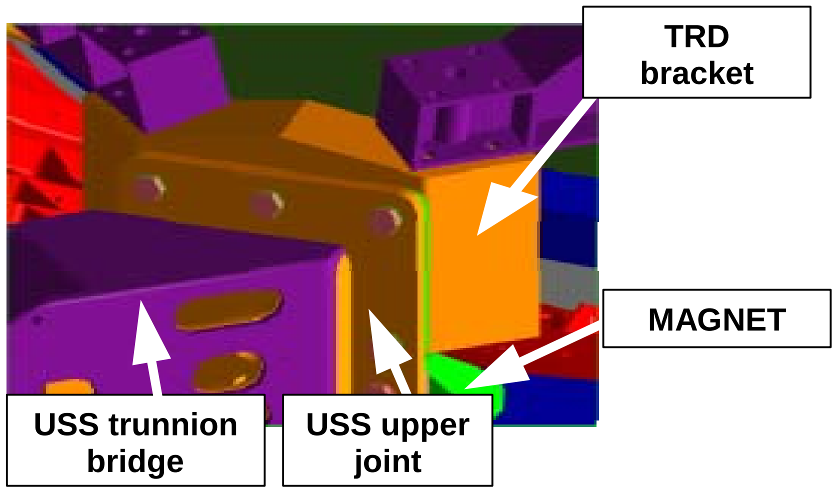
  +/-1°C top to bottom

  +/- 1°C on periphery



TRD

- Passive Thermal control achieved by radiation of TRD electronics on periphery and conduction to USS-02.
- TRD (along with upper TOF) enclosed in MLI.
- I/F to USS-02 is thermally isolated.



TRD Gas Supply

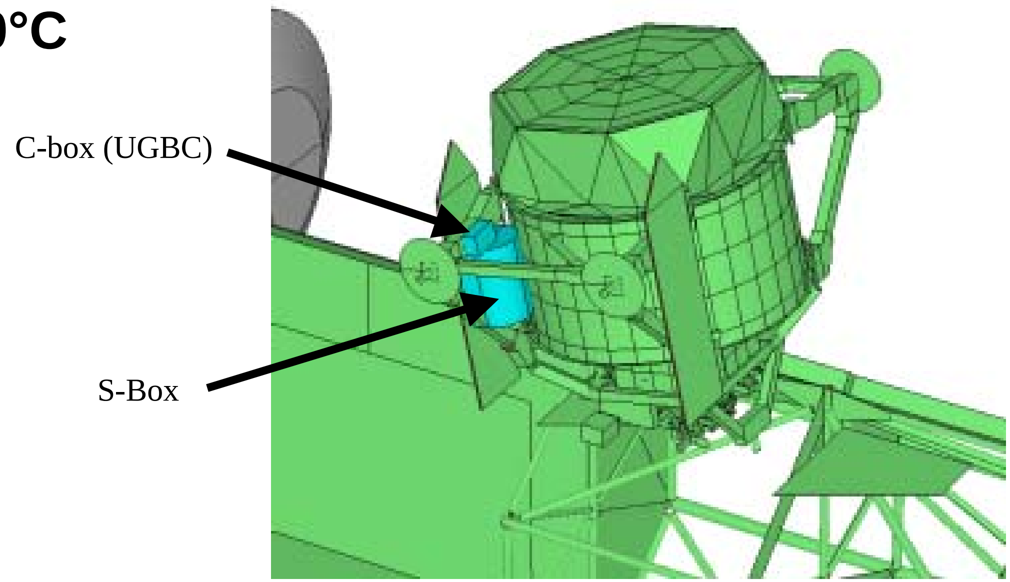
- **6 W dissipated in S-box and 4 W in C-box**
- **Component Limits include:**

