PHASE II FLIGHT SAFETY DATA PACKAGE FOR THE ALPHA MAGNETIC SPECTROMETER-02 (AMS-02)

Engineering Directorate

March 19, 2007 – Revision A

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

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PHASE II FLIGHT SAFETY DATA PACKAGE

FOR THE

ALPHA MAGNETIC SPECTROMETER-02 (AMS-02)

NASA/JSC APPROVAL

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

March 19, 2007

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FOR THE

ALPHA MAGNETIC SPECTROMETER-02 (AMS-02)

Delivery Order Number: C001-01-R2

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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March 19, 2007

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PAGE __1__ OF __1___

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TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

APPENDICES

ACRONYMS AND ABBREVIATIONS

α	Absorptivity
A	Amp or Amps
ACC	Anti-Coincidence Counters
AFD	Aft Flight Deck
AHP	Accumulator Heat Pipe
AI	Action Item
Al	Aluminum
AMICA	Astro Mapper for Instrument Check of Attitude
AMS	Alpha Magnetic Spectrometer
APCU	Assembly Power Converter Unit
APO	AMS Program Office
arc-sec	Arc-Second
ASTC	AMICA Star Tracker Camera
ASTS	AMICA Star Tracker Support
atm	atmosphere
AWG	American Wire Gauge
BCE	Battery Charger Electronics
BFS	Backup Flight System
BMS	Battery Management System
BOL	Beginning of Life
BD	Burst Disk or Bursting Disk

ACRONYMS AND ABBREVIATIONS

Bps	Bits per second
µCi	micro Currie
C	Celsius
CAB	Cryomagnet Avionics Box
CAN	Controller Area Network
CAS	Common Attach System
cc	Cubic Centimeter
CCD	Charged Coupling Device
CCEB	Cryocooler Electronics Box
CCR	Crew Consensus Report
CCS	Cryomagnet Current Source
CCSC	Cryomagnet Control and Signal Conditioning
CDC	Cool Down Circuit
CDD	Cryomagnet Dump Diode
CFRC	Carbon Fiber Reinforced Composite
CFRT	Carbon Fiber Reinforced Thermoplastic
CGS	Carlo Gavazzi Space
CGSE	Cryomagnet (or Cryogenic) Ground Support Equipment
CHX	Cold Heat Exchanger
CLA	Capture Latch Assembly
cm	Centimeter

ACRONYMS AND ABBREVIATIONS

CMG	Control Moment Gyro
CO_2	Carbon Dioxide
CPU	Central Processing Unit
CRES	Corrosion Resistant Steel
CRISA	Computadoras, Redes e Ingeniería SA
CSP	Cryomagnet Self Protection
CSR	Customer Support Room
CU	Copper
DC or dc	Direct Current
DDRS	Digital Data Recording System
DLCM	Direct Liquid Content Measurement Device
DOE	Department of Energy
DOL	Discrete Output Low
DV	Digital (on/off) Valve
ε	Emissivity
E	Energy
e^+	positron
e^-	electron
EA	Engineering Directorate

ACRONYMS AND ABBREVIATIONS

EBCS	External Berthing Camera System
ECAL	Electromagnetic Calorimeter
EHV	ECAL High Voltage
ELV	Expendable Launch Vehicle
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESCG	Engineering and Sciences Contract Group
ESMD	Exploration Systems Mission Directorate
EOL	End of Life
ETH	Eidgenossische Technische Hochschule
EVA	Extravehicular Activity
F	Fahrenheit
Fe^{55}	Iron 55
FoV	Field of View
FPGA	Field Programmable Gate Array
FRGF	Flight Releasable Grapple Fixture
γ	Gamma Ray
G	Gauss
GeV	Giga Electron Volts
GFE	Government Furnished Equipment
GFRP	Glass Fiber Reinforced Polymer

ACRONYMS AND ABBREVIATIONS

GN&C	Guidance, Navigation and Control
GND	Ground
GPC	General Purpose Computer
GPS	Global Positioning System
G_{rms}	Gravity Root Mean Square
GSE	Ground Support Equipment
GSFC	Goddard Spaceflight Center
HBE	Hans Bieri Engineering
$\overline{He}$	Anti-helium
HP	Heat Pipe
HR	Hazard Report
HRDL	High Rate Date Link
HV	High Voltage
Hz	Hertz
ICD	Interface Control Document
ID	Inside Diameter
I/F	Interface
IFM	In-flight Maintenance
IR	Infra-Red
ISS	International Space Station
ISSP	International Space Station Program

ACRONYMS AND ABBREVIATIONS

ITS	Integrated Truss Segment
JMDC	AMS-02 Main DAQ Computer
JS	Jacobs Sverdrup
JSC	Johnson Space Center
K	Kelvin
KeV	Kilo Electron Volts
kg	Kilograms
kN	Kilo Newton
KSC	Kennedy Space Center
kW	Kilowatt or Kilowatts
L	Liter (also l)
LBBX	Laser Beamport Box
LCC	Launch Commit Criteria
LCC	Launch Control Center
LCL	Latching Current Limiter
LCTL	Laser Control Box
LDDR	Laser Diode Driver
LED	Light Emitting Diode
LFCR	Laser Fiber Coupler
LHFP	Liquid Helium Fill Port

ACRONYMS AND ABBREVIATIONS

LHP	Loop Heat Pipe
LRDL	Low Rate Data Link
LTOF	Lower Time of Flight
µm	Micrometer
m	meter
mm	millimeter
MAGIK	Manipulator Analysis, Graphics and Integrated Kinematics
Mbps	Megabits per second
MCA	Multi-Channel Analyzer
MCC	Mission Control Center
MCC	Main Control Computer
MDC	Main Data Computer
MDP	Maximum Design Pressure
MDP	Maximum Dynamic Pressure
MET	Mission Elapsed Time
MHT	Main Helium Tank
MIT	Massachusetts Institute of Technology
MJ	Megajoule
MLI	Multi-layer Insulation
MMOD	Micro-Meteoroid and Orbital Debris
MOSFET	Metal-Oxide-Silicon Field Effect Transistor
MV	Manually-actuated Valve

ACRONYMS AND ABBREVIATIONS

NaF	Sodium Fluoride
NASA	National Aeronautics and Space Administration
NBL	Neutral Buoyancy Laboratory
NbTi	Niobium Titanium
NGLS	Next Generation Laptop System
NSTS	National Space Transportation System
OD	Outside Diameter
OFHC	Oxygen Free High Conductivity
OHP	Oscillating Heat Pipe
OIU	Orbiter Interface Unit
P	Photon
p^+	proton
p^-	anti-proton
P&I	Process and Instrumentation
PAS	Payload Attach System
PCS	Portable Computer System
PDA	Payload Disconnect Assembly
PDIP	Payload Data Interface Panel
PDS	Power Distribution System
PEDS	Passive Electrical Disconnect System

ACRONYMS AND ABBREVIATIONS

PEEK	Polyetheretherketone
PFR	Portable Foot Restraint
PFTE	Teflon™
PGSC	Payload and General Support Computer
PGT	Pistol Grip Tool
PIP	Payload Integration Plan
PLB	Payload Bay
PMMA	Polymethyl Methacrylate (Plexiglas™)
PMT	Photo Multiplier Tube
PO	Payload Organization
POCC	Payload Operations Control Center
PPS	Passive Phase Separator
PRLA	Payload Retention Latch Assembly
PSE	Payload Safety Engineer
psi	Pounds per Square Inch
psia	Pounds per Square Inch, Absolute
psid	Pounds per Square Inch, Differential
PSRP	Payload Safety Review Panel
PVGF	Power Video Grapple Fixture
ρ	Density
RHV	RICH High Voltage
RICH	Ring Imaging Cerenkov Counter

ACRONYMS AND ABBREVIATIONS

RITF	Receiving Inspection Test Facility
ROEU	Remotely Operated Electrical Umbilical
RPCM	Remote Power Control Module
RWTH	Rheinisch-Westfälischen Technischen Hochschule (University of Technology)
µsec	microsecond
S3	Starboard 3 (Truss Designation)
SCL	Space Cryomagnetics Limited
SCL	Super Cooling Loop
SDP	Safety Data Package
SFHe	Superfluid Helium (He^{II})
SHV	TOF/ACC High Voltage
SiO_2	Silicon Dioxide
Si_3N_4	Silicon Nitride
SM	Scientific Magnetics
SOC	State of Charge
SRMS	Shuttle Remote Manipulator System
SSP	Space Shuttle Program
SSP	Standard Switch Panel
SSPC	Solid State Power Controller
SSPF	Space Station Processing Facility
SSRMS	Space Station Remote Manipulator System

ACRONYMS AND ABBREVIATIONS

STA	Structural Test Article
STADCO	Standard Tool & Die Company
STD	Standard
STS	Space Transportation System
SVP	Structural Verification Plan
TAS	Tracker Alignment System
TBD	To Be Determined
TBR	To Be Resolved
TCS	Thermal Control System
Te	Tellurium
TeV	Tera Electron Volts
Ti	Titanium
Tm^2	Tesla-Meter Squared
TMP	Thermo-Mechanical Pump
TPG	Thermal Prolytic Graphite
TOF	Time Of Flight Counters
TRD	Transition Radiation Detector and associated Gas System
TTCB	Tracker Thermal Control Box
TTCE	Tracker Thermal Control Electronics
TTCS	Tracker Thermal Control System
UMA	Umbilical Mechanism Assembly

ACRONYMS AND ABBREVIATIONS

UPS	Uninterruptible Power Supply
USCM	Universal Slow Control Module
USS-02	Unique Support Structure-02
UTOF	Upper Time of Flight Counters
V	Volt or Volts
VC	Vacuum Case
VCL	Vapor Cooled Leads
VCS	Vapor Cooled Shields
VME	VERSAmodule Eurocard
W	Watt or Watts
WIF	Worksite Interface Fixture
WSA	Worksite Assessment
Xe	Xenon

APPLICABLE SAFETY DOCUMENTS

NSTS 1700.7B	Safety Policy and Requirements for Payloads Using the Space Transportation System
NSTS 1700.7B ISS Addendum	Safety Policy and Requirements for Payloads Using the International Space Station
NSTS/ISS 13830C	Payload Safety Review and Data Submittal Requirements for Payloads Using the Space Shuttle/International Space Station
NSTS/ISS 18798B	Interpretations of NSTS/ISS Payload Safety Requirements
JSC 26943	Guidelines for the Preparation of Payload Flight Safety Data Packages and Hazard Reports for Payloads Using the Space Shuttle

1. INTRODUCTION

This Phase II Flight Safety Data Package for the Alpha Magnetic Spectrometer-02 (AMS-02) is submitted in response to the safety requirements of NSTS 1700.7B, "Safety Policy and Requirements for Payloads Using the Space Transportation System", and NSTS 1700.7B, ISS Addendum, “Safety Policy and Requirements for Payloads Using the International Space Station. This safety package has been prepared in accordance with NSTS/ISS 13830C, "Payload Safety Review and Data Submittal Requirements for Payloads Using the Space Shuttle/International Space Station”. Also, JSC 26943, "Guidelines for the Preparation of Payload Flight Safety Data Packages and Hazard Reports for Payloads Using the Space Shuttle", was used as a guideline document.

2. SCOPE

This safety data package contains the safety analysis performed for the AMS-02 Payload flight hardware and the flight operations of the AMS-02 mission. The major subsystems of the AMS-02 included in this safety analysis are listed below. Each subsystem and the operational scenarios will be discussed in detail in Section 5 of this safety data package.

- Cryogenic Superconducting Magnet (Cryomagnet)
- Unique Support Structure – 02 (USS-02) with integral Vacuum Case (VC)
- Transition Radiation Detector and associated Gas System (TRD)
- Time-of-Flight (TOF) Scintillator Assemblies
- Silicon Tracker
- Tracker Alignment System (TAS)
- Anti-Coincidence Counters (ACC)
- Ring Imaging Cerenkov Counter (RICH)
- Electromagnetic Calorimeter (ECAL)
- Star Tracker
- Global Positioning System (GPS)

- Data and Interface Electronics
- Thermal Control System (TCS)
- Micrometeoroid and Orbital Debris (MMOD) Shields
- Payload Attach System (PAS) (Passive Half)
- Digital Data Recording System – 02 (DDRS-02)
- Space Shuttle Program (SSP) and ISS Program (ISSP) Provided Hardware
  - Flight Releasable Grapple Fixture (FRGF) SSP
  - Remotely Operated Electrical Umbilical (ROEU) SSP
  - Power Video Grapple Fixture (PVGF) ISSP
  - Umbilical Mechanism Assembly (UMA) (passive half) ISSP
  - External Berthing Camera System (EBCS) ISSP

The AMS-02 Payload also requires the use of the Shuttle Remote Manipulator System (SRMS) and the Space Station Remote Manipulator System (SSRMS) for removing the payload from the Orbiter Payload Bay and berthing it on the station. The payload requires an active PAS and an active UMA, which are ISS hardware and part of the Integrated Truss Segment (ITS). The safety analyses for the SSP and ISS provided hardware are not included in this data package. However, the safety of the use and interfaces of the SSP and ISS provided hardware with the AMS-02 Payload is a part of this AMS-02 safety data package.

3. PURPOSE

The purpose of this safety analysis is to identify potential flight hazards associated with the AMS-02 Payload design and operation; to evaluate their cause and impact on the Space Shuttle, Orbiter, ISS, and flight crews; to define methods for eliminating or controlling the hazards; to verify the elimination or control methods; and to document the status of the verification methods. This safety package is intended to provide the information necessary for a Phase II review of the AMS-02 Payload by the JSC Payload Safety Review Panel (PSRP).

4. AMS-02 PROJECT OVERVIEW

The AMS-02 experiment is a state-of-the-art particle physics detector being designed, constructed, tested and operated by an international team organized under United States Department of Energy (DOE) sponsorship. The AMS Experiment will use the unique environment of space to advance knowledge of the universe and potentially lead to a clearer understanding of the universe's origin. Specifically, the science objectives of the AMS are to search for antimatter (anti-helium and anti-carbon) in space, to search for dark matter (90% of the missing matter in the universe) and to study astrophysics (to understand Cosmic Ray propagation and confinement time in the Galaxy).

4.1 AMS-02 EXPERIMENT

The AMS-02 Experiment utilizes large cryogenic superfluid helium (SFHe @ 2° K) superconducting magnet (Cryomagnet or Cryomag) to produce a strong, uniform magnetic field (~ 0.8 Tesla) within the interior of the Cryomagnet. The experiment has planes of detectors above, in the center of, and below the Cryomagnet (Figures 4.1-1 and 4.1-2). Electrically charged particles will curve when they pass through the magnetic field. Due to the differences in electrical charge, particles made of matter will curve one way, and the same particles of antimatter will curve the opposite way. Due to the various interactions with the AMS-02 detectors, the unique particle signatures will be electronically recorded (Figure 4.1-3). Physicists will be able to study the trajectory of curvature and determine the charge of the particles from the direction of curvature. They will also be able to determine the mass of the particles from the amount of curvature. They will then be able to tell whether it was matter or antimatter.

An Implementing Arrangement (IA) between NASA and DOE signed in September 1995 established two flights for AMS: an Engineering Test on Shuttle (STS-91 – June 1998) and a 3-year Science Mission on ISS (Launch Ready September 2007 – Date under review). The flight of AMS-01 was a precursor flight of the detectors proposed for AMS-02. AMS-01 utilized a permanent magnet in place of the Cryomagnet. The purpose of the precursor flight was to verify operation of the AMS experiment, verify command and data communications, collect thermal data for the ISS flight, determine actual accelerations on some AMS internal instruments and establish experimental background data.

The AMS-02 will be transported to the International Space Station (ISS) in the cargo bay of the Space Shuttle (Figure 4.1-4 and 4.1.5) for installation on the external truss of the ISS (Figures 4.1-6 and 4.1-7). Once on-orbit the AMS-02 will to remain on the ISS for at least three operational years of data collection, and due to limited space shuttle flights, AMS-02 will not return to Earth and will remain on the ISS.

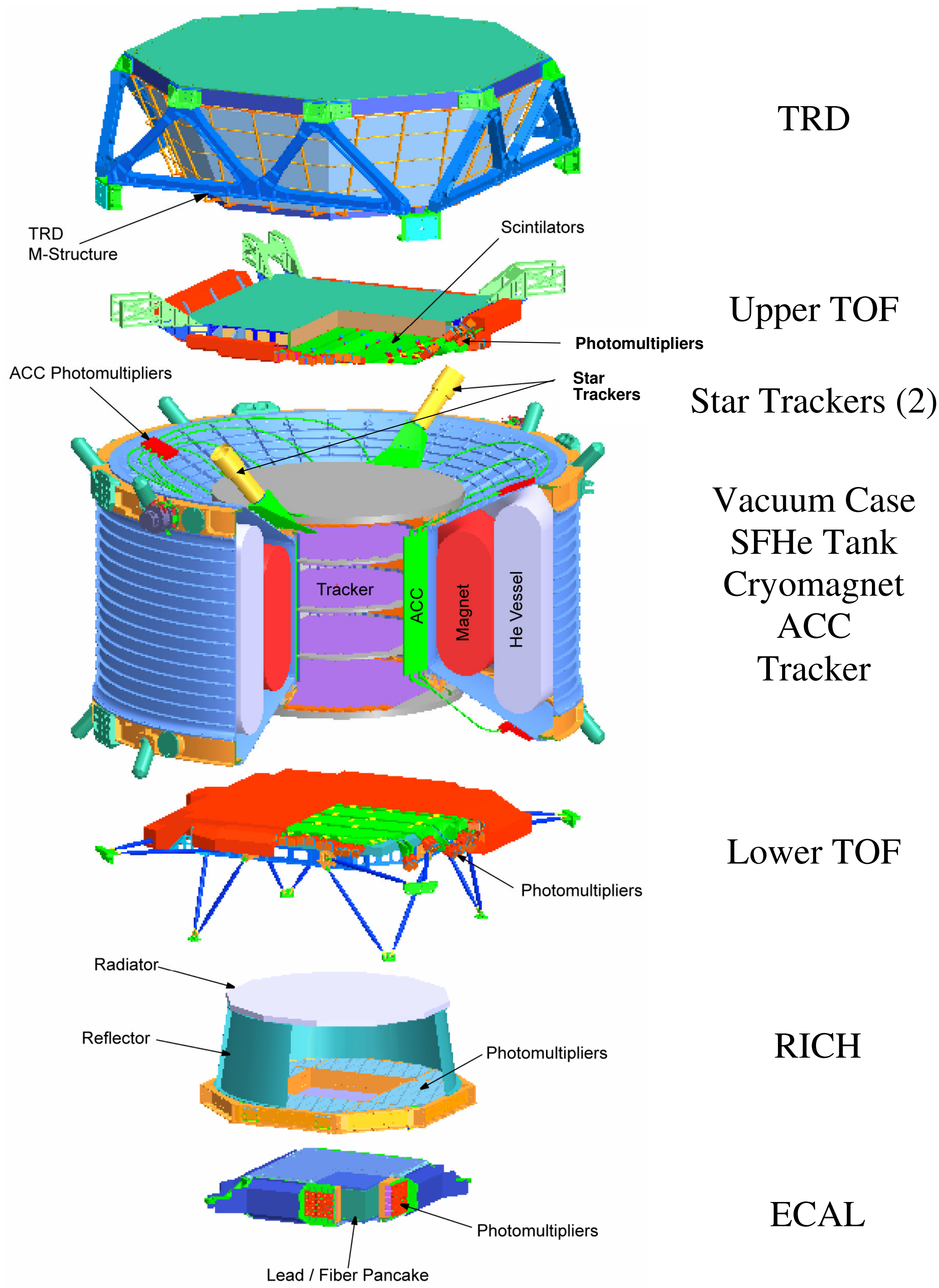


Figure 4.1-1 The AMS-02 Experiment

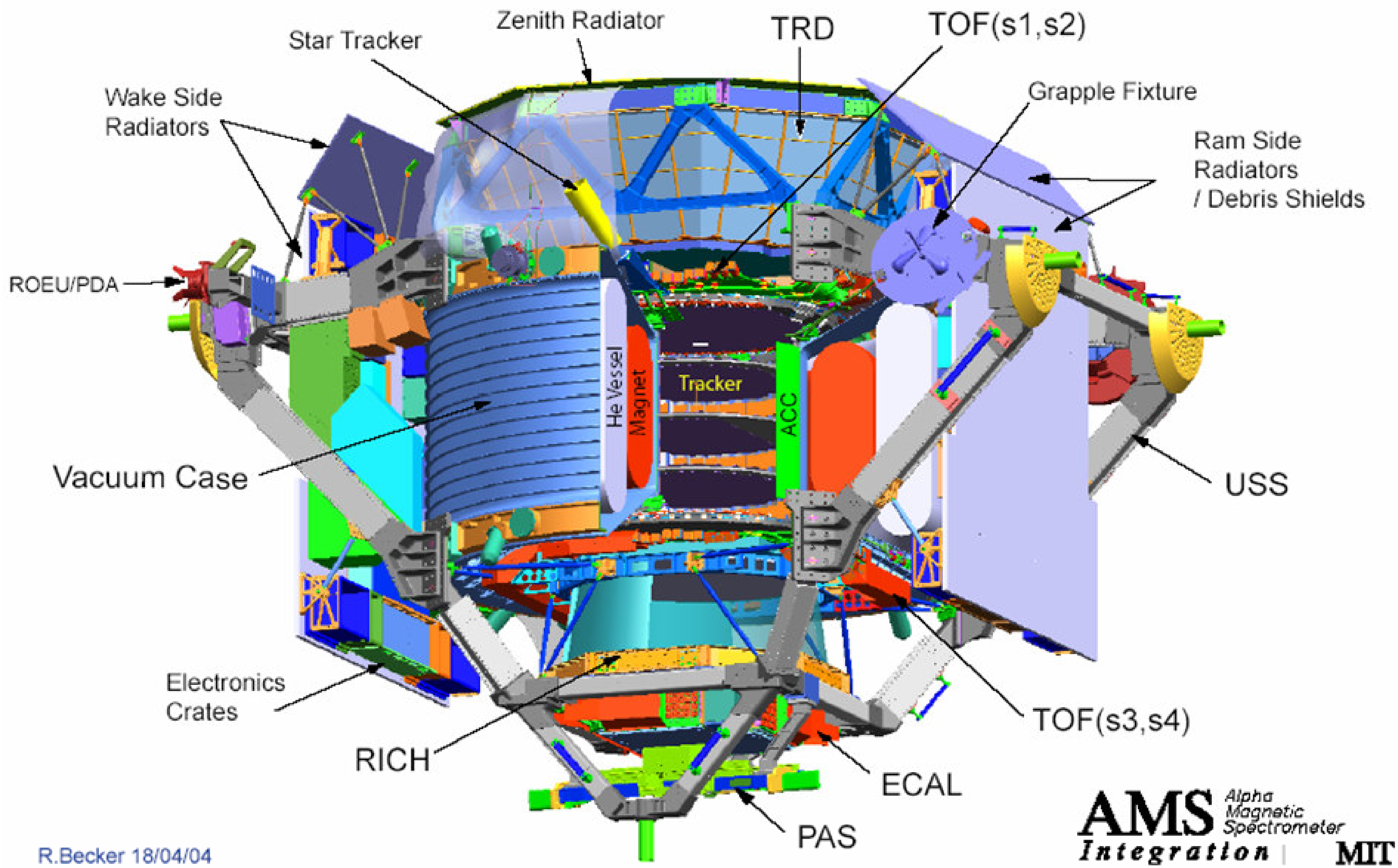


Figure 4.1-2 The AMS-02 Payload

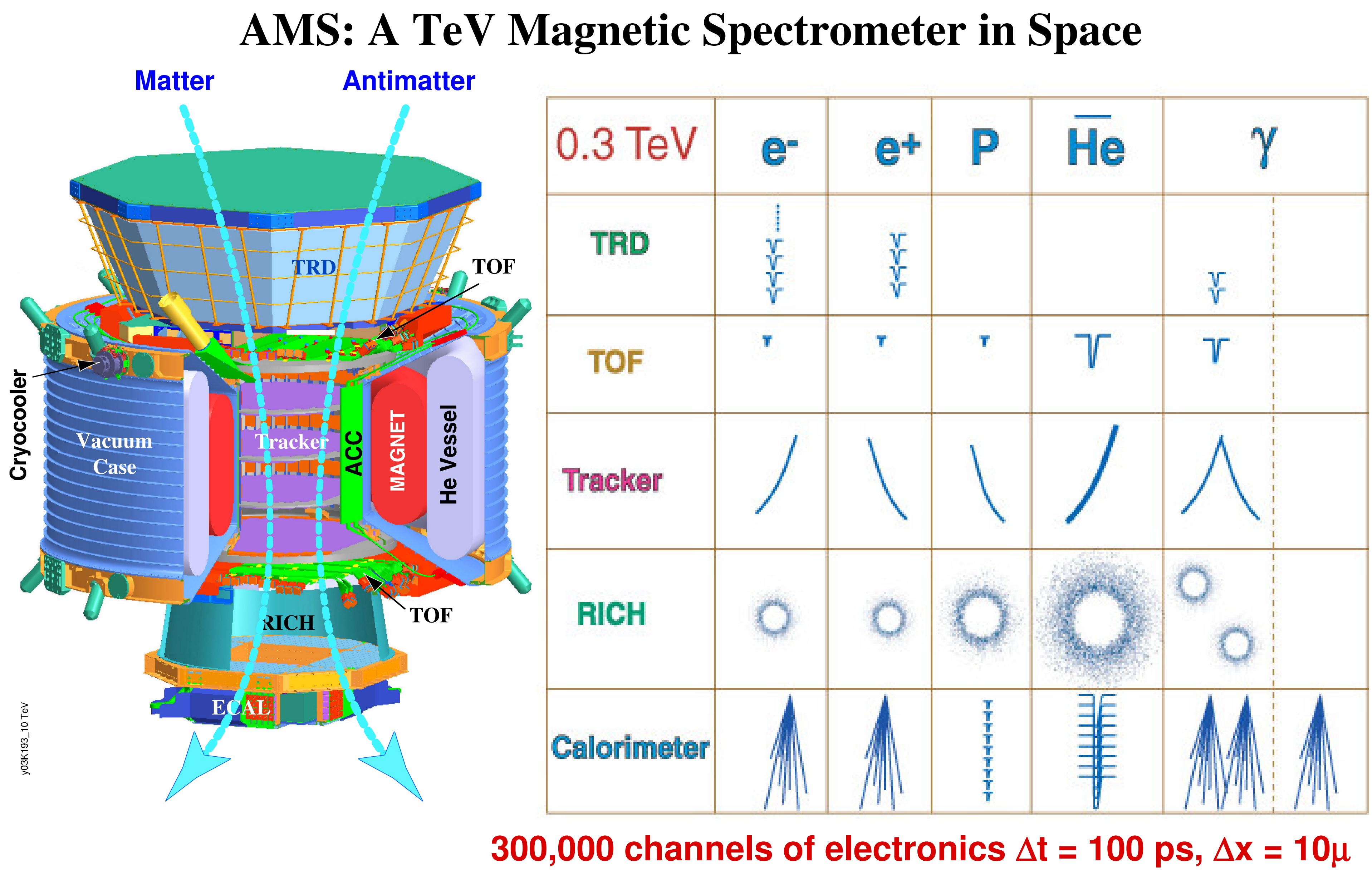


Figure 4.1-3 AMS-02 Detector Signatures

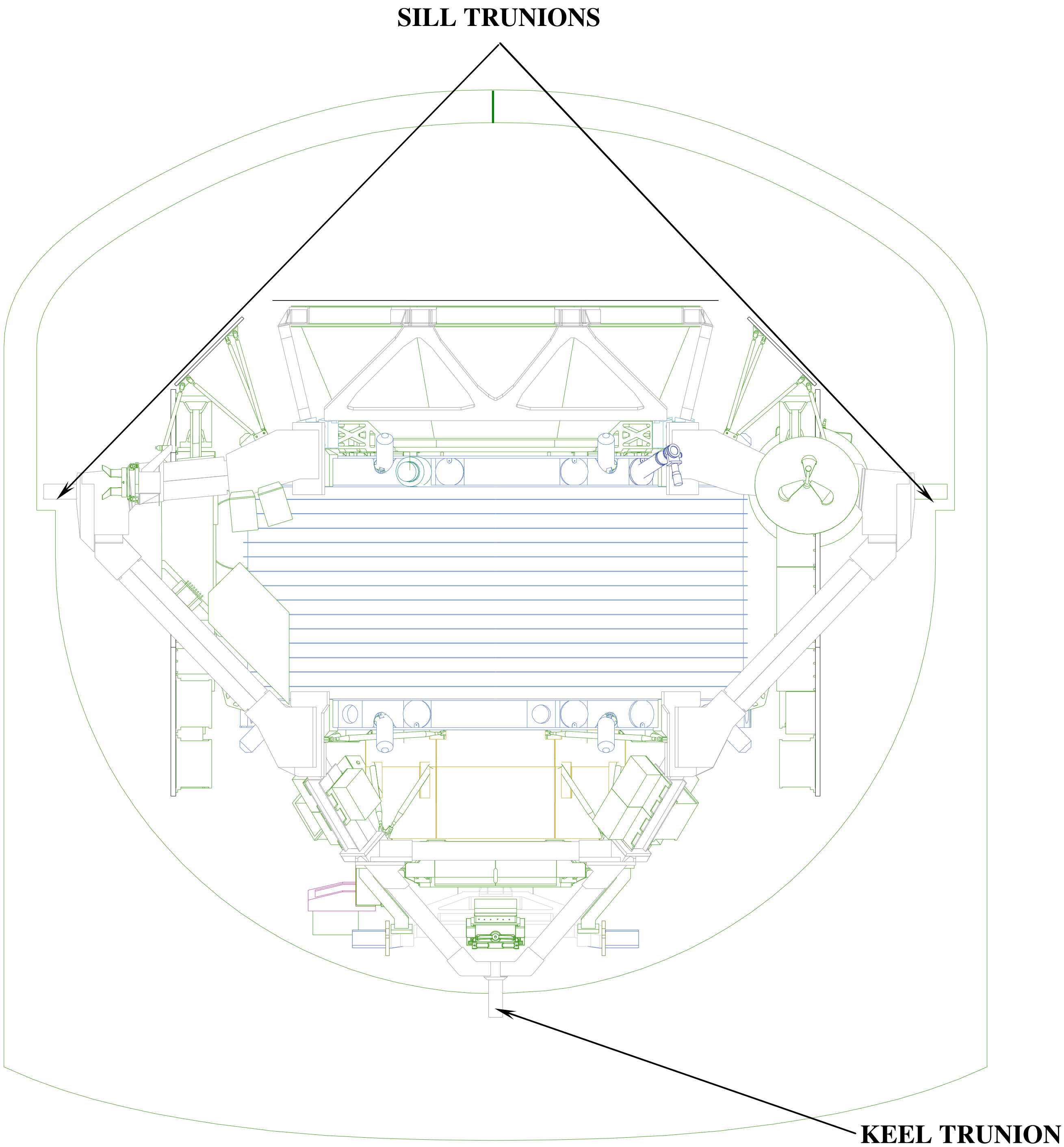


Figure 4.1-4 AMS-02 in the Space Shuttle Orbiter Cargo Bay

(From forward bulkhead looking aft.)

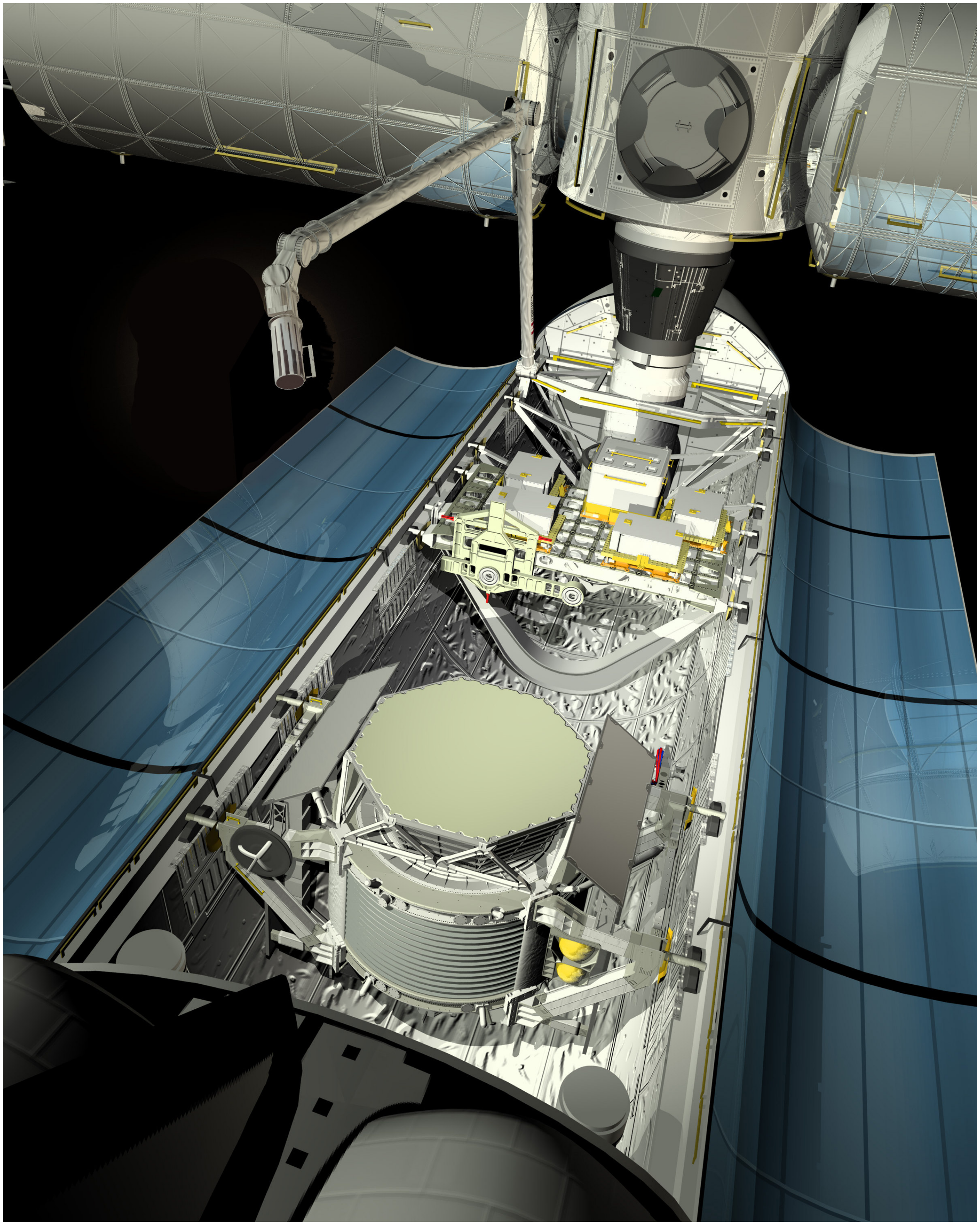


Figure 4.1-5 AMS-02 in the Space Shuttle Orbiter Cargo Bay
(From above looking forward.)

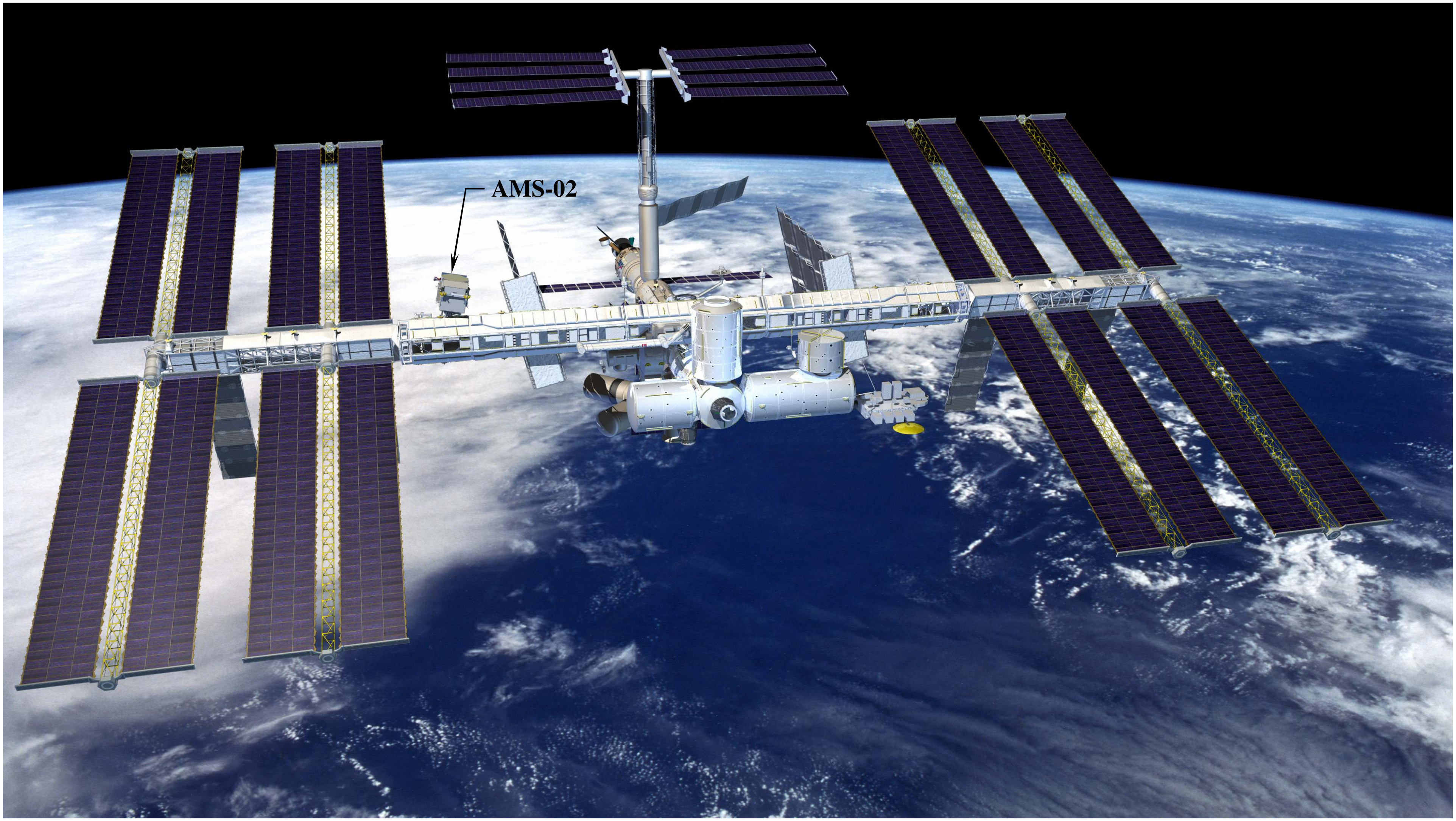


Figure 4.1-6 AMS-02 on the ISS

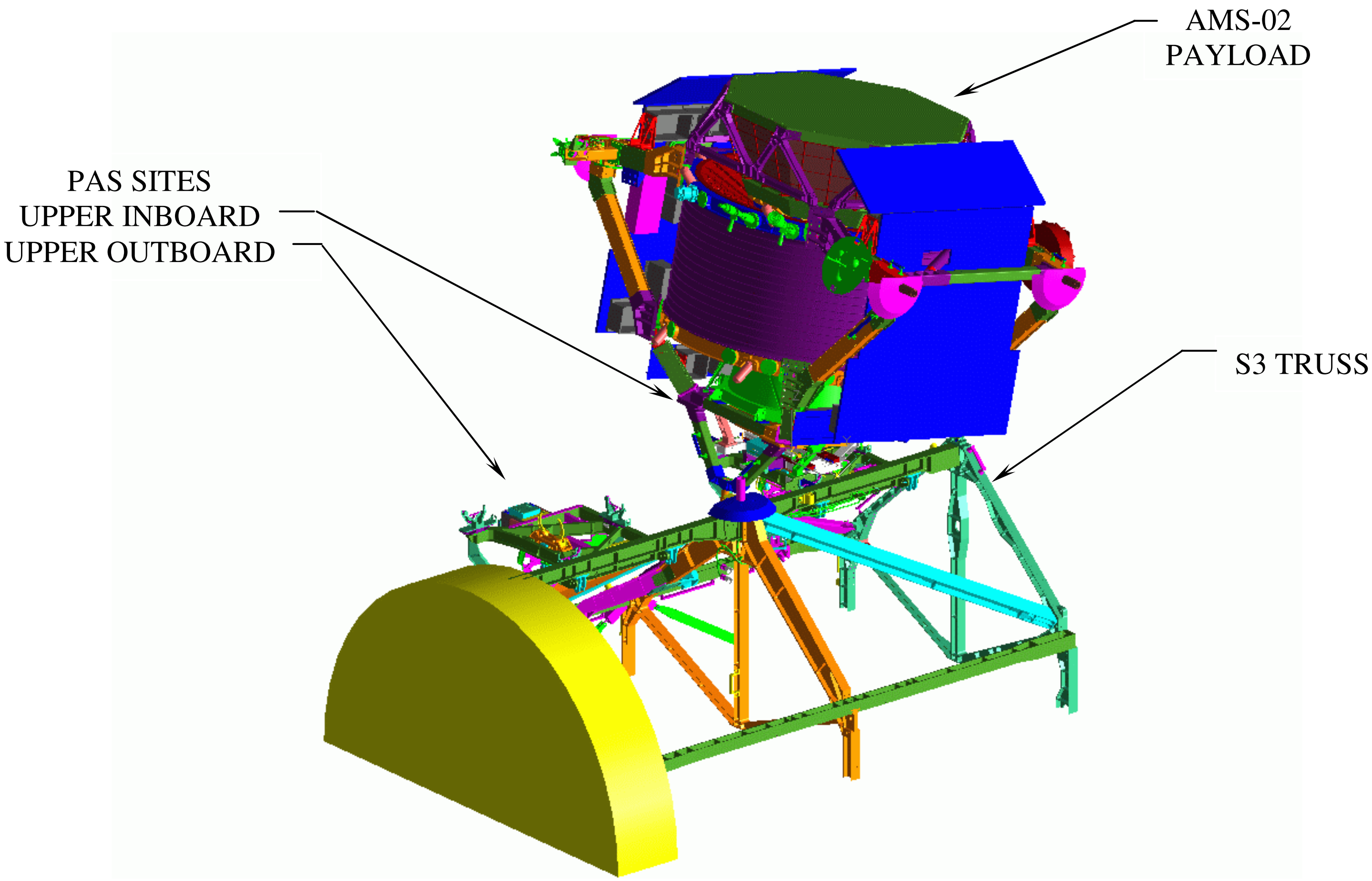


Figure 4.1-7 AMS-02 Payload Assembly on ISS S3 – Z Inboard PAS Site

4.2 AMS-02 ROLES AND RESPONSIBILITIES

The Implementing Arrangement between the Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA) establishes the roles and responsibilities of DOE and NASA with respect to the Alpha Magnetic Spectrometer (AMS) Program.

4.2.1 NASA Responsibilities

NASA Headquarters is responsible for the overall NASA management of the AMS Program interface activity between NASA and DOE and for overall program management of the NASA activities required to support the implementation of the flight of AMS-02 (Figure 4.2.1-1). The AMS Project Office (APO) of the Engineering Directorate (EA) at JSC has been assigned responsibility for implementing the AMS Program. The APO serves as the AMS representative and acts as the single point of contact between the AMS Program and the Shuttle and ISS Programs. The APO reports and is responsible directly to NASA Headquarters and is the AMS NASA representative to all other NASA organizations providing equipment, materials, and services to the AMS Program.

In order to implement the AMS Program, NASA will perform or provide the following:

- Fly the AMS-02 on the ISS as an external attached payload, and provide accommodation on the ISS; all necessary services, AMS-to-carrier integration, AMS transfer to and installation on the ISS. NASA shall include the AMS-02 in the Space Station utilization planning process.

- Provide mission-peculiar interface hardware and software for the AMS-02 on the ISS.

- Perform AMS-to-carrier integration support, payload certification, and payload safety certification.

- Provide necessary facilities and perform related services for the AMS-02 final assembly, testing and checkout at the launch site, as well as control center accommodations for AMS-02 operation and monitoring as required for the launch and transfer-to-ISS phases.

- Provide AMS-02 housekeeping, science (unprocessed) and carrier-ancillary data products to the DOE-sponsored team at the designated NASA data handling/distribution center.

- Perform a mission management function consisting of the following tasks in support of AMS:

    - Representation of the AMS to the Shuttle Program, the ISS Program, and to various supporting NASA organizations involved in the integration and flight of AMS.
    - Design and operations consulting and guidance to the AMS Program to minimize the potential for incorporation into the AMS design of features or characteristics which could result in functional and/or safety incompatibilities with either the Shuttle or the ISS or with ground systems at the launch or landing sites.
    - Performance of detailed engineering analyses (e.g. stress, loads, etc,) to ensure compatibility of the AMS with the Shuttle and ISS through its launch, operational, and return environments.
    - Systems engineering for the development of mission-peculiar interface hardware and software needed to analytically, physically, and operationally integrate the AMS into the Shuttle and ISS system.
    - Management of the physical integration of the AMS and mission-peculiar interface hardware onto the Shuttle and ISS carriers.
    - Guidance, identification and control of hazards, and lead role in development of Safety Compliance Documentation, and representation of AMS to the Shuttle, ISS, and KSC Safety Panels.
    - Guidance in the development of requirements levied on the Shuttle and ISS and lead role in negotiation of those requirements through the Shuttle Payload Integration Plan, (PIP), the ISS PIP, the associated annexes, and required Interface Control Documents (ICDs).
    - Provision of training related to Shuttle and Station operations, including the development of training requirements.
    - Provision of documentation required for payload verification of AMS compliance with Shuttle and ISS program requirements.
    - Representation of the AMS Program at KSC and support of testing, AMS-to-carrier integration, and flight operations.
    - Real-time mission support for the delivery flight to the ISS, through AMS deployment, installation, checkout, and verification of proper operation.

AMS Project Functional Organization Chart

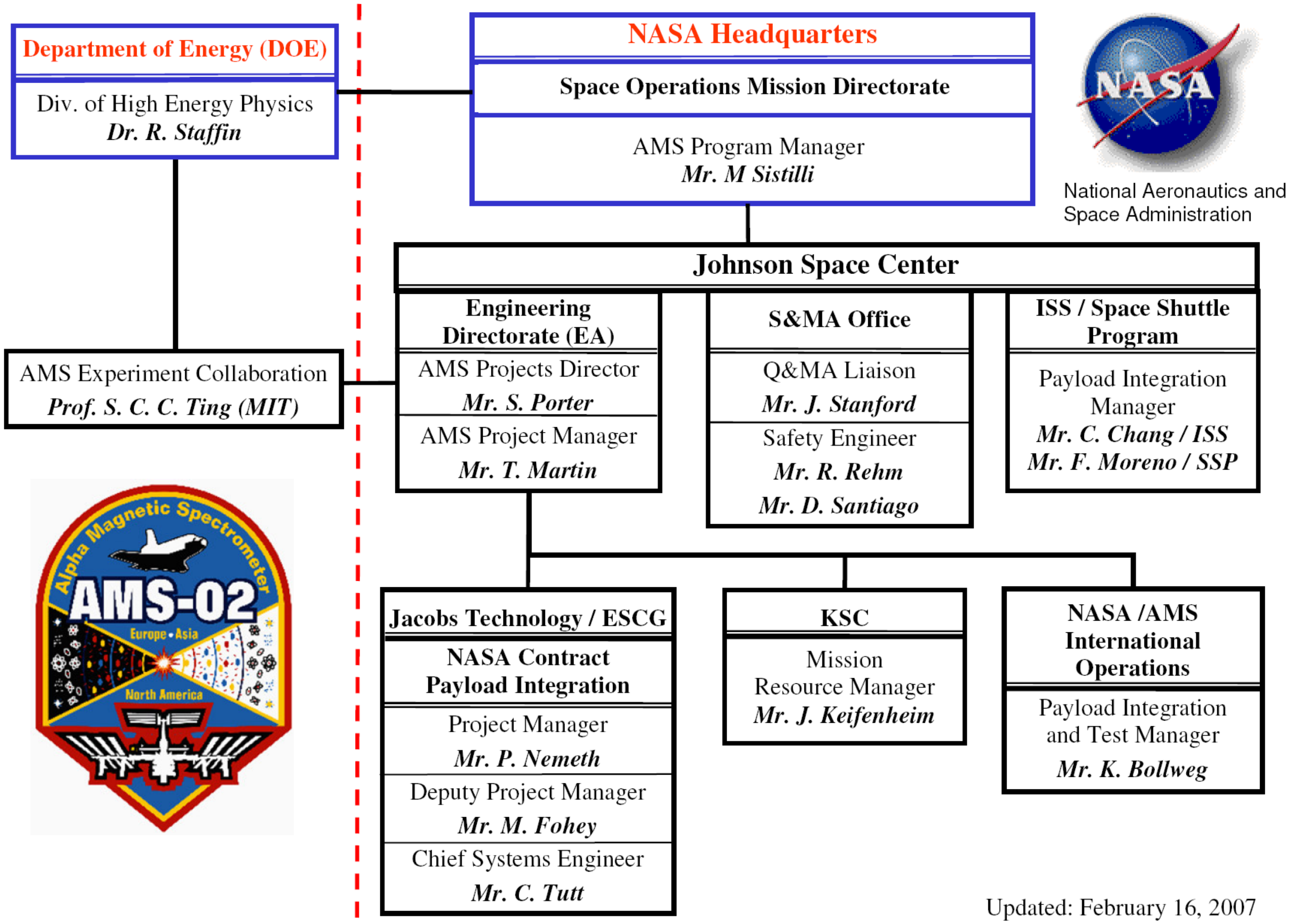


Figure 4.2.1-1 AMS Project Functional Organization

Flight hardware to be provided by NASA/APO is listed in Table 4.2.1-1.

TABLE 4.2.1-1 NASA/APO PROVIDED FLIGHT HARDWARE

ITEM	UNITS
* External Berthing Camera System (EBCS), w/cables and brackets	1
* EVA (Extravehicular Activity) Handrails/ Tether Attach Points	9 (requirements for two additional locations under review)
* Flight Releasable Grapple Fixture (FRGF), w/cables and brackets	1
* Portable Foot Restraint (PFR) Worksite Interface Fixture (WIF)	1 (2 if required by ROEU redesign)
* Power Video Grapple Fixture (PVGF), w/cables and brackets	1
* Remotely Operated Electrical Umbilical (ROEU)/Payload Disconnect Assembly (PDA), w/cables and brackets	1
* Umbilical Mechanism Assembly (UMA) (Passive Half), w/cables and brackets	1
Cryomagnet Vacuum Case (VC) (Flight Article)	1
Micrometeoroid and Orbital Debris (MMOD) Shields	As Required
Payload Attach System (PAS) (Passive Half)	1
EVA Interface Panel (Interface to UMA)	1
Interface Panel A (Interface to ROEU)	1
Cabling from interface panels to J-Crate and PDS	16
Cabling for T0 connections (PDIP)	1
DDRS–02 and associated cabling/interface cards	1
Trunnion scuff plates for deployable payload	4 (Part of USS-02)
Thermal Blankets	As Required
Unique Support Structure-02 (USS-02)	1

* Items (excluding brackets) supplied by NASA SSP or ISSP and integrated into AMS Payload by NASA/APO.

4.2.2 DOE Responsibilities

The DOE Headquarters Division of High Energy Physics, under the Department's Office of Energy Research is responsible for the administration of a Cooperative Agreement with the Massachusetts Institute of Technology (MIT) for a basic science program in particle physics. Under this agreement, the MIT Principle Investigator for the AMS Program has organized, and is the spokesman for, the AMS International Collaboration, currently consisting of over 500 physicists and engineers from 16 countries representing over 56 institutions, to implement its part in the AMS Project (Figure 4.2.2-1). The DOE or, as appropriate, its MIT Cooperative Agreement Principle Investigator, will be responsible for: the definition, design, and development of the AMS hardware and related ground support equipment (GSE); delivery to and return from a location to be specified at the Kennedy Space Center (KSC) for integration or de-integration in the NASA processing system; and establishment of the science mission requirements. These responsibilities will include:

- All necessary interagency coordination and obtaining necessary concurrences within the U.S. Government for the AMS Project regarding international arrangements among the DOE Program Collaborators involved in the definition, design, development, fabrication, assembly, test, checkout, and operation of the AMS.
- Management of all international transfer and shipment, unless otherwise agreed. This includes, but is not limited to, customs clearances, import and export licenses required for AMS systems, subsystems, or components, or, as mutually agreed, for any NASA tests, integration, or mission-peculiar equipment or technical data that is required to be shipped abroad.
- Establishment of the AMS science plan, including science requirements, definition of data requirements, and definition of mission success criteria.
- Provision, when requested by NASA, of DOE technical and management support for all formal NASA reviews involving AMS (Safety Reviews, Cargo Integration Reviews, Ground Operations Reviews, Flight Operations Reviews, etc.) and other related NASA reviews and activities.
- Development and management of an AMS implementation schedule consistent with NASA program milestone schedules and provision of updates to keep NASA advised of AMS schedule status.

- Provision of technical and management data required by NASA to complete programmatic requirements (e.g. Safety, ICDs, MIP, reviews, material lists, etc.).
- Provision of all transport equipment (shipping containers, other AMS handling ground support equipment) required for AMS transport to and from NASA KSC.
- Management of: (1) All AMS science and engineering team activities, including travel, visa issuances, and related in-country logistical expenses; (2) support for science operations before, during, and after AMS flights; and (3) science data analysis, distribution, and publication.

Flight hardware to be provided by DOE/MIT is listed in Table 4.2.2-1.

TABLE 4.2.2-1 DOE/MIT PROVIDED FLIGHT HARDWARE

ITEMS	UNITS
Cryomagnet System including SFHe Tank, Non-linear Support Straps, and Cryomagnet Avionics Box (CAB)	1
Transition Radiation Detector and associated Gas System (TRD)	1
TRD Gas System	1
Upper and Lower Time-Of-Flight (TOF) Scintillator Assembly	1 each
AMS-02 Silicon Tracker Assembly	1
Tracker Alignment System (TAS)	1
Anti-Coincidence Counters (ACC)	1
Ring Imaging Cerenkov Counter (RICH)	1
Electromagnetic Calorimeter (ECAL)	1
Thermal Control System (TCS) including Tracker TCS	1
Star Tracker	2
Global Positioning System (GPS) Receiver	1

5. AMS-02 FLIGHT HARDWARE DESCRIPTION

5.1 CRYOGENIC SUPERCONDUCTING MAGNET (CRYOMAGNET)

The Cryogenic Superconducting Magnet, or Cryomagnet, is at the heart of the AMS-02 experiment. Trajectories of incoming particles are bent by the magnetic field. The Silicon tracker detects this trajectory, which allows AMS-02 to identify the magnitude and sign of the particles' electrical charge. The Cryomagnet has a bending power of 0.86 Tm^2, which combined with the spatial resolution of the tracker allows measurements of particles extending into the multi-TeV energy range. The high field strength of the Cryomagnet is possible through the use of superconductors that are chilled by a superfluid helium Cryosystem serving as a heat sink operating at 4 K or below.

Most of the Cryomagnet and related special test equipment has been developed and manufactured by Eidgenossische Technische Hochschule (ETH) in Zurich through a sub-contract with Scientific Magnetics (SM) (registered trading name for Space Cryomagnetics, Limited (SCL)) in Culham, England and Hans Bieri Engineering (HBE) in Winterthur, Switzerland. The Cryomagnet and its Cryosystem are controlled through the Cryomagnet Avionics Box (CAB), which is being developed by Computadoras, Redes e Ingeniería SA (CRISA) in Madrid, Spain. The Vacuum Case (VC) was designed by Lockheed Martin and was built at the Standard Tool and Die Company (STADCO) in Los Angeles. The entire system is currently estimated to weigh 7050 lbs (3198 Kg).

5.1.1 Magnetic Coils

The Cryomagnet, shown in Figure 5.1.1-1, consists of 14 coils. The primary component of the field is created by the two large dipole coils. The twelve racetrack coils further shape the field, raising the strength within the bore of the Cryomagnet to 8600 Gauss (G) while minimizing the stray field external to the VC. The external field has a maximum value of 2000 G at the outer surface of the vacuum case and drops rapidly as distance increases away from the center of the AMS-02. Figure 5.1.1-2 shows the overall strength of the field at various radii from the geometric center of the Cryomagnet. The field in the primary measurement volume and the fringe field will be completely mapped as part of the Cryomagnet functional testing.

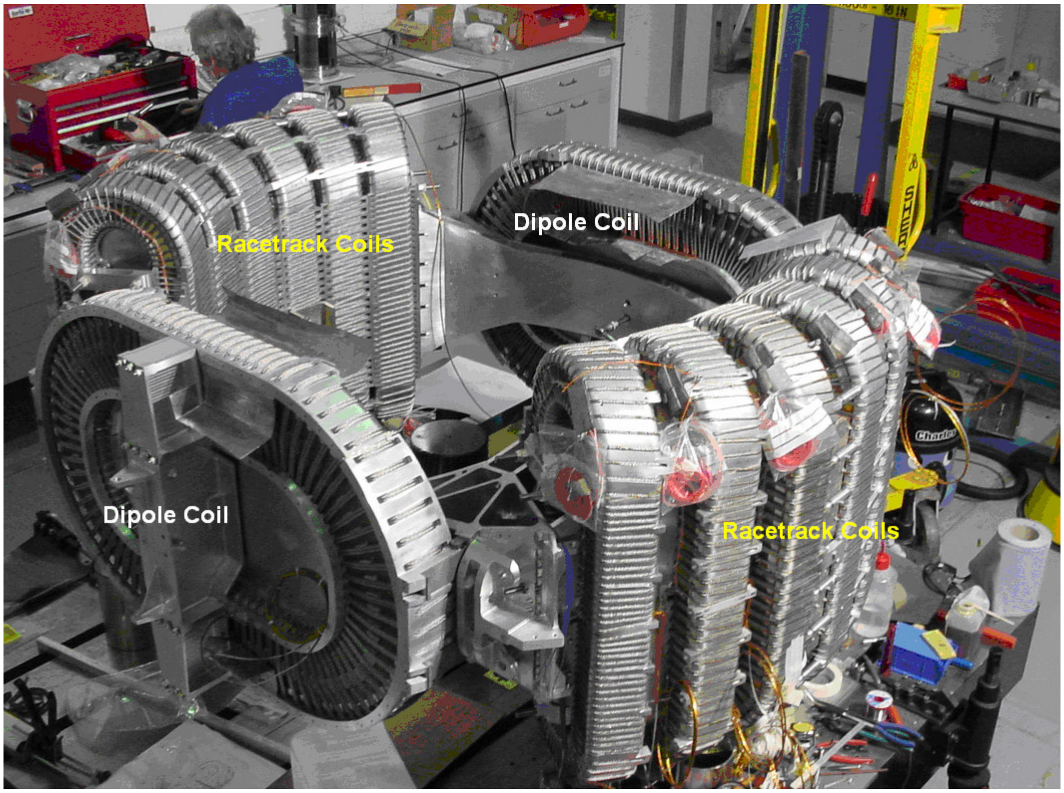


Figure 5.1.1-1 Cryomagnet Coils

Contoured surfaces defining the location of AMS-02 magnetic field threshold values of 35G, 10G, and 6G were provided to the MAGIK team for their use in assessing all nearby ISS hardware which could be susceptible to magnetic interference as well as robotic operations on that ORUs associated with the ISS hardware. This analytic model of the field will be correlated to the actual measurements taken of the flight Cryomagnet. In all cases, the AMS-02 magnetic field would not interfere with the proper operation of any equipment located within the field. MAGIK also assessed the field strength in all EVA translation paths along the S3 truss using the Mobile Transporter. Once again, the field was found to be within acceptable limits and would not present a hazard to astronauts. The final MAGIK assessment was a study of field strength in the EVA translation paths on the AMS-02 structure itself. In this case, field strengths were high enough to affect some equipment. To prevent any hazard to the crew, the Cryomagnet will be required to be discharged and powered off during all EVA operations on the AMS-02 itself.

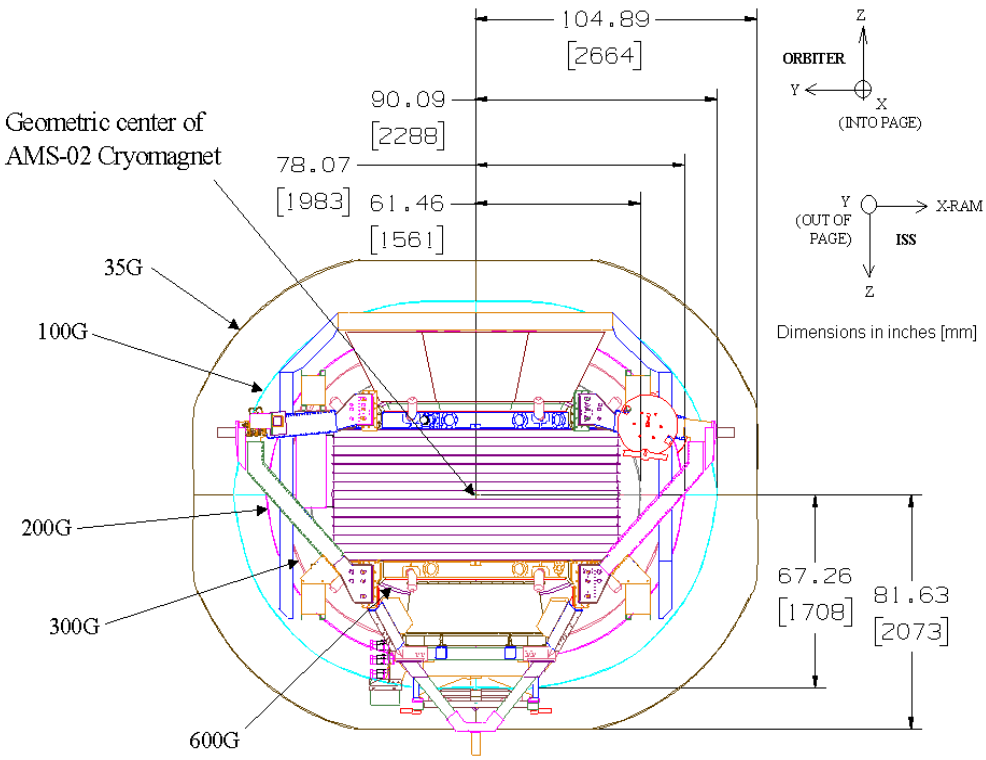


Figure 5.1.1-2 External Magnetic Field

The overall magnetic field will interact with the Earth's magnetic field and create a constant torque input to the station. The ISS Guidance, Navigation and Control (GN&C) Team provided maximum magnetic dipole moment levels which would ensure that this torque would not be beyond the ISS ability to control. Analysis has shown that the field generated by AMS-02 is five times less than the CMG limit provided to AMS-02 to meet. The magnetic field mapping of the flight Cryomagnet mentioned above will verify this prediction.

Figure 5.1.1-3 shows a cross section of the wire used in the coils. This wire was originally developed at ETH for the AMS-02 and has quickly become the standard for particle physics detector magnets. The superconducting element is NbTi filaments embedded in a 0.76 mm diameter copper matrix. This is then encased in a 2.0 mm x 1.5 mm square sheath of high-purity Al. The wire will be superconducting if the overall temperature is kept below 4 K. To generate the required field of 8600 G, the AMS-02 Cryomagnet will run with a nominal current of 459.5 A.

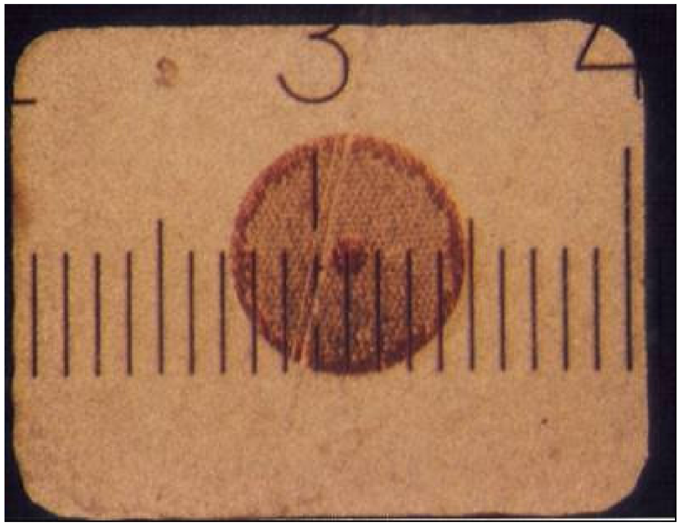


Figure 5.1.1-3 Superconducting Wire Cross Section

If the local temperature of a given section of wire rises above 4K or sees excessive strains, that section will no longer superconduct and will develop a finite resistance. This loss of superconductivity is known as a "quench." The energy stored in the Cryomagnet would immediately begin dissipating as heat in the resistive area. At nominal operating current, the AMS-02 contains 5.15 MJ of magnetic energy. NbTi is a poor thermal conductor, so uncontrolled dissipation of this energy would cause a massive temperature spike at the location of the quench and quickly burn through the wire, rendering the Cryomagnet useless. This is the reason for the thermally conductive Al layer in the AMS-02 wire. This sheath quickly conducts heat away from the site of the quench and spreads the energy over the entire coil. Use of this type of wire in many large-scale research magnets has demonstrated that peak temperatures seen during quenches are not hazardous to the magnets.

While this construction is sufficient to prevent all safety hazards, dissipation of 5.15 MJ even throughout an entire coil could generate enough thermal stresses to deform it and adversely affect future performance of that coil. To prevent this, AMS-02 has a quench detection system which is constantly monitoring the magnetic field. If a quench is detected in one coil, the system uses a series of heaters attached to each coil to force a controlled quench in all the others. This ensures that the energy is dissipated evenly throughout the Cryomagnet and no single coil sees a major heat load and associated thermal stresses. This system will undergo multiple functional tests on the ground to verify that it can detect a quench and shut down the entire system evenly. (The avionics and control system associated with this Cryomagnet self-protection system are discussed in more detail in Section 5.12, AMS Electronics.)

A second potential issue associated with quenching occurs in systems with multiple coils. A quench in a single coil and the collapse of its associated magnetic field will generate increased currents and field in any coil coupled to it through mutual inductance. This additional magnetic load can overstress the other coil. Additionally, the shifting shape of the overall magnetic field could expand the 35G envelope mentioned above to envelop susceptible ISS hardware. The quench detection system is designed to detect the onset of quench rapidly enough to shut all the coils down simultaneously. However, even if this system fails to function, AMS-02 avoids this effect by having all the coils linked in series. Loss of current in one coil will thus lead to an identical loss of current in the other coils and the magnetic field will ramp down evenly.

5.1.2 Structural Support

Each coil is wrapped around a structural support made of Al 6061, which keeps the coil in its elliptical shape. The large racetrack end frames seen in Figure 5.1.1-1, also made of Al 6061, hold the coils in their proper relative positions and resists the magnetic forces generated when the Cryomagnet is active. These magnetic forces are on the order of 250 tons and are much larger than any other loads the Cryomagnet will see during either flight or ground operations. Since the Cryomagnet will be activated on the ground multiple times for functional testing, the flight unit will have been shown by demonstration to survive the maximum expected load conditions without deformation or damage.

The Cryomagnet is attached to the Vacuum Case (VC) by sixteen support straps as shown in Figure 5.1.2-1. Each strap attaches to one of the VC support rings and a clevis at the corner of the racetrack end fittings. The design prevents the high magnetic operational loads from being transmitted back to the rest of the structure and the thermal loads of the rest of the structure from being transmitted to the coils.

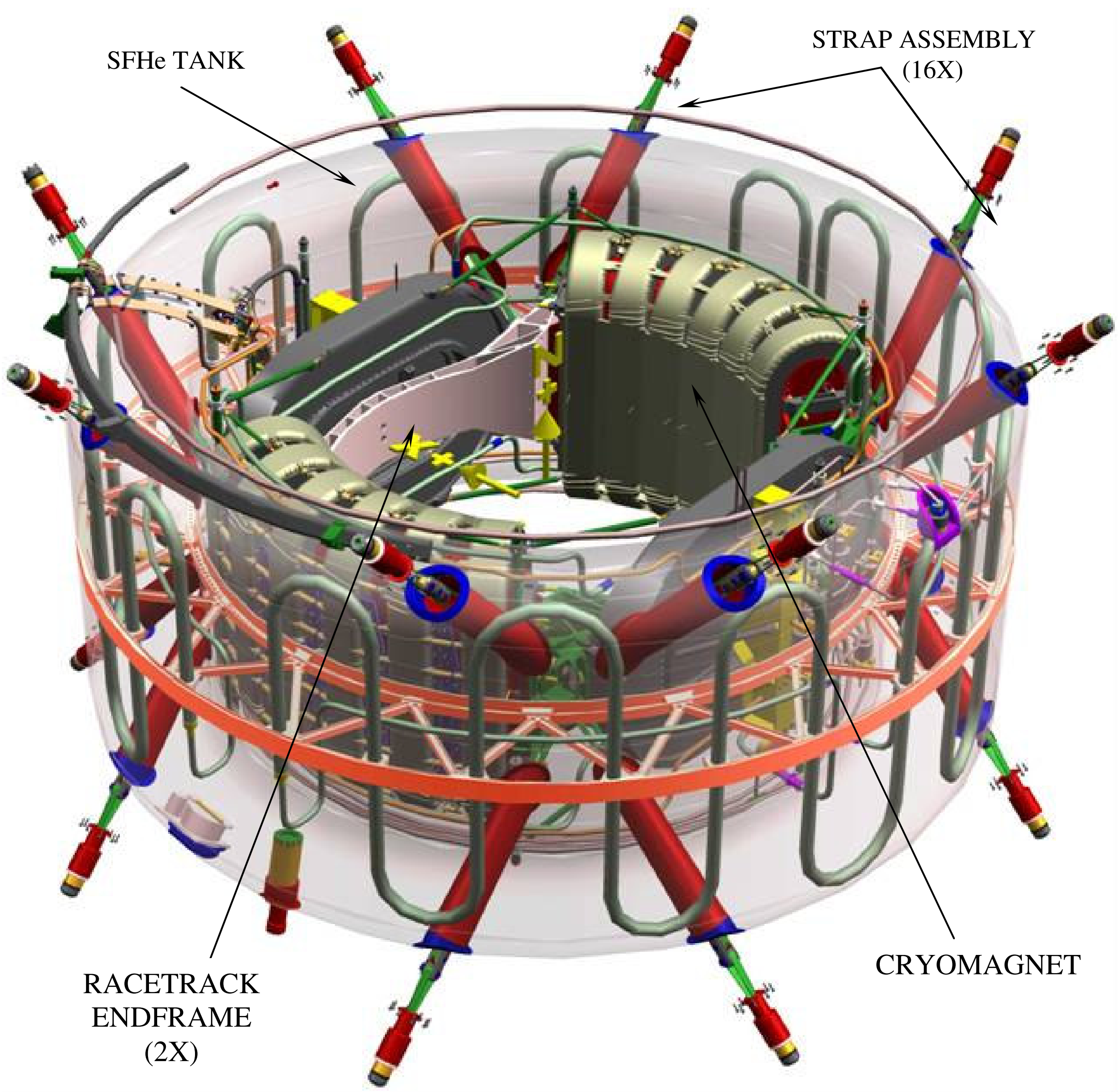


Figure 5.1.2-1 Cryomagnet, Helium Tank, and Support Straps

The challenge of the strap design was conflicting requirements. On the one hand, the system is required to resist the inertial loads of the Cryomagnet assembly during launch and landing events and prevent any contact with the inner surface of the VC. This requirement demands a system which is both stiff and strong. On the other hand, these support straps also serve as the primary heat path into the system. This second requirement dictates the thermal flux through the straps must be kept to an absolute minimum forcing the design to be long and slender. The strap support system developed by SCL is capable of meeting both requirements.

The basic layout of each strap assembly is shown in Figure 5.1.2-2. Figure 5.1.2-3 shows the four component bands that make up each assembly. Each band is made up of a high-strength fiber composite, with the specific material of each band chosen to provide minimal heat loss at the operational temperature it will see. At the coldest end, a carbon fiber band is used (the black band seen in Figures 5.1.2-3 and 5.1.2-4), while S2 fiberglass bands are used in the interior section and at the warm end (the white bands). These three bands provide sufficient stiffness for on-orbit load conditions, but are not sufficient to hold the Cryomagnet in its proper position under the launch and landing load environments. A fourth band, a Zylon fiber composite, is added to the interior sections to resist these loads (the brown band). This latter band is usually referred to as the launch/landing strap to distinguish it from the inner, on-orbit strap. This band has a passive thermal disconnect feature; when the strap assembly is not under high load, the strap does not have a thermal connection to the cold end of the system and thus its conduction does not contribute to the heat leak of the overall system.

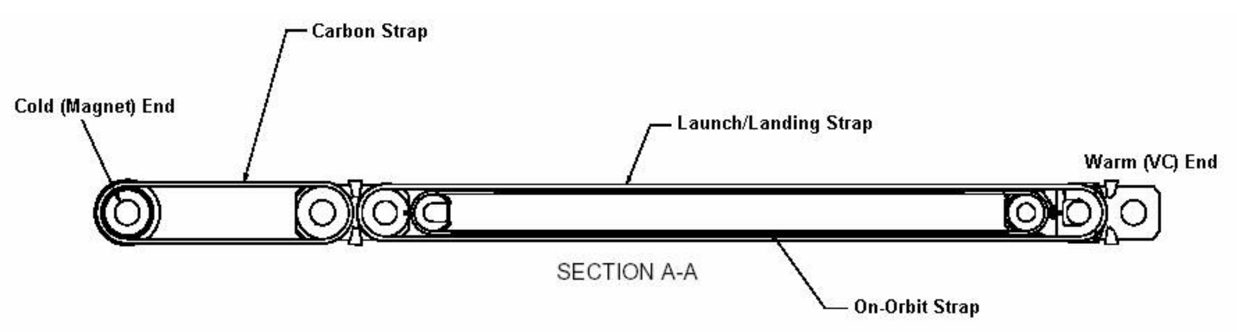


Figure 5.1.2-2 Strap Assembly Layout (Final Component Band not shown)

Figure 5.1.2-3 Strap Component Bands

Figure 5.1.2-4 Full Strap Assembly Under Test

The warm end of each strap assembly rests on a stack of Belleville washers inside a cylindrical fitting known as the "wineglass." The wineglass is in turn bolted to one of the support rings of the VC. An overall schematic of the fitting is shown in Figure 5.1.2-5. The Belleville washers are present in order to reduce the stiffness of the overall system and avoid causing long-term assembly stresses in the VC. This low-stiffness response will continue until the washer stack fully flattens and becomes for all practical purposes infinitely rigid.

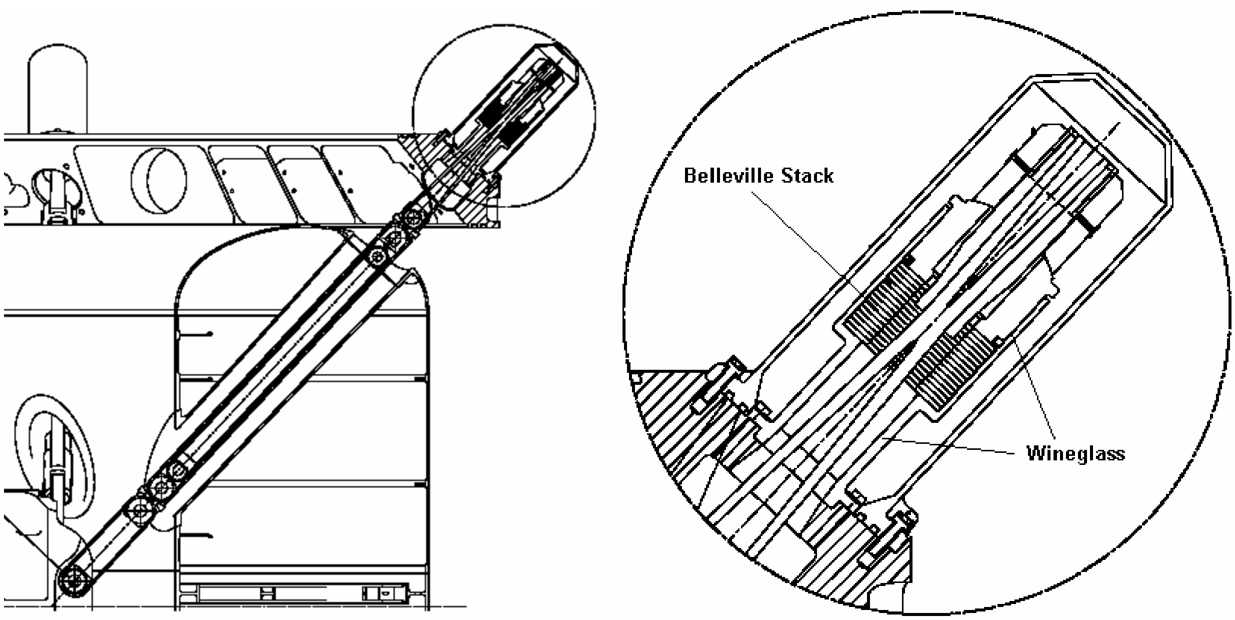


Figure 5.1.2-5 Wineglass Fitting

The radical stiffness changes seen when the Belleville stack bottoms out and when the thermal disconnect closes indicate that the entire system has a highly nonlinear force-displacement relationship. Predicting, modeling, and validating the dynamic response of this system has been a significant effort for the project. The AMS-02 Structural Verification Plan describes the extensive series of tests and analysis used to accomplish this task. The test-correlated force-displacement curves for a single strap are shown in Figure 5.1.2-6. Each flight strap has been acceptance tested to 1.2 times the Maximum Expected Flight Load and the force-displacement response will be verified to the ICD limits shown in the figure.

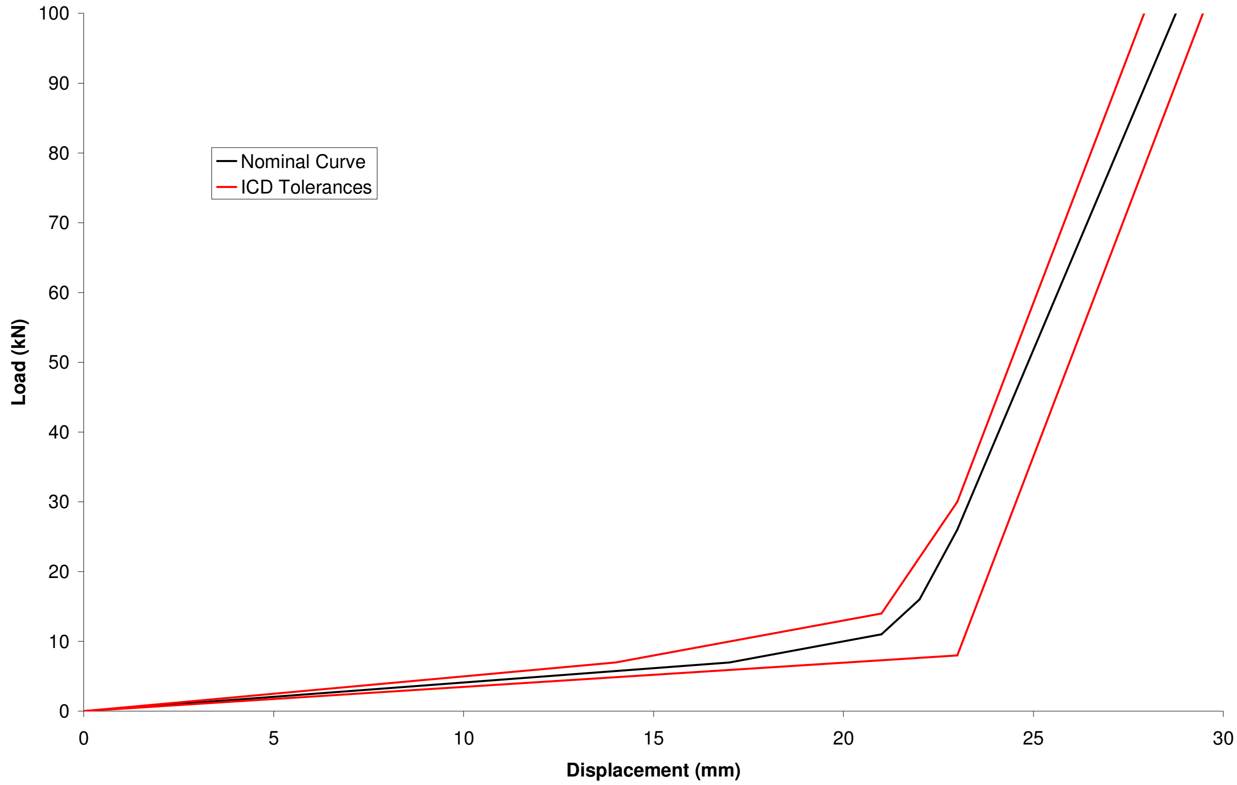


Figure 5.1.2-6 Overall Strap Assembly Test Correlated Force-Displacement Relationship

5.1.3 Cryogenic System

As discussed in Section 5.1.1, the Cryomagnet coils must be kept at a temperature of 4 K or less in order to remain superconductive. Not only must the temperature be maintained for the entire mission, but the Cryomagnet must also be able to be recharged after an on-orbit quench without EVA support. SCL has met these requirements through a cryogenic system based on superfluid Helium. Helium becomes a superfluid when normal liquid helium is cooled below 2.17 K. In this state, it has three major advantages over normal liquid Helium:

1) It has a significantly higher density and higher specific latent heat than liquid Helium, allowing a given volume of superfluid to absorb significantly more heat than a similar volume of liquid helium.

2) Superfluid Helium has extremely high thermal conductivity, allowing the Cryomagnet to be cooled through a thermal bus rather than being in a cryogen bath.

3) Superfluid Helium can be pumped using Thermo-Mechanical Pump (TMP) technology. TMPs are actuated solely by heaters and have no moving parts. This makes them extremely reliable and well-suited for orbital use.

The AMS-02 cryogenic system schematic is shown in Figure 5.1.3-1. Heat is removed from the Cryomagnet coils through the Superfluid Cooling Loop, which then conducts the heat into the main Helium tank. This tank is at 1.8K and is the ultimate heat sink for the entire system. As the Helium slowly boils away, vapor is removed from the system and flows through a series of four vapor cooled shields operating between 1.8K and 60K which surround the Cryomagnet assembly. Small thermal shorts run between these shields and the metallic fittings on the support straps further reduce the heat leak into the main tank. Finally the outermost vapor-cooled shield is thermally attached to four Cryocoolers, which further reduce the overall temperature and slow the rate of helium loss. The helium is then released through a zero-thrust vent. During nominal operations, the maximum venting rate is 5 mg/s and does not present an over-pressurization hazard to the Orbiter. The following paragraphs cover each of these subsystems in greater detail.

All valves have been selected to have burst pressures in accordance with the requirements of NSTS 1700.7B. Additionally, all will be acceptance tested and shown to operate normally within the AMS-02 magnetic field. All external GSE interfaces will either be 1) crimped or welded after use or 2) will have two valves in series which will be closed to prevent either helium venting or a breach of the dewar vacuum space. Burst disks use a circumferentially-scored, reverse buckling design which is considered single-fault tolerant based on the requirements in NSTS/ISS 18798B, letter TA-88-074. This was presented to the safety panel and accepted by them on 17 Jan 2003. As part of the qualification plan, multiple discs have been burst at cryogenic temperatures and all have operated normally without generation of debris.

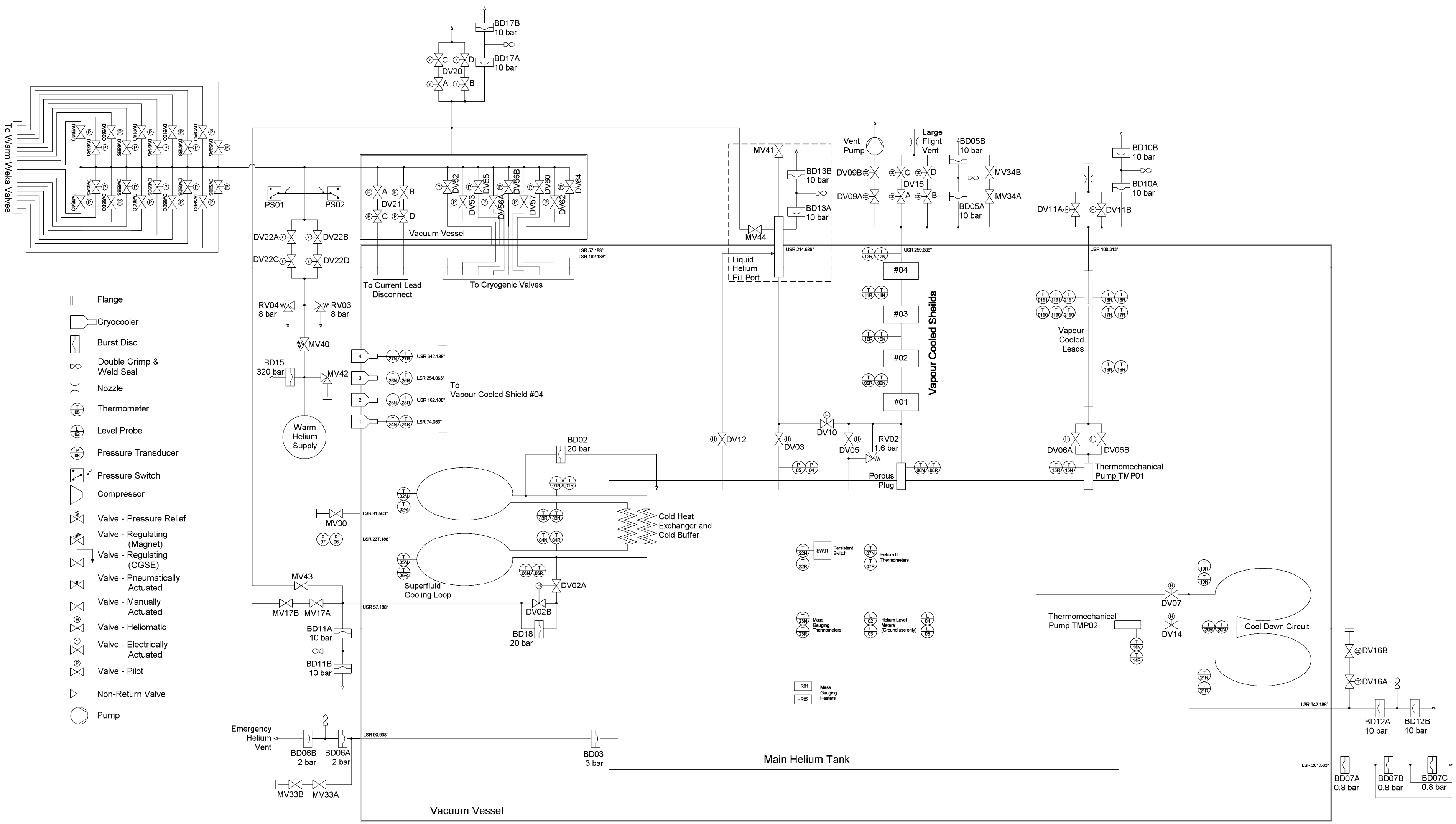


Figure 5.1.3-1 Cryogenic Process Diagram

5.1.3.1 Coil Cooling

Each Cryomagnet coil has two thermal shunts attached to the Superfluid Cooling Loop, which runs along the top and bottom of the Cryomagnet. The loop is a copper pipe filled with superfluid helium at 1 bar pressure. Heat in the coils is conducted through the shunt into the liquid inside the loop. The cooling loop in turn extends into the main Helium Tank where a serpentine heat exchanger (Figure 5.1.3.1-1) dissipates the heat into the superfluid helium.

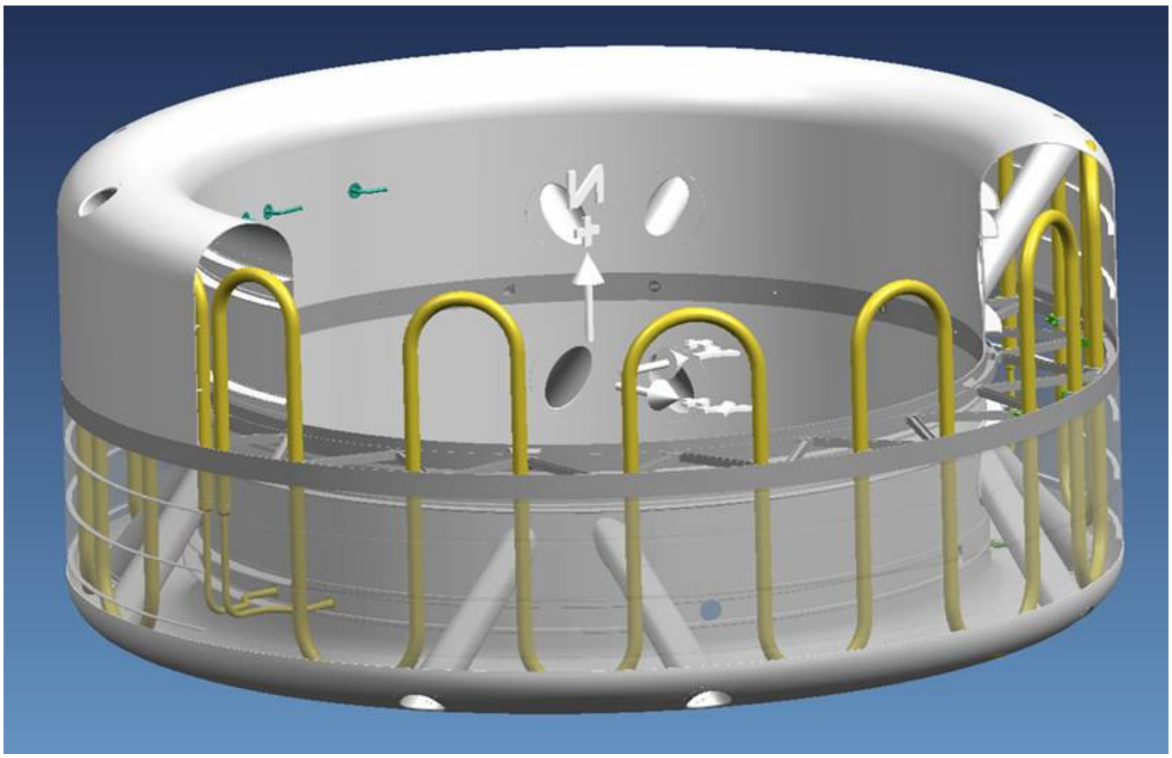


Figure 5.1.3.1-1 Heat Exchanger

Cooling the Cryomagnet by means of a thermal bus and external tank provides AMS-02 the ability to recover from a quench. A ground-based magnet typically resides in a helium bath. When a quench occurs, the large thermal loads transmit directly into the helium, which quickly boils and vents away. More helium must then be added to the bath to cool and restart the magnet. By storing the helium in an external tank, the heat from a quench can be bled off slowly and the overall helium loss in the system can be minimized. The Cryomagnet self-protection system discussed in Section 5.1.1 prevents the temporary significant heat rise in the Cryomagnet from causing a hazardous situation.

The Superfluid Cooling Loop is filled on the ground through valve DV02 and MV17A and B, which are then closed on the ground and never reopened. This loop has been designed to a maximum design pressure of 20 bar and is protected from over-pressurization by the burst disk BD02. Nominal operating pressure is 1.85 bar. This disk would vent the loop into the main helium tank, not externally, and thus presents no safety hazard. For this reason, only one burst disk has been used.

5.1.3.2 Helium Tank

The main Helium Tank is a 2500 liter toroidal vessel which contains the bulk of the cryogen used by AMS-02. As shown in Figures 5.1.3.2-1 and 5.1.3.2.-2, the tank consists of a central support ring attached to two rib-stiffened cylinders. The inner cylinder has a radius of 0.96 meters and the outer cylinder has a radius of 1.29 meters. The tank is made up of Al 5083 forgings and all interfaces are welded. The construction technique used to fabricate the tank optimizes the ability of the tank to withstand helium permeation of the aluminum by careful control of the material “grain” orientation.

Sixteen through-tubes are included in the tank to allow the strap assemblies to pass. Structural analysis has shown that these tubes are wide enough to prevent the strap from contacting the side of the tank. The remainder of the ports seen in the figure are thermal and electrical interfaces with components inside the tank or ports designed to support filling and venting operations. The tank itself has been designed to a maximum positive pressure of 3 bar and a maximum negative pressure of 1 bar. The maximum pressure is established at 3 bar (43.5 psi) through three burst disks, two set to 3 bar (BD03 and BD06A) and one set to 2 bar (BD06).

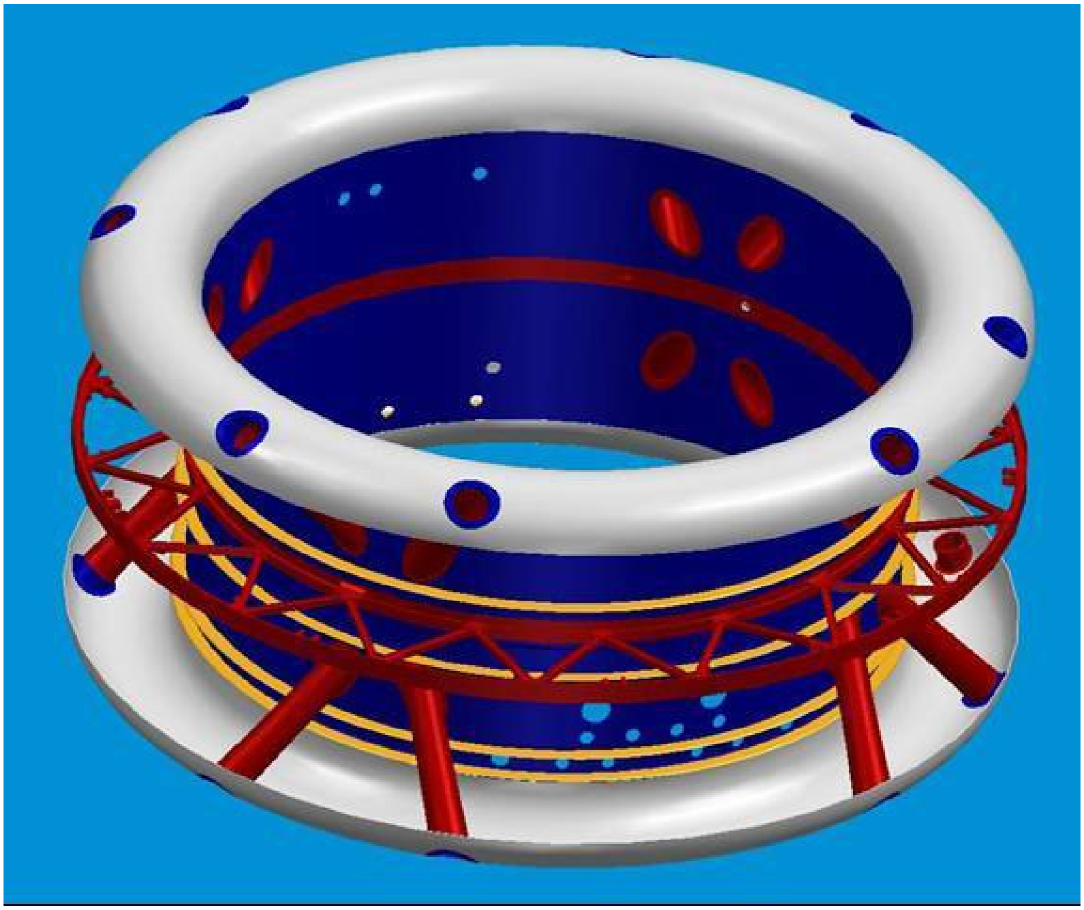


Figure 5.1.3.2-1 Helium Tank (Outer Cylinder not shown)

Helium leakage from the tank in significant quantities could pose an over-pressurization hazard to the Shuttle. The project has therefore developed a special testing program for all welded interfaces which is described in the AMS-02 Weld Control Plan (JSC 29779). When completed, the entire tank will undergo leak checks using both liquid helium and superfluid helium. The superfluid helium has zero viscosity, and many tanks which are leak tight for liquid helium are not leak tight for superfluid helium. In order to fully qualify the AMS-02 tank, SCL has built a dedicated leak testing unit which can not only cool the system to superfluid temperatures, but is also capable of rotating the tank about its central axis, ensuring that all surfaces of the tank will be wetted during the leak test.

Figure 5.1.3.2-2 Helium Tank Lower Half

5.1.3.3 Vapor Cooled Shields

As heat is dissipated into the main Helium Tank, the vapor generated is separated from the liquid by means of a porous plug. This vapor then flows into small tubes inside a series of four Vapor Cooled Shields (VCS). These shields surround the Cryomagnet and helium tank assembly and are connected via small thermal shunts to the metallic portions of the support strap assemblies. As mentioned earlier, these intermediate heat sinks reduce the overall heat leak into the He tank itself and greatly increase the overall endurance of the system. The shields themselves are thin foils of nearly pure Al. Two of the shields have a carbon fiber honeycomb structure underlying them for additional structural support. As with the Helium Tank, each shield has sixteen holes to allow passage of the support straps. Figure 5.1.3.3-1 shows the shield structural support.

Figure 5.1.3.3-1 Vapor Cooled Shield Structural Support

5.1.3.4 Cryocoolers

The final stage of the Cryomagnet thermal control system is four Stirling-cycle Cryocoolers which attach to the outermost VCS. The coolers themselves are based on a Sunpower design and have been analyzed and verified by the Cryogenics and Fluids Branch at the Goddard Space Flight Center (GSFC). Together the Cryocooler remove approximately 12W of heat from the system. This additional temperature drop has been calculated to reduce Helium consumption by a factor of four. This heat is conducted to a loop heat pipe (LHP) which then conducts the heat to the zenith radiator. (The LHP/Zenith Radiator system is discussed in more detail in Section 5.13.1.3 and does not interface directly with the cryogenic system.) After this final cooling stage, the helium gas is allowed to vent to space from a zero-thrust vent aligned with the ISS Y-axis. This vent will be shown not to impinge on AMS-02 or ISS hardware, or into any potential EVA path.

Flight-like coolers have undergone a full acceptance testing cycle to demonstrate structural strength and proper workmanship. A qualification cooler has also undergone a fatigue test to demonstrate the system lifetime.

5.1.3.5 Cryosystem Operations

In the payload bay prior to launch, the system will be in its standard ground steady-state. The Superfluid Cooling Loop controls the Cryomagnet temperature by conducting small amounts of heat into the main tank. The small amount of helium vapor generated will leave the tank through the porous plug and travel through the VCS circuit described above. The vent pump outboard of the valves at DV09 continually pumps the excess helium vapor from the VCS circuit and releases it to the atmosphere. The valve groups DV15 will remain closed, ensuring that all helium leaves through the vent pump and that no air enters the system.

At nine minutes prior to launch, the pump and Cryocoolers will be switched off and valves DV09A and DV09B will be closed. The system is now completely sealed, causing the overall pressure to slowly increase. (This effect has been considered in the MDP calculation for all pressure systems.) The system will have been actively monitored on the ground prior to this to ensure that the vacuum space has not been breached and the Helium Tank remains thermally isolated from the environment.

During launch, when the exterior pressure has dropped below the main tank pressure, the valves at DV15 are opened to allow venting through the flight vent, relieving the added pressure. This is controlled by both a barometric switch and a Backup Flight System (BFS) computer. The valve is opened while the helium is experiencing the acceleration forces so helium vapor only and not fluid is in contact with the porous plug. Once the Shuttle has reached orbit and the large flight vent is open to vacuum, the Cryocoolers will be reactivated and the system pressure drop to its orbital equilibrium value. At some stage during the mission, the valves marked DV11 and DV16 will be opened in order to release any residual gases trapped in the vapor-cooled lead lines and the cool-down circuit, respectively.

In the case of a launch abort, no action is required to keep AMS-02 from creating a safety hazard. If the flight vent remains closed, eventually the helium tank would reach 3 bar pressure and burst disks BD03, BD06A, and BD06B would burst. This would not happen for several hours after landing, and the flow rate has been assessed and does not pose a hazard to the orbiter. This venting can be avoided through reactivation of the vent pump. If the valve remains open, the venting would be consistent with the pre-launch venting conditions and pose no threat to the Orbiter.

The Cryomagnet charging operations are discussed in great detail in the Section 5.12, AMS Electronics, but it should be noted here that current leads which are capable of carrying the 459.5A nominal Cryomagnet current would be an immense heat load on the system unless they are cooled to cryogenic temperatures. SCL has solved this problem through development of hollow current leads through which superfluid helium from the main tank can be pumped to bring the leads down to the temperature of the main tank. This is accomplished by opening the valves marked DV06 and heating thermo-mechanical pump TMP01, causing the helium to flow into the leads themselves. Once they are cooled to the appropriate temperature, a mechanical switch closes connecting the leads to the Cryomagnet circuit and charging begins. Once the Cryomagnet has been charged and is operational, the leads are disconnected. TMP01 is then stopped and the DV06 valves are closed. The valves marked DV11 are then opened and the remaining helium vapor is allowed to vent to vacuum through a small zero-thrust vent.

Once the Cryomagnet has been charged and the current leads disconnected, the system is in its operational state and nominally will require no further action. All valves are closed and helium vapor in the tank is being released through the porous plug, flowing through the vapor cooled shields, and then slowly venting to vacuum.

If the Cryomagnet does quench from full field at some point during the mission, the average coil temperature will rise to about 65K. This will also cause a pressure rise in the superfluid cooling loop, but it will not exceed the system maximum design pressure of 20 bar. The pressure rise in the SFHe tank will be negligible. To re-cool the coils, valve DV14 is opened and thermo-mechanical pump TMP02 is activated to pump superfluid helium from the main tank into the cool-down circuit. The combination of this loop with the nominal cooling loop will bring the coils back to superconducting temperatures within two hours. It should be noted that if DV14 fails to operate, the system can still be brought back to operational temperatures with just the primary loop – it will simply take longer and use more helium since the primary loop will be overheated at this point (but not exceeding the system MDP).

5.1.4 Vacuum Case (VC)

The design and analysis for the Cryomagnet Vacuum Case (VC) is provided by the Engineering & Sciences Contract Group (ESCG) in Houston and fabrication is being performed by Standard Tool & Die Company (STADCO) in Los Angeles with oversight by ESCG personnel. The VC serves a dual purpose; it is a primary structural support that works in conjunction with the USS-02 to form the foundation structure of the AMS-02 and serves as a vacuum jacket for the superfluid helium tank and Cryomagnet suspended inside by 16 support straps. The Vacuum Case assembly and cross section is shown in Figure 5.1.4-1 and 5.1.4.1-2.

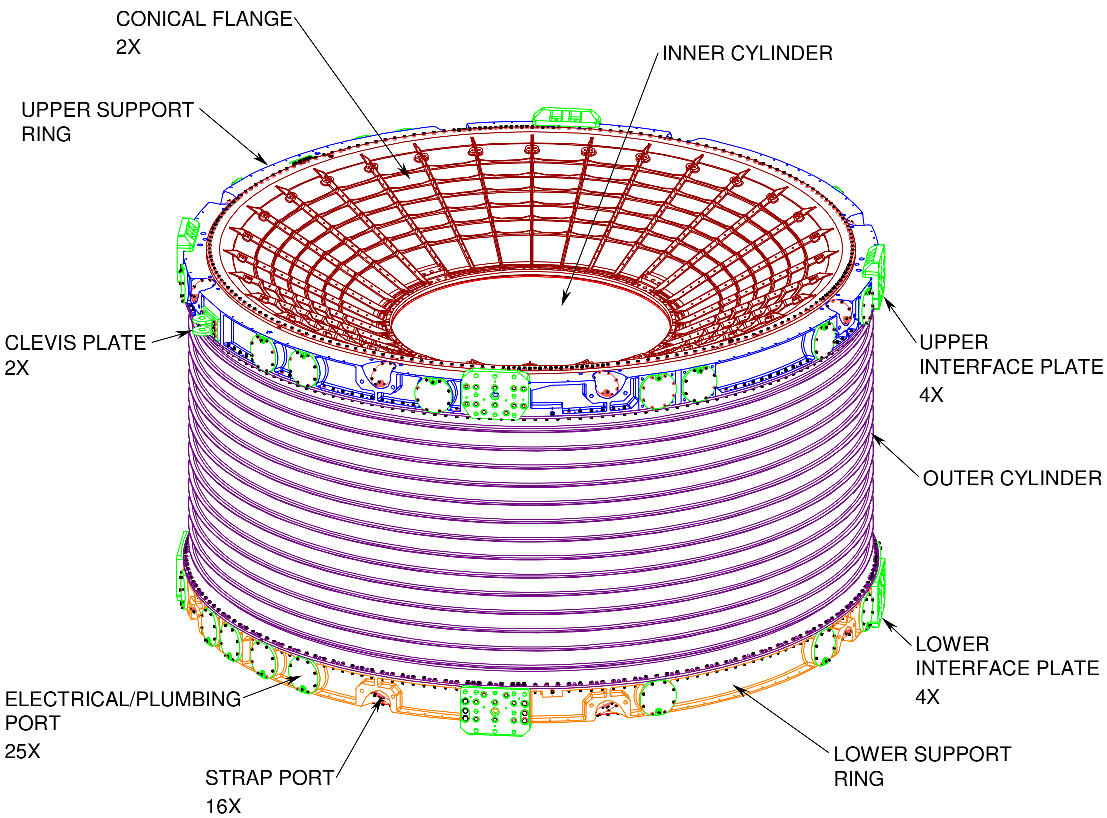


Figure 5.1.4-1 Vacuum Case

5.1.4.1 Vacuum Case Structural Components

The main structural components of the VC are described in the following paragraphs.

5.1.4.1.1 <u>Conical Flanges</u>

The Upper and Lower Conical Flanges are made of spin formed Al 2219-T62. The Conical Flanges start as an annealed plate (T0) and spin formed to rough shape using two dies. They are then solution heat treated and quenched (T42) followed by aging to final condition (T62) to complete a spin form blank One blank was cut up through the entire thickness along the entire cone for tensile test samples to qualify this process. The remaining blanks are qualified by tensile samples along the inner and outer diameters. All blanks must meet the design requirements for Aluminum 2219-T62 in MIL-HDBK-5 and all samples are tested per ASTM B557. The blanks are then machined to final dimensions. The recessed O-ring grooves, which help prevent inadvertent damage, are machined to a 16 micro-inch finish. All other surfaces are machined to the standard 125 or better micro-inch finish. All exterior surfaces, with the exception of sealing surfaces and weld area, are anodized. All interior surfaces, sealing surfaces, and O-ring grooves, are chemical filmed to prevent corrosion. The chemical film process does not affect the sealing capability of the O-ring. The weld joint area is kept bare for welding purposes. It is coated with a maskant to prevent corrosion and keep the aluminum clean prior to welding. This maskant will be removed prior to welding.

5.1.4.1.2 Support Rings

The Upper and Lower Support Rings are made of a rolled ring forged Al 7050-T7451. The forgings are qualified to AMS 4108 and inspected per NASA/JSC PRC-6504, Class A. In addition to this qualification, additional tensile samples are removed from both ends of the forging and tested per ASTM B557. The forging is then machined to final dimensions. The Support Rings contain all of the ports for the Cryomagnet support straps along with ports for electrical/plumbing feed-throughs and cyrocooler interfaces. The dove-tail O-ring grooves, which prevent the O-ring from falling out during VC assembly, are machined to a 16 micro-inch finish along with the sealing faces of the feed thru ports. All other surfaces are machined to the standard 125 or better micro-inch finish. All exterior surfaces, with the exception of sealing surfaces, are anodized. All interior surfaces, sealing surfaces, and O-ring grooves, are chemical filmed to prevent corrosion. The chemical film process does not affect the sealing capability of the O-ring.

5.1.4.1.3 Outer Cylinder

The Outer Cylinder is milled from a rolled ring forging of Al 7050-T7451. The forgings are qualified to AMS 4108 and inspected per NASA/JSC PRC-6504, Class A. In addition to this qualification, additional tensile samples are removed from both ends of the forging and tested per ASTM B557. The forging has been machined to provide reinforcing ribs along the height of the cylinder. The ribs are spaced approximately 3.0 inches apart and are .10 inch thick. The recessed O-ring grooves, which help prevent inadvertent damage, are machined to a 16 micro-inch finish. All other surfaces are machined to the standard 125 or better micro-inch finish. All exterior surfaces, with the exception of sealing surfaces, are anodized. All interior surfaces, sealing surfaces, and

O-ring grooves, are chemical filmed to prevent corrosion. The chemical film process does not affect the sealing capability of the O-ring.

5.1.4.1.4 Inner Cylinder

Inner Cylinder (Al 2219-T852 Rolled Ring Forging). The forgings are qualified to AMS 4108 and inspected per NASA/JSC PRC-6504, Class A. In addition to this qualification, additional tensile samples are removed from both ends of the forging and tested per ASTM B557. All exterior surfaces, with the exception of the weld area, are anodized. All interior surfaces are chemical filmed to prevent corrosion. The weld joint area is kept bare for welding purposes. It is coated with a peelable maskant to prevent corrosion and keep the aluminum clean prior to welding.

5.1.4.1.5 Clevis Plates

The Clevis Plates are fabricated from CRES A286 and are used to attach the diagonal struts from the USS-02 to the Upper Support Ring

5.1.4.1.6 Interface Plates

The Upper and Lower Interface Plates are fabricated from Al 7050-T7451 plate and are the main interface with the USS-02 at 8 locations.

5.1.4.1.7 Feed Thru Cover Plates

The Feed Thru Port Cover Plates are fabricated from Al 6061-T651 plate. The Feed Thru Port Cover Plates protect the access ports during ground processing and for unused ports, during flight. Plates will be removed to allow for installation of necessary plumbing components and electrical feed-throughs for the Cryomagnet System. Strap Port blank cover plates are used to protect the surfaces of the strap ports until the straps are installed. The rectangular O-ring grooves are machined to a 16 micro-inch finish. All other surfaces are machined to the standard 125 or better micro-inch finish. All exterior surfaces, with the exception of O-ring grooves, are anodized. All interior surfaces and O-ring grooves are chemical filmed to prevent corrosion. The chemical film process does not affect the sealing capability of the O-ring.

Figure 5.1.4.1-1 Vacuum Case Assembly

The weight of the VC is 1626 lbs (738 kg), which includes all of the Feed Thru and Strap Port blank cover plates. The VC attaches to the USS-02 at the 8 Interface plates and the 2 Clevis Plates. Since the VC is an integral part of the primary structure with the USS-02, a Structural Test Article (STA) was developed and fabricated at the same time as the Flight VC. The STA VC will be used for much of the AMS-02 structural testing. The Flight unit and the STA unit are identical.

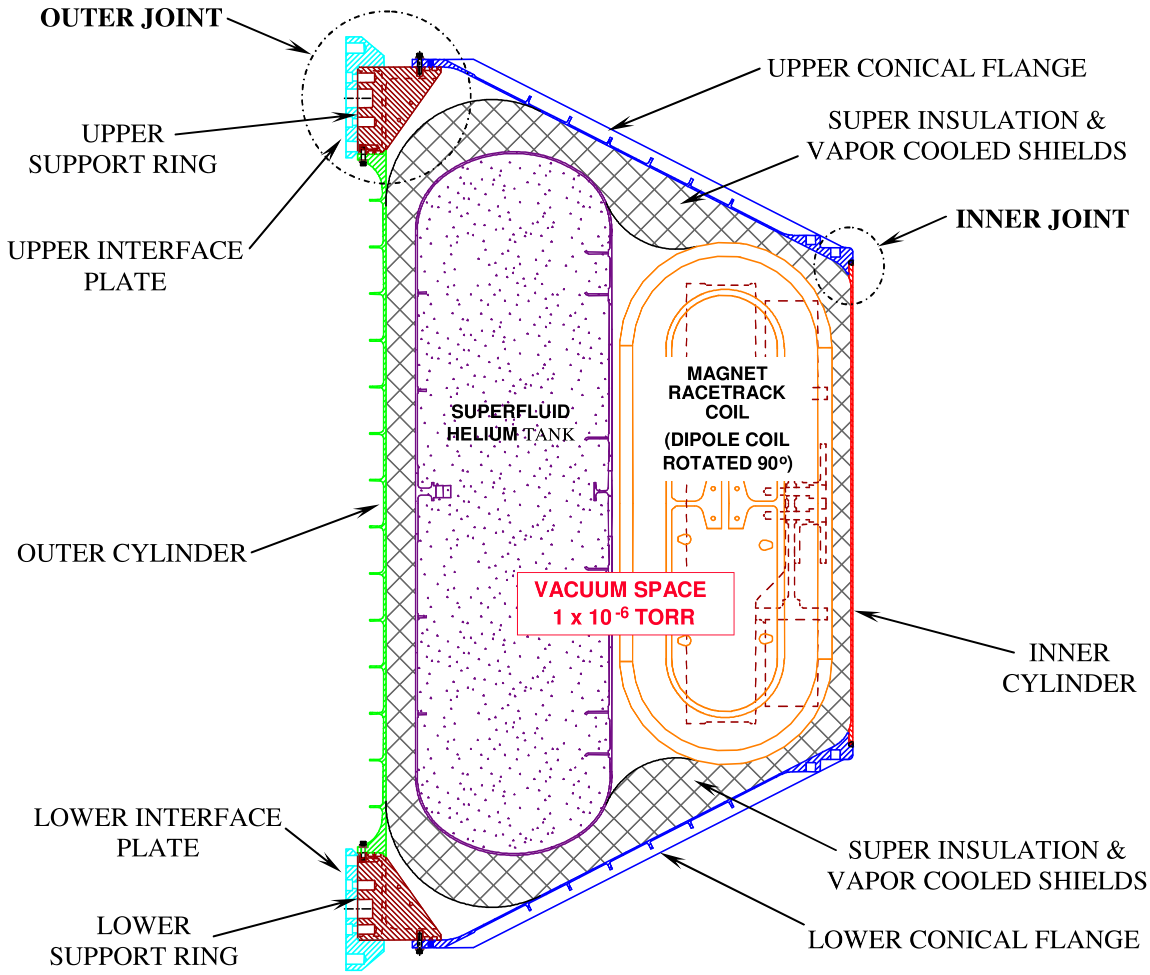


Figure 5.1.4.1-2 Vacuum Case Cross Section

5.1.4.2 Vacuum Case Assembly Details

The VC Inner Joint, which consists of the Upper or Lower Conical Flange and Inner Cylinder, is welded using a U-groove configuration on both ends (Figure 5.1.4.2-1). This design allows for 3 complete welds on this joint (the initial weld plus two contingencies).

The VC Outer Joint, which consists of the Upper or Lower Conical Flange to the Upper or Lower Support Ring and the Outer Cylinder to the Upper or Lower Support Ring, is bolted using 1/4 and 5/16 inch fasteners at each location (Figure 5.1.4.2-2). All fasteners meet the requirements of the JSC Fastener Integrity Testing Program, JSC 23642. The interface is sealed using a double O-ring configuration (Figure 5.1.4.2-3). The O-ring material is Viton and made from extruded cord stock that is joined at the seams by using the Parker hot vulcanizing process. These O-rings are also coated with Dow Corning High Vacuum Grease prior to installation. Test ports are located between each O-ring so that each O-ring can be tested individually and verified. The test port will be closed out with a hex plug and sealed with a Viton O-ring.

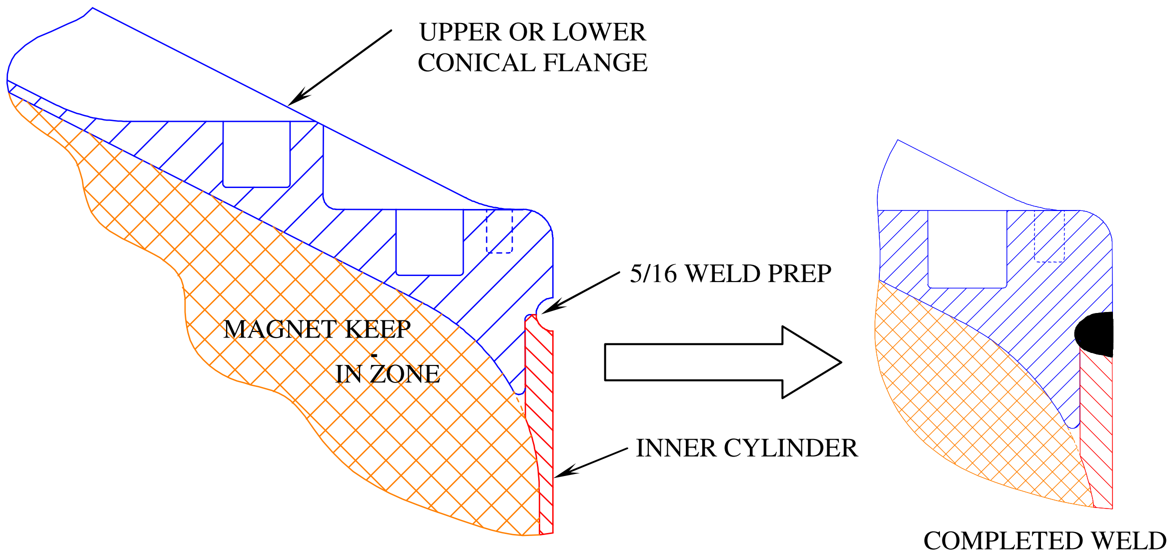


Figure 5.1.4.2-1 Inner Joint (Closeout Weld) Assembly Detail

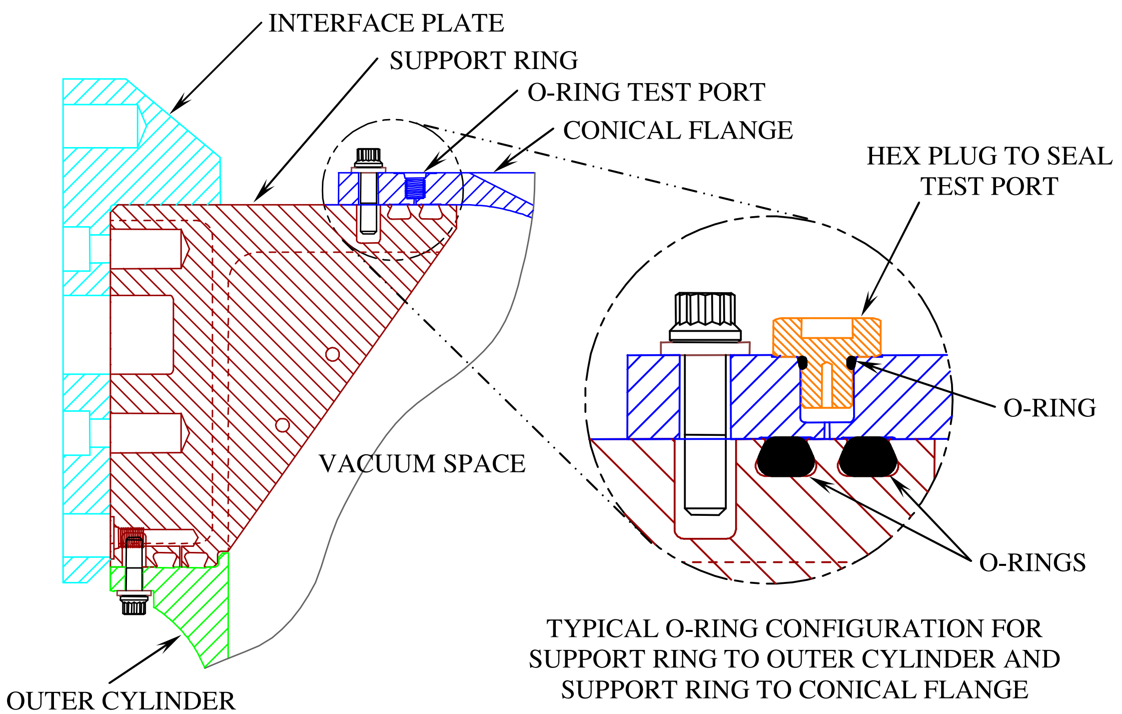


Figure 5.1.4.2-2 Outer Joint Assembly Detail

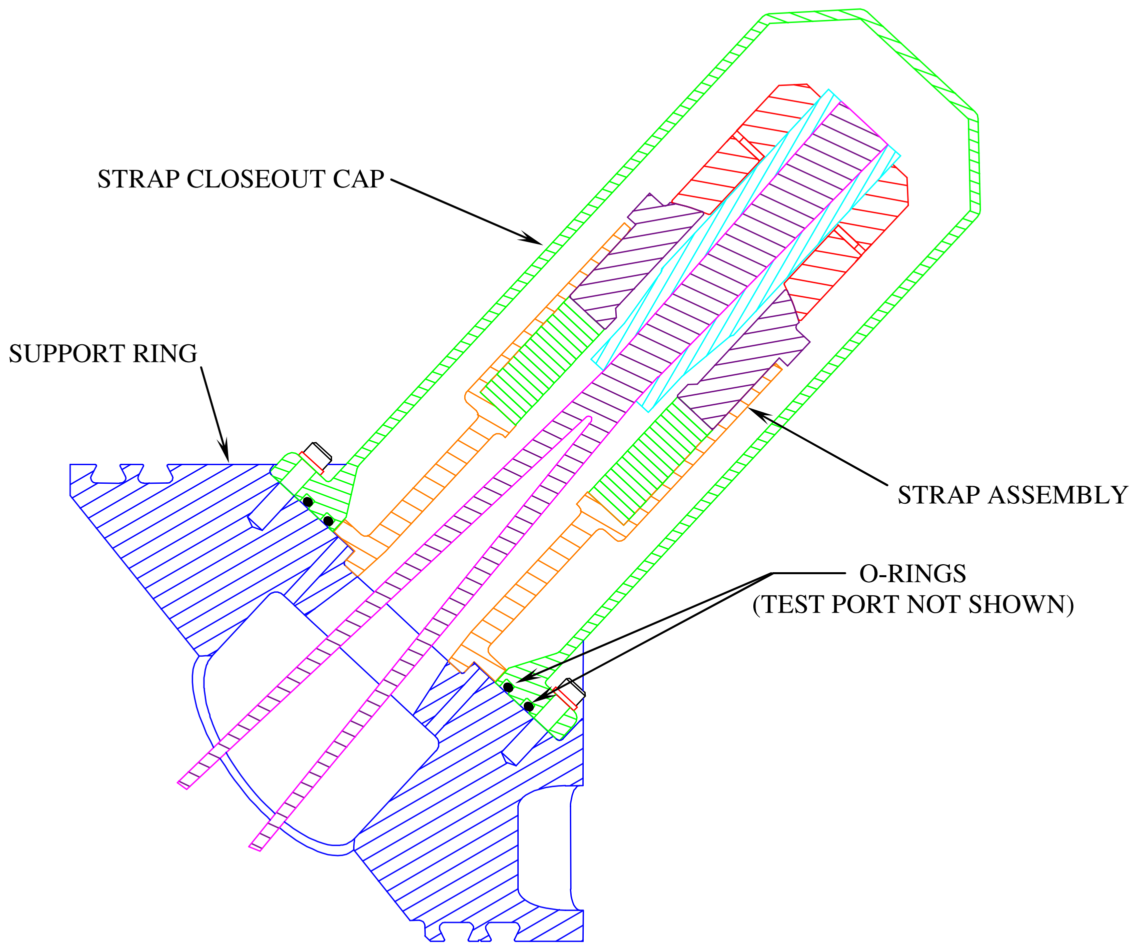


Figure 5.1.4.2-3 Strap Port Cross Section

5.1.4.3 Feed Thru Ports

There are 41 ports on the Vacuum Case. Sixteen ports are for the Cryosystem support straps and 25 ports are for plumbing lines and servicing equipment, Cryocoolers, burst disks, and electrical connections (Figures 5.1.4.3-1 through 5.1.4.3-3). Double O-rings will be used at each of these ports and a test port will be incorporated between the O-rings so that each one can be tested individually. The O-ring material is Viton and is an off-the-shelf item. These O-rings are also coated with Dow Corning High Vacuum Grease prior to installation. The test port will be closed out with a hex plug fitted with a Viton O-ring.

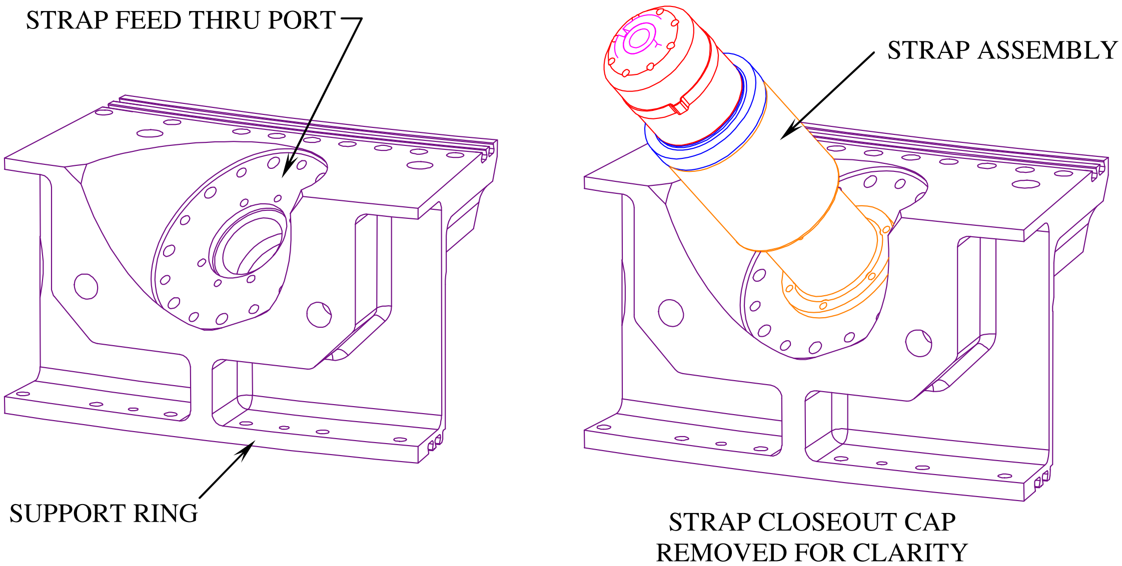


Figure 5.1.4.3-1 Strap Port ISO Views

The VC will also have 3 burst disks in series for emergency venting. The VC has a positive pressure rating of +0.8 atm and a negative pressure rating of -1.0 atm. The burst disks have a positive pressure rating of +0.8 atm and a negative pressure rating of -1.5 atm. Reference Figure 5.1.3-1 for a schematic showing the location of the burst disks.

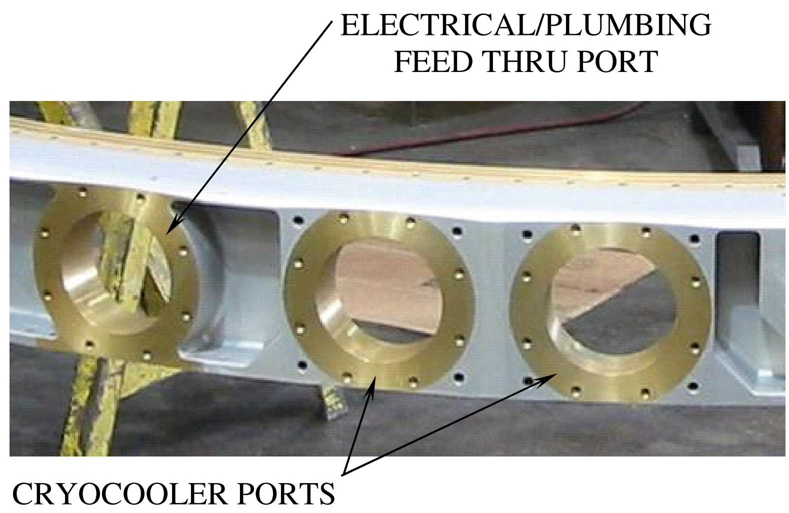


Figure 5.1.4.3-2 Feed Thru Ports

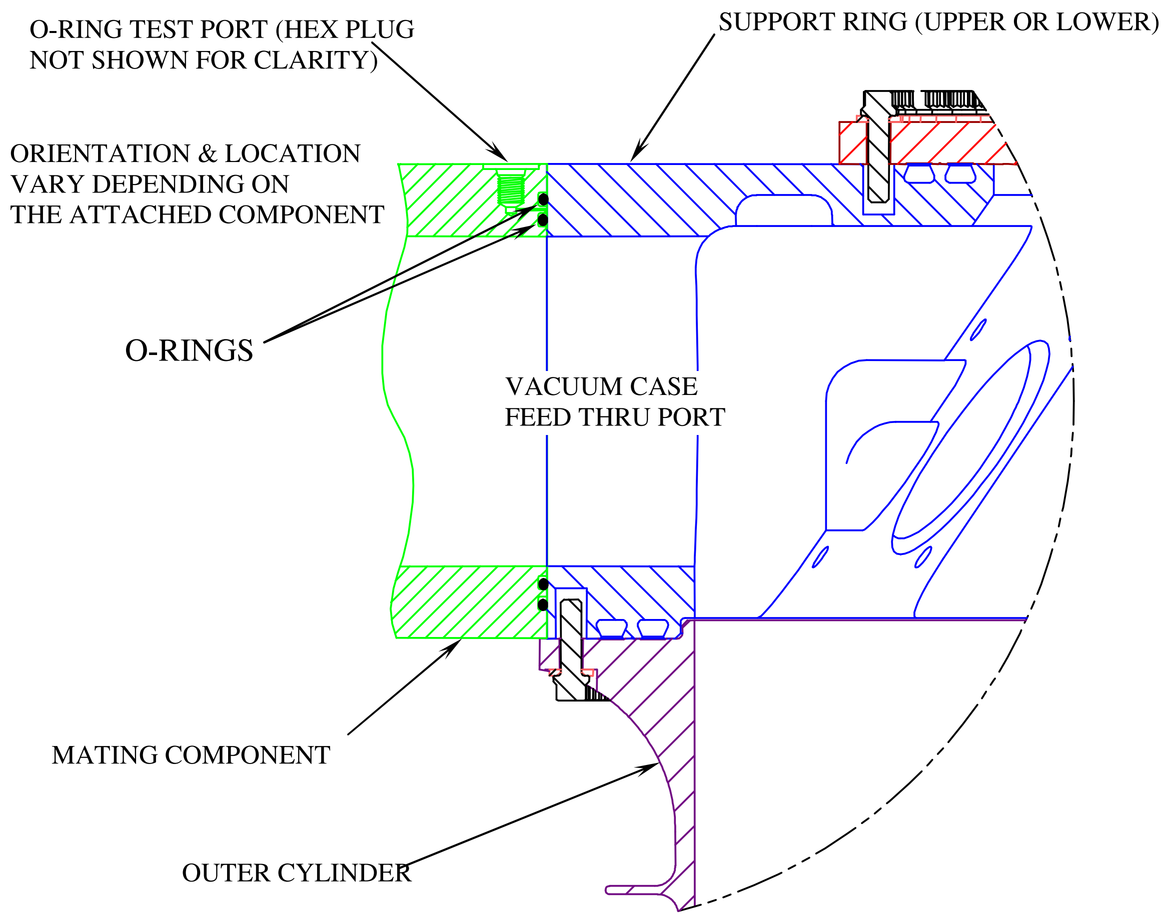


Figure 5.1.4.3-3 Mating Component Layout

5.1.4.4 Design Requirements and Verification Methods

The lower design temperature limit of the Vacuum Case is -58° F and the upper limit is 122° F. Both the STA and Flight VCs were vacuum and pressure leak checked at STADCO. This testing will also be conducted after the cold mass replica (for the STA VC) and Cryomagnet installation (for the flight VC) is completed.

Each VC, STA and flight, is pumped down to reach a minimum vacuum level of 1×10^{-6} torr and each o-ring is tested to assure a helium permeation rate of 1.0×10^{-7} std cc/sec or less. The STA VC is proof pressure tested to 1.8 atm at STADCO after the closeout weld is completed and prior to removal of the Inner Cylinder. Both VCs are proof pressure tested to 1.8 atm after cold mass replica or Cryomagnet installation and the closeout weld is completed.

Direct monitoring of possible leaks and the vacuum quality inside the VC during preflight operations is not possible as atmosphere that leaks inside of the VC will instantly freeze to the components that are the at superfluid helium temperature (4.7 K or less), restoring the vacuum. An indirect measurement methodology will be used to ascertain if the VC has begun to leak. This method utilizes the temperature of the superfluid helium and the helium vent rate to establish if there is a heat flux into the system. The only credible source of such heat flux will be the introduction of atmosphere into the VC. These parameters will be monitored and used to determine if there are any leaks into the VC prior to launch as a safety critical Launch Commit Criteria.

5.2 UNIQUE SUPPORT STRUCTURE-02 (USS-02)

The Unique Support Structure – 02 (USS-02) is the primary structural element of the AMS-02 Payload (Figure 5.2-1). Its purpose is to structurally support the Cryomagnet Cold Mass and the AMS-02 Experiment during launch, landing, and on-orbit loading and integrates them with Shuttle and ISS.

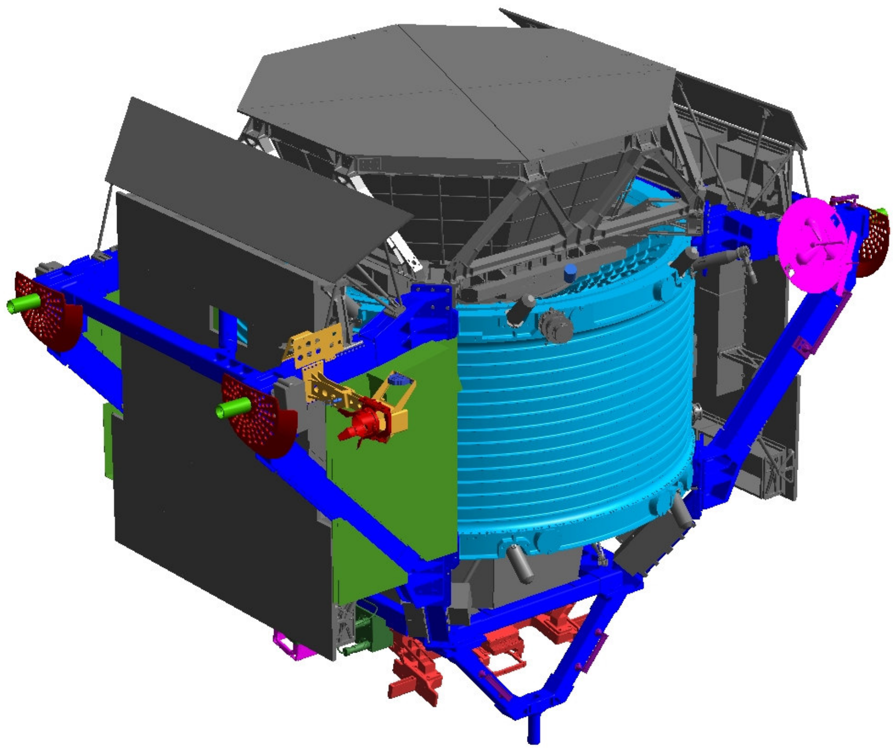


Figure 5.2-1 Alpha Magnetic Spectrometer (AMS) – 02 Payload

The USS-02 (Figures 5.2-2 and 5.2-3) consists of five primary subassemblies – the Upper USS-02, Vacuum Case (VC), Lower USS-02, Keel, and the AMS Payload Attach System (PAS). Each of these subassemblies is bolted together to form the top-level USS-02.

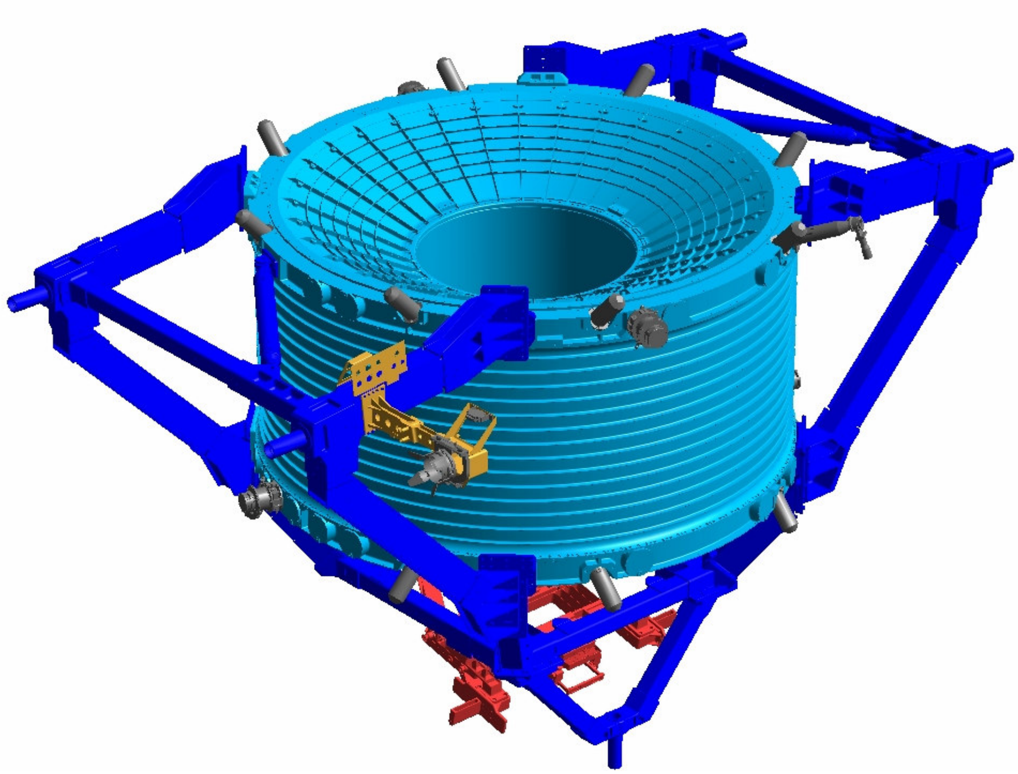


Figure 5.2-2 Unique Support Structure (USS) - 02

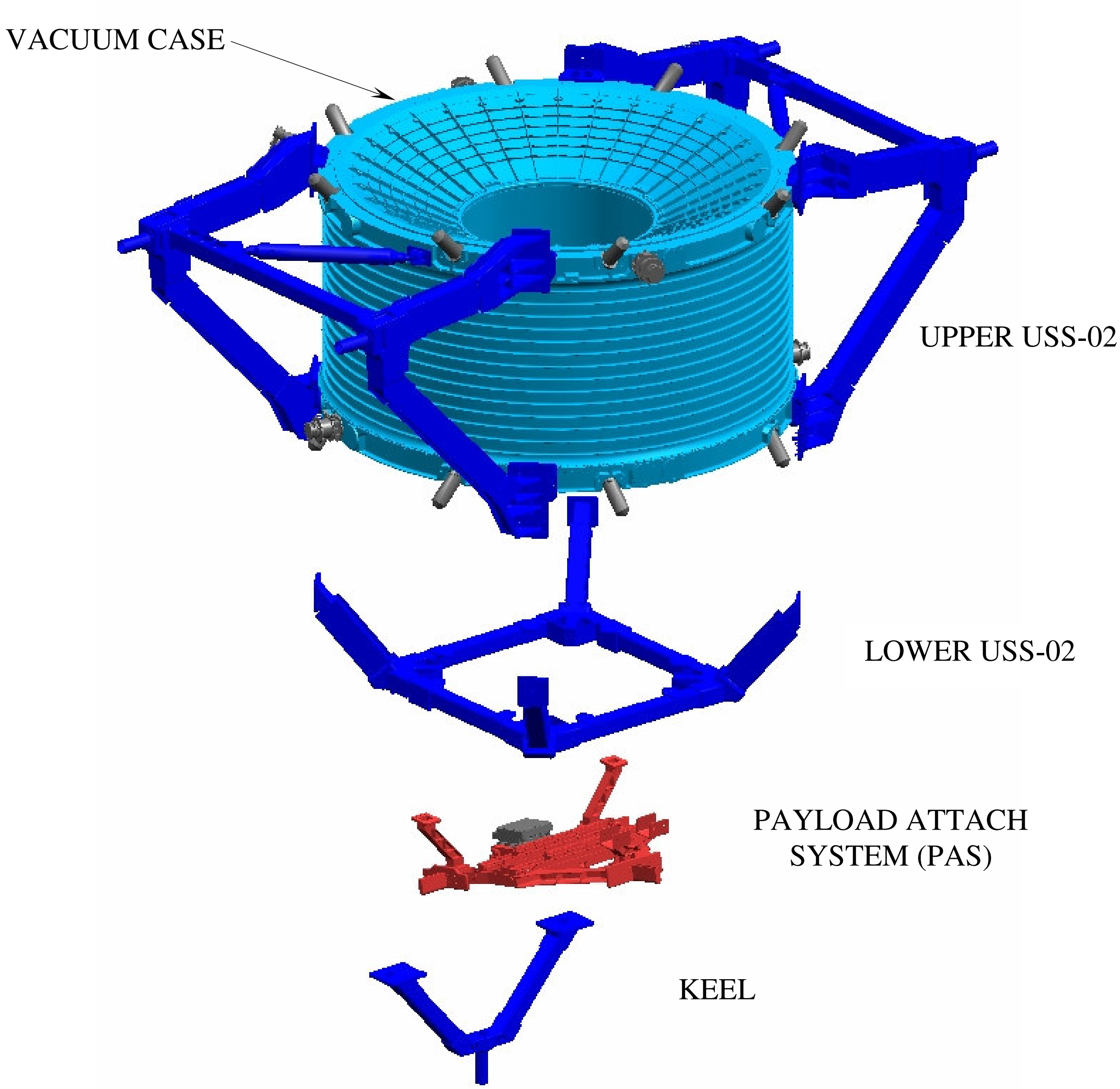


Figure 5.2-3 Subassemblies of the Unique Support Structure (USS) – 02

The Upper USS-02, Lower USS-02 and Keel are comprised of joints riveted to hollow tubes Figure 5.1-4. The joints are made of machined aluminum alloy 7050-T7451 plate and the hollow tubes are made of machined aluminum alloy 7075-T73511 extrusions.

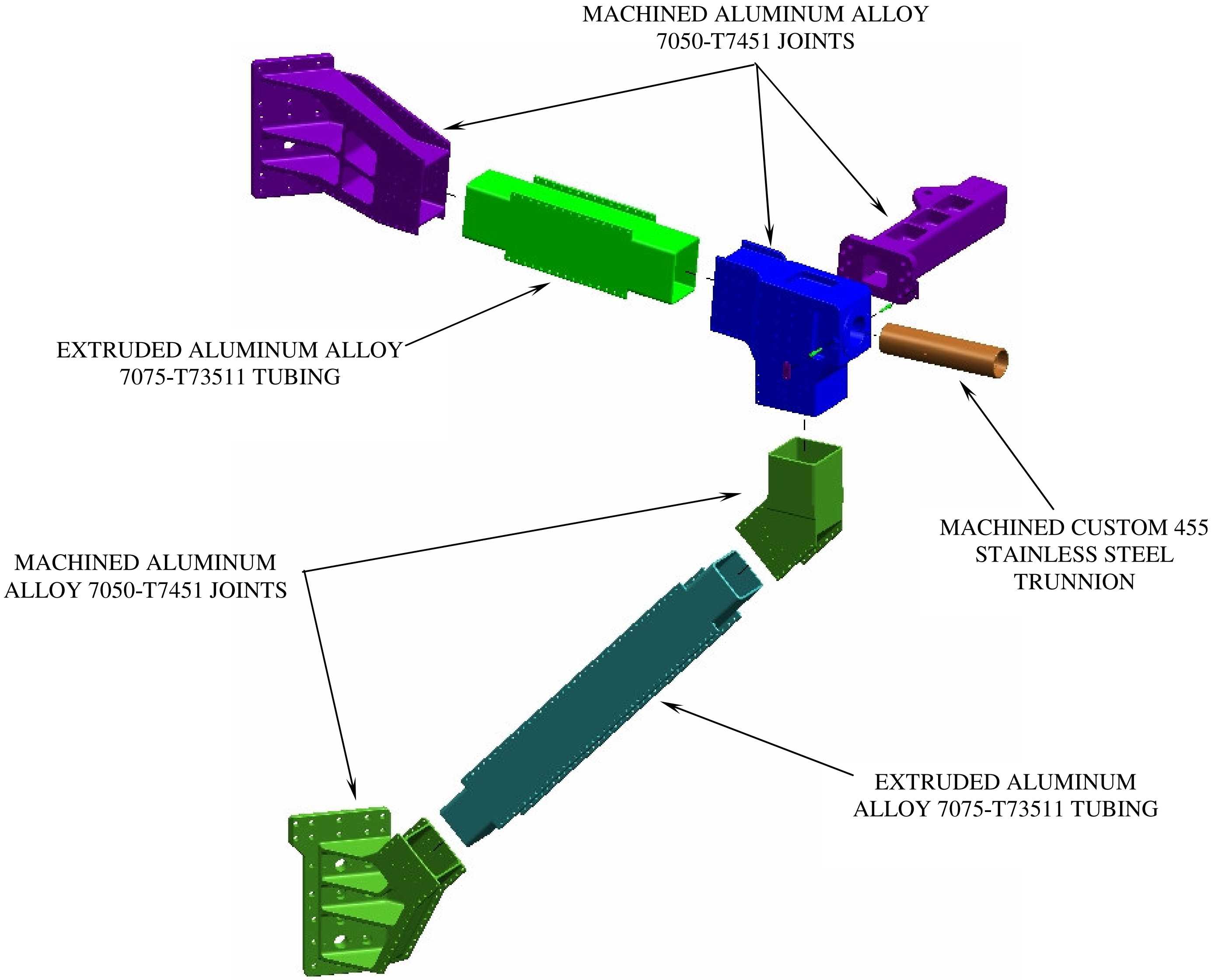


Figure 5.2-4 USS-02 Construction with Aluminum Tubes and Machined Joints

The Upper USS-02 includes two struts (Figure 5.2-5). The struts are made from machined 6061-T6511 extruded tubing, machined end fittings that are riveted to the tube, and rod-end bearings that are threaded into the end fittings. The struts are pinned to the Upper USS-02 at both ends using custom made custom 455 stainless steel shear pins.

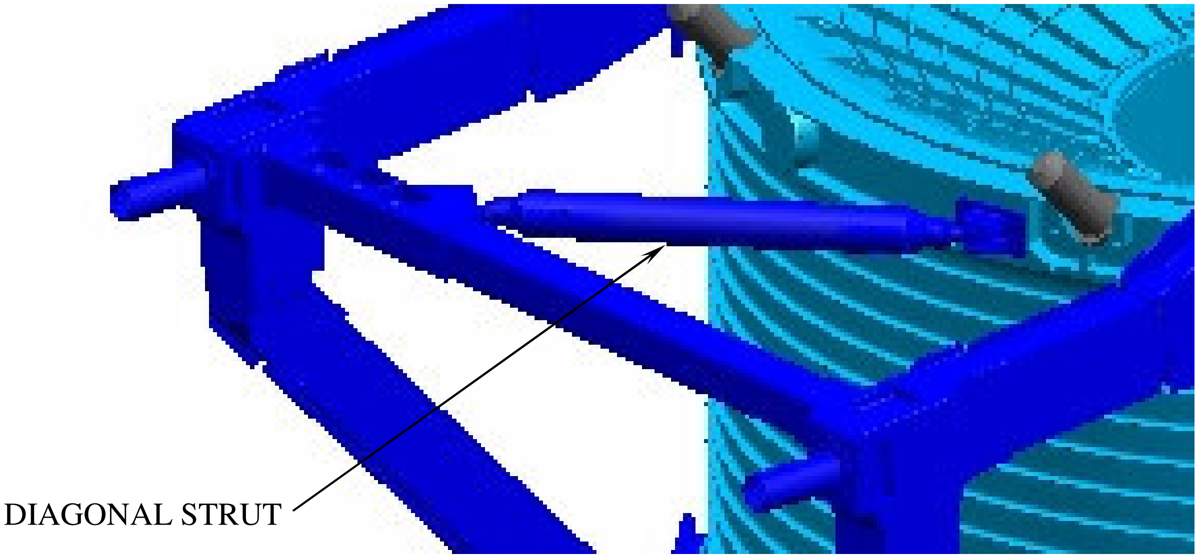


Figure 5.2-5 Location of the Diagonal Strut on the USS-02

The VC is comprised of machined parts made of aluminum alloy 7050-T7451 ring forgings and plate; aluminum alloy 2219-T7351 spin-formed plate, and A-286 stainless steel plate.

The AMS-02 PAS is comprised of components machined from 7075-T7351 plate, 7050-T7451 plate, Custom 455 stainless steel bar, and spherical bearings made from stainless steel with self-lubricating Teflon liners.

All threaded fasteners are made from A-286 stainless steel ranging in strength from 180 to 200 KSI. All structural threaded fasteners are tested and certified per the NASA/JSC Fastener Integrity Program by the NASA/JSC Receiving Inspection Test Facility (RITF) lab. All installed structural threaded fasteners have a secondary means of back-out prevention including locking inserts, locking nuts, self-locking bolts, or lock wire (in non-EVA accessible areas only).

Shear pins are made from Custom 455 stainless steel. Portions of the shear pins fit inside aluminum bronze bushings that fit inside holes in the aluminum alloy USS-02 joints. All shear pins are secured by machined aluminum alloy 6061-T651 block-off plates that are secured to the USS joints with two screws per plate.

All USS-02 parts except the aluminum bronze bushings have corrosion resistant metal finish. The aluminum bronze bushings are inherently corrosion resistant and do not require additional metal finish. Exposed aluminum surfaces are anodized. Stainless steel parts are passivated. Aluminum faying surfaces that require electrical conductivity are Alodined or nickel-plated.

Many of the Joints and all of the tubes that make up the USS-02 have .25 inch (nominal, ¼ inch bolts use 0.280 inch) thru holes or 0.190 inch inserts for hardware mounting. These holes are referred to as the “generic holes” of the USS.

