JSC 29076

PHASE 0/I GROUND SAFETY DATA PACKAGE FOR THE ALPHA MAGNETIC SPECTROMETER-02 (AMS-02)

Space and Life Sciences Directorate
Flight Projects Division

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National Aeronautics and
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Lyndon B. Johnson Space Center
Houston, Texas

LMSEAT 33443

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FOR THE

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NASA/JSC APPROVAL

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Flight Projects Division

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
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For

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APPENDIX A – AMS-02 GROUND PAYLOAD HAZARD REPORTS:

ACRONYMS AND ABBREVIATIONS

A	Amps
AC	Alternating Current
ACASS	Active Common Attach System Simulator
ACC	Anti-Coincidence Counter
ACGIH	American Conference of Governmental Industrial Hygienists
ACOP	AMS Crew Operations Post
AFD	Aft Flight Deck
AHV	Air-Heated Vaporizer
AMS	Alpha Magnetic Spectrometer
APCU	Assembly Power Converter Unit
APS	Automated Payload Switch
ASSY	Assembly
ATC	Advanced Technology Center
atm	atmosphere
AWG	American Wire Gauge
BC	Bus Coupler
BD	Burst Disk
BEI	Biological Exposure Index
BFS	Backup Flight System
BV	Buffer Volume
C	Celsius
CAB	Cryomagnet Avionics Box

CAS	Common Attach System
cc	cubic centimeter
CCS	Cooling Control System
CCS	Cryomagnet Current Source
CDC	Cool Down Circuit
CDU	Cool Down Unit
CERN	European Organization for Nuclear Research
CFC	Carbon Fiber Composite
CG	Center of Gravity
CHX	Cold Heat Exchanger
CIM	Customer Integration Manager
CITE	Cargo Integration Test Equipment
CLA	Capture Latch Assembly
cm	centimeter
Cmd	Command
Cntl	Control
CO_2	Carbon Dioxide
COBE	Cosmic Background Explorer
COTS	Commercial Off The Shelf
CP	Circulation Pump
CPU	Central Processing Unit
CRISTA	Cryogenic Infrared Spectrometer Telescope

ACRONYMS AND ABBREVIATIONS (Continued)

CSP	Cryo-Magnet Self Protection
Cu	Copper
cu	cubic
CV	Check Valve
D	Daily Supply Buffer (also Mixing Vessel)
DC	Direct Current
DDRS-02	Digital Data Recording System-02
Dist	Distribution
DLT	Digital Linear Tape
DV	Digital (on/off) Valve
E	Energy
e^+	positron
e^-	electron
EBCS	External Berthing Cues System
ECAL	Electromagnetic Calorimeter (also EMC)
EGSE	Electrical Ground Support Equipment
ELV	Expendable Launch Vehicle
EMC	Electromagnetic Calorimeter (also ECAL)
EMI	Electromagnetic Interference
EMU	Express Memory Unit
Ena	Enable
ETH	Eidgenossische Technische Hochschule

EVA	Extravehicular Activity
EXPRESS	EXpedite the PRocessing of Experiments to Space Station
F	Fahrenheit
F	Filter
F/E	Front-End
Fe^{55}	Iron 55
FF	Flip-Flop
FO	Fiber Optic (also F/O)
FP	Fill Port
FRGF	Flight Releasable Grapple Fixture
g	gram (also gravity)
G	Gravity (also g)
Gbytes	Giga Bytes
GeV	Giga Electron Volts
GHE	Ground Handling Equipment
GHe	Gaseous Helium
GND	Ground
GP-B	Gravity Probe B
GPC	General Purpose Computer
Grms	Gravity Root Mean Square
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center

h	hour
He	Helium
Hk	Housekeeping
HP	High Pressure
HR	Hazard Report
HRDL	High Rate Data Link
HRS	Helium Recovery System
Htrs	Heaters
HV	High Voltage
HVM	Helium and Vacuum Manifold
Hz	Hertz
ICD	Interface Control Document
ID	Inner Diameter
IDE	Integrated Drive Electronics
I/F	Interface
in	inch
IR	Infrared
IRAS	Infrared Astronomical Satellite
ISF	Intermediate Support Fixture
ISO	Infrared Space Observatory
ISS	International Space Station
IVT	Interface Verification Test

JSC	Johnson Space Center
K	Kelvin
KeV	Kilo Electron Volt
kg	kilogram
KHB	KSC Handbook
kJ	kilojoules
KSC	Kennedy Space Center
KW	Kilowatt
L	Liter (also l)
lbs	pounds
LCD	Liquid Crystal Display
LHe	Liquid Helium
LHSS	Liquid Helium Supply System
LM	Lockheed Martin
LMSEAT	Lockheed Martin Science, Engineering, Analysis & Test
LMSO	Lockheed Martin Space Operations
LN_2	Liquid Nitrogen
LP	Low Pressure
LPIS	Launch Package Integration Stand
LRDL	Low Rate Data Link
LSSO	Launch Site Safety Office
LTO	Linear Tape Open

ACRONYMS AND ABBREVIATIONS (Continued)

μ	micro
μC	microcurie
m	meter
MDM	Multiplexer/Demultiplexer
MHT	Main Helium Tank
min	minute
mm	millimeter
MCA	Multi-Channel Analyzer
MCC	Monitoring and Control Computer
MCDS	Multi-function Cathode-Ray Tube (CRT) Display System
MDP	Maximum Design Pressure
MHT	Main Helium Tank
MIL	Military
ml	milliliter
MLI	Multilayer Insulation
M/OD	Meteoroid and Orbital Debris
MPCA	Mid Power Control Assembly
MPLF	Multi-Purpose Lifting Fixture
MPLM	Mini-Pressurized Logistics Module
MPPF	Multi-Payload Processing Facility
MRDL	Medium Rate Data Link
MSDS	Material Safety Data Sheet

msec	millisecond
MTU	Master Timing Unit
MV	Manually Actuated Valve (ground use only)
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NCR	Noncompliance Report
NDI	Nondestructive Inspection
NEC	National Electric Code
NFPA	National Fire Protection Association
NH_3	Ammonia
NSP	Network Signal Processor
NSTS	National Space Transportation System
O	Orifice
O_2	Oxygen
OD	Outer Diameter
OIU	Orbiter Interface Unit
OPF	Orbiter Processing Facility
P	Pressure Sensor
p^+	proton
p^-	anti-proton
PAS	Payload Attach System
PC	Personal Computer

PCASS	Payload Common Attach System Simulator
PCI	Peripheral Connect Interface
PCMCIA	Portable Computer Memory Card International Adapter
PCMMU	Pulse Code Modulation Master Unit
PCR	Payload Changeout Room
PCS	Portable Computer System
PDA	Payload Disconnect Assembly
PDB	Power Distribution Box
PDI	Payload Data Interleaver
PDIP	Payload Data Interface Panel
PEEK	Polyether Ether Ketone
PEHB	Payload Ethernet Hub Bridge
PEHG	Payload Ethernet Hub Gateway
PGHM	Payload Ground Handling Mechanism
PGSC	Payload and General Support Computer
ph	phase
P/L	Payload
PLB	Payload Bay
PLF	Primary Lifting Fixture
PM	Photo Multiplier
PMA	Physical Medium Attachment
P-MDM	Payload Multiplexer/Demultiplexer

PMT	Photo Multiplier Tube
P/N	Part Number
PnA	Pump A for TRD Segment n
PnB	Pump B for TRD Segment n
Pnl	Panel
POP	Pump Out Port
PP	Porous Plug
PRCU	Payload Rack Checkout Unit
psi	pounds per square inch
psia	pounds per square inch absolute
psid	pounds per square inch differential
psig	pounds per square inch gauge
PSP	Payload Signal Processor
PSS	Primary Support Stand
PT	Pressure Transducer
PTB	Payload Timing Buffer
PTCS	Payload Test and Checkout System
PVGF	Power Video Grapple Fixture
PWM	Pulse Width Modulator
Pwr	Power
RAID	Redundant Arrays of Inexpensive Disks
RCV	Receive

RF	Radio Frequency
RGA	Residual Gas Analyzer
RIC	Rack Interface Controller
RICH	Ring Imaging Cherenkov Counter
ROEU	Remotely Operated Electrical Umbilical
RPCM	Remote Power Controller Mechanism
RPM	Revolutions Per Minute
RTN	Return
RV	Relief Valve
RWTH	Reinisch - West falische Technische Hochshule
SCL	Space Cryomagnetics Limited
SCL	Superfluid Cooling Loop
SCSI	Small Computer Systems Interface
SFHe	Superfluid Helium
SHOOT	Superfluid Helium On-Orbit Transfer
Si	Silicon
SIP	Standard Interface Panel
SIRTF	Space Infrared Telescope Facility
SM	Systems Management
SMT	Standard Mini Tower
SPAS	Shuttle Pallet Satellite
SPEC	Specification

SRD	Synchrotron Radiation Detector
SRMS	Space Shuttle Remote Manipulator System
SSOR	Space to Space Orbiter Radio
SSP	Space Shuttle Program
SSP	Standard Switch Panel
SSPC	Solid State Power Controller
SSPCM	SSPC Module
SSPF	Space Station Processing Facility
SSRMS	Space Station Remote Manipulator System
STA	Structural Test Article
STD	Standard
STE	Special Test Equipment
STS	Space Transportation System
T	Temperature Sensor
T	Terminator
TAS	Tracker Alignment System
TB	Tera-Bytes
TBD	To Be Determined
TBS	To Be Supplied
TCS	Thermal Control System
Te	Tellurium
TeV	Tera Electron Volts

TLV	Threshold Limit Value
TMP	Thermo-Mechanical Pump
TOF	Time Of Flight
TOPODS	Tension Only Passive Orbital Disconnect System
TRD	Transition Radiation Detector
TT	Temperature Transducer
TTL	Transistor-to-Transistor Logic
UF	Utilization Flight
UHF	Ultra High Frequency
UIP	Utility Interface Panel
UL	Underwriters Laboratory
UMA	Umbilical Mechanism Assembly
UPS	Uninterruptible Power Supply
USCM	Universal Slow Control Module
USS-02	Unique Support Structure-02
V	Valve
V	Volt
VC	Vacuum Case
VCL	Vapor Cooled Leads
VCS	Vapor Cooled Shield
VCSC	Vacuum Case Shipping Container
VnA	Valve A for TRD Segment n

VnB	Valve B for TRD Segment n
VnC	Valve C for TRD Segment n
VnD	Valve D for TRD Segment n
Xe	Xenon
XMT	Transmit
yrs	years

APPLICABLE SAFETY DOCUMENTS

ACGIH TLVs and BEIs 1997	American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) and Biological Exposure Indices (BEIs) for Chemical Substances and Physical Agents
KHB 1700.7C	Space Shuttle Payload Ground Safety Handbook
KHB 1860.1C	KSC Ionizing Radiation Protection Program
KHB 1860.2B	KSC Nonionizing Radiation Protection Program
KHB 5310.1C, General Operating Procedure 5-3	KSC Space Shuttle Tool Control Program
MIL-STD-1472F	Department of Defense Design Criteria Standard, Human Engineering
NASA-STD-3000	Man-Systems Integration Standards
NEC NFPA 70	National Electric Code, National Fire Protection Association (NFPA) 70
NSTS/ISS 13830C	Payload Safety Review and Data Submittal Requirements For Payloads Using the Space Shuttle/International Space Station

1.0 INTRODUCTION

This Phase 0/I Ground Safety Data Package for the Alpha Magnetic Spectrometer-02 (AMS-02) is submitted in response to the safety requirements of KHB 1700.7C, "Space Shuttle Payload Ground Safety Handbook". 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".

2.0 SCOPE

This safety package contains the safety analysis performed for the AMS-02 Ground Handling Equipment (GHE), Ground Support Equipment (GSE) and ground operations at the John F. Kennedy Space Center (KSC). The AMS-02 flight hardware was analyzed separately in the Phase 0/I Flight Safety Data Package, JSC 29075.

The AMS-02 Silicon Tracker Assemblies, Tracker Alignment System (TAS), Anti-Coincidence Counter (ACC) and Digital Data Recording System-02 (DDRS-02) are reflown/series elements from AMS-01. The reflown/series ground safety assessment for the GHE/GSE/ground operations for these elements will be included in the AMS-02 Phase III Ground Safety Data Package.

The two Orbiter Interface Units (OIUs), one Payload General Support Computer (PGSC) with expansion assembly and power cable, one middeck locker, one Flight Releasable Grapple Fixture (FRGF), and one Payload Disconnect Assembly (PDA) for the Remotely Operated Electrical Umbilical (ROEU) are Space Shuttle Program (SSP) provided hardware, and their ground safety analyses are not part of this safety data package. The two Assembly Power Converter Units (APCUs), one International Space Station (ISS) payload locker, one Power Video Grapple Fixture (PVGF), one passive Umbilical Mechanism Assembly (UMA), an External Berthing Cues System (EBCS) are ISS Program provided hardware, and their ground safety analyses are not part of this safety data package.

3.0 PURPOSE

The purpose of this safety analysis is to identify potential ground hazards associated with the AMS-02, to evaluate their cause and impact on KSC ground personnel/facilities and the Space Shuttle, 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 0/I review of the AMS-02 by the Space Shuttle Payload Ground Safety Review Panel.

4.0 AMS-02 PAYLOAD OVERVIEW

The AMS-02 flight hardware is shown in Figures 4.1 thru 4.4. The major subsystems of the AMS-02 which are addressed in this Ground Safety Data Package are the Cryogenic Superconducting Magnet (Cryomag), Unique Support Structure-02 (USS-02) (which includes the integral Vacuum Case for the Cryomag), Synchrotron Radiation Detector

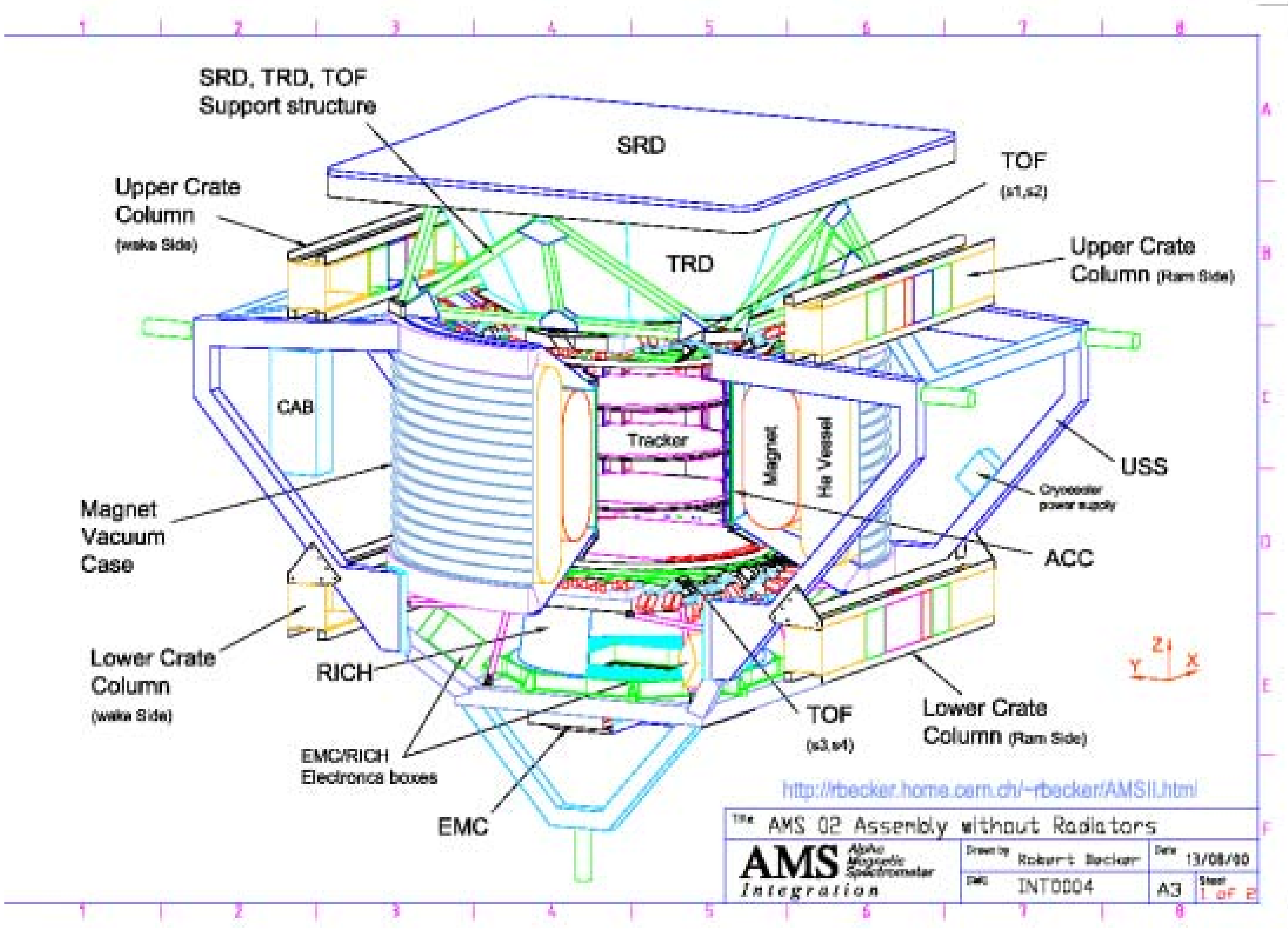


Figure 4.1 – AMS-02 with the USS-02 (Sheet 1 of 2)

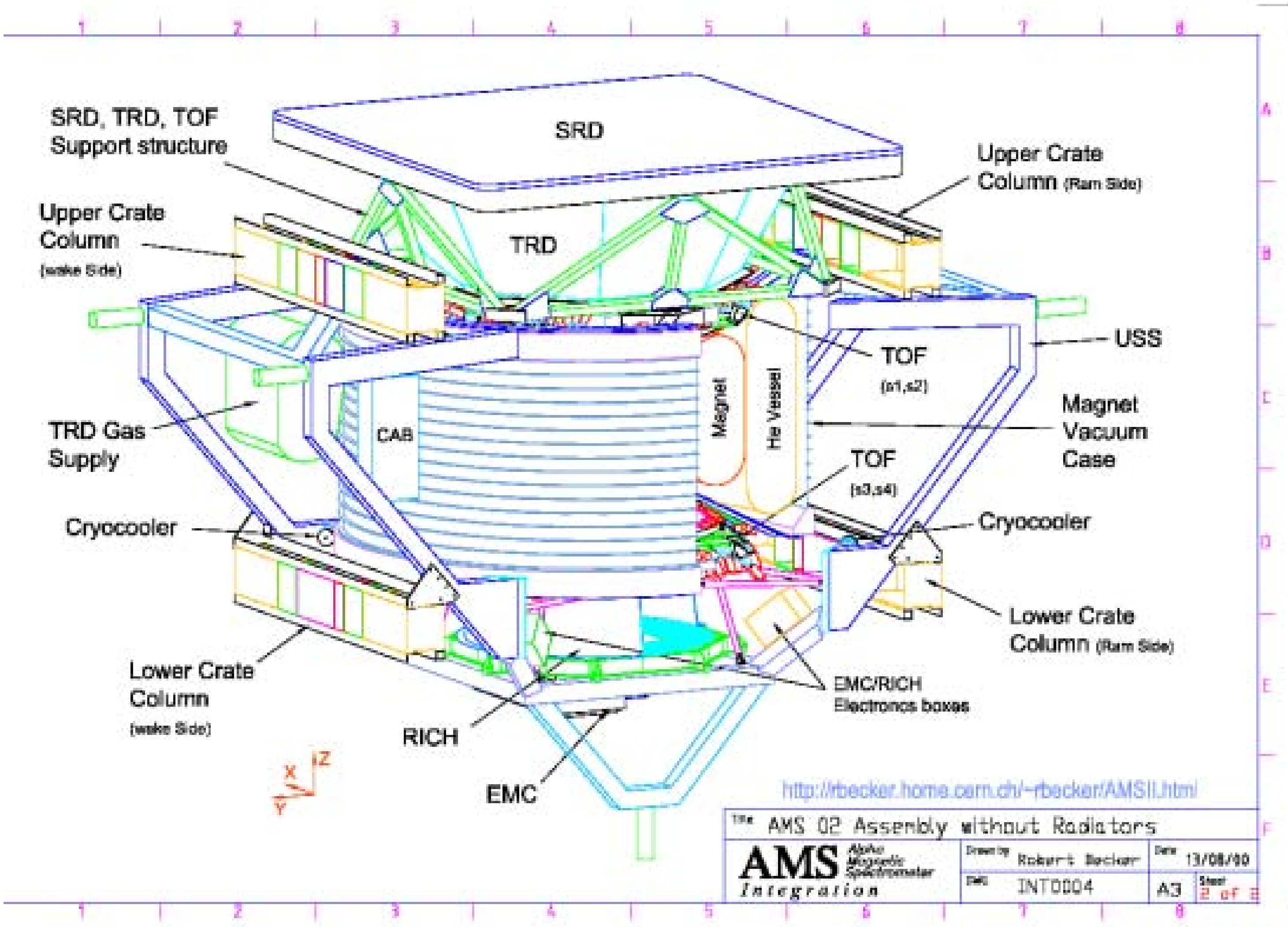


Figure 4.2 – AMS-02 with the USS-02 (Sheet 2 of 2)

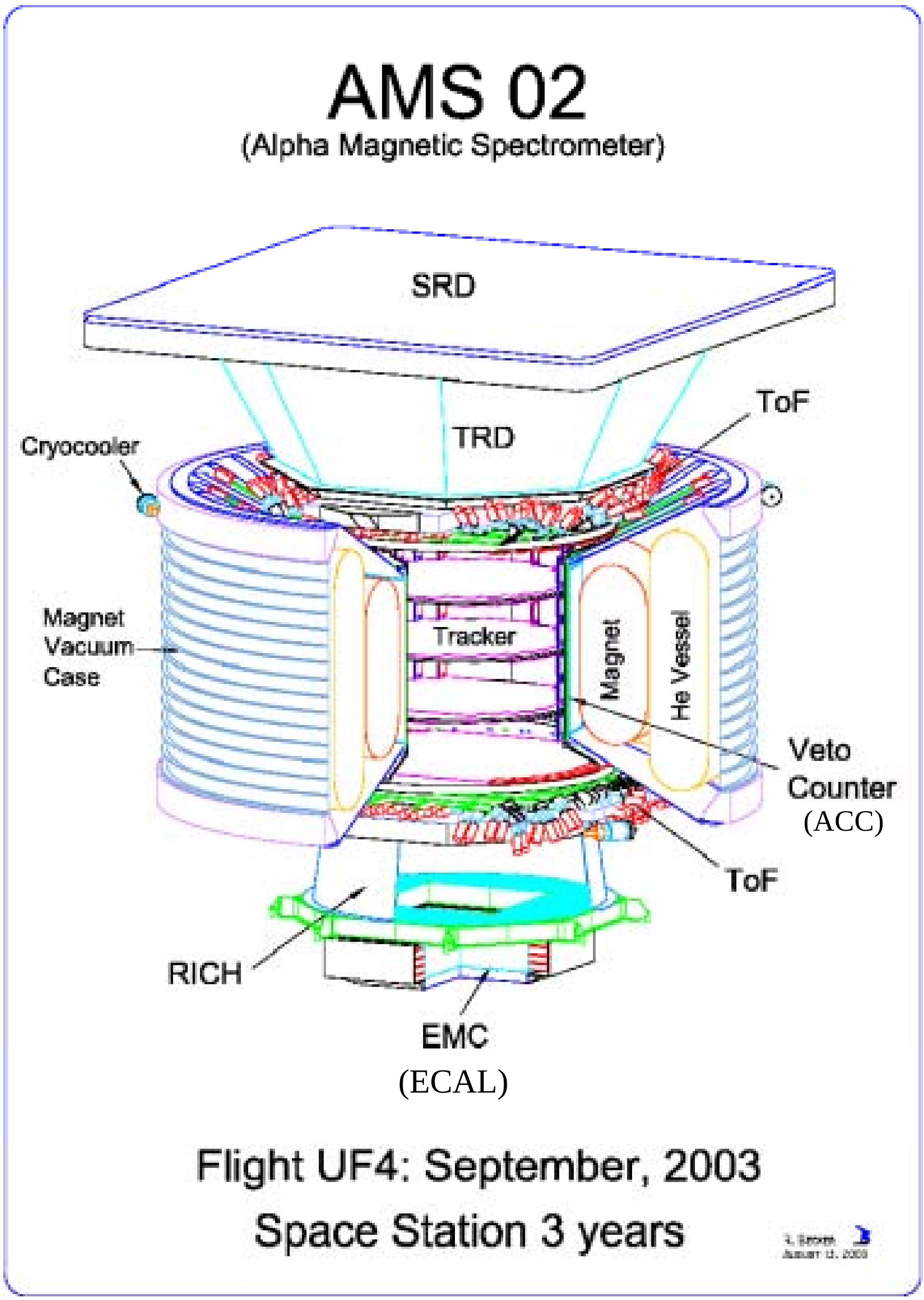


Figure 4.3 – AMS-02 without the USS-02 (Sheet 1 of 2)

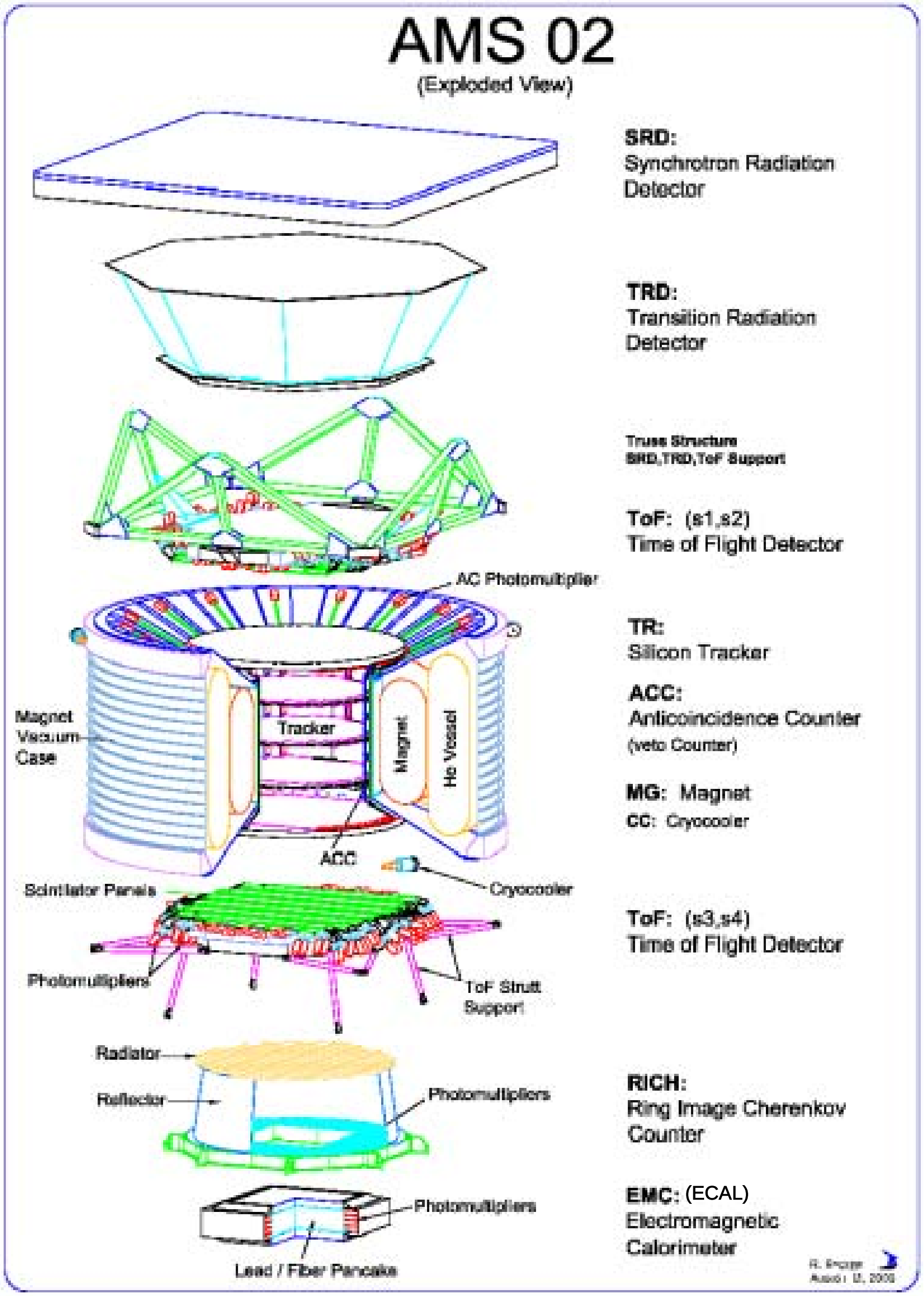


Figure 4.4 – AMS-02 without the USS-02 (Sheet 2 of 2)

(SRD), Transition Radiation Detector (TRD), Time-Of-Flight (TOF) Scintillator Assemblies, Ring Imaging Cherenkov Counter (RICH), Electromagnetic Calorimeter (ECAL or EMC), data and interface electronics, electrical cables, two Monitoring and Control Computers (MCCs), Power Distribution Box, AMS Crew Operations Post (ACOP), Thermal Control System (TCS), Meteoroid and Orbital Debris (M/OD) shields and passive Payload Attach System (PAS).

The AMS-02 experiment is a state-of-the-art high energy particle physics detector. The science objectives of the AMS-02 experiment 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).

The AMS-02 Experiment will utilize a Cryomag with planes of detectors on top, inside and below the magnet. Electrically charged particles which pass through the magnetic field will curve. Cosmic rays made of matter will curve one way, and those of antimatter will curve the opposite way. Electrons will be released as the charged particles pass through the detectors. The positions of the electrons will be electronically recorded. 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.

The Space Shuttle flight of AMS-01 was a precursor flight of some of the detectors with a permanent magnet in place of a Cryomagnet. The purpose of the precursor flight was to verify operation of the AMS experiment, verify command/data communications, collect thermal data for the ISS flight, determine actual accelerations on some AMS internal instruments and establish experimental background data. The Space Shuttle flight of AMS-02 (See Figure 4.5) is a mission to install the AMS-02 on the external truss of the International Space Station (ISS) (See Figures 4.6 & 4.7), where it is scheduled to remain for at least three operational years of data collection.

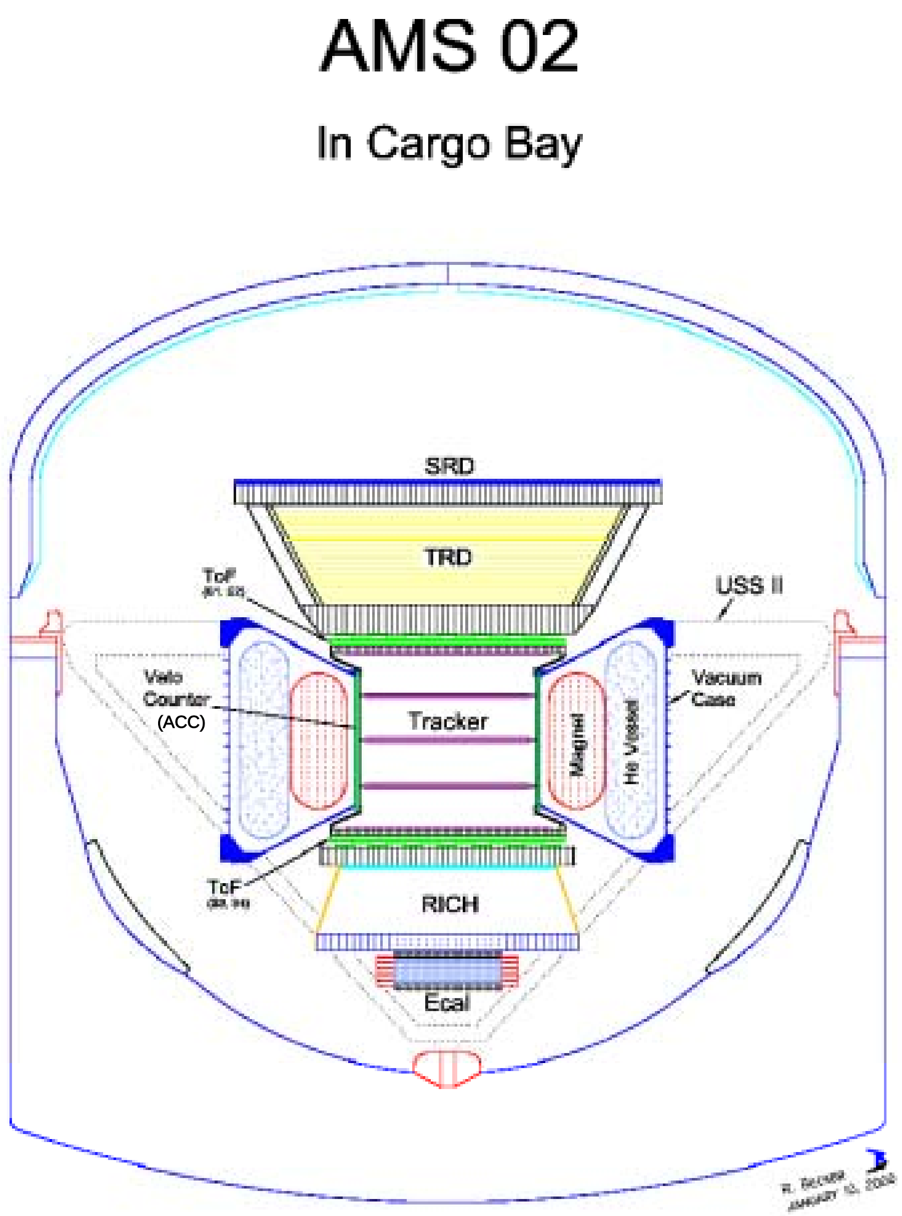


Figure 4.5 – AMS-02 in the Space Shuttle Orbiter Cargo Bay

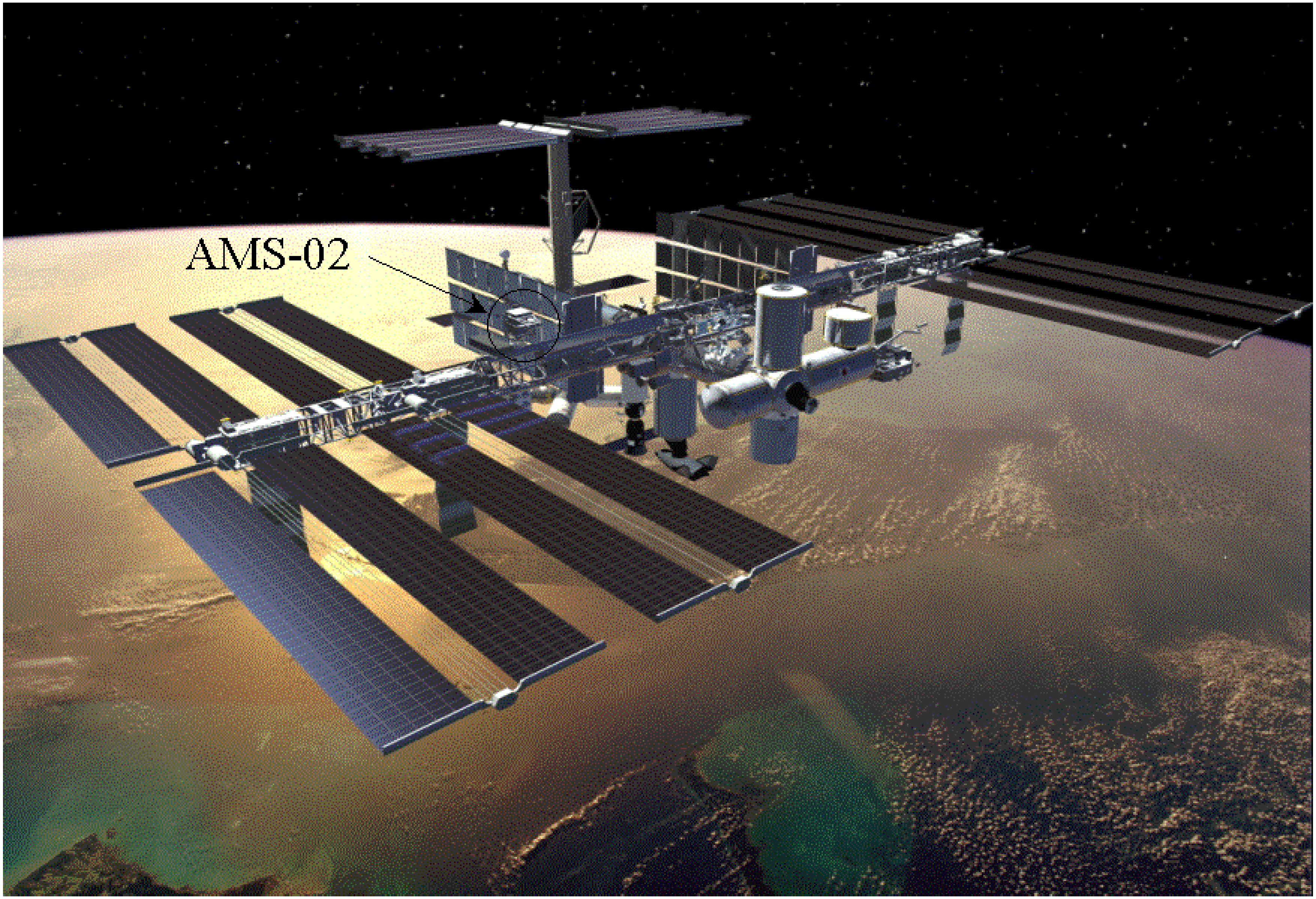


Figure 4.6 – AMS-02 on the ISS

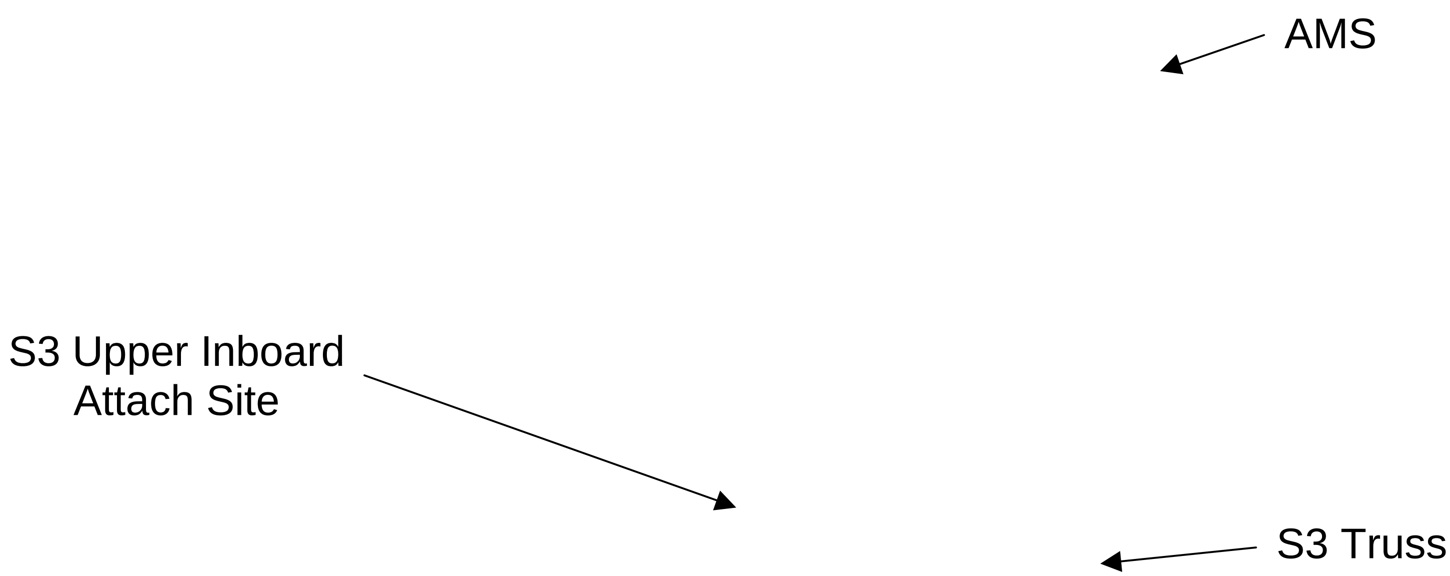


Figure 4.7 – AMS-02 Payload Assembly on ISS S3 – Z Inboard PAS Site

5.0 AMS-02 FLIGHT HARDWARE DESCRIPTION

5.1 CRYOGENIC SUPERCONDUCTING MAGNET (CRYOMAG)

5.1.1 Cryomag Description

Most of the Cryomag and any Cryomag related special test equipment (STE) will be developed and manufactured by Eidgenossische Technische Hochschule (ETH) in Zurich through a sub-contract with Space Cryomagnetics Limited (SCL) in England. All of the design and analysis technical support is provided by ETH. The system will consist of a large superconducting magnet and a large Superfluid Helium (SFHe) dewar. ETH will also provide any Ground Handling Equipment (GHE) and any Ground Support Equipment (GSE) for cryogenic systems (cryosystems) filling, servicing, monitoring, or control. This ETH provided hardware will be used in England, Zurich, JSC, and KSC. The total magnet system including the Vacuum Case is currently estimated to weigh ~6579 lbs (2984 Kg).

The cryocoolers for the Cryomagnet will be built by Sunpower (Ohio) and will be certified for flight by the Cryo systems group at Goddard Space Flight Center (GSFC). There is no fluid path connecting the cryocoolers to the magnet cryosystem. All cooling is accomplished through conduction.

LMSO will provide analysis and design for the Cryomag Vacuum Case hardware. The Vacuum Case (VC) (See Figures 5.1.1.1 thru 5.1.1.4) (weight currently estimated at 1508 lbs (684 Kg).) serves a dual purpose. It is a primary structural support and works in conjunction with the USS-02. In addition, it serves as a vacuum vessel for the cryosystem and magnet, which is suspended inside the VC by sixteen support straps. The toroidal VC will be made of aluminum 2219 and 7050. The main structural components of the VC are: upper conical flange, lower conical flange, upper support ring, lower support ring, inner cylinder and outer cylinder. On the VC inner joints, the upper and lower flanges will be butt welded to the inner cylinder (See Figure 5.1.1.5). On the VC outer joints, the upper and lower flanges will be attached to the outer cylinder with 192 fasteners at each interface. Double O-rings will be used at each outer joint interface (See Figure 5.1.1.6). The O-ring material is Viton. The O-rings are cord stock that has been joined at seams using the Parker hot vulcanizing process. There will be test ports between the O-rings to test them. There will be 41 ports in the vacuum case. Sixteen ports will be for the cryosystem support straps and 25 ports will be for plumbing lines, burst disks, electrical connections, etc. (See Figures 5.1.1.7 thru 5.1.1.9). Double O-rings will be used at each of the ports. The VC will also have 3 burst disks in series for emergency venting. The Vacuum Case has a positive pressure rating of +0.8 atm and a negative pressure rating of -1.0 atm. The Vacuum Case burst disks have a positive pressure rating of +0.8 atm and a negative pressure rating of -1.5 atm. The lower design temperature limit of the Vacuum Case is -58 degrees F. The upper design temperature limit of the Vacuum Case is 122 degrees F. Since the VC is considered to be an integral primary structure with the USS-02 for all structural design, analyses, testing, and safety assessments, a Structural Test Article (STA) of the vacuum case will be developed and used during much of the AMS-02 testing. The flight unit and STA unit will be identical.