  Valves: +5°C to +55°C

  CO2 tank: +5°C (+33°C for measurement) to +65°C

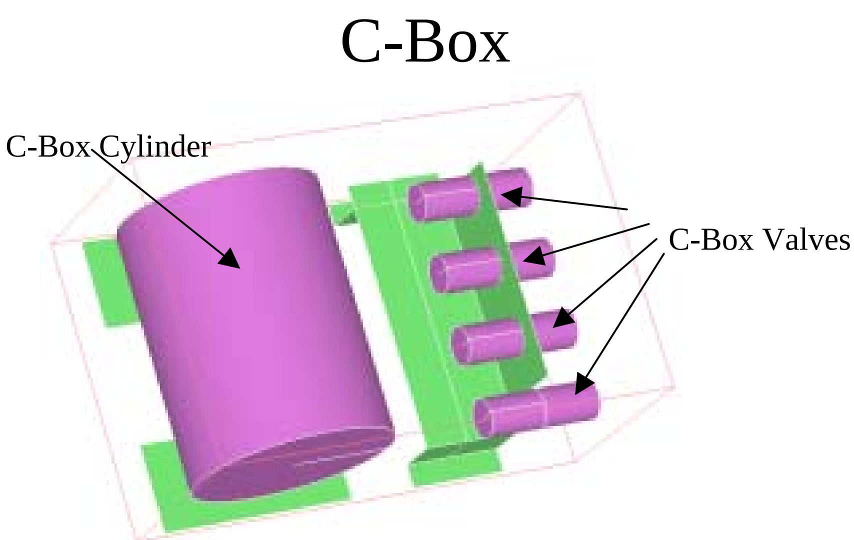
  Xe Tank: +5°C (+20°C for measurement) to +65°C

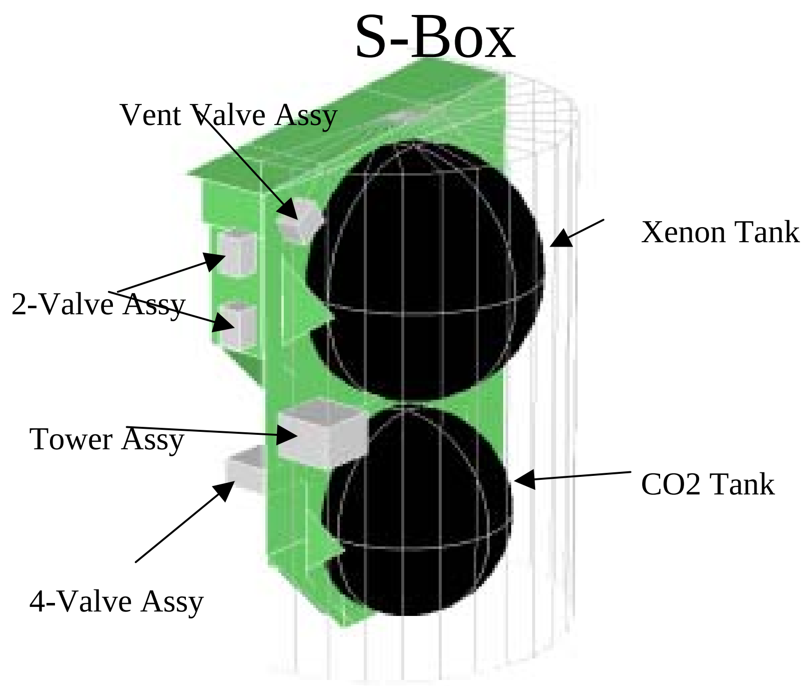
  Pump: 0°C to +40°C



TRD Gas Supply

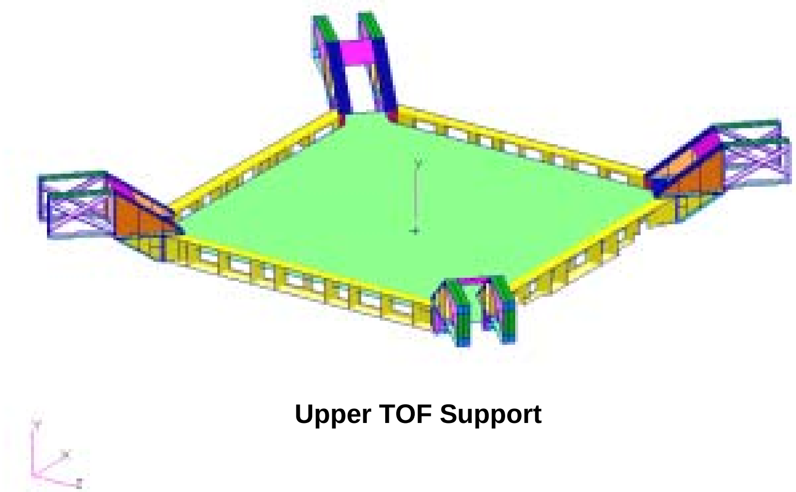
- MLI will enclose both "boxes"
- Dedicated heaters will maintain thermal limits
- Both boxes mounted to USS