The riveted components of the USS-02 are electrically bonded together via the large number of conductive rivet connections. Resistance of each riveted joint will be verified after assembly. Non-conductive bolted interfaces will be bonded using bonding straps secured to the USS-02 generic hole pattern. Anodize around the holes used will be removed and the resulting surfaces will be Alodined prior to installation of the bonding strap. The resistance across each bonding strap will be verified to be in compliance with Space Station Electrical Bonding Requirements (SSP30245) class “S.”

All of the AMS-02 Experiment components bolt to the USS-02 per JSC 29095, Alpha Magnetic Spectrometer - 02 (AMS-02) Experiment/Payload Integration Hardware (PIH) Interfaces (Part II). The USS-02 has unique interfaces for the TRD/Upper TOF, Tracker, Lower TOF, RICH, ECAL, Cryomagnet, Cryocoolers, and Cryomagnet Dump Diodes. All other AMS Experiment Hardware subcomponents bolt to generic holes on the USS-02 and VC.

The VC supports the Cryomagnet Cold Mass by 16 composite straps. The Cryocoolers are mounted to the VC Upper and Lower Support Rings. Details of the VC design are covered in Section 5.1.4 of this Safety Data Package.

The Shuttle interfaces consist of four sill trunnions and scuff plates, one keel trunnion, and one Remotely Operated Electrical Umbilical (ROEU) Payload Disconnect Assembly (PDA). The ROEU and PDA are GFE from the Shuttle Program. Shuttle Program provided hardware is discussed in Section 5.4. The PDA is mounted to the EVA

Retractable PDA Bracket. This bracket is a single hinged mechanism that is held in place by redundant PIP Pins. Pip pin can be inserted to hold the bracket in the nominal extended position and in the the retracted (or folded) position. Details of the EVA Retractable PDA Bracket are covered in Section 5.4.3.7.

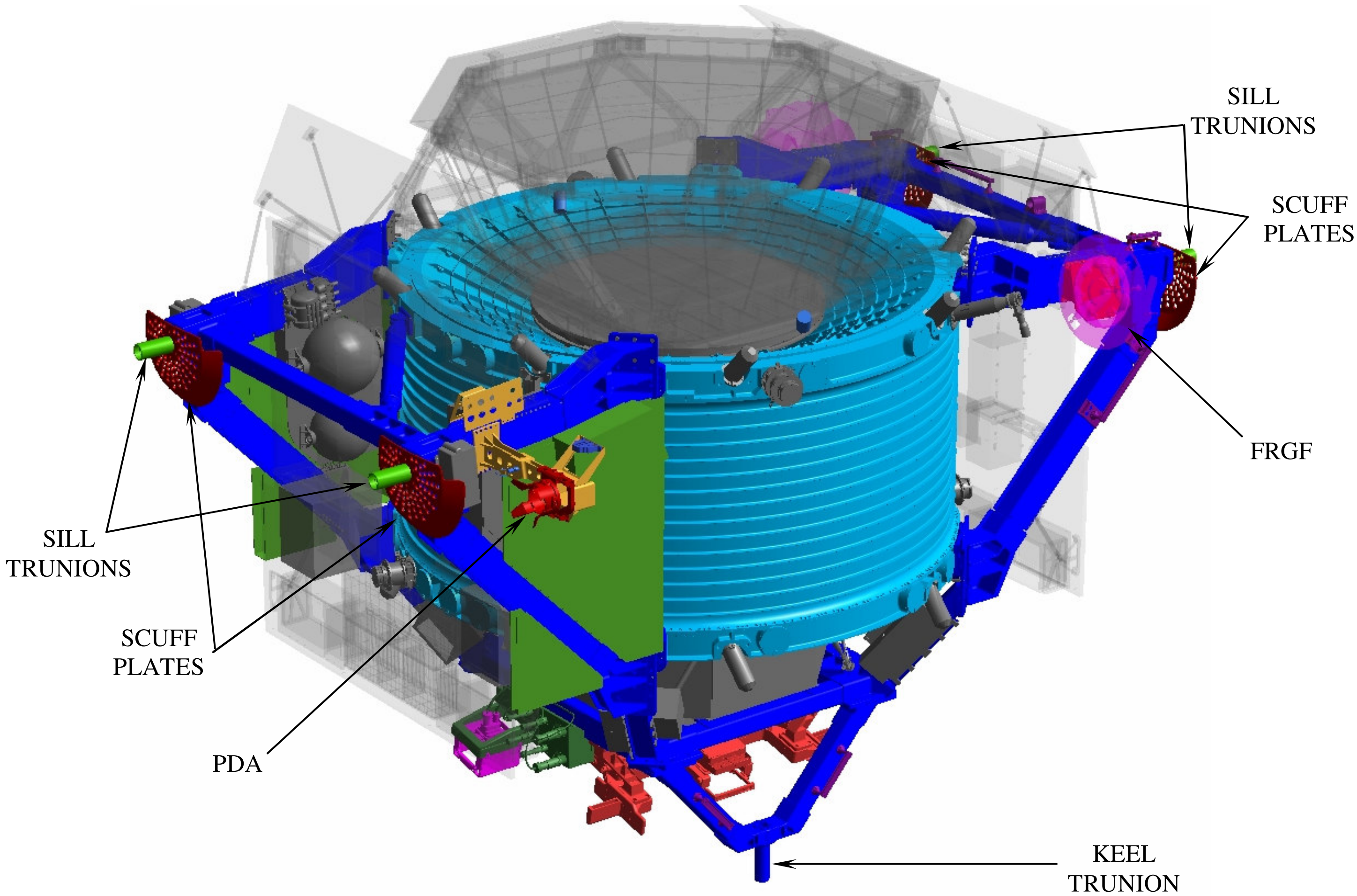


Figure 5.2-6 AMS-02 Shuttle Interfaces

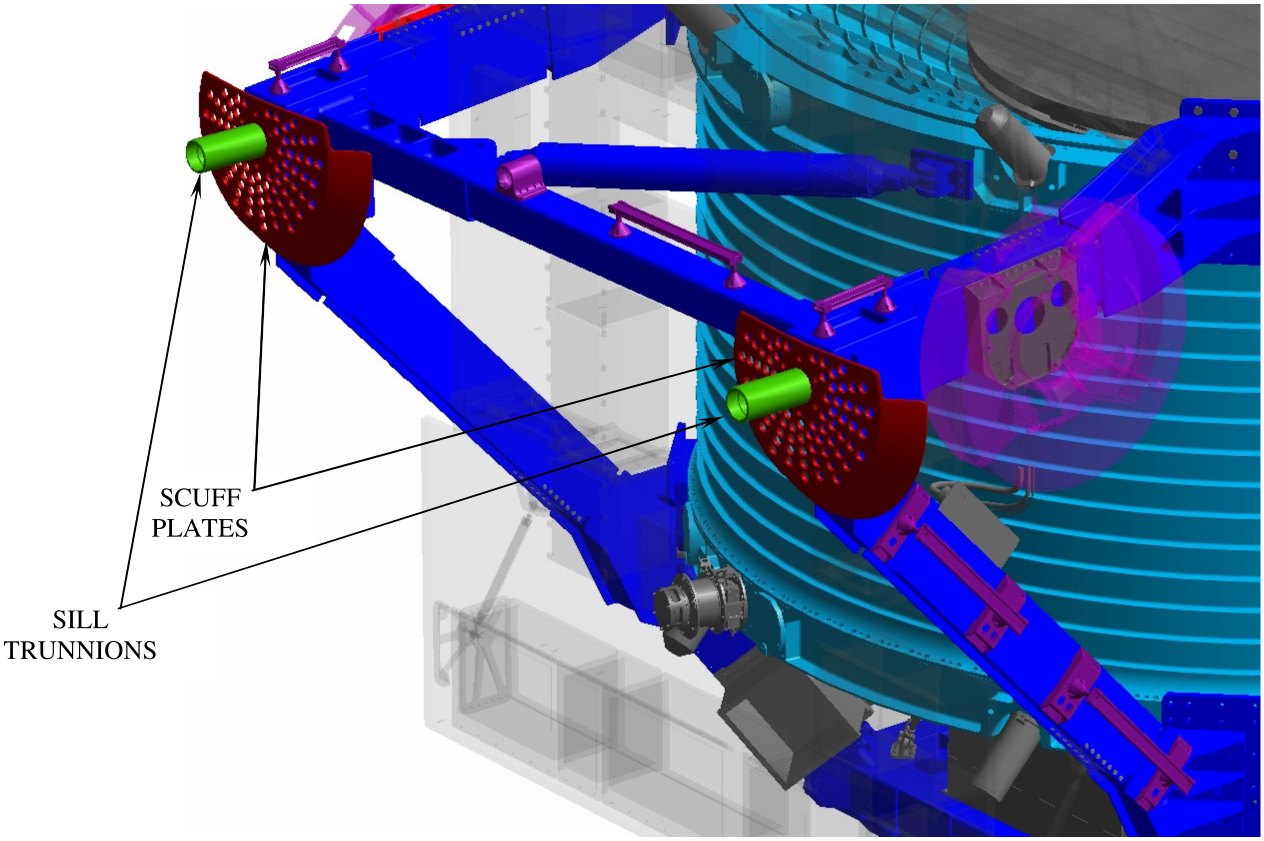


Figure 5.2-7 AMS-02 Shuttle Interfaces – Sill Trunnions and Scuff Plates

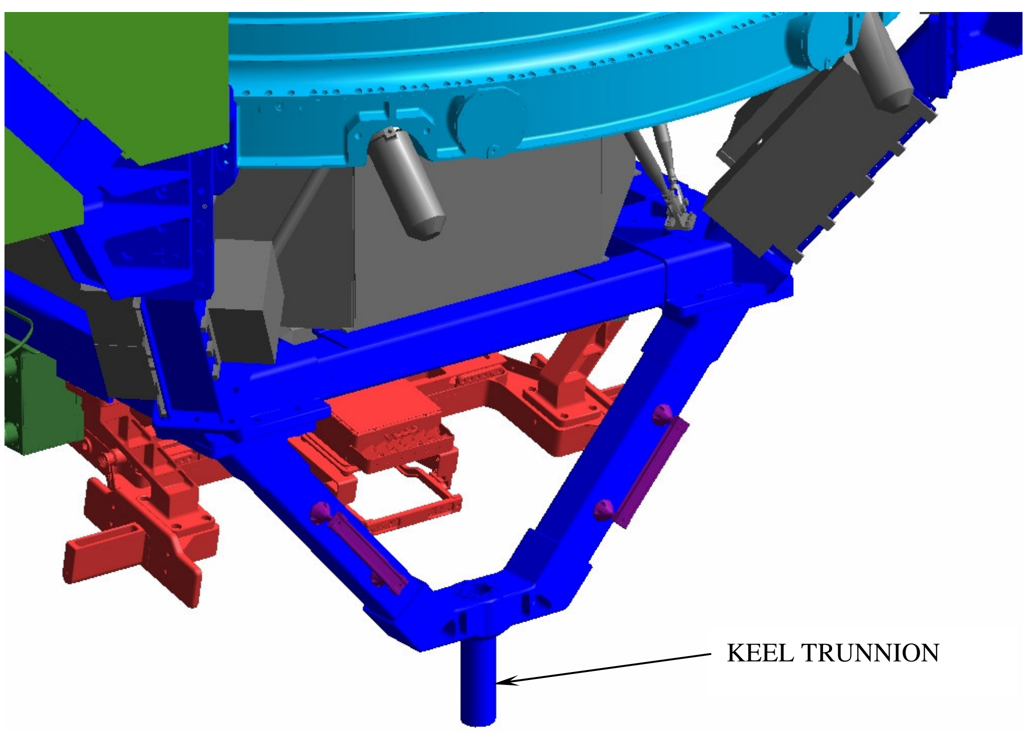


Figure 5.2-8 AMS-02 Shuttle Interfaces – Keel Trunnion

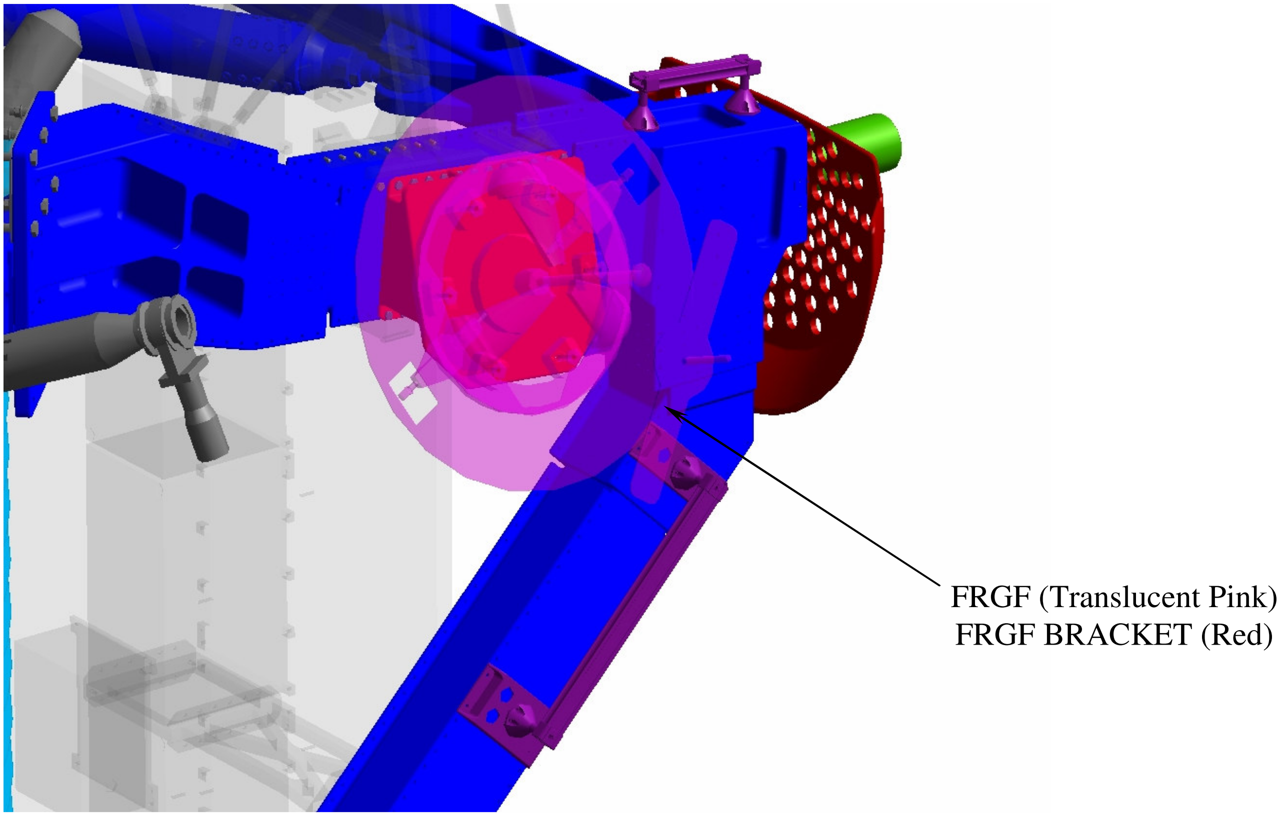


Figure 5.2-9 AMS-02 Shuttle Interfaces – FRGF

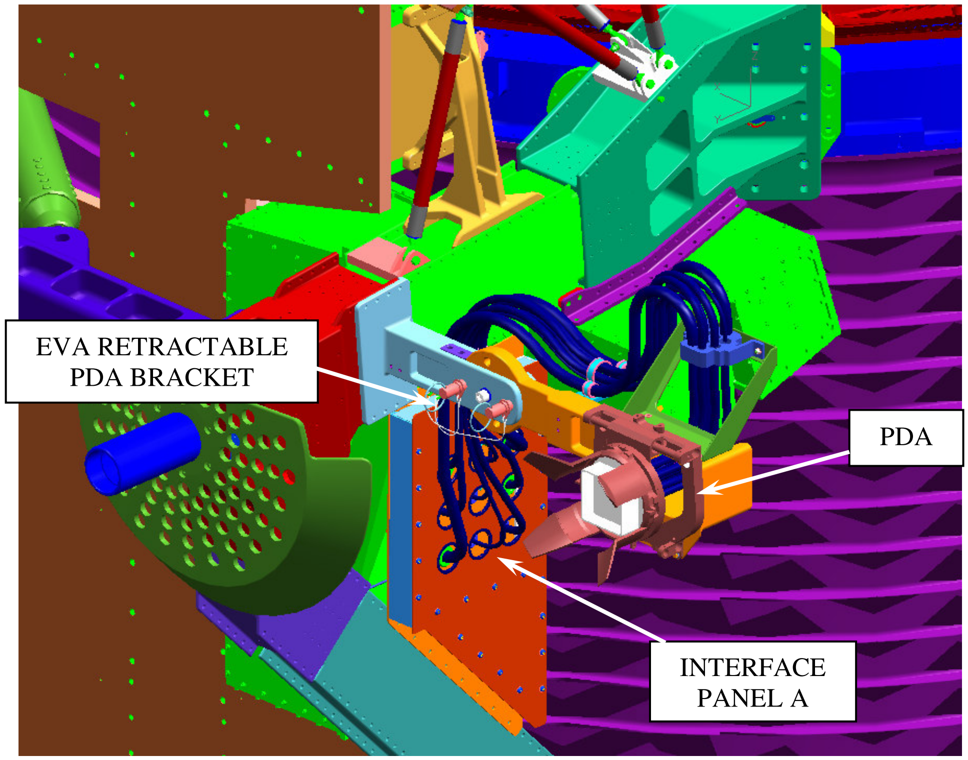


Figure 5.2-10 AMS-02 Shuttle Interfaces – PDA

The ISS interfaces include the AMS-02 Payload Attach System (PAS), UMA, and the PVGF. The AMS-02 PAS interfaces with the ISS at the three Guide Pins, the Capture Bar, and the ISS provided passive Umbilical Mechanism Assembly (UMA) per the ISS Attached Payload ICD (SSP57003). The PAS has a mechanism to allow for an EVA crewmember to unload and release the capture bar so that the Payload can be removed from ISS in the event of a failure. Details of the AMS-02 PAS are covered in Section 5.3 of this SDP. The UMA is the power and data interface to ISS. It is GFE that is bolted to the Payload per SSP57003. The Power Video Grapple Fixture is the SSRMS interface used to berth the payload to ISS. It is bolted to the payload via a custom designed, machined 6061-T651 aluminum alloy bracket. The PVGF has the capability to provide power, video and data interfaces via the ISS SSRMS; however, the AMS-02 payload will only utilize the video (for EBCS operations) and power interfaces.

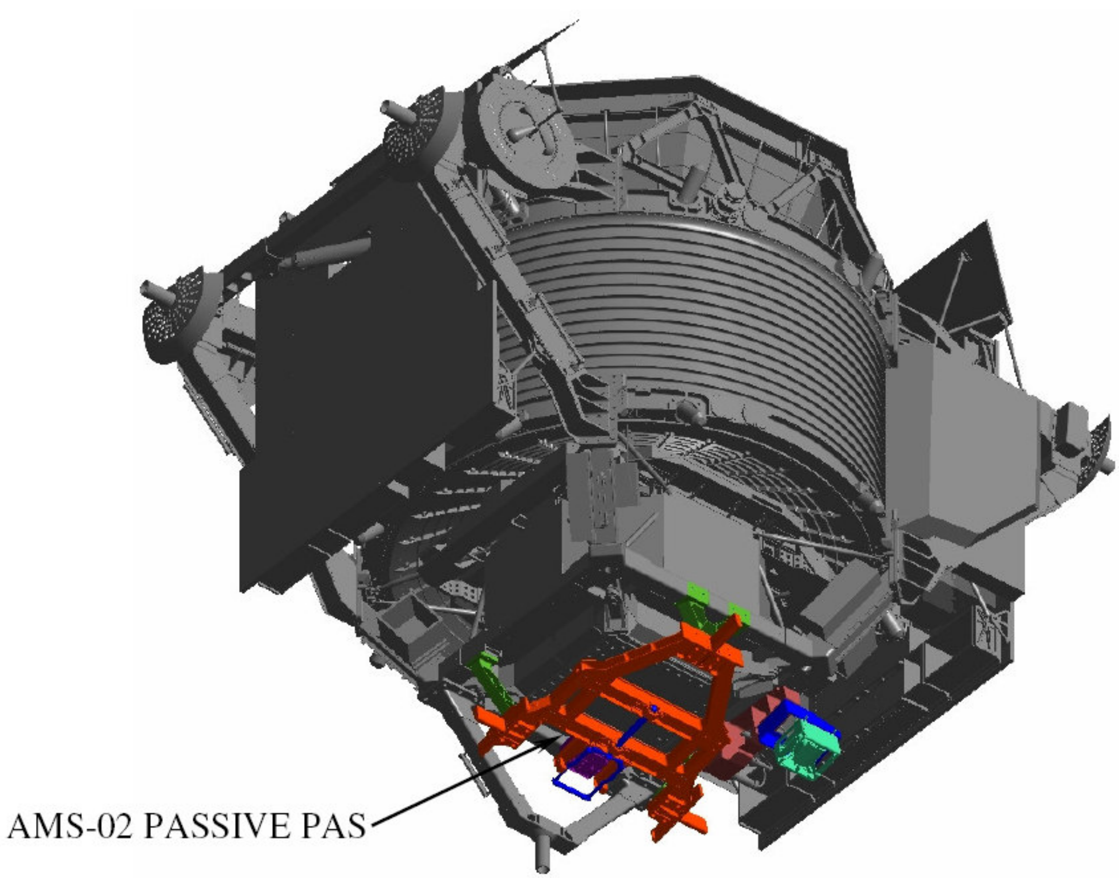


Figure 5.2-11 ISS Interfaces – Passive PAS

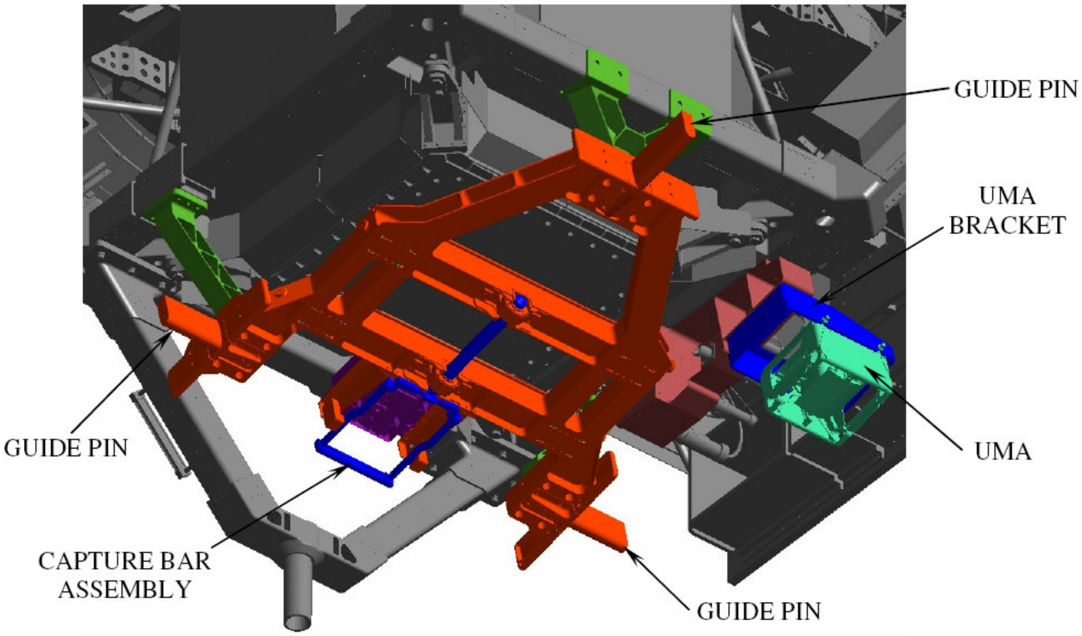


Figure 5.2-12 ISS Interfaces – Passive PAS

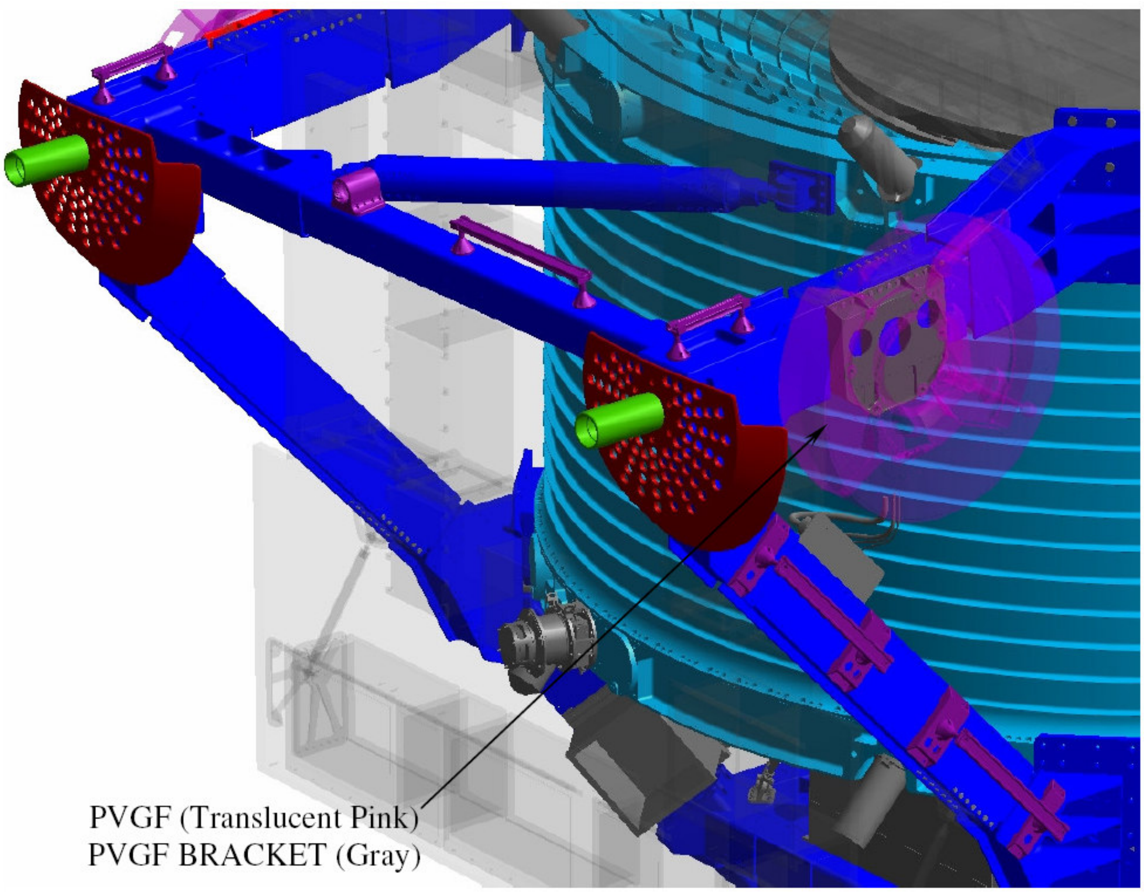


Figure 5.2-13 ISS Interfaces – PVGF

EVA interfaces include nine handrails, two WIFs, two sets of grapple release bolts on the PVGF and FRGF, two PAS unload bolts, one Capture Bar Release Handle, and the EVA Foldable ROEU PDA Bracket. All but three of the handrails are mounted to the USS-02 generic hole pattern via aluminum alloy 6061-T651 adapter brackets. The other three handrails are bolted to the aluminum alloy 7075-T73511 square tube extrusions. The WIF is mounted to an aluminum alloy 6061-T651 adapter bracket that is mounted to a square tube extrusion. The PAS unload bolts and the Capture Bar Release Handle are discussed in Section 5.3.2. The EVA Foldable ROEU PDA Bracket is discussed in Section 5.4.3.7.

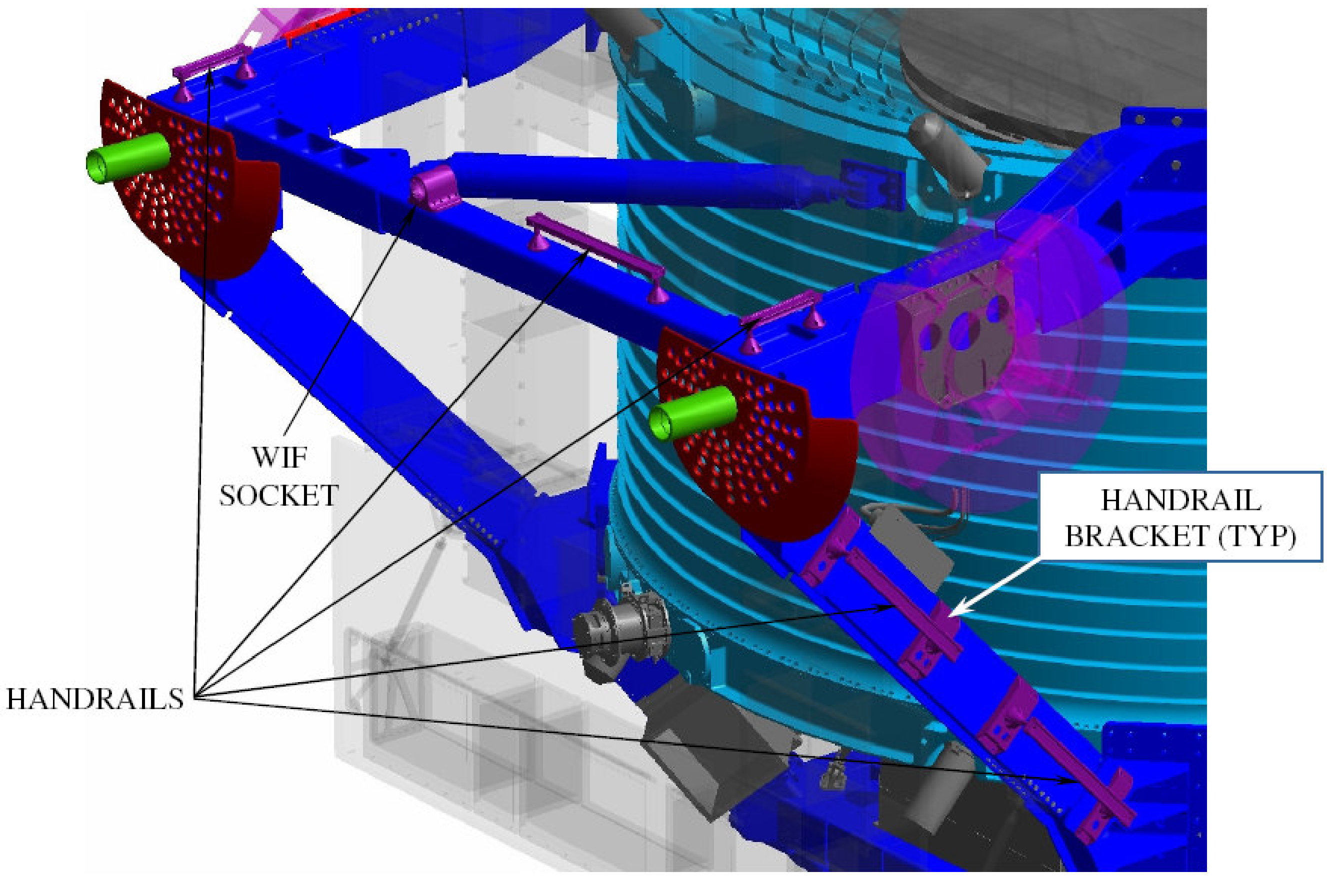


Figure 5.2-14 EVA Interfaces – WIF Socket and Handrails

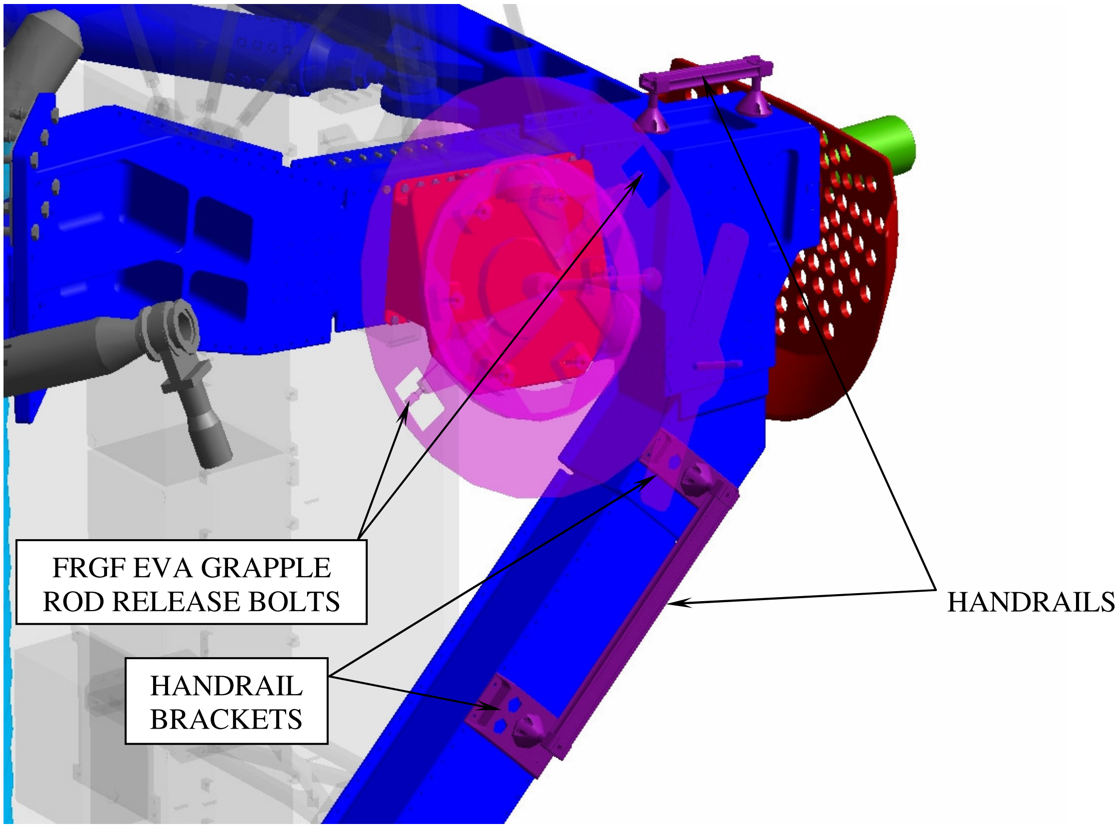


Figure 5.2-15 EVA Interfaces – Handrails and FRGF Release Bolts

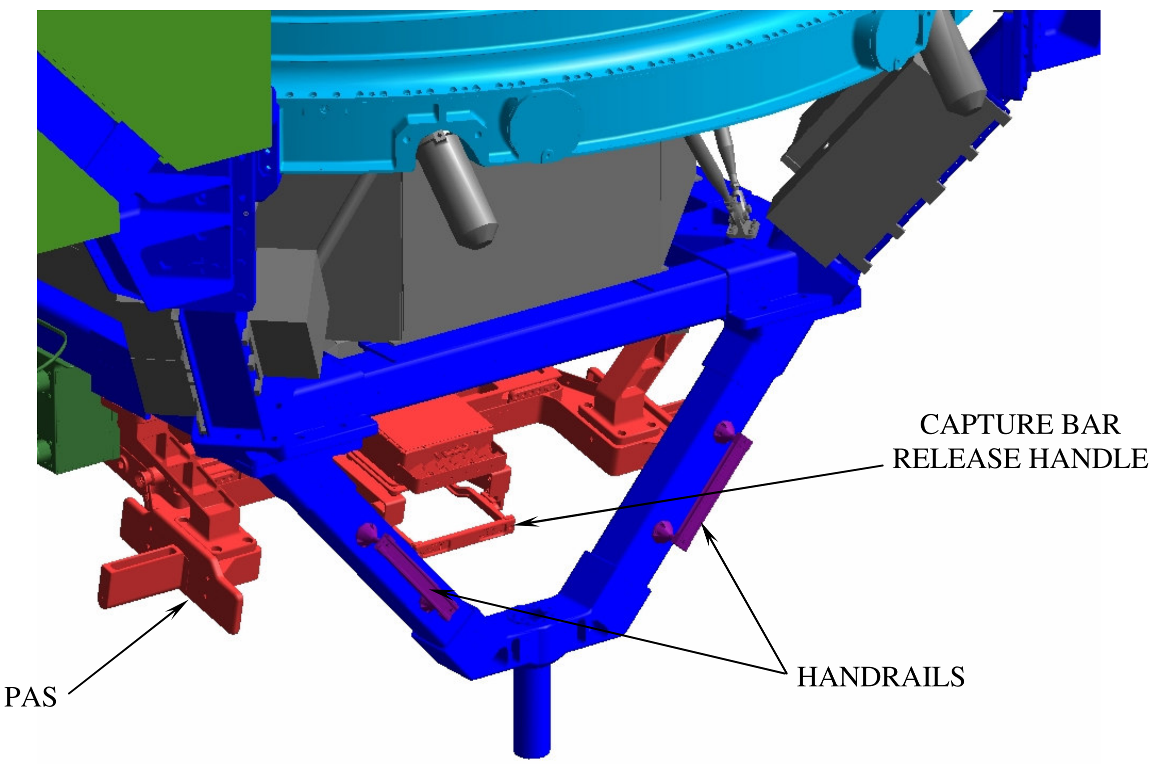


Figure 5.2-16 EVA Interfaces – Handrails and PAS Capture Bar Handle

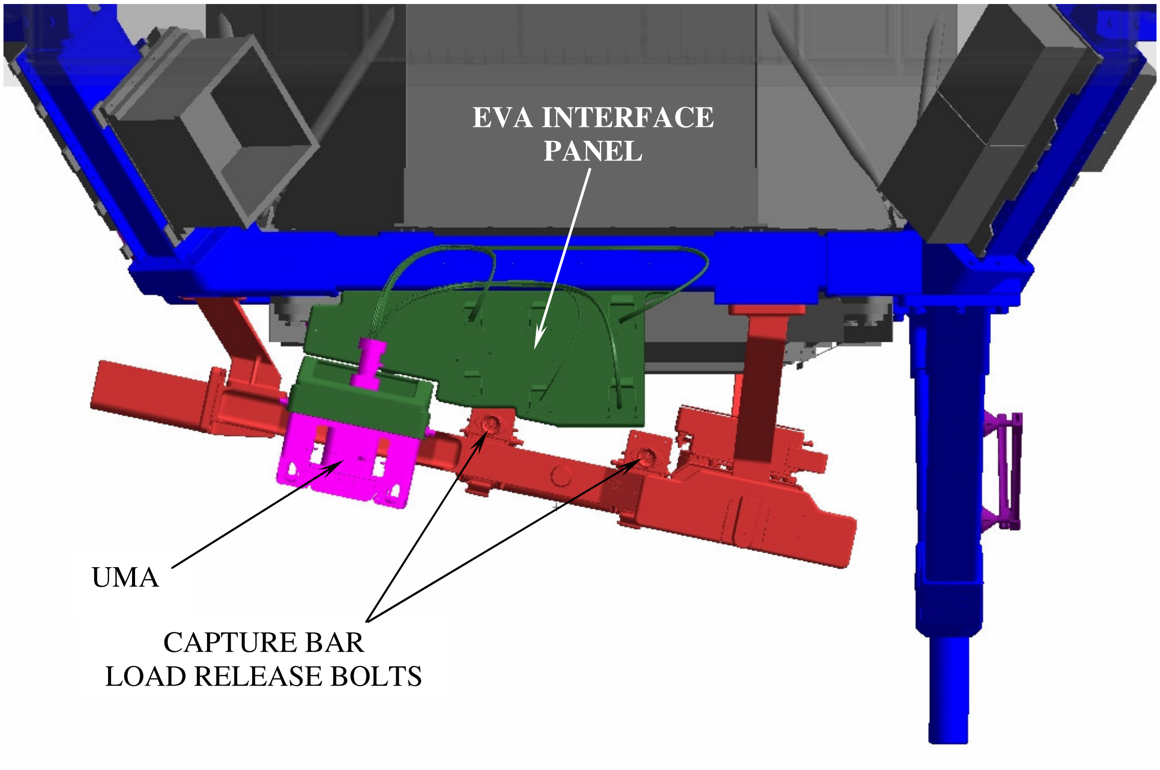


Figure 5.2-17 EVA Interfaces – PAS Capture Bar Handle

A single USS-02 will be built to completion and a number of significant subassemblies of a second USS-02 are available. The Lower USS-02 also has a single unit built to completion for flight and testing purposes with significant assemblies available..

The USS-02 will undergo structural testing. Structural testing will be performed per JSC 28792, AMS-02 Structural Verification Plan (SVP). This testing will include a full static test to 1.1 x limit load and a modal test.

5.3 PASSIVE PAYLOAD ATTACH SYSTEM (PAS)

The AMS-02 Payload interfaces with the ISS S3 truss via the Payload Attach System (PAS) (Figure 5.3-1). The PAS is comprised of two halves, the active and passive halves. The active half is an integral part of the truss. The passive PAS is an integral part of the Payload (Figures 5.3-2 & 5.3-3). The AMS-02 PAS Assembly was developed by the AMS-02 Project specifically for the AMS-02 Payload per SSP57003.

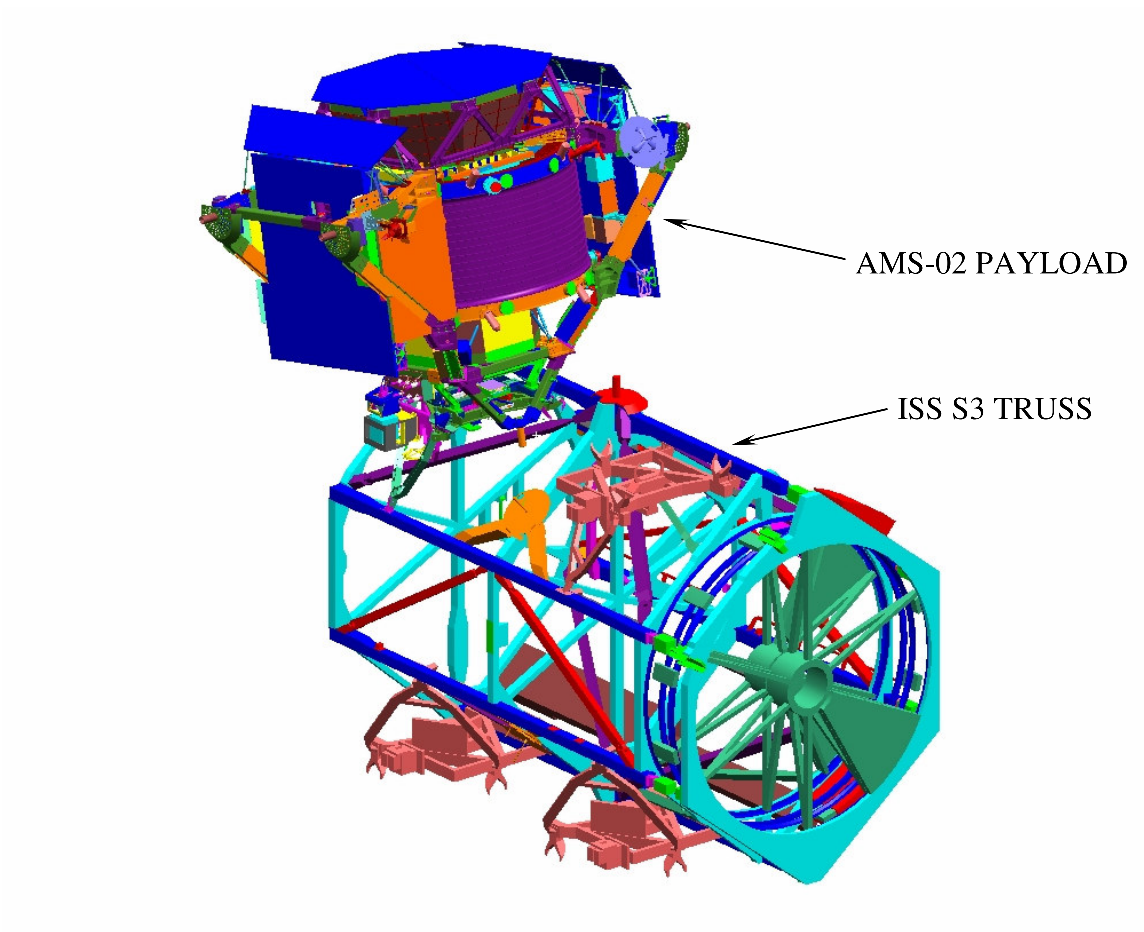


Figure 5.3-1 The AMS-02 Payload on the ISS Starboard 3 (S3) Truss

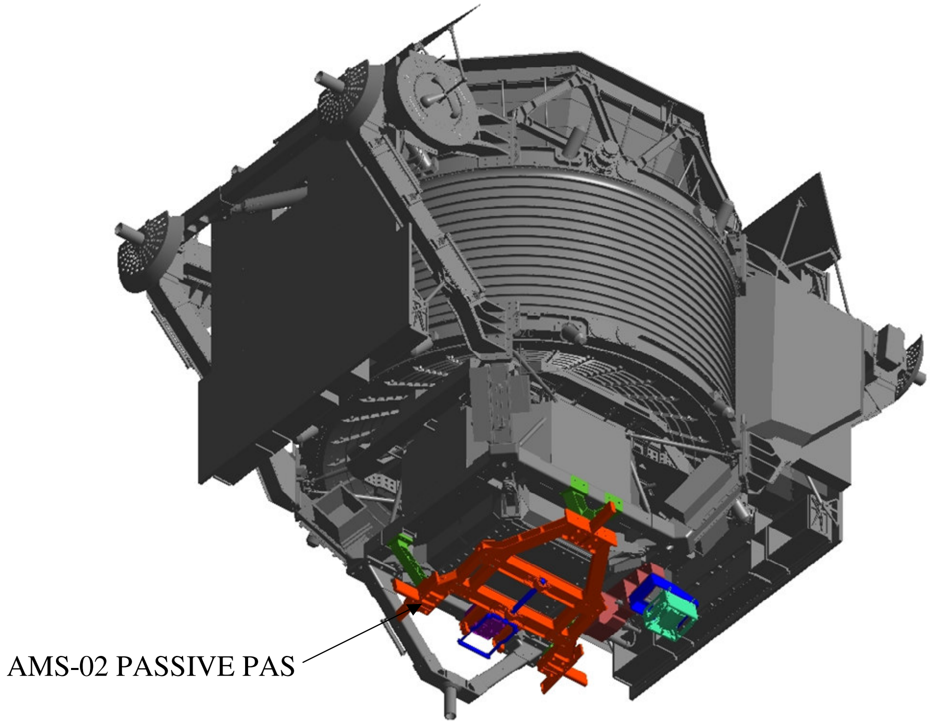


Figure 5.3-2 The Passive PAS on the bottom of the AMS-02 Payload (1 of 2)

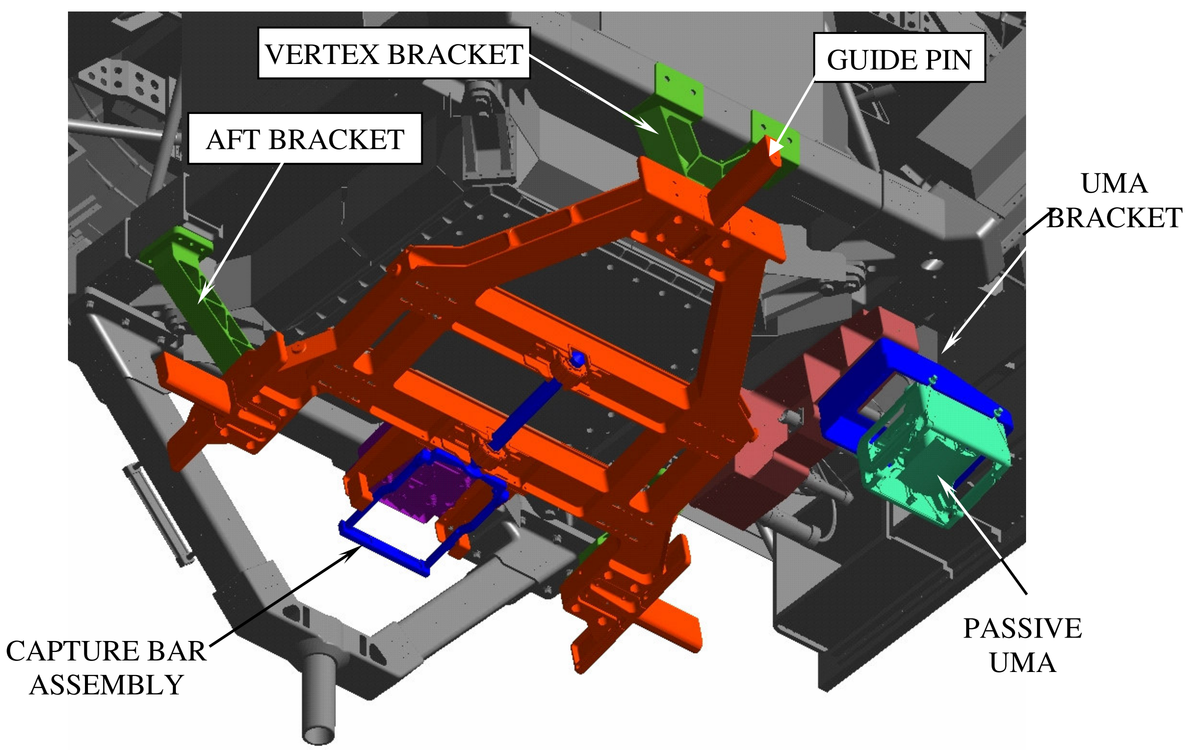


Figure 5.3-3 The Passive PAS on the bottom of the AMS-02 Payload (2 of 2)

The PAS (active and passive) consists of three basic pairs of components that interact to mate the payload to the ISS (Figures 5.3-4 thru 5.3-6): the active half Capture Claw and passive half Capture Bar, the three active half Guide Vanes and the passive half Guide Pins, and the active Umbilical Mechanism Assembly (UMA) and the passive UMA. The Capture Claw, Capture Bar, Guide Vanes, and Guide Pins provide the structural attachment for the Payload to ISS and the active and passive UMA provide power and data connection from ISS to the Payload.

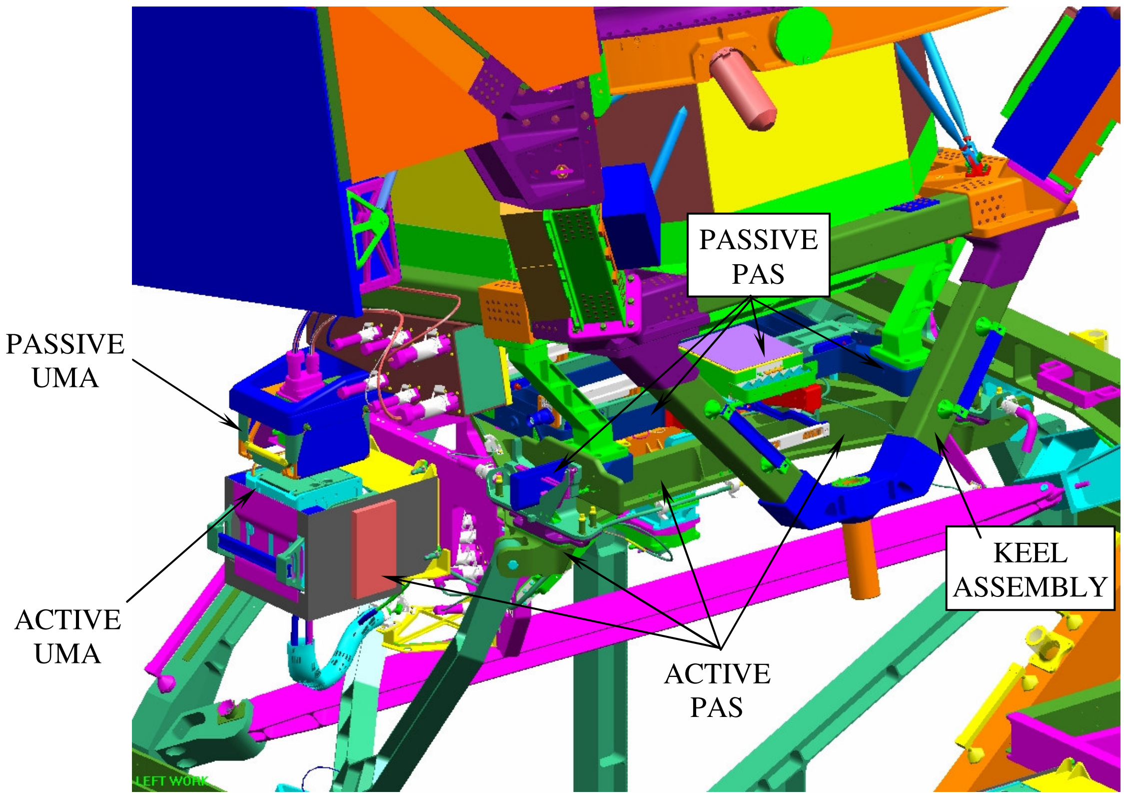


Figure 5.3-4 The AMS-02 Passive PAS attached to the ITS3 Active PAS (1 of 3)

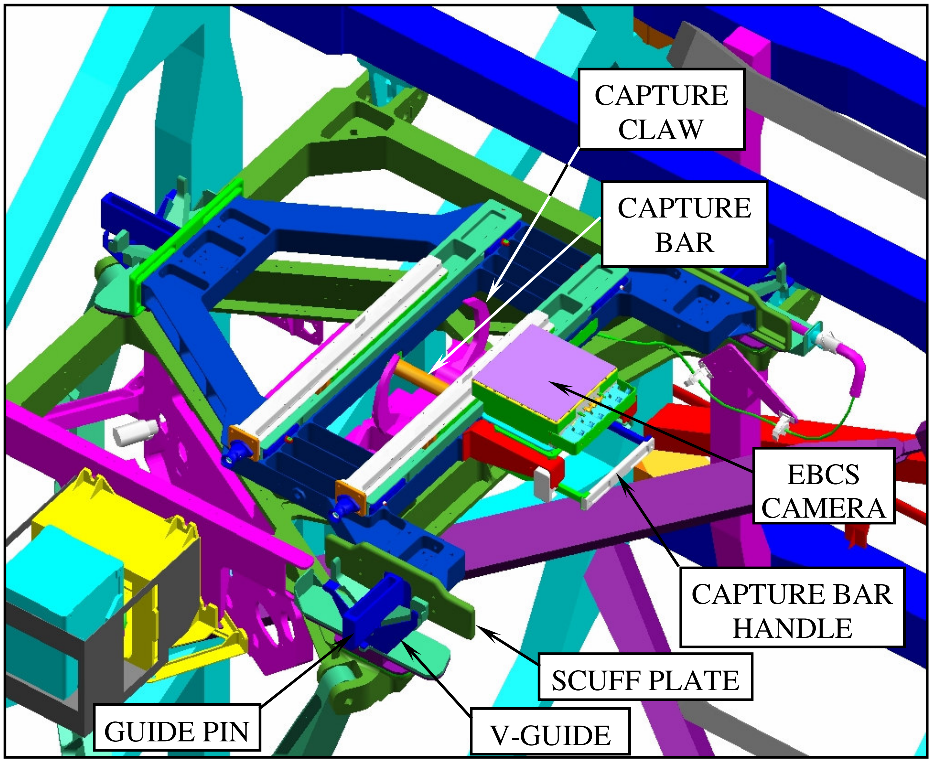


Figure 5.3-5 AMS-02 Passive PAS attached to the ITS3 Active PAS (2 of 3)

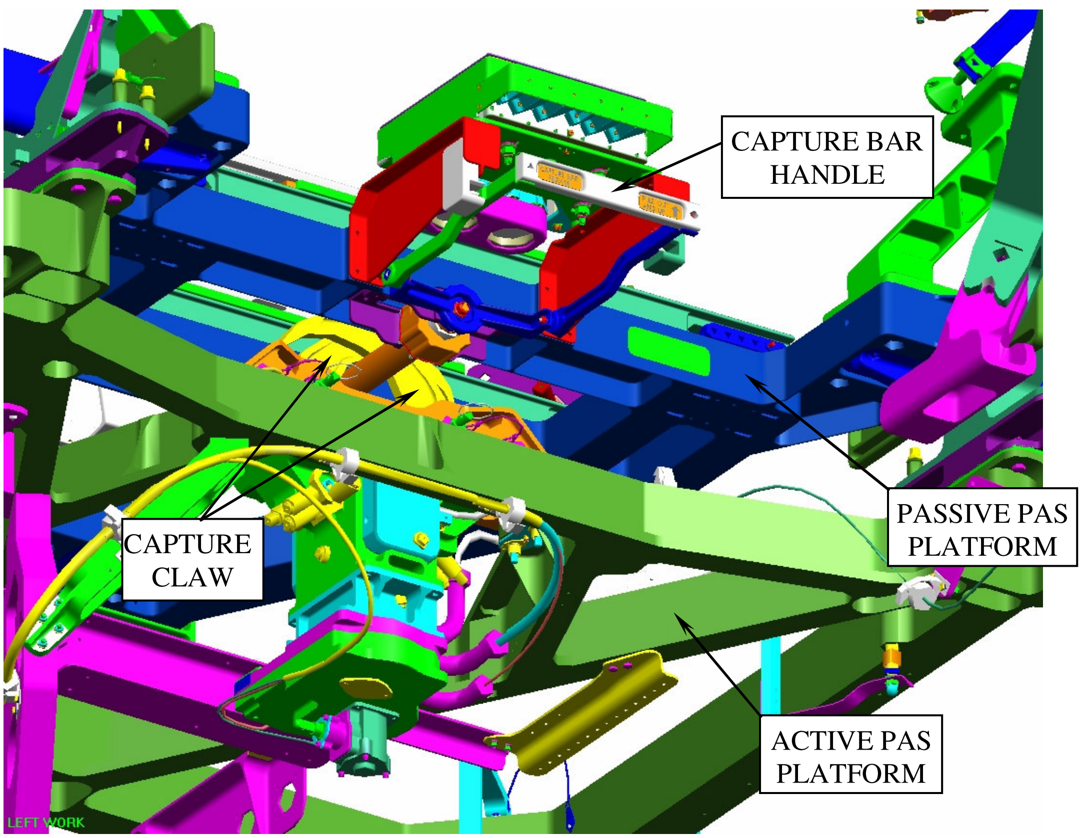


Figure 5.3-6 AMS-02 Passive PAS attached to the ITS3 Active PAS (3 of 3)

The Capture Claw latches onto and pulls down on the Capture Bar. This induces a load in the system that is reacted via the Guide Vane / Guide Pin interface. When the Capture Claw is fully closed, it is required to impart a 6430 lb maximum and a 4900 lb minimum load into the system thus clamping the two halves together. This load holds the payload to the ISS. Once the Payload is structurally mounted to ISS the active UMA is driven into the passive UMA. The passive UMA is GFE from ISS. The Payload only provides structural mounting and power and data connectors to the passive UMA.

5.3.1 EVA Releasable Capture Bar

Per SSP 57003, the AMS-02 PAS incorporates a mechanism to unload the capture bar and release the Payload from the ISS (Figure 5.3.1-1). To unload and release the AMS-02 Payload from ISS, an EVA crewmember first unloads the capture bar, by driving two EVA bolts using the Pistol Grip Tool (PGT). Turning the bolts a defined number of turns and alternating between the two lowers the Capture Bar and relieves any load in the system. The crewmember then retracts the capture bar by reaching thru the AMS-02 Keel structure, grasping the Capture Bar Assembly handle, and pulling the capture bar out towards the keel and up towards the Payload. Once the capture bar is retracted, the Payload is free from the PAS and the ISS.

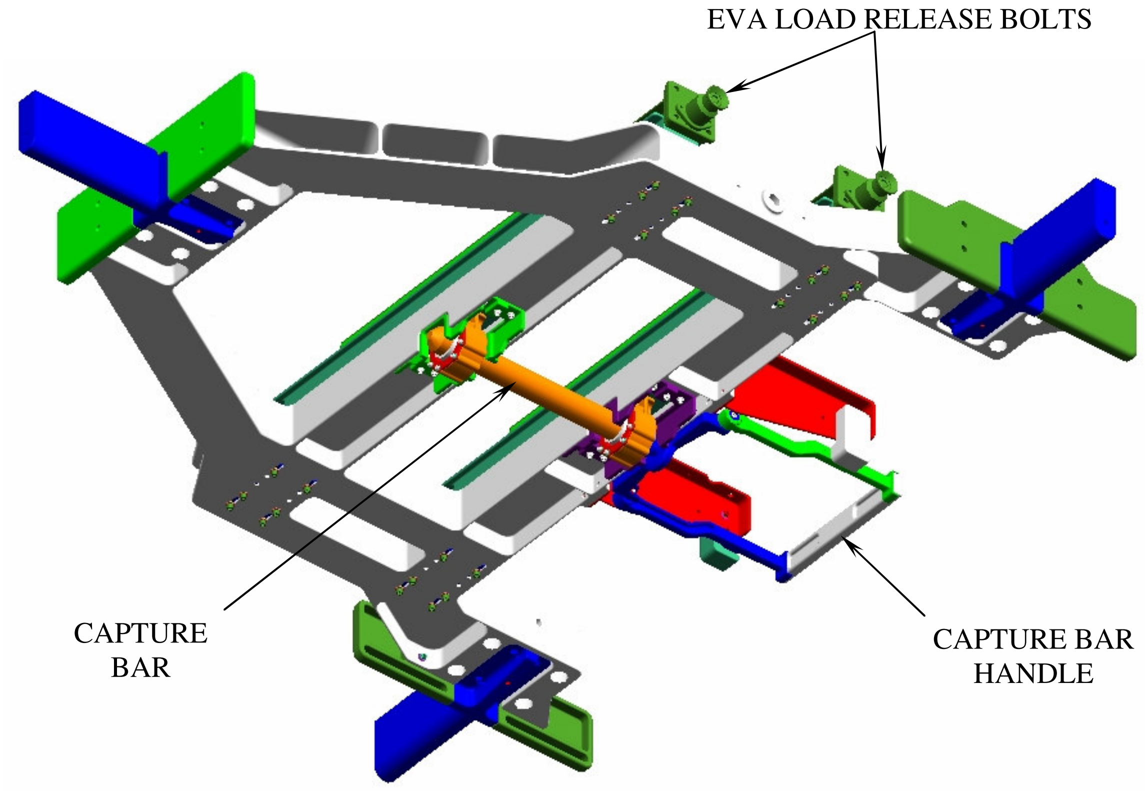


Figure 5.3.1-1 PAS EVA Releasable Capture Bar

The AMS-02 PAS Assembly is bolted to the Lower USS-02 via four brackets, the Vertex Bracket, two Aft Brackets and the UMA Bracket. The AMS-02 PAS Assembly (Figure 5.3.1-2) consists of five bolted subassemblies, the PAS Base Assembly, EVA Extension Assembly, PAS Bridge Assembly, Capture Bar Assembly, and EBCS Avionics Assembly. All bolts used in the AMS-02 PAS Assembly are certified by the NASA/JSC Fastener Integrity Program and utilize locking nut or inserts or self-locking bolts as a secondary method of back-out prevention.

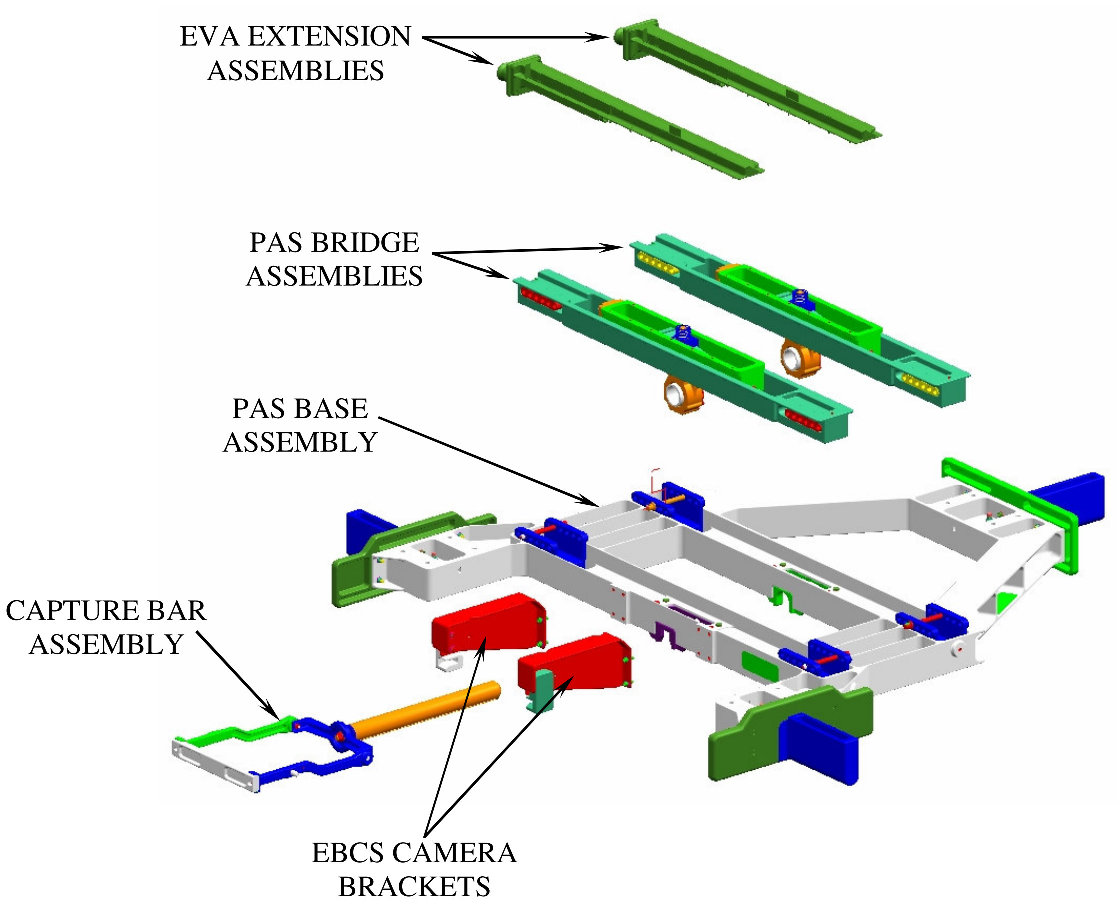


Figure 5.3.1-2 AMS-02 PAS Component Detailed Description

The PAS Base Assembly is the overall structural member of the PAS Assembly. All other subassemblies are supported by it. The PAS Bridge Assembly supports the Capture Bar Assembly and houses the Capture Bar Release Mechanism. The EVA Extension Assembly provides a standard 7/16" EVA socket interface, a locking feature to prevent back out of the Capture Bar Release Mechanism and a cover for the PAS Bridge Assembly. The EBCS Avionics Assembly locates and supports the EBCS Camera and provides brackets to retain Capture Bar Handle.

The PAS Base Assembly is composed of the PAS Platform, Guide Pins, Scuff Plates, and Capture Bare Retainer Brackets as show in Figure 5.3.1-3. The PAS Platform is a single piece of machined 7050-T7451 aluminum plate. It is the structural element that ties all the PAS components to the brackets that attach it to the Lower USS-02 and the rest of the

Payload. The aluminum Guide Pins, Scuff Plates, and stainless steel Capture Bar Retainer Brackets are all bolted to the PAS Platform.

PAS BASE ASSEMBLY COMPONENTS

- PAS PLATFORM
- GUIDE PINS
- SCUFF PLATES
- CAPTURE BAR RETAINER BRACKETS

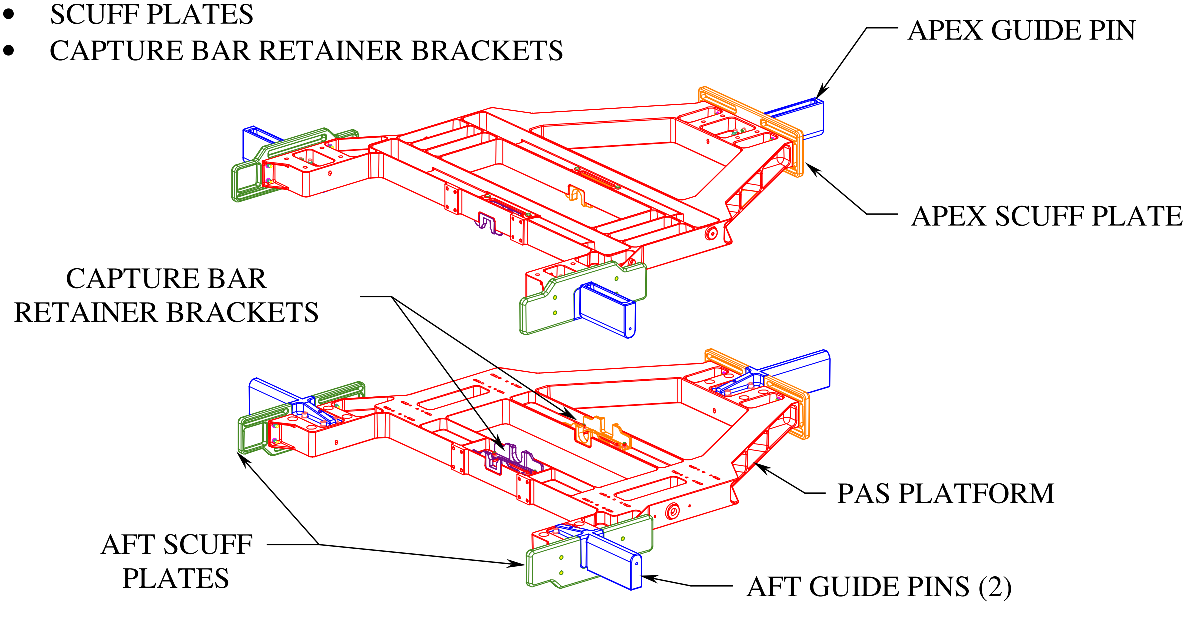


Figure 5.3.1-3 PAS Base Assembly

The EVA Extension Assembly is composed of the EVA Screw Extension, Screw Locking Housing, Lock Retractor, Compression Spring, and Release Mechanism Cover. The EVA Screw Extension, Compression Spring, Locking Retractor and Locking Mechanism Base are all made from A286 stainless steel. The Release Mechanism Cover is made from 7075 aluminum alloy. The EVA Extension (Figure 5.3.1-4) has an internal hex on one end and an external EVA tool compatible hex on the other end. Just below the external hex is a flange that prevents the extension from passing thru the Release Mechanism Cover. The Compression Spring and Locking Retractor stack on top of the flange. The Locking Mechanism fits over and retains the assembly with two screw threaded into the Release Mechanism Cover.

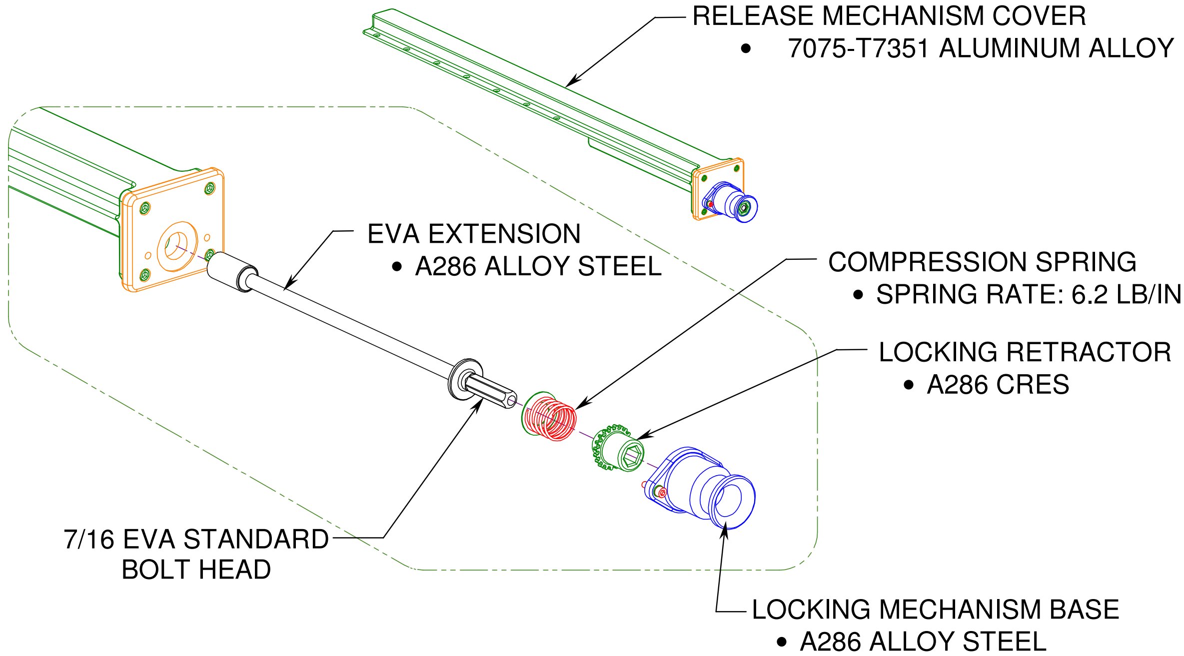


Figure 5.3.1-4 EVA Extension Assembly

The PAS Bridge Assembly (Figure 5.3.1-5) is composed of the Bridge, Load Release Mechanism and the Bearing Assembly. The Bridge is machined from one piece of 7075 aluminum alloy. The Release Mechanism Assembly is bolted onto the Bridge with four bolts. The Bearing Assembly's threaded shaft passes thru a hole in the Bridge and Release Mechanism Housing and thru a slot in the Wedge and is retained by a nut and mating wedge shaped washer. This washer is held against the Wedge by a compression spring that bears up against the EVA Extension Assembly Cover.

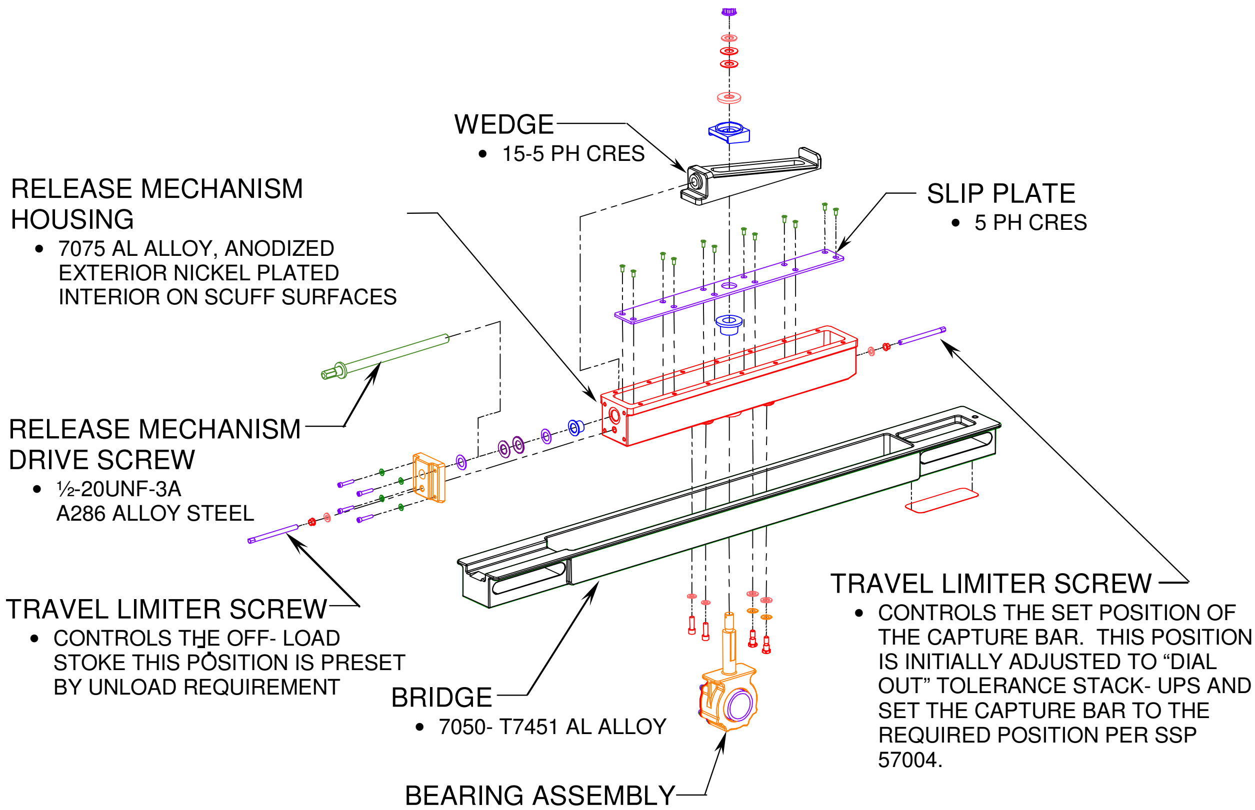


Figure 5.3.1-5 PAS Bridge Assembly and Load Release Mechanism

The Load Release Mechanism is composed of the Release Mechanism Housing, the Release Mechanism Drive Screw and Wedge, and Travel Limiter Screws. The Release Mechanism Drive Screw is made from A286 stainless steel and is sandwiched between the 7075 aluminum alloy Release Mechanism Housing and an aluminum alloy retainer bracket. Its threaded shaft passes thru the housing and threads into the Wedge. The15-5PH stainless steel Wedge has a threaded hole on one end for the Release Mechanism Drive Screw, and a slot along its length for the Bearing Assembly rod to pass thru. The A286 stainless steel Travel Limiter Screws thread into and pass thru the Release Mechanism Housing. A nut on the inside of the Release Mechanism Housing provides as secondary locking feature for the Travel Limiter Screws. The limiter screw on the same side as the thick portion of the Wedge sets the unloaded limit of the Bearing Assembly. The opposite limiter screw sets the loaded position of the Bearing Assembly.

The Bearing Assembly is comprised of a 15-5PH stainless steel Bearing Housing, a stainless steel, PTFE lined spherical bearing and an A-286 stainless steel retainer plate. The spherical bearing is pressed into the Bearing Housing and is retained by the retainer plate. The retainer plate is secured using 5 screws threaded into the Bearing Housing.

The primary components of the Capture Bar Assembly (Figure 5.3.1-6) are the Capture Bar, Capture Bar Removal Handle and Capture Bar Handle Base, Handle Extensions and Handle Pins.. The Capture Bar is a dry film lubricated A286 stainless steel bar with a closed ended slot machined down the side and a treaded boss on one end. The slot interfaces with a key in the Spherical Bearing Assembly to retain the Capture Bar with the PAS Assembly. The 6061 aluminum alloy Capture Bar Removal Handle bolted to two 6061 aluminum alloy Handle Extensions. The Handle Extensions are bolted to the 15-5PH stainless steel Handle Base with two screws and aluminum bronze bushing which allow the handle to pivot. The Capture Bar Handle Base is fixed to the Capture Bar by a nut and prevented from rotating using a boss and a hole in the bar onto a boss machined into Capture Bar. The handle base has a groove machined into it that interfaces the Capture Bar Retainer Bracket in two locations to retain the Capture Bar Assembly while in the nominal position.

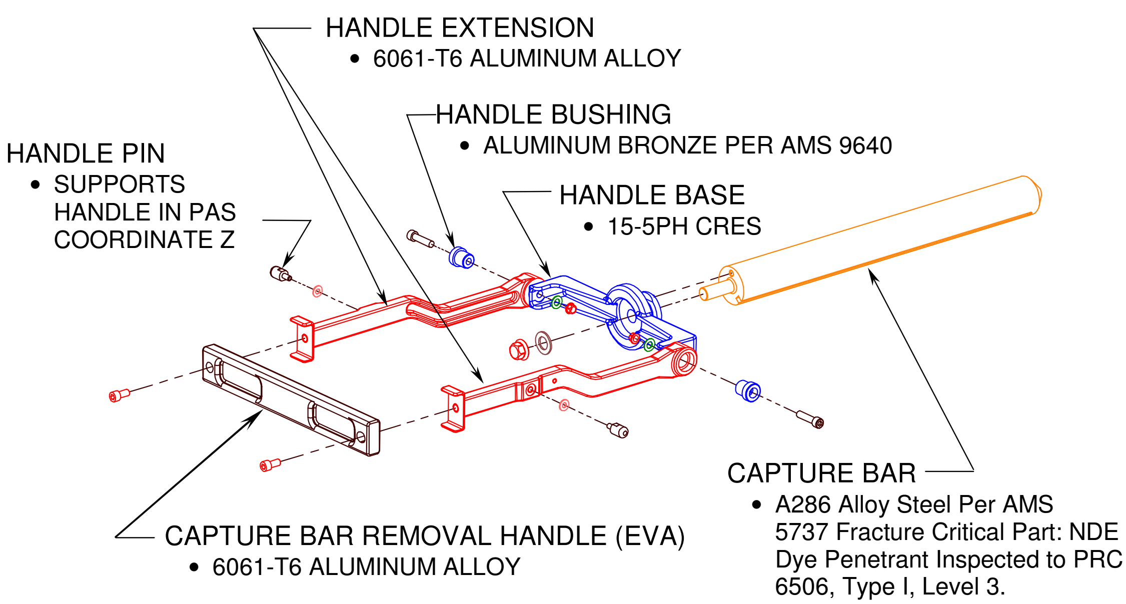


Figure 5.3.1-6 Details of the PAS Capture Bar

The EBCS Avionics Package (Figure 5.3.1-7) consists of the EBCS Camera and the EBCS Camera mounting Brackets. The 7075-T7351 aluminum alloy EBCS Camera Mounting Brackets bolt to the PAS Base Assembly with four screws per bracket. Each bracket contains another bracket to hold the Capture Bar Assembly Handle. The EBCS Avionics Package is bolted to the EBCS Camera Mounting Brackets.

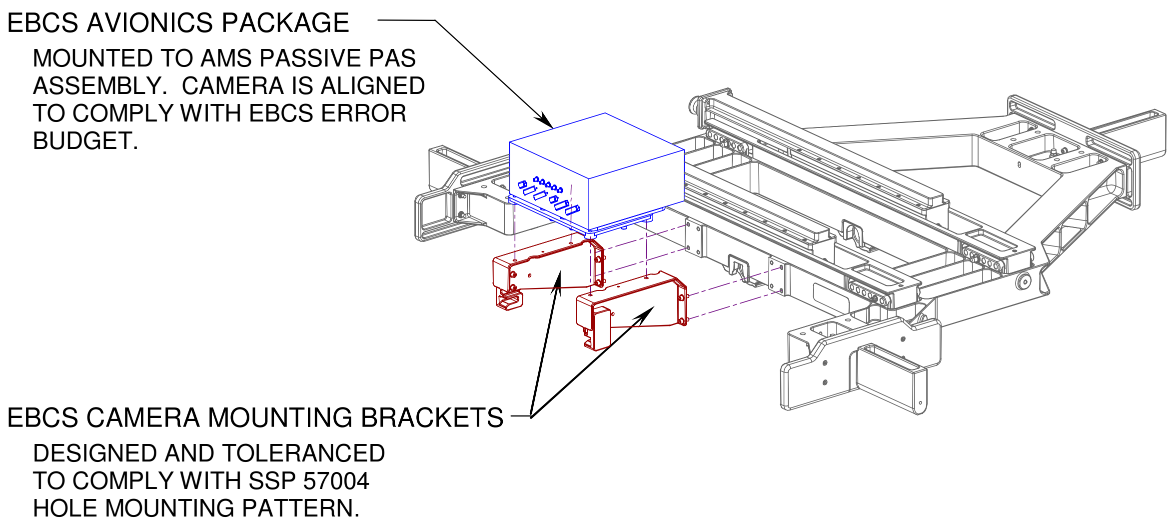


Figure 5.3.1-7 EBCS Avionics Package mounting to the PAS

5.3.2 EVA Release Mechanism

The EVA bolt head that the crewmember drives with the PGT to unload the AMS-02 PAS is machined into one end of the EVA Extension (Figure 5.3.2-1). The other end is mechanically coupled to the Release Mechanism Drive Screw that is captured by the Release Mechanism Housing and threaded into the Wedge. When the EVA Extension is turned, the Wedge translates along the axis of the drive screw as a nut would on a threaded rod. On top of the Wedge is another wedge shaped block that supports the spherical Bearing Housing that, supports the Capture Bar Assembly. When the Wedge translates, the inclined plane of the Wedge forces the Capture Bar Assembly up or allows it translate down depending on the direction of the Wedge translation. The torque required to drive the EVA unload mechanism is 2.25 ft-lbs

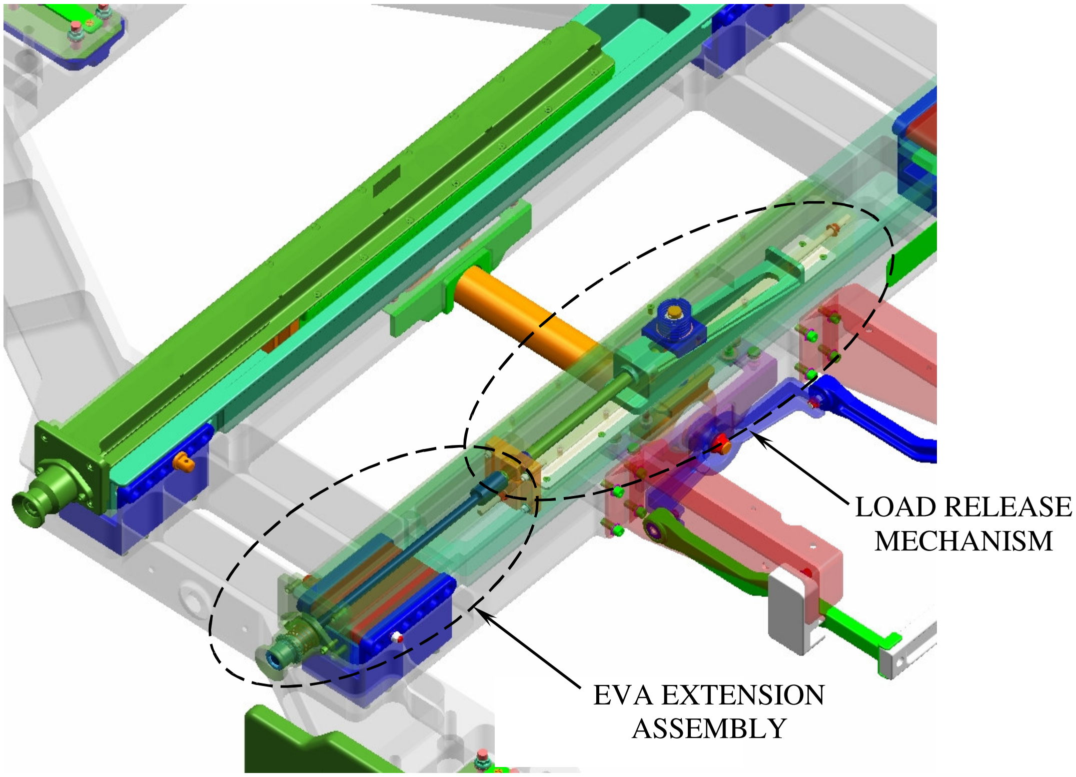


Figure 5.3.2-1 PAS Load Release Mechanism

In the nominal flight configuration, the EVA Extension is captured and prevented from turning by a locking mechanism (Figures 5.3.2-2 & 5.3.2-3) that is part of the EVA Extension Assembly. This assembly contains the Locking Retractor that has a hex shaped thru hole that fits around the hex of the EVA Extension bolt head and external teeth that mesh with teeth machined in the Locking Mechanism Base. The Locking Retractor is held up against the inside of the Locking Mechanism Base by spring force imparted by the compression spring. The Locking Mechanism Base is held in place by two screws that mount it to the EVA Extension Assembly. Locking Retractor must be pushed inward to disengage its locking teeth with the teeth in the Locking Mechanism Base. The force required to overcome the spring force of the compression spring and disengage the locking teeth is 5 LBS.

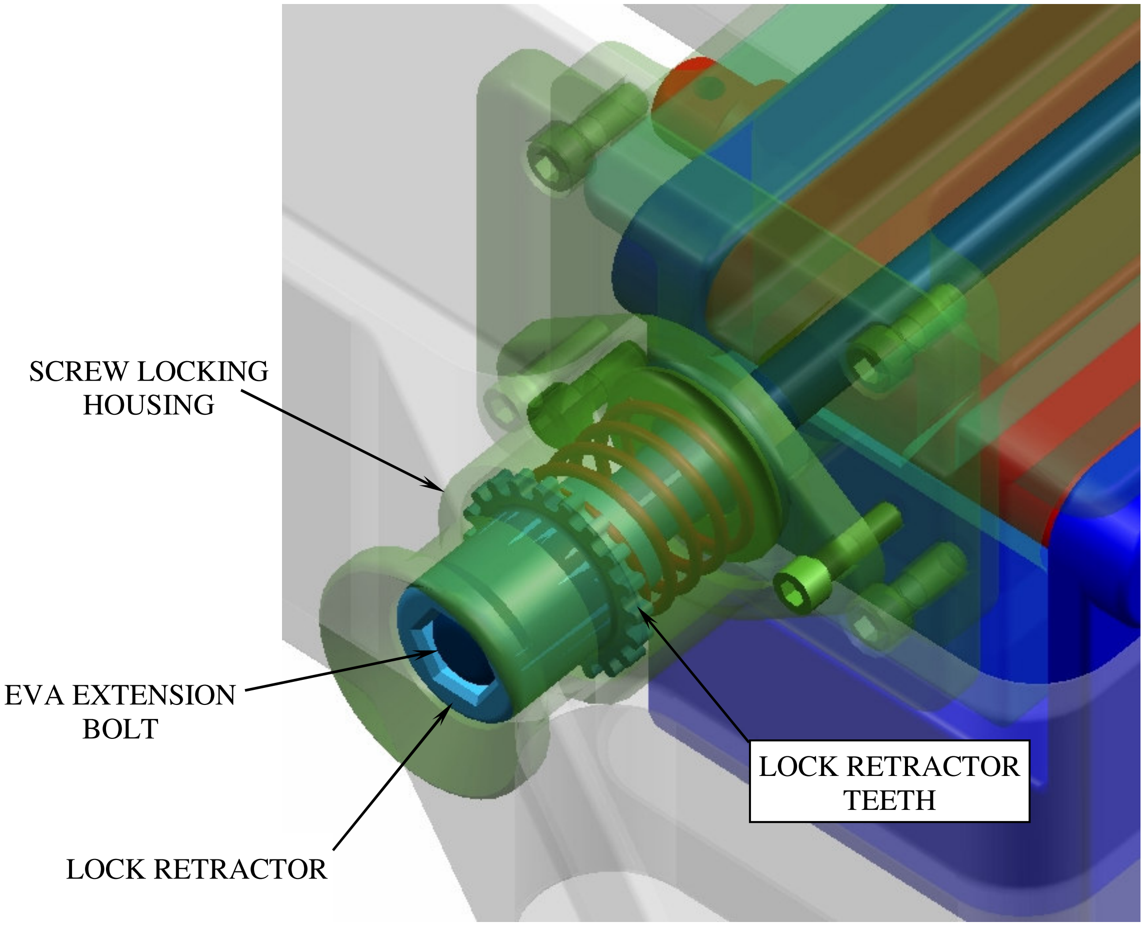


Figure 5.3.2-2 EVA Extension Locking Mechanism

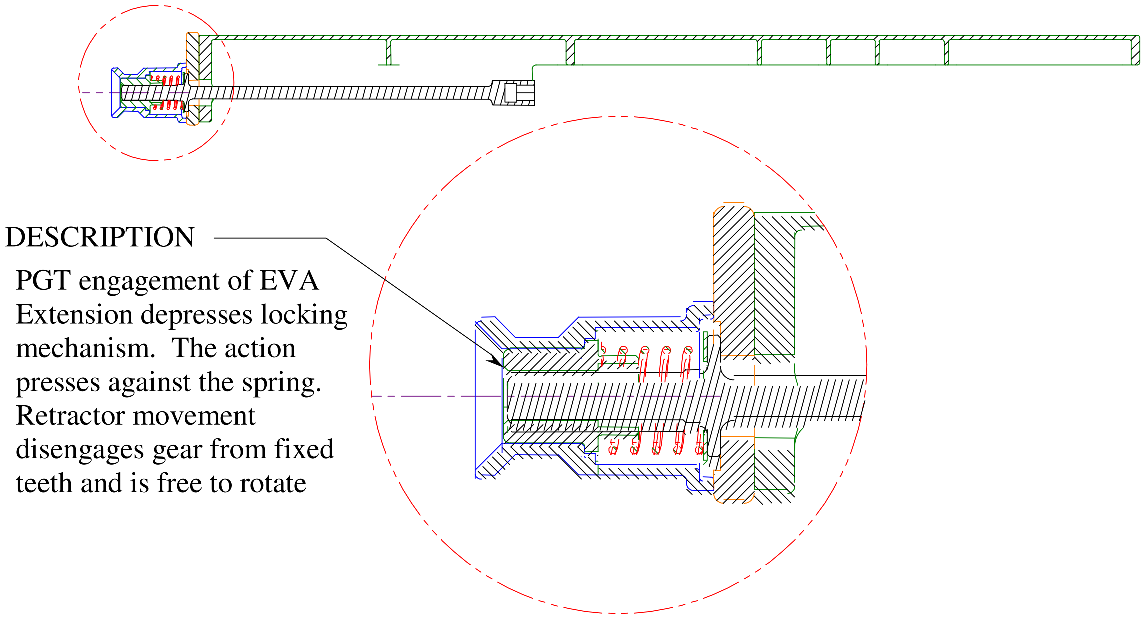


Figure 5.3.2-3 EVA Extension Locking Mechanism

Travel Limiter Screws are threaded into the Release Mechanism Housing that controls the Wedge translation limits. They provide a hard stop for the Wedge and set the height limits of the Capture Bar when the Wedge is at the ends of its stroke.

When the AMS-02 PAS is in the nominal flight configuration, the Wedge is butted up to the upper limit Travel Limiter Screw (Figure 5.3.2-4). This configuration positions the Bearing Housings closest to the PAS Base. Turning the EVA bolt interface of the EVA Extension clock-wise pulls the Wedge out from underneath the Bearing Housing wedge, allowing the Bearing Housing to drop, thus relieving the load imposed on the Capture Bar by the ISS Capture Claw. A compression spring forces the bearing housing down in case there is no load on the Capture Bar.

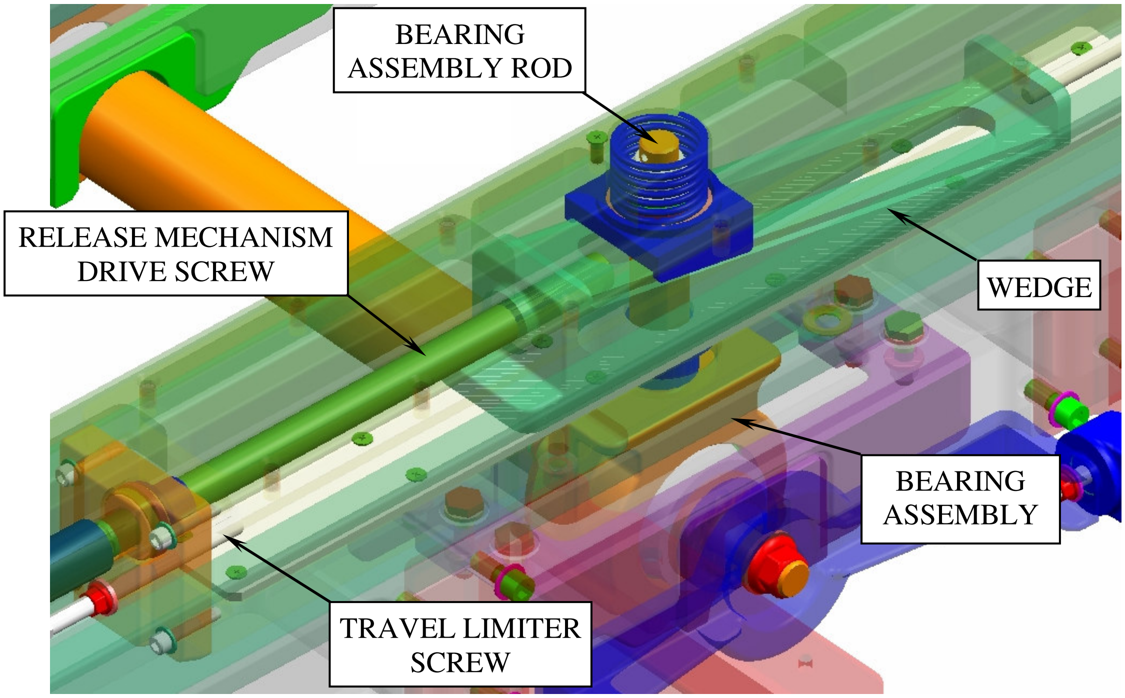


Figure 5.3.2-4 Load Release Mechanism Details

The Capture Bar Assembly (Figures 5.3.2-5 & 5.3.2-6) contains the Capture Bar and the Capture Bar Removal Handle. The Capture Bar is supported by the spherical bearings in the Bearing Assemblies and the Removal Handle is held in place by slots in EBCS Camera Brackets. In the nominal flight configuration, the Capture Bar Assembly is locked in place by mating grooves in the Capture Bar and Capture Bar Retainer Bracket. Four bolts secure the Capture Bar Retainer Bracket to the PAS Base. Once the Capture Bar is unloaded and driven fully down, where the Wedge is against the lower limit Travel Limiter Screw, it will clear the slots in the retainer brackets and it can be slid out of one of the spherical Bearing Housing by pulling the Capture Bar Removal Handle. The Capture Bar Assembly is prevented from sliding free of the PAS by means of a key that fits into a close-ended groove machined into the Capture Bar. The key is fixed to the Bearing Housing nearest to the Capture Bar Removal Handle.

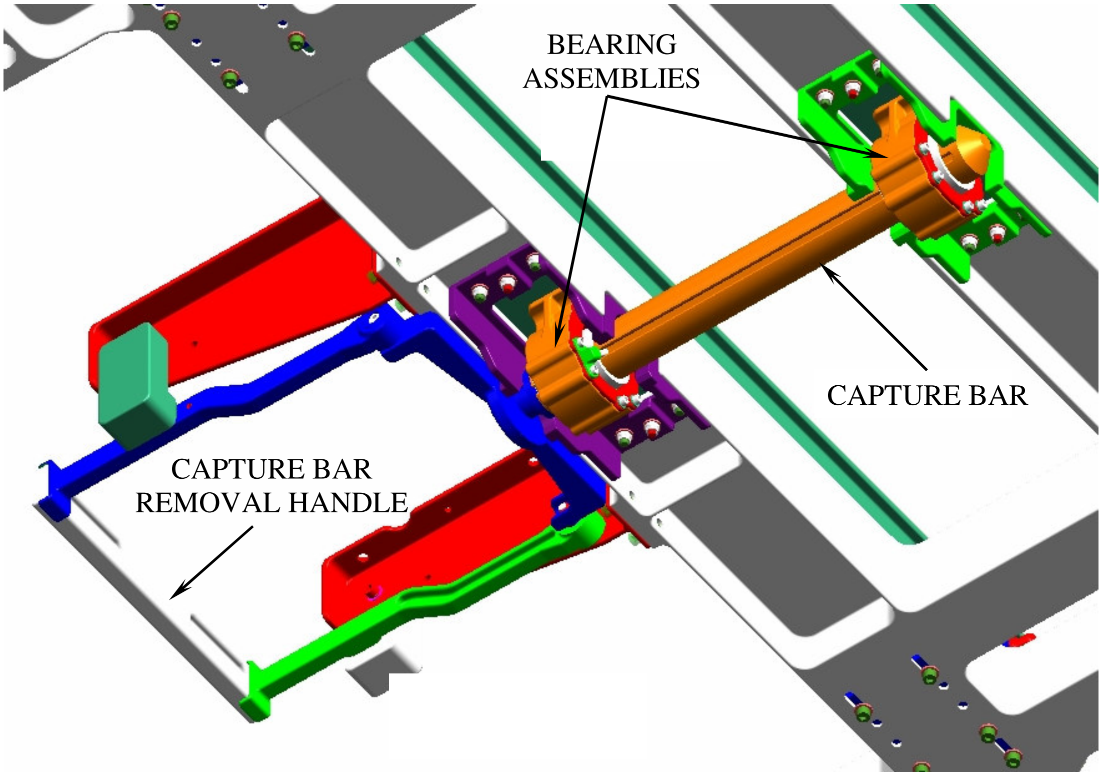


Figure 5.3.2-5 EVA Removable Capture Bar Assembly (1 of 2)

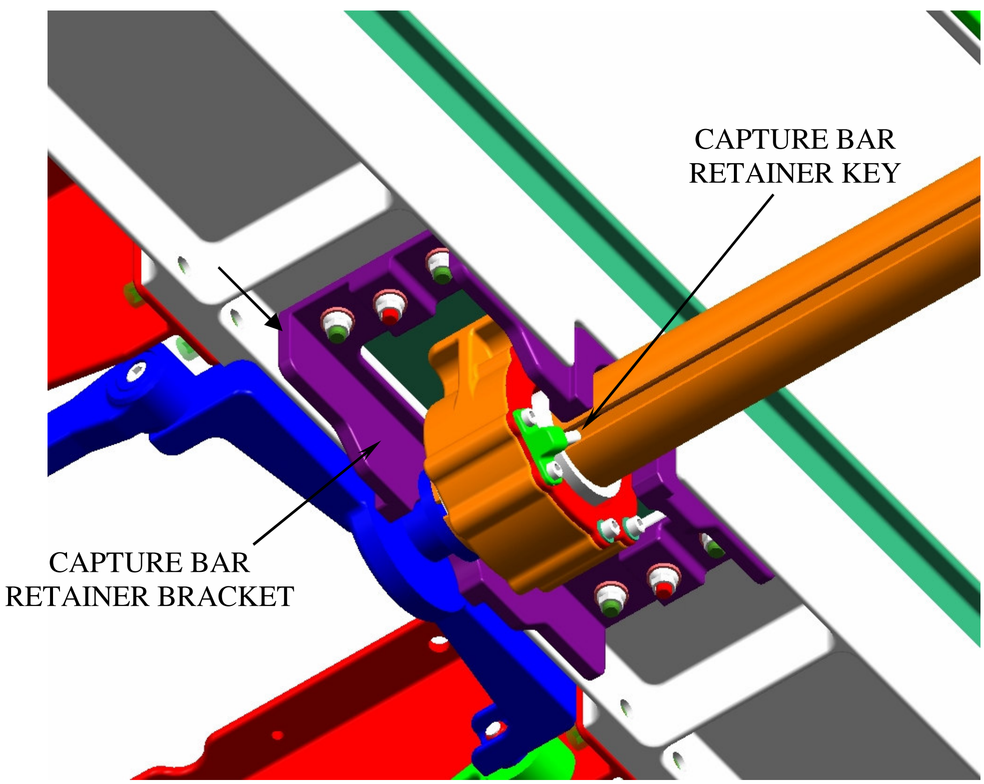


Figure 5.3.2-6 EVA Removable Capture Bar Assembly (2 of 2)

5.3.3 PAS Testing

Static and Interface Verification tests were performed on the AMS-02 PAS. Thermal extreme testing of the EVA release mechanism and vibration testing are scheduled.

5.3.3.1 Static Test

The Static Test (Figures 5.3.3.1-1 & 5.3.3.1-2) was performed to:

- Correlate the NASTRAN model with the flight hardware
- Demonstrate the maximum preload capability
- Set the PAS stiffness as close as possible to the required stiffness per SSP 57003
- Demonstrate the ability to off-load the Capture Bar Preload using the Capture Bar Release Mechanism
- Use the adjustability of the spring system to level the Capture Bar
- Determine the final configuration of the hardware

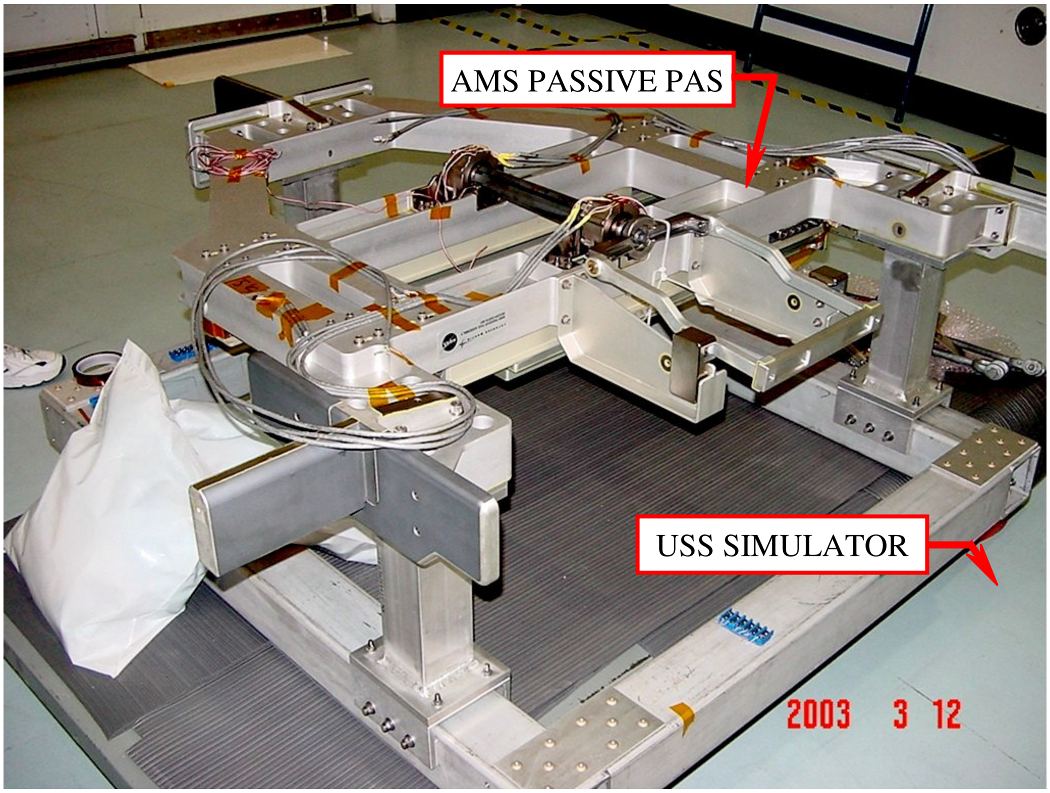


Figure 5.3.3-1 AMS Passive PAS with USS Simulator – Test Configuration

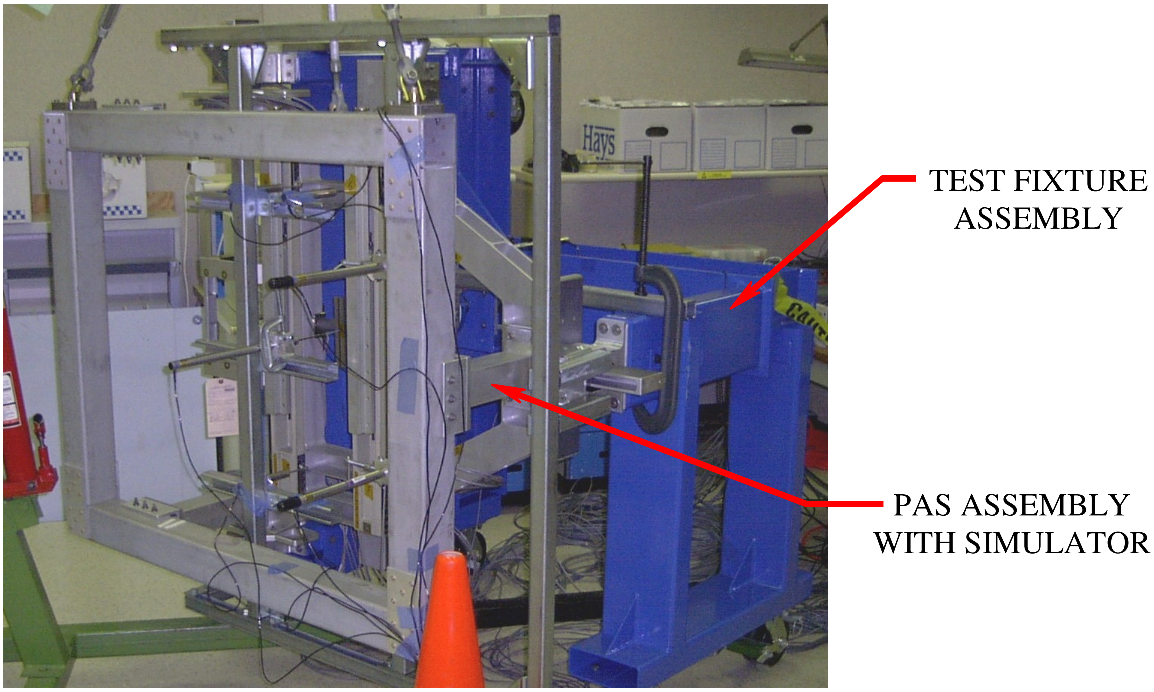


Figure 5.3.3-2 AMS Passive PAS/USS Simulator Assembly On Test Stand

5.3.3.2 Interface Verification Test

The Interface Verification Test was performed to verify the AMS-02 PAS interfaces with the actual ISS active PAS hardware (Figure 5.3.3.2-1). The AMS Passive PAS was lifted to the Upper Inboard PAS number 2 Active PAS site (Figure 5.3.3.2-2). The PAS 2 Capture Claw was then closed on the AMS PAS Capture Bar (Figure 5.3.3.2-3). Once the capture claws were closed, the preload at full closure was measured. The proximity of the PAS Capture Bar mounting hardware to the EBCS Target Assembly was measured at loaded condition. The AMS Passive PAS Release Mechanism was used to unload the Capture Claw Preload (Figure 5.3.3.2-4). Proximity to Target was measured in unloaded condition. The Capture Bar was removed demonstrating the required contingency capability to unload and remove the payload

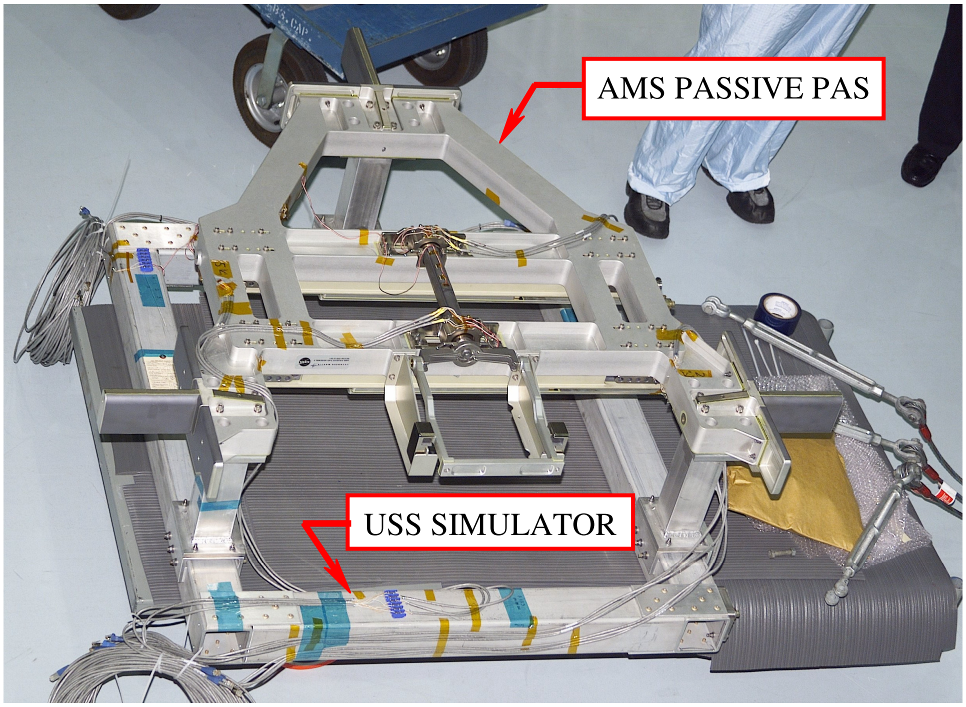


Figure 5.3.3.2-1 IVT Test Configuration

(NOTE: The IVT Configuration was identical to the AMS PAS Static Test)

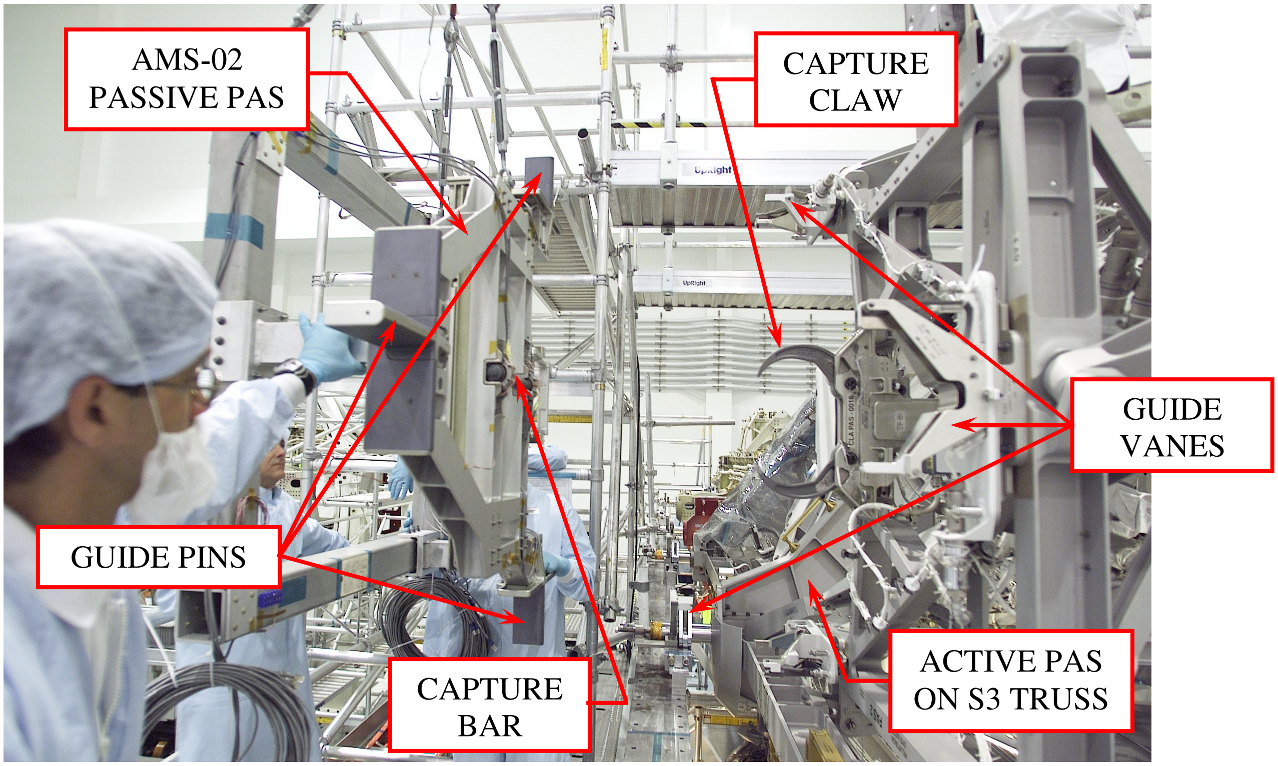


Figure 5.3.3.2-2 The AMS Passive PAS on Berthing Approach to PAS site 2

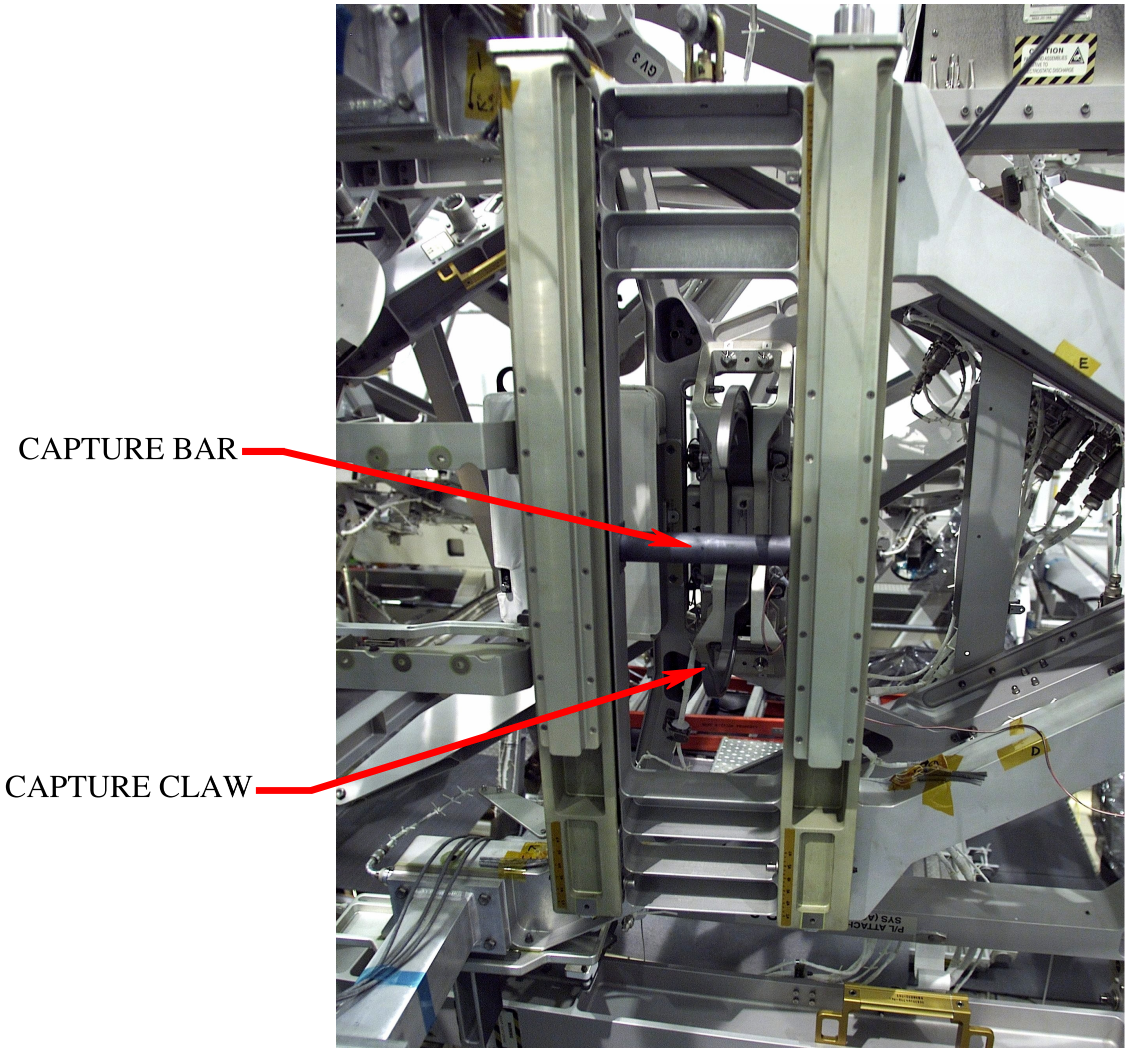


Figure 5.3.3.2-3 AMS Passive PAS Berthed to the S3 Active PAS 2

Figure 5.3.3.2-4 Removing the Preload with the EVA Release Mechanism

5.4 SPACE SHUTTLE PROGRAM (SSP) AND ISS PROGRAM PROVIDED HARDWARE

All Shuttle and ISS Program supplied hardware is being utilized consistent with the hardware ICDs and certifications.

5.4.1 Shuttle Program Hardware

The AMS-02 will utilize a number of Space Shuttle Program (SSP) supplied components. This hardware includes:

- Two Orbiter Interface Units (OIUs)
- One Payload General Support Computer (PGSC)/Next Generation Laptop System (NGLS) and power cable,
- One middeck locker,
- One Flight Releasable Grapple Fixture (FRGF)
- One Payload Disconnect Assembly (PDA) for the Remotely Operated Electrical Umbilical (ROEU).

The AMS-02 will interface structurally with the Shuttle cargo bay by way of four Payload Releasable Latch Assemblies (PRLAs), one Keel Latch, and the ROEU. AMS-02 will electrically interface with the standard switch panel. The locations of the dedicated switches on the standard switch panel are circled as shown in Figure 5.4-1. The AMS-02 payload will also require the use of the SRMS and the power from dual Assembly Power Converter Units (APCU).

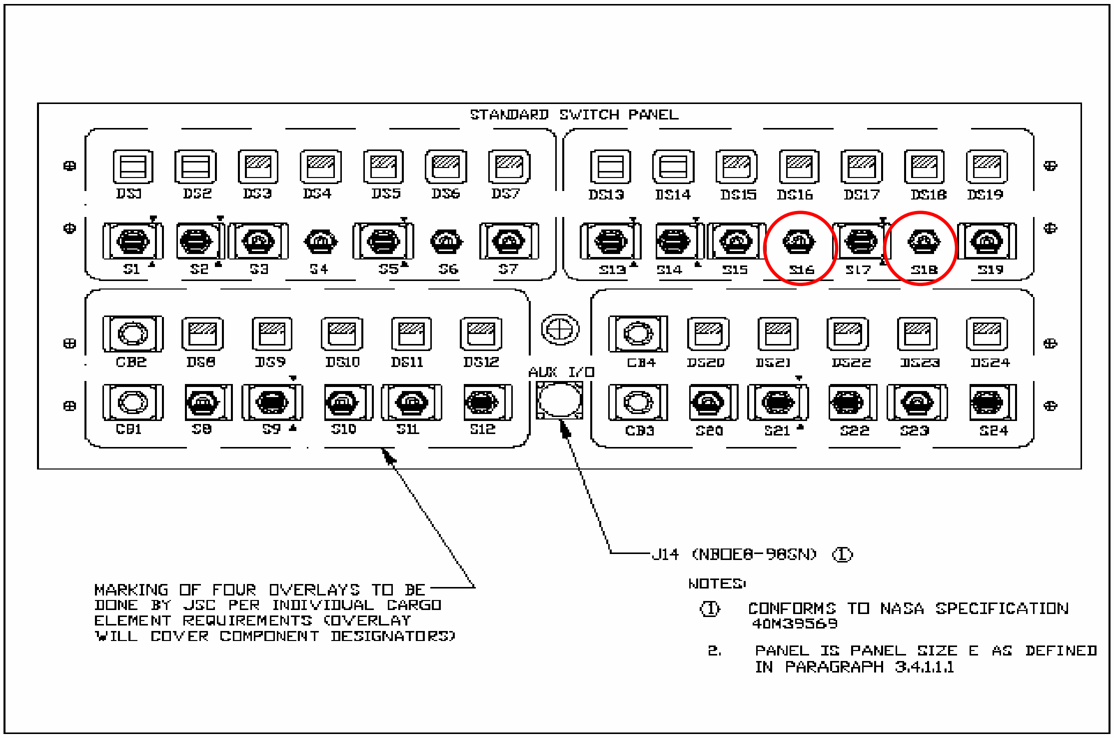


Figure 5.4-1 AMS-02 Switch Locations on Standard Switch Panel

5.4.1.1 Orbiter Interface Units

The two OIUs (one will be a backup) will be used as 1553 bus controllers and will serve as the uplink/ downlink interface for housekeeping data and commands. The OIUs will be mounted in the Payload Station L11 Console in the Orbiter aft flight deck, as designed as shown in Figure 5.4-2. The OIUs provide an interface between PGSC/NGLS and the ROEU connected payload.

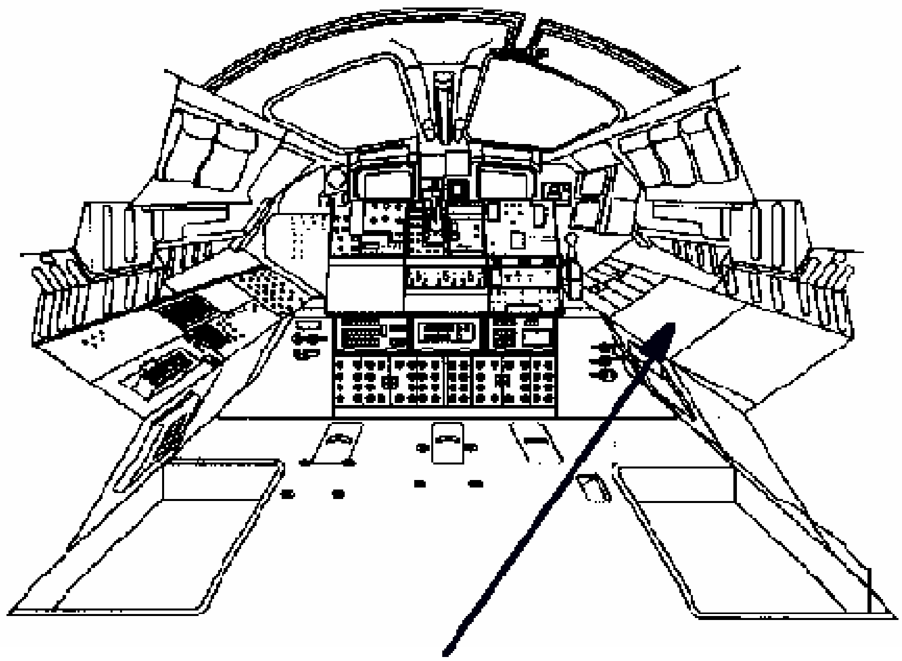


Figure 5.4-2 Orbiter Interface Unit Location on Console L-11

5.4.1.2 Middeck Locker

The middeck locker will be used for stowage of the Digital Data Recorder System (DDRS-02) hardware which includes the PGSC/NGLS and cables. In addition for return from orbit the PDIP cable, installed for launch, will be stowed in the Middeck Locker with the DDRS cables and hardware.

5.4.1.3 Flight Releasable Grapple Fixture (FRGF)

A FRGF, mounted to the AMS-02 payload, will be used by the SRMS to lift the AMS-02 out of the Orbiter payload bay. The FRGF is mounted to the FRGF Bracket using 6 high strength (200 ksi ultimate) ⅜" diameter bolts. The FRGF Bracket is bolted to the forward face of the port Upper Trunnion Bridge Beam using 24 high strength (180 ksi ultimate) ¼" diameter bolts. The FRGF placement on the USS-02 is shown in Figure 5.4-3. An exploded view of the attachment hardware is shown in Figure 5.4-4.

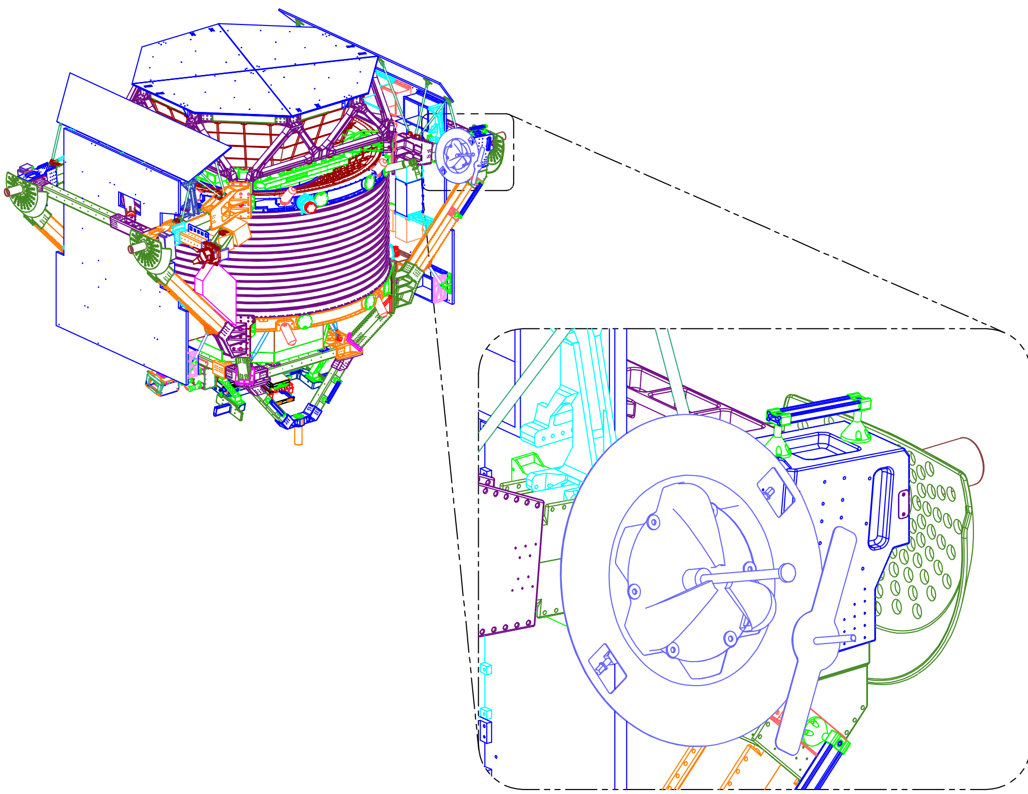


Figure 5.4-3 The FRGF Mounted to the Upper Trunnion Bridge Beam USS-02

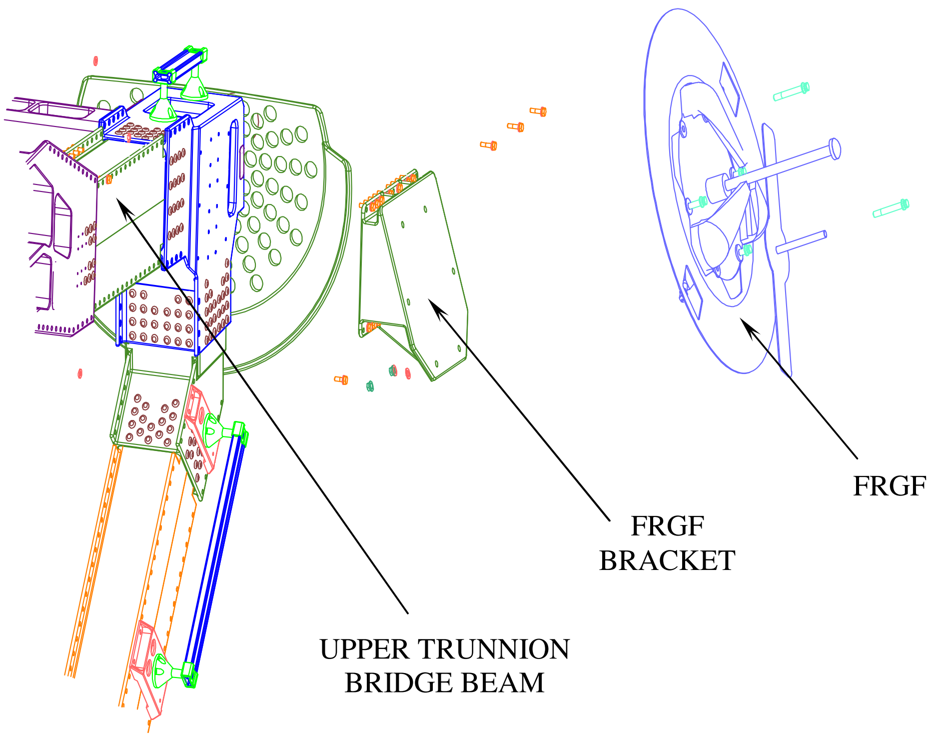


Figure 5.4-4 The FRGF to USS-02 Mounting Hardware

5.4.1.4 Payload Disconnect Assembly (PDA)

The PDA for the ROEU is the AMS-02 half of the ROEU system. This will be used to make the electrical interface between the Shuttle and the AMS-02 payload. The PDA will be mounted to the ROEU bracket that is attached to both the Primary Sill Joint and the Upper Trunnion Bridge Beam with 12 high strength (180 ksi Ultimate Strength) ¼" diameter bolts. The PDA mounted to the ROEU Bracket Assembly is shown in Figure 5.4-5.

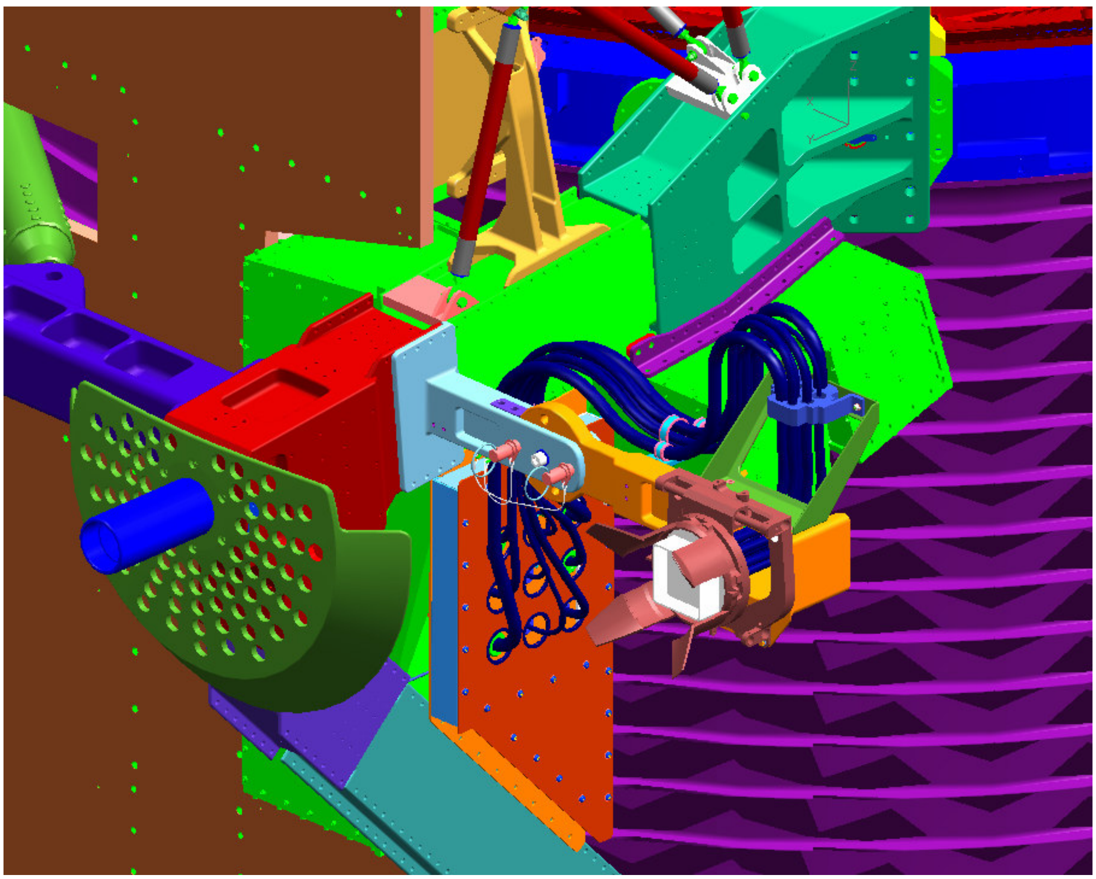


Figure 5.4-5 PDA Mounted on the Upper USS-02

5.4.1.5 Scuff Plates

The scuff plates are manufactured from aluminum and mount to the front face of the Sill Trunnion Joints, as shown in figure 5.4-6. The scuff plates are meant to preclude excessive port/starboard motion for berthing/unberthing operations using the SRMS and SSRMS operations. The scuff plates are designed to meet the requirements specified NSTS-21000-IDD-ISS.

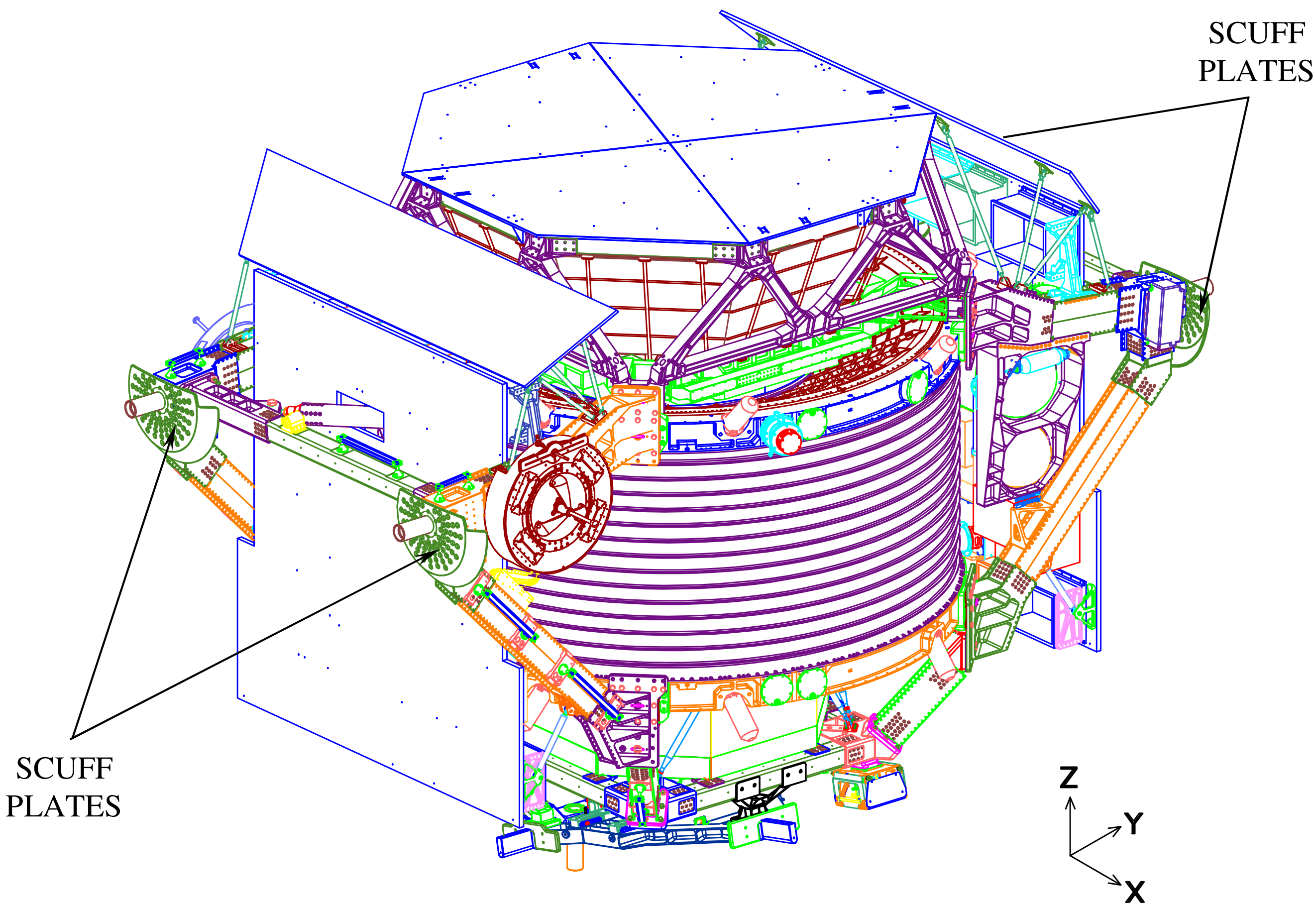


Figure 5.4-6 Scuff Plate Locations on AMS-02

5.4.2 ISS Provided Hardware

The ISS Program provided hardware that will be used with the AMS-02 includes:

- Two Shuttle installed Assembly Power Converter Units (APCUs),
- One Power Video Grapple Fixture (PVGF)
- One passive Umbilical Mechanism Assembly (UMA)
- One External Berthing Camera System (EBCS)

The AMS-02 payload will also require the use of the SSRMS. The SSRMS attaches to the Power Video Grapple Fixture and moves AMS-02 from the SRMS to the upper inboard payload attach site two, located on the ISS S3 truss shown in Figure 5.4-7.

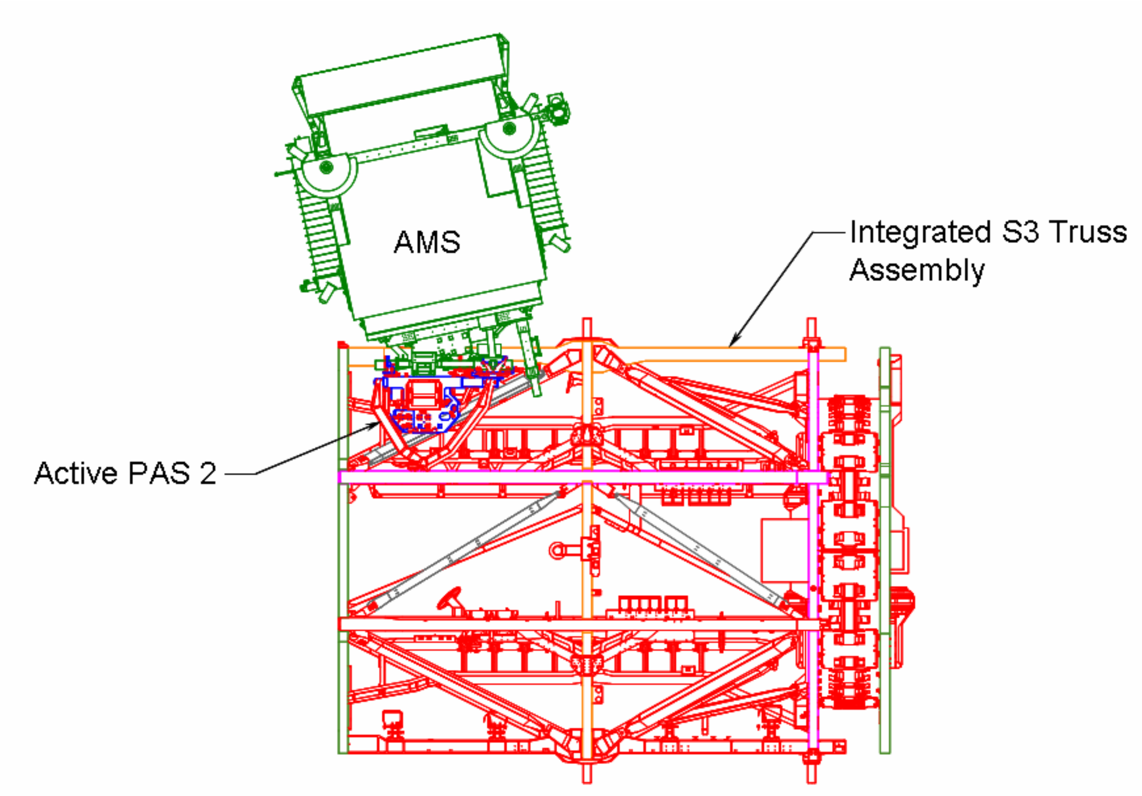


Figure 5.4-7 AMS Mounted to ISS S3 Truss

5.4.2.1 Assembly Power Converter Units

The APCUs (one will be a backup) will be used to supply 120v DC power to the AMS while operating on the Orbiter. Two APCUs are being used for redundancy. They will be mounted in bay 5 on the port side of the Orbiter, as designed, per the APCU Interface Control Document (ICD).

5.4.2.2 Power Video Grapple Fixture (PVGF)

A PVGF, mounted on the aft port side of the Upper Trunnion Bridge Beam of the AMS-02 payload, provides an additional structural/mechanical interface with the Mobile Servicing System allowing the SSRMS or the Payload/Orbiter Replacement Unit (ORU) Accommodation to grapple the payload. The PVGF mounts to the PVGF Bracket using 6 high strength (200 ksi ultimate) ⅜" diameter bolts. The PVGF Bracket is mounted to the Upper Trunnion Bridge Beam with 24 high strength (180 ksi ultimate) ¼" diameter bolts. The PVGF attachment location on AMS-02 is shown in figure 5.4-8. An exploded view of the attachment hardware is shown in Figure 5.4-9. Electrically the PVGF will supply power but not data communication to AMS-02. Power supplied to AMS-02 during this operation is for heater operations only.

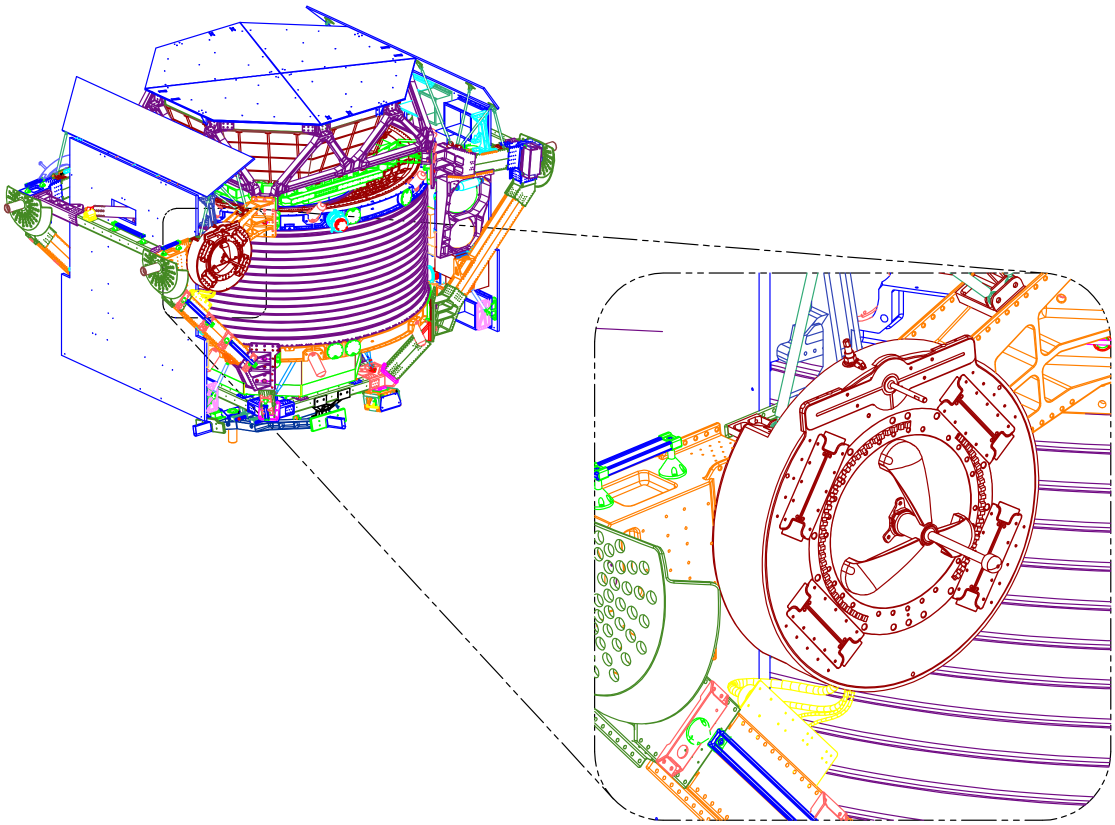


Figure 5.4-8 PVGF Mounted to the Upper Trunnion Bridge Beam USS-02

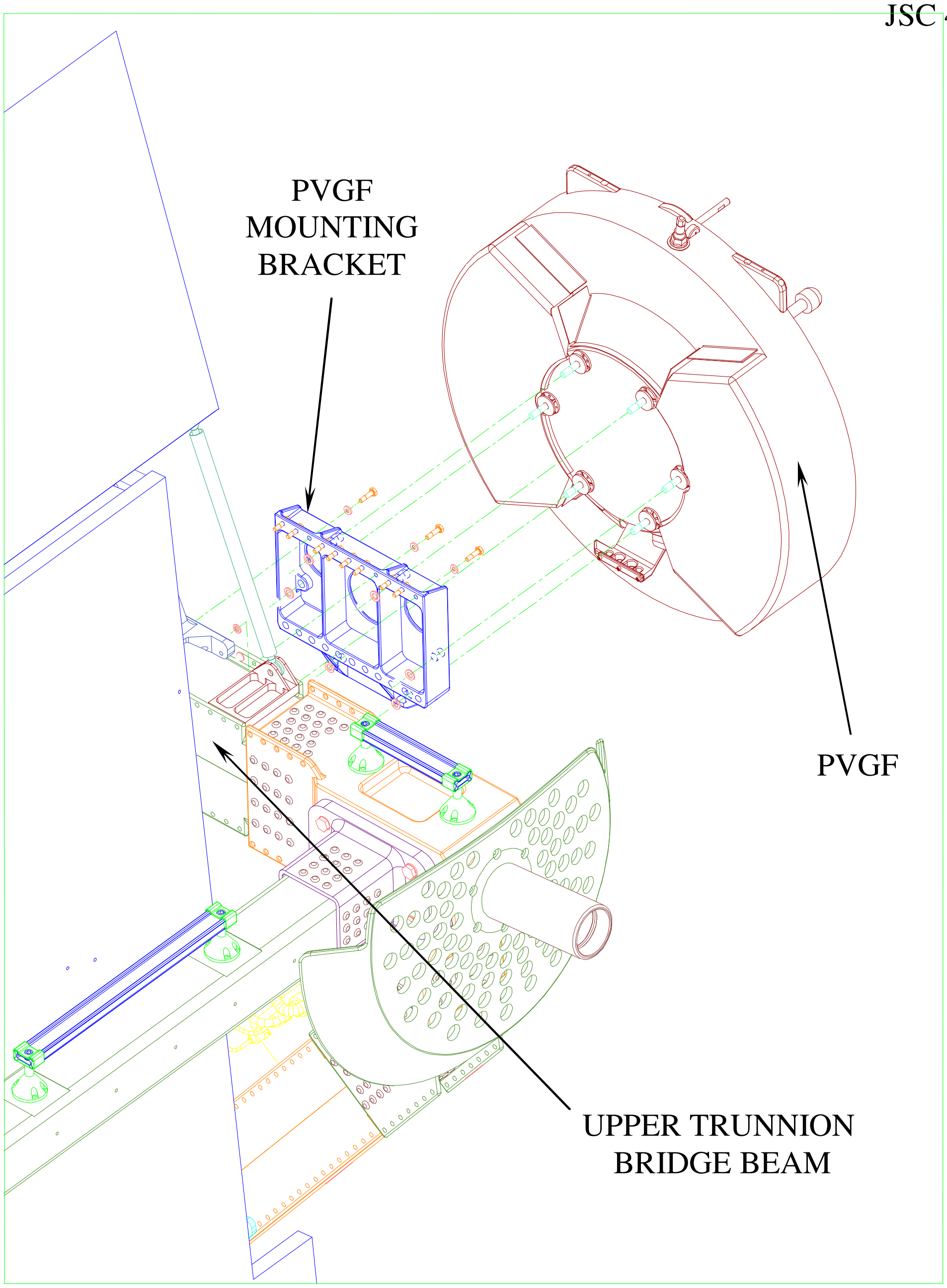


Figure 5.4-9 The PVGF to USS-02 Mounting Hardware

5.4.2.3 Passive Umbilical Mechanism Assembly (UMA)

The passive UMA will be used to electrically connect the AMS-02 payload to the ISS truss attach site. The UMA attaches to the lower USS-02, as shown in figure 5.4-10, and will interface with the active UMA mounted to the ISS PAS site as per SSP-57003.