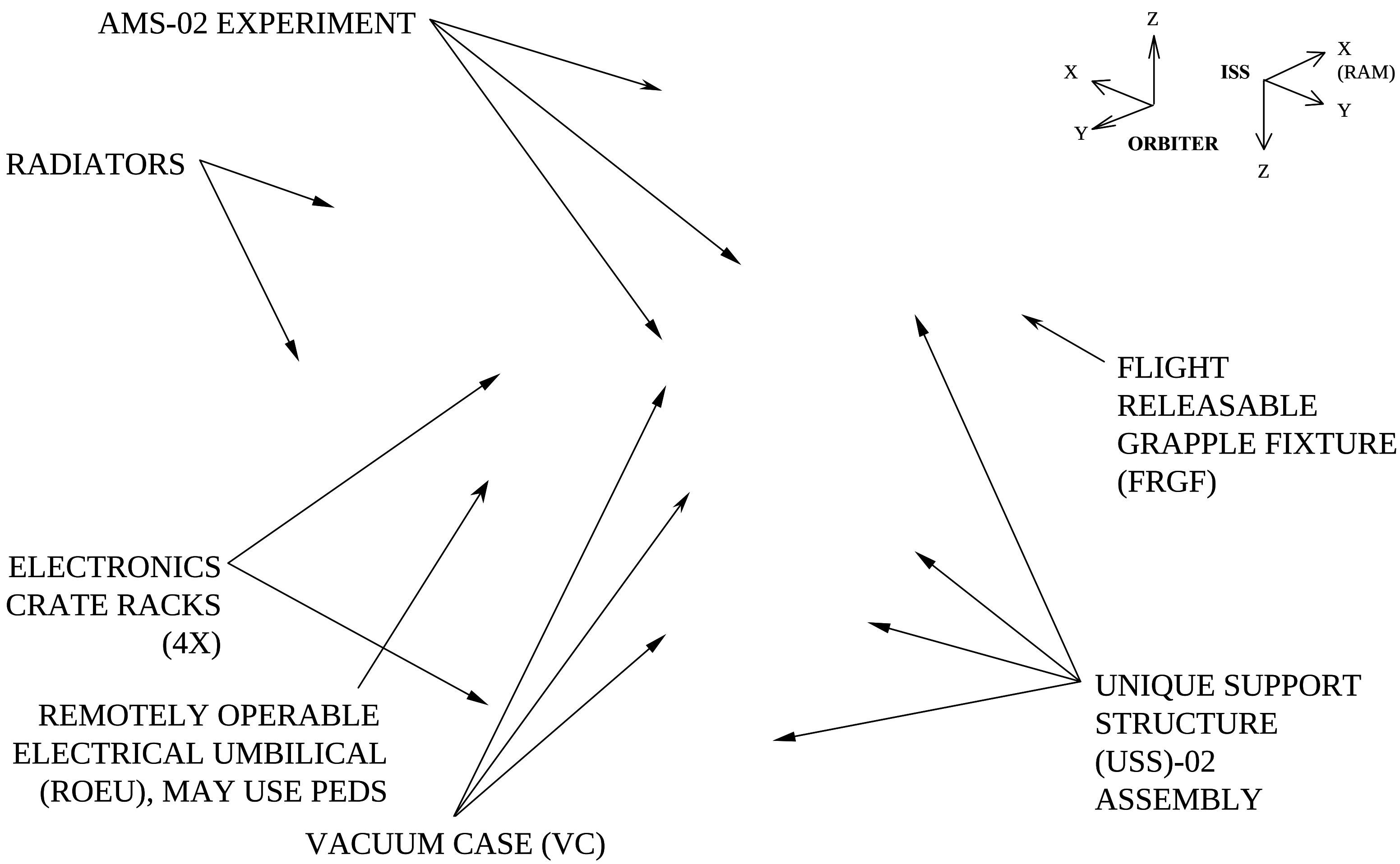


Figure 5.1.1.1 – Vacuum Case as a part of AMS-02 Payload

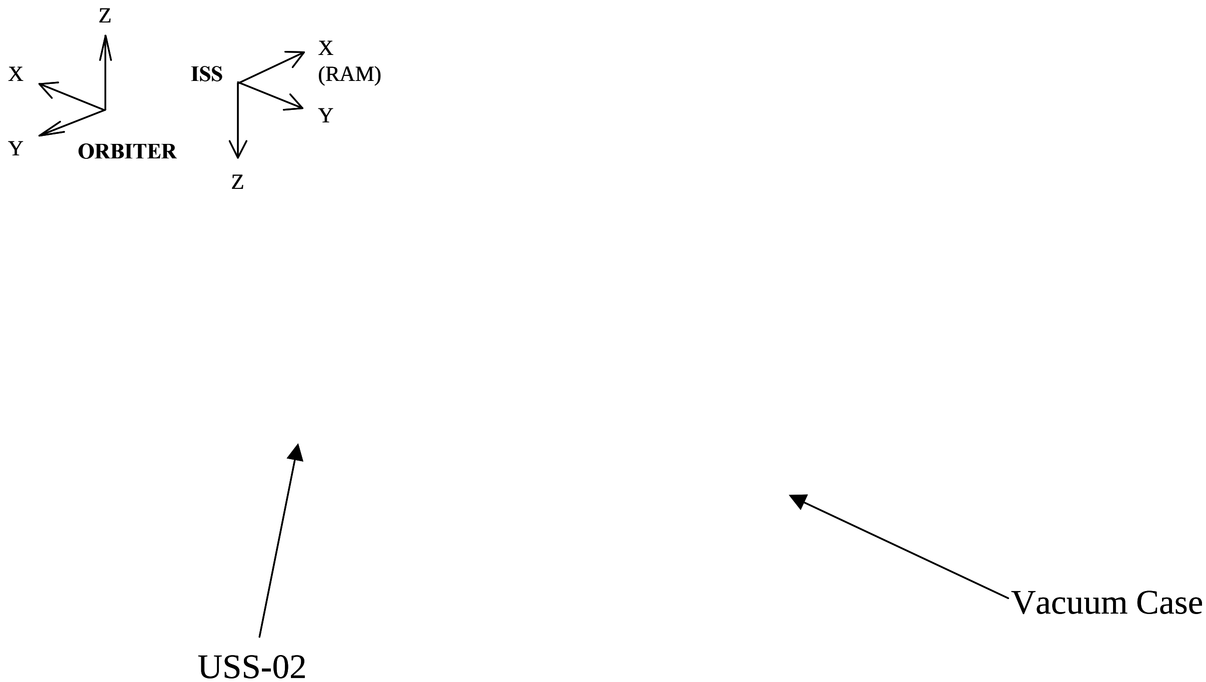


Figure 5.1.1.2 – Vacuum Case and USS-02

Figure 5.1.1.3 – Vacuum Case Assembly

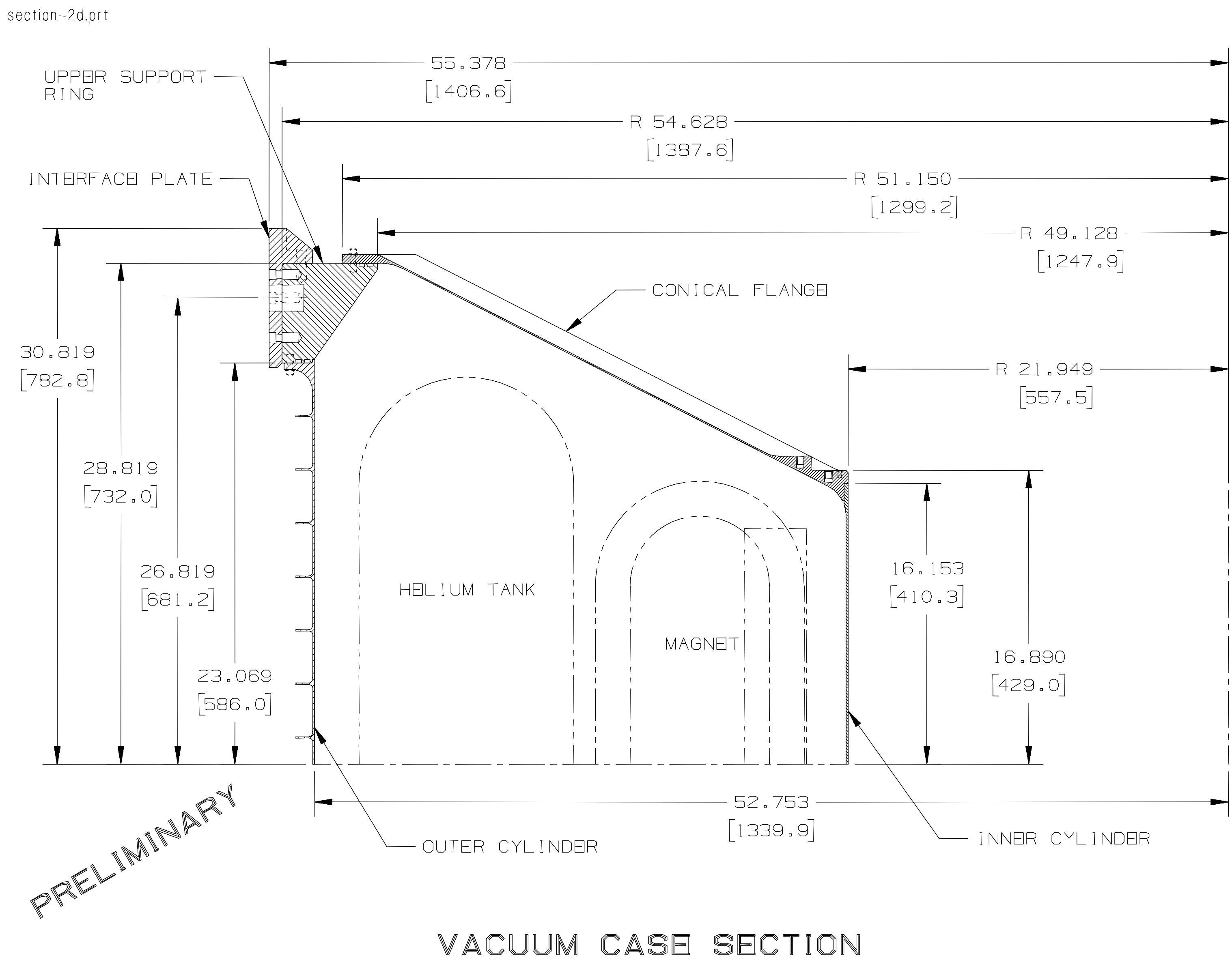


Figure 5.1.1.4 – Vacuum Case Section

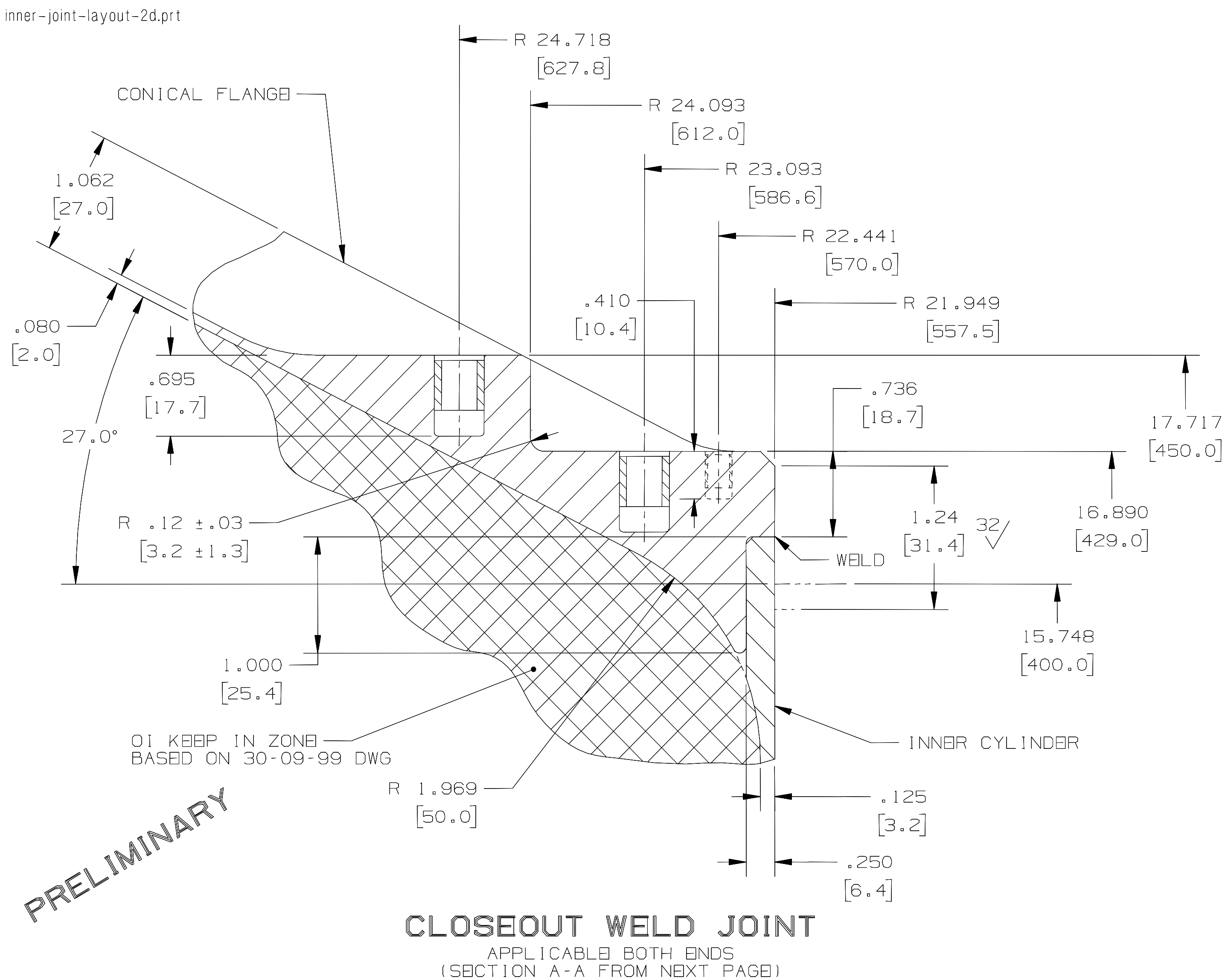


Figure 5.1.1.5 – Close-out Weld Joint

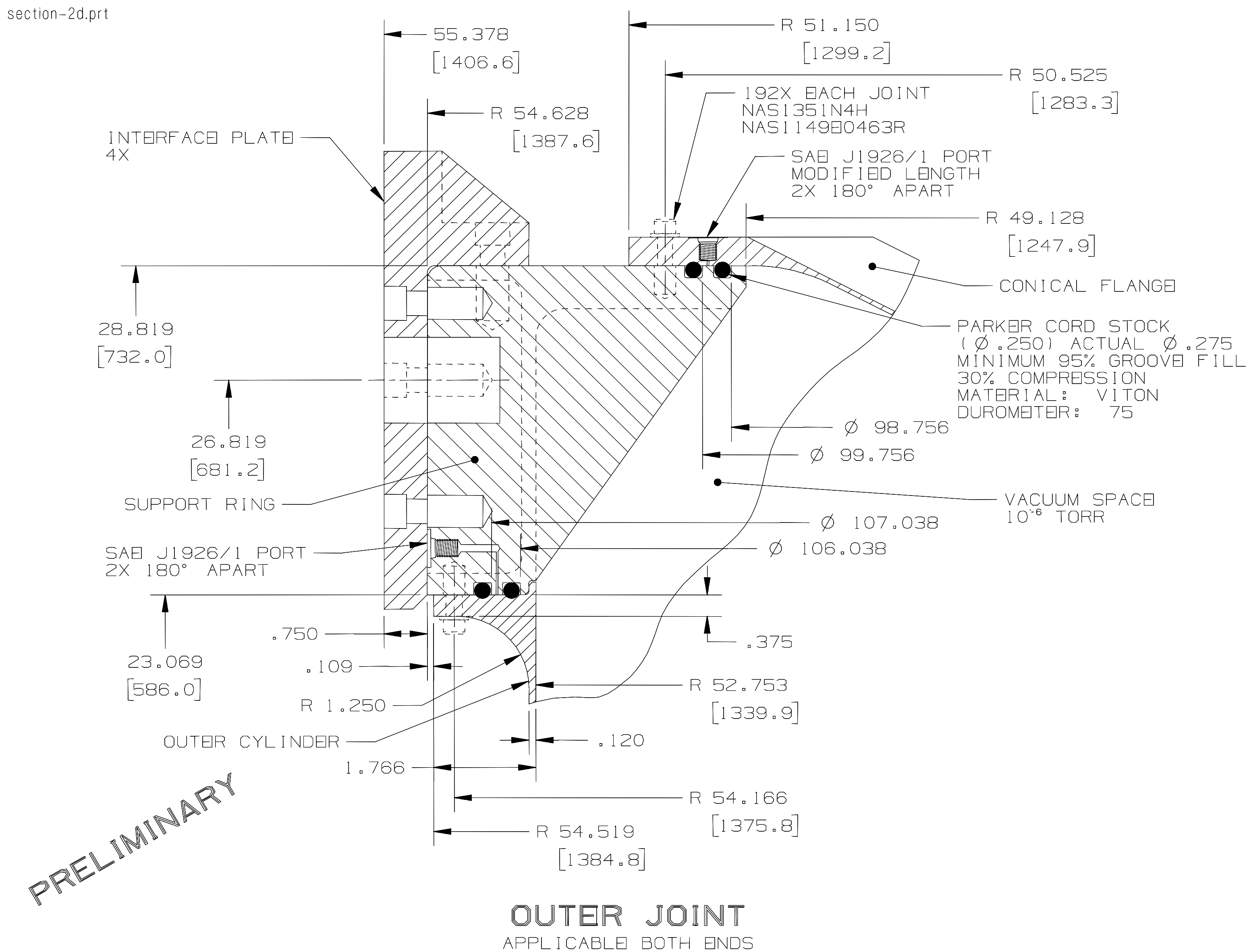


Figure 5.1.1.6 – Outer Joint

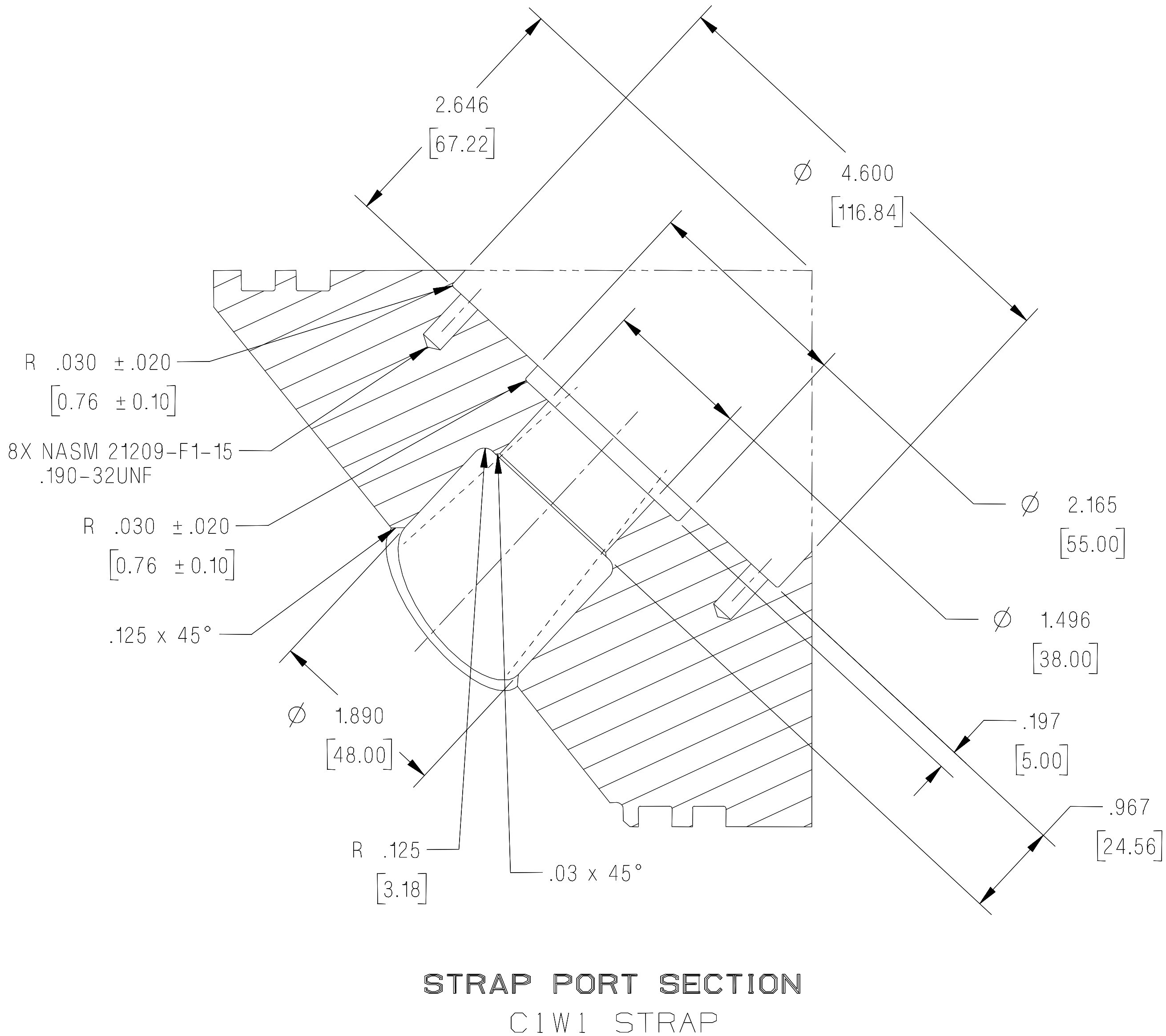


Figure 5.1.1.7 – Strap Port Section

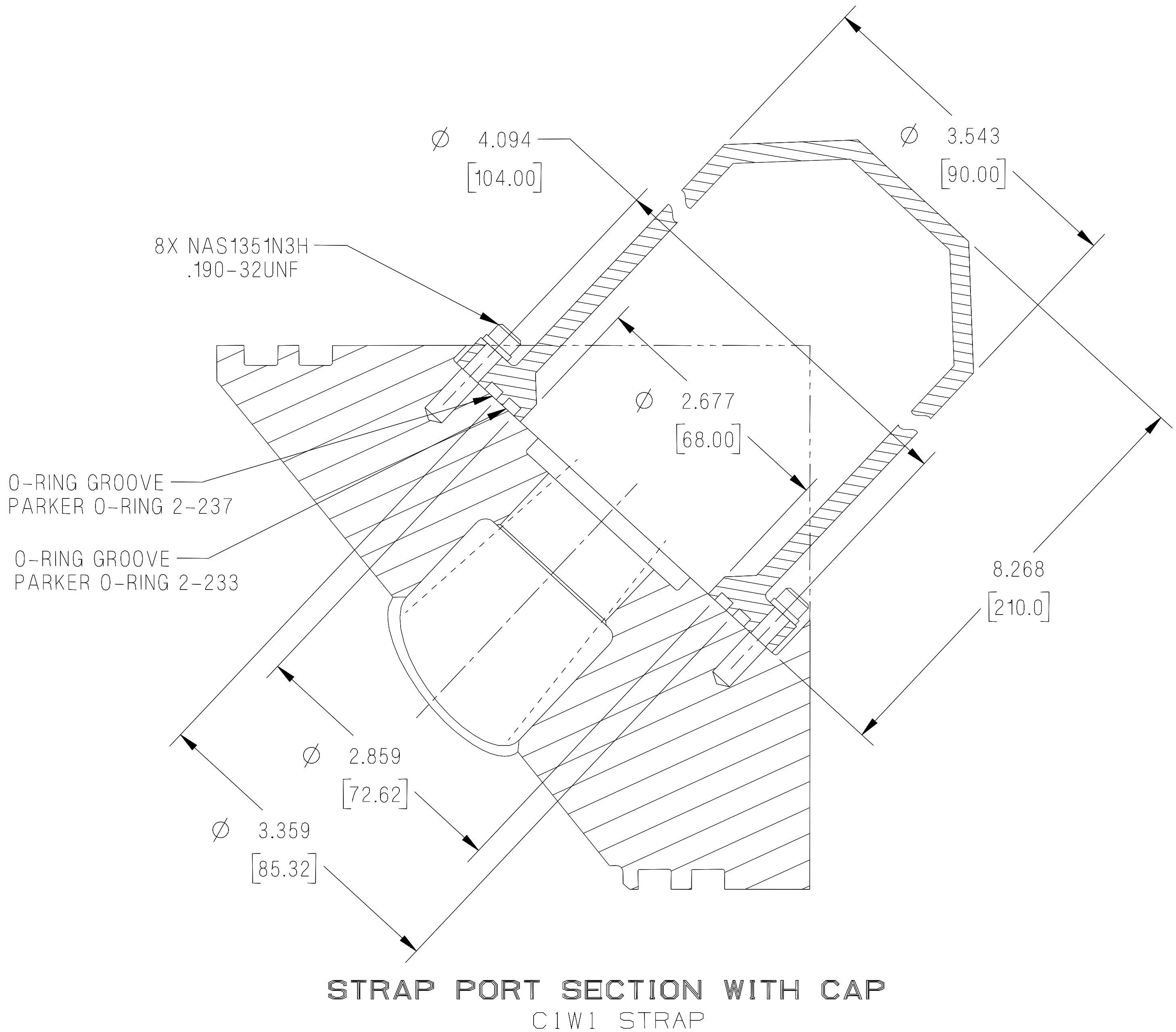


Figure 5.1.1.8 – Strap Port Section With Cap

Figure 5.1.1.9 – 4 inch Port Design

The cryogenic insulation system is composed of 200 layers of Multilayer Insulation (MLI) and 4 Vapor Cooled Shields (VCSs). The VCSs will be thin, nearly pure aluminum layers. Two of these layers are supported from two thin aluminum core epoxy glass skin honeycomb structures.

The cryogenic system also includes valves both internal and external to the VC. All of the valves that are inside the VC are helium pressure operated and are of a design that is similar to one that was flown on the Cryogenic Infrared Spectrometer Telescope for Atmosphere Shuttle Pallet Satellite (CRISTA SPAS) mission. All of the valves that are outside of the VC will be electrically activated, but the details for both of these valve systems are TBD. The overall cryogenic schematic is show in Figure 5.1.1.10.

The cryogenic and magnet servicing and operations are described in Sections 2.5.1.2 & 2 5.1.3. In order to operate the pneumatic valves, a tank of warm helium must be mounted outside of the VC to the USS-02. It will most likely be mounted next to the TRD Gas Supply box. The current proposal is to use a tank that is developed by Arde, Inc. This is the same company that is delivering tanks for the TRD Gas Supply system and has made numerous tanks for other payloads and components of the ISS, STS, and other space vehicles including the X-33. Stainless steel plumbing lines will come out of the warm helium tank and feed two different solenoid control boxes which will be mounted on opposite sides of the VC rings. The solenoid control boxes will be small aluminum boxes that are used to house the various solenoids that will be used to control the gas flow to the pneumatic valves. There will be a small control box for the electrical valves. This box will most likely be located on or inside the Cryomagnet Avionics Box (CAB), which is mounted to the USS-02. The CAB is an aluminum box that is used to house all of the Cryomagnet avionics.

The superfluid helium tank (~2500 liters) will be designed by ETH through a subcontract. The tank will be manufactured and assembled in Switzerland and England. The toroidal tank design is composed of a central support ring, a rib stiffened inner and outer cylinder, two dome covers, and 16 strap feed-thru tubes (See Figures 5.1.1.11 & 5.1.1.12). The tank will also have 3 burst disks in series, which will vent outside the VC, for emergency helium venting. The tank is made of aluminum 5083-T0 and 5083-H321 and has all welded interfaces. The system is built up in two complete halves (top and bottom) that are welded to the center support ring (washer shaped). This allows for complete radiographic inspection prior to the last closeout welds. The inner cylinder has a radius of ~37.8 inches (961 mm), and the outer cylinder has a radius of ~50.8 inches (1290 mm). The height of the helium tank is ~46.4 inches (1180 mm). The Superfluid Helium (SFHe) tank has a positive pressure rating of +3.0 bar and a negative pressure rating of -1.0 atm. The SFHe tank burst disks have a positive pressure rating of +3.0 bar and a negative pressure rating of TBD. The lower design temperature limit of the SFHe tank is 1 Kelvin. The upper design temperature limit of the SFHe tank is TBD.

The superfluid helium tank attaches directly to the magnet support structure at eight locations around the center support ring. The arrangement allows for differential thermal expansion of the tank relative to the magnet. The tank operating temperature is 1.8 Kelvin. The magnet will be at a very similar temperature, but could be slightly higher.

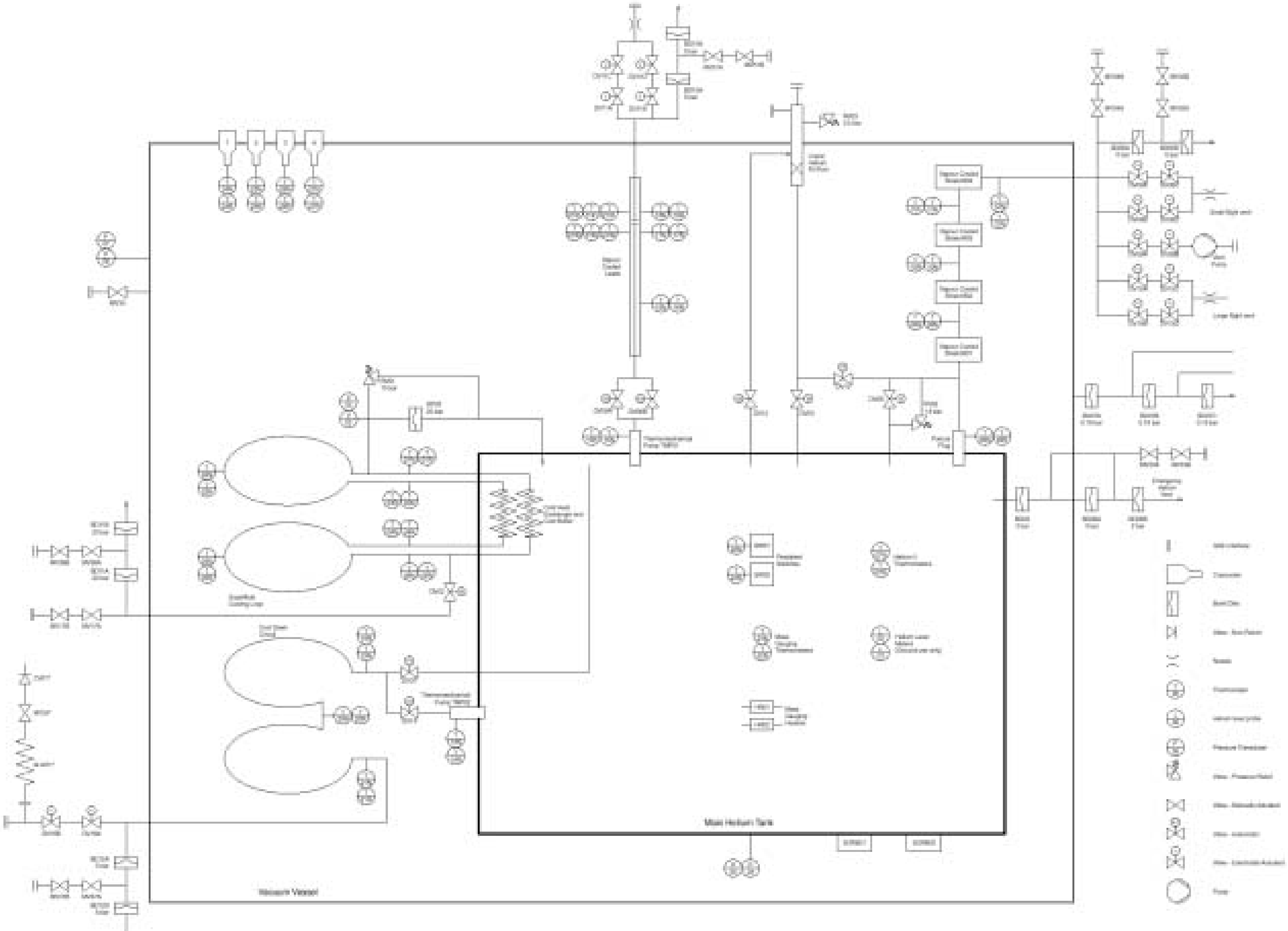


Figure 5.1.1.10 – Cryogenic Process and Instrumentation (P&I) Diagram

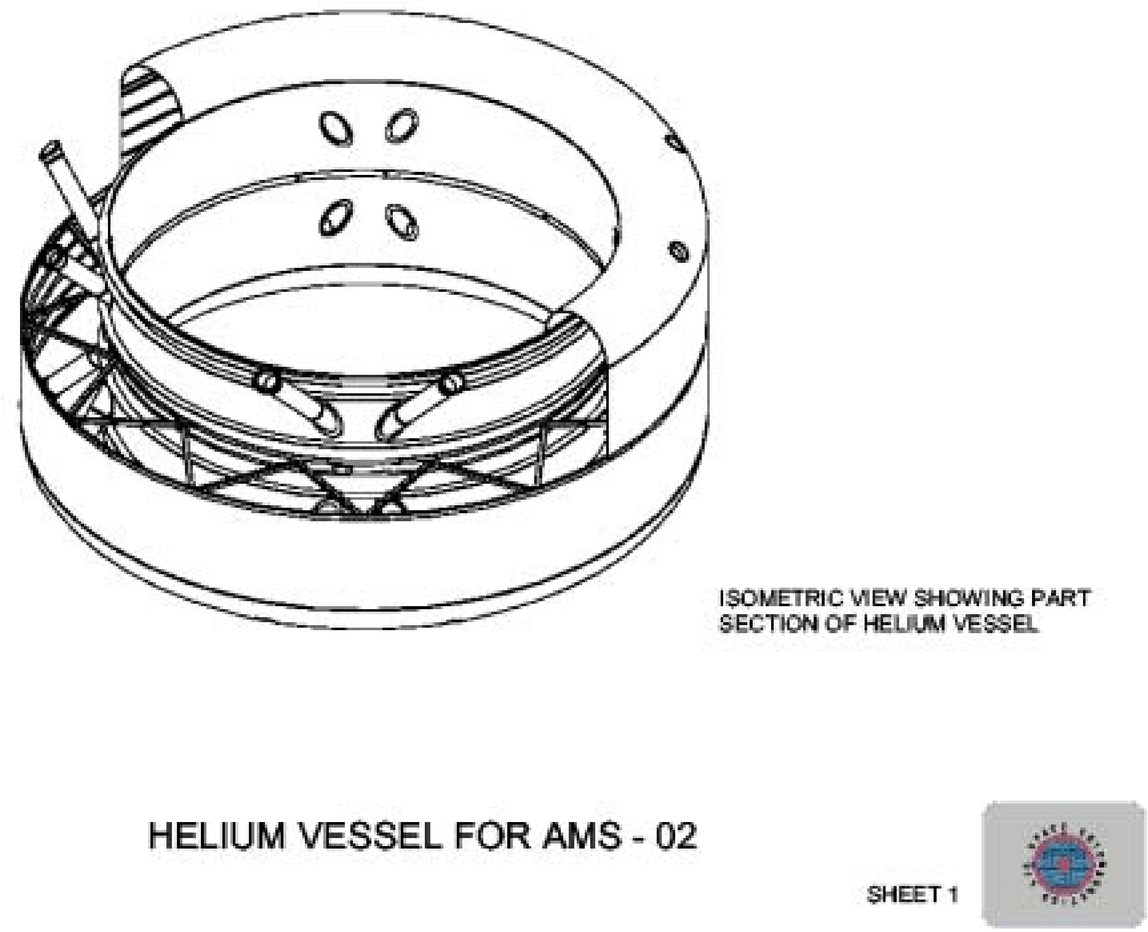


Figure 5.1.1.11 – Superfluid Helium Vessel for AMS-02 (Sheet 1 of 2)

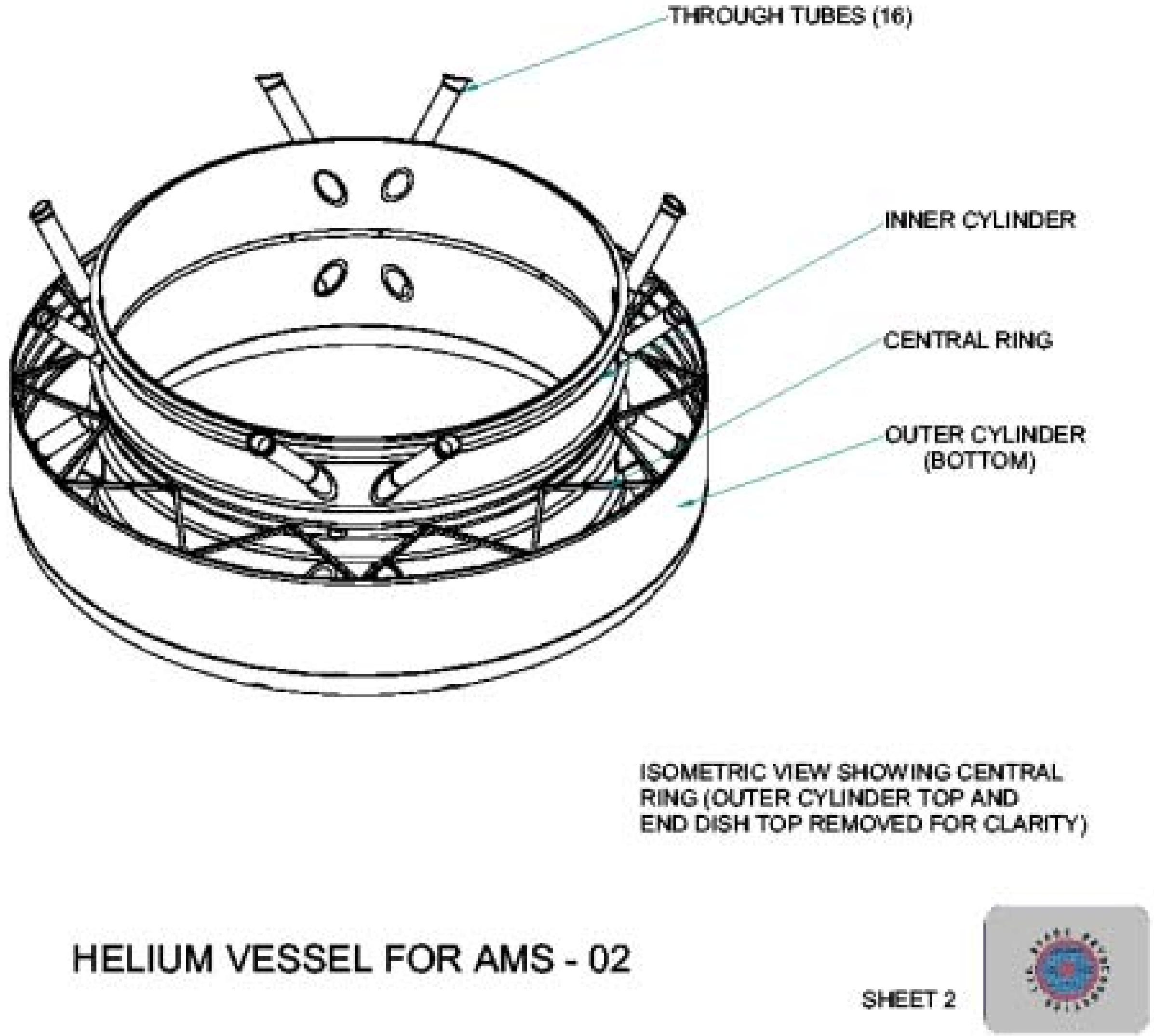


Figure 5.1.1.12 – Superfluid Helium Vessel for AMS-02 (Sheet 2 of 2)

The magnet itself is composed of 12 racetrack coils and two dipole coils (See Figure 5.1.1.13). The coils are supported by aluminum 6061-T6 islands. The niobium/titanium, copper stabilized conductor is co-extruded with an aluminum stabilizer and the resulting conductor is wrapped with insulation and then wrapped around the aluminum islands. The islands of the 12 racetrack coils are bolted, pinned, and preloaded with four (for each quarter section) stainless steel ties to make 2 quarters of the magnet. The remaining 2 quarters are the dipole coils, which have a similar design, but are much larger. The support structure of these sections is called the racetrack endframe. At the 4 corners of the magnet, and at the ends of the racetrack endframe is where the magnet support straps attach. This is also the location where the superfluid helium tank attaches to the magnet, in the z-axis.

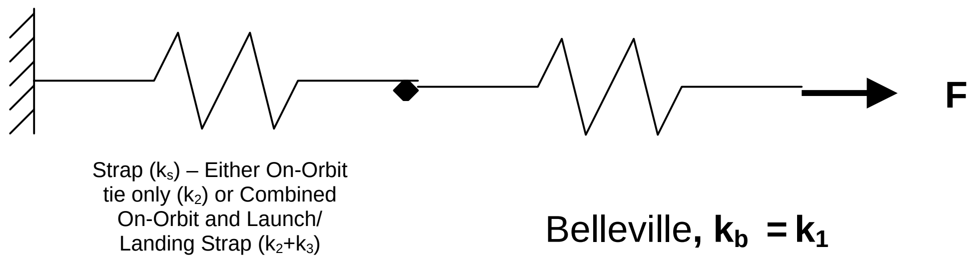
The magnet support system key design driver is to allow a minimal heat leak into the magnet. The strap system is designed to minimize the heat load, absorb the thermal contraction, fit within the very tight geometric constraints, require very little pre-load so as to avoid long duration loading concerns, and maintain tension during all loading phases. The non-linear straps operation is shown in Figures 5.1.1.14 thru 5.1.1.17. (Note: Drawings of the straps are available by request.) The system is called the Tension Only Passive Orbital Disconnect System (TOPODS). The system is composed of three different composite strap systems that create a non-linear strap system. The system is defined by three distinct stiffness regions. The stiffness characteristics allow the strap system to carry more load during launch and landing than they will under unloaded cases. In the warm condition, both ends of the strap system are at room temperature. Under this condition, the launch/landing portion of the strap is engaged and the strap will carry more load. In the cold condition with the system in the unloaded configuration (i.e., No launch/landing loads, but does have nominal preload), one end at room temperature (~300 Kelvin) on the vacuum case, the other end at 1.8 Kelvin, the launch/landing strap is disengaged. As the launch/landing loads are applied, the launch/landing strap becomes engaged and carries more load. The straps are attached to the Vacuum Case at the upper and lower support rings. They go through the strap feed-thru tubes in the superfluid helium tank and then attach to the magnet. The pin ended straps never touch the strap feed-thru tubes on the superfluid helium tank. A minimum distance of 0.25 inches has been maintained by analysis with a safety factor of 1.4 included.

The strap design is based on the following:

Assumptions:

- The composite strap (either the on-orbit tie or a combination of the on-orbit tie and the launch/landing tie) is attached to the Belleville washer forming the equivalent of two linear springs in series.
- The stiffness of the composite strap is significantly larger than the stiffness of the Belleville washer
- Belleville washer stiffness = k_1
- On-Orbit strap stiffness = k_2
- Launch/Landing strap stiffness = k_3

(1) When load is initially applied to the combined system, both the strap and the Belleville will have a deflection due to the applied load.



$\boldsymbol{\delta_s = F/k_s}$ $\boldsymbol{\delta_b = F/k_b}$

The combined stiffness for two springs in series is equal to the applied load divided by the sum of the total deflection:

$$k_c = \frac{F}{\frac{F}{k_b} + \frac{F}{k_s}} = \frac{F}{\frac{Fk_b + Fk_s}{k_b k_s}} = \frac{k_b k_s}{k_b + k_s}$$

Since $k_s >> k_b$, k_c is approximately equal to k_b i.e. the equivalent stiffness of the combined system is approximately the stiffness of the Belleville.

(2) When sufficient load is applied to cause the Belleville to bottom out, the stiffness of the Belleville effectively becomes much greater than the stiffness of the strap. (The Belleville is now a flat disk in compression.)

The combined stiffness for the system with $\mathbf{k_b >> k_s}$ is given by the same equation as previously shown above.

$$k_c = \frac{k_b k_s}{k_b + k_s}$$

However, now the resulting stiffness from this equation is k_c is approximately equal to k_s i.e. the combined system stiffness is approximately the stiffness of the strap alone.

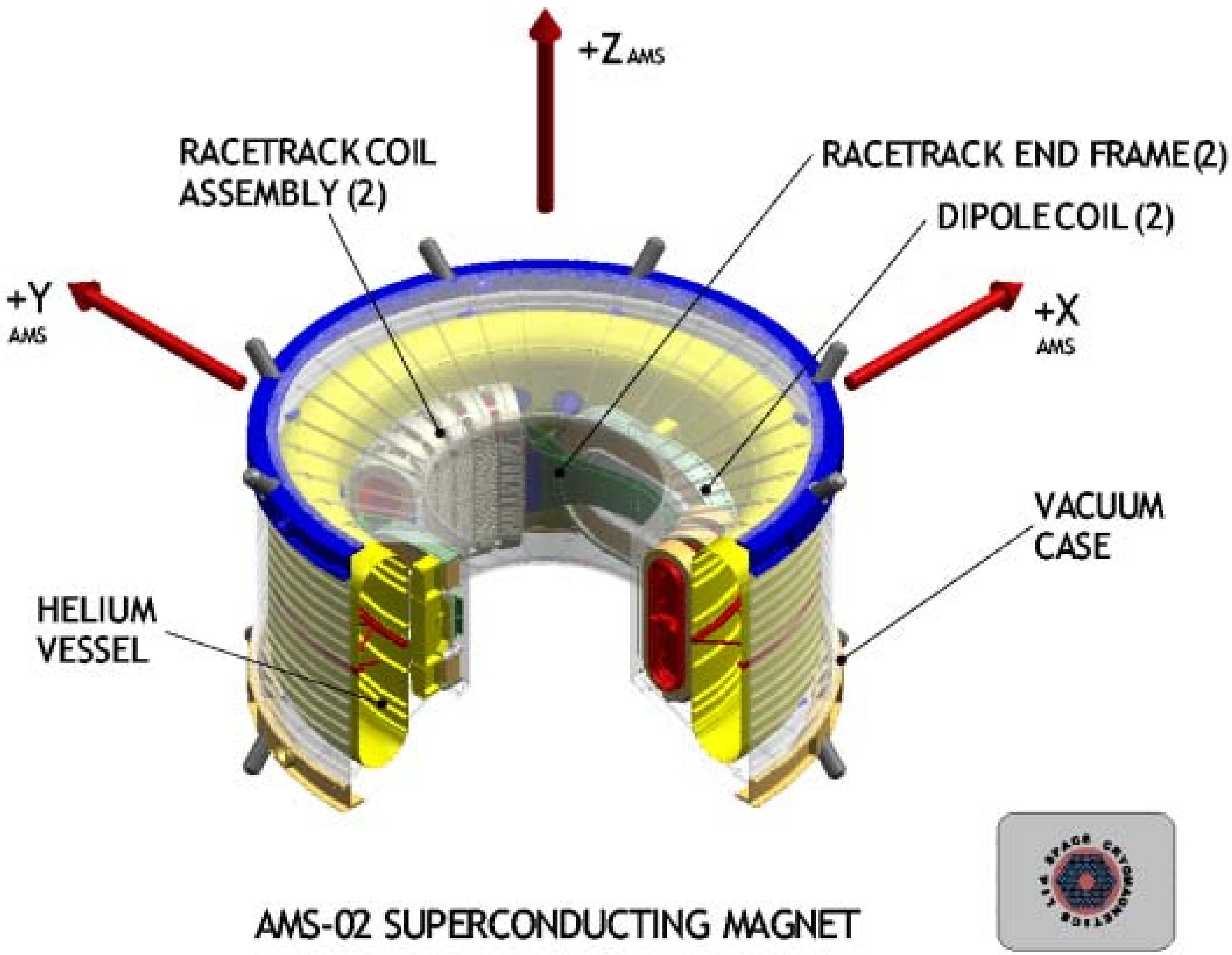


Figure 5.1.1.13 – AMS-02 Superconducting Magnet Layout

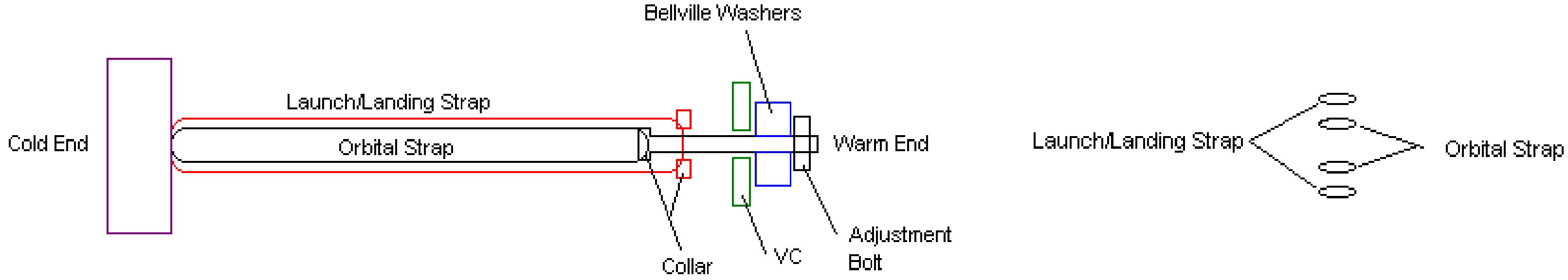


Figure 5.1.1.14 – Cryosystem Support Strap Diagram

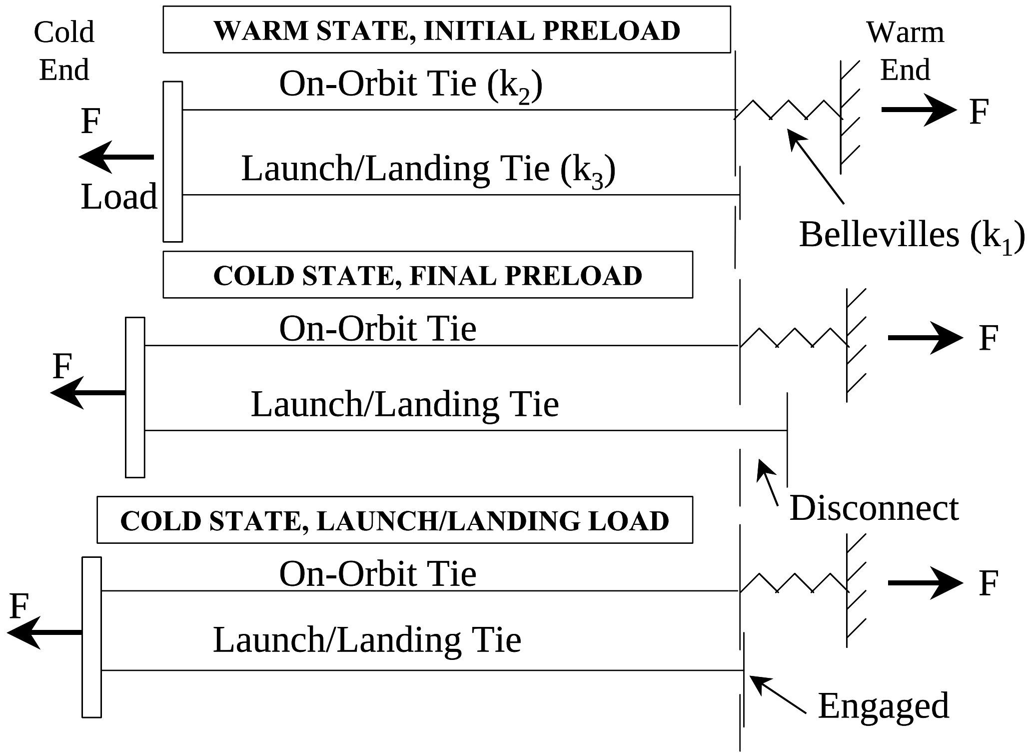


Figure 5.1.1.15 – Cryosystem Support Strap Configuration and Functional Diagram

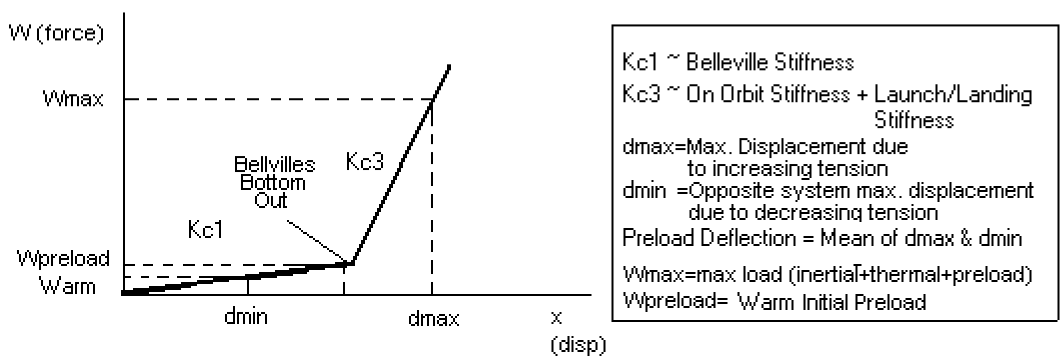


Figure 5.1.1.16 – Cryosystem Support Strap Warm State

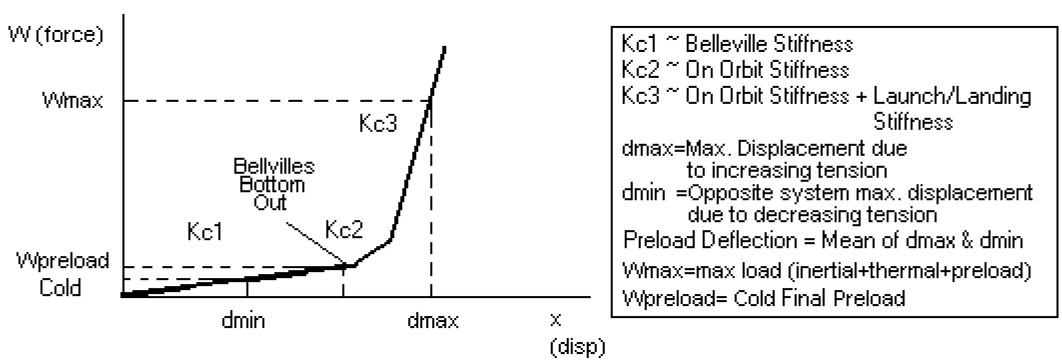


Figure 5.1.1.17 – Cryosystem Support Strap Cold State

5.1.2 <u>SFHe Servicing at KSC</u>

There have been numerous space flight experiments that have utilized cryogenic dewars. Some of these experiments are listed in the following table.

