PAYLOAD FLIGHT HAZARD REPORT				a. NO:	AMS-02-F05
b. PAYLOAD	Alpha Magnetic Spectrometer-02 (AMS-02)			c. PHASE:	II
d. SUBSYSTEM:	Pressurized Systems	e. HAZARD GROUP:	Explosion, Contamination	f. DATE:	May 22, 2006
g. HAZARD TITLE:	Rupture of AMS-02 Pressurized Systems: TRD Gas System (Xe & CO_2), Cryomagnet Warm Helium Gas System, Tracker Thermal Control System, Thermal Control Systems, Cryocooler			i. HAZARD CATEGORY:	CATASTROPHIC X CRITICAL
h. APPLICABLE SAFETY REQUIREMENTS:	NSTS 1700.7B and ISS Addendum: 200.1, 200.1b, 200.2, 200.3, 200.4a, 201.3, 205, 206, 208.1, 208.2, 208.3, 208.4, 208.4a, 208.4b, 208.4c & 208.4e				
j. DESCRIPTION OF HAZARD:	Rupture/Explosion of the pressurized systems results in significant damage to or loss of the STS, ISS, crewmembers and/or other payloads.				

k. CAUSES *(list)*

1. Inadequate design strength for pressure and other loading environments.
2. Improper material selections and processing.
3. Improper workmanship and/or assembly.
4. Propagation of crack-like defects.
5. Liquefaction/freezing/thawing in lines.
6. Improper filling/over filling of vessel/system.
7. Incorrect commanding of valves.
8. Heater Failure
9. Meteoroid and Orbital Debris (M/OD) impact.
10. Damage to Composite Overwrapped Pressure Vessel

o. APPROVAL	PAYLOAD ORGANIZATION	SSP/ISS
PHASE I		
PHASE II		
PHASE III		

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F05
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

l. HAZARD CONTROL (CONTROL), m. SAFETY VERIFICATION METHODS (SVM), n. STATUS OF VERIFICATIONS (STATUS)	OPS CONTROL
1. CAUSE: Inadequate design strength for pressure and other loading environments.	
1.1 CONTROL: The AMS-02 hardware is being designed to provide positive margins using appropriate factors of safety. The attached tables provides the MDP, factors of safety and associated margins for the pressurized systems addressed in this hazard report. The loading factors and conditions, mechanical, pressure and thermal have been considered in establishing a positive margin of safety of the pressure systems associated with the pressurized systems. 1.1.1 SVM: AMS-02 Pressure Systems Structural/Stress Analysis and Tests as defined in AMS-02 SVP (JSC 28792). 1.1.1 STATUS: Open	
1.2 CONTROL: TRD SYSTEM. The TRD consists of three zones of pressure control by design. The first zone, referred to as Box S, contains two pressure zones within it. The high pressure supply and the low pressure supply to Box C. The high pressure side pressure is driven by the pressure vessels that provide the Xenon (at 1550 psia, nominal) and carbon dioxide (at 940 psia). Within these high pressure tanks the MDP has been established to be 2960 and 2040 psia respectively in isolation. These values are based on worst case thermal environments and quantities loaded. As there is a conceivable failure mode that can cross-link the two high pressure tanks, the mixing of the two gas supplies yields an approximate **MDP of 3000 psi** (2980 psi calculated), which is the value used for the Box S high pressure side tanks and lines. Within Box S these high pressure sources are fed through valves and orifices to fill a mixing tank which has an **MDP of 300 psia**. Pressure monitors are provided in the system to allow for computer control of the valves to regulate pressure/gas management by opening and closing a series of valves in each supply line. This MDP is kept from being exceeded by the computer-controlled valves and orifice delivery system (level 1) and two parallel, series coupled pressure relief devices set to 300 psia. Either branch of the pressure relief devices (Burst disk and pressure relief valve) is capable of handling the full flow of the gas supplies if all the valves were to open. The burst discs is provided up-stream of the pressure relief devices for isolation of the pressure relief valves from the operating loops (Rated 295 psig by BS&B Safety Systems). The pressure relief devices will be shown to be insensitive to any debris that the burst disc may generate in providing MDP protection. The next zone of the TRD is fed from the mixing tank into Box C, which provides pumping of the gas to the manifold and TRD sensor segments (straws). This section also includes the monitor tubes, which contain a small radioactive source, that monitor the quality of the gas mixture. Pressure is regulated to a **maximum of 300 psi** from Box S through valves and	

orifices, and computer controlled valves can vent the gas in addition to two pressure relief valves, these three levels of control (computer controlled valves, two pressure relief valves) regulate the pressure to **29.4 psia MDP**. TRD pump design can provide gas flow but is designed not to add to the pressure head within the system.

The third zone is the manifold and sensor "straws" the pressure of which is controlled by **Box C to 29.4 psia MDP**. Gas is supplied through the flow provided by the Box C pumps.

1.2.1 SVM: Manufacturer's Certification/Testing of relief valves to verify opening pressure and flow capacity.

1.2.2 SVM: Functional testing of computer controlled valves.

1.2.3 SVM: Flow rate analyses (orifice, valve, relief valve flow)

1.2.4 SVM: Functional testing of gas flow pumps

1.2.5 SVM: Pressure system thermal analyses (included in stress analysis)

1.2.6 SVM: Manufacturer's qualification/certification of burst disk.

1.2.7 SVM: Acceptance Testing of Burst disc

1.2.8 SVM: Ground loading procedures to provide proper filling conditions, quality and quantities.

1.2.9 SVM: COPV Stress Analysis Per ANSI/AIAA S-081

1.2.1 STATUS: Open.

1.2.2 STATUS: Open

1.2.3 STATUS: Open

1.2.4 STATUS: Open

1.2.5 STATUS: Closed. Main TRD gas tank stress analysis documented thermal analysis results in EG 10348, Fracture and Stress Report of CO_2/Xenon Tank Assembly PN C4810/D4852 for TRD Gas Supply System, Nov 6, 2001. Tanks are identical to Arde tanks previously flown on ISS.

1.2.6 STATUS: Open

1.2.7 STATUS: Open

1.2.8 STATUS: Open

1.2.9 STATUS: Open

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F05
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

1.3 CONTROL: WARM HELIUM GAS SUPPLY. The Warm Helium Gas Supply is designed to have two distinct pressure zones. The high pressure helium source has an MDP of 321 bar (4655.7 psi), established by the high pressure burst disk that is set at 320 bar (4641.2 psi). The 8.3 liter gas bottle, a composite wrapped bottle manufactured by Arde, is filled to have a pressure of 200 bar (2900.7 psi), and under worst case environmental thermal conditions the pressure could rise to 273 bar (3959.5 psi). The Warm Helium Gas Supply does not utilize any heaters. The MDP for the bottle has been set to the burst disk value although the highest pressure has been established by fill quantity and thermal conditions. The high pressure side with the MDP of 321 bar (4655.7 psi) comprises the gas bottle, pressure manifold, fill and drain valve MV42, 320 bar burst disk and the 6 bar pressure regulator. The burst disk has been qualified per NSTS/ISS 18798, Letter NASA/JSC TA-88-074 to be single fault tolerant equivalent.

The low pressure side of the Warm Helium Gas Supply is nominally regulated to 6 bar (87.0 psi) and is protected by over pressurization by an 8 bar (116.0 psi) pressure relief device RV03 and by 10 bar (145.0 psi) burst disks that protect each isolated volume. The plumbing in the low pressure side is 1/8 inch stainless steel piping. The regulated Cryogenic Valves and Current Lead Disconnect have an MDP of 10 bar (145.0 psi) based on this supply pressure. All components and lines meet the appropriate factors of safety as required by NSTS 1700.7.

1.3.1 SVM: Manufacturer's Certification/Testing of relief valve to verify opening pressure and flow capacity.

1.3.2 SVM: Flow rate analyses (orifice, valve, relief valve flow)

1.3.3 SVM: Pressure system thermal analyses

1.3.4 SVM: Manufacturer's qualification/certification of burst disk.

1.3.5 SVM: Acceptance Testing of Burst disc

1.3.6 SVM: Ground loading procedures to provide proper filling conditions, quality and quantities.

1.3.7 SVM: COPV Stress Analysis Per ANSI/AIAA S-081

1.3.1 STATUS: Open.

1.3.2 STATUS: Open

1.3.3 STATUS: Open

1.3.4 STATUS: Open

1.3.5 STATUS: Open

1.3.6 STATUS: Open

1.3.7 STATUS: Open

1.4 CONTROL: TTCS TWO PHASE LOOP. The nominal TTCS MDP has been established by TTCS fill and the worst case thermal profile of the TTCS. Heater failure for this system is addressed under Cause 8 of this hazard report. This value is 160 bar (2320 psi) and encompasses the extremely small pressure differential across the circulation pump. All other components and lines are designed to maintain a safety factor of 4.0 per NSTS 1700.7B and ISS Addendum. NOTE: *The TTCS has a special consideration addressed in Control 5.4 where segments of the TTCS are susceptible to freezing of the carbon dioxide working fluid, these components will have a new MDP established based on the stress of the freeze/thaw cycle.*

1.4.1 SVM: Thermal Analysis

1.4.2 SVM: Manufacturer's Certification of TTCS Filling.

1.4.1 STATUS: Open

1.4.2 STATUS: Open. .

1.5 CONTROL: TTCS RADIATOR HEAT PIPES. The AMS-02 TTCS utilizes a seven sealed heat pipes in each of the two Tracker Radiators that are situated atop the AMS-02. These heat pipes are of identical design throughout but with varying length, constructed of Al 6063 and filled with ammonia with pipe quantities varying with length (44.6 – 52.6 grams), 14 mm diameter with a minimum thickness of 1.25 mm. This heat pipe is manufactured with a 40 mm flange that is used to interface with the TTCS condensers. These flanges are milled down for the rest of the heat pipe's length along the Tracker Radiator. The MDP of the heat pipes are based on the worst case thermal profile while on-orbit for the ammonia filled tubes, considering the worst case heater failures, with a final temperature of the systems as being 50°C. This MDP is 290 psi (20 bar) and is inclusive of all heat pipes although not all heat pipes could possibly see this particular temperature and hence this MDP. The heat pipes meet a 4.0 factor of safety satisfying the required 2.5 factor of safety per NSTS 1700.7B and ISS Addendum. Heater Failure Tolerance is discussed under Cause 8.

1.5.1 SVM: Thermal Analysis of AMS-02 for worst case thermal condition of heat pipes

1.5.2 SVM: Manufacturer's Certification of heat pipe filling.

1.5.1 STATUS: Open

1.5.2 STATUS: Open

1.6 CONTROL: TTCS OHP. The TTCS Oscillating Heat Pipe (OHP) Experiment is a heat pipe that utilizes "slugs" of FC-

87 flourinated fluid with gas filled voids between the slugs to transport heat. The entire pipe's MDP is established based on the worst case thermal profile of the system and the fill quantity of FC-87. This MDP has been established to be 129.8 psi (8.95 bar). The components and lines of the OHP will meet the factors of safety required by NSTS 1700.7B and the ISS Addendum.

1.6.1 SVM: Thermal Analysis of AMS-02 for worst case thermal condition of OHP

1.6.2 SVM: Manufacturer's certification on filling OHP with FC-87

1.6.1 STATUS: Open

1.6.2 STATUS: Open

1.7 CONTROL: TTCS Accumulator Heat Pipe. The TTCS accumulator heat pipe (one on primary and one on secondary TTCS systems) is unique in that it is integrated into the TTCS carbon dioxide accumulator structure, a portion of the heat pipe experiences external pressure as defined by the TTCS system (160 bar) and the rest (100mm extending outside of the TTCS Accumulator) it's own internal pressure (29.5 bar) under worst case thermal loading conditions of the ammonia working fluid. The construction of the TTCS Accumulator heat pipe also differs from other heat pipes as it has a smooth bore with an inserted artery wick structure along the periphery of the tube and bridging singularly across the heatpipe to supply wicking effects. The MDP established by the thermal condition of the heat load applied by the dedicated heaters in the worst case environment has been established to be 29.5 bar (427.9 psi) relative to vacuum and the MDP of the portion interior to the accumulator has been set to the MDP of the accumulator (160 bar, 2320.6 psi)**.** This "interior" MDP could be set to 160 bar minus the lowest pressure of the heat ~~pIpe~~pipe, but for simplicity the worst case is assumed. The heat pipes meet a 2.5 factor of safety per NSTS 1700.7B and ISS Addendum. Heater Failure Tolerance is discussed under Cause 8.

1.7.1 SVM: Thermal Analysis of TTCS and TTCS Accumulator Heat Pipe Operations including failure conditions.

1.7.2 SVM: Manufacturer's certification on filling the TTCS Accumulator Heat Pipe

1.7.1 STATUS: Open

1.7.2 STATUS: Open

1.8 CONTROL: HEAT PIPES. The AMS-02 utilizes a number of sealed heat pipes throughout its TCS design. These heat pipes are of similar design throughout, constructed of Al 6063 and of three sizes, 14 mm diameter with a thickness of 1.25 mm, 10 mm diameter with a 0.8 mm thickness and 8 mm in diameter with a TBD thickness. The MDP of the heat pipes are based on the worst case thermal profile while on-orbit for the ammonia filled tubes, considering the worst case heater failures, with a final temperature of the systems as being 60°C. This MDP is 362.5 psi (25 bar) and is inclusive of all heat pipes although not all heat pipes could possibly see this particular temperature and hence this MDP. The heat pipes meet a 4.0 factor of safety satisfying the required 2.5 factor of safety per NSTS 1700.7B and ISS Addendum. Heater Failure Tolerance is discussed under Cause 8.

1.8.1 SVM: Thermal Analysis of AMS-02 for worst case thermal condition of heat pipes

1.8.2 SVM: Manufacturer's Certification of heat pipes for proper filling.

1.8.1 STATUS: Open

1.8.2 STATUS: Open

1.9 CONTROL: CAB LOOP HEAT PIPE. The CAB Loop Heat Pipe is a continuous open loop composed of an evaporator, reservoir, vapor, liquid and condenser tubes. The entire loop's MDP is established based on the worst case thermal profile of the system and the fill quantity of ammonia. This MDP has been established to be 294.4 psi (20.3 bar). The components and lines of the CAB Loop Heat Pipe will meet the factors of safety required by NSTS 1700.7B and the ISS Addendum.