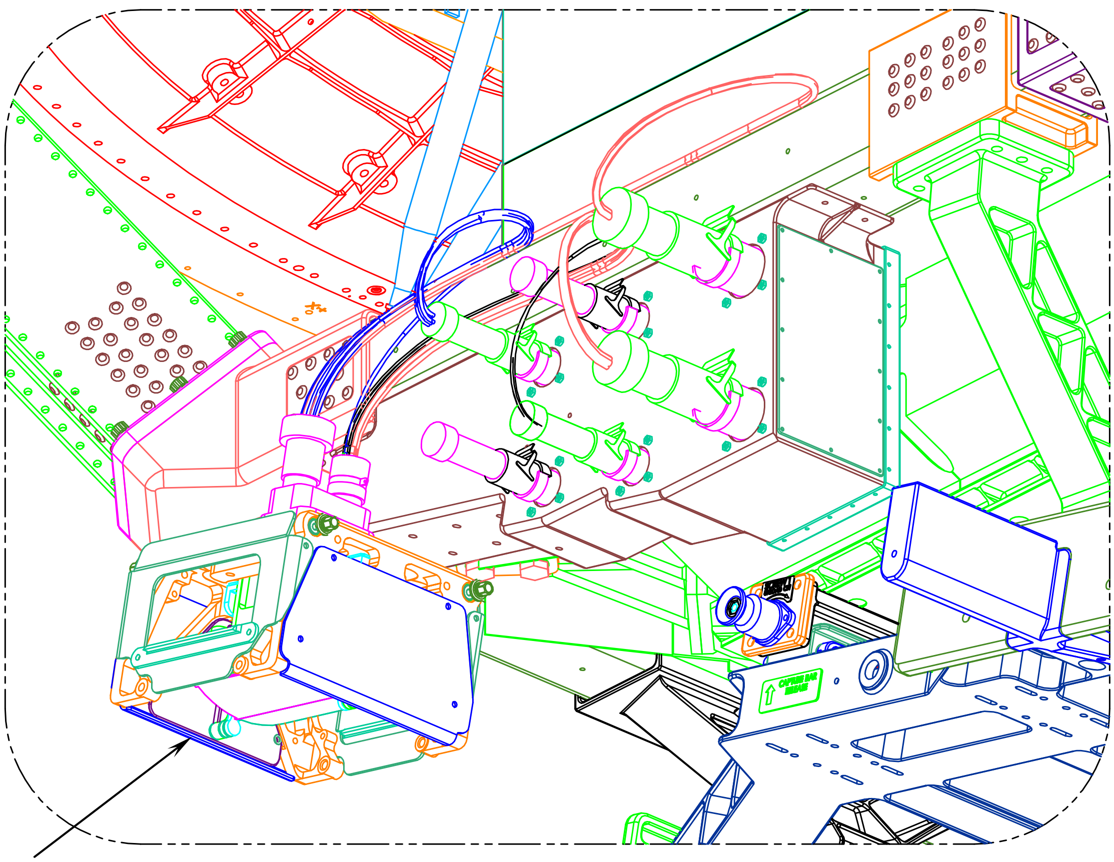


Figure 5.4-10 The UMA Mounted to the EVA Connector Panel

5.4.2.4 External Berthing Camera System (EBCS)

The EBCS is a camera and avionics package provided by the ISS Program that is electrically connected to the PVGF and structurally mounted to the passive PAS assembly on the AMS-02. The EBCS provides visual cues to robotic workstation monitors to assist ISS Mobile Servicing System operators in berthing AMS-02. The system is comprised of an avionics package which contains both a primary and secondary video camera and an EBCS Target which his mounted on the PAS site. The electrical services of EBCS include video, power, heater power and AMS-02 heater power. The EBCS Avionics mounting is the responsibility of AMS-02. The mounting requirements are defined in SSP 57003 Section 3.7.6.1, SSP 57004 Figures 3.1.2.2-1 and SSP 57004 Figures 3.7.1-1. Additional mounting data is contained in MDR-BCS-TM-7498, EBCS Avionics Package Detailed Installation Instructions produced by MD Robotics per NASA contract NAS9-00089.

Refer to Figure 5.4-11 for the location of the EBCS mounted on the PAS Assembly.

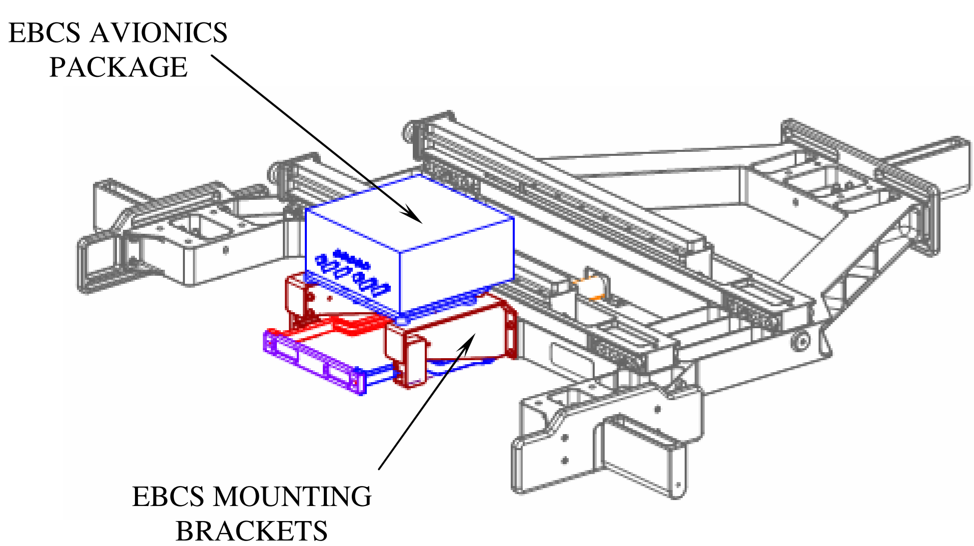


Figure 5.4-11 The EBCS Mounted on the AMS-02 Passive PAS

5.4.3 EVA Hardware

The AMS-02 has been designed to support contingency EVAs to the AMS-02. These potential contingency EVAs include:

- ROEU Manual Release/Mate
- UMA Manual Release/Mate
- FRGF Release
- PVGF Release
- PAS Capture Bar Release
- EVA Connector Panel Operation
- ROEU Bracket Folding Operation

Each of the above EVAs may include multiple EVA work locations. These sites have been identified and work site aids have been positioned to facilitate EVA operations. Payload hardware associated with these EVA operations is described and shown in the sections that follow.

5.4.3.1 UMA EVA Bolts

The passive UMA can be released from the active half via four EVA bolts shown in figure 5.4-12. Once this is complete the EVA Connectors are uncoupled, the AMS-02 will be free from the UMA leaving only the UMA Bracket attached to the EVA Connector Panel.

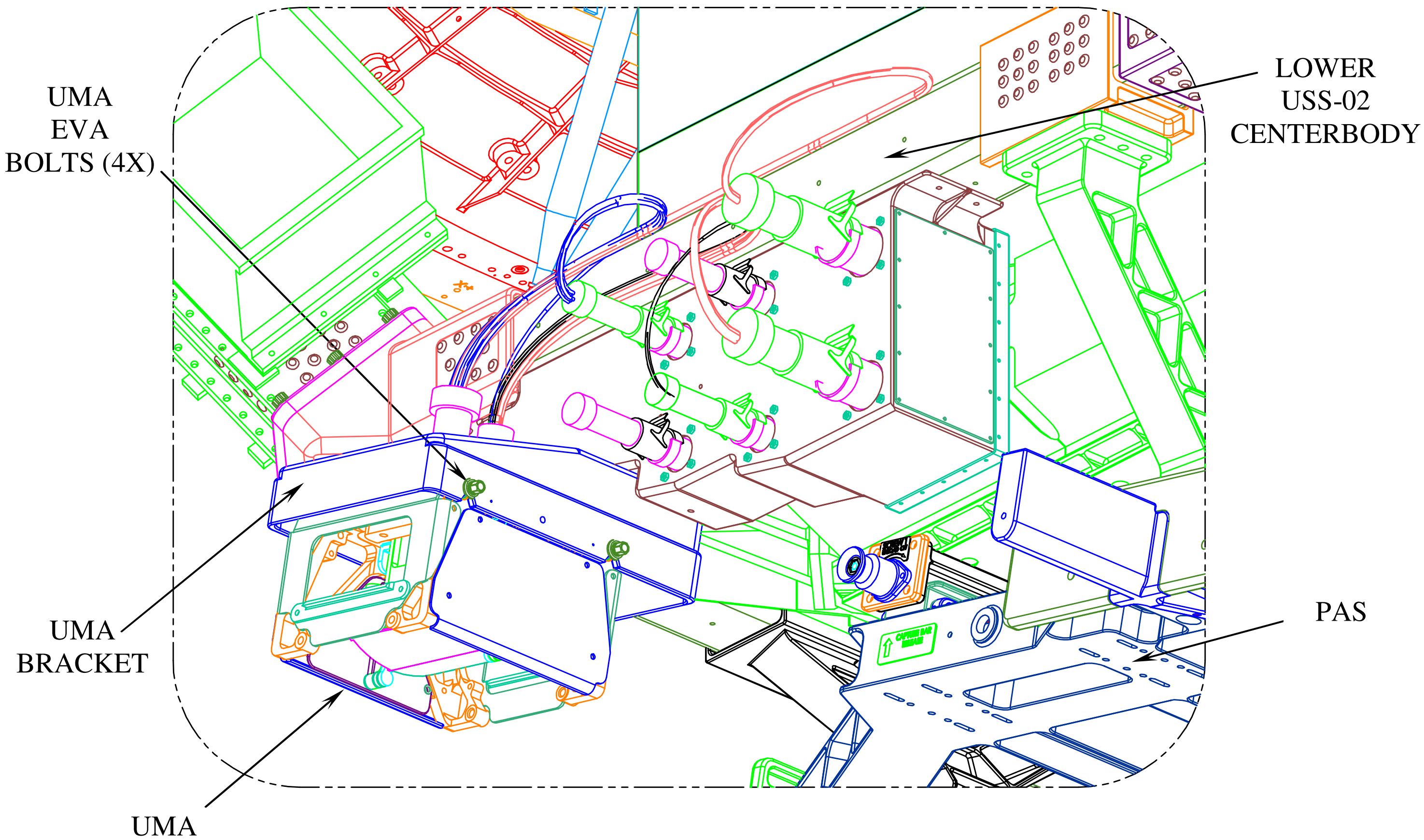


Figure 5.4-12 UMA EVA Bolt Locations

5.4.3.2 FRGF Release

The AMS-02 payload can be a manually released from the FRGF by way of the Rod Release. The Rod Release is a standardized ISS EVA process which AMS-02 is compatible with. The locations of the EVA bolts and Rod Release are shown in figure 5.4-13.

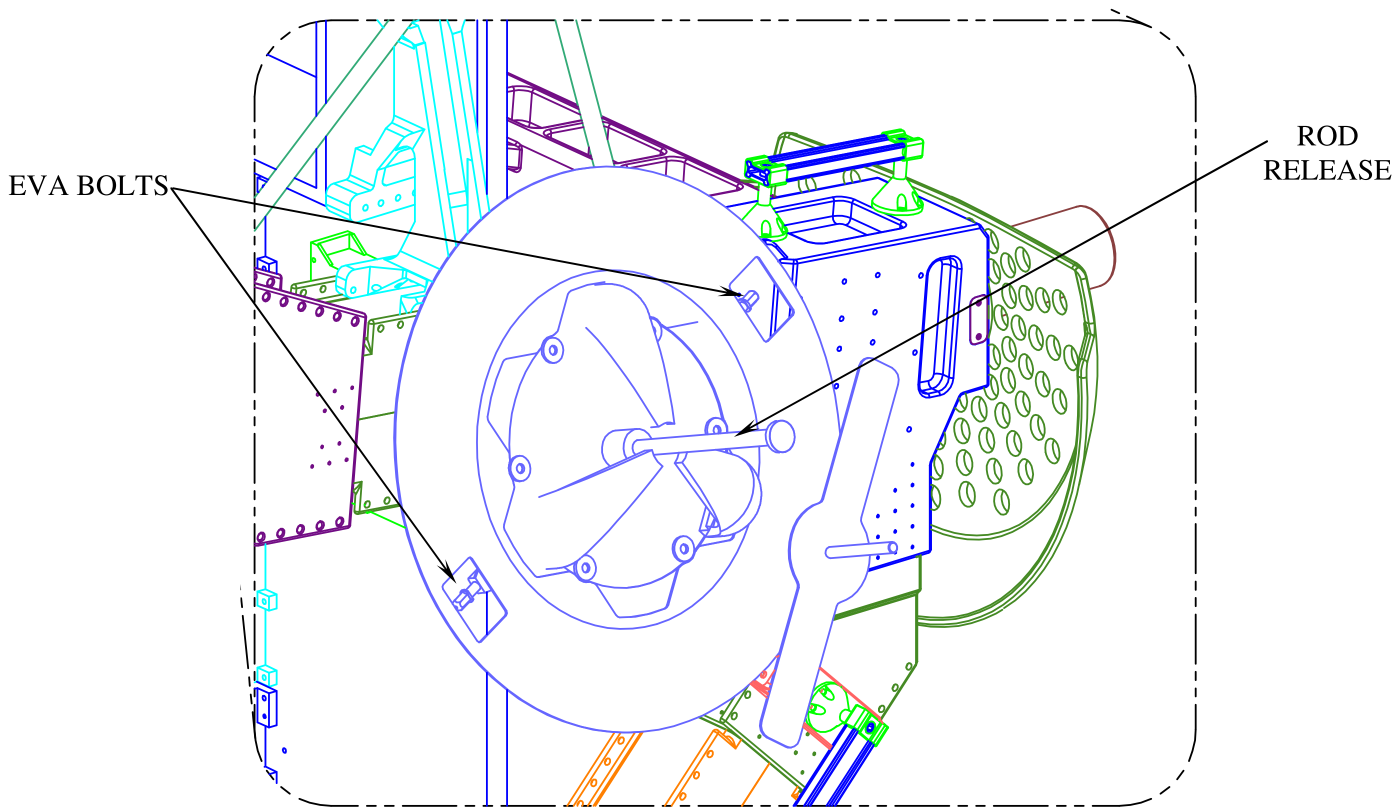


Figure 5.4-13 FRGF Rod Release Location

5.4.3.3 PVGF Release

The AMS-02 payload can be manually released from the SSRMS by removing the Rod Release from the PVGF bracket. The Rod Release is a standard shuttle program EVA process that the AMS-02 is compatible with. Locations of the PVGF EVA bolts and Rod Release are shown in figure 5.4-14.

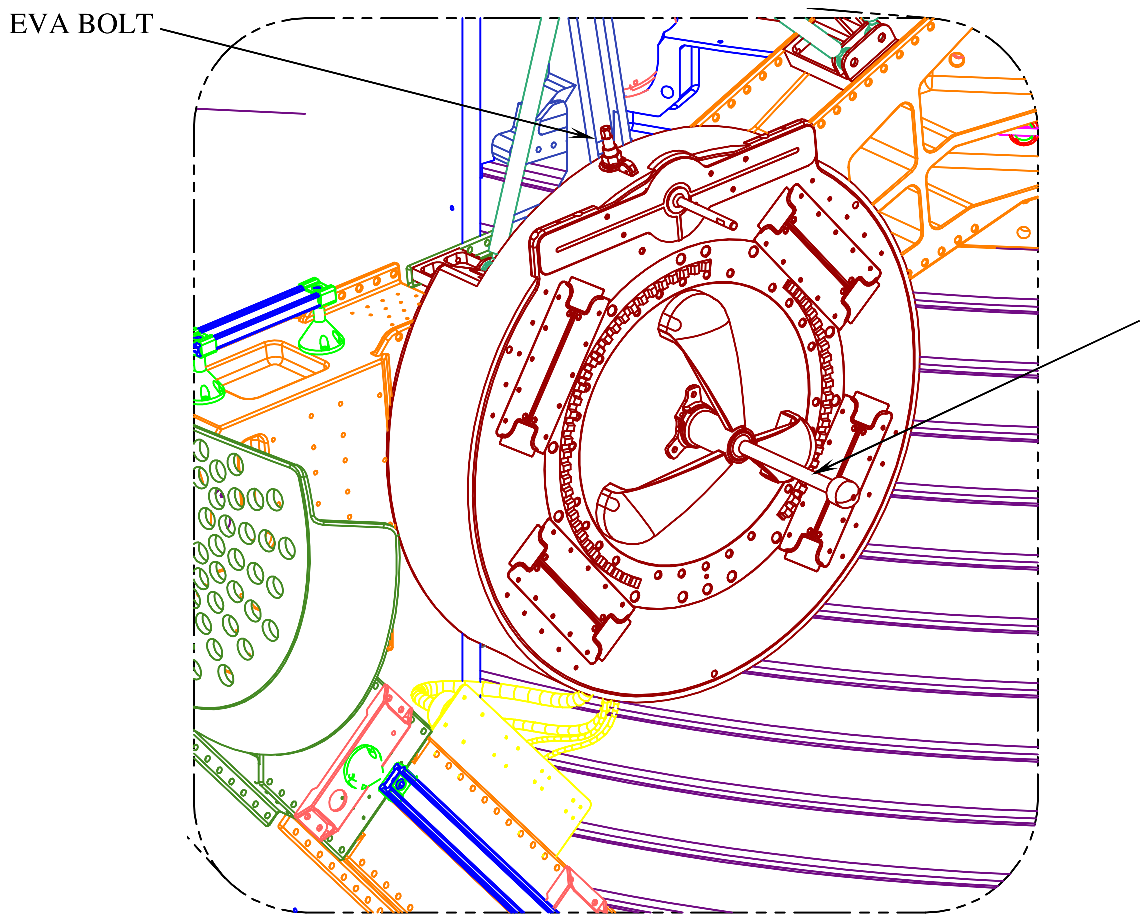


Figure 5.4-14 PVGF Rod Release Location

5.4.3.4 The PAS Capture Bar Release Mechanism

The PAS Capture Bar Assembly's preload is released mechanically by unloading the two Drive Screws using an EVA PGT. After the Capture Bar is unloaded and lowered the crew member pulls the Capture Bar Assembly out from the Bearing Assemblies using the Capture Bar Removable Handle. Figure 5.4-15 shows the location of the PAS Assembly mounted to AMS-02. Figure 5.4-16 shows the location of the drive screw interface on the PAS. Labels indicating the location of the release mechanisms and the direction required to release the capture bar are noted with the appropriate decals. The Capture Bar Assembly's removal from the PAS Assembly is shown in Figure 5.4-17.

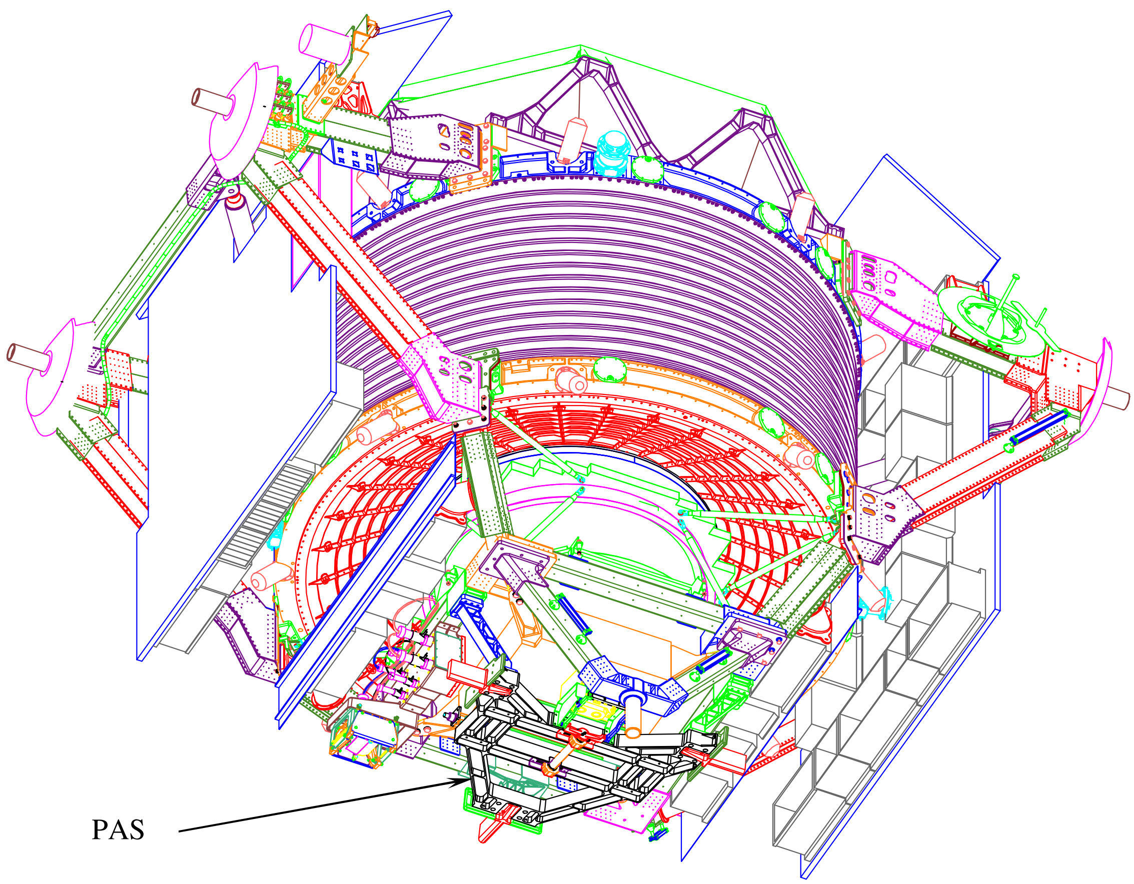


Figure 5.4-15 PAS Location on AMS-02

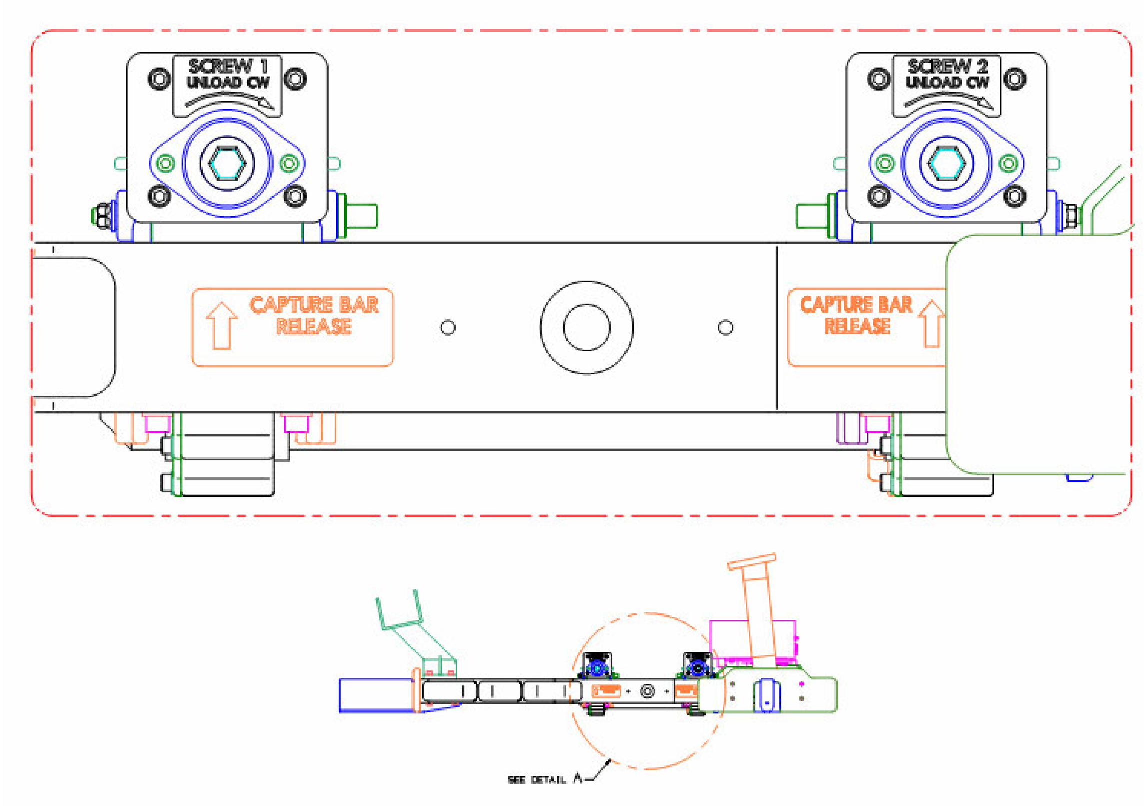


Figure 5.4-16 Drive Bolt Location on the PAS

(Note: Label "SCREW" will be replaced with "BOLT")

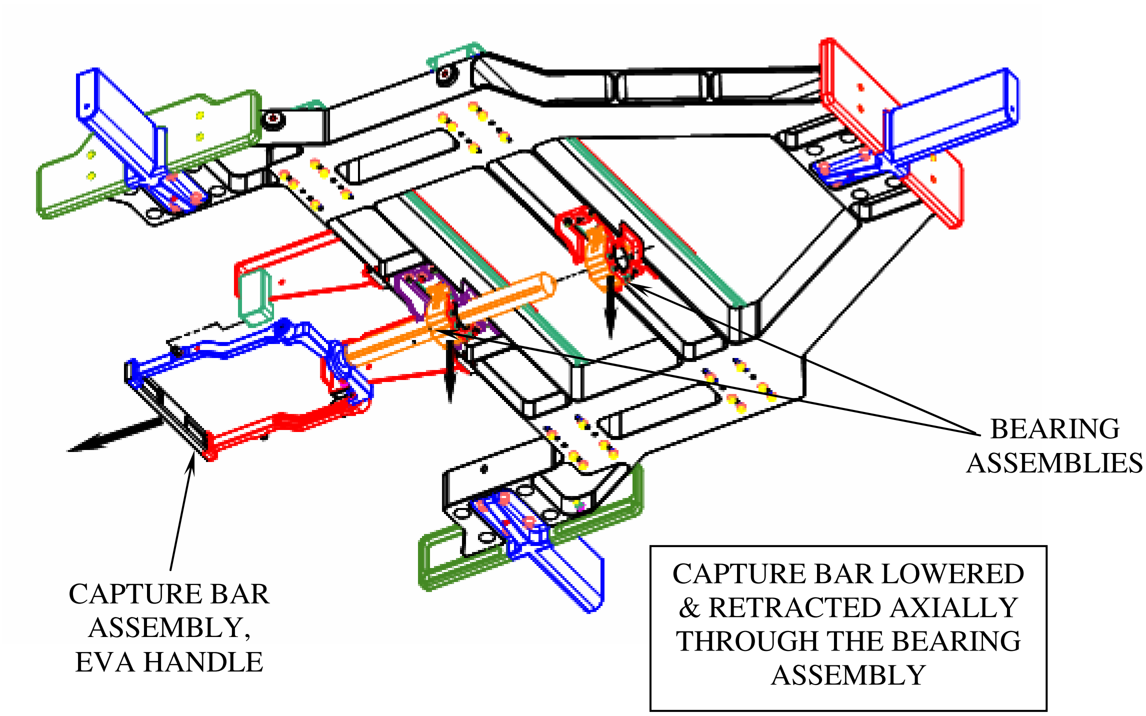


Figure 5.4-17 Capture Bar Assembly from AMS-02 Passive PAS

5.4.3.5 EVA Compatible Electrical Connectors

The connectors used to connect to the EVA panel are EVA compatible lever-actuated connectors per SSG-21635. The unused connectors on the EVA panel are protected by connector caps that are tethered to the panel. The power and data cables connect the UMA to the EVA panel with sufficient length to be routed to either channel A or channel B. The EVA Panel Assembly is bolted to the Lower Centerbody of the USS-02 with 16 ¼" high strength fasteners (160 ksi ultimate) as shown in figure 5.4-17.

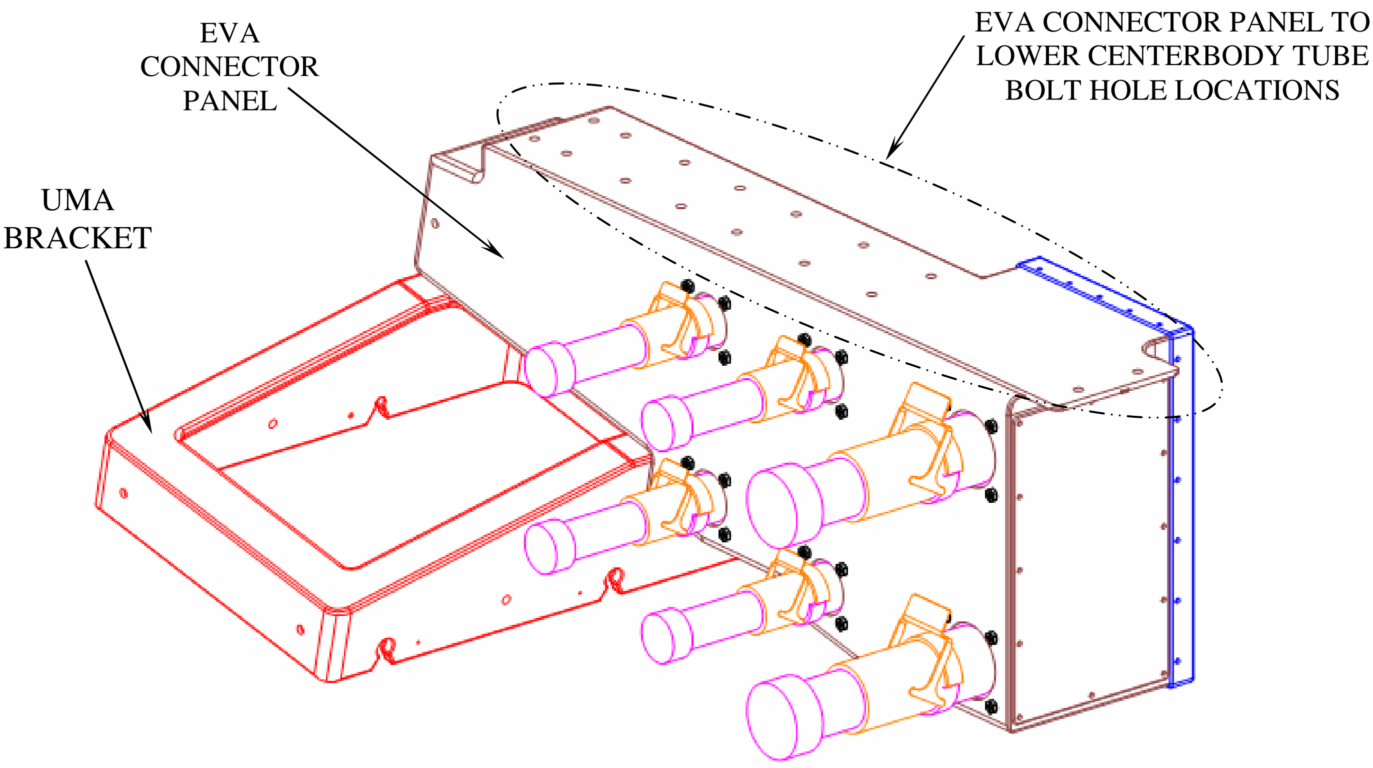


Figure 5.4-18 EVA Connector Panel with UMA Bracket

5.4.3.6 Worksite Interface Fixture (WIF) Socket

A standard WIF socket is mounted to the starboard Sill Tube with 8 high strength (160 ksi ultimate) ¼" fasteners, as shown in figure 5.4-18 This work site location will be used during the EVA operations to release either the FRGF from the SRMS or the PVGF from the SSRMS. A proposed second WIF socket located on the port Sill Tube may be necessary for Foldable ROEU Bracket operations. The exact location of this second WIF would be determined by conducting a Worksite Assessment (WSA). As of Phase II the requirement to install the second WIF and any additional handrails is yet to be established.

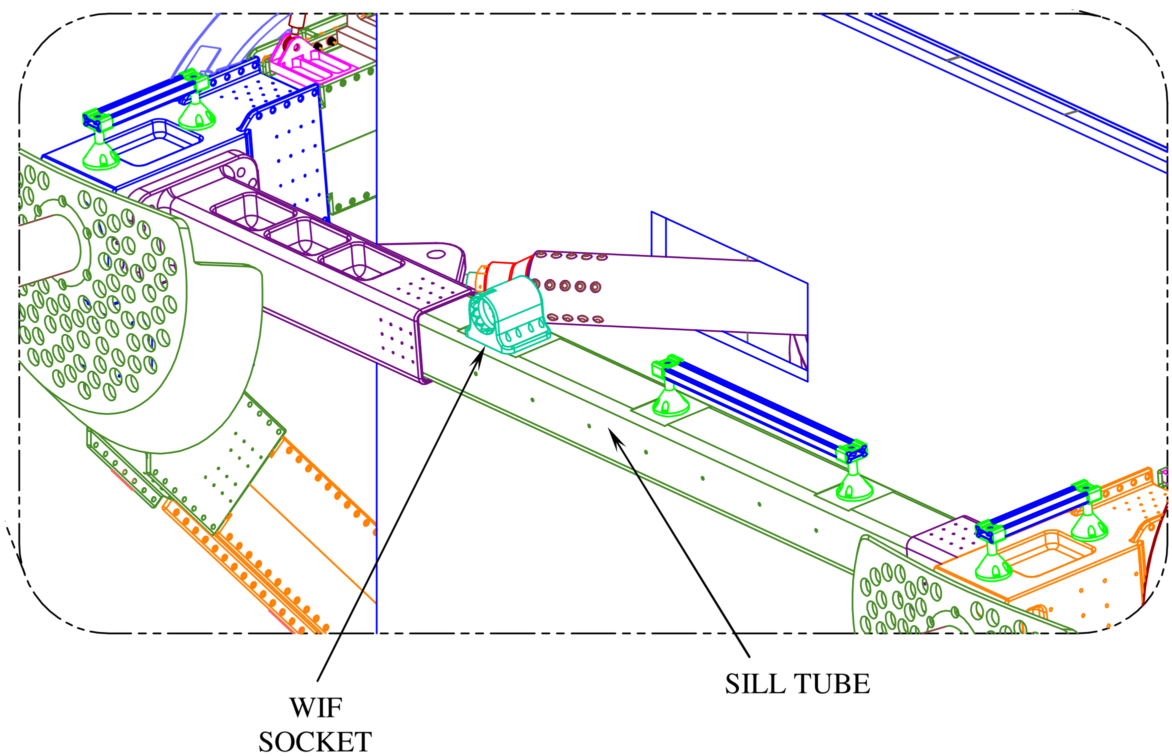


Figure 5.4-19 WIF Socket Location on Sill Tube

5.4.3.7 ROEU Foldable Bracket Assembly

The EVA operated ROEU Foldable Bracket Assembly is designed to fold down to prevent any potential interference with the installation of a payload adjacent to AMS-02 while on the S3 truss of the ISS. The primary components of the ROEU Foldable Bracket Assembly are the Arm Flange, Arm, PDA Bracket, a pivot pin and a two tethered EVA compatible pip pins. The pip pins are space-qualified Double-acting Space Pins (1/2" Diameter, Ring Handle, 1.8" Grip, Drive Out Option, 6" Lanyard) manufactured by Avibank to their specification 56789. The ROEU arm is allowed to rotate to the folded position by releasing the two pip pins which prevent the arm from rotating about a fixed pivot pin. Once the arm is in the final folded position, established by a hardstop, the two pip pins are then reinserted through the arm flange and arm to prevent any "spring back" due to the bending of the cables about the arm. Figures 5.4-19 and 5.4-20 show the ROEU Bracket Assembly in the nominal configuration. Figures 5.4-21 and 5.4-22 show the ROEU Foldable Bracket Assembly in the folded position.

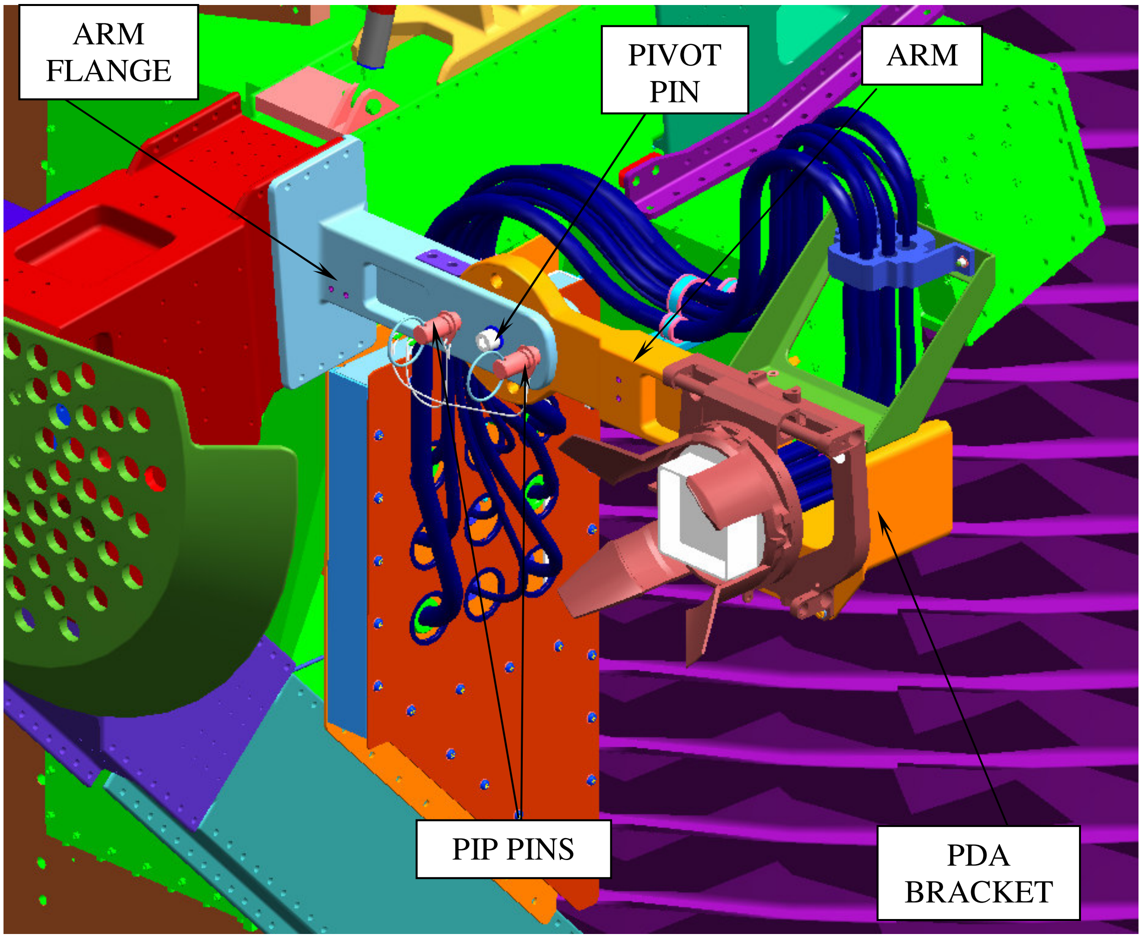


Figure 5.4-20 ROEU Foldable BracketAssembly Nominal Configuration (Iso View from Starboard Side)

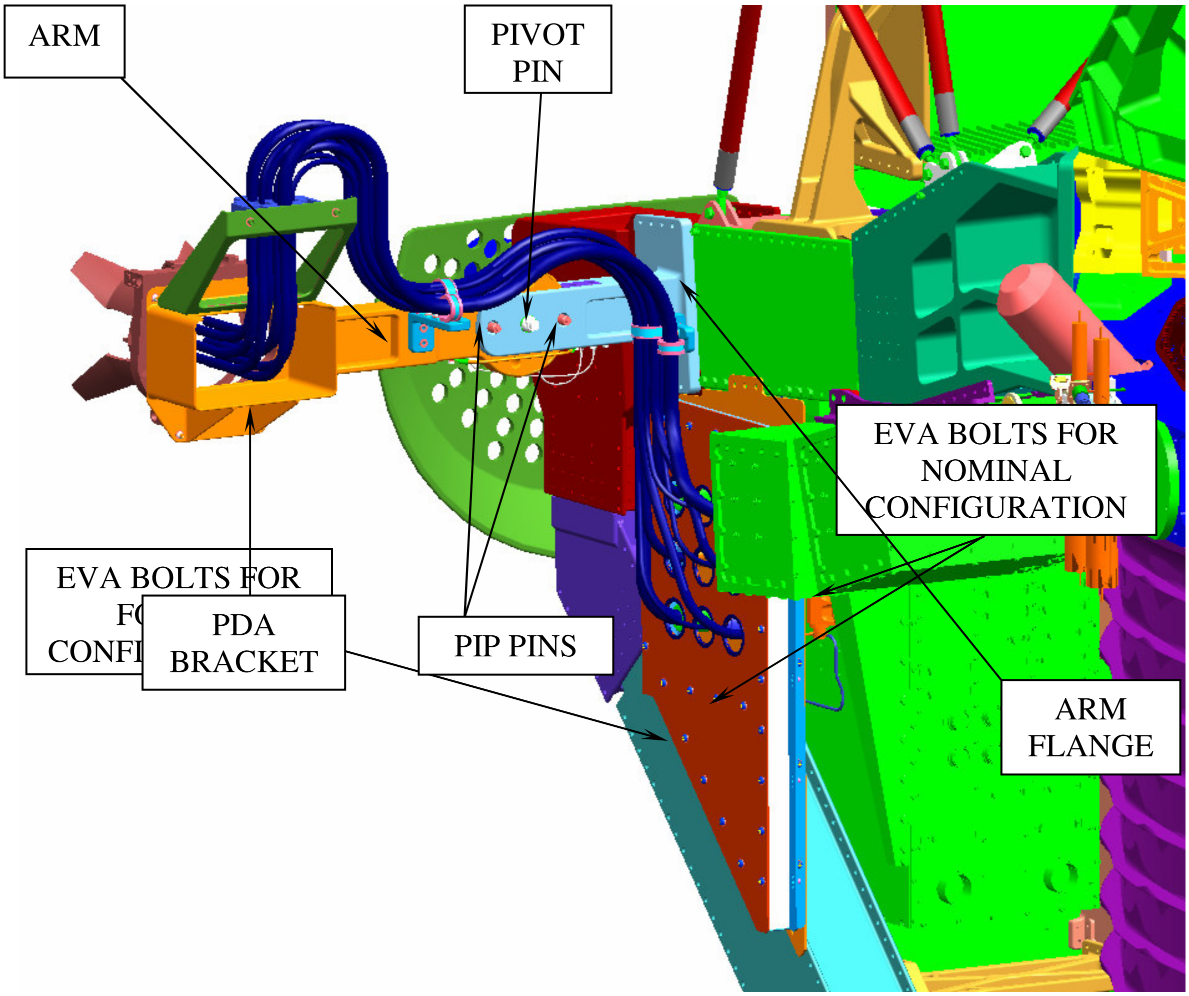


Figure 5.4-21 ROEU Foldable Bracket Assembly Nominal Configuration (Iso View from Port Side)

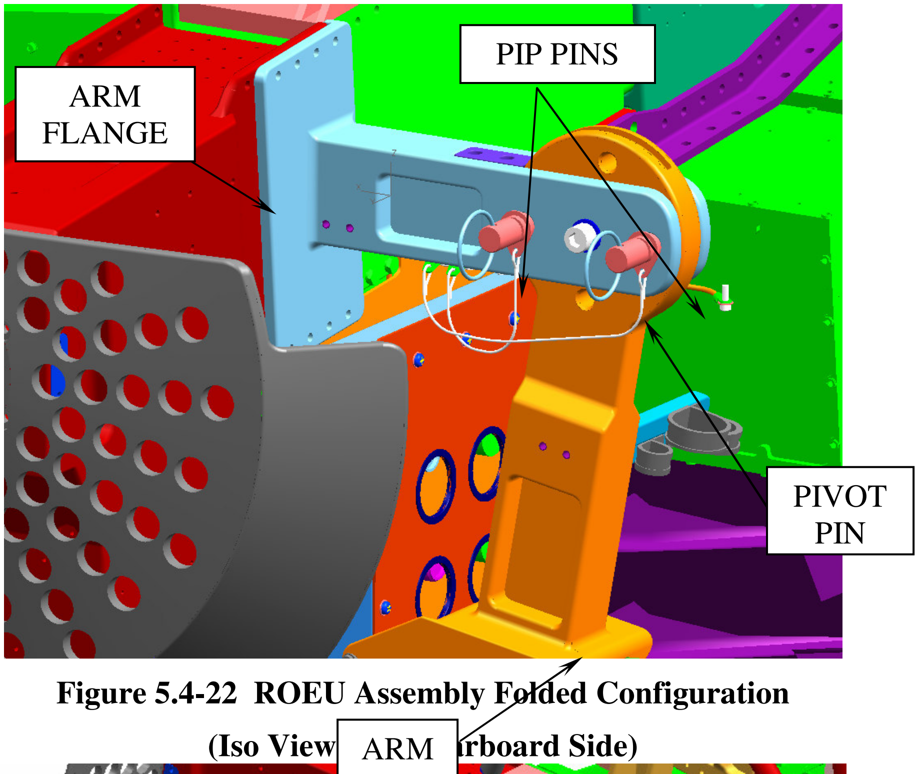


Figure 5.4-22 ROEU Assembly Folded Configuration
(Iso View [illegible]rboard Side)

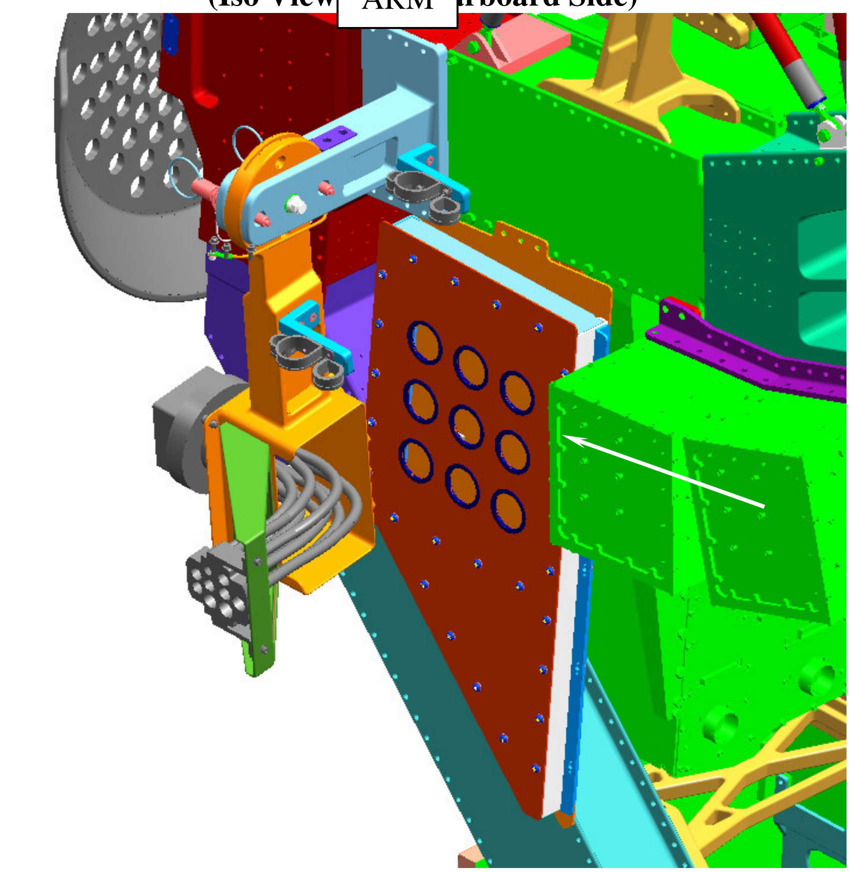


Figure 5.4-23 ROEU Foldable Bracket Assembly Folded Configuration
(Iso View from Port Side)

5.4.3.8 EVA Handrails

EVA handrails are mounted to the USS-02 as shown in figures 5.4-23 through 5.4-25. The EVA handrails provide a crew member access to the WIF socket used as a worksite to release the grapple fixtures. EVA handrails will also be used for crew translation during contingency EVA operations on AMS-02. The locations of the handrails were assessed by either an EVA simulation by computer or weightless environment exercises. The locations of additional EVA handrails for on-orbit ROEU access would be determined by performing a WSA. All handrails and the WIF interface are provided by the JSC Extravehicular Activity Office (XA) to the AMS-02 Project for installation on the USS-02.

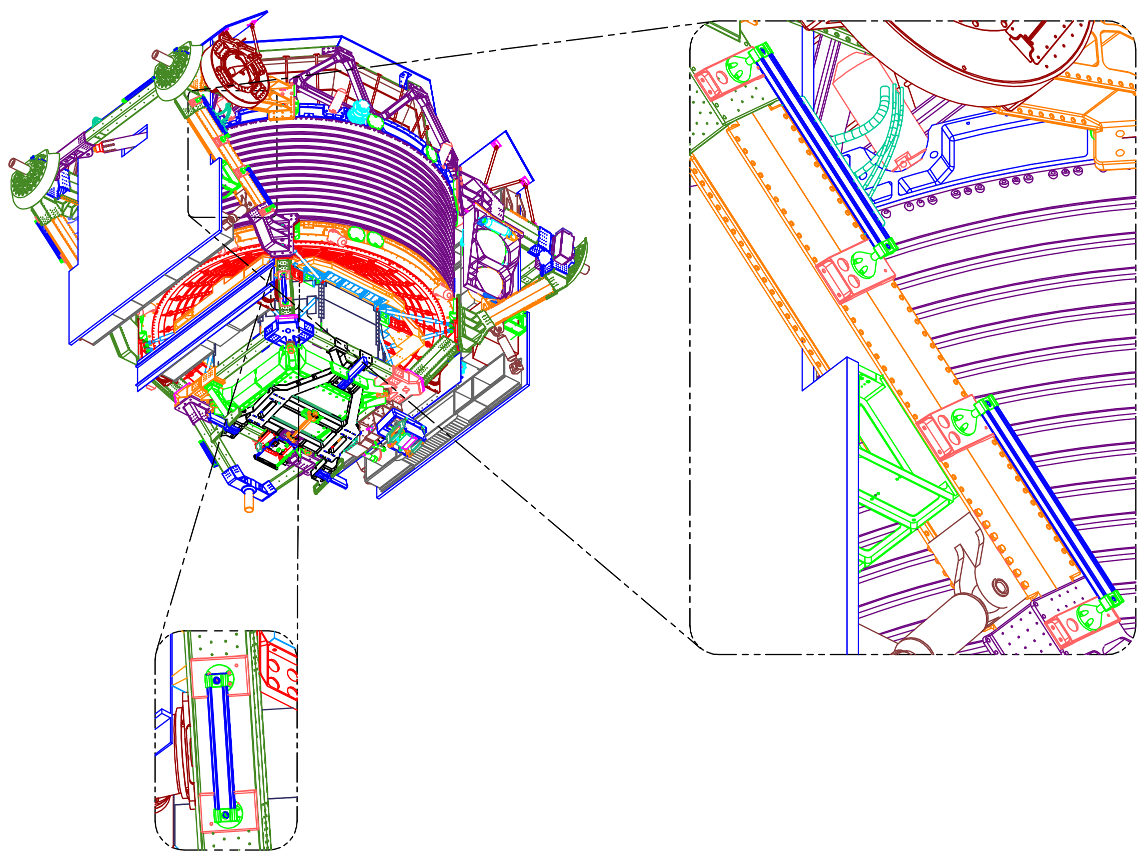


Figure 5.4-24 EVA Handrails Used To Access WIF Socket On-Orbit

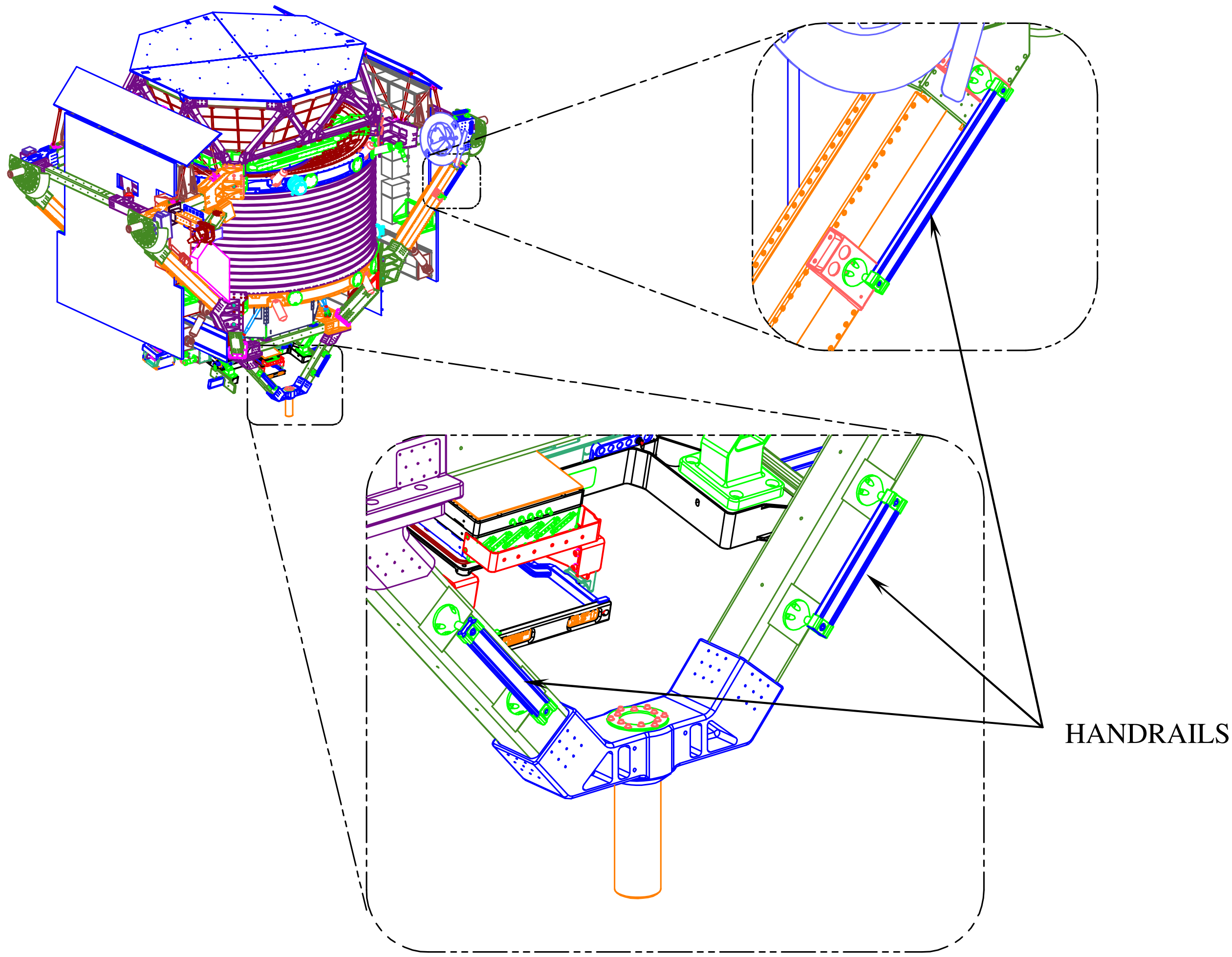


Figure 5.4-25 EVA Handrails for PAS Capture Bar Removal and FRGF Access

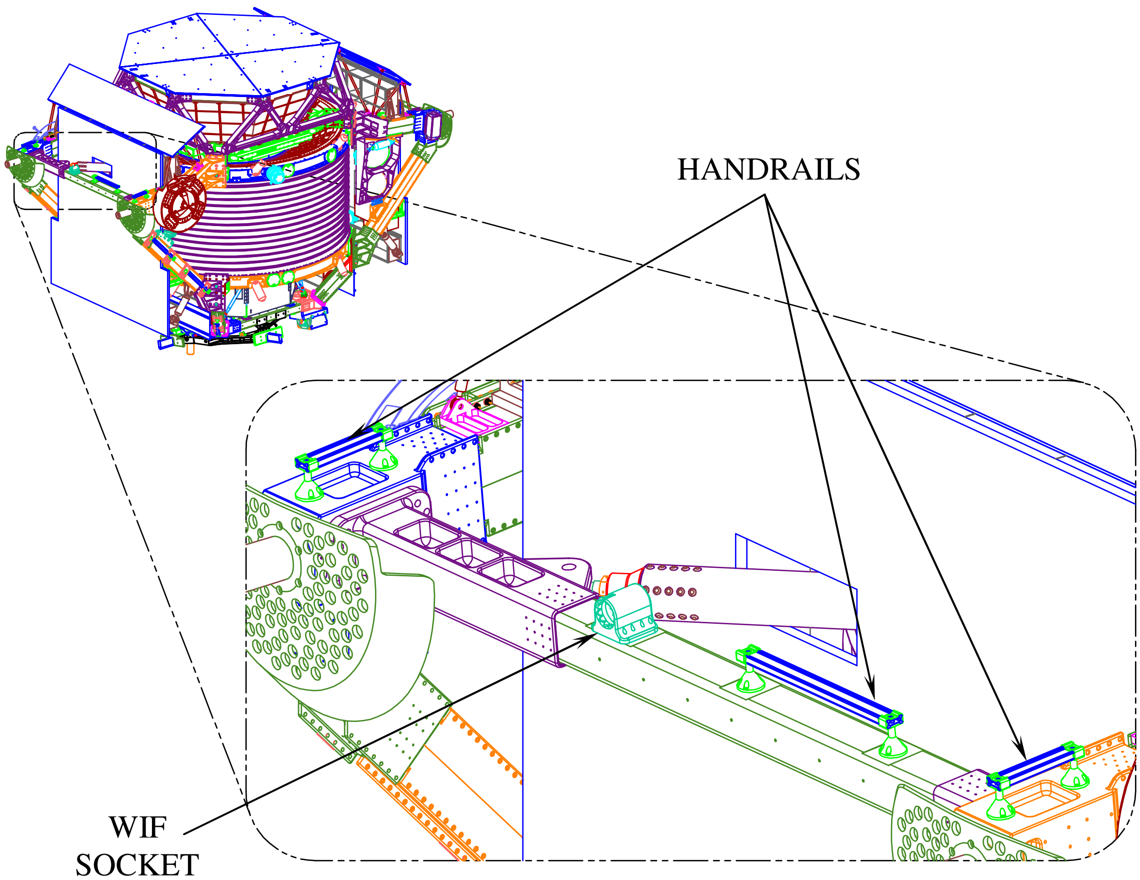


Figure 5.4-26 EVA Handrails Used for WIF Access

5.5 TRANSITION RADIATION DETECTOR (TRD) AND ASSOCIATED GAS SYSTEM

The role of the TRD (Figure 5.5.1-1) is to discriminate between electrons/anti-protons (e^-/p^-) and positrons/protons (e^+/p^+) over the Energy (E) range E = 1 – 500 GeV. This is accomplished by detecting X-ray photons emitted by highly energetic electrons and positrons when they pass through a radiator. For heavier particles such radiation is strongly reduced. The radiation is detected in tubes filled with Xe and CO_2 gas in an 80:20 ratio. Xenon gas ionizes very easily and is thus very sensitive to the passage of photons.

5.5.1 TRD Structure

The TRD detector is composed of 5248 proportional tubes which are made from a multi-layer wound composite structure. The composite includes layers of polyurethane, carbon-polyimide, aluminum, and Kapton (Figure 5.5.1-2). The straw tubes are grouped into 41 separate segments which are connected through gas manifolds. The straws have an inner diameter of 0.24 inch (6.02 mm), a wall thickness of 0.003 inches (72 microns), and vary in length from 31.5 inches (0.8m) to 78.7 inches (2.0m).

A straw module (Figure 5.5.1-3) consists of 16 straws glued together with 6 stiffeners running alongside the straws. Every 3.94 inches (10 cm), additional stiffeners are glued across the module for extra rigidity. The straw ends are glued into polycarbonate endpieces. The endpieces contain the wire fixation pieces (wire: gold plated tungsten, 0.001 inch (30 microns) diameter; wire fixation pieces (Cu/Te alloy)), the gas distributor, and the gas seal.

The TRD is constructed from 20 layers of the straw modules where a gap of 0.91 inch (23 mm) between the layers is filled with a radiator material (polypropylene fleece). The upper 4 layers (72 modules) and the lower 4 layers (56 modules) are oriented in the X-direction and the 12 middle layers (200 modules) in the Y-direction (Figures 5.5.1-4 and 5.5.1-5).

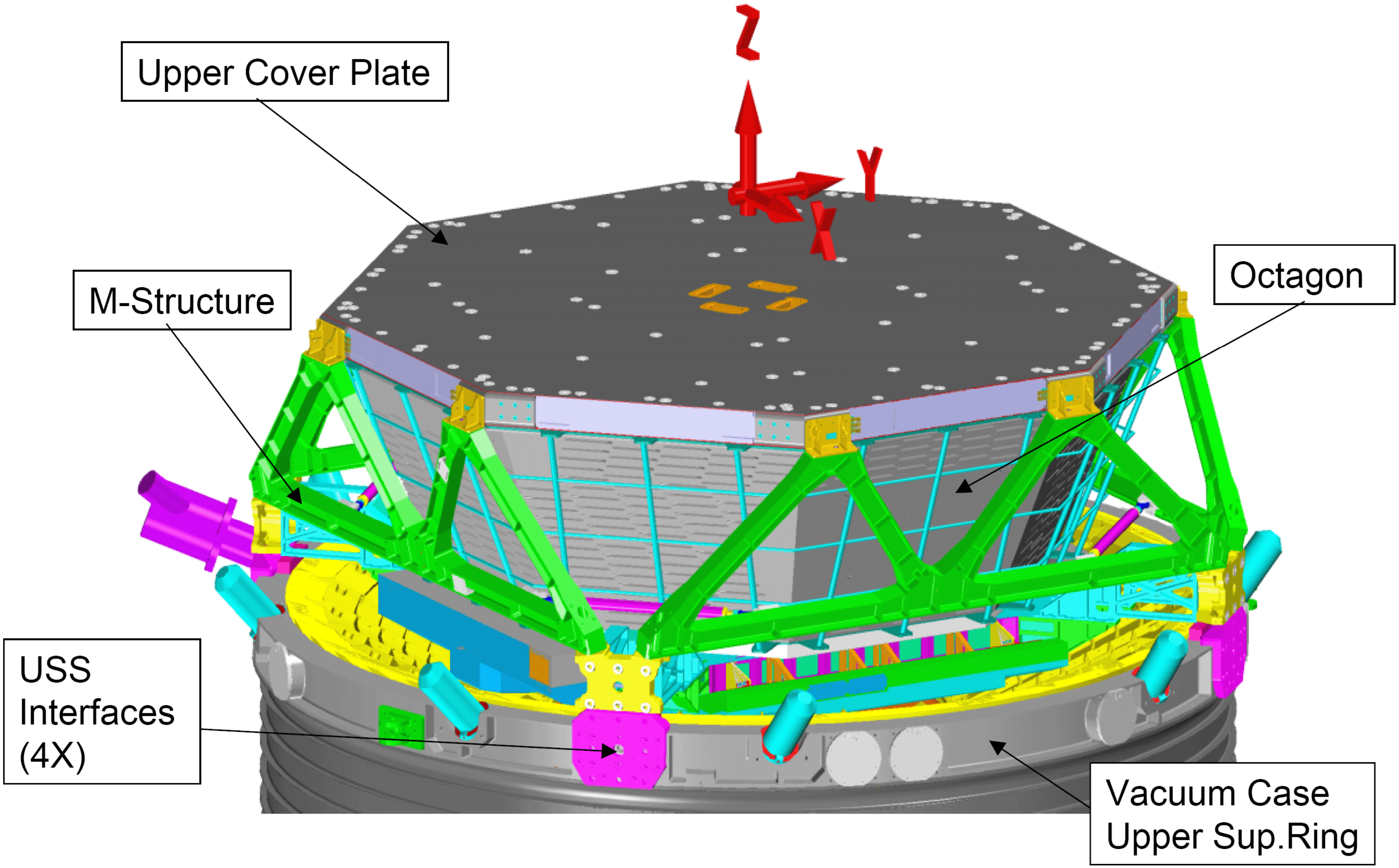
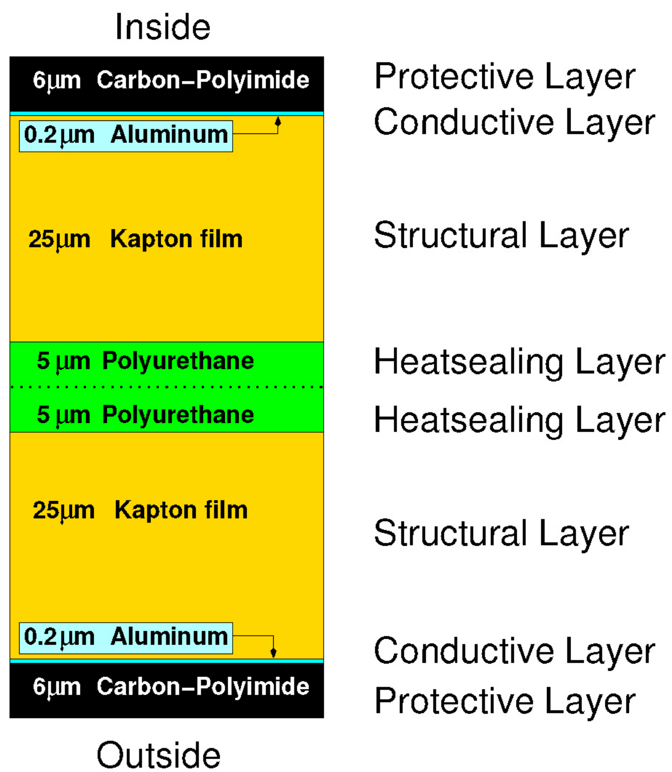


Figure 5.5.1-1 TRD Structure



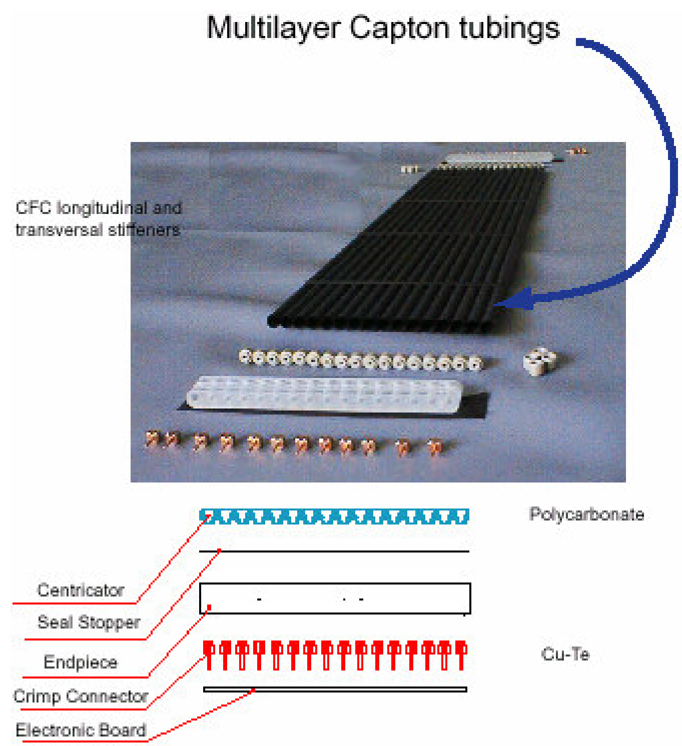


Figure 5.5.1-2 Composition of Straw Wall

Figure 5.5.1-3 Straw Module Production

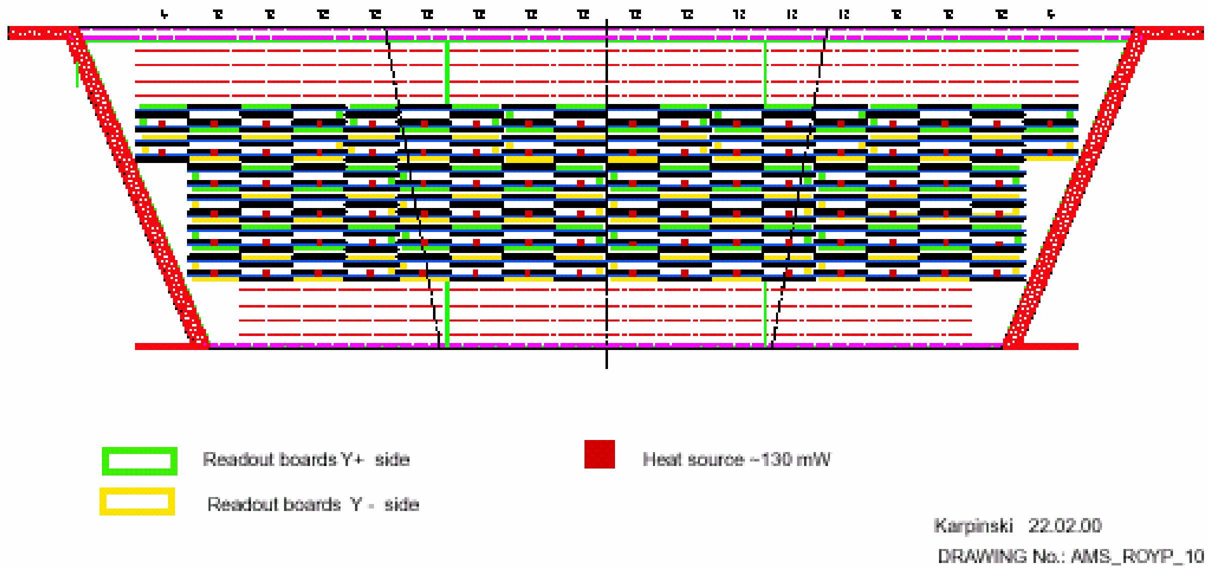


Figure 5.5.1-4 TRD X-Z Cross Section

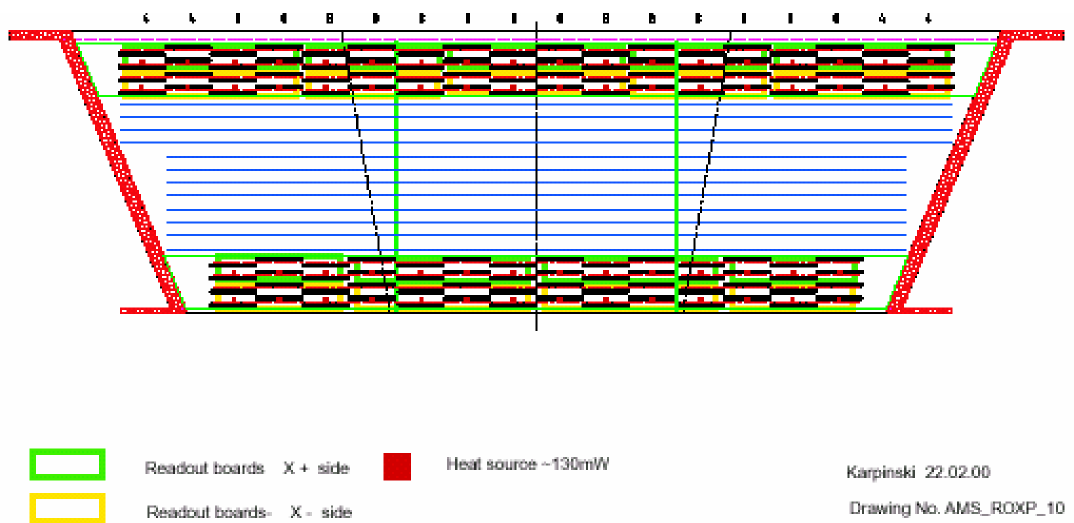


Figure 5.5.1-5 TRD Y-Z Cross Section

The 20 layers of straw modules and radiators are mounted in an octagon structure which consists of 8 honeycomb side panels (1.18 inches (30 mm) thickness), a lower honeycomb support plate, and an upper honeycomb plate. The size of the octagon structure is 91 inches x 24.5 inches (height) (2.3 m x 0.6 m). The combined weight of the TRD is 728 lbs (330.4 kg). Inside the octagon structure, the straw modules are further supported by 6 bulkheads (0.1 inch (3 mm) thick), 2 in the Y-direction and 2 times 2 smaller ones in the X-direction (Figure 5.5.1-6).

The TRD is located at the top of the experiment stack above the Upper TOF. The Octagon Structure is supported by the M-Structure, which is mounted to the USS-02 at 4 locations, just above the vacuum case interface. The TRD corner joints are hard-mounted to the corner joints on the upper USS-02 (Figure 5.5.1-1).

The front-end readout electronics and the High Voltage (HV) distribution boards are mounted on special boards close to the straw module end pieces. The gas distribution system is also mounted close to the ends of the straw modules on the opposite side of the electronics.

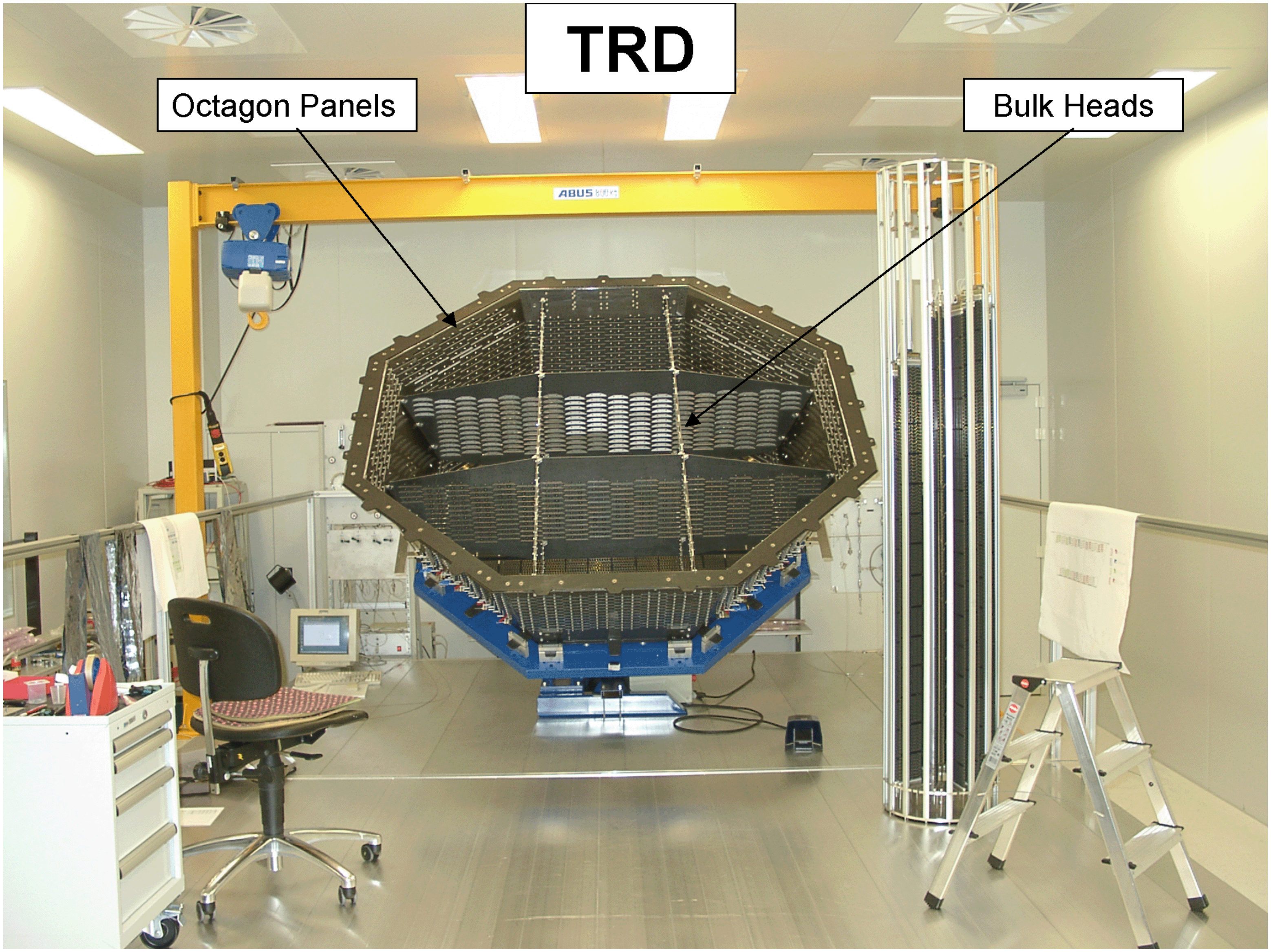


Figure 5.5.1-6 TRD Bulkheads Inside the Octagon (Full Scale TRD Mockup)

Figure 5.5.1-7 TRD Integrated Flight Module

5.5.2 TRD Gas Supply System

The TRD Gas Supply System supplies a mixture of 80% Xenon (Xe) and 20% Carbon Dioxide (CO_2). The density and purity of the gas mixture is monitored and adjusted to ensure efficient photon detection. The gas supply system includes three tanks, one for the Xe, one for the CO_2, and one mixing tank (Figures 5.5.2-1 and 5.5.2-2). These tanks are mounted to a support bracket and covered by shields to protect them from orbital debris. The support bracket is mounted to the wake side of the USS-02 (Figure 5.5.2-3), which also helps protect them from debris.

The Xe tank is a composite over-wrapped stainless steel tank that is designed and built by Arde, Inc. This tank is the same design as one that is used on the Plasma Contactor Unit for ISS. It has a maximum design pressure (MDP) of 3000 psid with a minimum temperature rating of –60°F and a maximum temperature rating of 150°F. The tank was designed with a minimum proof test factor of 1.5 x MDP and a minimum burst factor of 3.1 x MDP. It has an outside diameter of 15.4 inches (390 mm) and a volume of 1680 cubic inches (27.5 liters). It carries 109 lbs (49 Kg) of Xe at launch and has been tested to 8.9 G_{rms} at 0.08 g^2/Hz.

The CO_2 tank is also a composite over-wrapped stainless steel tank designed and built by Arde, Inc. This tank was designed for use on the X-33 vehicle and also has a maximum design pressure of 3000 psid with a minimum operating temperature of –100°F and a maximum operating temperature of 300°F (tank rating, AMS-02 qualification requires 150°F). The tank is designed with a proof test factor of 1.6 x MDP and a minimum burst factor of 2.1 x MDP. The outside diameter is 12.4 inches (315 mm) and it has a volume of 813 cubic inches (13.3 liters). The tank weighs 9.5 lbs (4.3 kg) and it can hold a maximum of 12.1 lbs (5.5 kg) of CO_2. A vibration test has been performed to 8.9 G_{rms} at 0.08 g^2/Hz axially and 4.5 G_{rms} at 0.02 g^2/Hz laterally.

The small mixing tank will also be manufactured by Arde, Inc. It will have a nominal operating pressure of 200 psia, a normal operating temperature of 77°F and an MDP of 300 psid established by dual pressure relief devices and the source gas supply control. A proof test factor of 2.0 x MDP and a minimum burst factor of 4,0 x MDP will be used. The volume will be 61 cubic inches (1 liter).

The fittings and connections in the gas system include stainless steel tubing, welded joints, and numerous gas manifolds. The stainless steel tubing will range from 0.06 - 0.25 inch (1.6 - 6 mm) outer diameter. Connections will be made with welded joints (as an alternate, metal sealed fitting could be used). The connections between the gas manifolds and the TRD segments are made with 0.05 inch (12 mm) inner diameter stainless steel tubing and brazed metal connectors.

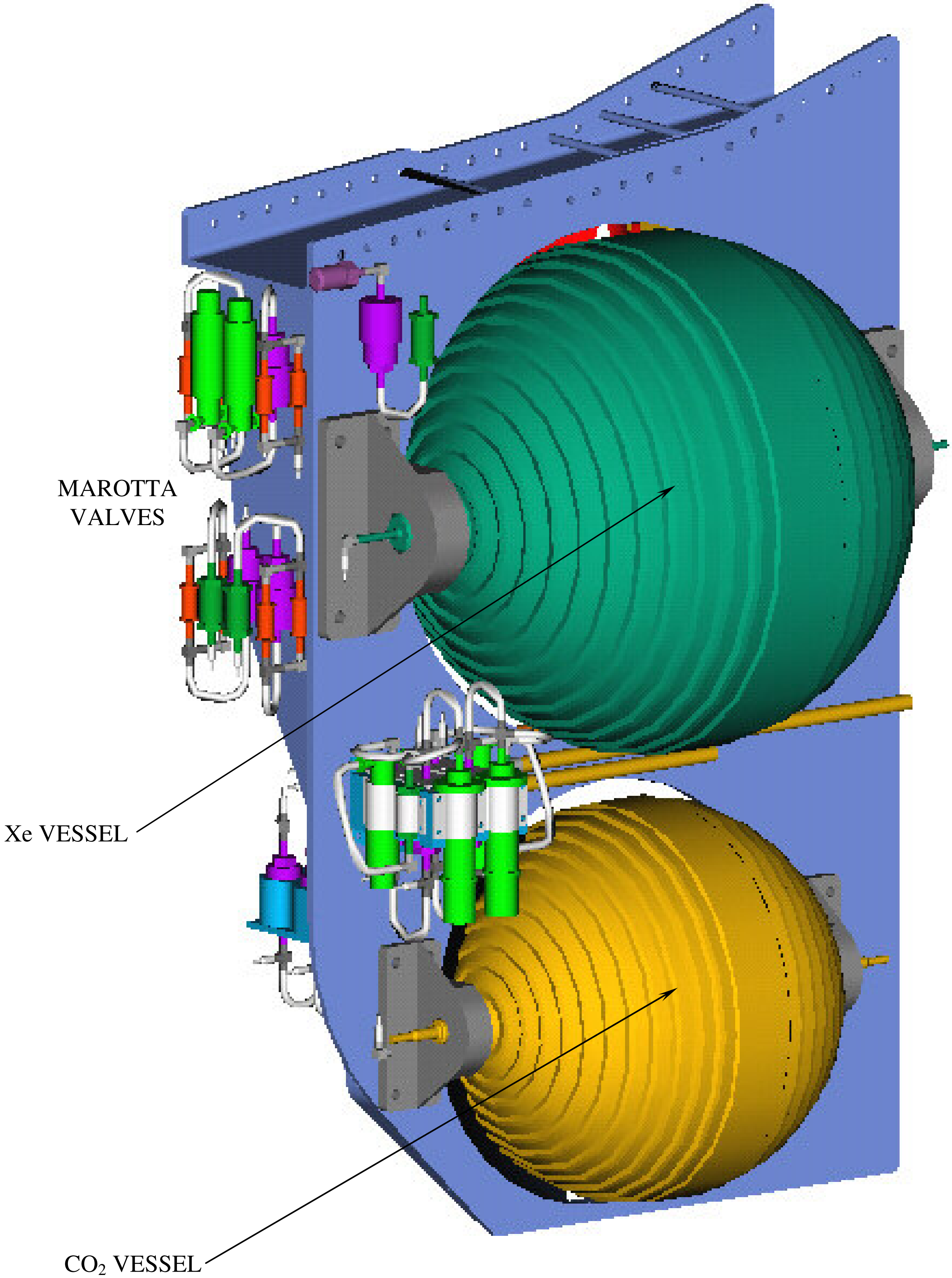


Figure 5.5.2-1 TRD Gas Supply System (Box S)

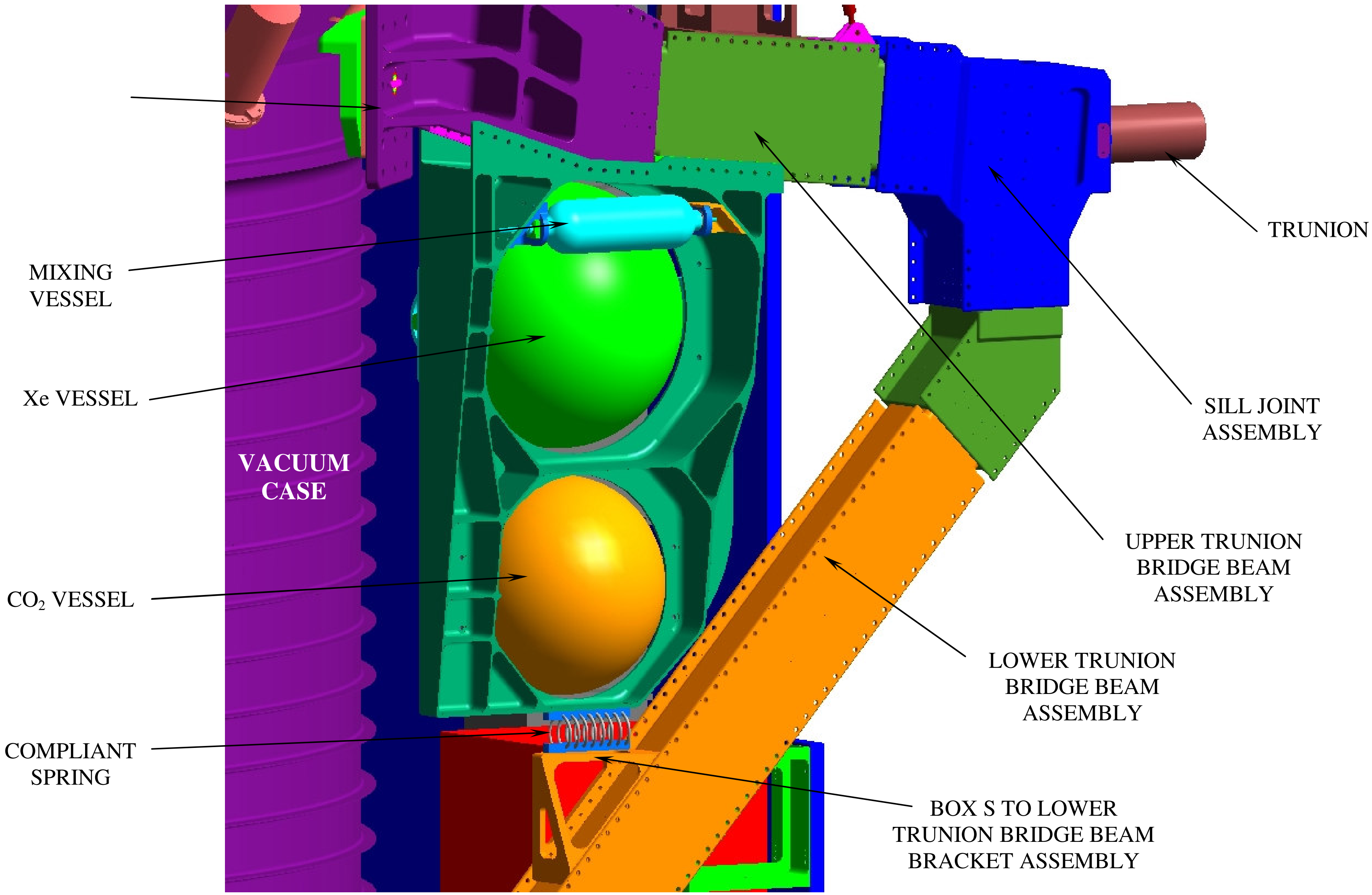


Figure 5.5.2-2 TRD Gas Supply System (Box S and Mixing Vessel) on the Upper USS-02 Structure (Wake Side – Port)

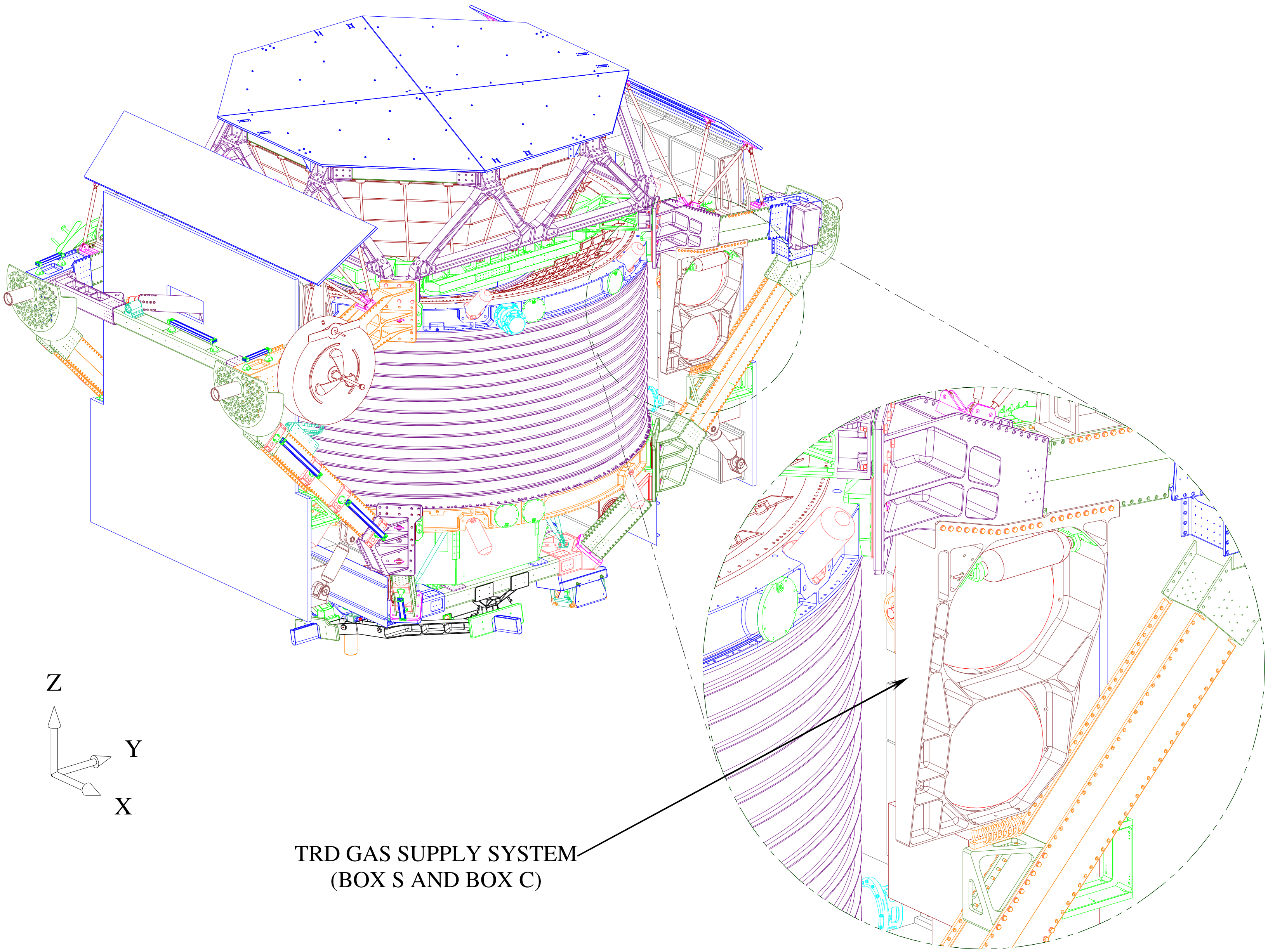


Figure 5.5.2-3 TRD Gas Supply System Mounted to the USS

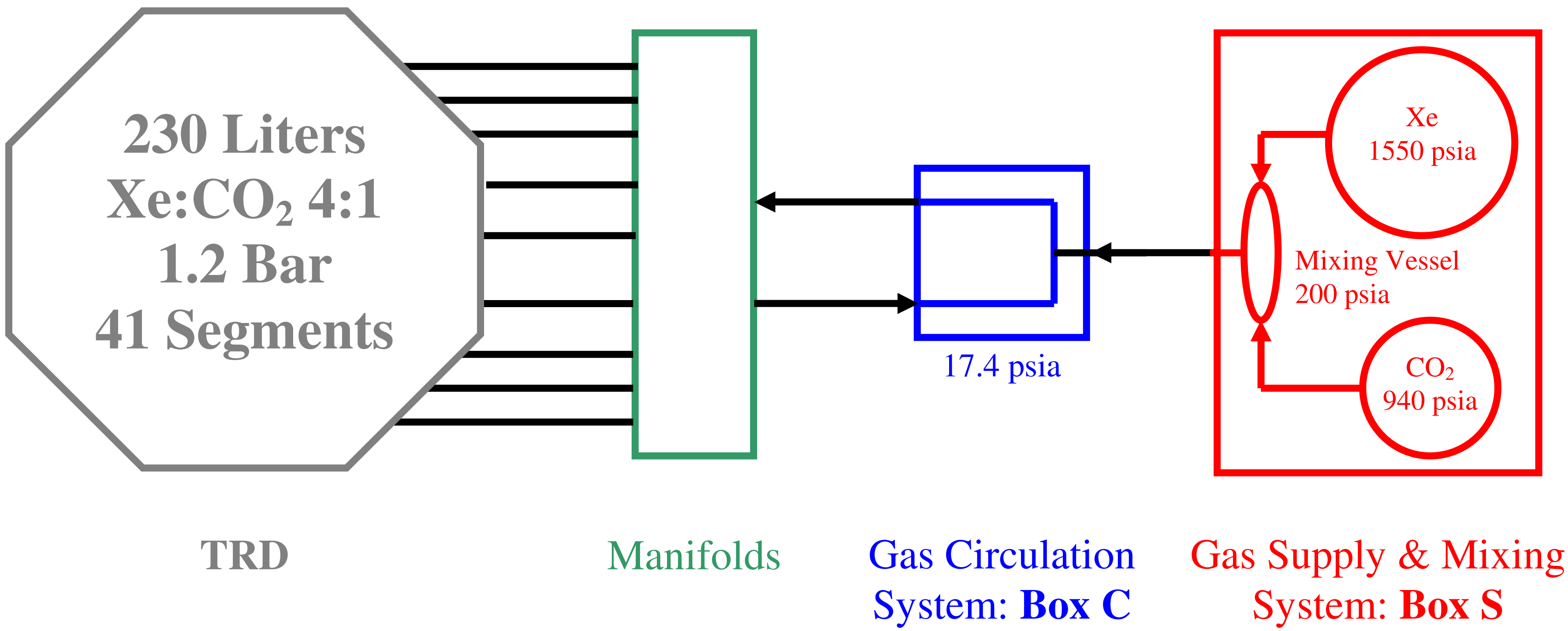


Figure 5.5.2-4 Schematic of the TRD Gas System [All pressures are at 77° F (25° C)]

The TRD straw tubes have a maximum design pressure of 29.4 psid. The minimum design temperature is 13.5°F and maximum design temperature is 105°F. Thermal/vacuum testing has been performed to verify these numbers. The relief valves will be set to 30 psia. The normal operating pressure is 11.6 to 17.4 psid on-orbit and 17.4 psid on the ground. The proof test factor of 1.5 x MDP will be employed and a minimum burst factor > or = 2.0 x MDP will be employed. Each of the 41 separate segments contains 244 – 427 in^3 (4 – 7 liters) of gas, for a total gas volume of 8.1 ft^3 (0.23 m^3). The nonflammable gas mixture is circulated through these tubes in a continuous loop. The density and purity of the gas mixture is monitored and corrected.

The 41 TRD segments are connected through manifolds to Box C, containing controls, monitors, and recirculation pumps. Box S provides Box C with pre-mixed gas from the gas supplies in a limited transfer volume (approximately 1 liter). A feed control between Box S and C is activated by computer when required (approximately once a week). The general layout is shown in Figure 5.5.2-4. The 41 sealed TRD segments of average 342 in^3. (5.6 liters) each are held at 17.4 psi. Box C has an estimated volume of 150 in^3, held below 30 psi by relief valves. Mounted on the Gas Supply System Box C cylindrical vessel are 4 calibration tubes (Reference Figure 5.5.4-1), which monitor the gas gain changes of the circulating mixture. The calibration tubes have an inside diameter of 0.24 inch (6 mm) like the straw tubes; however, they are inside a stainless steel container/structure (Figure 5.5.4-3). On the inner wall is a deposit of Fe^{55} (estimated 0.17 microCuries at time of launch, ~0.27-0.3 microCuries at loading). The calibration tube construction attenuates the 5.9 KeV radiation to a level less than detectable exterior to the component.

5.5.3 Box S Description

Box S, shown in Figure 5.5.3-1, contains the gas reserves for the TRD. Gas is released from the two reservoirs into the mixing vessel (D), where it is combined in the required ratio and stored until such time as the straw tubes need to be refilled. Once needed, the combined gas is transferred to Box C for circulation.

The straw tubes are measured to lose approximately 0.25 liters of gas per week. At that rate, the mixing operation should take place once per day. For Xenon, valve V1a is opened for 1 second, releasing gas into the 15 cc buffer volume between V1a and V2a. After V1a is closed, V2a is opened for 1 sec, releasing gas into the 60 cc buffer volume between V2a and V3a. After V2a is closed V3a is opened for 30 seconds transferringthe small amount of pressurized gas from the 60 cc buffer volume into the 1 liter mixing vessel. By use of two buffered volumes at a gradual, controlled step down of pressure is achieved. The release of gas through this three stage (areas) process (called one cycle) occurs several times until the required quantity of Xenon gas is in the 1 liter mixing volume. Similarly CO_2 is released in the same three-stage (using the “b” indices for the “a") into the 1 liter mixing volume.

Valves V3a or V3b are always closed at the end of the cycle and the gases are allowed to settle for 3 minutes to measure the pressure increase and to ensure good mixing. After the gases reach the correct quantity in the 1 liter vessel, and settled for >10 minutes, valves V4a can be opened to allow the gas to flow into Box C.

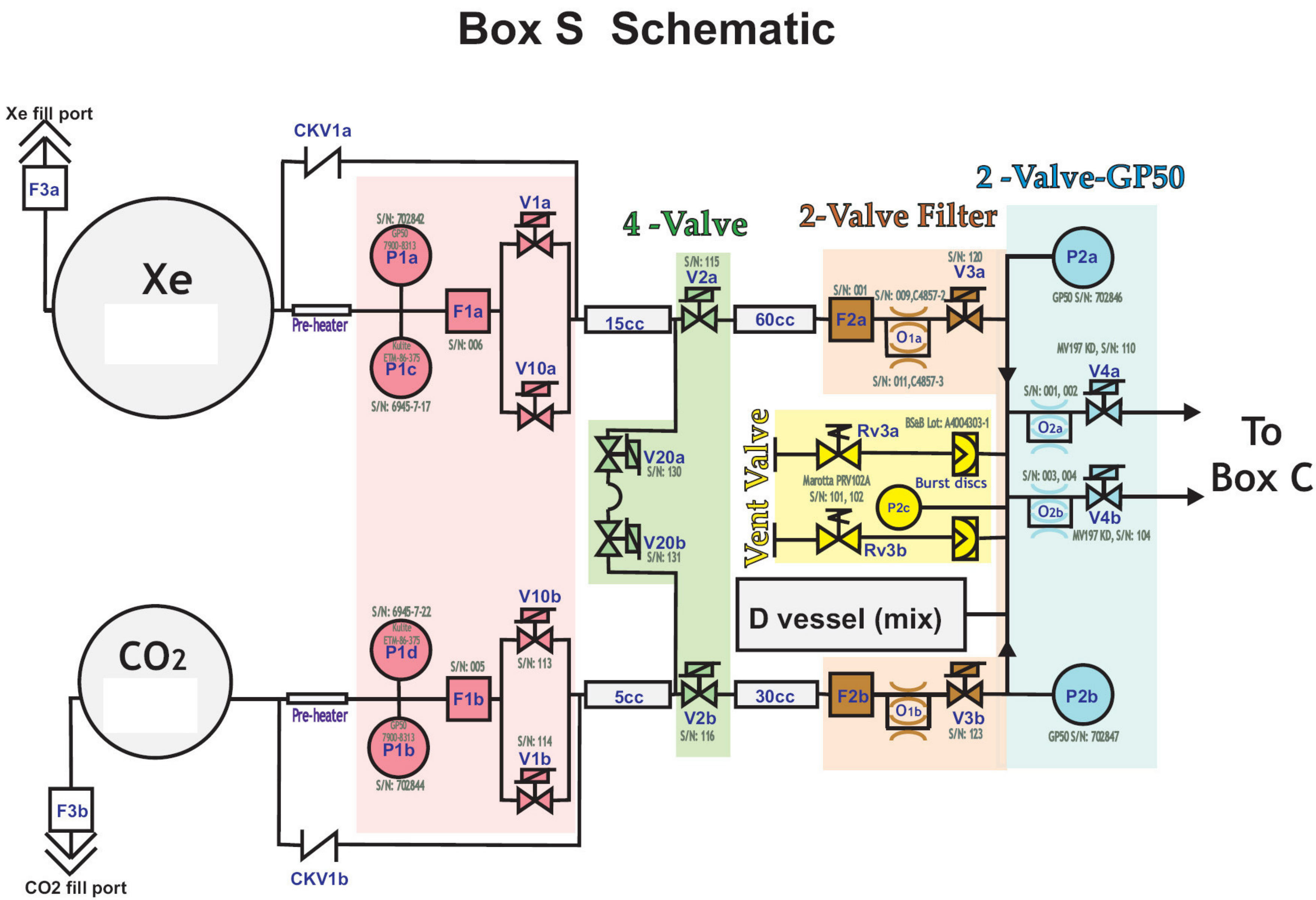


Figure 5.5.3-1 Box S TRD Gas Supply Detailed Schematic [PV pressures are at 77° F (25° C) with a nominal fill level]

The reservoirs are filled through the GSE fill ports equipped with recoil check valves. Valves V1a (V10a) and V1b (V10b) are closed (all Marotta MV 197 and MV100 valves are normally closed unless energized) and each tank is filled from a ground source. Temperature and pressure are then monitored for four hours. If performance is as desired, then the fill ports are capped with metal seals (2).

Several redundant valves have been included in the system to reduce the risk of mission failure, but are not required for safety:

- Valves V10a and V10b provide a secondary path from the reservoir to the first buffer volume in case of failure in valves V1a and V1b, respectively.
- Valves V20a and V20b provide a channel between the two reservoirs and the two sets of buffer volumes. If one of the valves V2a, V2b, V3a, or V3b were to fail closed, this allows each reservoir access to the buffer volumes on the opposite side.
- Flow restrictor O2b and valve V4b allow for a redundant path into Box C.

During launch and landing, all valves are closed and the mixing vessel will be at 1.2 bar. All pressure and temperature sensors will be monitored from the ground as long as possible prior to launch. There are no planned go-no go launch restrictions for this monitored value. Temperature sensors will also be monitored during all transfer and berthing operations by the global temperature network.

Maximum design pressure for the gas reservoirs, the buffer volumes, and the associated piping through valves V3a and V3b have been determined through thermal analysis and all items have been shown to have sufficient structural margin. MDP of the mixing vessel and all plumbing between V3a/V3b and V4a/V4b is set at 300 psi based on the redundant burst disks shown in Figure 5.5.3-1. This hardware has also been shown to have adequate margin through structural analysis.

5.5.4 Box C Description

Box C, shown in Figure 5.5.4-1, contains the pumps for the primary TRD gas circuit. By causing the gas to flow continuously throughout each of the TRD's 41 straw module, the gas is not able to separate into pockets and uniform properties are ensured. Box C is mounted on the USS-02 just above the main TRD Gas Supply, as shown in Figure 5.5.4-2.

Newly mixed gas from Box S arrives in Box C through valve V6a, where it merges with the gas coming out of the manifolds that have passed through the Monitor Tube, shown in Figure 5.5.4-3 and 5.5.4-4. The Monitor Tube (also referred to as Calibration Tubes) analyze the pulse height spectrum from a Fe^{55} source (estimated 0.17 microCuries at time of launch, ~0.27-0.3 microCuries at loading) to monitor the quality of the gas with a gain measurement. This source is contained within a thin layer of iron citrate deposited on the interior surface of the 6mm inner diameter of the Monitor Tube Structure. Radiation from the source is completely contained by the Monitor Tube's steel walls.

After leaving the tubes, the gas enters the canister, where two KNF Neuberger UNMP30 pumps provide the circulation through the system. These pumps operate in the open environment of the canister shown in Figure 5.5.4-1, with only one side of the pump connected directly to the plumbing. Only one pump is needed – a redundant pump is for mission success purposes. The gas then flows through an ultrasonic spirometer, which measures the CO_2 content in the gas flow and provides an independent check of the Xe/CO_2 ratio. The gas then flows back into the manifolds and re-enters the straw tubes.

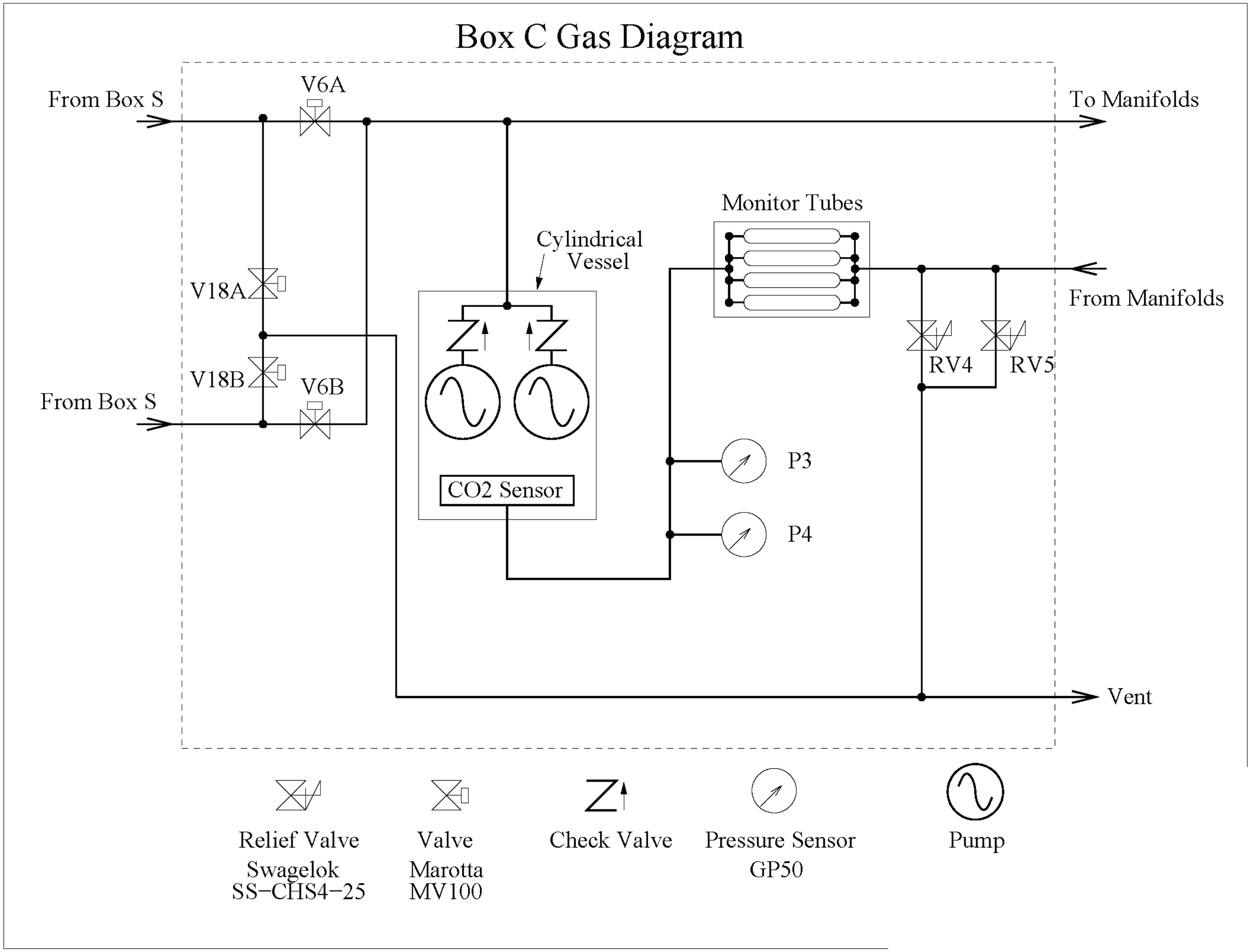


Figure 5.5.4-1 Box C TRD Gas Circulation System

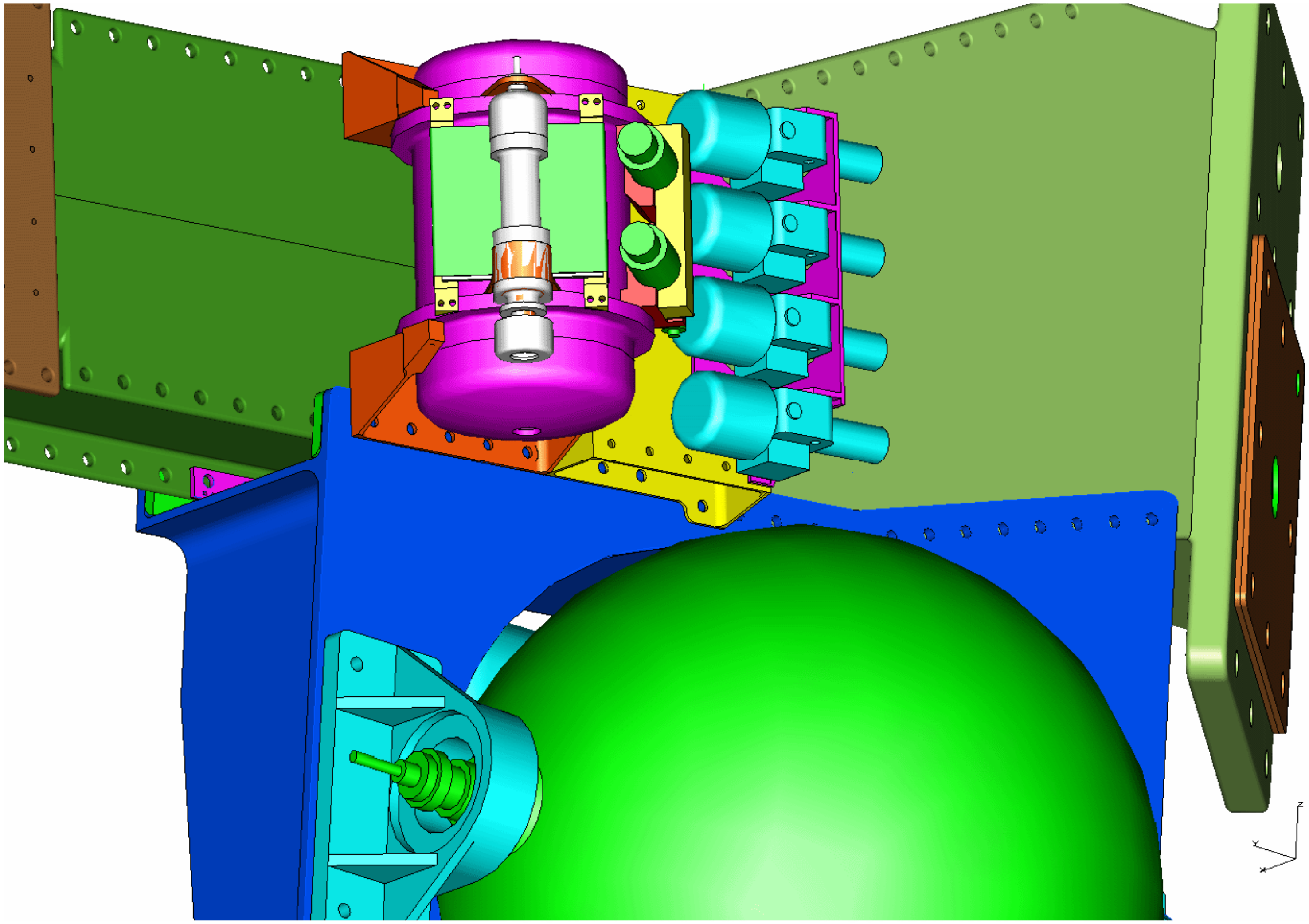


Figure 5.5.4-2 TRD Gas Circulation System (Box C) Mounted to the USS

As with Box S. several redundant valves have been included in the system to reduce the risk of mission failure, but are not required for safety:

- Valve V6b pairs with valve V4b in Box S and allows a redundant entry point for incoming gas.
- Valves V18a and V18b allow gas to be purged to space through a zero thrust vent in the case of incorrect gas mixing or contamination.

Note that valves V8a and V8b recoil check valves are used to preclude backflow during ground filling operations.

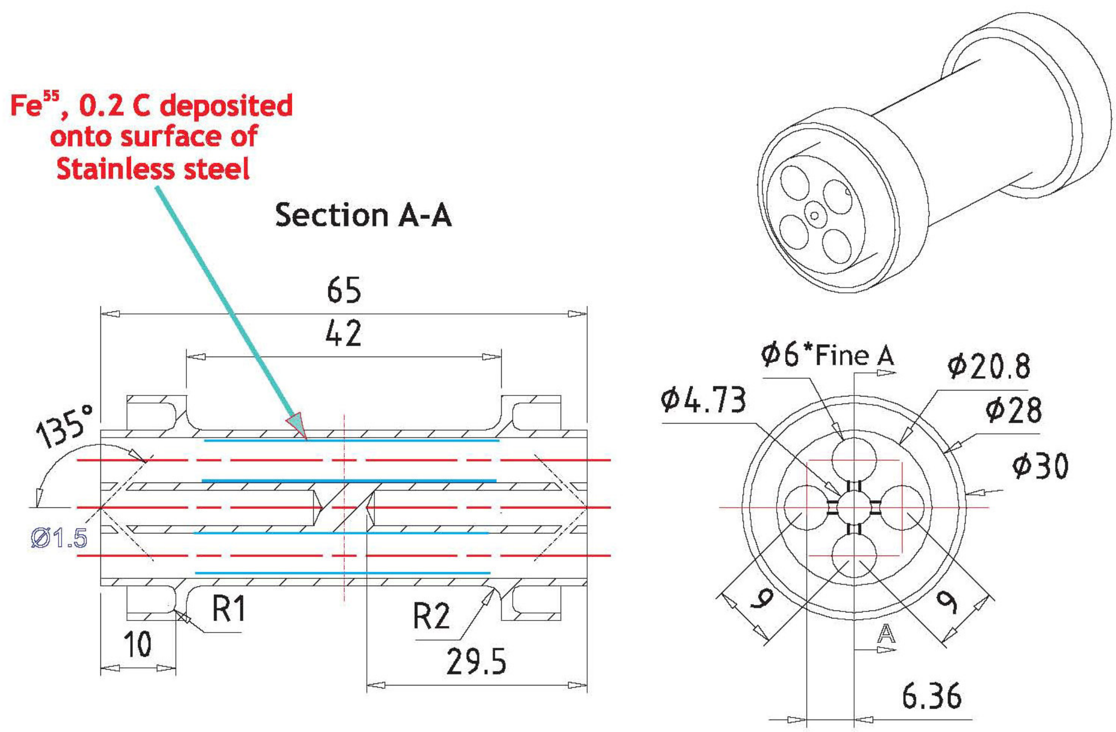


Figure 5.5.4-3 Calibration/Monitor Tube

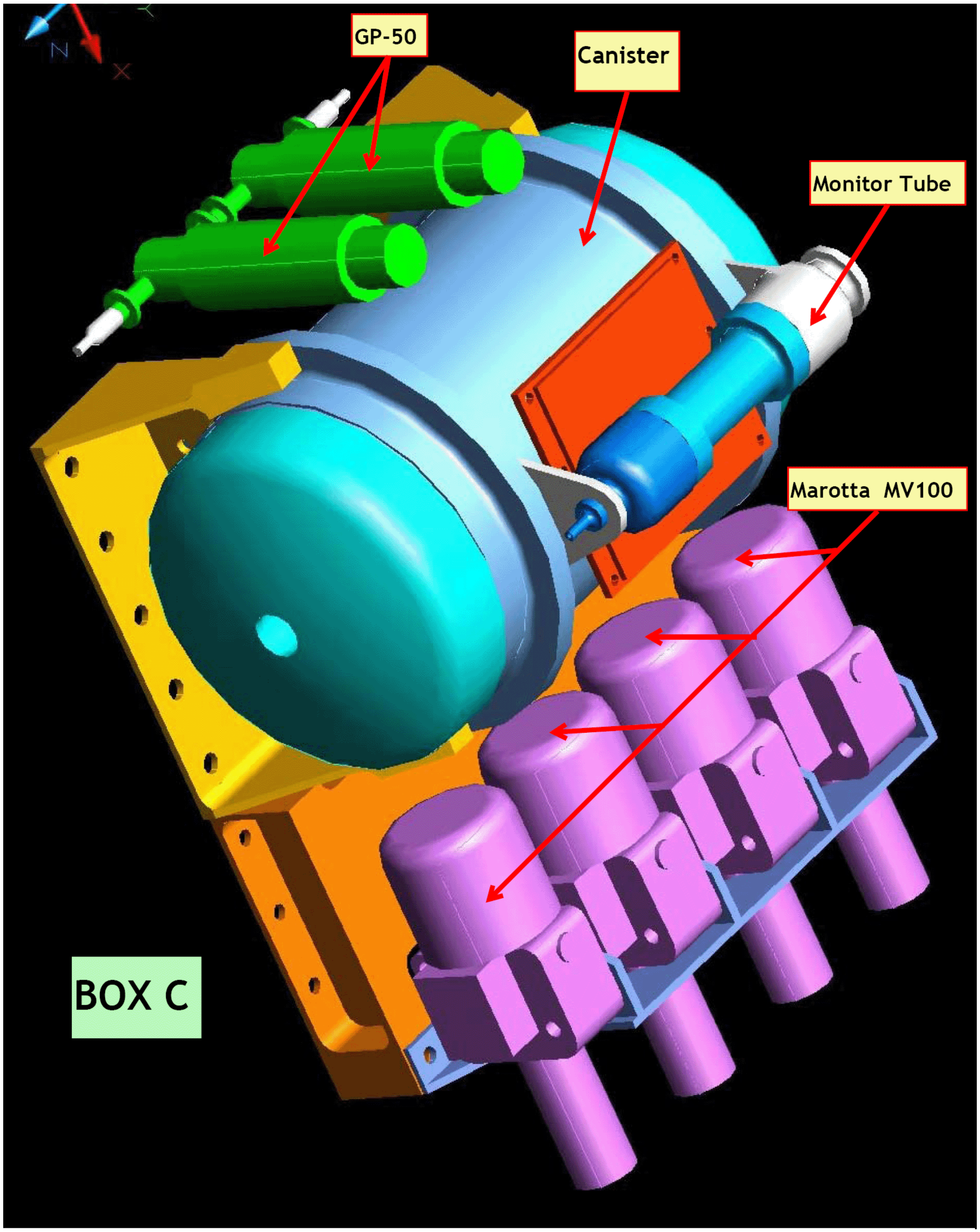


Figure 5.5.4-4 Location of TRD Calibration/Monitor Tube

5.5.5 Straw Tube Segments

From Box C, 3 mm stainless steel gas lines run to the top rim of the TRD, where input and output manifolds are located. The 5248 tubes of the TRD are grouped into 41 separate segments, each separately attached to input and output manifolds (Figure 5.5.5-1). Each segment is small enough so as not to be considered a pressure vessel (1 bar×7 liters=0.7 kJ). Each manifold is connected to the 41 TRD segments via pressure controlled isolation valves. 0.06 inch (1.6 mm) steel tubing runs from the isolation valves to the segment inputs and outputs, where it is joined to the straws via RWTH Aachen designed special connectors. Where other connections need to be made, Cajon VCR fittings are used. Figure 5.5.5-2 shows the locations of the gas manifolds and the input and output connections to the straw modules (one of 41 segments shown).

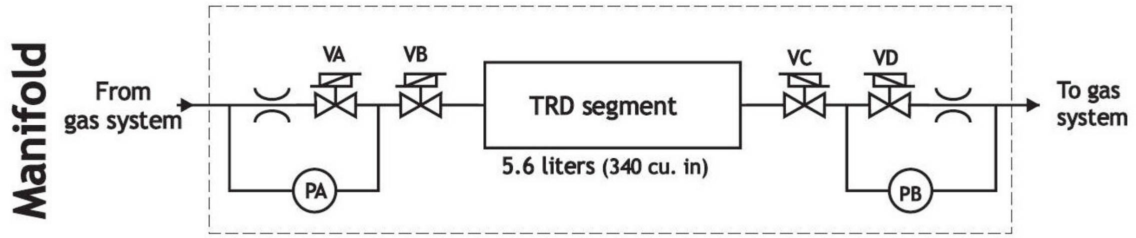


Figure 5.5.5-1 One of 41 TRD Straw Tube Segments

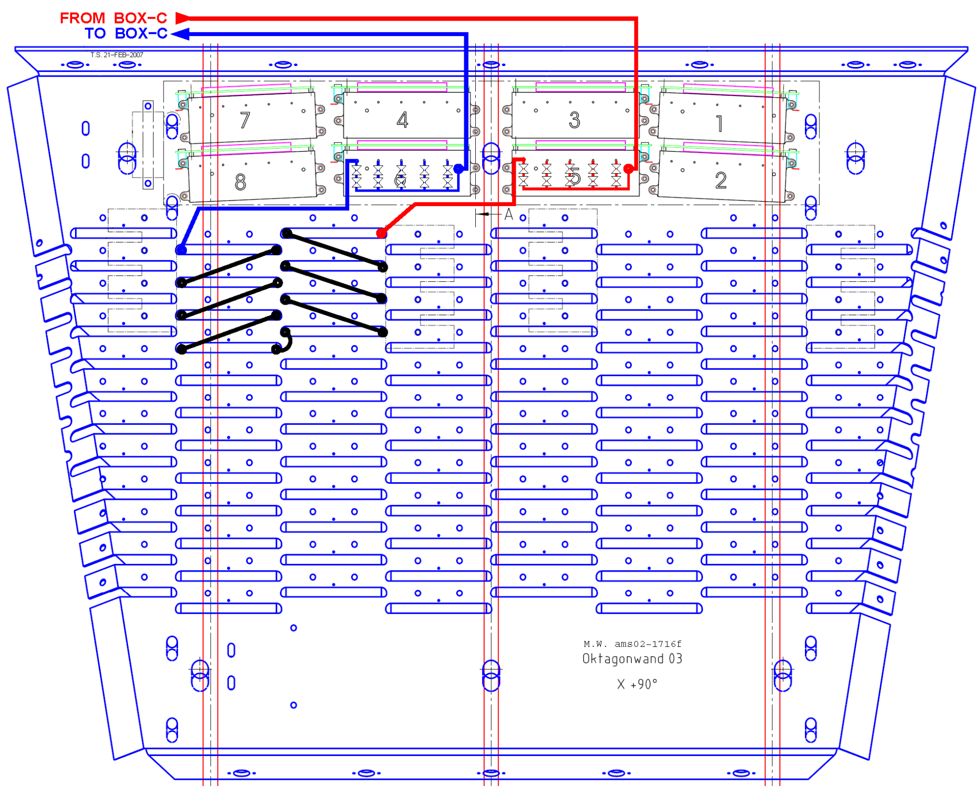


Figure 5.5.5-2 Gas Manifold Connections to TRD Segments

The isolation system is designed to protect the TRD against gas loss in order to maximize efficiency. Leakage of the Xe/CO_2 gas cannot produce a safety hazard, but can cause the gas supply to be used at a faster rate than anticipated and reduce the operational life of the TRD. The system works in two modes. In case of a sudden pressure drop in a segment, the control computer will close all four valves leading to the segment automatically to prevent further gas loss. In case of an increase in gas consumption, or as a periodic check, the computer will close two valves and monitor the differential pressure P_A and P_B. This will be used to detect slow leaks. Failure of any of the shutoff valves or pressure sensors cannot cause MDP to be exceeded.

The shutoff valve/pressure sensor assembly will be potted inside a magnetic shielding box to preclude any leak from the gas system volume. The isolation valves will be Burkert Type 6124 2/2 Way Flipper Valves. Closed, they hold 43.6 psi (3 bar) in either direction and have been leak tested to better than 1 ml/day loss, 14.5 psi (1 bar) to vacuum through a closed valve. They can be flipped from open to closed and vice-versa by a 12V, 20 μsec pulse, and otherwise consume no power. They are located near the top flange of the TRD in a region of low magnetic field. The pressure sensors are Honeywell type 24PC.

5.5.6 Monitoring and Control

The electronics that control the gas system will be located in the UG-crate. This crate will contain a Universal Slow Control Module (USCM) computer that will manage the monitoring and control tasks, as well as maintain communication with the AMS-02 Main DAQ Computer (JMDC). The USCM will be provided with interface electronics to the various gas transducers and actuators distributed throughout the gas system. The USCM and interface electronics will perform the following tasks:

1. Close or open emergency isolation valves in the manifolds.
2. Provide housekeeping data (temperature of valves, pressure vessels, etc.)
3. Store calibration constants.
4. Condition and perform analog to digital conversion for over 100 pressure sensors and approximately 500 temperature sensors distributed around the TRD and gas system.

5. Control two recirculation pumps.
6. Provide logic control for approximately 200 gas valves.
7. Provide HV for the calibration tubes in Box C.
8. The interface electronics will provide the power electronics to drive valves, etc.
9. Read out digital signals from the gas analyzer (spirometer) and calibration tube MCA.
10. Have control logic to switch the gas system to "Safe Mode" (for mission success) in case of communication failure.

The USCM, interface electronics, and calibration tubes are doubled to provide single fault tolerance for mission success. The USCM does not require or use batteries. If there is a power failure, the pumps stop, and all the Marotta valves close (they require power and special authorization to open). This ensures that the Xe and CO_2 gas tanks are sealed, and that no gas is transferred, either within Box S (e.g. to the mixing tank or other sealed volumes), or from Box S to Box C and the rest of the gas system. All mechanical safety release valves, for overpressure, remain operational. All of the flipper valves, which are used to isolate individual sectors of the gas system in case of leak, remain in whatever state they were when power went off. This means that, on-orbit, if there is a leak in a sector which develops in the TRD when power is off, the worst that would happen is the loss of the approximately 230 liters of gas in the TRD over a period of 5 hours, which is small compared to the 10,000 liters of gas in the Xe and CO_2 tanks. Any sector previously isolated because of a leak will remain isolated. On the ground, a leak with power off would slowly contaminate the gas in the TRD with air so that it would not work well when power was switched on again, but would have no safety impact.

The TRD HV system consists of HV generation cards (UHVG). One is located in the UG crate to provide HV for the calibration tubes in the Box C and is monitored by the UGSCM. Six each are located in the two U crates to provide the HV for 82 TRD straw tube HV channels. They are monitored by the U crate interface cards. Each UHVG card drives 7 HV lines with twofold internal redundancy to provide single fault tolerance for mission success. Each line is connected via shielded HV cabling to a HV distribution board (UHVD) mounted on the octagon in the vicinity of the readout cards to distribute the HV to 4 modules (64 tubes). The schematic of the HV system is shown in Figures

5.5.6-1 and 5.5.6-2. Each unit provides +1600V (control range: 700-1750V) with current limited to <100 microamps.

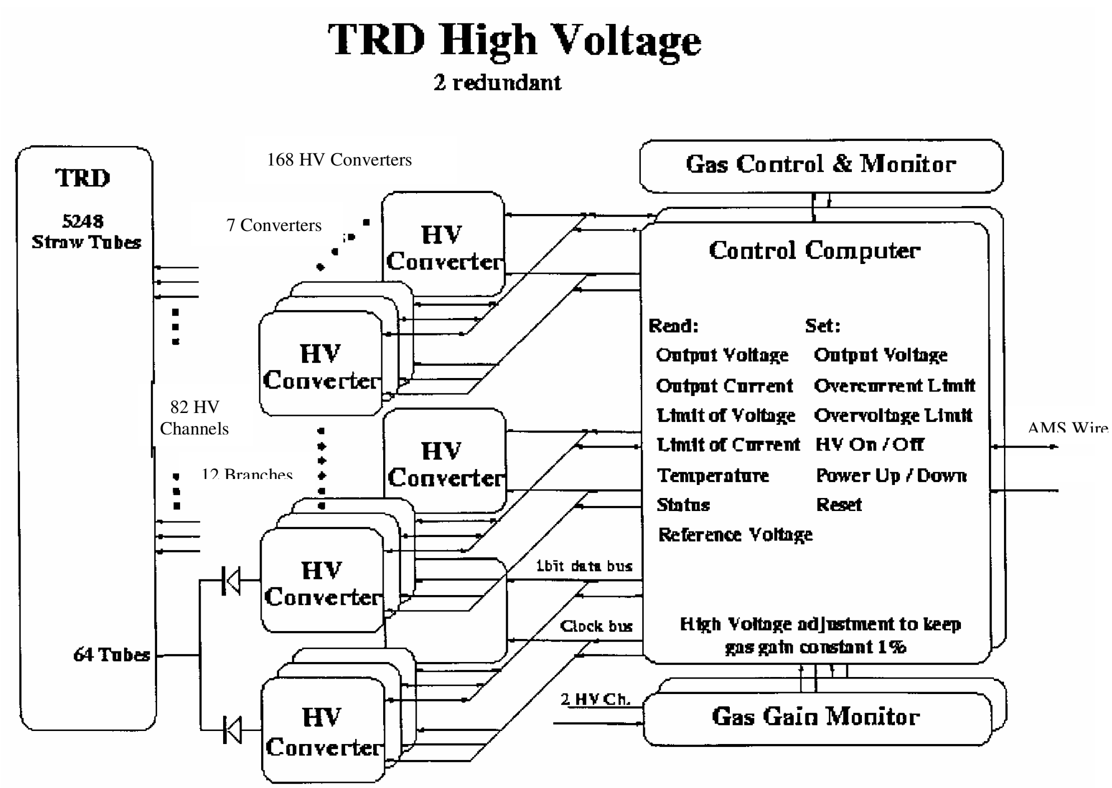


Figure 5.5.6-1 TRD High Voltage System

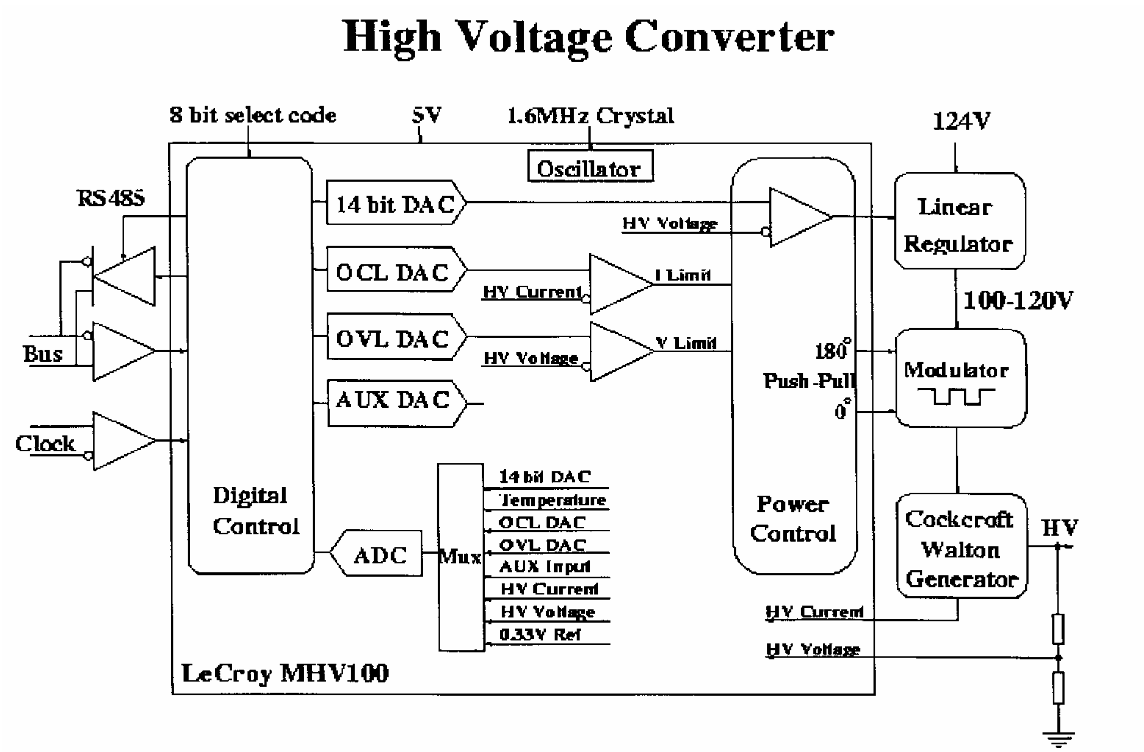


Figure 5.5.6-2 High Voltage Converter

5.6 TIME-OF-FLIGHT (TOF) SCINTILLATOR COUNTERS

The TOF serves a) as the fast trigger for the experiment when a particle crosses the bore of Cryomagnet and Silicon Tracker, b) to measure the particles traversing the detector to a resolution sufficient to distinguish between upward and downward traveling particles and c) measure the absolute charge of the particle.

The TOF is composed of four planes of detectors, two atop the AMS tracker, two below as shown in Figure 5.6-1. Numbered from the top down, detector assemblies 1, 2 and 4 have eight detector paddles per plane and detector assembly 3 has ten. The pairs of detector assemblies are oriented 90° to each other, shown in Figure 5.6-2. This configuration gives a 12 x 12 cm^2 resolution for triggering particle events over the 1.2 m^2 area the TOF covers. Each plane is contained inside a vented carbon fiber box.

Charged particles that pass through the scintillators generate photons that are collected at the two ends of each counter paddle, this is accomplished by special light guides directing the photons to the photomultiplier tubes (PMT). The light guides are situated at either end of the paddles for reasons of redundancy.

Each individual detector paddle is made of polyvinyl toluene (a Plexiglas-like material) that is 12 cm wide and 1 cm thick. Each detector paddle is enclosed in a cover made of carbon fiber. As shown in Figure 5.6-3, each detector paddle enclosure is open at the ends and no longer requires special venting pipe as flown on AMS-01. At the ends of each panel are Lucite light guides which direct the light of scintillation to photo multipliers. These light guides are curved to orient the photomultiplier tubes within the AMS-02 magnetic field for minimum impact to photomultiplier operations. These complex curves can be seen in Figure 5.6-3 and 5.6-6.

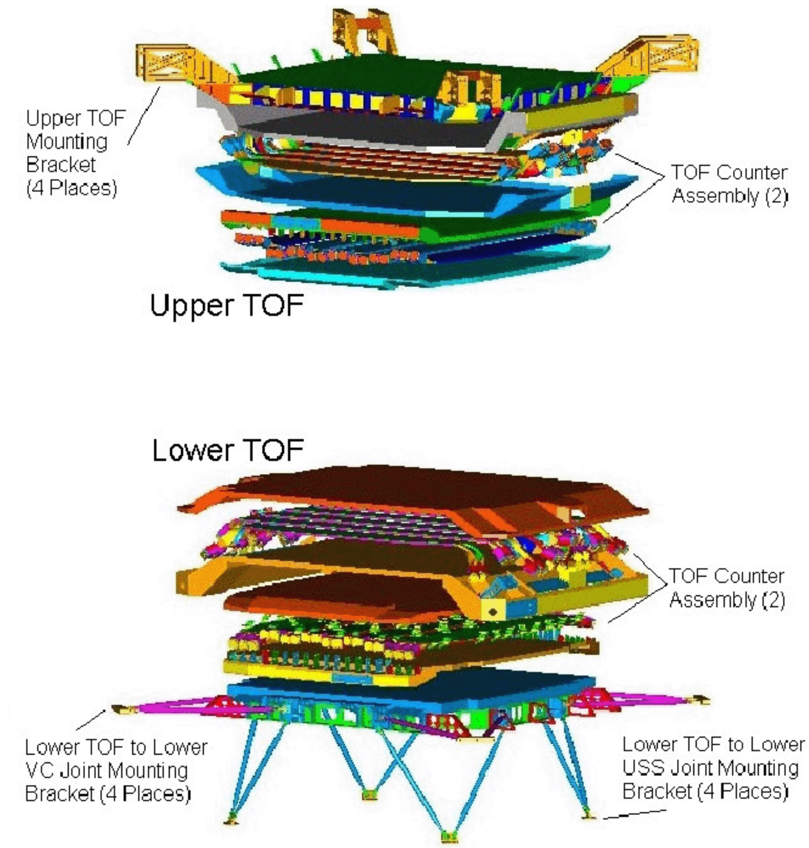


Figure 5.6-1 Time of Flight Counter Construction

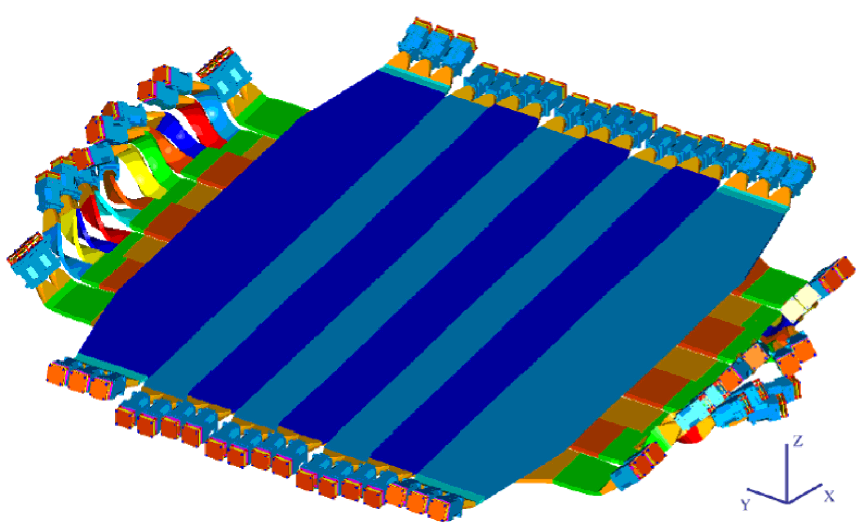


Figure 5.6-2 TOF Detector Paddles Orientation

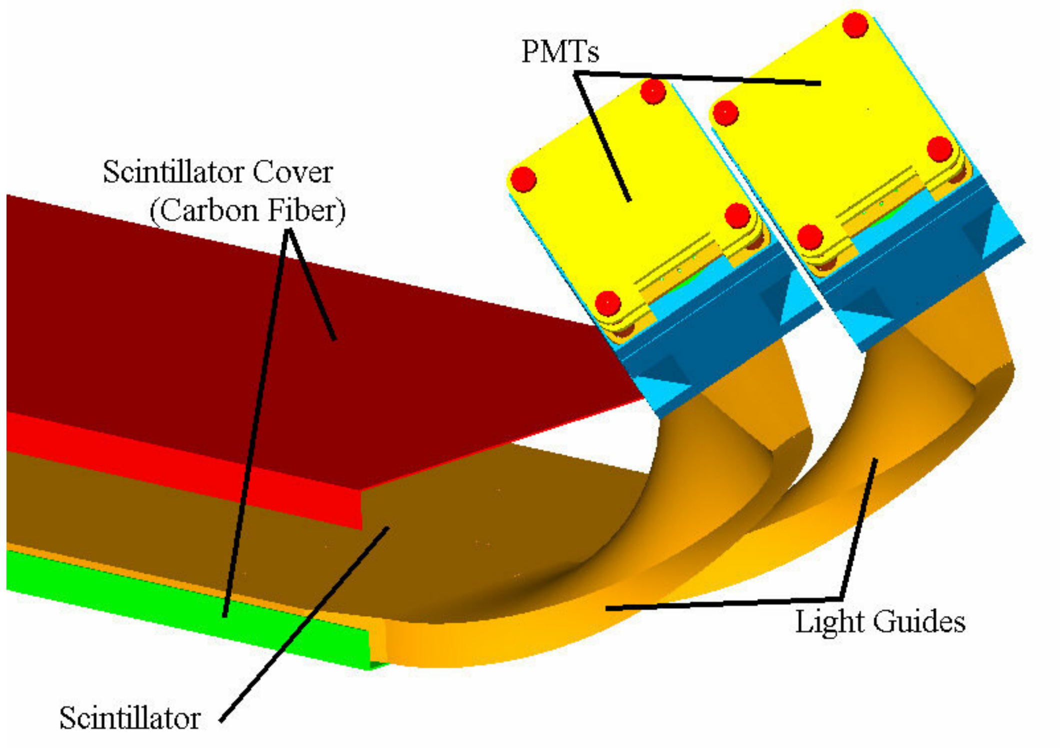


Figure 5.6-3 TOF Detector Paddle Construction

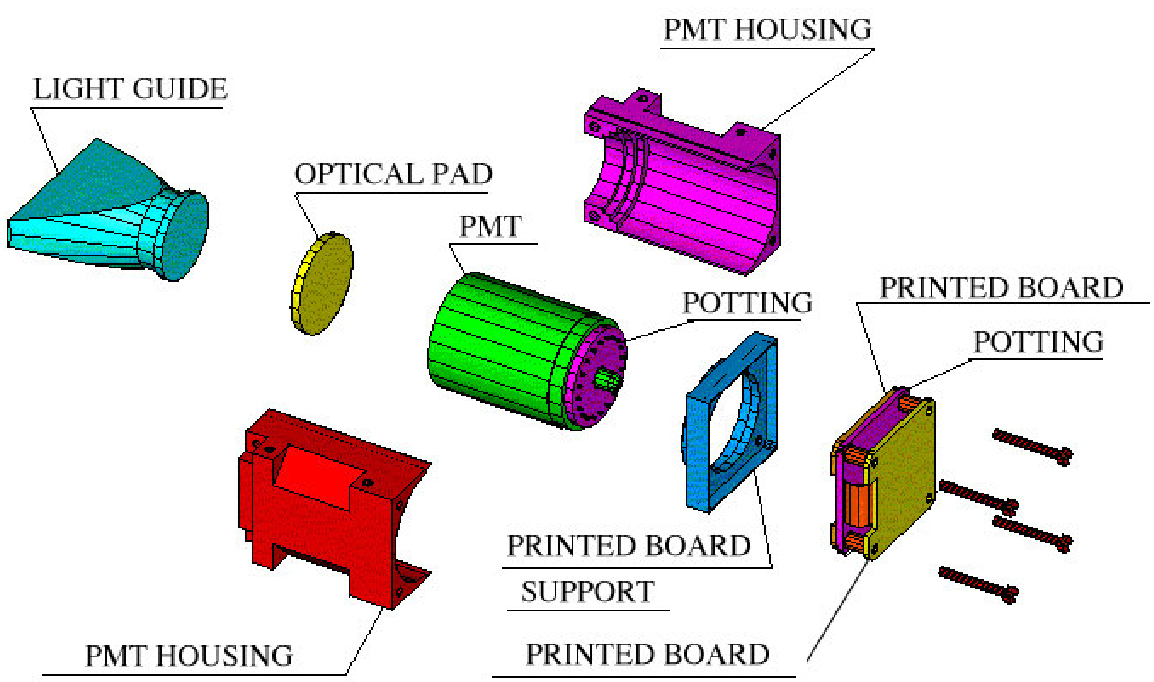


Figure 5.6-4 TOF PMT Exploded View

The TOF is instrumented with 144 Hamamatsu R5946 photomultipliers, used to detect the scintillating light. The PMT operated with a 1700-2300 Vdc voltage that is supplied by the SHV Crates. Each plane has two printed circuit boards that provide the high voltage sources for the detectors. The design of the TOF has considered the potential of discharge of high voltages at low atmospheric pressures and has implemented potting and coating of the PMT and high voltage interfaces. Access to the insulated and potted high voltage sources by an EVA crewmember is restricted as the TOF are under thermal blankets/MLI. The output from the PMTs on each end of the TOF detectors are summed to provide the necessary triggering signal that is provided to the four S Crates for data processing.

The Hamamatsu R5946 PMT is within a PMT housing, shown in Figures 5.6-4 and 5.6-5, made of black polycarbonate that is potted in place. The PMT is pressed into the light guides with an optical pad assuring optical transmission and providing a containment plane for the PMT tube itself.

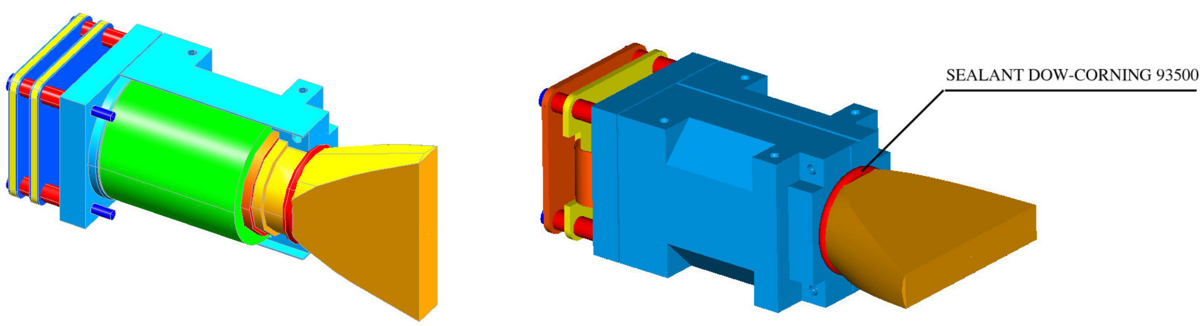


Figure 5.6-5 TOF PMT Construction

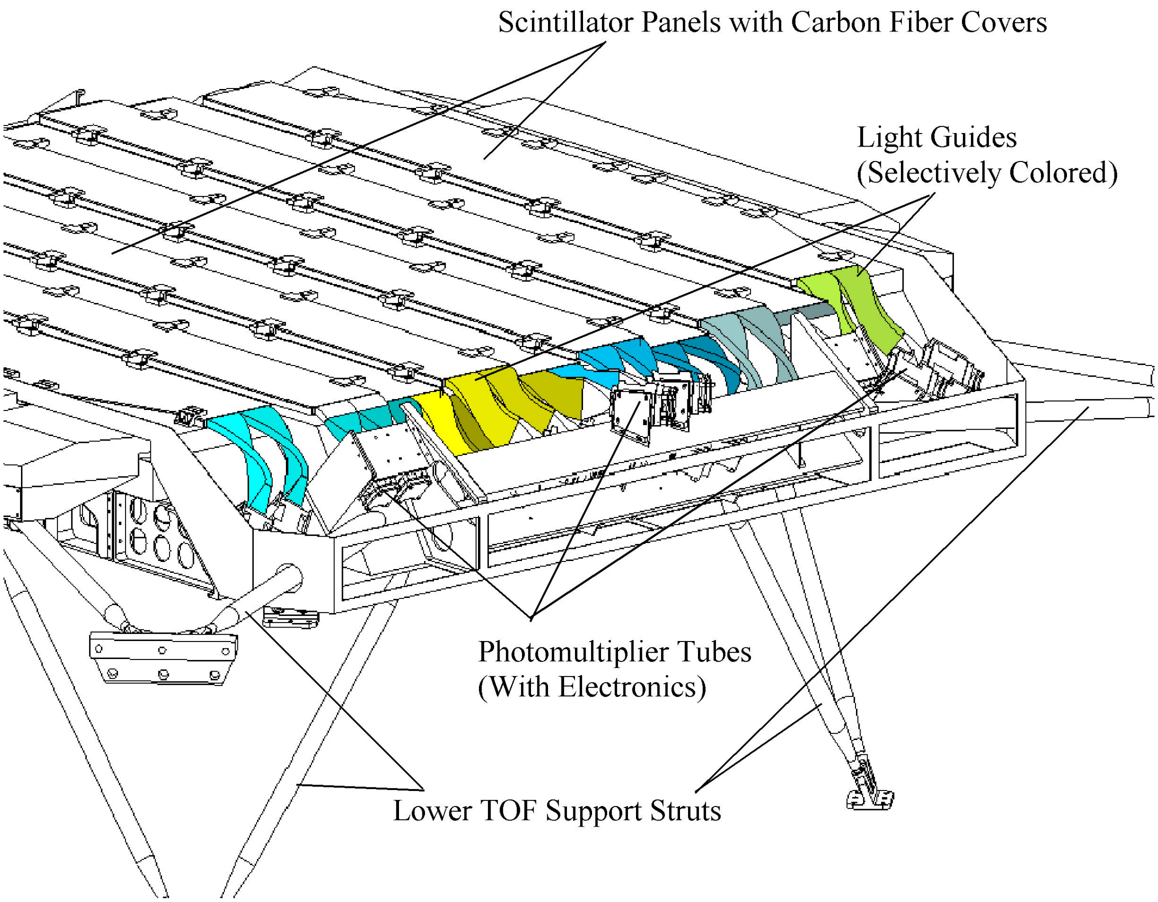


Figure 5.6-6 Mounting of TOF PMT and Detector Paddles

The upper TOF honeycomb structure attaches via brackets to the TRD corner joints which hard-mount to the USS-02 upper corner joints (Figure 5.6-7). The lower TOF honeycomb is connected to the lower USS-02 (Figure 5.6-8) via struts. The honeycomb panels are roughly square with a 60.6 inches (1540 mm) sides. The thickness of the honeycomb aluminum core is 1.97 inches (50 mm) and the aluminum skin is 0.04 inch (1 mm) thick for the lower TOF. The upper TOF honeycomb core is 3.92 (100 mm) thick with the 0.04 inch (1 mm) aluminum skin.