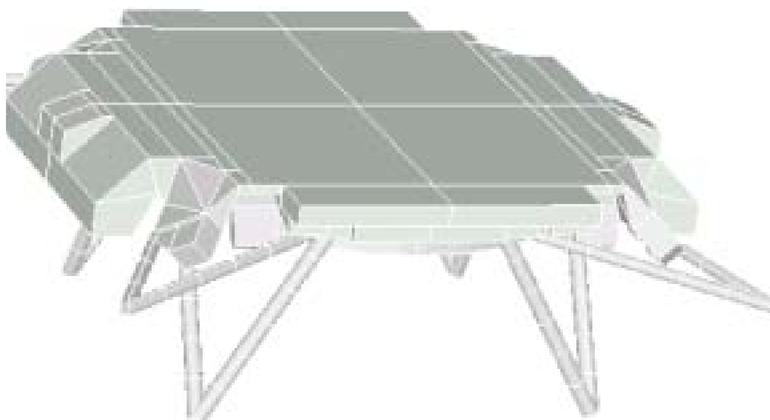


TOF

- Heat dissipation on PM's (3.2 W on Upper and 3.6 W Lower TOF)
- Limits: -20°C to +40°C Operating, -50°C to +50°C Non-Operating
- Upper TOF "lumped" with TRD
- Lower TOF PM boxes include radiators



Upper TOF Support



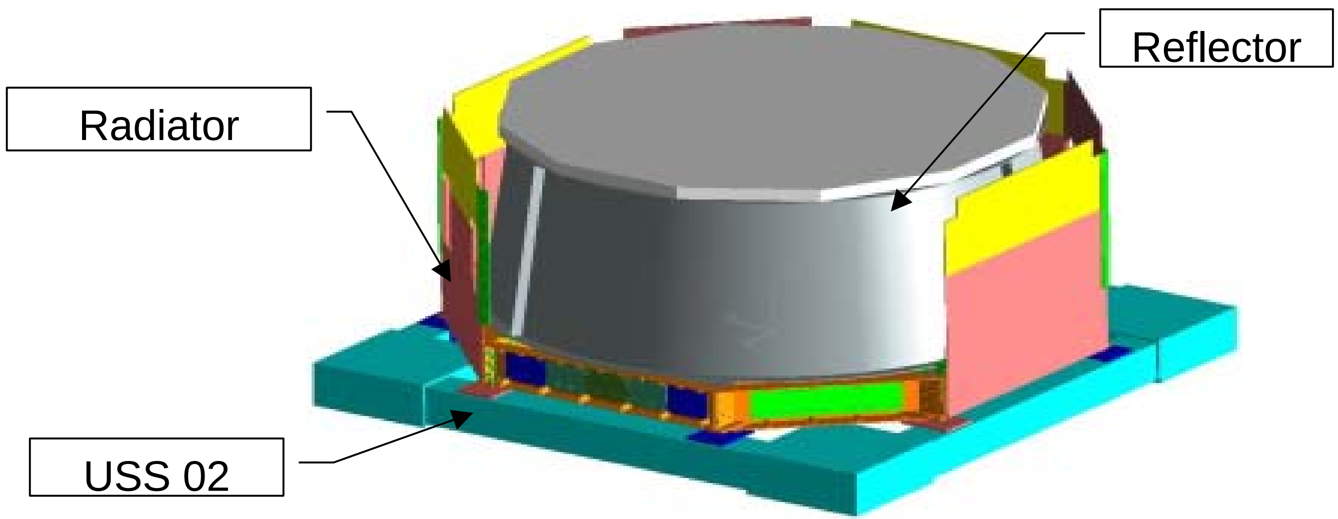
Lower TOF

Anti-Coincidence Counter (ACC)

- **Almost identical to what was flown on AMS-01**
- **Limits: -20°C to +40°C Operating and Non-Operating**
- **Small heat dissipation (~1 watt) in Photo Multiplier Tubes (PMT's) mounted on VC conical flange.**
- **ACC support shell coated with low e surface to minimize radiation from Tracker support shell.**