1.9.1 SVM: Thermal Analysis of AMS-02 for worst case thermal condition of CAB Loop Heat Pipe

1.9.2 SVM: Manufacturer's Certification of CAB Loop Heat Pipe for proper filling.

1.9.1 STATUS: Open

1.9.2 STATUS: Open

1.10 CONTROL: CRYOCOOLER LOOP HEAT PIPE/ZENITH RADIATORS. There are four Cryocooler Loop Heat Pipes systems, internally each of the four loop heat pipes have parallel, redundant heat loops. The heat is taken from the cryocoolers through evaporators (AISI 321) connected to the Cryocooler collar. The heat pipe at the junction of the evaporator are stainless steel (AISI 321) tubing, this tubing goes to the bimetallic transition joint to connect to the AL 6063 tubing (4mm OD, 3mm ID) which is soldered to the underside of the zenith radiator panel. The MDP of the Cryocooler Loop Heat Pipe system is established based on propylene quantity (working fluid) and the maximum temperature that system can attain. This has been established considering the thermal load from the cryocoolers, heaters (failed on at 68.5 W) and the environment. The MDP has been assessed to be 261 psi (18 bar) with a maximum propylene fill of 42 grams. A bypass valve has been implemented in the Loop to allow for bypass of the radiators at low temperatures for performance. This valve does not create any entrapped volume, only directs flow although its operation is based on the thermal response of a sealed argon environment within the bypass valves. All components and lines of the Cryocooler Loop Heat Pipe meet the appropriate factors of safety of NSTS 1700.7B and ISS Addendum.

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F05
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

1.10.1 SVM: Thermal Analysis of Cryocooler Loop Heat Pipe to establish MDP. 1.10.2 SVM: Cryocooler Loop Heat Pipe Filling Certification from Manufacturer 1.10.1 STATUS: Open 1.10.2 STATUS: Open	
1.11 CONTROL: CRYOCOOLERS. The Cryocooler is a Sterling cycle heat pump that consists of the single component that interfaces thermally with the Cryomagnet system and the Cryocooler Loop Heat Pipe, but does not interconnect with those pressure systems. The linear piston (magnetically operated) creates a maximum operating pressure of 20 bar (294 psi). The MDP has been established not by operations but while inert at the worst case design temperature of 80°C (176 °F), this value is 20.3 bar. This non-operational condition is a worst case thermal condition compared to full operations with the heater failed on meant to encompass all possible thermal loads. The Cryocooler will meet the factors of safety required by NSTS 1700.7B for pressurized components. 1.11.1 SVM: Thermal Analysis of AMS-02 for worst case thermal environment 1.11.2 SVM: Manufacturer's Filling Certification for the Cryocooler 1.11.1 STATUS: Open 1.11.2 STATUS: Open	
2. CAUSE: Improper material selections and processing.	
2.1 CONTROL: All AMS-02 pressure system materials will be selected to meet the requirements of MSFC-STD-3029 for stress corrosion cracking. Materials with high resistance to stress corrosion cracking will be used where possible. Where materials with moderate to low resistance to stress corrosion cracking are utilized, MUAs have been prepared and will be submitted for approval. 2.1.1 SVM: Stress Corrosion Evaluation of materials list and drawings. 2.1.2 SVM: ES4/Material and Processes Branch Certification for materials usage. 2.1.1 STATUS: Open 2.1.2 STATUS: Open	
2.2 CONTROL: Working fluids/gasses are inert and will be non-reactive, with the exception of ammonia and propylene. All working fluids are compatible with all materials of construction. Materials of construction are principally stainless steel	

and aluminum. The TRD (working fluids carbon dioxide and xenon) and Warm helium gas bottle (Arde) are stainless steel lined, composite overwrapped tanks. The TRD also has composite-wound sensors through which gas is pumped at low pressure. 2.2.1 SVM: Materials Compatibility Assessment 2.2.2 SVM: Approval of material use and MUAs by JSC ES4/Materials and Processes Branch 2.2.1 STATUS: Open 2.2.2 STATUS: Open	
2.3 CONTROLS: Cleaning materials will be compatible with working fluid and materials of construction. 2.3.1 SVM: Materials Compatibility Assessment/Review 2.3.1 STATUS: Open	
2.4 CONTROL: Metallic materials that touch in the pressure system will be assessed for potential galvanic reactions that could degrade welds and other joints. 2.4.1 SVM: Material Compatibility Assessment 2.4.2 SVM: Approval of material use and MUAs by JSC ES4/Materials and Processes Branch 2.4.1 STATUS: Open 2.4.2 STATUS: Open	
3. CAUSE: Improper workmanship and/or assembly.	
3.1 CONTROL: Manufacturing and Assembly AMS-02 pressurized systems will be done in accordance with approved drawings and procedures. Manufacturing and Assembly processes have certification processes in place to document compliance with approved drawings and procedures. 3.1.1 SVM: All discrepancies and deviations from approved drawings/procedures are reconciled through a MRB process to assure compliance with requirements. 3.1.1 STATUS: Open	
3.2 CONTROL: All welds will be made to the standards of the AMS-02 weld policy (compliant with JSC standards for welding).	

3.2.1 SVM: Review of weld plans, processes and certification of welds of the AMS-02 systems.

3.2.2 SVM: Proof Pressure Testing, Dye Penetrant inspection, -Radiological (or ultrasound) inspection of welds.

3.2.1 STATUS: Open

3.2.2 STATUS: Open

4. CAUSE: Propagation of crack-like defects.

4.1 CONTROL: The AMS-02 pressurized systems uses JSC 25863A to implement the fracture control requirements of NASA-STD-5003 and SSP 30558C.

4.1.1 SVM: Compliance with the fracture control requirements of NASA-STD-5003 and SSP-30558C will be verified by approval of fracture control summary by JSC ES4/Materials and Processes Branch.

4.1.1 STATUS: Open

5. CAUSE: Liquefaction/freezing/thawing in lines

5.1 CONTROL: TRD GAS SUPPLY. The TRD Gas Supply system (CO2 & Xenon) will not freeze under the worst case thermal conditions that the system will experience on-orbit. The high pressure TRD system is mounted on a common thermal plate to keep the entire high pressure side thermally uniform. The lowest temperature that has been assessed for the TRD system, using an indefinite period at the worst possible cold attitude with no other attitudes occurring (extremely conservative), to be -50°C (-43°C at 200 hours of exposure with asymptotic approach to approximately -50°C). Even with TRD heaters failed on for the tank only (more than two failures), driving the pressure up, and heaters off for the lines and components, the pressure-temperature curve for CO_2 will not transition to solid phase. Xenon's physical properties make it more difficult to freeze than CO_2. The low pressure side does not have a constant supply of carbon dioxide sufficient to fill a potentially frozen segment with CO_2. Liquid CO_2 is prevented from going from the CO_2 tank to the lines by a dual heater system (Side A and B) that will keep the CO_2 gaseous before entering the high pressure lines. If power is lost for the heaters, power is also lost for operating the valves (normally close) that would allow for the introduction of liquid CO_2 into potentially isolated segments. Heater operations on these isolated segments are controlled in a 2 fault tolerant manner, reference Control 8.1.

5.1.1 SVM: AMS-02 Thermal Assessment

5.1.2 SVM: TRD Thermal Assessment for Freezing of CO_2 and Xenon

5.1.3 SVM: Review of TRD Heater Design for single fault tolerant design.

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F05
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

5.1.1 STATUS: Open

5.1.2 STATUS: Open

5.2 CONTROL: WARM HELIUM GAS SUPPLY. The Cryomagnet Warm Helium Supply will utilize the same quality of helium as used to fill the Cryomagnet for superfluid helium, minimizing the potential for contaminants that could freeze solid, plug lines and create a pressure build up. In order to achieve solid (frozen) helium a pressure in excess of 25 atmospheres is required to compress the cryogenic helium, a pressure the AMS-02 can not achieve.

5.2.1 SVM: Loading procedures to assure purity of helium loaded into Warm Helium Gas Supply.

5.2.2 SVM: Analysis/Review of Helium Freezing Potential

5.2.1 STATUS: Open

5.2.2 STATUS: Closed. Memo ESCG-4390-06-SP-MEMO-0002, "Freezing of Helium withing AMS-02" dated 8 December 2005, from AMS-02 Chief Engineer Chris Tutt.

5.3 CONTROL: TTCS TWO PHASE LOOP. The Tracker Thermal Control System (TTCS) will freeze under a loss of power from the ISS under worst case thermal conditions at the condensers. The TTCS components subject to freezing have had their MDPs established based on a freezing event and subsequent heating/thawing that results in a trapped volume of carbon dioxide. The condenser tubes of the TTCS could freeze and thaw and the resulting MDP has been established to be 3000 bar (43511 psi). Special proof testing and NDE will be conducted on the sample lot of the tubing used in the construction of the condensers to allow for a reduction in the acceptable factor of safety (per ES4). Using standard techniques of analysis, the tubing indicates a burst proof factor of safety of 2.14, but if the material's strain hardening is taken into account this value rises to 5.21. Thermal Analysis indicates that all other TTCS system components and lines are not subjected to freezing potential.

5.3.1 SVM: Testing of carbon dioxide freezing/heating cycles

5.3.2 SVM: Thermal Analysis

5.3.3 SVM: MDP Analysis based on worst case thermal profiles and two failures (if applicable)

5.3.4 SVM: Review and approval of testing plan for freezing/thawing lines by JSC/ES4.

5.3.5 SVM: Testing/analysis of flight hardware per testing plan of 5.3.4.

5.3.6 SVM: Thermal Analysis of TTCS System to establish freezing/non-freezing elements.

5.3.1 STATUS: Open

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F05
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

5.3.2 STATUS: Open

5.3.3 STATUS: Open

5.3.4 STATUS: Open

5.3.5 STATUS: Open

5.3.6 STATUS: Closed. ESCG-4470-06-TEAN-DOC-0032, "Alpha Magnetic Spectrometer (AMS-02) Tracker Thermal Control System (TTCS) Cold Environment Temperatures), Dated March 22, 2006, from ESCG/E. L. Yagoda indicates no other system elements will freeze.

5.4 CONTROL: TTCS ACCUMULATOR HEAT PIPE. The TTCS Accumulator Heat Pipe is filled with 3 grams of ammonia and will not reach temperatures that can freeze the ammonia. NOTE: Even if the ammonia were capable of freezing, the straight pipe construction with interior mesh and fill quantity of the heat pipe would preclude an accumulation of a solid block of ammonia.

5.4.1 SVM: Thermal Analysis

5.4.1 STATUS: Open

5.5 CONTROL: HEAT PIPES. The design of the ammonia heat pipes allows for the ammonia to condense and freeze without damage to the heat pipes. The low quantity of ammonia, interior shape of heat pipes and the melting/vaporization of the ammonia cannot create trapped volumes that can generate elevated pressures.

5.5.1 SVM: Review of design

5.5.2 SVM: Vendor Certification/Testing

5.5.1 STATUS: Open

5.5.2 STATUS: Open

5.6 CONTROL: TTCS OHP. Material properties of the FC-87 used in the TTCS Oscillating Heat Pipe Experiment indicate that the working fluid will not freeze under the worst case thermal environments the AMS-02 will be exposed.

5.6.1 SVM: Thermal Analysis

5.6.2 SVM: Review of FC-87 manufacturer's data for thermal compatibility

5.6.3 SVM: Manufacturer's (OHP) certification of fill material.

5.6.1 STATUS: ~~Open~~Closed. Thermal Analysis Results reported in ESCG-4390-06-SP-MEMO-0008 dated 15

August, 2006 from Chris Tutt. Lowest temperature that TTCS OHP will experience is -45°C.

5.6.2 STATUS: Closed. Review of manufacturer's published data reported in ESCG-4390-06-SP-MEMO-0008 dated 15 August, 2006 from Chris Tutt indicates that the freezing point of FC-87 is approximately -120°C, This value is based on the fluid's capability to be pourable at a temperature of -115°C and the pour temperature is usually reported as being 5°C above the freezing point.~~Open~~

5.6.3 STATUS: Open

5.7 CONTROL: CAB LOOP HEAT PIPE. The Cryogenic Avionics Box Loop Heat Pipe was established to have a small segment that had the potential to freeze ammonia with the loss of AMS-02 power. Thermal MLI insulation has been applied to these segments to allow a greater than 10°C margin over the freezing temperature of ammonia (-78°C).

5.7.1 SVM: Thermal Analysis of CAB Loop Heat Pipe

5.7.2 SVM: Review of Design

5.7.3 SVM: Inspection of as built hardware.

5.7.1 STATUS: Closed. AMS-02-TN-CGS-010. 7/03/2005

5.7.2 STATUS: Open

5.7.3 STATUS: Open

5.8 CONTROL: Cryocooler Loop Heat Pipe/Zenith Radiator. Propylene freezes at a temperature of -185.25°C (-301.4°F), this temperature is substantially colder than the worst case thermal environment that the Cryocooler Loop Heat Pipe/Zenith Radiator can achieve.

5.8.1 SVM: Thermal Analysis showing worst case cold temperature for Cryocooler Loop Heat Pipe/Zenith Radiator

5.8.2 SVM: Filling Procedure/Certification of Fill

5.8.1 STATUS: Open

5.8.2 STATUS: Open

5.9 CONTROL: Cryocoolers. The working fluid for the Cryocoolers is 0.72 grams of helium, and the Cryocooler is incapable of achieving temperatures (77 K, temperatures must approach <2 K to freeze) and pressures needed (MDP 20 bar, 25+ bar needed to freeze helium) to freeze helium. In addition as the system does not have lines and fittings of a traditional sort where freeze/thaw is considered to be a hazard, the cryocoolers have no risk even if the helium could freeze.