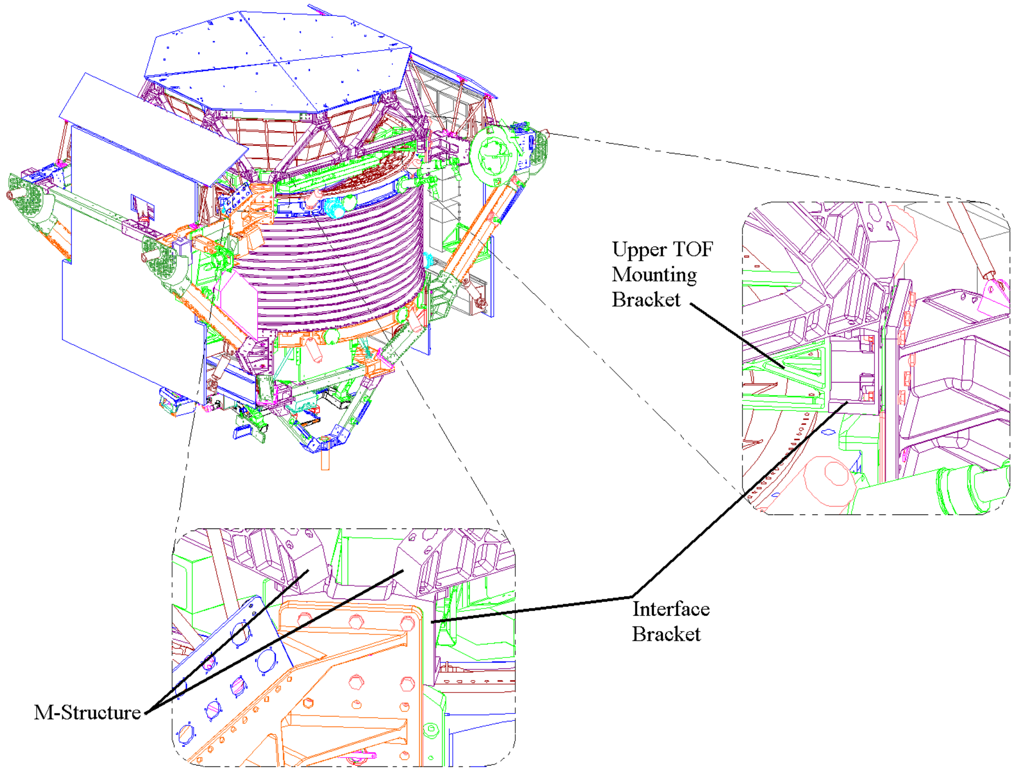


Figure 5.6-7 Structural Interfaces for the Upper TOF

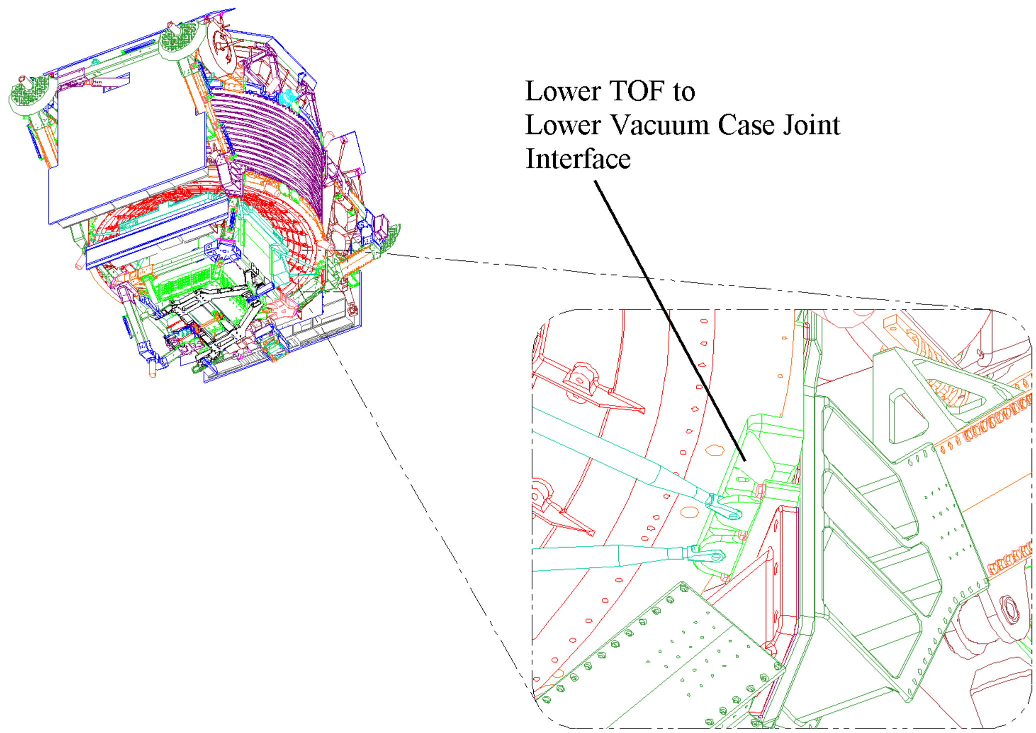


Figure 5.6-8 Structural Interfaces for the Lower TOF

5.7 STAR TRACKER

The Space Station, which is large and fairly flexible, cannot measure its own position with a high degree of accuracy and thus cannot directly tell the AMS-02 where it is exactly and where it is pointing. To optimize science from the Tracker detector carried by AMS it is important to have the capability to determine accurately the position of the AMS payload at the exact time that an event occurs. To accurately determine its position, AMS carries a Star Tracker called AMICA (for Astro Mapper for Instrument Check of Attitude). AMICA is equipped with a pair of small optical telescopes (AMICA Star Tracker Cameras or ASTCs). The ASTCs are mounted to the upper Vacuum Case Conical Flange on opposite sides of AMS to increase the probability that one has a clear view of the stars (Figure 5.7-1 and 5.7-2). The positioning of the Star Trackers while in the Shuttle Payload Bay does not place the ASTCs within nominal EVA translation paths. The location atop of the tracker places the ASTCs outside of EVA translation paths on the ISS and EVA operations that may be performed on the AMS-02 are not in proximity of the Star Trackers.

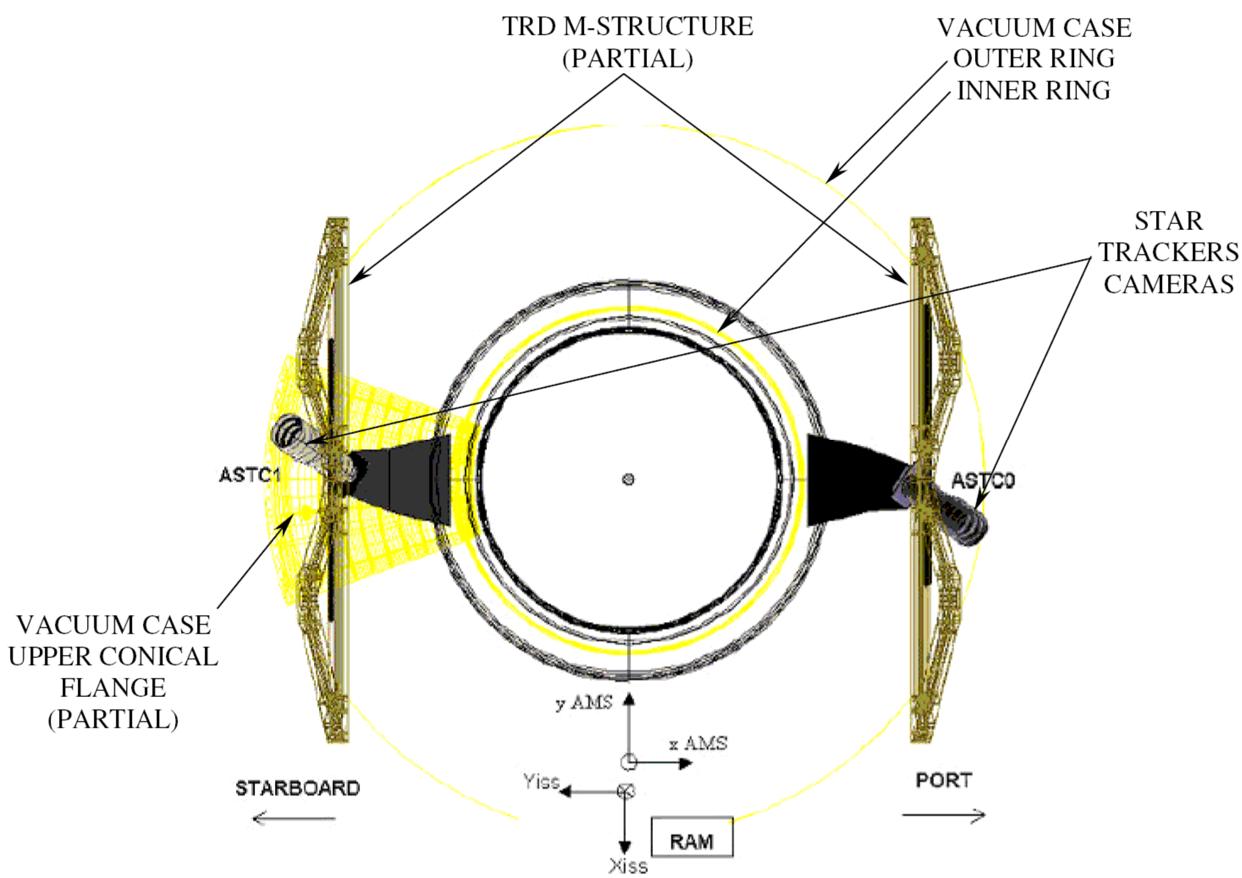


Figure 5.7-1 Star Tracker Position on the AMS-02

Each camera acquires an image of the stars with a Charged Coupling Device (CCD) detector and compares the resultant image to an on-board sky map. With this information, the attitude of AMS can be determined within a few arc-seconds (arc-sec) accuracy.

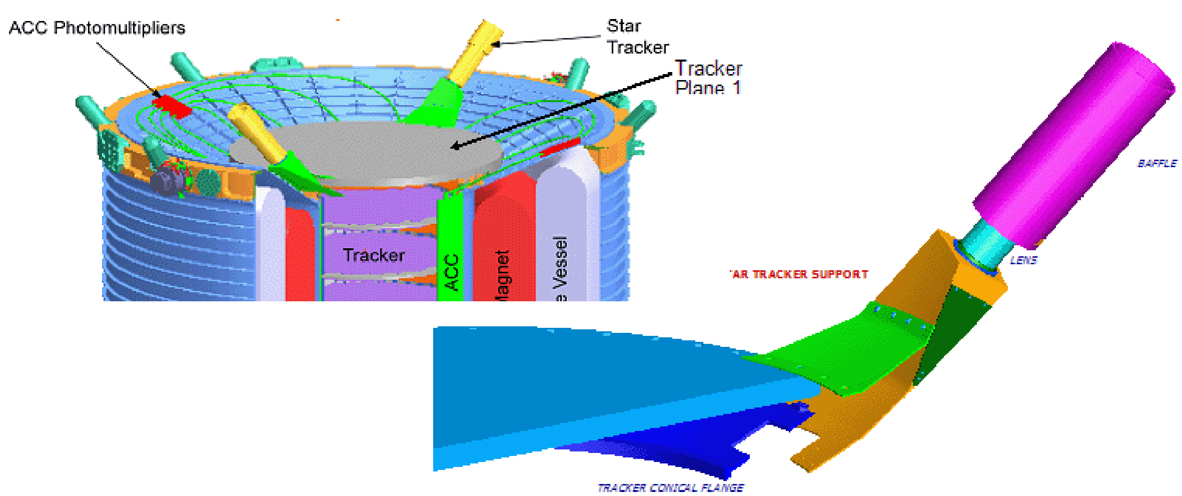


Figure 5.7-2 Star Tracker Mounting on the AMS-02

The hardware consists of an optics system [f/1.25 lens with 75 mm focal length and a 6.3° X 6.3° field of view (FoV)]; a lens cover containing a 3 mm thick blue filter and a 2 mm thick red filter; a low noise frame-transfer CCD (512 X 512 pixels); and a baffle to limit the stray light intrusion to the optics. The baffle is made of black anodized aluminum Al 6061 that is 1 mm thick, the exterior covered with silver coated Teflon. The Star Tracker optical components are shown in Figures 5.7-3 and 5.7-4. The baffle is not mechanically connected to the lens assembly and is supported independently by a bracket mounting the baffle to the M-Structure, the configuration allowing for relative motion between the baffle and the lenses without leaking light into the optical path. The interface between the baffle and the lens assembly is made light tight by a fabric MLI cover.

The interior of the baffle is being considered sharp enough to cut EVA gloves, the interior of the baffle cannot be rounded to meet the sharp edge requirements without losing the optical properties of a baffle to limit stray light. This will be controlled with an EVA keepout zone for each baffle.

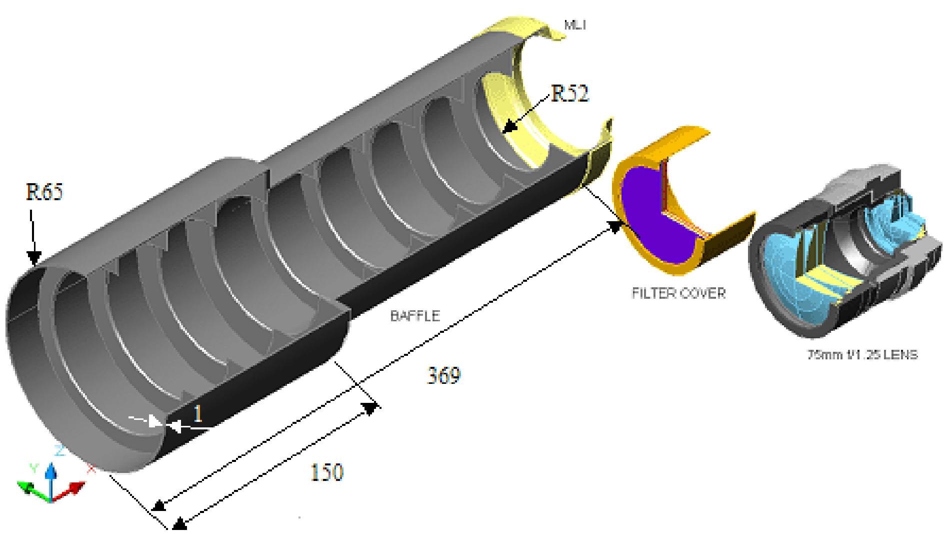


Figure 5.7-3 Star Tracker Optical Components

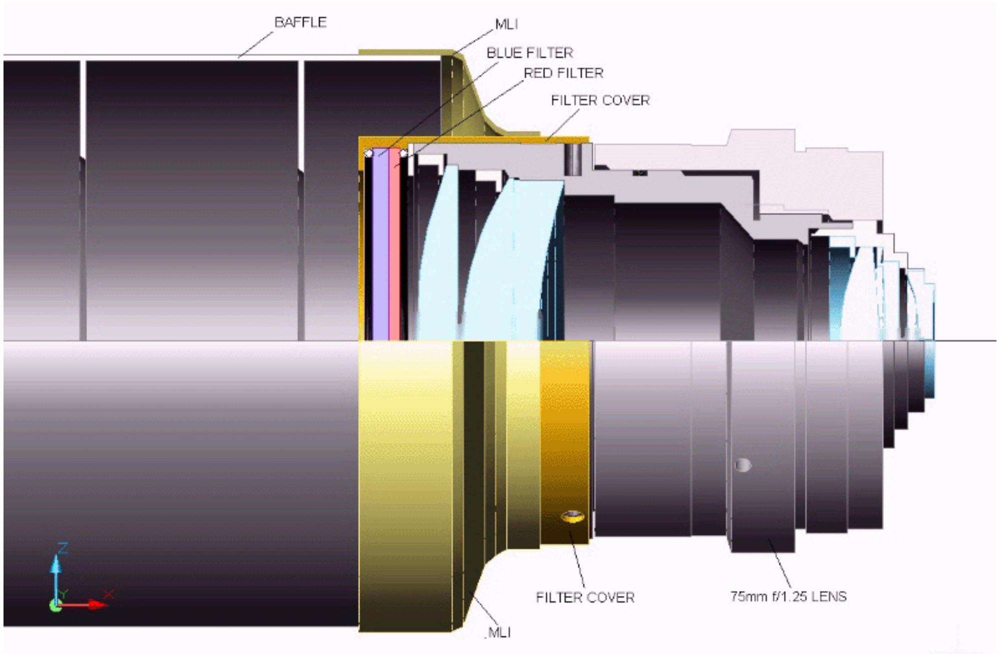


Figure 5.7-4 Star Tracker Optics

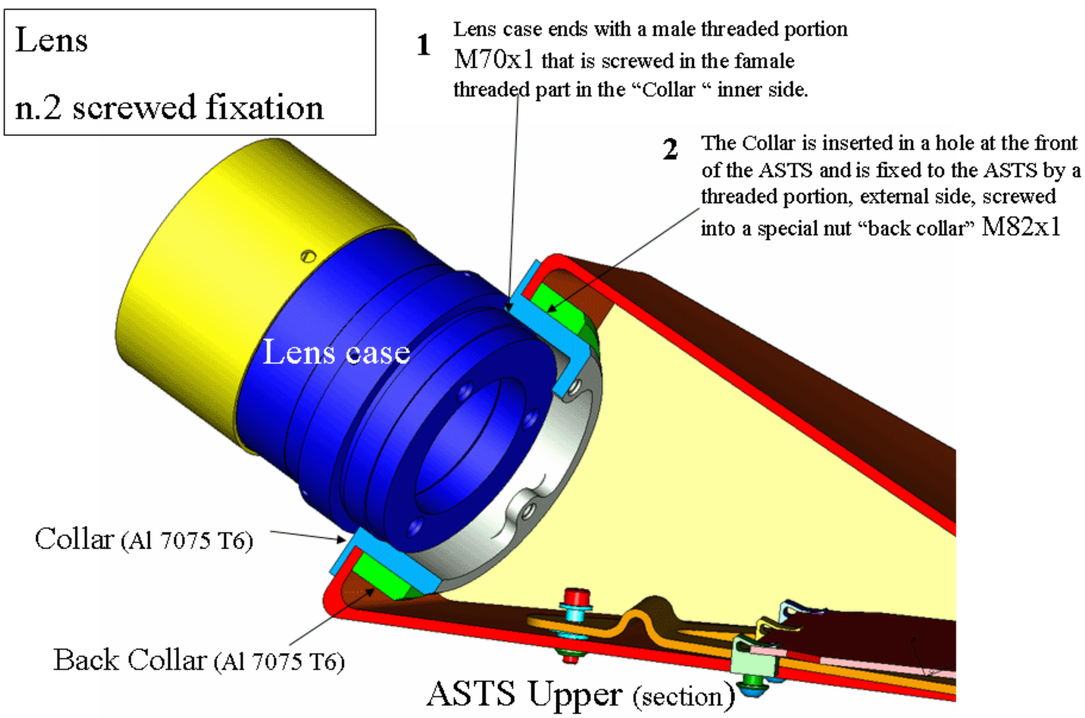


Figure 5.7-5 Star Tracker Lens Mounting

The AMICA lenses utilize standard optics mounting techniques (Figure 5.7-5) attaching to the housing body and in the construction of the lenses and filters. There is no specific venting paths provided for in the design of the lens assemblies, however the threaded body provides ample venting paths as shown during venting tests.

The enclosed volume of the Star Tracker is vented through the fastener access holes that are used for tool access when installing the Star Tracker to the AMS-02 as shown in Figure 5.7-6.

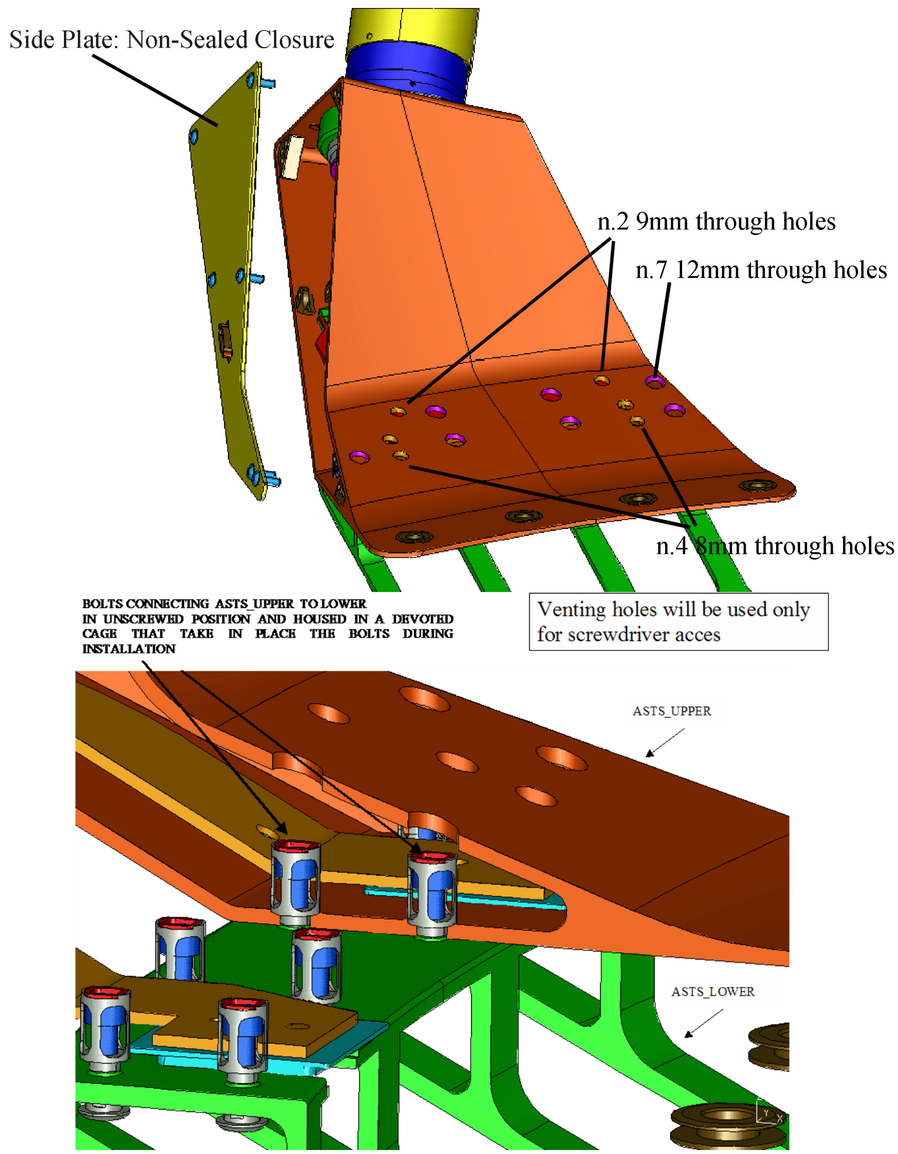


Figure 5.7-6 Star Tracker Assembly and Venting Paths

The AMICA operates on +5, ±12 Vdc and converts power internally to +35 V, +12 V, +7 V and +5 V distributed power.   One small section of the circuitry operates at a maximum of +45 V. The boards are conformally coated to reduce any potential for high voltage effects. The ASTCs are interfaced to the M-crate located on the ram side by two cables, one 8 conductor 24 AWG shielded cable to provide the SpaceWire Link for data and one four conductor 22 AWG cable for power. The thermal load from the Star Tracker CCD and electronics board inside the sensors is carried by a copper "bus" to the thermal blocks connecting to the Tracker Thermal Control System (Figure 5.7-7). The electronics unit is based on a VME bus, which contains the processor (DSP21020) and power switching boards. The CCD front end electronics boards for each ASTC are contained in the AMICA Star Tracker Supports (ASTSs) that attach the instrument to the Tracker.

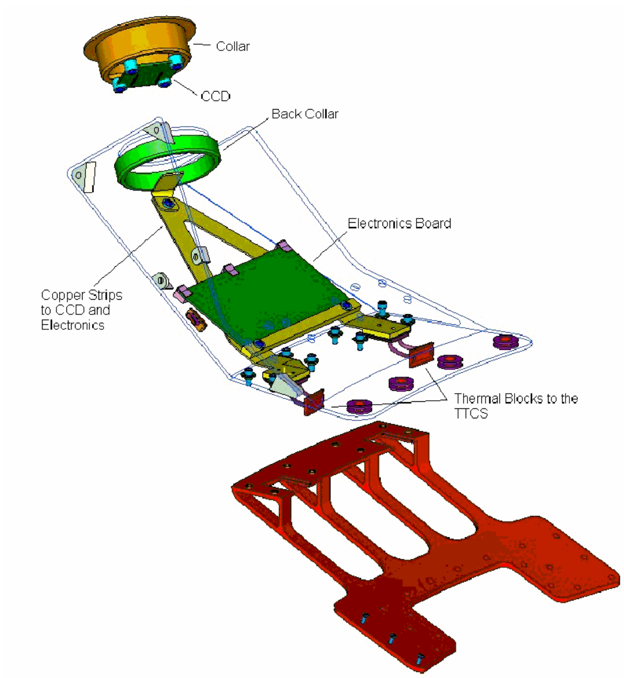


Figure 5.7-7 Star Tracker Thermal Interface and CCD Electronics

5.8 ANTI-COINCIDENCE COUNTERS (ACC)

The ACC is a single layer of scintillating panels that surround the AMS-02 Silicon Tracker inside the inner bore of the Cryomagnet (Figure 5.8-1). The ACC detects and identifies particles that enters or exits the Tracker through the side or that have not cleanly traversed the Tracker. The ACC provides a means of rejecting particles that may confuse the charge determination if they leave “hits” in the Tracker close to the tracks of interest.

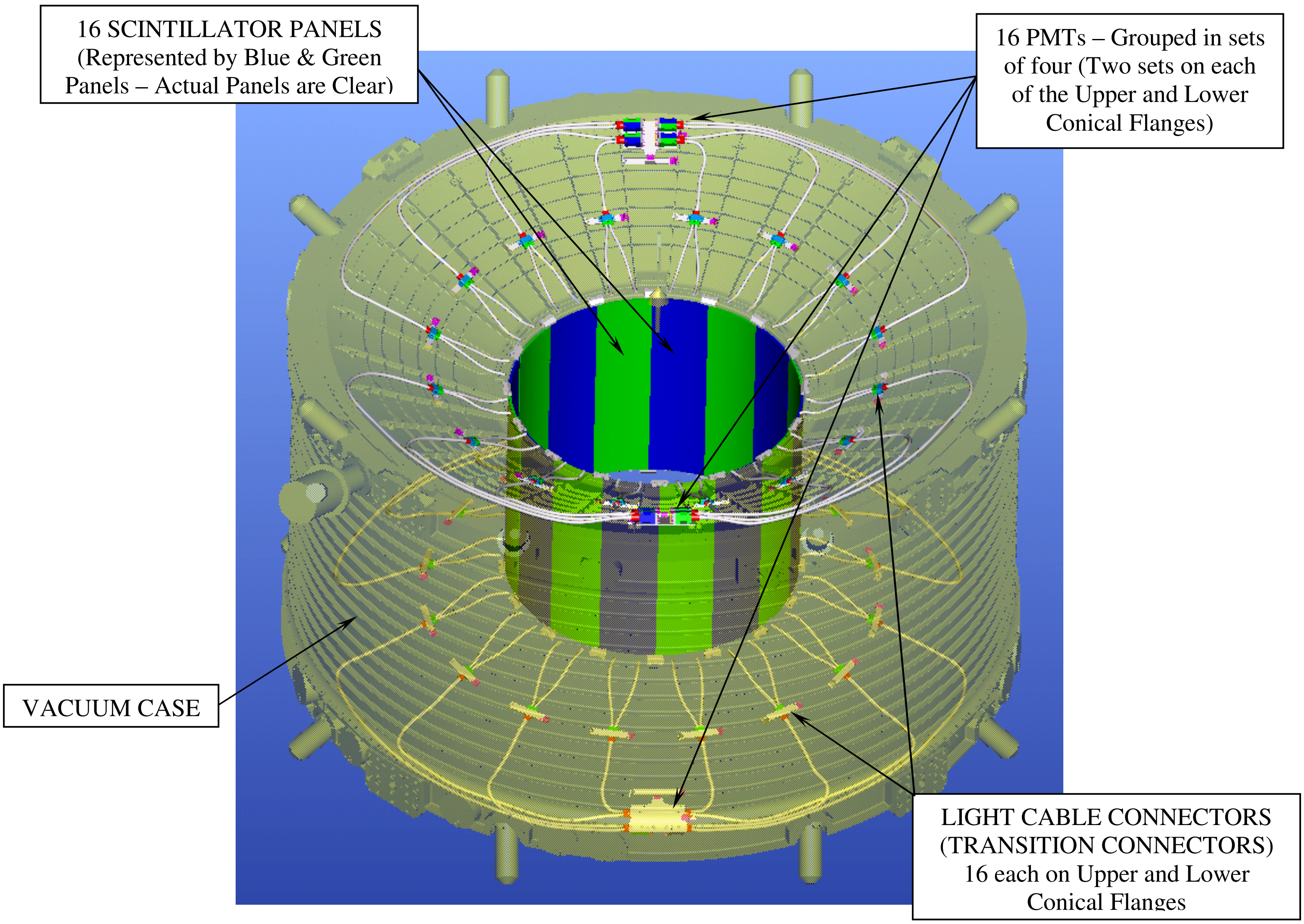


Figure 5.8-1 ACC Location Within the Inner Cylinder of the Vacuum Case

The ACC scintillating panels are fitted between the Tracker shell and the inner cylinder of the Vacuum Case, which contains the Cryomagnet system. The ACC is composed of sixteen interlocking panels fabricated from BICRON BC414 (Figures 5.8-2 and 5.8-3). The panels are 8 mm thick (as opposed to the 10 mm panels used for the AMS-01 ACC) and are milled with tongue and groove interfaces along their vertical edges to connect adjacent panels. This provides hermetic coverage for the ACC detection function around the Silicon Tracker. The panels are supported by a 33.46 in (850 mm) tall x .78 in (1086.7) diameter x 0.047 in (1.2 mm) thick M40J/CE Carbon Fiber Composite (CFC) Support Cylinder (Figure 5.8-4).

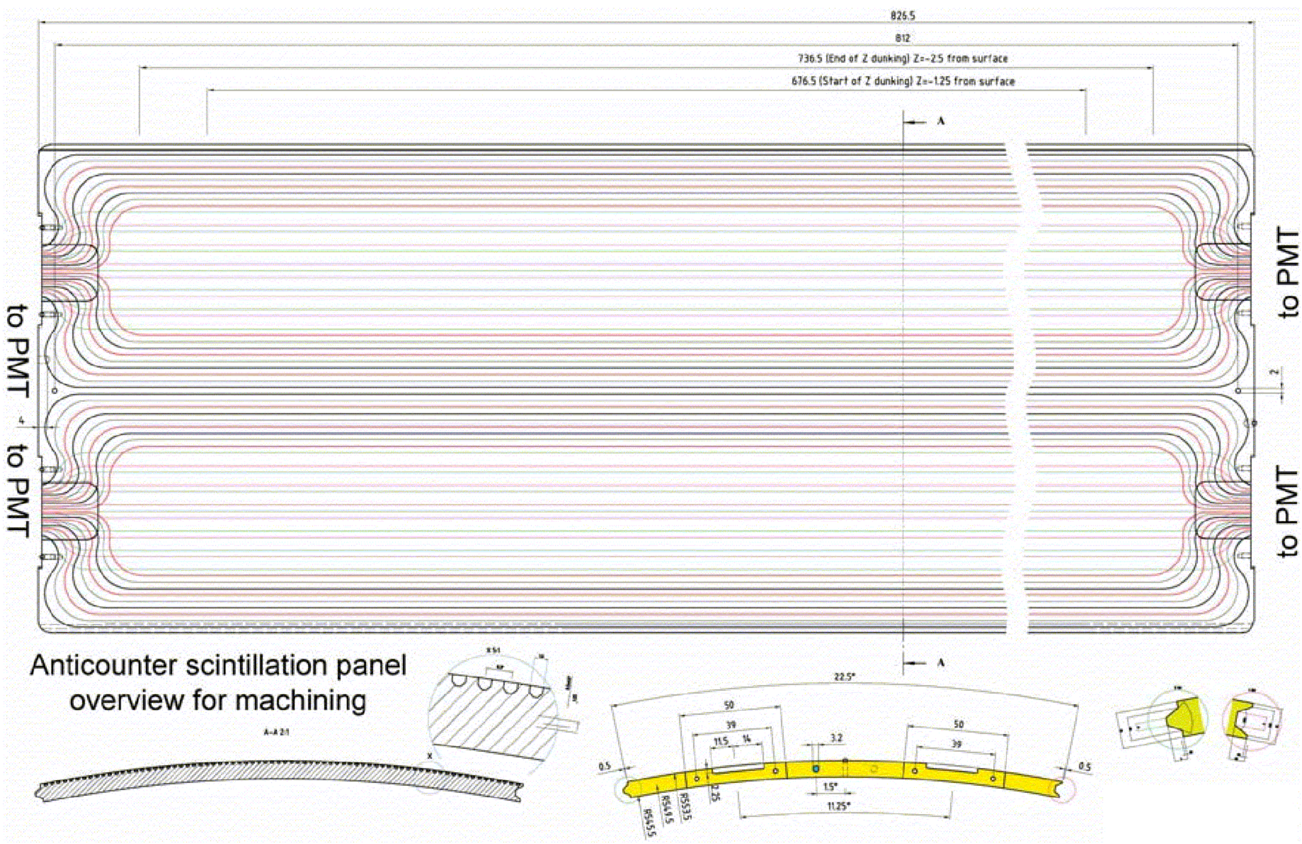


Figure 5.8-2 Design Details of an ACC Scintillator Panel

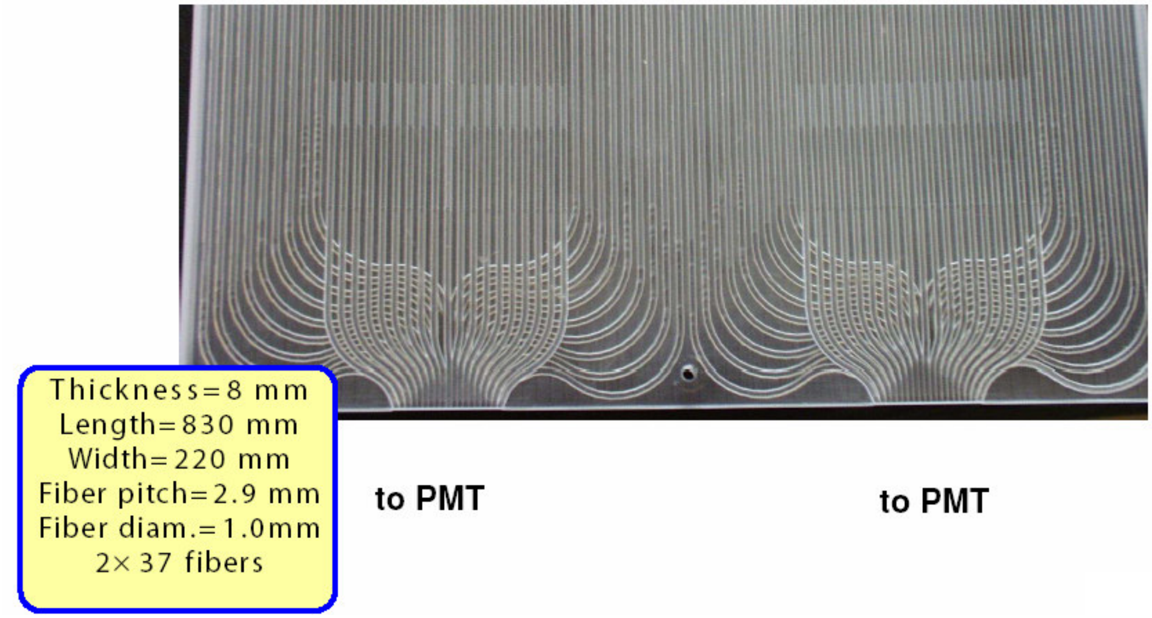


Figure 5.8-3 Finished End of an ACC Scintillator Panel

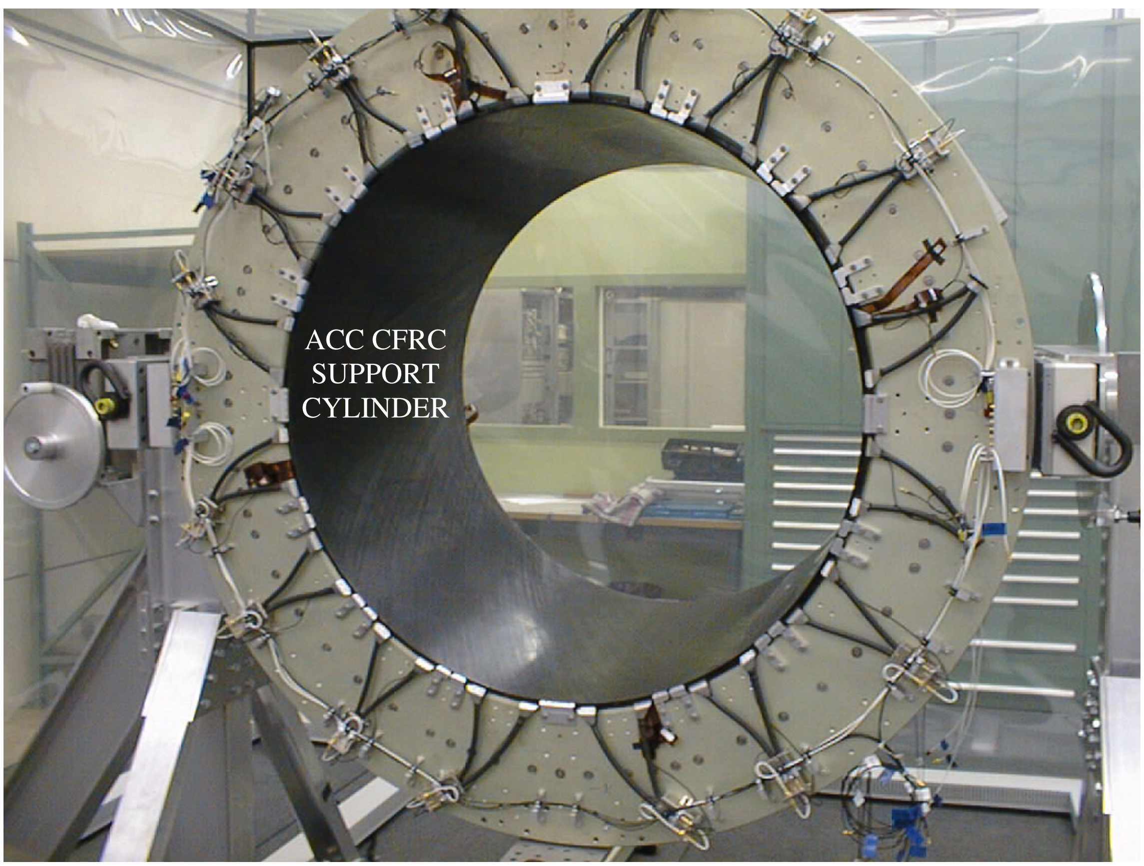


Figure 5.8-4 ACC Carbon Fiber Reinforced Composite Support Tube (installed for AMS-01)

The light of scintillation from particles passing through the panels are collected by 1 mm wavelength shifter fibers (Kuraray Y-11(200)M) that are embedded in groves milled into the panel surface. A panel has two collection arrays, each consisting of 37 fibers. The embedded fibers are collected into 2 output ports of 37 fibers each at both ends of the panel (Figures 5.8-2 and 5.8-5). For each panel there are two transition connectors (Figure 5.8-6), one each located on the upper and lower conical flanges of the Vacuum Case (Figure 5.8-7). From these transition connectors the light is routed through clear fibers up to PMTs mounted on the rim of the Vacuum Case (Figure 5.8-8).

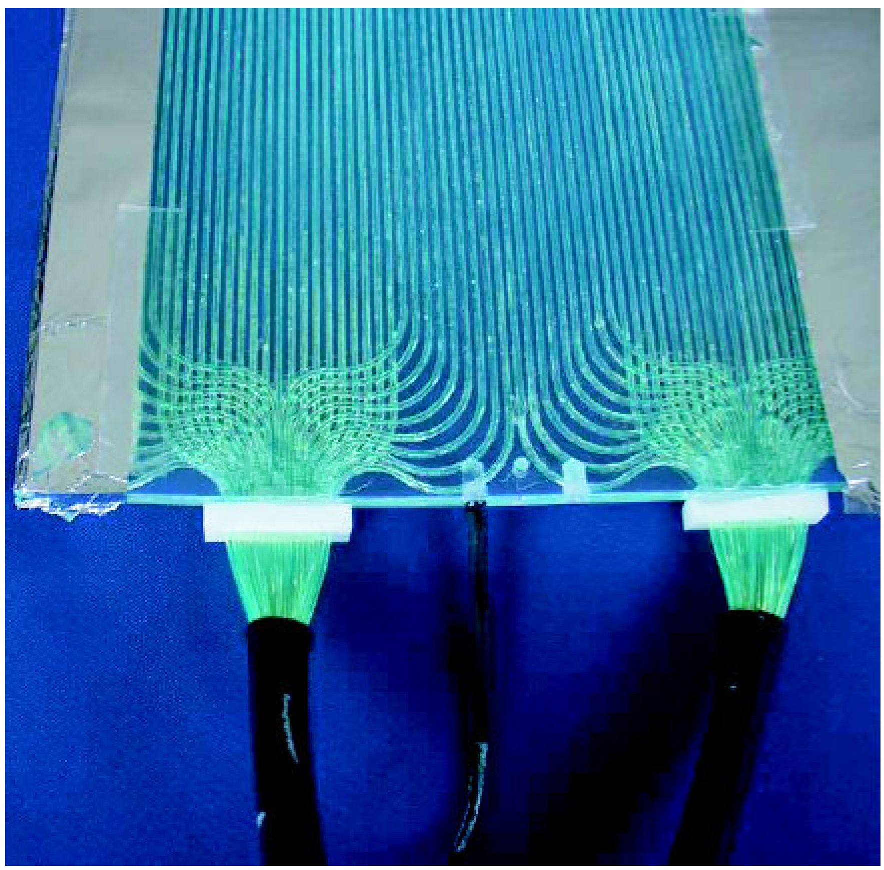


Figure 5.8-5 Fibers Collected at the End of an ACC Scintillator Panel

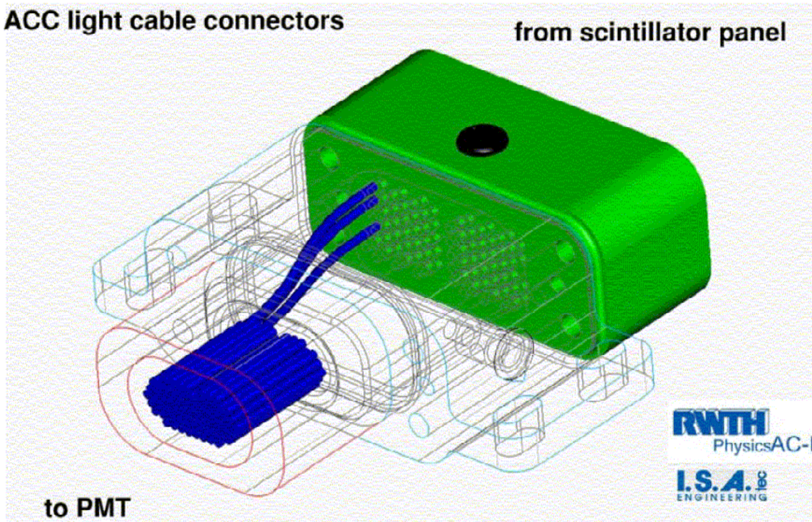


Figure 5.8-6 ACC Fiber Optic Transition Connector

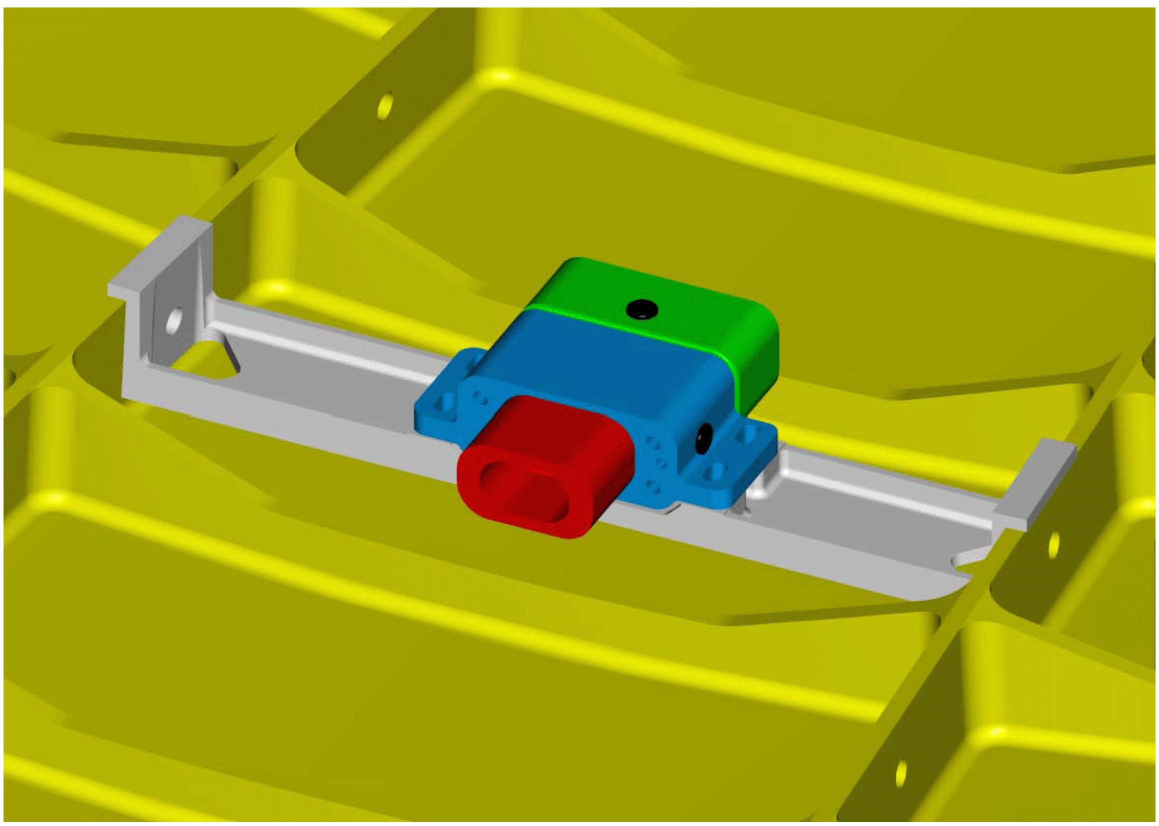


Figure 5.8-7 ACC Transition Connector Mounted to the Conical Flange

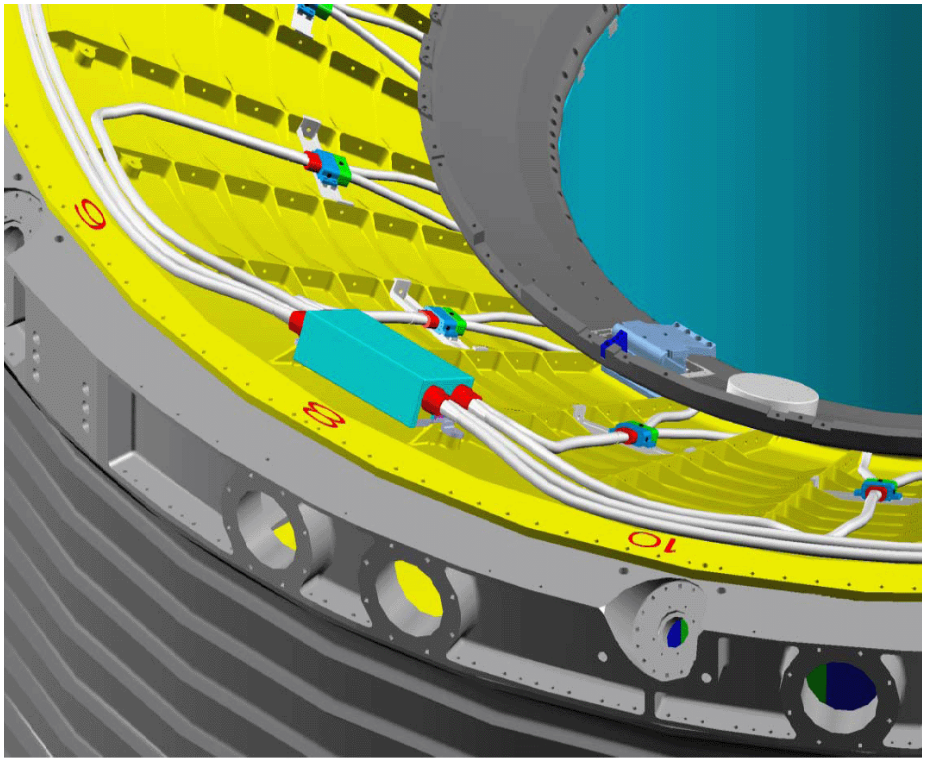


Figure 5.8-8 Routing of the ACC Fiber Optic Cables
from the Scintillating Panels through the Transition Connectors to the PMTs

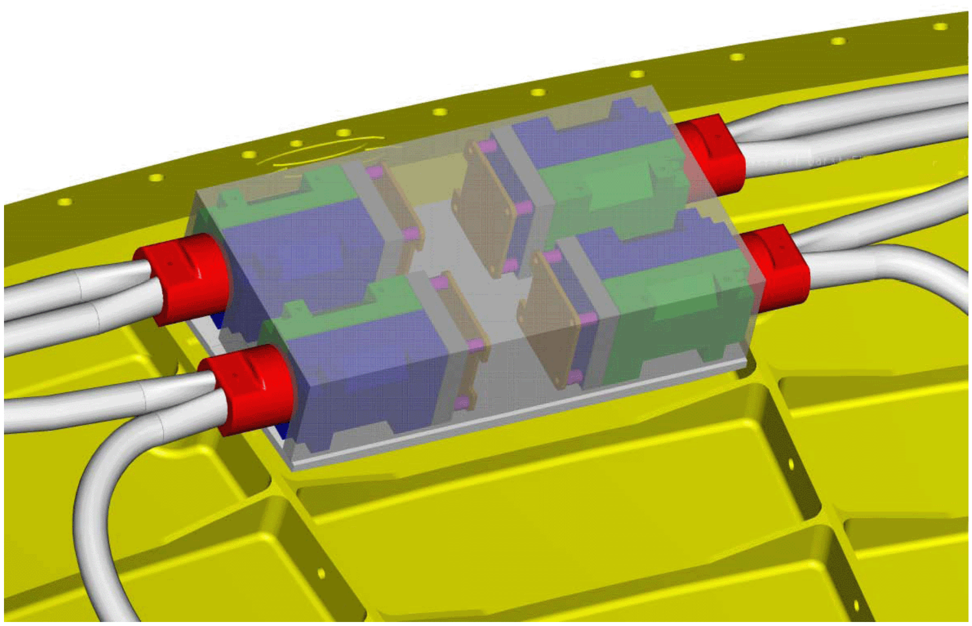


Figure 5.8-9 PMTs Mounted to the Conical Flange

The PMTs that record the light signals from the ACC panels are identical to the PMTs used in the TOF system (Hamamatsu R5946) (Figures 5.8-10 & 5.8-11). The ACC PMTs have to work in a moderate (~1.2 kG) magnetic field at locations on the top and bottom of the Vacuum Case, approximately 40 cm from the racetrack coils. To minimize the impact of this, the PMTs are oriented with their axes parallel to the stray magnetic field.

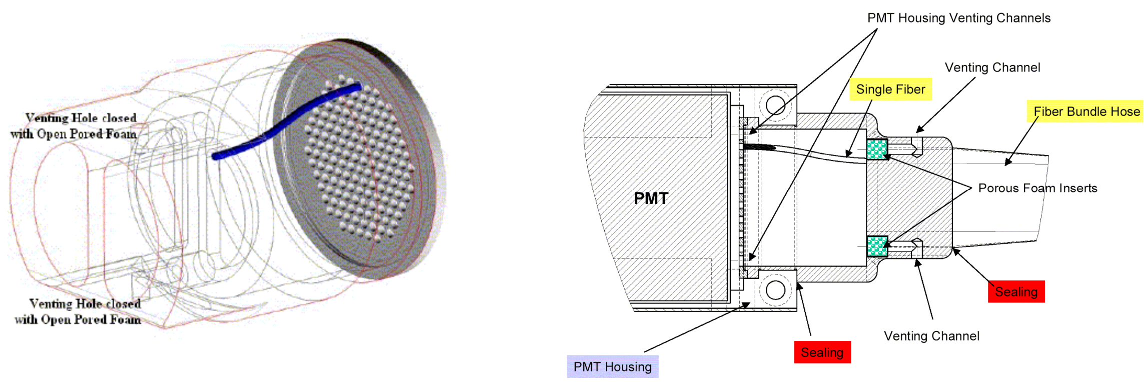


Figure 5.8-10 ACC PMT Fiber Optic Interface Construction

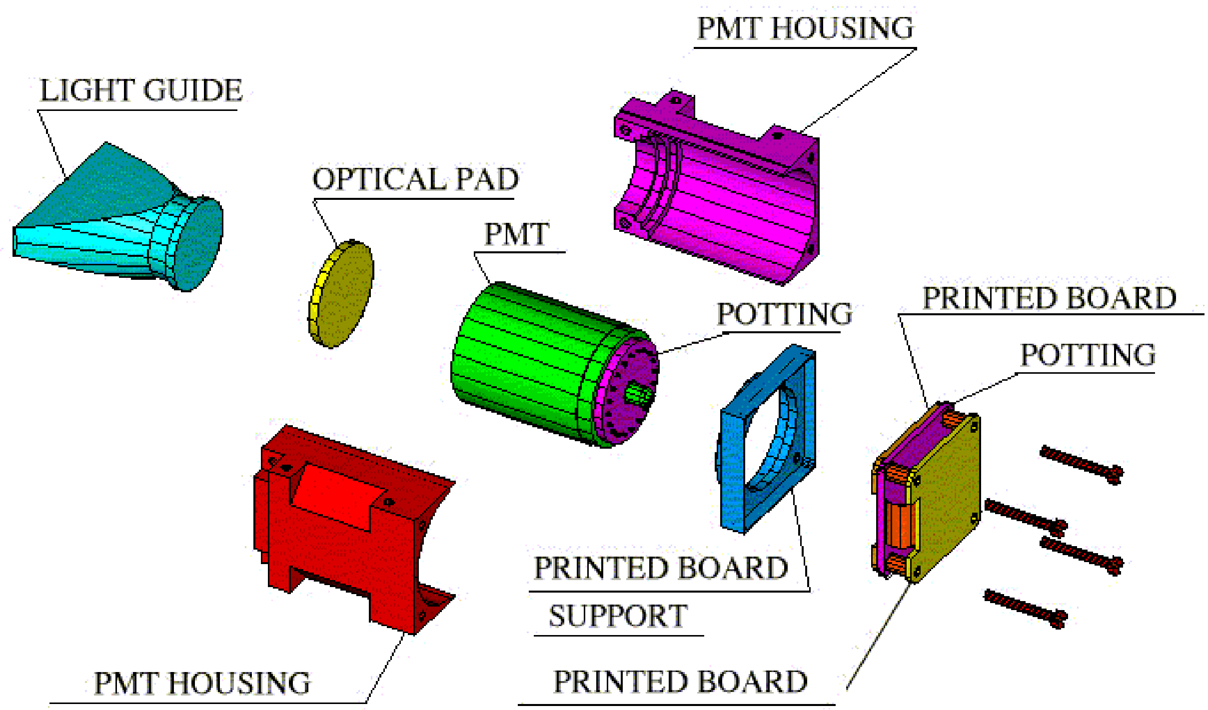


Figure 5.8-11 Basic Construction of ACC PMT

(Similar to TOF PMT Shown with Light Guide Replaced with Fiber Optic Interface)

The ACC also utilizes the same avionics architecture as the TOF to detect and interpret the passage of particles through the scintillating panels. Cables from the ACC PMTs are routed out from under the MLI covering the conical flanges to high voltage sources the S-Crate (Figure 5.8.12).

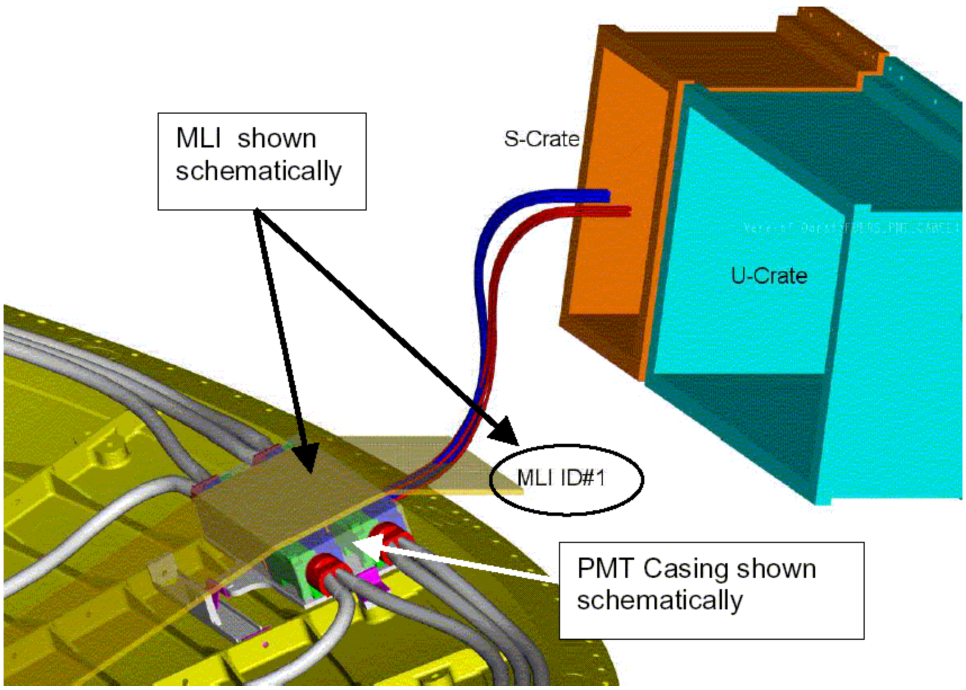


Figure 5.8-12 Wiring of the ACC PMTs to the S-Crate

5.9 SILICON TRACKER

In combination with the Superconducting Cryomagnet, the Silicon Tracker represents the centerpiece of the AMS-02 suite of detectors. The Tracker (Figure 5.9-1) consists of eight layers of double-sided silicon micro-strip detectors (ladders) on five support planes. Within the bore of the Cryomagnet three of the double sided planes will operate. The two outermost single sided planes are located at the entrance and exit of the Cryomagnet's field volume. The spatial resolution will be better than 15 μm in the Cryomagnet's bending plane and 30 μm perpendicular to that. All eight tracker planes together comprise 192 silicon ladders corresponding to an active area of about 6 m^2 of silicon and 200,000 readout channels. The entire tracker electronics consume 800 W of power.

In addition, the Tracker is equipped with an infra-red (IR) laser Tracker Alignment System (TAS). The TAS will periodically monitor the X- and Y-position of the tracker layers with respect to each other by passing IR laser beams through selected spot areas, called Alignment Holes, in each detector plane where the laser can penetrate and be measured on that detection plane by a silicon ladder. Measurement of the beam location allows for any relative distortions between the layers being reflected in the calculations of particle trajectory. For redundancy, the full alignment system will consist of five pairs of beamports, directing the lasers along the approximate center line of the tracker, one pair set traversing the beams up and the other set down. Each beamport accepts four fiber optic cables supplying laser pulses that are generated external to the Silicon Tracker in the five Laser Fibre Coupler (LFCR) boxes.

The AMS-02 Tracker is the second generation of the Tracker that flew on STS-91 (AMS-01). It utilizes the same honeycomb panels and exterior cylindrical shell (Figure 5.9-2). The flat flanges on both the top and bottom of the AMS-01 Tracker have been replaced by conical flanges on the AMS-02 detector (Figure 5.9-3) and the Tracker feet were redesigned to interface with the Vacuum Case. The Tracker mounts at eight attach locations (4 at the top, 4 at the bottom) to the Vacuum Case conical flanges. Data from accelerometers flown on STS-91 was used to develop the design load factors for AMS-02.

Three additional layers of silicon ladders have been added to the AMS-02 Tracker by placing ladders on both sides of the three interior planes. The three inner planes are ≈ 3.6 ft (1.07 m) in diameter and the top and bottom planes are a ≈ 4.9 ft (1.43 m) in diameter. The Tracker is ≈ 3.9 ft (1.2 m) high and weighs ≈ 438 lbs (198.5 kg) including cables.

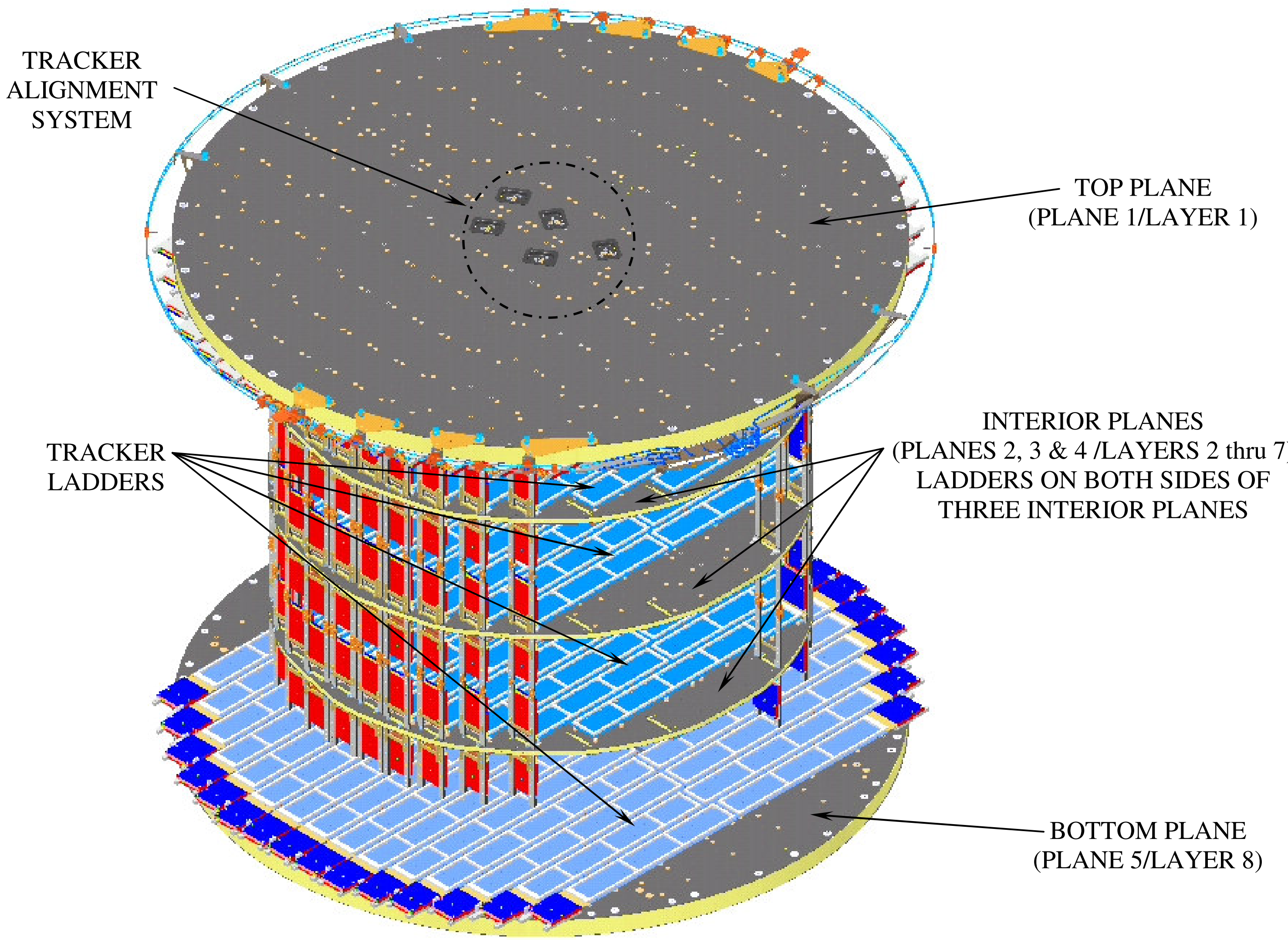


Figure 5.9-1 Layout of the AMS-02 Silicon Tracker

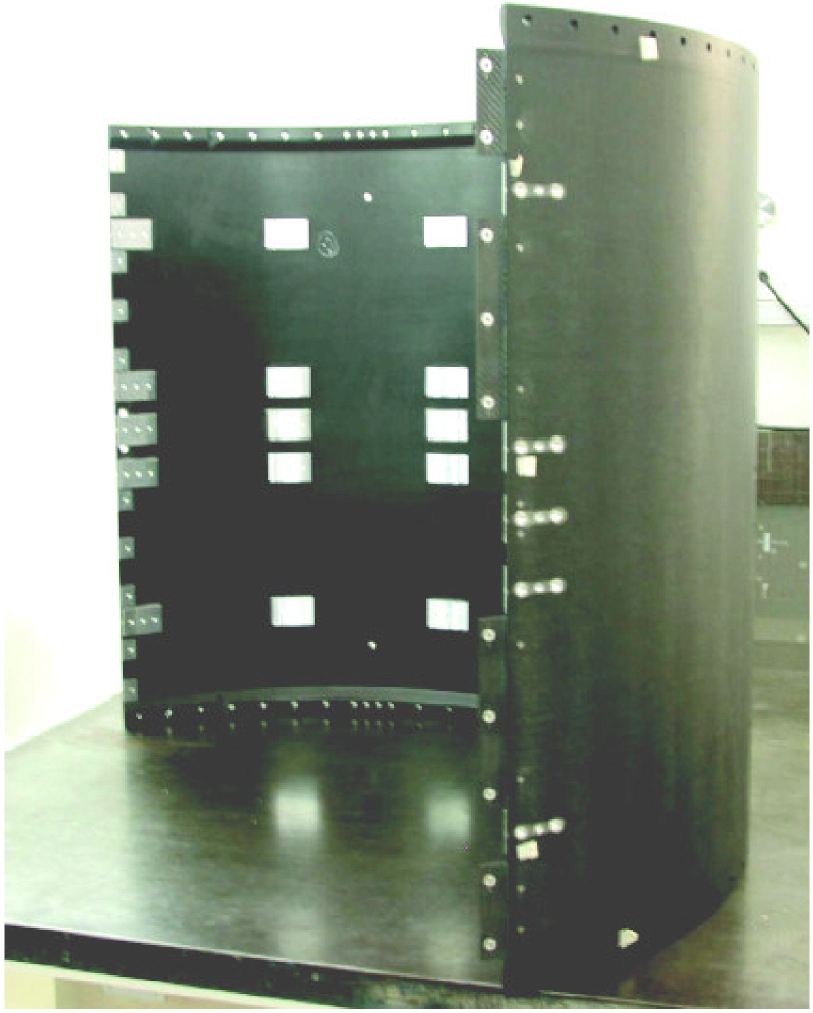


Figure 5.9-2 A Section of the Tracker Support Structure Cylindrical Shell

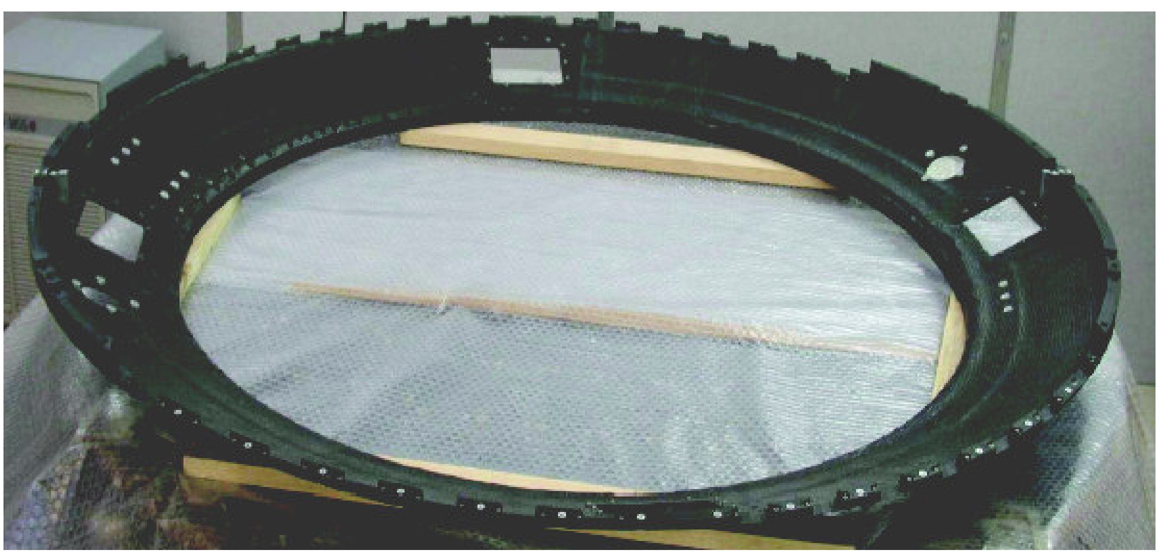


Figure 5.9-3 Tracker Support Structure – Upper Conical Flange

5.9.1 Silicon Sensors and Ladders

The AMS experiment silicon detector assemblies (Figure 5.9.1-1) contain silicon ladders made up of a series of 2.836 inch (72.045 mm) x 1.628 inch (41.360 mm) x 0.012 inch (0.300 mm) double-sided silicon micro-strip sensors, electrically connected by microbonds. The silicon sensors are reinforced by sandwich structures made of foam with light-weight carbon composite backing. Hybrid boards at the ends of the ladders enable the sensors to be electrically connected to the tracker electronics. The ladder assemblies vary in length from ≈ 11.47 inches (290 mm) to ≈ 22.45 inches (621 mm), and are 2.836 inches (72.045 mm) wide and ≈ .394 inches (10 mm) thick.

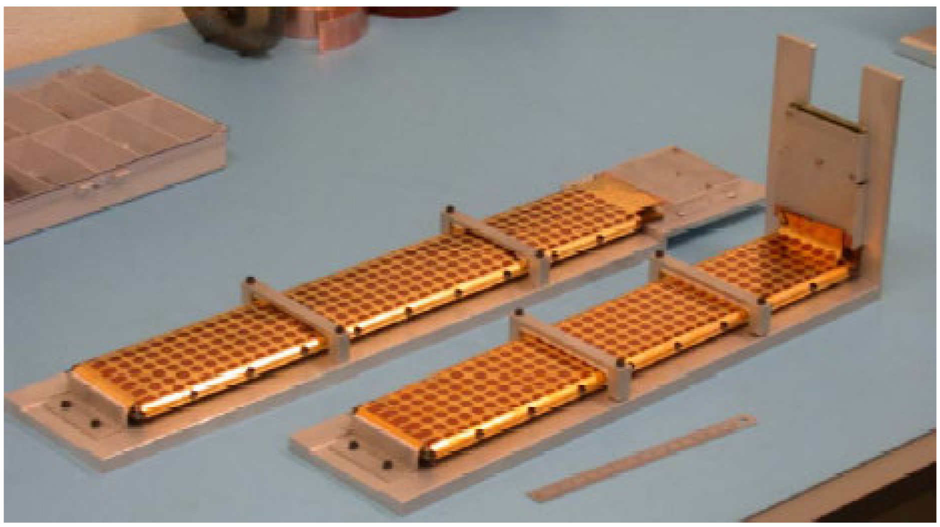


Figure 5.9.1-1 Tracker Ladders (typical) prior to mounting on a Tracker Support Plane

Figure 5.9.1-2 shows the principal elements of the silicon ladder and the main components of the readout hybrids. Thin-film, 50 µm Upilex (an ultra-high heat-resistant polyimide film) is used extensively in the ladder. A metalized Upilex film, glued directly to the silicon sensors, serves as a routing cable to bring the n-side signals to the n-side front end hybrid, which is located at the ladder end closest to the Cryomagnet wall. The flexible Upilex film and a second short Upilex film joining the p-side strips to their hybrid allow the hybrids to be placed back-to-back, perpendicular to the detection plane, thus minimizing the material in the sensitive region of the tracker. Finally, an electromagnetic shield in the form of a doubly-metalized Upilex film surrounds each ladder.

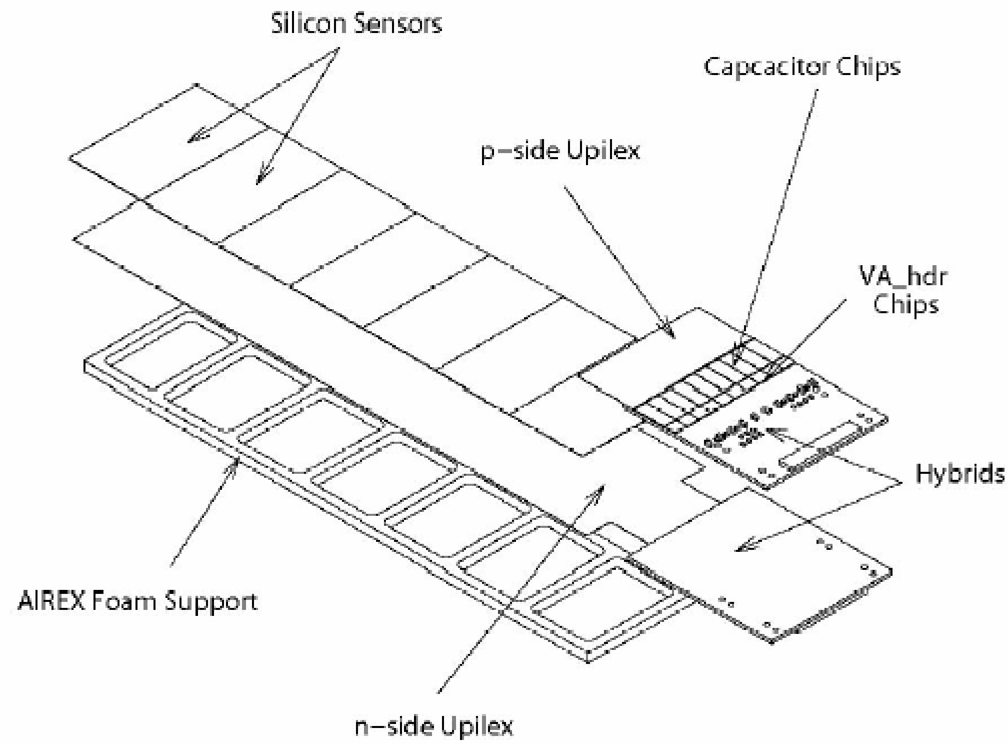


Figure 5.9.1-2 The principle components of the Silicon Ladder

The silicon sensors of each ladder are supported by a 0.2 inch (5 mm) thick Airex foam that is glued to the K-side Upilex film. The exposed surface of the foam is covered with a 100 µm thick layer of carbon fiber. Small (5 mm^3) 7075 aluminum support feet are glued to the carbon fiber surface; the exact number depends on the ladder length. The feet contain screw fixation holes which are used to attach the ladder to its tracker plane.

The silicon sensors are grouped together, for readout and biasing, in ladders of different lengths to match the cylindrical geometry of the AMS Cryomagnet (Figures 5.9.1-3 and 5.9.1-4). The maximum combined strip length in the silicon for a single readout channel is ~24.4 in (62 cm).

Figure 5.9.1-3 Tracker Support Plane 2 with Ladders installed

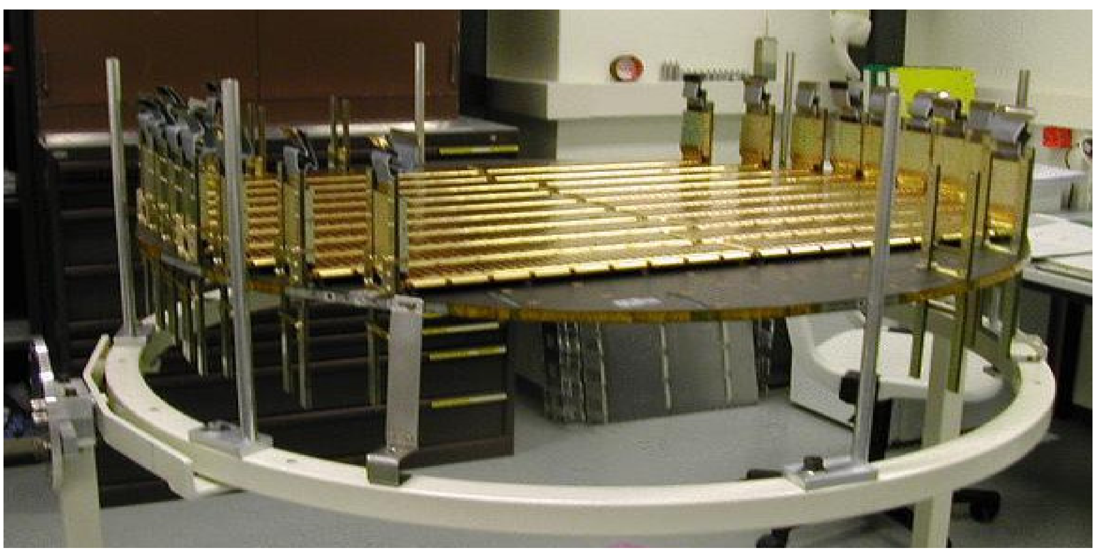


Figure 5.9.1-4 Tracker Support Plane 3 with Ladders installed

5.9.2 Tracker Support Structure

The tracker support structure is divided into three sections: a carbon fiber cylindrical shell which supports the planes 2 to 4 located "inside" the Cryomagnet bore, and two carbon fiber flanges which support the exterior planes 1 and 5, these planes being considered "outside" the Cryomagnet bore. The Tracker planes located inside are the same as those used for AMS-01. The inside planes have a composite structure with two 220 µm thick layers of carbon fiber surrounding a 12 mm thick, low density aluminum honeycomb interior, $\rho = 16.02\ kg/m^3$. The outside planes have a composite structure with two 700 µm thick layers of carbon fiber surrounding a 40 mm thick, low density aluminum honeycomb interior, $\rho = 32\ kg/m^3$. The diameter of the interior planes is 1.07 m the outside planes 1.43 m. The AMS-01 interior planes have been modified to accommodate the second layer of ladders. To equalize the pressure inside the Tracker with the pressure in the payload bay during launch and landing, the Upper and Lower Conical Flanges each contain two light tight, filtered vents (Figures 5.9.2-1 through 5.9.2-3) that permit air to exit or enter the enclosed Tracker volume of 40.26 ft^3 (1.14 m^3).

The Tracker Support Planes, Cylindrical Shell, and Conical Flanges are fabricated from M55J Fiber/Cyanate Ester Composite face sheet with a Hexcell Composite Honeycomb Core. The Tracker Support Feet are made from Titanium Ti6AlV4.

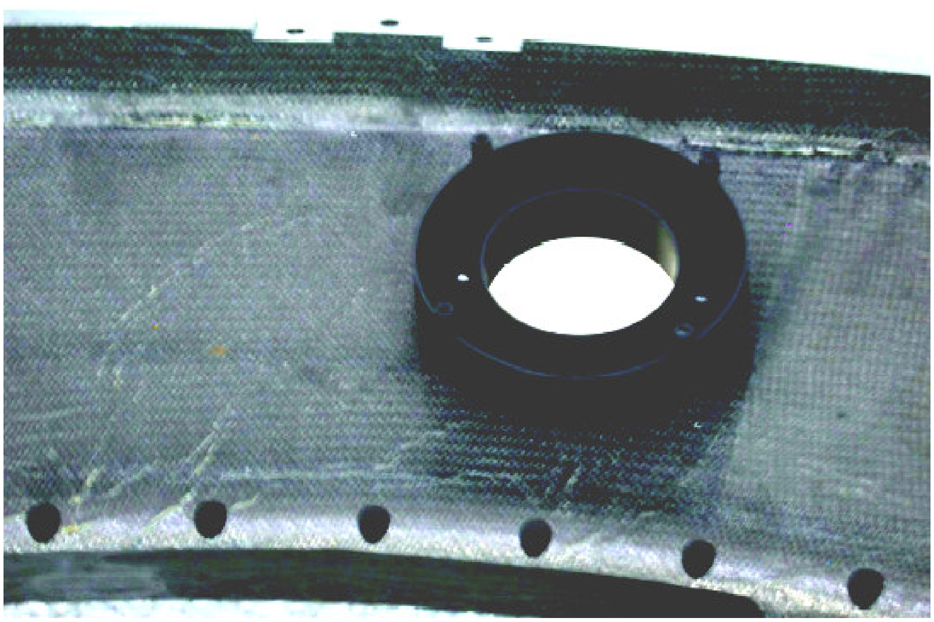


Figure 5.9.2-1 Light Trap/Vent Hole – Upper Conical Flange (with cover and filter mesh removed)

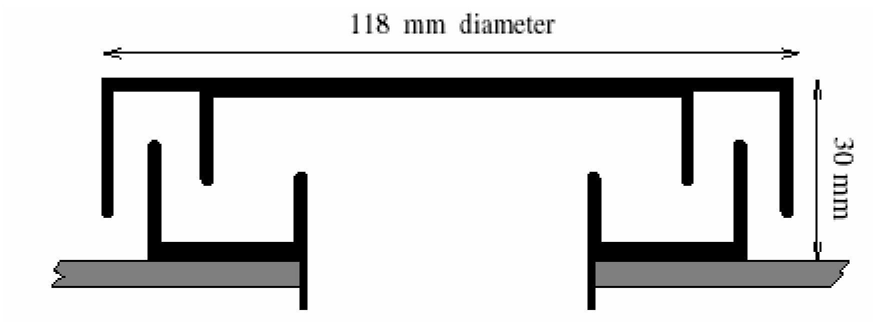


Figure 5.9.2-2 Light Trap/Vent Hole (Cross Section)
Filter mesh not shown

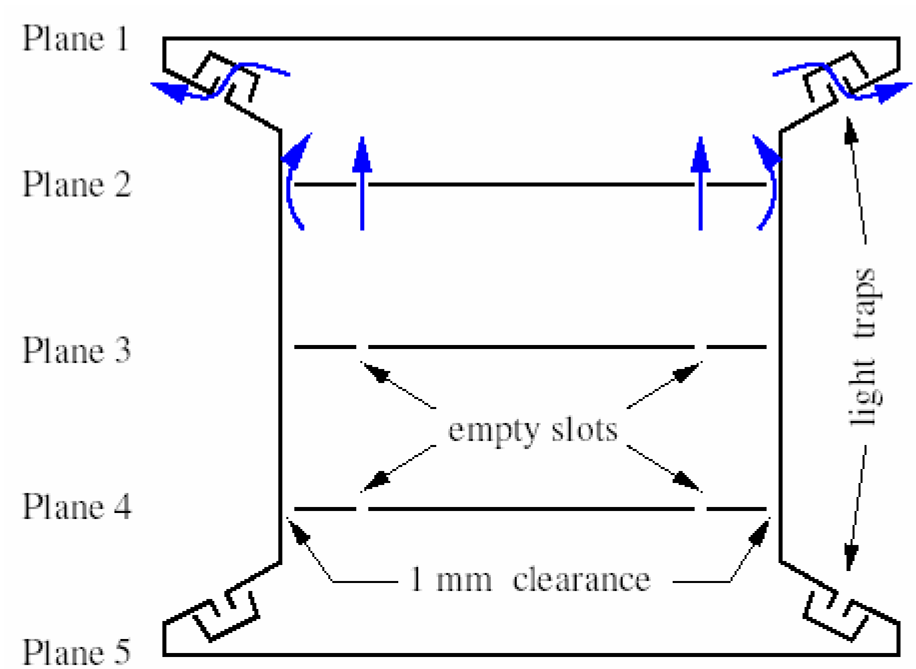


Figure 5.9.2-3 SiliconTracker Typical Vent PathsFor Depressurization

5.9.3 Tracker Alignment System (TAS)

The Tracker Alignment System (TAS) provides optically generated signals in the 8 layers of the silicon tracker that mimic straight (infinite rigidity) tracks of particles. It has been shown with AMS-01 that these artificial straight tracks allow the tracing of changes of the tracker geometry with a position (angular) accuracy of better than 5 µm (2 µrad). The system uses the same silicon sensors for both particle detection and control of the alignment. It serves to generate position control data within seconds at regular time intervals (4 to 6 times per orbit), for example, while the ISS flies into the shadow of the Earth or comes back into the sunlight.

The TAS is represented in Figure 5.9.3-1. A total of 40 fiber optic carried laser beams are used in generating the alignment beams. The beams are narrow (diameter < 0.5 mm) and of small divergence (< 1 mrad). The TAS generates laser energy from ten independent laser diodes, each pair of the diodes are contained within one of five Laser Fiber Coupler (LFCR) boxes (Figure 5.9.3-2). This energy is generated by Eagleyard EYP-RWL-1083 infrared (1083 nm) laser diodes with a maximum power output of 80 mW. Each laser diode will emit at a 1 kHz interval with a pulse duration less than 8 μs when operating. Each laser diode's emissions are split into four mono-mode optical fibers as an output of the LFCR, each optical fiber with approximately one quarter of the total power output. The LFCR boxes are light tight and cannot release any laser emissions with the exception of the fiber ports where laser emissions are nominal design features.

The beams enter the tracker volume through 5 pairs of beamport boxes (LBBX) mounted on the outer face of the two outer tracker support planes (Figures 5.9.3-3 thru 5.9.3-5). Each beamport box accepts four fibers and directs these independent laser sources through a common beam location on the Tracker (allowing for minor source location differences of the forty independent beam because of beamport interior reflector positioning). The tracker sensors on the alignment beams are equipped with antireflective coatings (SiO_2 and Si_3N_4) optimized for the wavelength chosen (residual reflectivity ~ 1%). In addition, the readout strip metallization width was reduced to 10 μm width in the coated areas and the other implants not metallized. Together these measures have resulted in a transparency of the alignment sensors of 50% and the 8th layer of the tracker receives about 0.8% of the intensity coming out of the LBBX. Alignment beams are arranged in pairs in order to distinguish between changes in beam geometry and sensor displacements. Laser alignment will be performed coincident with data taking. The operation of the TAS consists of less than 1% of the AMS-02 operational time.

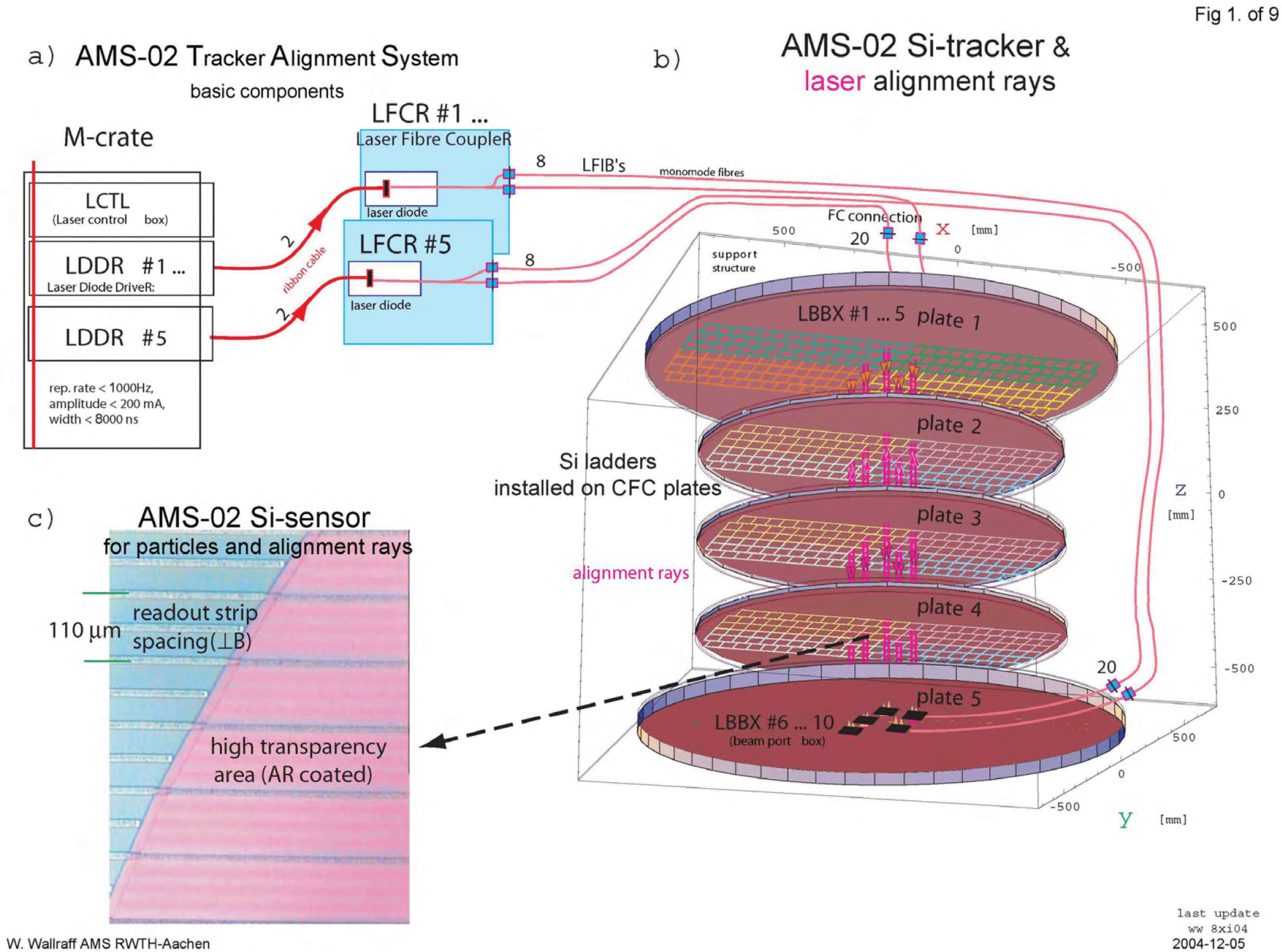


Fig 1. of 9
a) AMS-02 Tracker Alignment System
basic components
M-crate
LCTL
(Laser control box)
LDDR #1 ...
Laser Diode DriveR:
LDDR #5
rep. rate < 1000Hz,
amplitude < 200 mA,
width < 8000 ns
2
ribbon cable
2
LFCR #1 ...
Laser Fibre CoupleR
laser diode
LFCR #5
laser diode
8
LFIB's
monomode fibres
8
b) AMS-02 Si-tracker &
laser alignment rays
FC connection
20
x [mm]
support structure
LBBX #1 ... 5
plate 1
plate 2
plate 3
plate 4
plate 5
Si ladders
installed on CFC plates
alignment rays
LBBX #6 ... 10
(beam port box)
20
z [mm]
y [mm]
c) AMS-02 Si-sensor
for particles and alignment rays
110 µm
readout strip
spacing(⊥B)
high transparency
area (AR coated)
W. Wallraff AMS RWTH-Aachen
last update
ww 8xi04
2004-12-05

Figure 5.9.3-1 AMS-02 Silicon Tracker Laser Alignment System (TAS) Overview

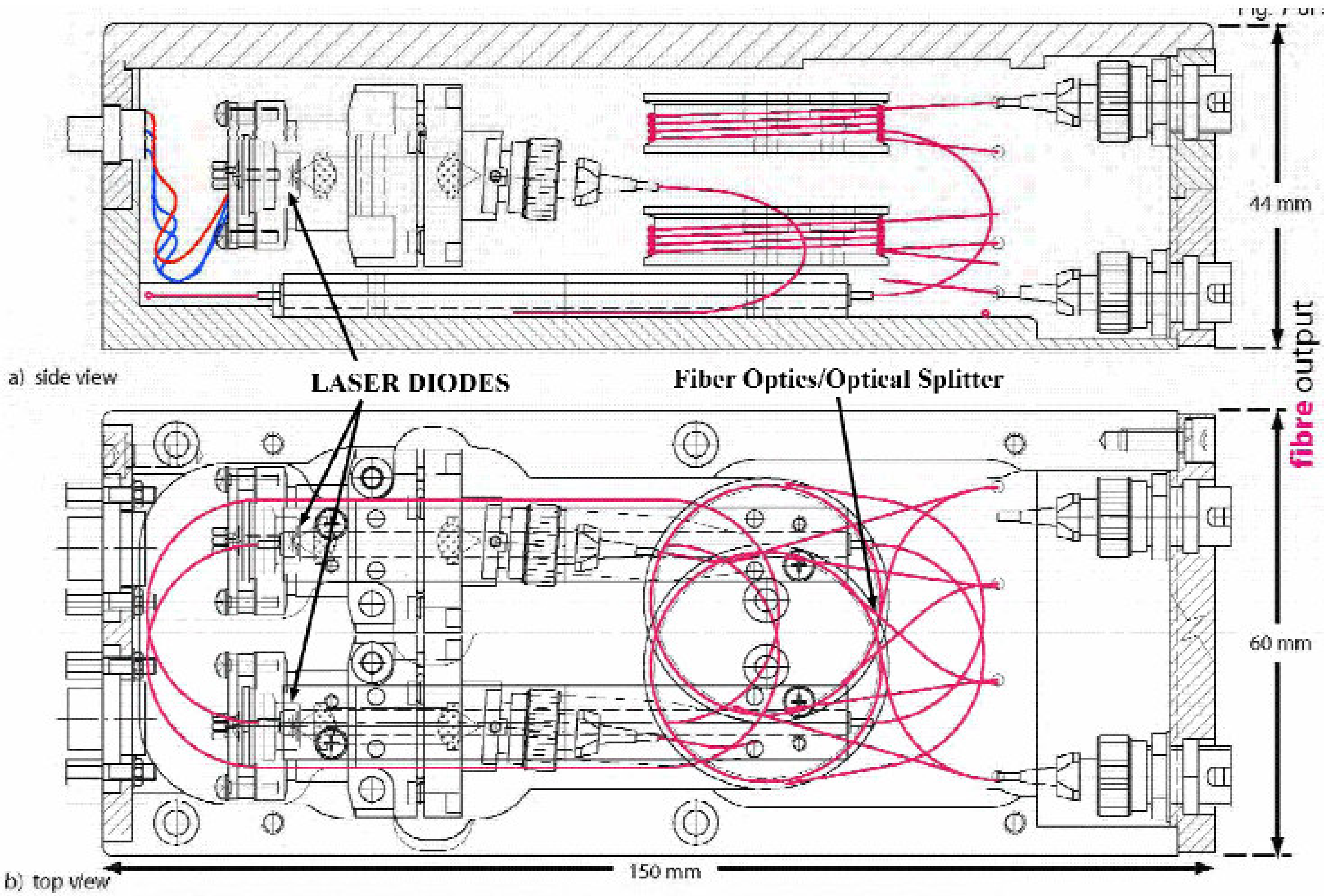


Figure 5.9.3-2 LFCR Box Design

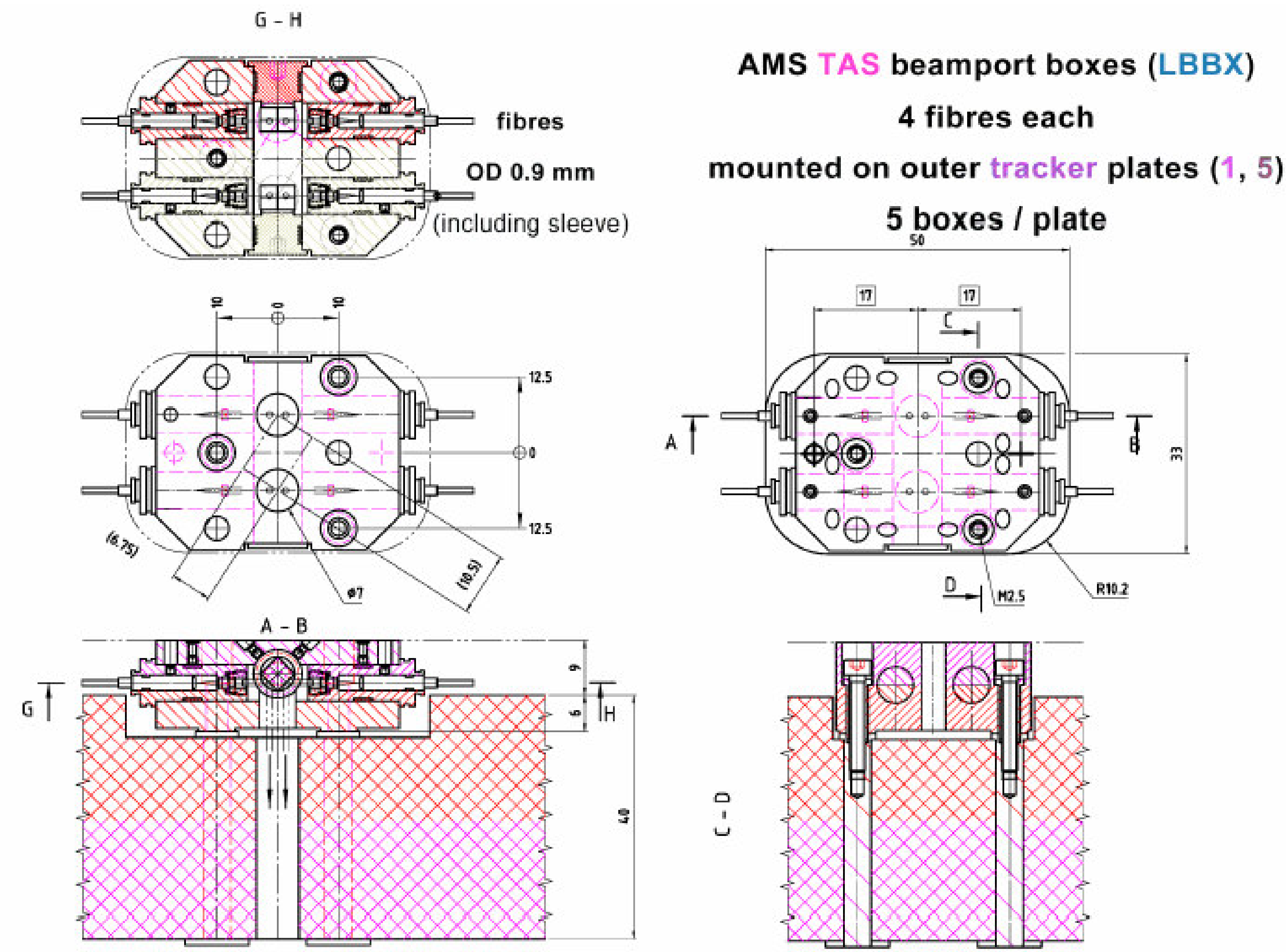


Figure 5.9.3-3 TAS Laser Beamport Box (LBBX) Design

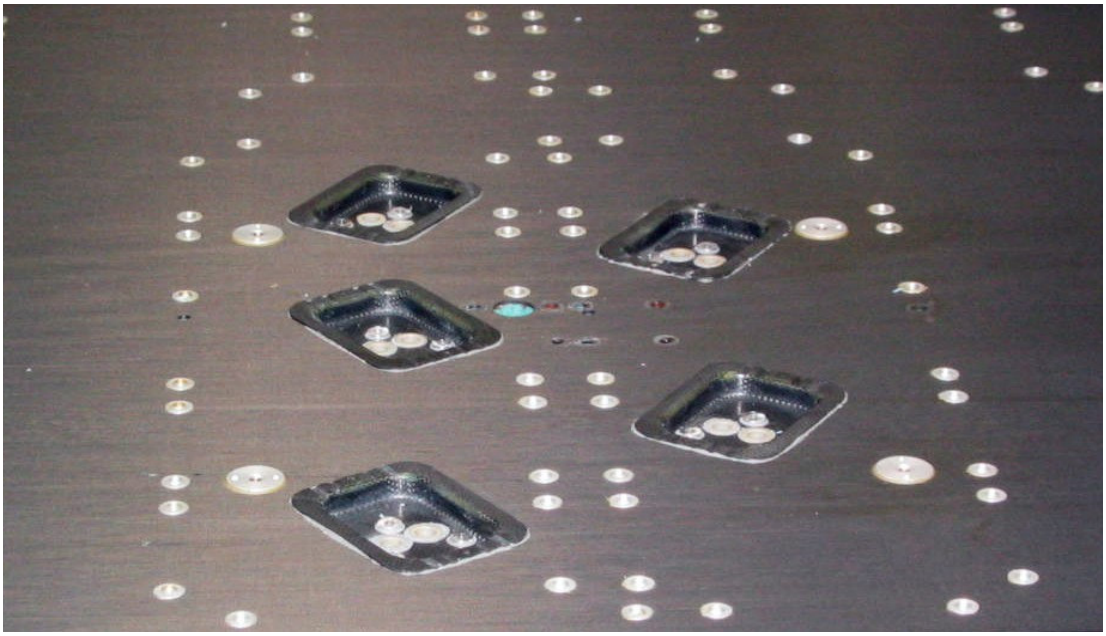


Figure 5.9.3-4 LBBX on Tracker Plane 1

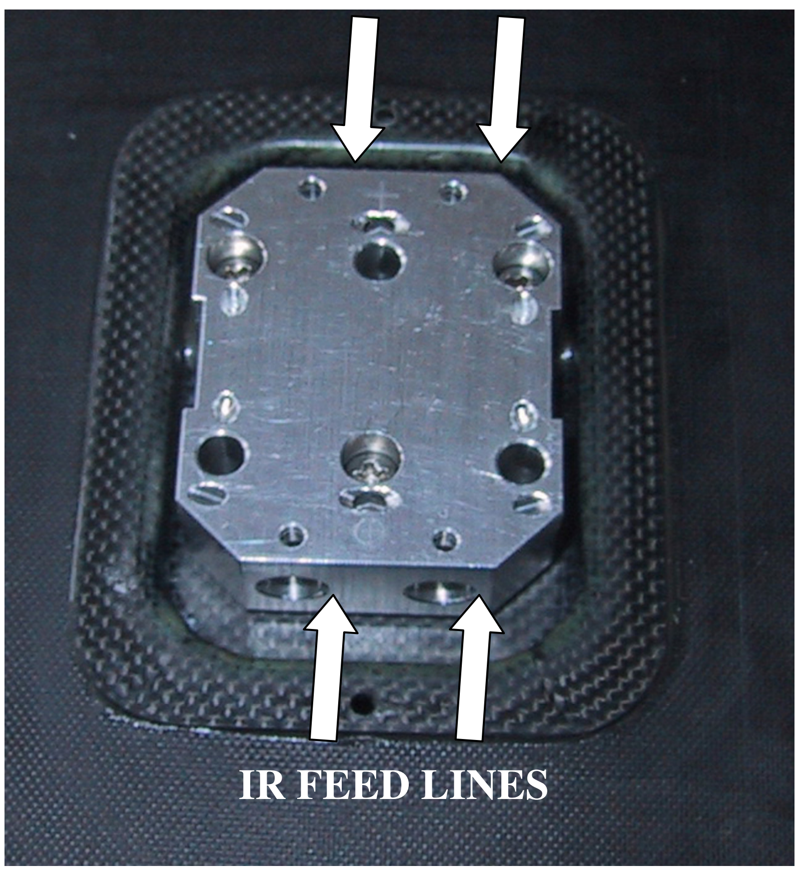


Figure 5.9.3-5 A Laser Beamport Box (LBBX) installed on Tracker Plane 1

5.9.4 Tracker Thermal Control System (TTCS)

The TTCS is one of the most complex thermal control systems used on AMS-02. The Tracker, which is completely encased inside the inner bore of the Vacuum Case, generates 144 watts which need to be rejected while minimizing heat flow to the vacuum case inner cylinder. The TTCS thermal design includes thermal bars, a pumped CO_2 cooling loop, radiators, manifolds, accumulators and numerous other components. A detailed description of the TTCS is included in Section 5.13.7 of this SDP.

5.10 RING IMAGING CERENKOV COUNTER (RICH)

The RICH subdetector is located near the bottom of the experiment stack, below the Lower TOF and above the ECAL. The RICH is used to measure the velocity of the particles that traverse the AMS-02. The RICH is able to determine the velocity of charged particles by measuring the vertex angle of the cone of Cerenkov light e,otted as the particle passes through a tile of the silica aerogel or sodium fluoride that forms the "radiator". Cerenkov radiation from the Cherenkov Effect is emitted as a charged particle passes through a transparent non-conducting material at a speed greater than the speed of light in that material. It consists of visible and ultraviolet light that can be detected and counted by means of the RICH photomultipliers (PMTs). The number of photons per particles gives a measure of the charge of the traversing particle. The use of a high efficiency reflector ring allows for greater data acquisition than direct incident of the photons on the PMTs alone, without the ring, the plane of sensitive PMTs would be much larger..

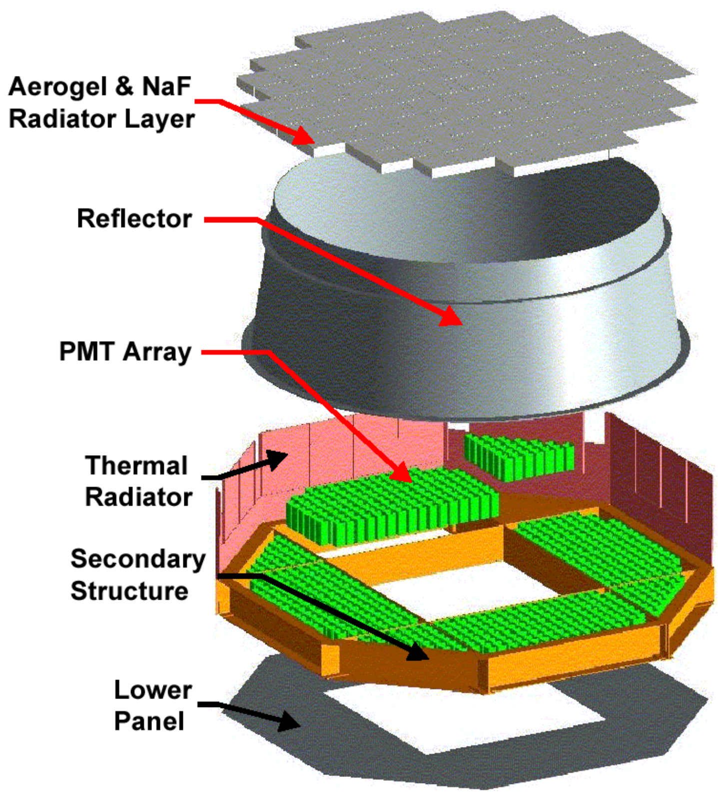


Figure 5.10-1 RICH Basic Elements

Functionally the RICH is composed of three basic elements, the top layer, the Cerenkov radiator, is composed of silica aerogel and sodium fluoride (NaF) blocks that serve as sources for the Cerenkov photons. An intermediate conical mirror and the lower the PMTare supported by a strong aluminum frame that constute the primary structural interface. In the top layer the aerogel and NaF blocks are mounted within a carbon fiber reinforced composite (CFRC) container that provides mechanical rigidity of the elements and provides an enclosure. The aerogel and NaF blocks are between a PORON spacer and carpet and a Polymethylmethacrylate (PMMA) cover that seals with a viton gasket to the CRFC structure The PMMA cover allows the photons generated by the passage of the high-energy particles to be observed by the photomultipliers while containing the radiator inside the container.

Figures 5.10-2, 5.10-3 and 5.10-4 show the general construction of the assembly.

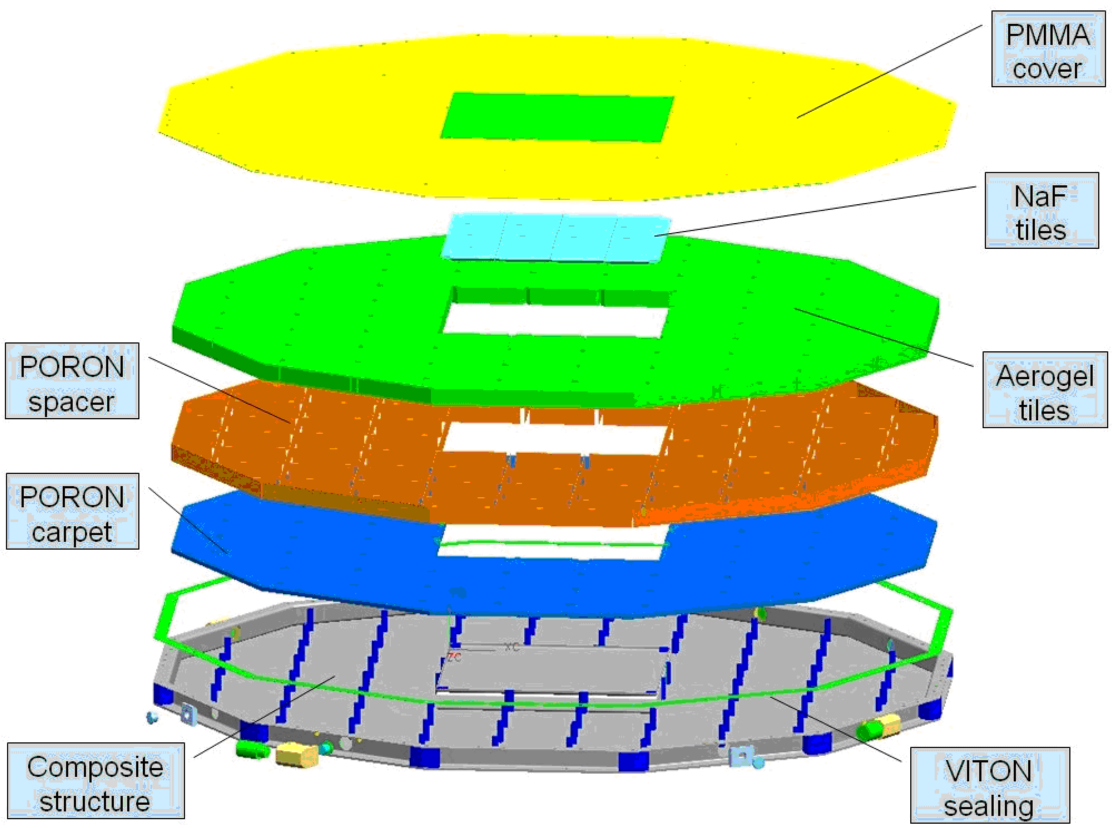


Figure 5.10-2 RICH Aerogel & NaF Container

The RICH upper assembly of aerogel and NaF blocks is vented during ascent by four vent valves and during descent repressurization is controlled by three vent valves. In order to protect this volume once constructed it will be purged through a dedicated valve port with dry nitrogen to provide a clean controlled environment within the Cerenkov Radiator. 50 µm filter screens on the valves will prevent large aerogel or NaF particles that could possible evolve from being released or exterior contaminants becoming ingested. The locations of these valves are shown in Figures 5.10-3 and 5.10-4 and a cross section of the selected breather valve is shown in Figure 5.10-6. These valves will be Halkey Roberts C770RP 1.0 one way valves that have a cracking pressure with a 1 psi differential. The valves will be interfaced to the 50 µm filter screens through a polyetheretherketone (PEEK) interface block as shown in Figure 5.10-7. During ground handling/transportation and processing this interior volume is protected from thermal and atmospheric pressure variation introducing humidity into the interior of the Cerenkov Radiator by having a buffer volume contained within an expandable reservoir (0.5 1) made of Teflon®/Tedlar® supported within a vented enclosure. This expandable reservoir is represented in Figures 5.10-5 and 5.10-8 a-c. Design of this assembly assures that there will not be more than a 1 psi differential between the interior and exterior pressure. Reentry loads of pressure loading on the aerogel during repressurization have been conservatively established to be approximately 1/15th of aerogel compression allowable. The aerogel is considered the most sensitive element of the sandwich of materials.

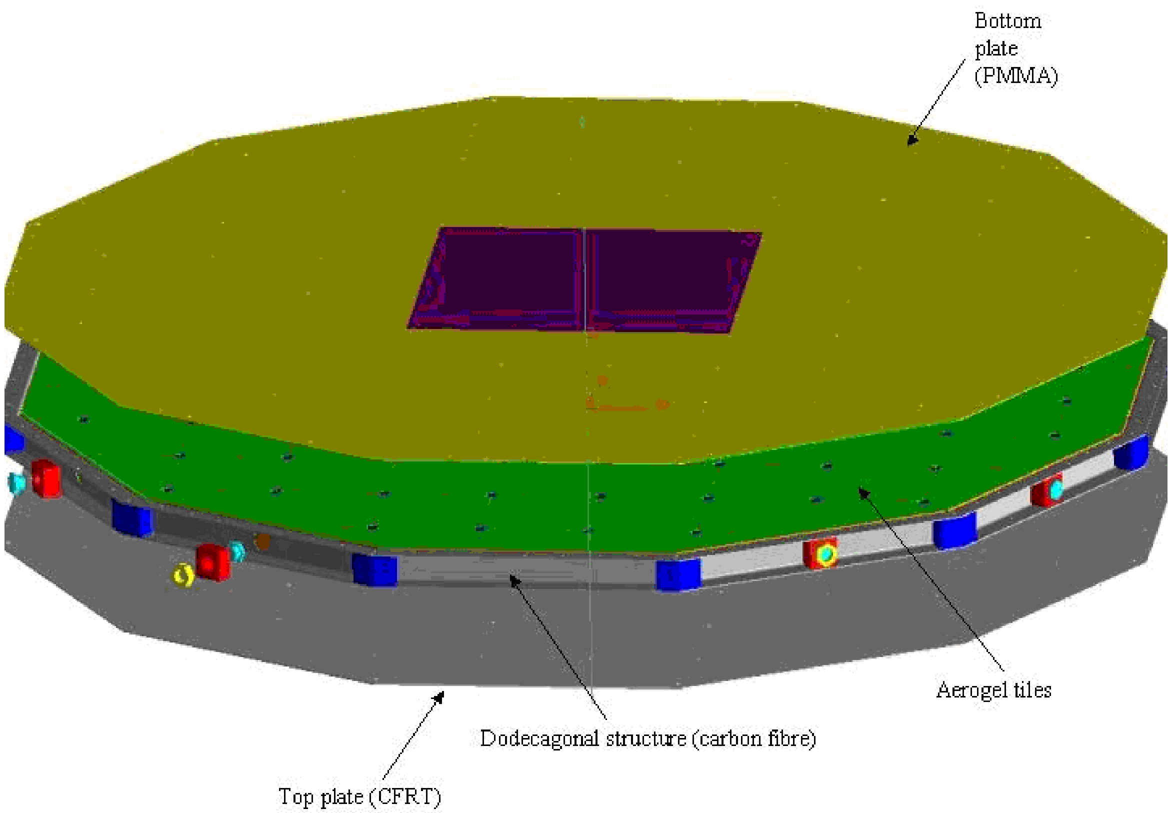


Figure 5.10-3 RICH Aerogel and NaF Assembly

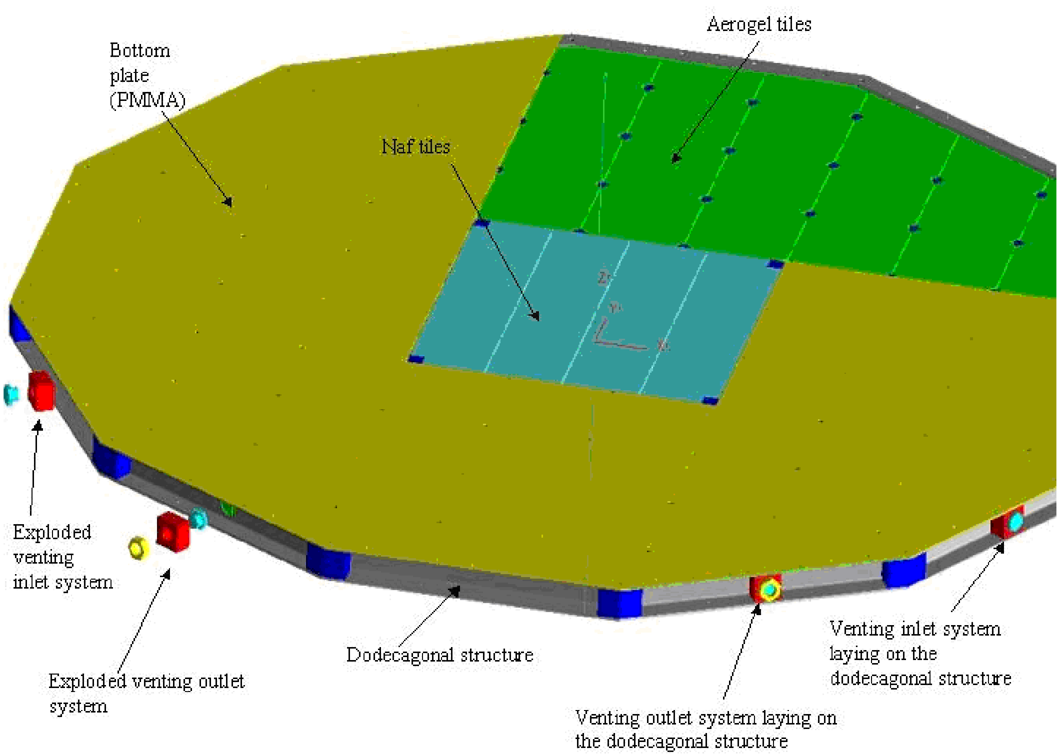


Figure 5.10-4 RICH Aerogel and NaF Assembly

(Vent interface updated in Figure 5.10-7)

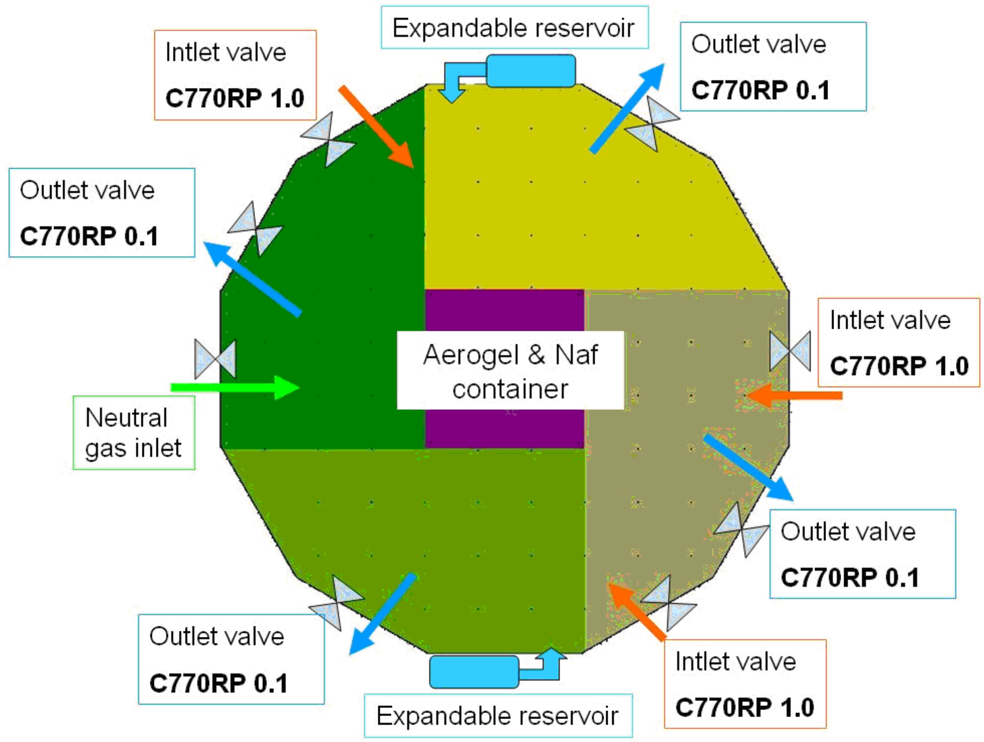


Figure 5.10-5 RICH Functional Venting, Interior Environment Control

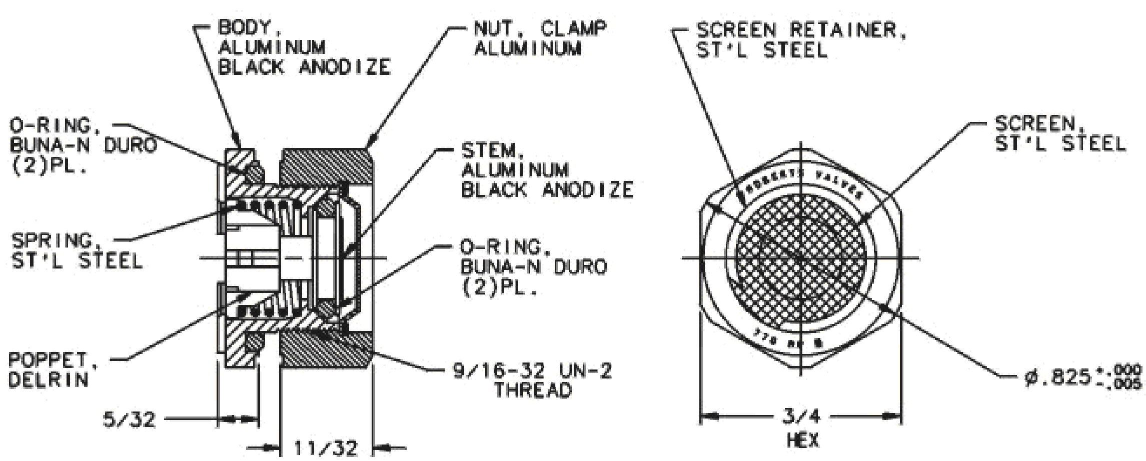


Figure 5.10-6 RICH Halkey-Roberts C770RP 1.0

(Cracking Pressure =- 1.0 psi)

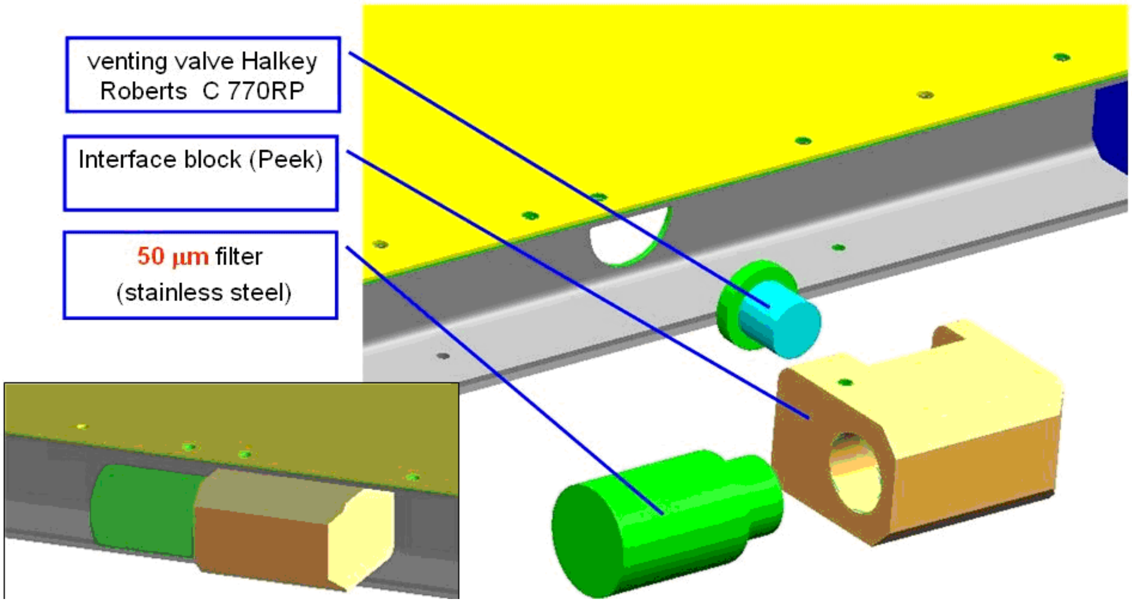


Figure 5.10-7 RICH Vent Valve and Filter Installation

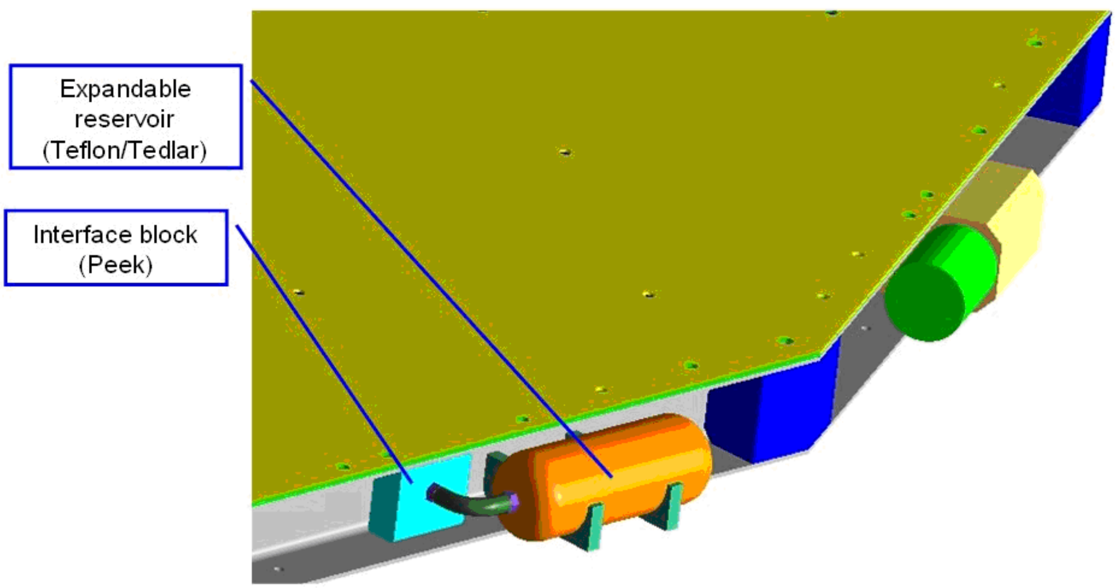


Figure 5.10-8a RICH Expandable Reservoir

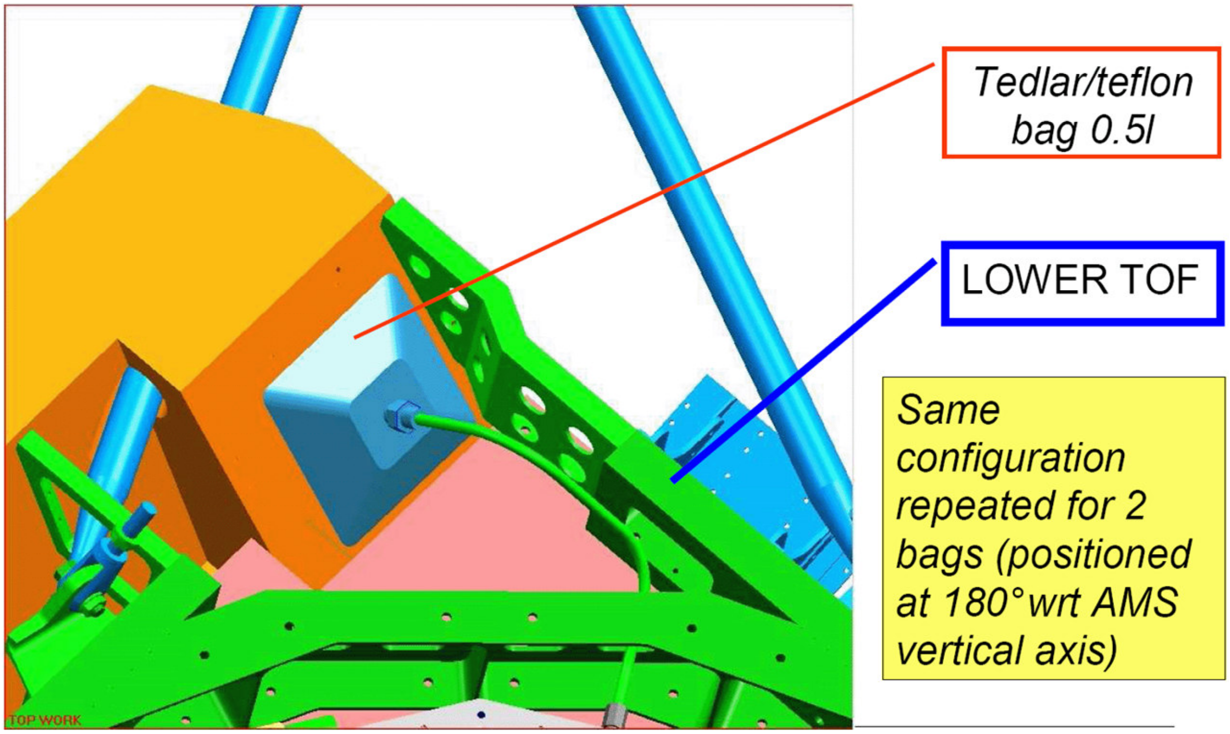


Figure 5.10-8b RICH Expandable Reservoir

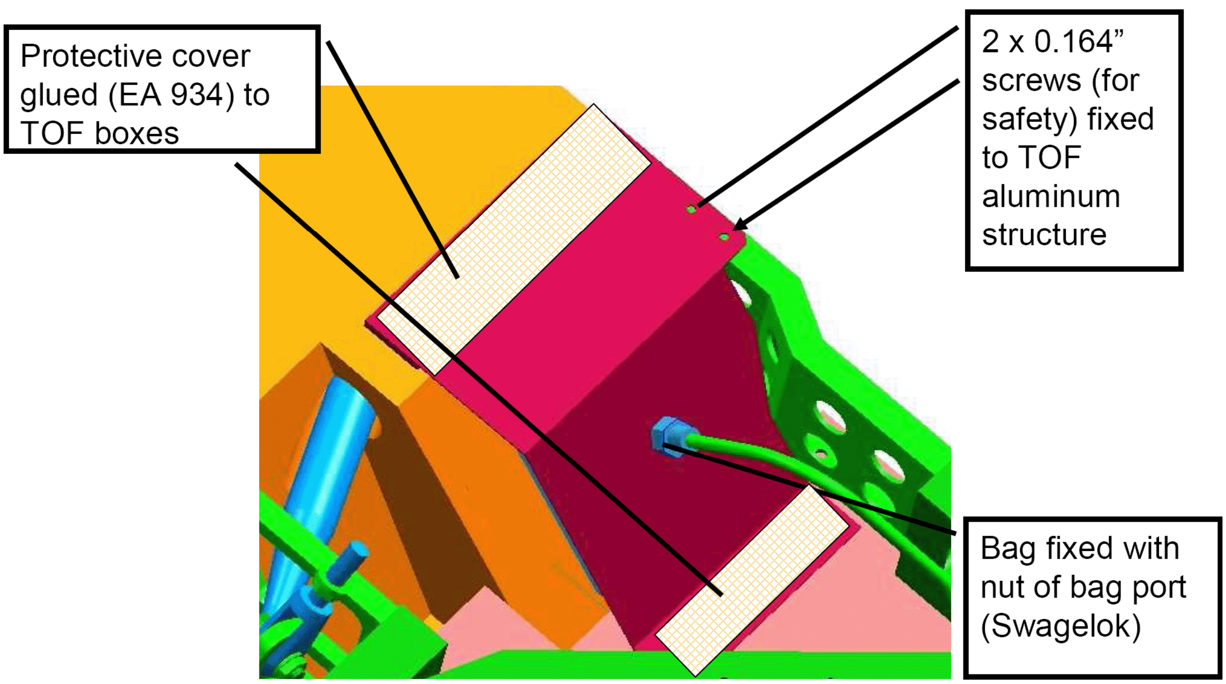


Figure 5.10-8c RICH Expandable Reservoir Cover

The second layer of the RICH is a reflector that is shaped as a truncated cone. The interior surface of this element is a highly polished composite/metal mirror. The mirror is manufactured in three pieces (Figure 5.10-9) to be very light and have a precise, highly reflective, surface. The reflector is made of carbon fiber composite material with layers of deposited aluminum and transparent quartz (to protect from oxidation). A debris shield consisting of eight carbon fiber composite /aluminum honeycomb panels surround the reflector to protect it from penetrations that would damage the mirrored surface and allow light to enter the RICH and disturb detection.

TABLE 5.10-1 RICH MIRROR COMPOSITION

Carbon Fiber/Epoxy Resin	1.5 mm
Aluminum	0.1 μm
Quartz	200 nm

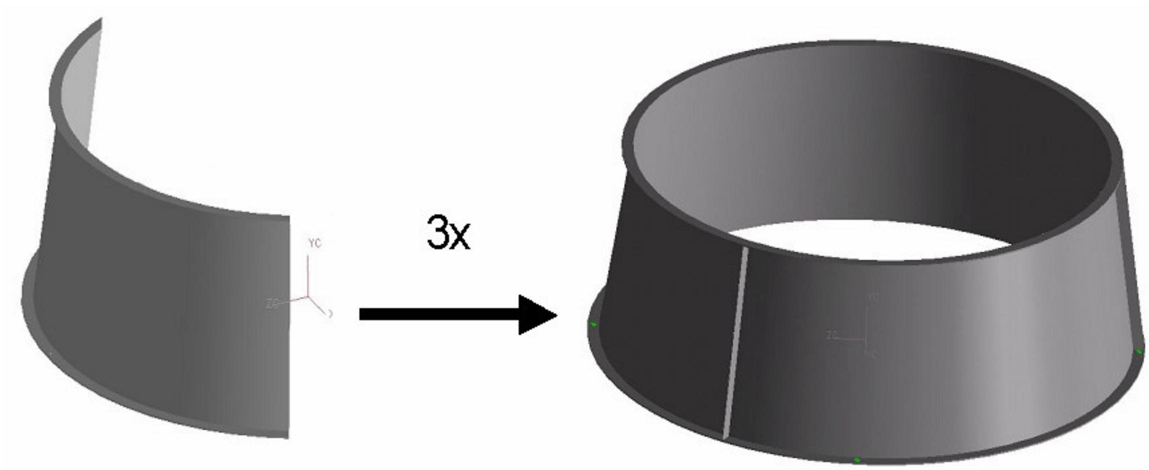


Figure 5.10-9 RICH Reflector Construction

The lower layer of the RICH is the primary structure that supports the RICH and interfaces to the Lower USS-02. Within the secondary structure of the lower assembly are the rectangular and triangular arrays of photomultiplier tubes that will detect the photons from the Cerenkov radiation. Construction of the Lower RICH support structure and PMT support grids are shown in Figure 5.10-10.

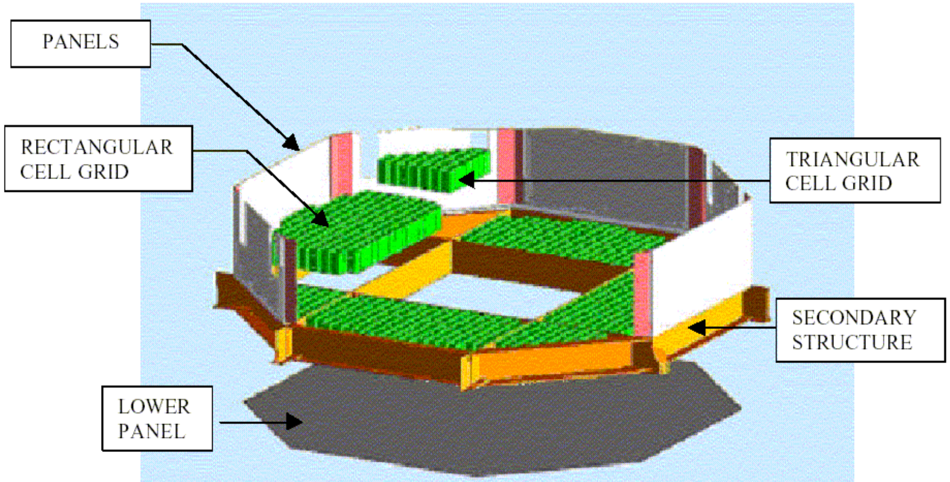


Figure 5.10-10 Lower RICH Construction

The PMTs for the RICH are constructed using Hamamatsu R7600 M16 photomultiplier tubes and a 4x4 matrix of light guides to correlate with the 4x4 photocathode grid of the photomultiplier tube. An optical pad assures the proper transmission of light into the photomultiplier tube and also seals off the glass front of the vacuum tube. The light guides are glued into the optical pad and futher retained by using Nylon cords. The assembly of an individual PMT is shown in Figure 5.10-11.

The base of the photomultiplier tube is potted and the boards of the PMT are conformally coated to protect the electronics and to limit the coronal breakdown potential for the high voltage system. This can be seen in the upper left image of Figure 5.10-12. The welded soft iron outer body provides attenuation of the magnetic fields and support interfaces for integrating into the RICH secondary structures as shown in the lower graphic of Figure 5.10-12.

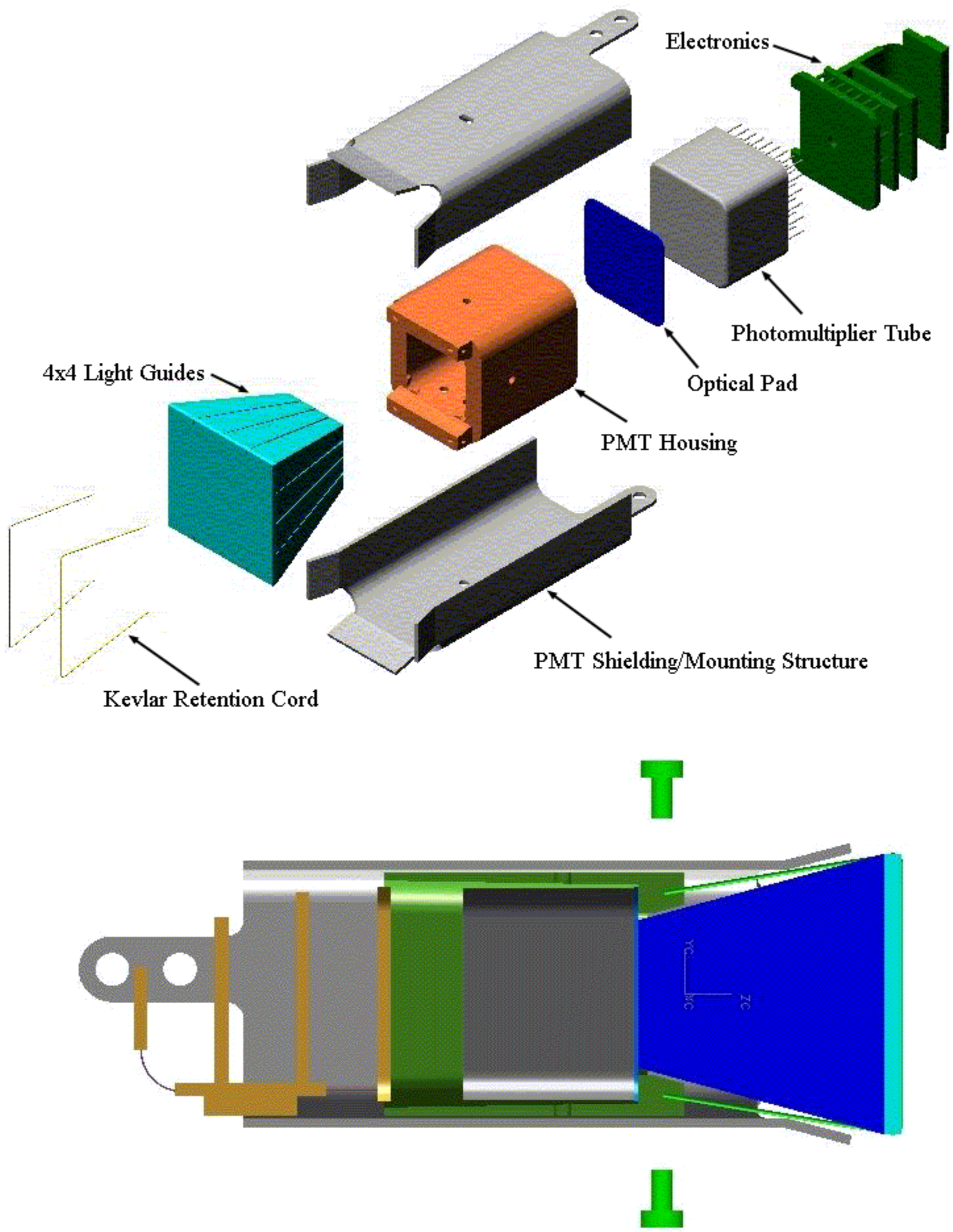


Figure 5.10-11 RICH PMT Construction
(Kevlar cord replaced with Nylon wire)

The individual PMTs are mounted to the triangular and rectangular grids shown in Figure 5.10-10. The upper right image of Figure 5.10-12 shows the mounting technique used within the grids.

The RICH PMTs are powered by four RICH high voltage bricks attached to the Lower USS-02 structure. Each of these bricks generates voltages at 1000 VDC and supplies this voltage to the PMTs. The RICH high voltage bricks are fully potted as are the high voltage electronics on the PMTs. The cabling used to route this power is rated in excess of the voltages present and use high voltage connection techniques to eliminate possible sources for discharge, corona and electrical shock. Figure 5.10-13 shows the mounting locations for the high voltage bricks.

The signals from the PMTs are sent to the R Crate for data processing to establish the high energy particle or radiation incident characteristics.

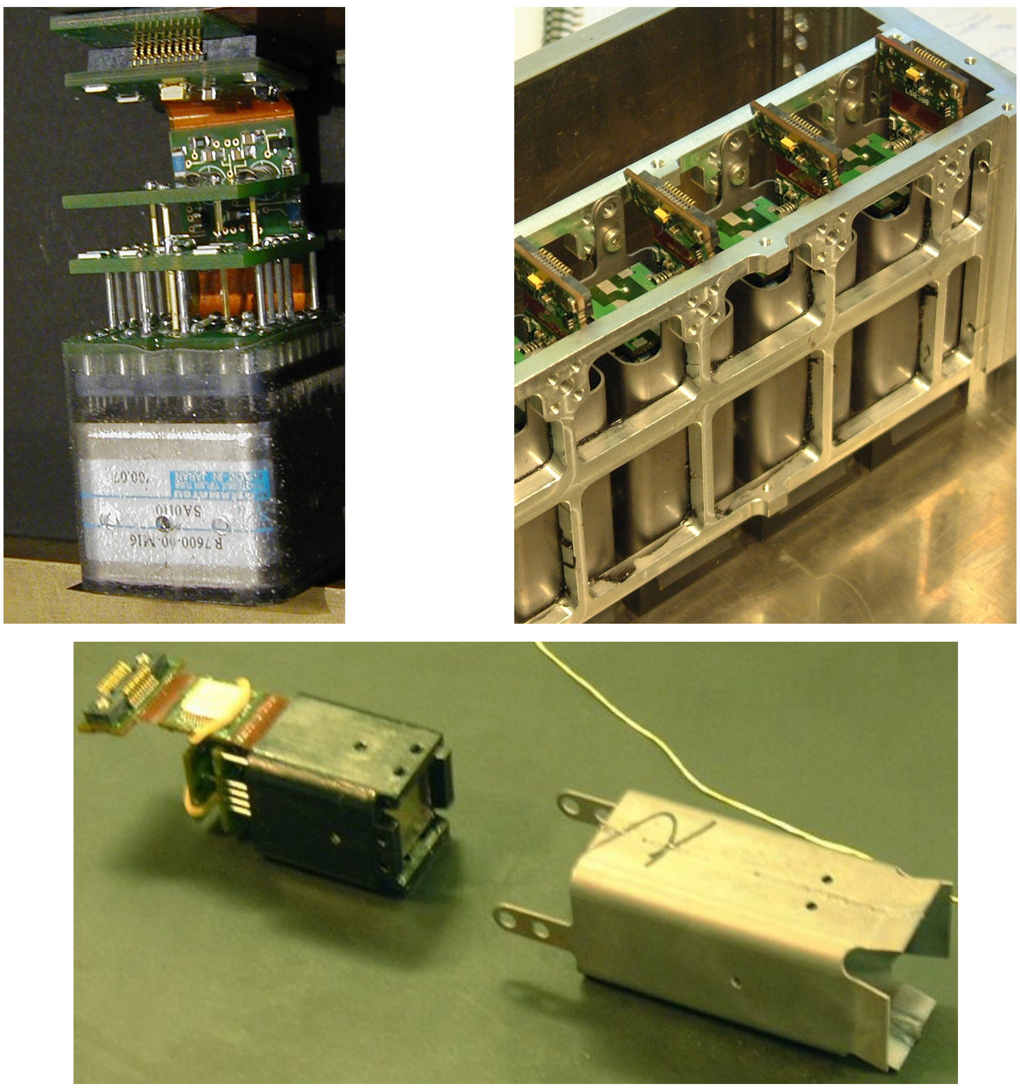


Figure 5.10-12 RICH PMT Construction and Mounting

The 406 lb (184 kg) RICH interfaces with 8 flanges on the Lower USS-02 as shown in Figure 5.10-14. Each interfaces uses 2 bolts per flange (16 total) secure the RICH to the Lower USS-02. Each of these flanges is riveted to the Lower USS-02 box beams with 24 structural rivets.

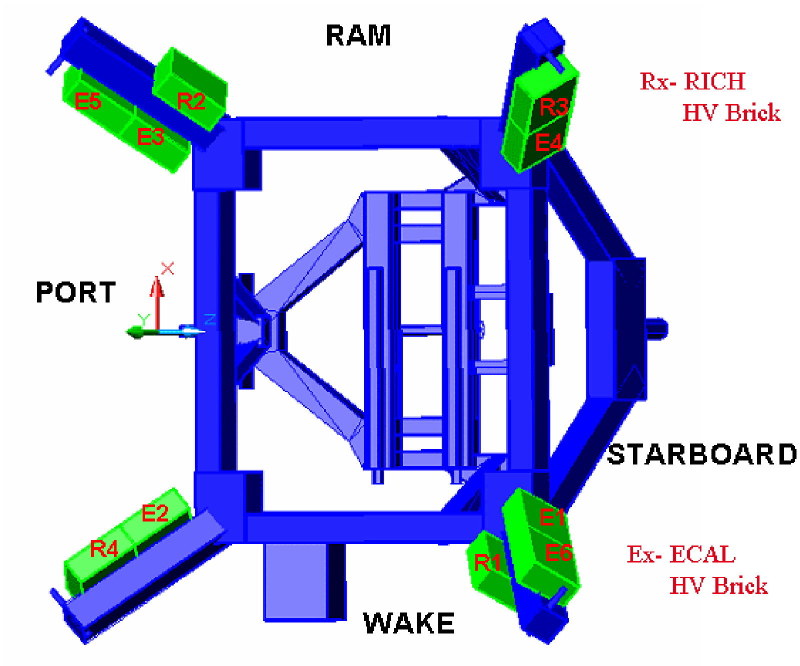


Figure 5.10-13 Lower USS-02 Mounting of RICH & ECAL HV Bricks

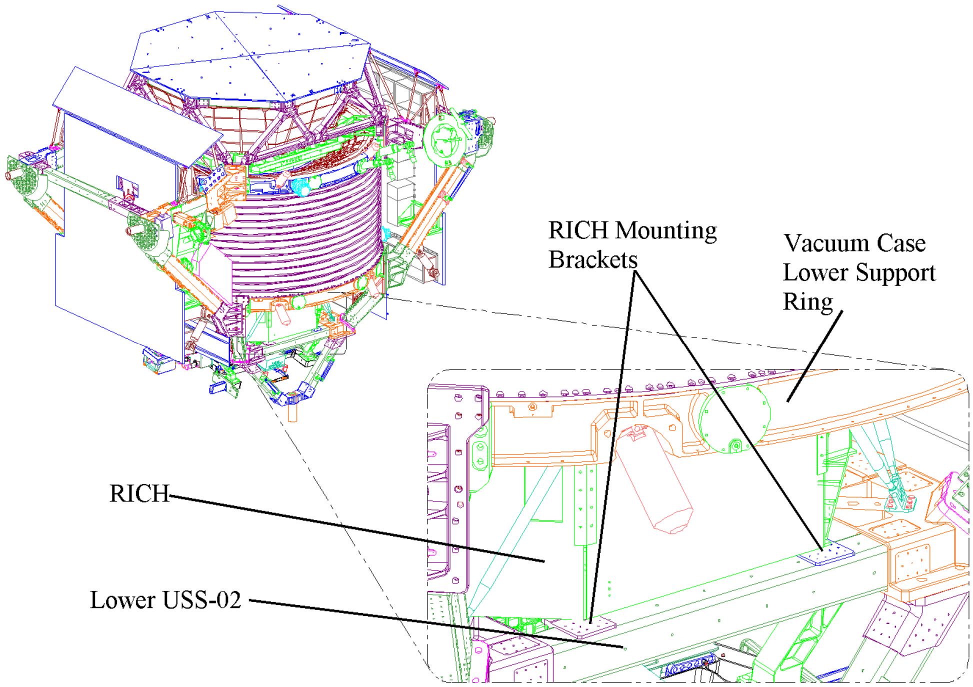


Figure 5.10-14 RICH Structural Interface

5.11 ELECTROMAGNETIC CALORIMETER (ECAL)

The Electromagnetic Calorimeter (ECAL) of the AMS-02 experiment is a fine grained lead-scintillating fiber sampling calorimeter that allows precise, 3-dimensional imaging of the longitudinal and lateral shower development, providing high ($\geq 10^6$) electron/hadron discrimination (identify particle type) in combination with the other AMS-02 detectors and good energy resolution (energy measurement). The calorimeter also provides a stand-alone photon trigger capability to AMS. The ECAL measures the energy of electrons, positrons and gamma rays up to 1 TeV.