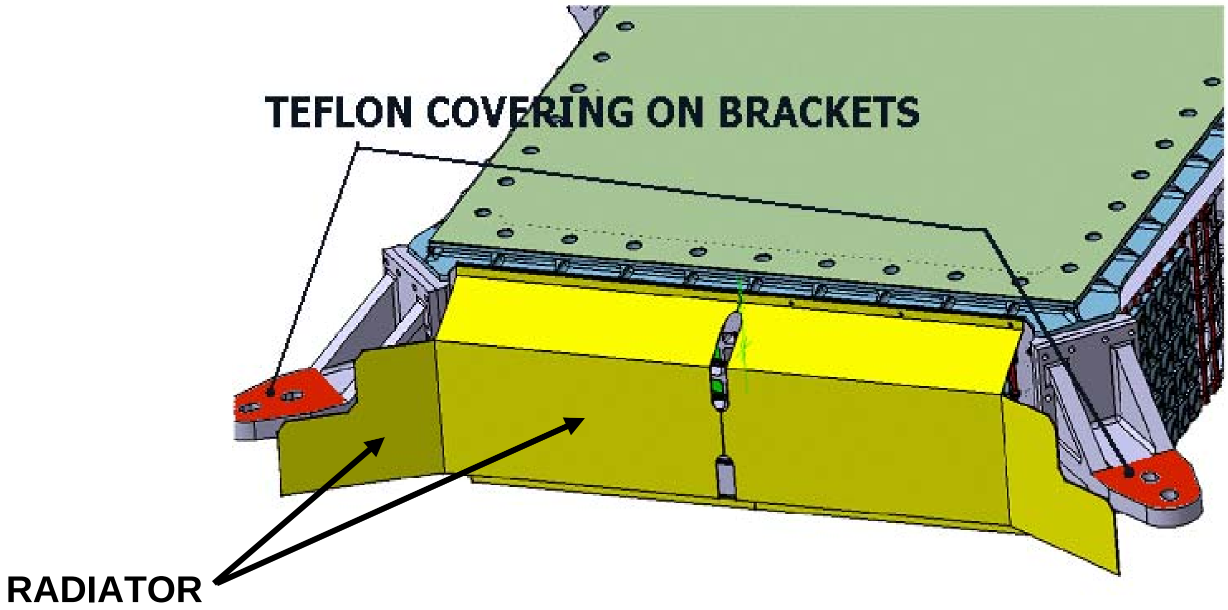
RICH

- Heat produced in 680 PMT's (17.7 W total) located at bottom of RICH. An additional 9.8 W is dissipated around octagonal structure. Heat is rejected by dedicated radiator along with some conduction to USS.
- Limits: -20°C to +40°C Operating, -40°C to +40°C Non-Operating
- RICH Reflector and backside of radiators will be covered with MLI blankets.



ECAL

- ECAL heat (46 W) is rejected via a combination of direct radiation via “winglet” radiators and side panels.
- Limits: -20°C to +40°C Operating, -40°C to +40°C Non-Operating
- Bottom (-Z) of ECAL will be covered with MLI.



TRACKER

See Tracker Thermal Control System Presentation

Thermal Control Hardware – MLI Blankets

- All MLI blankets will meet NASA requirements for venting and grounding
- Known MLI blankets include:
  - Vacuum Case (+/- Y quadrants, conical flanges, upper and lower skirts)
  - USS-02 VC joints and Upper Trunnion Bridges
  - Cryo-coolers
  - Radiator backsides (Tracker, RAM, WAKE, RICH/ECAL)
  - TRD sides and below Zenith radiator
  - RICH mirror and backside of RICH radiators
  - Between TOF and Tracker (upper and lower)
  - Between RICH and ECAL
  - ECAL bottom
  - TRD Gas System boxes C and S
  - UPS
  - CAB

Thermal Control Hardware - Heaters

- There will be various thermostatically controlled heaters on the AMS-02 payload.
- Most heaters will be disabled as experiment electronics are powered.
- In some cases both Main and Redundant heaters may be activated simultaneously
- Final heater sizes and set points still need to be confirmed.