5.9.1 SVM: Analysis/Review of Helium Freezing Potential

5.9.2 SVM: Manufacturer's certification of fill.

5.9.1 STATUS: Closed. Memo ESCG-4390-06-SP-MEMO-0002, "Freezing of Helium withing AMS-02" dated 8 December 2005, from AMS-02 Chief Engineer Chris Tutt.

5.9.2 STATUS: Open

6. CAUSE: Improper filling/over filling of vessel/system.

6.1 CONTROL: All pressurized systems will be filled with high purity gases and appropriate quantities.

6.1.1 SVM: Review of TRD Ground Filling Procedures.

6.1.2 SVM: Review of Warm Helium Gas Supply Filling Procedures.

6.1.3 SVM: Review of Tracker Thermal Control System Filling Procedures.

6.1.4 SVM: Manufacturers' certifications on filling of Ammonia Heat Pipes.

6.1.5 SVM: Manufacturer's certification on filling OHP with FC-87

6.1.6 SVM: Manufacturer's certification on filling of CAB Loop Heat Pipe

6.1.7 SVM: Manufacturer's certification on filling Cryocooler Loop Heat Pipe/Zenith Radiators

6.1.8 SVM: Manufacturer's certification on filling Cryocooler.

6.1.1 STATUS: Open

6.1.2 STATUS: Open

6.1.3 STATUS: Open

6.1.4 STATUS: Open

6.1.5 STATUS: Open

6.1.6 STATUS: Open

6.1.7 STATUS: Open

6.1.8 STATUS: Open

7. CAUSE: Incorrect commanding of valves.

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F05
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

7.1 CONTROL: TRD SYSTEM. The TRD system has a potential for entrapping gas and liquid between controlling valves. Nominally redundant line heaters on the gas feed lines from the tanks will prevent liquid from being present in the lines and thus taken into the entrapped volume. Heater operations may individually fail, but a total power loss for the system would preclude opening the valves as the valves are normally closed. Computer operations will not allow the valves to cycle if the temperature of the line is not at a level to prevent the introduction of liquid into the lines. A pressure relief device set ~~at TBS~~to leak back starting at a 25 psi differential and full flow capability at a 100 psi differential, is provided in the first entrapped volume to allow any liquid in the line to be relieved back into the tank (which can not be at or near MDP to have liquid present). NOTE: In addition to these three levels of control, the TRD valves (Marotta MV 197) will relieve under a back pressure differential of 1535 psid (Manufactuer's Data). Assuming that the highest pressure upstream is the MDP of the system (which can not be the case and have ~~liquire~~ liquid to ingest into the lines to cause it to occur) the maximum pressure of this segment considering two failures would be 4535 psia. In this extreme unrealistic case, after three failures, the factor of safety of the lines, and fittings are 2.8 not the required 4.0.

7.1.1 SVM: Review of TRD Design

7.1.2 SVM: Inspection of TRD Flight hardware

7.1.3 SVM: Functional testing of thermal interlock of valve operations

7.1.4 SVM: Testing of Pressure Relief Valves

7.1.5 SVM: Thermal Analysis

7.1.1 STATUS: Open

7.1.2 STATUS: Open

7.1.3 STATUS: Open

7.1.4 STATUS: Open

7.1.5 STATUS: Open

7.2 CONTROL: TRD SYSTEM. The TRD Gas Supply Cross link valves V20 a&b are modified Marotta MV197 valves that utilize a additional valve in the seat operations that allows for a low pressure backflow between the systems, thus any gas entrapped between these volumes will relieve to the lowest pressure side at a delta pressure of 3000-3300~~TBS~~ psid.[LDH1]

7.2.1 SVM: Testing of modified Marotta MV197 valves.

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F05
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

7.2.2 SVM: Review of design

7.2.3 SVM: Inspection of as built hardware

7.2.1 STATUS: Open

7.2.2 STATUS: Open

7.2.3 STATUS: Open

7.3 CONTROL: TTCS TWO PHASE LOOP. The operation of the TTCS valves allows for the correction of a "vapor block" where gas becomes entrapped and precludes normal operations and for cooling system testing and study during AMS-02 operations. Operations of the valves can not impact the pressure within the system, being incapable of isolating systems or providing additional pressure to the system. There are no hazardous configurations of TTCS valves.

7.3.1 SVM: Review of Design

7.3.1 STATUS: Open

7.4 CONTROL: WARM HELIUM GAS SUPPLY. Valve operations within the Warm Helium Gas Supply do not result in entrapped volumes that can exceed the established MDPs for the systems.

7.4.1 SVM Pressure Analysis of Design

7.4.1 STATUS: Open

8. CAUSE: Heater Failure

8.1 CONTROL: TRD GAS SUPPLY. The TRD utilizes heaters to allow for pressure sensing within the TRD tanks (unable to measure liquid state). These heaters are capable of causing a condition where the MDP would be exceeded if the heaters are failed on and the system is exposed to the worst case thermal environment. To preclude these heaters from failing on, there are three (four in place three are counted for safety) thermostatic control devices controlling the operation of the heaters (one in return leg of heaters) in addition to a computer control of the heater's operations through heater power application and thermal feedback from temperature sensors. Each of the TRD tanks utilizes two strings of heaters, and each string has independent controls (computer is not tallied as a safety control). Thermal set points for the TRD system are attached to this hazard report.~~ for the carbon dioxide tank is +39°C. Thermal set point for the xenon tank is +26°C.~~ TRD Gas Supply isolated segments from the xenon and carbon dioxide tanks, used to control the mass of gas introduced into the system, are protected from thermal extremes generated by the valve block heater runaway by the use of two fault tolerance thermostatic control on each heater, with one of the thermostatic devices in the return leg of the heater circuit.

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F05
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

8.1.1 SVM: Review of Design 8.1.2 SVM: Thermal Analysis (establishing maximum temperature settings and thermal sensitivity of thermostatic control locations. 8.1.3 SVM: Functional testing/Acceptance testing of thermostatic switches. 8.1.4 SVM: Inspection of flight hardware for proper installation of thermostatic switches. 8.1.1 STATUS: Open 8.1.2 STATUS: Open 8.1.3 STATUS: Open 8.1.4 STATUS: Open	
8.2 CONTROL: WARM HELIUM GAS SUPPLY. The Warm Helium Gas Supply does not utilize any heaters nor is the warm helium gas supply tank subject to excessive heating. 8.2.1 SVM: Review of Design 8.2.1 STATUS: Open	
8.3 CONTROL: TTCS HEAT PIPES. The heaters on the TTCS radiator heat pipes will utilize two fault tolerance in the implementation of thermostatic control of the heaters. To preclude these heaters from failing on, there are three thermostatic control devices controlling the operation of the heaters (one in return leg of heaters) in addition to a computer control of the heater's operations through heater power application and thermal feedback from temperature sensors. Each string of the heaters on the radiators is controlled in this two fault tolerance manner. The thermostatic threshold for the heaters is set to TBD. 8.3.1 SVM: Review of Design for inclusion of heater thermostatic control and thermal threshold values 8.3.2 SVM: Thermal Analysis to Establish MDP 8.3.3 SVM: Functional testing/Acceptance Testing of thermostatic switches. 8.3.4 SVM: Inspection of flight hardware for proper installation of thermostatic switches. 8.3.1 STATUS: Open 8.3.2 STATUS: Open 8.3.3 STATUS: Open	

8.3.4 STATUS: Open

8.4 CONTROL: TTCS TWO PHASE LOOP. The Tracker Thermal Controls System utilizes heaters on the two phase loop that are not controlled in a two-fault tolerant means to prevent continuous heater operation. Thermal analysis of the two phase loop indicates that only the temperature of the accumulator is capable of driving the pressure of the system to MDP. Failed on heaters on the "loop" will only force the liquid phase of the working fluid to an alternate location. Only single thermostatic control is implemented at these line heaters. The accumulator heater system implements a two-fault tolerant heater control circuitry as described in Control 8.5. Note: Controls 8.5 and 8.11 document heater elements that are capable of driving the pressure of the TTCS Two Phase Loop.

8.4.1 SVM: Analysis of TTCS Two Phase Loop thermal response to failed heater operations.

8.4.1 STATUS: Open

8.5 CONTROL: TTCS ACCUMULATOR HEAT PIPE/TTCS ACCUMULATOR. The TTCS Accumulator is heated by the TTCS accumulator heat pipe that is situated down the center of the accumulator and possibly by Peltier Devices attached to the Accumulator shell. The accumulator heat pipe extends out of the accumulator and is fitted with heaters ~~that will drive the overall pressure of the TTCS system~~and thermostatic switches. These heaters/Peltier devices will be controlled by thermostatic control devices that are attached to the heat pipe and accumulator by way of ~~a~~ thermally conductive fixtures. The thermostatic control for the heaters/Peltier devices is two fault tolerant, with one thermostatic control device implemented in the return leg of the heaters. NOTE: In addition to heater control by thermostatic devices, the pressure of the TTCS is monitored and a computer system is capable of shutting down the ~~heaters~~heater sources if the pressure is too high for efficient operations, this value is lower than the MDP.

8.5.1 SVM: Review of Design for inclusion of heater thermostatic control and thermal threshold values

8.5.2 SVM: Thermal Analysis to Establish MDP

8.5.3 SVM: Functional testing/Acceptance Testing of thermostatic switches.

8.5.4 SVM: Inspection of flight hardware for proper installation of thermostatic switches.

8.5.1 STATUS: Open

8.5.2 STATUS: Open

8.5.3 STATUS: Open

8.3.4 STATUS: Open

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F05
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

8.6 CONTROL: HEAT PIPES. The worst case thermal conditioning for heat pipes consider the heaters that have been provided on the Tracker Radiator – RAM, Main Radiator – RAM, Tracker Radiator – Wake, Main Radiator – Wake, CAB heat pipe and the PDS heat pipes. Each of these heater systems have implemented a two fault tolerant system for inhibiting heater operations over the thermal threshold that could induce pressures over the MDP. (Set points for some thermostats are lower than the thermal environments that actually drive the MDP.) All heater systems utilize one thermostatic switch in the power leg, one in the return leg that are set to lower, health maintenance temperatures below the safety limit and a third "safety" thermostat that is dedicated to precluding exceeding the safety threshold for temperature (60°C, main radiators) under worst case conditions and faults. Note: Independent of the safety controls there is a computer based, thermal sensor driven control of the entire heater circuitry power supply that will activate if temperature gets too high to protect the electronics.

8.6.1 SVM: Heater Fault Tolerance Thermal Analysis

8.6.2 SVM: Review of design for inclusion of heater thermostatic control and thermal threshold values

8.6.3 SVM: Inspection of Flight Hardware to assure proper thermostatic control placement and parts used.

8.6.4 SVM: Functional testing of thermostatic switches/Acceptance testing.

8.6.1 STATUS: Open. Christian Vettore has completed the essential work and will be producing the final report. (11/18/2005)

8.6.2 STATUS: Open

8.6.3 STATUS: Open

8.6.4 STATUS: Open

8.7 CONTROL: CAB LOOP HEAT PIPE. The CAB Loop Heat Pipe is indirectly heated by heaters within the CAB box used to keep the avionics within an operating temperature range. These heaters are limited by thermostatic control (single fault tolerant) and computer based control from exceeding the CAB operating threshold temperatures. The upper thermal limit of the CAB Loop Heat Pipe are established by this temperature and hence the MDP for the heat pipes. At least one thermostatic control devices will be located in the return leg of the heater circuit.

8.7.1 SVM: Review of Design for inclusion of heater thermostatic control and thermal threshold values

8.7.2 SVM: Thermal Analysis to Establish MDP

8.7.3 SVM: Functional testing/Acceptance Testing of thermostatic switches and computer control

8.7.4 SVM: Inspection of flight hardware for proper installation of thermostatic switches.

8.7.1 STATUS: Open

8.7.2 STATUS: Open

8.7.3 STATUS: Open

8.7.4 STATUS: Open

8.8 CONTROL: CRYOCOOLER LOOP HEAT PIPE. The Cryocooler Loop Heat Pipe and the extension of those heat pipes into the Zenith Radiators (four heat pipes) utilize a heater attached to the individual Cryocoolers attached thermally to the loop heat pipes evaporators. The thermal load of the cryocoolers under worst case conditions, fault and environmental conditions have been used to establish the MDP for the loop heat pipes. This fault condition is controlled by a single thermostat dedicated to the heater (68.5 W) itself, and as the cryocooler provides the actual driving heat source, two independent thermocontrol devices will shut down the cryocooler operations (150W max) when the thermal threshold is met. The MDP of the Cryocooler Loop Heat Pipe is established under this fault condition.

8.8.1 SVM: Review of design to assure single thermostatic control of heater and cryocooler thermal cut off devices and control.

8.8.2 SVM: Inspection of the flight hardware for inclusion of thermostatic control for heater and cryocooler cut off devices.

8.8.3 SVM: Thermal Analysis of Cryocooler Loop Heat Pipe to establish MDP.

8.8.1 STATUS: Open

8.8.2 STATUS: Open

8.8.3 STATUS: Open

8.9 CONTROL: CRYOCOOLERS. The each Cryocooler is equipped with a 68.5 watt heater with a single thermostatic control and the heat load of the cryocooler operating at it's maximum capability is 150W. This heater has been assessed for failed on conditions and with the operating thermal load of the Cryocooler. MDPs of the Cryocooler and the Cryocooler Loop Heat Pipe/Zenith Radiator have been established based on this analysis.

8.9.1 SVM: Review of design to assure single thermostatic control of heater and cryocooler thermal cut off devices and control.

8.9.2 SVM: Inspection of the flight hardware for inclusion of thermostatic control for heater and cryocooler cut off devices.

8.9.3 SVM: Thermal Analysis of Cryocooler to establish MDP.

8.9.1 STATUS: Open

8.9.2 STATUS: Open

8.9.3 STATUS: Open

8.10 CONTROL: TTCS OHP. The OHP utilizes a heater block with wire heaters. Thermal analysis indicates that failed on heaters will not result in the OHP exceeding the established MDP for the system.