The active sensing element of the ECAL consists of layers of lead foils and polymer scintillating fibers (Figure 5.11-1). Each lead foil a lead-antimony alloy with a density of 11.2 ± 0.5 gr/cm^{3}with an effective thickness of 0.04 inch (1 mm). Each lead layer is grooved (rolled) on both sides (Figure 5.11-2) to accommodate the PolyHiTech Polifi 0244-100 scintillating fibers. Each fiber is 1.0 mm in diameter and is secured in the aligned groves with BICRON BC-600 Optical glue that is applied as lead layers are assembled and pressed together. Each layer consists of 490 fibers across the 25.9 inch (658 mm) width of the layers Lead layers are grouped together in “superlayers” (Figure 5.11-3) that are comprised of eleven layers of lead foil and ten layers of scintillating fibers. Each superlayer has all scintillating fibers oriented in the same direction, alternating the direction orthogonally of the fibers with each of the superlayers (Figure 5.11.1), 9 in total. Once assembled and pressed, each cured superlayer is milled to a uniform thickness of 0.7 inch (18.5 mm) thick. The superlayers are assembled as larger elements and sized (milled) for flight into squares with 25.9-inch (658 mm) long sides. The last (bottom) lead layer of the bottom superlayer has been replaced with a milled aluminum plate to reduce weight of the overall ECAL. Estimated savings by replacing the last plate with aluminum is approximately 2 kg.

Figure 5.11-1 Three ECAL Superlayers

Alternating Layers Of Lead Foil And Scintillating Fibers And Alternating Superlayer Orientation

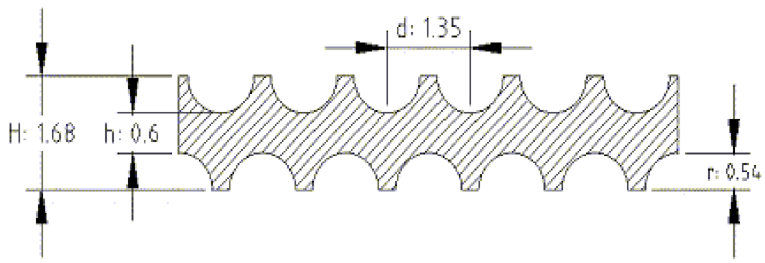


Figure 5.11-2 Individual Lead Foil Profile (Dimensions in mm)

The "pancake" of lead layers with scintillating fibers is the foundation of the ECAL sensor. Sensitive photomultiplier tubes (PMTs) are positioned around the periphery of the brick to sense photons generated by the passage of particles, secured against the edges of the brick where the Superlayer fibers terminate. A position of one of these PMT locations with its four pixels is depicted in red in figure 5.11-3. A side view of the ECAL (before the PMTs are installed) is provided in Figure 5.11.4.

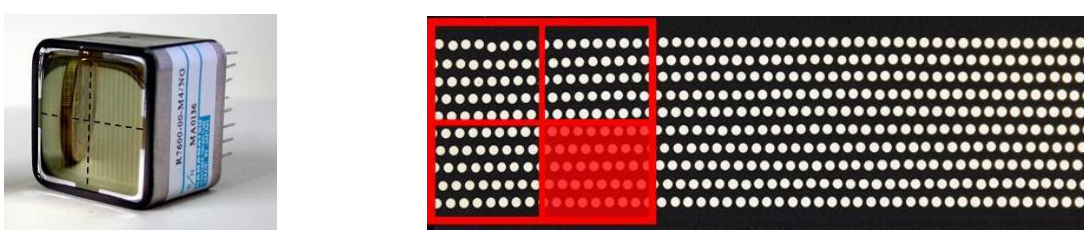


Figure 5.11-3 The 4-Anodes Photomultiplier and Superlayer Coverage

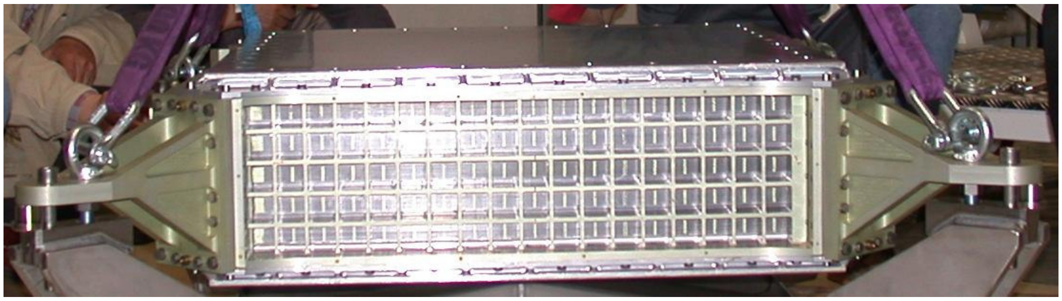


Figure 5.11-4 ECAL Side Panel Grid
Prior to the installation of the PMTs

The ECAL is approximately 31.5 inches (800 mm) square x 9.8 inches (250 mm) high and weighs approximately 1478 lbs (643 Kg). Approximately 75% of this weight is due to the lead foils.

The ECAL "pancake" is supported by the ECAL "box". The box is made of 6 elements (Figure 5.11-5). The top and bottom pieces are aluminum honeycomb plates framed with aluminum. The plates are bolted to four lateral panels along the edges. The four lateral panels are made of Aluminum plates, 4 inch (10.16 cm) thick, carved with squared holes of 1.26-inch (32 mm) sides to house the light collection system. Four corner brackets, made of Aluminum plate, link the four plates together and connect the detector to the USS-02 at the bottom of the AMS-02 instrument (Figure 5.11-6). The four mounting locations include a pair of radially slotted holes so that the loads of the ECAL are transferred to the USS-02, but the loads from the USS-02 that are transferred into the ECAL are limited.

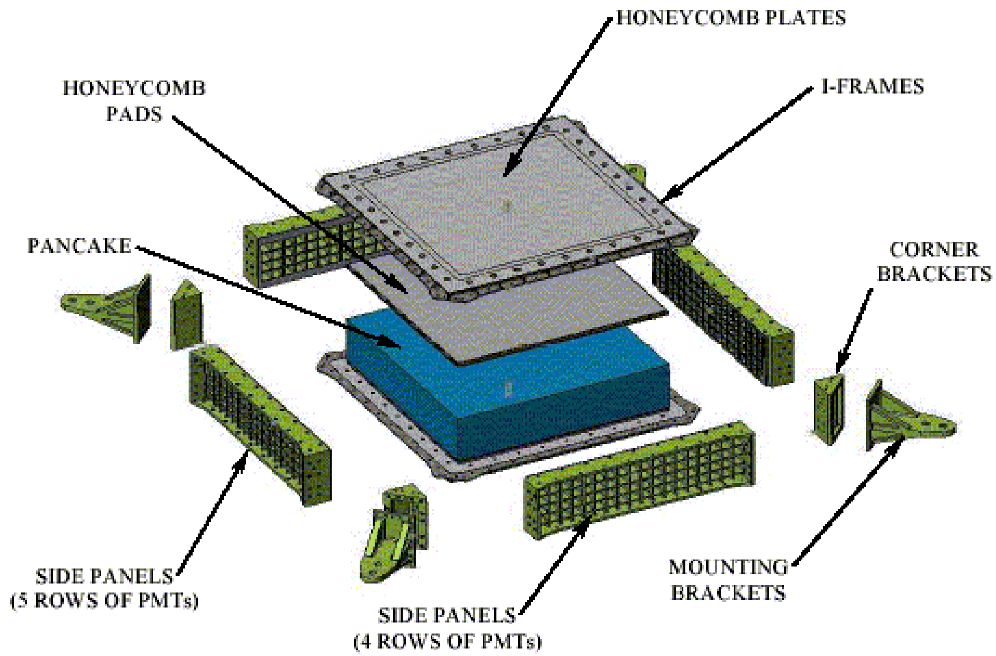


Figure 5.11-5 ECAL Construction

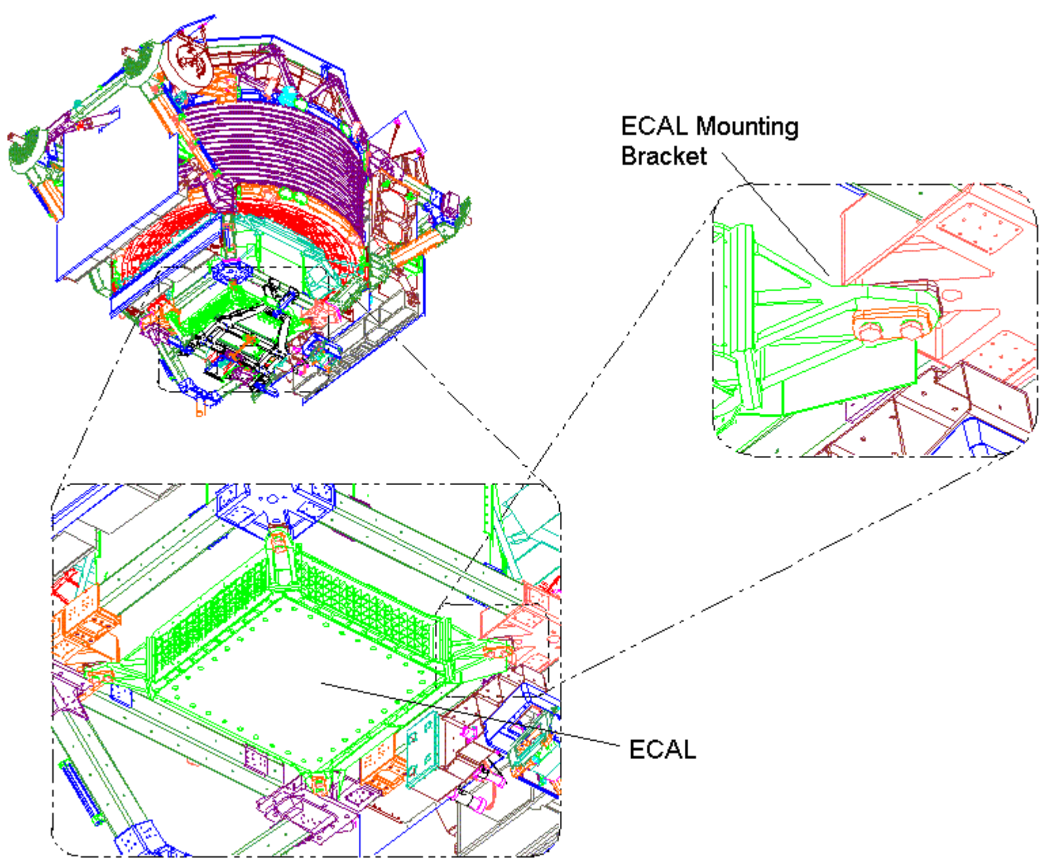


Figure 5.11-6 Location of the ECAL on the AMS-02

The light collection system is mounted about the periphery of the ECAL pancake in the four lateral panels. Two sides, serving 4 superlayers, have 72 holes while the two other faces, serving 5 superlayers, have 90 holes each (Figure 5.11-7).

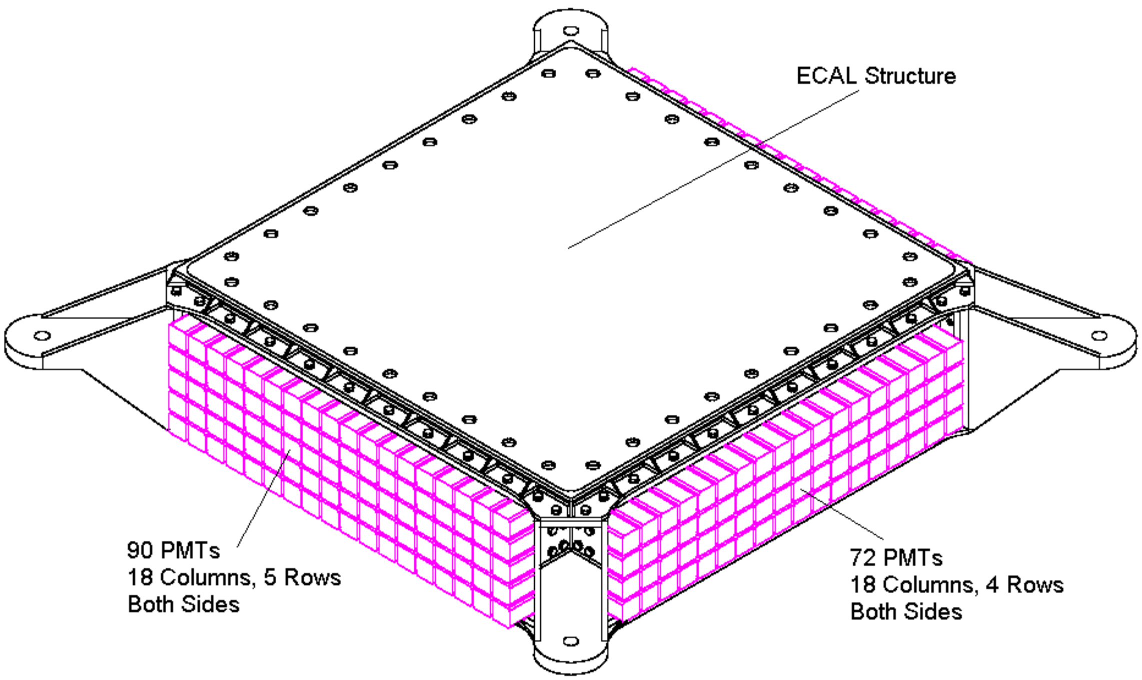


Figure 5.11.7 ECAL Assembly showing the location of the 324 PMTs

For each hole, the light collection consists of a mu-metal square tube for magnetic field shielding, light guides and Photomultiplier Tubes (PMTs) with driver electronics (Figure 5.11-8). An Aluminum backplate is fixed on the rear side of each lateral panel to keep all the light collection systems in the correct position, securely engaged with the lead foil surface and scintillating fibers, and to prevent any displacements of the systems themselves. The glass front of the ECAL PMT is covered with a DC 93-500 Optical coupling pad and is potted in the same material, encapsulating the glass element. The ECAL Intermediate Boards (EIBs) (Figure 5.11-9) are electronic boards coated and fixed in aluminum frames directly mounted on the ECAL back panels. The EIBs provide the interface for the PMTs to get commands from the data acquisition system and to send data from driver electronics to it.

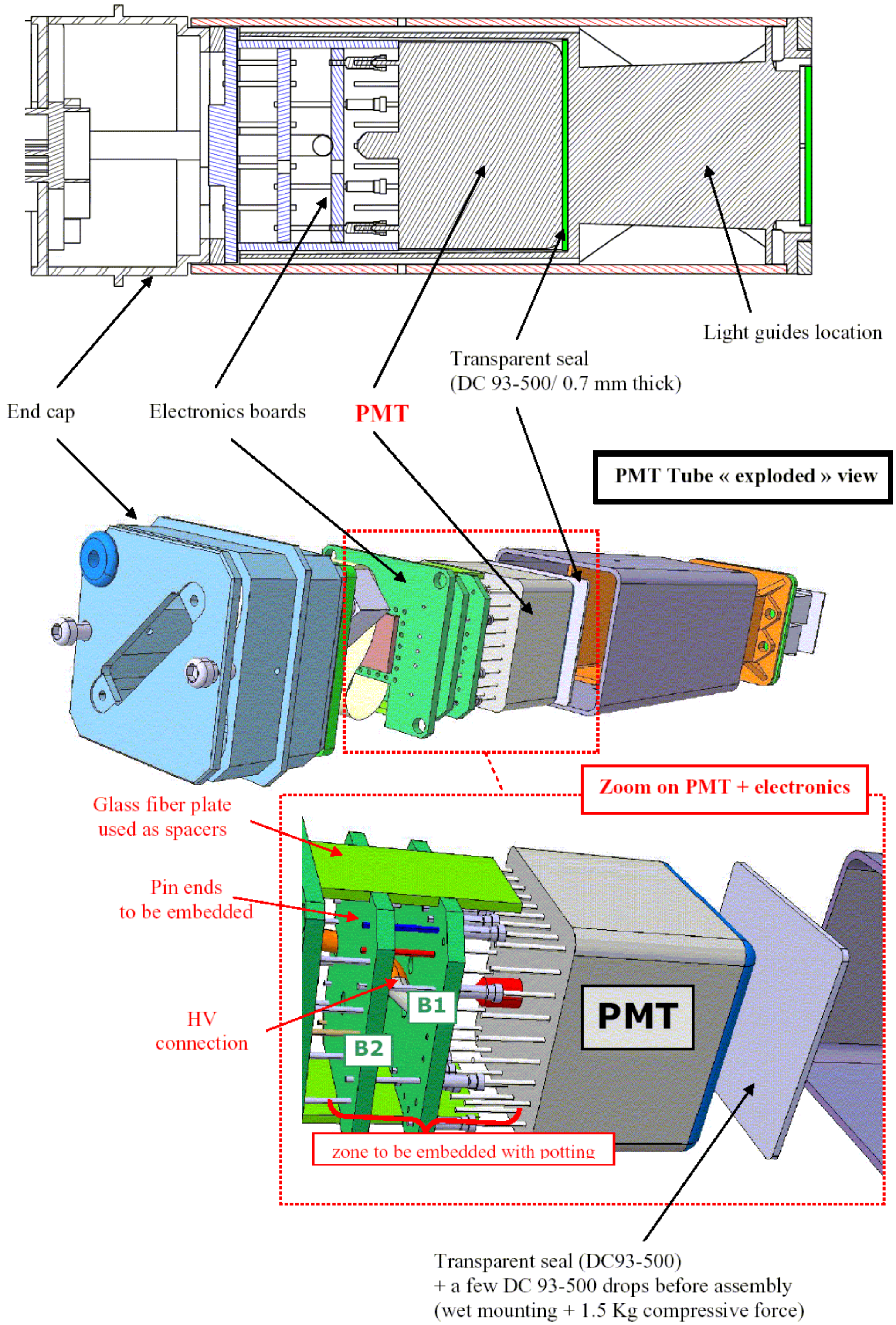


Figure 5.11-8 ECAL PMT Construction

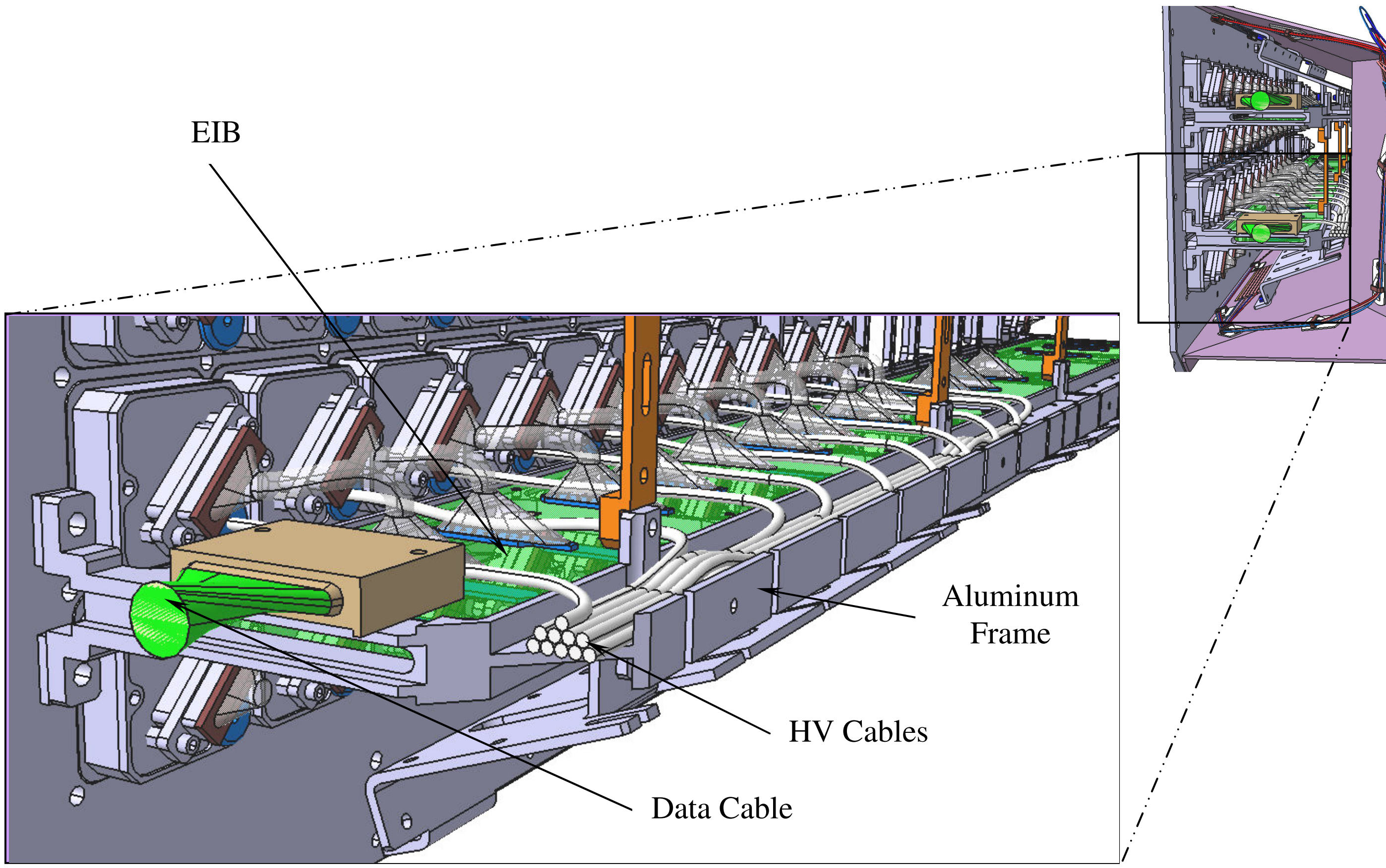


Figure 5.11-9 ECAL Backpanel Showing EIBs in Frames

Figure 5.11-10 ECAL Engineering Model
ECAL Intermediate Boards (EIBs) mounted in their frames

The ECAL utilizes two types of electronics boxes, the E-Crate and ECAL High Voltage (EHV) boxes, which are mounted to the lower USS-02 structure (Figure 5.11-11). The two E-Crates provide data acquisition and triggering functions and the four EHV boxes contain high voltage (HV) bricks (Figure 5.11-14) – each with 55 HV channels per brick –supply the high voltages for PMT operations. The HV bricks are fully potted. Two EHV boxes mounted on diagonally opposite legs of the lower USS-02 accommodate two HV bricks each, while the EHV boxes mounted on the two other legs accommodate one brick each. Three bricks are packaged per each of the four EHV boxes. The ECAL utilizes high voltages up to 800 VDC to operate the PMTs. Figure 5.11-15 provides a graphical representation of the HV design.

The cabling for HV, data and triggering are routed about the lower USS-02 using cable guides (Figures 5.11-11 through 5.11-13), the HV being routed separately from the data and trigger cabling. Figures 5.11-10 and 5.11-11 show the routing for data and trigger cabling. Cable runs are carefully designed to keep the critical timing of recorded events synchronized.

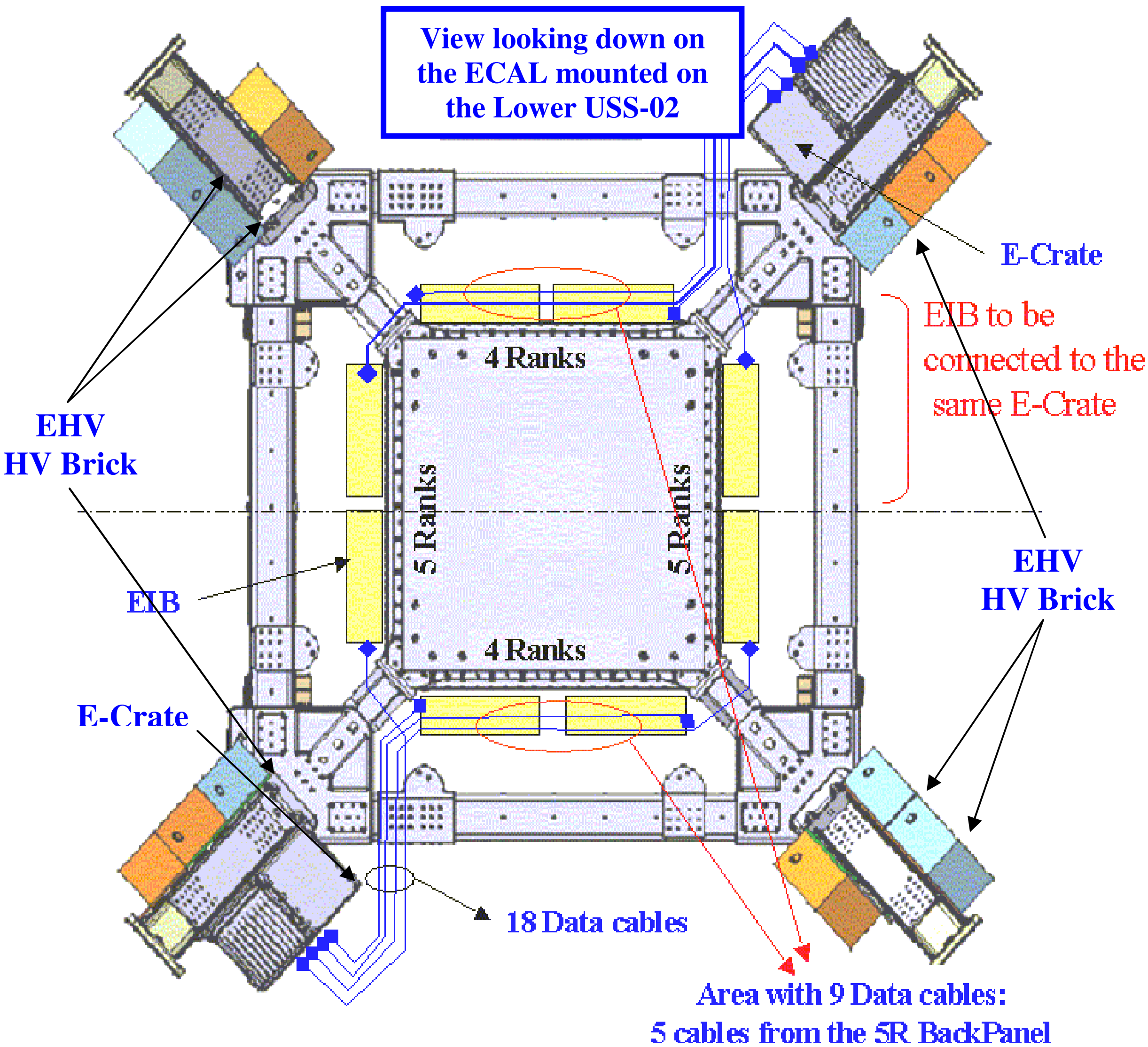


Figure 5.11-11 Routing of ECAL Data Cables
Location of E-Crates and EHV High Voltage Bricks

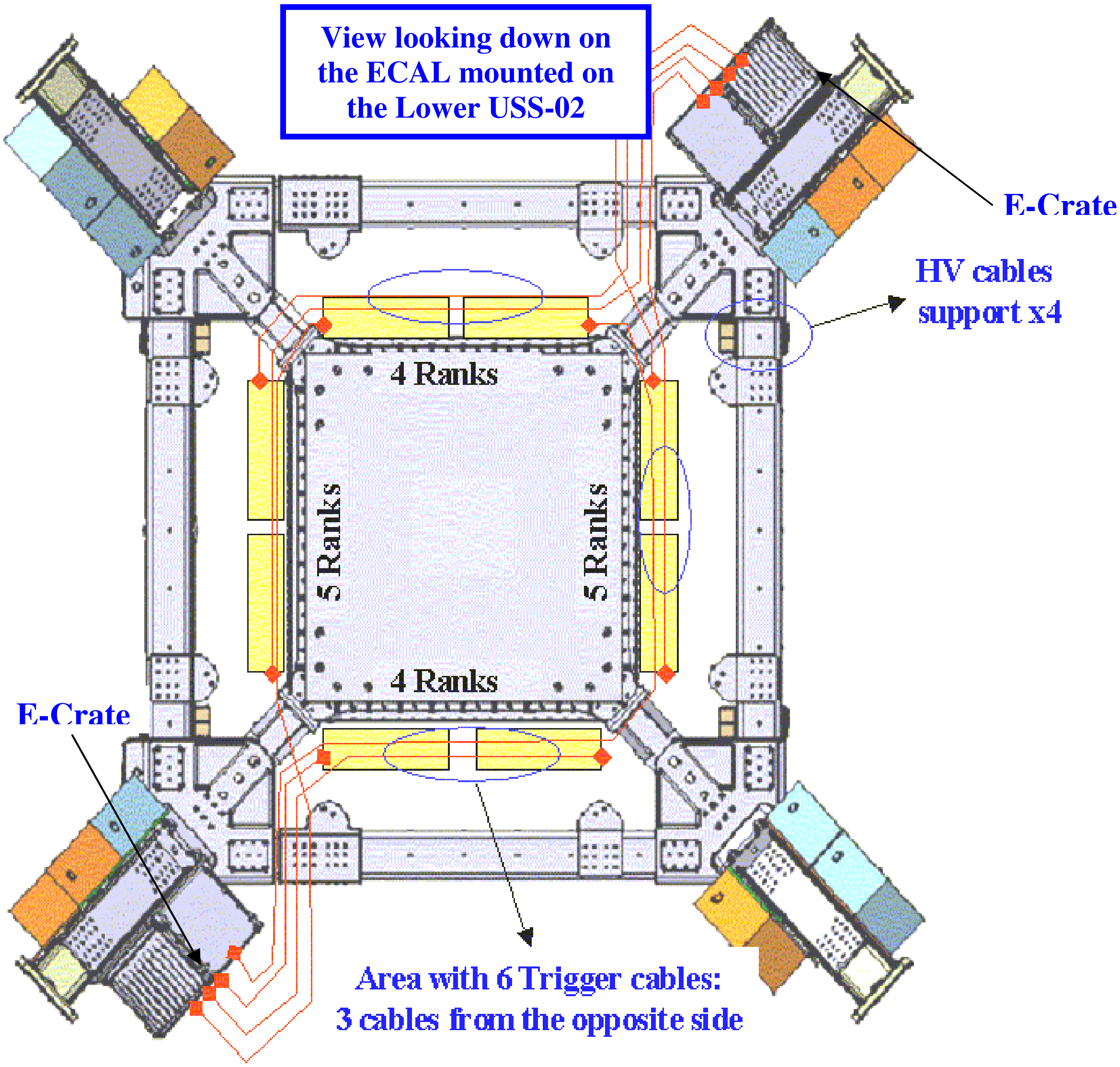


Figure 5.11-12 Routing of ECAL Trigger Cables

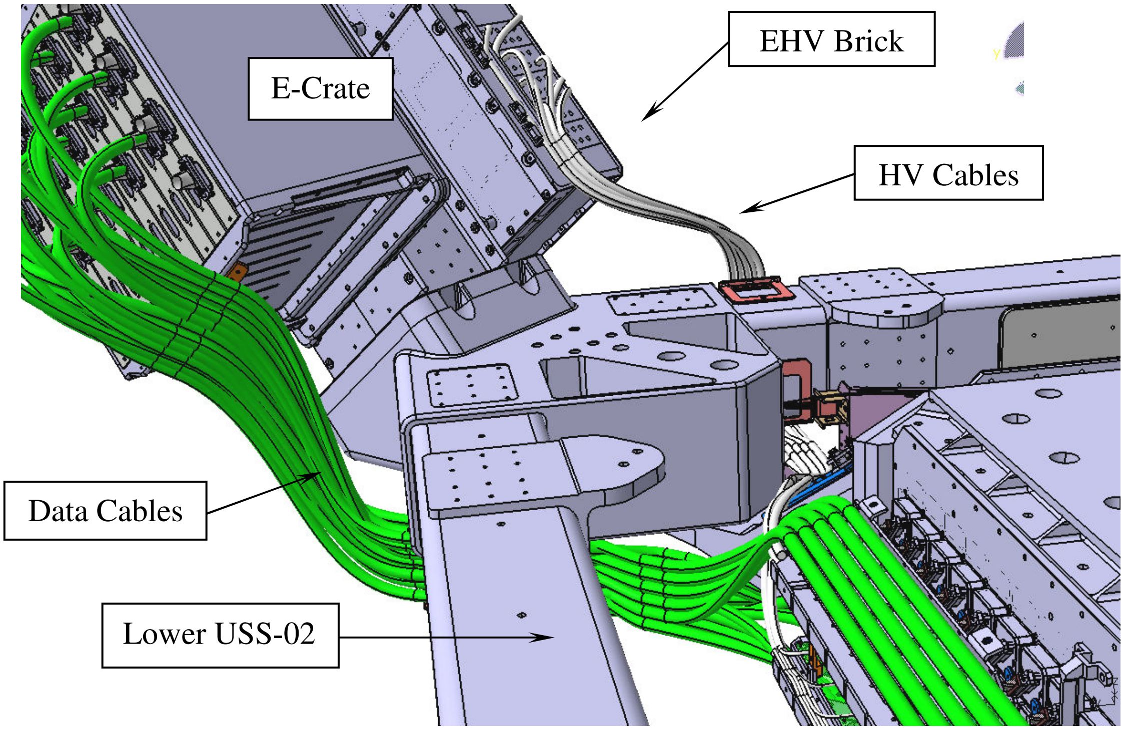


Figure 5.11-13 HV & Data Cable Routing from the ECAL to the HV Bricks and E-Crate

Figure 5.11-14 ECAL HV Brick

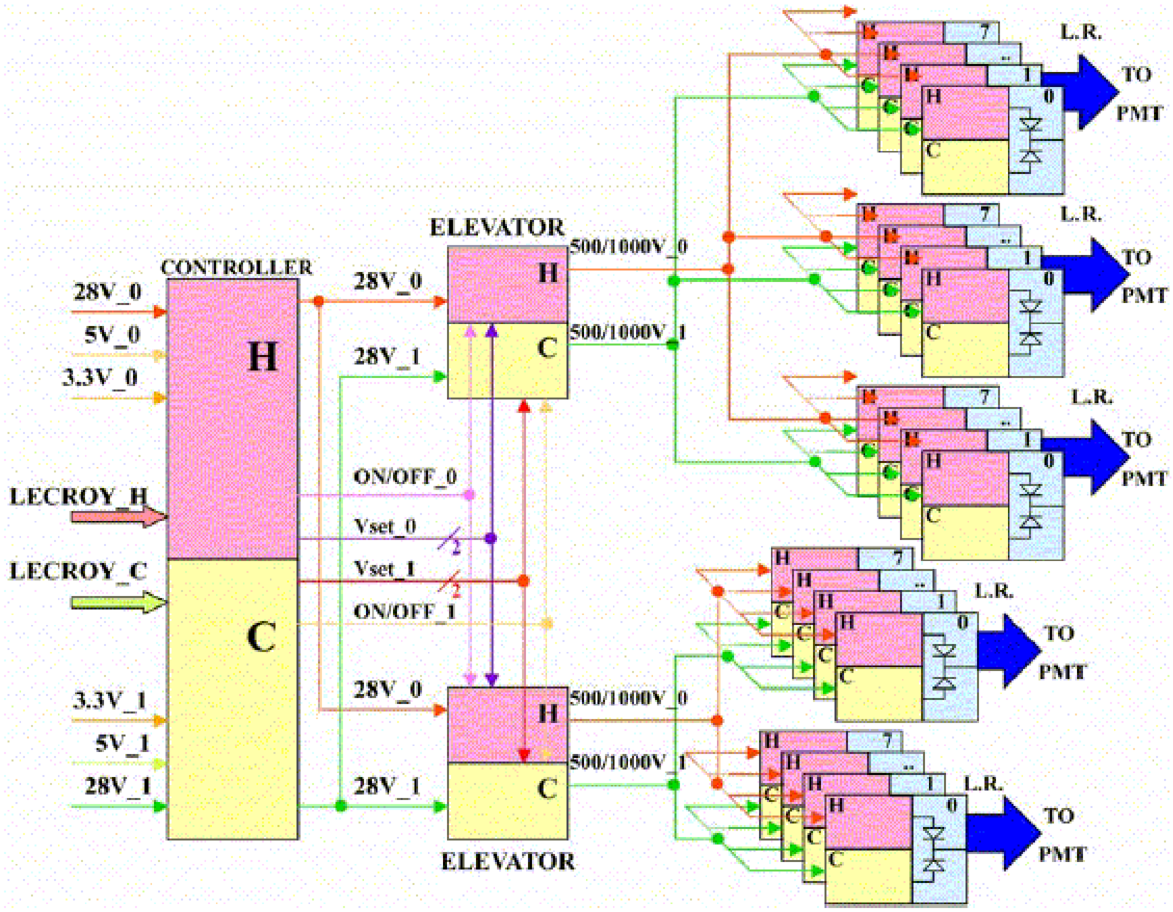


Figure 5.11-15 ECAL High Voltage Design

5.12 AMS ELECTRONICS

The AMS avionics primary functions are front end data collection for the scientific instruments, data and command communication interface between the various portions of the payload, as well as between the payload and the STS and ISS; and power distribution throughout the payload. The details provided in this section are broken down into the following subsections:

- AMS-02 Electronics Systems Architecture Description
- Power Interfaces
- Power Distribution System (PDS)
- Cryomagnet Avionics Box (CAB)
- Cryocooler Electronics Box (CCEB)
- High Voltage Sources
- Grounding/Bonding Scheme for the AMS-02 Experiment
- AMS-02 Integration Cabling De-Rating
- AMS-02 Data Systems and Interfaces

5.12.1 AMS-02 Electronics Systems Architecture Description

AMS-02 contains numerous electronics boxes, some termed "Crates," that supply the necessary readout/monitor/control electronics and power distribution for each detector (Figures 5.12.1-1 and 5.12.1-2). The box nomenclature is generically x-Crate or xPD, where "x" is a letter designating the detector function, and "Crate" refers to the readout/monitor/control electronics box and "PD" refers to the Power Distribution box for that specific detector. Similarly xHV bricks provide high voltage for some detectors. Values of "x" are designated as follows:

- E ECAL
- J Main Data Computers (MDC) and Command & Data Handling interfaces
- JT Trigger and central data acquisition
- M Monitoring
- R RICH
- S Time of Flight (TOF) Counters and Anti-Coincidence Counters (ACC)

- T Tracker
- TT Tracker Thermal
- U Transition Radiation Detector (TRD)
- UG TRD Gas

Additionally, electronics are mounted in the Power Distribution System (PDS), the Cryomagnetic Avionics Box (CAB), the Uninterruptible Power Supply associated with the CAB, and the Cryocooler Electronics Box (CCEB). A small amount of electronics are also mounted directly on the detectors themselves, and are described in the detector section.

The interface boxes PDS and J-Crate provide the isolation and protection functions necessary to protect the STS and ISS vehicles from damage. Therefore, detailed internal box design for each of the detector crates will not be supplied; however, those which contain High Voltage sources will be identified, and the controls explained in Section 5.12.7.

One of the most critical safety functions to be performed for ISS protection is the isolation and protection of the Power Distribution System from the ISS, as described in Section 5.12.3. In most cases the PDS provides the isolation and circuit protection required to prevent feedback to the ISS; however, the Cryomagnet Avionics Box (CAB); the Cryocooler Electronics Box (CCEB); and some Heater Circuits receive 120Vdc pass-through power from the PDS. Explanation of their isolation and protection schemes is also included.

Finally, a brief description of the AMS-02 data systems and their interfaces can be found in Section 5.12.9. The AMS-02 computers and their functions have been reviewed and been deemed mission success only. The only computer control that is a safety critical function is the command to execute magnet charging, and the AMS-02 main data computers have no commands stored on-board to perform this function; it requires an up-linked command sequence60 to execute. As such, the description of the AMS-02 data systems is top-level, and for reference only.

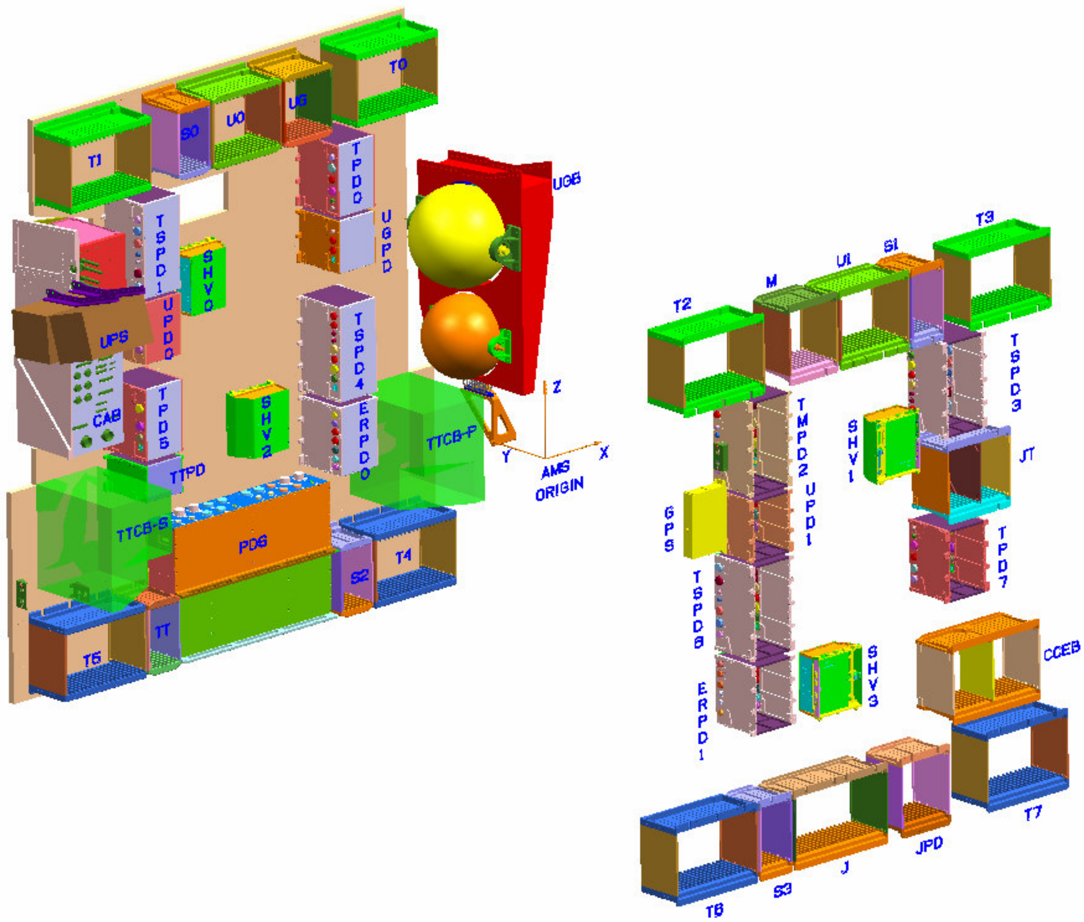


Figure 5.12.1-1 Electronics Crate Locations

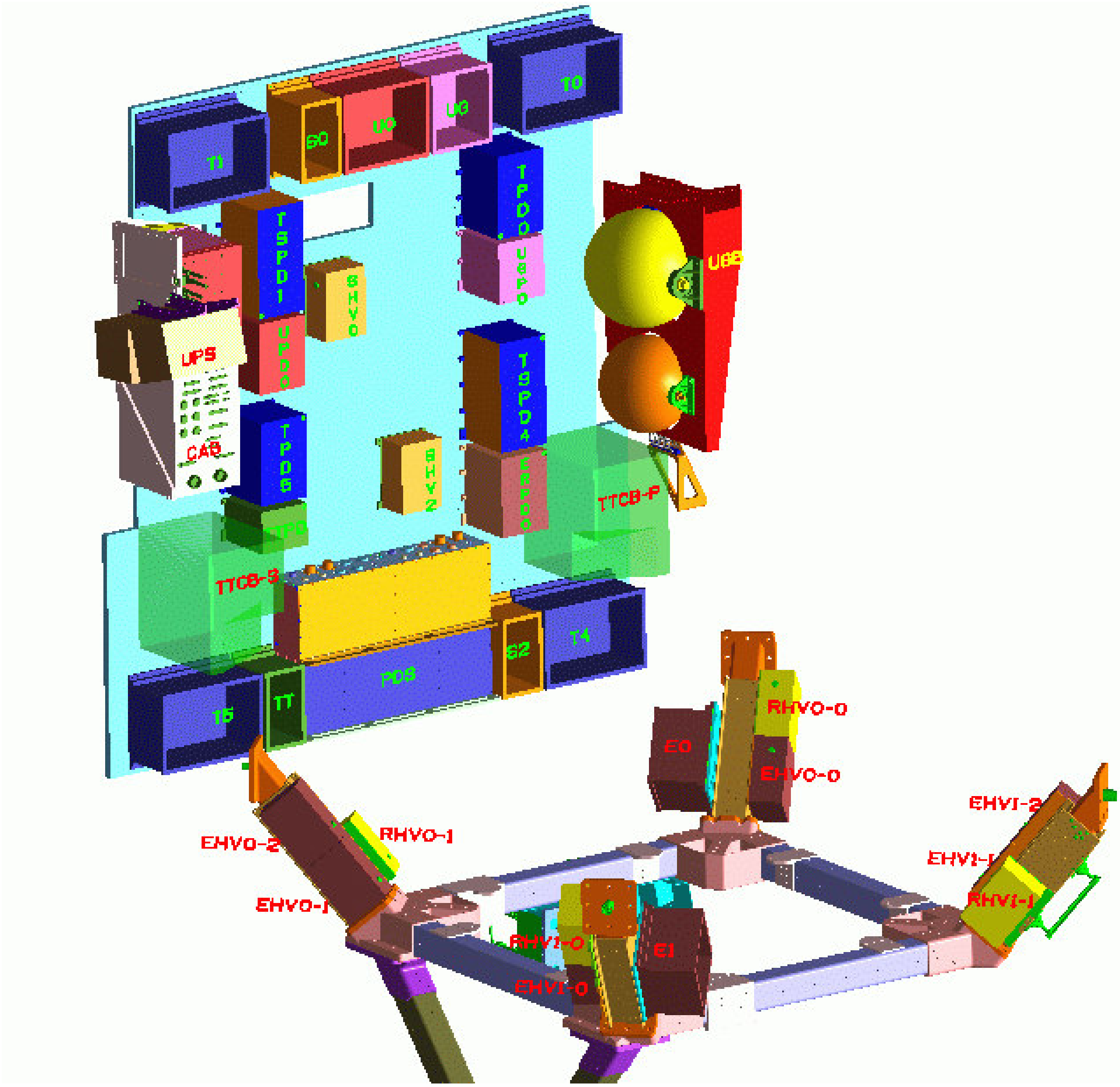


Figure 5.12.1-2 Electronics Crate Locations

5.12.2 Power Interfaces

The AMS-02 Power Distribution System (PDS) serves as the primary front-end for the power distribution to the subsystems and experiment detector electronics. It performs power conversion and distribution functions described in Section 5.12.3. The power isolation within the PDS, also described in Section 5.12.3, is designed to meet the 1 Mega Ohm Isolation requirement defined in SSP-57003.

Wire sizing has been selected in compliance with the requirements defined in NSTS 1700.7b, “Safety Policy and Requirements for Payloads Using the Space Transportation System”, NSTS 1700.7b ISS Addendum, “Safety Policy and Requirements for Payloads Using the International Space Station”, and NASA Technical Memorandum TM 102179, “Selection of Wires and Circuit Protection Devices for NSTS Orbiter Vehicle Payload Electrical Circuits”.

Power for the AMS-02 Payload is supplied from several sources dependent upon mission phase, as described in the following sections. For reference see Figure 5.12.2-1 and Figures 5.12.7-1 through 5.12.7-4.

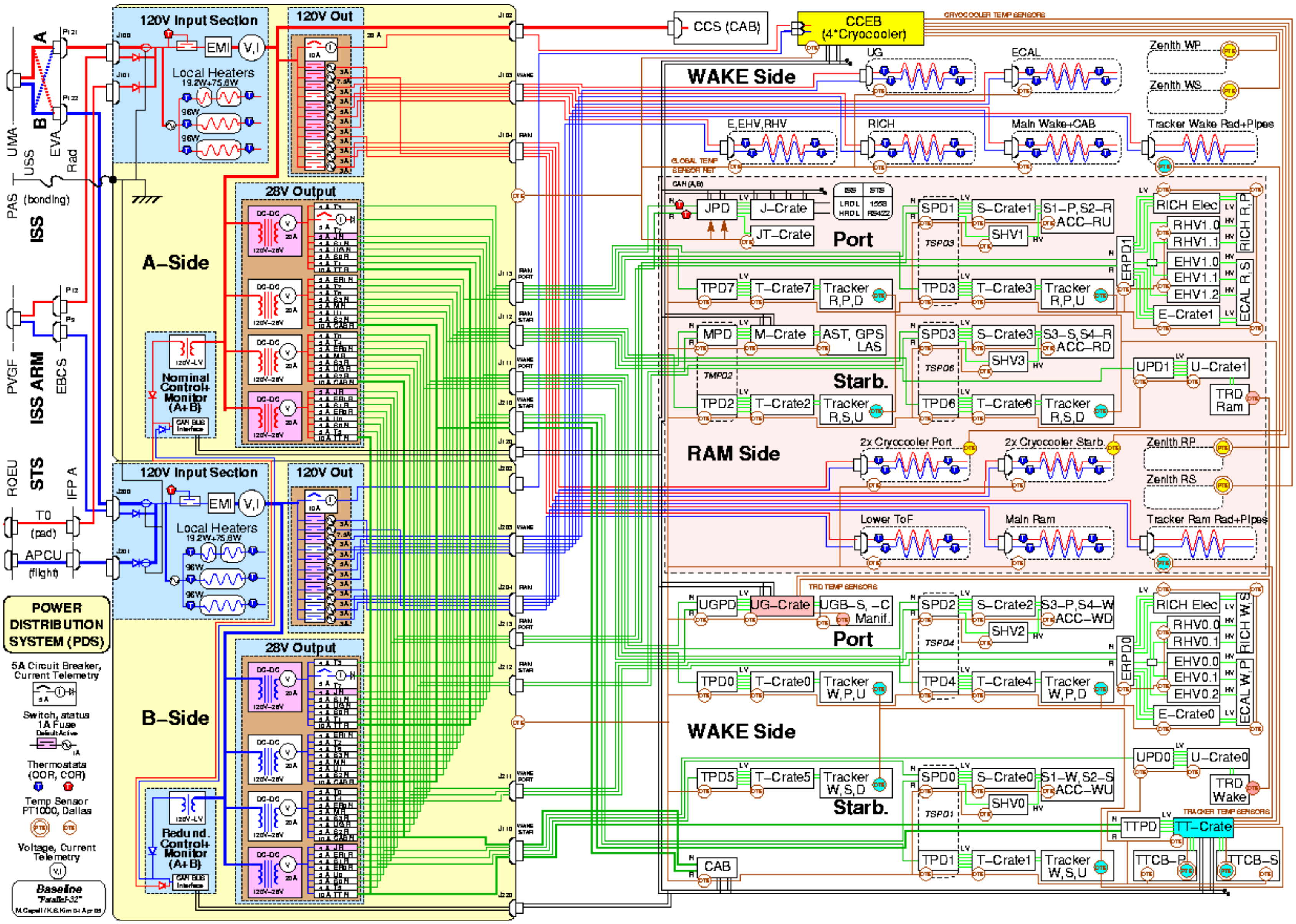


Figure 5.12.2-1 Payload Power Interfaces

5.12.2.1 Power Interface for Ground Operations in the STS

During ground operations, 120Vdc power is supplied via the T0 Umbilical, through the Remotely Operated Electrical Umbilical (ROEU) to the PDS to power experiment electronics. The GSE T0 power supply is a 3 kW Type B power supply per SSP 30482, Volume I, Rev. C. A separate 120 VAC power feed, via the T0, through the ROEU is used to power a vent pump on the AMS-02 that allows the SFHe tank to vent the boil-off of the Helium during ground pre-launch operations until T-30 minutes. Although located on the AMS experiment, this vent pump is operated during ground operations only, and is not operated in flight. For safety purposes, structural integrity must be preserved. Just prior to deactivation of the Vent Pump prior to launch, the SFHe "Vent Valve" is commanded closed.

Following payload installation, roughly 650W of power is required for vent pump operation, operation of the four Cryocoolers and for critical monitoring functions. During these periods, monitoring capability is supplied via both 1553 Bus and RS422 serial communications each routed through the T0 umbilical interface.

5.12.2.2 Ascent Power Interface on the STS

During Ascent, momentary power is required to open the SFHe Vent Valve. This valve must be opened prior to the Orbiter getting on-orbit, to allow venting of the boil-off Helium once the pressure in the Payload Bay drops below the operating pressure of the SFHe Tank. There are two means of ensuring that this vent valve opens, as discussed in the following paragraphs. Should the vent valve fail to open, burst disks will vent the He boil-off, thus preventing helium tank rupture, again discussed in the following paragraphs.

The vent valve must be operated during ascent when the tank is still experiencing acceleration, and when the exterior pressure within the payload bay is less than the He boil-off pressure within the tank. The SFHe tank contains a liquid-vapor phase separator called a "porous plug" at the vent line. This plug allows vapor to pass through, but no liquid. The SFHe vent valve must be opened with only He vapor in contact with the "porous plug" at the initiation of flow to avoid a condition that can cause the porous plug to operate as a SFHe pump, which would speed the depletion of helium from the tank. To ensure that no liquid is in contact with the porous plug, the vent valve and porous plug are located on the experiment in the direction of the acceleration vector of the Space Shuttle, and the valve is opened during powered flight.

A barometric switch on the AMS-02 is used as the primary signal to open the SFHe Vent Valve, and 28Vdc power from a Standard Switch Panel (SSP) is used to open the valve. A module called the AMS-02 Baroswitch Electronics (BSE) receives 28 Vdc ascent power from the two powered maintained switches (S16 and S18) on 5A circuit breaker CB4 at the standard switch panel (SSP 2A) through connector J7 on Interface Panel A. Switch S16 is designated as the primary and S18 as the back-up 28 Vdc power feed. Two redundant, parallel switches are closed pre-flight, to provide this power. If there was a return of the AMS in the Cargo Bay due to an Orbiter contingency; AMS would request reconfiguration of the switches to the pre-launch configuration during De-orbit Prep activities; this is not a safety issue, but is an AMS-02 turnaround concern. This would allow the barometric switch to close the SFHe vent valve. The SSP switch power is limited to less than 5A by an upstream circuit breaker, CB4. This equipment is detailed in Table 5.12.2.2-1 and Figure 5.12.2.2-1.

TABLE 5.12.2.2-1 STANDARD SWITCH PANEL CONFIGURATION

ITEM	DEVICE TYPE	AMS-02 FUNCTION
CB4	Circuit breaker, 5 Ampere IN – Closed OUT – Open	IN: Applies orbiter pwr to switches S16 and S18 (Prelaunch/Ascent Configuration). OUT: Removes orbiter pwr from switches S16 and S18 (performed sometime after Post Insertion)
S16	Toggle switch, 2 positions (Maintained – Maintained) ON – Up Position OFF – Down Position	ON: Applies 28 VDC to AMS-02 Control Electronics Assy (Prelaunch/Ascent Configuration). OFF: Removes 28 VDC from AMS-02 Control Electronics Assy (performed on-orbit sometime after Post Insertion)
S18	Toggle switch, 2 positions (Maintained – Maintained) ON – Up Position OFF – Down Position	ON: Applies 28 VDC to AMS-02 Control Electronics Assy (Prelaunch/Ascent Configuration). OFF: Removes 28 VDC from AMS-02 Control Electronics Assy (performed on-orbit sometime after Post Insertion)

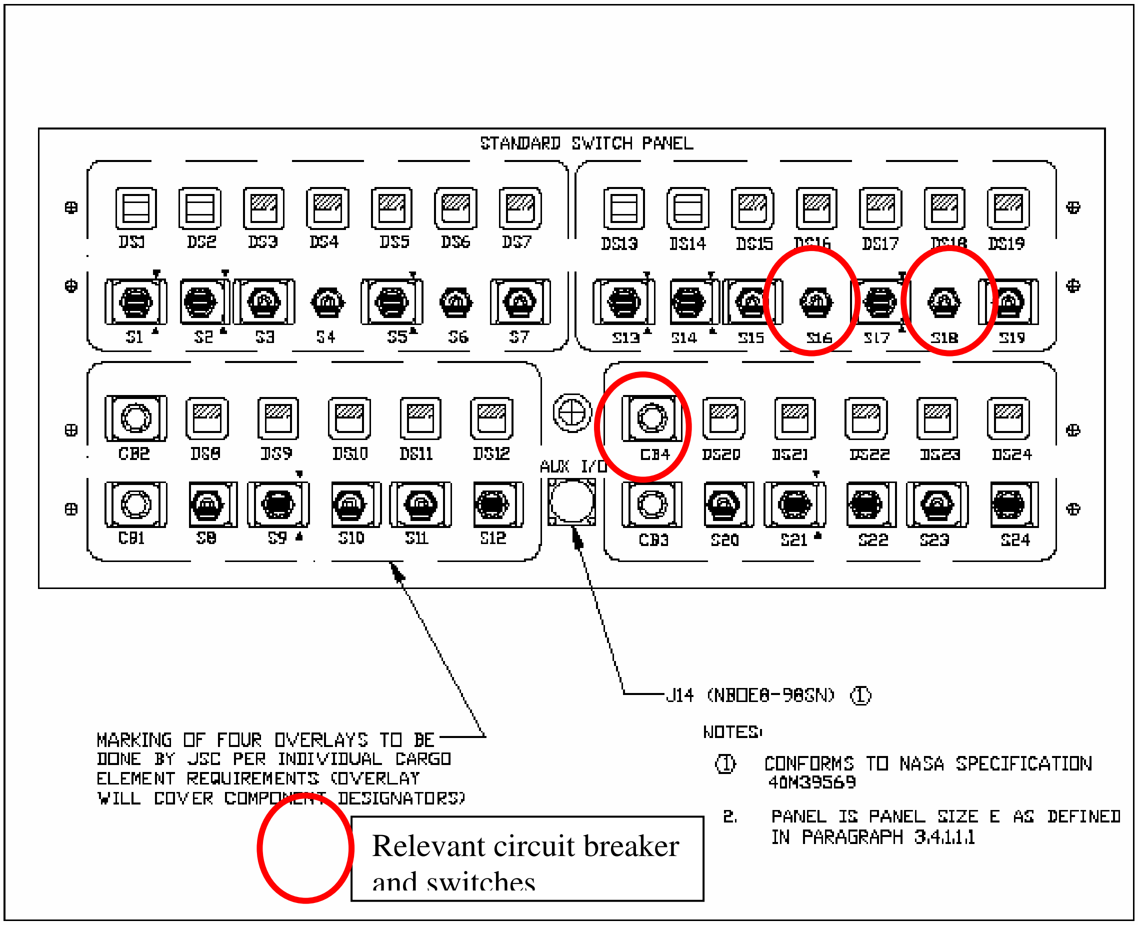


Figure 5.12.2.2-1 – Orbiter Aft Flight Deck Standard Switch Panel

The barometric switch is being selected to open the valve once the pressure in the Payload Bay drops below the operating pressure of the SFHe Tank (presently estimated at less than 15 mbar, or approximately three minutes into the flight).

As a backup, a time-tagged command from the Backup Flight System (BFS) General Purpose Computer (GPC) will issue a Discrete Output Low (DOL) to the Vent Valve Electronics to open the valve if the barometric switch has failed to do so. This time-tagged command will be set to a Mission Elapsed Time (MET) after the point at which the barometric switch should have opened the valve but while still in “powered flight”. The STS has collected extensive data on Payload

Bay pressure during ascent, and this data will be used to determine the proper MET, that corresponds to this pressure, at which point the command will be issued.

Barometric switch selection is ongoing and the BSE module remain under design. As these elements are powered during ascent and descent, specific selection and design criteria have been used to ensure that they do not pose flammable atmosphere ignition sources. However, as the helium system is designed with burst disks, the operation of the vent valve is critical for mission success – to prevent the loss of the SFHe, but its function is not essential for safety.

5.12.2.3 Power Interface for On-Orbit Operations on the STS

While in the Shuttle payload bay, on-orbit 120Vdc power for the AMS-02 comes from two ISS provided Assembly Power Converter Units (APCUs) through the ROEU to the PDS. Up to a maximum of 2 kW can be drawn during Shuttle based operations to power experiment electronics. Since the cooling system for the AMS-02 consists of radiators (that will be mostly pointing at the PLB walls), cooling on the STS will be limited. A continuous power of approximately 650W is expected, with excursions up to 2 kW as environmental conditions allow. The Cryomagnet can not be charged while on-board the STS, as the ROEU provided power is routed solely to the B side of the Power Distribution System. As Sections 5.1.2, 5.12.2.5, and 5.12.3.2 explain, only side A of the PDS has power connectivity to the Cryomagnet charging circuits within the CAB.

The ROEU PDA is mounted on a boom that positions it such that it can interface the Orbiter side of the ROEU while the AMS-02 is mounted in the payload bay. The extension of the PDA on this boom extends out of the attached payload physical envelope for the AMS-02 ISS PAS location, as defined in SSP-57003 (It does not intrude into the adjacent envelope directly.). This boom is designed to be manually folded by an astronaut during an Extra-Vehicular Activity (EVA) if required by the addition of an adjacent PAS berthed payload or ISS equipment.. The astronaut will position himself at the EVA worksite by handrail that is located near the PDA, and will release the boom by extracting space qualified pip-pins. The boom will be folded down and locked in place, again by using the pip-pins. The power supply characteristics for the ROEU provided power are shown in Table 5.12.2.3-1.

TABLE 5.12.2.3-1 STS ROEU POWER SUPPLY CHARACTERISTICS

INPUT BUS	Internal BUS connection	PIN	Max Power [KW]	Current Rating	Lowest Current Limitation Level	Minimum Trip Decision Time	TYPE	CONNECTOR I/F	PDS connector
T0	A	4 x AWG12	1.8	14.7 A (1)	22 A (1)	100 msec (1)	--	IFPA P8	J101
APCU	B	3 x AWG8	1.8 3.6 (2)	14.7 A 29.4A (2)	22 A	100 msec	--	IFPA P1	J201

(1) These value are for reference only. The power supply will be a ground power provided by the KSC with performances similar to the APCU.

(2) (2) If two APCU in parallel are used

5.12.2.4 Power Interface for Extra Vehicular Robotics (EVR) Activities

Just prior to transfer activities, the AMS-02 is powered down, the APCUs are deactivated, and the ROEU is disconnected from the PDA attached to the AMS-02. The AMS-02 is grappled by the SRMS via a FRGF attached to the payload. The FRGF has no power interface capabilities.

The SRMS maneuvers the AMS-02 for an Arm-to-Arm transfer to the SSRMS) The SSRMS grapples the payload via a PVGF located on the opposing side of the AMS-02 from the FRGF. The PVGF provides pass-through ISS power from the SSRMS to the Electronic Berthing Camera System (EBCS) mounted on the AMS Passive Payload Attach System (PAS). The EBCS uses this 30 W of power to operate avionics that provide a video signal, which is returned to the crew compartment via the PVGF and SSRMS. The EBCS is used to align the payload and determine closure range during payload berthing operations. Additionally, the EBCS can pass through power from the PVGF to the AMS-02 payload. AMS-02 contains thermostatically controlled heaters that may utilize some or all of this power to maintain the payload temperature within design limits. The amount of power required is dependant on environmental conditions during transfer and the length of time the payload spends on the SSRMS.

The nominal power supply characteristics, provided in *SSP 42004, Mobile Servicing System (MSS) to User (Generic) Interface Control Document Part I*, for the PVGF provided power are shown in Table 5.12.2.4-1. Due to SSRMS payload bus wire sizing, and worse case thermal analysis for these wires, the SSRMS payload bus operating current has been limited to 16.7 Amps. Detailed design analysis by the developer of the PDS, Carlo Gavazzi Space (CGS), shows that for all SSRMS based operations, and over the entire range of possible input voltages, the AMS-02 payload will comply with this current limit. The upstream Remote Power Control Module (RPCM) that supplies SSRMS payload power bus is a Type II RPCM, which limits the power at 25 Amps. It is therefore required to further protect the SSRMS payload power bus wiring, which cannot handle 25 Amps, by installing aprotective device before the input of the EBCS, as shown in Figure 5.12.2.4-1, AMS-02 SSRMS Operations Power Schematic.

In Figure 5.12.2.4-1, the SSRMS payload back-up bus and PDS A-side are shown for completeness, even though the CAB will not be ON during SSRMS Ops. The SSRMS payload prime bus and PDS B-side (not shown) are identical except they have no connectivity to the CAB. This also includes a 16.7 Amp protective device, that will be protect the SSRMS wiring thatcannot withstand the entire 25 Amps available from the RPCM. Finally, 30 W has been added as the power consumed by the EBCS avionics.

TABLE 5.12.2.4-1 ISS PVGF TO USER ELECTRICAL INTERFACE PARAMETERS

Circuit Name	INTERFACE V_{range} (volts) 3	Operating Current (amps)	Overcurrent Protection
PVGF1	107.5 to 126	0 to 16.7	1, 2
PVGF2	107.5 to 126	0 to 16.7	1, 2

NOTES:

1 Protection is equivalent with SSP 30263:002, Type II RPCM Standard ICD
2 Protection is equivalent with SSP30263:002, Type VI RPCM Standard ICD.
3 Minimum voltage includes 1 volt drop across the PVGF harness.

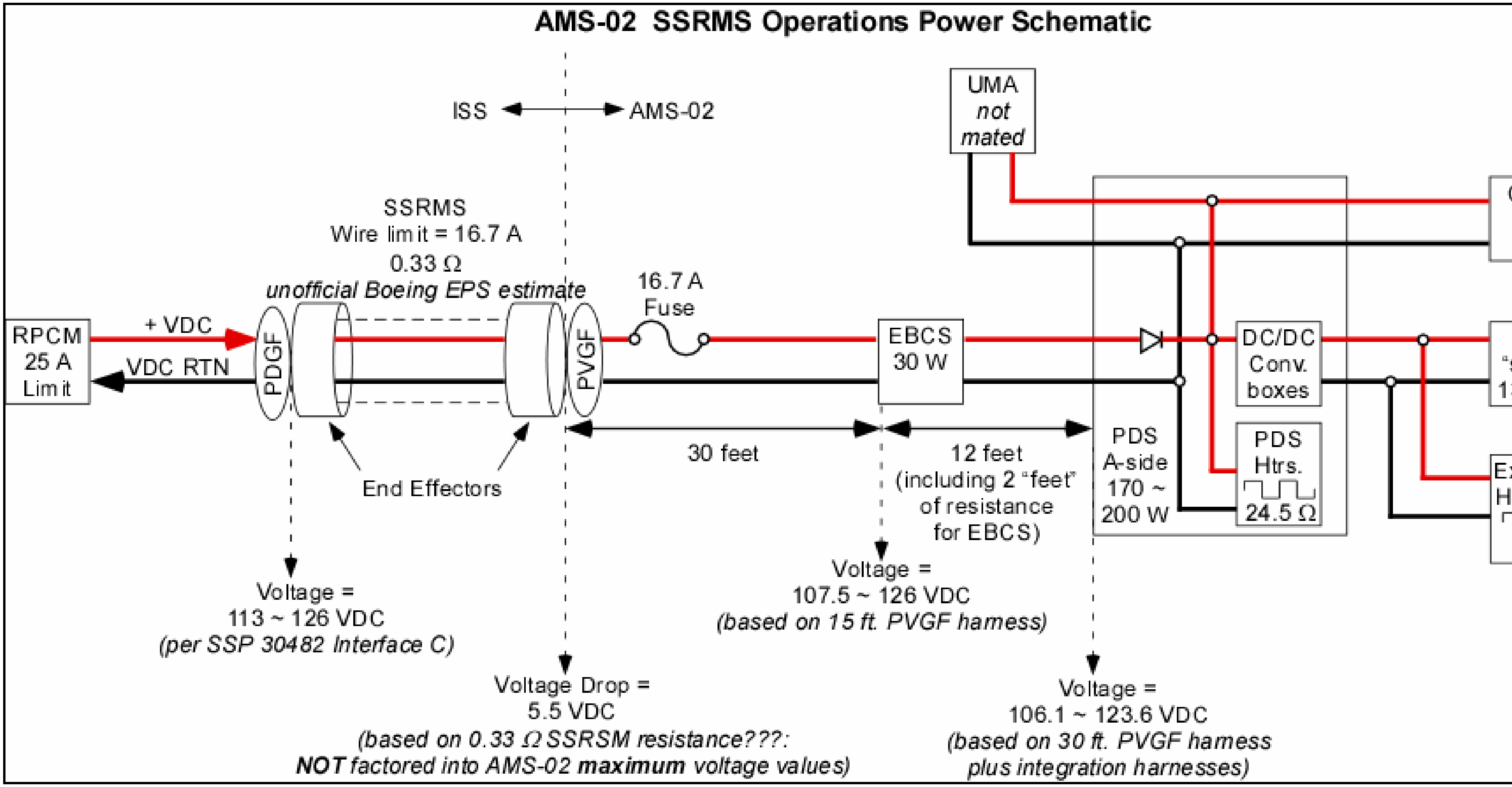


Figure 5.12.2.4-1 – AMS-02 SSRMS Operations Power Schematic

5.12.2.5 Power Interface for ISS Operations

All power and data services for the AMS-02 payload are provided through an Umbilical Mechanism Assembly (UMA) mounted to the Payload Attach Site. ISS provides two 120 Vdc power feeds, each controlled by Type II RPCM (25A). AMS-02 is capable of operating from either or both buses; however, Cryomagnet charging requires that Bus A be active because the Cryomagnet Avionics Box (CAB) is connected to Bus A only. The choice of going with only one Bus for this operation was made for simplicity and reliability; otherwise a bus switcher would have been required, a potential single point failure. In the event of a loss of the ISS power input bus that feeds Bus A, an EVA operation can be performed to switch EVA connectors for Bus A and Bus B, thus re-establishing the capability to charge the cryomagnet. This operation is performed on the EVA Connector Panel (schematically shown in Figure 5.12.7-4, and depicted physically in Figure 5.12.2.5-1). It should be noted that Bus A and Bus B have independent PDS output sections to preclude cross linking. During Cryomagnet charging operations a maximum power of 2.3 kW will be required near the end of the charging cycle for the Cryomagnet Avionics Box (CAB) and critical monitoring equipment only. Once charging is complete, the charging system is isolated from the Cryomagnet, and the remaining power is devoted to detector operation. The power supply characteristics for the UMA provided power are shown in Table 5.12.2.5-1.

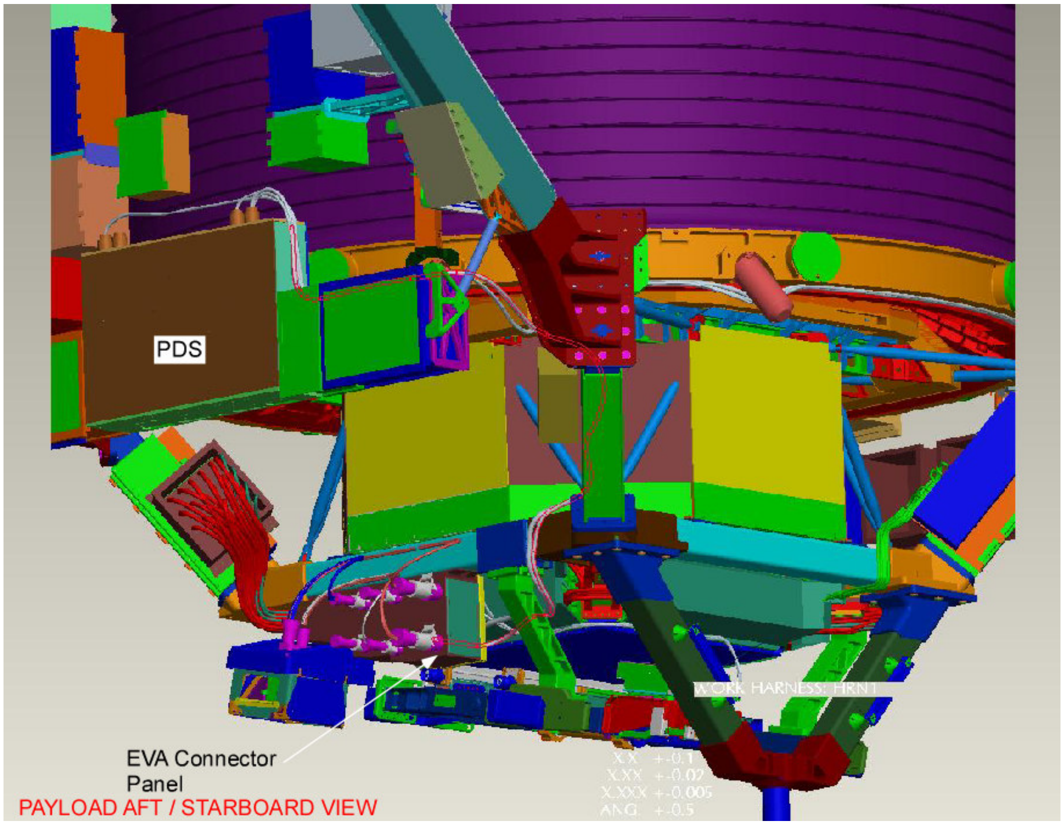


Figure 5.12.2.5-1 – EVA Connector Panel

TABLE 5.12.2.5-1 ISS UMA POWER SUPPLY CHARACTERISTICS

INPUT BUS	Max Power [KW]	PIN	Current Rating	Lowest Current Limitation Level	Minimum Trip Decision Time	TYPE	CONNECTOR I/F	PDS connector
A	3	3 x AWG8	25 A	27.5 A	31 ms	RPCM II	EVA PANEL P121	J100
B	3	3 x AWG8	25 A	27.5 A	31 ms	RPCM II	EVA PANEL P122	J200

5.12.3 Power Distribution System (PDS)

The PDS, the yellow shaded box in Figure 5.12.2-1, also shown schematically in excerpt in Figure 5.12.3-1, consists of four distinct sections: 120 Vdc Input; 120 Vdc Output; 28 Vdc Output; and Low Voltage Control and Monitor. The PDS physical location is shown in Figure 5.12.2.5-1. The bus to bus isolation of the 120Vdc outputs is provided by the end-subsystem, by either DC-to-DC or AC converters, or relays. The isolation for all other outputs is provided internally to the PDS by DC-to-DC converters. The PDS has two independent "channels" side A and side B (Figure 5.12.3-2), which have four identical subsections. The only difference between the two channels is that side A is the only side that provides power to the CAB for Cryomagnet charging, as described in Section 5.12.3.2.

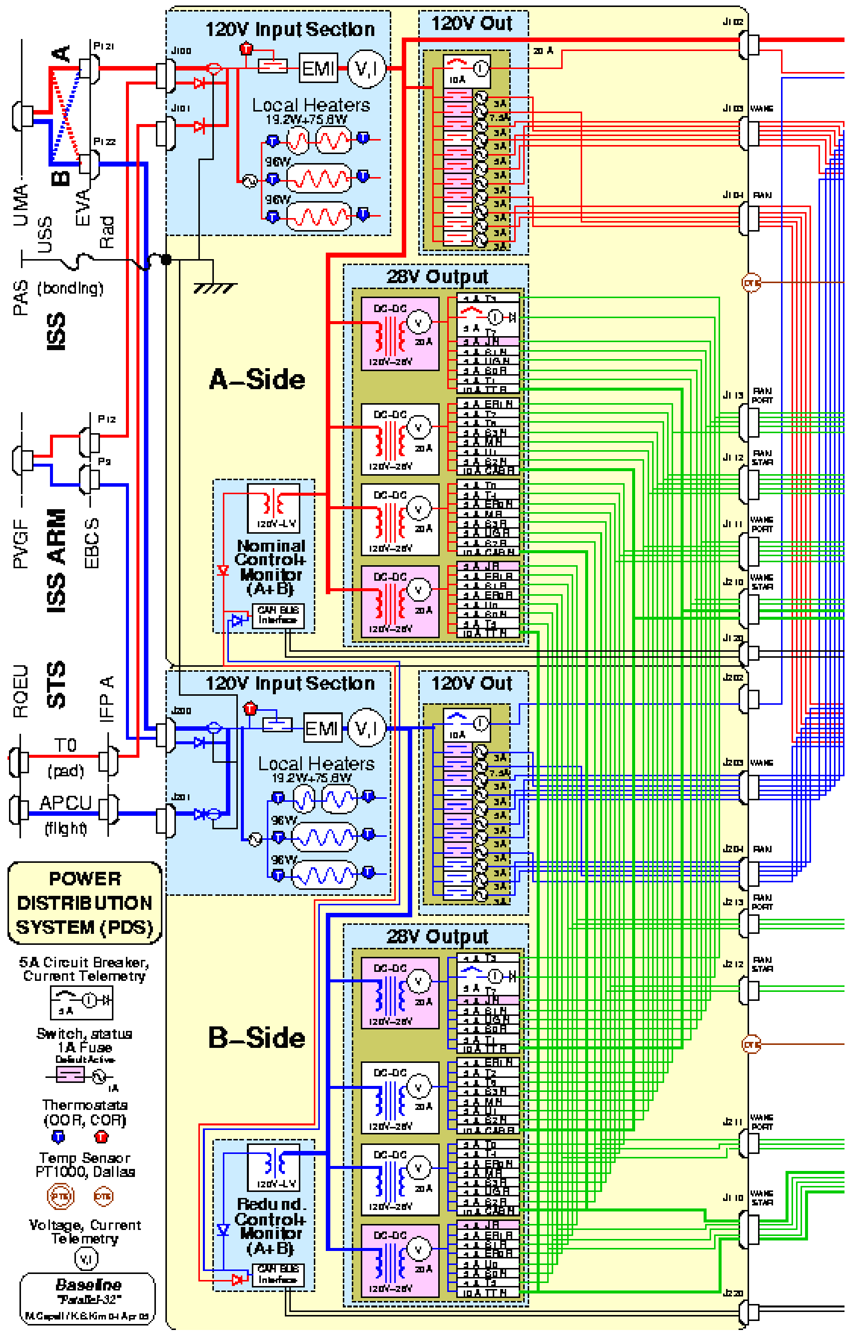


Figure 5.12.3-1 AMS-02 Power Distribution System (Excerpt from Figure 5.12.2-1)

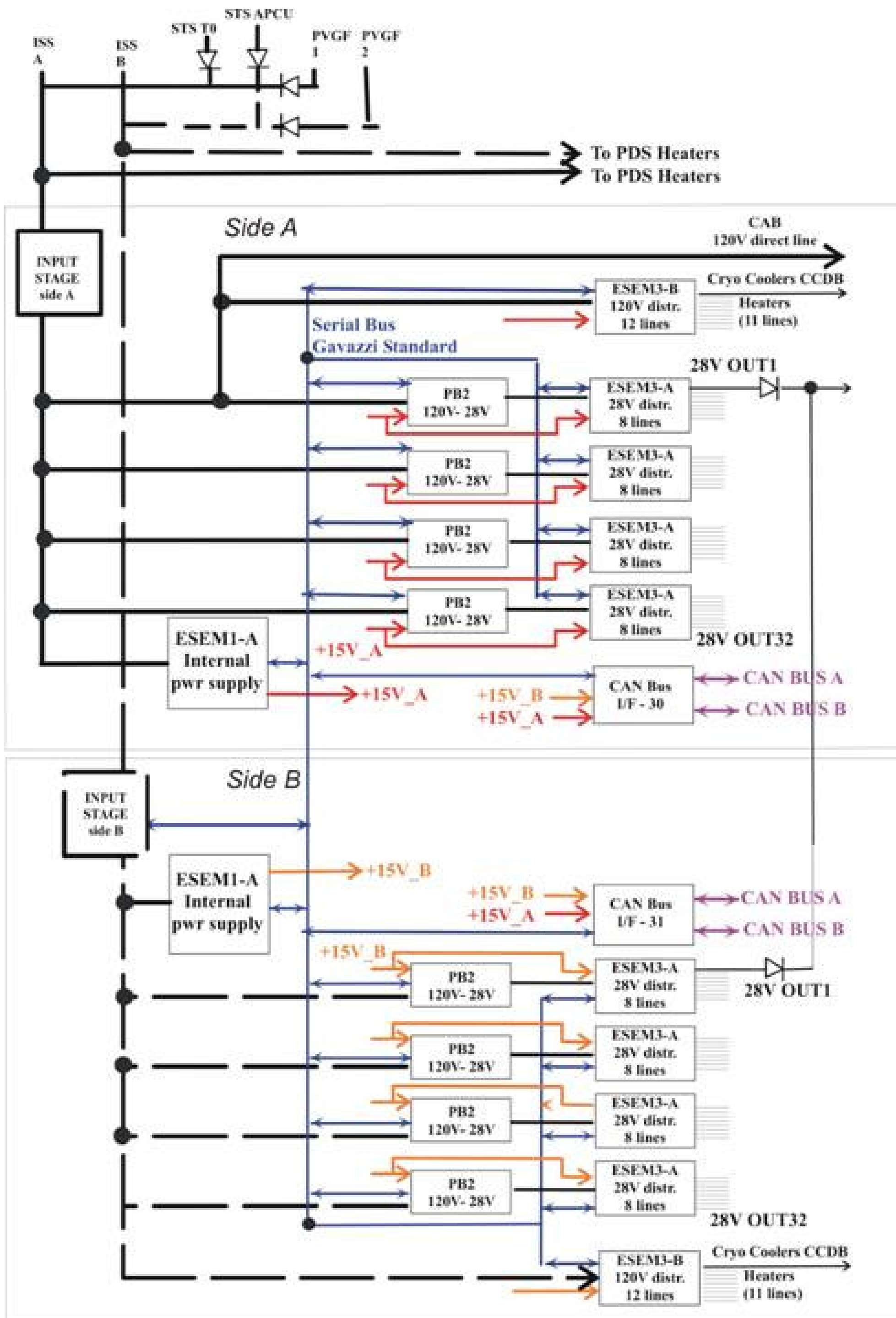


Figure 5.12.3-2 AMS-02 Power Distribution System, Sides A and B

The interfaces for the individual sections shown in Figure 5.12.3-2 are detailed in Table 5.12.3-1.

TABLE 5.12.3-1 PDS SECTION INTERFACE DETAILS

PDS SIGNAL & POWER INTERFACES		
INPUT SECTION		
ISS	Power I/F input	• 120V Feeder A • 120V Feeder B
STS	Power I/F input	• 120V Feeder APCU • 120V Feeder T0
BCS (PVGF)	Power I/F input	• 120V Feeder PVGF 1 • 120V Feeder PVGF 2
EMI FILTER		• EMI I/F
INPUT TELEMETRY		
INPUT TELEMETRY	Signal I/F	(Via internal serial I/F to the CAN BUS module) • INPUT CURRENT • INPUT VOLTAGE
INTERNAL POWER SUPPLY SECTION		
ESEM 1-A	Power I/F	15V Internal Power Supply

	Signal I/F	(Via internal serial I/F to the CAN BUS module)
		• ON/OFF DC/DC CONVERTER
		• DIGITAL Board Status Monitoring
		  • OK/NOK
		  • OVERTEMP
		  • DC/DC 1 OVERCURRENT
		  • DC/DC 2 OVERCURRENT
		  • DC/DC 1 MAIN ON/OFF
		  • DC/DC 2 MAIN ON/OFF
		  • MAIN POWER ON
		  • DIGITAL TEST OUT
		• ANALOGUE Board Monitoring
		  • TEMPERATURE
		  • ANALOG REFERENCE VOLTAGE
		  • MAIN POWER VOLTAGE

120V OUTPUT SECTION		
DIRECT OUTPUT	Power I/F	• 120V Feeder to CCS in CAB
ESEM 3-B	Power I/F	• OUT 1 for AMS heaters • OUT 2 for AMS heaters • OUT 3 for AMS heaters • OUT 4 for AMS heaters • OUT 5 for AMS heaters • OUT 6 for AMS heaters • OUT 7 for AMS heaters • OUT 8 for AMS heaters • OUT 9 for AMS heaters • OUT 10 for AMS heaters • OUT 11 for AMS heaters • OUT 12 CCEB (Cryocoolers)

TABLE 5.12.3-1 PDS SECTION INTERFACE DETAILS (CONTINUED)

PDS SIGNAL & POWER INTERFACES		

	Signal I/F	(Via internal serial I/F to the CAN BUS module)
		• ON/OFF OUTLET Command
		• DIGITAL Board Status Monitoring
		  • OK/NOK
		  • OVERTEMP
		  • OUTLET STATUS (ON/OFF)
		  • OUTLET TRIP STATUS (only for CCEB line)
		• ANALOGUE Board Monitoring
		  • TEMPERATURE
		  • OUTLET CURRENT (only for the CCEB line)
		  • ANALOG REFERENCE VOLTAGE

120V TO 28V CONVERSION SECTION		
PB2	Power I/F	• 28V OUTPUT to the ESEM 3-A distribution board

PB2	Signal I/F	(Via internal serial I/F to the CAN BUS module)
		• ON/OFF DC/DC CONVERTER Command
		• DIGITAL Board Status Monitoring
		  • OK/NOK
		  • OVERTEMP
		  • DC/DC CONVERTER STATUS (ON/OFF)
		  • INPUT OVERCURRENT
		  • OUTPUT OVERVOLTAGE
		• ANALOGUE Board Monitoring
		  • TEMPERATURE
		  • 28V OUTPUT VOLTAGE
		  • ANALOG REFERENCE VOLTAGE

ESEM 3-A	Power I/F	• 8 x 28V output lines
		  • out 1 to 7 @ 5A each
		  • out 8 @ 10A

ESEM 3-A	Signal I/F	(Via internal serial I/F to the CAN BUS module)
		• ON/OFF OUTLET Command
		• DIGITAL Board Status Monitoring
		  • OK/NOK
		  • OVERTEMP
		  • OUTLET STATUS (ON/OFF)
		  • OUTLET TRIP STATUS
		• ANALOGUE Board Monitoring
		  • TEMPERATURE
		  • OUTLETS CURRENT
		  • ANALOG REFERENCE VOLTAGE

DIGITAL I/F SECTION		
CAN BUS I/F	Signal I/F	• CAN BUS I/F • PDS INTERNAL BUS I/F • DIGITAL Command to the boards • ANALOGUE ACQUISITIONS of the boards telemetry • DIGITAL ACQUISITIONS of the boards status

The design of the PDS is such that the power conversion and distribution is performed by four different printed circuit board types. These types, and quantities per sides A and B, along with current protection details, are described in Table 5.12.3-2.

TABLE 5.12.3-2 PDS PRINTED CIRCUIT BOARD & CURRENT PROTECTION DETAILS

Board Type	Quantity	Function	Outputs	Current Protection	Notes
ESEM3-A	4 per side	Distribution of the 28V secondary voltage, provided by the PB2 modules, to AMS-02 Payloads	8	MOSFET Current limiter, trips @ 130% nominal current between 5 and 6 msec. • Channels 1 - 7: 5 Amp • Channel 8: 10 AMP	Eight output channels individually: • Equipped with MOSFETs for ON/OFF switching • Provided with status and current measurement circuitry
ESEM3-B	1 per side	Distribution of the 120V provided by the power input BUS to supply AMS-02 heaters and the CCEB device.	12	• Channels 1 - 11: Fuses, derated (see Table 5.8.3-3) • Channel 12: MOSFET Current limiter, trips @ 130% nominal current between 5 and 8 msec.	Twelve outlets that are independently: • Equipped with MOSFETs for ON/OFF switching • Protected by fuse is series with MOSFET except for outlet 12 where current limiter circuit is used • Provided with status monitor circuitry • For outlet 12 (CCEB) a current telemetry circuit is added Considering the maximum bus value of 126V, the current rating of each outlet is set to a nominal output current of one of the follow: • 1.4A (>50% derating) • 3.2A (>50% derating) • 2.3A (>50% derating) • 10A (Channel 12)
PB2	4 per side	120Vdc to 28Vdc converter module.	1	Redundant DC-DC converters with current limiting and breaking element comprised of two power MOSFETs (2N7225) connected in parallel	Current intervention threshold is fixed at 9A±0.4A (the timing of the protections is lower than 1ms to guarantee for trip coordination with upstream characteristics). If the current rises above this threshold, the MOSFETs are switched off bringing the gate voltage to zero.
ESEM1-A	1 per side	Provides for the generation of the internal power line (15V/5A) required for PDS operation.	1 @ 15VDC 1 @ 5VDC	Redundant DC-DC converters with current limiting - current breaking element comprised of one power MOSFET (2N6798) trips @ 200% nominal current.	Each DC/DC converter includes an in-rush current limiter and an over current circuitry with, •a PWM controller, • a power cell based on half bridge topology, • input under voltage detection circuit, • input EMI filter

The fuses for the ESEM3-B printed circuit board 120 VDC outputs are detailed in Table 5.12.3-3.

TABLE 5.12.3-3 PDS 120 VDC FUSE DETAILS

DESCRIPTION	PROC.SPEC	SUPPLIER	P/N-ID.CODE	EM Notes
Fuse 3A FM12 style fuse (subminiature, high performance)	MIL-PRF-23419	AEM - USA	P600L-135-3	3A fuse Nework code: 251003
Fuse 7.5A FM12 style fuse (subminiature, high performance)	MIL-PRF-23419	AEM - USA	P600L-135-7.5	7A fuse Nework code: 251007
Fuse 5A FM12 style fuse (subminiature, high performance)	MIL-PRF-23419	AEM - USA	P600L-135-5	5A fuse Nework code: 251005

The PDS has associated heaters, which serve to raise the PDS temperature to its minimum operation limit when power is applied to the AMS, as shown in Figure 5.12.3-3.

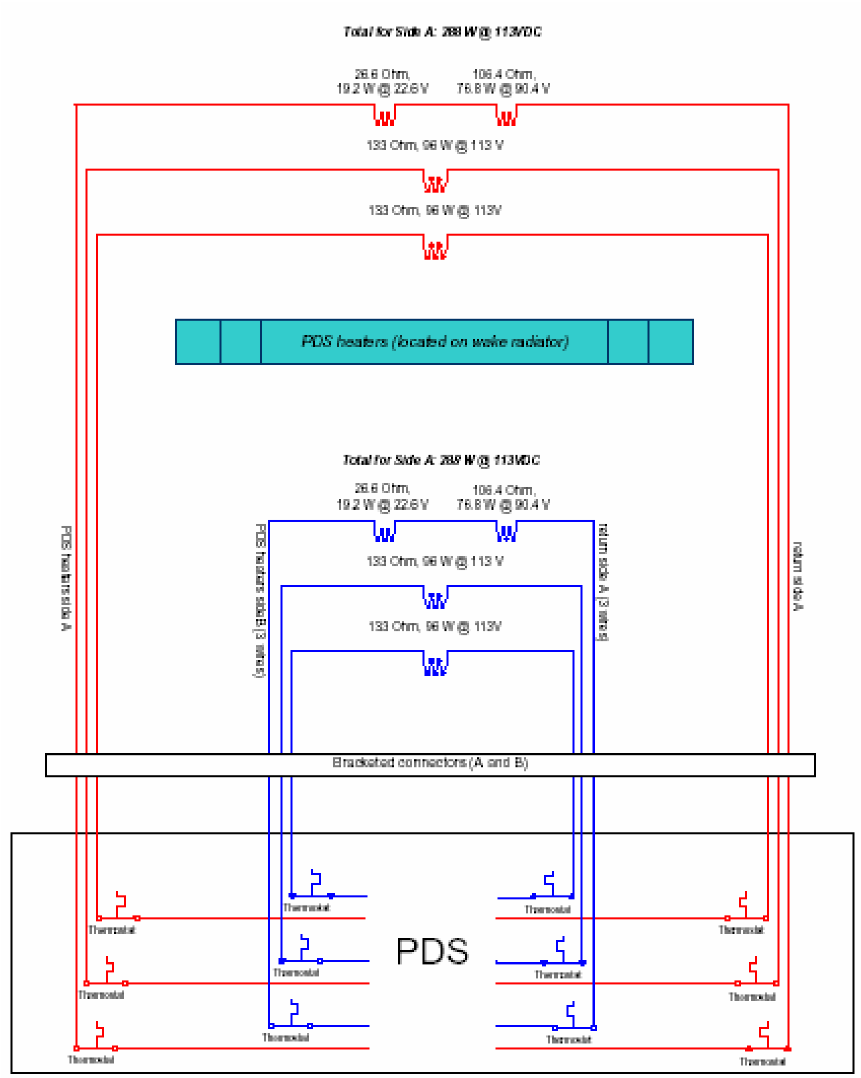


Figure 5.12.3-3 PDS Internal Heaters

The PDS is located on the Main Wake Crate Rack very close to the Passive Umbilical Mechanism Assembly (Figure 5.12.3-4).

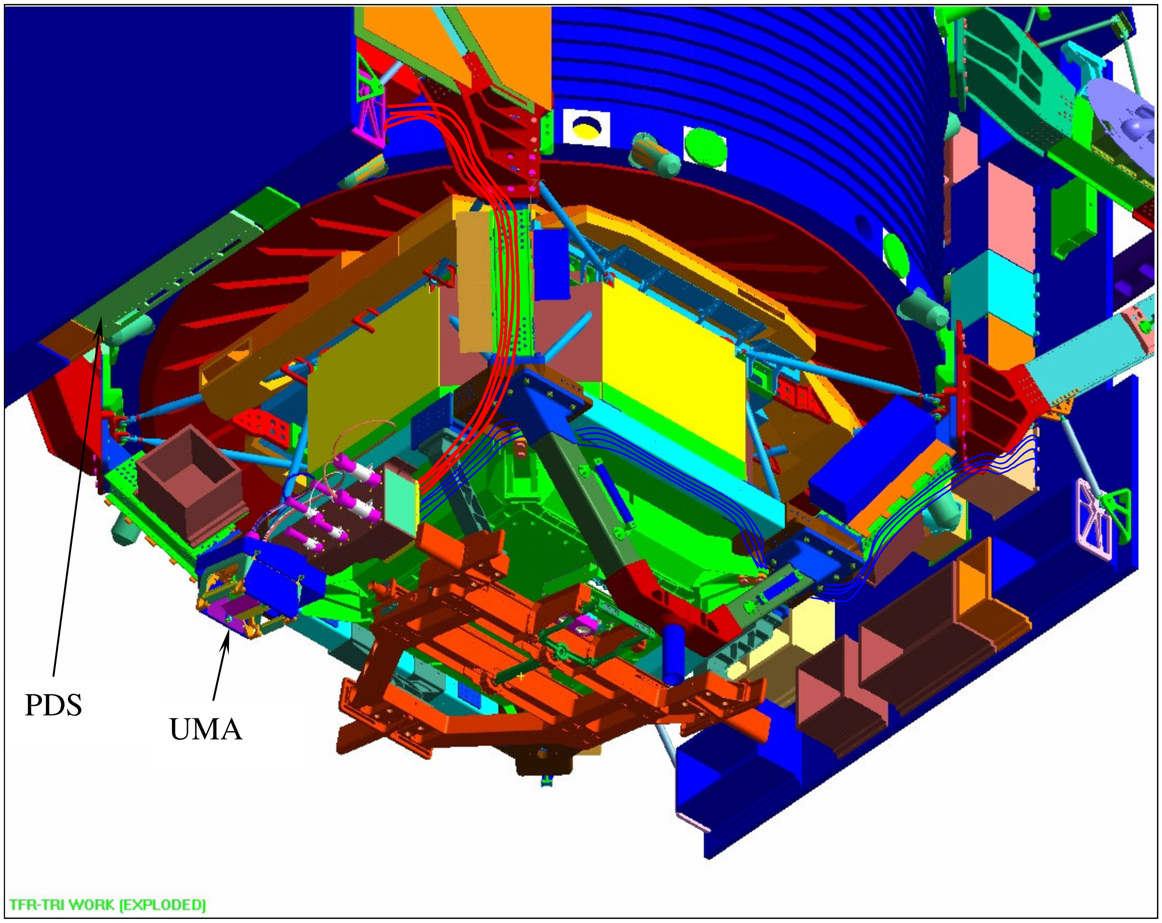


Figure 5.12.3-4 Location of the PDS and UMA on AMS-02

The PDS shall comply with the bonding requirements as defined in SSP 57003 Attached Payload Interface Requirements Document, Revision B, paragraph 3.2.2.4.2 between:

- Different parts of the equipment chassis
- Connector receptacles and equipment chassis/connector brackets
- Equipment chassis and bond strap
- Bond strap and structure

The method proposed for the PDS bonding to the AMS structure is Bond Strap using one (1) attachment point on the structure. The attachment point location is on the rear wall. All PDS metallic components and surface shall be bonded in order to preclude accumulations of static charge inside the PDS Box.

The bonding diagram for the PDS, representative of Side A or Side B, only, is shown in Figure 5.12.3-5.

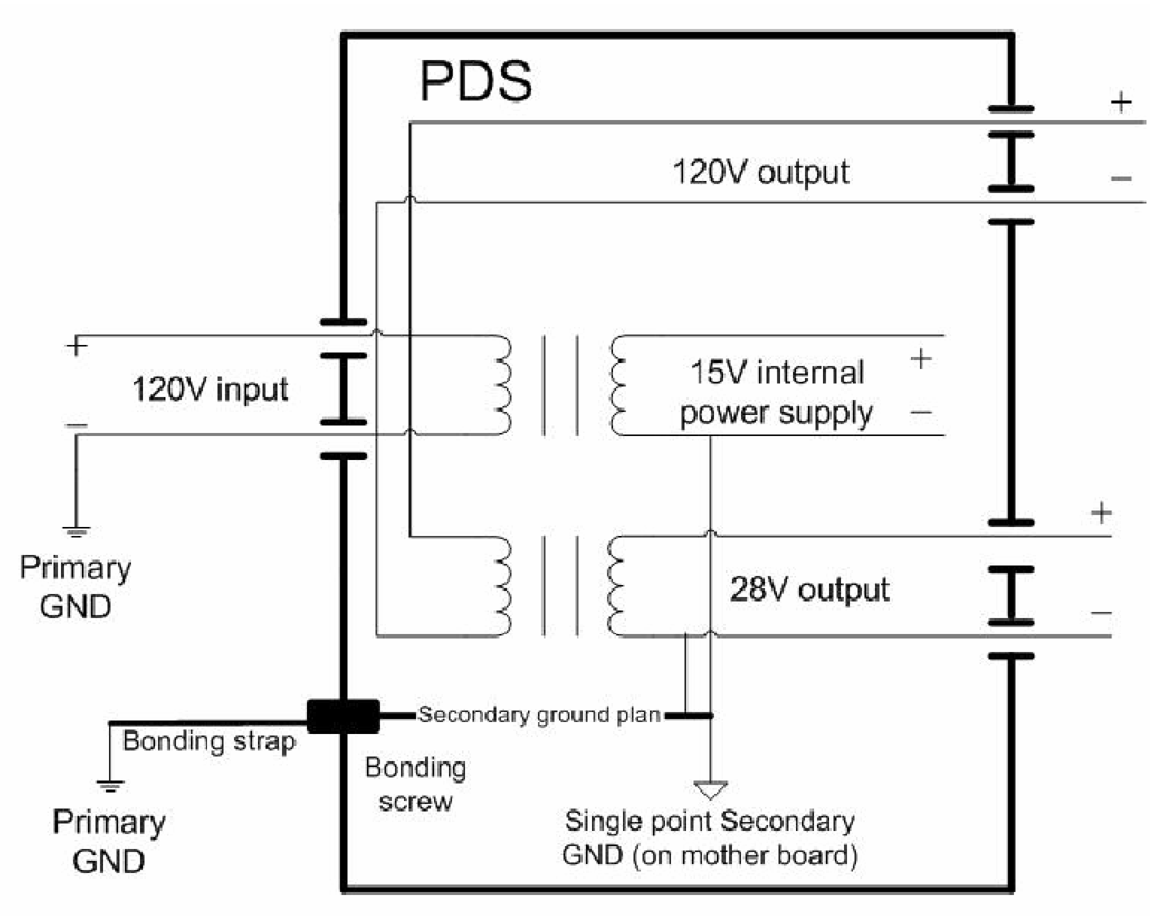


Figure 5.12.3-5 Bonding Diagram of the PDS, representative of Side A or Side B, only

The PDS avionics, with respect to the overall grounding system, shall be based on the following concepts as per SSP 30240 Space Station Grounding Requirements, Revision C:

- The primary electrical power shall be isolated from PDS chassis by a minimum of 1MΩ
- Implementation of a galvanic isolation between the primary power bus and all the secondary internal or distributed powers
- All the secondary power references are connected together and to the PDS structure in a single point represented by a bonding stud located on one PDS wall
- The secondary power references shall be isolated from the PDS chassis by a minimum of 1MW when the single point bonding is not connected.

All the parts of the box housing the PDS electronic are electrically connected together in order to offer a low impedance path. The PDS box is equipped with a bonding stud. A copper bus bar shall be placed inside the PDS in order to collect the single point bonding from the Power Boards. The copper bus bar shall be isolated from the PDS wall. The copper bus bar shall be connected internally to the PDS bonding stud by means of ring terminals and the PDS Bonding Stud shall be connected to the AMS structure by means of a bond strap. The bonding stud will be connected to the AMS support structure in such a manner:

- To conduct electrical faults current without creating thermal or electrical hazard
- To minimize differences in potential between all equipment

The mechanical box will operate as a shield against the internally generated emissions and the externally generated emissions.

The functions of the four subsections of the PDS are described in detail in the following sections.

5.12.3.1 PDS 120 Vdc Input Section

The 120Vdc Input Section is designed to receive power from three sources, and dependent on mission phase these three source powers are supplied from either T0 or APCUs via the ROEU, the PVGF or the ISS UMA power sources. The inputs use diode protection or connector protective covers to prevent crew or ground personnel from potential exposure to “hot-pins”.

As described earlier, during ground operations, this power may be supplied via the T0 umbilical (for normal operations); and the APCUs for end-to-end type testing with power supplied through the ROEU. During Shuttle flight operations, power is supplied solely via the APCU interface. The ROEU PDA does not provide a “protective cover” to prevent incidental contact with hot pins or sockets after disconnection from the active half. Therefore, diode protection is provided for the ROEU power feeds to prevent power feeds from the SSRMS and the ISS UMA from being present on the ROEU PDA.

For transfer operations on the SSRMS, power may be supplied by either feed via the PVGF interfaces. Standard ISS Operations Procedures dictate only one or the other feed from the SSRMS will be active at any time. While the EBCS will use this power to operate camera avionics, AMS-02 will use the feed-through power from the EBCS to operate thermostatically controlled heaters while the payload is on the SSRMS. Ideally, this operation will be relatively short (entire transfer should take less than 4 hours); and AMS-02 will be thermally conditioned prior to transfer, so no heater power should be required. The PVGF does not provide a protective cover to prevent incidental contact with hot pins or sockets when not connected to the SSRMS. Therefore, diode protection is provided for the PGVF power feeds to prevent power from other sources being present on the PVGF connector.

Once mated to the ISS (following deactivation of PVGF power and activation of ISS power via the UMA), the AMS-02 will be capable of operation from either or both ISS Buses. As stated earlier, Cryomagnet Charging Operations requires that Bus A be activated. The UMA passive half does include a protective cover to prevent incidental contact with "hot-pins" and therefore precludes the need for additional diode protection.

Internally to the PDS, these power source feeds are combined into the two internal PDS buses and EMI Filters are used for compatibility with ISS Complex Impedance and EMC requirements. Voltage and Current measurements are provided within this "input section" to determine overall power consumption.

PDS "box-level" thermostatically controlled heaters are provided to ensure the PDS maintains operational thermal limits. There is a lockout feature that prevents operation of the PDS if it is not within operational thermal specifications when power is applied. Only these heaters operate until the PDS operational lower limit is reached, after which the distribution circuitry is activated. The heaters have two thermostats in series (one in the return leg of the heaters as demonstrated in Figure 5.12.3-3). All heaters and thermostats are redundant to accommodate either the A or B power feed. Following activation, internal electronics power consumption is expected to be sufficient to maintain thermal limits without requiring additional heating.

Note: A "Global Temperature Sensor Network" is used: to monitor box temperatures across the entire experiment, ensure that each box is activated only after operating temperatures are achieved; and to determine when the Solid State Power Controllers (SSPCs) can be opened to disable the heaters.

5.12.3.2 PDS 120 Vdc Output Section

For each 120 Vdc output, isolation is provided by the end-subsystem, by either DC-to-DC converters or relays. 120 Vdc feed-through power from the PDS includes outputs to the CAB, the Cryocooler Electronics Box (CCEB), and heaters (8 zone heaters and 4 Cryocooler heaters).

The 120 Vdc output from the PDS to the CAB includes no internal PDS circuit protection (other than wire sizing to meet ISS power requirements). A current sensor is provided to monitor the current to the CAB. This feed is used solely for Cryomagnet charging operations, described in Section 5.1.2. No matter what the source of 120 Vdc power, the design of the PDS is such that this power can be delivered from ISS Power Bus A only. However via an EVA the ISS power inputs A and B may be switched after arriving to the AMS-02, providing Cryomagnet charge capability redundancy in the event that input from ISS Power Bus A is lost.

The 120 Vdc output power to the CCEB is provided by either or both ISS Power Bus A and/or B. The PDS does include SSPCs (rated for 8A) for over-current protection. Current measurements for these feeds are provided for downlink.

Bus isolation of the heater outputs from the PDS is provided by the operation of two independent heater circuits (one for each power feed). Thus, ISS Power Bus A feeds the “A” heaters and ISS Power Bus B feeds the “B” heaters independently. All of the heater power is delivered “on demand” to the thermostatically controlled heaters. Application of power to both buses can result in both heater sets operating or the SSPCs can be used to deactivate either or both heater circuits. Zone and Cryocooler heaters outputs from the PDS are current limited to between 3A and 7.5A by the SSPCs.

5.12.3.3 PDS 28 Vdc Output Section

The 28 Vdc Output Section provides isolation from the 120 VDC input for all 28 Vdc outputs via DC-to-DC Converters. This output section provides the bulk of the power to operate the Detector and Command and Data Handling Avionics. As a general rule, power from these outputs is routed to an xPD (subsystem Power Distribution Box) for powering of the x-Crate electronics and the detectors.

The 28 Vdc Output Section receives power from either of the internally generated 28 Vdc Buses, and 5 Amp SSPCs are used for power management and circuit protection. Therefore each output can be controlled to operate from either bus. The outputs of the SSPC from each bus are connected exclusively via diodes to their respective load. Voltage and current measurements are provided from the DC-to-DC converters and current measurements are provided at each SSPC for downlink.

5.12.3.4 PDS Control and Monitor Section

The Control and Monitor Section provides isolation for the low-voltage power system via DC-to-DC Converters (voltage and current measurements provided for downlink). This section is used primarily for autonomous control and monitoring of the PDS to ensure activation only after the minimum operating temperature is achieved, and ground control and monitoring of the all PDS outputs for power management. Communications with this section are maintained via a Controller Area Network (CAN) Bus Interface used for low-rate data and command interfaces. All PDS telemetry is passed through this section to the Main Data Computers for downlink.

5.12.4 Cryomagnet Avionics Box (CAB)

The CAB (Figure 5.12.4-1) is designed to perform all control and monitoring functions for the Cryomagnet Subsystem (including SFHe Tank and Vacuum Case). The CAB consists of four sections: the Cryomagnet Current Source (CCS); the Cryo Controller and Signal Conditioner (CCSC); the Cryomagnet Self Protection (CSP); and the Power Switches (PS).

The CAB is located on the Unique Support Structure (USS) very close to the current input port of the Vacuum Case to minimize the length of the Cryomagnet Current Leads (Figure 5.12.4-2).

High Voltage Isolation is provided at all inputs to the CAB from the ISS side to prevent passing any high-voltage that could be developed during a multiple fault “unassisted” quench back to the ISS power or data systems. Isolation for the 120Vdc line (feed thru from PDS) is performed via DC-to-DC Converters in the CCS (Section 5.12.4.1). Analysis has shown that the maximum voltage that could be achieved during an “unassisted” quench is 5.5kV. 8kV isolation is provided at all these points to ensure margin. The unassisted quench is an off-nominal scenario, and would result in damage to the CAB and the Cryomagnet that would render them unusable, but not create a safety hazard. The one fault “assisted” quench would prevent these voltage levels from arising and protect the CAB and the Cryomagnet for mission success.

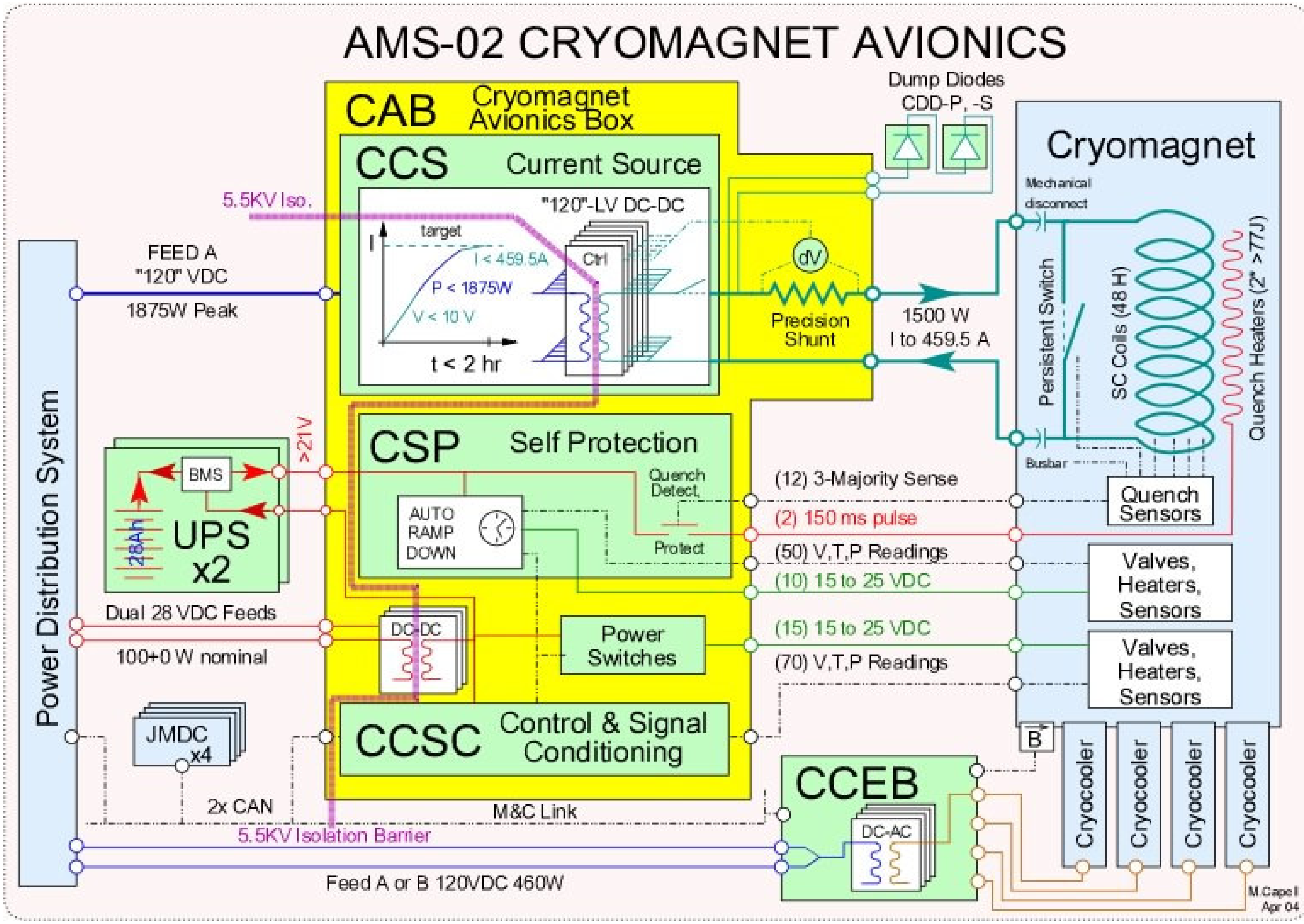


Figure 5.12.4-1 AMS-02 Cryomagnet Avionics Box and Cryomagnet Schematic

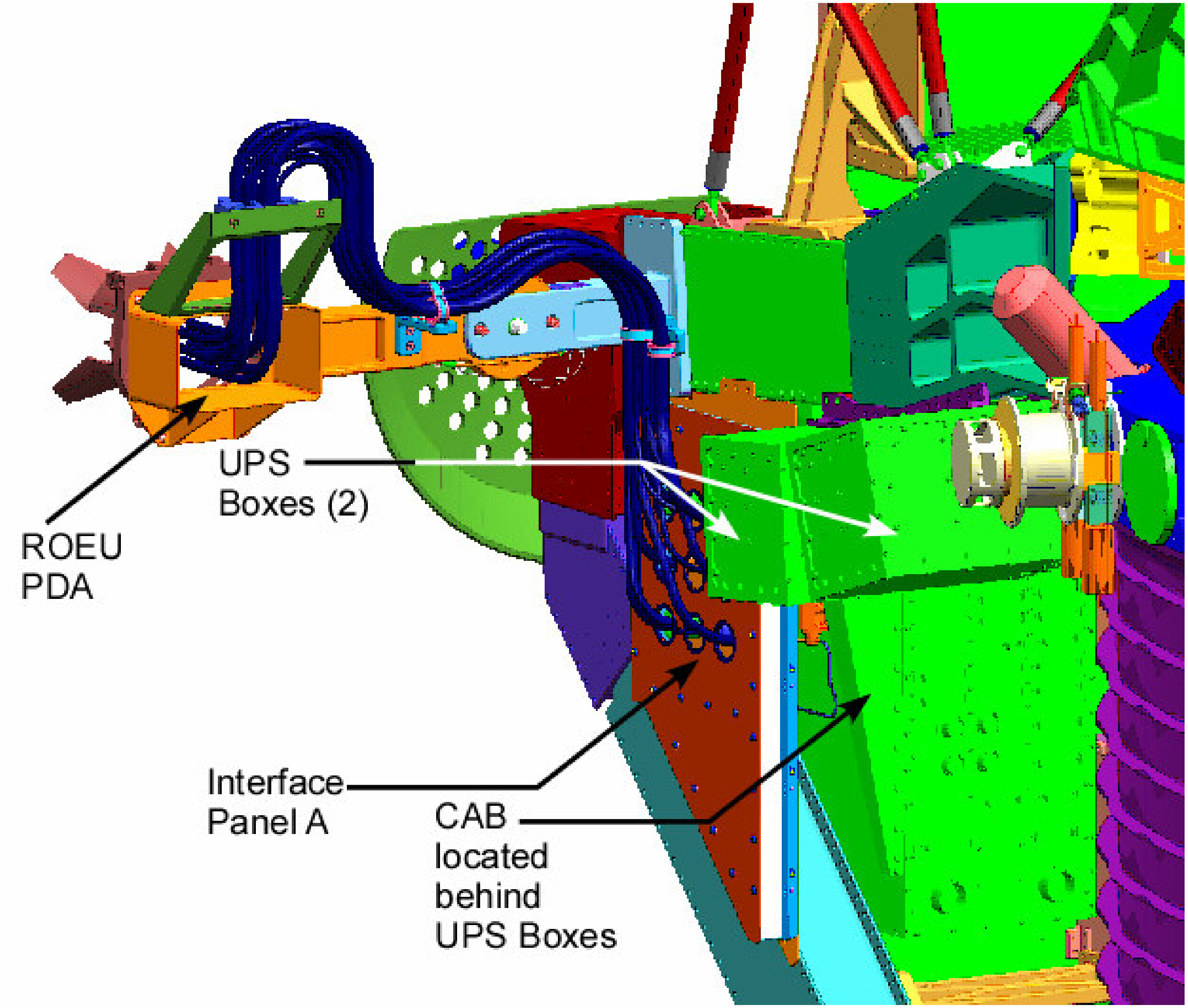


Figure 5.12.4-2 Cryomagnet Avionics Box (CAB) on the USS-02

The bonding diagram for the CAB is shown in Figure 5.12.3-3.

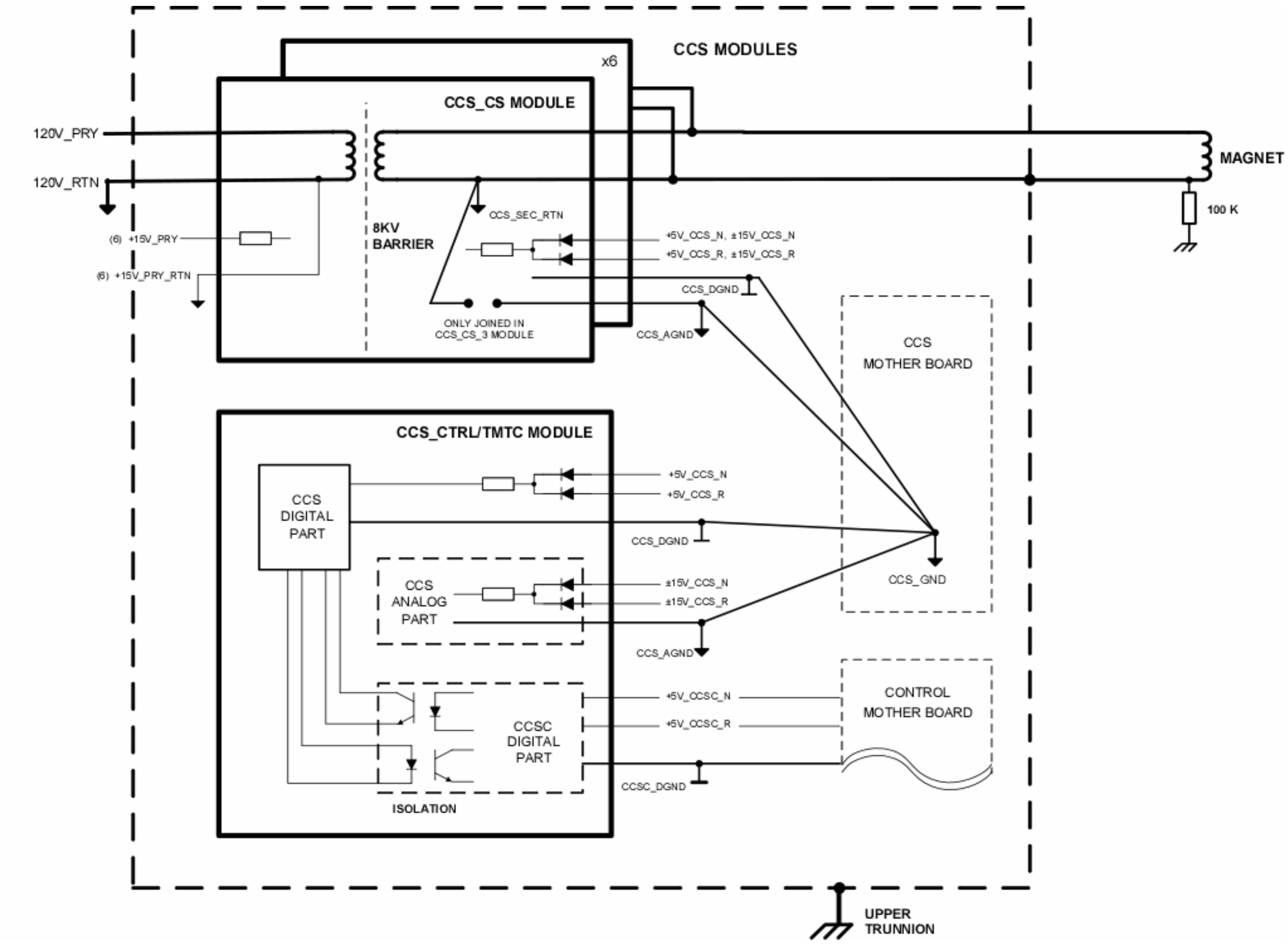


Figure 5.12.4-3 Bonding Diagram of the CAB

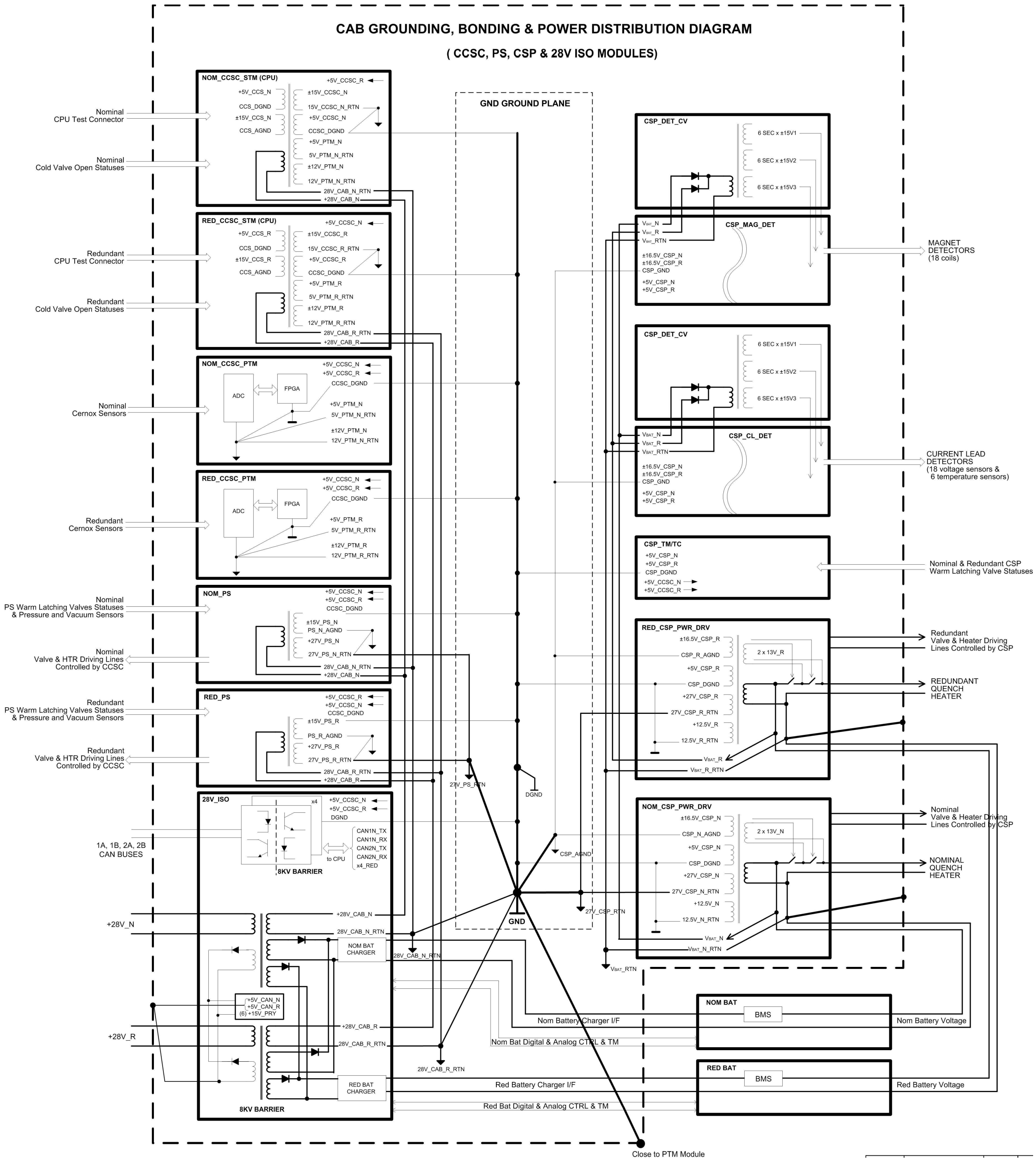


Figure 5.12.4-3 Bonding Diagram of the CAB (continued)

The CAB design includes three protection barriers in series in order to not permit an actual current of the Cryomagnet higher than 459A. The protection barriers are:

1. Software protection (digital value)
2. Field Programmable Gate Array (FPGA) protection (digital value)
3. Hard-wired control electronics protection circuitry

The software protection prohibits the electronics which controls the ramping to be set to an end of ramp current greater than 459A. From a worst case analysis, the setting error (the difference between the current value targeted by the electronics and the actual value of the current produced including errors in both translating the target current into a DC level and the measurement of the resulting current) is less than 3.5A. The final SW limit value will be decided after testing of the flight unit, but will be a value between 455.33A and 459. This barrier avoids continuous operation of the hardwired protection of the third barrier.

The second protection is implemented in firmware at the FPGA level. This protection barrier would be engaged in the case that failures of the CPU software or hardware lead to the request for a target current that is too high. The FPGA protection limit is 459A. This second barrier avoids also the continuous operation of the third barrier in case of internal failure of the active CPU.

The third protection is implemented in a majority voting configuration (three conditioning circuits of the control circuitry). The nominal value of this third protection is 455.5A. In case of failure, and in worst case analysis, the current limit of the third protection will again depend on the setting errors from the protection circuitry error (±1.5A) and the control electronics error (±2A). This represents an inaccuracy of ±3.5A for the third protection barrier.

Figure 5.12.4-4 illustrates the three barriers in series. The third barrier really represents the safety barrier. This never permits any Cryomagnet current larger than 459A. The control electronics uses a majority voting configuration with three conditioning circuits in parallel. As seen in the diagram, the majority voting topology is obtained by joining the three conditioning circuits in one set of electronics. This electronics is implemented using double transistors for the three circuits and therefore providing a single point failure free topology. Therefore, any transistor in short or open circuit will be tolerated by the majority voting electronics without propagating the failure.

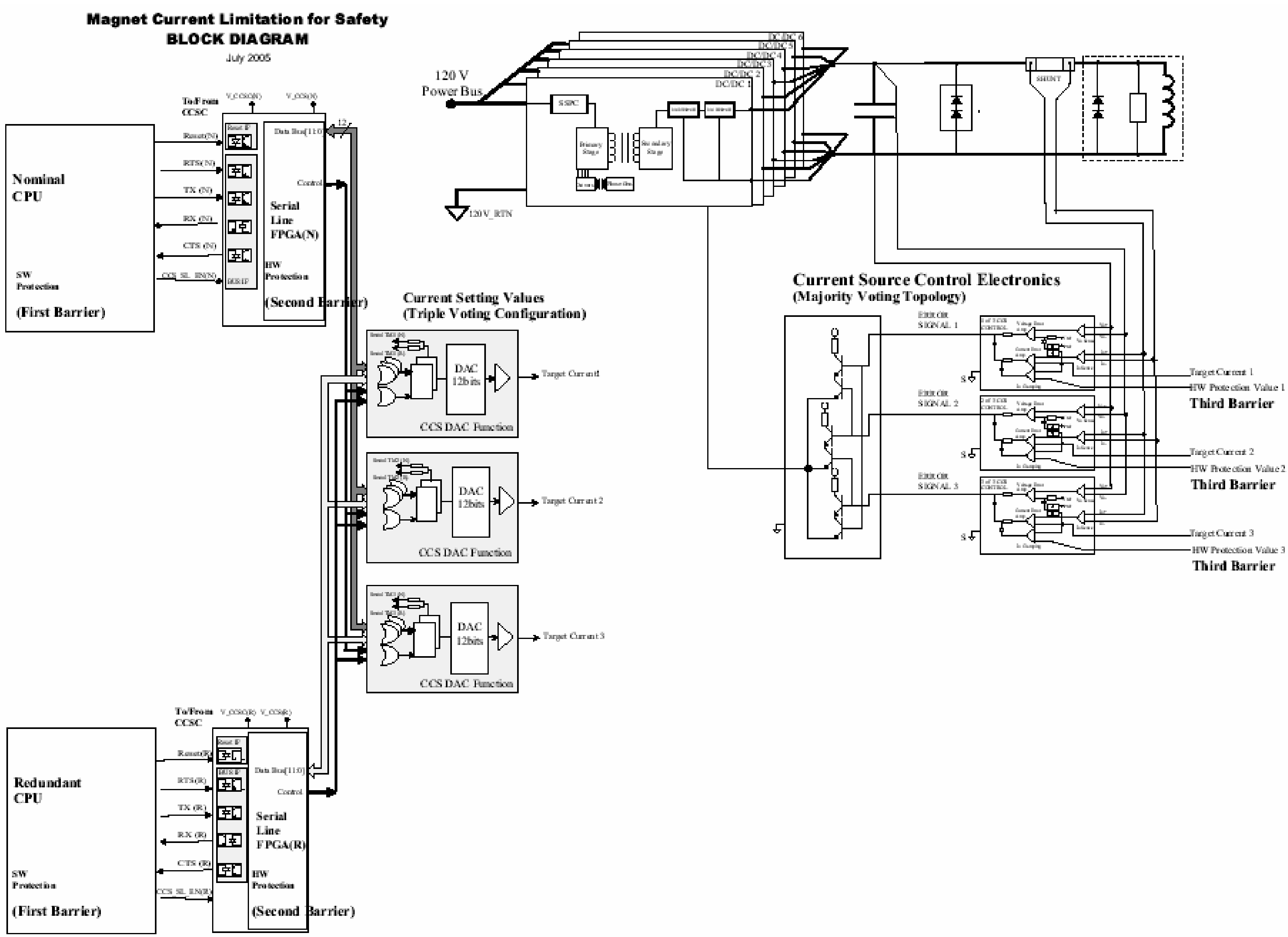


Figure 5.12.4-4 CAB Cryomagnet Current Limitation Barriers

5.12.4.1 Cryomagnet Current Source (CCS)

The 120 Vdc Power input (feed through from the PDS) is routed solely to the CCS. A DC-to-DC converter at the input to the CCS provides isolation for this Power Bus. The 120 Vdc power is required only for Cryomagnet charging. All other sections of the CAB are operated with 28 Vdc from the PDS.

The 120 Vdc input is limited to a maximum of 2200 W for power management. Power supplied to the DC-to-DC converter is controlled by Opto-Isolating feedback from the DC-to-DC converter output with a power switch and pulse width modulation of the input.

To charge the Cryomagnet, the Semiconductor switch on the charging circuit (reference Figure 5.12.2-1) is closed, and power is supplied to the transformer input. The current is slowly ramped up over a period of approximately 1.5 hours to 459 Amps. Current during charge and discharge operations is monitored using a 500A shunt. The connection from the CCS to the Cryomagnet is made via three pairs of AWG 2/0 wires. Once full operating current is reached, the Persistent Switch is closed (the switch consists of a pair of super-conducting wires – "closed" by cooling them down to superconducting temperatures). With the persistent switch closed, 459 A is running through both sides of the circuit (the Cryomagnet side and the charger side). To avoid ripple currents through the persistent switch, the current on the charger side is slowly reduced to zero. Once the current on the charger side is depleted, the Semiconductor Switch is opened, and the Charging System is disconnected from the Magnet Circuit.

Note: Mechanical disconnects on the Charging Leads for the Cryomagnet (not indicated in Figure 5.12.4-3, see Figure 5.12.4-1) are used to provide thermal isolation from the outside environment during all operations except charging and discharging. Prior to charging or discharging, the mechanical disconnects must be connected, and then disconnected after the operation is complete. Additional detail of this hardware is included in the Cryomagnet Description, Section 5.1.

If an event occurs that necessitates a power down of the Cryomagnet, the system is designed to perform a nominal "ramp down" function. The nominal ramp down is the most acceptable method for powering down the Cryomagnet without the potential for substantially decreasing the endurance of the Cryomagnet. To perform a ramp down, the mechanical leads are connected and the persistent switch is opened (by allowing it to warm to a non-superconducting state), diverting the current from the Cryomagnet through the Cryomagnet Dump Diodes (CDDs) (Figures 5.12.4-1 & 5.12.4-5). The connection from the Cryomagnet is to the CAB with three pairs of AWG 2/0 wires, and then on to the CDD, with a loop of one AWG 2/0 wire. This cable routing is shown in Figure 5.12.4-6. The energy from the Cryomagnet is dissipated in the form of heat through the CDD chain. The CDD consists of six sets in series of three diodes in parallel that are used solely for the purpose of dissipating the stored energy of the Cryomagnet. These dump diodes are located on the two wake-side sill trunnion joints (three sets on each joint), which were selected for their large thermal mass. The CDDs are protected by a metal cover to prevent incidental contact by ground personnel or crew. The total time required to dissipate the Cryomagnet energy is estimated to be 80 minutes.

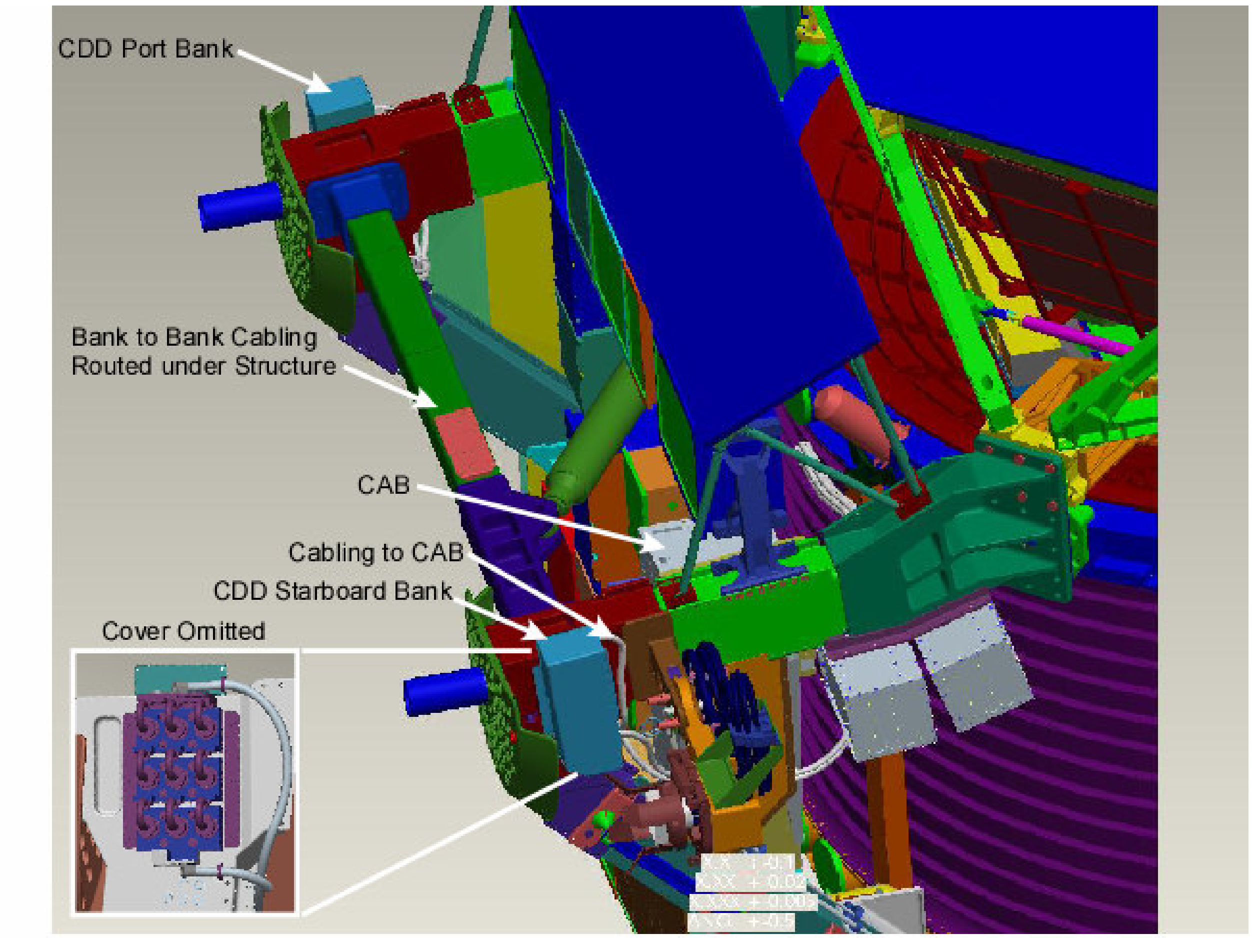


Figure 5.12.4-5 Cryomagnet Discharge System and Cable Routing

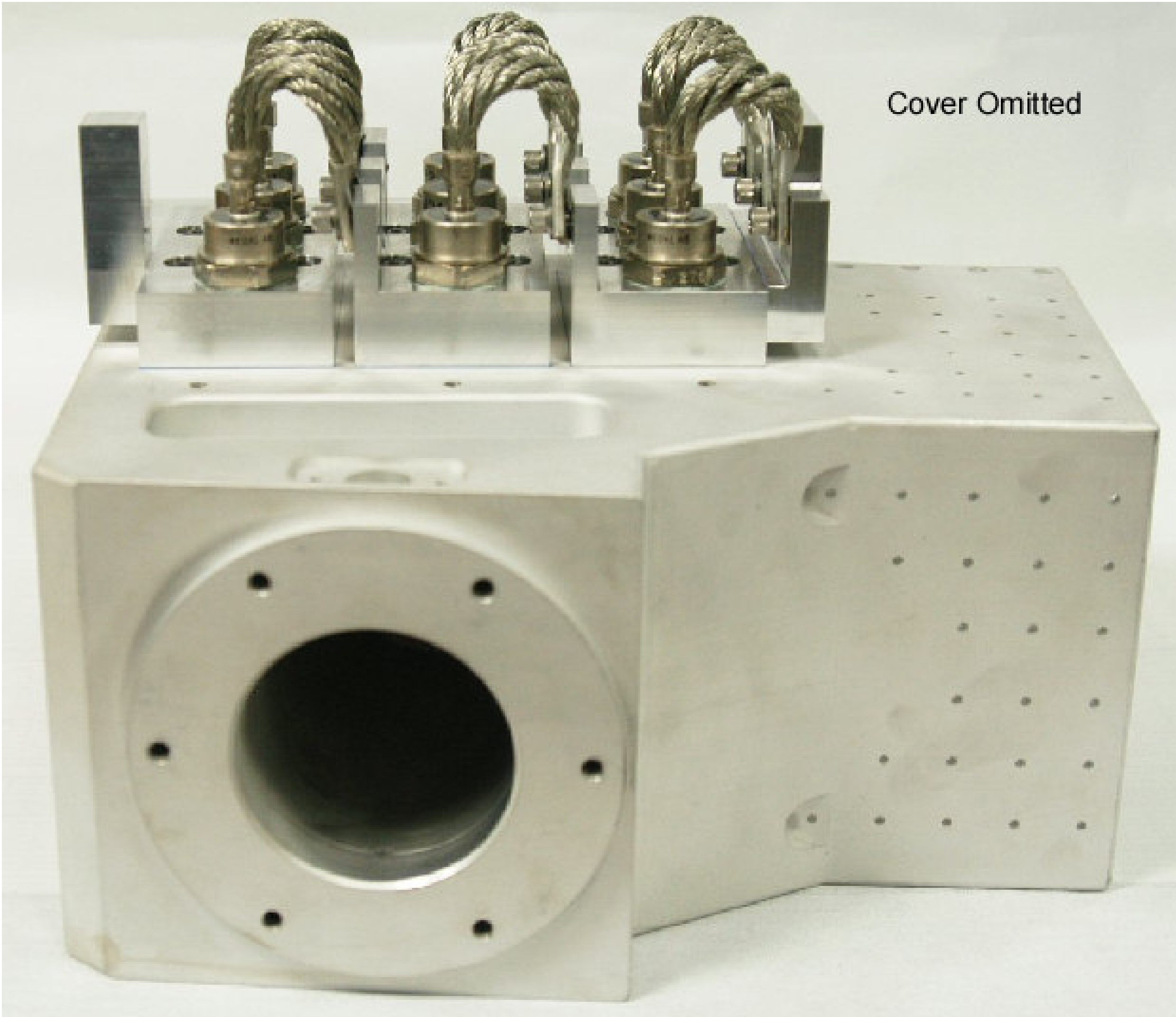


Figure 5.12.4-6 Cryomagnet Discharge Diode Qualification Model and Sill Trunnion Joint

5.12.4.2 Cryomagnet Control and Signal Conditioning (CCSC)

The CCSC provides the interface between the AMS-02 Main Data Computers (MDCs) and the Cryomagnet. The CCSC is responsible for:

- reception of commands from the MDCs
- transmission of telemetry to the MDCs
- commanding of the CCS
- control of the Cryomagnet auxiliary functions (i.e. heaters, valves, etc.)
- monitoring of the CCS, Cryomagnet, and CAB operating parameters and status

The CCSC also performs system fault detection and management functions, formatting of telemetry, and data storage for system status. The CCSC is required to interface with the Uninterruptible Power Source (UPS).

5.12.4.3 Power Switches

The power switches control the 28 VDC power supply to valves and cryogenic heaters. With the exception of the power switches controlled directly by the CSP, the power switches are galvanically isolated from the 28 VDC power bus.

5.12.4.4 Cryomagnet Self Protection (CSP)

Super-conducting magnets, such as the one utilized by AMS-02, may develop a condition where a portion of the coil begins to rise above super-conducting temperatures. When this condition occurs, the section of wire affected begins to develop resistance, and the current running through this resistance begins to heat the wire rapidly. This eventually leads to dissipation of the magnet energy (in the form of heat) within the magnet, and is referred to as a magnet quench. This condition is highly undesirable from a mission success standpoint because resulting unbalanced magnetic forces in the different sections of the magnet may cause it to deform, making it unable to be recharged to the maximum field or even to return to a superconducting state, thus preventing the recharging of the magnet. This is a possible mission success critical failure, not a safety issue. Alterations in the magnetic field have already been accounted for in the safety assessment for nominal field strengths.

To protect the Cryomagnet from this condition, referred to as an unassisted quench, electronics have been designed that will detect the initiating condition and apply heat quench evenly throughout the Cryomagnet coils, causing the magnetic field to dissipate uniformly. This will prevent the heating from being isolated to a small section of the Cryomagnet, which could become damaged if the quench was uncontrolled. By performing an assisted quench, mission success criteria can be maintained. The Cryomagnet Self Protection (CSP) section (Figure 5.12.4-7) of the CAB was developed to detect a change in voltage across a coil and perform this assisted quench.

The CSP contains quench detection electronics that monitor the status of the Cryomagnet coils to determine if a quench condition is starting to occur. To perform this function, redundant voltage measurements are taken across each coil. If a quench condition is imminent, a voltage will develop across the affected coil. When the CSP detects a change in voltage, the quench protection electronics issues a command to the Uninterruptible Power Source (UPS) to provide a pulse of at least 45A to quench heaters located throughout the Cryomagnet. The pulse, for a duration of 150 ms, is required to raise the entire Cryomagnet up to a non-superconducting state. This spreads the quench throughout the Cryomagnet and prevents isolated heating that could result in degraded performance.

The quench heater chains are redundant and supplied by two separate UPS systems. The chains are routed to alternate coils throughout the Cryomagnet. Both heater chains are nominally used by the CSP to control a quench, however either chain independently is sufficient to protect the Cryomagnet coils from deformation.

It is important to note that the CSP system is required only for mission success. Failure of the CSP does not constitute a safety hazard. The Cryomagnet is designed to withstand the forces that would be generated by an unassisted quench (see also the Cryomagnet description, Section 5.1).

The CSP provides additional functions (Figure 5.12.4-7) to protect the Cryomagnet during off-nominal conditions. A "watch dog" timer, powered by the UPS, is continuously counting down. Periodically the timeout is reset via external command to about 8 hours. In the event of a power loss, or the loss of communication to the AMS-02 payload, the timeout is not reset and if power or communications are not restored to the AMS within the eight-hour period, the timer will trigger the CSP Control Electronics to initiate the nominal ramp down function, discharging the Cryomagnet. During the eight hour period and the ramp down, the UPS will continue to power the Quench Detection Electronics, and maintain the capability to perform an assisted quench (if necessary) until the Cryomagnet is completely discharged. The CSP, showing the cross-strapping configuration between the power busses coming from the PDS and the two batteries of UPS, is shown in Figure 5.12.4-7.

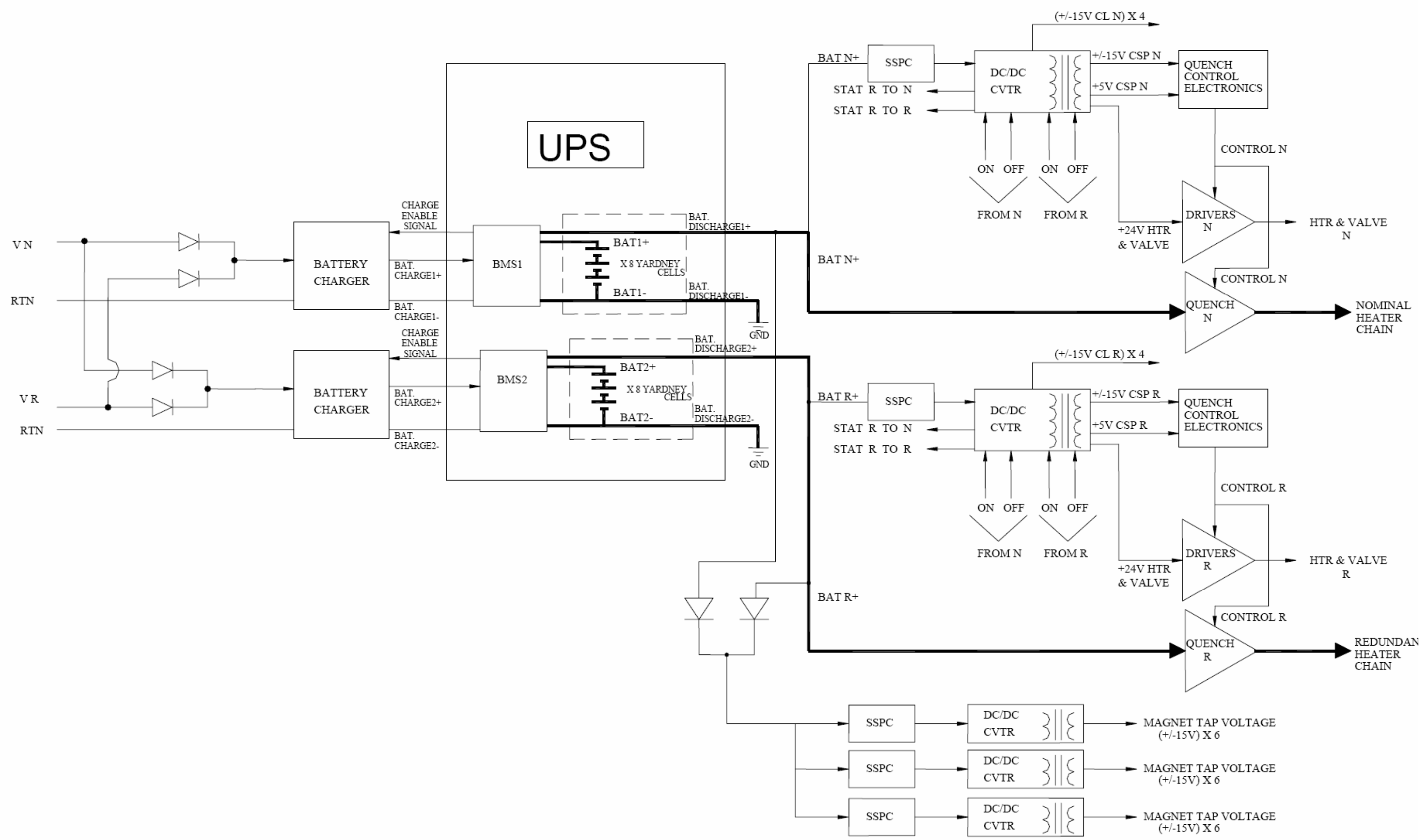


Figure 5.12.4-7 Cryomagnet Self Protection (CSP) Functional Block Diagram

5.12.4.5 CSP Uninterruptible Power Source (UPS)

The UPS consists of dual redundant 28 Amp-hour (A-h) Lithium Ion Batteries and a Battery Management System (BMS) for each, developed by Yardney/Lithion Corporation, Pawcatuck, CT. Each battery consists of eight cells in series to generate the required nominal 28 Vdc for the system. To ensure mission success during loss of ISS power or communication, the UPS is required to supply power for the watchdog timer function, quench monitoring functions, nominal ramp-down at watchdog timer rundown, and initiation of a quench pulse of at least 45 A for 150ms anytime during the sequence.

Figure 5.12.4-8, 9 shows the protection circuitry for the CAB Battery Charger Electronics (BCE), providing isolation between the UPS and PDS. The CAB BCE design includes the following protection electronics:

- Two double diodes in a cross-strapping configuration of the nominal and redundant 28Vdc primary power busses coming from PDS unit.
- SSPC (Solid State Power Conditioner), implemented by means of an Latching Current Limiter (LCL), which opens in case of failure.
- The HV power transformer barrier, which provides galvanic isolation between the electronics on primary side and the electronics on secondary side.
- The control electronics to provide the fit current to the battery, and also includes a power transformer with galvanic isolation.
- The blocking diode included in the BMS Battery Management System Electronics, which only permits the current way in only one direction.

All the above-mentioned protections included in the CAB BCE guarantee no propagation of failure to the ISS or any other unit, such as the PDS, which provides the 28Vdc primary power busses.

On the other hand, the CSP electronics design includes the following protection electronics between UPS and the loads (quench heaters, Cryomagnet valves):

- Two switches in series to power the quench heaters. These switches are only closed during 150ms of time required for the quenching sequence.
- SSPC (Solid State Power Conditioner), implemented by means of an LCL Latching Current Limiter, which opens in case of failure.

- The power transformer barrier, which provides galvanic isolation between the electronics on secondary side and the electronics on the load side.
- Two switches in series to open or close the valves.