Table 5.1.2.1 - Space Flight Cryogenic Projects

Project	Dewar Type	Operating Temperature	Volume	Launch Vehicle
Infrared Astronomical Satellite (IRAS)	Superfluid Helium	1.8 K	540 L	ELV
Space Infrared Telescope Facility (SIRTF)*	Superfluid Helium	1.8 K	360 L	ELV
Gravity Probe B (GP-B)*	Superfluid Helium	1.8 K	2300 L	ELV
Superfluid Helium On-Orbit Transfer (SHOOT) Experiment	Normal Helium / Superfluid Helium	4.2 K / 1.8 K	400 L	Shuttle
Infrared Space Observatory (ISO)	Superfluid Helium	1.8 K	2400 L	ELV
Cosmic Background Explorer (COBE)	Superfluid Helium	1.8 K	660 L	ELV

* Has not been launched.

There have been numerous reports written to help describe the lessons learned during the ground operations and ground processing phases of these experiments. AMS-02 intends to heed these lessons learned and incorporate the best practices that have been developed over the past several years. Based on the knowledge that has been gained by NASA and other organizations during the development of these projects, the following safety precautions will serve as the primary drivers for all safety related operations.

1. Since air-ice blockage is a constant threat, the system must be properly leak checked before and after all ground operations that require penetration of a vacuum or helium space. The system operating characteristics will be tracked to observe degradation of performance. This will include constant redundant temperature and pressure monitors.
2. Complete procedures will be developed for all cryogenic operations that will be performed at KSC/JSC. These procedures will be developed, checked, and verified by Space Cryomagnetics Limited. These procedures will include evacuation plans, Oxygen deprivation monitors and alarms, cryogenic system monitors and alarms, building overpressure assessments, cryogenic temperature assessments, etc. Lockheed Martin Space Operations (LMSO), in conjunction with Lockheed Martin (LM) Advanced Technology Center (ATC), will perform an independent check of all ground operations procedures. These procedures will include all contingency operations and a notification protocol in the case of

unexpected events. In the case of off-nominal events, the system will be brought into a safe operating mode, and the cryogenic team will meet to determine what further action will be necessary.

3. All personnel who operate cryogenic systems at KSC/JSC will be thoroughly trained and all procedures will be adequately rehearsed prior to arrival at KSC/JSC. Pre-test and pre-procedure briefings will be held to familiarize all operating personnel, system management, KSC/JSC personnel, safety and quality control personnel with all procedures and their associated hazards. The briefings will be held prior to arrival of the cryogenic system, and prior to each cryogenic operation that is performed at KSC/JSC.

The payload will arrive at the KSC MPPF (Multi-Payload Processing Facility) approximately 4.5 months prior to launch. Offline processing will occur for approximately 4 weeks. The payload will then be transferred to the SSPF (Space Station Processing Facility) for further off-line processing. Once the payload has been completely checked out by the AMS team, the payload will be turned over to KSC for on-line processing at the SSPF. There will be cryogenic operations during all of these stages.

5.1.3 Cryomag Operation

This section describes the operating modes and control for the cryosystem of the AMS-02 superconducting magnet. It should be understood in conjunction with Figure 5.1.1.10, "Cryogenic Process and Instrumentation (P&I) Diagram" (SCL drawing number ABC1234), Figure 5.1.3.1, "Cryosystem States Diagram" (SCL drawing number DEF5678), and Table 5.1.3.1, "Cryosystem Valve Positions in Each State". Eighteen different states have been identified for the magnet system, covering all operations on the ground, during launch and in space. Sections 5.1.3.3 through 5.1.3.11 are prelaunch ground operations.

Due to some recent venting analyses performed by the AMS-02 Project and STS Integration, the emergency venting of the helium from the SFHe tank has a direct impact on the prelaunch operations.

Although no credible scenarios could be found that would cause an emergency vent in the Orbiter Payload Bay during launch/landing, AMS-02 and Shuttle Integration have assessed the AMS-02 emergency vent rate assuming a complete loss of vacuum on the ground. Based on the conservative AMS-02 and STS Integration Helium Venting analyses that have been performed to date:

- The only time that there is an overpressure issue with the Orbiter Payload Bay is if the SFHe tank burst disks rupture between ~T+30 & ~T+60 seconds.
- There is no landing or other scenarios that can cause an overpressure of the Payload Bay.

- Launch Commit Criteria (up to T-9 minutes) will be in place to show that there is no substantial loss of vacuum from the time that the payload is installed in the Payload Bay until T-9 minutes. It has been shown that no credible failure exists that would cause a total loss of vacuum from T-9 minutes until launch given nominal performance prior to this time.
- Venting tests will confirm both the time to SFHe tank burst disk rupture and the Helium flow rate.
- Test data will be compared to analysis data to confirm these predicted results.
- The thermal issue due to helium venting is still open and in work.
- STS Integration agrees with this assessment.

NOTE: These operations are for mission success only and are NOT safety critical. All pressure and temperature sensors will be redundant to ensure accurate measurements. Both the VC and the SFHe tank pressure and temperature will be monitored.

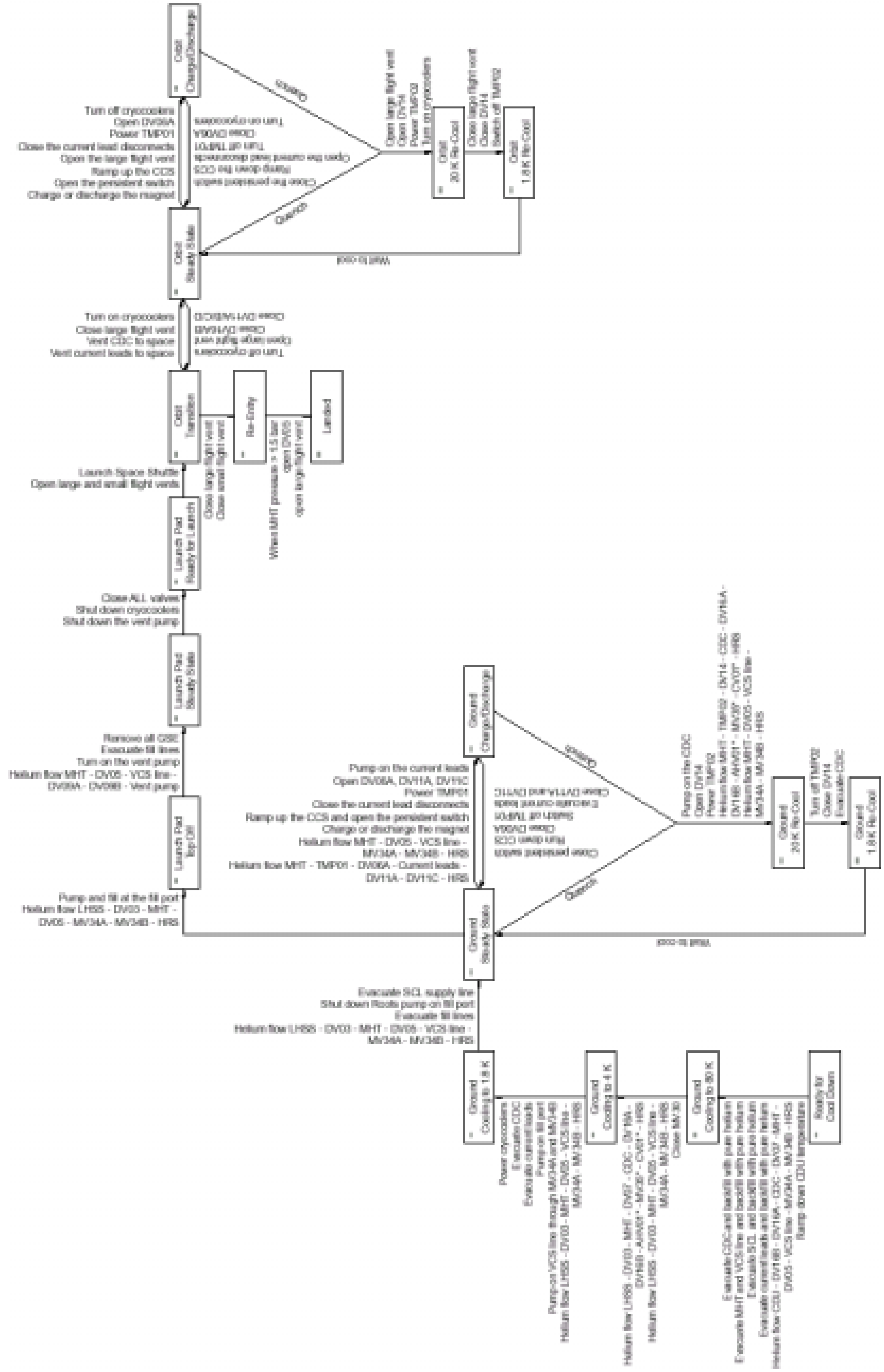


Figure 5.1.3.1 – Cryosystem States Diagram

Table 5.1.3.1 – Cryosystem Valve Positions in Each State

State 01 READY FOR COOL DOWN

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Closed
DV06A	Cryogenic	Current leads supply	Closed
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Closed
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Closed
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Closed
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Closed
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Closed
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Closed
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Closed
DV16B	Electric	CDC outlet	Closed

MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Closed
MV34B	Manual	VCS outlet for ground operations	Closed
MV35*	Manual	GSE	Closed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated
SCL	Filled with warm helium from the HVM
Current leads	Filled with warm helium from the HVM
CDC	Filled with warm helium from the HVM
Helium fill lines	Filled with warm helium from the HVM
MHT	Filled with warm helium from the HVM
VCS line	Filled with warm helium from the HVM
Cryocoolers	Off

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 02 GROUND – COOLING TO 80 K

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Open
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Open
DV06A	Cryogenic	Current leads supply	Closed
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Open
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Closed
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Closed
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Open
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Open
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Closed
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Closed
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Open
DV16B	Electric	CDC outlet	Open
MV17A	Manual	SCL outlet	Open
MV17B	Manual	SCL outlet	Open
MV30	Manual	Vacuum case	Open
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Open
MV34B	Manual	VCS outlet for ground operations	Open
MV35*	Manual	GSE	Closed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Pumping through MV30
SCL	Filled with helium from HVM
Current leads	Filled with helium from HVM
CDC	Connected to CDU and MHT
Helium fill lines	Filled with helium from HVM
MHT	Connected to CDC and VCS line
VCS line	Connected to MHT and HRS
Cryocoolers	Off

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 03 GROUND – COOLING TO 4 K

Valve	Type	Position	Status
DV02	**Cryogenic**	**SCL supply line**	**Open**
DV03	**Cryogenic**	**Liquid helium inlet**	**Open**
DV05	**Cryogenic**	**Porous plug by-pass**	**Open**
DV06A	**Cryogenic**	**Current leads supply**	**Closed**
DV06B	**Cryogenic**	**Current leads supply**	**Closed**
DV07	**Cryogenic**	**MHT to CDC**	**Open**
DV10	**Cryogenic**	**MHT by-pass**	**Closed**
DV12	**Cryogenic**	**MHT to fill port cold gas return**	**Closed**
DV14	**Cryogenic**	**MHT to CDC via TMP02**	**Closed**
DV08A	**Electric**	**Small flight vent**	**Closed**
DV08B	**Electric**	**Small flight vent**	**Closed**
DV08C	**Electric**	**Small flight vent**	**Closed**
DV08D	**Electric**	**Small flight vent**	**Closed**
DV09A	**Electric**	**Vent pump**	**Closed**
DV09B	**Electric**	**Vent pump**	**Closed**
DV11A	**Electric**	**Current leads outlet**	**Open**
DV11B	**Electric**	**Current leads outlet**	**Closed**
DV11C	**Electric**	**Current leads outlet**	**Open**
DV11D	**Electric**	**Current leads outlet**	**Closed**
DV15A	**Electric**	**Large flight vent**	**Closed**
DV15B	**Electric**	**Large flight vent**	**Closed**
DV15C	**Electric**	**Large flight vent**	**Closed**
DV15D	**Electric**	**Large flight vent**	**Closed**
DV16A	**Electric**	**CDC outlet**	**Open**
DV16B	**Electric**	**CDC outlet**	**Open**

MV17A	**Manual**	**SCL outlet**	**Open**
MV17B	**Manual**	**SCL outlet**	**Open**
MV30	**Manual**	**Vacuum case**	**Open/Closed**
MV31A	**Manual**	**BD10 interspace**	**Closed**
MV31B	**Manual**	**BD10 interspace**	**Closed**
MV32A	**Manual**	**BD05 interspace**	**Closed**
MV32B	**Manual**	**BD05 interspace**	**Closed**
MV33A	**Manual**	**BD03/BD06 interspace**	**Closed**
MV33B	**Manual**	**BD03/BD06 interspace**	**Closed**
MV34A	**Manual**	**VCS outlet for ground operations**	**Open**
MV34B	**Manual**	**VCS outlet for ground operations**	**Open**
MV35*	**Manual**	**GSE**	**Open**
MV36A	**Manual**	**BD11 interspace**	**Closed**
MV36B	**Manual**	**BD11 interspace**	**Closed**
MV37A	**Manual**	**BD12 interspace**	**Closed**
MV37B	**Manual**	**BD12 interspace**	**Closed**

Circuit	Status
Vacuum space	**Pumping through MV30 or evacuated**
SCL	**Filled with helium from HVM**
Current leads	**Filled with helium from HVM**
CDC	**Connected to HRS and MHT**
Helium fill lines	**Connected to LHSS**
MHT	**Connected to CDC and VCS line**
VCS line	**Connected to MHT and HRS**
Cryocoolers	**Off**

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 04 GROUND – COOLING TO 1.8 K

Valve	Type	Position	Status
DV02	**Cryogenic**	**SCL supply line**	**Open**
DV03	**Cryogenic**	**Liquid helium inlet**	**Open**
DV05	**Cryogenic**	**Porous plug by-pass**	**Open**
DV06A	**Cryogenic**	**Current leads supply**	**Closed**
DV06B	**Cryogenic**	**Current leads supply**	**Closed**
DV07	**Cryogenic**	**MHT to CDC**	**Closed**
DV10	**Cryogenic**	**MHT by-pass**	**Closed**
DV12	**Cryogenic**	**MHT to fill port cold gas return**	**Open**
DV14	**Cryogenic**	**MHT to CDC via TMP02**	**Closed**
DV08A	**Electric**	**Small flight vent**	**Closed**
DV08B	**Electric**	**Small flight vent**	**Closed**
DV08C	**Electric**	**Small flight vent**	**Closed**
DV08D	**Electric**	**Small flight vent**	**Closed**
DV09A	**Electric**	**Vent pump**	**Closed**
DV09B	**Electric**	**Vent pump**	**Closed**
DV11A	**Electric**	**Current leads outlet**	**Closed**
DV11B	**Electric**	**Current leads outlet**	**Closed**
DV11C	**Electric**	**Current leads outlet**	**Closed**
DV11D	**Electric**	**Current leads outlet**	**Closed**
DV15A	**Electric**	**Large flight vent**	**Closed**
DV15B	**Electric**	**Large flight vent**	**Closed**
DV15C	**Electric**	**Large flight vent**	**Closed**
DV15D	**Electric**	**Large flight vent**	**Closed**
DV16A	**Electric**	**CDC outlet**	**Closed**
DV16B	**Electric**	**CDC outlet**	**Closed**
MV17A	**Manual**	**SCL outlet**	**Open**
MV17B	**Manual**	**SCL outlet**	**Open**
MV30	**Manual**	**Vacuum case**	**Closed**
MV31A	**Manual**	**BD10 interspace**	**Closed**
MV31B	**Manual**	**BD10 interspace**	**Closed**
MV32A	**Manual**	**BD05 interspace**	**Closed**
MV32B	**Manual**	**BD05 interspace**	**Closed**
MV33A	**Manual**	**BD03/BD06 interspace**	**Closed**
MV33B	**Manual**	**BD03/BD06 interspace**	**Closed**
MV34A	**Manual**	**VCS outlet for ground operations**	**Open**
MV34B	**Manual**	**VCS outlet for ground operations**	**Open**
MV35*	**Manual**	**GSE**	**Closed**
MV36A	**Manual**	**BD11 interspace**	**Closed**
MV36B	**Manual**	**BD11 interspace**	**Closed**
MV37A	**Manual**	**BD12 interspace**	**Closed**
MV37B	**Manual**	**BD12 interspace**	**Closed**

Circuit	Status
Vacuum space	**Evacuated and sealed**
SCL	**Filled with helium from HVM**
Current leads	**Evacuated**
CDC	**Evacuated**
Helium fill lines	**Connected to LHSS**
MHT	**Connected to fill port and VCS line**
VCS line	**Connected to MHT and HRS**
Cryocoolers	**On**

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 05 GROUND – STEADY STATE

Valve	Type	Position	Status
DV02	**Cryogenic**	**SCL supply line**	**Closed**
DV03	**Cryogenic**	**Liquid helium inlet**	**Closed**
DV05	**Cryogenic**	**Porous plug by-pass**	**Open**
DV06A	**Cryogenic**	**Current leads supply**	**Closed**
DV06B	**Cryogenic**	**Current leads supply**	**Closed**
DV07	**Cryogenic**	**MHT to CDC**	**Closed**
DV10	**Cryogenic**	**MHT by-pass**	**Closed**
DV12	**Cryogenic**	**MHT to fill port cold gas return**	**Closed**
DV14	**Cryogenic**	**MHT to CDC via TMP02**	**Closed**
DV08A	**Electric**	**Small flight vent**	**Closed**
DV08B	**Electric**	**Small flight vent**	**Closed**
DV08C	**Electric**	**Small flight vent**	**Closed**
DV08D	**Electric**	**Small flight vent**	**Closed**
DV09A	**Electric**	**Vent pump**	**Closed**
DV09B	**Electric**	**Vent pump**	**Closed**
DV11A	**Electric**	**Current leads outlet**	**Closed**
DV11B	**Electric**	**Current leads outlet**	**Closed**
DV11C	**Electric**	**Current leads outlet**	**Closed**
DV11D	**Electric**	**Current leads outlet**	**Closed**
DV15A	**Electric**	**Large flight vent**	**Closed**
DV15B	**Electric**	**Large flight vent**	**Closed**
DV15C	**Electric**	**Large flight vent**	**Closed**
DV15D	**Electric**	**Large flight vent**	**Closed**
DV16A	**Electric**	**CDC outlet**	**Closed**
DV16B	**Electric**	**CDC outlet**	**Closed**
MV17A	**Manual**	**SCL outlet**	**Closed**
MV17B	**Manual**	**SCL outlet**	**Closed**
MV30	**Manual**	**Vacuum case**	**Closed**
MV31A	**Manual**	**BD10 interspace**	**Closed**
MV31B	**Manual**	**BD10 interspace**	**Closed**
MV32A	**Manual**	**BD05 interspace**	**Closed**
MV32B	**Manual**	**BD05 interspace**	**Closed**
MV33A	**Manual**	**BD03/BD06 interspace**	**Closed**
MV33B	**Manual**	**BD03/BD06 interspace**	**Closed**
MV34A	**Manual**	**VCS outlet for ground operations**	**Open**
MV34B	**Manual**	**VCS outlet for ground operations**	**Open**
MV35*	**Manual**	**GSE**	**Closed**
MV36A	**Manual**	**BD11 interspace**	**Closed**
MV36B	**Manual**	**BD11 interspace**	**Closed**
MV37A	**Manual**	**BD12 interspace**	**Closed**
MV37B	**Manual**	**BD12 interspace**	**Closed**

Circuit	Status
Vacuum space	**Evacuated and sealed**
SCL	**Sealed**
Current leads	**Evacuated**
CDC	**Evacuated**
Helium fill lines	**Evacuated**
MHT	**Connected to VCS line**
VCS line	**Connected to MHT and HRS**
Cryocoolers	**On**

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 06 GROUND – CHARGE/DISCHARGE

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Open
DV06A	Cryogenic	Current leads supply	Open
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Closed
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Closed
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Open
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Open
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Closed
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Closed
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Closed
DV16B	Electric	CDC outlet	Closed
MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Open
MV34B	Manual	VCS outlet for ground operations	Open
MV35*	Manual	GSE	Closed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated and sealed
SCL	Sealed
Current leads	Cooling; connected to HRS
CDC	Evacuated
Helium fill lines	Evacuated
MHT	Connected to VCS line and current leads
VCS line	Connected to MHT and HRS
Cryocoolers	On

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 07 GROUND – 20 K RE-COOL

Valve	Type	Position	Status
DV02	**Cryogenic**	**SCL supply line**	**Closed**
DV03	**Cryogenic**	**Liquid helium inlet**	**Closed**
DV05	**Cryogenic**	**Porous plug by-pass**	**Open**
DV06A	**Cryogenic**	**Current leads supply**	**Closed**
DV06B	**Cryogenic**	**Current leads supply**	**Closed**
DV07	**Cryogenic**	**MHT to CDC**	**Closed**
DV10	**Cryogenic**	**MHT by-pass**	**Closed**
DV12	**Cryogenic**	**MHT to fill port cold gas return**	**Closed**
DV14	**Cryogenic**	**MHT to CDC via TMP02**	**Open**
DV08A	**Electric**	**Small flight vent**	**Closed**
DV08B	**Electric**	**Small flight vent**	**Closed**
DV08C	**Electric**	**Small flight vent**	**Closed**
DV08D	**Electric**	**Small flight vent**	**Closed**
DV09A	**Electric**	**Vent pump**	**Closed**
DV09B	**Electric**	**Vent pump**	**Closed**
DV11A	**Electric**	**Current leads outlet**	**Closed**
DV11B	**Electric**	**Current leads outlet**	**Closed**
DV11C	**Electric**	**Current leads outlet**	**Closed**
DV11D	**Electric**	**Current leads outlet**	**Closed**
DV15A	**Electric**	**Large flight vent**	**Closed**
DV15B	**Electric**	**Large flight vent**	**Closed**
DV15C	**Electric**	**Large flight vent**	**Closed**
DV15D	**Electric**	**Large flight vent**	**Closed**
DV16A	**Electric**	**CDC outlet**	**Open**
DV16B	**Electric**	**CDC outlet**	**Open**
MV17A	**Manual**	**SCL outlet**	**Closed**
MV17B	**Manual**	**SCL outlet**	**Closed**
MV30	**Manual**	**Vacuum case**	**Closed**
MV31A	**Manual**	**BD10 interspace**	**Closed**
MV31B	**Manual**	**BD10 interspace**	**Closed**
MV32A	**Manual**	**BD05 interspace**	**Closed**
MV32B	**Manual**	**BD05 interspace**	**Closed**
MV33A	**Manual**	**BD03/BD06 interspace**	**Closed**
MV33B	**Manual**	**BD03/BD06 interspace**	**Closed**
MV34A	**Manual**	**VCS outlet for ground operations**	**Open**
MV34B	**Manual**	**VCS outlet for ground operations**	**Open**
MV35*	**Manual**	**GSE**	**Open**
MV36A	**Manual**	**BD11 interspace**	**Closed**
MV36B	**Manual**	**BD11 interspace**	**Closed**
MV37A	**Manual**	**BD12 interspace**	**Closed**
MV37B	**Manual**	**BD12 interspace**	**Closed**

Circuit	Status
Vacuum space	**Evacuated and sealed**
SCL	**Sealed**
Current leads	**Evacuated**
CDC	**Connected to MHT and HRS**
Helium fill lines	**Evacuated**
MHT	**Connected to VCS line and CDC**
VCS line	**Connected to MHT and HRS**
Cryocoolers	**On**

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 08 GROUND – 1.8 K RE-COOL

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Open
DV06A	Cryogenic	Current leads supply	Closed
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Closed
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Closed
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Closed
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Closed
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Closed
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Closed
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Closed
DV16B	Electric	CDC outlet	Closed
MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Open
MV34B	Manual	VCS outlet for ground operations	Open
MV35*	Manual	GSE	Closed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated and sealed
SCL	Sealed
Current leads	Evacuated
CDC	Evacuated
Helium fill lines	Evacuated
MHT	Connected to VCS line
VCS line	Connected to MHT and HRS
Cryocoolers	On

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 09 LAUNCH PAD – TOP OFF

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Open
DV05	Cryogenic	Porous plug by-pass	Open
DV06A	Cryogenic	Current leads supply	Closed
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Open
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Closed
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Closed
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Closed
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Closed
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Closed
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Closed
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Closed
DV16B	Electric	CDC outlet	Closed
MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Open
MV34B	Manual	VCS outlet for ground operations	Open
MV35*	Manual	GSE	Closed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated and sealed
SCL	Sealed
Current leads	Evacuated
CDC	Evacuated
Helium fill lines	Connected to LHSS
MHT	Connected to VCS line and fill port
VCS line	Connected to MHT and HRS
Cryocoolers	On

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 10 LAUNCH PAD – STEADY STATE

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Open
DV06A	Cryogenic	Current leads supply	Closed
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Closed
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Closed
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Open
DV09B	Electric	Vent pump	Open
DV11A	Electric	Current leads outlet	Closed
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Closed
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Closed
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Closed
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Closed
DV16B	Electric	CDC outlet	Closed

MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Closed
MV34B	Manual	VCS outlet for ground operations	Closed
MV35*	Manual	GSE	Removed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated and sealed
SCL	Sealed
Current leads	Evacuated
CDC	Evacuated
Helium fill lines	Evacuated
MHT	Connected to VCS line
VCS line	Connected to MHT and vent pump
Cryocoolers	On

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 11 LAUNCH PAD – READY FOR LAUNCH

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Closed
DV06A	Cryogenic	Current leads supply	Closed
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Closed
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Closed
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Closed
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Closed
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Closed
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Closed
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Closed
DV16B	Electric	CDC outlet	Closed
MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Closed
MV34B	Manual	VCS outlet for ground operations	Closed
MV35*	Manual	GSE	Closed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated and sealed
SCL	Sealed
Current leads	Evacuated
CDC	Evacuated
Helium fill lines	Evacuated
MHT	Sealed
VCS line	Sealed
Cryocoolers	Off

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 12 ORBIT – TRANSITION

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Closed
DV06A	Cryogenic	Current leads supply	Closed
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Open
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Open
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Closed
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Closed
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Open
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Open
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Closed
DV16B	Electric	CDC outlet	Closed

MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Closed
MV34B	Manual	VCS outlet for ground operations	Closed
MV35*	Manual	GSE	Removed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated and sealed
SCL	Sealed
Current leads	Evacuated
CDC	Evacuated
Helium fill lines	Evacuated
MHT	Connected to VCS line via PP
VCS line	Connected to large and small vents
Cryocoolers	Off

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 13 ORBIT – STEADY STATE

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Closed
DV06A	Cryogenic	Current leads supply	Closed
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Open
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Open
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Open
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Open
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Closed
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Closed
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Open/Closed
DV16B	Electric	CDC outlet	Open/Closed
MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Closed
MV34B	Manual	VCS outlet for ground operations	Closed
MV35*	Manual	GSE	Removed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated and sealed
SCL	Sealed
Current leads	Evacuated
CDC	Evacuated
Helium fill lines	Evacuated
MHT	Connected to VCS line (via PP)
VCS line	Connected to small vent
Cryocoolers	On

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 14 ORBIT – CHARGE/DISCHARGE

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Closed
DV06A	Cryogenic	Current leads supply	Open
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Open
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Open
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Open
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Open
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Open
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Open
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Open/Closed
DV16B	Electric	CDC outlet	Open/Closed
MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Closed
MV34B	Manual	VCS outlet for ground operations	Closed
MV35*	Manual	GSE	Removed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated and sealed
SCL	Sealed
Current leads	Connected to MHT; venting to space
CDC	Evacuated
Helium fill lines	Evacuated
MHT	Connected to VCS line (via PP) and Current leads
VCS line	Connected to large and small vents
Cryocoolers	Off

State 15 ORBIT – 20 K RE-COOL

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Closed
DV06A	Cryogenic	Current leads supply	Closed
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Open
DV08A	Electric	Small flight vent	Open
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Open
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Open
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Open
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Open
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Open
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Open
DV16B	Electric	CDC outlet	Open
MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Closed
MV34B	Manual	VCS outlet for ground operations	Closed
MV35*	Manual	GSE	Removed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated and sealed
SCL	Sealed
Current leads	Evacuated
CDC	Venting to space
Helium fill lines	Evacuated
MHT	Connected to VCS line (via PP)
VCS line	Connected to large and small vents
Cryocoolers	On

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 16 ORBIT – 1.8 K RE-COOL

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Closed
DV06A	Cryogenic	Current leads supply	Closed
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Open
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Open
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Open
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Open
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Closed
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Closed
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Open/Closed
DV16B	Electric	CDC outlet	Open/Closed

MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Closed
MV34B	Manual	VCS outlet for ground operations	Closed
MV35*	Manual	GSE	Removed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated and sealed
SCL	Sealed
Current leads	Evacuated
CDC	Evacuated
Helium fill lines	Evacuated
MHT	Connected to VCS line (via PP)
VCS line	Connected to small vent
Cryocoolers	On

State 17 RE-ENTRY

Valve	Type	Position	Status
DV02	Cryogenic	SCL supply line	Closed
DV03	Cryogenic	Liquid helium inlet	Closed
DV05	Cryogenic	Porous plug by-pass	Closed
DV06A	Cryogenic	Current leads supply	Closed
DV06B	Cryogenic	Current leads supply	Closed
DV07	Cryogenic	MHT to CDC	Closed
DV10	Cryogenic	MHT by-pass	Closed
DV12	Cryogenic	MHT to fill port cold gas return	Closed
DV14	Cryogenic	MHT to CDC via TMP02	Closed
DV08A	Electric	Small flight vent	Closed
DV08B	Electric	Small flight vent	Closed
DV08C	Electric	Small flight vent	Closed
DV08D	Electric	Small flight vent	Closed
DV09A	Electric	Vent pump	Closed
DV09B	Electric	Vent pump	Closed
DV11A	Electric	Current leads outlet	Closed
DV11B	Electric	Current leads outlet	Closed
DV11C	Electric	Current leads outlet	Closed
DV11D	Electric	Current leads outlet	Closed
DV15A	Electric	Large flight vent	Closed
DV15B	Electric	Large flight vent	Closed
DV15C	Electric	Large flight vent	Closed
DV15D	Electric	Large flight vent	Closed
DV16A	Electric	CDC outlet	Closed
DV16B	Electric	CDC outlet	Closed
MV17A	Manual	SCL outlet	Closed
MV17B	Manual	SCL outlet	Closed
MV30	Manual	Vacuum case	Closed
MV31A	Manual	BD10 interspace	Closed
MV31B	Manual	BD10 interspace	Closed
MV32A	Manual	BD05 interspace	Closed
MV32B	Manual	BD05 interspace	Closed
MV33A	Manual	BD03/BD06 interspace	Closed
MV33B	Manual	BD03/BD06 interspace	Closed
MV34A	Manual	VCS outlet for ground operations	Closed
MV34B	Manual	VCS outlet for ground operations	Closed
MV35*	Manual	GSE	Removed
MV36A	Manual	BD11 interspace	Closed
MV36B	Manual	BD11 interspace	Closed
MV37A	Manual	BD12 interspace	Closed
MV37B	Manual	BD12 interspace	Closed

Circuit	Status
Vacuum space	Evacuated and sealed
SCL	Sealed
Current leads	Evacuated
CDC	Evacuated
Helium fill lines	Evacuated
MHT	Connected to VCS line (via PP)
VCS line	Sealed
Cryocoolers	Off

Table 5.1.3.1 (Continued) – Cryosystem Valve Positions in Each State

State 18 LANDED

Valve	Type	Position	Status
DV02	**Cryogenic**	**SCL supply line**	**Closed**
DV03	**Cryogenic**	**Liquid helium inlet**	**Closed**
DV05	**Cryogenic**	**Porous plug by-pass**	**Open**
DV06A	**Cryogenic**	**Current leads supply**	**Closed**
DV06B	**Cryogenic**	**Current leads supply**	**Closed**
DV07	**Cryogenic**	**MHT to CDC**	**Closed**
DV10	**Cryogenic**	**MHT by-pass**	**Closed**
DV12	**Cryogenic**	**MHT to fill port cold gas return**	**Closed**
DV14	**Cryogenic**	**MHT to CDC via TMP02**	**Closed**
DV08A	**Electric**	**Small flight vent**	**Open/Closed**
DV08B	**Electric**	**Small flight vent**	**Closed**
DV08C	**Electric**	**Small flight vent**	**Open/Closed**
DV08D	**Electric**	**Small flight vent**	**Closed**
DV09A	**Electric**	**Vent pump**	**Closed**
DV09B	**Electric**	**Vent pump**	**Closed**
DV11A	**Electric**	**Current leads outlet**	**Closed**
DV11B	**Electric**	**Current leads outlet**	**Closed**
DV11C	**Electric**	**Current leads outlet**	**Closed**
DV11D	**Electric**	**Current leads outlet**	**Closed**
DV15A	**Electric**	**Large flight vent**	**Open/Closed**
DV15B	**Electric**	**Large flight vent**	**Closed**
DV15C	**Electric**	**Large flight vent**	**Open/Closed**
DV15D	**Electric**	**Large flight vent**	**Closed**
DV16A	**Electric**	**CDC outlet**	**Closed**
DV16B	**Electric**	**CDC outlet**	**Closed**

MV17A	**Manual**	**SCL outlet**	**Closed**
MV17B	**Manual**	**SCL outlet**	**Closed**
MV30	**Manual**	**Vacuum case**	**Closed**
MV31A	**Manual**	**BD10 interspace**	**Closed**
MV31B	**Manual**	**BD10 interspace**	**Closed**
MV32A	**Manual**	**BD05 interspace**	**Closed**
MV32B	**Manual**	**BD05 interspace**	**Closed**
MV33A	**Manual**	**BD03/BD06 interspace**	**Closed**
MV33B	**Manual**	**BD03/BD06 interspace**	**Closed**
MV34A	**Manual**	**VCS outlet for ground operations**	**Closed**
MV34B	**Manual**	**VCS outlet for ground operations**	**Closed**
MV35*	**Manual**	**GSE**	**Removed**
MV36A	**Manual**	**BD11 interspace**	**Closed**
MV36B	**Manual**	**BD11 interspace**	**Closed**
MV37A	**Manual**	**BD12 interspace**	**Closed**
MV37B	**Manual**	**BD12 interspace**	**Closed**

Circuit	Status
Vacuum space	**Evacuated and sealed**
SCL	**Sealed**
Current leads	**Evacuated**
CDC	**Evacuated**
Helium fill lines	**Evacuated**
MHT	**Connected to VCS line**
VCS line	**Venting if p_{MHT} > 1.5 bar via large and small vents**
Cryocoolers	**Off**

5.1.3.1 Abbreviations and Some Limited Definitions

AHV	Air-Heated Vaporizer
BD	Burst Disc
CCS	Cryomagnet Current Source
CDC	Cool Down Circuit
CDU	Cool Down Unit
CHX/BV	Cold Heat Exchanger/Buffer Volume
DV	Digital (on/off) Valve
HRS	Helium Recovery System
HVM	Helium and Vacuum Manifold
LHSS	Liquid Helium Supply System
MV	Manually Actuated Valve (ground use only)
MHT	Main Helium Tank
PP	Porous Plug – The unique properties of SFHe are utilized on-orbit to allow the separation of the liquid and vapor of SFHe. A porous plug is typically a small cylinder shape piece of porous metal (often made of stainless steel).
SCL	Superfluid Cooling Loop
TMP	Thermo-Mechanical Pump – This pump uses the unique nature of superfluid helium to generate hydraulic head simply by the application of heat. The pump consists of a very fine filter and a heater element. The heater is positioned on the downstream side of the filter. When heated, it causes helium to flow through the filter. This will only operate if the helium is below the lambda transition temperature (2.17 K). The maximum pressure which can be generated is around 10.2 psi (0.7 bar). Pumps of this type (but larger than the AMS version) were flown on SHOOT. The AMS pump is currently under development.
VCL	Vapor Cooled Leads
VCS	Vapor Cooled Shield

5.1.3.2 Ground Support Equipment (GSE)

(i) The Cool Down Unit (CDU) is a TBD device used for cooling down the system from ambient temperature to 80 K. It consists of a liquid nitrogen-cooled heat exchanger and control system which cools pure helium gas to a predetermined and programmable temperature between ambient and 80 K. The cooled helium is used for cooling the magnet and helps prevent contamination (air or water) of the cryogenic system.

(ii) The Helium Recovery System (HRS) is a TBD system for removing exhaust helium from the system and transferring it to a safe position where it can be recycled, saved or released to the atmosphere. The HRS incorporates Roots pumps to allow the helium in the MHT to be pumped down.

(iii) The Helium and Vacuum Manifold (HVM) is a TBD system for supplying pure, ambient temperature helium gas at a pressure of 1.2 ± 0.1 bar (absolute) to various parts of the cryogenic circuit during cool down. Its purpose is to allow filling of closed volumes with slightly pressurized helium to prevent air ingress. It also has a vacuum pump, so that the closed volumes can be evacuated when required.

(iv) The Liquid Helium Supply System (LHSS) is a TBD unit for supplying clean, filtered liquid helium at between 1.2 and 1.5 bar (absolute) to the fill port on the magnet. It consists of a system of storage dewars and vacuum insulated transfer lines designed to minimize the possibility of air or water contamination entering the magnet cryogenic system.

(v) Connected to the CDC is an arrangement of an Air-Heated Vaporizer (AHV) and valves. This is used during cool down to 4 K.

5.1.3.3 Preparations for Cool Down

(i) All circuits, vessels and pumping lines must be thoroughly leak checked.

(ii) All system (including GSE) pipework, components and vessels must be thoroughly cleaned, including pumping and purging cycles with clean helium gas.

(iii) Connect a vacuum pump set – consisting of a turbo-molecular pump and a rotary backing pump to the vacuum case pumping port via manual high vacuum valve MV30. (Note: For operational reasons, we may decide later to actuate this valve.) Turn on the pumps and open the valve.

(iv) Evacuate the vacuum space to 10^{-4} mbar or lower pressure. Keep pumping throughout the ambient temperature to 80 K cool down.

(v) Evacuate the interspace between BD10A and BD10B through MV31A/B to 10^{-3} mbar or lower pressure. Close MV31A and MV31B.

(vi) Evacuate the interspace between BD05A and BD05B through MV32A/B to 10^{-3} mbar or lower pressure. Close MV32A and MV32B.

(vii) Evacuate the interspaces between BD03 and BD06A, and between BD06A and BD06B, through MV33A/B to 10^{-5} mbar or lower pressure. Close MV33A and MV33B.

(viii) Evacuate the interspace between BD11A and BD11B through MV36A/B to 10^{-3} mbar or lower pressure. Close MV36A and MV36B.

(ix) Evacuate the interspace between BD12A and BD12B through MV37A/B to 10^{-3} mbar or lower pressure. Close MV37A and MV37B.

(x) Close DV06A and DV06B. Open DV11A/B/C/D and evacuate the current leads to 10^{-5} mbar or lower pressure. Connect the current leads outlet (DV11) to the HVM helium supply.

(xi) Close DV03, DV10 and DV12 to isolate the liquid helium fill port pipework. Evacuate the fill port and pipework to 10^{-5} mbar or lower pressure. Connect the fill port to the HVM helium supply.

(xii) Open DV02 and MV17A/B. Evacuate the SCL to 10^{-5} mbar or lower pressure. Connect the SCL to the HVM helium supply.

(xiii) Magnet status: **READY FOR COOL DOWN**.

5.1.3.4 Cool Down to 80 K

(i) Magnet status: **READY FOR COOL DOWN**.

(ii) Maintain the connections from the SCL, current leads and helium fill lines to the HVM helium supply.

(iii) Connect the CDU to the CDC via EV16A/B.

(iv) Connect the VCS line to the HRS via MV34A/B.

(vi) Open DV07 to connect the CDC to the MHT.

(vi) Open DV05 to connect the MHT to the VCS line.

(vii) Magnet status: **GROUND – COOLING TO 80 K**.

(viii) Flow helium from the CDU through the CDC, MHT and VCS line to the HRS. Ramp down the temperature of the helium leaving the CDU. Continue until the magnet temperature is less than 90 K.

5.1.3.5 Cool Down to 4 K

(i) Magnet status: **GROUND – COOLING TO 80 K**.

(ii) Maintain the connections from the SCL and current leads to the HVM helium supply.

(iii) Connect the CDC to the HRS via DV16A/B, AHV01* and MV35*.

(iv) Connect the LHSS to the helium fill port.

(v) If necessary, use DV10 to bypass the MHT to purge any warm helium in the transfer line.

(vi) Magnet status: **GROUND – COOLING TO 4 K**.

(vii) Fill the MHT with liquid helium from the LHSS. Take the exhaust through the CDC and the VCS line to achieve maximum cooling efficiency.

(viii) When temperatures in the system are below 30 K, close MV30 and remove the vacuum pump. Fit a blank over the outlet from MV30.

5.1.3.6 Cool Down to 1.8 K

(i) Magnet status: **GROUND – COOLING TO 4 K**.

(ii) Maintain the connection from the SCL to the HVM helium supply.

(iii) Evacuate the current leads using the HVM.

(iv) Close DV07 and evacuate the CDC using the HVM.

(v) Turn on the cryocoolers if available.

(vi) Magnet status: **GROUND – COOLING TO 1.8** K.

(vii) Use Roots pumps to pump on the VCS line and fill port.

(viii) Continue to fill the system from the LHSS.

5.1.3.7 Steady State on the Ground

(i) Magnet status: **GROUND - COOLING TO 1.8 K, GROUND - 1.8 K RE-COOL** or **GROUND - CHARGE/DISCHARGE**.

(ii) Close DV02. Evacuate the SCL supply line then close MV17A/B.

(iii) Evacuate the helium fill line.

(iv) Close DV14 and turn off TMP02. Evacuate the CDC and close DV16A/B.

(v) Continue pumping on the VCS line outlet.

(vi) Magnet status: **GROUND – STEADY STATE**.

5.1.3.8 Change Current on the Ground

(i) Magnet status: **GROUND – STEADY STATE**.

(ii) Pump on the current leads outlet using the HVM.

(iii) Open DV06A and DV11A/C. Turn on TMP01 to cool the leads.

(iv) Close the current leads disconnects.

(v) Magnet status: **GROUND – CHARGE/DISCHARGE**.

(vi) Ramp up the CCS to the desired current and open the persistent switch.

(vii) Charge or discharge the magnet.

(viii) Close the persistent switch.

(ix) Discharge the CCS.

(x) Open the current lead disconnects.

(xi) Close DV06A. Turn off TMP01.

(xii) Evacuate the current leads and close DV11A/C.

(xiii) Magnet status: **GROUND – STEADY STATE**.

5.1.3.9 Quench Re-Cool on the Ground

(i) Magnet status: **GROUND – STEADY STATE** or **GROUND – CHARGE/DISCHARGE** followed by a quench.

(ii) Pump on the CDC outlet using the HVM.

(iii) Turn on TMP02. Open DV14, DV16A/B and MV35* to pump helium from the MHT through the CDC to the HRS, cooling the coils.

(iv) If necessary, close DV06A, turn off TMP01 and evacuate the current leads. Close DV11A/C and open the current lead disconnects. Close the persistent switch.

(v) Magnet status: **GROUND – 20 K RE-COOL**.

(vi) Continue to cool the coils by pumping helium through the CDC until all temperatures are below 20 K.

(vii) Once the magnet is below 20 K, close DV14 and turn off TMP02.

(viii) Evacuate the CDC; close DV16A/B.

(ix) Magnet status: **GROUND – 1.8 K RE-COOL**.

(x) Allow the magnet to cool by heat transfer through the SCL.

(xi) When all temperatures are below 2 K, magnet status is **GROUND – STEADY STATE**.

5.1.3.10 Prepare for Launch

(i) Magnet status: **GROUND – STEADY STATE**.

(ii) Connect the LHSS to the helium fill port. Pump on the fill port and the VCS line outlet.

(iii) Magnet status: **LAUNCH PAD – TOP OFF**.

(iv) Fill the MHT as full as possible.

(v) Remove all GSE. Close MV34A/B

(vi) Evacuate the helium fill lines.

(vii) Turn on the vent pump. Open DV09A/B.

(viii) Magnet status: **LAUNCH PAD – STEADY STATE**.

(ix) The magnet can remain in this state indefinitely, as long as the vent pump continues to operate.

5.1.3.11 Launch

(i) Magnet status: **LAUNCH PAD – STEADY STATE**.

(ii) Close all valves.

(iii) Shut down the vent pump.

(iv) Turn off the cryocoolers.

(v) Magnet status: **LAUNCH PAD – READY FOR LAUNCH**.

(vi) The magnet can remain in this state for up to TBD hours before it becomes necessary to pump down and/or top off again.

(vii) Launch the Space Shuttle.

5.1.3.12 Entering Orbit

(i) Magnet status: **LAUNCH PAD – READY FOR LAUNCH**.

(ii) About 3 minutes into launch, while the Shuttle is still accelerating, the barometric switch causes the large and small flight vents to open by opening DV08A/C and DV15A/C.

(iii) Magnet status: **ORBIT – TRANSITION**.

(iv) When the MHT is near to operating temperature, shut off the large flight vent by closing DV15A/C.

(v) Vent the current leads to space by opening DV11A/C.

(vi) Turn on the cryocoolers.

(vii) Magnet status: **ORBIT – STEADY STATE**.

5.1.3.13 Mission Abort

(i) If the magnet is already in steady conditions on orbit the status will be: **ORBIT – STEADY STATE**.

(ii) Return to **ORBIT – TRANSITION** state by closing all valves except the flight vents.

(iii) If the magnet has not yet reached steady state the status will already be: **ORBIT – TRANSITION**.

(iv) Close all valves.

(v) Magnet status: **RE-ENTRY**.