8.10.1 SVM: Thermal Analysis

8.10.2 STATUS: Open

8.11 CONTROL TTCS Start Up Heaters. The TTCS Start Up Heaters have been assessed as being capable of driving the pressure of the TTCS CO2 loops sufficiently to warrant two fault tolerant thermostatic control devices to be implemented on each of the TTCS Start Up Heater loops. These thermostatic switches have been set to thermal threshold values that will preclude the TTCS Start Up Heaters from driving the pressure of the TTCS two phase loop beyond the established MDP. Two thermostatic control devices are in the source (power) to the heater elements and a single thermostatic control device in the return leg from the heater elements.

8.11.1 SVM: Review of Design for inclusion of heater thermostatic control and thermal threshold values

8.11.2 SVM: Thermal Analysis to Establish MDP

8.11.3 SVM: Functional testing/Acceptance Testing of thermostatic switches.

8.11.4 SVM: Inspection of flight hardware for proper installation of thermostatic switches.

8.11.1 STATUS: Open

8.11.2 STATUS: Open

8.11.3 STATUS: Open

8.11.4 STATUS: Open

9. CAUSE: Meteoroid and Orbital Debris (M/OD) impact.

9.1 CONTROL: All pressurized tanks will be protected by M/OD shields. The shields are designed to meet the Probability of Non-Penetration (PNP) requirement of SSP 52005. While the AMS-02 will have an extended on-orbit life, the pressurized tanks will only represent a hazardous condition for a limited period of time before the pressure reserves are spent. Each tank will be assessed for PNP for the duration of operational life.

9.1.1 SVM: AMS-02 M/OD Risk Analysis

9.1.2 SVM: Analysis of AMS-02 pressurized system utilization to establish on-orbit penetration threat life duration (period during which M/OD represents a hazard to the pressure vessel.)

9.1.1 STATUS: Open

9.1.2 STATUS: Open

10.0 CAUSE: Damage to Composite Overwrapped Pressure Vessel

10.1 CONTROL: All Composite Overwrapped Pressure Vessels will implement the ground handling damage control requirements of ANSI/AIAA S-081 for the protection and inspection of COPV.

10.1.1 SVM: Review of TRD COPV Protection Protocols

10.1.2 SVM: Review of Warm Helium Gas Supply COPV Protection Protocols

10.1.3 SVM: Inspection of TRD COPVs (at late in process as possible prior to flight)

10.1.4 SVM: Inspection of Warm Helium Gas Supply COPV (at late in process as possible prior to flight)

10.1.1 STATUS: Open

10.1.2STATUS: Open

10.1.3STATUS: Open

10.1.4STATUS: Open

10.2 CONTROL: Thermostatic control of the heaters mounted to the exterior of the TRD Composite Overwrapped Pressure Vessels have four thermostatic control devices that are set to a thermal limit below the temperature that could possibly induce delaminations.

10.2.1 SVM: Arde Certification of thermostatic control acceptability.

10.2.2 SVM: Inspection of as built hardware for proper thermostat installation.

10.2.1 STATUS: Open

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F05
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

10.2.2 STATUS: Open

NOTES:

ACRONYMS	
°C – degrees Centigrade (Celsius)	mm – millimeter
AIAA – American Institute Aeronautics and Astronautics	MUAs – Material Usage Agreements
AMS-02 – Alpha Magnetic Spectrometer - 02	OHP – Oscillating Heat Pipe (experiment)
ANSI – American National Standards Institute	PNP – Probability of No Penetration
CAB – Cryomagnet Avionics Box	psi – Pounds per square inch
CO_2 – Carbon Dioxide	psia – Pounds per square inch absolute
COPV – Composite Overwrapped Pressure Vessel	SVM – Safety Verification Method
He – Helium	SVP – Structural Verification Plan
HP – Heat Pipe	TRD – Transition Radiation Detector
M/OD – Meteoroid/Orbital Debris	TTCS – Tracker Thermal Control System
MDP – Maximum Design Pressure	USS-02 – Unique Support Structure 02
MLI – Multilayer insulation	Xe – Xenon

A. TRD Gas Supply

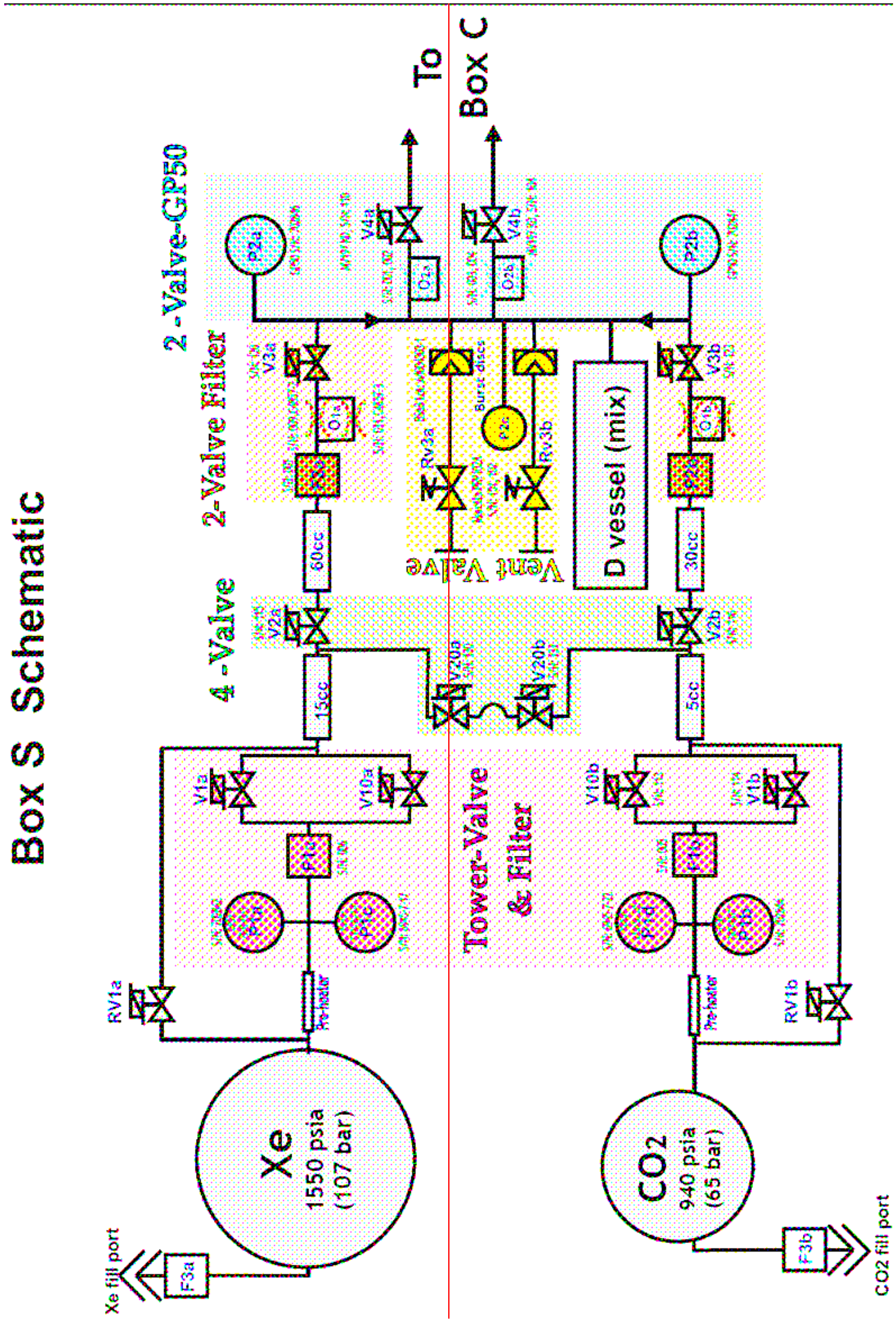
TRD Pressure System Components

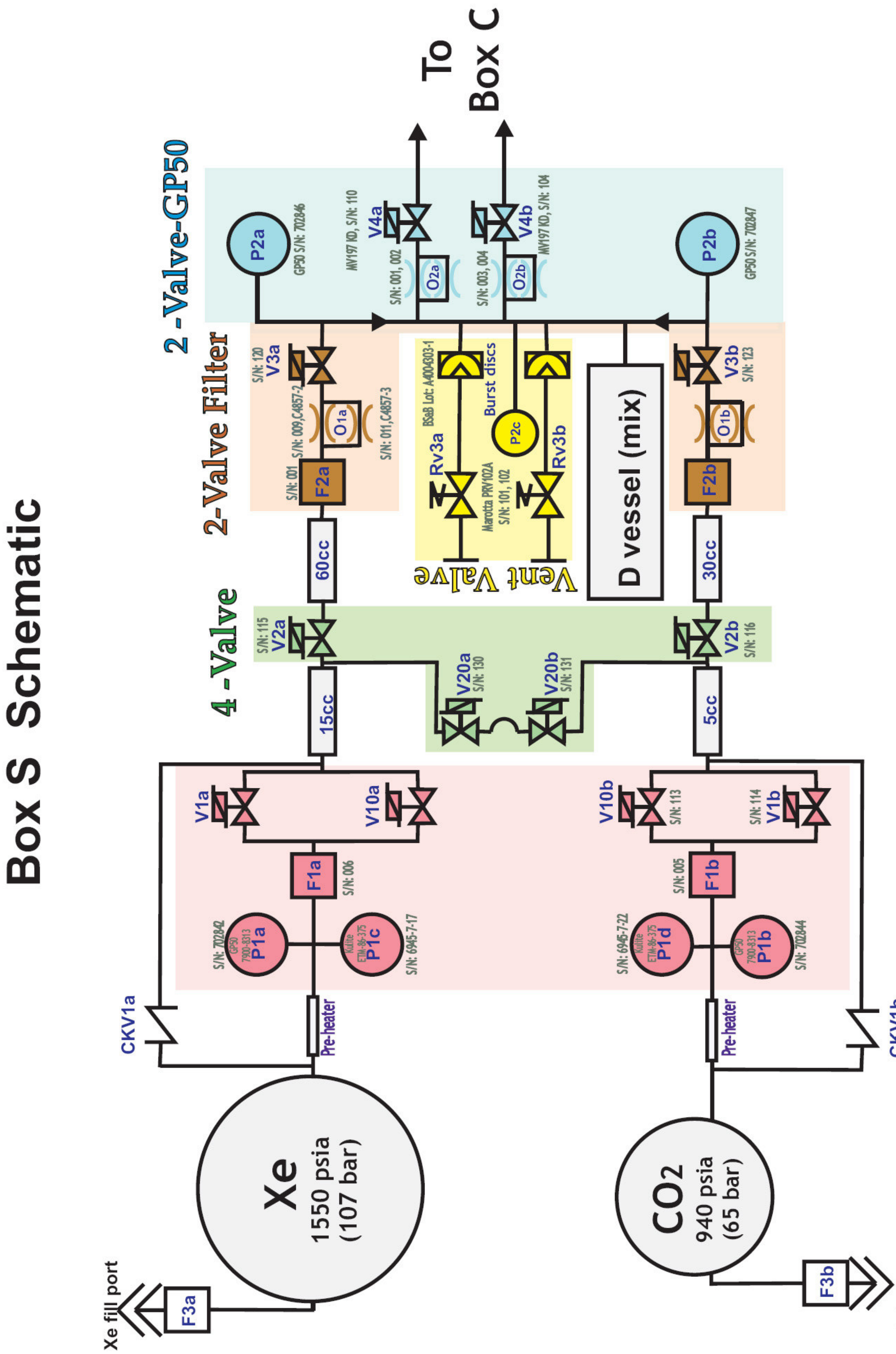
Description	Material Of Construction	Mass Of Fluid		Operating Pressure (max)		MDP[1]		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	bar	psid	bar	psid	bar	psid	Req	Actual	bar	psid			
Xe Storage Vessel, ARDE D4815 (similarirty: D4636) [2]	Carbon Fiber Overwrapped Stainless Steel Liner	49.4	109	106.9	1,550	206.8	3,000	641.2	9,300	2	3.1	310.3	4500	1.5	Similarity & Test	MIL-STD-1522A SSP 30559C
CO_2 Storage Vessel, ARDE D4816 (similarity: D4683) [2]	Carbon Fiber Overwrapped Stainless Steel Liner	5.0	11.0	64.8	940	206.8	3,000	441.3	6,400	2	2.1	330.9	4800	1.6	Similarity & Test	SSP 30559C
Mixing Vessel, ARDE C4810 [2]	Stainless Steel	0.1	0.22	13.8	200	20.7	300	82.7	1,200	2	4.0	41.4	600	2	Test	SSP 30559C
TRD "Straw" Tubes	Wrapped Carbon-Kapton-Aluminum Composite			1.4	20.4	2.0	29.4	4.1	58.8	2	2.0	3.0	44.1	1.5	Test	NSTS 1700.7B SSP 30559C
Plumbing Line 1/8"	Stainless Steel	0.003	0.01	120.0	1,740	206.8	3,000	882.5	12,800	4	4.3	413.7	6,000	2	Test	
Plumbing Line 1/4"	Stainless Steel	0.005	0.01	120.0	1,740	206.8	3,000	882.5	12,800	4	4.3	413.7	6,000	2	Test	NSTS 1700.7B SSP 30559C
Marotta MV 100 Valves [2]	See Data Sheet	<0.002	0.004	2.0	29.4	20.7	300	517.1	7,500	2.5	25	310.3	4,500	15	Similarity & Test	NSTS 1700.7B Marotta Spec SP 1200
Marotta MV 197 Valves [2]	See Data Sheet	<0.002	0.004	106.9	1,550	206.8	3,000	1,723.7	25,000	2.5	8.3	868.7	12,600	4.2	Similarity & Test	NSTS 1700.7B Marotta Spec SP 1200
Bürker Type 6124 Flipper Valves (Box C: V8a,b and Manifold: VA, B, C, D)	See Data Sheet	N/A	N/A	1.7	25	2.0	29.4	8.6	125	2.5	4.3	TBD	TBD	TBD	Similarity & Test	
GP-50 Pressure Sensors [3]	See Data Sheet	<0.002	0.004	1.4	20.4	2.0	29.4	41.4	600	2.5	20.4	13.8	200.0	6.8	Similarity & Test	NSTS 1700.7B SSP 30559C
GP-50 Pressure Sensors [3]	See Data Sheet	<0.002	<0.004	13.8	200	20.7	300	62.1	900	2.5	3.0	41.4	600	2	Similarity & Test	NSTS 1700.7B SSP 30559C
GP-50 Pressure Sensors [3]	See Data Sheet	<0.002	<0.004	106.9	1,550	206.8	3,000	620.5	9,000	2.5	3.0	413.7	6,000	2	Similarity & Test	NSTS 1700.7B SSP 30559C
Kulite Pressure Senosrs [3]	Stainless Steel	<0.002	<0.004	13.8	200	20.7	300	62.1	900	2.5	3.0	41.4	600	2	Similarity & Test	NSTS 1700.7B SSP 30559C