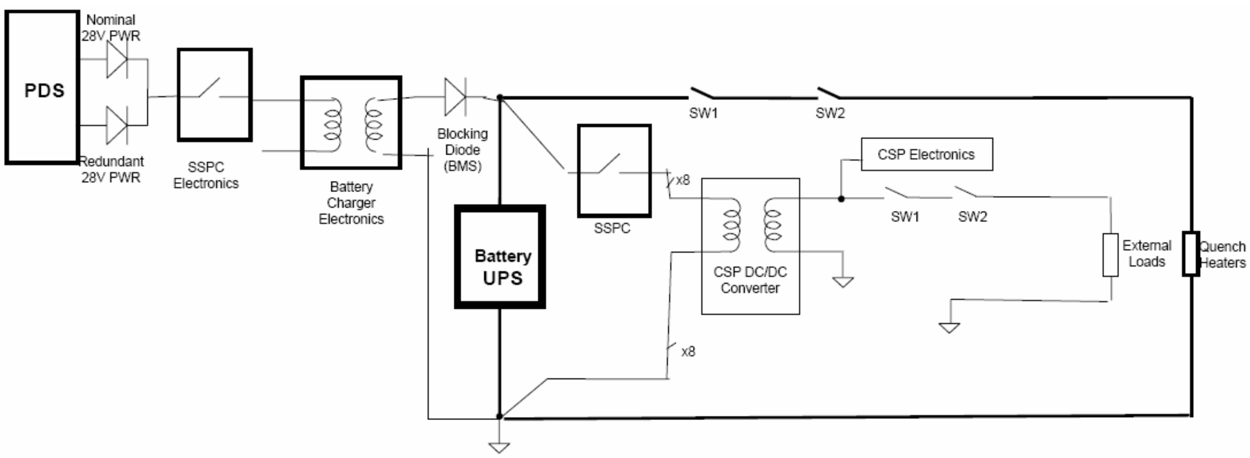


Figure 5.12.4-8 PDS to UPS Interface Diagram

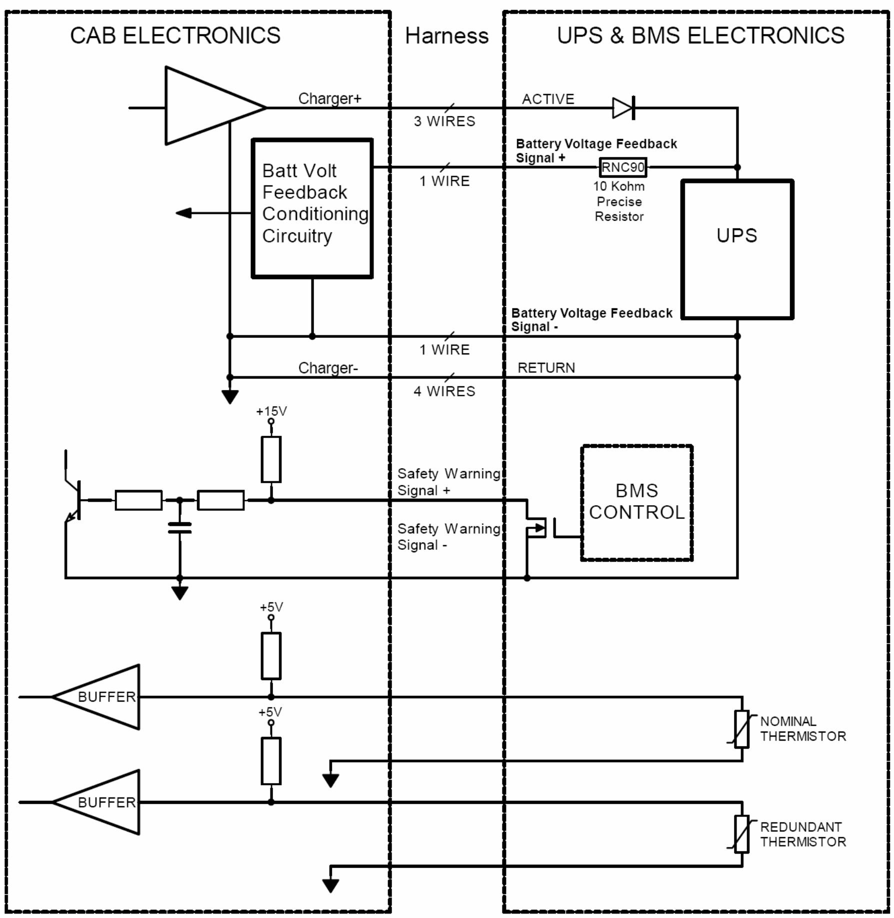


Figure 5.12.4-9 – CAB to UPS Interface Diagram

5.12.4.5.1 Cells/Brick

The cells are a prismatic design, weigh approximately 2 pounds, and have an operating temperature range from –25° C to +50° C. The mechanical design of the cells is heritage from the Mars Lander program, certified for flight on an expendable launch vehicle (ELV) but not flown. The electrolyte for the cells is an upgrade from the Mars Lander design and is currently used in the B2 Bomber program. It was selected for its broad operating temperature range.

The overall packaging for each cell is shown in Figure 5.12.4-9. Cell features are shown in Figure 5.12.4-10. An exploded view of the UPS battery cell is shown in Figure 5.12.4-11.

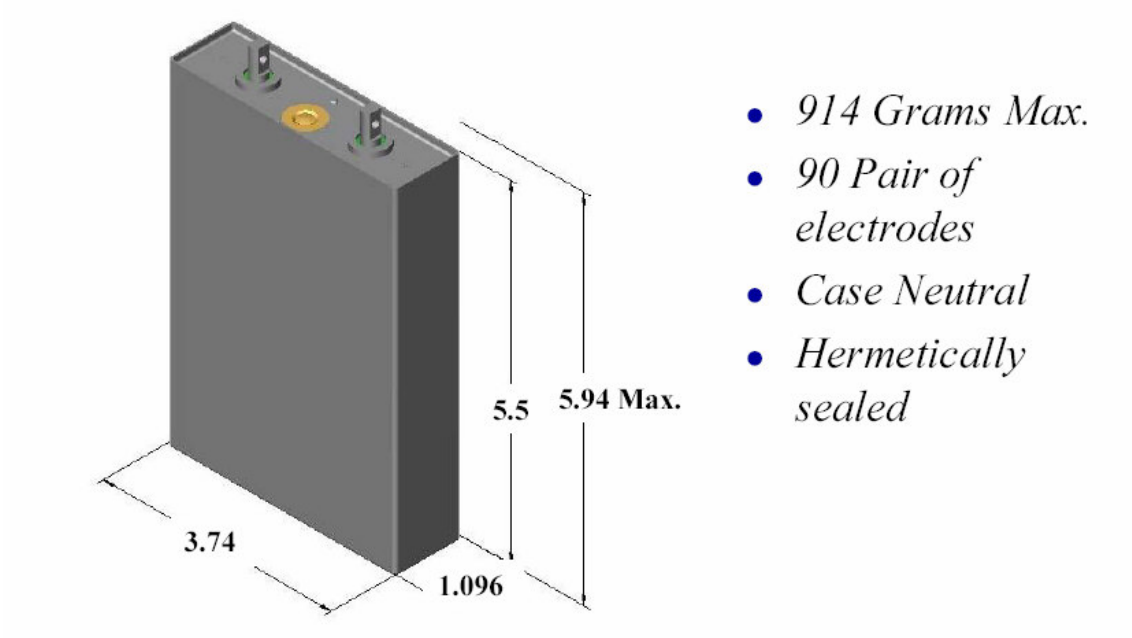


Figure 5.12.4-9 UPS Battery Cell Packaging

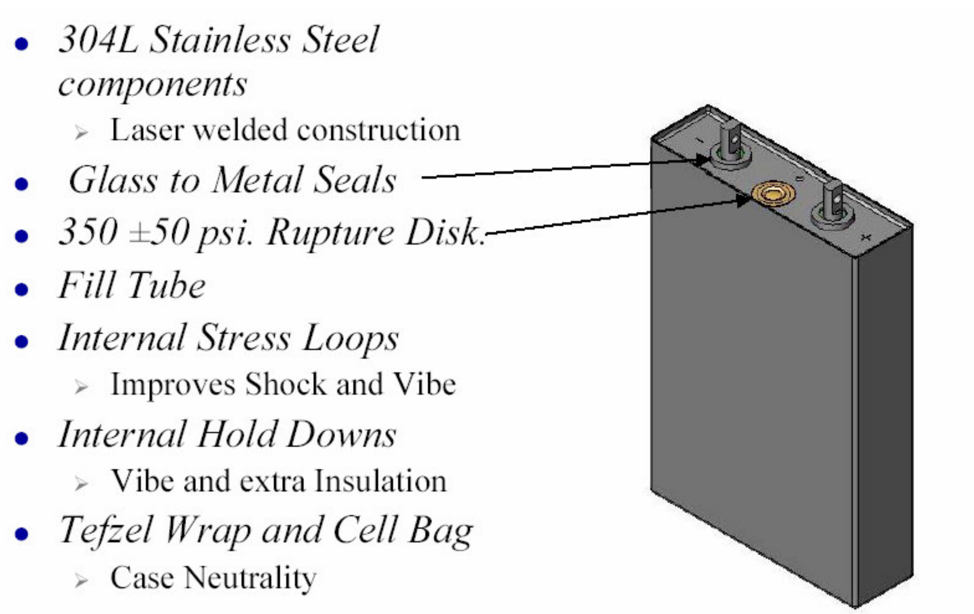


Figure 5.12.4-10 UPS Battery Cell Features

NOTE: Listed specification for burst disk is unmounted manufacturer's value, installed, the burst disk will operate at 200 ± 50 psi.

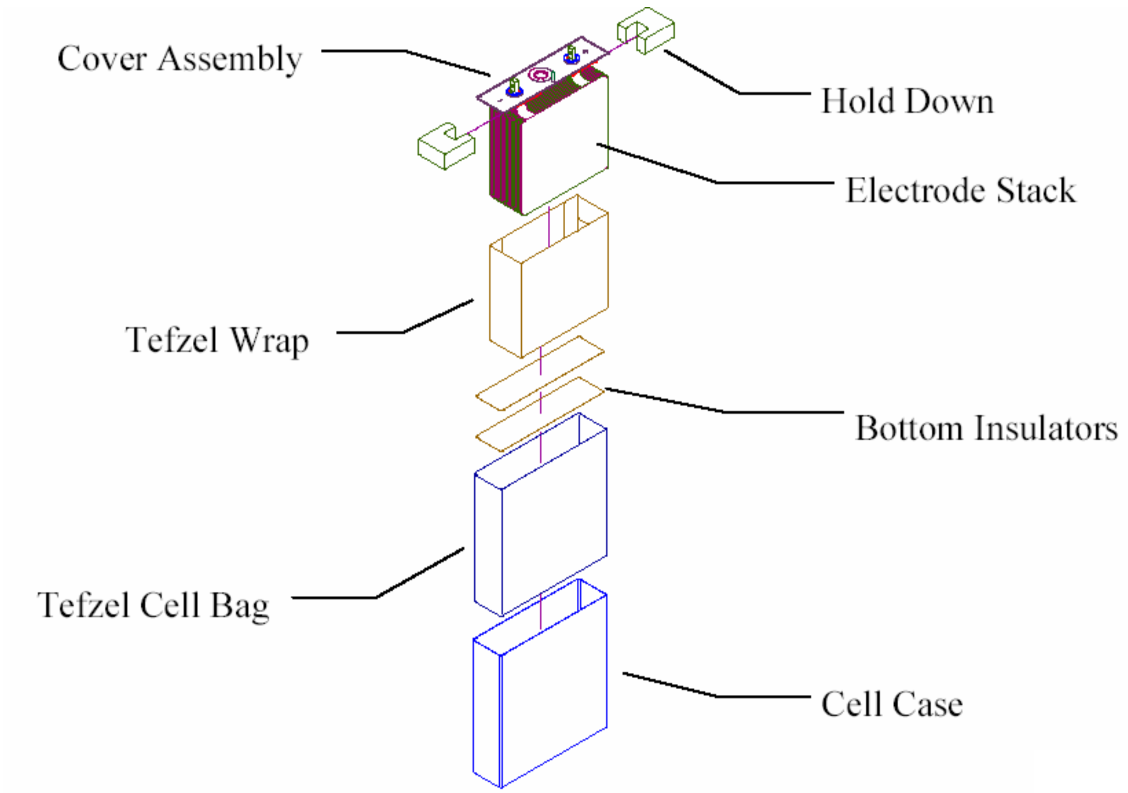


Figure 5.12.4-11 UPS Battery Cell, Exploded View

The cells are delivered in a configuration, called a brick (Figure 5.12.4-12). The brick contains eight cells encased in a bracket (with two endplates), designed for a nominal preload of approximately 1100 lb. The preload tolerates minor swelling of the individual cells, but offers a fixed volume for mounting.

Figure 5.12.4-12 UPS Battery Configuration "Brick"

5.12.4.5.2 Battery Management System

The Battery Management System (BMS), Figure 5.12.4 – 13, consists of three independent circuit boards and is designed to have the primary responsibility for battery condition (along with good design). The three boards consist of: a master controller board, and two monitor/equalizer boards.

The BMS master controller board communicates with the two monitor/equalizer boards to obtain cell voltage and temperature. The master controller board uses this information to calculate the battery state of charge (SOC) for use in the charge algorithm and to control the battery pack cell equalization. In case of a critical hardware failure, such as loss of communication to the monitor equalizer boards, the master controller board determines this condition and activates the protection board or charger switch.

The two monitor/equalizer boards monitor cell voltage and pack temperature. They perform cell equalization on each charge cycle by resistively bypassing any cell with a voltage in excess of a predetermined maximum. The bypass current is dissipated through a resistor array on the board.

The master control board determines when the voltage condition is reached and activates the bypass. The master control board also determines when a cell voltage is exceeding allowable safety limits commands the CAB battery charger electronics as well. The master control board is also used to disconnect the pack from the load during fault conditions that include high cell temperature, low battery voltage and excessive current.

The protection/regulator board is used to disconnect the pack from the load during fault conditions that include high cell temperature, low battery voltage and excessive current (high load/short).

Additionally, a charger switch will disconnect the battery from the charger in cases of high cell temperature, high cell voltage or if the charger becomes uncontrollable. The switch will open in the case of a critical hardware failure, such as loss of communication to the monitor equalizer boards. The master controller board determines these conditions and sends the signal to the protection board or charger switch. The protection board employs multiple parallel metal-oxide-silicon field effect transistors (MOSFET) to carry the battery load current.

The BMS contains both hardware and software inhibits to control potential safety issues such as overcharge, over-discharge, over-temperature, and over-current. Regardless of failure of any of these items, a catastrophic failure of the battery is not credible. The battery management methodologies are:

- Over Charge: If a cell charge exceeds 4.43 V the BMS commands a changes the charge discrete to stop the battery charge until the load, which is still connected to the system, draws the charge of the cells to the charge resume threshold of 4.26V. If an over voltage condition in a cell occurs a voltage comparator will detect and engage a resistive shunt across the cell that will bypass the charging current and partially discharge the cell. This bypass initiates at 4.10V and disengages at 4.05V. This function is used to extend the battery life and maintain pack capacity.
- Over Discharge: The BMS is designed to prevent overdischarge by measuring voltage state of the battery The cell stack is monitored by discrete hardware devices for output

voltage and if the voltage drops below 18 VDC the cell stack is switched off the load by a BMS solid state relay to allow charging of the cell stack to proceed.

- Over Temperature: Exceeding 60° C on a battery pack for 3-4 seconds causes software to disconnect the battery from the Charger.
- Over Current: A current draw between 7A and 80 A for ~800 milliseconds causes a software/firmware inhibit to disconnect the battery from the discharge circuitry. A hardware inhibit initiates if a current draw 80 amps or larger for 200 µsec that will remove the battery from the load. The battery circuit will attempt to reconnect every 1.5 seconds, testing for fault conditions as described above. The time delays associated with each of the test methodologies allow for testing without a threat to the batteries occurring.

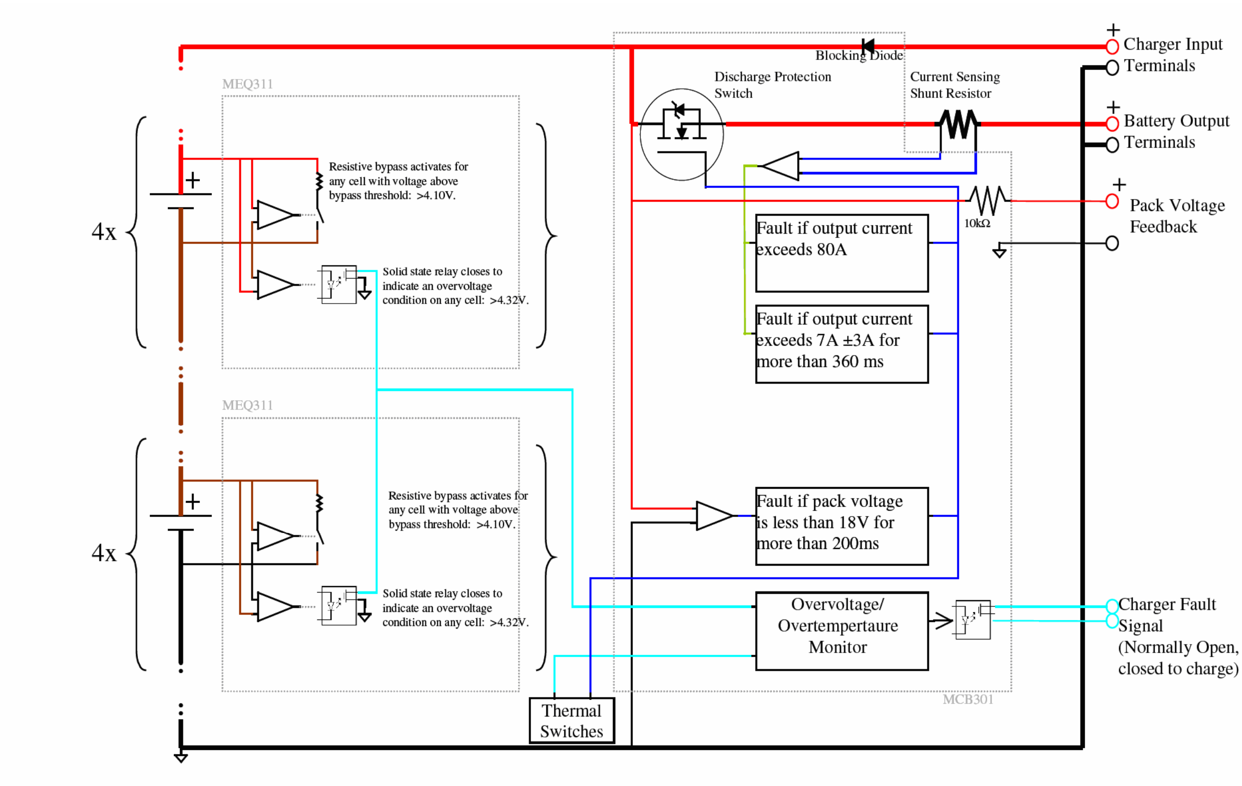


Figure 5.12.4-13 Battery Management System

5.12.4.5.2 UPS Mechanical Packaging

Two sets of bricks and BMSs are mounted into a UPS box, apiece, which provide further containment and protection from MM/OD, as shown in Figure 5.12.4-14. Both UPS boxes are mounted to the USS in proximity to the CAB and the input port on the Vacuum Case to decrease line resistance (Figure 5.12.4-15).

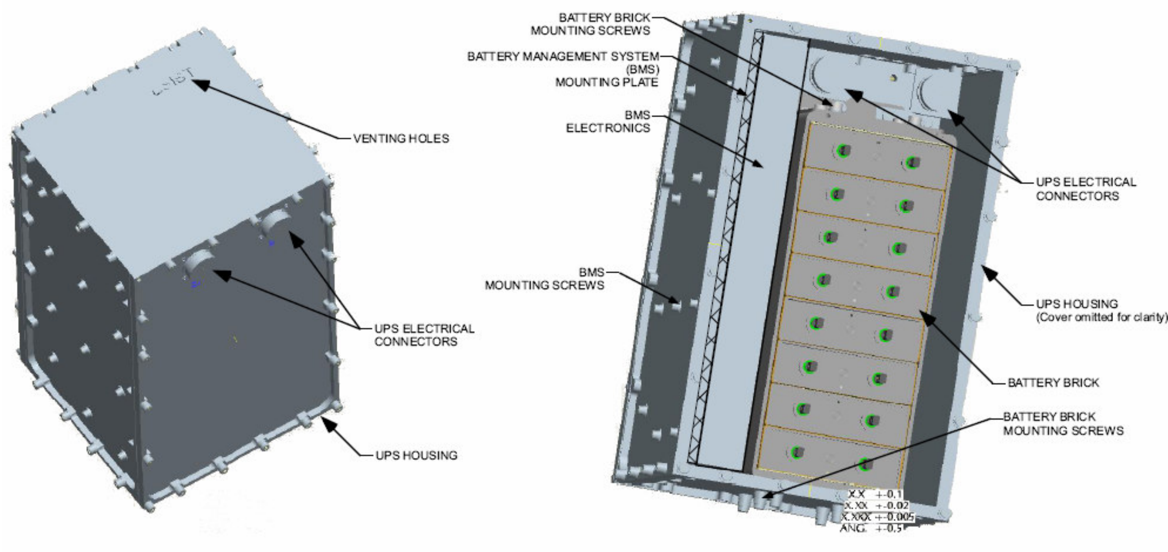


Figure 5.12.4-14 Battery and BMS mounted in UPS Box

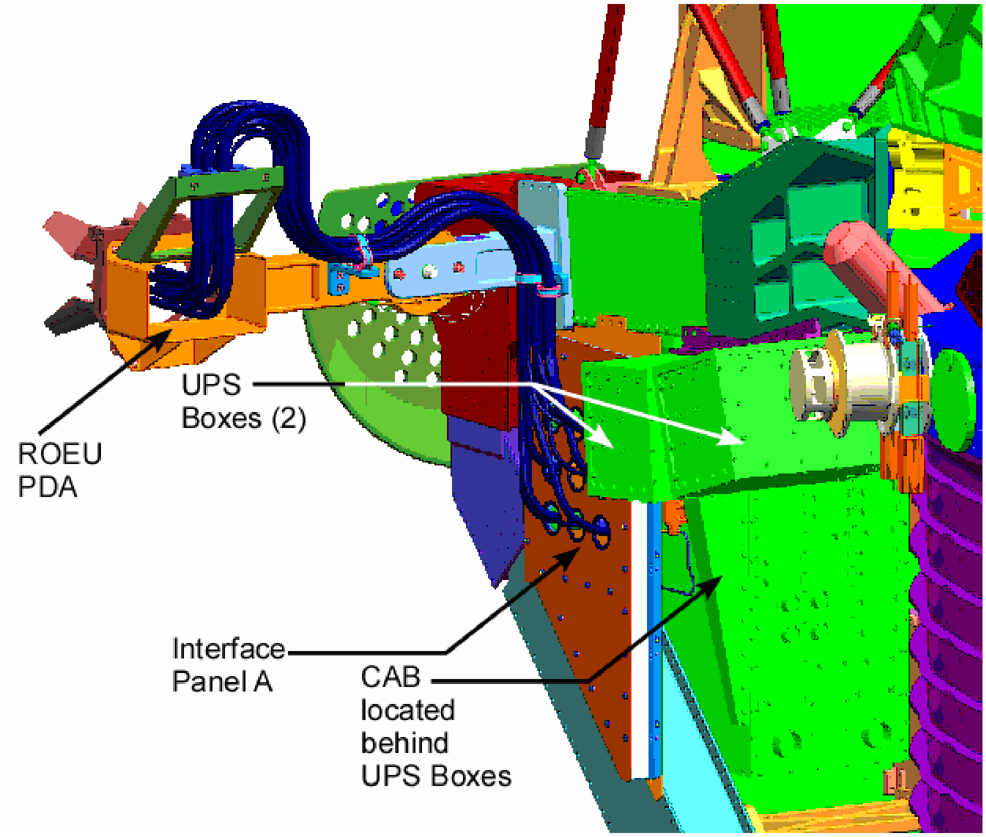


Figure 5.12.4-15 The UPS Mounted on the USS-02

5.12.5 Cryocooler Electronics Box (CCEB)

The CCEB receives 120 Vdc from either or both buses to power the Cryocoolers and their Monitor & Control Electronics. Bus-to-Bus isolation for the 120 Vdc is provided by relays. Over-current protection is provided by dedicated circuitry in eight power amplifiers. An SSPC in the PDS and fuses (TBR) in the CCEB provide additional circuit protection.

Monitor and Control Power for the CCEB is supplied by DC-to-DC converters operating from both buses (Figure 5.12.5-1). The DC-to-DC converters provide the necessary isolation bus-to-bus for the low voltage power.

Cryocooler power is routed from each bus through a set of four power amplifiers and passed through a power switch to each Cryocooler (Figure 5.12.5-2). The power amplifier consists of a 60-hertz pulse width modulated H-bridge with clamp logic, to improve efficiency and reduce electromagnetic interference (EMI). This provides the required drive signal for the Cryocoolers. The output of the power amplifier is then routed to the power switch. Each power amplifier has a current limiting circuit with a shutdown option.

The power switch (Figure 5.12.5-3) contains inputs for the power amplifier signals from both buses. Four-pole, double throw relays select which bus each Cryocooler will be powered from. One pair of the poles are used to select the Hi and Lo signals from the selected power amplifier to power the Cryocoolers, and the other two poles are used for feedback of the relay position. Control of the power switch is provided by a Universal Slow Control Module (USCM), an AMS standard board with firmware used for control of low rate equipment. The USCM uses both ground command and automated configuration setting capabilities to control the Cryocoolers.

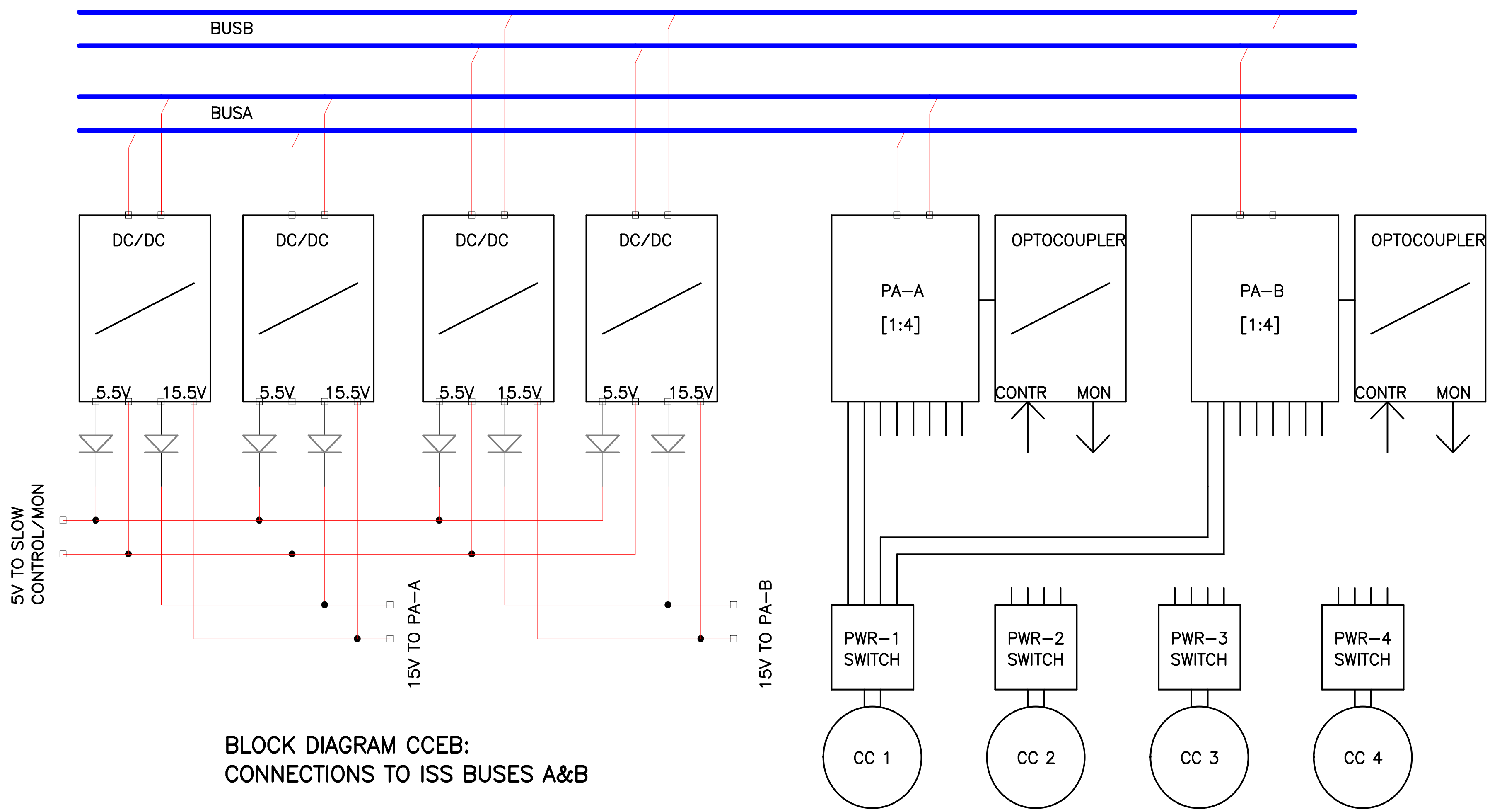


Figure 5.12.5-1 Block Diagram of Cryocooler Electronics Box (CCEB)

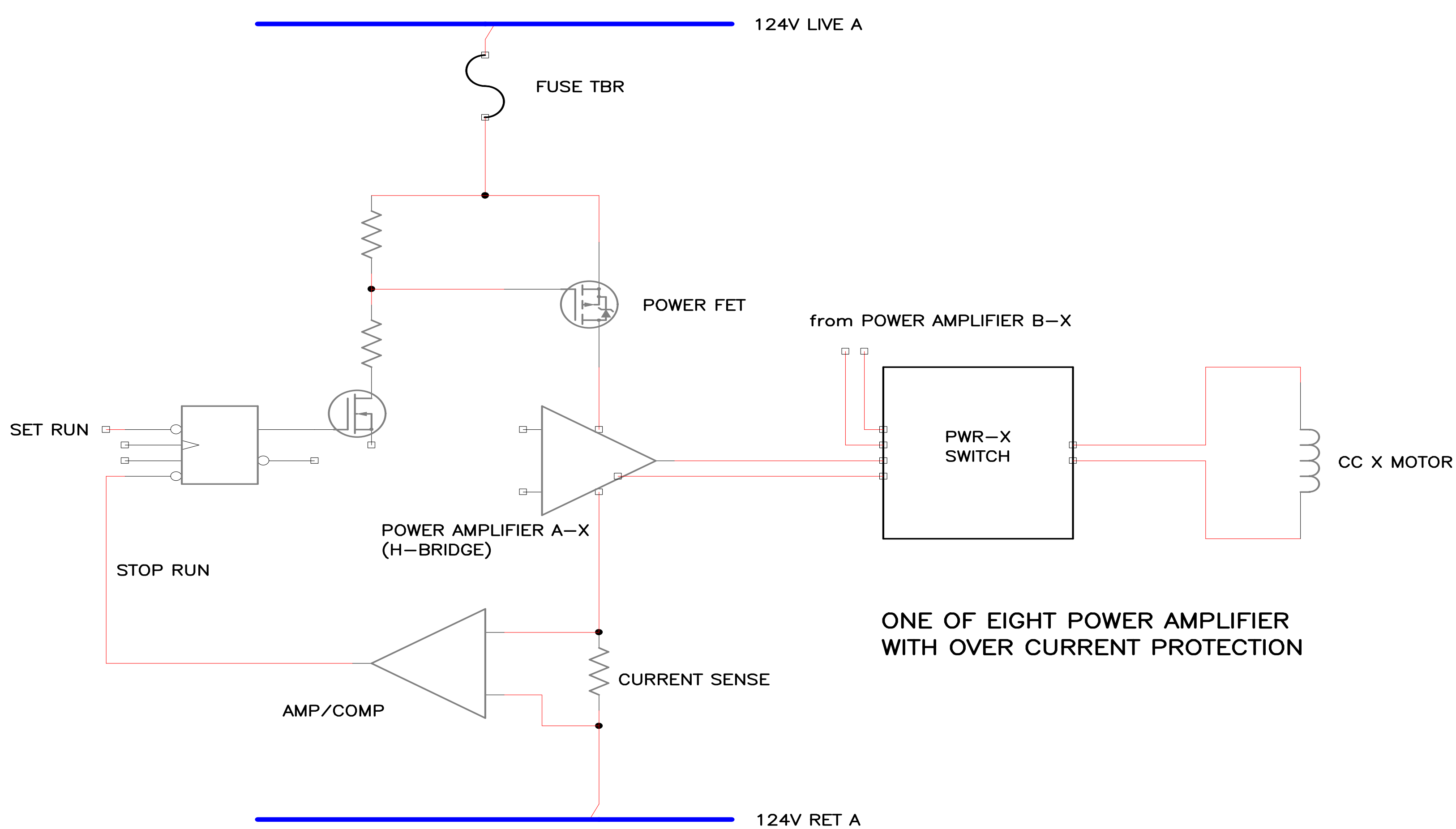


Figure 5.12.5-2 CCEB Power Amplifier with Over-current Protection

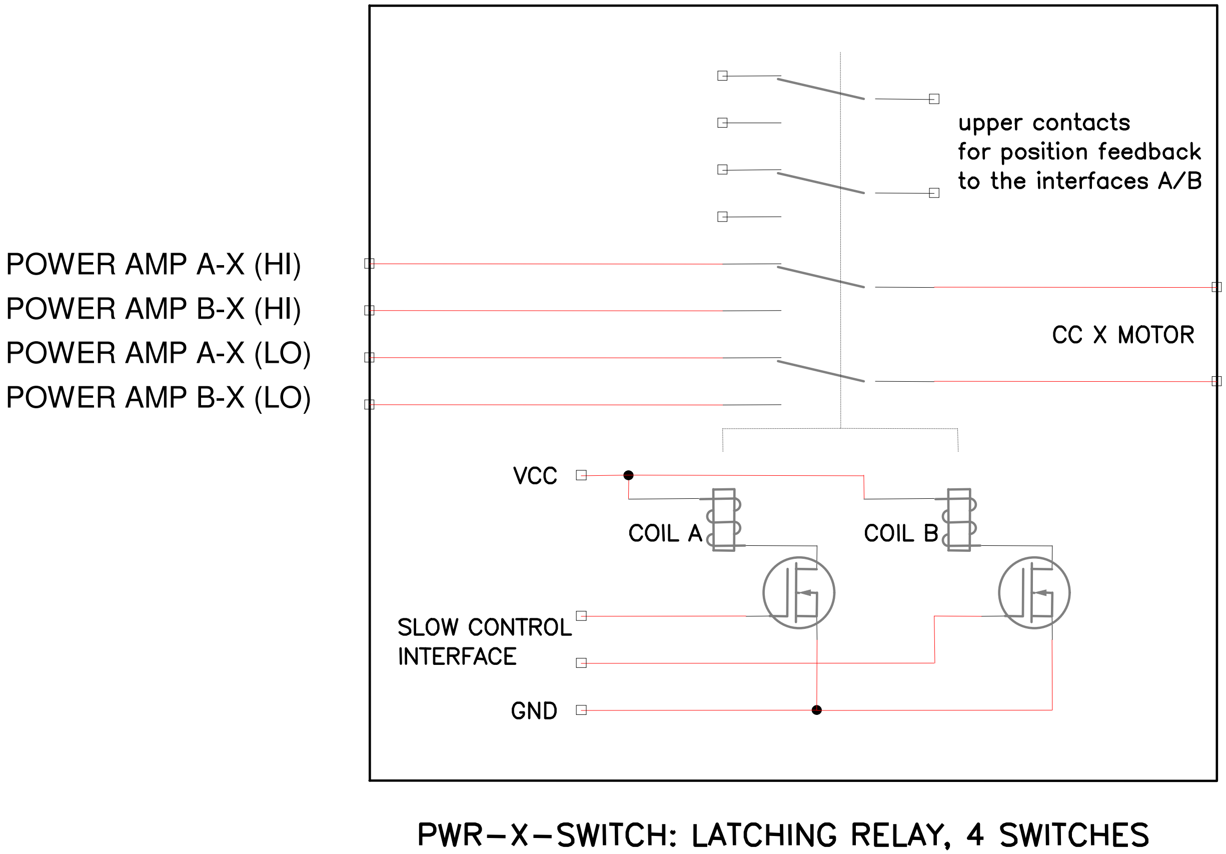


Figure 5.10.5-3: CCEB Cryocooler Power Switch

5.12.6 High Voltage Sources

The Cryomagnet is a potential high-voltage source in the event of a quench and the protection scheme is described in the CAB description. Other than the path to the CAB, the Cryomagnet generated high voltage would be contained within the Vacuum Case, which is grounded to the Unique Support Structure (USS).

Table 5.12.6-1 lists the remaining high voltage and current sources on the AMS-02.

TABLE 5.12.6-1 AMS-02 HIGH VOLTAGE OR CURRENT SOURCES

High Voltages (and Currents) in AMS-02.						
Item	**Subsystem**	**Source**	**Load**	**Voltage**	**Current**	**AWG**
1	Cryocooler	CCEB	Cryocooler 1	<90VAC	<2.5A	3x22
2	Cryocooler	CCEB	Cryocooler 2	<90VAC	<2.5A	3x22
3	Cryocooler	CCEB	Cryocooler 3	<90VAC	<2.5A	3x22
4	Cryocooler	CCEB	Cryocooler 4	<90VAC	<2.5A	3x22
5	Cryomagnet	CCS in CAB	Thermal Strain Relief Device	<10VDC	<460A	3x00
6	Cryomagnet	Thermal Strain Relief Device	Cryomagnet	<10VDC	<460A	16x 0.175” Cu rope w/Kynar heatshrink
7	Cryomagnet	Cryomagnet	CDD-P, CDD-S	<10VDC	<460A	00
8	Cryomagnet	UPS-0	CSP in CAB	<32VDC	<90A	3x12
9	Cryomagnet	UPS-1	CSP in CAB	<32VDC	<90A	3x12
10	Cryomagnet	CSP in CAB	Quench Heaters	<32VDC	<90A	3x12
11	Cryomagnet	CSP in CAB	Quench Heaters	<32VDC	<90A	3x12
12	Cryomagnet	Cryomagnet	Quench Detectors 1-9	<1KV	<1A	HV-24
13	Cryomagnet	Cryomagnet	Quench Detect. 10-18	<1KV	<1A	HV-24
14	ECAL	EHV0-0	55 ECAL PMTs	<1000VDC	<250uA	Coax-26
15	ECAL	EHV0-1	55 ECAL PMTs	<1000VDC	<250uA	Coax-26
16	ECAL	EHV0-2	55 ECAL PMTs	<1000VDC	<250uA	Coax-26
17	ECAL	EHV1-0	55 ECAL PMTs	<1000VDC	<250uA	Coax-26
18	ECAL	EHV1-1	55 ECAL PMTs	<1000VDC	<250uA	Coax-26
19	ECAL	EHV1-2	55 ECAL PMTs	<1000VDC	<250uA	Coax-26
20	Interface	ISS	AMS-PDS	120VDC	<25A	8
21	Interface	ISS/PVGF	AMS-PDS	120VDC	<15A	12
22	Interface	ISS/T0	AMS-PDS	120VDC	<25A	12
23	Interface	STS/APCU	AMS-PDS	120VDC	<25A	8
24	Power	PDS	CCS in CAB	120VDC	<20A	12
25	Power	PDS	CCEB	120VDC	<7.5A	12
26	RICH	RHV0-0	40 RICH PMTs	<1000VDC	<80uA	Coax-26
27	RICH	RHV0-1	40 RICH PMTs	<1000VDC	<80uA	Coax-26

Wire: AWG 00=M22759/41-02-5D, AWG 12 – 24=M22759/44-*, HV 24= Reynolds 178-8066, Coax 36=Reynolds 167-2896

TABLE 5.12.6-1 AMS-02 HIGH VOLTAGE OR CURRENT SOURCES (CONTINUED)

High Voltages (and Currents) in AMS-02.						
Item	**Subsystem**	**Source**	**Load**	**Voltage**	**Current**	**AWG**
28	RICH	RHV1-0	40 RICH PMTs	<1000VDC	<80uA	Coax-26
29	RICH	RHV1-1	40 RICH PMTs	<1000VDC	<80uA	Coax-26
30	S:TOF+ACC	SHV0	34 TOF+4 ACC PMTs	<2500VDC	<50uA	Coax-26
31	S:TOF+ACC	SHV1	34 TOF+4 ACC PMTs	<2500VDC	<50uA	Coax-26
32	S:TOF+ACC	SHV2	38 TOF+4 ACC PMTs	<2500VDC	<50uA	Coax-26
33	S:TOF+ACC	SHV3	38 TOF+4 ACC PMTs	<2500VDC	<50uA	Coax-26
34	Thermal	PDS	ECAL Heaters	120VDC	<3A	20
35	Thermal	PDS	Ram Heaters	120VDC	<7.5A	20
36	Thermal	PDS	TRD Heaters	120VDC	<3A	20
37	Thermal	PDS	Tracker Wake Heaters	120VDC	<3A	20
38	Thermal	PDS	Wake Heaters	120VDC	<5A	20
39	Thermal	PDS	LUSS Boxes	120VDC	<3A	20
40	Thermal	PDS	RICH Heaters	120VDC	<3A	20
41	Thermal	PDS	LTOF Heaters	120VDC	<3A	20
42	Thermal	PDS	CC1&2 Heaters	120VDC	<3A	20
43	Thermal	PDS	Tracker Ram Heaters	120VDC	<3A	20
44	Thermal	PDS	CC3&4 Heaters	120VDC	<3A	20
45	Tracker	TPD0	2 TBS in T0-Crate	<120VDC	<10mA	22
46	Tracker	TPD1 in TSPD1	2 TBS in T1-Crate	<120VDC	<10mA	22
47	Tracker	TPD2 in TMPD2	2 TBS in T2-Crate	<120VDC	<10mA	22
48	Tracker	TPD3 in TSPD3	2 TBS in T3-Crate	<120VDC	<10mA	22
49	Tracker	TPD4 in TSPD4	2 TBS in T4-Crate	<120VDC	<10mA	22
50	Tracker	TPD5	2 TBS in T5-Crate	<120VDC	<10mA	22
51	Tracker	TPD6 in TSPD6	2 TBS in T6-Crate	<120VDC	<10mA	22
52	Tracker	TPD7	2 TBS in T7-Crate	<120VDC	<10mA	22
53	Tracker	2 TBS in T0-Crate	24 Tracker Ladders	<80VDC	<10mA	26
54	Tracker	2 TBS in T1-Crate	24 Tracker Ladders	<80VDC	<10mA	26
55	Tracker	2 TBS in T2-Crate	24 Tracker Ladders	<80VDC	<10mA	26
56	Tracker	2 TBS in T3-Crate	24 Tracker Ladders	<80VDC	<10mA	26
57	Tracker	2 TBS in T4-Crate	24 Tracker Ladders	<80VDC	<10mA	26
58	Tracker	2 TBS in T5-Crate	24 Tracker Ladders	<80VDC	<10mA	26
59	Tracker	2 TBS in T6-Crate	24 Tracker Ladders	<80VDC	<10mA	26
60	Tracker	2 TBS in T7-Crate	24 Tracker Ladders	<80VDC	<10mA	26
61	TRD	UPD0	6 UHVG in U0-Crate	<120VDC	<35mA	22
62	TRD	UPD1	6 UHVG in U1-Crate	<120VDC	<35mA	22
63	TRD	6 UHVG in U0-Crate	2624 TRD Straw Tubes	<1800VDC	<100uA	Coax-26
64	TRD	6 UHVG in U1-Crate	2624 TRD Straw Tubes	<1800VDC	<100uA	Coax-26
65	TRD-Gas	UGPD	UHVG in UG-Crate	<120VDC	<35mA	22
66	TRD-Gas	UHVG in UG-Crate	4 Rad Monitor Tubes	<1800VDC	<100uA	Coax-26
	ISS, STS Voltages after EMI filter					

Wire: AWG 00=M22759/41-02-5D, AWG 12 – 24=M22759/44-*, HV 24= Reynolds 178-8066, Coax 36=Reynolds 167-2896

5.12.7 Grounding/Bonding Scheme for the AMS Experiment

The AMS-02 payload shall comply with the bonding requirements as defined in *SSP 57003 Attached Payload Interface Requirements Document, Revision B.* The AMS-02 payload, with respect to the overall grounding system, shall comply with *SSP 30240 Space Station Grounding Requirements, Revision C*.

The AMS-02 payload structure is mechanically grounded, depending on mission phase, as follows:

A. STS – via the payload mounting trunnions
B. SSRMS – via the SSRMS / PVGF interface
C. ISS CAS site – via the PAS guide vane pins

The overall AMS-02 payload interface schematic is represented in Figures 5.12.7-1. The AMS-02 payload grounding scheme and interfaces are shown specifically for the various mission phases in Figures 5.12.7-2 through 5.12.7-5

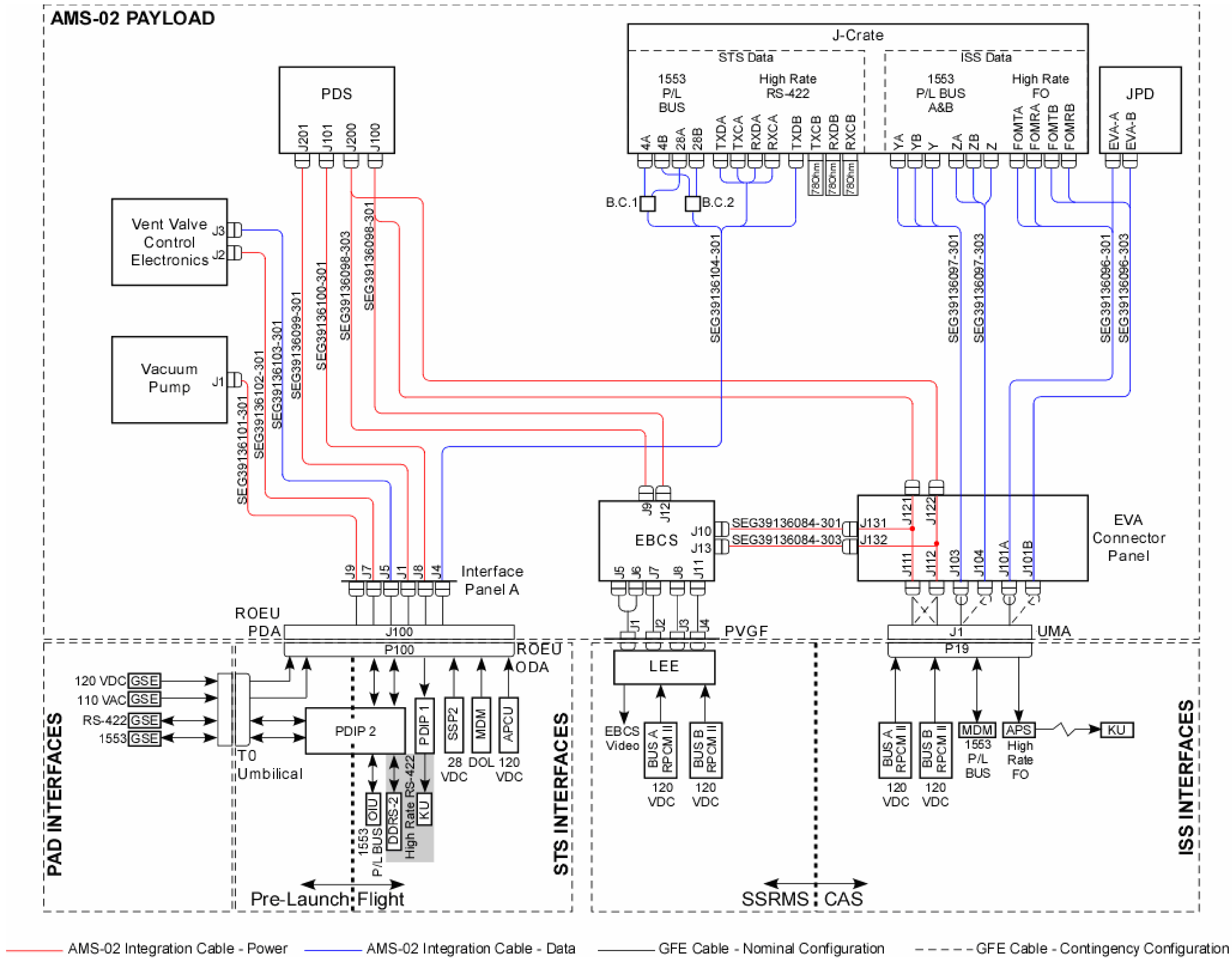


Figure 5.12.7-1 AMS-02 Top Level Interface Diagram.

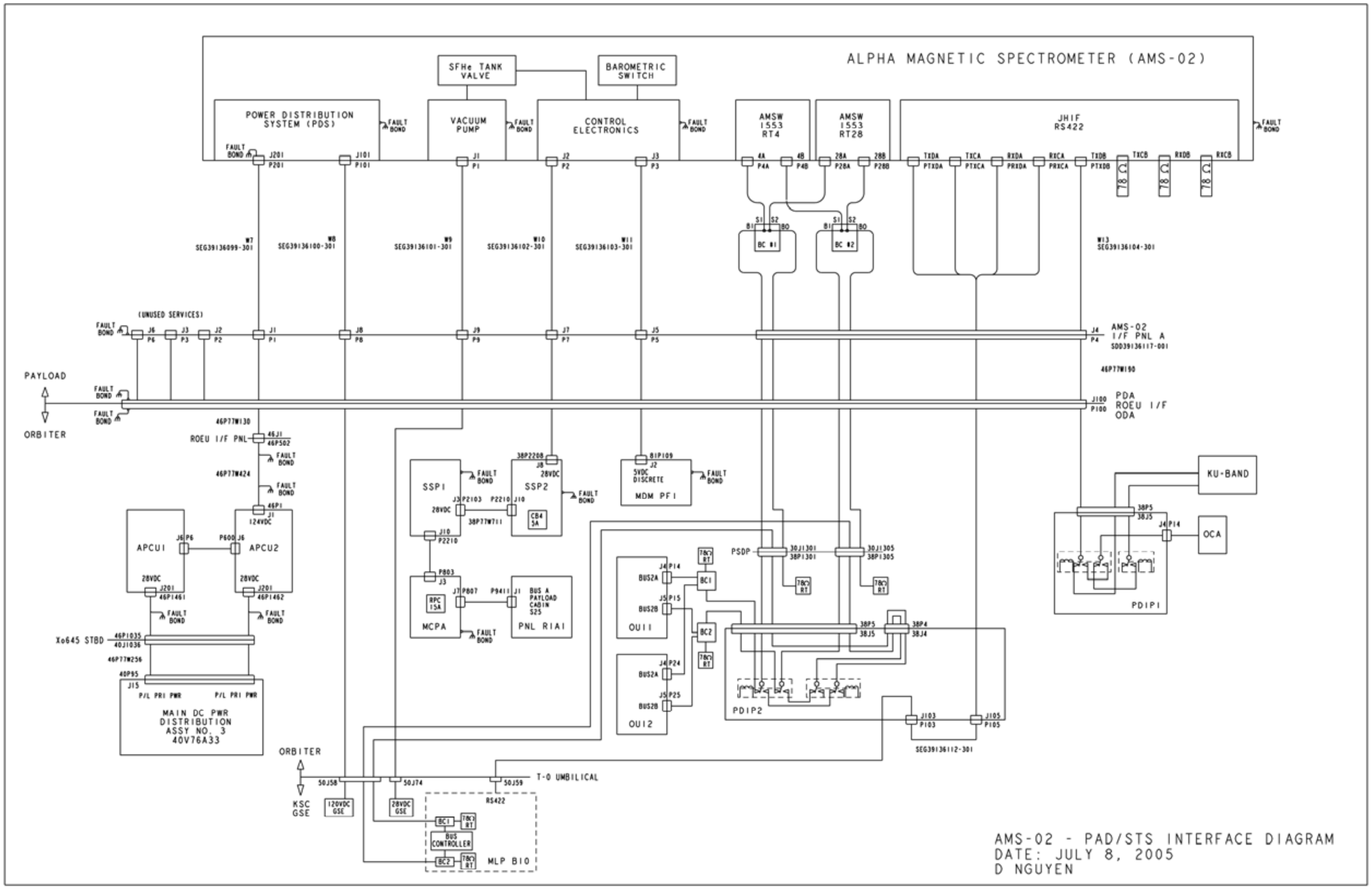


Figure 5.12.7-2 AMS-02 Pad and STS Interface Diagram

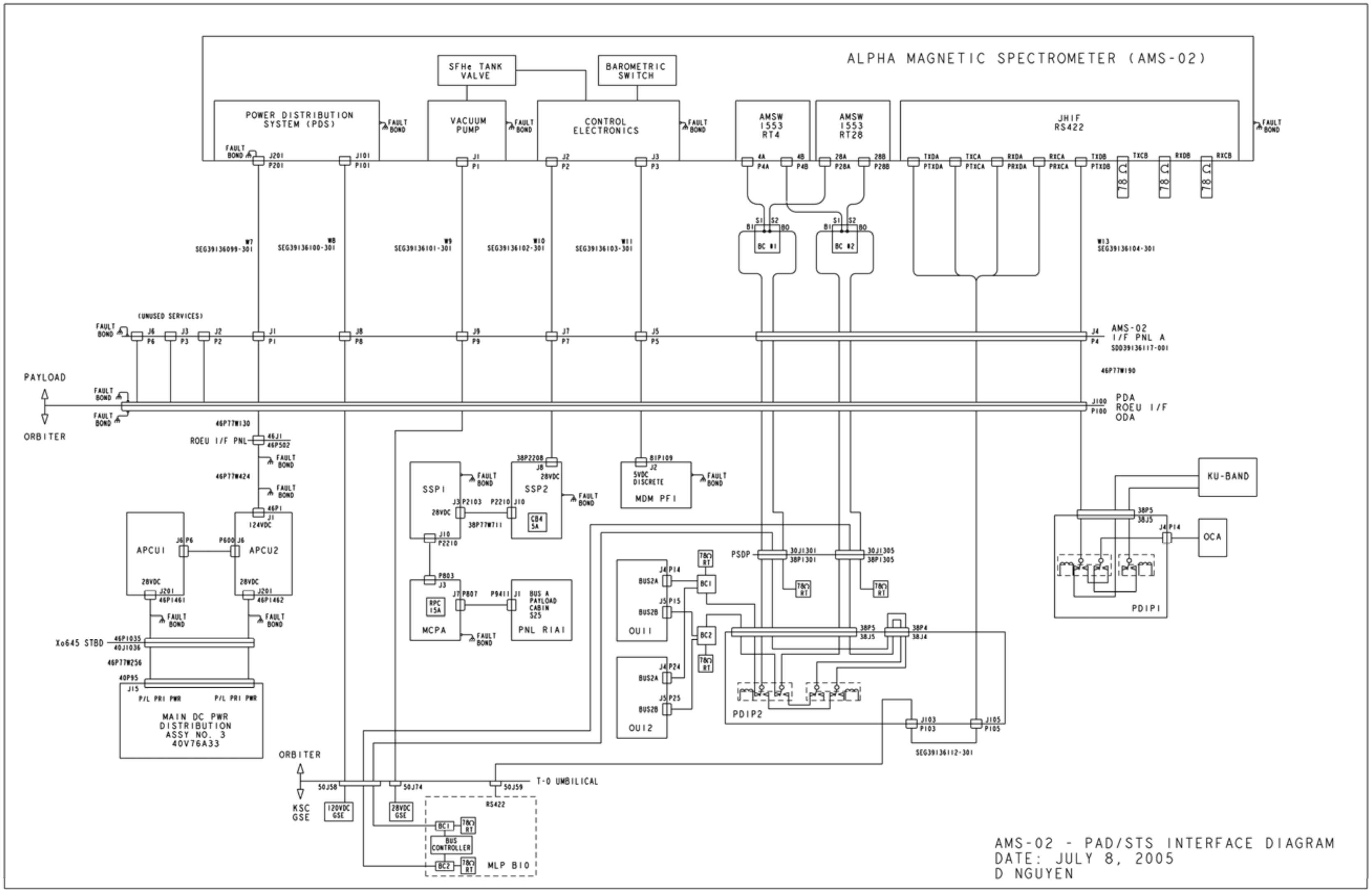


Figure 5.12.7-3 AMS-02 STS Interface Diagram

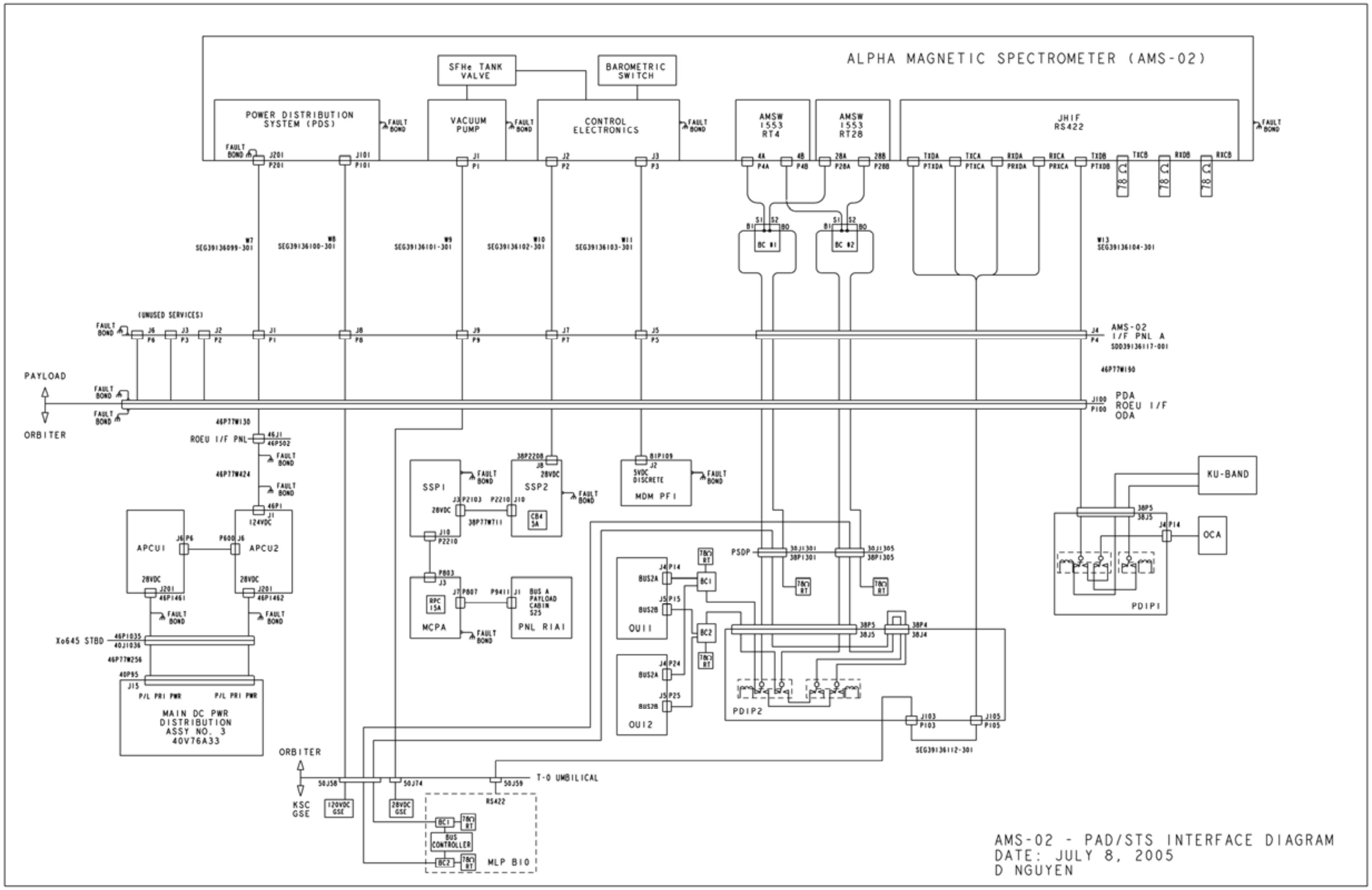


Figure 5.12.7-4 AMS-02 ISS SSRMS Interface Diagram

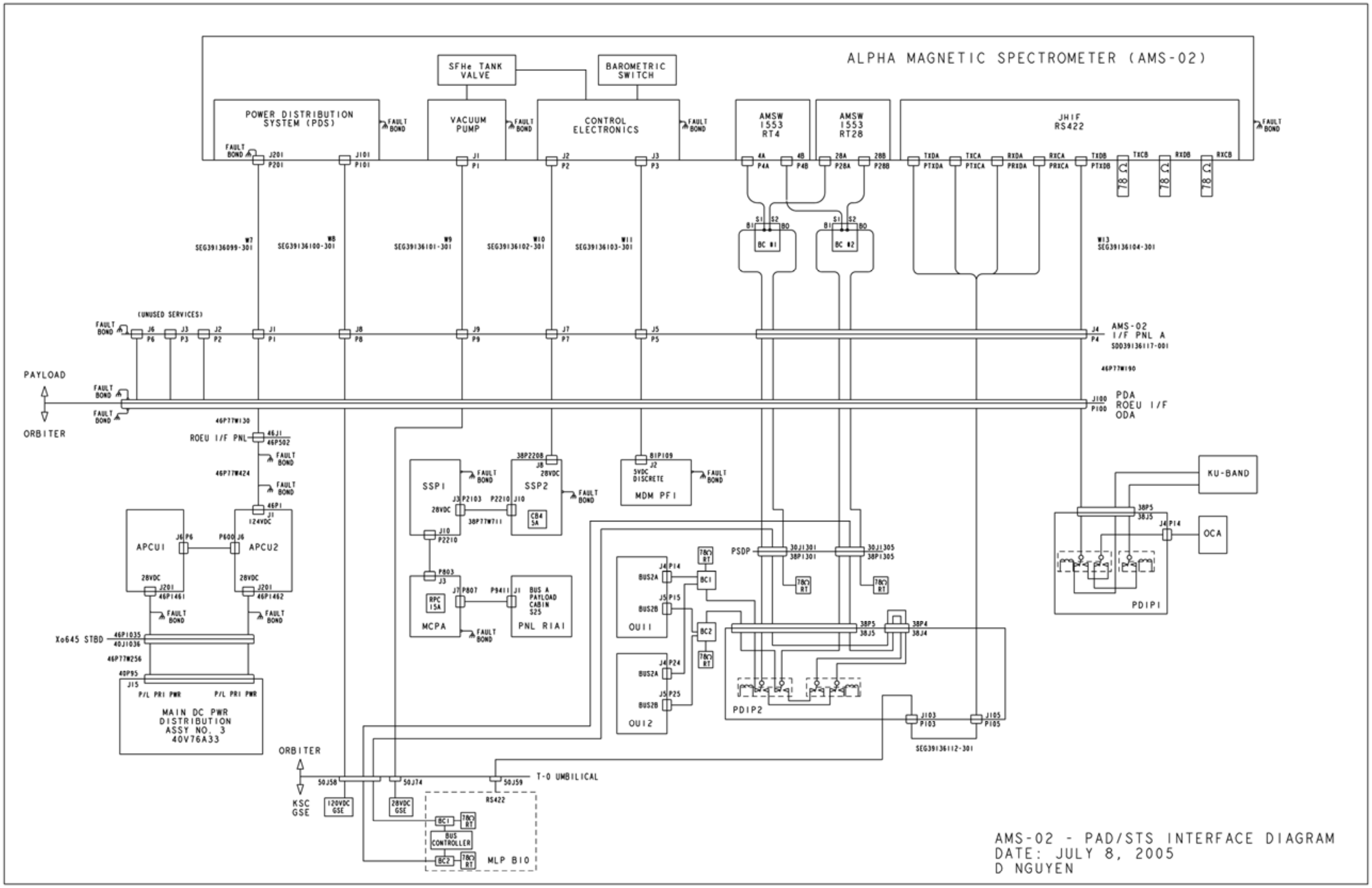


Figure 5.12.7-5 AMS-02 ISS PAS UMA Interface Diagram

The ISS supplies three 8 AWG wires for each of two power buses at the UMA interface. One wire is intended for power, one for return, and the third is a fault ground. The power and return lines are run from a Type II RPCM with an over-current set-point of 25 A. The Fault Ground wires are attached to the truss system as a ground and do not run through the RPCM. The RPCM maintains two fault ground paths:

A. Via a connecting wire from Station Structure through its input connector
B. Conductive path from chassis to structure).

The AMS will take these wires as input thru two separate connectors each into the Power Distribution System (PDS), which has three output sections:

A. 120VDC output
B. 28VDC output
C. Low Voltage (Control and Monitor) output.

The Fault Ground wires are tied to chassis within the PDS and provide the common ground for the entire USS. A short to chassis in the PDS would result in tripping the RPCM and current will be returned to ISS via the Fault Ground to ISS structure. A likely result of a bent pin in the UMA for either the Power or Return lines would be an open-circuit (high voltage/no current) with this implementation. A short circuit between power and return or ground in the UMA would trip the RPCM.

As far as downstream avionics boxes are concerned, extensive effort has been taken to isolate them from the ISS power supply and to current limit the output from the “front-end”. This current limiting and isolation is located within the PDS. So, the amount of current that could flow from a short in a downstream avionics box is very limited and will trip a breaker in milliseconds.

All avionics boxes on the AMS are electrically tied to structure as this provides the common ground. This grounding is effected either through direct bonding across the mechanical attach points via alodined faying surface of the footprint, or by bonding straps that are attached to alodined faying surfaces. All mechanical grounds will be measure post-integration to verify compliance with bonding and grounding requirements.

A type II RPCM is the first level protection for the ISS from the AMS. At 115 +/- percent of max current rating (i.e. 27.5 – 30Amps), the Type II RPCM initiates a current limiting mode at 0.2 milliseconds, and trips between 31 and 38 milliseconds.

Additionally, the PDS will have a Fault Ground wire. The primary purpose of the Fault Ground wire is to protect the ISS and payload against a fault that would dump the full 25A from ISS to payload. The PDS is the front end interface to the ISS Power feed. Protection against this fault is provided by tying these wires to chassis. In the event of a short to chassis, the Fault Ground wire is the lowest resistance return to the power source.

Again, the PDS serves as the front-end for the AMS experiment and it further isolates its outputs from the ISS power supply and provides much lower current limiting with DC to DC converters (current limiting and voltage step-down) and circuit breakers. For all of the lower voltage outputs (28VDC or less) these outputs are limited to 5A except for the CAB and TT-Crates, for which the redundant feeds are limited to 10A.

The only exceptions to this philosophy are the Cryomagnet itself, and the Cryomagnet Current Source. With regard to the Cryomagnet, the power supplied from the Cryomagnet is isolated from the ISS power by input transformer (DC-to-DC converter) with current limiting, but the Cryomagnet does eventually maintain 459Amps, and so extensive work has been done to ensure that this current cannot be released to structure in any failure mode. Additionally, designs are being implemented to ensure that the energy released from a quench is dissipated entirely within the Cryomagnet.

The measurements taken on the sample riveted joint interface (with 10 less rivets than the actual joints will have), led to a resistance measurement of less than 0.02 milliohms. From NSTS 37330, an STS specification, it states that a maximum resistance of .074 milliohms can be used to carry 1000A.

The worst case fault would be a short to chassis on the CAB CCS. This could lead to passing the full fault current directly back to the PDS through the AMS Structure. This would mean, depending of final locations of the PDS/CAB, 30 Amps could flow through the structure for up to 38 milliseconds. Based on the test results stated earlier this does not pose a great concern.

5.12.8 AMS-02 Integration Cabling De-Rating

The AMS-02 integration cabling de-rating information is provided in Table 5.12.8-1.

TABLE 5.12.8-1 AMS-02 INTEGRATION CABLING DE-RATING INFORMATION

Assembly Part Number	*Component Part Number*	*Component Description*	*Specification / Supplier*	*EMC*	*V (max) Rating (VDC)*	*V (max) Applied (VDC)*	*V Ratio*	*V (derating) Required*	*I (max) Rating (Amp)*	*I (max) Applied (Amp)*	*I Ratio*	*I (Derating) Required*	*Notes*
SEG39136099-301	MS3456L24-11SW	Plug, Cable Mount, P201	MIL-C-5015	EO	200	124	0.62	1	-	-	-	-	Box mount connector J201 designated by AMS Collaboration
	ME414-0234-7246	Receptacle, Flange Mount, J1	ME414-0234		200	124	0.62	1	-	-	-	-	Cable mounted connector P1 on cable assy P/N 46P77W190 supplied by program office
	M22759/12-8-9	Wire, 8 AWG, PTFE, Nickel Coated CU	MIL-W-22759/12		600	120	0.20	-	40.86	29.03	0.71	1	Two (2) APCU parallel config, 3600 W @ 124 VDC
SEG39136100-301	MS3456L24-11SW	Plug, Cable Mount, P101	MIL-C-5015	EO	200	120	0.60	1	-	-	-	-	Box mount connector J101 designated by AMS Collaboration
	NB0E18-8SNT3	Receptacle, Flange Mount, J8	40M39569		200	120	0.60	1	-	-	-	-	Cable mounted connector P8 on cable assy P/N 46P77W190 supplied by program office
	M27500-12RE2U00	Cable, 2 Cond, 12 AWG, Nickel Coated CU	MIL-DTL-27500		600	120	0.20	-	24.11	16.67	0.69	1	AMS-02 requires 2 kW for calibration and contingency
SEG39136101-301	NB6GE16-26SNT3	Plug, Cable Mount, P1	40M39569	HO	200	28	0.14	1	-	-	-	-	
	NB0E16-26SNT3	Receptacle, Flange Mount, J9	40M39569		200	28	0.14	1	-	-	-	-	Cable mounted connector P9 on cable assy P/N 46P77W190 supplied by program office
	M27500-20RE2N06	Cable, 2 Cond, 20 AWG, TSP, Nickel Coated CU	MIL-DTL-27500		600	28	0.05	-	6.27	3.5	0.56	1	Vacuum Pump p/n MVP020-3DC, Max current 3.5 A, 24 VDC
SEG39136102-301	NB6GE10-6SNT3	Plug, Cable Mount, P2	40M39569	HO	200	28	0.14	1	-	-	-	-	
	NB0E22-55SNT3	Receptacle, Flange Mount, J7	40M39569		200	28	0.14	1	-	-	-	-	Cable mounted connector P7 on cable assy P/N 46P77W190 supplied by program office
	M27500-20RE2N06	Cable, 2 Cond, 20 AWG, TSP, Nickel Coated CU	MIL-DTL-27500		600	28	0.05	-	6.27	5	0.80	1	Source: Standard Switch Panel circuit breaker rated at 5 A
SEG39136103-301	NLS6GT8-35SNT3	Plug, Cable Mount, P3	40M38277	ML	200	5	0.03	1	-	-	-	-	
	NLS0T14-35SNT3	Receptacle, Flange Mount, J5	40M38277		200	5	0.03	1	-	-	-	-	Cable mounted connector P5 on cable assy P/N 46P77W190 supplied by program office
	M27500-22RE4N06	Cable, 4 Cond, 22 AWG, Nickel Coated CU	MIL-DTL-27500		600	5	0.01	-	4.02	0.02	0.005	1	Source: MDM Low Level Discrete Output (DOL)
SEG39136104-301	5-0051-2-218	Plug, Cable Mount, 450 Series, Twinax, P4A	Trompeter	RF	900	30	0.03	1	-	-	-	-	Box mount connectors 4A, 4B, 28A, 28B, TXDA, TXCA, RXDA, RXCA, and TXDB designated by AMS Collaboration
	5-0051-2-218	Plug, Cable Mount, 450 Series, Twinax, P4B	Trompeter		900	30	0.03	1	-	-	-	-	Trompeter Voltage Rating @ sea level
	5-0051-2-218	Plug, Cable Mount, 450 Series, Twinax, P28A	Trompeter		900	30	0.03	1	-	-	-	-	1553 Application
	5-0051-2-218	Plug, Cable Mount, 450 Series, Twinax, P28B	Trompeter		900	30	0.03	1	-	-	-	-	
	5-0051-2-201	Plug, Cable Mount, 450 Series, Twinax, PTXDA	Trompeter		900	5	0.01	1	-	-	-	-	
	5-0051-2-201	Plug, Cable Mount, 450 Series, Twinax, PTXCA	Trompeter		900	5	0.01	1	-	-	-	-	
	5-0051-2-201	Plug, Cable Mount, 450 Series, Twinax, PRXDA	Trompeter		900	5	0.01	1	-	-	-	-	
	5-0051-2-201	Plug, Cable Mount, 450 Series, Twinax, PRXCA	Trompeter		900	5	0.01	1	-	-	-	-	
	5-0051-2-201	Plug, Cable Mount, 450 Series, Twinax, PTXDB	Trompeter		900	5	0.01	1	-	-	-	-	
	NLS0T16-35SNT3	Receptacle, Flange Mount, J4	40M38277		200	30	0.15	1	-	-	-	-	
	NDBC-TFE-22-2SJ-75	NASA Data Bus Cable, 2 Cond, TSP, 22 AWG, TFE, 75 Ohms	SSQ21655		600	30	0.05	-	4.34	0.25	0.06	1	

TABLE 5.12.8-1 AMS-02 INTEGRATION CABLING DE-RATING INFORMATION (CONTINUED)

Assembly Part Number	*Component Part Number*	*Component Description*	*Specification / Supplier*	*EMC*	*V (max) Rating (VDC)*	*V (max) Applied (VDC)*	*V Ratio*	*V (derating) Required*	*I (max) Rating (Amp)*	*I (max) Applied (Amp)*	*I Ratio*	*I (Derating) Required*	*Notes*
SED39136111-301	NLS6GT12-35P	Plug, Cable Mount, P105	40M38277	RF	200	5	0.03	1	-	-	-	-	
	DAMA-15S	Plug, Cable Mount, P201	MIL-DTL-24308		1250	5	0.004	1	-	-	-	-	
	M22759/12-22-9	Wire, 22 AWG, Nickel Coated CU	MIL-W-22759/12		600	5	0.01	-	3.21	0.25	0.08	1	
SED39136115-801	76000294	DATAFIRE SYNC/570i X.21	DIGI International	RF	300	5	0.02	-	4	0.25	0.06	-	COTS Cable RS422 Application
SEG39136098-301	MS3456L24-11S	Plug, Cable Mount, P100	MIL-C-5015	EO	200	124	0.62	1	-	-	-	-	
	ME414-0235-7247	Plug, Cable Mount, P121	ME414-0235		200	124	0.62	1	-	-	-	-	
	M22759/12-8-9	Wire, 8 AWG, PTFE, Nickel Coated CU	MIL-W-22759/12		600	124	0.21	-	40.86	25	0.61	1	
SEG39136120-301	MS3456L24-11S	Plug, Connector Mount, P200	MIL-C-5015	EO	200	124	0.62	1	-	-	-	-	
	ME414-0235-7247	Plug, Connector Mount, P122	ME414-0235		200	124	0.62	1	-	-	-	-	
	M22759/12-8-9	Wire, 8 AWG, PTFE, Nickel Coated CU	MIL-W-22759/12		600	124	0.21	-	40.86	25	0.61	1	
SEG39136097-301	5-0051-2-218	Plug, Cable Mount, PYA	Trompeter	RF	900	30	0.03	1	-	-	-	-	
	5-0051-2-218	Plug, Cable Mount, PYB	Trompeter		900	30	0.03	1	-	-	-	-	
	MWDM2L-21P-6J7-130	Plug, Cable Mount, PY	MIL-DTL-83513		600	5	0.01	1	-	-	-	-	
	NZGL00T1515N35SA	Receptacle, Wall Mount, NZGL Series, J103	SSQ21635		200	5	0.03	1	-	-	-	-	
	NDBC-TFE-22-2SJ-75	Cable, 2 Cond, 22 AWG, TFE, 75 Ohms	SSQ21655		600	30	0.05	-	4.34	0.2	0.05	1	
	M22759/33-26	Wire, 26 AWG, Silver Plated CU	MIL-W-22759/33		600	5	0.01	-	0.71	0.2	0.28	1	
SEG39136097-303	5-0051-2-218	Plug, Cable Mount, PZA	Trompeter	RF	900	30	0.03	1	-	-	-	-	Only used as contingency for 1553 interface
	5-0051-2-218	Plug, Cable Mount, PZB	Trompeter		900	30	0.03	1	-	-	-	-	
	MWDM2L-21P-6J7-130	Plug, Cable Mount, PZ	MIL-DTL-83513		600	5	0.01	1	-	-	-	-	
	NZGL00T1515N35SA	Receptacle, Wall Mount, NZGL Series, J104	SSQ21635		200	5	0.03	1	-	-	-	-	
	NDBC-TFE-22-2SJ-75	Cable, 2 Cond, 22 AWG, TFE, 75 Ohms	SSQ21655		600	30	0.05	-	4.34	0.2	0.05	1	
	M22759/33-26	Wire, 26 AWG	MIL-W-22759/33		600	5	0.01	-	0.71	0.2	0.28	1	
SEG39136096-301	FODT-PA1720BS	Plug, Cable Mount, PFOMTA	ITT CANNON	FO	-	-	-	-	-	-	-	-	Fiber Optic
	FODT-PA1720BS	Plug, Cable Mount, PFOMRA	ITT CANNON		-	-	-	-	-	-	-	-	
	MS27473E16F8P	Plug, Cable Mount, PEVA-A	MIL-C-38999		200	5	0.03	1	-	-	-	-	
	NZGL00T1717N13SN	Receptacle, Wall Mount, NZGL Series, J101A	SSQ21635		200	5	0.03	1	-	-	-	-	
	NFOC-2FFF-1GRP-1	NASA Fiber Optic Cable	SSQ21634		-	-	-	-	-	-	-	-	
	M27500-16RE2N06	Cable, 2 Cond, 16 AWG, TSP, Nickel Coated CU	MIL-DTL-27500		600	5	0.01	-	12.54	0.5	0.04	1	
SEG39136096-303	FODT-PA1720BS	Plug, Cable Mount, PFOMTB	ITT CANNON	FO	-	-	-	-	-	-	-	-	Only used as contingency for fiber optic interface
	FODT-PA1720BS	Plug, Cable Mount, PFOMRB	ITT CANNON		-	-	-	-	-	-	-	-	
	MS27473E16F8P	Plug, Cable Mount, PEVA-B	MIL-C-38999		200	5	0.03	1	-	-	-	-	
	NZGL00T1717N13SN	Receptacle, Wall Mount, NZGL Series, J101B	SSQ21635		200	5	0.03	1	-	-	-	-	
	NFOC-2FFF-1GRP-1	NASA Fiber Optic Cable	SSQ21634		-	-	-	-	-	-	-	-	
	M27500-16RE2N06	Cable, 2 Cond, 16 AWG, TSP, Nickel Coated CU	MIL-DTL-27500		600	5	0.01	-	12.54	0.5	0.04	1	

TABLE 5.12.8-1 AMS-02 INTEGRATION CABLING DE-RATING INFORMATION (CONTINUED)

Assembly Part Number	Component Part Number	Component Description	Specification / Supplier	EMC	V (max) Rating (VDC)	V (max) Applied (VDC)	V Ratio	V (derating) Required	I (max) Rating (Amp)	I (max) Applied (Amp)	I Ratio	I (Derating) Required	Notes
SEG391360095-303	NZGL06G2525LN7SN	Plug, Cable Mount, NZGL Series, P111	SSQ21635		200	120	0.60	1	-	-	-	-	UMA Connector J1 and pigtail supplied by program
	NZGL06G2525LN7SN	Plug, Cable Mount, NZGL Series, P112	SSQ21635		200	120	0.60	1	-	-	-	-	
	NZGL06G1515N35PA-1	Plug, Cable Mount, NZGL Series, P103	SSQ21635		200	5	0.03	1	-	-	-	-	
	NZGL06G1717N13PN	Plug, Cable Mount, NZGL Series, P101	SSQ21635		200	5	0.03	1	-	-	-	-	
SEG39136084-301	SCBM3W3F0000G	Plug, Cable Mount, P10	Positronic Industries		300	120	0.40	1	-	-	-	-	Connector P10 supplied by External Berthing Cue System (EBCS)
	NB6GE18-8PNT2	Plug, Cable Mount, P131	40M39569		200	120	0.60	1	-	-	-	-	
	M22759/12-12-9	Wire, 12 AWG, PTFE, Nickel Coated CU	MIL-W-22759/12		600	120	0.20	-	23.21	0.42	0.02	1	
SEG39136084-303	SCBM3W3F0000G	Plug, Cable Mount, P13	Positronic Industries		300	120	0.40	1	-	-	-	-	Connector P13 supplied by External Berthing Cue System (EBCS)
	NB6GE18-8PNT2	Plug, Cable Mount, P132	40M39569		200	120	0.60	1	-	-	-	-	
	M22759/12-12-9	Wire, 12 AWG, PTFE, Nickel Coated CU	MIL-W-22759/12		600	120	0.20	-	23.21	0.42	0.02	1	
SEG39136093-301	SCBM5W5F0000G	Plug, Cable Mount, P11	Positronic Industries		300	120	0.40	1	-	-	-	-	PVGF and pigtail supplied by program
	SCBM5W5F0000G	Plug, Cable Mount, P8	Positronic Industries		300	120	0.40	1	-	-	-	-	Connectors P11, P8, P7, P6, P5, P4, and P3 supplied by EBCS
	225609-4	Plug, Cable Mount, P7	AMP Inc		750	2	0.003	1	-	-	-	-	
	225609-4	Plug, Cable Mount, P6	AMP Inc		750	2	0.003	1	-	-	-	-	
	225609-4	Plug, Cable Mount, P5	AMP Inc		750	2	0.003	1	-	-	-	-	
	NB6E10-6SNT2	Plug, Cable Mount, P24	40M39569		200	120	0.60	1	-	-	-	-	
	NB6E18-8SNT2	Plug, Cable Mount, P23	40M39569		200	120	0.60	1	-	-	-	-	
	NB6E18-8SNT2	Plug, Cable Mount, P22	40M39569		200	120	0.60	1	-	-	-	-	
	BJ379-45	Plug, Cable Mount, P21	Trompeter		900	30	0.03	1	-	-	-	-	
	BJ379-45	Plug, Cable Mount, P20	Trompeter		900	30	0.03	1	-	-	-	-	
	BJ379-45	Plug, Cable Mount, P19	Trompeter		900	30	0.03	1	-	-	-	-	
	142-0303-401	Plug, Cable Mount, P4	Johnson Components		65	2	0.03	1	-	-	-	-	
	142-0303-401	Plug, Cable Mount, P3	Johnson Components		65	2	0.03	1	-	-	-	-	
Miscellaneous Items													
SDD39136117-001	650BS001M22	J2 Stowage Connector	MIL-C-5015		200	28	0.14	1	-	-	-	-	
	650BS001M22	J3 Stowage Connector	MIL-C-5015		200	28	0.14	1	-	-	-	-	
	NLS0T14-35SA	J6 Stowage Connector	40M38277		200	28	0.14	1	-	-	-	-	
SDG39136119-001	MS3115-10L	J24 Stowage Connector	MIL-C-26482		200	120	0.60	1	-	-	-	-	
	MS3115-18L	J23 Stowage Connector	MIL-C-26482		200	120	0.60	1	-	-	-	-	
	MS3115-18L	J22 Stowage Connector	MIL-C-26482		200	120	0.60	1	-	-	-	-	
	TNT1-1-78	J21 78 Ohm Terminator	Trompeter		900	30	0.03	1	-	-	-	-	
	TNT1-1-78	J20 78 Ohm Terminator	Trompeter		900	30	0.03	1	-	-	-	-	
	TNT1-1-78	J19 78 Ohm Terminator	Trompeter		900	30	0.03	1	-	-	-	-	
	142-0801-861	J4 50 Ohm Terminator	Johnson Components		250	2	0.01	1	-	-	-	-	
	142-0801-861	J3 50 Ohm Terminator	Johnson Components		250	2	0.01	1	-	-	-	-	
RS422 Terminators	TNG451P-1-78	TXCB 78 Ohm Terminator	Trompeter		900	5	0.01	1	-	-	-	-	
	TNG451P-1-78	RXDB 78 Ohm Terminator	Trompeter		900	5	0.01	1	-	-	-	-	
	TNG451P-1-78	RXCB 78 Ohm Terminator	Trompeter		900	5	0.01	1	-	-	-	-	

5.12.9 AMS-02 Data Systems and Interfaces

The AMS-02 payload uses a series of computers to process commands and data. The AMS-02 computers and their functions have been reviewed and deemed pertinent to mission success only. The only computer control that is a safety critical function is the sequence of commands to execute magnet charging, and the AMS-02 main data computers have no commands stored on-board to perform this function; it requires an up-linked command sequence to execute. Moreover, this function can only be performed during flight on the ISS when magnet charging is intended, as the only primary power interface connection that allows magnet charging is via the UMA when the AMS-02 payload is berthed at the CAS. Magnet charging is possible pre-flight via power connections through the T0 umbilical; however, it again requires an transmitted (non-stored) command sequence to execute and is not intended to be performed. Since the AMS-02 experiment computer avionics systems are mission success oriented, and not safety critical, the description of these AMS-02 command and data systems is top-level, and provided for informational reference only.

The top level-computer, to which command and data services are interfaced on both the STS and the ISS, is called the Main Data Computer (JMDC), located in the J-Crate. Figure 5.12.9-1 provides an overview of the AMS avionics elements. Figure 5.12.9-2 depicts the NASA provided interfaces on the ISS and STS, as they are routed to the AMS-02 experiment top-level avionics.

For the JMDC, as well as all other electronics, AMS-02 has taken the high performance technologies used in particle physics and implemented them for use in low Earth orbit. A unified approach has been made to meet the requirements imposed by the different AMS-02 subdetectors, by NASA and most importantly, by the physics goals. Particular effort has been made to ensure that the data acquisition and trigger electronics will meet the performance requirements on orbit during the 3-5 years of operation. Meeting the challenges of implementing high performance, space qualified electronics has been a key activity of the entire AMS-02 collaboration.

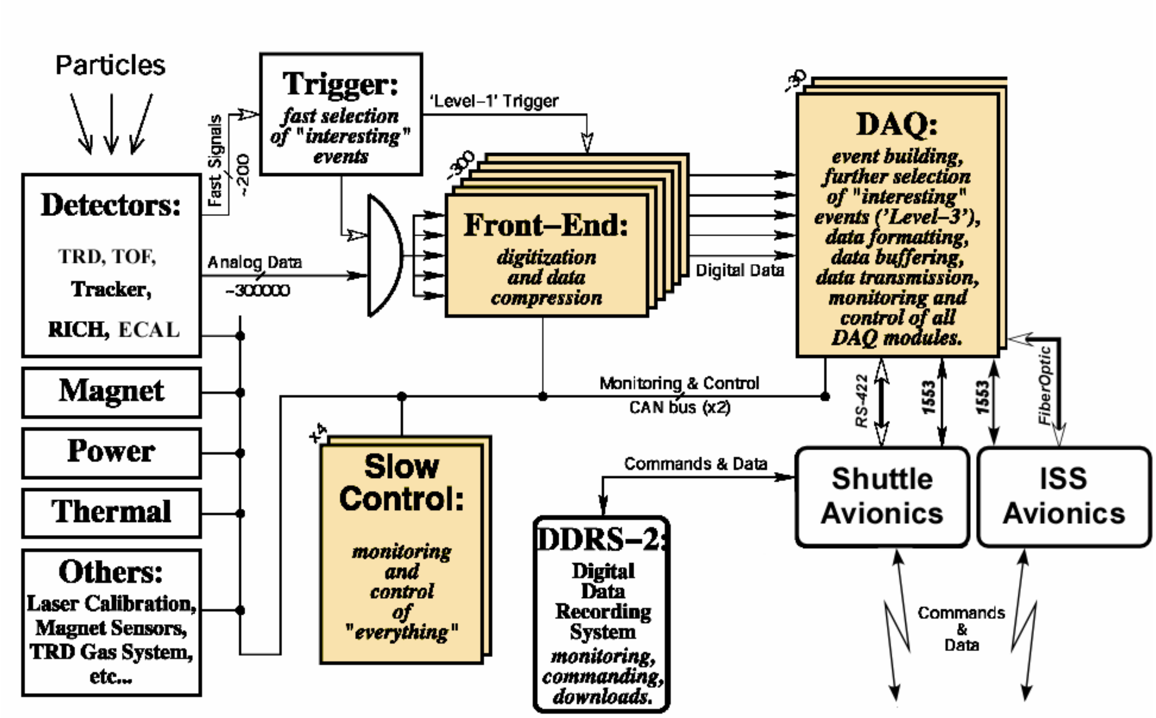


Figure 5.12.9-1 AMS-02 Electronics Elements

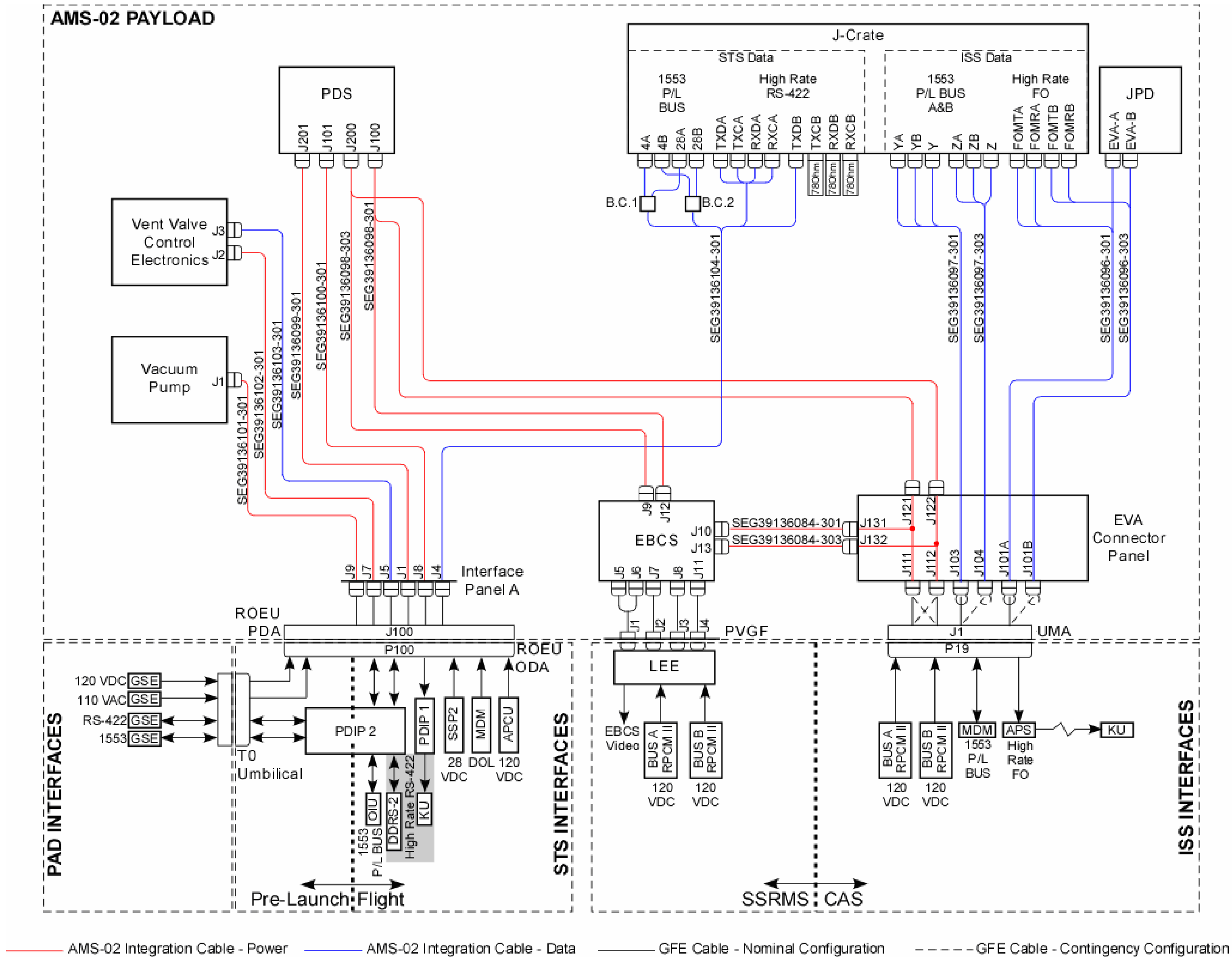


Figure 5.12.9-2 AMS-02 Electronics Interfaces

5.12.9.1 Data Interface for Ground Operations in the STS

During ground operations, control and data systems monitor capability will be provided by GSE located in the Mobile Launch Platform, connected via the T0 Umbilical, and through the Remotely Operated Electrical Umbilical (ROEU) to the experiment electronics. The command and data monitor capabilities are via both low-rate 1553 Bus and high-rate data system RS422 protocol serial dual communications.

As shown in Figure 5.12.9.1-1 below, low rate data (1553) is routed through T0 umbilical from the Shuttle Payload Data Interface Panel #2 (PDIP2) with the “AMS-02 1553” switch in the “T0” position, and a program provided jumper installed on PDIP2 front panel “J4” connector. High rate data (RS422) is routed through T0 umbilical from Shuttle PDIP2 via a payload provided cable installed between the PDIP2 front panel “J103” and “J105” connectors.

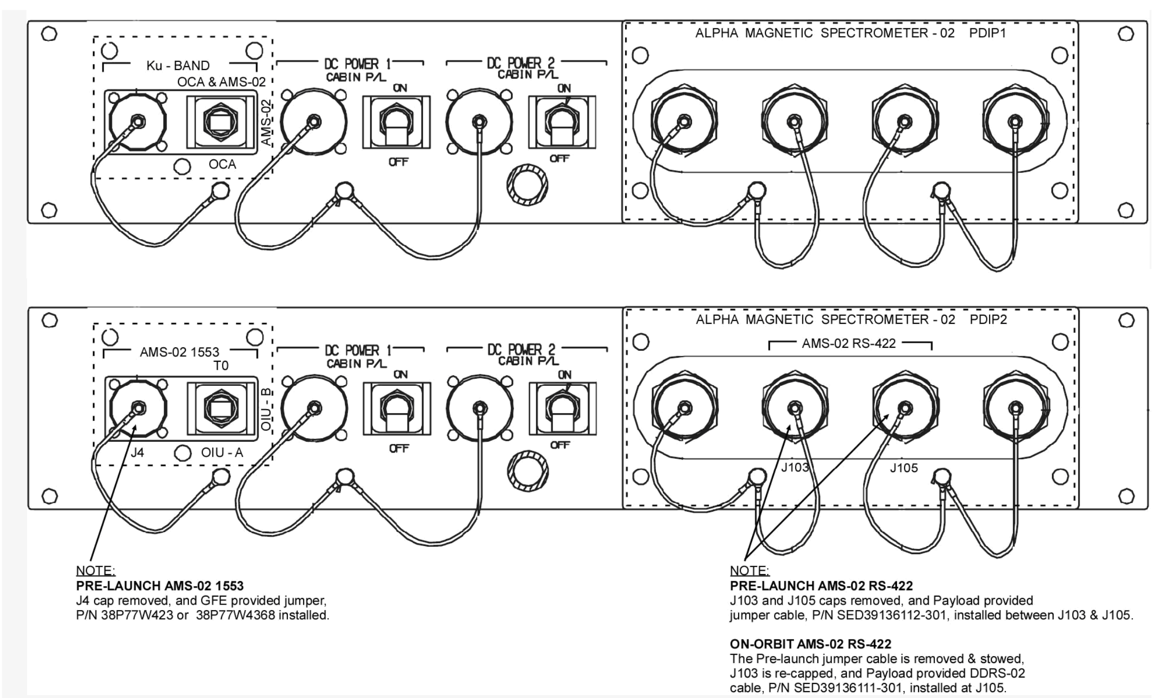


Figure 5.12.9.1-1 Payload Data Interface Panel #1 and #2 (PDIP1 and PDIP2) Layout

5.12.9.2 Ascent Data Interface on the STS

As discussed in Section 5.12.2.2, during Ascent it is required to open the SFHe Vent Valve. This valve must be opened prior to the Orbiter getting on-orbit, to allow venting of the boil-off Helium once the pressure in the Payload Bay drops below the operating pressure of the SFHe Tank. There are two means of ensuring that this vent valve opens, as discussed in Section 5.12.2.2. Should the vent valve fail to open, burst disks will vent the He boil-off, thus preventing helium tank rupture. The BFS GPC supplied DOL command, which is the back-up method, is interfaced to the AMS-02 payload via the ROEU.

5.12.9.3 Data Interface for On-Orbit Operations on the STS

Once on-orbit, and while in the Shuttle payload bay, command and monitoring capability is supplied via both 1553 Bus and RS422 serial communications each routed through the ROEU to the experiment electronics.

Following Post-Insertion activities, payload activation activities are expected to begin at approximately MET 00/02:30. At this time, a mid-deck locker stowed, STS provided, Next Generation Laptop System (NGLS, formerly PGSC) computer will be un-stowed, set-up, and activated on the Orbiter Aft Flight Deck (AFD). Setup includes the removal of the payload provided cable between front panel “J103” and “J105” connectors on PDIPD2, on the AFD, and attachment of a new payload provided cable to the PDIP2 “J105” (Figure 5.12.9.1-1) to interface with the NGLS, as shown in Figure 5.12.9.3-1 . The new cable will include a built-in multiplexer to interface the RS-422 signals into a USB on the NGLS for recording. This NGLS in conjunction with the payload cable is referred to as the AMS-02 Digital Data Recording System (DDRS-02); and will be used to record all high rate data generated by AMS-02 during checkout activities. Concurrent to these activities, or prior to them, the Orbiter Interface Unit (OIU) should be powered up and checked out in preparation for communication with the AMS-02 payload via PDIP2, with “AMS-02 1553” switch in “OIU” position (Figure 5.12.9.1-1).

During avionics checkout, RS-422 data is recorded on the hard-drive of the NGLS continuously, and AMS-02 RS-422 data from another feed-thru on the Payload Data

Interface Panel #1 (PDIP1) assembly, with the "Ku-Band" switch in the "AMS-02" position (Figure 5.12.9.1-1), will be down-linked via the STS Ku-Band as coverage and scheduling permit.

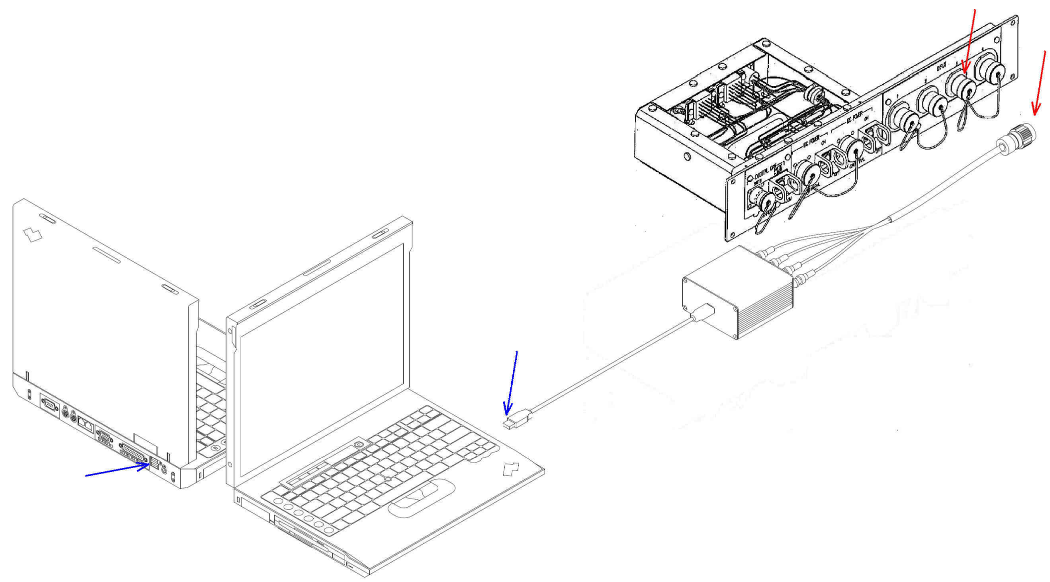


Figure 5.12.9.3-1 DDRS-02, PGSC/NGLS to PDIP2 Interface

5.12.9.4 Data Interface for Extra Vehicular Robotics (EVR) Activities

Just prior to transfer activities, the AMS-02 is powered down and the ROEU is disconnected from the PDA attached to the AMS-02. The AMS-02 is grappled by the SRMS via a FRGF attached to the payload. The FRGF has no data interface capabilities.

The SRMS maneuvers the AMS-02 for an Arm-to-Arm transfer to the SSRMS. The SSRMS grapples the payload via a PVGF located on the opposing side of the AMS-02 from the FRGF. The PVGF provides video signal interface for use by the EBCS camera during berthing operations. Additionally, the PVGF has 1553 Bus interface capability; however, this is not being utilized by the AMS-02 payload. During this mission phase, the AMS-02 payload requires only 120 VDC power via the PVGF for thermostatically controlled keep-alive heater power.

5.12.9.5 Data Interface for ISS Operations

All data services for the AMS-02 payload are provided through an Umbilical Mechanism Assembly (UMA) mounted to the Payload Attach Site. The interface consists of a low data rate link (LRDL) and a high data rate link (HRDL).

5.12.9.5.1 ISS Low Rate Data Link (LRDL) Interface

The LRDL used on ISS, like the STS LRDL, is based on the MIL STD 1553B dual serial bus. This is split to each of the four JMDCs in the J-Crate, one of which is selected to actively manage the link. As the point of splitting is a possible single point failure, AMS has two such splitters which can be selected by an astronaut swapping a cable on the EVA Connector Panel located at the bottom of the experiment, as shown in Figure 5.12.9.5.1-1, during a contingency EVA. This contingency capability is available for data transmission recovery on ISS only.

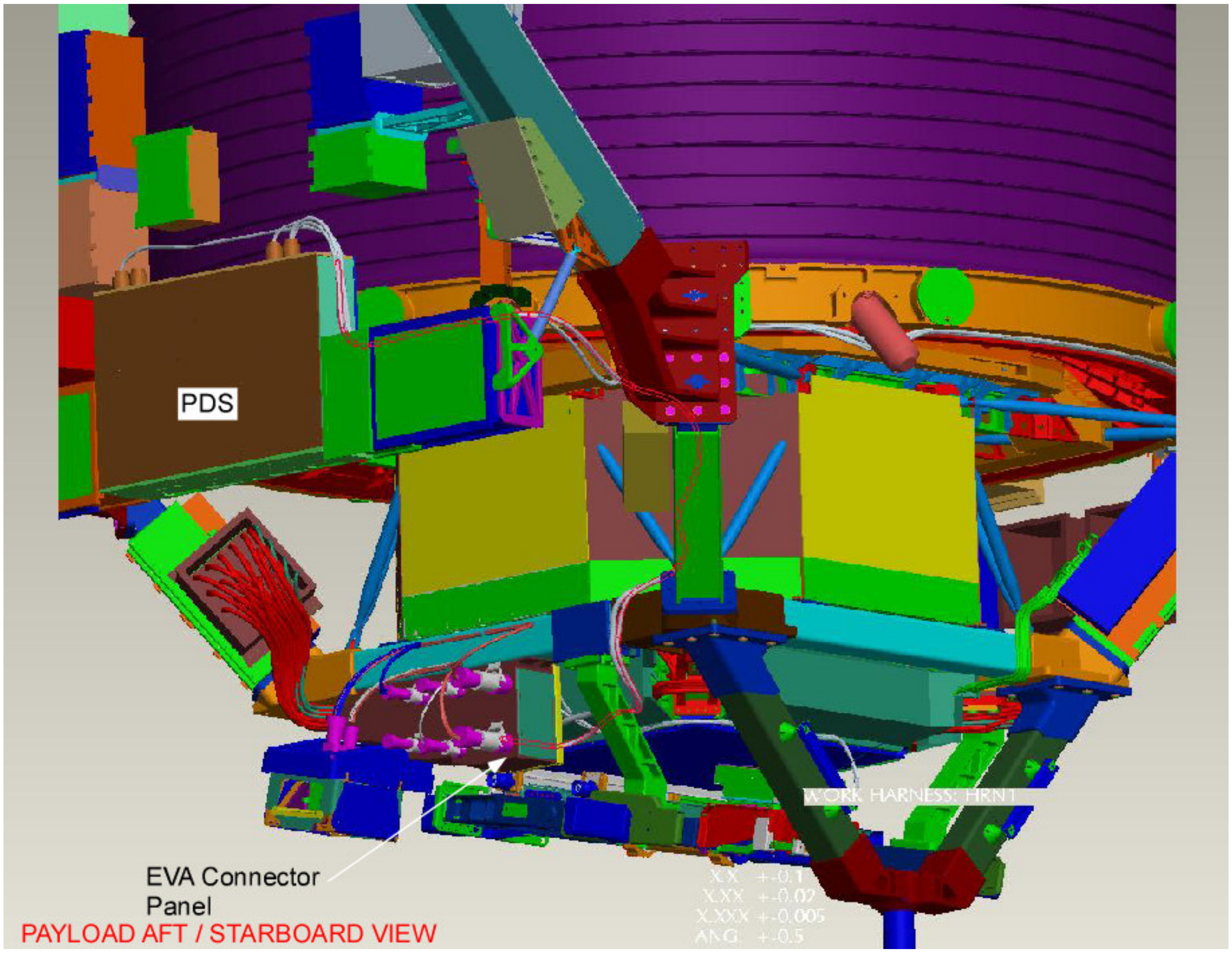


Figure 5.12.9.5.1-1 EVA Panel Location

The active JMDC receives commands and redistributes them within AMS, either to other software within that JMDC, to another JMDC or to the controllers of other electronics subsystems. The intra-experiment command and data monitoring communications are accomplished via either AMSWire protocol (similar to SpaceWire) or CAN Bus. The controllers in turn set switches and digital to analog converters (DACs) to control various experimental parameters, such as voltages. They also monitor numerous temperatures, voltages and currents and report these values when requested to the active JMDC, where they are appropriately formatted and sent on to the LRDL.

The LRDL telemetry data is then processed through the ISS avionics and down-linked, where it is routed to the AMS Payload Operation and Control Center (POCC). The NASA avionics involved include : the S-band (intended for transmission of Critical

Health Data) with 50% duty cycle, the ACBSP S-band receiver, the Command and Control Multiplexer/Demultiplexer (C&C MDM), the Payload Multiplexer/Demultiplexer (P/L MDM), the Automated Payload Switch (APS), the High Rate Communications Outage Recorder (HCOR), the High Rate Frame Multiplexer & High Rate Modem (HRFM/HRM), the Ku-band system connecting the ISS via the Tracking and Data Relay Satellite (TDRS) through the White Sands Ground Complex (WSGC) to the Marshall Space Flight Center (MSFC) and the Johnson Space Center (JSC). Within the US Lab on the ISS, the astronaut crew has access to this data via their Portable Control System (PCS).

In total AMS is allocated about 20 KBits/sec of data bandwidth on the LRDL, with an expected duty cycle of up to 70%. Ten highly summarized bytes per second of critical health data are being proposed to be transmitted via the S-Band system with near to 100% duty cycle. Along the way the ISS crew and NASA ground controllers can monitor this data and, should the need arise, have the facility to issue a few key commands, for example to put the experiment into a standby state. In nominal conditions, all commands originate in the POCC and follow the inverse path, the maximum command rate being about 1 Kbit/second.

As commanding and telemetry are critical to the operation of the experiment and as the NASA provisions for payloads are not fault tolerant, substantial effort has been made to implement a parallel set of the LRDL data paths over the HRDL for both monitoring and commanding of AMS-02.

5.12.9.5.2 ISS High Rate Data Link (HRDL) Interface

The HRDL is the main data conduit out of AMS-02. It is based on a NASA specific implementation of fiber optic communications. The link can move data on the ISS at speeds up to 90 MBit/sec, and the radio down link supports up to 43 Mbit/sec, again with an at best duty cycle of 70%. Of this AMS has been allocated an orbit average of 2 Mbit/sec. Within AMS-02, the data is collected by the data acquisition (DAQ) system to a buffer within the JMDCs. As with the LRDL, each of the four JMDC is connected to the HRDL and a cable swap during EVA avoids a possible single point of failure. On the

HRDL the data flows over the paths shown in Figure 5.12.9.5.2-1. A key element in this path is. On the ground the data is routed to the AMS-02 POCC and Science Operation Center.

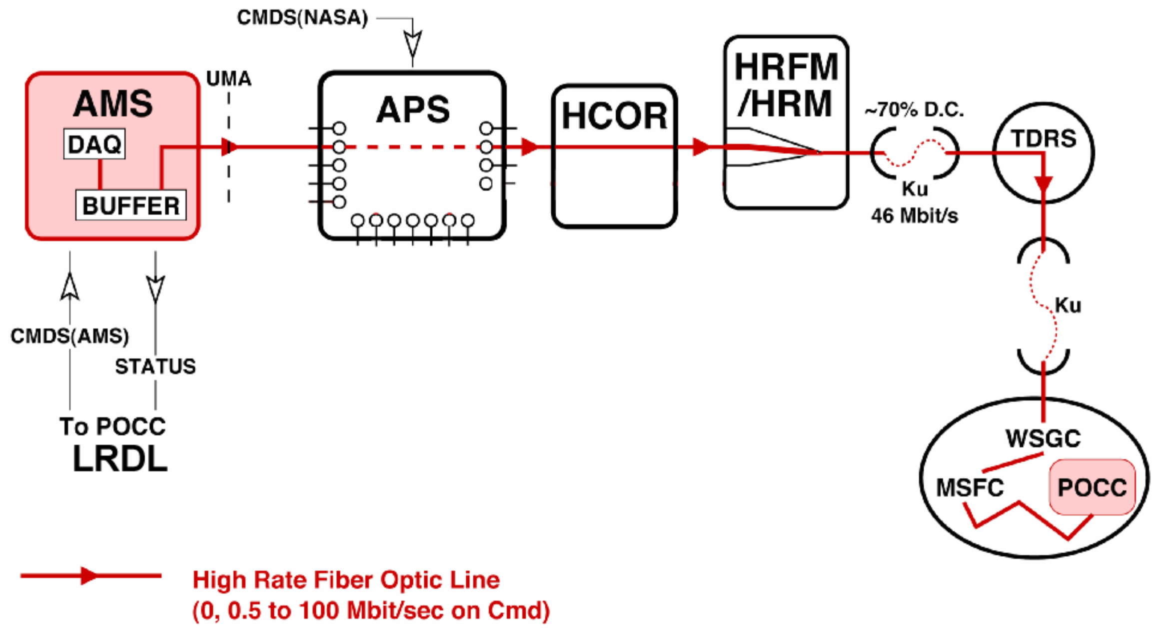


Figure 5.12.9.5.2-1 AMS-02 Science data flow over the of HRDL

5.13 THERMAL CONTROL SYSTEM (TCS)

The AMS-02 Thermal Control System (TCS) is being developed and designed by the AMS experiment team. During nominal operations on ISS, AMS-02 draws up to 2600 watts of power. This power must be dissipated as heat, while maintaining all components within their temperature limits and maintaining the Vacuum Case as cold as possible. The payload also must be able to survive STS environments, handoff between STS and ISS, periods with no power (both during transfer and while berthed on ISS) and peak power excursions (e.g. Cryomagnet charging). Passive thermal design options are utilized as much as possible, but more complex thermal control hardware is required for some sub-detector components to assure mission success. TCS specific hardware includes radiators, heaters, thermal blankets, heat pipes, loop heat pipes, optical coatings and a dedicated CO_2 pumped loop system for Tracker cooling. AMS-02 is designed such that passive thermal control is all that is required to sustain the payload safely through extended periods of power loss without hazard.

5.13.1 Radiators

Most of the heat generated by AMS-02 is rejected to space via dedicated radiators (Figure 5.13.1-1). Ram and Wake Main radiators dissipate heat from numerous electronics crates. Ram and Wake Tracker radiators reject the heat generated inside the Tracker. A zenith radiator rejects heat from the Cryocoolers.

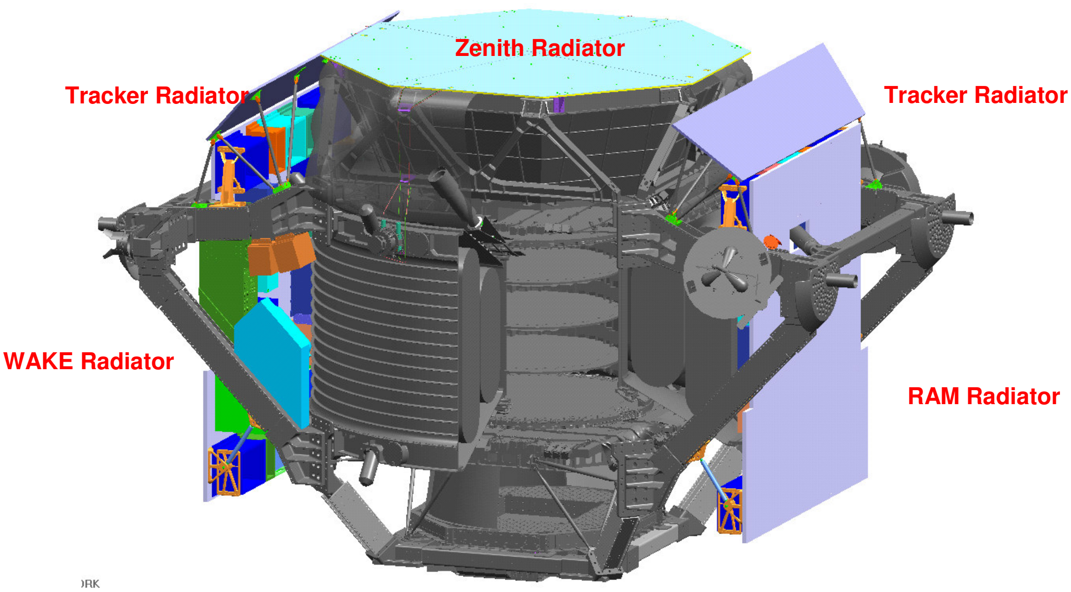


Figure 5.13.1-1 AMS-02 Radiators

5.13.1.1 MAIN (Electronics Crate) Radiators

The Ram and Wake Main Radiators are designed to both dissipate heat from the electronics crates and provide their structural support. The crates, which are optimized to transfer heat to the radiator, are bolted directly to the honeycomb panel using inserts. A silicone based thermal interface filler, Chotherm 1671, is used to minimize the thermal resistance across this interface. During nominal operations the Ram radiator dissipates 525 watts over its 4.24 m^2 surface area, while the Wake dissipates up to 812 watts over its 3.99 m^2 area. Heaters mounted on these radiators are used to bring electronics above their minimum turn-on temperature after periods without power. The outer surfaces of the radiator face sheets are painted with SG121FD white paint to optimize heat rejection. Portions of the crates and inner radiator surfaces are covered with MLI blankets to minimize heat rejection back to the vacuum case and to adjacent ISS payloads.

These radiators consist of a 25mm thick ROHACELL® 51WF core with 0.5mm thick 2024 T81 aluminum face sheets and imbedded heat pipes. A cross section is shown in Figure 5.13.1.1-1. Heat pipe layout are shown in Figures 5.13.1.1-2 a and b. The heat pipes are standard axial groove, made of aluminum 6063-T5 and filled with high purity ammonia. Each Main Radiator mounts to the USS-02 at six locations. Two brackets at the top fix the radiator to the Upper Trunnion Bridge Beams; two mid-brackets fix the middle portion of the radiator to the Lower Trunnion Bridge Beams and two pin-ended struts span the distance from the lower row of crates on the radiator to the Lower Vacuum Case Joint (Figure 5.13.1.1-3).

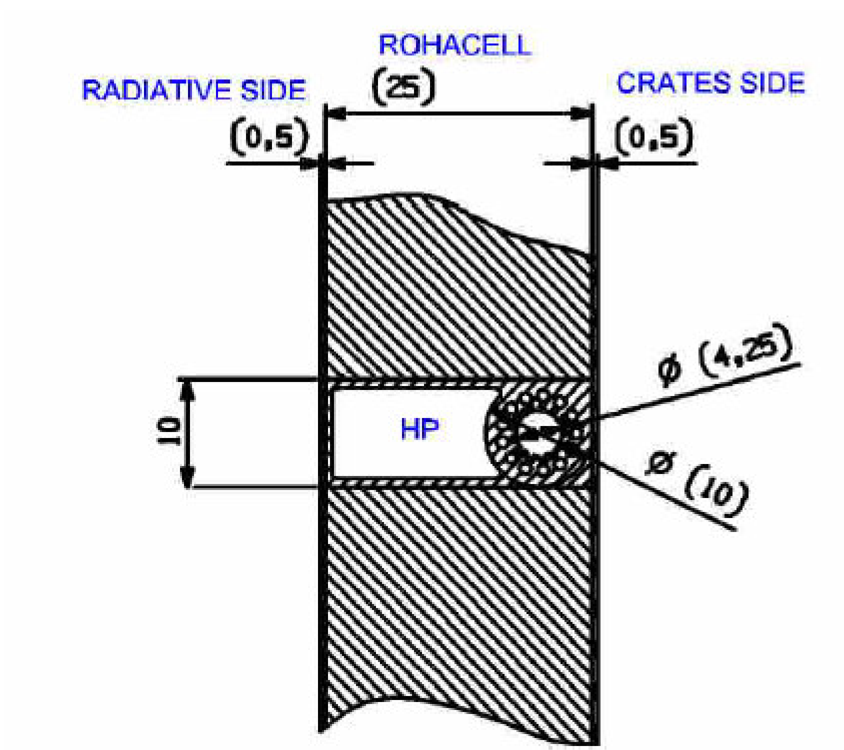
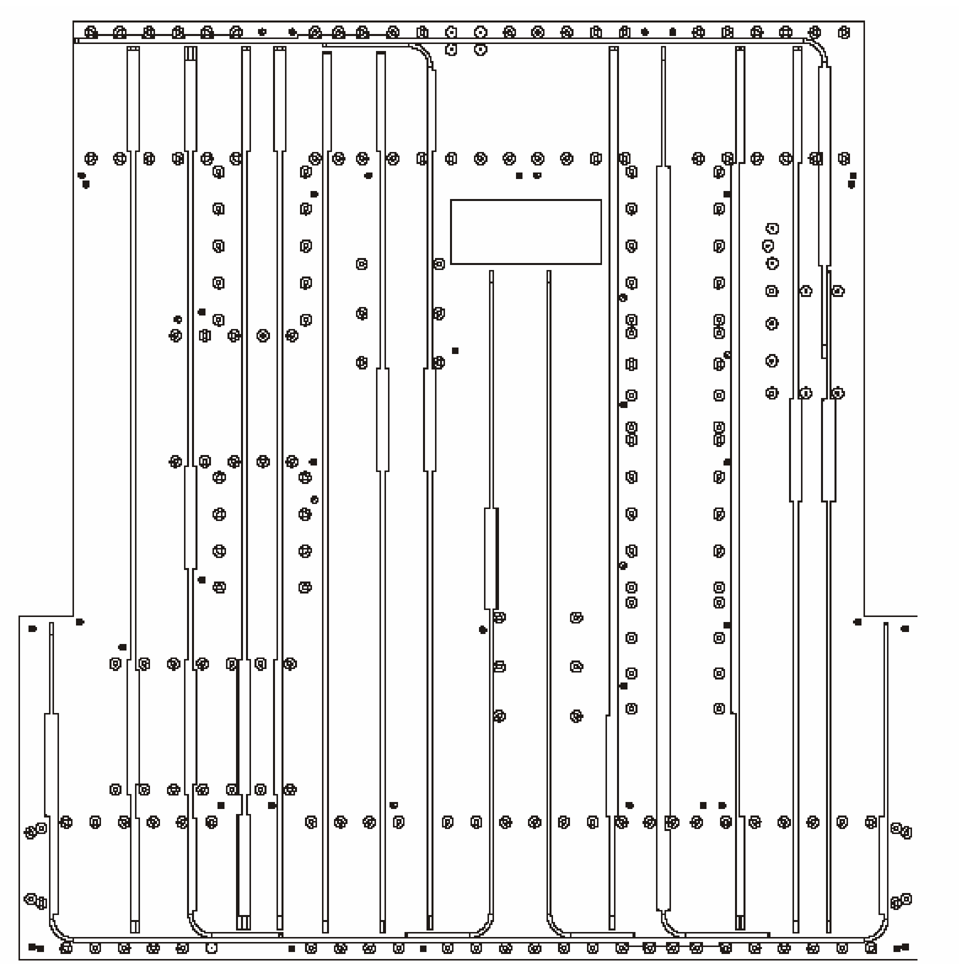
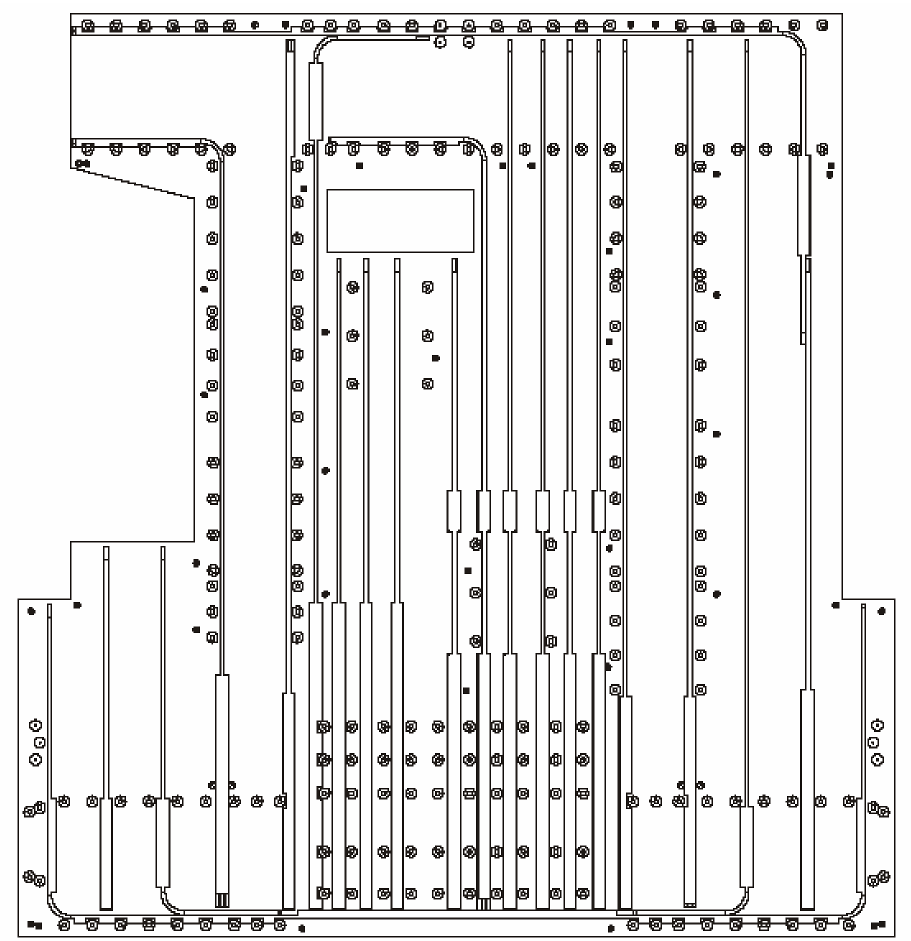


Figure 5.13.1.1-1 Main Radiator Cross Section



a) Ram Main Radiator Heat Pipes



b) Wake Main Radiator Heat Pipes

Figure 5.13.1.1-2 Ram and Wake Main radiator Heat Pipe Layout

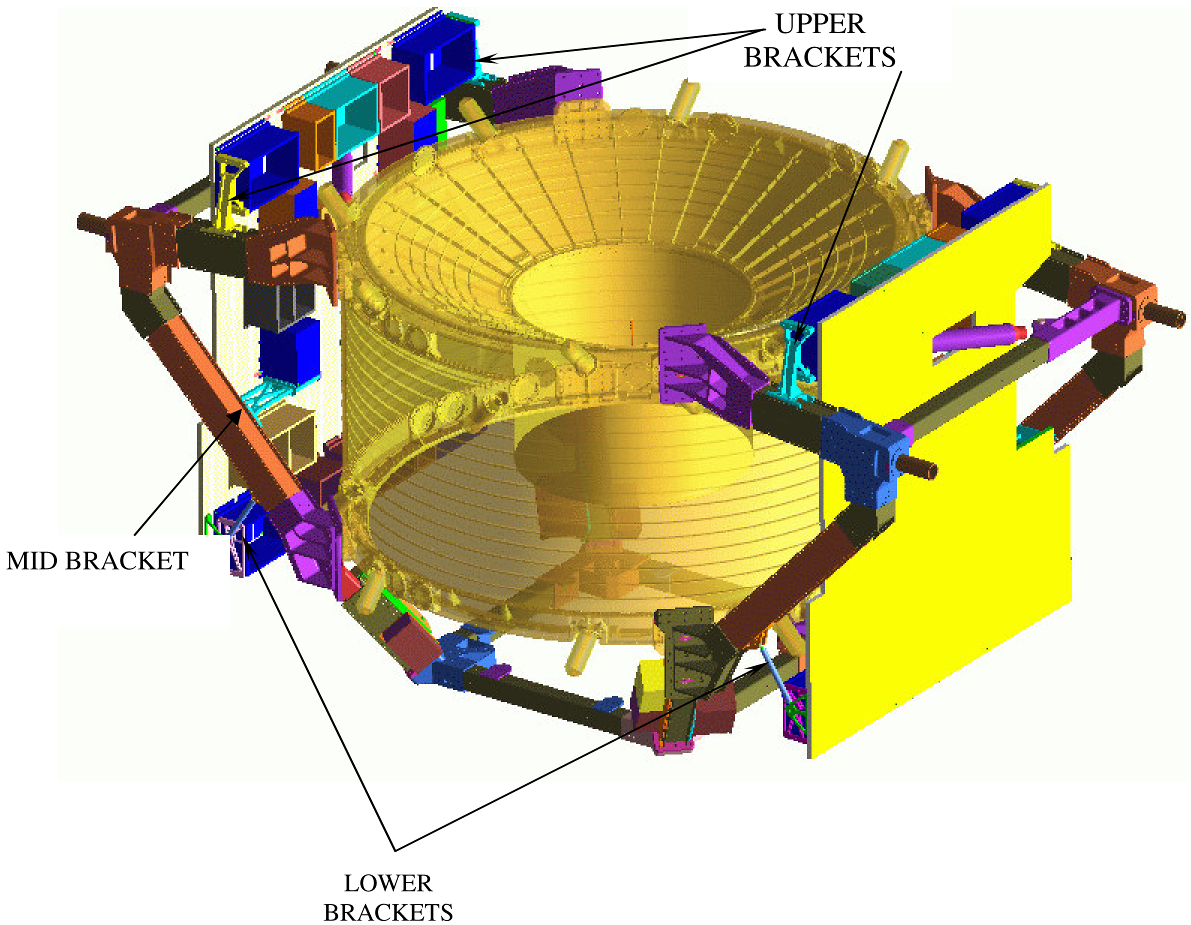


Figure 5.13.1.1-3 Main Radiator Attachment to USS-02

5.13.1.2 Tracker Radiators

The Ram and Wake Tracker radiators are designed to reject the heat transported by the Tracker Thermal Control System (TTCS), a two-phase CO_2 loop running from inside the Tracker (~144 watts) to condensers mounted on the Radiators (Figures 5.13.1.2-1 and 5.13.1.2-2). This CO_2 cooling loop is discussed in more detail in Section 5.13.6. Tracker radiators use Aluminum 2024 T81 face sheets with a ROHACELL® 51WF core and imbedded aluminum/ammonia heat-pipes (Figure 5.13.1.2-3). The tracker radiators are trapezoidal, with a lower width of 2126.8 mm, an upper width of 2600 mm, and a height of 518.6 mm. 7 heat pipes are embedded in each Tracker Radiator (Figure 5.13.1.2-4). CO_2 loop condensers mount directly to the heat pipes by bolting through the radiator (Figure 5.13.1.2-5). Each radiator is mounted using 8 pin-ended struts; 1

attached to each of the Upper Trunnion Bridge Beams and 3 attached to each of the Upper Vacuum Case joint (Figure 5.13.1.2-2). There is also a bracket attaching each Tracker Radiator to the adjoining Main Radiator. The outer surfaces of the Tracker Radiators are painted with SG121FD white paint. The back sides will be covered with MLI blankets.

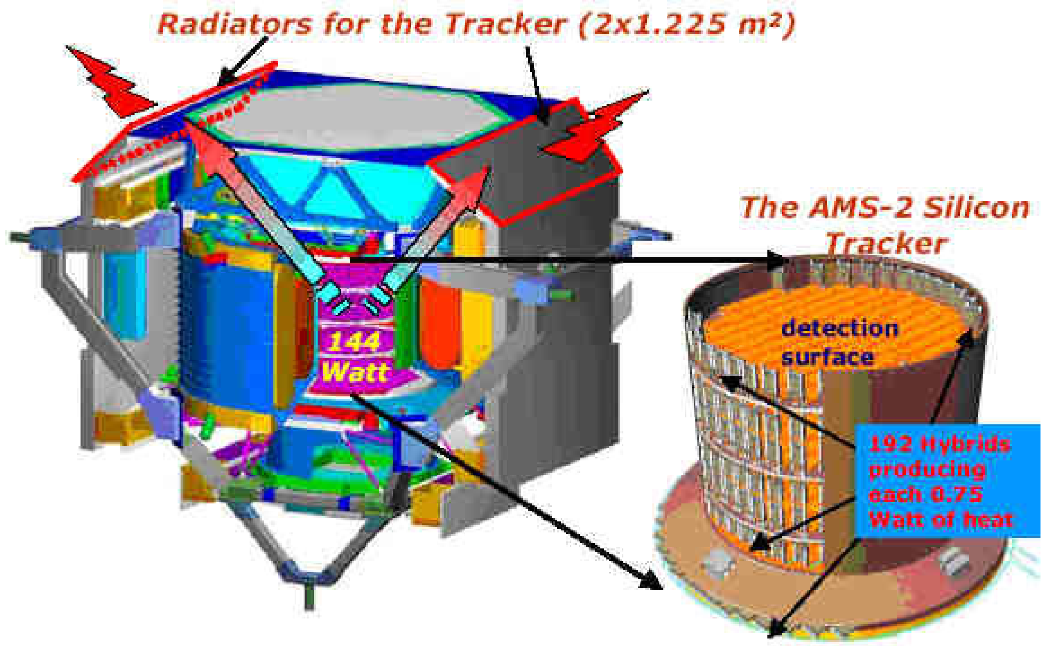


Figure 5.13.1.2-1 Tracker Cooling

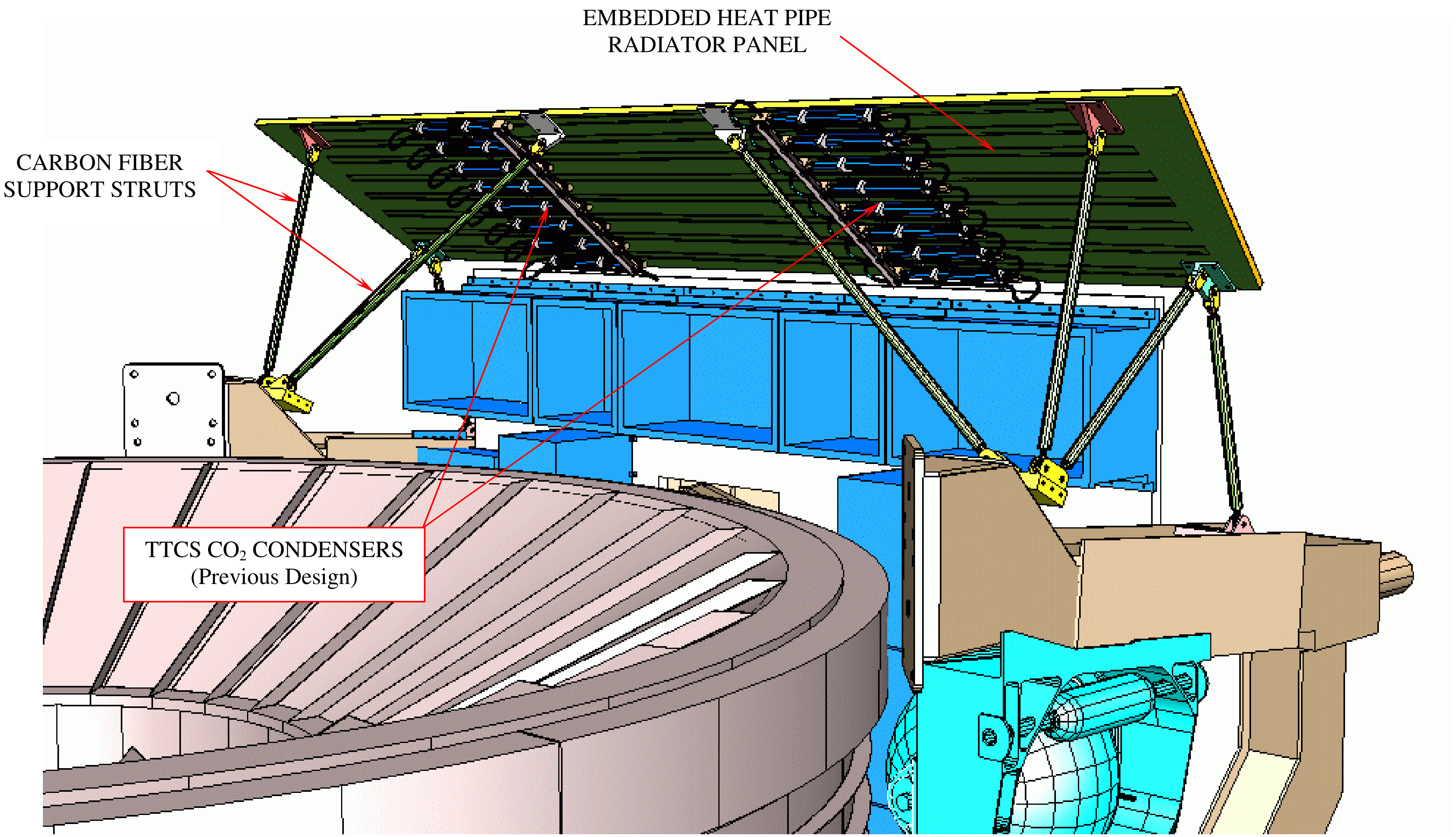


Figure 5.13.1.2-2 Tracker Radiator with TTCS Condensers Mounted

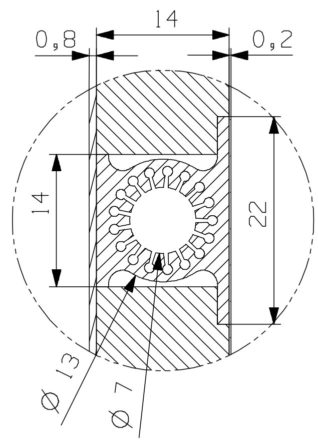


Figure 5.13.1.2-3 Tracker Radiator Cross Section

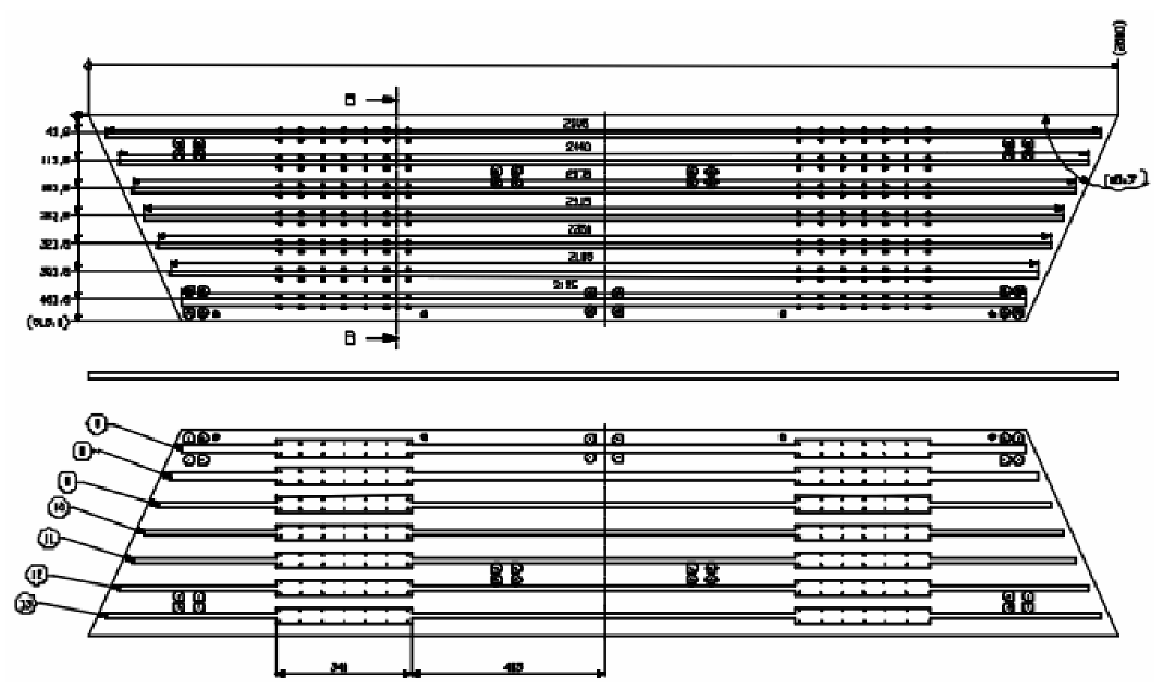


Figure 5.13.1.2-4 Tracker Radiator HP Layout

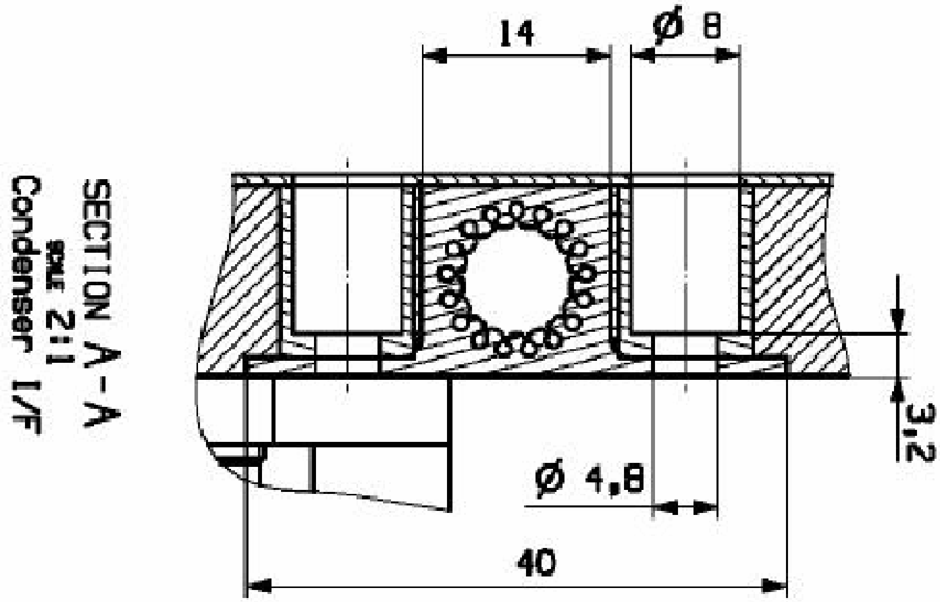


Figure 5.13.1.2-5 TTCS Condenser Mounting

5.13.1.3 Zenith Radiator

The Zenith Radiator actually consists of four separate panels, each design to reject heat (up to 150 watts) transported via two Loop Heat Pipes (LHPs) from a single Cryocooler (Figures 5.13.1.3-1 and 5.13.1.3-2). The radiator panels are constructed with aluminum 2024 T81 face sheets (1.6 mm for the upper face sheet and 0.3 for the lower), with a 10 mm ROHACELL® core (Figure 5.13.1.3-3). The condenser portion of each Loop Heat Pipes is a 4mm OD (3mm ID) aluminum 6063 tube, which is brazed to the upper face sheet of the radiator along a path designed to optimally reject heat. At the outer edge of each panel, the aluminum condenser tubes transition to stainless steel tubes via bimetallic joints. Each radiators panel is mounted to the top of the Upper TRD honeycomb panel via 14, 3mm OD x 35 mm long carbon-fiber pins, design to minimize heat leak, and two brackets; a Glass Fiber Reinforced Polymer (GFRP) bracket in the center and an aluminum one on the outer edge (Figure 5.13.1.3-4). The outer face of the Zenith Radiator is covered with Silver-Teflon film to maximize heat rejection capability. An MLI blanket is used on the under side to isolate the Zenith Radiator from the TRD.

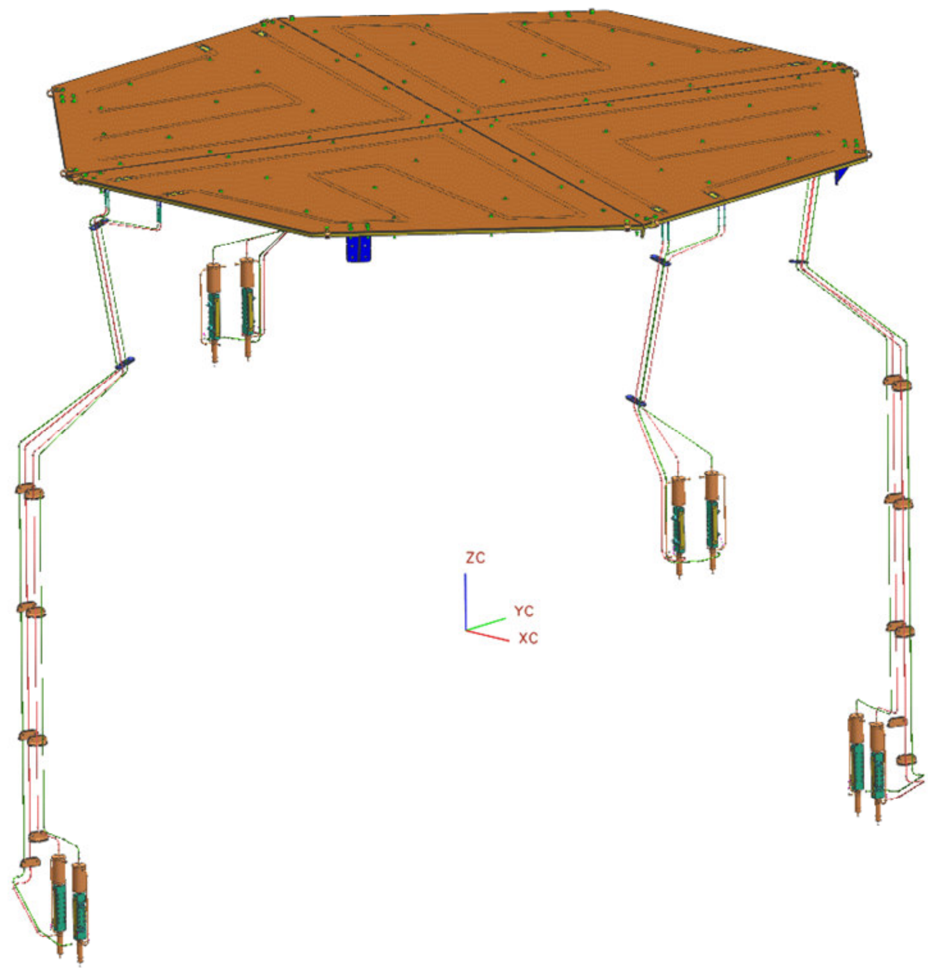


Figure 5.13.1.3-1 Zenith Radiator Panels

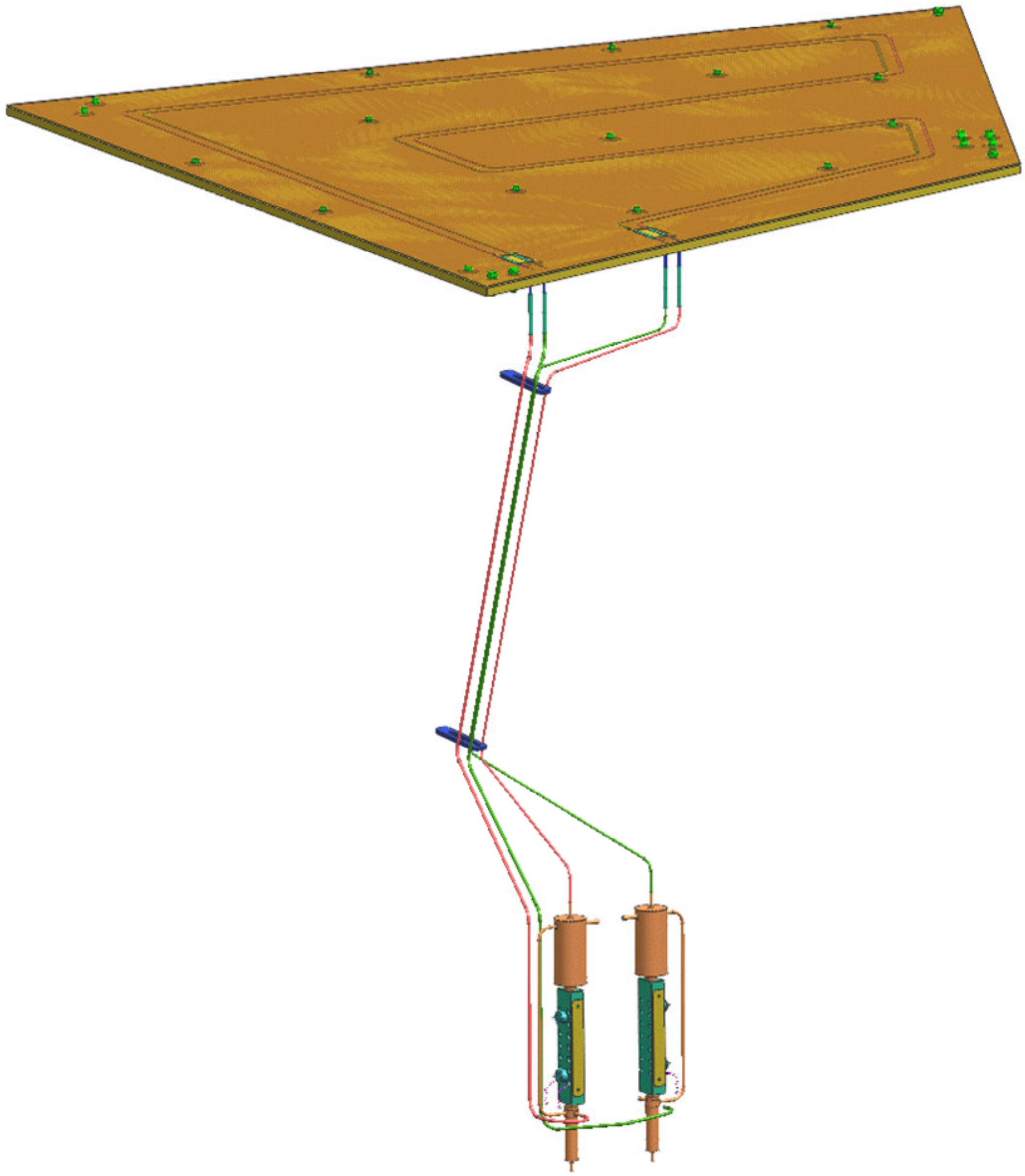


Figure 5.13.1.3-2 Zenith Radiator Panel with LHP

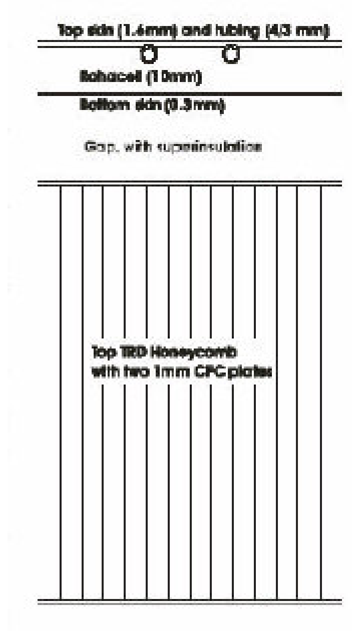


Figure 5.13.1.3-3 Zenith Radiator and Upper Honeycomb Panel Cross Section

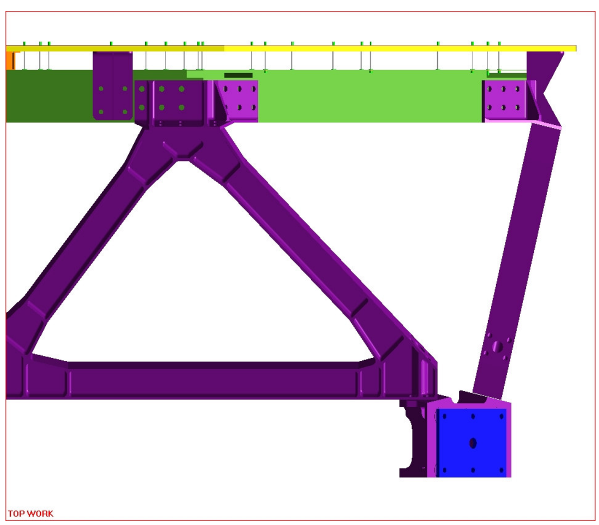


Figure 5.13.1.3-4 Zenith Radiator Mounting

5.13.2 Multi-Layer Insulation (MLI) Blankets

AMS-02 will have numerous MLI blankets on various components and sub-detectors. Concepts for a few of the larger blankets are shown in Figure 5.13.2-1. Typical construction will include Beta cloth as the outermost surface, 5 to 20 layer of aluminized Mylar separated by Dacron scrim, and reinforced aluminized Kapton as an inner surface. All MLI blankets used on AMS-02 will meet or exceed the NASA requirements for grounding and venting. These specifications are called out in JSC 65095, Multi-Layer Insulation for the Alpha Magnetic Spectrometer Requirements Document

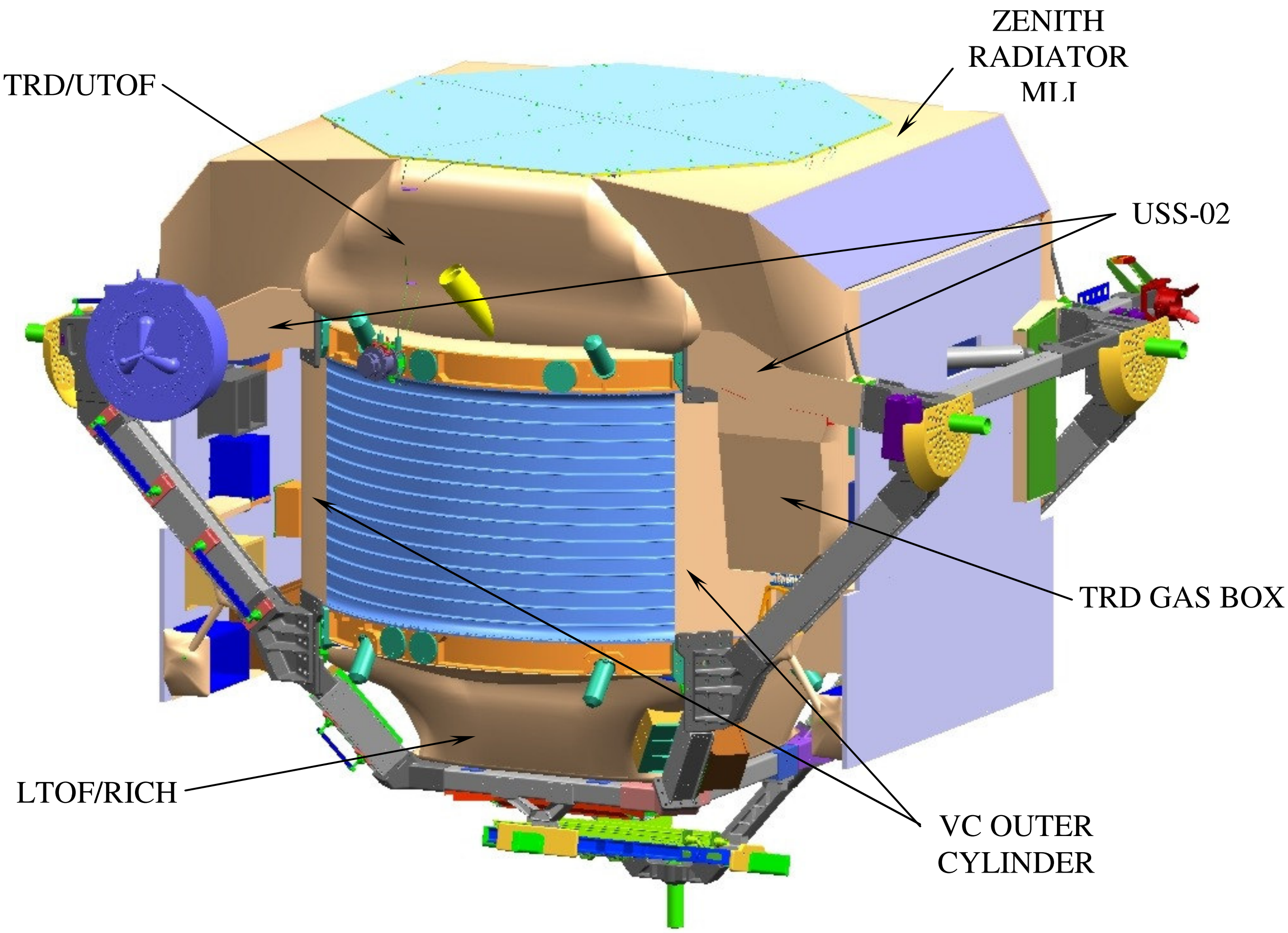


Figure 5.13.2-1 AMS-02 MLI Blankets

5.13.3 Heaters

Most heaters on AMS-02 will be used to assure that electronics are sufficiently warm before they are turned on. These heaters are mounted on the Main Radiators at locations where the embedded heat pipes can conduct heat to the crates. When AMS-02 first receives power, thermostatically controlled heaters warm up the Power Distribution System (PDS) crate to its minimum switch-on temperature. After the PDS is turned on, it then enables other heaters to warm up other electronics. When switch-on temperatures are achieved, heaters are disabled (by the PDS) prior to turning on electronics. The PDS provides 11 distinct 120V heater circuits which may be disabled or enabled as needed. A more detailed discussion of this system and the start-up procedure is found in Section 6.0

Additional heaters that will be activated during normal operation include those for the RICH, ECAL, Lower TOF, TRD, TRD Gas System, Tracker Thermal Control System, CAB, High Voltage Bricks, and possibly for the Warm Helium Supply. Heaters on the TTCS CO_2 lines will be used to thaw frozen CO_2 in the event of a loss of power while in a cold environment (see Section 5.13.7.3). Heaters on the Cryocoolers are used to heat then up to their minimum switch-on temperature and to start the Loop Heat Pipes.