(vi) Re-enter the atmosphere and land the Shuttle.

(vii) When the pressure in the MHT exceeds 1.5 bar, open DV05 to bypass the porous plug, and open DV15A/C to open the large flight vent.

(viii) Magnet status: **LANDED**.

(ix) The magnet can remain in this state indefinitely. To prevent damage to BD02, DV02 and MV17A/B may be opened to vent the SCL to atmosphere.

5.1.3.14 <u>Steady State in Space</u>

(i) Magnet status: **ORBIT – TRANSITION**, **ORBIT – CHARGE/DISCHARGE** or **ORBIT – 1.8 K RE-COOL**.

(ii) Turn on the cryocoolers.

(iii) Close all valves except DV08A/C (small flight vent) and DV11A/C (venting current leads to space). DV16A/B (venting CDC to space) can be open or closed. If one or more cryocoolers have failed, it may also be necessary to open the large flight vent through DV15A/C, at least some of the time.

(iv) Magnet status: **ORBIT – STEADY STATE**.

(v) The magnet can remain in this state until it runs out of helium.

5.1.3.15 <u>Change Current in Space</u>

(i) Magnet status: **ORBIT – STEADY STATE**.

(ii) Turn off the cryocoolers.

(iii) Open DV06A and turn on TMP01 to cool the current leads.

(iv) Open DV15A/C to open the large flight vent.

(v) Magnet status: **ORBIT – CHARGE/DISCHARGE**.

(vi) Close the current lead disconnects.

(vii) Charge the CCS to the magnet current (if any).

(viii) Open the persistent switch.

(ix) Charge or discharge the magnet as required.

(x) Close the persistent switch.

(xi) Discharge the CCS.

(xii) Open the current lead disconnects.

(xiii) Close DV06A and switch off TMP01.

(xiv) Magnet status: **ORBIT – STEADY STATE**.

5.1.3.16 <u>Quench Re-Cool in Space</u>

(i) Magnet status: **ORBIT – STEADY STATE** or **ORBIT – CHARGE/DISCHARGE** followed by a quench.

(ii) Open DV15A/C to open the large flight vent.

(iii) Open DV14 and turn on TMP02 to pump helium through the CDC.

(iv) Magnet status: **ORBIT – 20 K RE-COOL**.

(v) Continue to cool the coils by pumping helium through the CDC until all temperatures are below 20 K.

(vi) Once the magnet is below 20 K, close DV14 and turn off TMP02.

(vii) Close DV15A/C to shut the large flight vent.

(viii) Magnet status: **ORBIT – 1.8 K RE-COOL**.

(ix) Allow the magnet to cool by heat transfer through the SCL.

(x) When all temperatures are below 2 K, magnet status is **ORBIT – STEADY STATE**.

5.2 UNIQUE SUPPORT STRUCTURE-02 (USS-02)

The USS-02 is used to support the AMS-02 Cryomagnet and detectors and to interface the entire AMS-02 Experiment with the Space Shuttle Orbiter and ISS. The Vacuum Case is also an integral part of the USS-02. The USS-02 is comprised of the following five subassemblies: (1) Upper USS-02 Assembly, (2) Vacuum Case Assembly, (3) Lower USS-02 Assembly, (4) Keel Assembly, and (5) passive Payload Attach System (PAS)/Umbilical Mechanism Assembly (UMA) Assemblies (See Figures 5.2.1 - 5.2.2).

The USS-02 primary members consist of 4 inch (101.6 mm) square tubing with 0.25 inch (6.4 mm) walls made from 7075-T73511 extruded aluminum tubing, 5 to 6.25 inch (127 to 158.75 mm) square tubing with 0.25 inch (6.4 mm) walls made from 7050-T7451 aluminum plate. The 7050 tubes are friction stir welded. Most USS-02 joints are made of 7050-T7451 eight inch (203.2 mm) thick plate and are machined. The USS-02 attaches to the Space Shuttle Orbiter with four longeron trunnions and one keel trunnion. The AMS-02 payload attaches to the ISS via the PAS. The PAS hardware on the AMS-02 is the passive half and consists of three guide pins and a capture bar.

Several AMS-02 components are mounted to the USS-02. These components include: the SRD, TRD, TRD gas supply system, TOF, RICH, ECAL, electronics crates, RICH electronics, ECAL electronics, Cryo Avionics Box (CAB), Cryomag rectifiers, electrical cables and components of the Thermal Control System (TCS). The Space Shuttle Program (SSP) provided hardware that will be attached to the USS-02 include: one Flight Releasable Grapple Fixture (FRGF) and one Payload Disconnect Assembly (PDA) for the Remotely Operated Electrical Umbilical (ROEU). The ISS Program provided hardware that will be attached to the USS-02 includes: one Power Video Grapple Fixture (PVGF), one passive Umbilical Mechanism Assembly (UMA) and an External Berthing Cues System (EBCS). The passive PAS and Meteoroid and Orbital Debris (M/OD) shields attached to the USS-02 are ISS integration hardware that is being developed by the NASA/LM Mission Management Office.

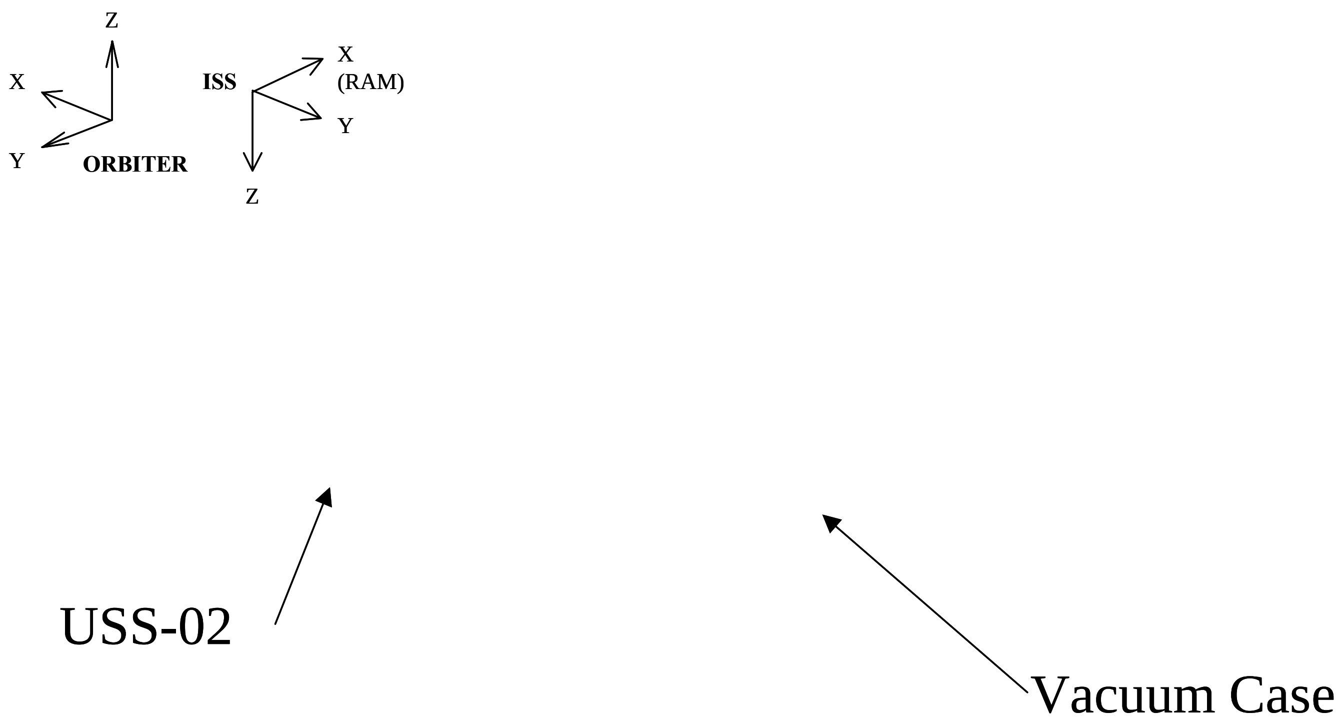


Figure 5.2.1 – Unique Support Structure – 02 (Sheet 1 of 2)

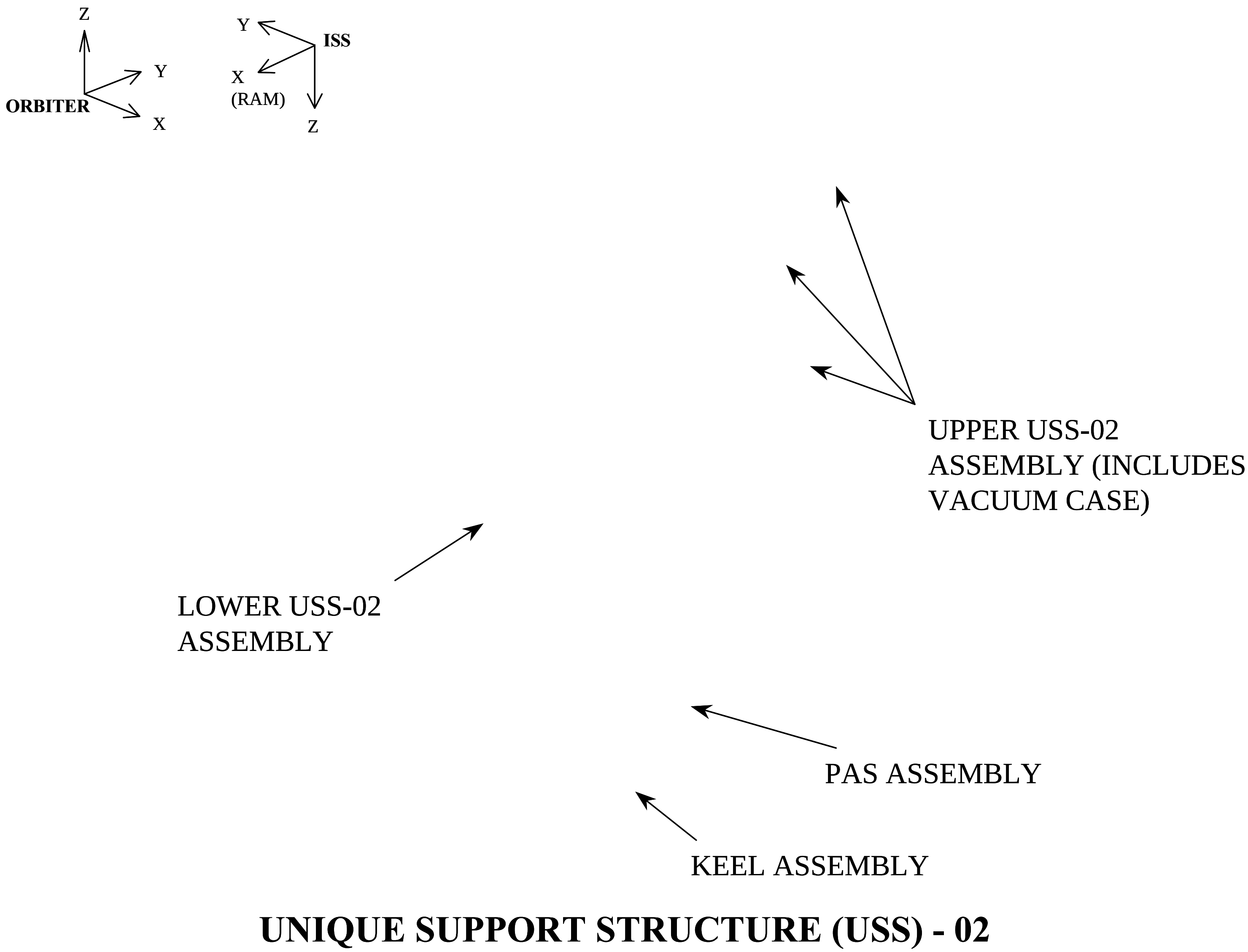


Figure 5.2.2 – Unique Support Structure – 02 (Sheet 2 of 2)

5.3 SYNCHROTRON RADIATION DETECTOR (SRD)

The SRD is located on the top of the experiment stack and attaches to the top of the TRD support at 4 locations. The SRD is approximately 100 x 100 x 4 inches (2540 x 2540 x 101.6 mm) and weighs about 441 lbs (200 Kg). The SRD detector is supported by a large honeycomb panel. The panel will most likely have carbon fiber face sheets and an aluminum core.

The SRD is a particle physics experiment with different detector materials configurations to measure photons, X-rays and low energy charged particles. The SRD is able to extend the accessible energy range beyond 400 GeV to tens of TeV, a range which is of great interest for astro-particle physics. The details of this detector are still under development and are awaiting positive flight results from the Proto-type SRD, which flew on STS-108 in December 2001.

5.4 TRANSITION RADIATION DETECTOR (TRD)

5.4.1 Structure

The role of the TRD is to discriminate between electrons/anti-protons (e^-/p^-) and positrons/protons (e^+/p^+) over the Energy (E) range E = 3 – 300 GeV. This is accomplished by detecting the presence of X-ray photons emitted by electrons and positrons when they pass through a radiator. p^+, p^- and nuclei do not emit such radiation. The radiation is detected in proportional tubes filled with preferentially Xe:CO_2 (80:20). Xenon is chosen as it gives a very high efficiency for photon detection. By proportional multiplications, the ionization electrons are converted into a measurable signal.

The TRD detector is composed of 5248 proportional tubes which are made from a multi-layer wound composite structure. The composite includes layers of poluyurethane, conductive carbon-polyamide, aluminum and kapton. 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 3.0e-3 inches (72 microns) (See Figure 5.4.1.1) and varies in length from 59.1 inches to 86.6 inches (1.5 m to 2.2 m).

A straw module consists of 16 straws (See Figure 5.4.1.2, prototype module) glued together with 6 CFC stiffeners running alongside the straws. Every 3.94 inches (10 cm) strips 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 built 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 fibers). 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 (See Figures 5.4.1.3 & 5.4.1.4)).

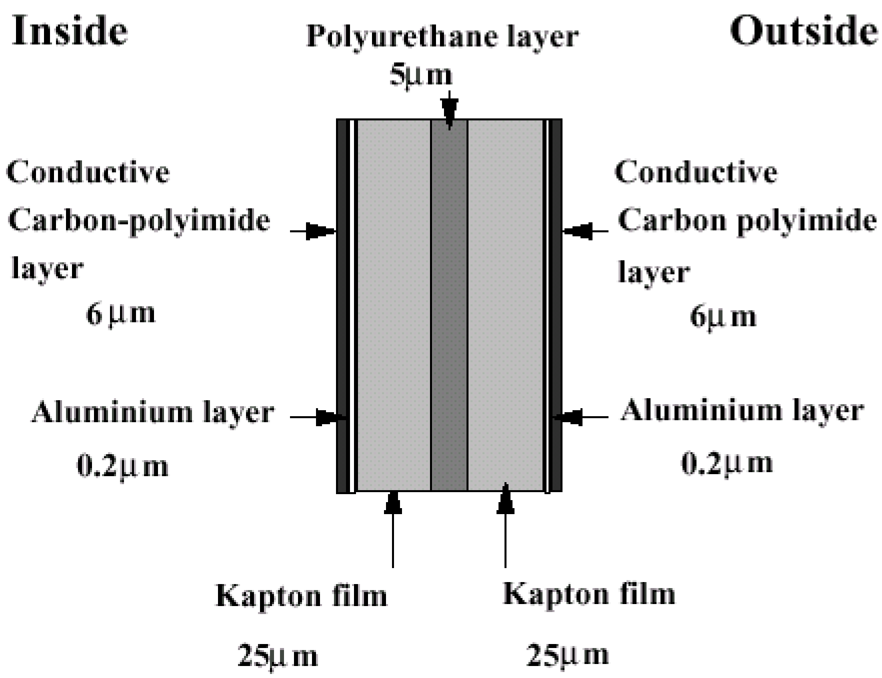


Figure 5.4.1.1 – Composition of Straw Wall

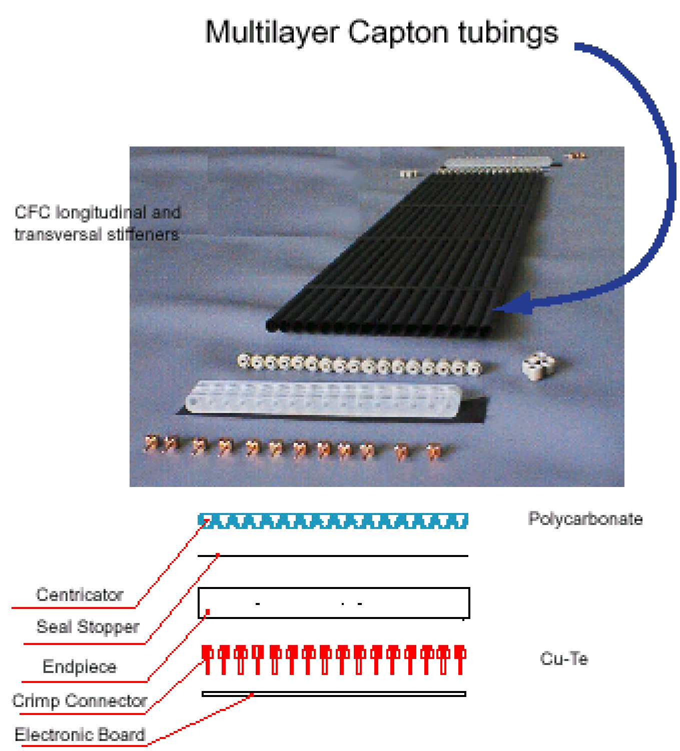


Figure 5.4.1.2 – Straw Module Production

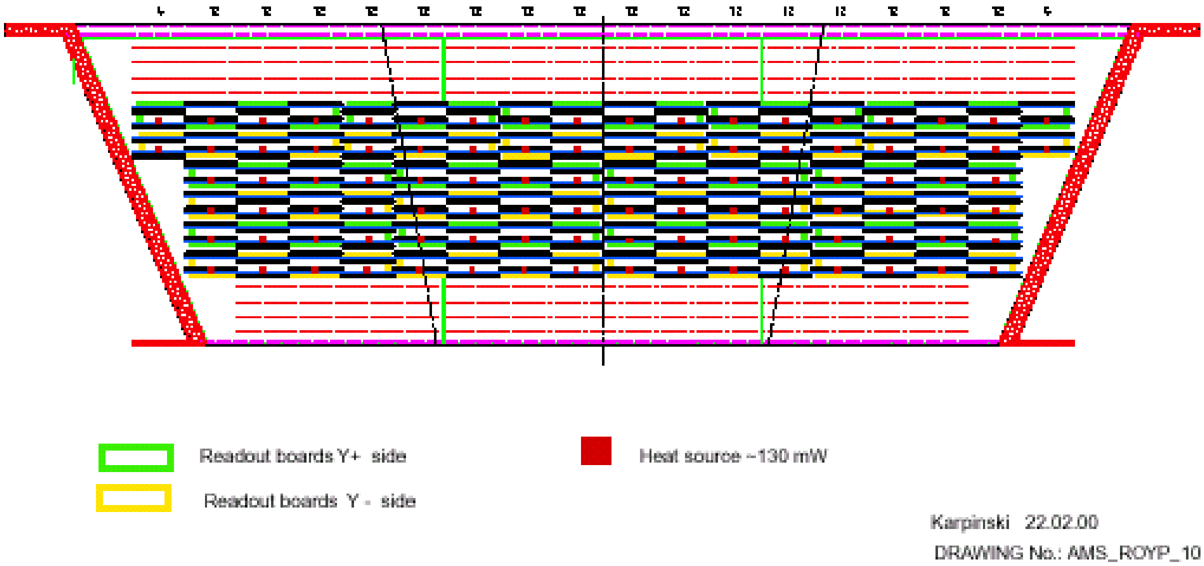


Figure 5.4.1.3 – TRD X-Z Cross Section

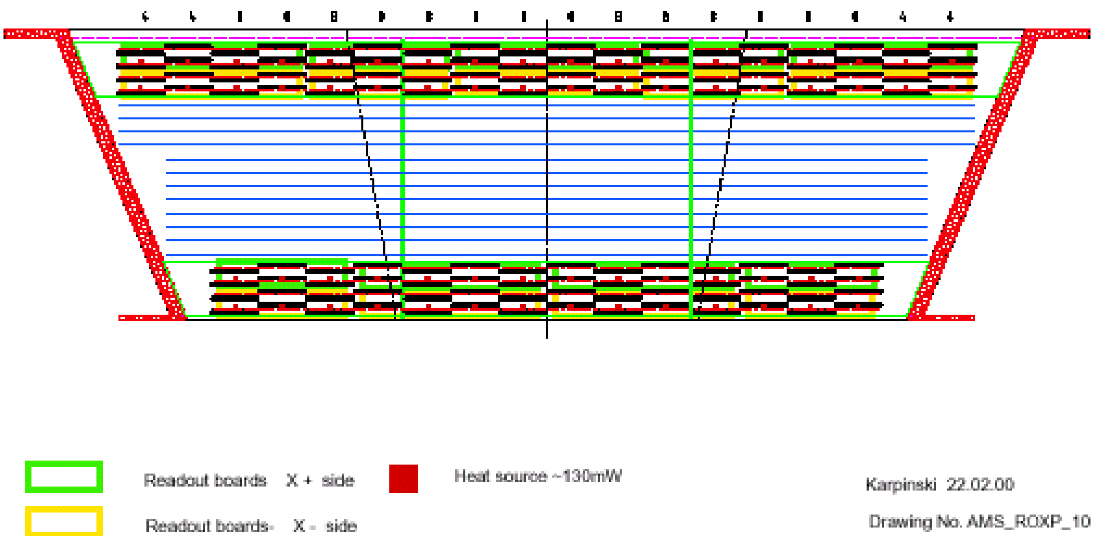


Figure 5.4.1.4 – TRD Y-Z Cross Section

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 octagon structure and the upper TOF honeycomb is ~1000 lbs (454 Kg). Inside the octagon structure, the straw modules are further supported by 4 bulkheads (0.1 inch (3 mm) thick), 2 in the Y-direction and 2 times 2 smaller ones in the X-direction (See Figure 5.4.1.5).

The TRD is located below the SRD and above the upper TOF on the experiment stack (See Figure 5.4.1.6). The octagon structure is mounted to the USS-02 at 4 locations, just above the vacuum case interface. The TRD corner joints hard-mount to the USS-02 upper corner joints.

The frontend readout-electronics and the High Voltage (HV) supply units are mounted on special boards close to the module endpieces (See Figure 5.4.1.7). A dedicated electrostatic shielding of the electronic boards is foreseen. The Xenon gas distribution system is also mounted close to the ends of the modules on the opposite side of the electronics (See Figure 5.4.1.7).

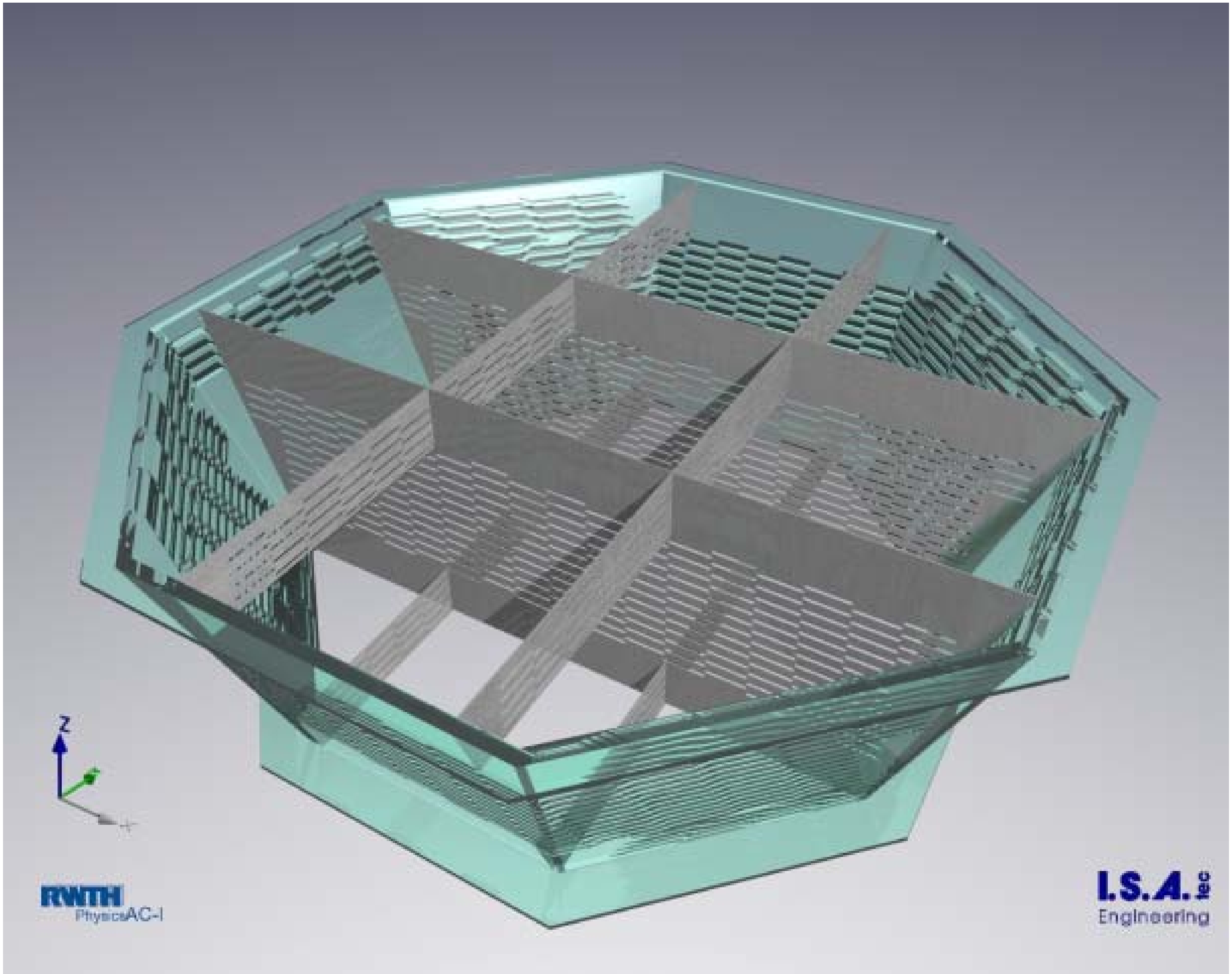


Figure 5.4.1.5 – TRD Bulkheads Inside the Octagon

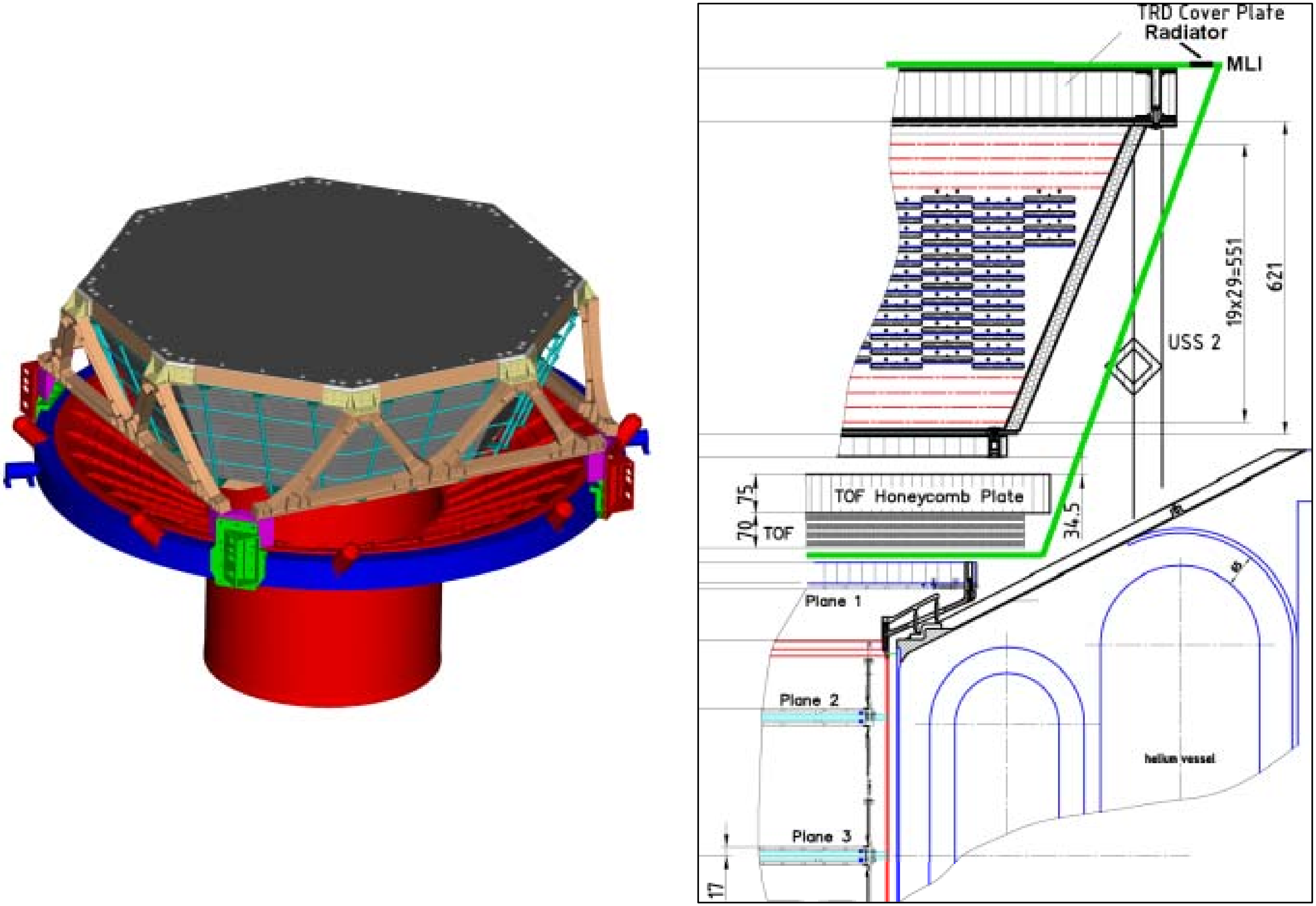


Figure 5.4.1.6 – TRD Structure

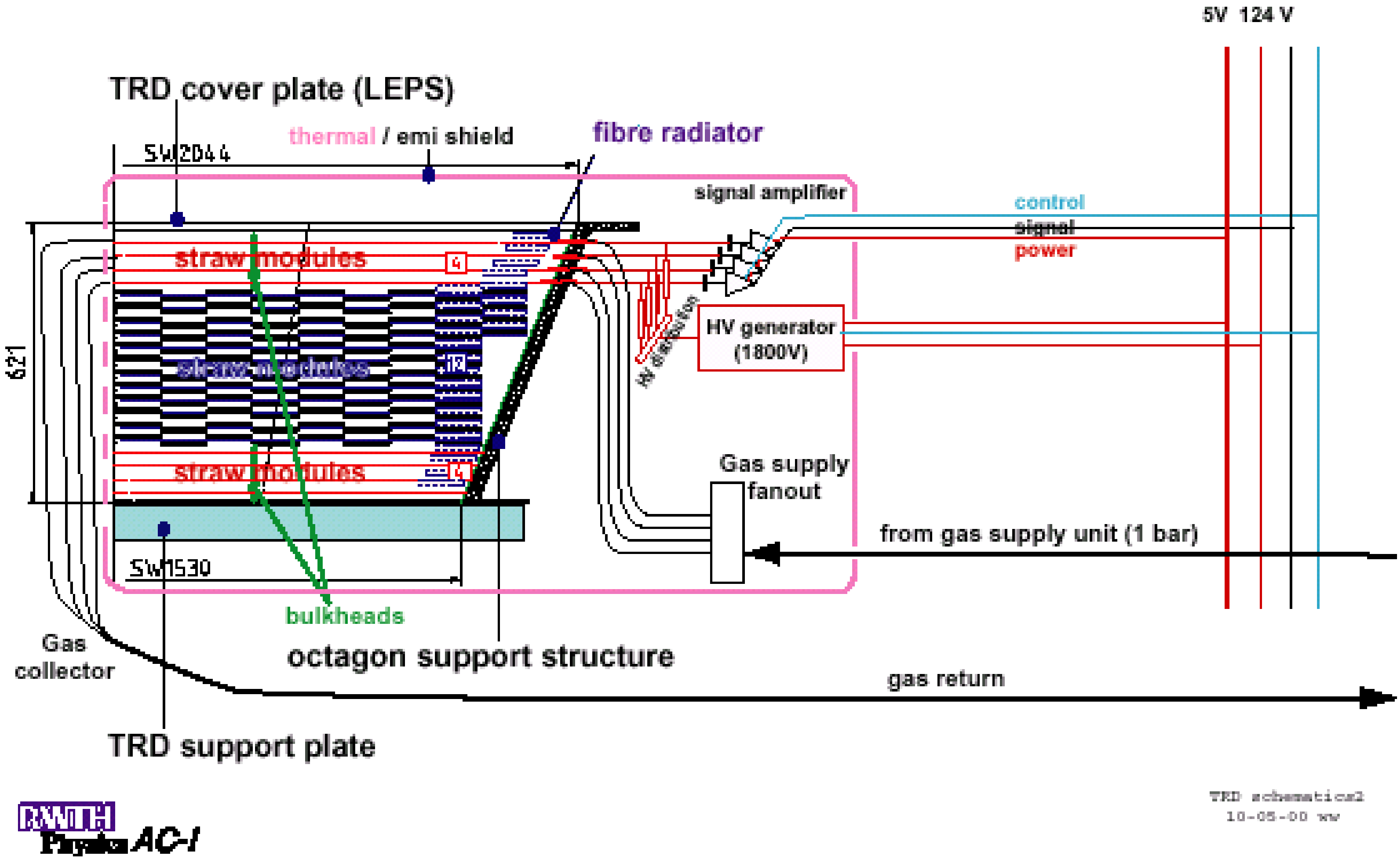


Figure 5.4.1.7 – TRD System Components

5.4.2 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 corrected 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 (See Figures 5.4.2.1, 5.4.2.2 & 5.4.2.3). These tanks are all housed in a box or covered by a debris shield to protect them from meteoroids and orbital debris. The box is mounted to the USS-02 on the wake side (for ISS flight). This location also helps to protect them from damage.

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 of 3000 psid with a minimum temperature rating of –60°F and a maximum temperature rating of 150°F. The normal operating temperature is 77°F (25°C). The tank was designed with a 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 can carry up to 109 lbs (49 Kg) of Xe and has been tested to 8.9 Grms at 0.08 g^2/Hz.

The CO_2 tank is a composite over-wrapped stainless steel tank that is also designed and built by Arde, Inc. This tank was designed for use on the X-33 vehicle and has a maximum design pressure of 3200 psig. This tank operates at 77°F, but has a minimum operating temperature of –100°F and a maximum operating temperature of 300°F. The normal operating pressure for the CO_2 is TBD. The tank is designed with a proof test factor of 1.5 x MDP and a minimum burst factor of 2.125 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 (20.9 Kg) and it can hold a maximum of 8.5 lbs (3.9 Kg) of CO_2. A vibration test has been performed to 8.9 Grms at 0.07 g^2/Hz axially and 4.5 Grms 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 psid, a normal operating temperature of 77°F and an MDP of 300 psid. A proof test factor of 1.5 x MDP and a burst factor of 4 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 0.1 - 0.25 inch (3 - 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 0.04 inch (1 mm) inner diameter Polyether Ether Ketone (PEEK) tubing and metal connectors.

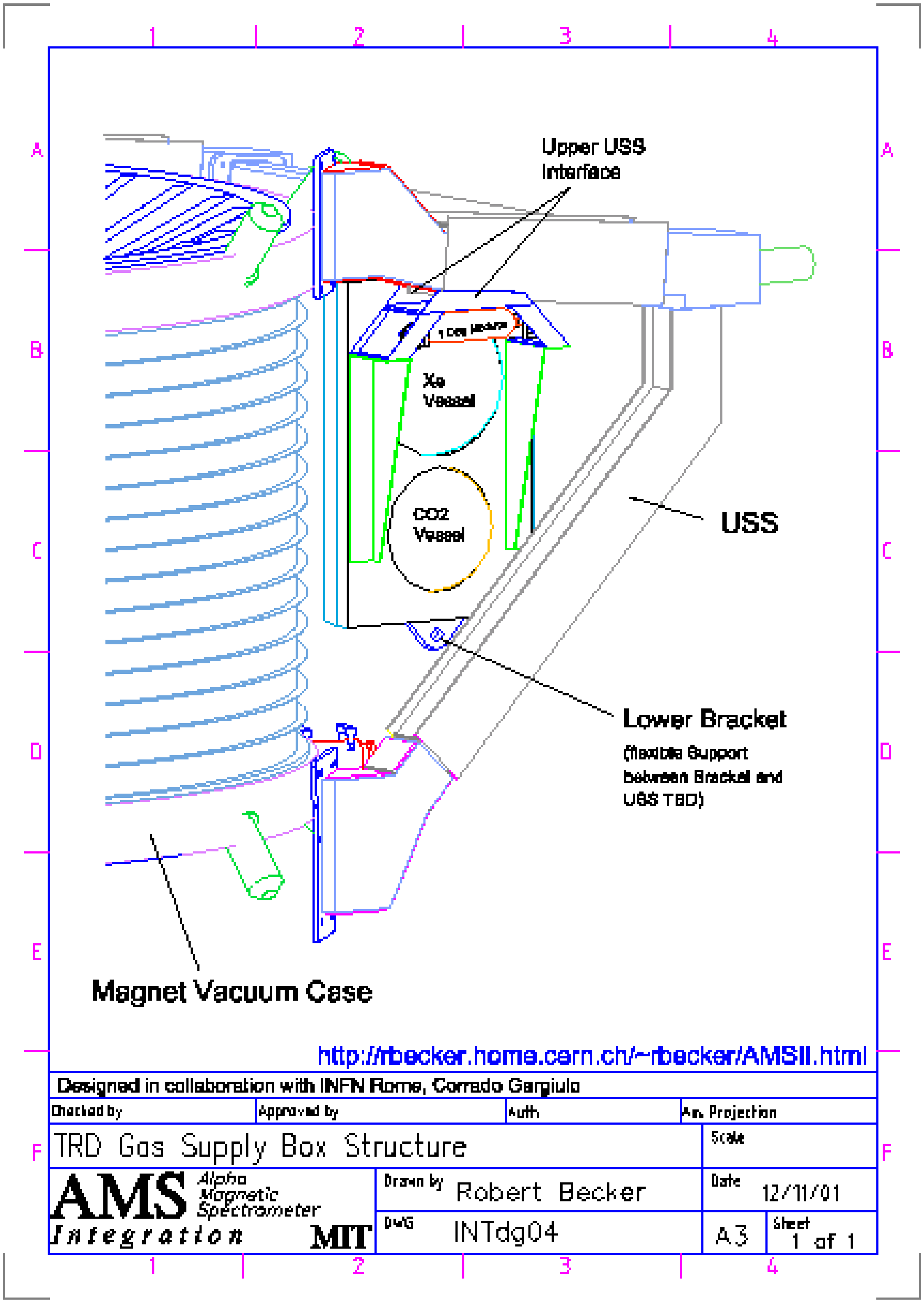


Figure 5.4.2.1 – TRD Gas Supply Box Structure (Sheet 1 of 3)

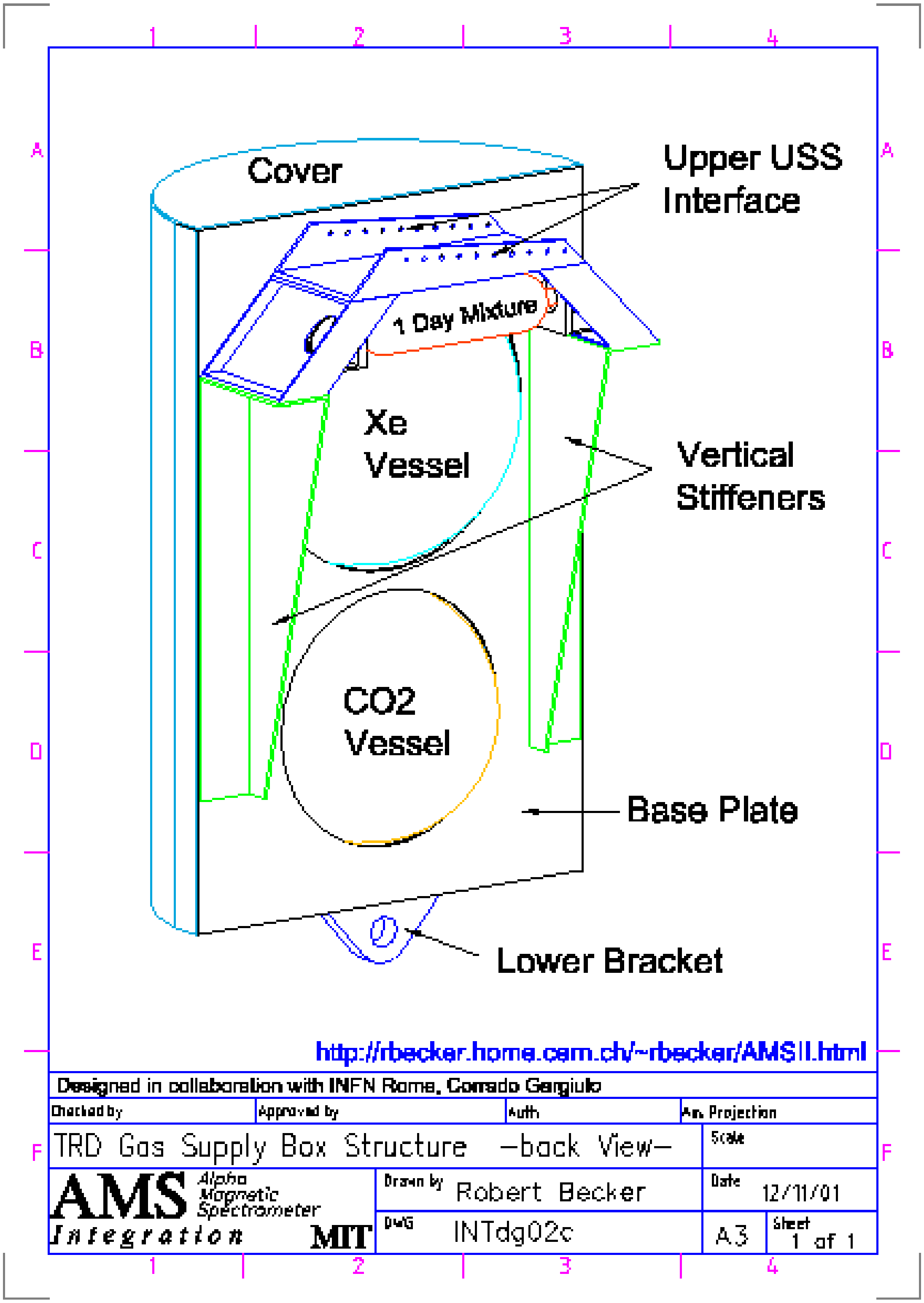


Figure 5.4.2.2 – TRD Gas Supply Box Structure (Sheet 2 of 3)

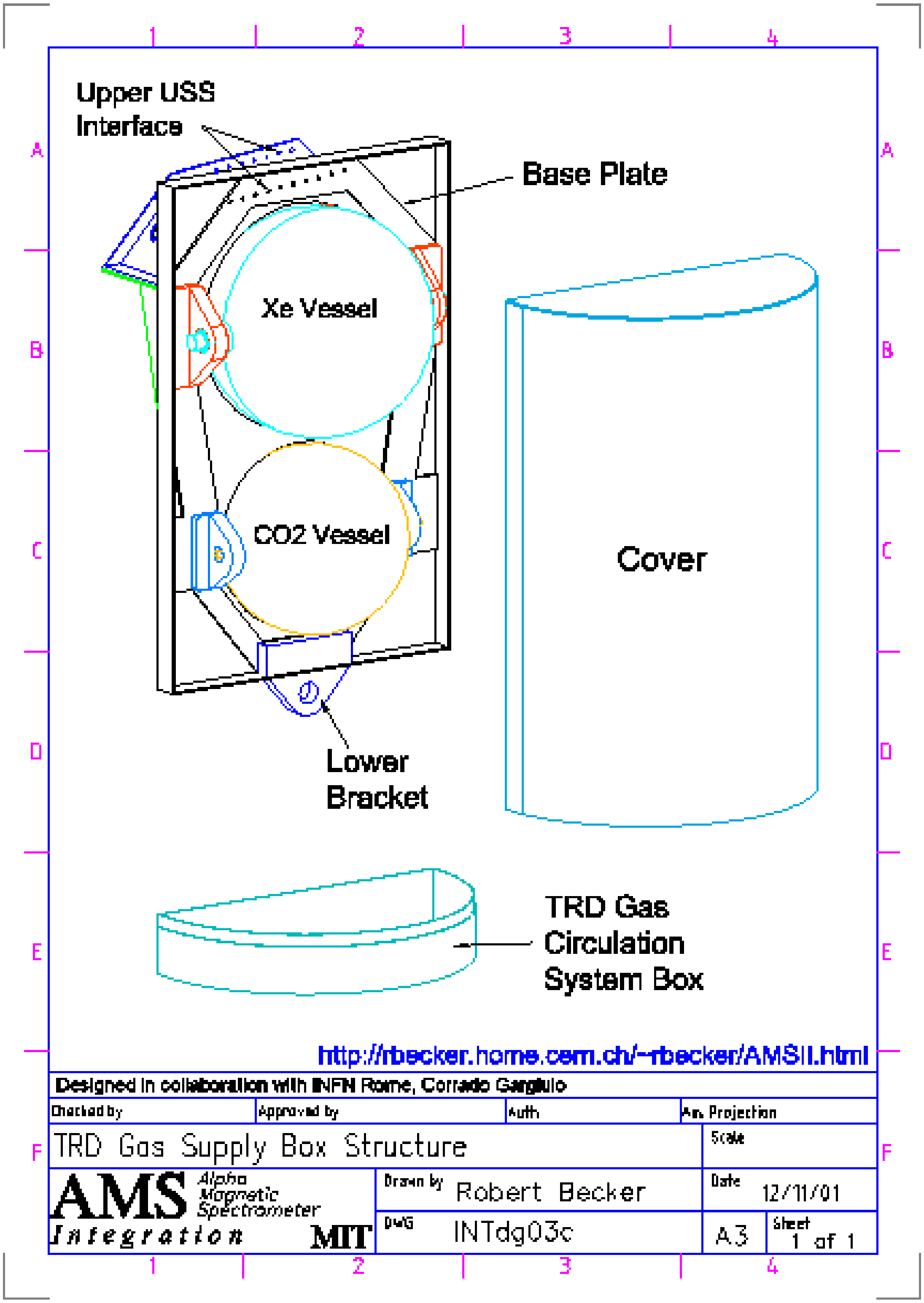


Figure 5.4.2.3 – TRD Gas Supply Box Structure (Sheet 3 of 3)

The TRD straw tubes have a maximum design pressure of 29.4 psid. The minimum and maximum design temperature is still TBD, but tests are ongoing. The relief valves will be set to 30 psia. The normal operating pressure is 14.7 to 20.4 psid on-orbit and 20.4 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 contain 430 cu. in. (7 liters) of gas. 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 the 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 Boxes S and C is activated by computer approximately once a day. The general layout is shown in Figure 5.4.2.4. The 41 sealed TRD segments of approximately 430 cu. in. (7 liters) each are held at 17.4 psi. Box C has an estimated volume of 150 cu. in., held below 29 psi by relief valves.