TRD Pressure System Components

Description	Material Of Construction	Mass Of Fluid		Operating Pressure (max)		MDP[1]		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	bar	psid	bar	psid	bar	psid	Req	Actual	bar	psid			
Kulite Pressure Senosrs [3]	Stainless Steel	<0.002	<0.004	106.9	1,550	206.8	3,000	620.5	9,000	2.5	3.0	310.3	4,500	1.5	Similarity & Test	NSTS 1700.7B SSP 30559C
TheLeeCo restictors	Stainless Steel, 304L	N/A	N/A	20.7	300	206.8	3,000	413.7	6,000	2.5	2.0	TBD	TBD	TBD	Test	
7 micron Inline Filters	See Data Sheet	N/A	N/A	106.9	1,550	206.8	3,000	827.4	12,000	2.5	4.0	TBD	TBD	TBD	Similarity & Test	
Pressure Container for CO_2 sensor, pumps, and relief valves in Box C [4, 5]	Stainless Steel	<0.01	<0.02	1.0 - 1.4	14.7 - 20.3	2.0	29.4	4.1	58.8	2	2.0	3.0	44.1	1.5	Test	MIL-STD-1522A SSP 30559C
Monitor Tubes	Stainless Steel CrNi 18.10	<0.002	<0.004	1.0 - 1.4	14.7 - 20.3	2.0	29.4	8.1	117.6	4	4.0	3.0	44.1	1.5	Test	NSTS 1700.7B SSP 30559C
Pumps	See Data Sheet	<0.002	<0.004	1.0 - 1.4	14.7 - 20.3	1.7	25.0	2.4	35.0		2.0	N/A	N/A	N/A	Test	NSTS 1700.7B SSP 30559C
Marotta Pressure Relief Valves [2]	See Data Sheet	<.002	<0.004	18.6	270	20.7	300	61.0	885	2	3.0	32.8	475	1.6	Similarity & Test	NSTS 1700.7B SSP 30559C
Pressure Relief Valve Box C	See Data Sheet	<.002	<0.004	1.4	20.4	2.0	29.4	20.7	300.0	2	10.2	3.0	44.1	1.5	Test	MIL-STD-1522A SSP 30559C
Burst Disks Box S [2,6]	Stainless Steel	<.002	<0.004	20.3	295	20.3	295	20.3	295	N/A	N/A	N/A	N/A	N/A	Similarity & Test	BS & B, M.S. 18
Xe Fill Port Valves	Stainless Steel			106.9	1550	206.8	3,000	TBD	TBD	2.5	TBD		TBD	TBD		
CO_2 Fill Port Valves [4]	Stainless Steel			64.8	940	206.8	3,000	TBD	TBD	2.5	TBD		TBD	TBD		
Xe Fill Port Caps [4]	Stainless Steel			106.9	1550	206.8	3,000	TBD	TBD	2.5	TBD		TBD	TBD		
CO_2 Fill Port Caps [4]	Stainless Steel			64.8	940	206.8	3,000	TBD	TBD	2.5	TBD		TBD	TBD		
Box C GSE Interface Valves [4]	Stainless Steel			1.0 - 1.4	14.7 - 20.3	2.0	29.4	TBD	TBD	2.5	TBD		TBD	TBD		
Box C GSE Interface Caps [4]	Stainless Steel			1.0 - 1.4	14.7 - 20.3	2.0	29.4	TBD	TBD	2.5	TBD		TBD	TBD		

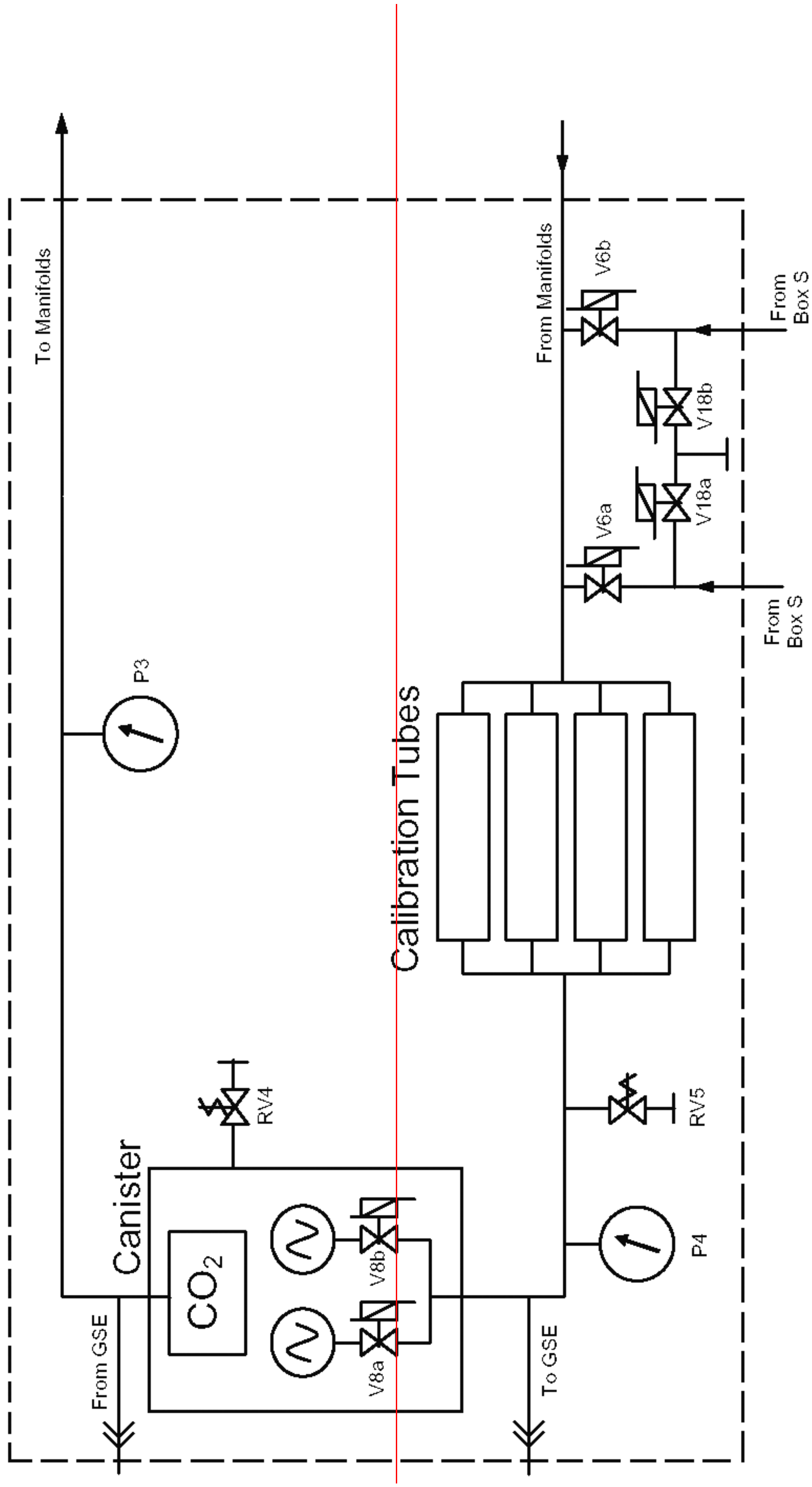
Notes:
[1] MDP has been established based on worst case thermal profile and where applicable (with mechanisms to fail) worst case two fault condition.
[2] Pressure is in psig.
[3] Pressure is in psia
[4] Manufactured at CERN and pressure is in psia
[5] As per data approved by Peter Fisher, file: TRD_gas-press.doc, 06/23/2004
[6] Burst pressure equals 5% to the stamped burst pressure of 295 psig; proof SF is 80% of stamped burst pressure.

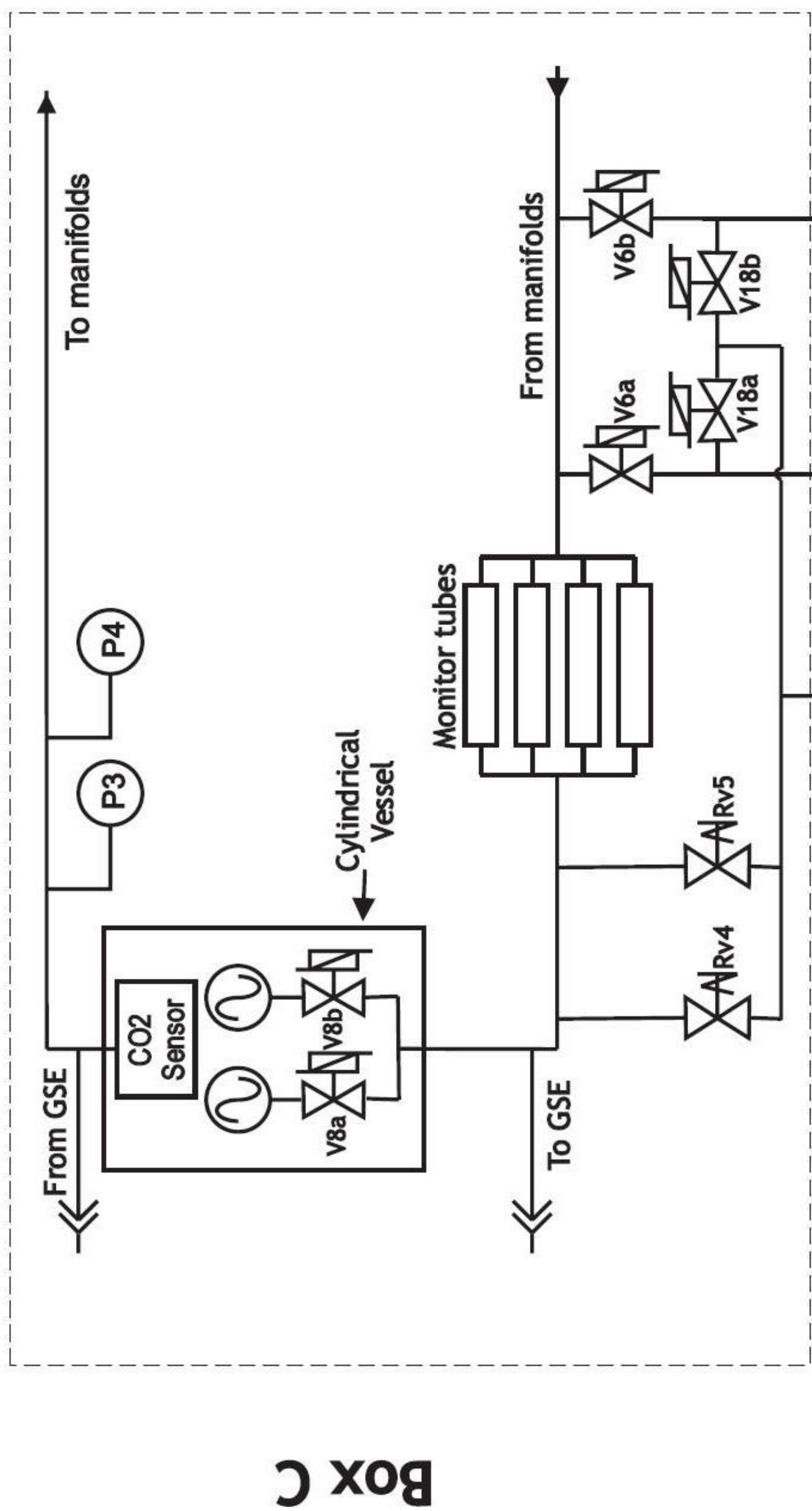

Box S Schematic
To
Box C
2 -Valve-GP50
2-Valve Filter
4 -Valve
Vent Valve
Burst discs
D vessel (mix)
Tower-Valve
& Filter
Xe
1550 psia
(107 bar)
CO2
940 psia
(65 bar)
Xe fill port
CO2 fill port
F3a
F3b
RV1a
RV1b
Pre-heater
Pre-heater
V1a
V10a
V10b
V1b
15cc
5cc
V20a
V20b
V2a
V2b
60cc
30cc
Rv3a
Rv3b
P2c
V3a
V3b
O1a
O1b
O2a
O2b
V4a
V4b
P2a
P2b