Analysis will be performed to evaluate the effects of "run away" heaters. Heaters will be sized based on the minimum expected voltage, but failure analysis will be performed at the maximum voltage. Appendix B provides details for all heaters used on AMS-02.

5.13.4 Heat Pipes

Passive thermal control of AMS-02 includes the use of various axial groove heat pipes. These "standard" heat pipes are not to be confused with the Loop Heat Pipes discussed in Sections 5.13.6 and 5.13.8. While AMS-02 heat pipes vary in terms of length and cross section, all are constructed of aluminum and filled with high-purity ammonia. The amount of ammonia in each pipe is so small that freezing poses no concern.

As discussed in Section 5.13.1, heat pipes are embedded in both the Tracker and Main Radiators to help distribute heat. Besides radiators, heat pipes are also used in the Cryomagnet Avionics Box (CAB) base plate (Section 5.13.8), the TTCS control box (Section 5.13.7) and to minimize temperature gradients across one of the USS-02 joints (Section 5.13.8).

5.13.5 Optics

Thermal optical properties of external AMS-02 surfaces play a critical role in the thermal control of the payload. Typically surface optical properties are selected to bias temperatures cold where needed. This is achieved by selecting coatings which have a low ratio of solar absorptivity (α) over Infra-Red (IR) emissivity (ε)

Much of AMS-02 is covered with MLI blankets, which use a glass-fiber cloth (e.g. Betacloth) as the outer surface. The Main Radiators and Tracker Radiators are painted with SG121FD white paint, a very stable, low α / ε coating similar to what is used on the ISS radiators. The Zenith radiator, +/- X quadrants of the Vacuum case, portions of the USS-02, +Y face of the CAB, and various other small electronics are covered with a silver-Teflon film (typically 5 or 10 mil FEP over vapor deposited silver over vapor deposited Inconel with 966 acrylic adhesive). This film has the lowest ratio of α / ε, but since it is highly specular, its use is limited to surfaces where it is absolutely needed. All exposed aluminum surfaces are anodized for corrosion protection. Except for a few exceptions (handrails, grapple fixtures) this is a clear anodize which keeps temperatures reasonably cool. Table 5.13.5-1 lists optical coatings and properties for all significant exposed surfaces (bolt heads, rivets, cable ties, etc. are not considered thermally significant).

TABLE 5.13.5-1 AMS-02 SURFACE OPTICAL PROPERTIES

Surface Optical Property	Beginning of Life (BOL)		End of Life (EOL)	
	Absorptivity (α)	Emissivity (ε)	Absorptivity (α)	Emissivity (ε)
Beta Cloth	0.22	0.9	0.47	0.86
White paint (SG 121)	0.18	0.94	0.27	0.88
aluminized polyimide	0.14	0.05	0.14	0.05
Silver Teflon 5mil	0.08	0.78	0.13	0.75
Silver Teflon 10mil	0.09	0.89	0.15	0.85
Mixed properties (on Magnet)	0.16	0.80	0.32	0.77
anodized aluminum (clear anodize)	0.35	0.84	0.77	0.81
RICH Mirror	0.03	0.82	0.10	0.75
black anodized	0.88	0.82	0.88	0.78
gold anodized AL	0.59	0.84	0.68	0.84

5.13.6 Cryocooler Cooling

Cryocooler cooling is achieved using two redundant Loop Heat Pipes (LHPs) to collect and transport heat from each of the four Cryocoolers to a zenith-mounted, direct-flow radiator (Figure 5.13.6-1). The Loop Heat Pipes (along with the Zenith Radiators) are being built by IberEspacio/Madrid and are similar to those successfully demonstrated as part of the Combined Two Phase Loop Experiment (COM2PLEX) flown on STS-107. The evaporator portion of each LHP is attached to a heat rejection collar on the Cryocooler body (Figure 5.13.6-2). This bolted interface includes an Indium interface filler to minimize the thermal resistance. The LHP does not interface directly with the Cryomagnet pressurized systems.

Heaters are used for Cryocooler startup and to keep them above minimum storage limits (Figure 5.13.6-3). A control valve is used to redirect flow into a bypass loop if Cryocooler temperatures start getting too cold (Figure 5.13.6-4). This valve uses a bellows system, filled with Argon at a predetermined pressure to control the direction of propylene flow (Figure 5.13.6-5). Each LHP is made primarily of stainless steel, with nickel wicks and high purity propylene as a working fluid. 3 mm stainless steel tubing runs to the edge of the radiator, where it is transitioned to aluminum tubing via a bi-metallic joint. As mention in the previous section, this aluminum tubing is brazed to the upper aluminum skin of the zenith radiators.

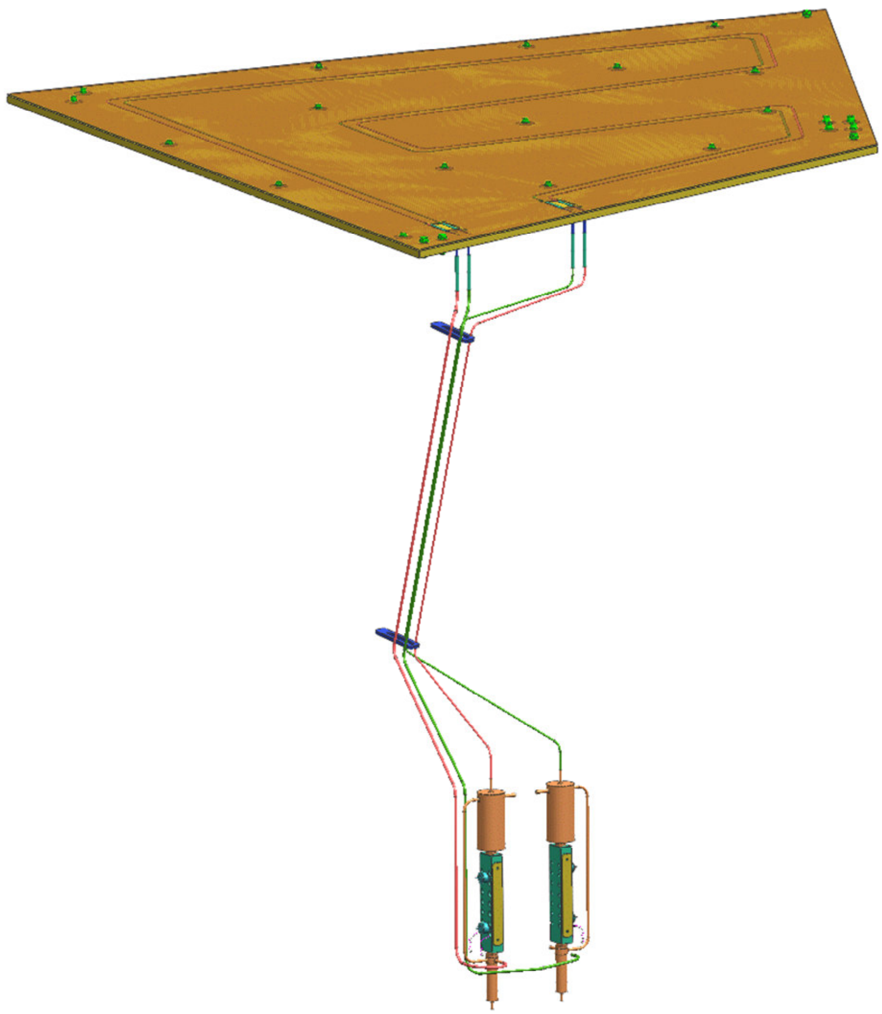


Figure 5.13.6-1 Zenith Radiator Panel with LHP

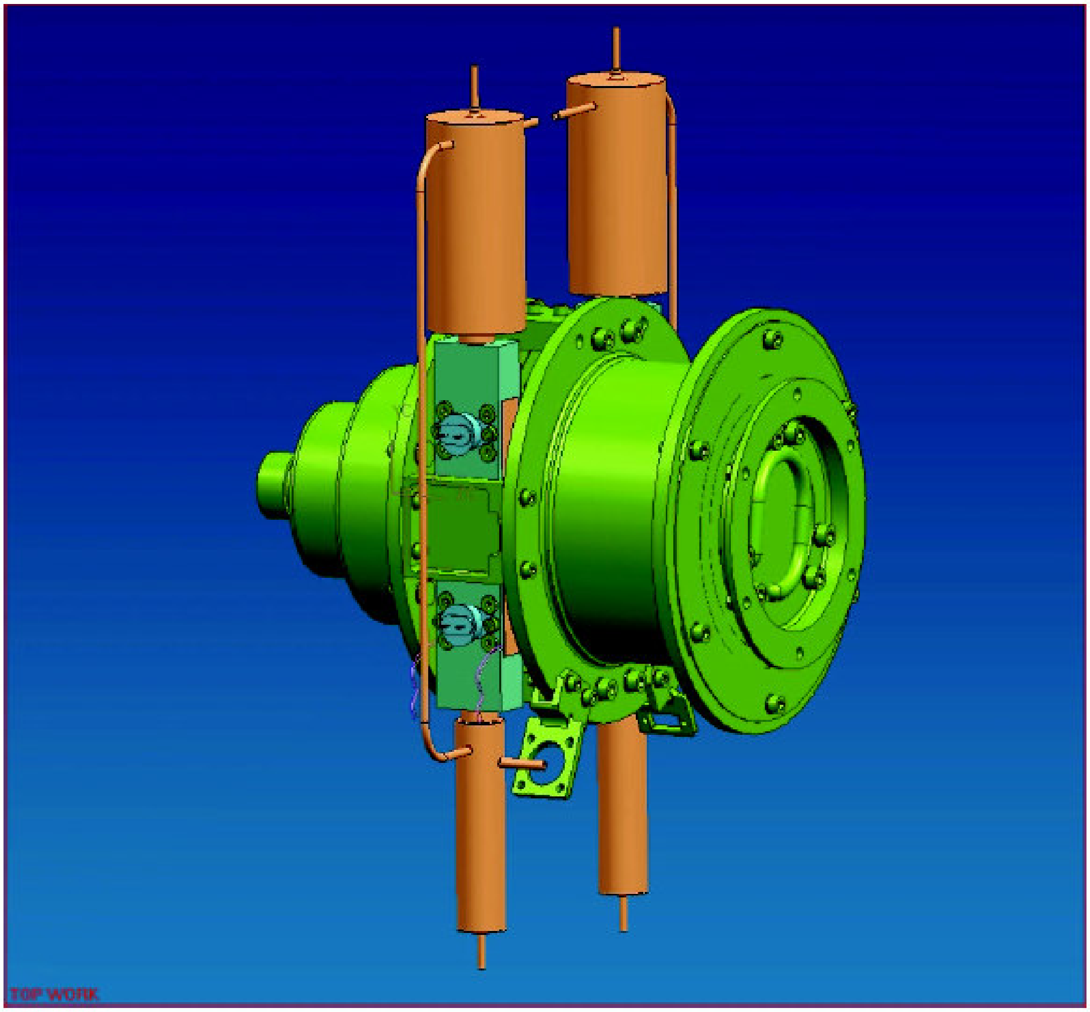


Figure 5.13.6-2 LHP Evaporators Mounted on Cryocooler

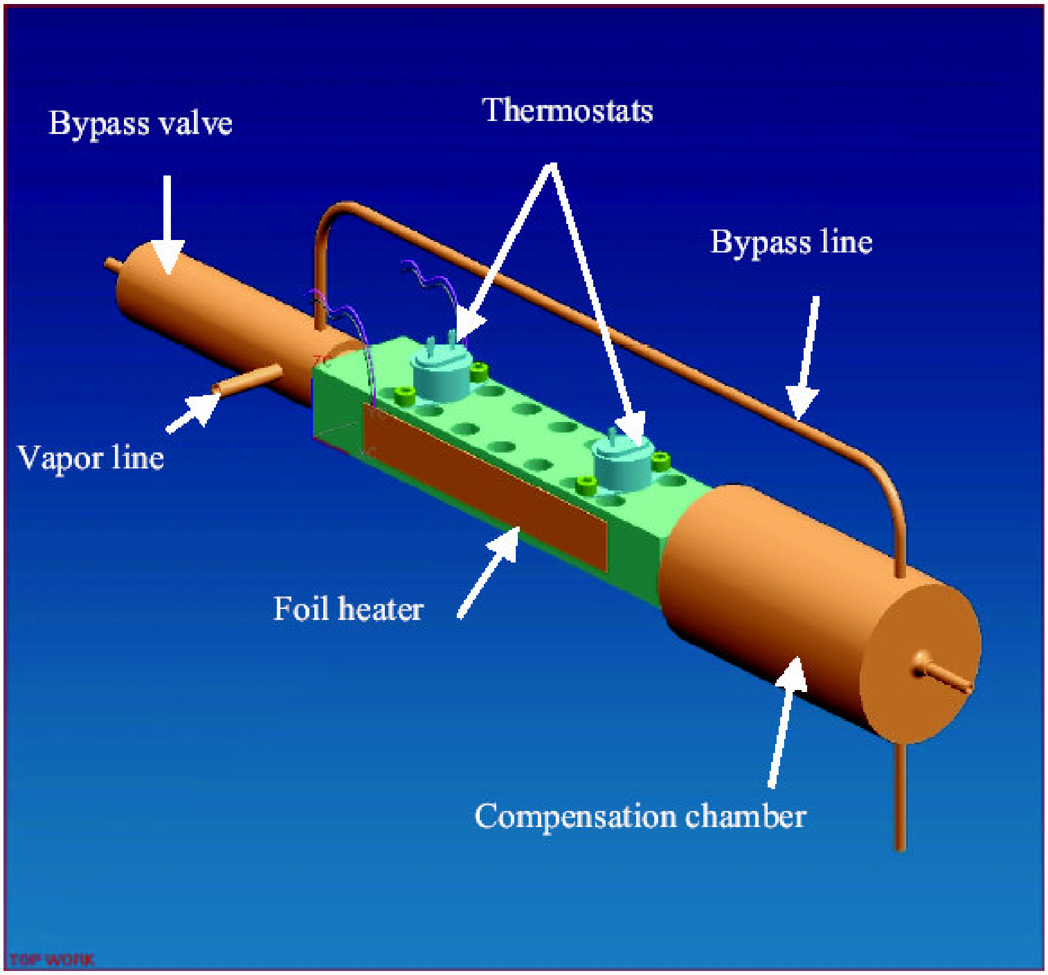


Figure 5.13.6-3 LHP with Bypass

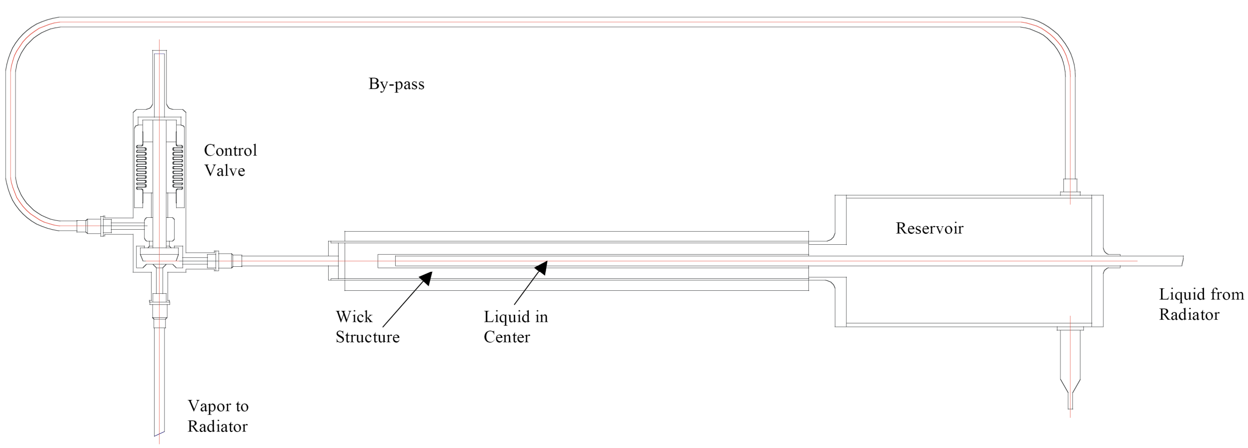


Figure 5.13.6-4 Schematic of LHP with Bypass

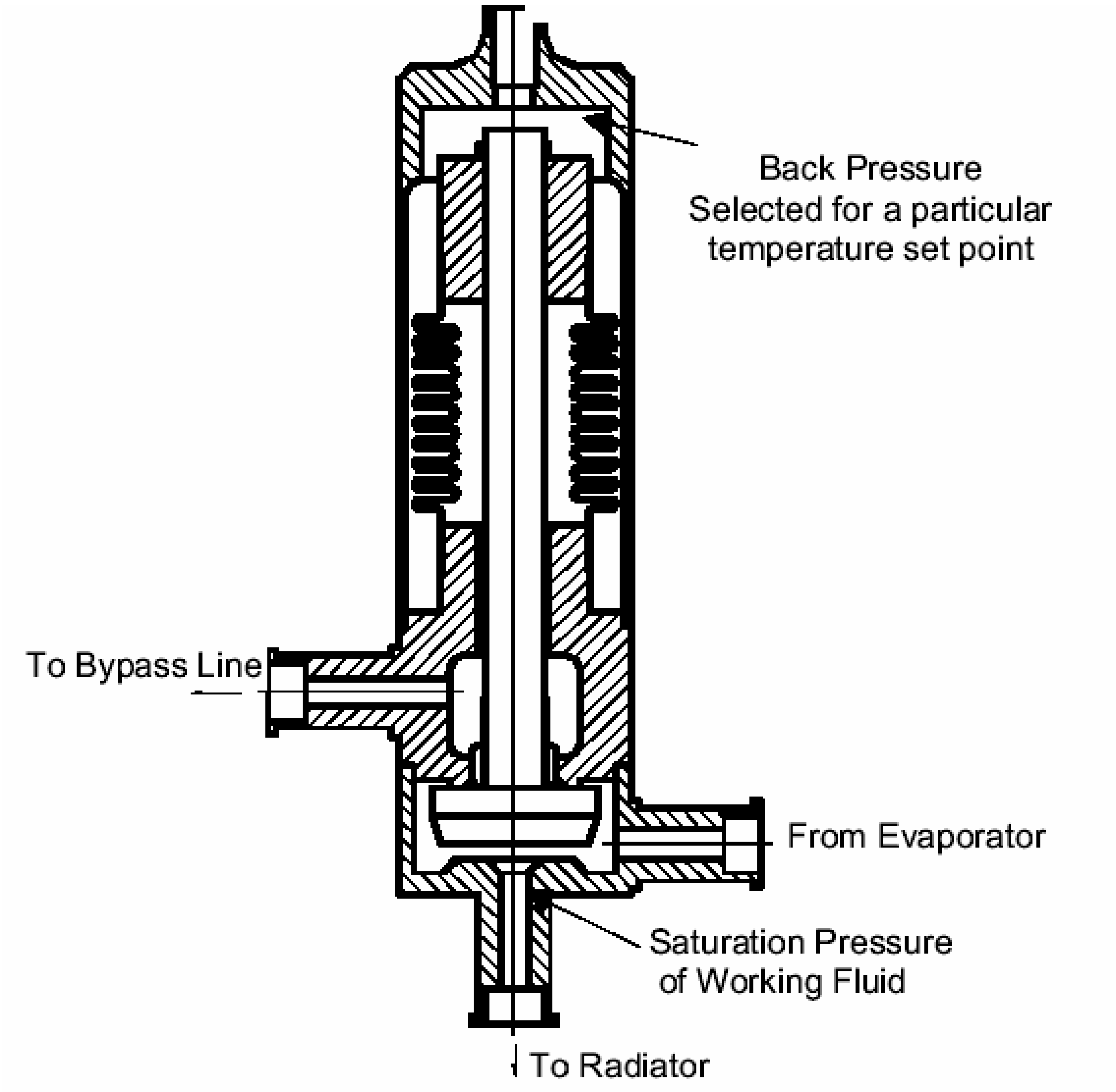


Figure 5.13.6-5 LHP Bypass Valve Cross Section

5.13.7 Tracker Thermal Control System (TTCS)

The TTCS is one of the most complex thermal control systems used on AMS-02 (Figure 5.13.7-1). The Tracker, completely encased inside the inner bore of the Vacuum Case, generates 144 watts which need to be rejected while minimizing heat flow to the vacuum case inner cylinder. The TTCS thermal design includes thermal bars, a pumped CO_2 cooling loop, radiators, manifolds, accumulators and numerous other components.

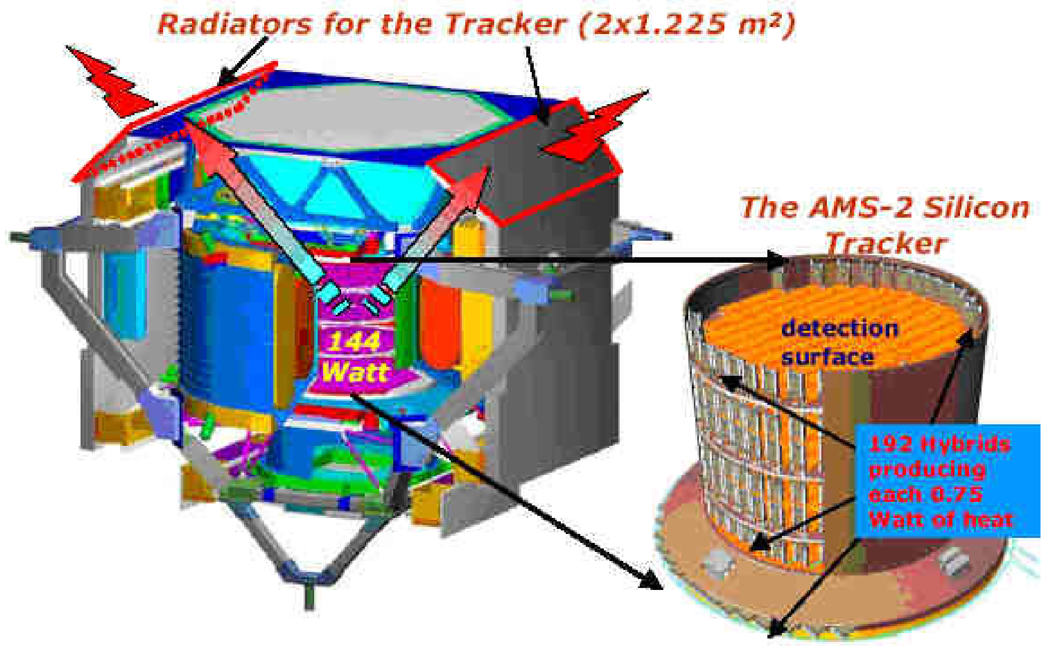


Figure 5.13.7-1 TTCS System

5.13.7.1 TTCS Evaporator

Each of the 192 hybrid electronic boards or Hybrids, located on the periphery of 8 Tracker planes, generates 0.75 watts (Figure 5.13.7.1-1). There are 6 inner rings of Hybrids inside the Vacuum Case Inner Cylinder, 1 above and 1 below. The Hybrids are attached to thermal bars, frames made of Thermal Pyrolytic Graphite (TPG) encased in aluminum 6061 (Figure 5.13.7.1-3). Between inner planes, the Thermal Bars are thermally connected to each other via flexible connecters made of copper. Thermal

Bridges, also made of copper, connect the end thermal bars to the inner evaporator ring tubes (Figure 5.13.7.1-4). Hybrids on the two Outer Planes connect to the outer ring evaporator tubes via copper braids (Figure 5.13.7.1-5). There is an Inner and Outer ring evaporator on both the upper and lower Tracker flange (Figure 5.13.7.1-6). For redundancy, all evaporators include two separate tubes connected to independent cooling loops.

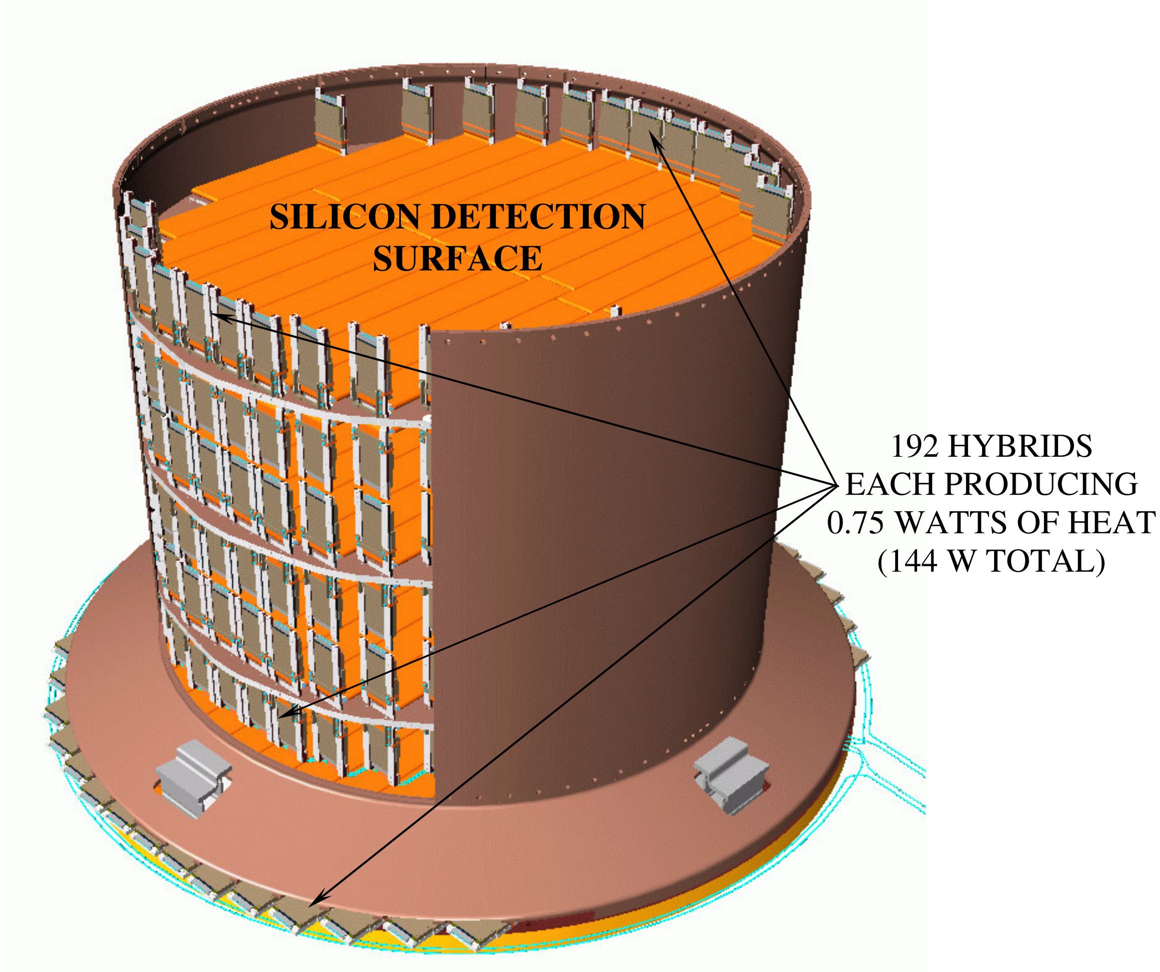


Figure 5.13.7.1-1 Tracker Hybrids

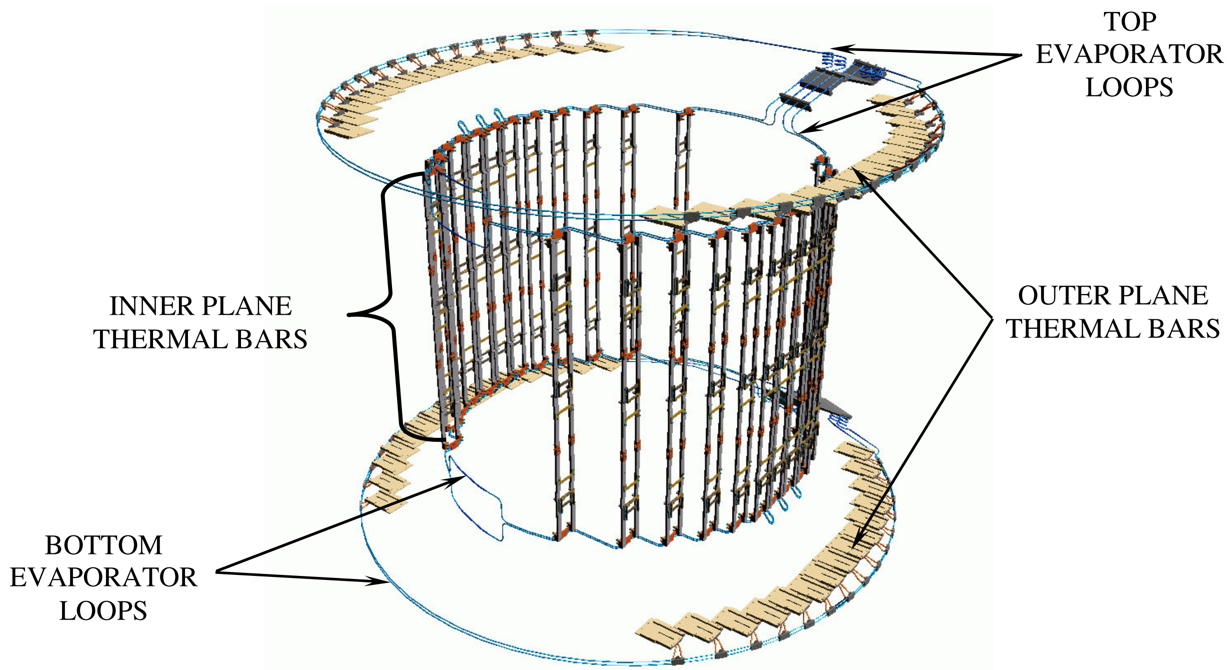


Figure 5.13.7.1-2 TTCS Evaporator

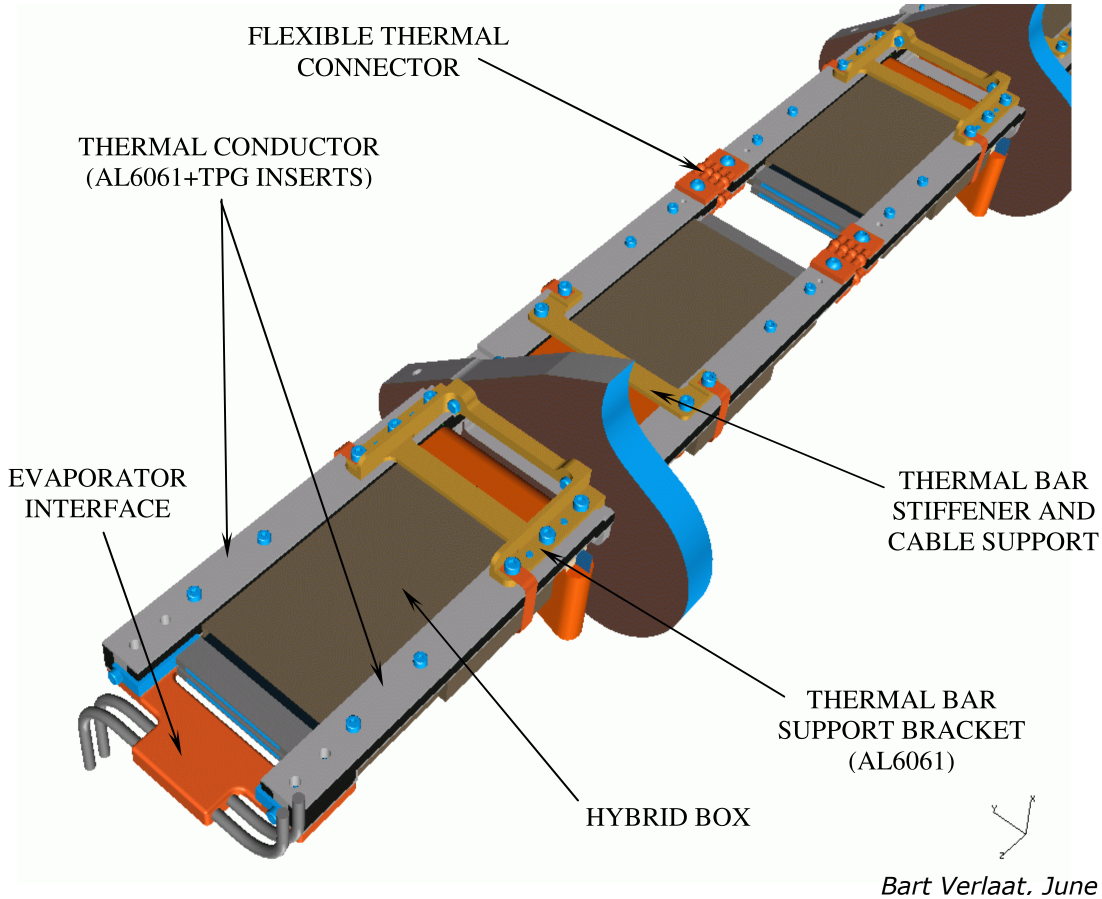


Figure 5.13.7.1-3 Internal Thermal Bar design for AMS-02

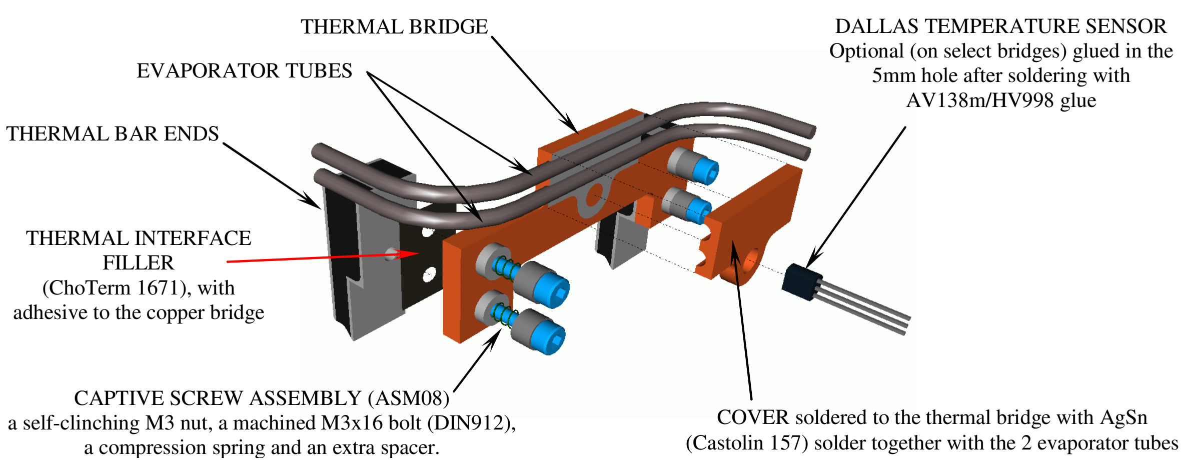


Figure 5.13.7.1-4 Connection between End of Thermal Bars and Inner Evaporator

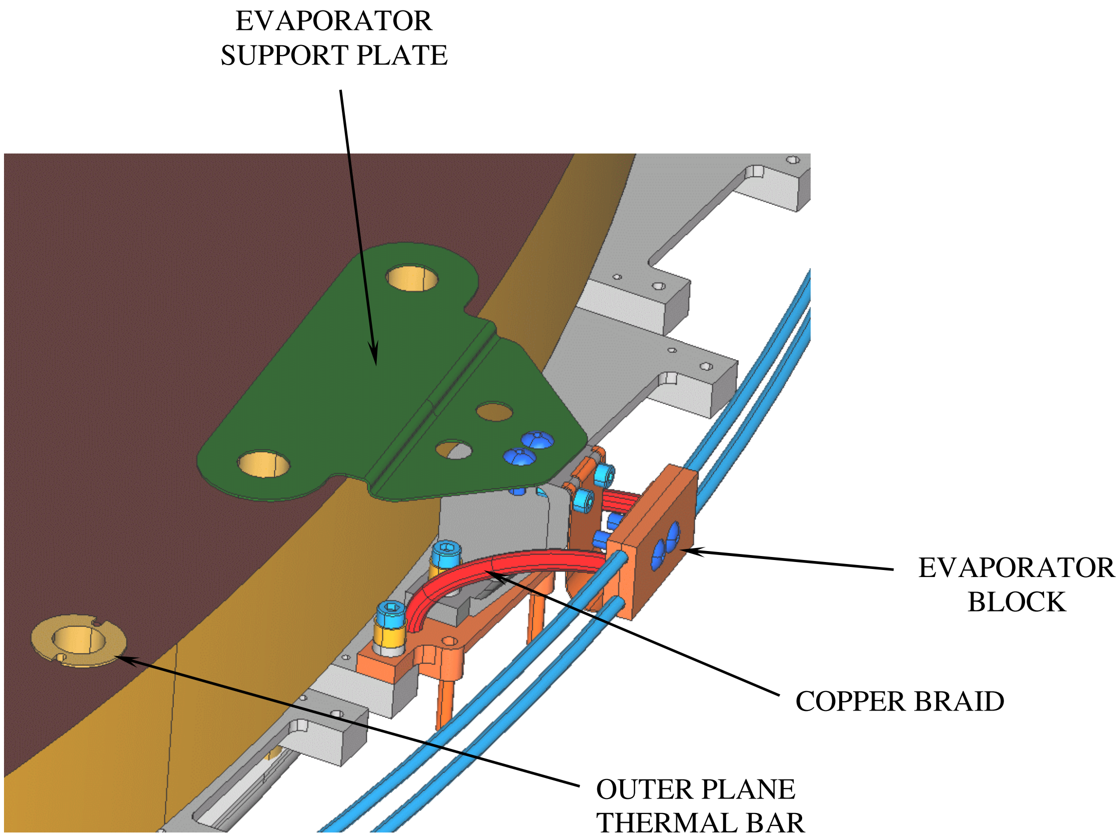


Figure 5.13.7.1-5 Connection between Outer Plane Thermal Bars and Evaporator

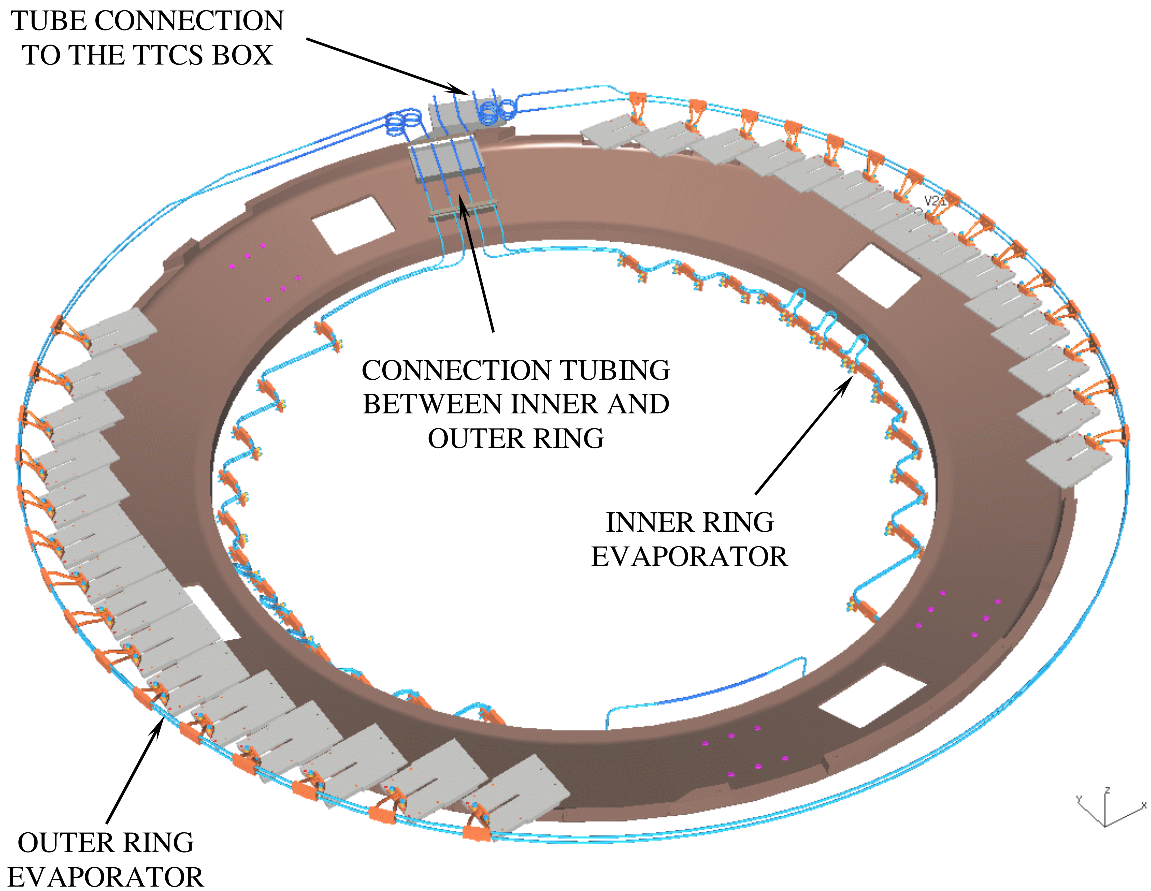


Figure 5.13.7.1-6 TTCS Evaporators

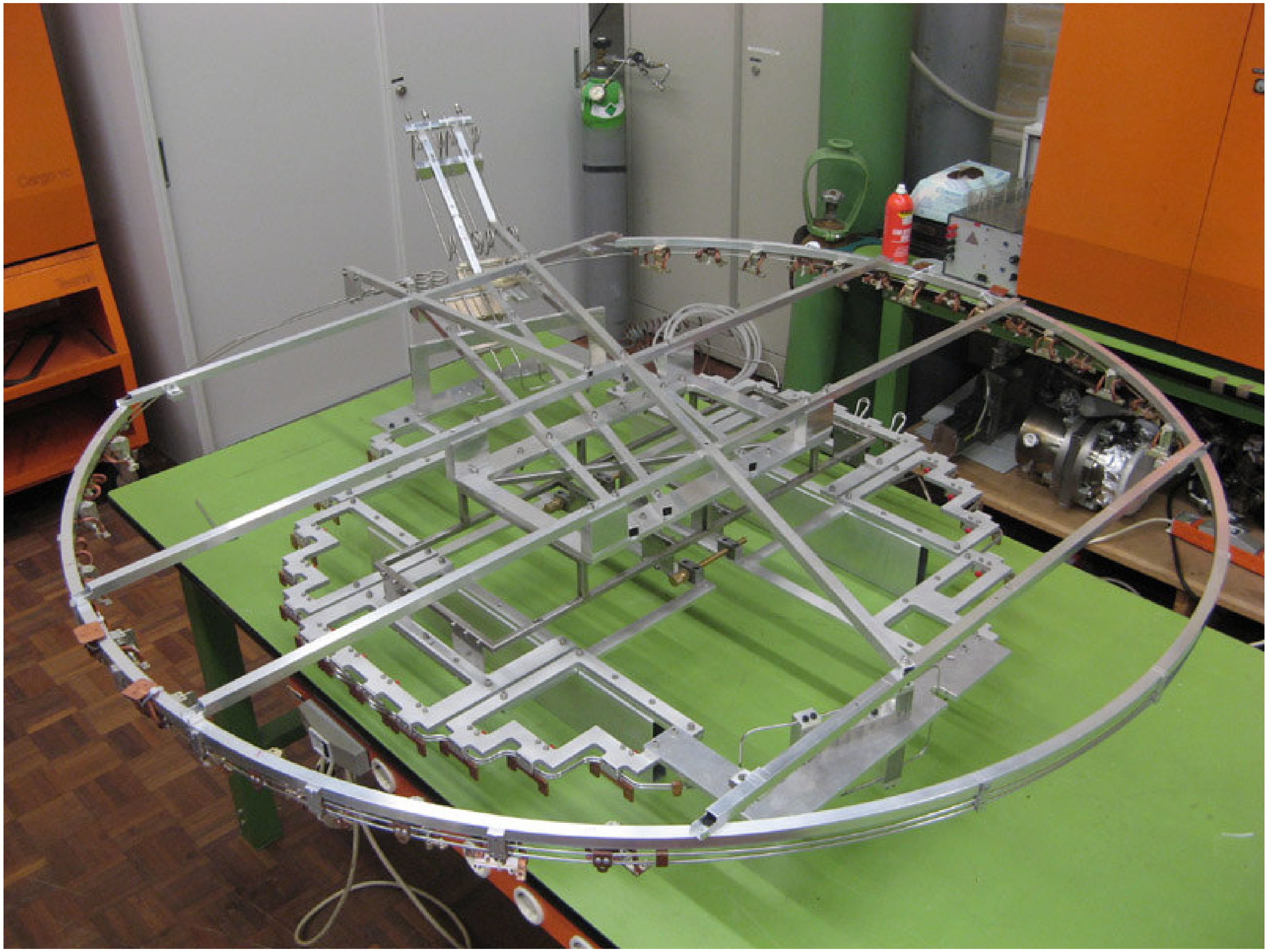


Figure 5.13.7.1-7 Photo of Upper TTCS Evaporator

5.13.7.2 TTCS CO_2 Cooling Loop

The TTCS cooling loop uses carbon dioxide to pick up heat from the evaporator rings inside the Tracker. The CO_2 transports heat to condensers connected to radiators on both ram and wake sides of AMS. Fluid is transported back to the evaporator by means of a mechanical pump. Condensers and radiators are design to assure that the CO_2 is sufficiently cooled so that only liquid will enter the pump.

Two-phase cooling is desired throughout the evaporator in order to maintain the Tracker as isothermal as possible. This is achieved by using an electric heater to pre-heat the fluid to the saturation temperature before it enters the evaporator. To minimize required heater power, a heat exchanger connects the evaporator inlet and outlet near the electric pre-heater. Figures 5.13.7.2-1 and 5.13.7.2-2 show schematics of the Primary and Secondary TTCS Cooling Loops (Figure 5.13.7.2-3 is the legend for the two preceeding diagrams). The loops are identical except that the Primary Loop includes a small independent experiment, an Oscillating Heat Pipe (OHP), which will be described later, and four balancing valves used to adjust performance of the primary loop.

For each loop, the pump, accumulator, heat exchanger, start-up heater, pre-heater and valves are located in the Tracker Thermal Control Box (TTCB) as shown in Figure 5.13.7.2-4. The Oscillating Heat Pipe and valves in the Primary Loop are located in the Primary TTCB. The Primary TTCB is mounted on the +X +Y Lower Trunnion Bridge Beam while the Secondary is mounted to the –X +Y Lower Trunnion Bridge Beam. The boxes are thermally isolated from the beams and covered with an MLI blanket, except for the Wake facing surface which is used as a radiator. TTCS tube routing is shown in Figure 5.13.7.2-5.

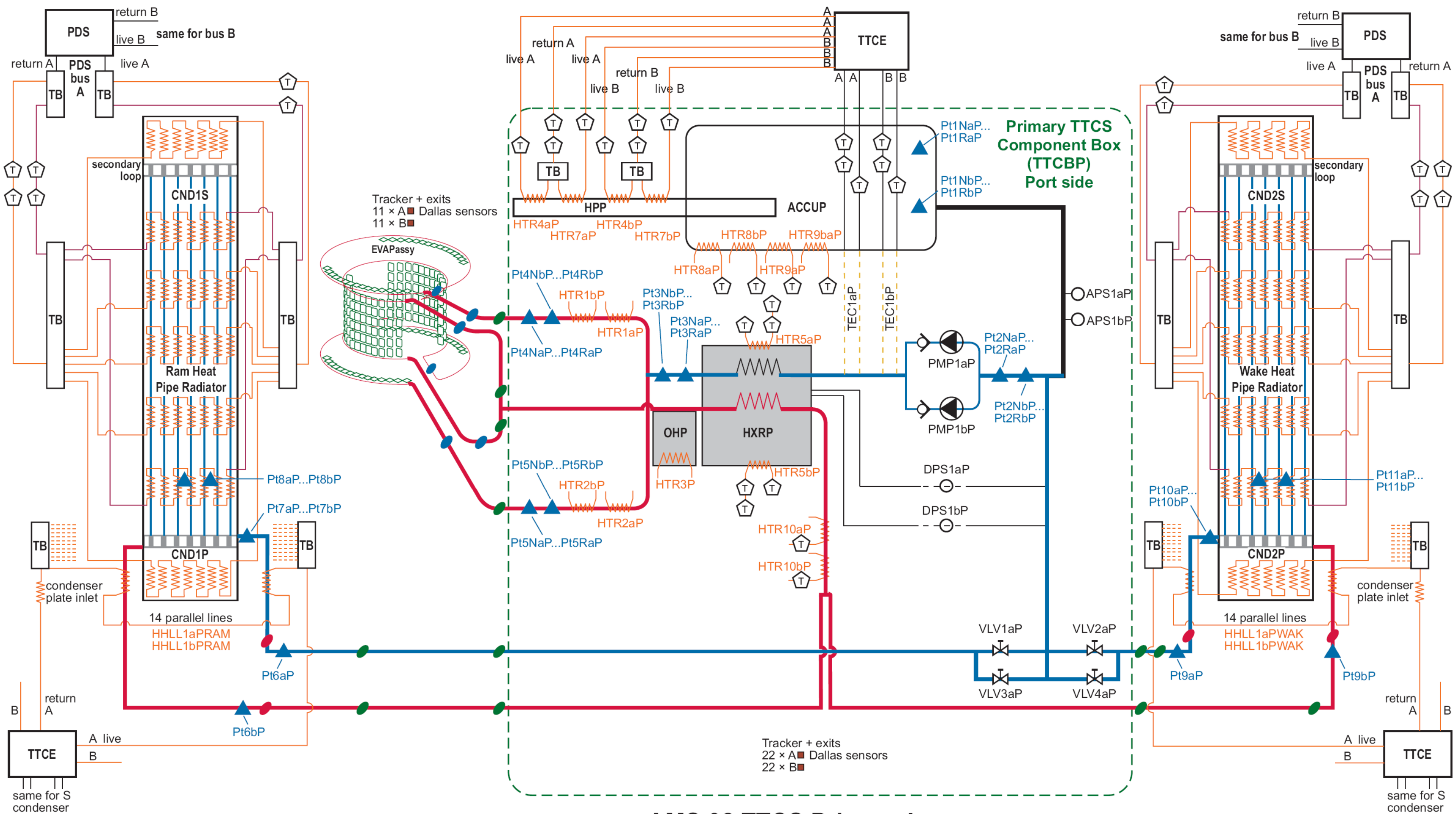


Figure 5.13.7.2-1 AMS-02 Tracker Thermal Control System Primary Loop

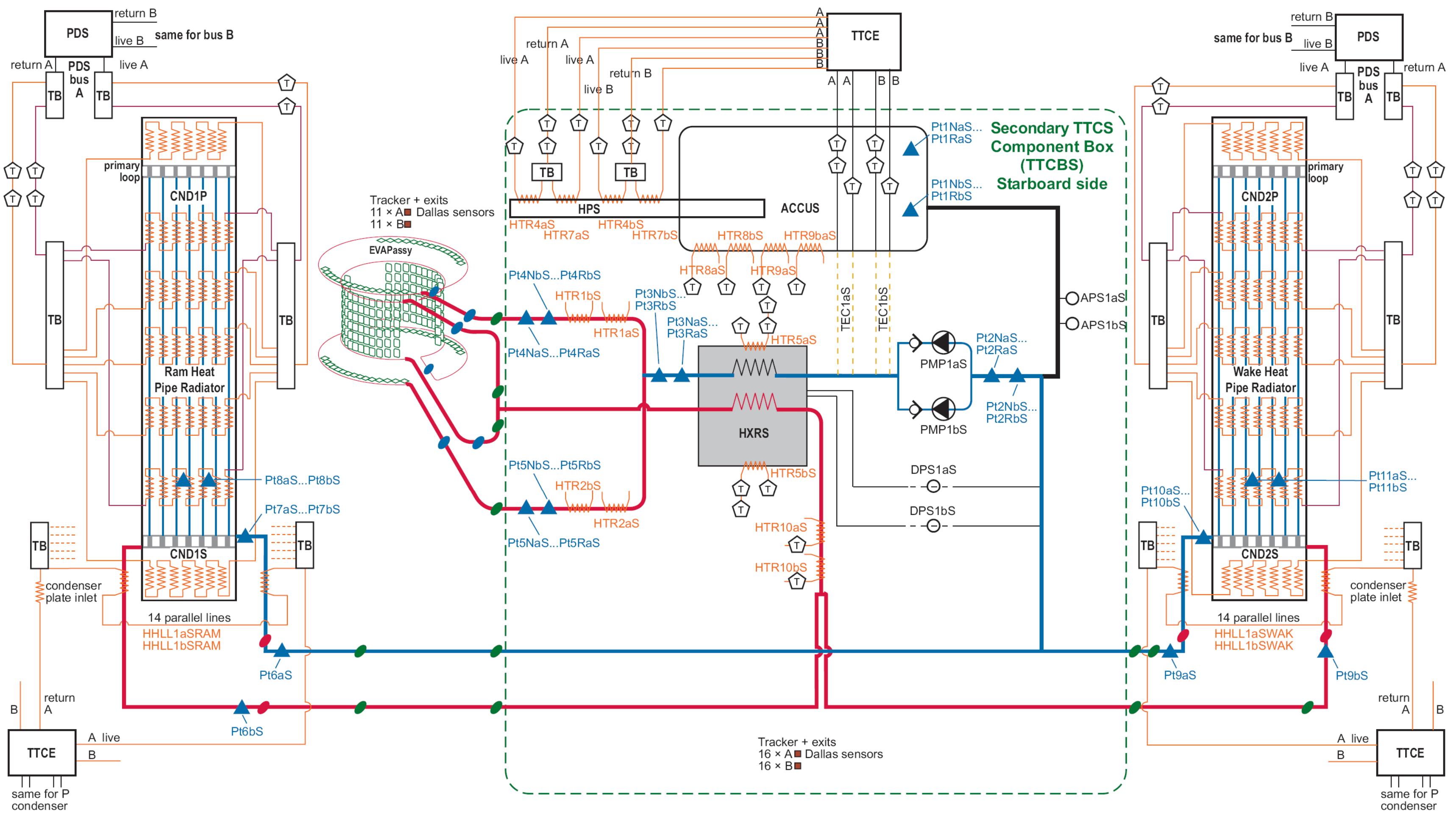


Figure 5.13.7.2-2 AMS-02 Tracker Thermal Control System Secondary Loop

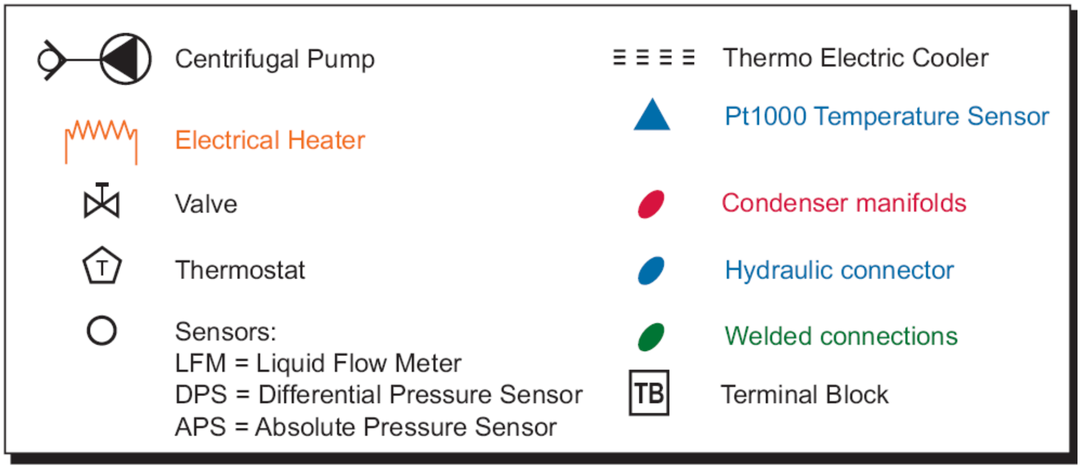


Figure 5.13.7.2-3 AMS-02 Tracker Thermal Control System Diagrams Legend

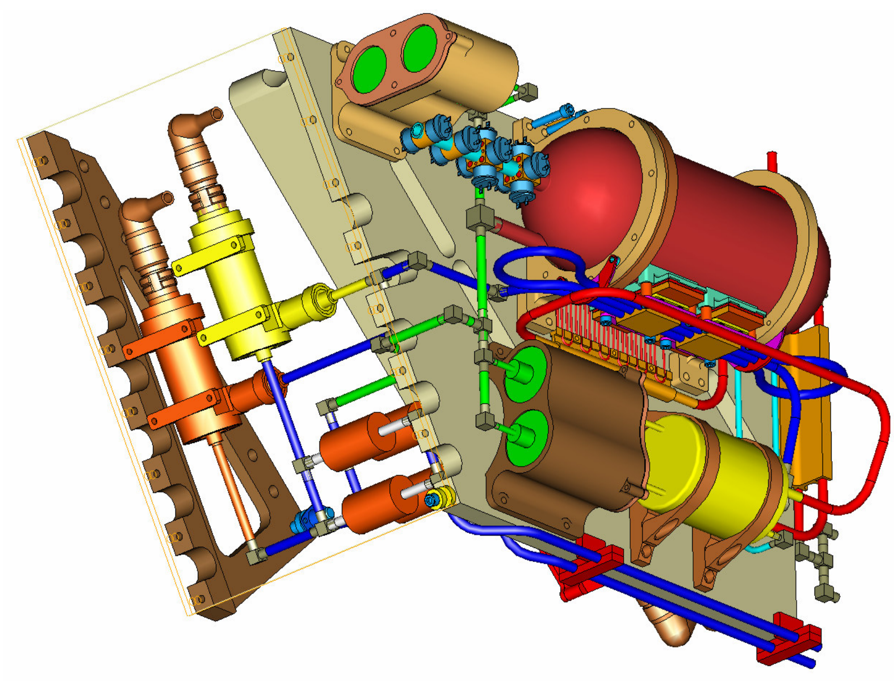


Figure 5.13.7.2-4 Primary TTCB

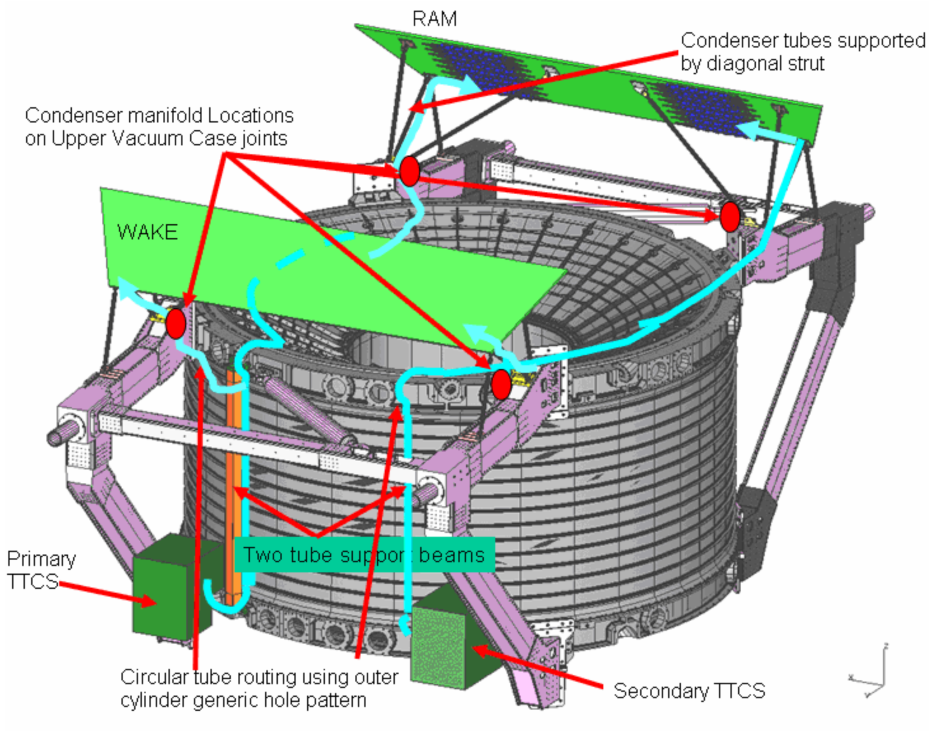


Figure 5.13.7.2-5 Proposed TTCS Tube Routing

5.13.7.2.1 Condensers

There are 2 TTCS condensers mounted on each of the Ram and Wake Tracker Radiators, one Primary and one Secondary (Figure 5.13.7.2.1-1). Each condenser is thermally connected to each of the 7 heat pipes embedded in each radiator. Mounting is achieved by bolting through the radiator with Chotherm 1671 used as a thermal interface filler (Figure 5.13.7.2.1-2).

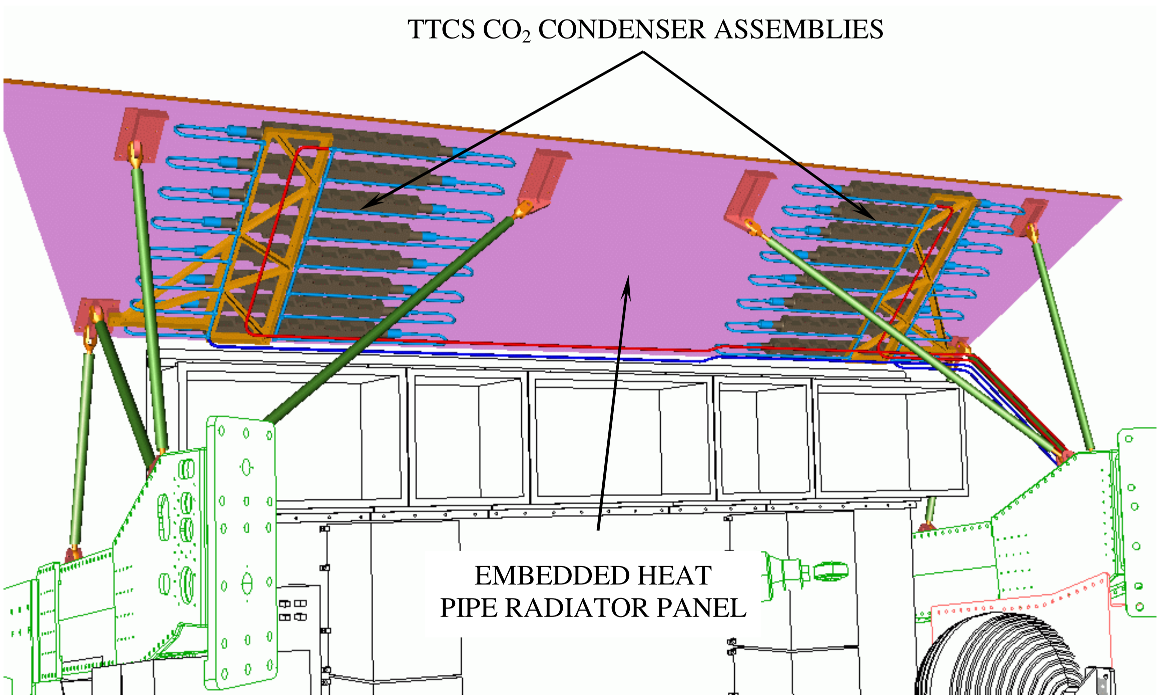


Figure 5.13.7.2.1-1 TTCS Condensers
Graphic does not show current Condensers in place

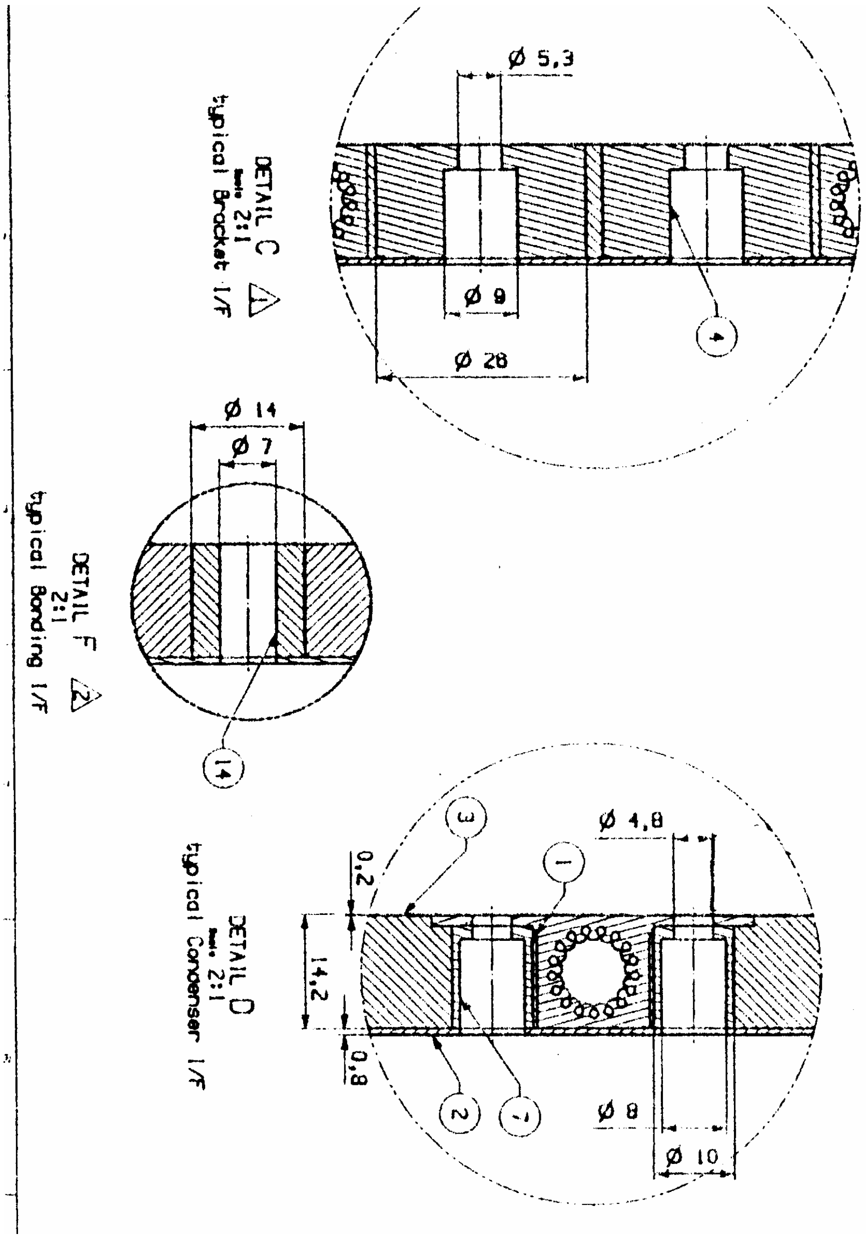


Figure 5.13.7.2.1-2 TTCS Condenser Mounting to Radiator

The condenser is constructed with 7 parallel lines of capillary tubing made of Inconel 718, glued to an aluminum plate (Figure 5.13.7.2.1-3 through -6) and covered with another aluminum top place. These two plates, with the embedded capillary tubing are glued together and bolted to theTracker Radiator (At the location of the previous design represented in Figure 5.13.7.2.1-1 individual condenser locations (with seven, not eight heat pipes).

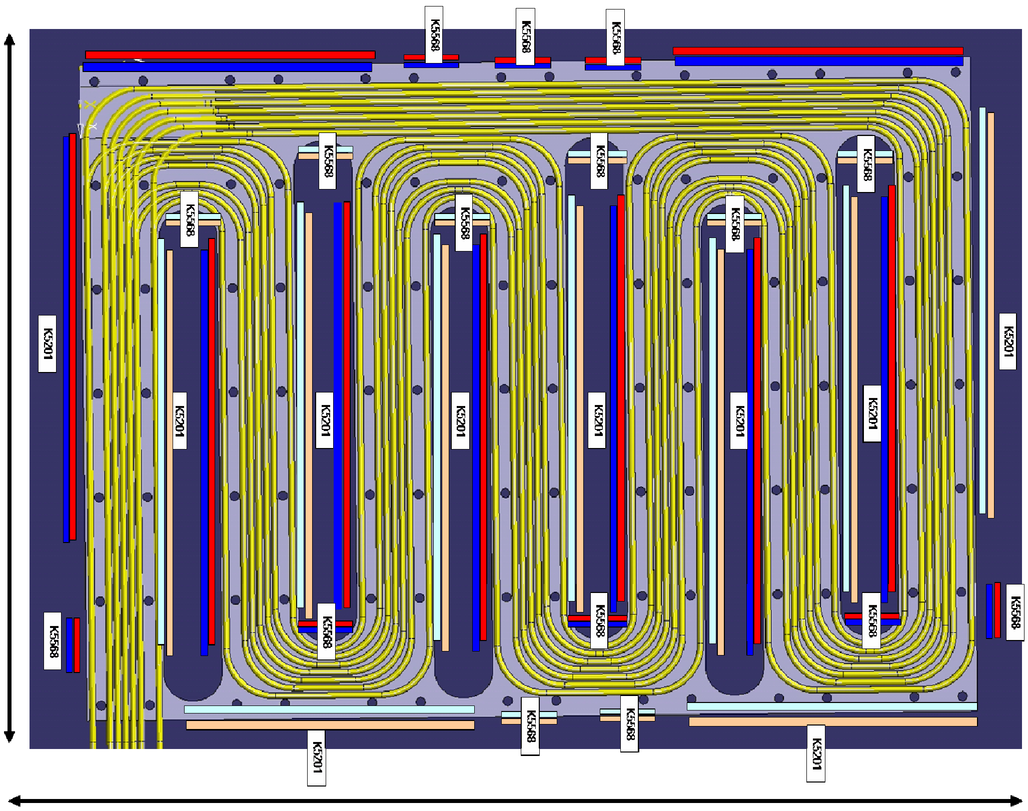


Figure 5.13.7.2.1-3 TTCS Condenser

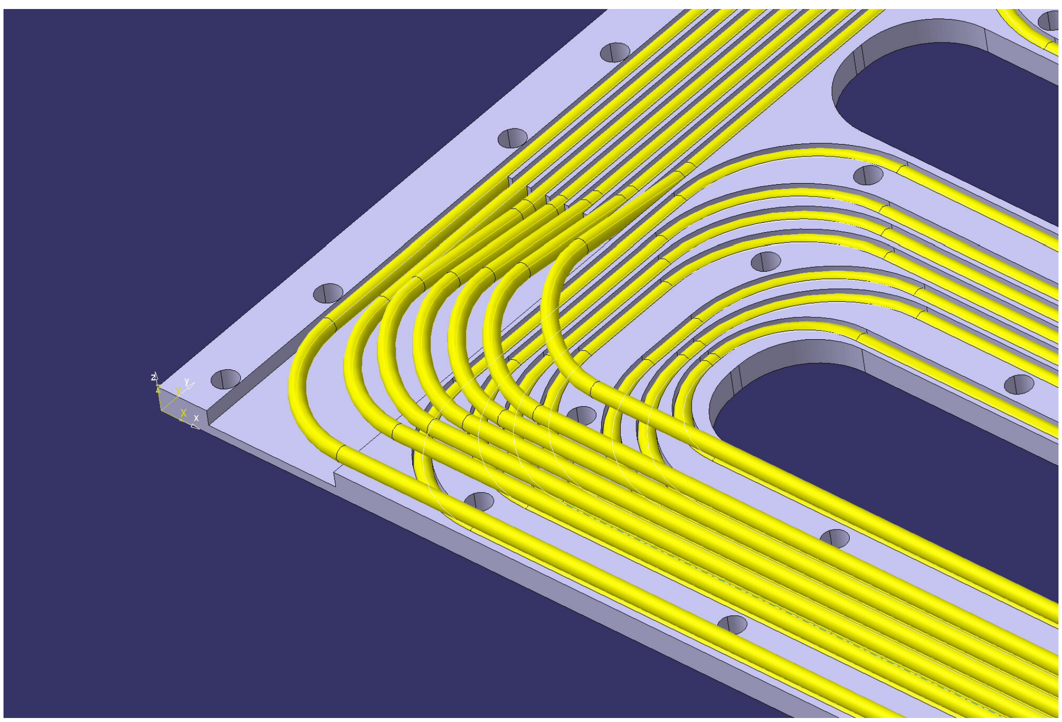


Figure 5.13.7.2.1-4 TTCS Condenser Detail

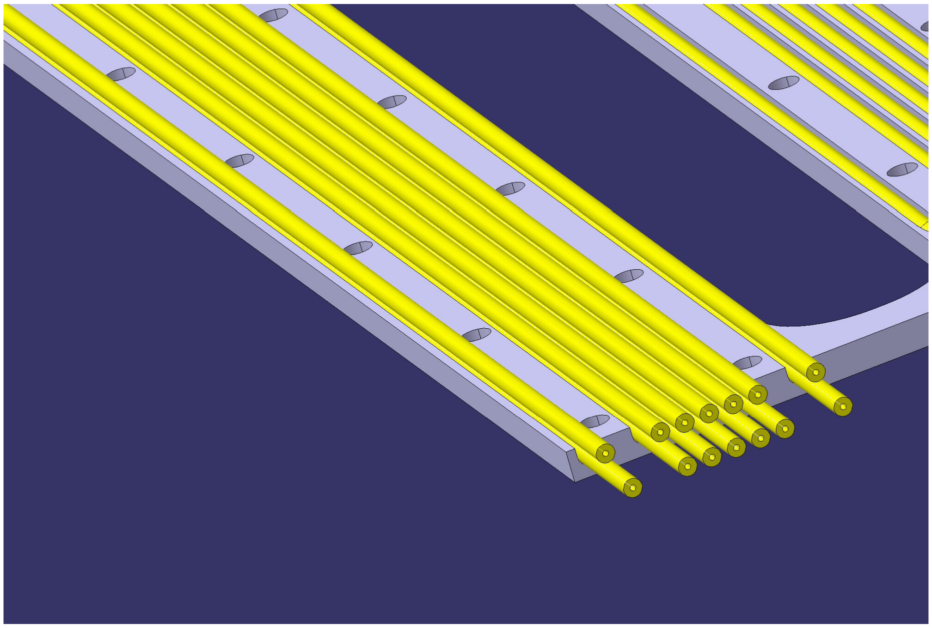


Figure 5.13.7.2.1-5 TTCS Condenser Detail

The Inconel tubing (1mm ID) runs from the condensers to manifolds mounted on the Upper Vacuum Case Interface Joints (Figure 5.13.7.2.1-7. The manifold combines the parallel flow from the 7 capillary tubes and transitions it to 2.6 mm ID stainless steel tubing (Figure 5.13.7.2.1-8). The condensers (including all capillary tubes) are designed to withstand freezing and thaw of CO_2. Heater wires are mounted on the capillary tubes to thaw the lines in case of freezing after loss of power. All exposed tubes will be covered with MLI.

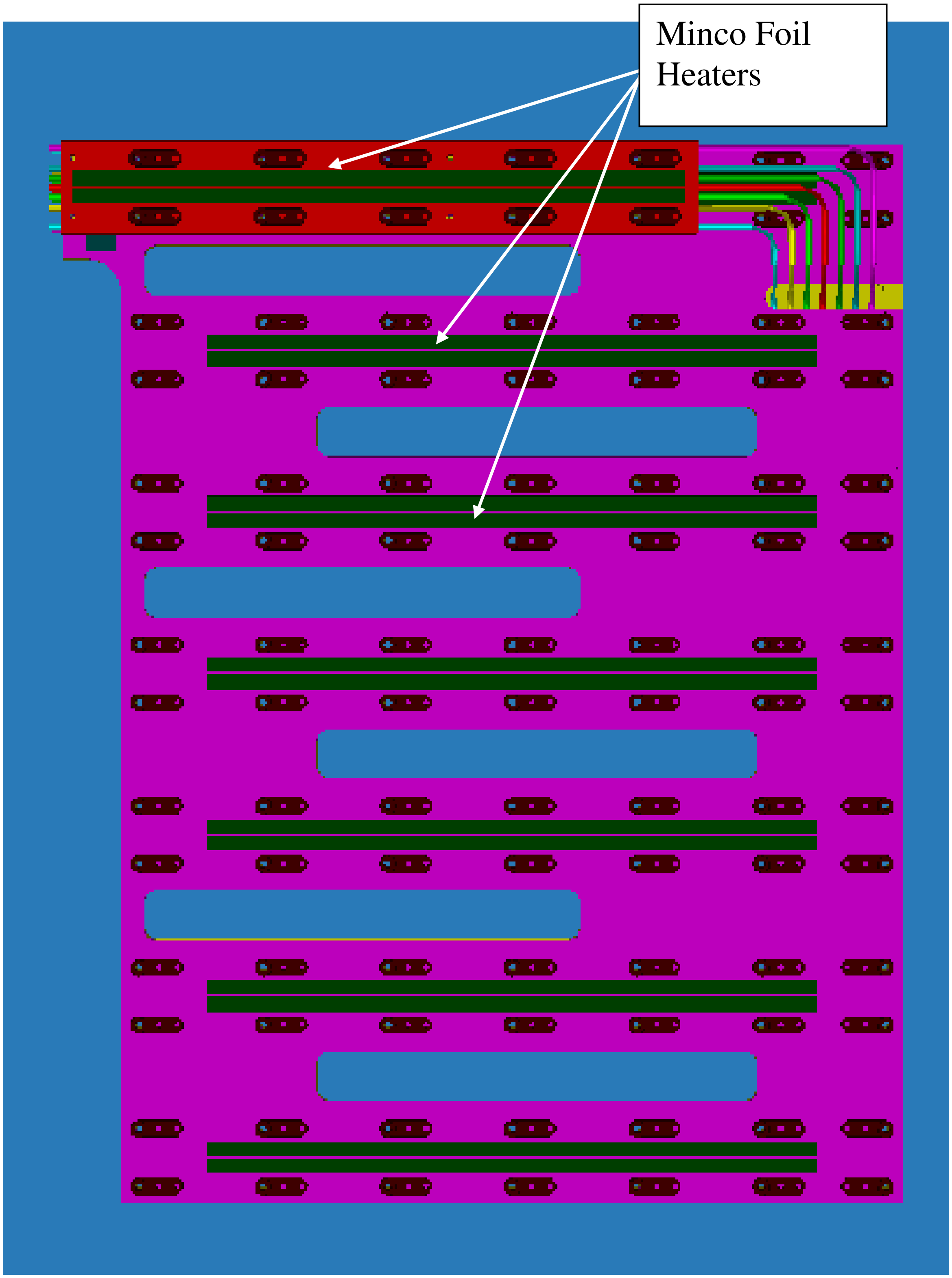


Figure 5.13.7.2.1-6 TTCS Condenser Heaters

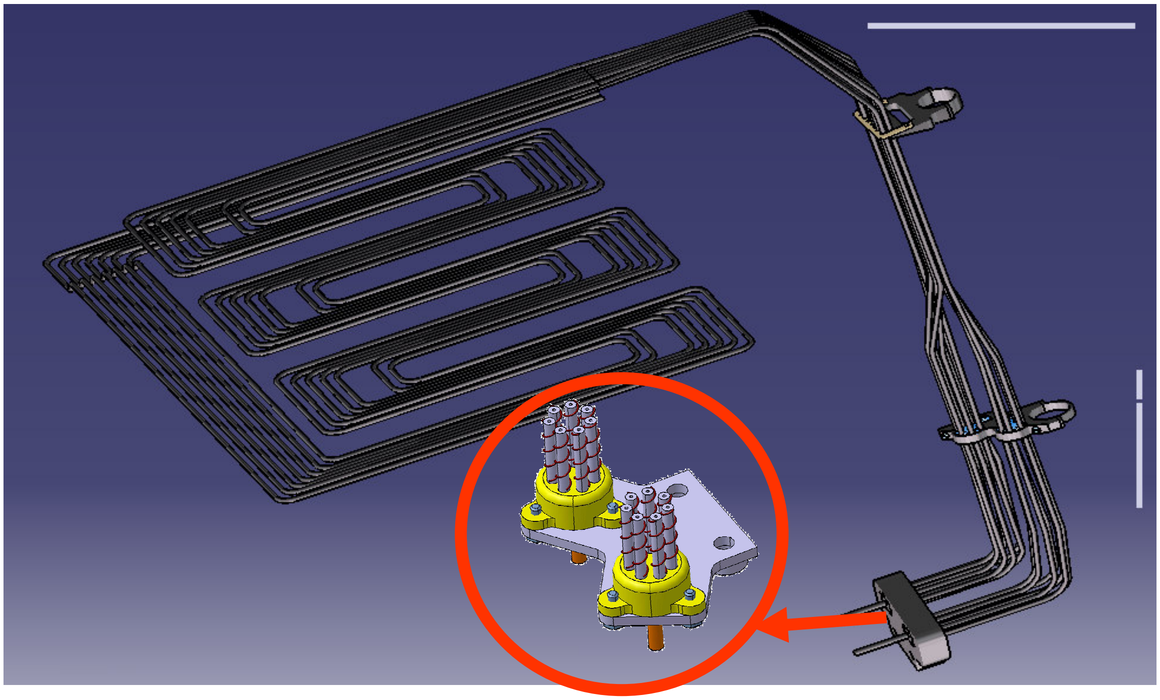


Figure 5.13.7.2.1-7 Capillary tubes from Condenser to Manifold

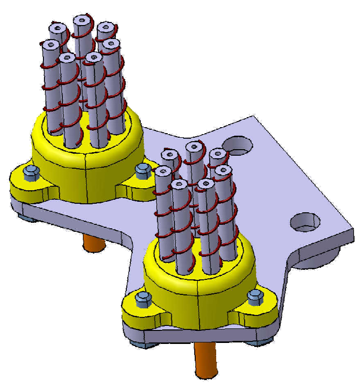


Figure 5.13.7.2.1-8 TTCS Manifolds (with heaters on tubes)

5.13.7.2.2 Pump

There are a total of 4 TTCS pumps; two for each redundant loop. The single stage centrifugal pumps are provided by Pacific Design Technologies and are similar to those successfully flown on the Mars Pathfinder mission. The rotating mass of these pumps is 0.5 inch in diameters with a maximum rotating speed of 9000 RPM. These pumps operate in an "open" environment and are not subject to pressure differentials other than those thsy generate themselves.

5.13.7.2.3 Accumulator

The accumulator is a CO_2 reservoir tank used to set the evaporation temperature for Tracker cooling and account for expansion of the working fluid (Figure 5.13.7.2.3-1). There are two TTCS accumulators, one Primary and one Secondary, mounted in each of the TTCB;s. The 1 liter cylindrical tanks (one for each loop) are made of 316LN CRES with an 82mm ID and 4mm wall thickness. The accumulator shell is penetrated to provide a liquid line to the TTCS CO2 loop and by an Accumulator Heat Pipe (AHP) that traverses the interior of the accumulator along the longest axis. The heat pipe is made of 316L CRES with a 304 CRES wick and ammonia as the working fluid. Heaters mounted to this heat pipe (2 x 22.5 + 2 x 15 watts) are used for warming of the CO_2 within the accumulator, controlling the mix of liquid and gaseous CO_2. A series of intricate 316L CRES mesh screens are mounted inside the tanks to act as a capillary wicks to assure that the liquid CO_2 is drawn to the inner surface of the tank and to the plumbing junction to the loop (Figure 5.13.7.2.3-2 and -3). Temperature set point control of the two-phase CO_2 loop is achieved by using Peltier elements (2x Melcor CP 1.0-127—05 L2 in series) to cool the accumulators and the heat pipe with its exterior mounted heaters to heat the accumulator contents. The Peltier elements are mounted to a saddle on the tank. Each set of two Peltiers have a cooling power of about 20 watts, corresponding with waste heat of about 30 watts. Thermostats are mounted with copper saddles on the accumulator heat pipe and the Peltier devices to provide two-fault tolerance against heaters exceeding a thermal threshold capable of driving the TTCS loops above the established MDP (Figure 5.13.7.2.3-4). One thermostatic control device for each heater element string and Peltier element has been placed in the power return leg of the circuit. The thermostatic switches have been placed to sense as directly as possible the heat load that is generated by each of the heater/Peltier devices.

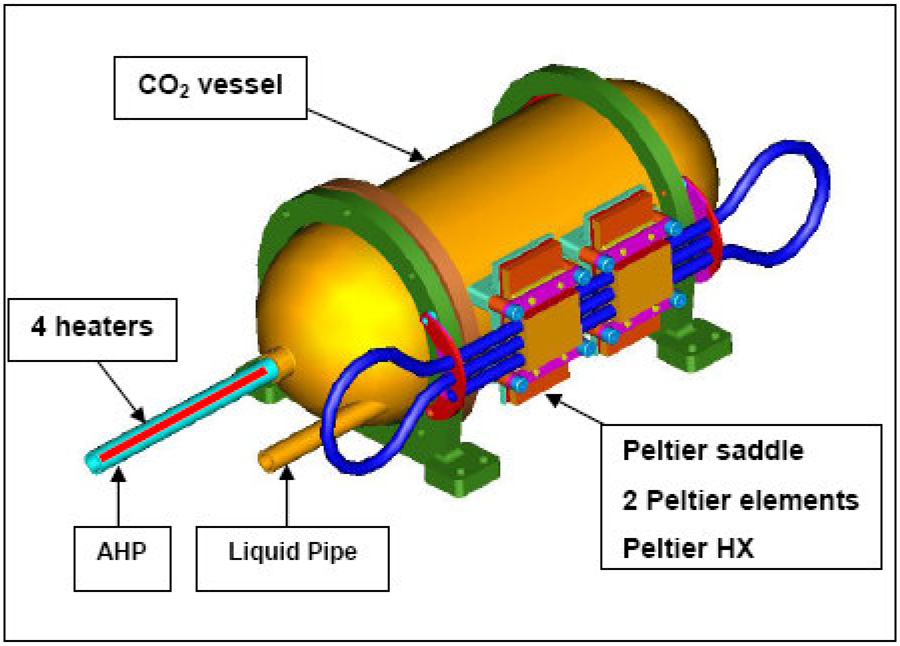
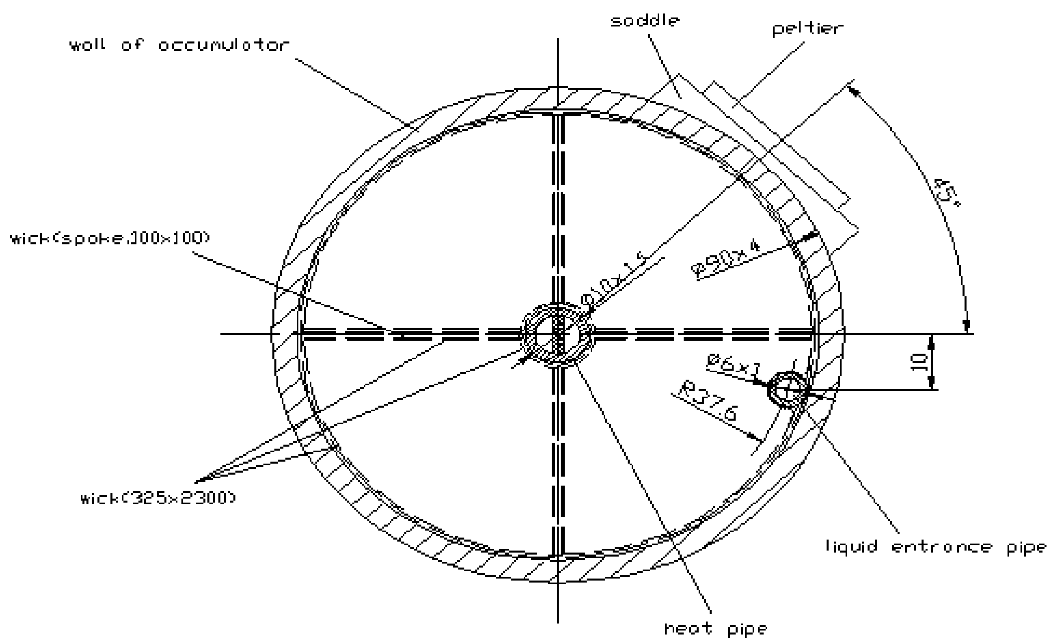


Figure 5.13.7.2.3-1 Accumulator Cross section (no wicking shown)



5.13.7.2.3-2 Accumulator Cross section (along heatpipe, portion of wicking shown.)

Figure 5.13.7.2.3-3 Accumulator Shell Heat Pipe And Wicking Material

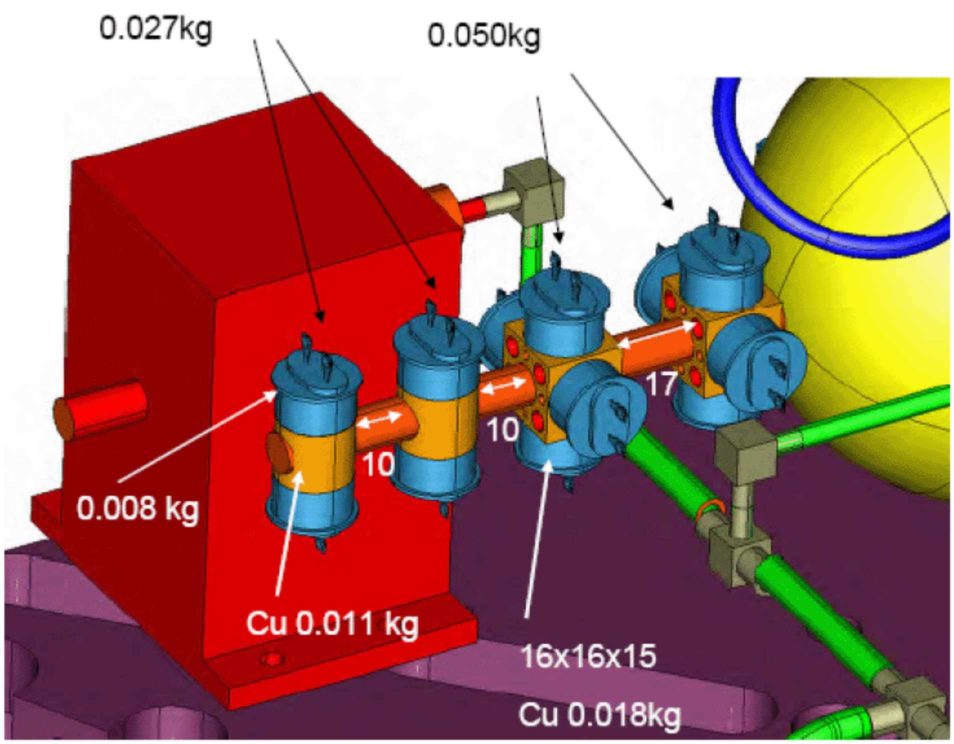


Figure 5.13.7.2.3-4 Accumulator Heat Pipe Thermostatic Control Devices

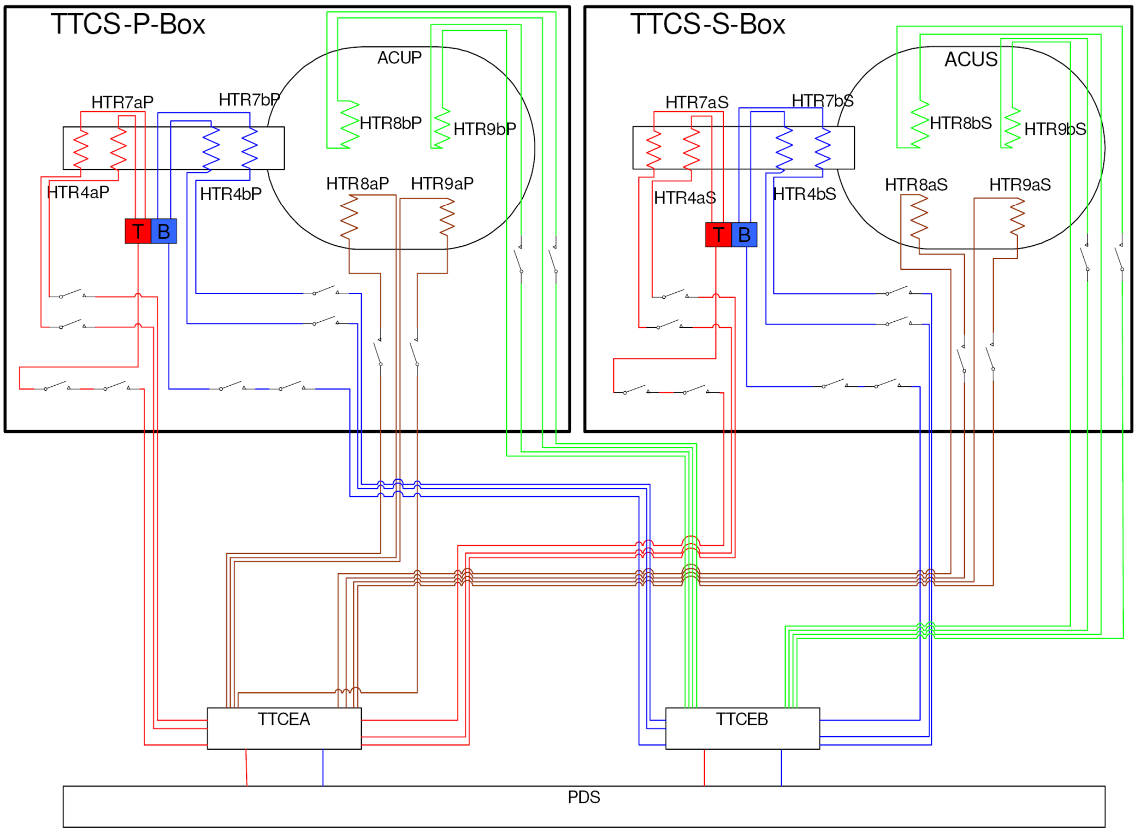


Figure 5.13.7.2.3-5 Accumulator Thermostatic Heater Control Circuitry

5.13.7.2.4 Heat Exchanger

The TTCS heat exchanger, mounted inside the TTCB, is designed to transfer heat between the Evaporator inlet and exit. This minimizes the amount of pre-heating needed to assure that the CO_2 entering the evaporator is at the saturation temperature. The heat exchanger is a two phase to single phase plate type made of Inconel with 4mm wall thickness. Inside are 36 plates soldered together (Figure 5.13.7.2.4-1). Two sets of heaters are mounted on the body of the heat exchanger, each controlled by three thermostats in series (Figure 5.13.7.2.4-2.)

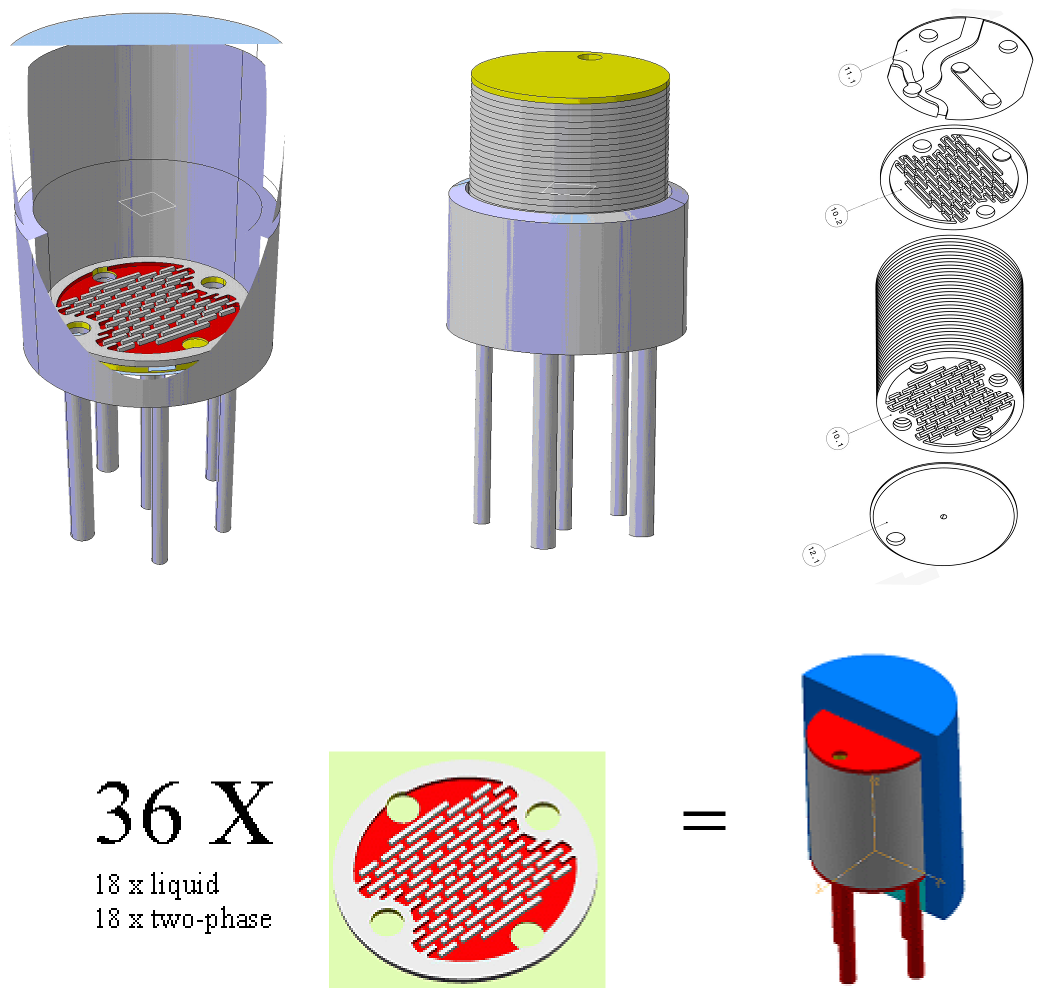


Figure 5.13.7.2.4-1 TTCS Heat Exchanger

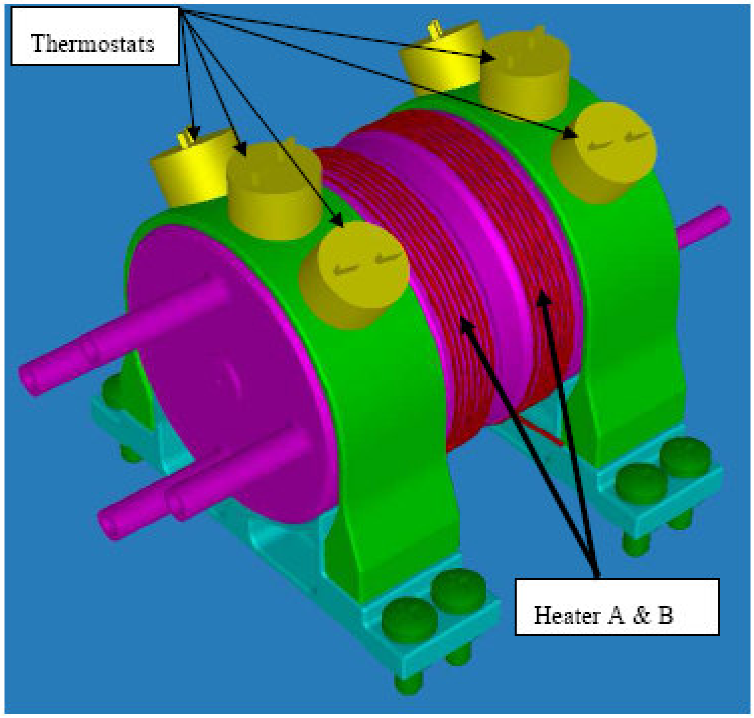


Figure 5.13.7.2.4-2 TTCS Heat Exchanger with Mounted Heaters

5.13.7.2.5 Pre-heaters

The pre-heaters are used to heat the sub-cooled liquid to the saturation point (i.e. set-point) before it enters the evaporator. Redundant, 8.9 watt heaters (Thermocoax SEA 10/150) are soldered to each of the 4 evaporator branches. Heater duty cycle will be determined by the temperature and flow rate of the liquid in each branch. The Pre-heaters are incapable of experiencing a thermal maximum condition that can drive the pressure of the TTCS above the MDP.

5.13.7.2.6 Start-up heaters

Start-up heaters, similar to the pre-heaters are used to heat the liquid CO_2 above -20C, to avoid over cooling the Tracker electronics prior to their switch-on. Two 55.8 watt heaters are mounted on each TTCS heat exchanger and have the potential to drive the pressure of the TTCS system. Three thermostatic switches are included in the power circuitry to assure that excessive temperatures are not possible. One of these thermostatic control devices has been place in the return leg of the heater power circuitry. .

5.13.7.2.7 Cold Orbit Heaters

Cold orbit heaters are used to raise the CO_2 temperature in order to prevent freezing in the condenser during cold orbits. While the condensers are designed to survive freezing, this is not desirable for system operation. The cold orbit heaters are located in each TTCB after the exit of the heat exchanges and before the split into the Wake and Ram condenser feed lines. This is shown in Figure 5.13.7.2.7-1.

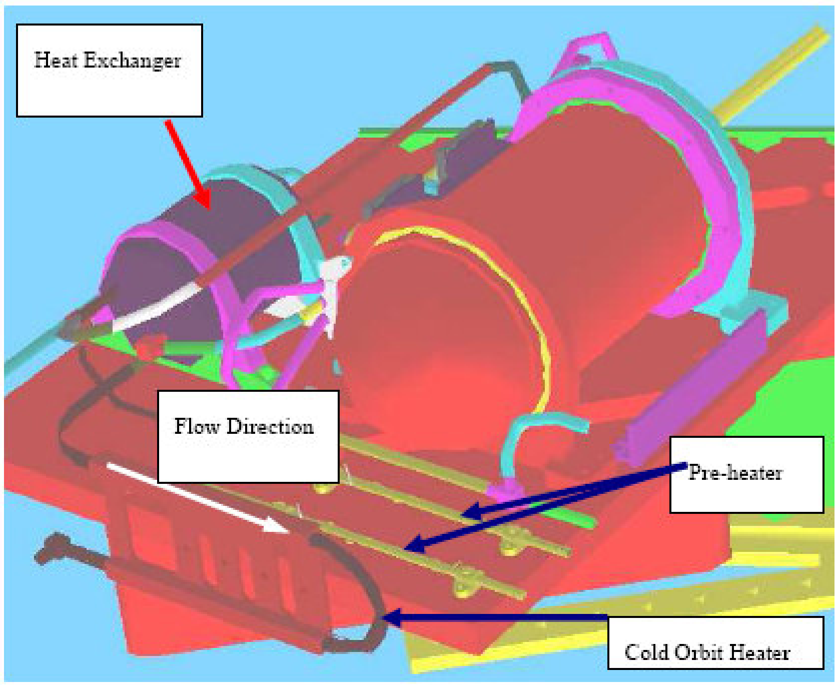


Figure 5.13.7.2.7-1 Cold Orbite Heaters on TTCB Baseplate

The cold orbit heaters include a copper structure approximately 5 x 12 cm. Wire heaters are soldered to the structure along with the liquid line from the heat exchanger. The liquid line passes two times for a total heating length of 24 cm. Each cold orbit heater provides nominal heating of 60 watts. Control is by software.

5.13.7.2.8 Oscillating Heat Pipe Experiment

The Oscillating Heat Pipe (OHP) experiment is a small, non-intrusive piggy back experiment located in the TTCB. The OHP is a single undulating capillary tube partially filled with liquid slugs and vapor plugs (Figure 5.13.7.2.8-1). Oscillation is achieved by pressure pulses due to evaporation of the liquid on the hot side; however, heat transport is achieved mainly by the sensible heat of the liquid slugs moving back and forth. The principle of this operation is poorly understood, which is a primary driver for this experiment.

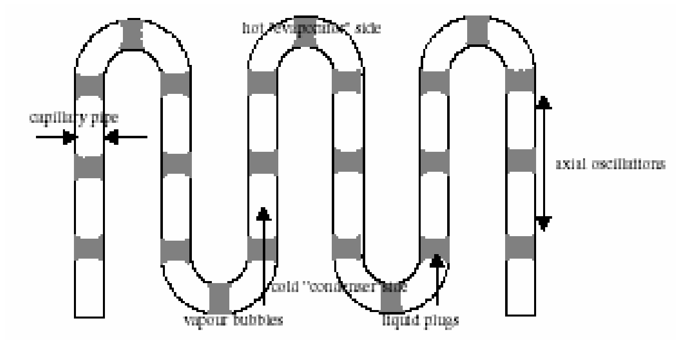


Figure 5.13.7.2.8-1 Oscillating Heat Pipe

Figure 5.13.7.2.4-2 shows the configuration of the OHP experiment. A stainless steel pipe is routed as shown on a bases plate. The ends of this pipe are pinched and welded after being filled with the working fluid, 3M FC-87. The "cold" side of the OHP is connected to the CO_2 loop just before the Heat exchanger inlet. A temperature gradient will be imposed using a 50 watt heater (Minco foil K5229 type 1) mounted on the "hot" side. This experiment will only be operated during cold environments.

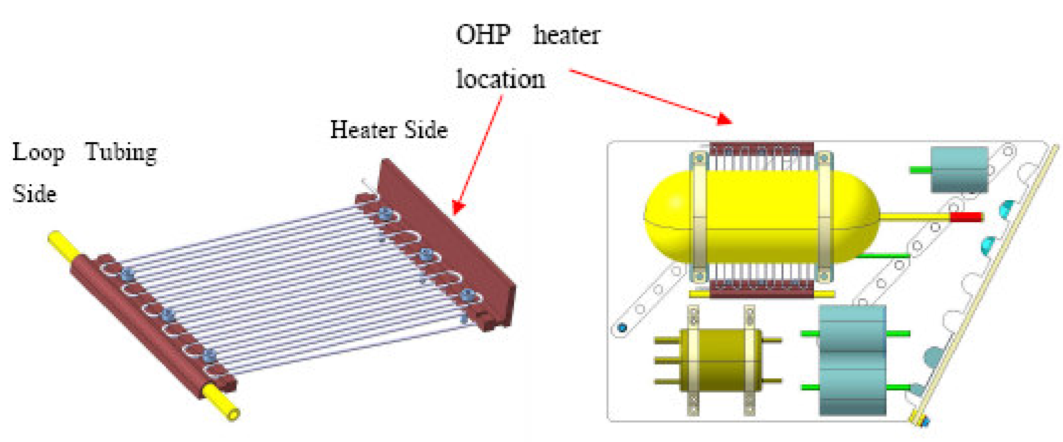


Figure 5.13.7.2.8-2 Oscillating Heat Pipe Experiment

5.13.7.3 CO_2 Freezing/Thawing

The TTCS is designed to reject heat generated in the Tracker as efficiently as possible. A results of this efficient design, is that when AMS experiences a loss of power the Tracker Radiators will drop in temperature rapidly. Subsequently, the TTCS condensers will also cool down to the environmental sink temperatures. In cold ISS attitudes, temperatures could drop below the freezing point of CO_2 (approximately -55ºC based on fill quantity and pressure) and frozen CO_2 could accumulate in the condenser capillary tubes. By design, the condenser manifolds are mounted in a location (under MLI on the Vacuum case conical flange) which will never freeze. Line heaters on the capillary tubes are design to thaw the CO_2 from the manifold to the condenser after power is restored. The capillary tubes are made of extremely high strength Inconel 718 which is capably of withstanding the pressures due to uncontrolled heating of a plugged section of frozen CO_2. To measure these pressures and verify this design, testing was performed using lower strength stainless steel tubing. This test successfully measured pressures due to freezing/thawing of a plugged section (by measuring induced strain in the tubing) and showed no sign of tube failure. A more detailed description of this test can be found in the TTCS Condenser Freezing test report (NLR-Memorandum AMSTR-NLR-TN-039-Issue03, 23 August 2005).

5.13.8 CAB Thermal Control

The Cryomagnet Avionics Box (CAB) is used to monitor and control the AMS-02 Cryomagnet. Power dissipation can vary from as low as 35 watts to over 800 watts during Cryomagnet charging. This severe range poses extreme challenges to the CAB thermal design. The CAB itself is design to conduct heat from internal electronics to the box walls. Two Loop Heat Pipes (LHPs) will be used to transport heat from the baseplate (-X side) to the Wake Main Radiator (Figure 5.13.8-1). During Cryomagnet charging, most other AMS-02 electronics are turned off, so this radiator has excess capacity to reject heat. A bypass valve on each LHP will be used to bypass the radiator if CAB temperatures approach low temperature limits. The LHP and bypass design is identical to those used for the Cryocoolers (see Section 5.13.6), except that ammonia will be used as the working fluid and the bypass valve temperature setting will be based on CAB limits.

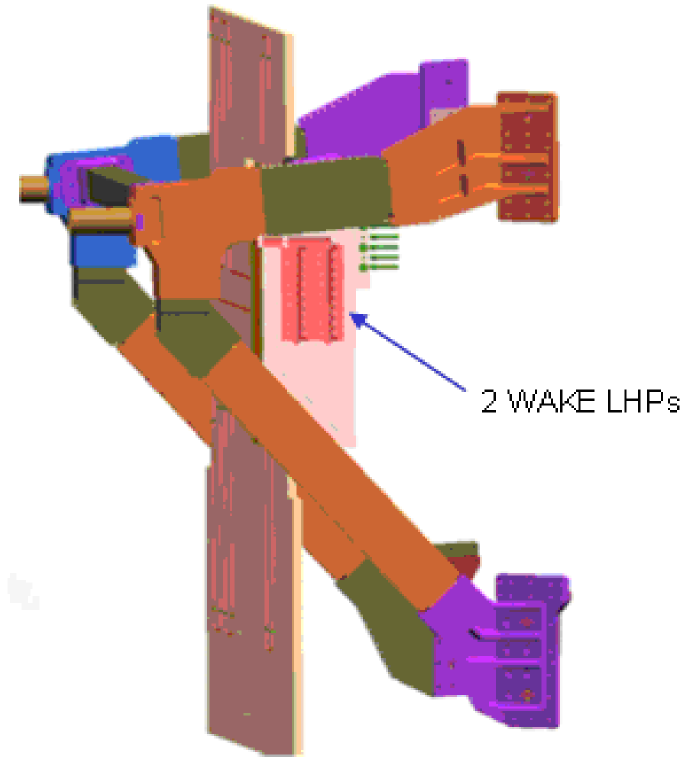


Figure 5.13.8-1 CAB Cooling System

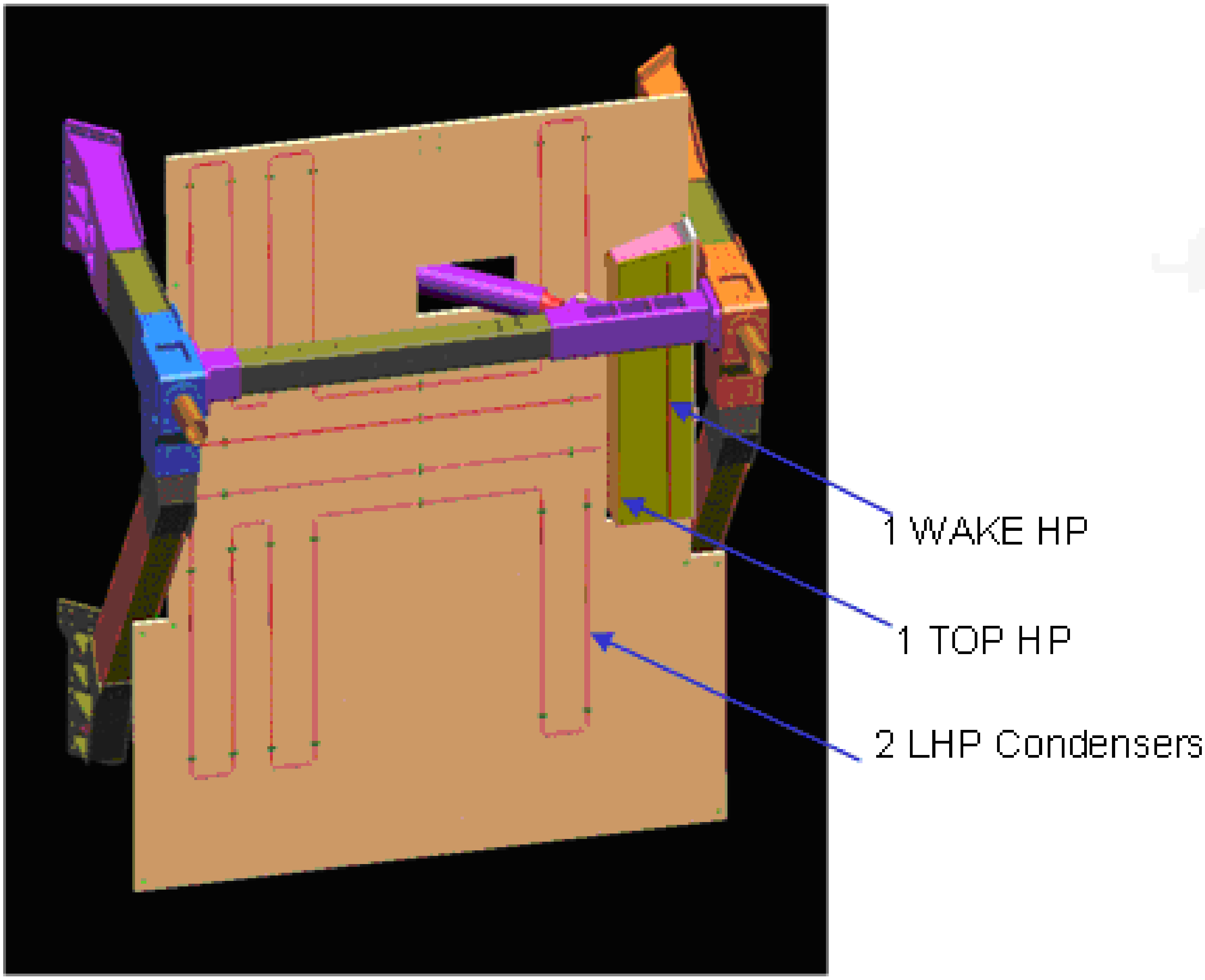


Figure 5.13.8-2 CAB LHP routing on Wake radiator

Additional axial groove heat pipes will be mounted to the base plate and top (+Y side) to help distribute heat. Heat pipes are also mounted between the USS-02 Upper Trunnion Bridge Beam and the Upper Vacuum Case Interface Joint (Figure 5.13.8-3). This is needed to help the CAB reject heat during Cryomagnet charging. The outer surface of the CAB is covered with silver Teflon to bias it cold. Heaters will be used to maintain the CAB above minimum temperature limits.

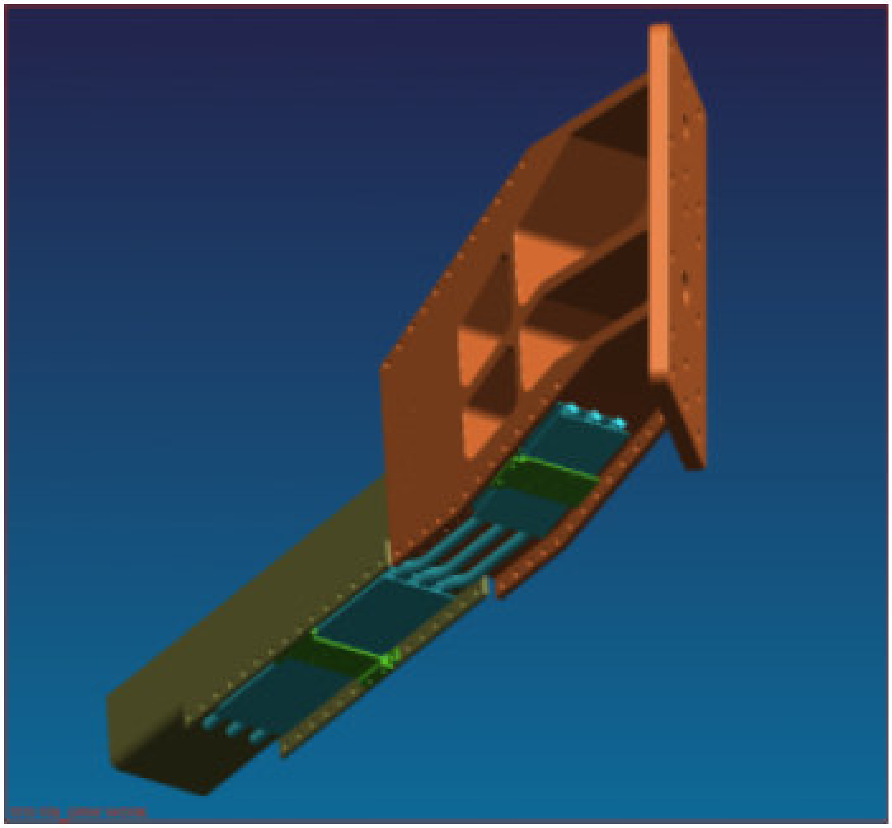


Figure 5.13.8-3 Heat Pipes on USS-02

5.13.9 TRD Thermal Control

The Transition Radiation Detector (TRD) has some of the most severe thermal requirements on all of AMS (Figure 5.13.9-1). In addition to component temperature limits, the entire detector needs to be isothermal within +/- 3ºC. To achieve this goal the 4 main structural interfaces to the USS-02 are isolated as much as possible with titanium spacers and the 4 Zenith Radiators-panels are mounted to the top of the TRD, each with 14 glass-fiber pins, design to minimize heat leak. Cable and plumping feed-throughs are also kept at a minimum and insulated to reduce heat leak. The entire detector, along with the Upper Time-of-Flight (UTOF) is completely enclosed in a 10-layer MLI blanket (Figure 5.13.9-2). Resistive heaters heaters are glued to the M-structure (17.35 watts (4 x 3320 Ω heaters) per side x 4 sides = 69.40 watts total (using nominal 120 Vdc)) to minimize gradients and keep the entire detector within the desired temperature range.

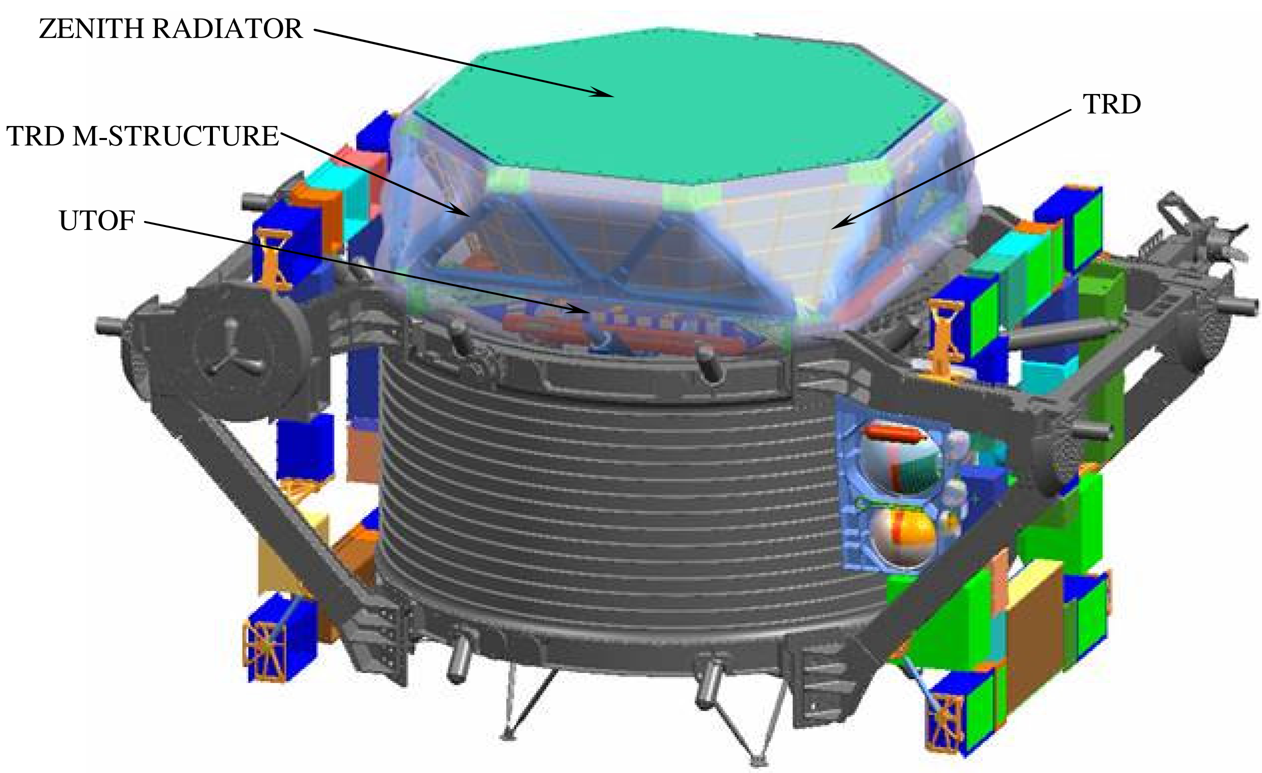


Figure 5.13.9-1 TRD on AMS-02

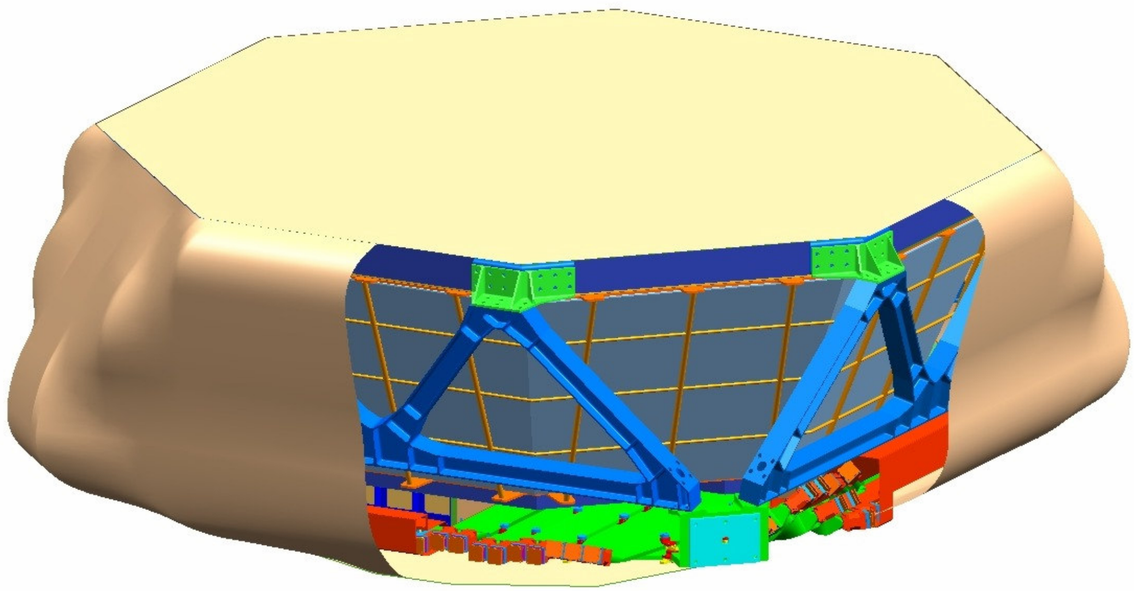


Figure 5.13.9-2 TRD MLI

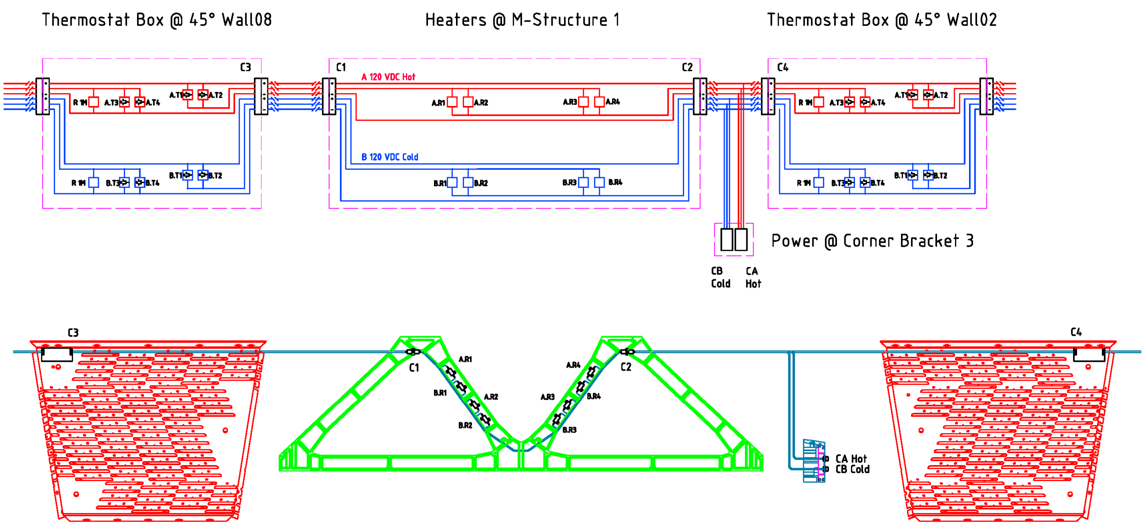


Figure 5.13.9-3 TRD M-Structure Heater Schematics

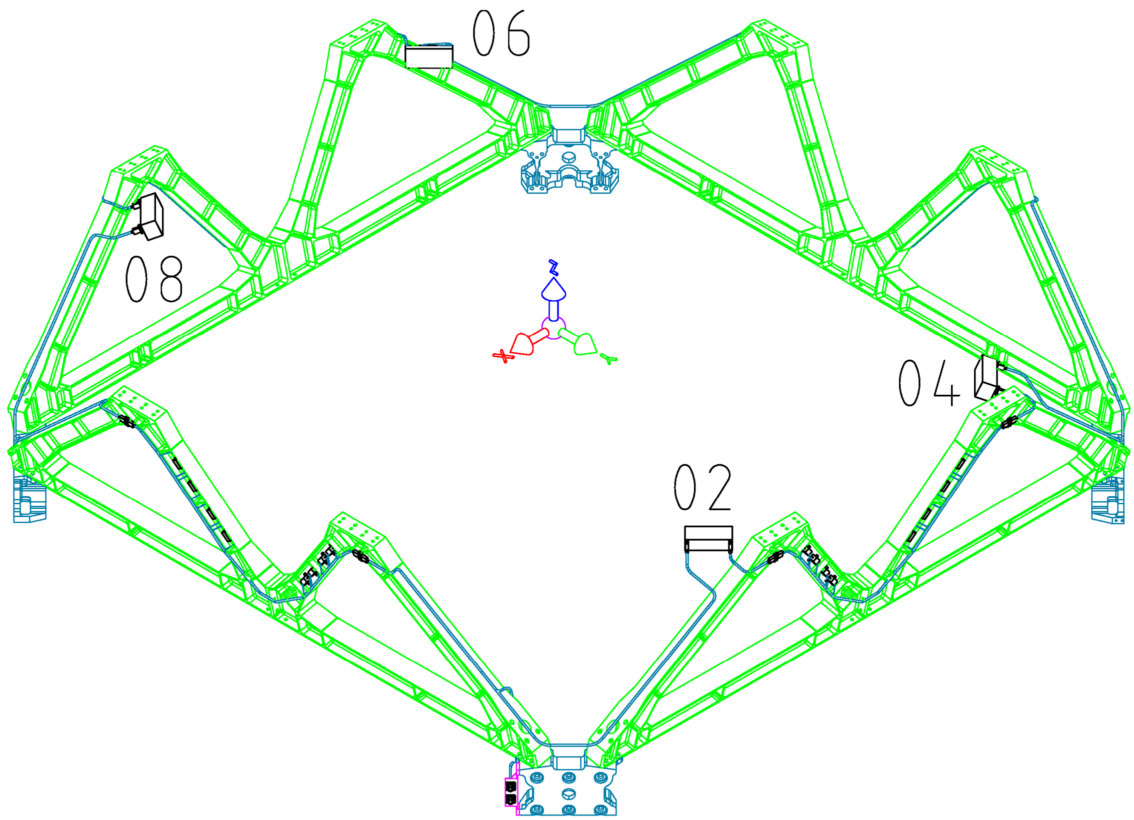


Figure 5.13.9-4 TRD M-Structure Heater Placement and Heater Cable Routing

5.13.10 TRD Gas Supply Thermal Control

The TRD Gas System (Figure 5.13.10-1) consists of two parts; the Supply (Box S) and the Control (Box C). Box S includes a high pressure Xenon tank, a high pressure CO_2 tank, a mixing tank, pre-heater volumes, sets of valves, pressure sensors and associated tubing, all mounted on an aluminum support plate. Box C includes two pumps, monitoring tubes and valves. The entire subsystem is structurally mounted to the AMS Unique Support Structure (USS-02). The thermal design of the TRD Gas System is intended to maintain components (valves, pressure sensors and pumps) above their minimum temperature limits, to heat pressure vessels above the critical point of the gasses (Xe and CO_2), and to assure that no enclosed volume will be overheated in the event of any two failures.

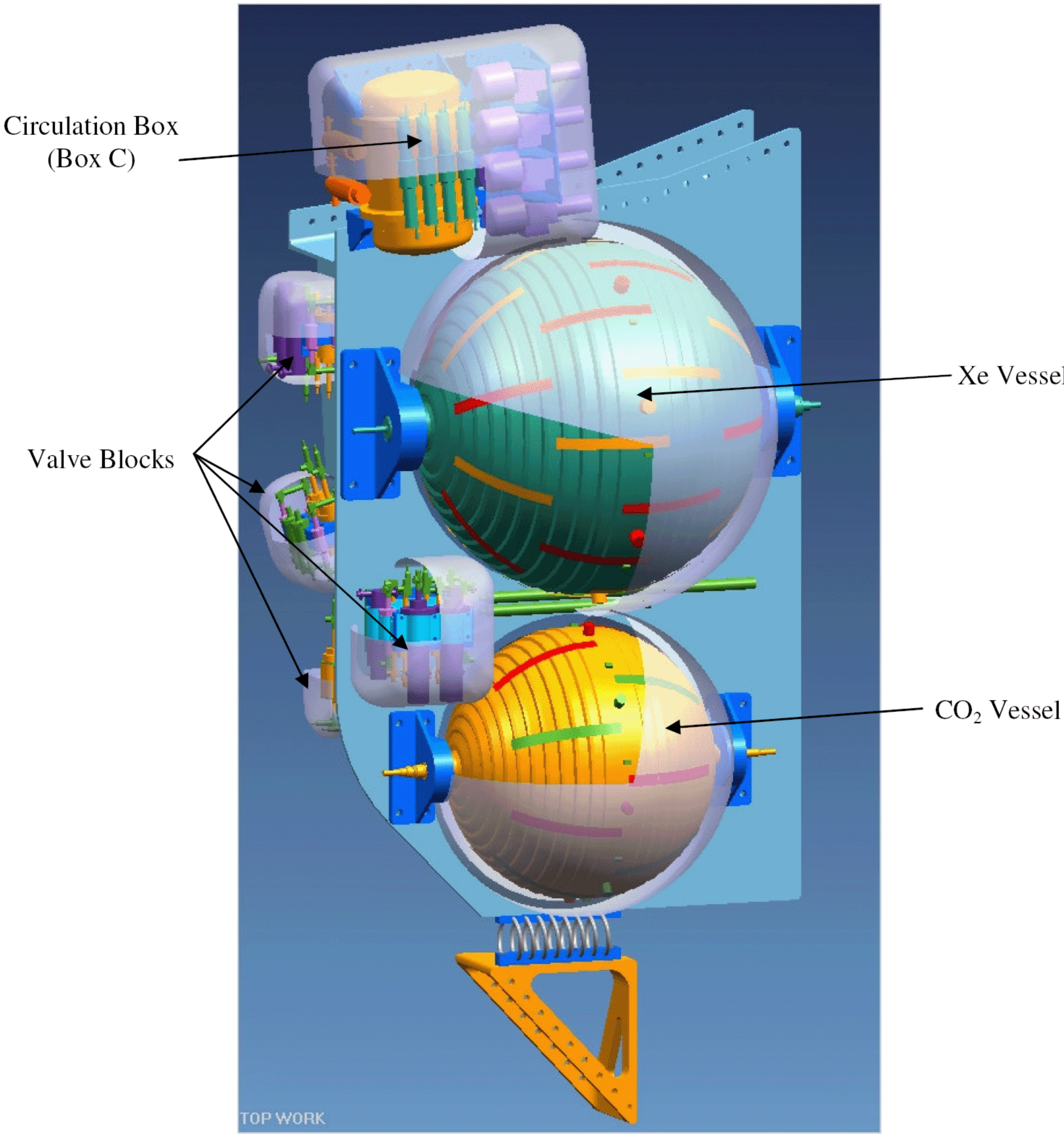


Figure 5.13.10-1 TRD Gas Supply (Box S)

Active heating is required to keep both the Xenon and CO_2 tanks above their respective saturation temperatures. This is needed in order to monitor the amount of fluid remaining in each tank by means of a pressure sensor. Due to an extremely long time constant, it is not possible to quickly warm up the fluid in the tank. The Xenon must be maintained above 20ºC and CO_2 above 34ºC. Kapton foil heaters are glued to the surface of the composite over-wrapped stainless steel tanks. Two strings of eight heaters patches (one for each power feed) are distributed around the tank surface (Figures 5.13.10-2). Four thermostats in series are used for each heater string to protect against overheating of the pressure vessel. There are two redundant heaters strings, one for power feed A and one for power feed B. A cloth belt provides additional support for the thermostats and thermal sensors. Engineering evaluations in thermal-vacuum were performed to quantify any temperature gradients between thermostats and heaters. Each individual tank is wrapped in multi-layer insulation (MLI) and the entire TRD Gas Supply S-box in another MLI blanket.

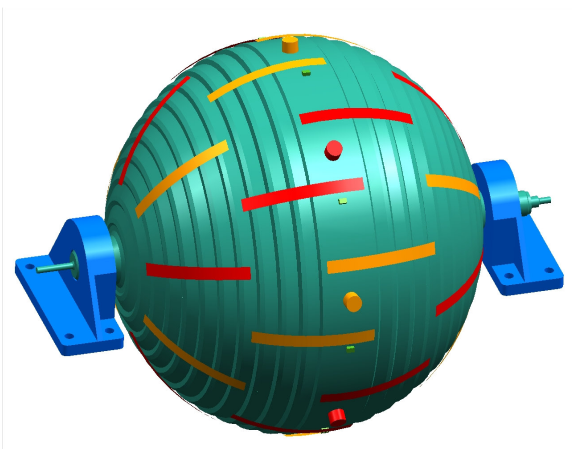
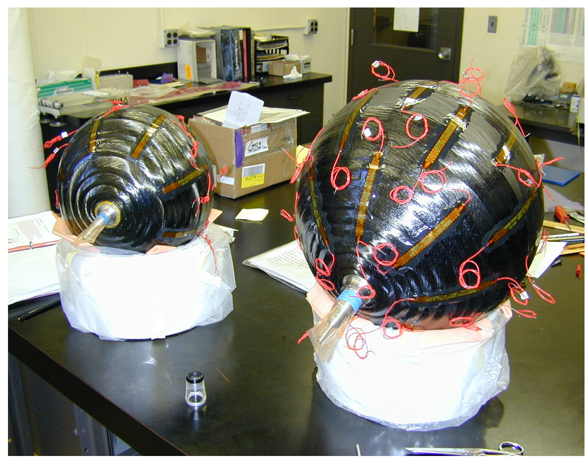



Figure 5.13.10-2 Xe and CO_2 Vessels with heaters

Box S also has 5 groups of valves mounted together with support brackets. Resistance heaters are mounted to each bracket in order to keep valves above their minimum operating temperatures limit. A single thermostat is used to control each heater. Additionally, two thermostats in series are mounted to the support plate to avoid overheating in the case of a stuck on thermostat. The brackets are bolted to the support plate using G10 spacers for insulation. Each group of valves is also enclosed within a 7-layer MLI blanket. These blankets are also made with aluminized Kapton for both the inner and outer layers.

The TRD Gas Circulation System (Box C), shown in Figure 5.13.10-3, includes pumps the low pressure gas mixture from the mixing tank into the TRD straw tubes. A pressurized canister encloses two diaphragm pumps. Heaters mounted on this can maintain the pumps above their minimum temperature limit. Resistance heaters mounted to a support bracket maintain a group of valves above their limit. Both the can and valve bracket heaters are controlled with a single thermostat. A 7-layer MLI blanket (Betacloth on the outside) encases Box C.

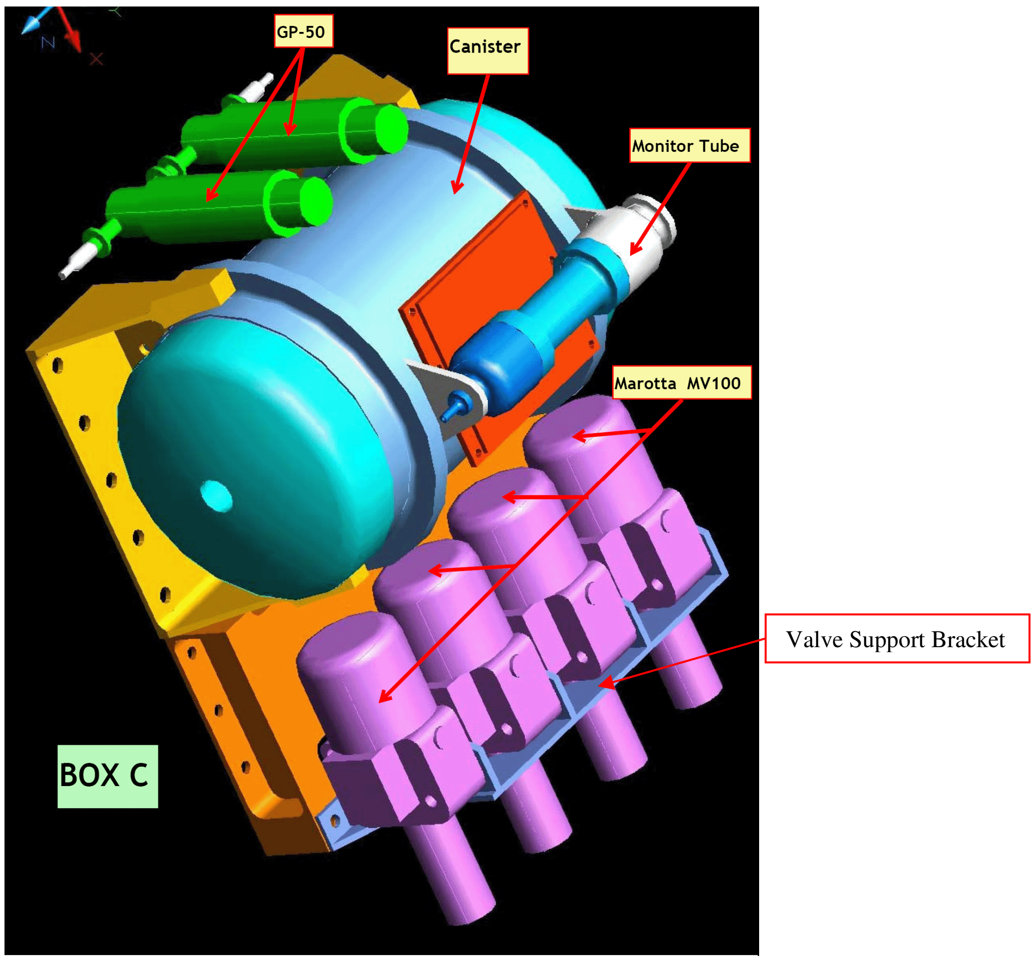


Figure 5.13.10-3 TRD Gas Circulation (Box C)

5.14 MICROMETEOROID AND ORBITAL DEBRIS (MMOD) SHIELDING

The MMOD will be designed, analyzed, built and integrated by NASA/ESCG. The shielding is designed to protect the pressure systems on the AMS-02 experiment according to the environments specified in SSP 30425, paragraph 8.0. These systems include the Vacuum Case, Warm Helium Supply, and the TRD Gas System which contains both the Xe tank and CO_2 tank. The location of these components on AMS-02 is shown in figures 5.14-1 and 5.14-2.

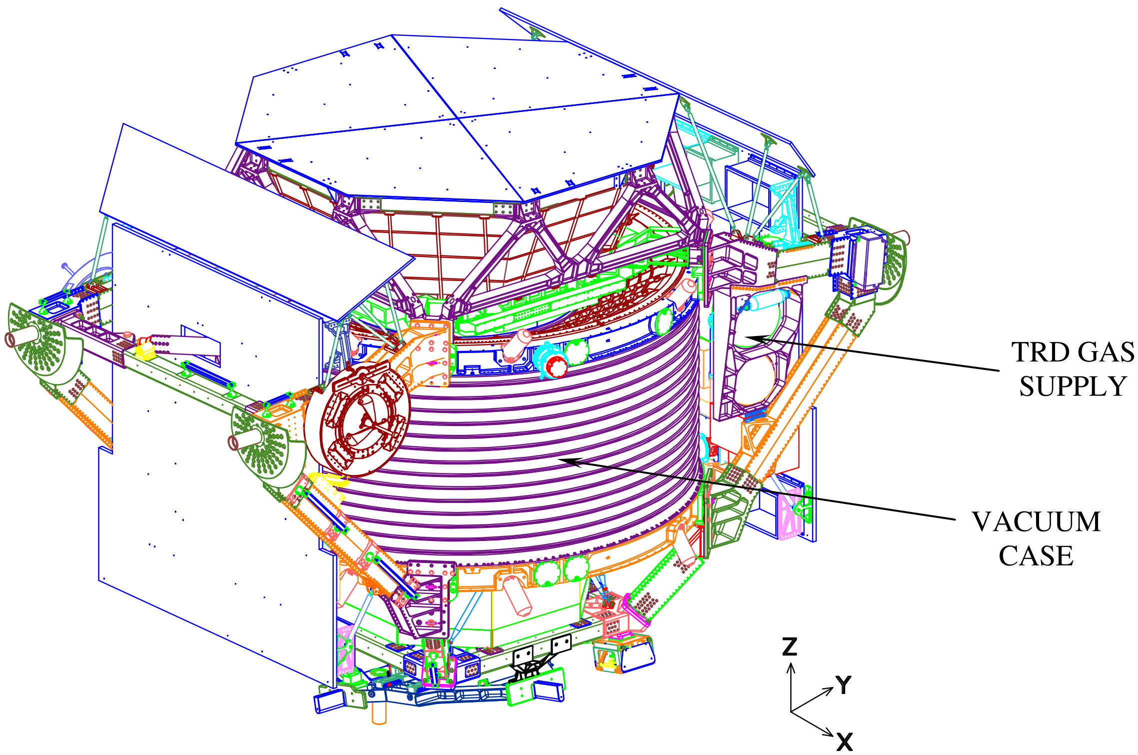


Figure 5.14-1 AMS-02 Payload Assembly (1 of 2)

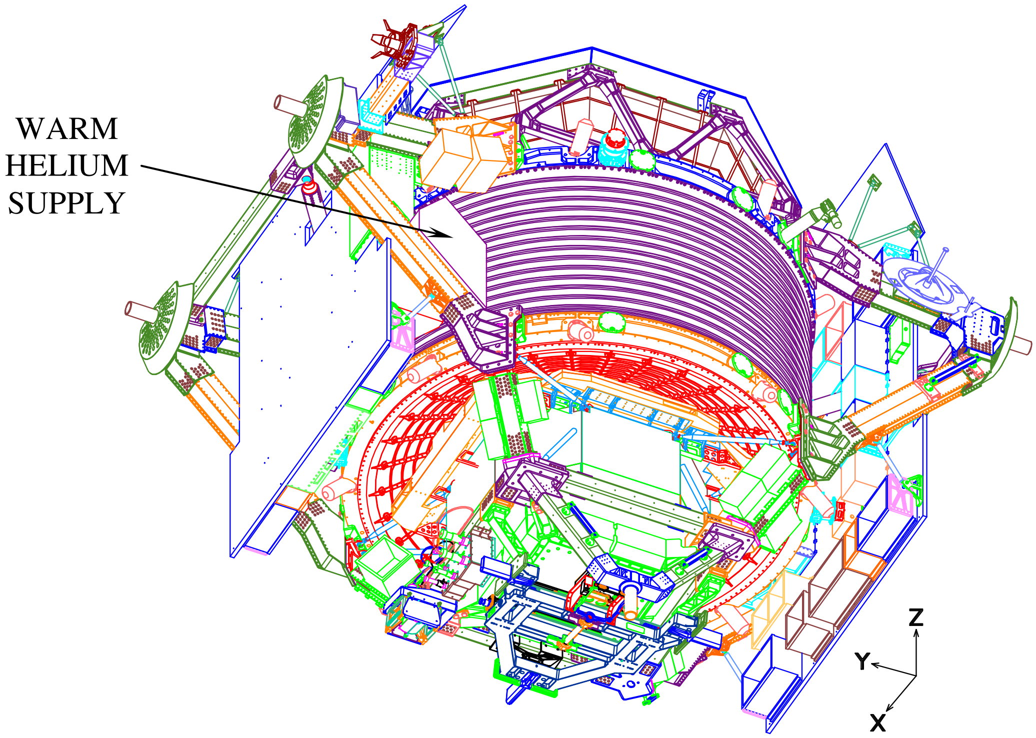


Figure 5.14-2 AMS-02 Payload Assembly (2 of 2)

The shielding will be made from various components in different locations depending on the required shield thickness, shape and size. The proposed MMOD shielding for AMS-02 consists of a 0.1 inch outer and inner aluminum sheet with a layer of 0.1 inch Kevlar/Nextel. Standoffs will be used to separate the outer aluminum sheet from the inner aluminum sheet. The proposed shield design is shown in figure 5.14-3. Both sets of MMOD shields will have the same general design.