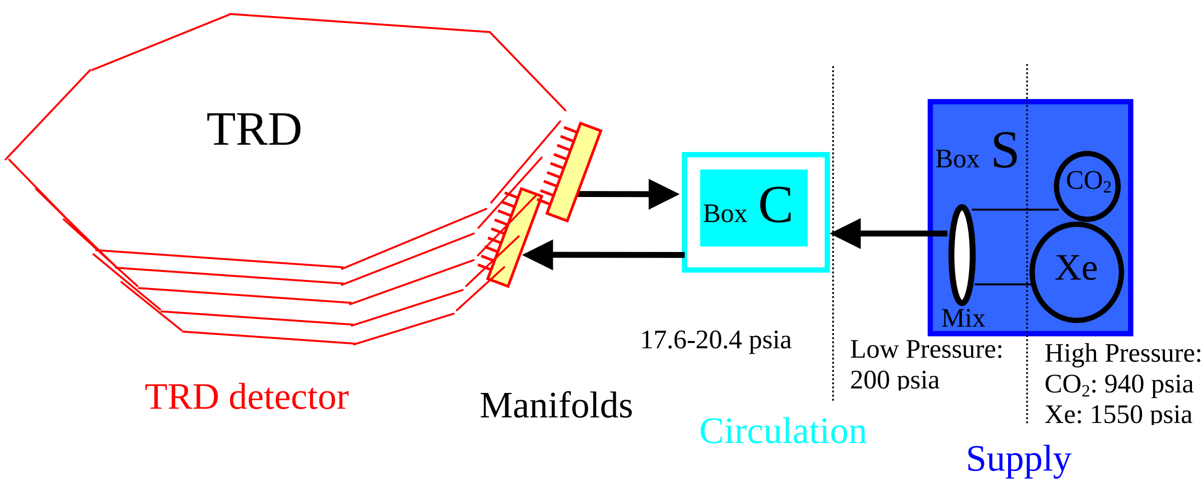


Figure 5.4.2.4 – Schematic Arrangement of the AMS-02 TRD gas system. All pressures are given at 77°F (25°C).

5.4.3 Box S Description

Box S contains the gas supply so that 7 liters/day of the fresh gas mixture may be provided to the TRD straw tube system. The flow diagram of Box S is shown in Figure 5.4.3.1.

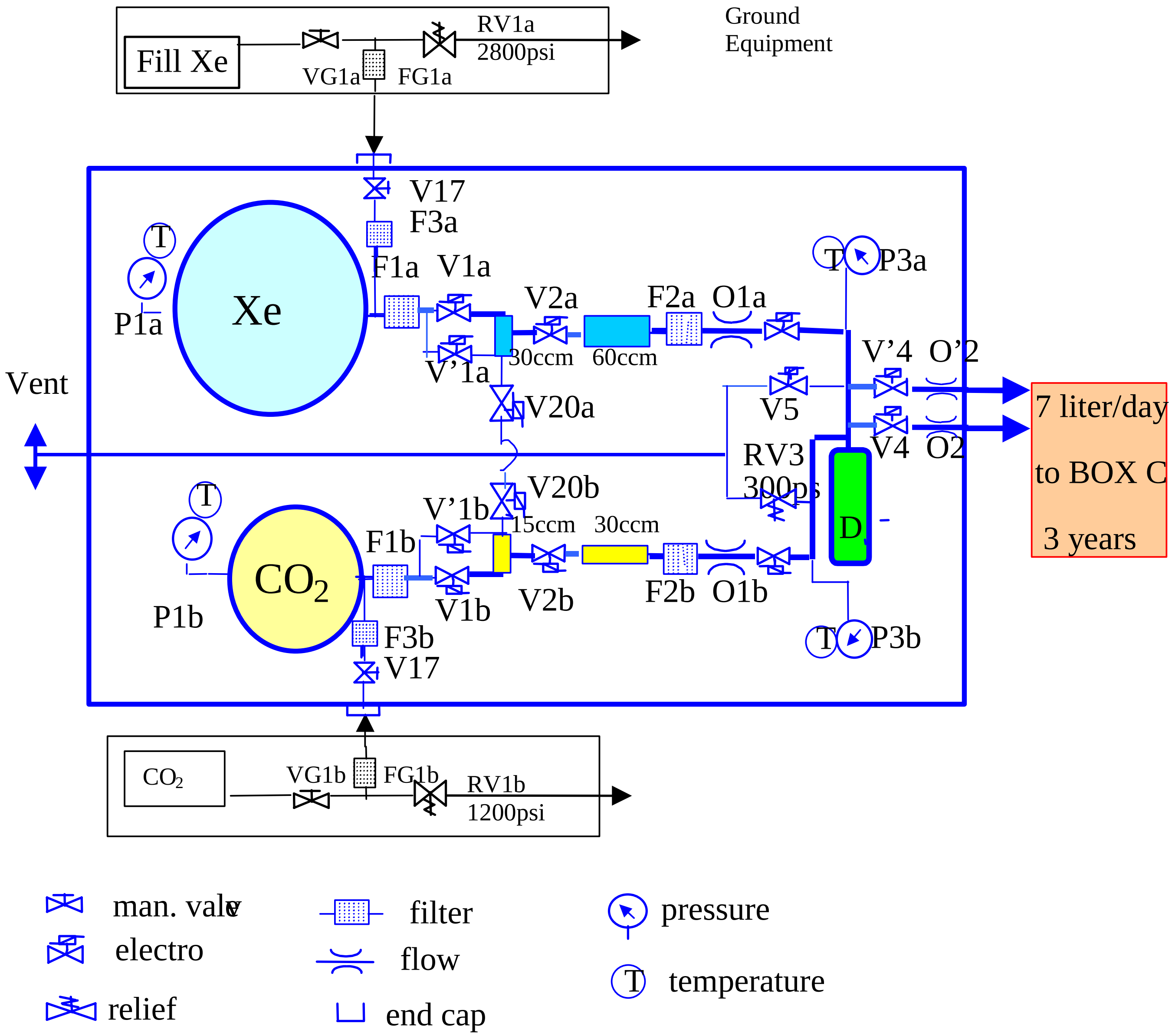


Figure 5.4.3.1 – Box S: TRD Gas Supply

5.4.3.1 Box S Component List

1. 3 Pressure Vessels, ARDE PN D4815 (Xe), PN D4816 (CO2),SKC 13181(mix)
2. 13 solenoids MV100, Marotta (V1a, V'1a, V1b, V'1b V2a, V3a, V2b, V3b, V20a, V20b, V4, V4', V5).
3. 2 Recoil valves with caps, Schwer (V17a 2mm thread, V17b 1.5 mm thread)
4. 4 Pressure sensors, T-compensated, GP50, Model.7900 (P1a,b 3000 psi, P3a,b 300 psia)
5. 6 Filters 7μm, Swagelok, ARDE mounts, (F1a,b, F2a,b)
6. 3 Flow restrictors/orifices, Lee Company's JEVA Jets (O1a: 2x 17.6 LKOhm JEVA 1840176H restrictors in parallel. O1b: 2x 80.0 LKOhm JEVA 1820800H restrictors in parallel. O2: 2x 7.3 LKOhm JEVA 1850773D restrictors in parallel)

5.4.3.2 Box S Operations

Filling ground state:

Vessels cleaned. Connect Xe ground supply to filling port of Box S at V17a. Close V1a and V2a and evacuate the fill lines and pressure vessel. Open valve to Xe ground supply (VG1). Transfer liquid Xe into container until weight = 109lb. Close V1a. Close V17a. Record temperature and pressure for 4 hours. If performance is as desired, cap V17a. Repeat process for CO_2 line. Filling ports will have different threads so that the wrong tank is not filled by accident.

Normal operation:

Mixing: Once per day: For the Xe line: Open V1a briefly (approx.100 ms) to fill the buffer volume between V1a and V2a. Open V2a briefly (approx.100 ms) to fill buffer volume between V2a and V3a. The filling of one buffer volume from another buffer volume allows us to reduce the pressure across O1a and results in better control of mixture composition. Open V3a until desired partial pressure of Xe has entered the mixing vessel D through the flow restrictor O1a. This may require the buffer volumes to be filled several times, during which V3a will be closed. Repeat procedure with the CO_2 branch until desired partial pressure of CO_2 is achieved. Wait 30 min. before transfer. Tests with a prototype system shows that this operation can be controlled via a computer and Universal Slow Control Module (USCM) and obtain the desired mixing accuracy.

Transfer: Several times per day V4 is opened under computer control to release fresh gas from the mixing vessel D into the circulation module BOX C. Transfer is limited to < 7 liters at 1 atm/day in normal mode. V4' is a redundant valve for gas transfer and is included for mission success.

Before Launch and During Power Off: All valves are closed. Mixing Vessel D will be at 1.2 Bar, as will the TRD straw tubes. Pressure and temperature monitoring from the ground should continue uninterrupted for as long as possible prior to launch, during flight to the ISS and mounting on the ISS.

5.4.4 Box C Description

The schematic for Box C is shown in Figure 5.4.4.1. The circulation pumps serve to move the gas through the system to ensure uniform gas properties. The purifier will be mounted on the outside of Box C for ground operations and will be removed prior to flight. It is connected by self-sealing connectors, which will be capped before launch.

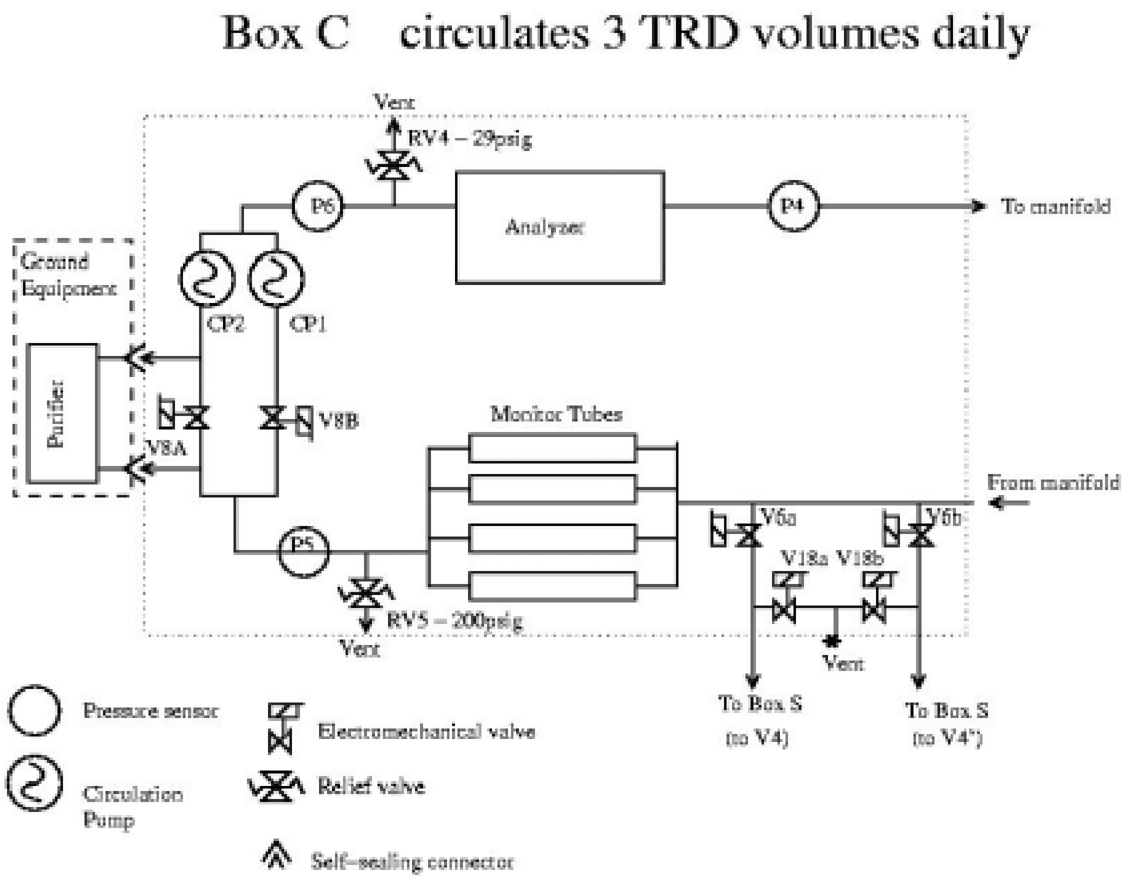


Figure 5.4.4.1 – Box C: TRD GAS Recirculation System

NOTE: The calibration tubes are labeled as monitor tubes in the figure.

5.4.4.1 Box C Component List

1. V6a, V6b, V18a, V18b; electromechanical solenoid valves, Marotta MV100
2. V8A, V8B; electromechanical flipper valves, Burkert, type 6123
3. CP1, CP2; circulation pumps, KNF Neuberger Inc, type UNMP30 KNDC B
4. P4, P5, P6 ; GP :50 pressure sensors, model 7950, range : 0--25psi.
5. RV4, RV5 ; Relief valves; StraVal
6. 4 Monitor tubes; hermitically sealed tubes for measuring gain. Each tube contains a weak (1 microcurie, 37kBq) Fe^{55} source.
7. Square One Technology model 2115 CO_2 analyzer.

5.4.4.2 Box C Operations

Definitions:

Normal – gas circulates through the straws, no purification.
Gas cleaning – (on earth) to remove oxygen and water from gas.
Daily filling – replace gas lost in normal operation.
System pressure test – check for loss anywhere in straw system by looking for pressure change when system is closed.
Segment pressure test – isolate single segment and monitor pressure while isolated.
Recovery Xe from AMS – remove Xe from Xe storage tank in Box S on ground if need arises.
Gas composition check – check for contamination of gas with residual gas analyzer (on ground only).

Operations before launch:

System should be filled and circulating through the purifier well before launch. Circulation should continue until as close to launch time as possible, at which point the pumps are turned off. Before power off for launch, all segment valves should be closed.

Operations after launch at startup:

1. Isolate all segments.
2. Check for losses in each segment.
3. Open all working segments.
4. Start CP1, begin normal operation.

Operations for return:

1. Stop CP1 or CP2.
2. Close all segment valves.

5.4.5 Straw Tube Segments

From the Box C/Box S assembly, 6mm 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 the input and output manifolds (See Figure 5.4.5.1). Each segment is small enough so as not to be considered a pressure vessel (1 bar$\times$7 liters=0.7 kJ). Each manifold is connected to the 41 TRD segments via pressure controlled isolation valves. 0.1 inch (3mm) steel tubing runs from the isolation valves to the segment inputs and outputs, where it is joined to PEEK tubing via RWTH Aachen designed special connectors. Where other connections need to be made, Cajon VCR fittings are used. (See Figure 5.4.5.2 for gas manifold locations.)

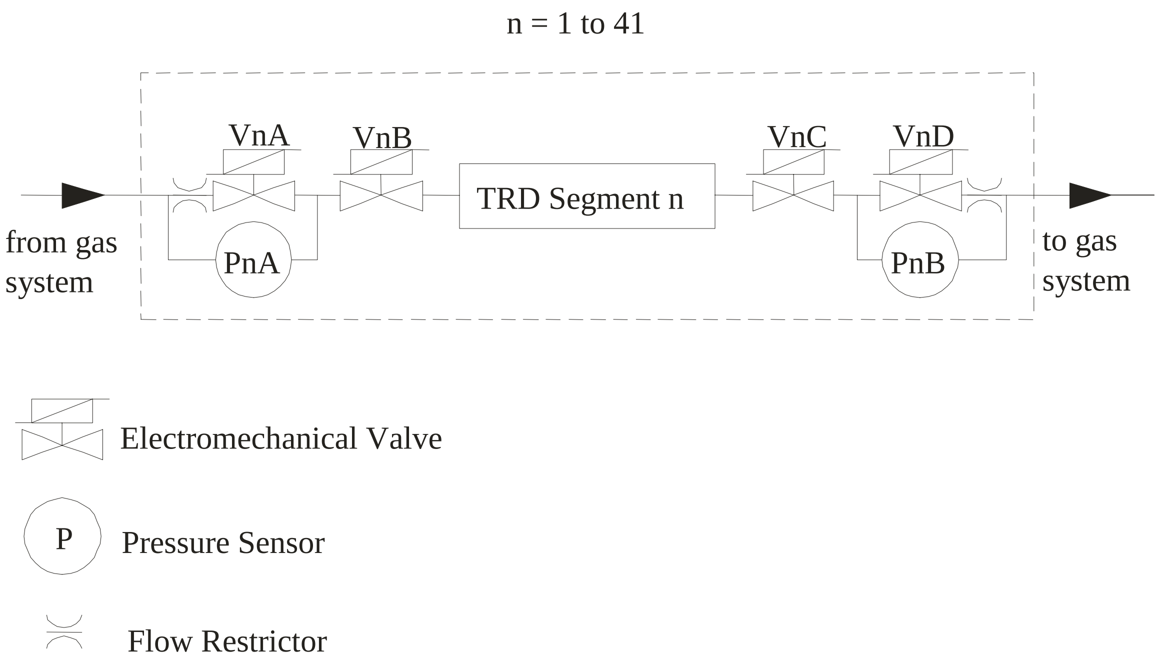


Figure 5.4.5.1 - One of 41 TRD Straw Tube Segments

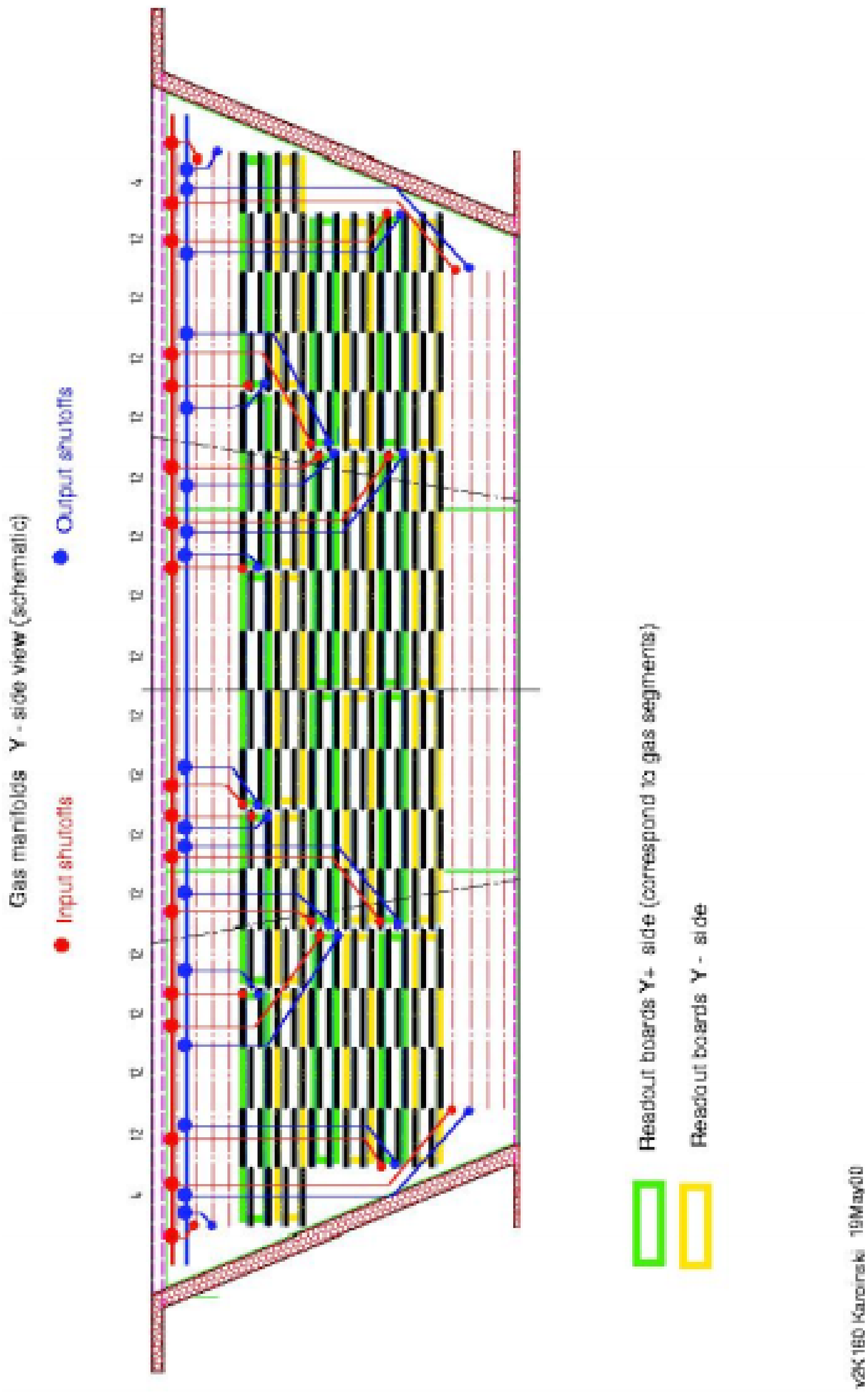


Figure 5.4.5.2 - Gas Manifold Connections to TRD Segments

The isolation system works in two modes. In case of a sudden pressure drop in a segment, the control computer will shut 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 all four valves and monitor the pressure. 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 6123 2/2 Way Flipper Valves. Closed, they hold 43.6 psi (3 bar) in either direction and have been leak tested to better than 0.1 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, 100 ms 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.

5.4.6 Monitoring and Control

The electronics that control the gas system will be located in a single crate. The 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 Control Computer (MCC). The USCM will be provided with interface electronics to the various gas transducers and actuators scattered 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 100 temperature sensors distributed around the TRD and gas system.
5. Control two recirculation pumps.
6. Provide logic control for about 200 gas valves.
7. Provide HV for the calibration tubes in Box C. The tubes analyze the pulseheight spectrum from a weak (approximately 1 microcurie, 37kBq) Fe^{55} source to monitor the quality of the gas with a gain measurement.
8. The interface electronics will provide the power electronics to drive valves, etc.
9. Read out digital signals from the gas analyzer and 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 gas gain tubes are doubled to provide single fault tolerance for mission success. The USCM does not have any 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, and to choose which pump is in-line with the overall gas circuit, remain in whatever state they were when power went off. This means that, on-orbit, if there is a leak which develops in the TRD when power is off, the worst that would happen is that we would lose (slowly, if the leak is in a single sector) the approximately 300 liters of gas in the TRD, which is small compared to the 10,000 liters of gas taken up in the Xe and CO_2 tanks. Any sector previously isolated because of a leak would 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 HV system consists of 88 HV boards distributed around the TRD in the vicinity of the readout cards. The HV boards are doubled to provide single fault tolerance for mission success. The schematic of the HV system is shown in Figures 5.4.6.1 & 5.4.6.2. Each unit provides +1600V (control range: 700-1750V) with current limited to <100 micro amps. The boards are directly located at the ends of the tubes to which they supply HV, so that there is no exposed HV or cabling.

Mounted inside the Gas Supply System Box C are 4 calibration tubes (See Figure 5.4.4.1), which monitor the gas gain changes for locally different temperatures. The calibration tubes have an inside diameter of 0.24 inch (6 mm) like the straw tubes; however, they are mounted inside a stainless steel container (See Figure 5.4.6.3). On the inner wall is a 0.2 microcurie deposit of Fe^{55}. The 0.04 inch (1 mm) wall attenuates the 5.9 keV radiation to a level less than detectable. The outer stainless steel container seals in the radiation again and supplies the gas for calibration.

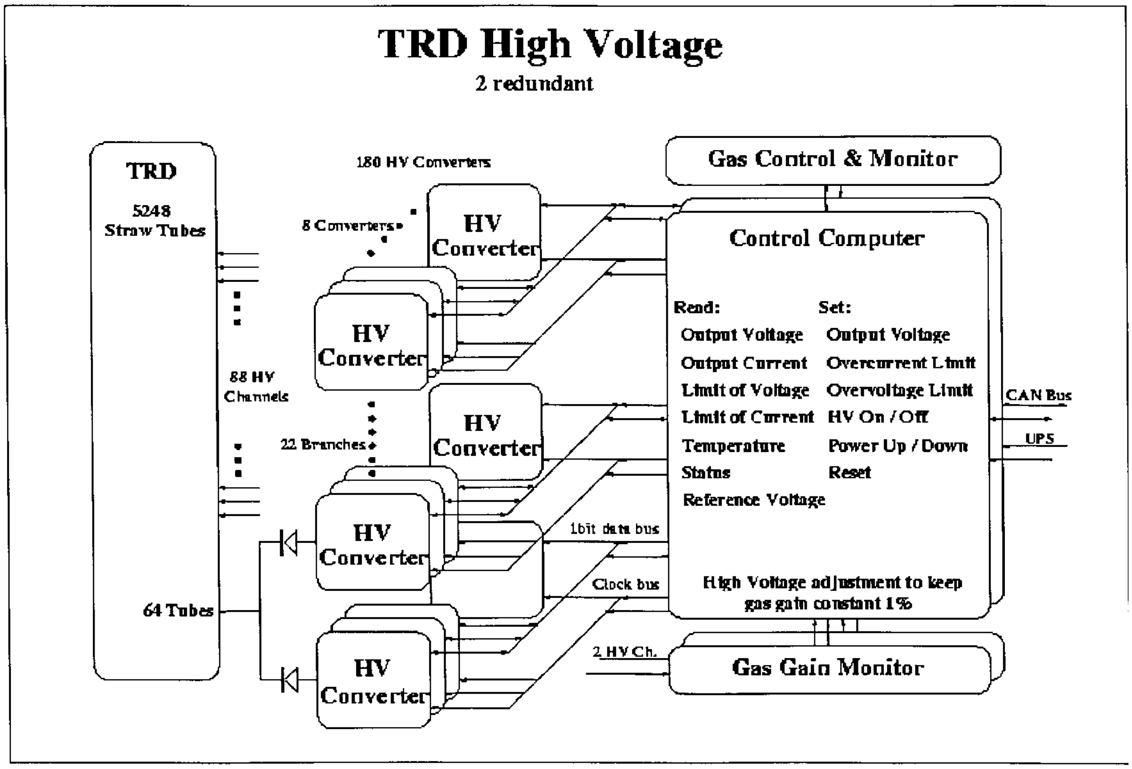


Figure 5.4.6.1 – TRD High Voltage System

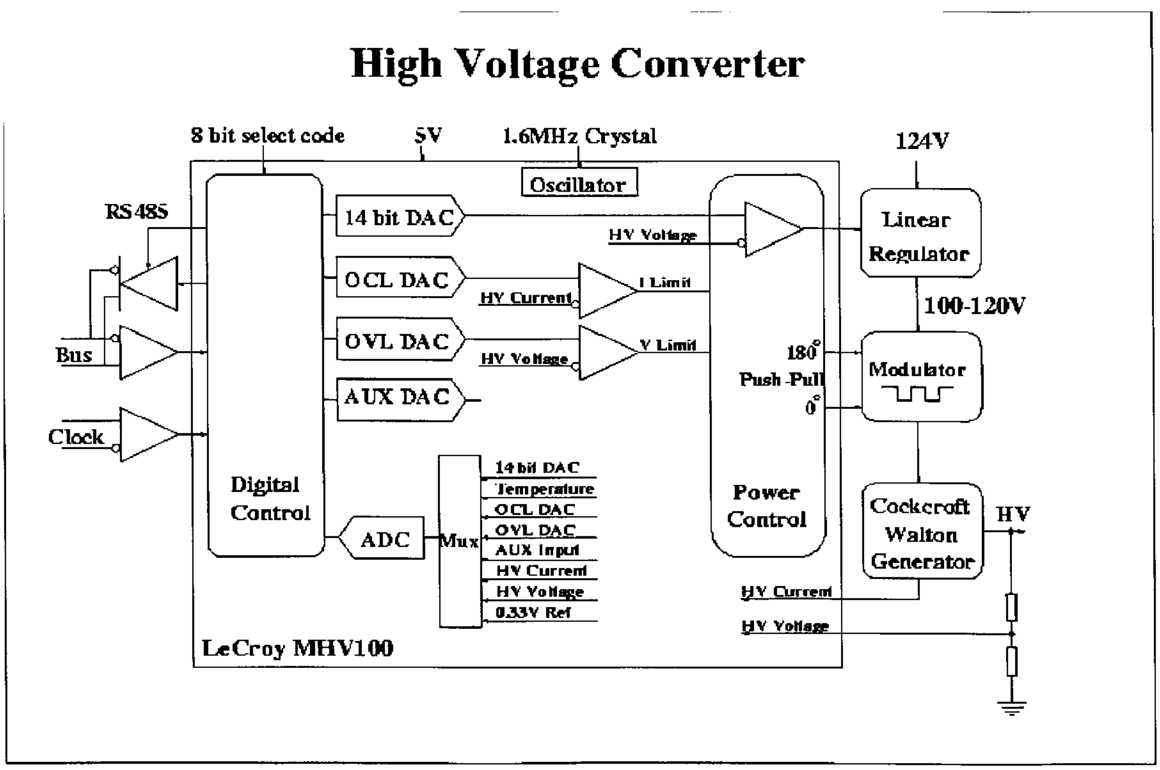


Figure 5.4.6.2 – High Voltage Converter

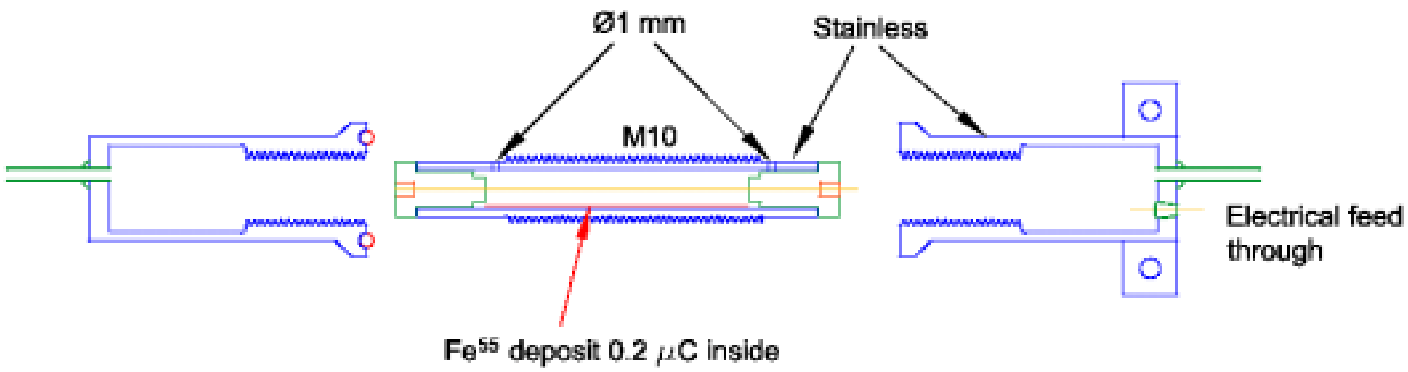


Figure 5.4.6.3 – Calibration Tube with Doubly Contained Weak Source

5.5 TIME-OF-FLIGHT (TOF) SCINTILLATOR COUNTERS

Across the top and bottom of the cylindrical magnet are 4 layers (2 on the top and 2 on the bottom) of TOF scintillator counters. The scintillators provide the trigger function for selection of a single particle or nucleus cleanly traversing the magnet bore. The counters are 10 mm thick and are made of polyvinyl toluene (a Plexiglass-like material) (See Figures 5.5.1 thru 5.5.3). They are enclosed in a cover made of carbon fiber with an aluminum foil surface on the inside and outside. At the ends of each panel are light guides which direct the light of scintillation to photo multipliers. Two large flat aluminum honeycomb panels are used to support the scintillator counters. The upper TOF attaches via brackets to the TRD corner joints which hard-mount to the USS-02 upper corner joints. The lower TOF honeycomb is supported to the lower USS-02. The honeycomb panels are roughly circular with a 60.6 inches (1540 mm) equivalent outside diameter. The thickness of the honeycomb aluminum core is 1.97 inches (50 mm) and the aluminum skin is 0.04 inch (1 mm) thick.

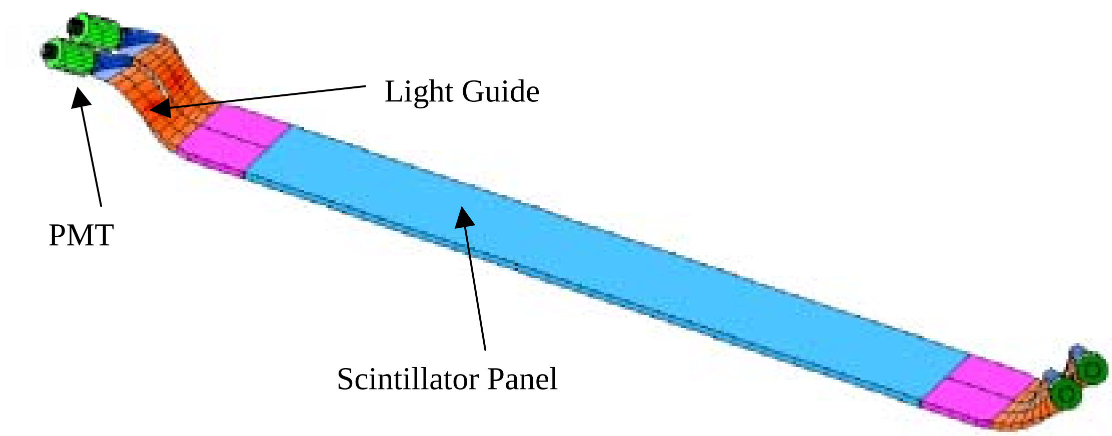


Figure 5.5.1 – Single TOF Counter

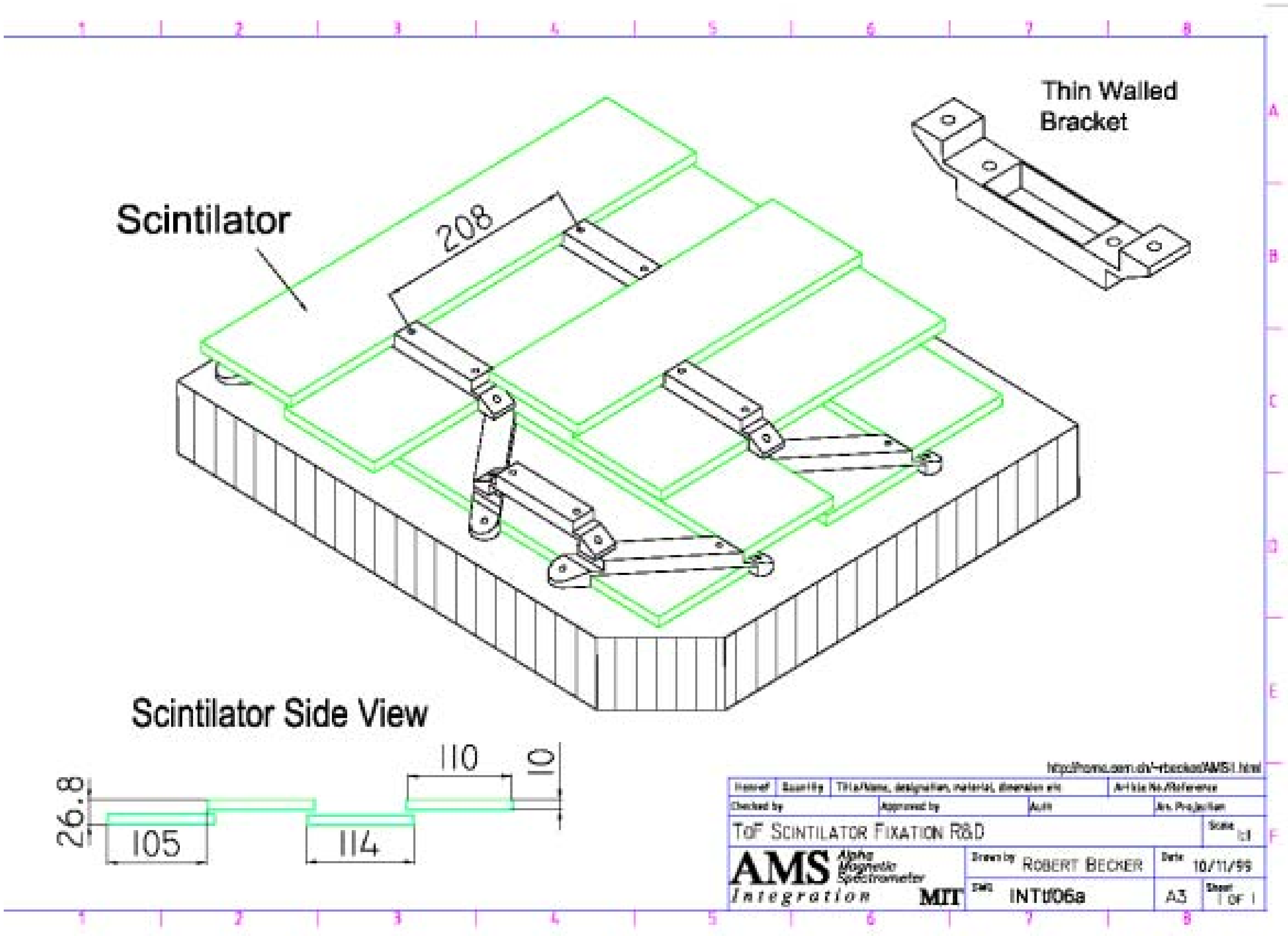


Figure 5.5.2 – TOF Scintillator Fixation

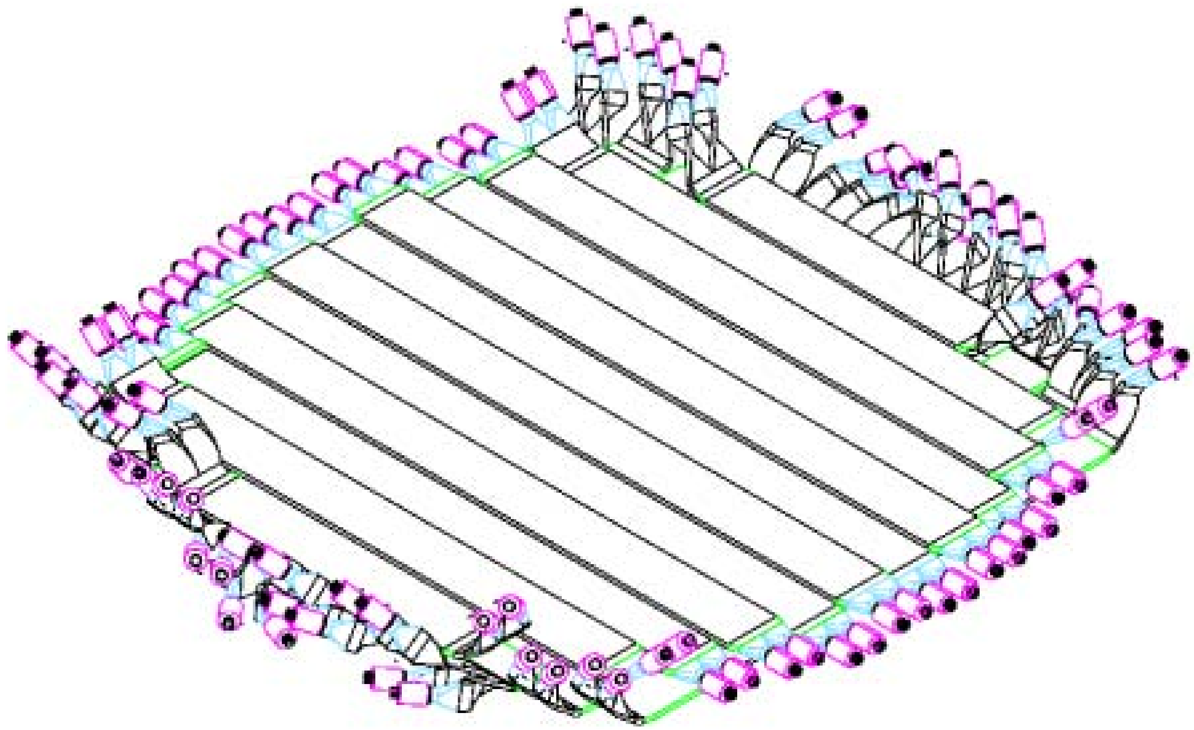


Figure 5.5.3 – TOF Counters Assembly

5.6 RING IMAGING CHERENKOV COUNTER (RICH)

The RICH is located near the bottom of the experiment stack and weighs ~406 lbs (184 Kg). The RICH assembly is shown in Figures 5.6.1 & 5.6.2. The RICH is composed of two primary pieces. The first section contains all of the Photomultiplier Tubes (PMTs) and the second section is the reflector. The first section is made of aluminum cross braces that attach to the USS-02 at 8 locations. The 8 connections to the USS-02 are made with pins/bolts and isolated with Bellville washers. This allows the RICH to be supported without carrying a significant load from one side of the USS-02 through the RICH to the other side. In between the welded cross bracing, the rectangular and triangular PMT units are screwed in place. The PMT units house the numerous PMTs. The reflector section is extremely light and is made of composite material with several layers of spray-on gold, alumina, chromium, and quartz. The alumina/quartz is used as the reflective surface. This surface is completely inside the detector and must be light tight. It is likely that a meteoroid and orbital debris shielding will be used on the outside of the reflector, but the details are still TBD. The RICH utilizes an aerogel radiator material, but this material is physically attached to the lower TOF honeycomb.

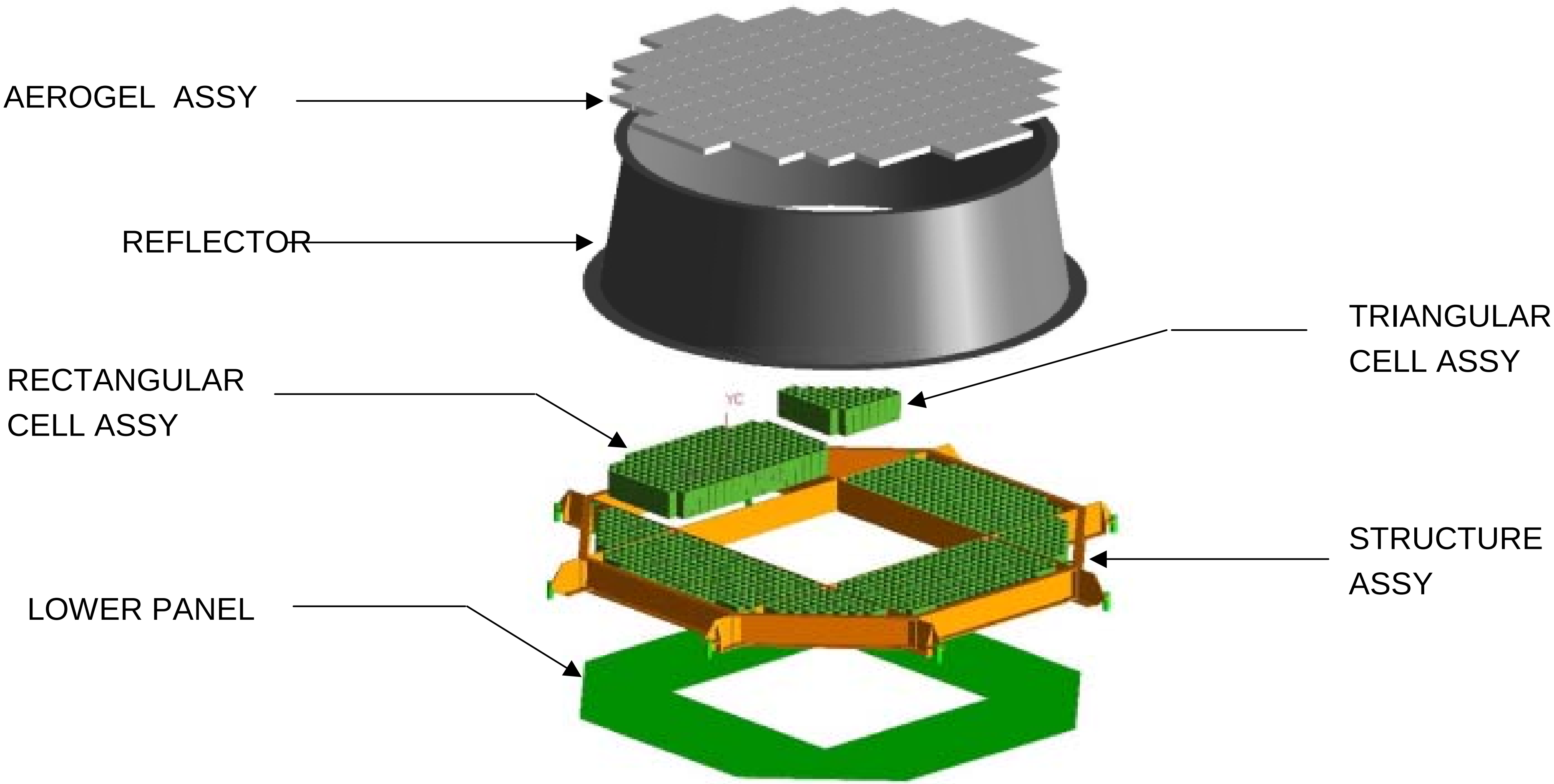


Figure 5.6.1 – RICH Assembly (Exploded View)

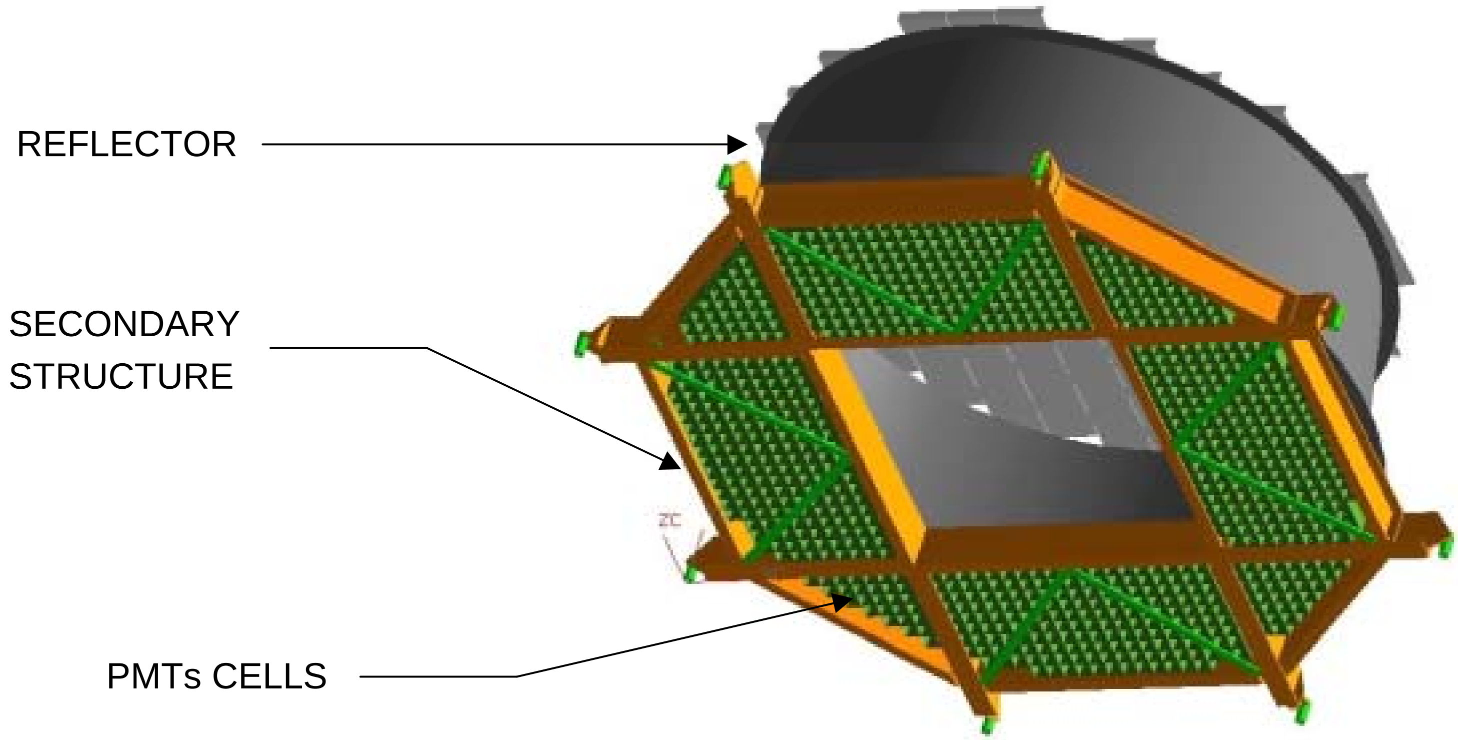


Figure 5.6.2 – RICH Assembly (Lower View)

5.7 ELECTROMAGNETIC CALORIMETER (ECAL)

The main physics goals of the AMS-02 ECAL are: a) to measure the energy of electrons, positrons and gammas up to 1 TeV, b) to ensure the identification of electromagnetic (e.m.) and hadronic cascades with a discrimination capability better than 10^{-4}. To reach these objectives, the ECAL must be able to reconstruct the electromagnetic showers development with high accuracy.