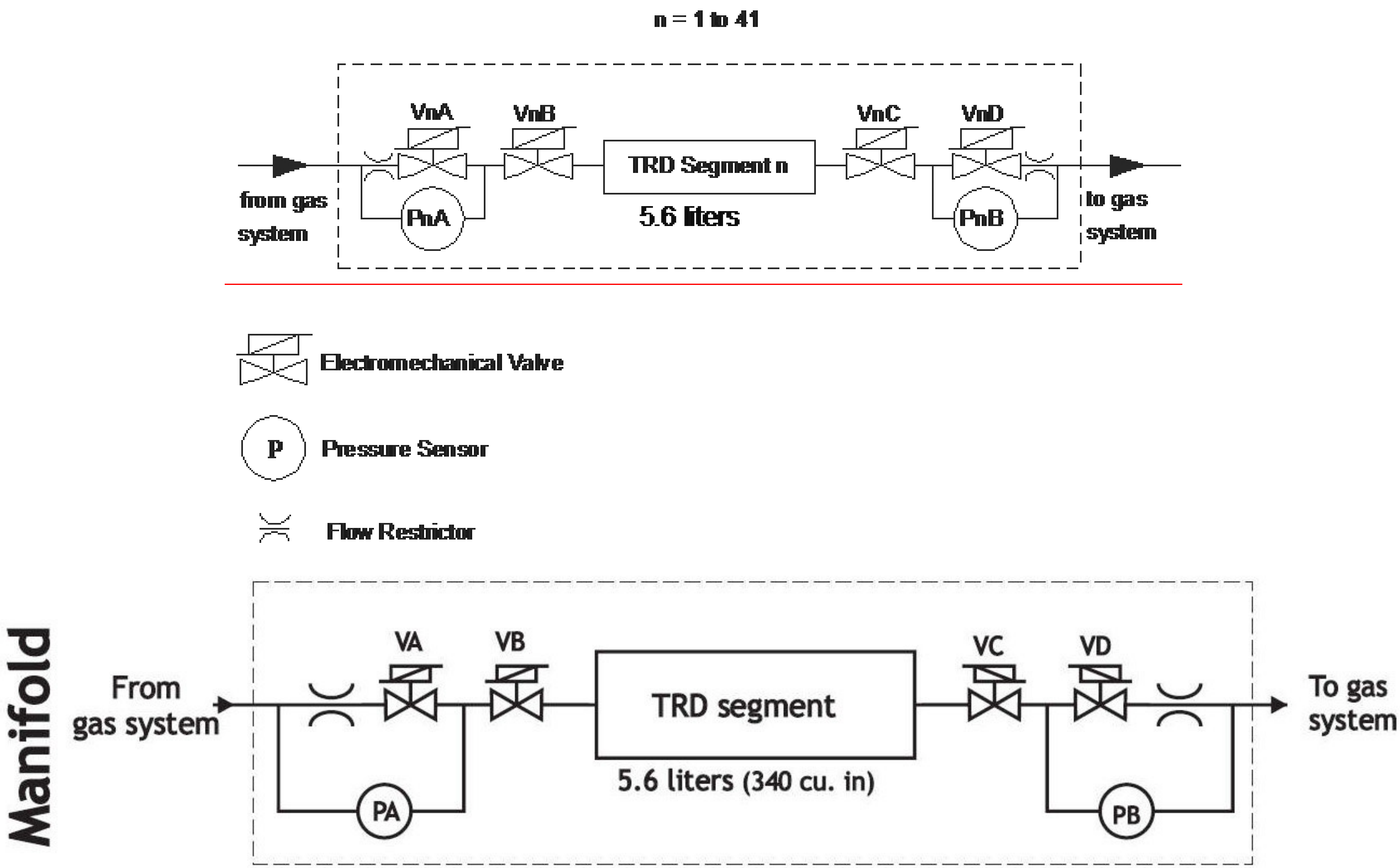
Box S Schematic
To Box C
2 -Valve-GP50
2-Valve Filter
4 -Valve
Vent Valve
D vessel (mix)
Burst discs
Xe
1550 psia
(107 bar)
CO2
940 psia
(65 bar)
Xe fill port
CO2 fill port
F3a
F3b
CKV1a
CKV1b
Pre-heater
P1a
P1b
P1c
P1d
F1a
F1b
V1a
V1b
V10a
V10b
15cc
5cc
V20a
V20b
V2a
V2b
60cc
30cc
F2a
F2b
O1a
O1b
V3a
V3b
Rv3a
Rv3b
P2c
P2a
P2b
O2a
O2b
V4a
V4b

TRD Box S

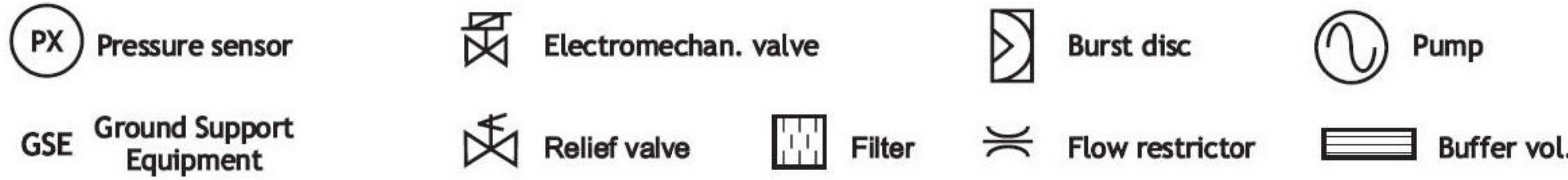

To Manifolds
From Manifolds
V6b
From Box S
V18b
V18a
V6a
From Box S
P3
Calibration Tubes
RV4
RV5
Canister
CO_2
V8b
V8a
P4
From GSE
To GSE


Box C
To manifolds
From GSE
To GSE
P3
P4
CO2 Sensor
V8a
V8b
Cylindrical Vessel
Monitor tubes
From manifolds
Rv4
Rv5
V6a
V6b
V18a
V18b
From S
From S
Vent