Thermal Control Hardware – Heaters (continued)

- **A preliminary list of heaters include:**

Heaters line		Main [W]	Redundant [W]
	PDS	150	150
1	Ram Tracker Radiator	50	50
2	Ram main radiator	210	210
3	Ram Rich/Ecal crates radiator	30	30
4	Wake Tracker Radiator	50	50
5	Wake main radiator	250	250
6	Wake Rich/Ecal crates radiator	30	30
7	Cryocoolers	250	200
8	TRD Gas Box	50	14
8	Tracker Thermal Control System	100	100
	TOT	**1170**	**1084**

THERMAL ANALYSES

- AMS-02 Thermal model integrated with ISS Assembly Complete model
- Thermal analysis survey performed for 259 ISS attitudes (37 combinations of YPR for 7 different beta angles) to cover the ISS attitude envelope both with and without the orbiter docked.
- Additional detailed analyses performed for worst case attitudes
- Magnet charging/discharging analyses
- Active radiation surface assessment
- Specular surface assessment

PENDING THERMAL ANALYSES

- **Launch-to-activation (LTA) analysis of AMS-02 in payload bay**
- **Analysis of transfer from STS to ISS**
- **EVA touch temperature analyses (as required)**
- **"Failed On" heater analyses**
- **Auto-ignition assessment**
- **Stuck open vent door**
- **Evaluation of NASA Integration hardware (PVGF, BCS Camera, etc.)**

THERMAL RESULTS

- **Thermal models are still being refined.**
- **No thermal concerns for NASA hardware.**
- **VC On-Orbit Temperature Predictions:**

  Instantaneous (all surfaces): -55°C to +45°C (-67°F to +113°F)

  Orbit average (VC average): -27°C to +12°C (-17°F to +54°F)

- **USS On-Orbit Temperature Predictions:**

  All surfaces (except blankets): -64°C to +55°C (-84°F to +131°F)

  Capture bar: -18°C to +40°C (0°F to +104°F)

  VC Interface Joints: -34°C to +46°C (-30°F to +115°F)

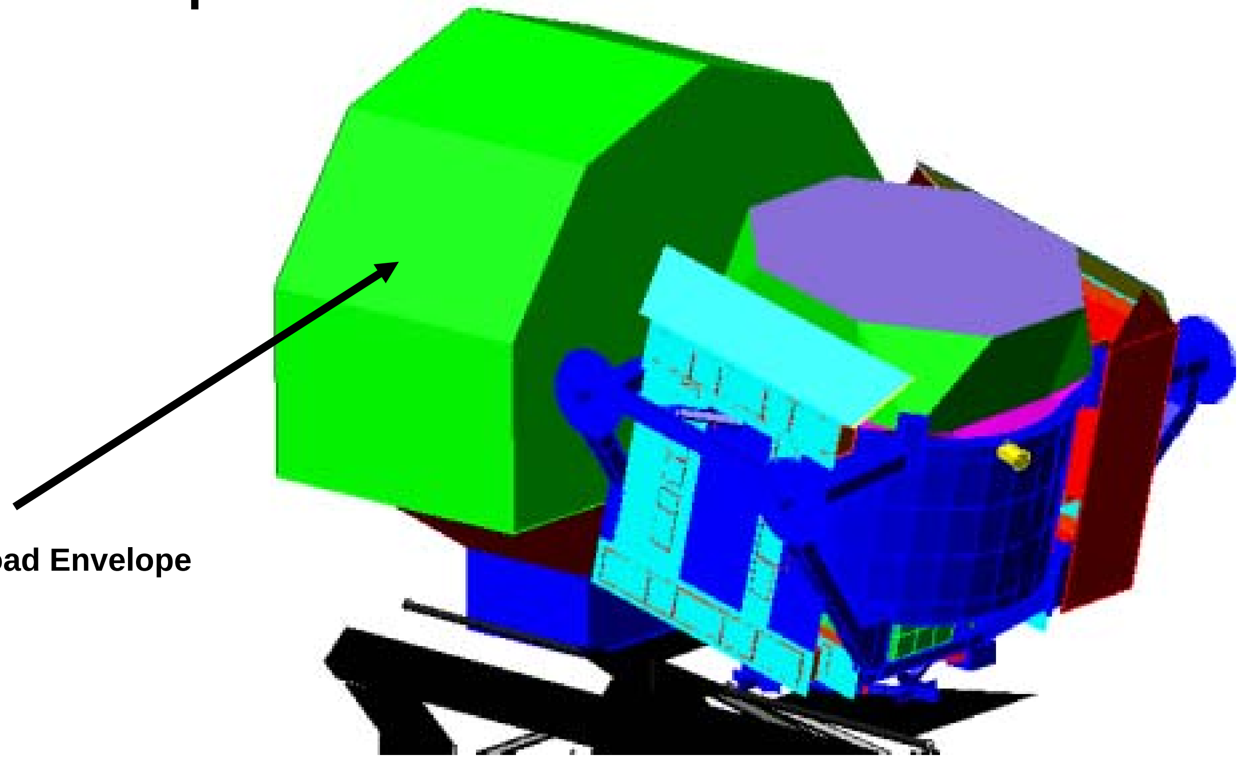
THERMAL RESULTS (continued)