The active part of the ECAL consists of layers of lead foils and scintillating fibers (See Figure 5.7.1). Each lead foil is 0.04 inch (1 mm) thick and is shaped to accommodate scintillating fibers. Small semicircular grooves are machined on both sides of the lead foil. The scintillating fibers are placed in each of the grooves and then another layer of the machined lead is glued to the top and bottom of the first layer. The fibers are glued to the lead foils by means of a bicomponent epoxy glue. The lead foils are squares with 25.9 inch (658 mm) long sides. The scintillating fibers have a 0.04 inch (1 mm) diameter and are 25.9 inch (658 mm) long. Horizontally the fibers are 0.05 inch (1.35 mm) apart, while vertically they are 0.07 inch (1.88 mm) apart.

The active part is subdivided into 9 sub-samples, called “superlayers”. Each superlayer consists of eleven layers of the glued lead foils, as described above, with the fibers running in the same direction. Each superlayer is 0.7 inch (18.5 mm) thick. The superlayers are assembled so as to have fibers running in orthogonal directions (X and Y), alternatively. With this kind of structure, e.m. showers development can be studied with the required accuracy.

The ECAL is ~ 31.5 inches (800 mm) square x 9.8 inches (250 mm) high and weighs ~1407 lbs (638 Kg). Nearly half of this weight is due to the lead foils. The mechanical supporting structure for the ECAL comprises a box embedding the sensitive part of the detector and four brackets attaching the box by its four corners to the USS-02 (See Figures 5.7.2 thru 5.7.4). The box is made of 6 elements. 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 plate, 4 inch (10.16 cm) thick, carved with squared holes of 1.26 inch (32 mm) sides to house the light collection system. Two sides, serving 4 superlayers, have 72 holes while the two other faces, serving 5 superlayers, have 90 holes each. For each hole, the light collection system consists mainly of a mu-metal square tube for magnetic field shielding, light guides and Photomultipliers (PMs) (See Figures 5.7.5). They are located together with the PM base and front end electronics. An Aluminum backplate is fixed on the rear side of each lateral panel to keep all the light collection systems in the right position and to prevent any displacements of the systems themselves.

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. The four mounting locations include a radially slotted hole 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.

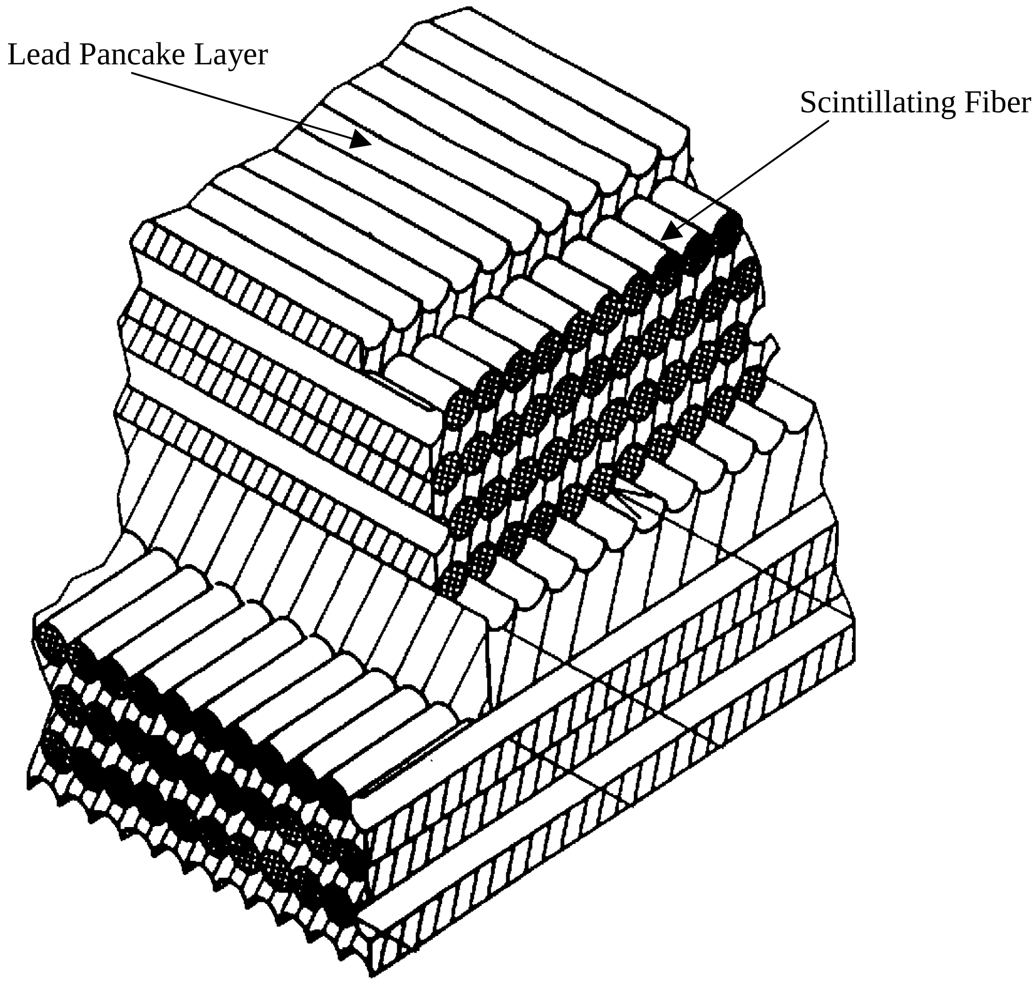


Figure 5.7.1 – ECAL Active Detector

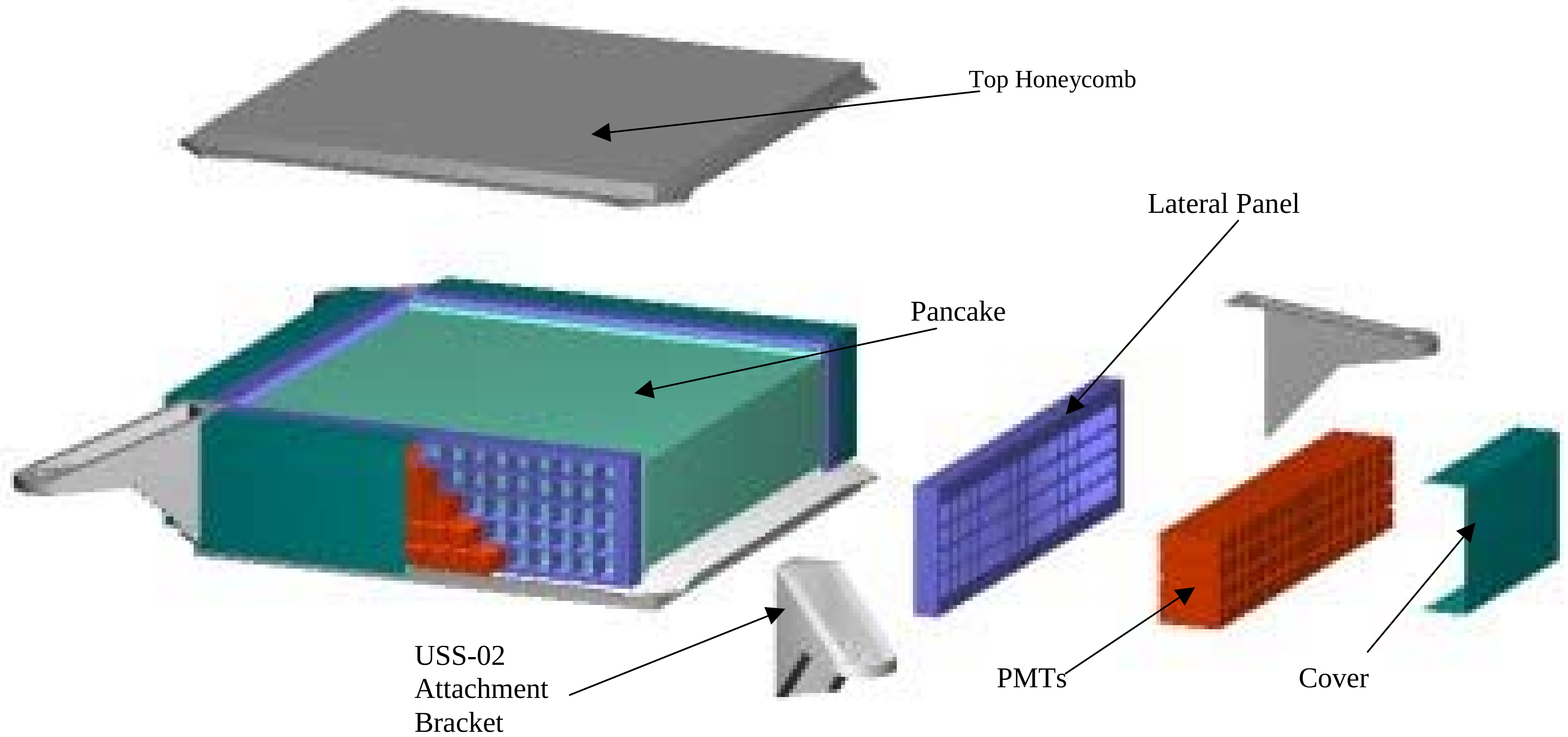


Figure 5.7.2 – Main Parts in ECAL Structure

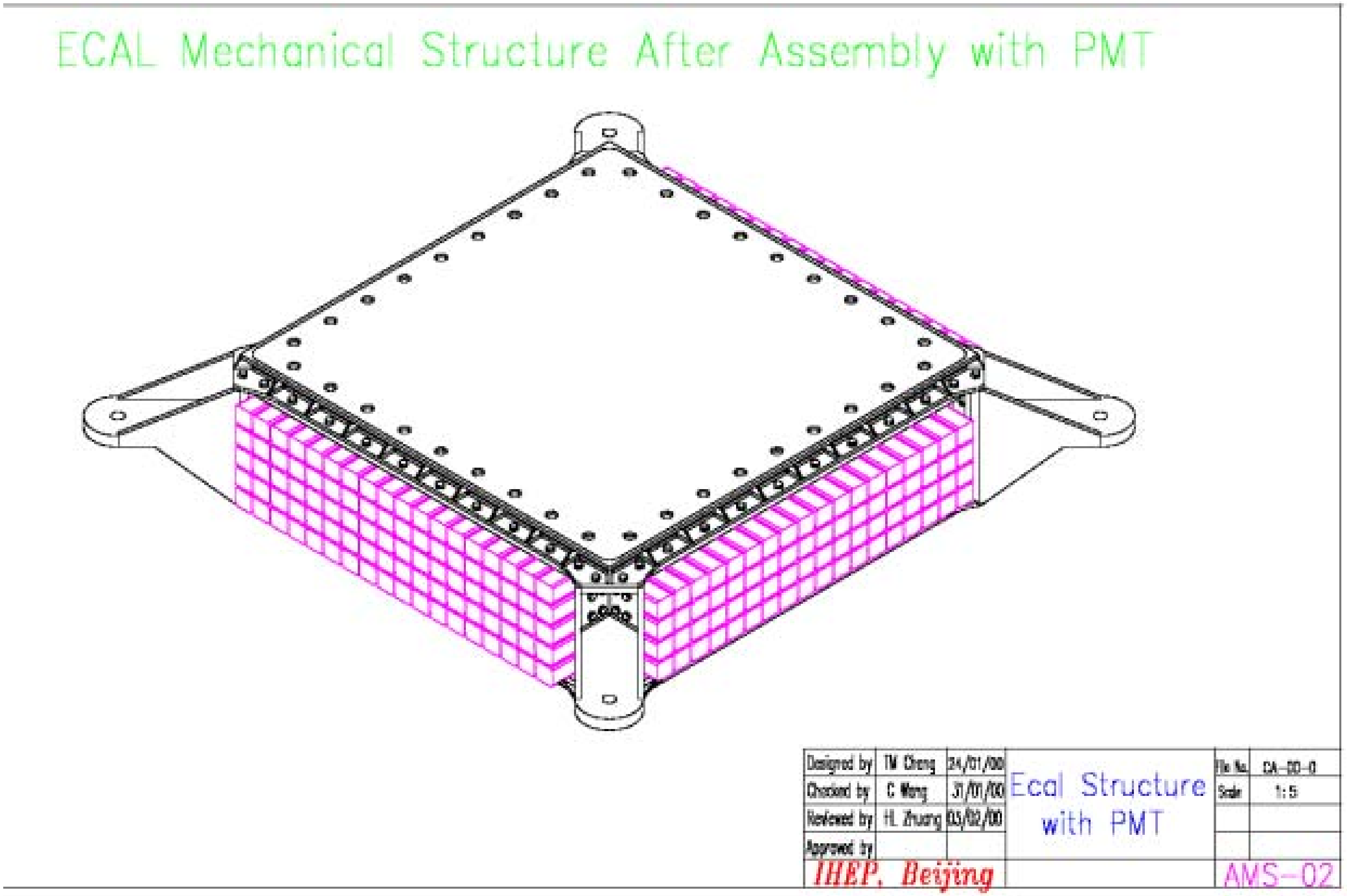


Figure 5.7.3 – ECAL Mechanical Structure After Assembly with PMTs

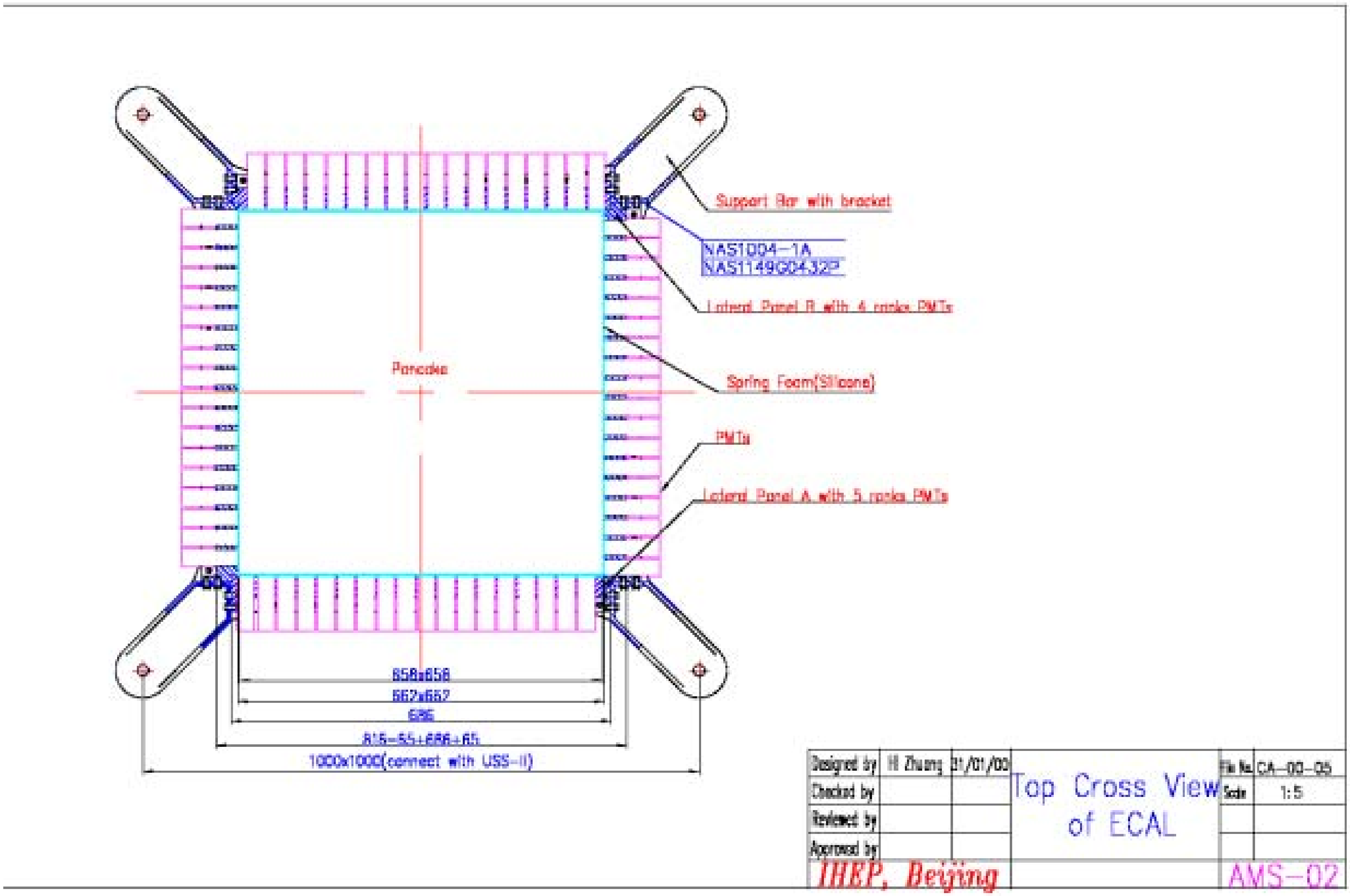


Figure 5.7.4 – Top Cross View of ECAL

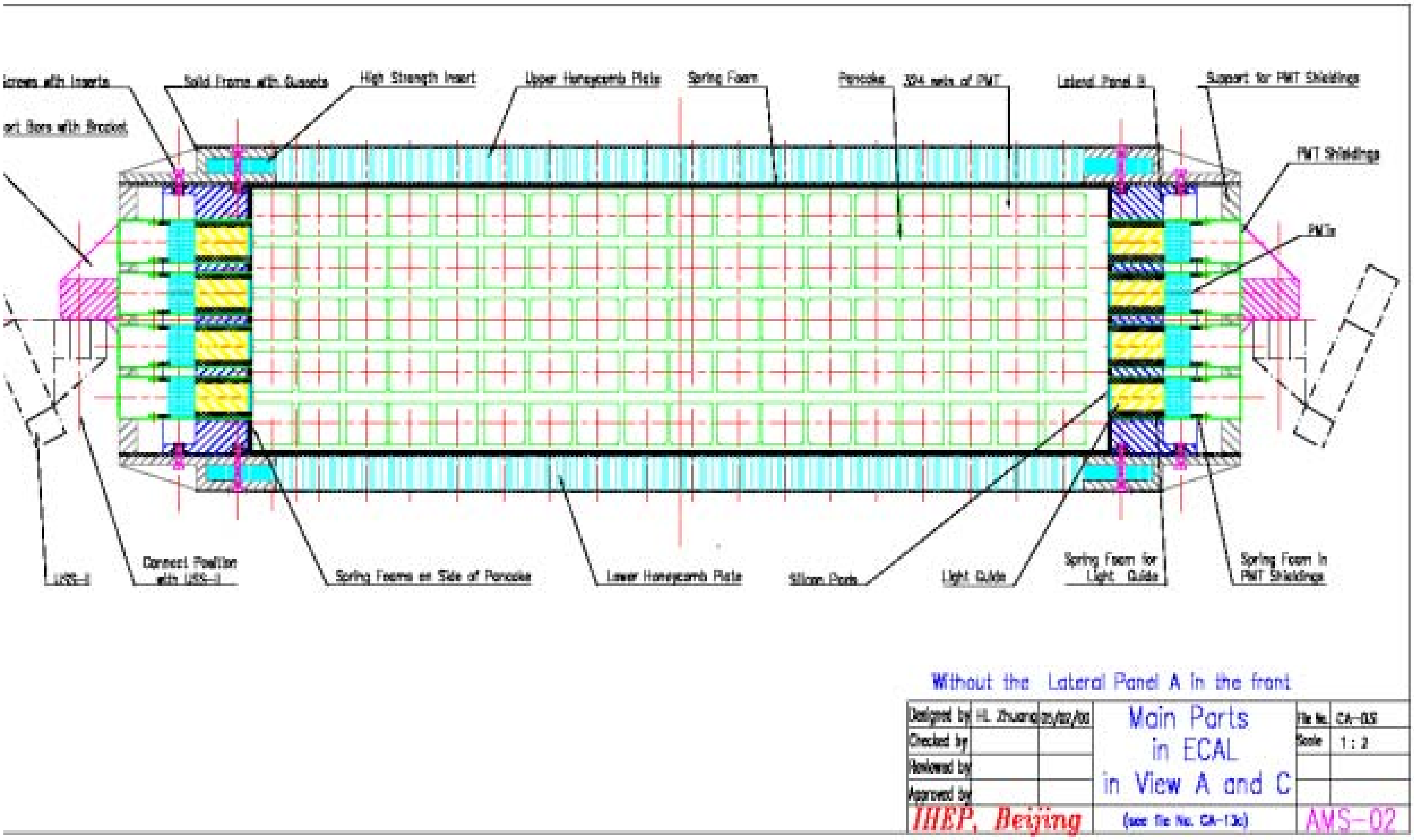


Figure 5.7.5 – Main Parts in ECAL in View A and C

5.8 DATA & INTERFACE ELECTRONICS

The data and interface electronics for the AMS-02 experiment will be housed in electronics crates on the outside of the Unique Support Structure-02 (USS-02). The electronics crates will have aluminum covers. The data and interface electronics will enable the connection of the AMS-02 experiment to the ISS and STS data systems.

During the Shuttle portion of the mission, the AMS-02 will utilize an SSP provided Portable Computer System (PCS) level PC with expansion chassis, replaceable hard-drives, internal Small Computer Systems Interface-II (SCSI-II), and a payload supplied DIGI-board interface card to record AMS-02 High Rate data. Cabling will be provided to a Payload Data Interface Panel (PDIP) in the Aft Flight Deck to interface with the AMS-02 via a bi-directional RS-422 connection (See Figure 5.8.1). This data will be recorded continuously during the AMS-02 operation on the Shuttle. A separate RS-422 connection from the AMS-02 via the PDIP, will allow for downlink of this data via the Ku-Band, as scheduling permits.

During ground operations on the Shuttle, the cabling for the DDRS-02 will be looped-back to the PDIP to allow for transmission of the data through the T0 umbilical.

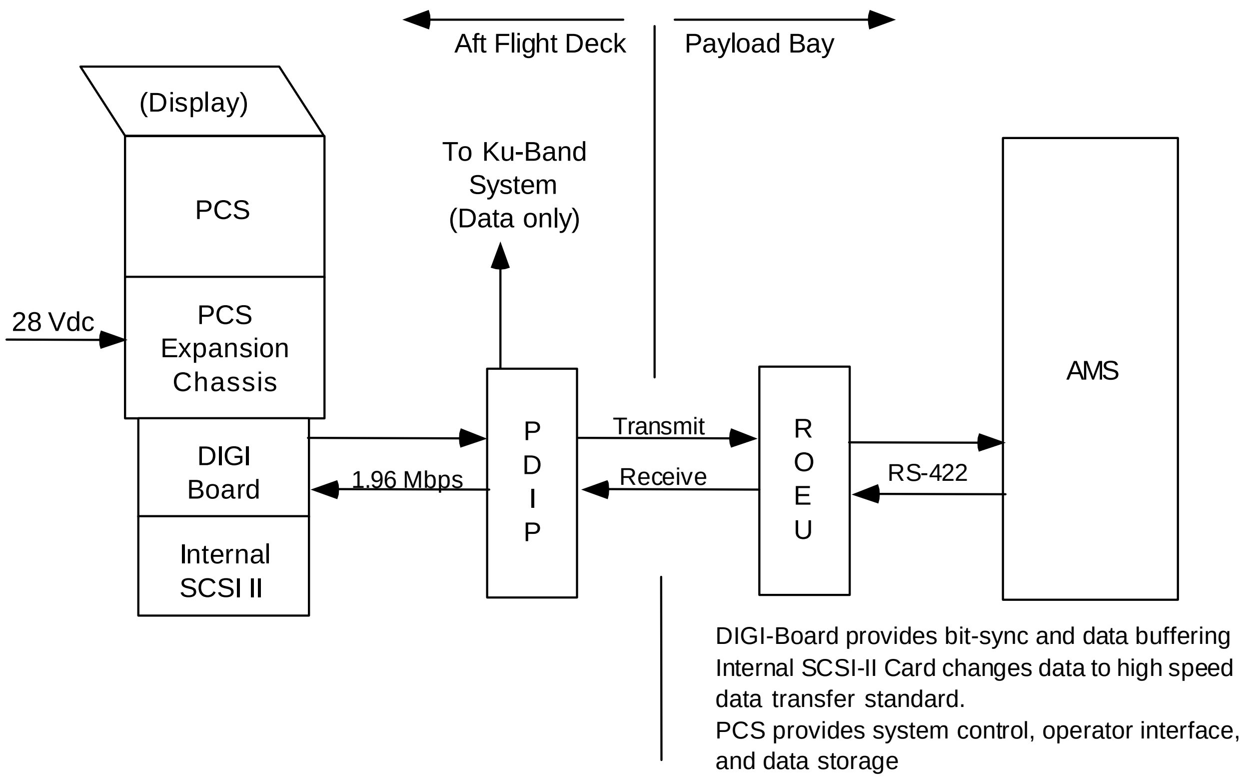


Figure 5.8.1 – AMS-02 Digital Data Recording System-02 (DDRS-02)

5.9 ELECTRICAL CABLES

The AMS-02 will be equipped with an ISS provided passive Umbilical Mechanism Assembly (UMA) which will be mated to the ISS active UMA when the AMS is installed on the ISS. Mission Integration provided cables will run from the passive UMA to an Extravehicular Activity (EVA) accessible interface panel that will be used to attach to the AMS-02 instrument for both data and power cables. This will be to provide the interfacing between the AMS-02 data/interface electronics and the ISS data systems, and the AMS-02 experiment power distribution system and the ISS electrical power system via the UMA.

Some AMS-02 electrical cables will be required in the pressurized module to provide data interfacing between the ACOP and the AMS-02 instrument located on S3. The ACOP will house the hard drive recorder and other data interfaces for the AMS-02, as well as power for the ACOP from the EXpedite the PRocessing of Experiments to Space Station (EXPRESS) Rack.

5.10 MONITORING AND CONTROL COMPUTERS (MCCs)

Two MCCs are mounted on the USS-02 or the electronics racks. The MCCs provide the primary data interface between the AMS-02 Experiment low rate data system and the ISS 1553 data bus. The ISS 1553 data bus provides the housekeeping data from the AMS-02 Experiment (for transmission to the ground) and command capability to the AMS-02 Experiment via ground uplink or ISS provided PCS laptops.

5.11 POWER DISTRIBUTION BOX (PDB)

The AMS-02 PDB is mounted on the USS-02 near the passive UMA. The purpose of the PDB is to provide the power interface circuitry between the AMS-02 and the ISS and STS. The PDB receives 124v dc power from either or both of the ISS power buses or the STS. It converts this voltage to 28v dc for distribution to the various AMS-02 subsystems, assuring compliance to the power requirements of SSP 57003 and ICD-2-19001 (See Figure 5.11.1). The PDB also distributes the 124v dc power to the AMS-02 Magnet Cryo Avionics Box (CAB) and to the Cryocooler Controllers. The AMS-02 avionics interfaces block diagrams and interconnect diagrams with the STS and ISS are shown in Figures 5.11.2 thru 5.11.5.

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Figure 5.11.1 – AMS-02 Power Schematic

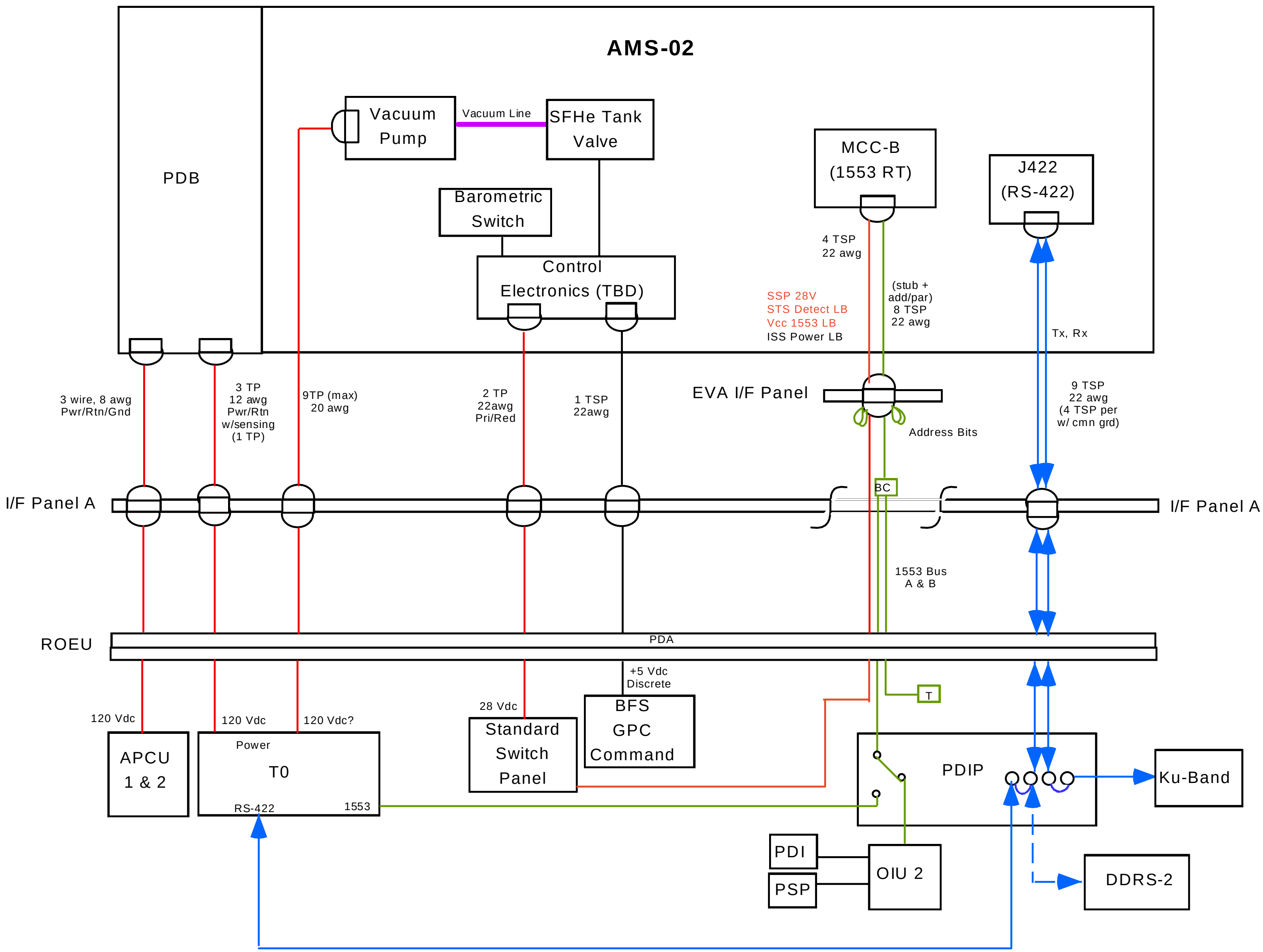


Figure 5.11.2 – AMS/Pad & STS Avionics Interconnect Diagram

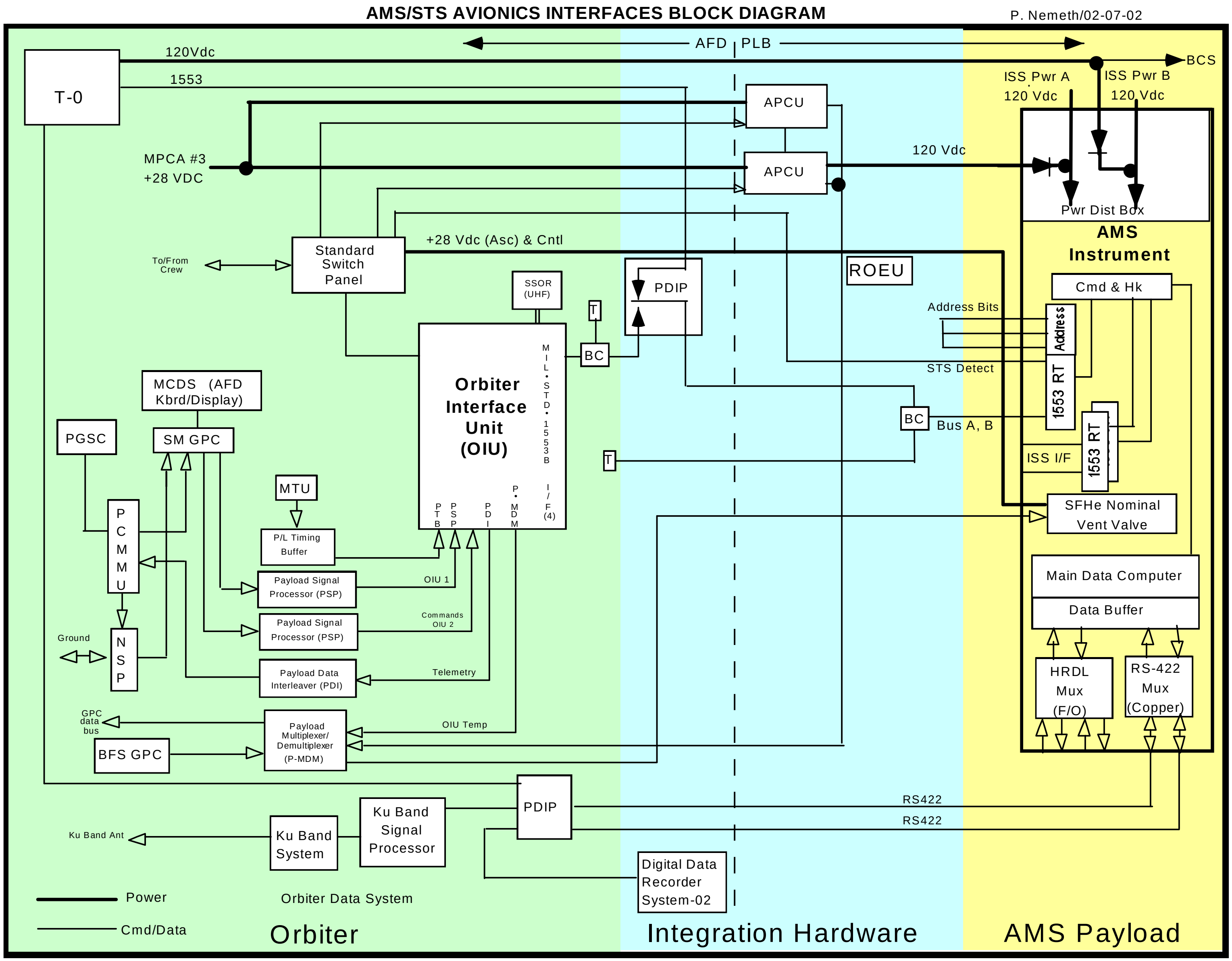
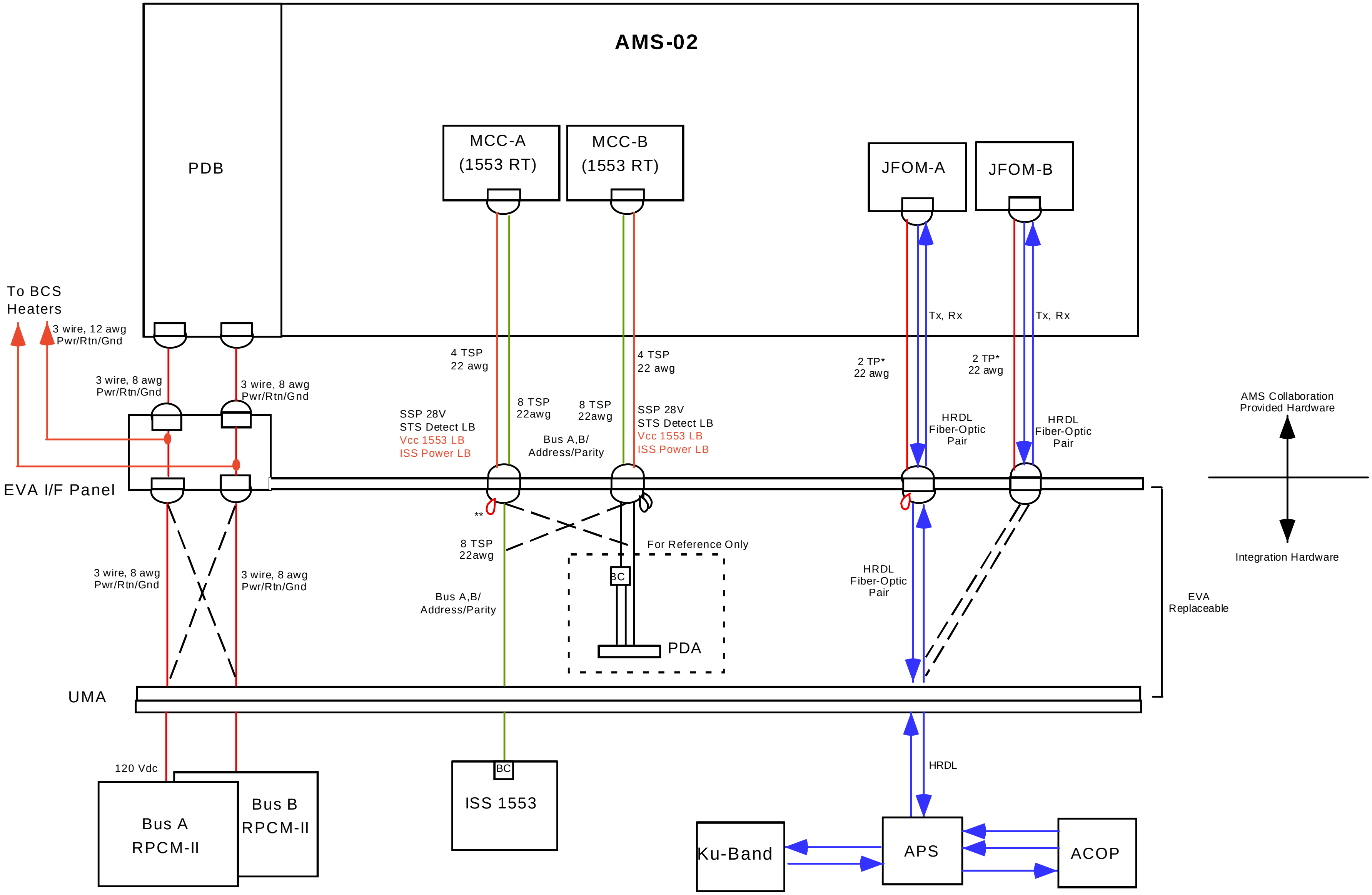


Figure 5.11.3 – AMS/Pad & STS Avionics Interfaces Block Diagram



* These Twisted Pairs are designed to be looped back on the EVA connector which attaches to the UMA cable, to supply power to the Fiber Optic modules (from AMS) only when required.

** AMS internal loop back for Vcc 1553

Figure 5.11.4 – AMS/ISS Avionics Interconnect Diagram

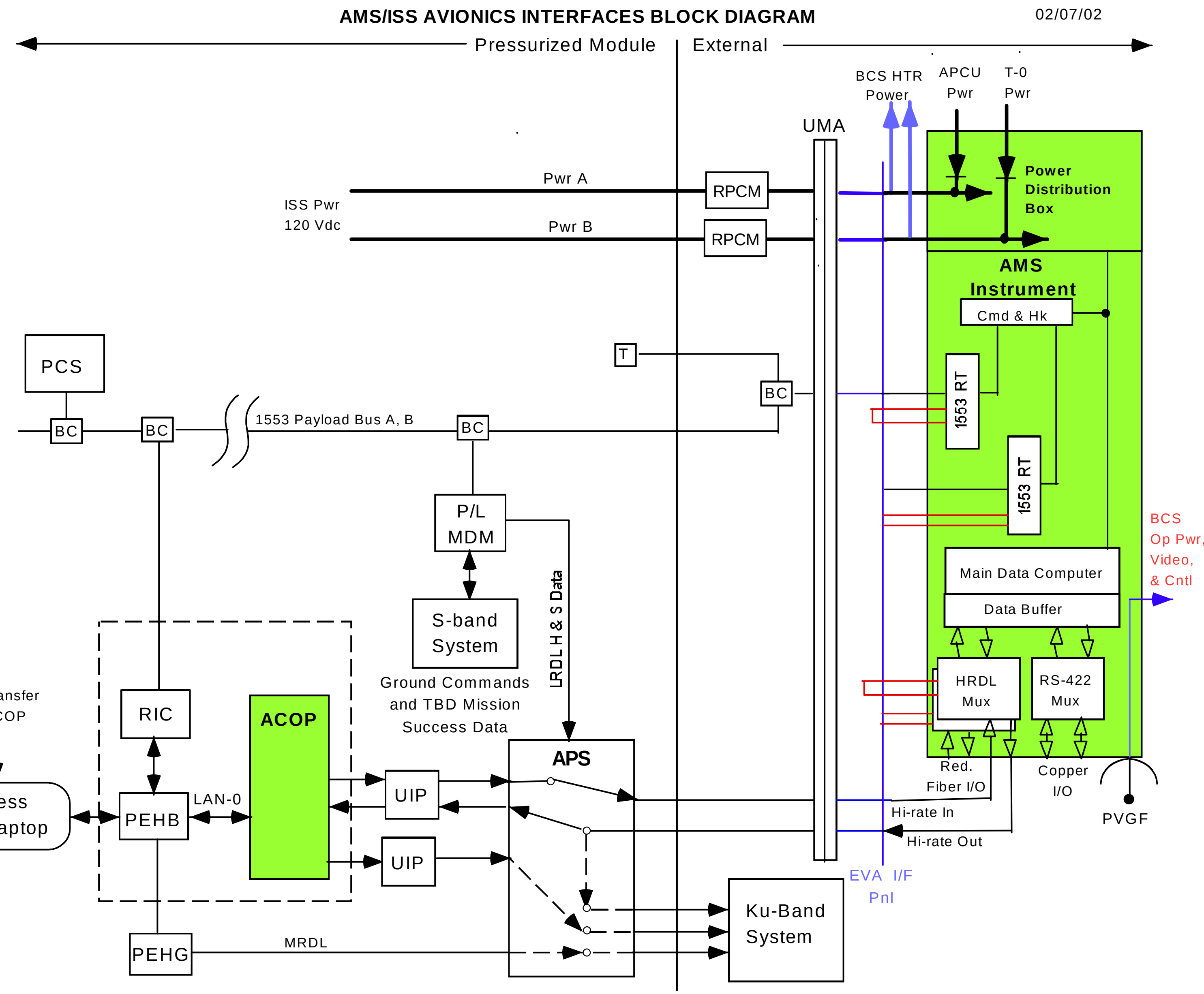


Figure 5.11.5 – AMS/ISS Avionics Interfaces Block Diagram

5.12 CRYOMAGNET AVIONICS BOX (CAB)

The CAB is mounted between the horizontal and diagonal members of the USS-02 near the sill trunnion. The purpose of the CAB is to provide power to the Charging Circuitry in the Magnet as well as to provide control and monitoring circuitry for charging/discharging operations. The CAB receives unswitched 124v dc power directly from ISS Bus A via the PDB. Magnet charging operations depend upon the operation of Bus A from the ISS. Isolation from the magnet is performed by a transformer contained within the CryoMagnet Current Source (CCS) contained within the CAB, assuring compliance with SSP 57003. All other power requirements in the CAB are supplied from the already isolated PDB supplied 28v dc sources.

The CAB also controls the discharge circuitry for the magnet. Controlled discharges are commanded either by automatic control circuitry or crew/ground commanding. The commanding causes opening of the Magnet persistent switch which then routes the current to a set of 18 rectifiers (shown as the flywheel diode assembly in the AMS power diagram). These rectifiers cause the discharge of the magnet and convert the energy into heat. Each rectifier is capable of dissipating 200 Watts. The magnet discharges in approximately 90 minutes and each rectifier will remain below 212 deg F (100 deg C). Cages are being developed to ensure that the astronauts cannot access these high temperature items.

The CAB also contains the Cryo-Magnet Self Protection (CSP). This control system is designed to monitor the temperature of the coils in the magnet. In the event that the temperature of one of the coils begins to rise toward a non-superconducting temperature (exact set-point is still TBD), the CSP can initiate a “controlled” quench, by releasing the stored energy in a set of capacitor banks to fire quench heaters throughout the magnet. These heaters will cause the entire magnet to quench evenly, avoiding individual “hot-spots” that could damage the magnet coils.

The control system for the discharge circuitry will require an Uninterruptible Power Source (UPS). This will allow AMS to perform a quench or a controlled run-down of the magnetic field in the event of loss of commanding or loss of power for an extended (unplanned) period. This UPS system will consist of a battery and a capacitor bank located externally on the payload. The details of this UPS system are being developed at this time; however, both the battery and the capacitor bank will be designed to meet the requirements documented in JSC-20793, Manned Space Vehicle Battery Safety Handbook as well as NSTS 1700.7B and the ISS Addendum.

5.13 CRYOCOOLERS

AMS will fly four Cryocoolers to assist in maintaining the Superfluid Helium temperature requirements. These Cryocoolers (M87 manufactured by Sunpower Inc.) utilize a free-piston technology to avoid life-limiting components and increase mechanical efficiency. The Cryocoolers will receive unswitched 124 Vdc power directly from ISS Buses A and B via the PDB, and can be operated from either or both buses (See Figure 5.13.1). Isolation from the ISS is performed by a transformer contained within the Cryocooler power supply; assuring compliance with SSP 57003. All other power requirements in the Cryocooler assembly are supplied from the already isolated PDB supplied 28 Vdc sources.

The M87 is designed to lift 7.5 W of heat at 77 Kelvin with an input of 150 W at 120 Vac. The power supply for the Cryocoolers is designed to convert the ISS supplied 120 Vdc to be compatible with the cryocoolers.