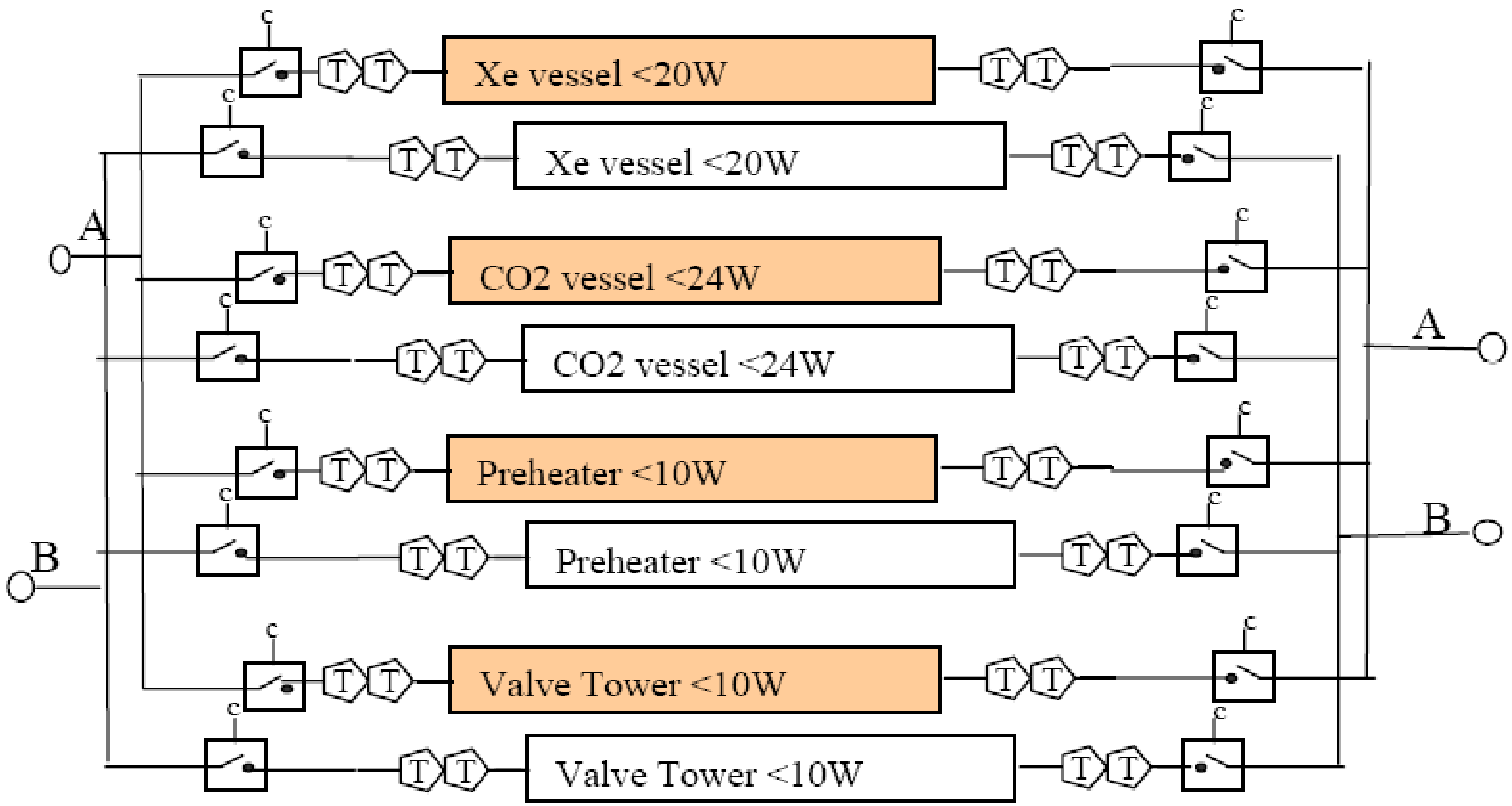
TRD Box C



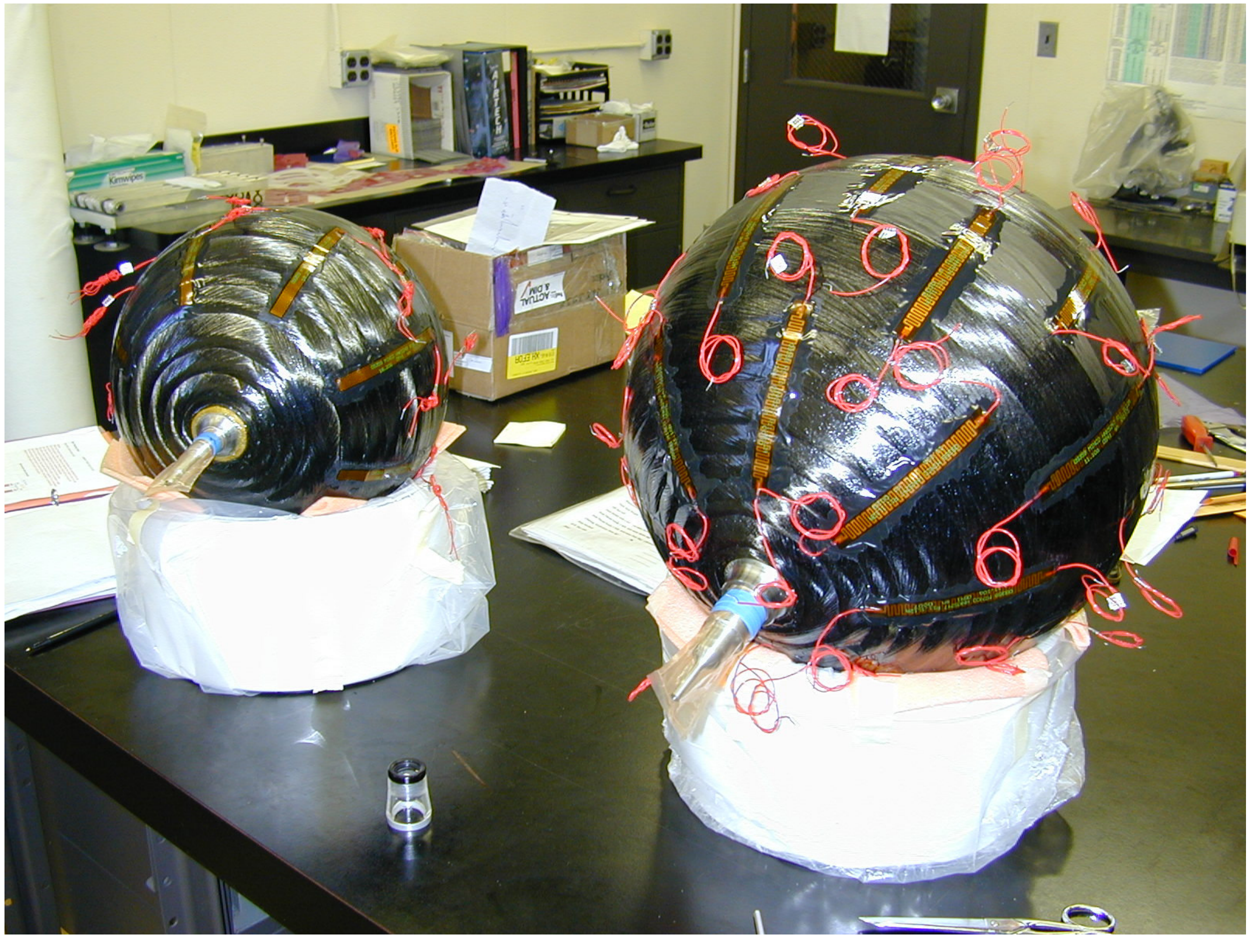
TRD Manifold-Straw Representation



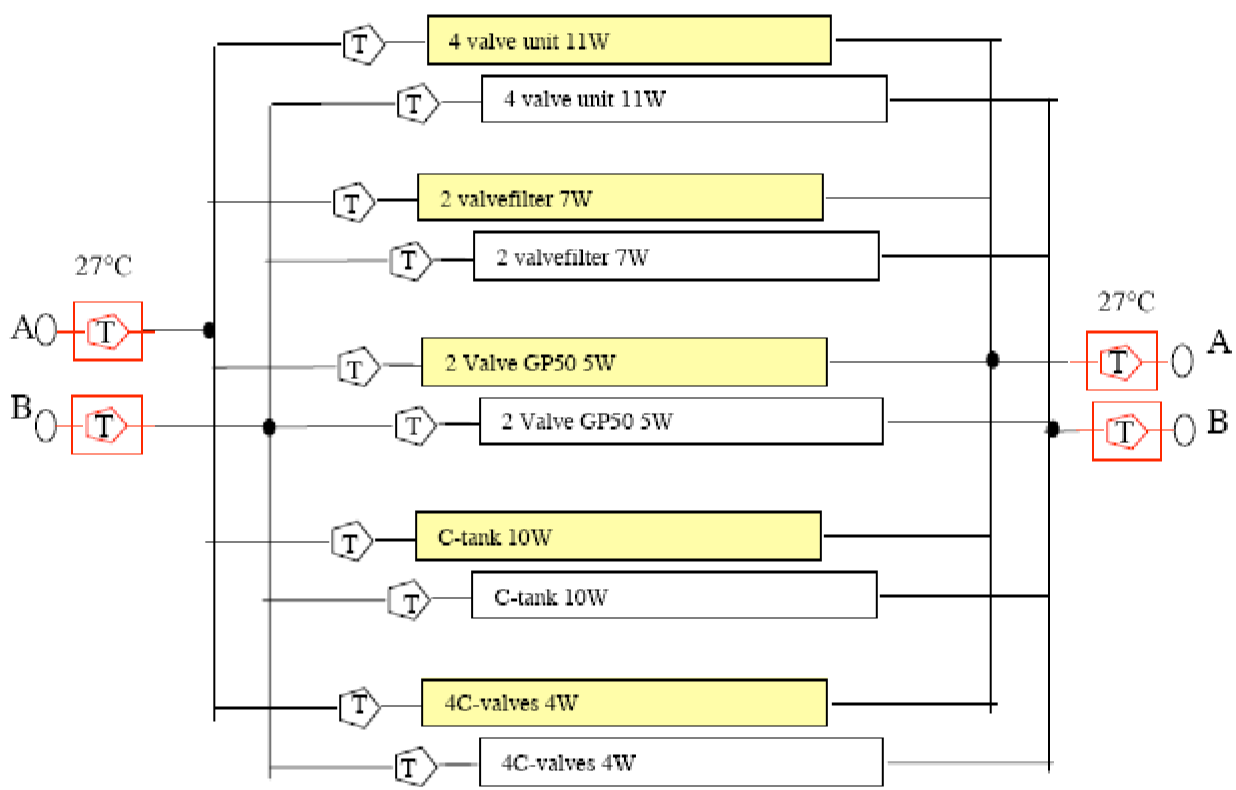
Legend for TRD Schematics



TRD Tank Heaters



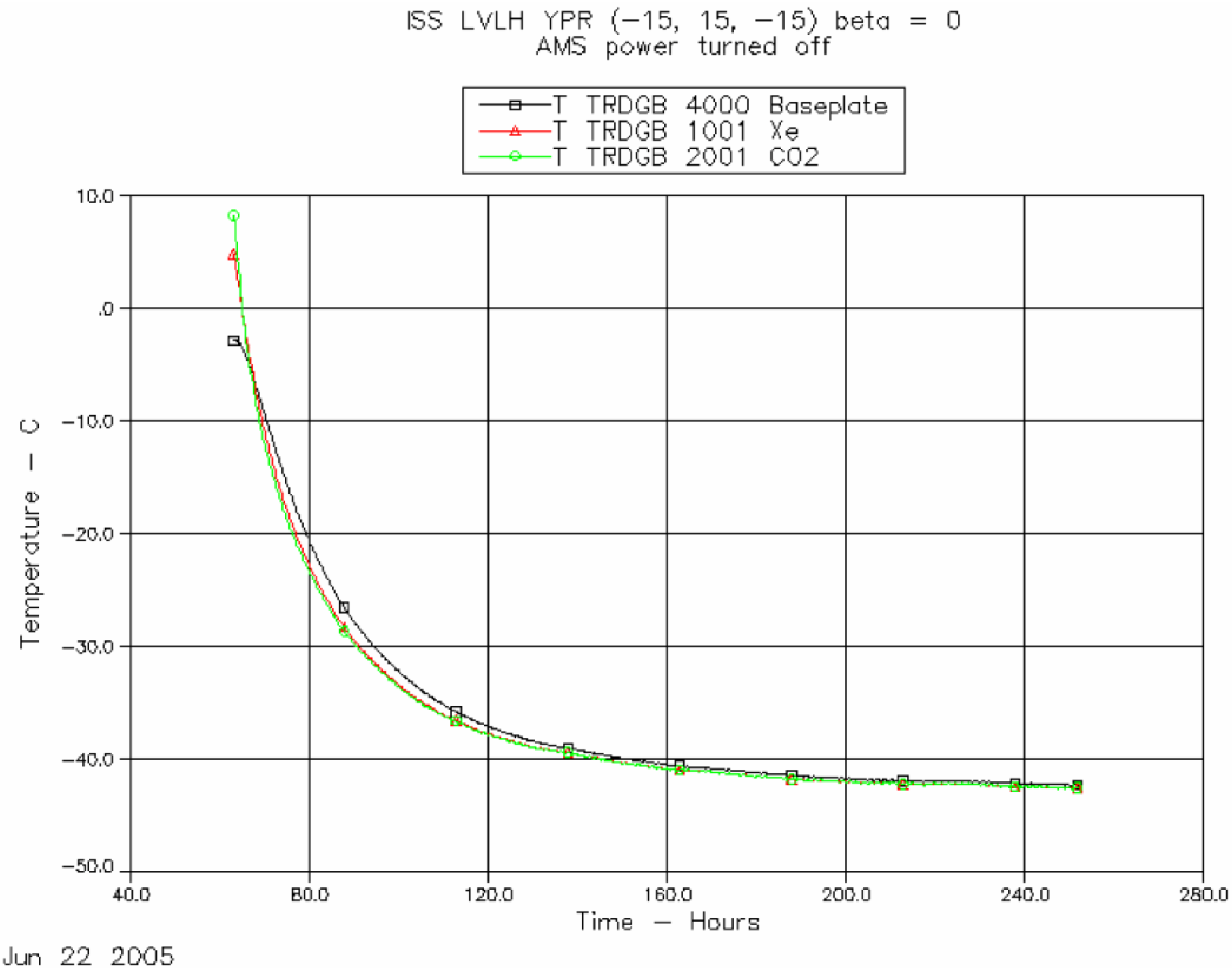
TRD GAS Tanks With Installed Heaters



TRD Gas Valve Block Heater

Location	Temperature Range	Average Temperature	T Open	T Close	Tolerance	Number
Xe Tank	20°C-65°C	42.5°C	49°C	38°C	±2.8°C	8
CO2 Tank	34°C-65°C	48.5°C	54	43	±2.8°C	8
Tower	24°C-41°C	32.5°C	38	27	±2.8°C	2
2 Valve Filters, 2 Valve GP50	5°C-39°C	22°C	27	16	±2.8°C	4
4 Valve, Vent Valve	5°C-39°C	22°C	27	16	±2.8°C	4+1
Box C	7°C-24°C	15.5°C	21	10	±2.8°C	2+1
Preheater	34°C -65°C	48.5°C	54	43	±2.8°C	8

TRD Gas Supply Thermostat List



TRD coldest thermal conditions assuming greater than 200 hours in coldest attitude and power off.

B. Warm Helium Gas Supply

Warm Helium Gas Supply Pressure System Components

Description	Material Of Construction	Mass Of fluid		Operating Pressure		MDP		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	Bar	psid	bar	psid	bar	psid	Required	Actual	bar	psid			
Warm Helium Tank	AL2219, Carbon Fiber	.241	.53	200	2940	301[1]	4433[1]	938	13789	2.5	3.1	500	7350	1.5	Test	
Relief Valve RV03	6061 T6 Al. Aly., 316 SST, VESPEL SP1, 320 SST, TEFLON			6	88	10	147	24.8	365	2.5	>2.5	15	220	1.5		Manufacturer's Data
Relief Valve RV04	6061 T6 Al. Aly., 316 SST, VESPEL SP1, 320 SST, TEFLON			6	88	10	147	24.8	365	2.5	>2.5	15	220	1.5		Manufacturer's Data
MV40 (High Pressure Side, Inlet)	Al. Aly., CRES 17-4H, CRES 300 SER, Nylon			200	2940	301[1]	4433[1]					450	6615	1.5	Test	
MV40 (Low Pressure Side, Outlet)	Al. Aly., CRES 17-4H, CRES 300 SER, Nylon			6	88	11[1]	162[1]	>27.5	>404	2.5	>2.5	11.5[8]	169[8]	1.05[8]	Test	
Fill and Drain Port, MV42 (High Pressure Side, Inlet)	6AI4V Titanium			200	2940	301[1]	4433[1]	750	11025	2.5	>2.5	450	6615	1.5	Test	
Heliomatic Cryogenic Valve DV03, DV05, DV06a, DV06b, DV07, DV10, DV12, DV14 (Helium Operating)	Stainless Steel 316L EN1.4404, 1.4432, 1.4435			0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0			
Burst Disk BD15	Stainless Steel 316L			200-273	2900-3960	301	4366									

Warm Helium Gas Supply Pressure System Components

Description	Material Of Constructio n	Mass Of fluid		Operating Pressure		MDP		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	Bar	psid	bar	psid	bar	psid	Req uire d	Actual	bar	psid			
	Nickel 200															
Warm Valve DV20A, DV20B, DV20C, DV20D	CRES			-1	-14.7	11[1]	162[1]	450	6525	2.5	40.9	225	3265	20.5	Test	Manufacturer's Qualification Documentation
Warm Valve DV21A, DV21B, DV21C, DV21D	PAA GF60, Brass Spring Steel, Steel, Nitric Rubber, POM, Aluminum			6	88	11[1]	162[1]	>27.5	>404	2.5	>2.5	>16.5	>243	>1.5	Test	
Warm Valve DV22A, DV22B, DV22C, DV22D	CRES			6	88	11[1]	162[1]	450	6525	2.5	40.9	225	3265	20.5		Manufacturer's Qualification Documentation
Warm Valve DV52, DV53, DV55, DV56A, DV56B, DV57, DV60, DV62, DV64	PAA GF60, Brass Spring Steel, Steel, Nitric Rubber, POM, Aluminum			6	88	11[1]	162[1]	>27.5	>404	2.5	>2.5	>16.5	>243	>1.5	Test	
Burst Disk BD17A, BD17B	Stainless Steel 316L Nickel 200			-1	-14.7	11[5]	162[5]	0	0			0	0			
4 mm, 3 mm I.D. line from pilot valves to Weka valves. See Note 11 for fittings	316 SS Grade A			6	88	11[1]	162[1]	>728	>10702	4.0	>66.1	728	10702	66.1	A	SCL – Warm Helium Supply Pipe Yield Pressures
6 mm, 4 mm I.D. line from warm helium supply to pilot valves. See Note 11 for fittings	316 SS Grade A			200	2940	301[1]	4425[1]	>1000	>14700	4.0	>3.3	1000	14700	3/3	A	SCL – Warm Helium Supply Pipe Yield Pressures
Bellows actuators in Current Leads	Stainless Steel 316L			6	88	11[1]	162[1]	>27.5	>404	2.5	>2.5	>16.5	>243	>1.5	Test	
Weka Activation Mechanism for DV09A-B DV11A-B DV15A-D	Stainless 316			6	88	11[1]	162[1]	>27.5	>404	2.5	>2.5	>16.5	>243	>1.5	T	

Warm Helium Gas Supply Pressure System Components

Description	Material Of Construction	Mass Of fluid		Operating Pressure		MDP		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	Bar	psid	bar	psid	bar	psid	Required	Actual	bar	psid			
DV16A-B																
Pilot Valve Vacuum Vessel	Stainless Steel 304-S12			-1	-14.7	11[1]	162[1]	88	1294	2.5	8	37.7	554	3.4	A	Testing of vessel to 16.5 bar will also be accomplished.
Warm valve pilot valves DV61AS-BS DV61AO-BO DV66AS-BS DV66AO-BO DV59AS-BS DV59AS-BO DV65AS-DS DV65AO-DO	PAA GF60, Brass, Spring Steel, Steel, Nitric Rubber, POM, Aluminium			6	88	11[1]	162[1]	>27.5	>404	2.5	>2.5	>16.5	>243	>1.5	T	

Notes:
MDP has been established based on worst case thermal profile and where applicable (with mechanisms to fail) worst case two fault condition.

[1] **Derivation of MDP values per NSTS 1700.7B and ISS Addendum, section 208.4**

The maximum design pressure (MDP) for all systems considered in this report is set by the upper defined limit of the relevant pressure relief device which is a space-qualified bursting disc or relief valve. The bursting disc systems have been extensively assessed by LM/NASA and SCL and accepted.

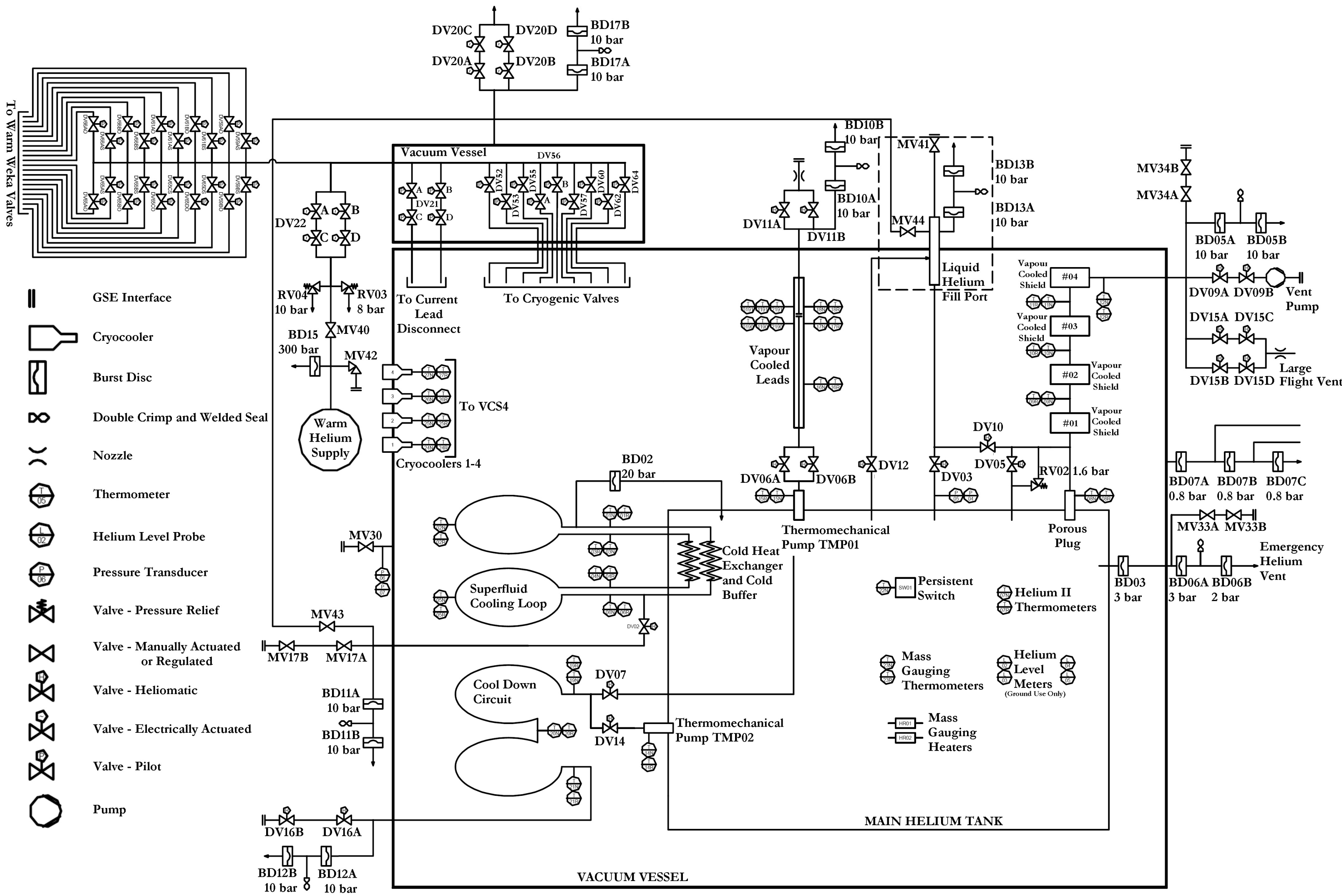
a) 3 bar Pressure Relief
The pressure is set by the upper limit on the differential pressure, when cold, necessary to rupture bursting disc BD03, shown on SCL Cryogenic System Schematic Drawing SCD 1000. In service and in test, the downstream pressure on this disc is kept at zero bar absolute. In the warm state, the bursting disc will rupture at less than 3 bar.