- **Sub-detector temperature predictions are provided by CGS.**
- **Analyses show some temperature violations (mission success) at extreme ISS environments.**
- **Thermal design and analysis are still being optimized and there are no show stoppers identified.**

	Minimum	Maximum	Comment
	°C	°C	
Main Radiators	-40.5	+30	
Crates	-17.2	+51.8	
Tracker Radiators	-72.7	+8.5	Active Loop Set Point temperature = -5°C to +15°C
RICH	-14.5	+39.7	
ECAL	-10.3	+37.3	
RICH/ECAL Crate Radiators	-19	+51.1	radiator optical properties may be improved
RICH/ECAL Crates	-12.5	+60.5	interface conduction improvements being investigated
TRD	-6	+38.5	TRD may be switched off at extreme hot conditions
TRD Gas System	-15	+40.4	heaters will control low temperature extremes
Cryo-Cooler Radiator	-53.8	+11.8	heaters and bypass valves are under investigation
CAB	-15.3	+45.0	

Verification of Requirements

- **Active Radiation Surface Assessment to satisfy SSP 57003 section 3.4.1.1.6.A (view factor from radiators to attached payload envelope)**



Attached Payload Envelope

- **Sum of view factors (VF) from each AMS-02 radiator to Attached Payload Envelope (requirement is <0.1)**

Active surfaces	VF
Main radiator RAM	0.026
Main radiator WAKE	0.005
R&E Crate Radiator RAM	0.026
R&E Crate Radiator WAKE	0.014
Tracker radiator RAM	0.002
Tracker radiator WAKE	0.0001
Zenith Radiator	0.01
RICH radiators	0.107
ECAL radiators	0.029
CAB radiator	0.004

- **Specular Surface Identification (per ISS 57003 3.4.1.1.5 and 3.4.1.1.6.B)**

- **Actual specularity values are TBD.**

- **Waivers may be required due to views to adjacent Attached Payload Envelope (APE)**

Specular surfaces	Surface Material	Specularity	VF to APE
R&E Crate Radiator RAM	Silver Teflon (5 mil FEP)	TBD	0.026
R&E Crate Radiator WAKE	Silver Teflon (5 mil FEP)	TBD	0.014
ECAL radiators	Silver Teflon (5 mil FEP)	TBD	0.029
CAB radiator	Silver Teflon (5 mil FEP)	TBD	0.004
Vacuum Case (+/-X quadrants)	Silver Teflon (5 mil FEP)	TBD	0.372

COMPONENT/SUB-DETECTOR TESTING

- **Tests to date**
  - TTCS "bread board model" (thermal)
  - Thermal bars (T/V)
  - TRD Module (T/V)
  - TOF PMT's (T/V)
  - RICH PMT mounting (T/V)
  - ECAL PMT mounting (T/V)
  - ECAL "pancake" thermal properties characterization
  - Crate Qualification tests (T/V Cycling, Thermal Balance)
  - Cryo-coolers (peformance)
- **Planned tests**
  - Crate (acceptance T/V Cycling)
  - TOF (proto-flight T/V)
  - ECAL (proto-flight T/V)
  - RICH (proto-flight T/V)
  - TRD Gas System (T/V)
  - TRD Front End Electronics (T/V)
  - CAB (T/V)
  - TTCS pumps (T/V)
  - ACC PMT (T/V)
  - Cryo-cooler (T/V)
  - Warm He valves (T/V)
  - UPS (T/V)

INTEGRATED T/V TESTING

- Integrated Thermal-Vacuum test will be performed
  - AMS-02 operated at various thermal environments and power levels
  - First opportunity for some components to operate in vacuum
  - Functional checks performed before, during and after
  - Verify thermal interfaces
  - Verify performance of some thermal hardware