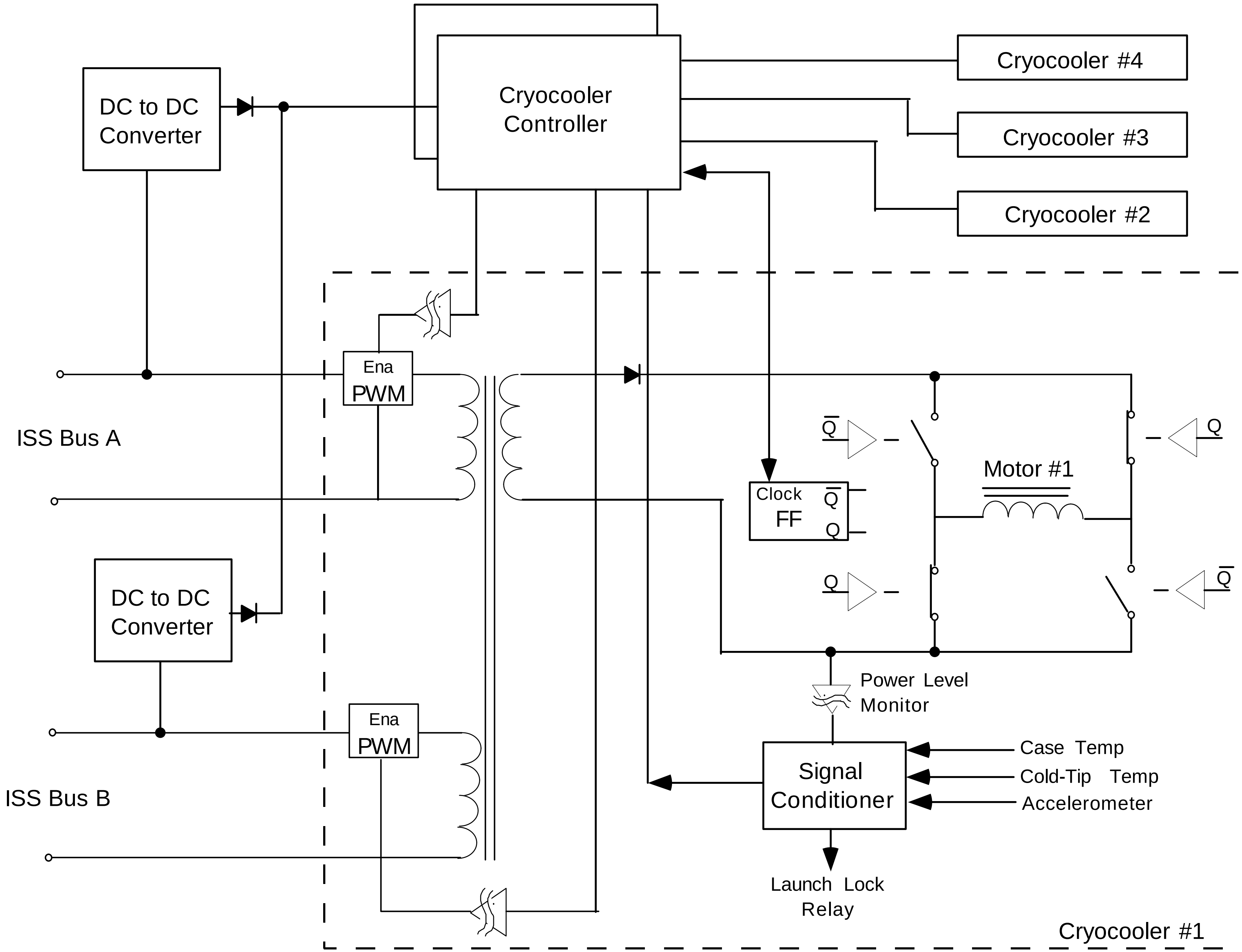


Figure 5.13.1 – Cryocoolers Interfaces Block Diagram

5.14 AMS CREW OPERATIONS POST (ACOP)

The ACOP system is currently envisioned as an ISS payload locker and one middeck locker equivalent (can be a soft stowage bag) of hard drive media, payload provided external cables, and spares. The developer of the ACOP is TBD. Although the present design for the ACOP calls for installation in a locker, drawings of an earlier "ISS drawer" configuration have been included for illustration (See Figures 5.14.1 thru 5.14.3). Present locker configuration drawings are not yet available. The ACOP will serve as a management system for the AMS-02 science data as well as a crew operations post. ACOP will be capable of simultaneously receiving, processing, and downlinking the AMS-02 science data stream as provided on the High Rate Data Link (HRDL). Crew control will be provided at a low level (power state functions) via the front panel interface. The ACOP power schematic is shown in Figure 5.14.4 (again, this is based on the earlier drawer configuration).

Mounted within the ISS payload locker will be five or six standard size 5¼ inch hot swap hard drive bays, a power supply, and operations interface consisting of a graphic LCD display and push buttons, a locker cooling fan, and a Compact PCI card cage assembly. The Compact PCI card cage will be populated with a TBD single board computer, a TBD high data rate link adapter, and a TBD operations interface. The single board computer will provide 100baseT Ethernet, and/or 10baseT Ethernet, serial ports, and SCSI interfaces as appropriate. The single board computer will contain a small battery, which will be used to maintain time synchronization and bios parameters. Specifications for this battery are TBD since the specific board has not yet been selected.

The Compact PCI card cage, single board computer, power supply, operations interface, and locker cooling fan are expected to be COTS equipment, suitable for space use.

The locker cooling fan will be a 4.5 inch diameter shrouded fan. This fan will be a ball bearing type fan and will rotate at a maximum speed of 5200 rpm.

The ACOP locker will be attached to the ISS HRDL by a payload provided fiber Y-cable. This cable will attach via a front panel connector on the ACOP and will be routed to the Utility Interface Panel (UIP) for connection to two J7 connectors.

The stowage volume will contain twenty hard drives, payload provided data cables, and spares.

The ACOP will be used as a display/controller for the AMS-02 payload and the science data will be recorded on the hard drives. The science data will be down linked via the KU band system as available. In the event of data congestion on the ISS KU band system, the removable drives can be returned via the STS. The hard drive recorder system will have the capability to accept five or six removable hard drives, of which only one will be active and powered at a time. The five or six drives, expected to be more than 100 Gbytes each, will provide storage for approximately 20 days of 1.96 Mega-bits per second high rate AMS-02 data without crew intervention. Should the HRDL system become congested, the crew will exchange the hard drives for ones provided in the storage bag.

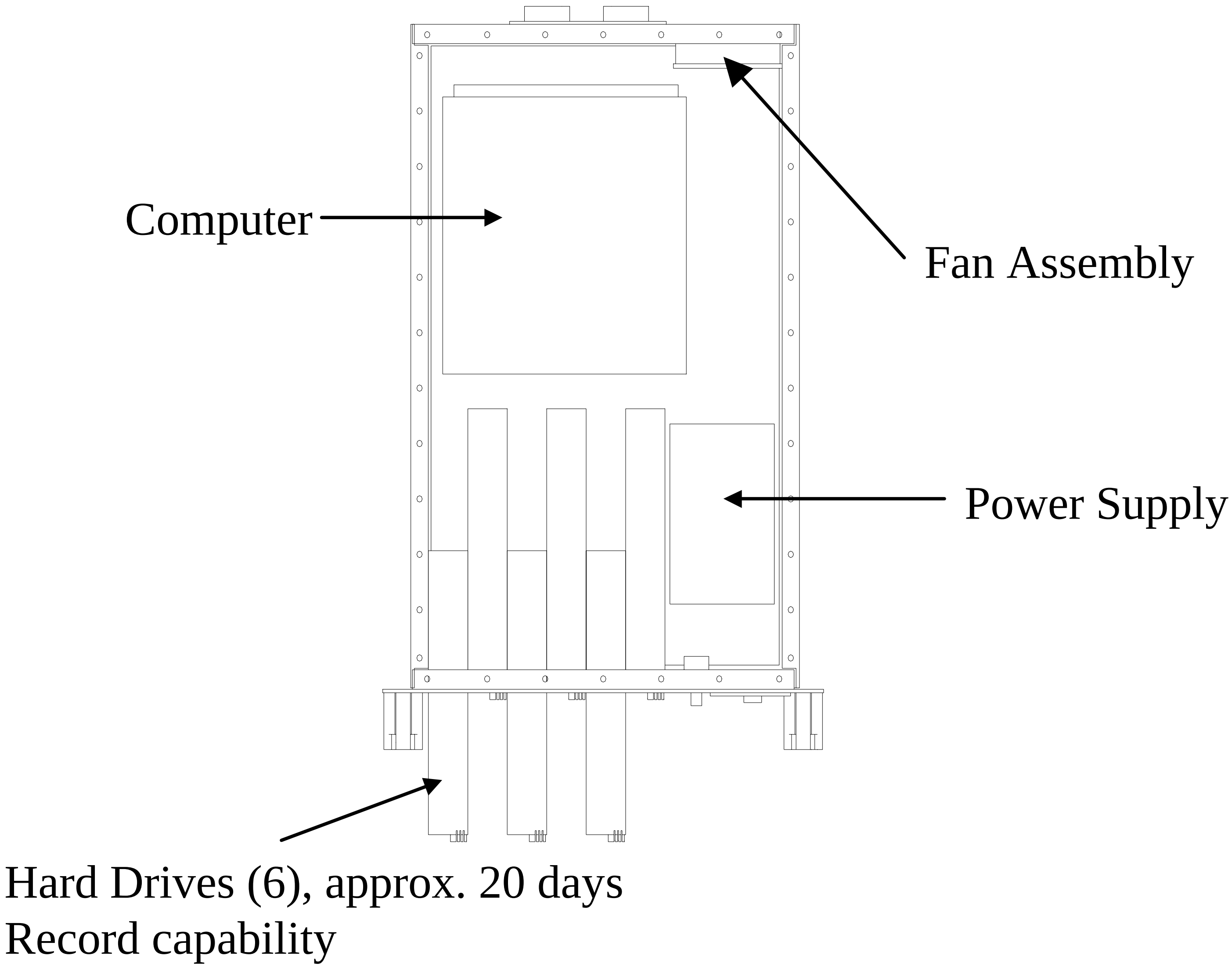


Figure 5.14.1 – ACOP Proposed ISS Payload Drawer Layout (Sheet 1 of 3)
Note: Design now incorporates an ISS Locker, but drawings are not yet available.

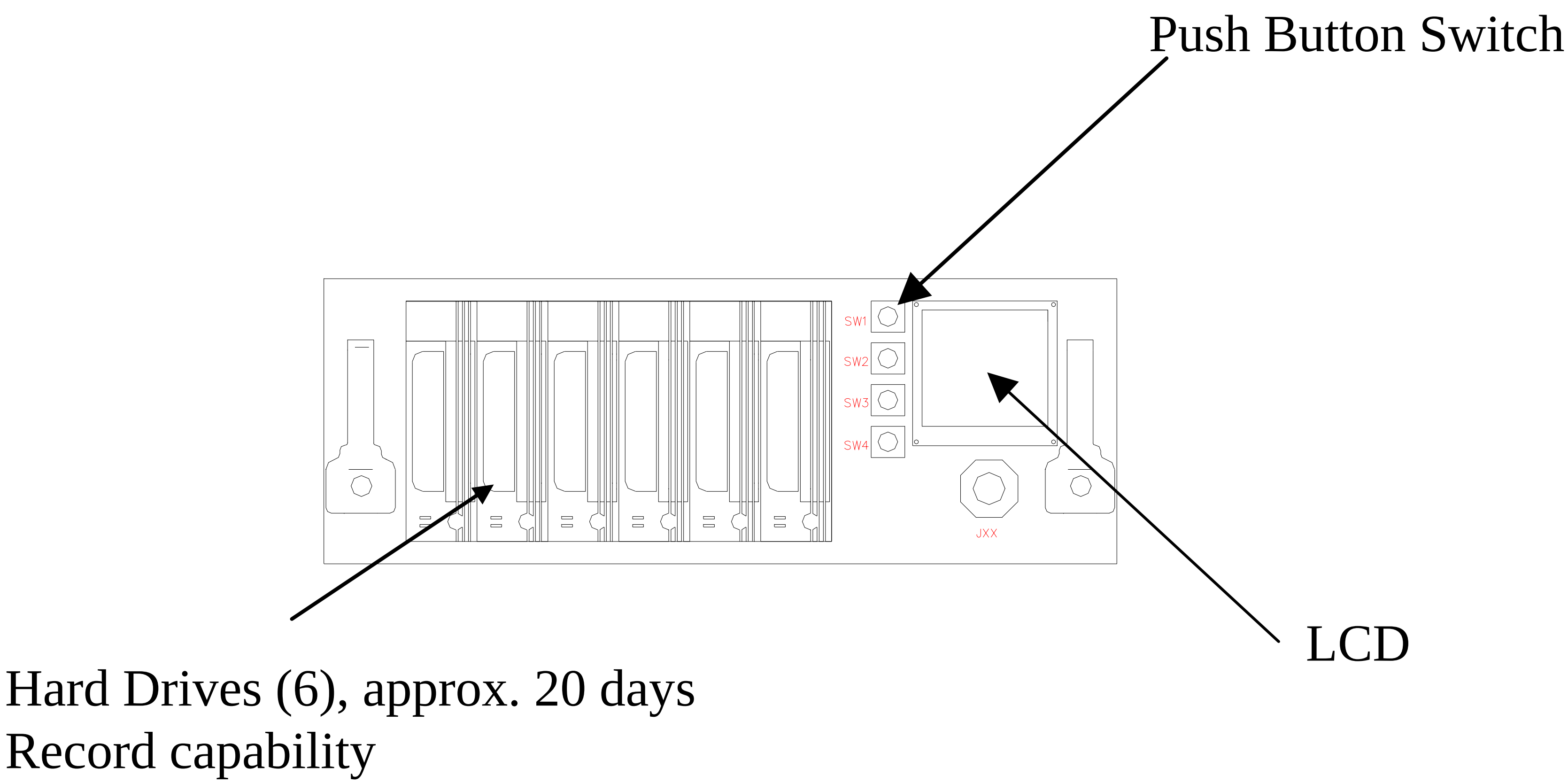


Figure 5.14.2 – ACOP Proposed ISS Payload Drawer Layout (Sheet 2 of 3)
Note: Design now incorporates an ISS Locker, but drawings are not yet available.

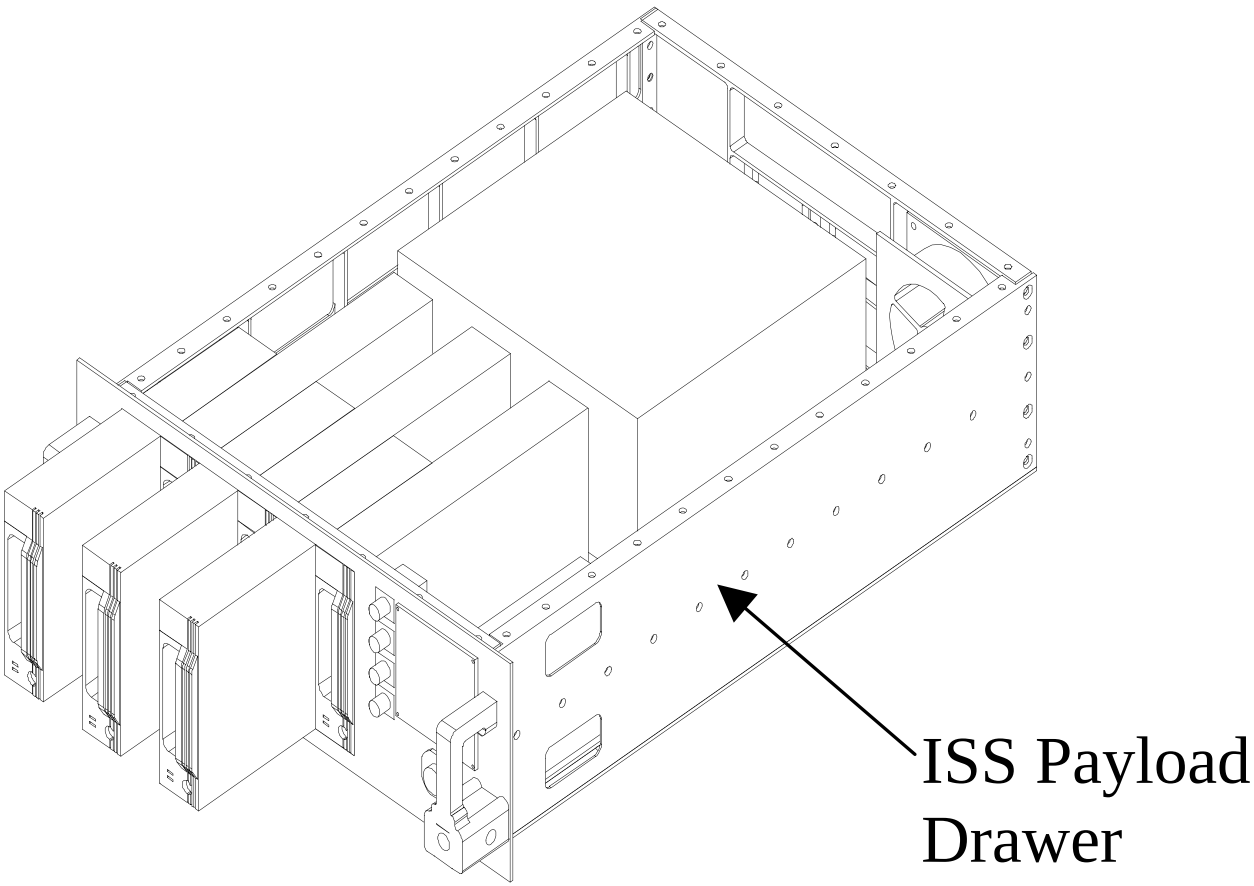


Figure 5.14.3 – ACOP Proposed ISS Payload Drawer Layout (Sheet 3 of 3)
Note: Design now incorporates an ISS Locker, but drawings are not yet available.

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Figure 5.14.4 – ACOP Power Schematic

The hard drives and hard drive hot swap bays will be commercial hardware. Comparable hardware was flown on STS-91 for the AMS-01 precursor mission. The plastic covers for the hard drive hot swap bays will be replaced with metal ones (except for the front faces). Each hard drive will contain a 3.75 inch diameter disk that weighs 23 grams and will rotate at a maximum speed of 7200 rpm.

Each hard drive hot swap bay will contain one 1.4 inch diameter shrouded fan for cooling. This fan will be a ball bearing type fan and will rotate at a maximum speed of 6500 rpm.

5.15 THERMAL CONTROL SYSTEM (TCS)

The AMS-02 TCS design is currently being developed by the AMS experiment team. Preliminary indications are that this system will consist of radiators mounted directly to the AMS-02 electronics and mounted on the USS-02. Total radiator surface area could be between 107 and 161 ft^2 (10 and 15 m^2). Numerous cooling loops will be used to transport heat from various electronic boxes to the radiators. It is probable that these loops will be driven by a pump and controlled with valves. Working fluids being considered are carbon dioxide (CO_2) and ammonia (NH_3). Other components being considered are capillary pumped loops and heat pipes. These also will use NH_3 as a working fluid. Heaters will also undoubtedly be required on various experiment components, but these have yet to be defined. Standard NASA Multilayer Insulation (MLI) thermal blankets will also be used.

5.16 Meteoroid and Orbital Debris (M/OD) Shielding

The M/OD will be designed, analyzed, built and integrated by NASA/LM Mission Management Office. The shielding is designed to protect the pressure systems on the AMS-02 experiment. These systems include the Cryomagnet system including the warm Helium tank, the TRD Gas System, and possibly the TCS. The shielding will be made from various components in different locations depending on the required shield thickness, shape and size. Much of the shielding will be thin aluminum plates, nextel or kevlar, with small standoffs from other AMS-02 experiment hardware.

The NASA Hypervelocity Impact Technology Facility has been and will continue to perform all of the analysis and testing for the M/OD 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.

5.17 Passive Payload Attach System (PAS)

The passive PAS (See Figures 5.17.1 & 5.17.2) is being designed, analyzed, built and integrated by NASA/LM Mission Management Office. The passive PAS is the AMS-02 interface to the active PAS on the S3 Truss Segment of ISS. It is designed to sit in the active PAS and react the loads from the active PAS Capture Latch Assembly.

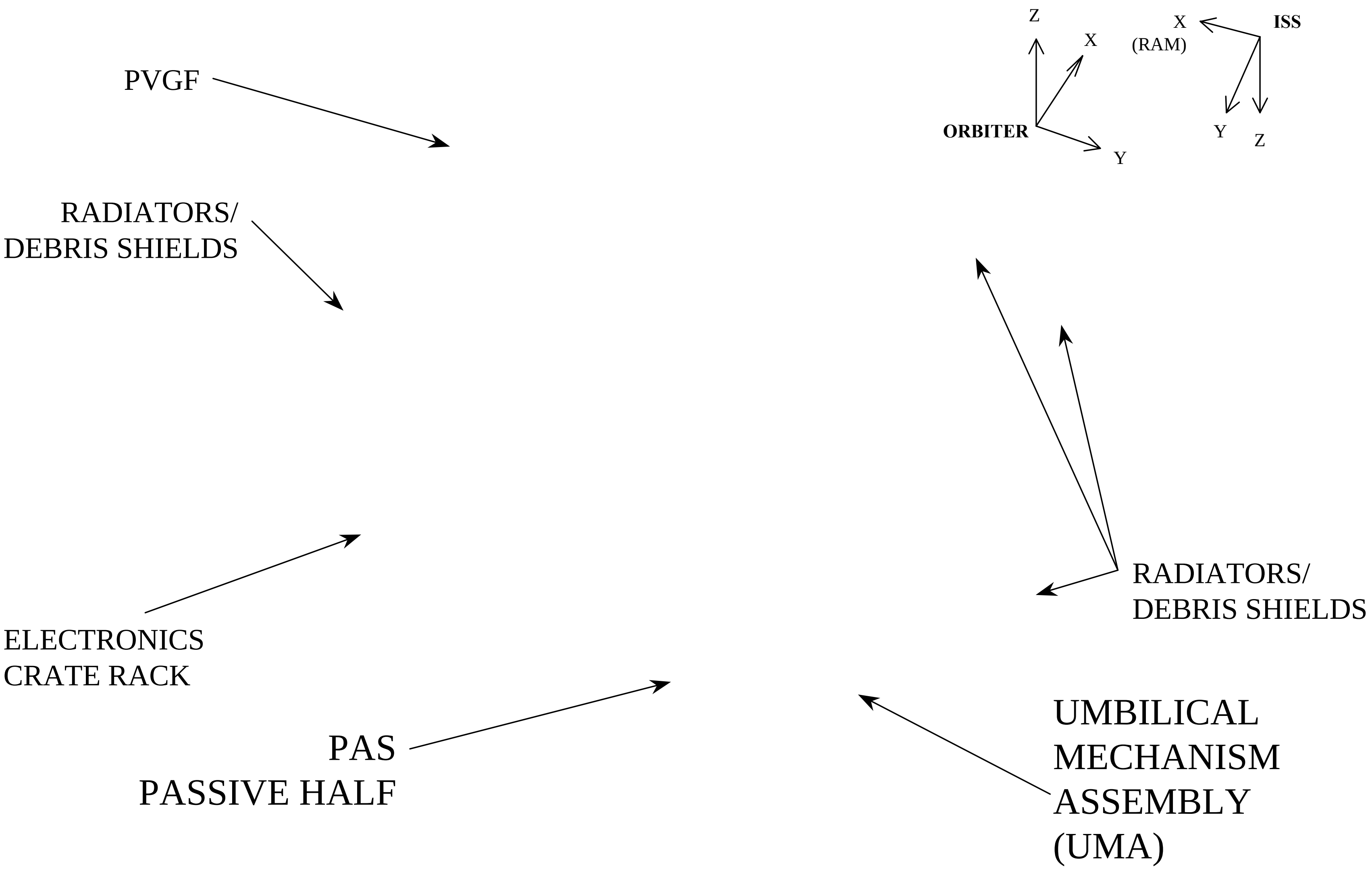

Figure 5.17.1 – USS-02 with Passive PAS & Passive UMA

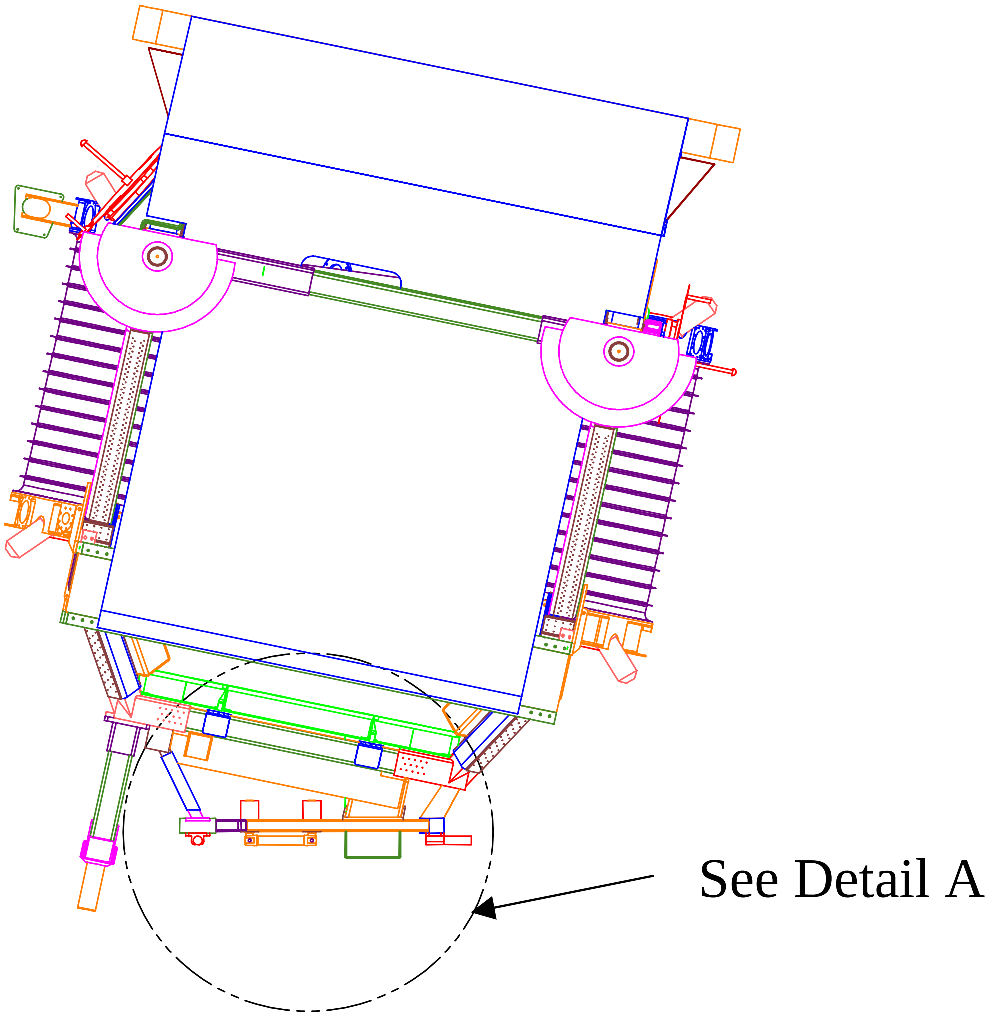

Figure 5.17.2 – Passive PAS

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

The Space Shuttle Program (SSP) provided hardware that will be used with the AMS-02 includes: Two Orbiter Interface Units (OIUs), one PGSC with expansion assembly and power cable, one middeck locker, one Flight Releasable Grapple Fixture (FRGF) and one Payload Disconnect Assembly (PDA) for the Remotely Operated Electrical Umbilical (ROEU). The AMS-02 payload will also require the use of the Shuttle Remote Manipulator System (SRMS).

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.

The middeck locker will be used for stowage of the DDRS-02 hardware.

A FRGF on the AMS-02 payload will be used by the SRMS to lift the AMS-02 out of the Orbiter payload bay. The mounting details for the FRGF are currently TBD.

The PDA for the ROEU will be used to make the electrical interface between the Shuttle and the AMS-02 payload. The PDA will be mounted to the USS-02 near the primary starboard trunnion.

The ISS Program provided hardware that will used with the AMS-02 includes: Two Assembly Power Converter Units (APCUs), one Power Video Grapple Fixture (PVGF), one passive Umbilical Mechanism Assembly (UMA), an External Berthing Cues System (EBCS) and one International Space Station (ISS) payload locker. The AMS-02 payload will also require the use of the Space Station Remote Manipulator System (SSRMS).

The APCUs (one will be a backup) will be used to supply 124v dc power to the AMS. Two APCUs are being used to provide redundancy. They will be mounted in bay 5 on the port side of the Orbiter, as designed, per the APCU Interface Control Document (ICD).

A PVGF on the AMS-02 payload will be used by the SSRMS to place the AMS-02 on to the truss attach site. The mounting details for the PVGF are currently TBD by ISS.

The passive UMA will be used to electrically attach the AMS-02 payload to the ISS truss attach site. The UMA attaches to the lower USS-02.

The EBCS is a camera and avionics package that is electrically connected to the PVGF. The system will be used during the berthing operation to the ISS truss attach site. The EBCS attaches to the passive PAS assembly.

The ISS payload locker will be used for the ACOP.

The AMS-02 payload is using all of the SSP and ISS provided hardware for the same purposes that they were designed.

6.0 AMS-02 GROUND HANDLING EQUIPMENT (GHE) DESCRIPTION

The AMS-02 GHE that will be used at KSC consists of the Primary Support Stand (PSS), the Primary Lifting Fixture (PLF), the Lower USS-02 Support Fixture, the Multi Purpose Lifting Fixture (MPLF), the four Intermediate Support Fixtures (ISFs) (contingency use only), and the Ground Support Equipment (GSE) Dewar and Pump Lifting Sling.

6.1 PRIMARY SUPPORT STAND (PSS)

The AMS-02 PSS will be used for three different functions. It will be used as a transportation fixture for the AMS-02 payload for airplane travel from Europe to KSC and travel/relocation at KSC (See Figures 6.1.1 & 6.1.2); as a support stand for the AMS-02 payload during assembly, testing and integration (See Figure 6.1.3); and to support the AMS-02 payload during lifting operations (See Figure 6.1.4).

6.2 PRIMARY LIFTING FIXTURE (PLF)

The AMS-02 PLF (See Figure 6.2.1) will be used to lift the PSS with the AMS-02 payload installed (See Figure 6.1.4), to lift the PSS by itself and to lift the AMS-02 payload out of the PSS (See Figure 6.2.2).

6.3 LOWER USS-02 SUPPORT FIXTURE

The AMS-02 Lower USS-02 Support Fixture (See Figure 6.3.1) will be used to support the Lower USS-02 during installation.

6.4 MULTI PURPOSE LIFTING FIXTURE (MPLF)

The AMS-02 MPLF (See Figure 6.4.1) will be used to lift the Lower USS-02 Support Fixture during installation (See Figure 6.4.2).

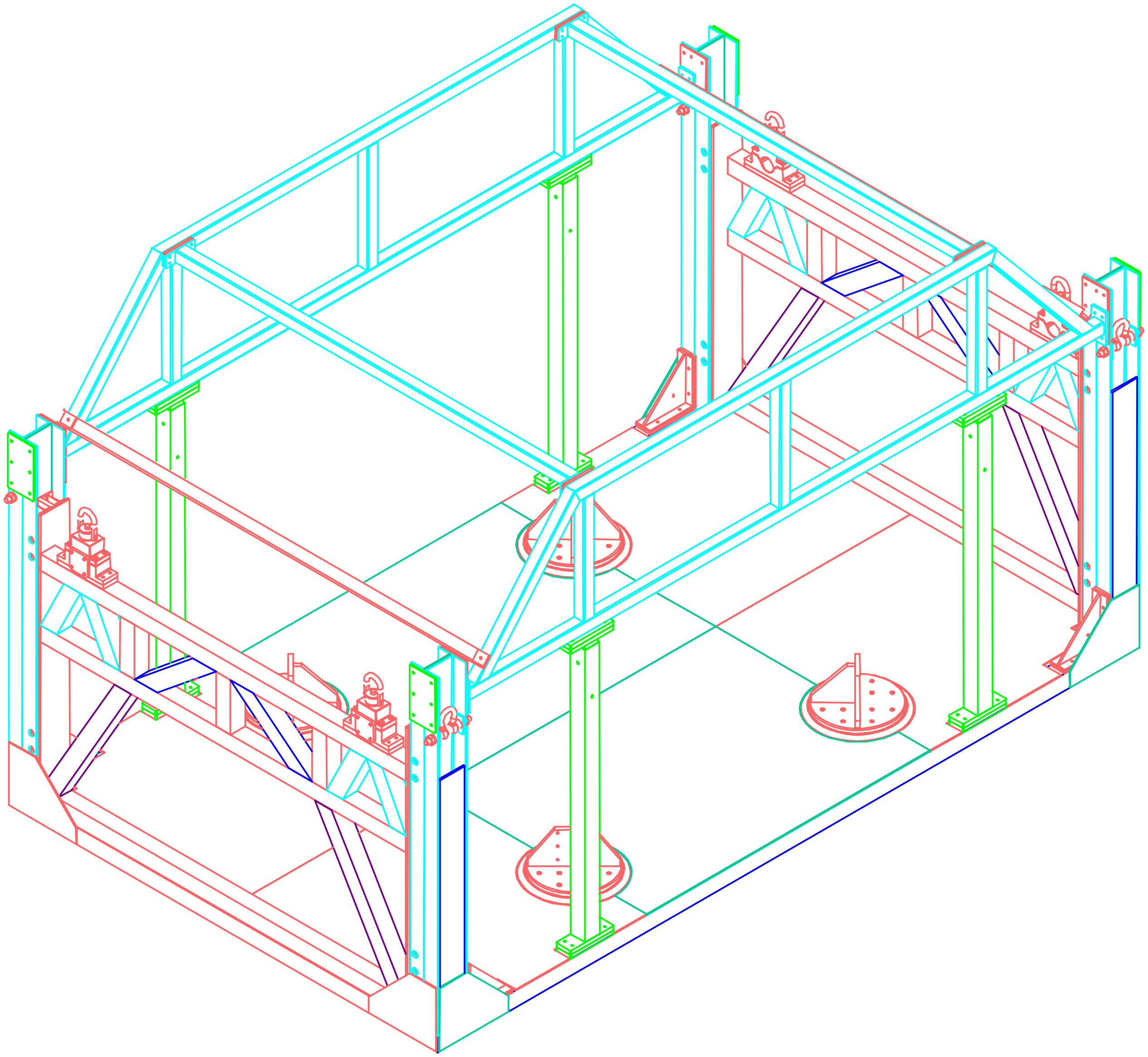

Figure 6.1.1 - Primary Support Stand, Shipping Configuration (Without the AMS-02)

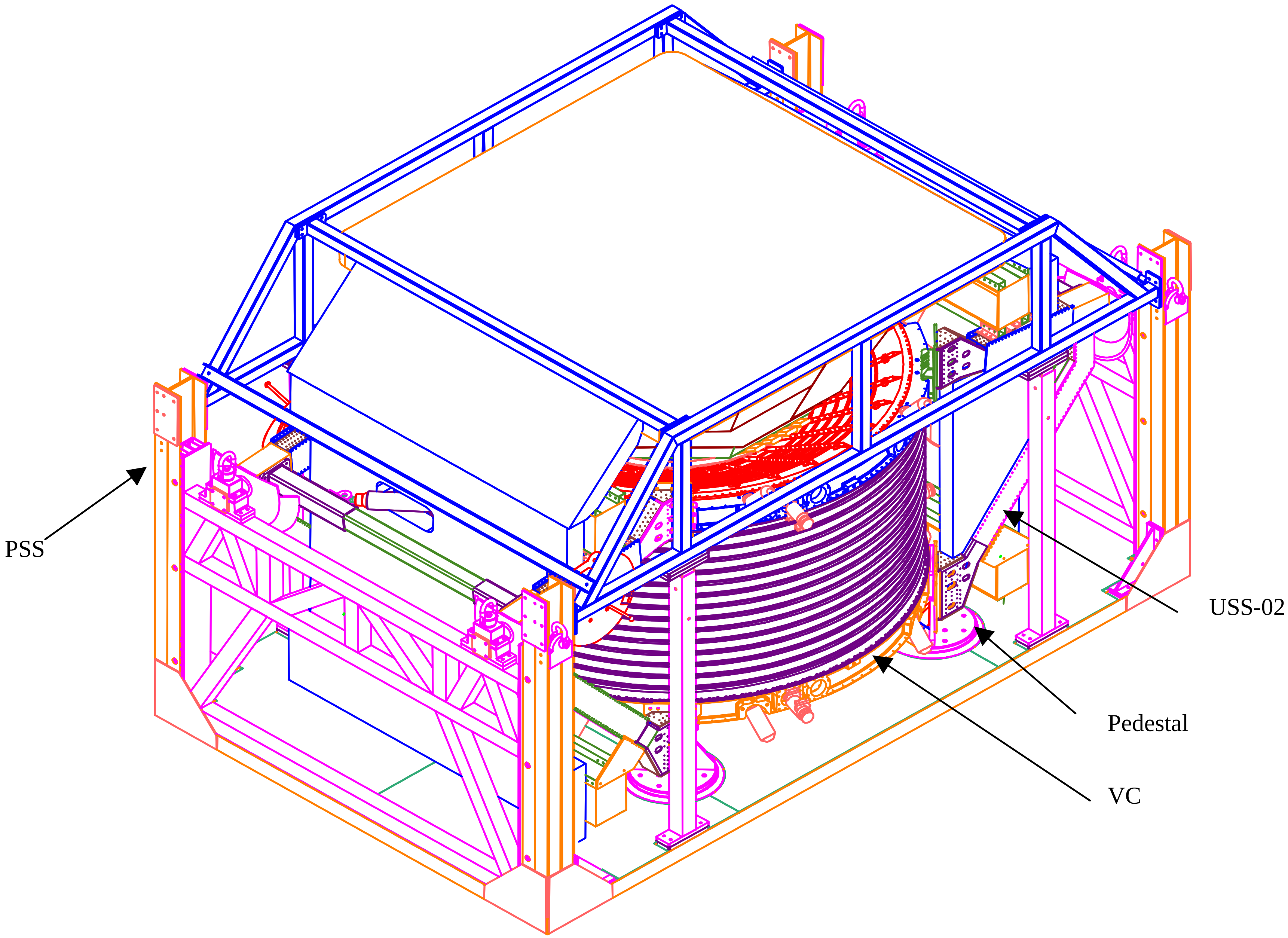

Figure 6.1.2 - Primary Support Stand, Shipping Configuration (With the Upper USS-02)

To Be Supplied

Figure 6.1.3 - Primary Support Stand (Non-lifting Configuration)

Figure 6.1.4 - Primary Support Stand (Lifting Configuration)

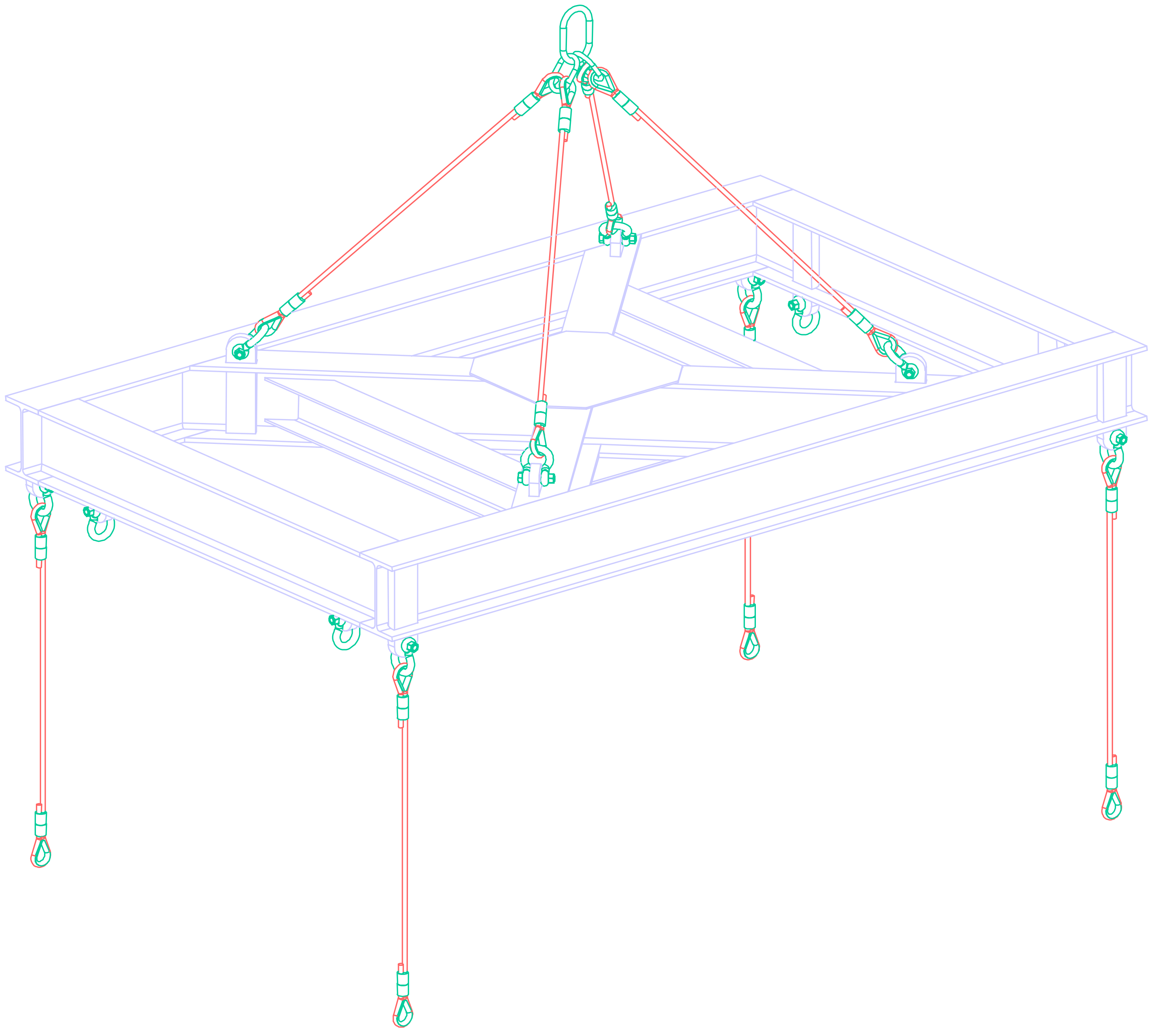

Figure 6.2.1 - Primary Lifting Fixture

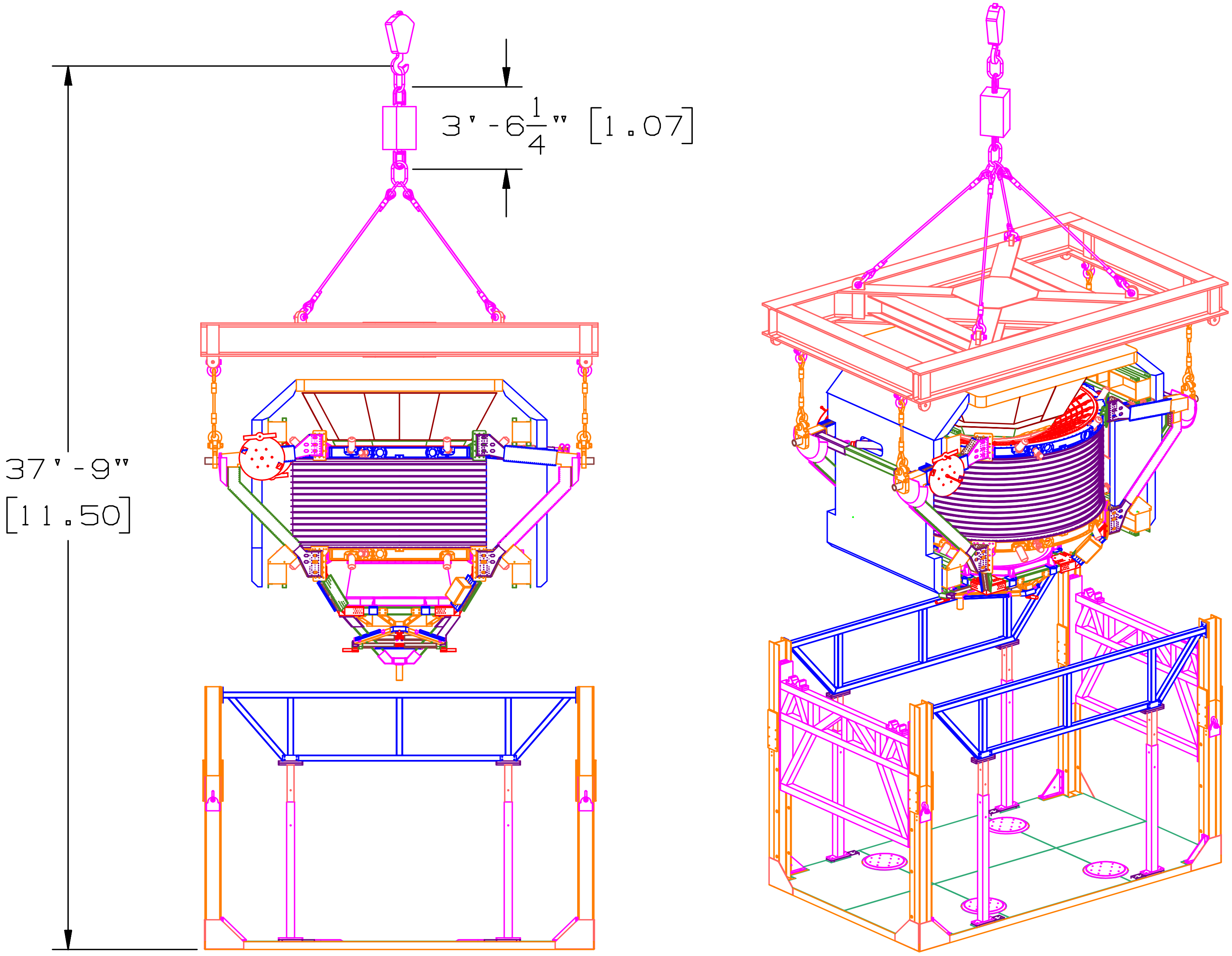

Figure 6.2.2 - Primary Lifting Fixture (Lifting the AMS-02)

Figure 6.3.1 - Lower USS-02 Support Fixture, Shipping Configuration (With the Lower USS-02 and the RICH Component)

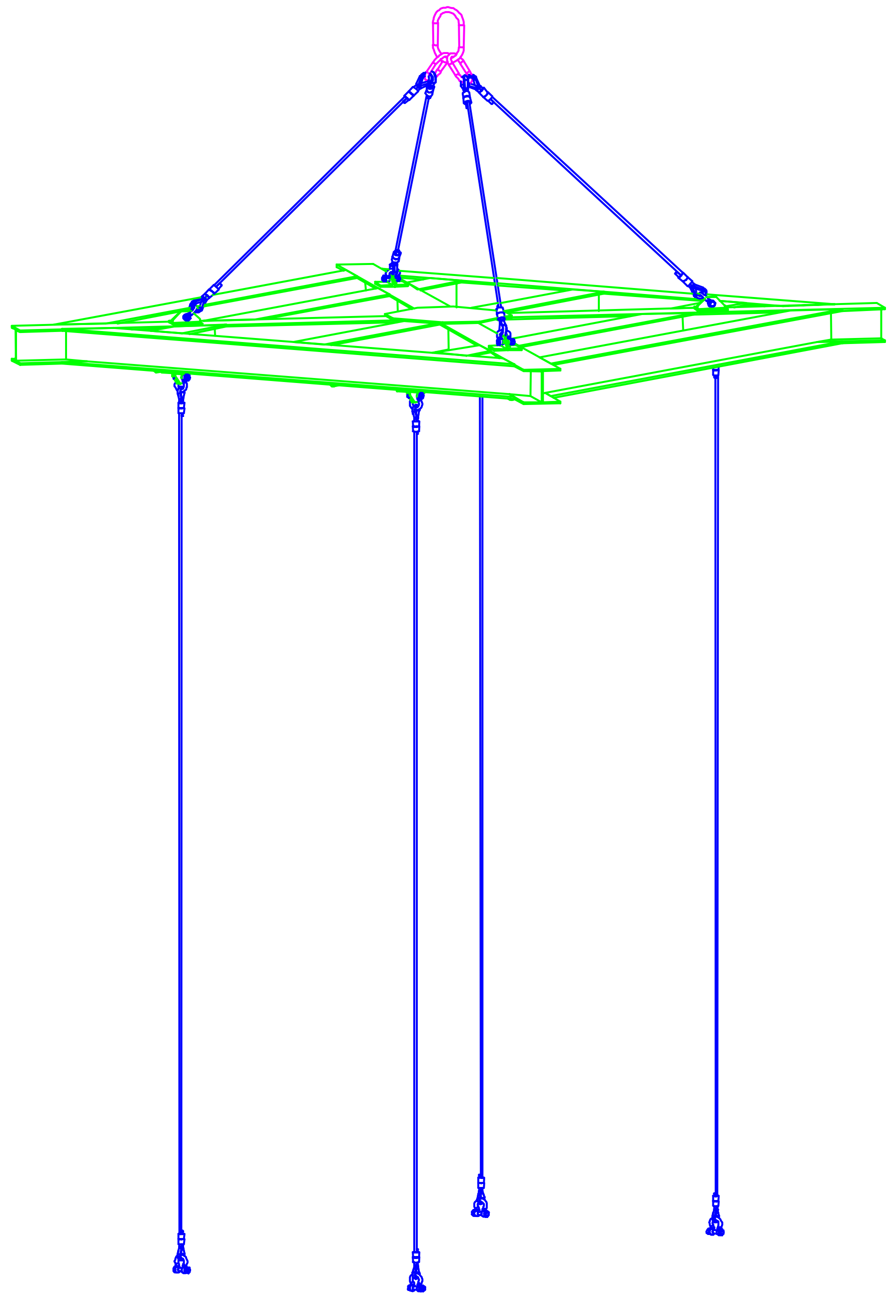

Figure 6.4.1 - Multi Purpose Lifting Fixture

Figure 6.4.2 - Multi Purpose Lifting Fixture (Lifting the Lower USS-02 Support Fixture)

6.5 INTERMEDIATE SUPPORT FIXTURES (ISFs) (Contingency Use Only)

The four ISFs (See Figure 6.5.1) will be used to support the USS-02 if the vacuum case is removed from the USS-02 at KSC.