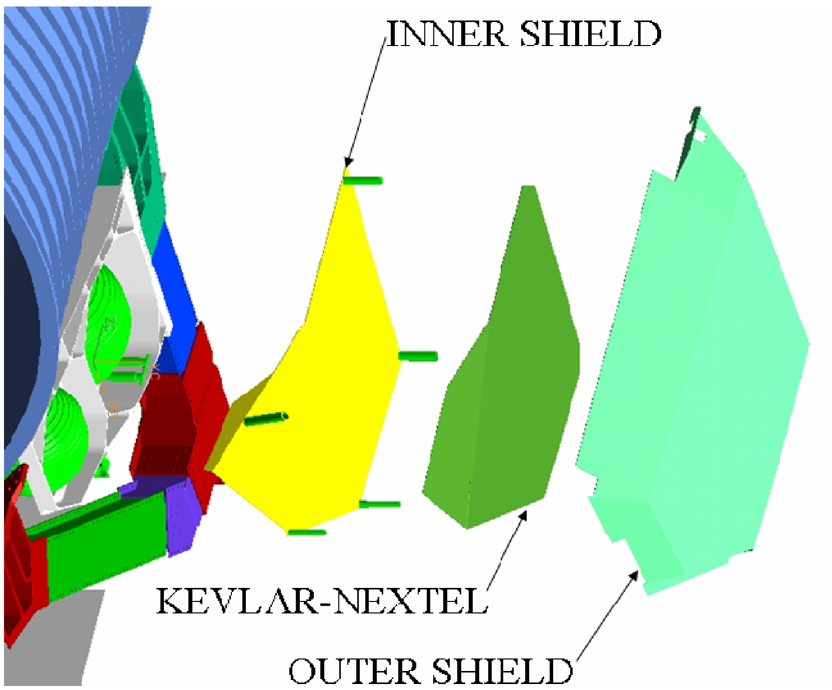


Figure 5.14-3 Proposed MMOD Shield Design

The shield assemblies will be bolted to the Upper and Lower Trunnion Bridge Beams of the USS-02. Proposed locations for the MMOD shielding are shown in figures 5.14-4 and 5.14-5.

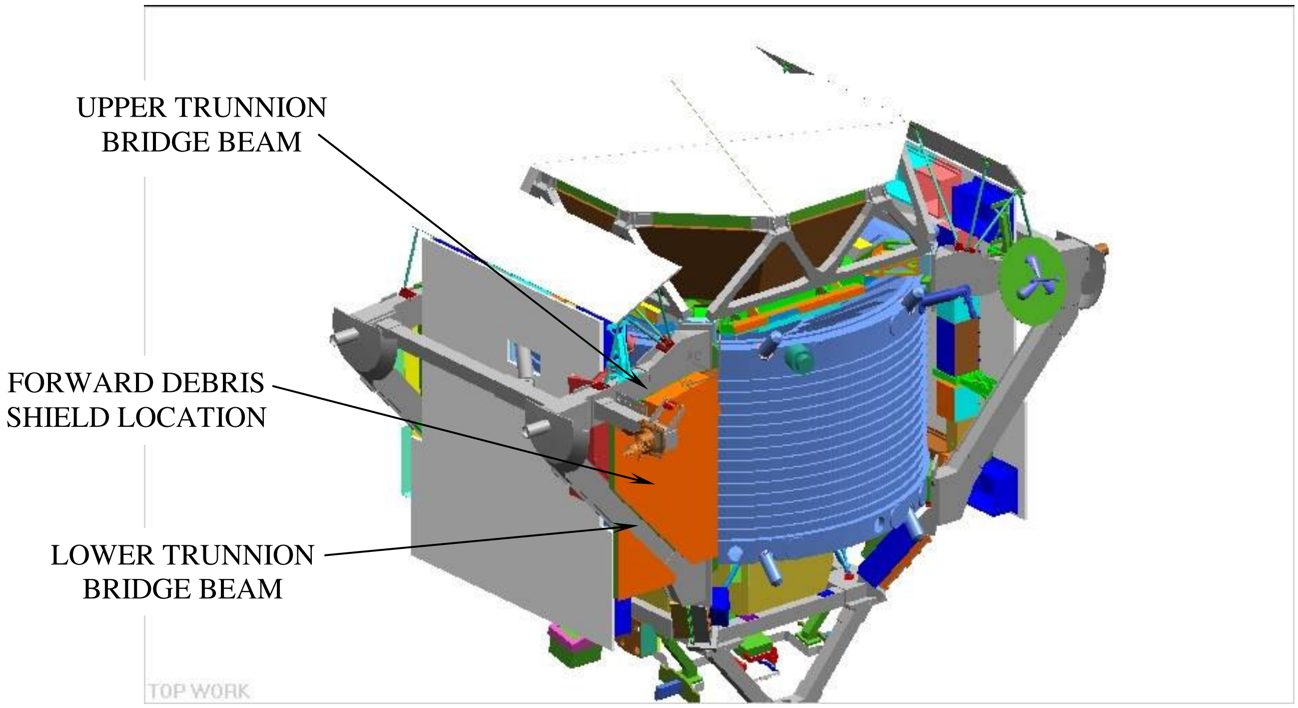


Figure 5.14-4 Warm Helium Supply Debris and Vacuum Case Debris Shield

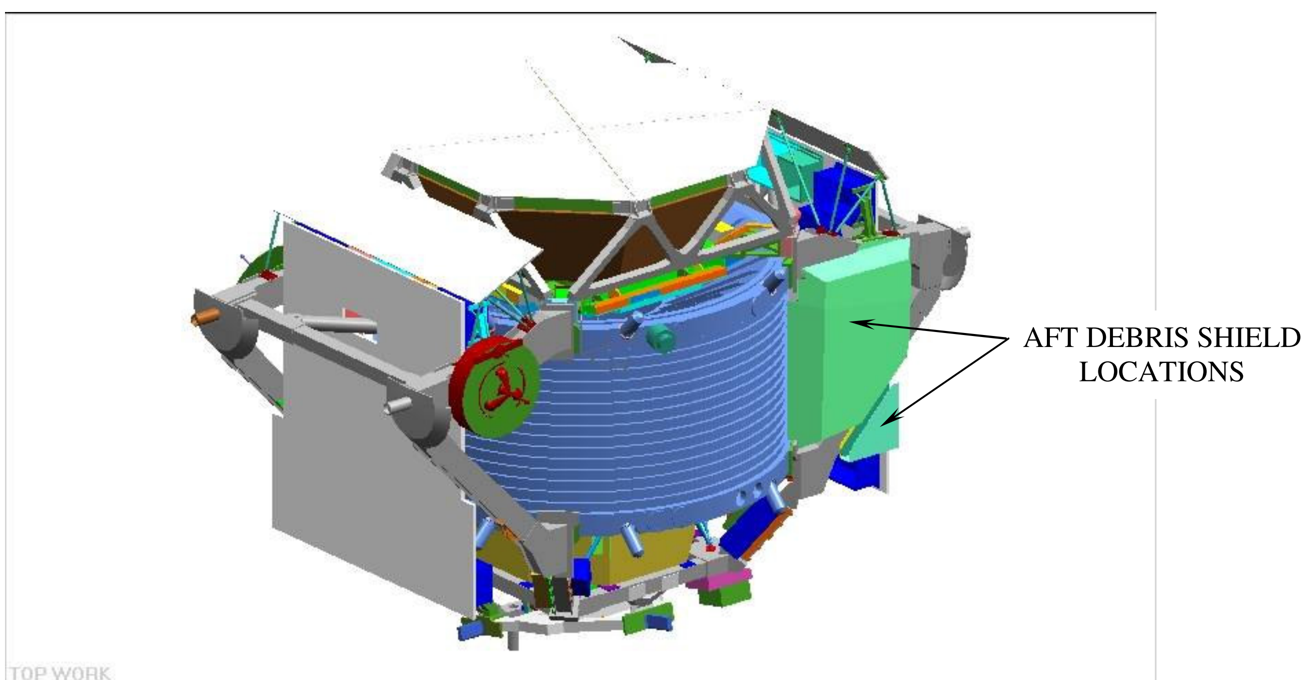


Figure 5.14-5 TRD-Gas Supply and Vacuum Case Debris Shield

The NASA Hypervelocity Impact Technology Facility has been and will continue to perform all of the analysis and testing for the MMOD requirements. Testing has been performed to ensure that the correct ballistic limit equations are used in the analysis. The shields will be designed to meet the ISS and STS requirements.

5.15 GLOBAL POSITIONING SYSTEM (GPS)

The AMS-02 utilizes an ALCATEL TOPSTAR 3000D which will be integrated into AMS by IN2P3-Montpellier. A single patch type antenna (Sextant Avionique model 3407-79) will be mounted on the TRD "M" structure (Figure 5.15-1). A signal from the GPS unit will be used for precision time correlation that exceeds the capabilities of the ISS to provide. The need for the GPS is to correct time drift over time within the precision timing systems that trigger the particle events.

Interface electronics within the M-Crate receive the precise time at which the timing pulse from the GPS unit was emitted and this is included, along with the value of the local timer, in the event data. To reach the required accuracy, software has been developed to include all the corrections required for low earth orbit GPS applications. The GPS operates off of the AMS-02 internal 28 VDC power bus.

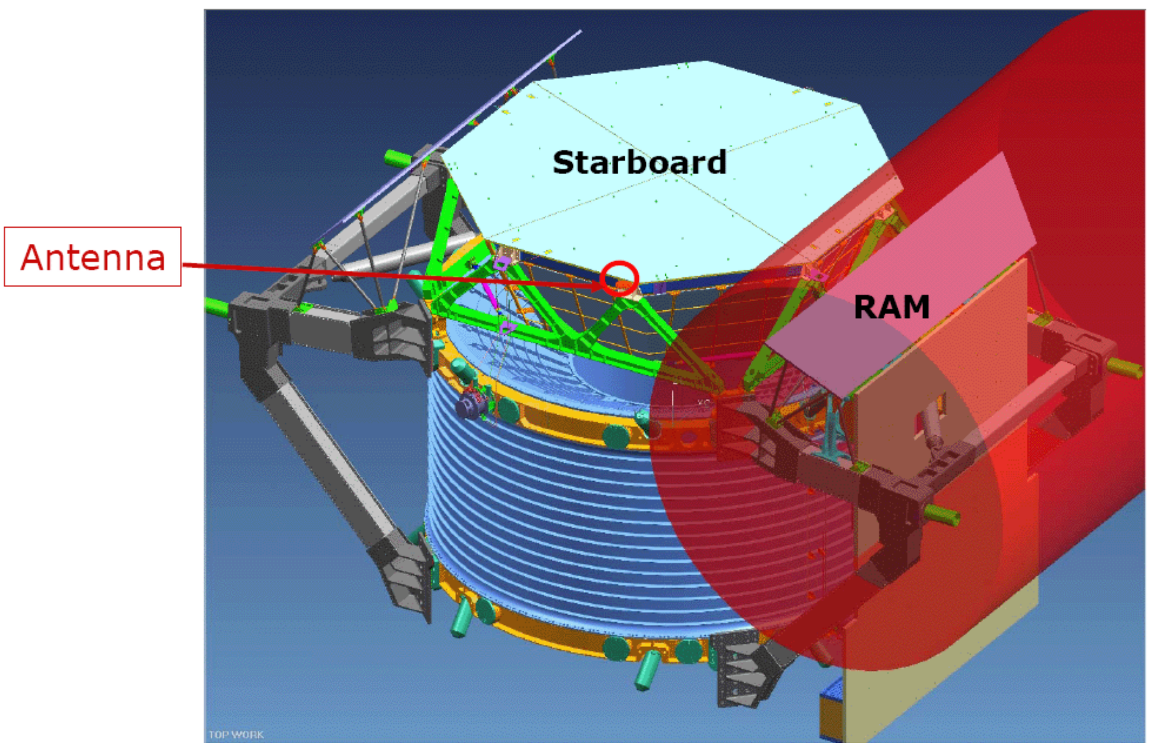


Figure 5.15-1 Location of AMS-02 GPS Antenna

6. AMS FLIGHT OPERATIONS SCENARIO

6.1 PRELAUNCH OPERATIONS

The AMS-02 requires power and data/command capability prior to launch. By utilizing AMS-02 supplied Ground Support Equipment, AMS-02 personnel monitor the 1553 Bus data for telemetry including temperature/pressure measurements and system operating characteristics. Health and Status of the Super Fluid Helium (SFHe) Tank is monitored by ground controllers and compared to trend data established over the lifetime of the experiment. This monitoring will continue until at least the end of the T-9 minute hold at which time AMS-02 ground controllers will make a “Go/No Go” decision for launch based on the health and status of the SFHe Tank. Trend data for the tank will be collected from initial assembly throughout all ground operations to establish a good baseline measurement of boil-off characteristics.

The only identified potential hazard specific to launch operations of the AMS-02 payload involves a rupture of the vacuum case just prior to launch that would lead to increased pressures in the SFHe Tank during ascent. If the tank was to over-pressurize and rupture the tank burst disks between L+30 seconds and L+1 minute, the payload bay could experience over-pressurization from the helium vented and the aft-bulkhead and payload bay doors could be damaged. The rupture of Cryosystem burst disks were at any other time does not pose a risk to Orbiter or the ISS from the pressure released. Health and status of the SFHe tank will be determined by a minimum of three measurements of temperature and pressure within the SFHe Tank. These measurements will be made available to the Mission Control Center (MCC) and the Launch Control Center (LCC) as desired; however, the “Go/No Go” call will be made by the AMS Project Management team in the Customer Support Room (CSR) at JSC in conjunction with the Payload Operations Control Center (POCC) at JSC. Additionally, AMS personnel will be monitoring these parameters from a User Room in the Space Station Processing Facility (SSPF) at KSC. The Ground path for these critical parameters is being worked with JSC and KSC personnel; and will require redundancy to ensure good communications during this critical period. The data will be available via 1553 Bus A, Bus B, or the RS-422 link.

GSE power via the T0 umbilical is independent of Orbiter power systems and located in MLP Room 10A. T0 operations include 120 Vdc power routed to the Power Distribution System (PDS) and a separate 120 Vac power feed to a Vent Pump designed to allow venting of the SFHe Tank for boil-off during ground operations until L-30 minutes. Following installation, 500-1000 W of power are required for vent pump operation, an additional ~450W are required for operation of the four Cryocoolers and for critical monitoring functions. Payload monitoring capability is supplied via the 1553 Bus and the high-rate data system (RS-422 protocol) routed from Shuttle Payload Data Interface Panel (PDIP2) assembly through the T0 umbilical interface to Ground Support Equipment (GSE).

As shown in Figure 6.1-1 below, low rate data (1553) is routed through T0 umbilical from Shuttle PDIP2 with the “AMS-02 1553” switch in the “T0” position, and program provided jumper installed on PDIP2 front panel “J4” connector. High rate data (RS422) is routed through T0 umbilical from Shuttle PDIP2 via payload provided cable installed between PDIP2 front panel “J103” and “J105” connectors.

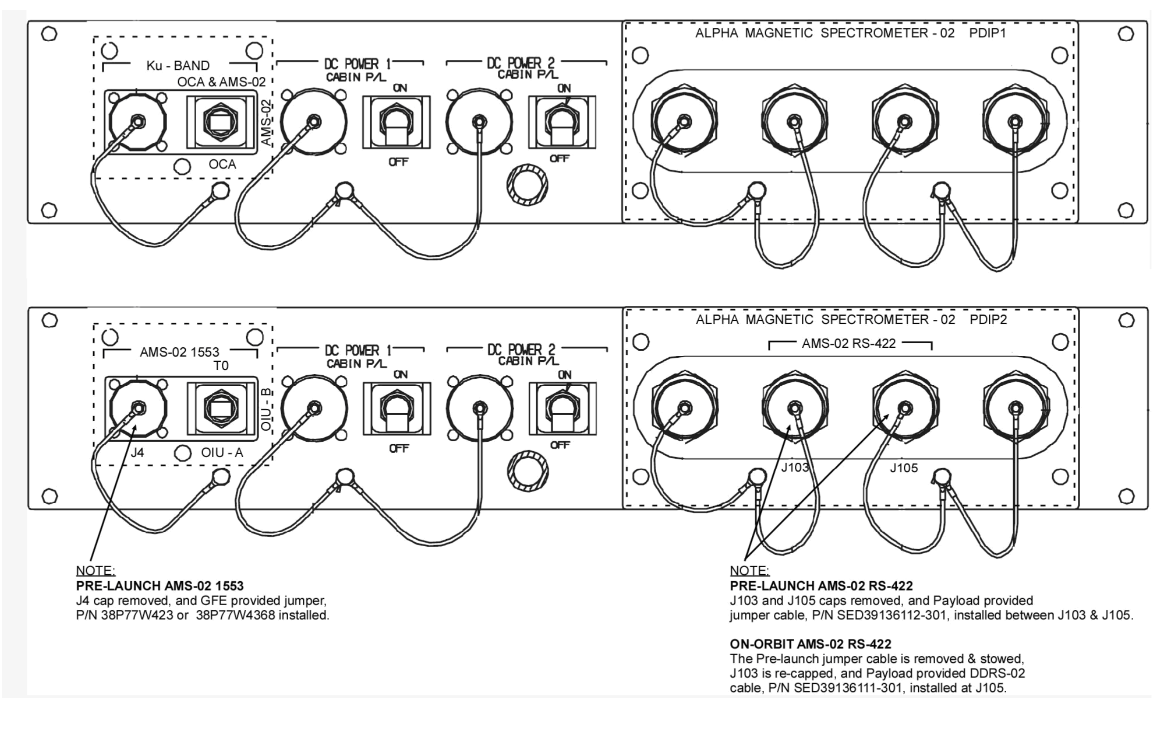


Figure 6.1.1 Payload Data Interface Panel #1 and #2 Layout

For brief periods prior to the L-30, a maximum of 2000 W may be required through the PDS for calibration and contingency troubleshooting of experiment avionics. Again, GSE allows ground controllers to access this control and data.

All non-essential power systems will be deactivated at T-30 minutes to minimize the current across the T0 connection. The SFHE vent valve will be closed, and the vent pump will be deactivated at this time. These activities are controlled via AMS GSE listed above; as well as KSC ground personnel remote commanding of the power supply for the vent pump to "off." Only systems required for power distribution and monitoring of the SFHe tank will remain active after this point. All monitoring and associated power distribution systems will be completely deactivated at L-9 minutes, and the AMS-02 payload will be powered off.

6.2 ASCENT

The AMS-02 experiment requires momentary power during ascent for operation of the SFHe nominal vent valve. This valve must be opened during powered flight once the pressure in the payload bay drops below the pressure of the SFHe Tank. The primary means of opening this valve is a barometric switch selected to open at a pressure below that of the SFHe Tank (present estimates are 15-20 millibars or roughly 3 minutes into the flight, but final definition will be made using the flight hardware). The Baroswitch Electronics (BSE) utilizes 28 Vdc power, supplied from a Standard Switch Panel (SSP) and triggered by a barometric switch, to be applied to a solenoid that operates the vent valve to perform this function. The current is limited by the SSP to less than 5A**. The** AMS-02 BSE receives 28 Vdc ascent power from the two powered maintained switches (S16 and S18) on 5A circuit breaker CB4 at the standard switch panel (SSP 2A) through connector J7 on Interface Panel A. Switch S16 is designated as the primary and S18 as the back-up 28 Vdc power feed, as shown in Table 6.2. Figure 6.2 illustrates the SSP layout. As a backup, a time-tagged command in the Backup Flight System (BFS) General Purpose Computer issues a discrete output low that will also command the BSE to open the vent valve. This will occur following the expected trigger from the barometric switch (L+~3 minutes). Potential ignition sources shall be compliant with NSTS/ISS 18978B, Letter NS2/81-M082.

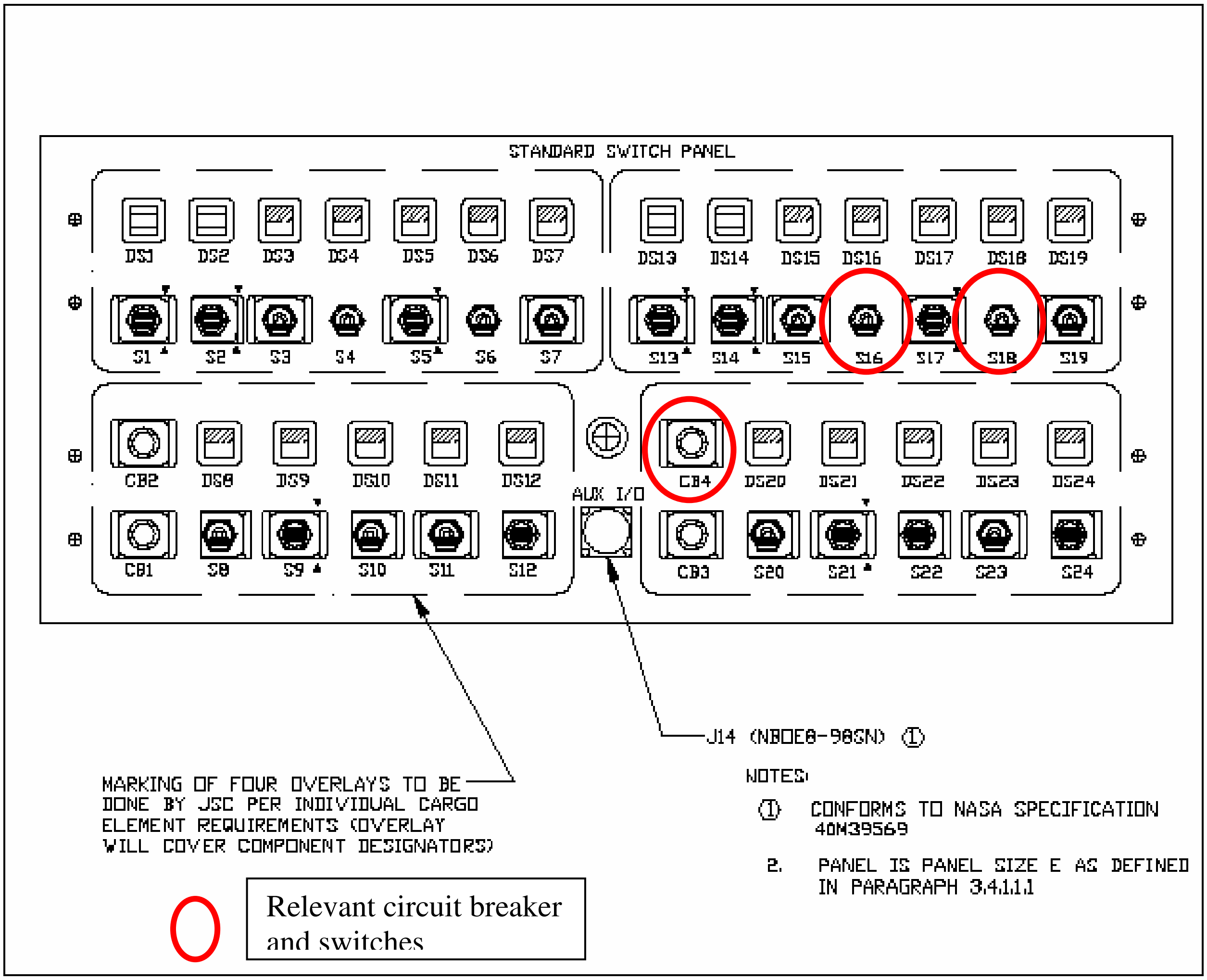


Figure 6.2-1 Standard Switch Panel Layout

TABLE 6.2-1 STANDARD SWITCH PANEL CONFIGURATION

ITEM	DEVICE TYPE	AMS-02 FUNCTION
CB4	Circuit breaker, 5 Ampere IN – Closed OUT - Open	IN – Applies orbiter pwr to switches S16 and S18 (Pre-launch/Ascent Configuration). OUT – Removes orbiter pwr from switches S16 and S18 (performed sometime after Post Insertion)
S16	Toggle switch, 2 positions (Maintained – Maintained) ON – Up Position OFF – Down Position	ON – Applies 28 VDC to AMS-02 Control Electronics Assy (Pre-launch/Ascent Configuration). OFF – Removes 28 VDC from AMS-02 Control Electronics Assy (performed on-orbit sometime after Post Insertion)
S18	Toggle switch, 2 positions (Maintained – Maintained) ON – Up Position OFF – Down Position	ON – Applies 28 VDC to AMS-02 Control Electronics Assy (Pre-launch/Ascent Configuration). OFF – Removes 28 VDC from AMS-02 Control Electronics Assy (performed on-orbit sometime after Post Insertion)

* A return of AMS in the Cargo Bay due to an Orbiter contingency; AMS would request reconfiguration of the switches to the pre-launch configuration during De-orbit Prep activities; not a safety issue, but is an AMS-02 turnaround concern.

The requirement for the opening of the vent valve during ascent stems from a device used as a phase separator for the SFHe; referred to as a “porous plug”, this device allows vapors to be vented while containing the liquid within the tank. When the valve is opened, liquid must not be in contact with the porous plug. The location of the plug is such that during acceleration associated with the launch, all liquid will be pulled away from the plug and only vapor will be in contact. If liquid were against the plug at this time it is theorized that the plug could act as a pump to remove the liquid helium from the tank. This is not a safety issue due the rate of pumping that would occur, but is a serious impact to mission success as the SFHe is required for operation of the Cryomagnet.

6.3 ASCENT ABORT OR AMS RETURN OPERATIONS

In the event of an abort that occurs following the vent valve opening, the barometric switch will automatically close the vent valve as pressure begins to increase in the payload bay. Failure to close this valve would result in air being drawn into the tank resulting in a freeze plug. Burst disks have been installed in the SFHe Tank to preclude any pressure build up that could be hazardous and the freeze plug does not result in a new unique hazard in the event the vent valve does not close. Operation of these burst disks however, would have a severe negative impact on payload turnaround time for a re-flight opportunity.

Power is applied post-landing to monitor the SFHe tank pressure and re-open the vent valve when the tank pressure exceeds one atmosphere (presently estimated to occur between 10 hours and 2 days after touchdown). Again, failure to apply power and re-open the vent valve would have a negative impact on payload refurbishment, as burst disks would need to be replaced, but is not a safety issue.

6.4 ON-ORBIT OPERATIONS

6.4.1 STS On-Orbit Operations

Once on-orbit, following Post-Insertion activities, payload activation activities are expected to begin at approximately MET 00/02:30. At this time, a middeck locker stowed, STS provided, PGSC/NGLS will be un-stowed, set-up, and activated on the Orbiter Aft Flight Deck (AFD). Setup includes the removal of a payload provided cable between two connectors on a Payload Data Interface Panel #2 (PDIP2) located on the AFD, and attachment of a new payload provided cable to the PDIP (Figure 6.1-1) to interface with the PGSC/NGLS, as shown in Figure 6.4.1-1 . The new cable will include a built-in multiplexer to interface the RS-422 signals into a USB on the PGSC/NGLS for recording. This PGSC/NGLS in conjunction with the payload cable is referred to as the AMS-02 Digital Data Recording System (DDRS-02); and will be used to record all high rate data generated by AMS-02 during checkout activities. Concurrent to these activities (or prior to), the Orbiter Interface Unit (OIU) should be powered up and checked out in preparation for communication with the AMS payload via PDIP2, with “AMS-02 1553” switch in “OIU” position (Figure 6.1-1).

Next, two ISS provided Assembly Power Control Units (APCUs) are activated by the crew (SSP controlled); and then front-end data interface electronics are activated to initiate the downlink of housekeeping data; then the Cryocoolers on the AMS-02 are activated. Shortly after this, the AMS-02 detectors and other subsystems are activated and checked out. During avionics checkout, RS-422 data is recorded on the hard-drive of the PGSC/NGLS continuously., AMS-02 RS-422 data from another feed-thru on the Payload Data Interface Panel #1 (PDIP1) assembly with the “Ku-Band” switch in the “AMS-02” position (Figure 6.1.1-1) will be down-linked via the Ku-Band as coverage and scheduling permit.

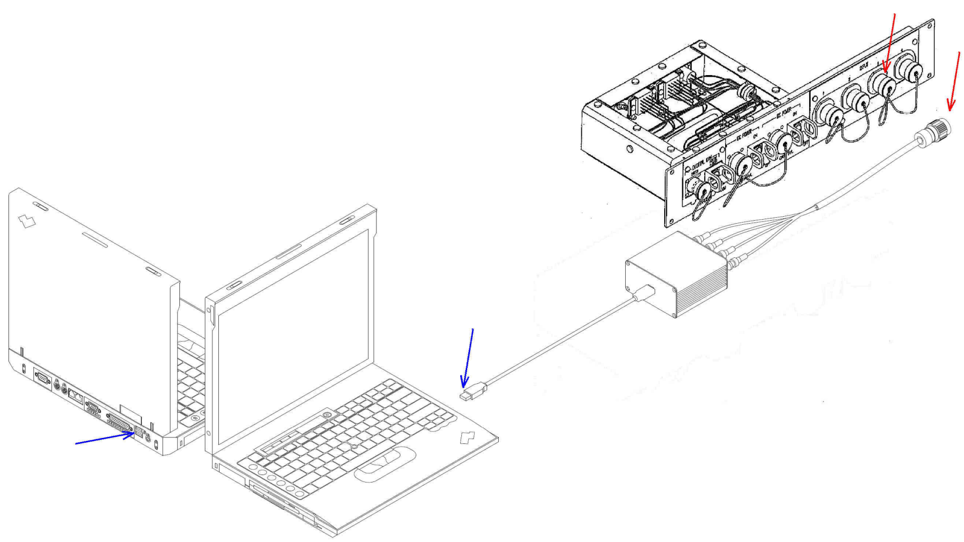


Figure 6.4.1-1 DDRS-02, PGSC/NGLS to PDIP Interface

No Cryomagnet charging can be performed while AMS-02 is located in the Orbiter PLB, as power distribution wiring does not accommodate power to the charging circuit. A maximum of 2 kW is required during these Orbiter operations; however, as AMS-02 heat rejection capabilities in the PLB are quite limited (primary radiators face the Orbiter sidewalls), these operations are limited by thermal constraints (dependent on attitude). All checkout activities are controlled by ground command or pre-programmed into the

PGSC/NGLS; crew intervention is not required. Checkout time is estimated at 40 hours with significant command uplink required.

On MET Day 3, the STS is expected to dock with the ISS. AMS-02 activities will continue as required for checkout and thermal conditioning. At the earliest opportunity, expected to be MET Day 4, the AMS-02 transfer to ISS should occur. Just prior to transfer, AMS-02 is powered down, the APCUs output is inhibited/deactivated and the DDRS-02 stowed. The SRMS is used to grapple the experiment via the FRGF (Figure 6.4.1-2, Frames 1 & 2); the Remotely Operated Electrical Umbilical (ROEU) is disconnected; the Payload Retention Latch Assemblies (PRLAs) and Active Keel Latches are opened; and the SRMS is used to remove AMS-02 from the PLB.

The SRMS then moves the AMS-02 to a position (Figure 6.4.1-2, Frames 3 & 4) for the SSRMS to grapple the PVGF located on the opposing side of the AMS from the FRGF.

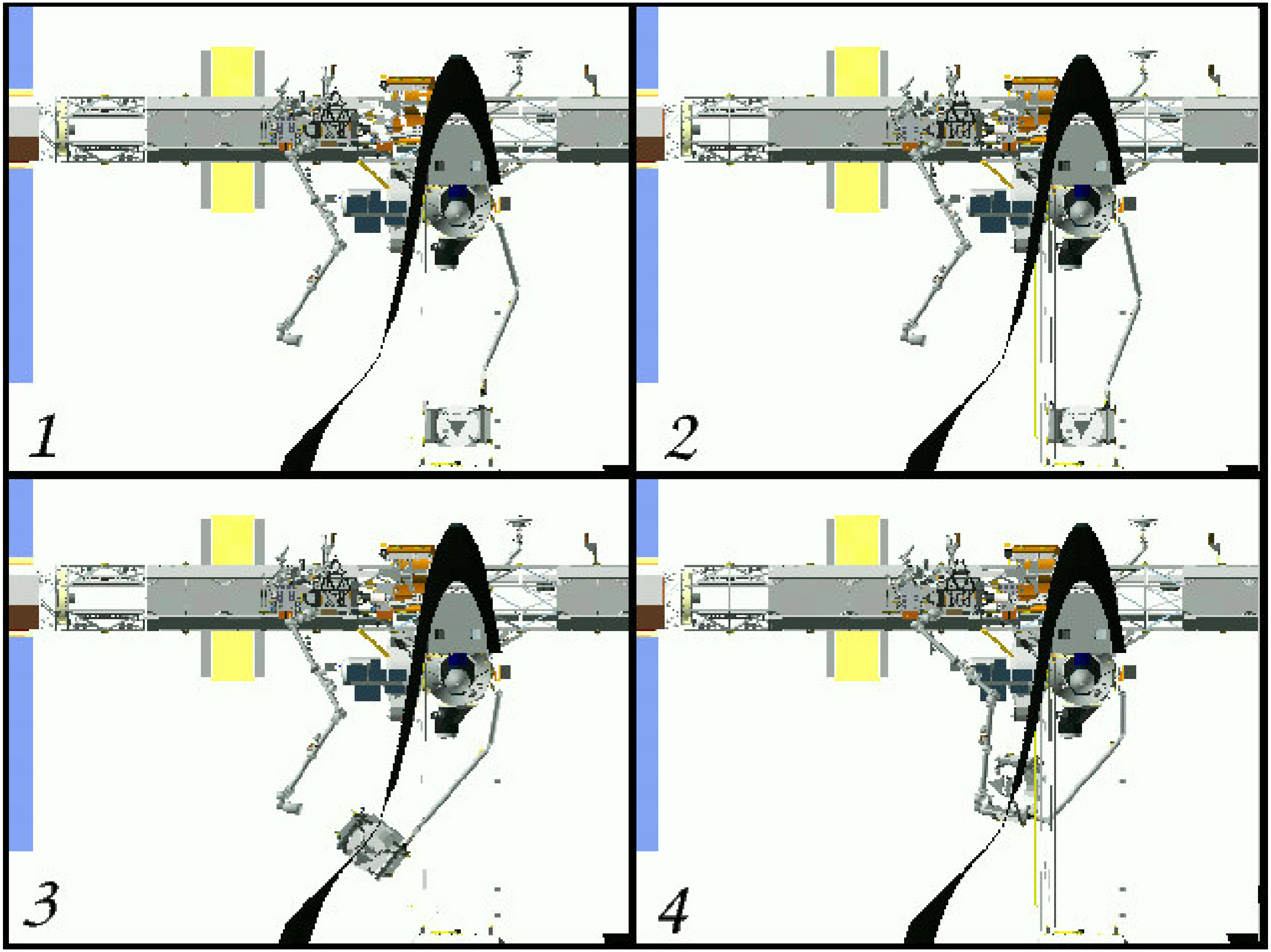


Figure 6.4.1-2 Robotic Transfer of the AMS-02 from the Orbiter the ISS (1 of 2)

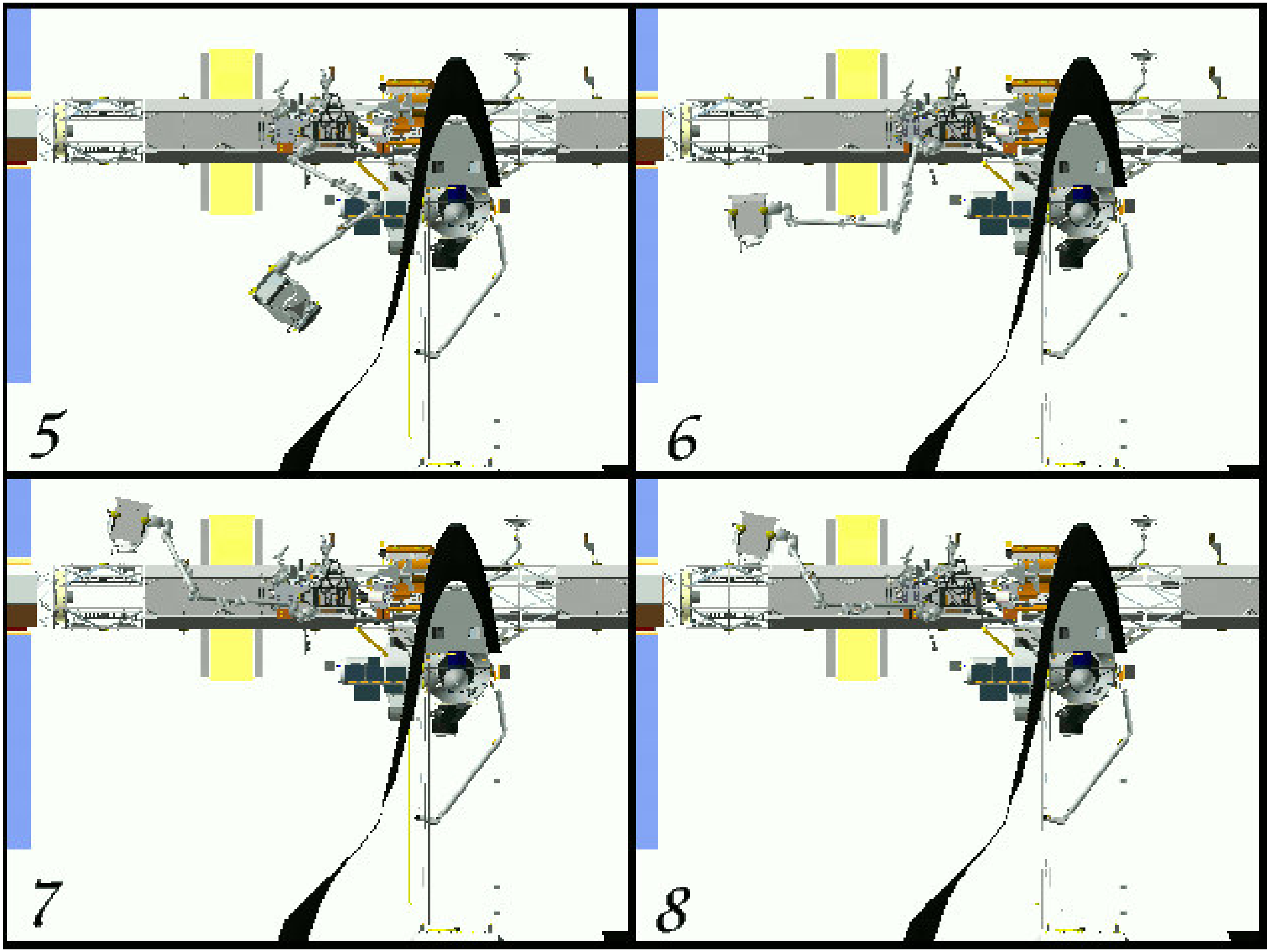


Figure 6.4.1-3 Robotic Transfer of the AMS-02 from the Orbiter the ISS (2 of 2))

6.4.1.1 EVA Operations on STS (Contingency Only)

The AMS experiment must be compatible with a Contingency EVA operation for removal of the FRGF in the event that the SRMS is unable to release the grapple fixture. Discussions are underway to determine what additional hardware, if any, will be required to support this activity either: a) in a “free-floating configuration while the AMS is grappled by both the SRMS and the SSRMS; or b) with AMS “re-berthed” in the Payload Bay. There is forward work with JSC EVA Operations personnel regarding this activity; including assessment of safety.

Another potential Contingency EVA that could be performed on the AMS experiment involves STS provided Government Furnished Equipment (GFE). This task is a standard contingency EVA planned for the contingency release of the ROEU from the PDA in the Payload Bay, in the event that the drive mechanism for the ROEU active half fails to operate. The planning for this operation is clearly performed by the EVA group at JSC. The access requirement was determined to be acceptable since the EVA could be performed from the Orbiter sill; however, no formal documentation of this acceptance has been received, and the project is prepared to supply any AMS models required to close this issue if necessary. Discussions are underway with JSC EVA personnel and EVA Safety personnel to determine what additional hardware, if any, will be required to support these EVAs, as well as what simulation requirements will be, up to and potentially including further Neutral Buoyancy Laboratory (NBL) testing. Procedures for this contingency operation will be provided by JSC EVA personnel.

Finally, the AMS must be compatible with the EVA Contingency task for manually opening the PRLAs. This is also a task involving GFE that will be planned and developed by JSC EVA personnel. This task would only be performed in the event that the drive mechanism for the PRLAs failed. This is also considered standard work by the EVA group. Sill translation activities are a part of all of these Orbiter Contingency EVAs; and AMS must be compatible with that activity.

In summary, AMS must be compatible with STS EVAs that involve: translation down the Orbiter sill; EVA release and re-mate of the ROEU; release of the FRGF; and release of the PRLAs.

6.4.2 ISS On-Orbit Operations

Once the grapple is verified with the SSRMS, the SRMS releases the FRGF (Figure 6.4.1-3, Frame 5). At this time, power is applied to the Electronic Berthing Camera System (EBCS) avionics via the SSRMS through the PVGF. The EBCS is ISS provided hardware used as an aid for berthing the experiment to the Active Payload Attach System (PAS). The EBCS provides a video image of the berthing to the crewmember controlling the SSRMS and utilizes an EBCS target on the truss to facilitate final approach and payload capture in the PAS. The EBCS provides feed-thru power of up to 16.7 A for use by the payload. AMS-02 contains thermostatically controlled heaters that may utilize some or all of this power to maintain the payload temperature within design limits. The amount of power required is dependant on environmental conditions during transfer and the length of time the payload spends on the SSRMS. During the transfer of the AMS-02 on the ISS SSRMS, Cryomagnet charging will be precluded by operationally selecting SSRMS power bus to the AMS-02 that correlates to the AMS-02 bus that can not charge the Cryomagnet. In addition to the power selection, the AMS-02 can not initiate charging without commanding, and the command path through the 1553 bus on the SSRMS is not connected to the AMS-02 systems through the PVGF.

To complete the transfer, the SSRMS moves the AMS-02 directly above the S3 Upper Inboard attach site so that the Passive PAS on the payload is correctly oriented with the Active PAS on the truss (Figure 6.4.2-3, Frames 6 & 7). As the AMS-02 is lowered toward the capture mechanism on the truss, the EBCS is used to verify closure distance and orientation for final mechanical mating. Once the guide pins on the payload are positioned in the guide vanes of the active PAS, the Capture Latch Assembly (CLA) on the PAS is driven to grapple the capture bar on the AMS Passive PAS to a minimum load (in the –Z direction) of 4900 lbs and a maximum load (in the –Z direction) of 6430 lbs

(Figure 6.4.2-3, Frame 8). When proper mechanical mating is verified, the power from the SSRMS to EBCS and AMS heaters is deactivated. The Umbilical Mechanism Assembly (UMA) Active half (located on the truss) is driven into the UMA Passive half (located on AMS). Following verification of mating, power is supplied from the ISS to AMS-02 via the UMA. Once power supply and data links from the Payload are verified by AMS-02 ground personnel, the PVGF is released from the SSRMS and the SSRMS is moved away from the payload.

Following installation of the AMS-02 on the truss, an abbreviated avionics checkout will be conducted. Once the avionics have been checked out, all unnecessary equipment (including all detector subsystems) will be powered down and Cryomagnet charging operations will be initiated. Cryomagnet charging requires 1850 W directly from the Cryomagnet Current Source (CCS) within the Cryomagnet Avionics Box (CAB). This does not include other power within the CAB or losses within the power distribution system, or the power for required monitoring electronics. For this reason, all unnecessary power devices must be deactivated to remain within power budget allocations. Cryomagnet charging is a complex activity, requiring extensive ground commanding and feedback including operations to: open semiconductor switches; close mechanical disconnects within the Cryomagnet; cool bus bars; warm up persistent switches; and operate various cryomagnet valves. Approximately one and a half hours are required to fully charge the Cryomagnet. Once fully charged, the Cryomagnet is disconnected from the charger and the detectors are again powered. At this point the recording of science data begins. Due to the complexity of the experiment, and the numerous critical subsystems that must operate nominally to achieve mission success, AMS-02 must operate for a period of time to verify that all critical systems are functioning correctly.

AMS-02 will operate continuously on the ISS for a minimum of 3-years, requiring 2 kW average power, and generating high-rate data at an average of 2 Mbps over its lifetime. AMS-02 also utilizes the ISS 1553 bus for low-rate telemetry (health and status) command/data. All of this data is down-linked via the ISS Ku-Band.

Due to limitations in Ku-Band coverage, and the relatively small overlap between S-Band and Ku-Band data; AMS-02 has requested the downlink of 10 Bps of “Critical Health” data via the ISS S-band. This data would be used to provide a greater insight into AMS health throughout the orbit. The entire data stream, which is substantially larger than 10 Bytes, would require numerous cycles to be down-linked.

In the event of a major contingency; the AMS could be required to be returned on the same shuttle flight. If this were required, the AMS-02 would be powered off; the SSRMS would grapple the PVGF; the UMA would be disconnected, and the CLAs would be driven to release the grapple bar. The SSRMS would then maneuver AMS to a position where the SRMS can grapple the FRGF; the SSRMS would release the PVGF; and the SRMS would be used to return AMS to the payload bay. The PRLAs and active keel latch would be closed and the SRMS released. At this point the ROEU would be driven to re-mate with the PDA; and power up activities would begin again. Power/data transfer would be deactivated during De-orbit Prep activities per the standard Payload deactivation section of this document.

Minimum safe return configuration of the AMS-02 requires that all PRLAs be fully closed on the AMS-02 trunnions and the Keel Latch closed on the Keel pin. The ROEU does not need to be engaged to affect a safety return.

6.4.2.1 EVA Operations on ISS (Contingency Only)

If an Extravehicular Activity (EVA) is required for any AMS-02 contingency operation on the ISS, power from the UMA will be deactivated at the Type II Remote Power Control Modules (RPCM) upstream of the UMA prior to commencement of the EVA. In addition to this (if required) the UMA Active half can be disconnected from the UMA passive half as a secondary method of assuring fault tolerance. This is not highly desirable as it inherently creates the risk of a failure to re-mate.

The AMS-02 is designed with redundant front-end data interface hardware. In the event that 1553 or Fiber communications are disrupted due to problems with AMS-02 front end data hardware, an EVA may be performed to switch the connectors from the primary to the redundant electronics hardware. These connectors are EVA compatible and are located on the EVA Connector Panel located on the lower end of the Unique Support Structure very close to the Passive UMA (Figures 6.4.2.1-1 and 6.4.2.1-2).

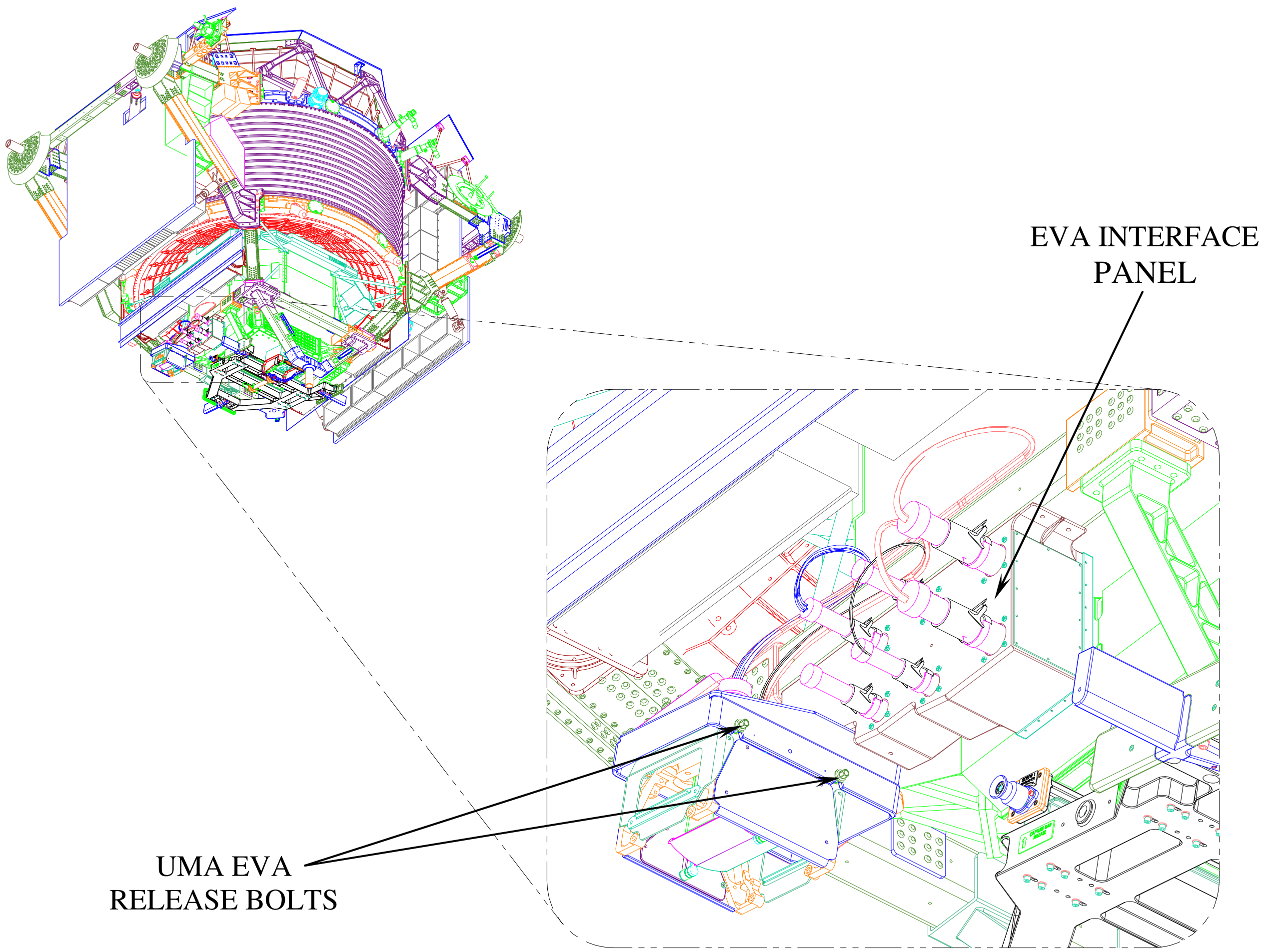


Figure 6.4.2.1-1 AMS-02 UMA (Passive Half) and EVA Interface Panel

AMS-02 was designed such that ISS Power Bus A is the primary bus for Cryomagnet charging. AMS-02 will define Launch Commit Criteria requiring that ISS Power Bus A is operable prior to launch. In the event that a station contingency renders Power Bus A inactive at a time when the Cryomagnet must be charged, the connectors for Power Bus A and Power Bus B can be interchanged at the EVA Interface Panel by a suited crewmember during a contingency EVA to power the Cryomagnet charging circuit.

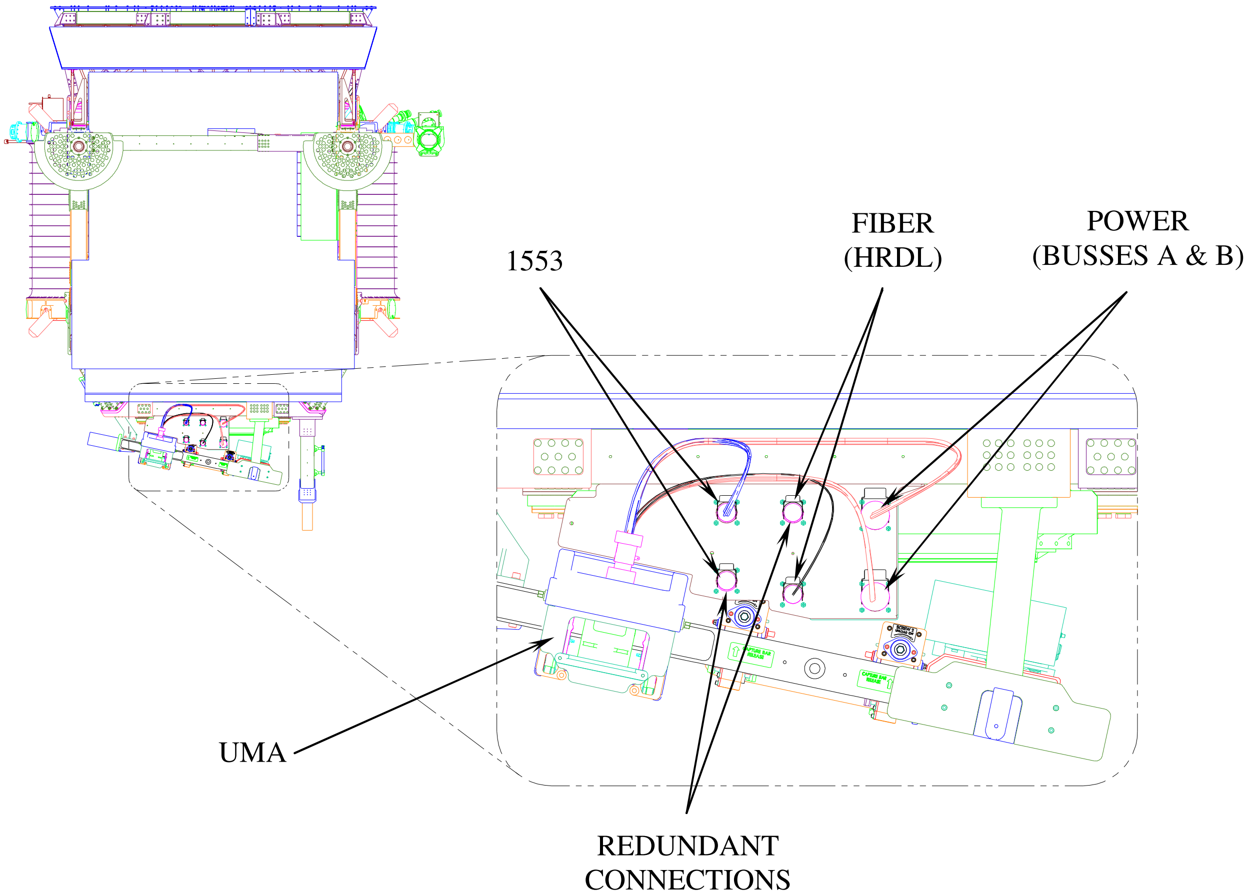


Figure 6.4.2.1-2 AMS-02 Power and Data Connectors on the EVA Interface Panel

Other AMS-02 Contingency EVA Operations include:

- UMA Removal (as required by SSP-57003) (Reference Figure 6.4.2.1-1)
- AMS-02 Passive PAS Capture Bar Removal/Replacement (Reference Figures 5.17-4, 6.4.2.1-3, 6.4.2.1-4, and 6.4.2.1-5)
- FRGF/PVGF contingency release operations (Reference Figures 6.4.2.1-6, 6.4.2.1-7, 6.4.2.1-8, and 6.4.2.1-9)

All the contingency activities and translation paths for AMS-02 on ISS EVAs, ISS Truss EVAs, and alternate Payload Attach Site EVAs were demonstrated using Worksite Analysis tools and in the NBL using a full scale AMS-02 volumetric mockup with high-fidelity EVA interfaces. Successful completion of these tests is documented in Crew Consensus Report (CCR) CB-02-129. Figures 6.4.2.1-10 illustrates an EVA translation path from the EVA Worksite Analysis tool. Figures 6.4.2.1-11 and 6.4.2.1-12 are scenes from the NBL testing performed in November 2002.

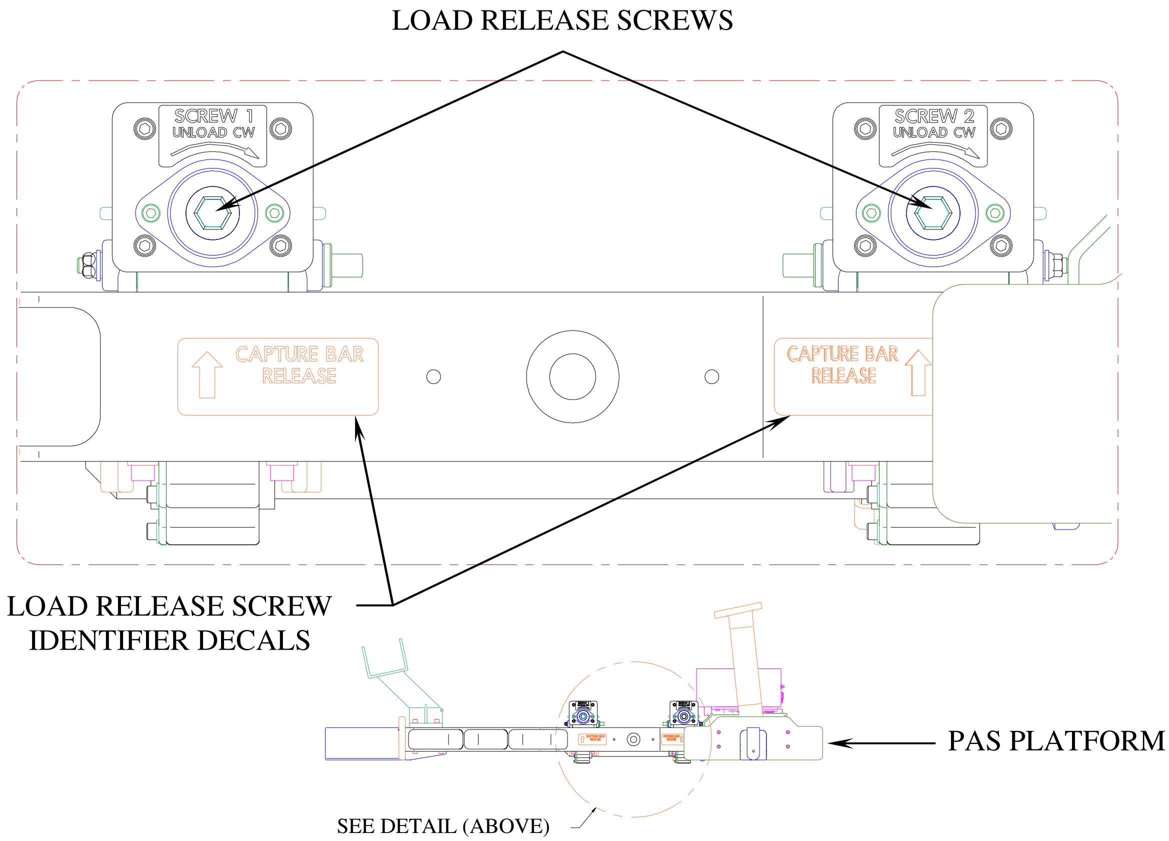


Figure 6.4.2.1-3 AMS-02 Contingency Capture Bar Release (1 of 2)

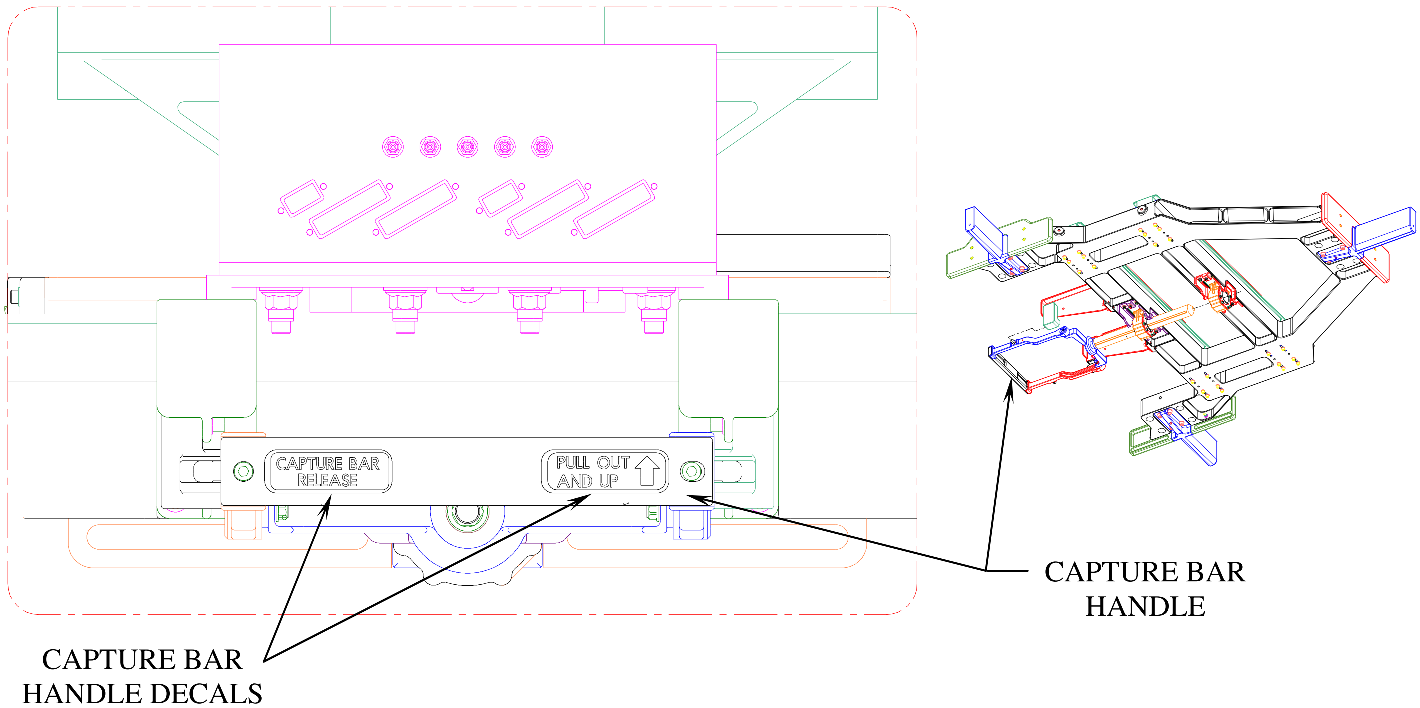


Figure 6.4.2.1-4 AMS-02 Contingency Capture Bar Release (2 of 2)

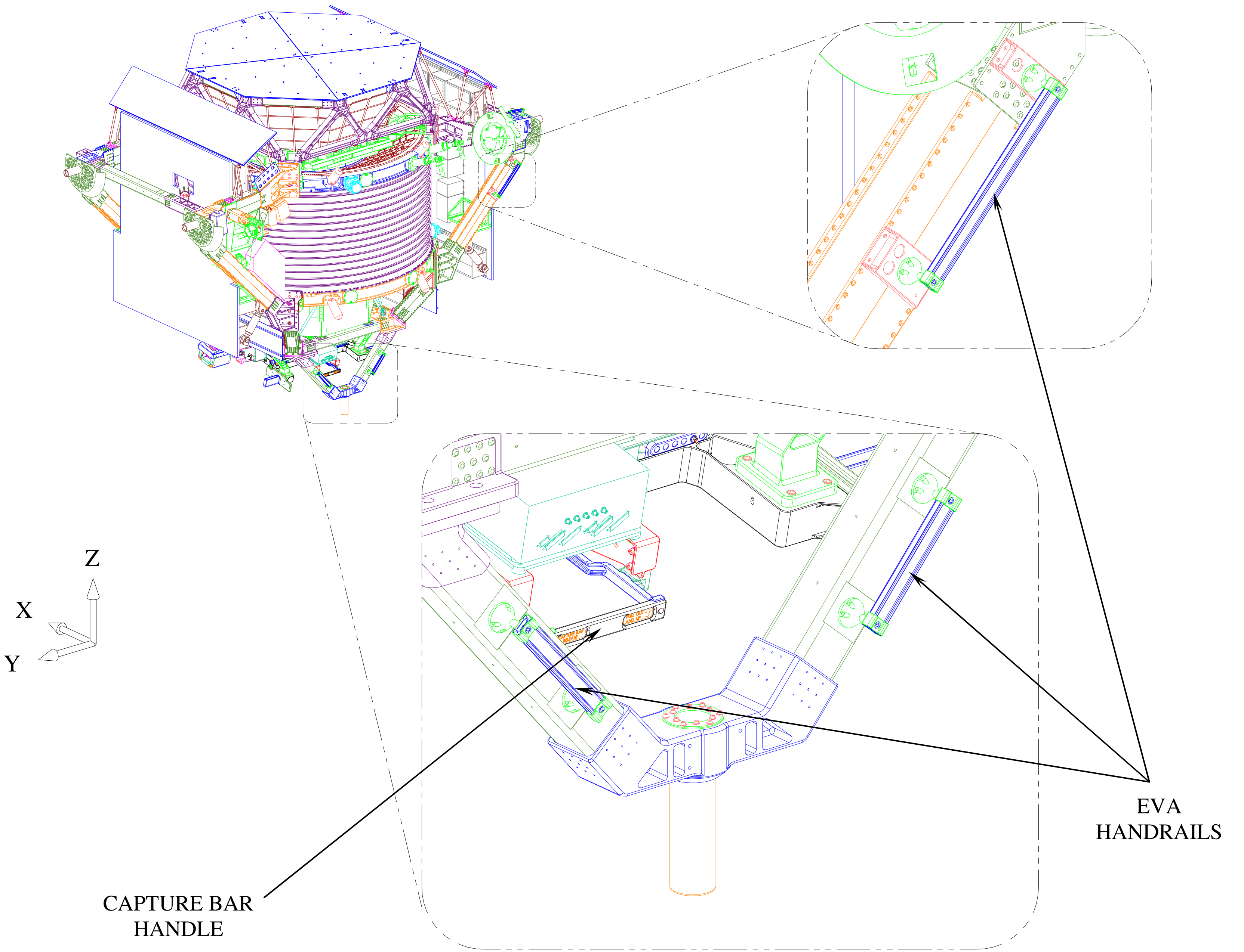


Figure 6.4.2.1-5 EVA Handrails in the Vicinity of the PAS Capture Bar Handle

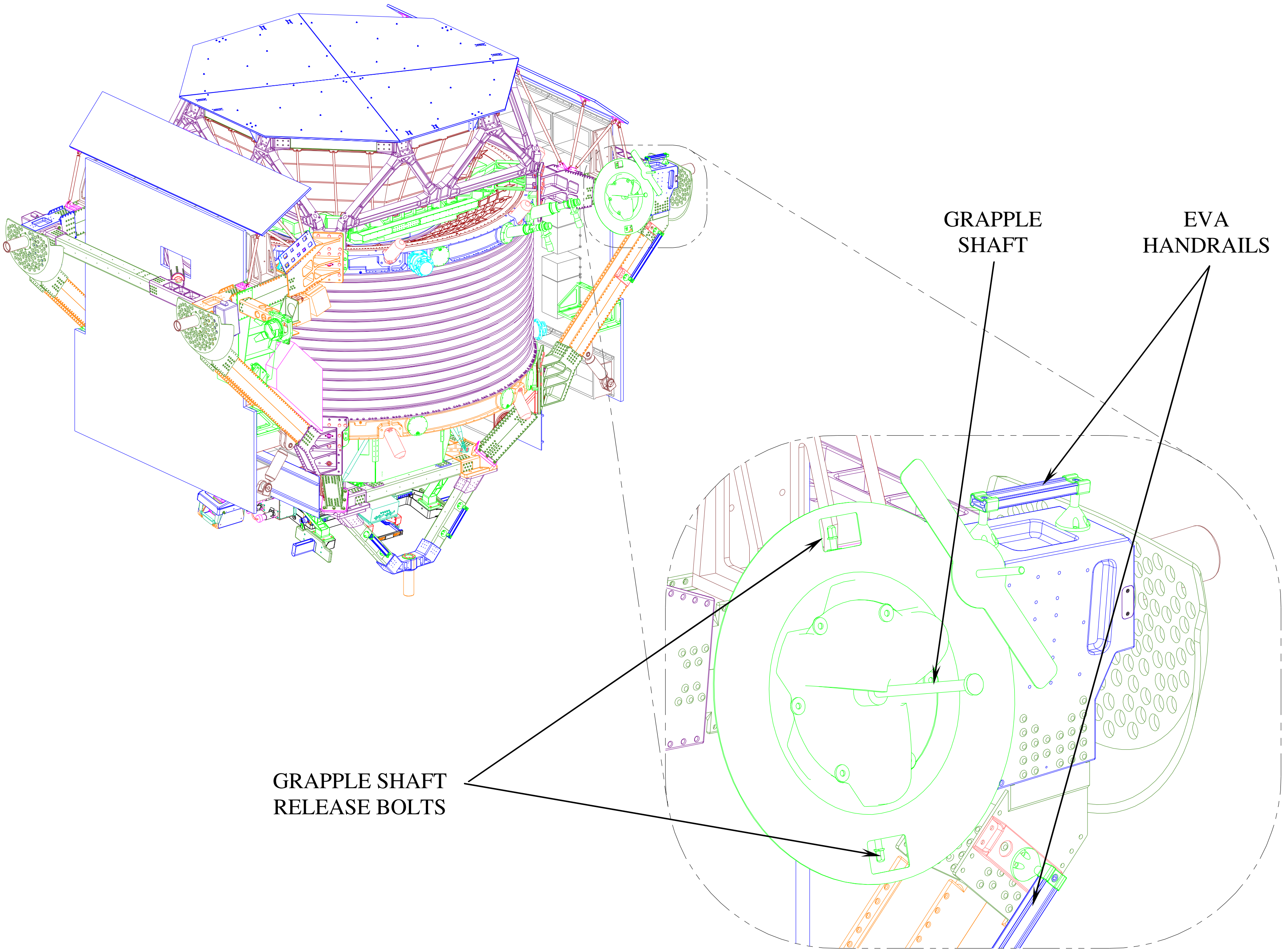


Figure 6.4.2.1-6 FRGF Grapple Shaft Contingency Release Mechanism

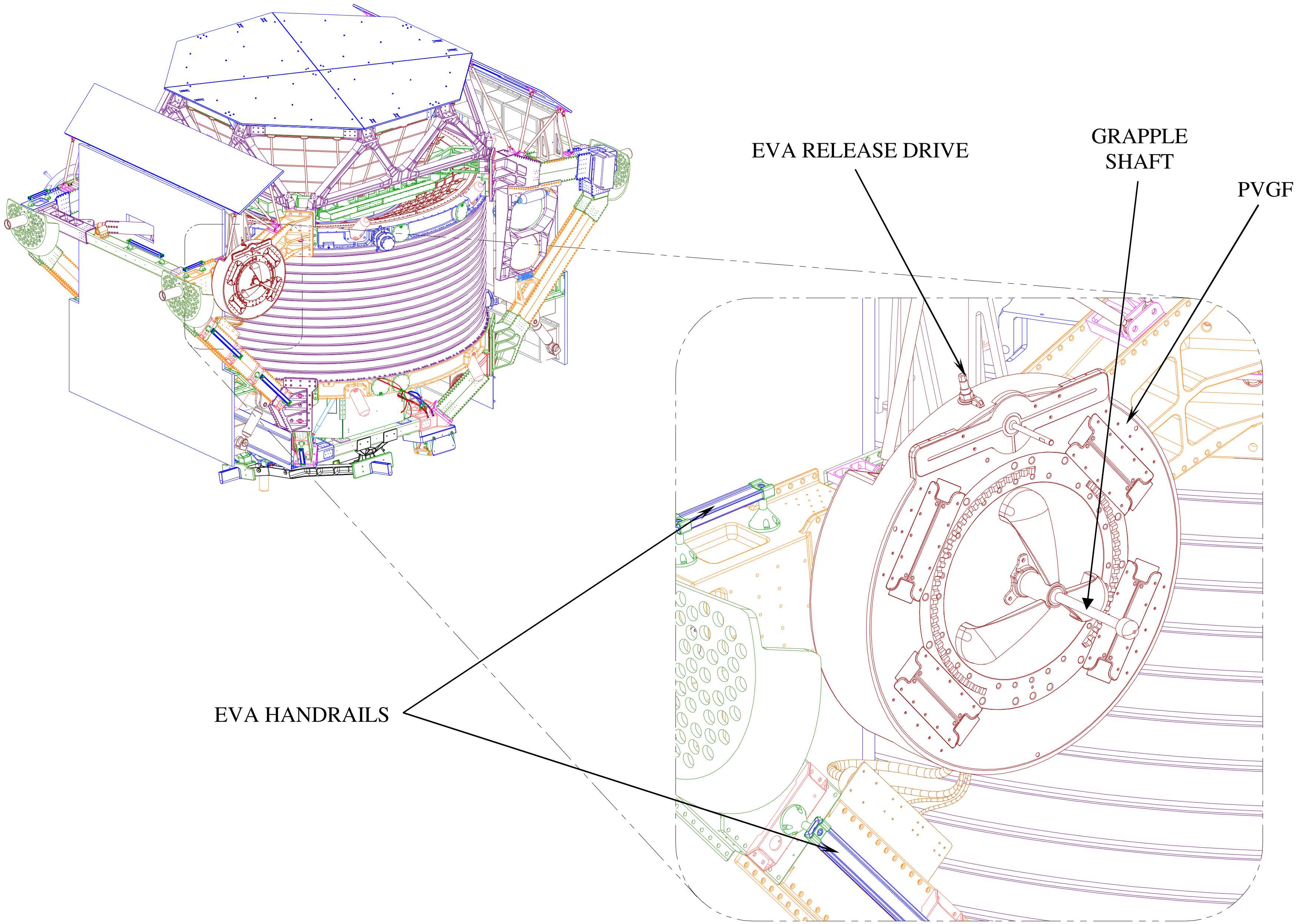


Figure 6.4.2.1-7 PVGF Grapple Shaft Contingency Release Mechanism

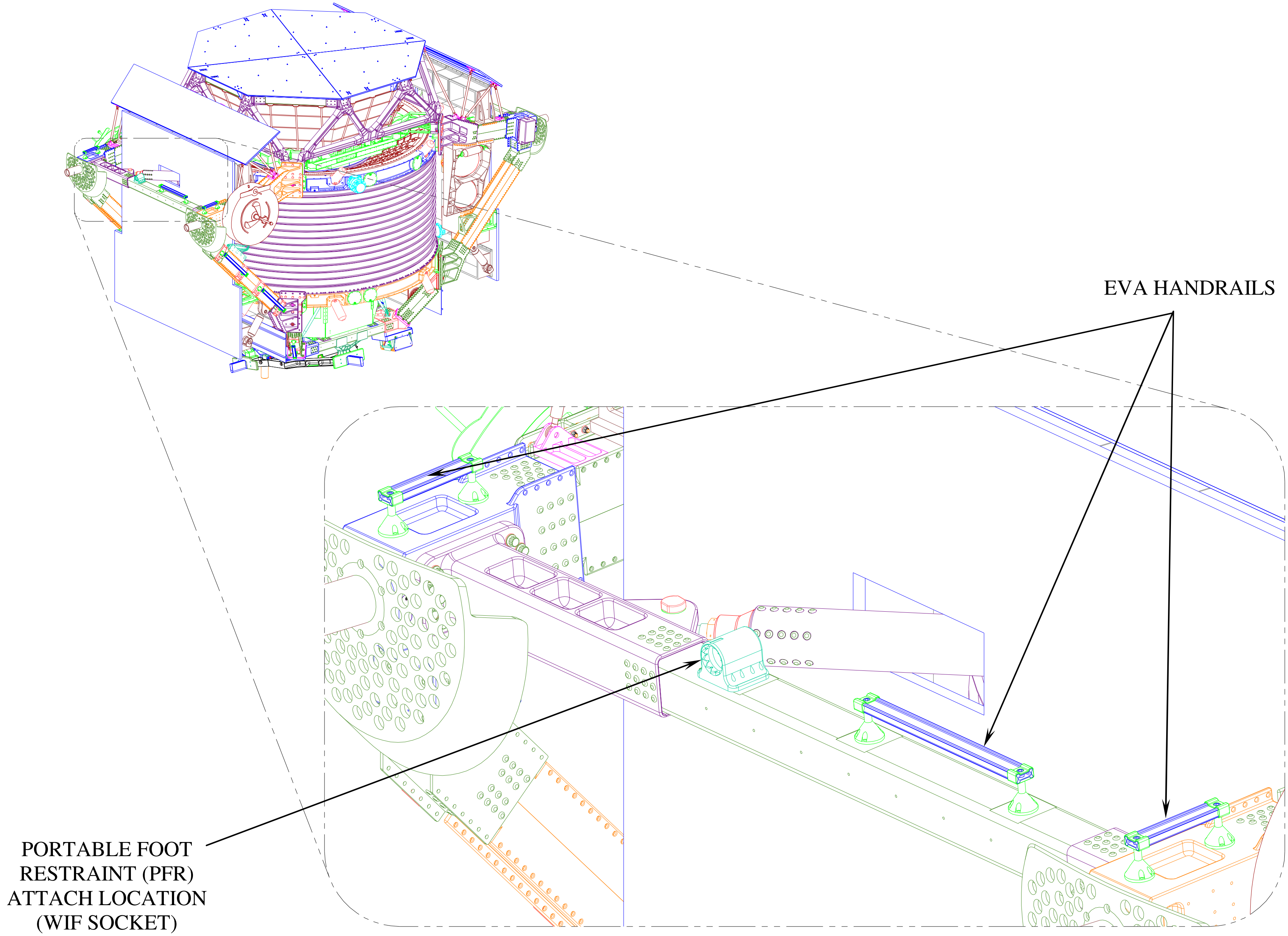


Figure 6.4.2.1-8 EVA Handrails and Worksite Interface Fixture (WIF)

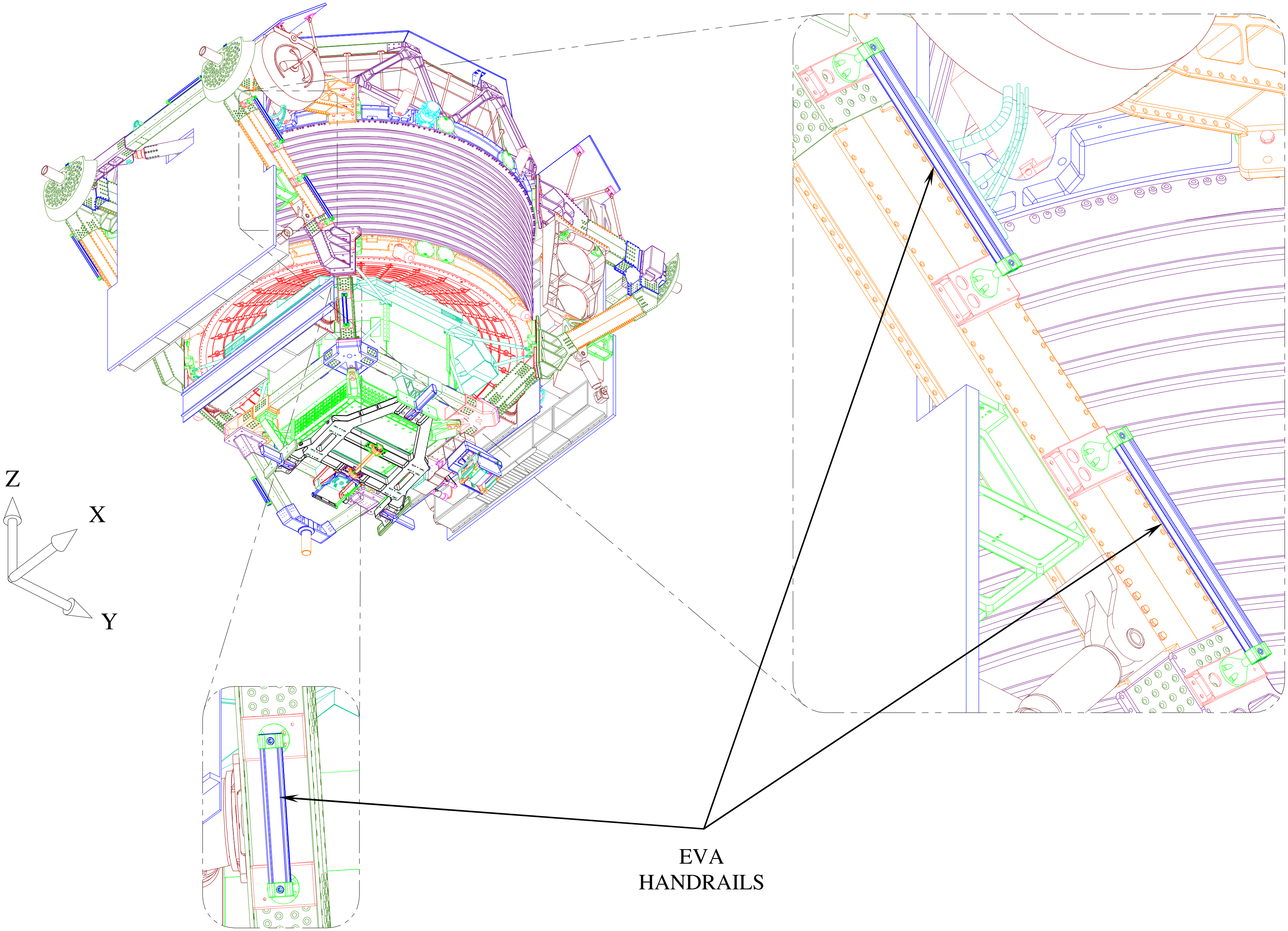


Figure 6.4.2.1-9 EVA Handrails in the Vicinity of the PVGF

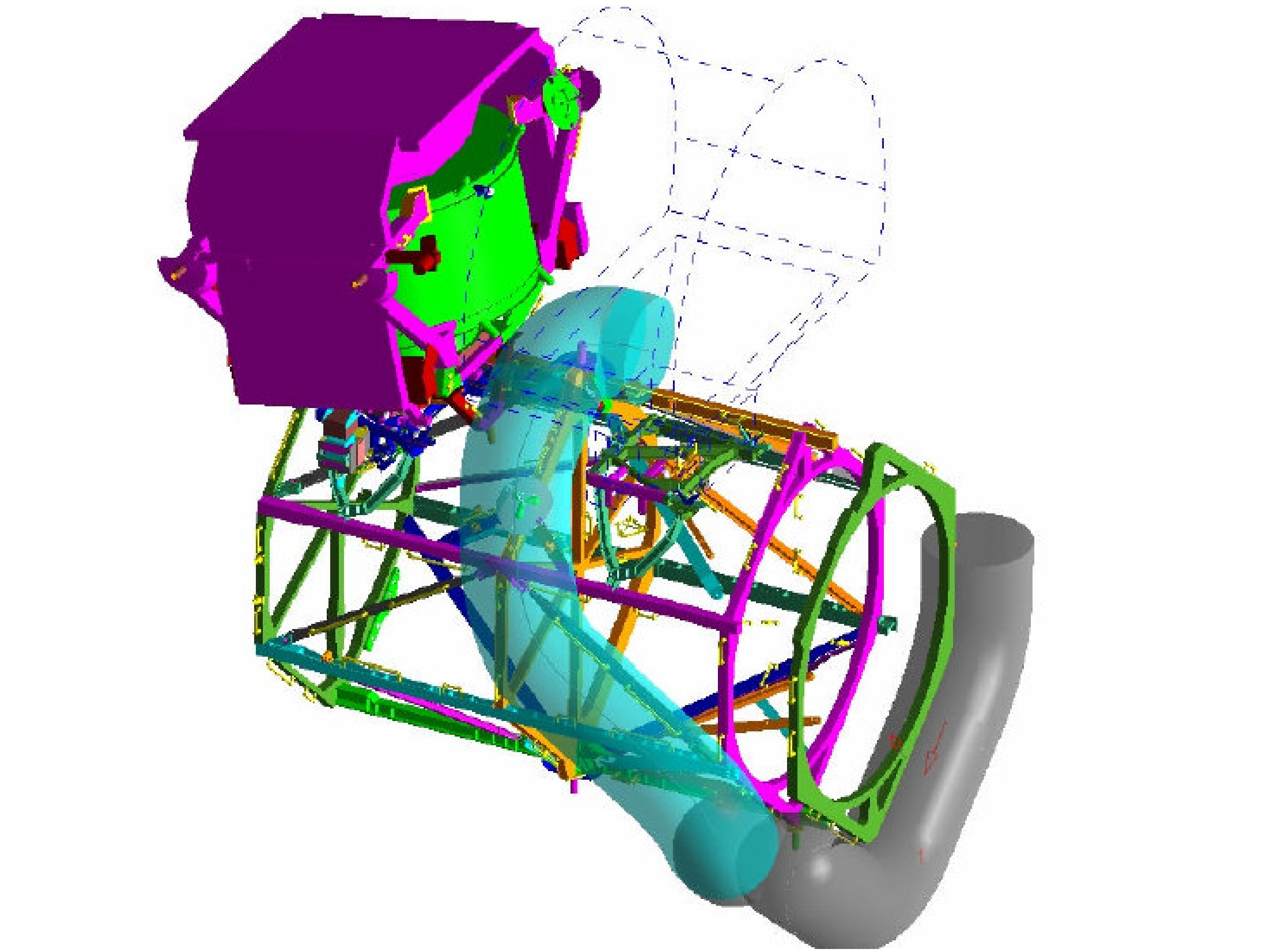


Figure 6.4.2.1-10 EVA Translation Path from Worksite Analysis

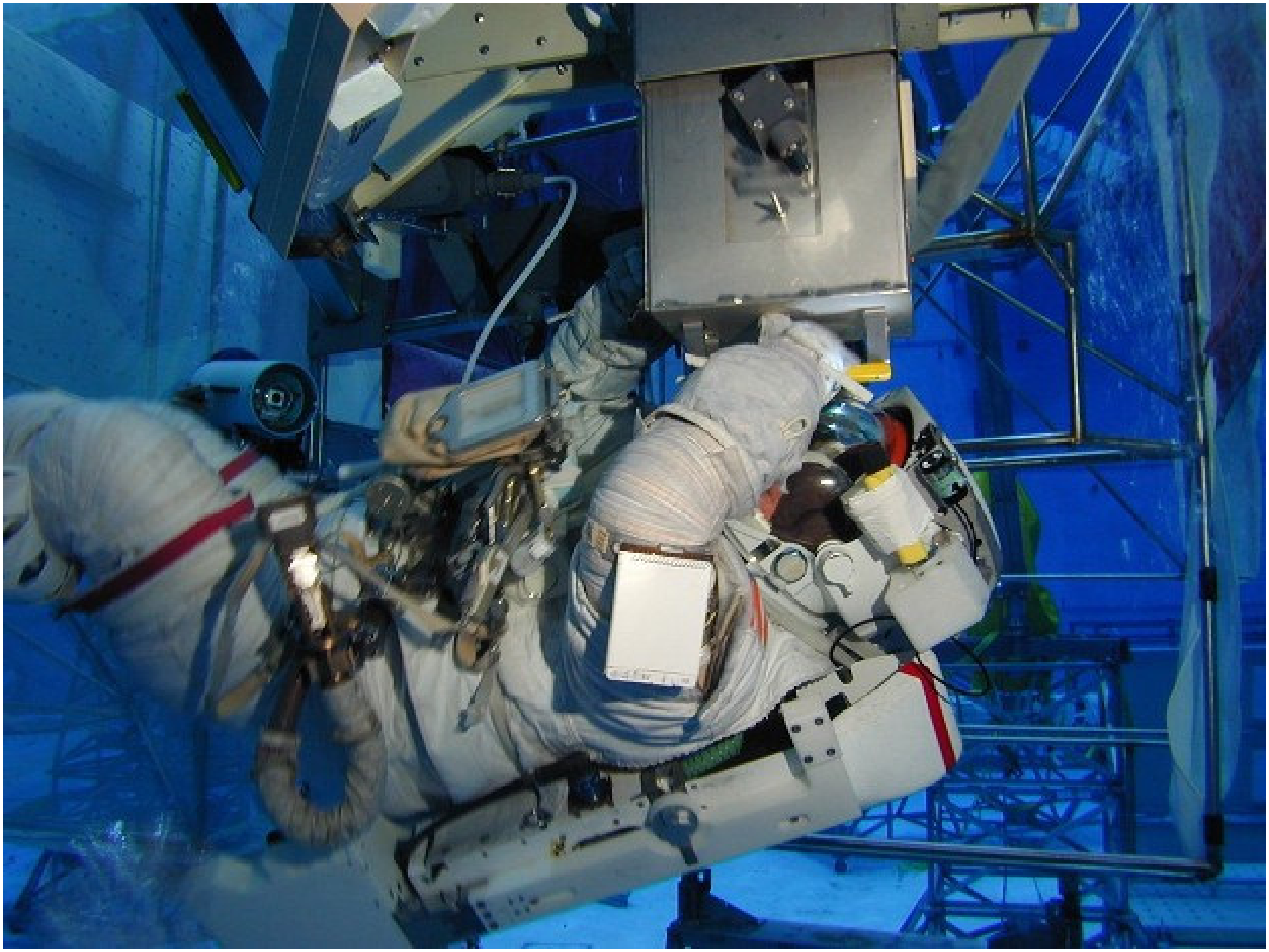


Figure 6.4.2.1-11 EVA Crewmember in NBL Testing (UMA Release Task)

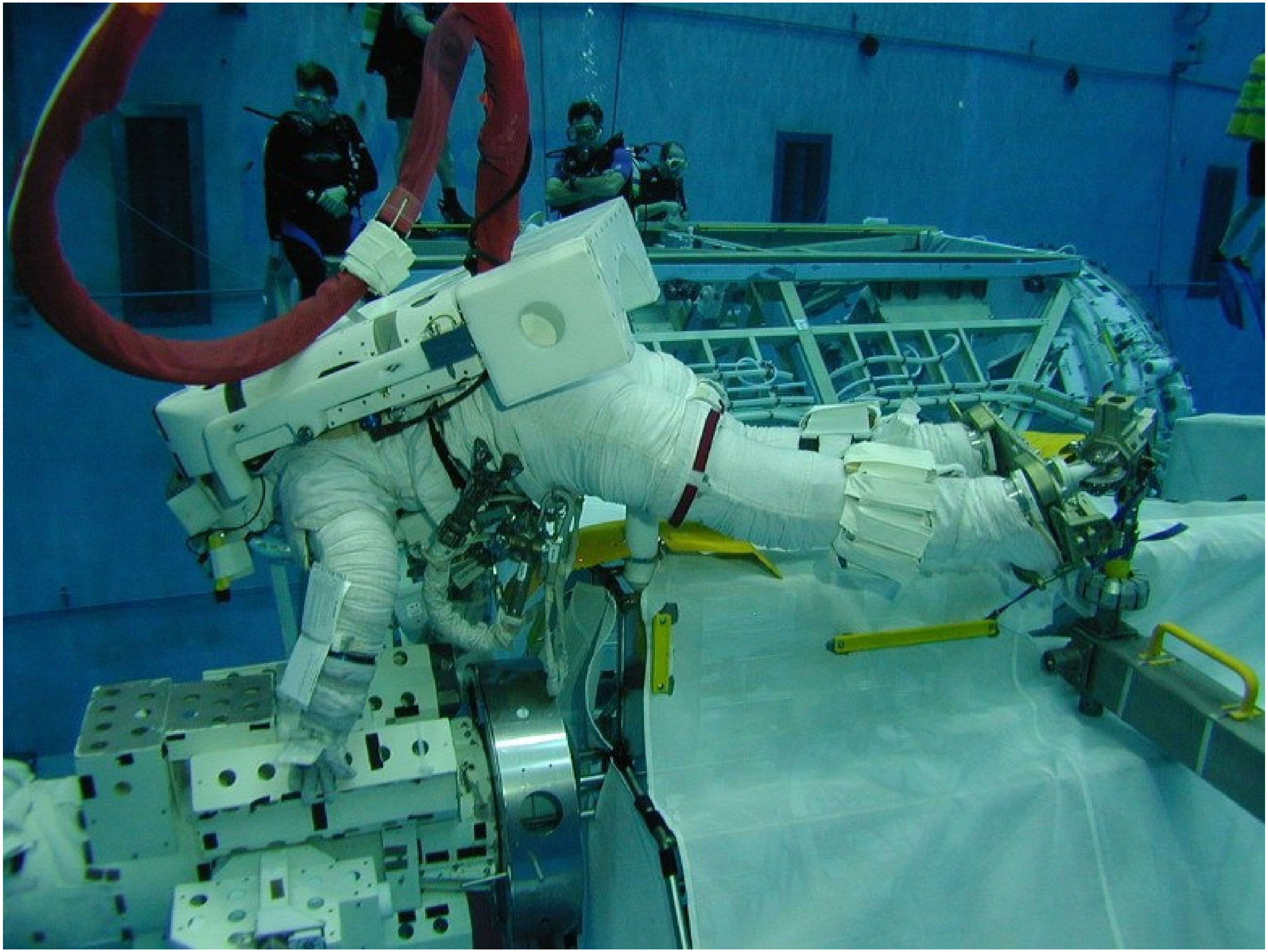


Figure 6.4.2.1-12 EVA Crewmember in NBL Testing (PVGF Release Task)

The AMS-02 Collaboration has also designed a "foldable" mounting bracket for the ROEU PDA. This was requested by OZ in response to a desire to decrease the AMS exceedance to the Standard Payload Envelope at the attach site in this particular location. This EVA is also considered a contingency and should only be executed if required prior to the arrival of another attached payload at the S3 Upper Outboard site. If implemented, this EVA would be performed on the AMS experiment while stationed on the S3 Truss. Details of the particular EVA are still in work, and the required worksite analysis or NBL verification of the EVA is still not defined. However, provisions have been made to add a handrail in the area that is expected to be compatible with this operation. Continued work is required with the EVA group at JSC to determine the final requirements. Figures 6.4.2.1-13 through 6.4.2.1-17 are included as representations of the design for this foldable PDA. Figures 6.4.2.1-13, 6.4.2.1-15 and 6.4.2.1-16 demonstrate the nominal configuration, while Figures 6.4.2.1-14, and 6.4.2.1-17 illustrate the "folded" position of the hardware. The pip pins identified in the figures are removed but retained by a tether; the arm is folded down, and the pip pins are replaced, locking the arm into the stowed position. The folding operation is manual, and it is expected that little force will be required to fold the arm; however, torque measurements shall be made of the folding operation to ensure compatibility with EVA crewmember requirements. No electrical connections would be broken during this EVA; the Cryomagnet would be powered down for this EVA; and the experiment would be powered down to ensure no potential hazards regarding hot-pins. Additionally diode protection is built-in as a secondary protection against hot-pins.

It should be noted that a Manipulator Analysis, Graphics, and Integrated Kinematics (MAGIK) analysis was performed using the AMS model and an SSRMS with a standard payload envelope to determine if there were any contact issues. This analysis included the standard "stacked" tolerances for the arm and still did not reveal an impact concern.

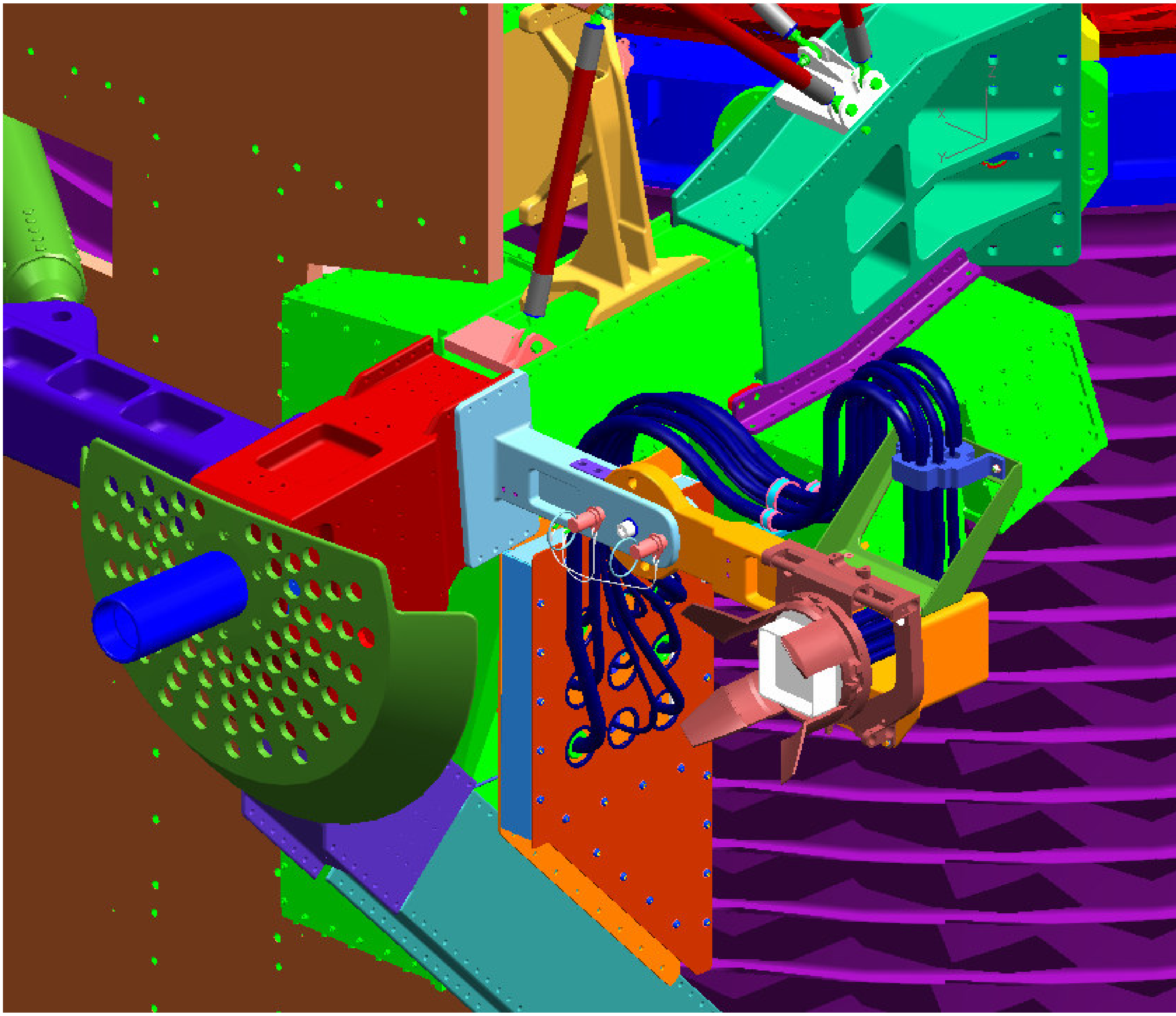


Figure 6.4.2.1-13 ROEU PDA in Nominal Configuration
(Isometric View from Starboard Side)

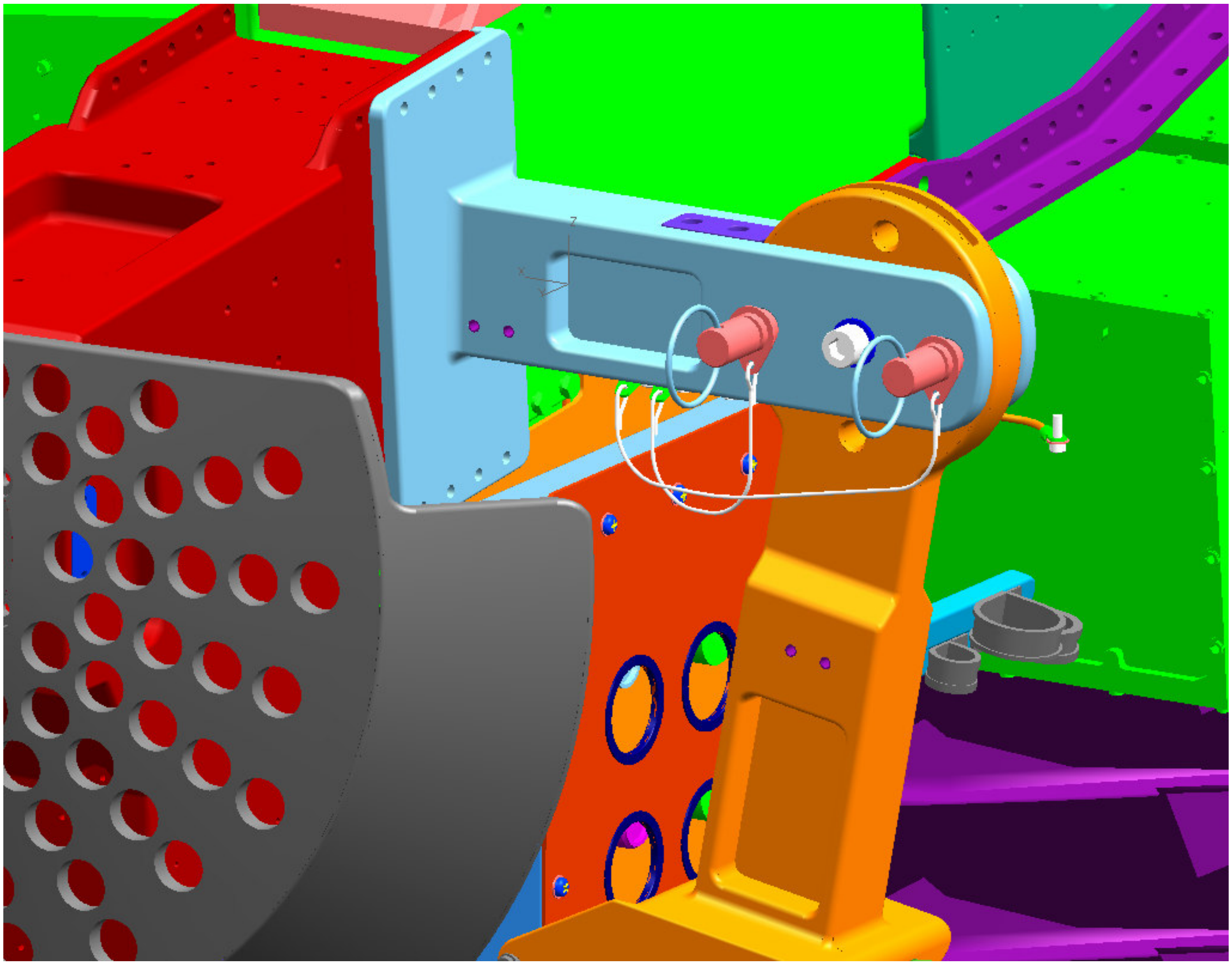


Figure 6.4.2.1-14 ROEU PDA in Folded Configuration (View from Starboard Side)

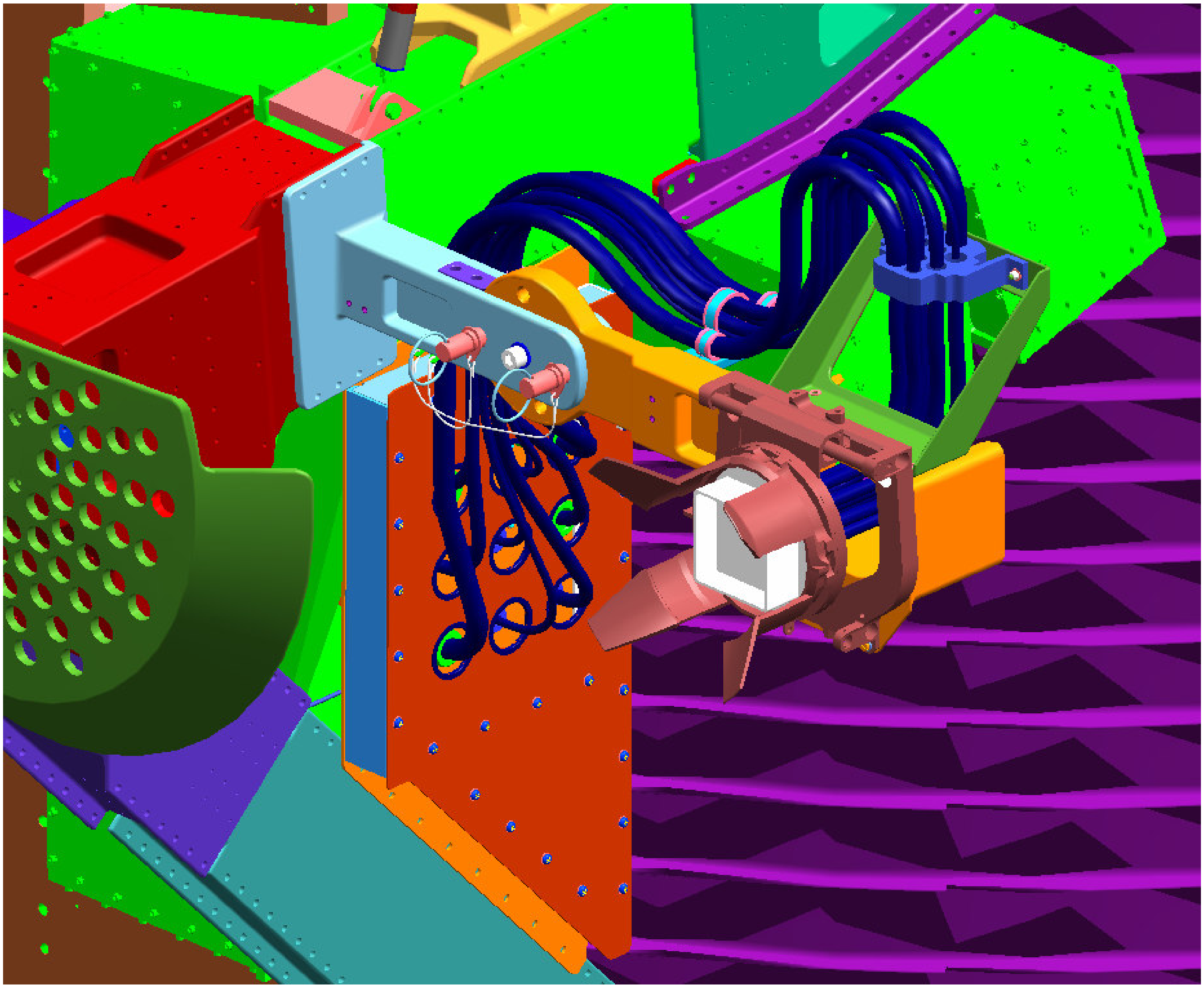


Figure 6.4.2.1-15 ROEU in Nominal Configuration (Iso View from Starboard Side)

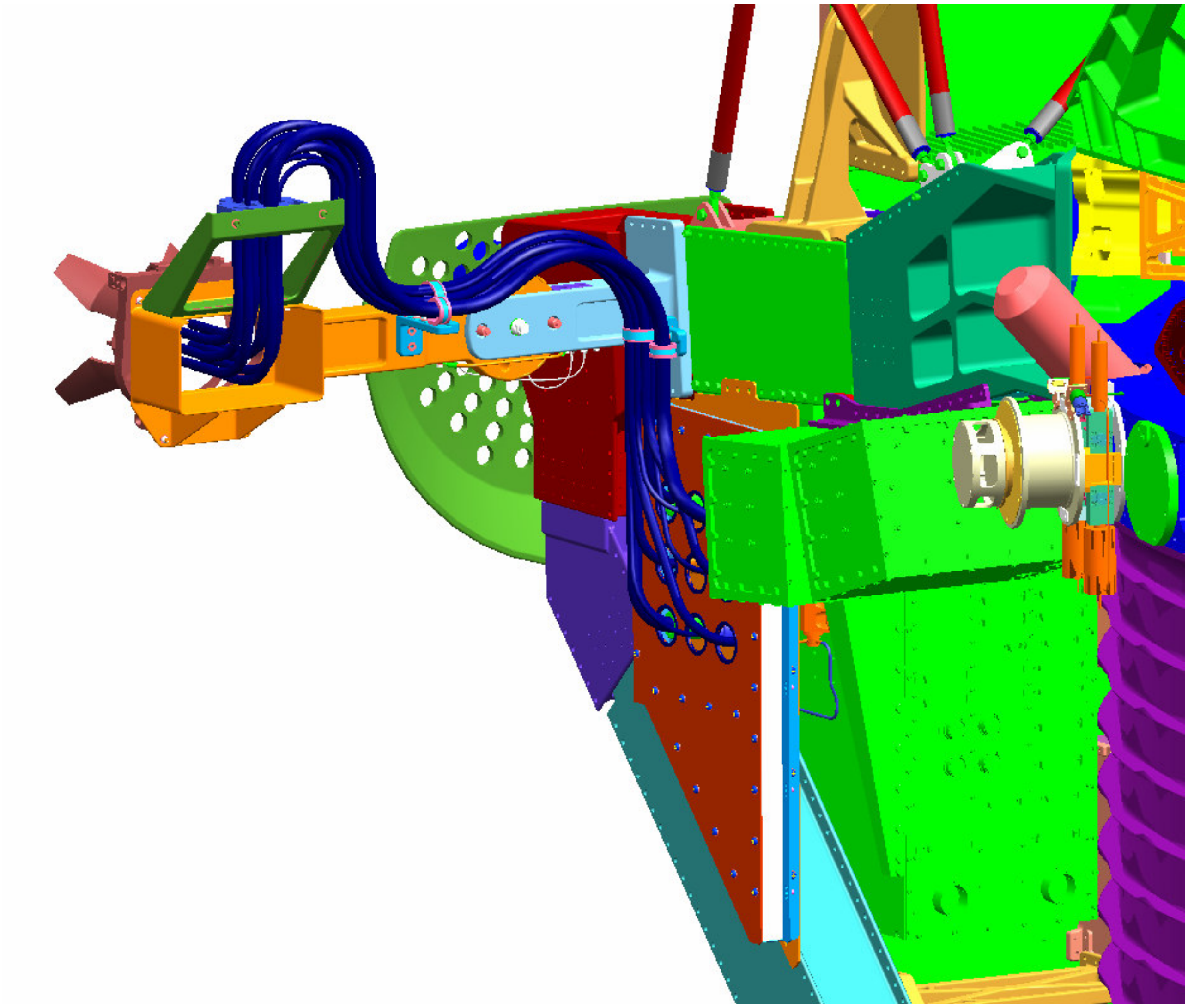


Figure 6.4.2.1-16 ROEU in Nominal Configuration (Iso View from Port Side)

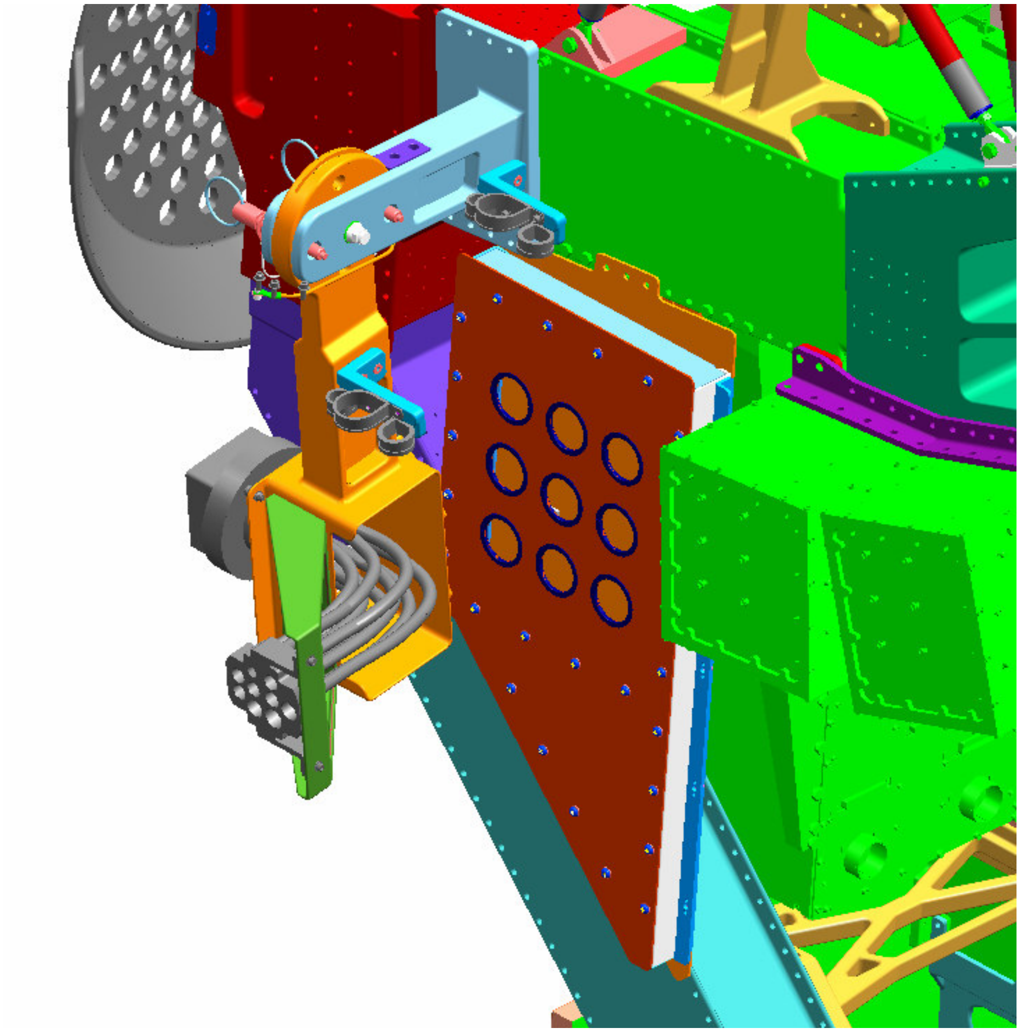


Figure 6.4.2.1-17 ROEU PDA in Folded Configuration (Iso View from Port Side)

7. SAFETY DISCUSSION

The AMS-02 Project has employed a methodical approach of for implementing a safe design for the AMS-02 payload. Safety has been a central focus of the Collaboration that has come together to create this international scientific instrument. With the evolution of the design of the AMS-02 since the Phase I Safety Review, held January 16, 2001, the design of the AMS-02 has undergone a renewed safety analysis to assure that all safety issues have been properly identified and addressed.

In the Phase I Safety Data Package (SDP) several systems were identified as being "re-flight" from the AMS (AMS-01) mission. Upon further review these systems were established to be sufficiently modified from the original flight design and configuration that they have now been directly addressed in the AMS-02 hazard analysis and hazard reports.

7.1 SAFETY ANALYSIS

The AMS-02 safety analysis considered the AMS-02 exterior elements and the interior elements that are to be utilized on the Shuttle Orbiter and the exterior elements to be berthed on the ISS. This analysis and SDP reflects the fact that the AMS-02 does not have any ISS interior elements.

The AMS-02 safety analysis and hazard reports generated consider the operations associated with the AMS-02 during the following operational phases:

- Pre-launch operations
- Launch and ascent
- On-orbit checkout of the AMS-02
- Shuttle RMS Operations
- ISS RMS Operations
- ISS PAS Installation
- ISS Operations

In addition the following contingency operations were considered in the safety analyses and hazard reports:

- Shuttle EVAs, past the AMS-02 and on Shuttle Program provided GFE (ROEU, FRGF)
- ISS EVAs past the AMS-02 and on ISS Program provided GFE (PVGF, PAS)
- AMS-02 Contingency EVA For Power Routing In-flight Maintenance (IFM)
- AMS-02 Contingency EVA For Data Routing IFM
- AMS-02 Contingency EVA For Manual Release of the PAS

7.1.1 Energy Analysis

The basic technique used to perform the safety analysis was identification of energy sources, energy transfer and energy concentration points in the AMS-02 design. This safety analysis technique utilizes the fact that in most cases, hazards cannot manifest without some form of energy existing and changing state or position. Energy can be categorized in a number of forms (generally), electricity, thermal, pressure, ionizing radiation, electromagnetic radiation, magnetic fields, chemical energy, kinetic, acoustic and organisms. By identifying these sources of energy and how they may be possibly transferred or concentrated, the fundamental hazards associated with AMS-02 have been identified.

7.1.2 Historical Comparative Analysis

In addition to the Energy Analysis technique for hazard analysis a complementary method of hazard analysis was utilized where a historical perspective of hazards addressed for payloads of the ISS and Shuttle was used to assure that there are no omissions in the AMS-02 hazard identification. This technique relied heavily on experiences of the safety and engineering community of the AMS-02 Project and an iterative approach to the design review and investigation.

7.1.3 Maintenance Hazard Assessment

The AMS-02 design does not require any regular maintenance procedures or conditional maintenance actions to be performed during the AMS-02 mission. A unique hazard analysis for maintenance operations has deemed to be unnecessary, all operations identified as nominal and contingency for the AMS-02 have been considered in the hazard analysis documented in this safety data package.

7.2 HAZARD REPORT GENERATION

The AMS-02 design was revisited with a renewed safety analysis in preparation of the Phase II Safety Data Package. As a result of the revised safety analysis the hazard reports were restructured and additional hazard reports added. To address this revision, new AMS-02 Project tracking identifiers were assigned to the hazard reports, differing from those used at the Phase I safety review. This difference is the addition of the "F" for flight in the number and a two digit numerical designator. With reorganization and additions of hazard reports, these designators may not correlate directly with previous hazard reports reviewed at Phase I. JSC Form 1230 has been used where possible to address Standard Hazards that satisfy the control and verification standards that are documented on the JSC 1230 Form. Two JSC Form 1230s have been prepared, one for AMS-02 exterior elements (Shuttle and ISS) and one for hardware that will be present within the Shuttle crew habitable environment. It was noted in the generation of the JSC Form 1230s for the AMS-02 phase II safety review that the JSC Form 1230 does not specifically address ISS Exterior Payloads, and in cases where it was clear the form was not able to address these payloads, a unique hazard report was generated.

AMS-02 hazard reports identified by the hazard analysis have been documented on a custom hazard report form that is compliant with the documented requirements of JSC/ISS 13830. The format of the hazard report groups controls and verifications together for direct correlation of the control and the associated safety verifications. Additionally a column that parallels the controls is present to identify all flight operational controls for quick reference. Character designators identify these controls, "I" for ISS based operation, and "S" for Shuttle based operations. Preflight ground operations are not identified in this column.

A consistent numbering convention has been applied to the hazard reports using the form "aa.bb.cc". In this format "aa" designates the Cause Number, "bb" the Control Number, and "cc" the safety verification method and status number. This methodology is maintained through the unique hazard reports, with the JSC Form 1230, the use of a slightly different numbering scheme utilizing the JSC Form 1230 letter designators required a minor deviation of the verification numbering methodology.

7.3 ACTION ITEM (AI) STATUS

The following actions were assigned at the AMS-02 Phase I Flight Safety Review held January 16, 2001.

Phase 0/I Action Items:

AI	Action	Date Due
1 Assigned to: SF3/J. Bates **(Now EA2/T. Martin)**	Continue to assess the helium venting analysis with Shuttle Integration and EP4 and develop a history of cryostat operations to determine the necessity of a Launch Commit Criteria (LCC) inside T-9 minutes to launch.	Date: Phase II Mandatory Reviewers: PSRP

Action item 1 was discussed in two special technical interchange meetings (TIMs) held with the PSRP on October 11 2001 and January 17, 2003. The monitoring of the Cryomagnet has been established to be an essential AMS-02 Verification Process and a Launch Commit Criteria has been established in hazard report AMS-02-F04, Overpressurization of Orbiter Payload Bay. The AMS-02 Project will seek to have this action closed at the Phase II Safety Review.

AI	Action	Date Due
2 Assigned to: SF3/J. Bates HR: AMS-02-6 **(Maps to Phase II HR AMS-02-F06)**	Pre-submit AMS-02 vent test data regarding TCS, warm helium supply, TRD, and the cryosystem to EP4/H. Flynn for approval; submit data to USA in April 2001 for analysis; and add results to HR AMS-02-6 for presentation at Phase II FSR.	Date: Phase II Mandatory Reviewers: PSRP

Action item 2 has been an ongoing effort to establish all possible venting rates and maximum volumes from all stored gas systems, exceeding the list of the action item. Special technical interchange meetings followed the Phase I safety review where the venting rates and thermal conductance that could lead to emergency venting of the superfluid helium as helium gas. The AMS-02 Project will seek to have this action closed at the Phase II Safety Review.

AI	Action	Date Due
3 Assigned to: NC55/S. Loyd HR: AMS-02-7 **(Maps to Phase II HR AMS-02-F07)**	Provide updates regarding changes to the magnetic requirements for the EMU and peripheral equipment, and status the relevant communication between the PO and EVA Project Office/XA. (PSRP may schedule a meeting with XA and AMS following review of the AI, if necessary.)	Date: February 18, 2001 Mandatory Reviewers:

This action item was closed at a special discussion meeting held by the PSRP on September 11, 2001.

7.4 AGREEMENTS

The following agreements were documented in the Phase 0/I minutes for the AMS-02 held January 16, 2001. Reference numbers to actions items are taken directly from the text of the minutes.

> *3.1 The Payload Organization (PO) agreed to accurately define the weight of the Xe transported in the Xe tanks in the TRD.*

As documented in AMS-02-F04 the total quantity of xenon in the xenon tank of the TRD will be 109 lbs (49.54 kg).

> *3.2 The PO agreed to highlight or differentiate any new material in the Phase II SDP.*

The Phase II Flight Safety Data Package has been substantially revised since the phase 0/I safety review, marking the new and updated material became impractical.

> *3.3 The PO agreed to research the rationale for the different requirements numbers from HQ, ISS, and AMS-02 personnel regarding MM&OD and coordinate the findings with the Payload Safety Engineers (PSEs) assigned to AMS-02.*

The differences in the MM&OD requirements have been reviewed and presented to the Payload Safety Review Panel by NE2/D. Londa on December 5, 2003. In this presentation the proposal to change the NSTS 1700.7B ISS Addendum to include Probability of No Penetration from the current 0.9999 for 1 yr to be compatible with the SSP 52005C requirement of 0.9999 or 0.99999^(A*Y) whichever is lower (A – Area, Y – Years). A change request to make this change wax originated but at this time it has not become formally a part of NSTS 1700.7B ISS Addendum. AMS-02 is compatible with this desired requirement change as documented in letter KX-06-001, “Micro-Meteoroid Debris (MMOD) Requirements for the Alpha Magnetic Spectrometer (AMS)” dated February 17, 2006 from KX2/ISS MMOD Protection Subsystem Manager and NASA MMOD Protection Discipline Technical Warrant Holder. In this document the PNP value of 0.997 is documented as being justified based on the PSRP acceptance of the proposal to change NSTS 1700.7B ISS Addendum to be consistent with SSP 52005. AMS-02 is not generating a noncompliance to NSTS 1700.7B ISS Addendum as we feel we are in compliance with the intent of the safety community and MMOD community for MMOD control. Additionally the AMS-02 Project has been informed that the PSRP is seeking to change NSTS 1700.7B ISS Addendum to reflect the methodology that AMS-02 is implementing.

3.4 The PO agreed to highlight the Avionics Operations Profile for Phase II to designate that the information regarding the SFHe Tank Nominal Vent Valve opening during ascent and closing during a possible abort are only goals for mission success, not safety issues.

During ascent, a baroswitch and Orbiter computer based timer command to open a valve serves only to protect the Superfluid Helium supply from a wicking effect caused by liquid SFHe being in contact with a filter material. The unique capillary action of SFHe can result in the SFHe being drawn through the filter and released at an increased rate during <u>on-orbit</u> operations. By delaying the opening of this valve until the exterior pressure is approximately 5 mbar while vapor only is in contact with the filter plug, the SFHe is conserved and mission life is maintained. Mass flow rate during this condition is not sufficient to increase the overpressurization threat to the Orbiter, but does significantly affect the overall mission life of the AMS-02 if the flow rate is increased due to liquid "pumping" through the filter plug. This phenomenon is not a driving factor for Over-pressurization of the Shuttle Payload Bay causes and does not affect flight safety if the valve either does not operate or operates an inappropriate time.

> *3.5 The PO agreed to present information related to the ACOP drawer assembly Hard Drives when available, and to ensure that fans/filters are kept cleaned to provide clean cabin air.*

The ACOP has been cancelled from the AMS-02 Project and will not be flown.

> *3.6 The PO agreed to define all TBDs in JSC Form 1230 for Standardized Hazards for Phase II.*

The use of JSC Form 1230s have been substantially updated for the Phase II Safety Review for the AMS-02. There are no occurrences of TBD upon the form itself aside from closure dates which are represented as "open".

> *3.7 The PO agreed to add information to part "d" of Letter TAA-88-074, "Burst Disk Certification Approach," regarding materials and process control.*

Excerpt from Space Cryomagnetics Memorandum 2484, "Burst Disc Qualification":

> It is not feasible to test burst discs for membrane actuation pressure. This requirement will instead be demonstrated through materials and process control. The burst disc manufacturer has been asked to advise SCL of the controls intended to be used. These will be passed on to ESCG/NASA for approval.

The control of the materials and processes of the burst disc manufacturer have been documented and reviewed for acceptability.

> *3.8 The PO agreed to add information to HR AMS-02-3 AMS-02 Pressure System-Cryomagnet table for Phase II.*

All tables associated with the pressurized systems and structural elements have been substantially updated for phase II.

> *3.9 NC44/(**Current PSE**) will verify that M. Golightly has a copy of the updated version of Form 44.*

A revised JSC Form 44 has been attached to AMS-02-F09 using the latest version of the form found on the JSC Payload Safety webpage as of the date of this document. The assigned NC44 PSE will have this form available to distribute to the appropriate technical representatives of the Space Radiation Working Group. The form has been submitted and reviewed through the automated submittal system, under the agreement it will be resubmitted once a specific flight identifier is available to assign to the Form 44.

3.10 The PO agreed to coordinate with Cargo Integration after the research on the source data profile for time from launch vent profile is completed.

AMS-02 project has worked with the Cargo Integration Office and their support personnel on the AMS-02 venting conditions. Boeing Technical Memorandum TS-TM-02-064, Alpha Magnetic Spectrometer II During Ascent and Descent Orbiter Operations, provides the acceptance of the AMS-02 design and analysis that demonstrates that the AMS-02 does not provide an uncontrolled risk to the Orbiter. The Cargo Integration Representative to the PSRP (JSC-MO2/S. Kunkle, 5/24/2005) has indicated that no further documentation beyond this memo will be generated.

The following agreements were generated at the Alpha Magnetic Spectrometer-02 Technical Interchange Meeting held on January 17, 2003:

3.1 The PO agreed to provide a thorough explanation of the continuous venting activity and characterization of the situation for the Phase II Review.

AMS-02 project has worked with the Cargo Integration Office and their support personnel on the AMS-02 venting conditions. Boeing Technical Memorandum TS-TM-02-064, Alpha Magnetic Spectrometer II During Ascent and Descent Orbiter Operations, provides the acceptance of the AMS-02 design and analysis that demonstrates that the AMS-02 does not provide an uncontrolled risk to the Orbiter. The Cargo Integration Representative to the PSRP (JSC-MO2/S. Kunkle, 5/24/2005) has indicated that no further documentation beyond this memo will be generated.

3.2 The PO agreed to submit details of the lot screening program materials and process data for JSC Engineering review.

The details of Cryosystem burst disk lot screening program and process data has been provided to JSC Engineering for review and concurrence. JSC Engineering has accepted the program and process and this is documented in hazard report AMS-02-F03.

7.5 HAZARD SUMMARY

The safety analysis of the AMS-02 has resulted in the generation of twenty integrated hazard reports and two unique JSC Form 1230 hazard compilation reports. Of the twenty integrated hazard reports, the previously deleted Phase I hazard report for Toxic Material Offgassing has been reopened for Phase II and although a complete nomenclature change has occurred with the hazard reports, the corresponding hazard report has been maintained with the same corresponding hazard report identifier (specifically AMS-02-2 at phase I and AMS-02-F02 for Phase II). Another hazard report has been withdrawn upon further investigation of the design and consequences of the potentially hazardous condition.

7.5.1 Structural Failure of Hardware

7.5.1.1 Structural Margin

The AMS-02 hardware to be launched in the Orbiter Payload Bay, transferred via SRMS and SSRMS to the ISS PAS location has been designed to maintain positive load factors for all required loading conditions. Hazard report AMS-02-F01 has been prepared to document the AMS-02 hardware’s capability to safely complete the AMS-02 mission without losing structural margins, damaging the AMS-02, the Orbiter, the ISS or these vehicles’ crew or the general public.

Structural safety of the hardware to be flown and used within the Orbiter habitable volume is addressed in hazard report STD-AMS-02-F01.

Fastener back-off, which is traditionally a concern of loss of structural load path or release of masses in excess of 0.25 pounds, has been addressed in STD-AMS-02-F01 with regards to the release of any fastener or mass as a result of fastener back-off. The release of a mass which can become a co-orbiting mass that can impact the ISS, the AMS-02 or other payloads has not been established to have a mass limitation, thus all fasteners have been shown to have the requisite back off prevent or be shown to be contained and not to release a mass with any possible back-off. Only in this latter condition, containment of any released mass, has the use of chemical thread lock been approved for use on the AMS-02.

7.5.1.2 Vented Volumes

The AMS-02 has been designed to have volumes that will equalize pressure during its mission. These volumes will either be shown to have adequate venting area for the enclosed volume or show adequate structural margin in the event that all vents are closed. This has been addressed in hazard report STD-AMS-02-F01.

7.5.1.3 Fracture Control

The AMS-02 structural and mechanical components have been assessed for fracture control per the JSC Fracture Control plan. This is addressed in hazard report AMS-02-F01. (Pressure systems are also addressed for fracture control, and documented in hazard reports AMS-02-F03 and AMS-02-F05.)

7.5.2 Mechanism Failure

The AMS-02 makes use of two mechanical devices, both implemented in the AMS-02 design by mandate from the ISS program,. These are the PAS release mechanism and the ROEU folding bracket mechanism. Both of these devices are addressed in hazard report AMS-02-F11.

7.5.2.1 EVA PAS Release Mechanism

The EVA releasable PAS requires an excess of three failures to occur to inadvertently release the preload of the ISS PAS grapple system and allow for the withdrawal of the capture bar. The requirement for operability of the EVA releasable PAS capture bar only requires that the system be zero fault tolerant (SSP 57021, Section 4.1.2.2.1) to add the last required means of clearing a payloads from the ISS truss.

7.5.2.2 ROEU Bracket Folding Mechanism

The ROEU Bracket folding mechanism is an ISS program requested mechanism to provide additional clearance between the AMS-02 and the adjacent payload envelop. Originally the AMS-02 had an agreement with the ISS Program that this volume would not be used and AMS-02's protrusion from the payload envelope was acceptable. A MAGIK analysis of the AMS-02 and a worst case berthing of an adjacent payload, such as an EXPRESS Pallet, showed a minimum clearance of 1.5 inches considering stacked misalignments. With the evolution of the EXPRESS Pallet to the Unpressurized Logistics Carrier (ULC), this clearance distance has been substantially increased. The folding mechanism for the ROEU Bracket will allow for a greater margin to exist, although it does still extend outside of the nominal payload envelope designated in SSP 57003, Section 3.1.3.1.1.1. The exceedences of the AMS-02 with the payload envelope, considering the folding of the ROEU Bracket, are accepted in the AMS-02 ICD by waiver. The original MAGIK with the EXPRESS Palley and the more recent MAGIK analysis of the ULC analysis does not indicate a collision is possible, and the mechanism will only be considered to be operated in the event of a direct request of the ISS program for additional clearance.

Once operated, the ROEU Bracket folding mechanism will need to restrain the motion of the hinged bracket. While there is little concern that structurally this will survive loads, providing this condition or that a loose hinge will impact an adjacent structure, the AMS-02 will be requiring the securing of the arm in place. With an unknown number of rotational impacts a specific structural analysis is not feasible. Thus at least a single securing EVA pip pin will be required, to keep the Bracket restrained.

7.5.2.3 Unable to Berth, Collision

The AMS-02 utilizes the shuttle and ISS robotic arms for maneuvering to berthing locations in the Orbiter (for a contingency return) and on the ISS (for nominal berthing for mission.) The AMS-02 has installed grapple fixtures in appropriate locations to meet the center of gravity requirements and other ICD requirements, for robotic handling and will provide accurate models of the entire AMS-02 for the robotic motion analysis and simulators. The AMS-02 is entirely passive with regards to berthing operations, with the exception that it has integrated into its structure and avionics the Electronic Berthing Camera System (EBCS). The EBCS has been installed according to the ICD and will have its critical alignment verified prior to launch. The mounting of the grapple fixtures and installation of the EBCS have been addressed in hazard report AMS-02-F11, Mechanical Failure.

7.5.3 Rotating Equipment

The AMS-02 makes use of pumps within three of the systems that comprise the payload: Cryosystem, TRD and TTCS. The Cryocooler does not utilize rotating equipment as it is a reciprocating pump. Thermo-mechanical pumps utilize a thermal property of Superfluid Helium to draw the liquid through a membrane by heat alone, thus contains no moving parts. All applications or rotating pumps are considered to be low energy and contained in the event of a dissolution of the rotating elements. The cryosystem pump will only be operated prior to launch and will be inert and inoperable while in flight and on-orbit. This is documented in hazard report STD-AMS-02-F01.

7.5.4 Pressurized Systems

The AMS-02 utilizes a number of pressurized systems in accomplishing its function. These systems are addressed in a number of hazard reports. The rupture of the pressurized systems have been addressed in two hazard reports, AMS-02-F03 for the Cryomagnet System and the Vacuum Case and AMS-02-F05 for the other pressurized or fluid containing systems on the AMS-02. The hazard of over-pressurization of the Orbiter Payload Bay has been addressed in hazard report AMS-02-F04, addressing the source potential of all fluids and the nature of the worst case evolution of helium from the cryogenic supply of superfluid helium.

7.5.5 Excessive Thrust/Overturning Moments

The AMS-02 has identified the potential for the AMS-02 to generate forces that could affect robotic operations and vehicle stability. The presence of high pressure gaseous systems and the generation of an intense magnetic field are direct potential causes for this condition.

All pressure system vents will either be capped or provided with zero-thrust vent caps/non-directional vent that will minimize the potential for generation of resulting forces. The AMS-02 magnetic field is designed to have a minimum exterior effect in generating a torque that is perceivable to the ISS. These potential hazards and controls are addressed in hazard report AMS-02-F06.

7.5.6 Radiation

The AMS-02 has systems that can generate radiation and strong field effects that are essential for the experiment objectives. These are addressed in the following paragraphs.

7.5.6.1 Excessive Radiated Field Strengths, EMI

The AMS-02 will be complying with both Orbiter and ISS EMI/EMC requirements, compliance is documented in hazard report AMS-02-F07.

7.5.6.2 Magnetic Fields

The AMS-02 makes use of an intense magnetic field within the bore of the instrument. The magnet coils have been designed to minimize the field external to the Cryomagnet and AMS-02 as much as possible. The EMU and standard EVA tools have been certified through a cooperative effort to show good for the maximum fields they could see why translating past the AMS-02. In the event an EVA to the AMS-02 is required, the magnetic field will be dispersed and prevented from being reformed until after the EVA operations at the AMS-02 are complete. This hazard is addressed in detail in hazard report AMS-02-F07.

7.5.6.3 High Intensity Light

The hazards from visible, infrared and ultraviolet electromagnetic energy have been established in the AMS-02 hazard analysis to have two possible sources, from an internal AMS-02 source and from an external source that is redirected. The internal source identified for AMS-02 comprises the ten laser diodes used to check the alignment of the AMS-02 Tracker and the external source the sun reflecting off of the AMS-02 thermal control features.

7.5.6.4 Exposure to Coherent Light (Lasers)

The only source of coherent light generated by lasers is within the Tracker Alignment System (TAS). The application of laser diodes (10 total) within the TAS is documented in unique hazard report AMS-02-F20. The Class IIIb laser source is contained within the source boxes and transmitted to the interior of the Tracker by fiber optic cables. The laser beam path is entirely closed from the light tight source boxes (LFCR) to the light tight tracker assembly. Even if the fibers carrying the laser illumination should be able to freely radiate, the laser power has been reduced by optical splitting of the beam into multiple fibers (individually sheathed and connected) to have a non-hazard zone (NHZ) of 2.4 cm. AMS-02-F20 is classified as catastrophic as the laser diodes are capable of emitting 80 mW at 1083 nm which could conceivably create permanent damage to human tissue and eyes. AMS-02-F20 demonstrates energy containment and design compliance with ANSI-Z 136.1.

7.5.6.5 Excessive Glare

Hazard report AMS-02-F19 was established to document the potential hazards identified in the hazard analysis associated with a highly reflective payload redirecting solar illumination. The AMS-02 utilizes a number of highly reflective thermal control devices including silver coated Teflon tape. The concern that these reflective surfaces could affect EVA operations, camera viewing and ISS based observations could result in the use of contingency operations warranted looking at this condition as a hazard. Further research into the concern among the ISS and EVA communities placed this not in an arena of contingency operations, making it critical hazard, but mission planning and for EVAs, such as the requirement of use of the visor if there is a glare situation. This hazard report has been withdrawn based on this information and the fact that the AMS-02 design in no way concentrates sunlight, only disperses it. The issue of thermal heat loads to adjacent payloads cause by the reflective surfaces is addressed not as a safety issue but as an environmental issue within the ISS attached payloads integration process and addressed thoroughly there. AMS-02-F19 has been withdrawn as an active hazard and this hazard report ID has been set aside and will not be used for a different hazard potential.

7.5.6.6 Exposure of the Crew to Excessive Ionizing Radiation

The AMS-02 utilizes iron citrate (Fe^{55}) as a calibration source for the TRD gas supply. This iron citrate is deposited (bonded chemically) to the interior of the four calibration tubes within the Monitor Tube. The thickness of the Monitor Tube is sufficient to eliminate any radiation penetration. Through the evolution of the Monitor Tube, it has been referred to in documentation as Calibration Tubes and Proportional Tubes.

During AMS-02 ground testing, the science instruments will be subjected to controlled particle beams. These particle beams will validate the science instrument operations. While this beam qualifies as a radioactive source, it can not induce residual radioactivity in the materials of construction of the AMS-02.

Exposure to radioactive materials and ionizing radiation is address in hazard report AMS-02-F09, "Exposure of the Crew to Excessive Ionizing Radiation."

7.5.7 EVA/EVR Operations Hazards

AMS-02 has been designed to be compatible with a number of contingency EVAs associated with the GFE used on the AMS-02. There are also three EVAs associated with contingency operations with AMS-02 hardware. These include the EVA rerouting of power and data cables for ISS bus connectivity, folding of the ROEU bracket to provide additional clearance for the adjacent payload, and the ISS required alternate means of releasing the AMS-02 from the PAS location. EVA compatibility issues have been addressed in hazard report AMS-02-F14. Hazards addressed in this hazard report include thermal extremes, sharp edges and corners, stored energy release, and electrical shock. Hazard associated with robotic manipulation are also included into this hazard report.

7.5.8 High Voltages

The AMS-02 utilized a number of voltages in excess of 32 volts direct current (Vdc). The AMS-02 utilizes protection techniques, appropriate selection of cabling and grounding to preclude hazards of electrical shock, discharge and corona. These hazards are addressed in hazard report AMS-02-F08.

7.5.8.1 Electric Shock/Discharge

The AMS-02 utilizes the ISS provided 120 VDC and converts that power to a number of different voltages, some of them exceeding 1000 VDC. Hazard Report AMS-02-F08 has been developed to document this catastrophic level hazard. The controls documented in AMS-02-F08 focus on the high voltage sources and loads and the compliance with high voltage wiring, connections, potting and grounding requirements. The primary control for exposure of EVA crew to electrical shock is the discharge of the stored energy of the Cryomagnet prior to the EVA, cessation of power application prior to an EVA and UPS battery circuit design that isolates continuously powered elements from EVA sites.

7.5.8.2 Coronal Discharge

As the AMS-02 utilizes high voltage sources and can release readily ionizable gases in the course of operations (principally from the TRD system) the AMS-02 has implemented high voltage insulation and potting protocols to limit the coronal discharge potential. AMS-02-F08 documents the techniques used to limit coronal discharge potential. Extensive testing of AMS-02 circuits and loads has shown that coronal initiation voltages for these designs are not met and the AMS-02 design. The actual coronal discharge could damage AMS-02 hardware through degradation and generate a “white noise” EMI, but there is no damage potential to the ISS directly from any conceivable coronal discharge with AMS-02 hardware.

7.5.9 Electrical Power Distribution Damage

The AMS-02 design protects the vehicle’s power supplies and its own internal wiring from damage due to excessive load. This is addressed in hazard report AMS-02-F17.

7.5.10 Mate/De-mate of Connectors

Nominal operations of the AMS-02 do not require the connection of any cable with the exception of the communications cable connecting the PGSC/NGLS interface card to the OIU. The AMS-02 does however have a number of contingency operations that it must support, Shuttle, ISS and its own where the de-mating and mating of connectors will occur. The mating and de-mating of connectors, by EVA, is addressed in hazard report AMS-02-F12.

7.5.11 Battery Failure

The AMS-02 utilizes a battery system to provide for Cryomagnet protection in the event of AMS-02 power loss. This battery system is addressed in hazard report AMS-02-F13.

7.5.12 Ignition of Flammable Atmospheres

The AMS-02 has a minimum of powered systems during ascent. These include the UPS battery system and the ascent valve system that is used to manage the proper flow of helium gas out of the Dewar without inducing an unacceptable loss rate (for mission success, this is not safety related). During ascent a baroswitch will make a valve open late in the ascent phase. These electronics and electrical components will be shown not to be able to ignite a flammable atmosphere in hazard report STD-AMS-02-F01

7.5.13 Flammable Materials

The hazard of fire, controlled by the use of materials which are non-flammable or possibly flammable but protected from being a significant threat, is addressed for the crew habitable volume of the Orbiter in hazard report STD-AMS-02-F02. The materials of construction of the AMS-02, the elements in the Orbiter Payload Bay, are addressed in hazard report AMS-02-F10. The AMS-02 also makes use of working fluids in the thermal control systems that can be flammable. These gaseous/liquids are addressed in hazard report AMS-02-F10.

7.5.14 Shatterable Material Release

The AMS-02 makes extensive use of photomultiplier tubes and frangible materials in order to accomplish its science objectives. Hazard report AMS-02-F16 addresses each of these sources and how the materials are either contained or qualified not to break during the AMS-02 mission.

7.5.15 Toxic Material Release

AMS-02 will have hardware within the Orbiter habitable volume, these items will be assessed for off-gassing compliance. Compliance is addressed in hazard report AMS-02-F02. The AMS-02 does not make use of other chemicals within the crew habitable environment that could have a toxicological effect.

7.5.16 Thermal Extremes

The use of cryogenic fluids creates a condition where the AMS-02 can be the source of an extreme cold. The design of the AMS-02 limits this exposure and is addressed in AMS-02-F15.

7.5.17 Rapid Safing/Payload Reconfiguration

The AMS-02 has a limited number of configurations that it can be placed in physically. Hazard report AMS-02-F18 addresses the AMS-02 operations and configurations and how they do not affect the ability of the AMS-02 to safety return in the Orbiter or handle ISS loads.

7.6 FIRE DETECTION AND SUPPRESSION SUMMARY

The AMS-02 does not include any hardware that will be operated within the ISS habitable volume. No Fire Detection and Suppression design features are required for the AMS-02.

7.7 OPERATIONAL CONTROLS

The prepared unique hazard reports for the AMS-02 has an additional data element beyond those required by NSTS/ISS 13830 for the content of payload safety hazard reports. This additional data element is a column that indicates the use of operational controls. A control that uses an operational control has a designator in this column, an "S" for a shuttle based operation and "I" for ISS based operation.

A reference list of all these designations is provided in Table 7.7-1.

TABLE 7.7-1 OPERATIONAL PROCEDURE CONTROLS

Hazard Report	Control	I/S	Summary
AMS-02-F05	9.2.2	I	In order to assure a limited life of the Warm Helium tank with regards to MMOD, when the usefulness of the system is over with the depletion of Superfluid Helium from the Cryomagnet system, this procedure will allow for the remainder of the Warm Helium Supply helium to be released from the system, eliminating the MMOD concern with the pressurized vessel. This is an AMS-02 operational procedure that must be coordinated with the ISS for scheduling of appropriate release time and rate.
AMS-02-F05	9.2.3	I	In order to assure a limited life of the TRD Xenon and Carbon Dioxide tanks with regards to MMOD, when the usefulness of the system is over with the first depletion of one of the two gas supplies, the other supply will be released from the system, eliminating the MMOD concern with the pressure vessels. This is an AMS-02 operational procedure that must be coordinated with the ISS for scheduling of appropriate release time and rate.
AMS-02-F06	4.2	I	Discharge stored energy/magnetic field of AMS-02 prior to any removal (robotic) from ISS berthing location.
AMS-02-F07	1.3	I	Discharge stored energy/magnetic field of AMS-02 prior to any removal (robotic) from ISS berthing location.
AMS-02-F07	1.6	I	Discharge stored energy/magnetic field of the AMS-02 prior to any EVA procedure to be conducted on or with the AMS-02.
AMS-02-F07	1.6	I	Keepout zone (warning) for EVA when Cryomagnet is charged.
AMS-02-F07	1.7	I	SSRMS handling of AMS-02 to assure that primary power feed is used when handling the AMS-02 to assure that power feed capable of charging AMS-02 Cryomagnet is not engaged.
AMS-02-F07	3.3	I	Discharge stored energy/magnetic field of AMS-02 prior to any removal (robotic) from ISS berthing location.
AMS-02-F08	1.1	S	Procedural controls to remove power to the AMS-02 before any EVA access while on the Shuttle.

Hazard Report	Control	I/S	Summary
AMS-02-F08	1.1	I	Procedural controls to discharge magnetic field and removal of power to the AMS-02 prior to EVA Access of the AMS-02 on the ISS. (Power removal recommended to occur late in EVA process for thermal conditioning.)
AMS-02-F08	2.6	S	Prior to ROEU to ROEU-PDA de-mate, power will be removed from connection and remain off once de-mated.
AMS-02-F08	3.1	S	Review of crew procedures for contingency return of AMS-02 to assure that high voltage supplied to the AMS-02 from the Orbiter is turned off prior to entry.
AMS-02-F12	1.1	I	Procedural controls calling for the removal of power to the AMS-02 prior to EVA Access of the AMS-02 on the ISS. (Power removal recommended to occur late in EVA process for thermal conditioning.)
AMS-02-F14	3.1	I, S	Identify the sharp edge keep away zone of the Star Tracker optical baffle.
AMS-02-F14	5.2	I	EVA procedures to establish correct process to release stored energy of the AMS-02 to PAS interface and remove the AMS-02 from the PAS.
AMS-02-F14	6.2	I	EVA procedures to call for the use of the EVA power tool to avoid excessive repetitive cycles for release of the AMS-02 from PAS by EVA technique.

A launch commit criteria exists for the AMS-02 that related directly to the AMS-02.

> During pre-launch activities, the status of the superfluid helium tank will be monitored for signs of loss of thermal isolation (vacuum case breach/leak). In the event that there is an increase in pressure indicating the loss of thermal isolation, launch will be scrubbed. Monitoring will continue at a minimum to within L-9 minutes. Credible loss of thermal isolation at L-9 minutes can not manifest to an over-pressurization of the Orbiter payload bay hazard in the time available.

The AMS-02 controls reflect the use of three flight rules.

Hazard Report	Control	I, S	Flight Rule Summary
AMS-02-F07	1.3	I	The SSRMS will not grapple the AMS-02 until the AMS-02 has discharge the magnetic field either through

			command or operation of the "watchdog timer".
AMS-02-F11	1.3	S	Four of four PRLAs and active keel latch must be secured to return with the AMS-02 installed in the Orbiter payload bay.
AMS-02-F18	1.5	S	Four of four PRLAs and active keel latch must be secured to return with the AMS-02 installed in the Orbiter payload bay.

7.8 FLIGHT SAFETY NONCOMPLIANCES

The AMS-02 Project has not identified any noncompliance to NSTS 1700.7B or NSTS 1700.7B ISS Addendum. No noncompliance reports have been generated for the AMS-02 payload.

The AMS-02 is proceeding with their design based on the PSRP's documented intent to alter the requirements of NSTS 1700.7B ISS Addendum section 208.4e to change the requirement of a Probability of No Penetration from 0.9999 to the requirement documented in a change request to NSTS 1700.7B ISS Addendum that would make the value for PNP consistent with SSP 52005. To that end the AMS-02 has been design for it's original mission life and area of PNP concern to yield a value of PNP=0.997. This is documented in letter KX-06-001, "Micro-Meteoroid Debris (MMOD) Requirements for the Alpha Magnetic Spectrometer (AMS)" dated February 17, 2006 from KX2/ISS MMOD Protection Subsystem Manager and NASA MMOD Protection Discipline Technical Warrant Holder. While the AMS-02 is not currently in compliance with the current version of NSTS 1700.7B ISS Addendum, AMS-02 has not generated a non-compliance in anticipation of the implementation of the CR into NSTS 1700.7B ISS Addendum.

7.9 HAZARD REPORT LIST

Table 7.9-1 provides a listing of all AMS-02 hazard reports with title and current Phase II status. Phase I status is not provided due to the restructuring and new numbering nomenclature used in the development of the Phase II SDP. All hazard reports presented at Phase I were approved with modifications at that time.

TABLE 7.9-1 AMS-02 HAZARD REPORT LIST

HR ID	Hazard Report Title	Phase II Status
STD-AMS-02-F01	Flight Payload Standard Hazard Report – Exterior Elements	Open
STD-AMS-02-F02	Flight Payload Standard Hazard Report – Interior Elements	Open
AMS-02-F01	Structural Failure of Hardware	Open
AMS-02-F02	Toxic Material Off-gassing	Open
AMS-02-F03	Rupture of Superfluid Helium Tank, Vacuum Case and/or Pressurized System	Open
AMS-02-F04	Over-pressurization of Payload Bay	Open
AMS-02-F05	Rupture of AMS-02 Pressurized Systems: TRD Gas System (Xe & CO_2), Cryomagnet Warm Helium Gas System, Tracker Thermal Control System, Thermal Control System, Cryocooler	Open
AMS-02-F06	Excessive Thrust/Overturning Moments	Open
AMS-02-F07	Excessive Radiated Field Strengths, EMI, Magnetic	Open
AMS-02-F08	Electric Shock/Discharge	Open
AMS-02-F09	Exposure of the Crew to Excessive Ionizing Radiation	Open
AMS-02-F10	Flammable Materials in the Payload Bay	Open
AMS-02-F11	Mechanism Failure	Open
AMS-02-F12	Mate/De-mate of Connectors	Open
AMS-02-F13	Battery Failure	Open
AMS-02-F14	EVA/EVR Hazards	Open
AMS-02-F15	Thermal Extremes	Open
AMS-02-F16	Shatterable Material Release	Open
AMS-02-F17	Electrical Power Distribution Damage	Open
AMS-02-F18	Rapid Safing/Payload Reconfiguration	Open
AMS-02-F19	Excessive Glare	Withdrawn
AMS-02-F20	Crew Exposure to Coherent Light	Open