6.6 GROUND SUPPORT EQUIPMENT (GSE) DEWAR GHE

The 1000 liter GSE dewar and pump lifting sling consists of a four leg sling made of wire rope. It will be used to lift the GSE dewars and cryogenic pumps in the SSPF, MPPF and into the Payload Changeout Room (PCR) at the launch pad.

6.7 KSC-PROVIDED GHE

The following KSC-provided GHE will be used during ground processing of the AMS-02 payload:

- Payload Rotation Fixture
- forklift
- dual cranes
- web straps
- slings
- hydrasets
- shackles
- turnbuckles
- scaffolding
- roll around stand
- support blocks
- bottle jacks
- dunnage
- thick polymer mats

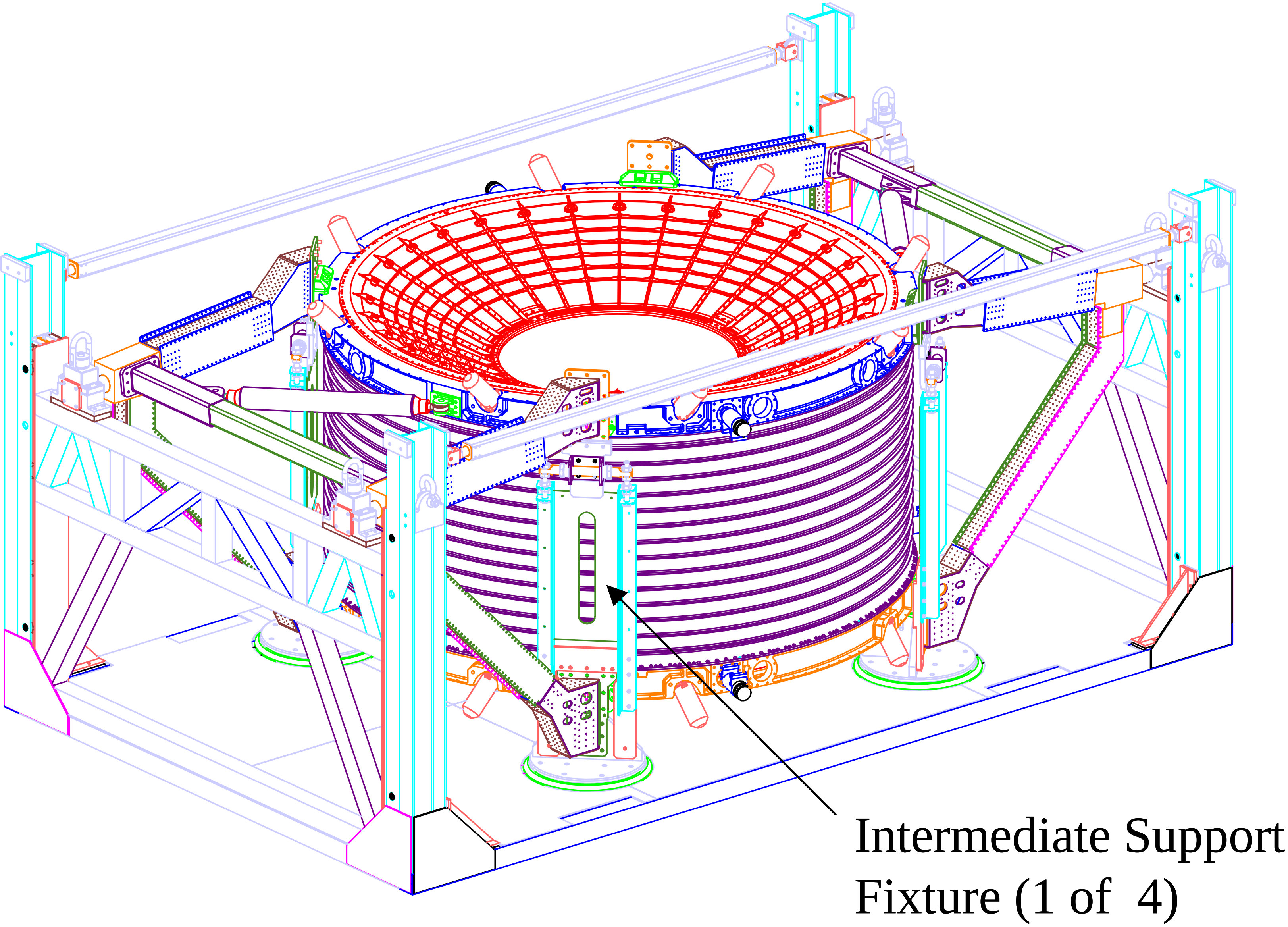

Figure 6.5.1 - Intermediate Support Fixtures

7.0 AMS-02 GROUND SUPPORT EQUIPMENT (GSE) DESCRIPTION

The AMS-02 GSE consists of the Cryomag GSE, TRD GSE, Experiment Electrical GSE (EGSE), tools, possible magnet operation alert system, possible metal detector and shipping containers.

7.1 CRYOMAG GSE

The Cryomag GSE to be used at KSC for ground processing is listed in Table 7.1.1.

7.1.1 Supply Dewars and Pressure/Vacuum System

The two liquid He supply dewars will have the capability of storing and transferring 1000 liters of liquid He in the normal or superfluid state. The pressure gauges, pumping ports and pressure relief devices will be mounted on the dewars. Pressure relief will consist of TBD relief valves. The pressure gauge will have a pressure relief device built in to prevent overpressurization of the gauge. The outer shell will have a relief pump-out port set at TBD and a relief valve set at TBD. The MDP of the inner tank will be TBD. The inner tank is designed to handle a maximum of TBD, and the outer shell a maximum of TBD. The inner tank will be tested to TBD. Both of the supply dewars will be used for servicing at the TBD. Prior to launch pad servicing, KSC-provided commercial dewars will be used. The KSC dewars will require a He pressurant for flow. The K-bottle will be supplied by KSC and the line and regulator will be supplied by the payload organization. The lines will have TBD relief valves.

The servicing lines used during servicing operations will connect the supply dewars and pumps to the flight dewars. The servicing lines will connect to the tank through a He extraction probe which fits into the dewar top extraction port. The servicing lines will have TBD relief valves. Lines will also be provided to vent dewar and pump effluents out of the PCR through the common vent manifold. All flexible lines will be secured. The servicing lines and regulator, which will connect the He supplied by KSC to the servicing dewars, will be supplied by KSC. Servicing lines will be used at the SSPF, MPPF and the launch pad.

The superfluid He pump carts (Roots pump system) will be used to lower and maintain the vapor pressure of the liquid He in both the GSE and flight dewars, thereby lowering the He temperature and converting it to the superfluid state. Each cart will contain a combined Roots blower/backing pump system of approximately TBD capacity. A heat exchanger will be used with each cart to warm the He exhaust to at least TBD before entering the pump. The lines and regulators will be provided by the payload organization. These pumps will be used for off-line payload testing in the SSPF, MPPF and at the launch pad.

Table 7.1.1 - AMS-02 Cryomag GSE[(1)]

Item	Quantity	Manufacturer	Model No.	Commercial (Yes/No)	Electrical Code	Power Requirement	3-Phase (Yes/No)	KSC Facilities	Batteries (Yes/No)
1000 Liter Liquid Helium (He) Supply Dewar	2	TBD	TBD	TBD	N/A	N/A	N/A	MPPF/SSPF/PCR	No
Servicing Line	at least 10	TBD	TBD	TBD	N/A	N/A	N/A	MPPF/SSPF/PCR	No
Superfluid He Pump Cart	3	TBD	TBD	Yes	*	440V / 40A 220V / 60A	Yes	MPPF/SSPF/PCR	No
He Leak Detector	1	TBD	TBD	Yes	*	120V / 20A	No	MPPF/SSPF/PCR	No
Turbomolecular Vacuum Pump/Cart[(2)]	1-2	TBD	TBD	Yes	*	220V / 30A	Yes	MPPF/SSPF/PCR	No
Tools/Parts/Servicing Kits Storage Cart[(3)]	1	TBD	TBD	TBD	N/A	N/A	N/A	MPPF/SSPF/PCR	No
Electronics Support Cart:	2					120V / 20A	No	MPPF/SSPF/PCR	
Personal Computer	1 per cart	Intel	TBD	Yes	*		No	MPPF/SSPF/PCR	Yes
DC Power Supply	1 per cart	TBD	TBD	Yes	*		No	MPPF/SSPF/PCR	No
UPS	1 per cart	TBD	TBD	Yes	*		No	MPPF/SSPF/PCR	Yes
Signal/Power Control Panel	1 per cart	TBD	TBD	Yes	*		No	MPPF/SSPF/PCR	No
Cryo Servicing Rack:	2					120V / 15A	No	MPPF/SSPF/PCR	
Personal Computer	1 per rack	Intel	TBD	Yes	*		No	MPPF/SSPF/PCR	Yes
DC Power Supply	1 per rack	TBD	TBD	Yes	*		No	MPPF/SSPF/PCR	No
UPS	1 per rack	TBD	TBD	Yes	*		No	MPPF/SSPF/PCR	Yes
Signal/Power Control Panel	1 per rack	TBD	TBD	Yes	*		No	MPPF/SSPF/PCR	No
Cryo Handling Units	TBD	TBD	TBD	No	*	TBD	No	MPPF/SSPF/PCR	No
Cool Down Unit	1	TBD	TBD	TBD	TBD	TBD	TBD	MPPF/SSPF/PCR	TBD
He Recovery System	1	TBD	TBD	TBD	TBD	TBD	TBD	MPPF/SSPF/PCR	TBD
He and Vacuum Manifold	1	TBD	TBD	TBD	TBD	TBD	TBD	MPPF/SSPF/PCR	TBD
Liquid He Supply System	1	TBD	TBD	TBD	TBD	TBD	TBD	MPPF/SSPF/PCR	TBD
Air-Heated Vaporizer	1	TBD	TBD	TBD	TBD	TBD	TBD	MPPF/SSPF/PCR	TBD

* UL approved or equivalent

NOTES: (1) All GSE dewars, carts and racks will be equipped with lifting eyes and locking casters.
(2) Contingency use only.
(3) Includes: Cryomag unique tools, spare parts storage and plumbing line storage.

The He leak detector will be a standard commercial unit. It will be used to ensure that the flight and GSE He connections are not leaking prior to use. It will be used during off-line testing in the SSPF and MPPF, and before low pressure top off at the launch pad. The leak detector will require a liquid nitrogen source. The lines and regulators will be provided by the payload organization.

The turbomolecular vacuum pump(s)/cart(s) will be used to pump down vacuum spaces to very high vacuum levels on the flight and GSE dewars. Each cart consists of a mechanical roughing pump and a high capacity turbomolecular pump. The cart(s) will be used at the SSPF and MPPF, but will not be used at the launch pad. These pumps will require two nitrogen gas sources and a liquid nitrogen source provided by KSC. The lines and regulators will be provided by the payload organization.

7.1.2 Cryomag Tools/Parts/Servicing Kits Storage Cart

The tools/parts/servicing kits storage cart will provide a central location for Cryomag unique tools and equipment. These include: hand tools, transfer and vent lines, spares and TBD cleaning supplies. All tools used in the SSPF, MPPF and PCR will be controlled in accordance with the AMS-02 Tool Control Plan to comply with the requirements of KHB 5310.1, General Operating Procedure 5-3. The servicing kits will contain parts, fittings, gloves, etc., as well as spare cryogenic servicing parts.

7.1.3 Cryomag EGSE

Each electronics support cart consists of a ground support personal computer (Intel), a DC power supply, an UPS and a signal/power control panel. They will be standard 19 inch racks. All equipment will be commercial office equipment and will be Underwriters Laboratory (UL) approved or equivalent.

The ground support computer will handle command, control and telemetry functions of the AMS-02 payload while it is being serviced. It will allow an operator to send commands to the AMS-02 command and data handling to configure the experiment for on-pad servicing of the dewars. The computer will also log, process and display the received telemetry.

Power required for each electronics support cart is 120 VAC, single phase, 20 amps. Each cart frame ground will be tied to the AC line ground. All equipment within the cart will be UL approved or equivalent. AC input power for the carts will be controlled by TBD so that all power can be removed from the equipment by a single cut-off switch.

A 28V DC power supply will be used with a TBD maximum output at TBD amps. The power supply will be UL approved or equivalent.

The UPS will consist of a TBD KW unit located within each electronics support cart. In the event of a main AC power failure, the UPS will provide the power for the EGSE for a maximum of TBD minutes. This will ensure servicing operations will not be interrupted at a critical moment. If necessary, this will allow valves and other components to be placed in positions which will allow a "graceful" recovery when main power is restored. The UPS will be manufactured by TBD and will be UL approved or equivalent. It will contain TBD battery cells of TBD chemistry. The battery will be sealed, no-maintenance, valve regulated and gas recombinant. It will be float charged to the optimum float voltage using a small variable rate charger only as needed. The nominal battery voltage will be TBD. The standard battery charger output will be variable and rated at TBD amps at low battery voltage, and TBD amps at TBD VDC. The voltage and the current will be monitored. The peak load (for an educated short) for the battery would be TBD amps for TBD msec and TBD amps for 1 sec. There will be an internal TBD amp fuse to prevent shorting to the case. The battery case and separator are TBD material with an insulation resistance of TBD V/mil. There will be TBD pressure relief vents permanently attached to the case for each cell set at TBD psig if excessive pressure is generated. The amount of worst case gas generated will be minimal due to the starved electrolyte design.

The signal/power control panels will be used to select the desired command and data handling.

The electronics support carts will be used in the SSPF, MPPF and at the launch pad.

7.1.4 Cryo Servicing Racks

The cryo servicing racks consist of TBD and will be used for TBD.

7.1.5 Cool Down Unit (CDU)

The CDU is a TBD device used for cooling down the system from ambient temperature to 80 K. It consists of a liquid nitrogen-cooled heat exchanger and control system which cools pure helium gas to a predetermined and programmable temperature between ambient and 80 K. The cooled helium is used for cooling the magnet and helps prevent contamination (air or water) of the cryogenic system.

7.1.6 Helium Recovery System (HRS)

The HRS is a TBD system for removing exhaust helium from the system and transferring it to a safe position where it can be recycled, saved or released to the atmosphere. The HRS incorporates Roots pumps to allow the helium in the main helium tank to be pumped down.

7.1.7 Helium And Vacuum Manifold (HVM)

The HVM is a TBD system for supplying pure, ambient temperature helium gas at a pressure of 1.2 ± 0.1 bar (absolute) to various parts of the cryogenic circuit during cool down. Its purpose is to allow filling of closed volumes with slightly pressurized helium to prevent air ingress. It also has a vacuum pump, so that the closed volumes can be evacuated when required.

7.1.8 Liquid Helium Supply System (LHSS)

The LHSS is a TBD unit for supplying clean, filtered liquid helium at between 1.2 and 1.5 bar (absolute) to the fill port on the magnet. It consists of a system of storage dewars and vacuum insulated transfer lines designed to minimize the possibility of air or water contamination entering the magnet cryogenic system.

7.1.9 Air-Heated Vaporizer (AHV)

Connected to the cool down circuit is an arrangement of an AHV and valves. This is used during cool down to 4 K.

7.2 TRD GSE

The Xenon (Xe) Handling Station for the AMS-02 TRD consists of a set of aluminum gas cylinders of various sizes, a pump station, and gas analysis equipment, connected via a manifold (See Figure 7.2.1). Most of the components are standard commercial gas and vacuum components:

- Gas cylinders: Haring Cylinder Company
- Valves, pipes, and fittings: Cajon VCR
- Pressure sensors: Omega
- Sorbtion pump: Thermionics
- RGA: Ametek
- Liquid Nitrogen (LN_2) containers: Branch River Foam
- Turbomolecular pump: Pfeiffer

Xenon Handling Station

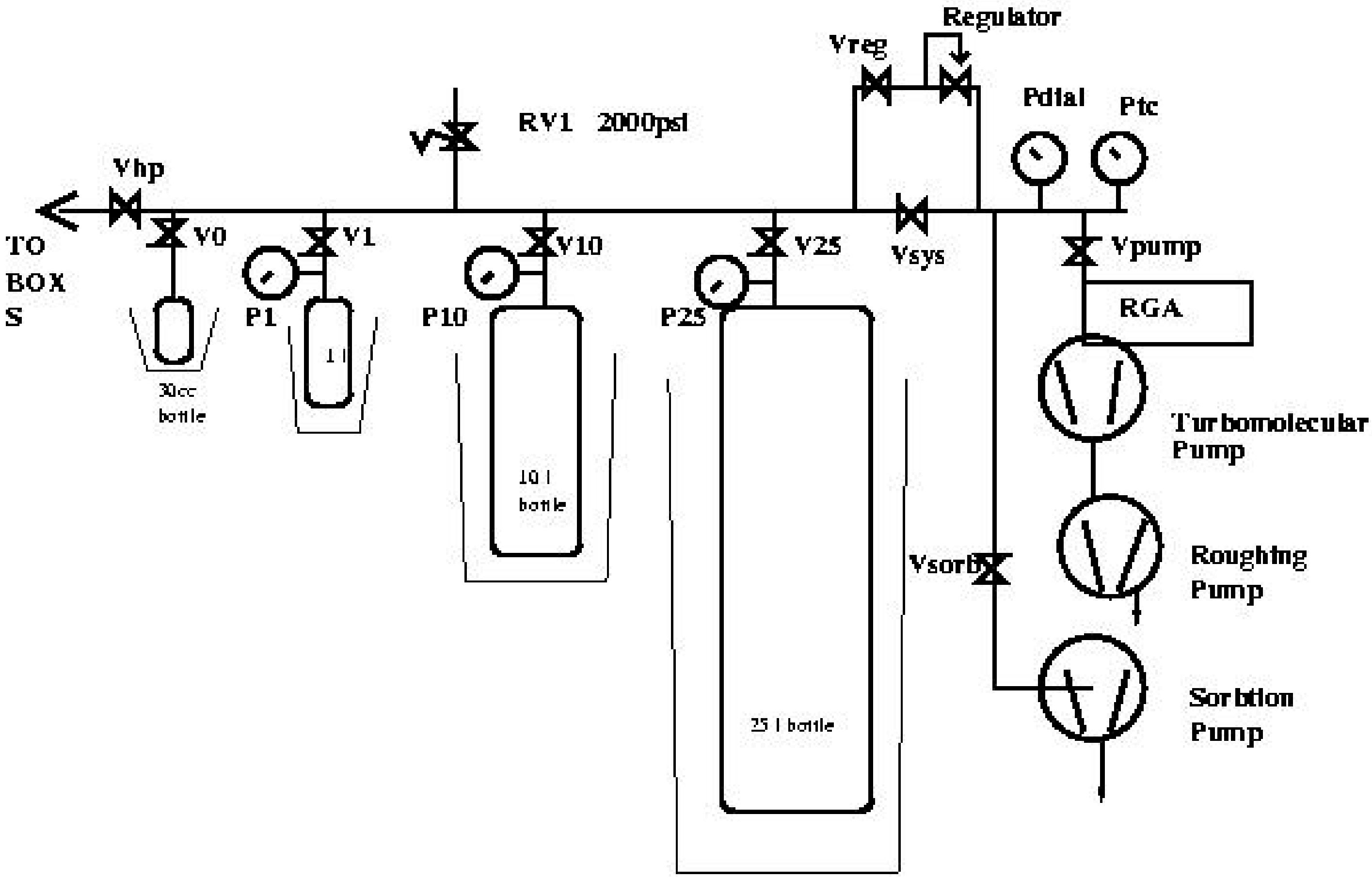

Figure 7.2.1 - Xenon Handling Station

The Xe Handling Station will be used to pump the Xe supply in and out of the Box S storage vessel, near the end of the AMS-02 launch preparations.

The pumping is accomplished stepwise. First, the station is connected to Box S, all lines are flushed and pumped to high vacuum. The initial vendor Xe supply is sucked into a 25 liter bottle by immersing the bottle in LN_2. The bottle, Outer Diameter (OD) = 8 in., is suspended inside of a dewar [Inner Diameter (ID) = 12 in., OD = 24 in.) made of expanded polystyrene. To freeze the bottle, the dewar is filled (about halfway) with LN_2, which boils off quickly while cooling the bottle. The full process requires about 100 liters. A vent/splash hood arrangement is TBD to carry away the cold nitrogen gas. In the current design, the dewar is at least partially open to atmosphere, so there is no pressure hazard associated with the nitrogen.

An additional step (TBD) may involve heating the bottle (temperature TBD, maybe 100 degrees C) to drive more Xe into the TRD tank. This would be accomplished with heating coil wrapped around the bottle inside of the dewar. Heating this bottle and venting it into Box S allows 1/2 of the gas to transfer before the pressure equilibrates.

Half of the gas remains in the Xe station bottle. This gas is sucked from the 25 liter bottle into a 10 liter bottle, again by immersing the 10 liter bottle in LN_2. After closing off the 25 liter bottle, the 10 liter bottle is warmed and vented into Box S. The gas in Box S is now (27/37) of the final total. The process is repeated with a 1 liter, then a 30 cc bottle. For any initial quantity of Xe, the fraction pumped into Box S (after the final stage, using a cold bottle of volume C) will be f = C/27. The successively smaller bottles use smaller amounts of nitrogen (~10 liters) so there is less or no asphyxiation hazard, and special venting arrangements are not anticipated.

The total time needed for the transfer operation is estimated on the order of an hour or two, dominated by the time needed to chill and rewarm the larger cylinders. The cylinders will be equipped with heaters. It requires a power source (to run the roughing pump and heaters) and several hundred liters of liquid nitrogen.

The system is also designed to remove the Xe from AMS-02 in case it is necessary (ie. after a scrubbed launch). The procedure here is to freeze the largest bottle, connect to Box S, flush and vacuum the lines, and open the valves on Box S and the cold bottle. The full volume of Xe will be sucked into the bottle and can be stored indefinitely. The residual pressure in Box S has to be monitored; the reclamation should be halted when $P = 2*P_{ambient}$ so as not to underpressure the Box S Xe ball. This process requires liquid nitrogen, but no electricity.

The entire system is built of welded stainless steel and VCR components, and is designed for medium high vacuum. This ensures that the Xe will not be contaminated during filling or recovery. Total pressures below 10^{-5} torr are attainable, and this is dominated by water vapor. Oxygen contamination will be negligible.

The Xe Handling Station is equipped to sample and analyze the gas, using an RGA, to watch for contamination.

7.2.1 Construction and Testing

The system has been built with three bottles (sized 25 liter, 1.5 liter, and ~3 cc). This system has been tested successfully using low pressures of krypton.

The 10 liter bottle and the 30 cc bottle remain to be added. Pending large-scale tests, the 25 liter bottle may be replaced by a set of smaller bottles, for the purpose of increasing the heat transfer rates (and thus the cryopumping speed).

Other minor modifications include: the addition of a burst disk in front of the relief valve; the purchase and installation of the regulator; and the upgrade of several of the pressure sensors.

7.2.2 Procedures for the Xe Reclamation System

General procedure for vacuuming lines:

1. close: v_{pump}, v_{sorb}, v_0, v_1, ,v_{10}, v_{25}, v_{hp}
2. open: v_{hp}, v_{sys}
3. fill sorb pump with LN2
4. when LN2 stops boiling, open v_{sorb} and all sorb valves
5. watch: Pdial will drop. When Pdial < 5 mbar:
6. watch: Ptc gauge will drop. When Ptc gauge < 500 mTorr:
7. open: v_{pump}
8. close: v_{sorb}
9. wait for Ptc to drop to > 1 mTorr
10. close: v_{pump}
11. If Ptc immediately starts rising it indicates a leak
12. close: v_{sys} Lines are now at vacuum.

Fill station from commercial supply:

1. Connect commercial bottle to HP port
2. Vacuum lines: see procedure #1.
3. close: V_{sys}, V_{10}, V_1, V_0, V_{reg}
4. immerse 25 liter bottle halfway in LN2. Wait for boiling to subside.
5. open: V_{25}, commercial supply regulator.
6. wait for P_{25} and commercial pressure sensor to stabilize near zero.
7. close: V_{hp}, V_{25}.
8. Drain LN2 and allow bottle to warm.
9. The 25 liter bottle is now stocked. Add or remove gas as needed.

Fill Box S:

1. Fill 25 liter bottle with Xe supply (Procedure #2)
2. Connect Box S to HP port.
3. Vacuum out lines (Procedure #1)
4. Immerse the 30 cc, 1 liter, and 10 liter bottles in LN2.
5. First transfer:
    a. open V_{hp}, V_{25}, Box S fill valve.
    b. 1/2 of gas will flow into Box S. Wait for equilibrium.
    c. close V_{hp}.
    d. open V_{10}. The gas in the 25 liter will freeze into the 10 liter. Wait for P25 to approach 0;
    e. close V_{25}. The gas is now in the 10 liter bottle.
6. Second transfer
    a. open V_{hp}
    b. Warm up 10 liter bottle.
    c. 3/5 of the gas will flow into Box S. Wait for equilibrium.
    d. close V_{hp}.

e. open V_1. The gas in the 10 liter will freeze into the 1 liter. Wait for P10 to approach 0.
f. close V_{10} The gas is now in the 1 liter bottle.

7. Third transfer
   a. open V_{hp}
   b. Warm up 1 liter bottle.
   c. 98% of the gas will flow into Box S. Wait for equilibrium.
   d. close V_{hp}.
   e. open V_0. The gas in the 1 liter will freeze into the 30 cc. Wait for P1 to approach 0.
   f. close V_1 The gas is now in the 30 cc bottle.
8. Final transfer
   a. Warm up 30 cc bottle.
   b. 99.5% of the gas will flow into Box S. Wait.
   c. close V_{hp}
   d. close the regulator (lowest pressure possible)
   e. open V_{sorb}, V_{reg}, and sorb outlet.
   f. The 1500 psi in the manifold will gently vent to atmosphere. Wait.
   g. Disconnect Box S.

Reclamation of Xe:

1. Make sure 25 liter bottle is at vacuum (or otherwise clean).
2. Connect HP port to Box S.
3. Vacuum out lines (General Procedure above)
4. Immerse 25 liter bottle in LN2.
5. open V_{25}, V_{hp}
6. Xe will flow from Box S into the 25 liter bottle.
7. Wait for P25 = 30 psia (15 psig) (also read pressure from Box S sensors).
8. Close V_{hp}.
9. Wait for P to approach 0.
10. close V_{25}, rewarm bottle.
11. 99% of the original Xe is now in the 25 liter bottle.

7.3 AMS-02 EXPERIMENT EGSE

The AMS-02 Slow Rate Front-End (F/E) EGSE to be used in the communications room of the MPPF and/or the SSPF is listed below. All equipment will be commercial office equipment and UL approved or equivalent.

- Primary F/E: 3 Dual Central Processing Unit (CPU) Personal Computers (PCs) (Intel or AMD)
- Secondary F/E: 3 Dual CPU PCs (Intel or AMD)

The AMS-02 Data Processing Farm EGSE to be used in the communications room of the MPPF and the SSPF is listed below. All equipment will be commercial office equipment and UL approved or equivalent.

- 20 dual-CPU PCs (Intel or AMD)
- 3 CPU Patch Panel Switches
- 5 Ethernet Switches/Hubs
- 7 UPSs
- Three 17-inch Monitors
- Miscellaneous Cables

The AMS-02 Data Servers and Archiving Tapes EGSE to be used in the communications room of the MPPF and the SSPF is listed below. All equipment will be commercial office equipment and UL approved or equivalent.

- 5 Dual-CPU PCs (Intel or AMD)
- 5 External SCSI Disk Towers [2 Tera-Bytes (TB) of disks per tower]
- 3 Super Digital Linear Tape (DLT) or Linear Tape Open (LTO) 100/200GB Tape Drives
- 4 UPSs
- 2 Ethernet Switches

The AMS-02 payload EGSE to be used at KSC for the Analysis Computing is:

- 2 to 3 Standard Mini Tower PCs
- 1 to 2 Attached Redundant Arrays of Inexpensive Disks (RAID)
- 2 UPSs
- Three 17-inch Monitors

AMS-02 payload Desktop Computer EGSE to be used at KSC includes:

- 30-40 PCs (with monitor and keyboard) (Intel or AMD)

AMS-02 miscellaneous EGSE to be used at KSC includes:

- 5 Laserjet Printers
- The AMS-02 payload organization will also bring miscellaneous diagnostic and support equipment to KSC (e.g. oscilloscopes, digital volt meters, power supplies, function generators, logic analyzers, etc.).

The AMS-02 EGSE will also contain a 124V DC power supply unit to provide power during AMS-02 standalone testing. This unit will also provide the 124V DC power for the AMS-02 payload stand alone integrated test prior to transfer to KSC for on-line operations.

The AMS-02 Experiment EGSE Matrix is shown in Table 7.3.1.

Table 7.3.1 - AMS-02 Experiment EGSE Matrix

Item	Quantity	Manufacturer	Model No.	Commercial (Yes/No)	Electrical Code	Power Requirement	3-Phase (Yes/No)	KSC Facilities	Batteries (Yes/No)
Front End Computers:									
Dual-CPU PCs	6	Intel or AMD	TBD	Yes	*	TBD	No	MPPF/SSPF	Yes
Data Processing Farm:									
Dual-CPU PCs	20	Intel or AMD	TBD	Yes	*	TBD	No	MPPF/SSPF	Yes
CPU Patch Panel Switches	3	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	No
UPSs	7	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	Yes
Ethernet Switches/Hubs	5	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	No
Misc. Cables	TBD	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	No
17" Monitors	3	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	No
Data Servers/Archiving Tapes:									
Dual-CPU PCs	5	Intel or AMD	TBD	Yes	*	TBD	No	MPPF/SSPF	Yes
External SCSI Disk Towers	5	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	No
SuperDLT or LTO Tape Drives	3	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	No
UPSs	4	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	Yes
Ethernet Switches	2	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	No
Analysis Computing Facilities:									
SMT Computers	2-3	Sun or Compaq	TBD	Yes	*	TBD	No	MPPF/SSPF	Yes
Attached RAID Arrays	1-2	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	No
UPSs	2	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	No
17" Monitors	3	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	No
Mouses/Cables/Keyboards	TBD	TBD	TBD	Yes	*	TBD	No	MPPF/SSPF	No
Desktop Computers:									
PCs(w/monitor & keyboard)	30-40	Intel or AMD	TBD	Yes	*	TBD	No	MPPF/SSPF	Yes
Printers:									
Laserjet Printers	5	Hewlett Packard	TBD	Yes	*	TBD	No	MPPF/SSPF	No

* UL approved or equivalent

7.4 KSC-PROVIDED GSE

The following KSC-provided GSE will be used during ground processing of the AMS-02 payload:

- Oxygen level monitor and alarm system
- Active Common Attach System Simulator (ACASS)
- One 124V dc power supply for online and Pad operations [same as used for the Mini-Pressurized Logistics Module (MPLM)]
- Two 28V dc power supplies
- Maximum of three 222-240V dc 50 Hz power and frequency converters

7.5 AMS-02 GSE BATTERIES

TBD

7.6 TOOLS

TBD

7.7 MAGNET OPERATION ALERT SYSTEM

TBD

7.8 MAGNETIC METAL DETECTOR

The AMS-02 payload organization is evaluating the possible use of a metal detector(s) in the payload processing areas around the AMS-02 Cryomagnet when it is powered. The purpose is to prevent personnel from entering the area with metal items that could be attracted by the AMS-02 Cryomagnet. A magnetic material exclusion policy will be used to ensure magnetic materials are not allowed within a TBD range of the magnet while it is operating.

7.9 SHIPPING CONTAINERS

The AMS-02 Vacuum Case Shipping Container (VCSC) will be used (contingency use only) to ship the vacuum case from KSC, if the vacuum case is removed from the USS-02 at KSC. The VCSC will be aluminum and its dimensions will be 120 inches long by 120 inches wide by 70 inches high. It will have permanently attached eyebolts for lifting in the MPLF.

The magnet GSE containers and other AMS-02 shipping containers are TBD.

7.10 AMS-02 GSE MATERIALS

The AMS-02 plastic films, solvents, epoxies, adhesive tapes, foams, etc. are TBD.

8.0 AMS-02 GROUND OPERATIONS SCENARIO

The AMS-02 payload will arrive at KSC by airplane. The AMS-02 processing flow at KSC is shown in Figures 8.1 & 8.2. The AMS-02 will be installed in the Orbiter at the PCR. The AMS-02 KSC procedures are TBD.

9.0 SAFETY DISCUSSION

A safety analysis was performed for the AMS-02 GHE, GSE and KSC ground operations using KHB 1700.7C to identify potential hazards. Hazards identified are documented on the Payload Hazard Report Forms in Appendix A.

To control failure of the AMS-02 lifting equipment, it is being designed to the factors of safety in KHB 1700.7C; proof load tests will be performed; NDI will be performed on AMS-02 shackles, swivel hoist rings, master link assemblies and removable eyebolts on the Lower USS-02 and Lower USS-02 Shipping Cover; torque values on drawings and visual inspections will be used to assure full thread engagement of swivel hoist rings and removable eyebolts; visual and structural inspections will be performed per KHB 1700.7C; equipment identification, next required test date, quality control stamp, rated load and proof load/date will be posted on equipment; part numbers for components which will be normally disassembled will be specified on drawings and in procedures to assure proper reassembly; approved drawings/procedures will be used; and only certified personnel will perform lifting operations. This is addressed on Hazard Report (HR)# G-AMS-02-1.

Structural failure of the AMS-02 Primary Support Stand (PSS) will be controlled by designing to the factors of safety in KHB 1700.7C, and using bolt part numbers and torque values in the vertical corner supports' adjustment procedure. This is addressed on HR# G-AMS-02-2.

To control possible injury to personnel and/or interference with GSE or other payloads from the AMS-02 magnetic field, the AMS-02 cryomag is being designed to reduce the magnetic field outside the magnet as much as possible. This has been done by careful arrangement of the racetrack and dipole coils to create a large magnetic field inside and a greatly reduced field on the outside. If the AMS-02 cryomag does not comply with the requirements of the ACGIH Biological Exposure Indices for magnetic fields, a keep-out zone may be required and a Noncompliance Report (NCR) will be submitted. Also, warning signs will be posted at control entry points [including on the Payload Ground Handling Mechanism (PGHM)] for pacemaker wearers. This is addressed on HR# G-AMS-02-3.

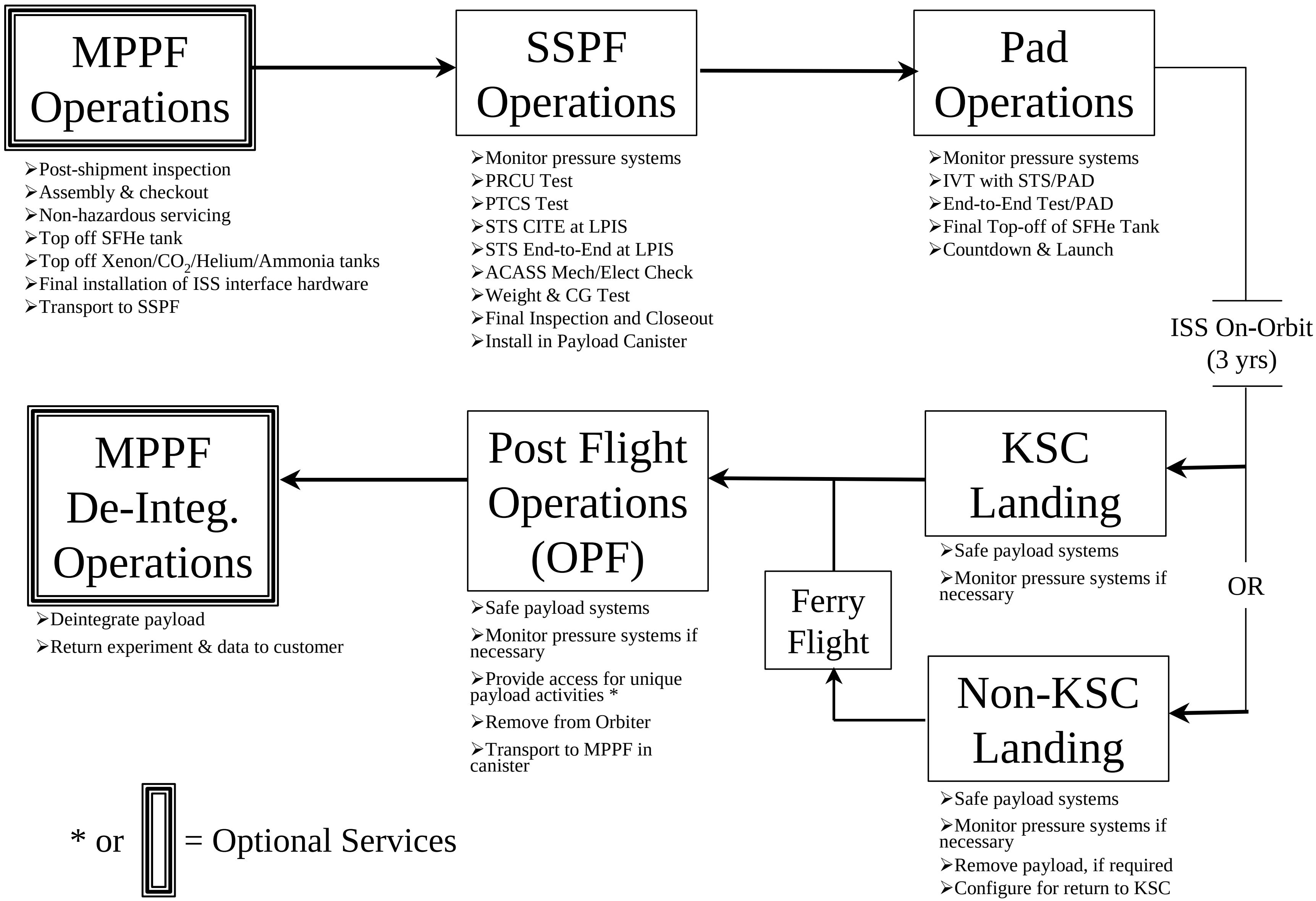

Figure 8.1 - AMS-02 Ground Processing Flow Chart

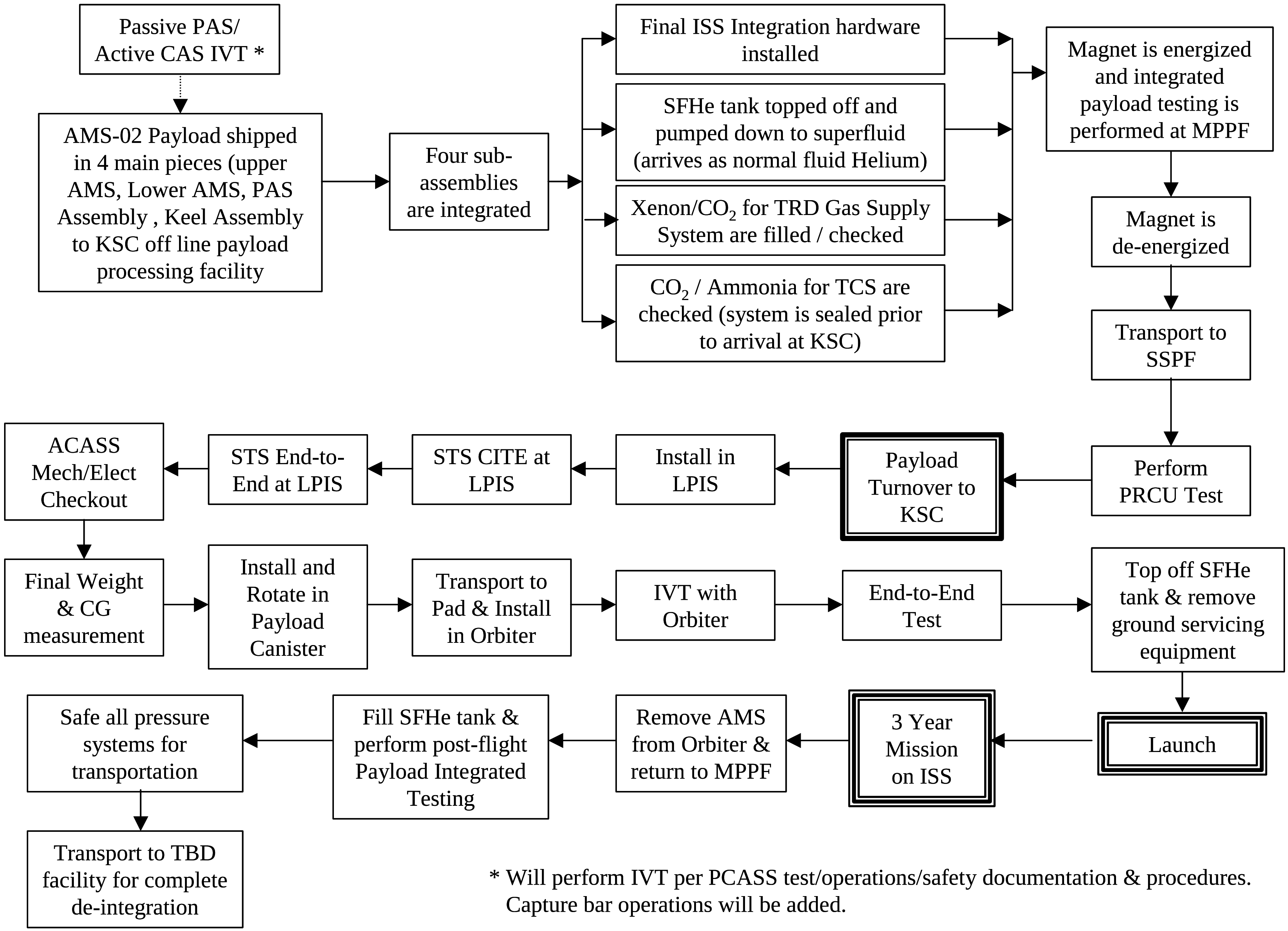

Figure 8.2 - AMS-02 Launch Site Operations Flow Chart

Use of flammable, static-producing or toxic materials will be controlled by using KSC-provided materials where possible and selecting materials from KSC lists of approved materials. A list of AMS-02 GSE materials and Material Safety Data Sheets (MSDSs) will be submitted to the AMS-02 Customer Integration Manager at KSC for all materials not on the KSC approved lists. This is addressed on HR# G-AMS-02-4.

Sharp edges, corners or protrusions will be controlled by designing to meet the requirements of KHB 1700.7C and MIL-STD-1472F. This is addressed on HR# G-AMS-02-5.

To control electrical damage from AMS-02 Electrical GSE (EGSE), AMS-02 EGSE will have overload protection devices (such as fuses and circuit breakers). The AMS-02 EGSE will meet the requirements of Section 4.3.2 of KHB 1700.7C and the National Electric Code (NEC) or equivalent. Three-phase power sequencing will be verified in each KSC facility prior to connecting any AMS-02 EGSE which requires three-phase power. Connectors which are physically impossible to mismate will be used where necessary to prevent a hazard from mismating. This is addressed on HR# G-AMS-02-6.

Personnel will be protected from electrical shock by enclosing AMS-02 voltages in excess of 30 VAC (rms) or 50 VDC, properly grounding/bonding AMS-02 hardware, providing a non-current carrying ground conductor in AMS-02 EGSE power cords, mating/demating connectors on de-energized electrical circuits only, and using connectors which are physically impossible to mismate where necessary to prevent an electrical shock from mismating. The AMS-02 EGSE will meet the requirements of Section 4.3.2 of KHB 1700.7C and the National Electric Code (NEC) or equivalent. This is addressed on HR# G-AMS-02-7.

Electrical ignition sources will be controlled by using proper wire size and overload protection devices (such as fuses and circuit breakers) in AMS-02 EGSE, mating/demating connectors on de-energized electrical circuits only, using connectors which are physically impossible to mismate where necessary to prevent an ignition source and monitoring AMS-02 heater circuits so that accessible surface temperatures will not exceed TBD degrees. The AMS-02 EGSE will meet the requirements of Section 4.3.2 of KHB 1700.7C and the National Electric Code (NEC) or equivalent. This is addressed on HR# G-AMS-02-8.

Personnel contact with high temperature surfaces will be controlled by restricting access to the AMS-02 payload during electrical operations which require the use of the Power Distribution Boxes (PDBs) or powering of the AMS-02 heaters. This is addressed on HR# G-AMS-02-9.

Rupture of the 1000 liter GSE Liquid Helium (LHe) supply dewars or TRD GSE pressure systems will be controlled by designing and testing to the requirements of Section 4.3.3.1 of KHB 1700.7C, using trained personnel with approved operation and handling procedures, only allowing access by qualified personnel, using He pressurant which meets the purity standards of MIL-P-27407A, using adequate redundancy for pressure relief and filtering the LHe to remove particles ≥ 2 microns before filling the GSE supply dewars. Rupture of the flight dewar will be controlled by using burst disks and emergency vent lines, designing to preclude puncture of the flight dewar Vacuum Case by a falling object, using trained personnel with approved operation and handling procedures, only allowing access by qualified personnel, using He pressurant which meets the purity standards of MIL-P-27407A, using adequate redundancy for pressure relief and filtering the LHe to remove particles ≥ 2 microns before filling the GSE supply dewars. This is addressed on HR# G-AMS-02-10.

To control failure of the GSE servicing lines, they will be designed to meet the requirements of Section 4.3.3.1 of KHB 1700.7C. Gauges and pressure relief devices on the servicing lines will be sized to protect downstream equipment. Structural support will be provided for relief devices and discharge plumbing. Servicing lines will be designed to prevent trapping pressure in parts of the pressure system which can get cold, without passive bleed-down capability. Adequate relief paths will be designed for high pressure regulated lines. Servicing operations will be performed by trained personnel using approved procedures. All high pressure lines will be tied down at both ends and every 6 feet. This is addressed on HR# G-AMS-02-11.

To control exposure to high-pressure gas, cold He/N_2 gas, LN_2 and/or cold surfaces, vents and relief devices (including emergency vent lines) will be directed out of the work area by proper GSE set-up and by vent shields and/or deflectors, if necessary; the TRD Xe Handling Station will be equipped with a splash hood/vent arrangement; vents, relief devices and cold surfaces will be clearly labeled; personnel will use appropriate protective clothing when using LHe and LN_2 equipment; access to the AMS-02 He flight dewar, GSE He supply dewars and the TRD Xe Handling Station dewar will be restricted during fill/transfer/removal operations; and trained personnel will be used. This is addressed on HR# G-AMS-02-12.

Personnel exposure to an asphyxiation hazard from Helium (He), Xenon (Xe), Carbon Dioxide (CO_2) or Nitrogen (N_2) displacement of oxygen will be controlled by adequate ventilation; use of an oxygen level monitoring and warning system, where necessary; use of labels to identify vent and relief device locations; use of personnel trained on evacuation procedures; and use of the "buddy" system, where necessary. This is addressed on HR# G-AMS-02-13.

Inadvertent tipping, sliding or rolling of AMS-02 GSE/GHE will be controlled by designing equipment with a low center-of-gravity, using locking features on wheels/castors, and using approved procedures for transporting and securing the AMS-02 GSE/GHE. This is addressed on HR# G-AMS-02-14.

Personnel exposure to ionizing radiation will be controlled by containment. The Transition Radiation Detector (TRD) has 4 calibration tubes mounted in Box C which contain ionizing radiation sources. Each calibration tube has a 0.2 microCurie deposit of Fe_{55} on the inner wall. This is addressed on HR# G-AMS-02-15.

APPENDIX A

AMS-02 GROUND PAYLOAD HAZARD REPORTS