b) 25 bar Pressure Relief
The pressure is set by the upper limit on the differential pressure, when cold, necessary to rupture bursting disc BD02, shown on SCL Cryogenic System Schematic Drawing SCD 1000. Although in service the downstream pressure is ~ 10 mbar (fill vacuum), the design allows for the downstream pressure being 3 bar abs. The superfluid cooling loop SCL is thus designed for 25 bar abs (and differential), whereas the bursting disc BD02 is set for a maximum differential of 23 bar, in the cold state. In the warm state, the bursting disc BD02 will rupture at less than 22 bar differential.

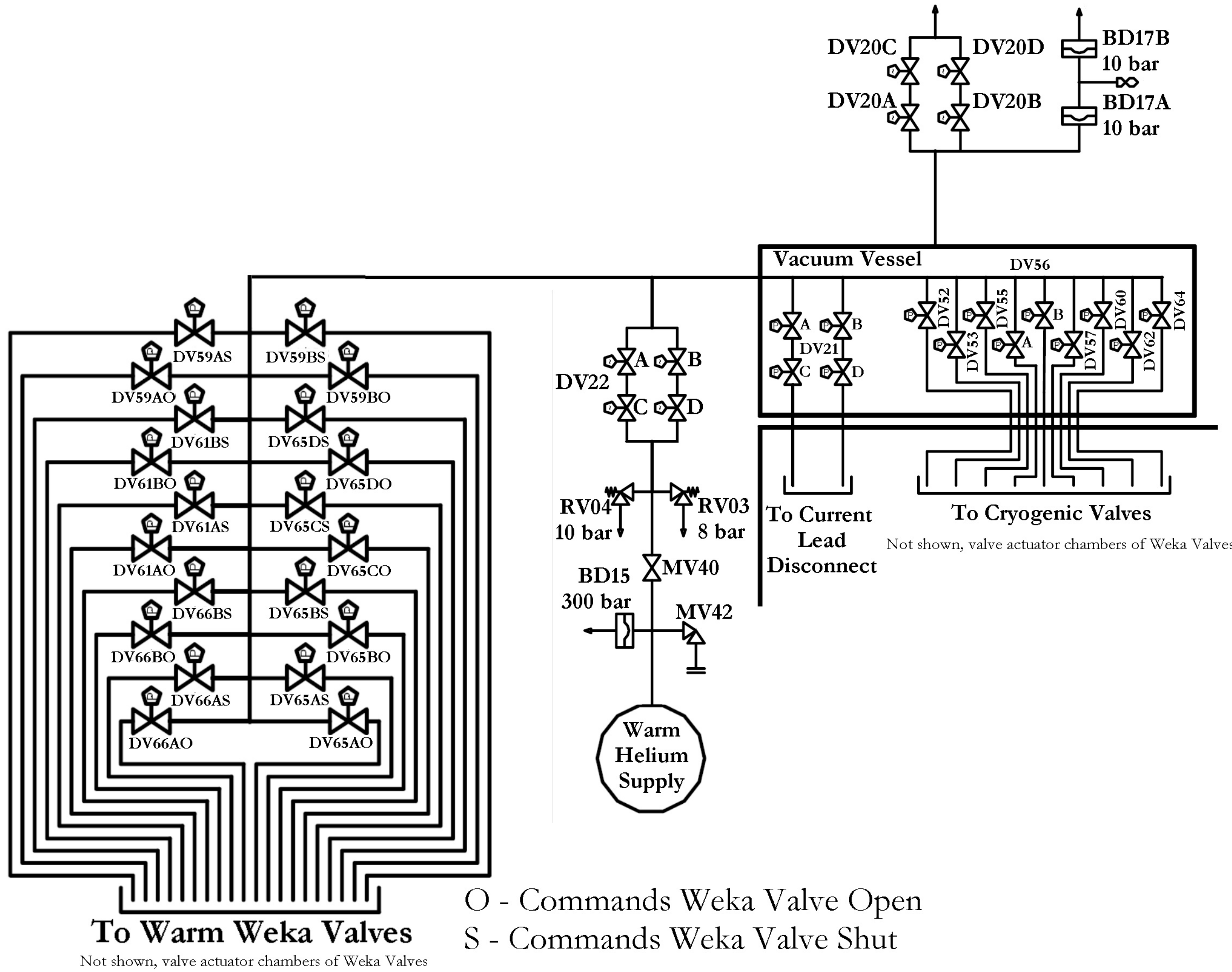
c) 10 bar Pressure Relief
The pressure is set by the upper limit on the burst disc differential pressure and vacuum case vacuum, when cold, necessary to rupture bursting discs BD05A, BD05B, BD10A, BD11A,BD11B, BD12A, BD12B, BD13 shown on SCL Cryogenic System Schematic Drawing SCD 1000.
Although in service the pipework pressure is < 1.0 bar, the design allows for the trapped volume pressures being up to 11 bar abs. (10 bar differential of the bursting disc failing to atmosphere + 1 bar vacuum in the Vacuum Case) The general pipework is thus designed for 11 bar abs (and differential), whereas the bursting discs listed are set for a maximum differential of 10 bar.

d)RV03 / RV04 RV03 and RV04 relief valves operate in parallel and pressure is set by the upper limit of the relief valve cracking pressures.

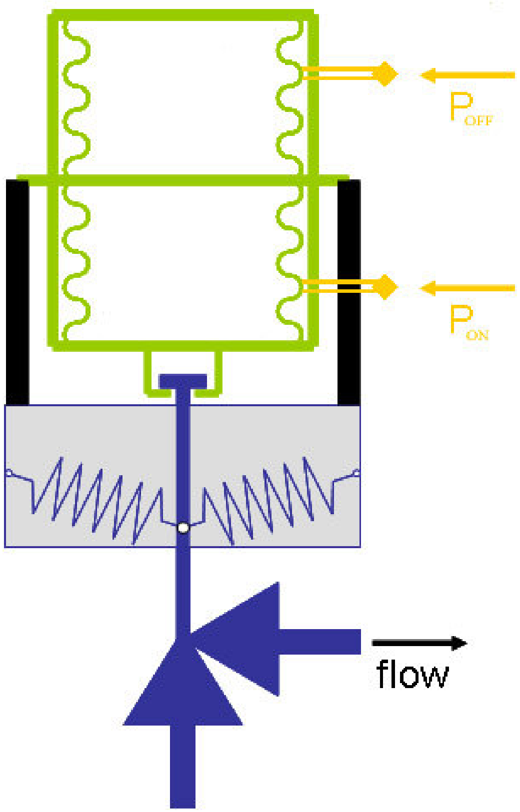
[5] – Pressure on upstream side of disc absolute



Cryogenic Superfluid Helium System (With Warm Helium Gas Supply)

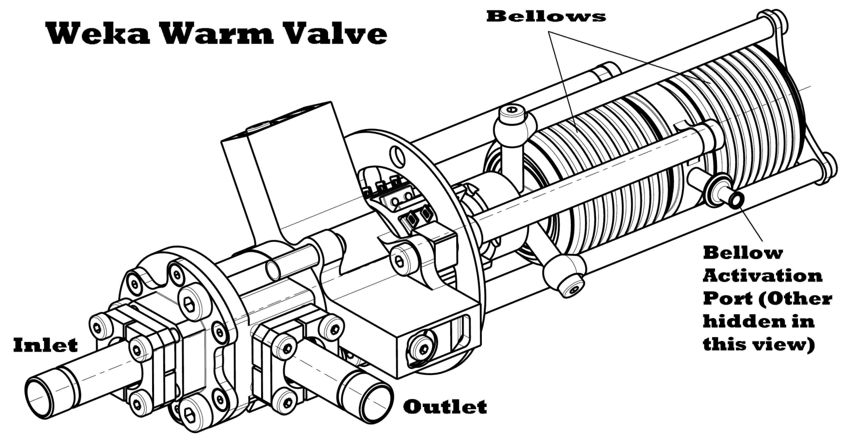


Warm Helium Gas Supply (See Legend on Cryosystem Diagram)

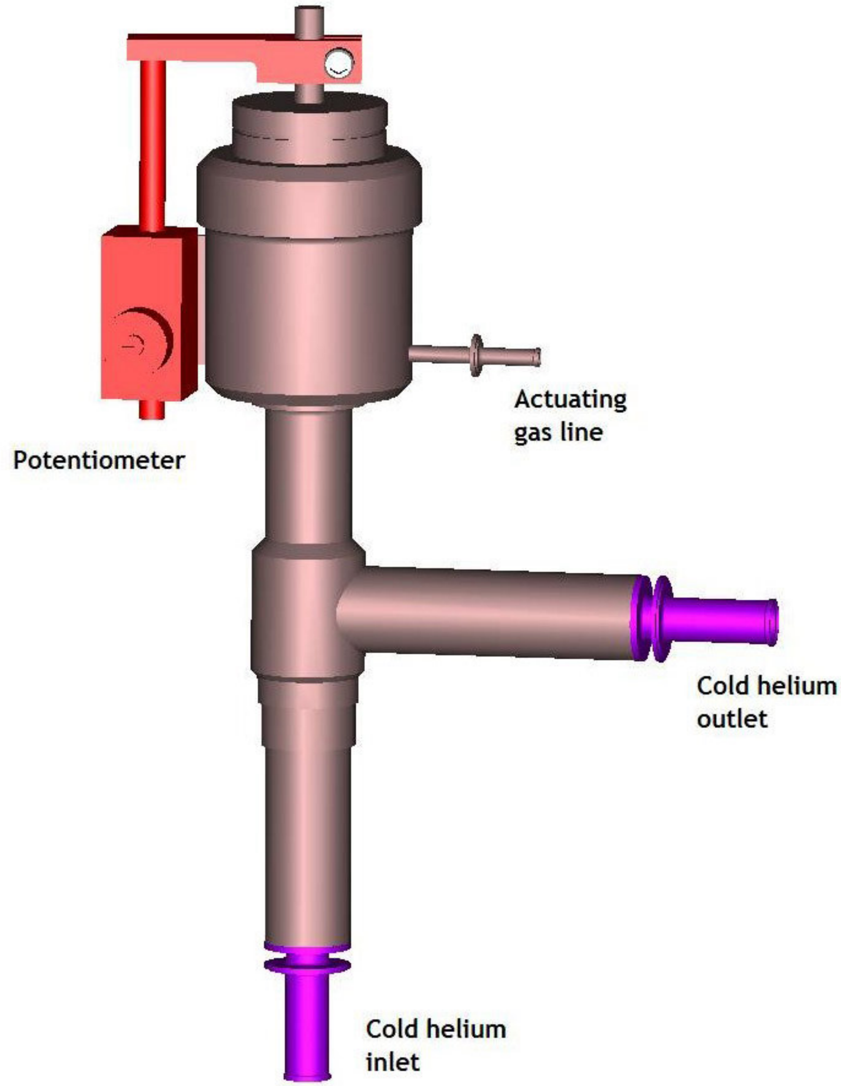


Functionally the Weka Heliomatic Valves use helium pressurant to activate a bellows that will either open or close a latching valve. Pressurizing the opposing bellows is required to reposition the valve.

This function is consistent with both the cryogenic and warm valves.



Weka Heliomatic Warm Valve



Weka Heliomatic Cryogenic Valve

C. Tracker Thermal Control System

Tracker Thermal Control System Pressure System Components

Description	Material Of Construction	Mass Of fluid		Operating Pressure		MDP[1]		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	bar	psid	bar	psid	bar	psid	Req	Actual	bar	psid			
Liquid Lines	ANSI 316L Stainless Steel	0.55	.1213	64.0	928.2	160.0	2320.0	2569.7	37270.0	4.0	16.1	239.9	3480.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Two Phase Lines to Condensers	ANSI 316L Stainless Steel	0.044	.0968	64.0	928.2	160.0	2320.0	2569.7	37270.0	4.0	16.1	239.9	3480.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Evaporator Lines	ANSI 316L Stainless Steel	.205	.4519	64.0	928.2	160.0	2320.0	927.7	13455.0	4.0	5.8	0.0	0.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Combined Evaporator Lines (i.e. 2-phase inlet and outlet heat exchanger)	ANSI 316L Stainless Steel	.0023	.0051	64.0	928.2	160.0	2320.0	1888.2	27386.0	4.0	11.8	0.0	0.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Pumps	304L CRES per SAE AMS-QQ-S-763	.0336	.7041	64	928.2	160	2320.0	400.0	5800.0	2.5		240.0	3490.9	1.5	Analysis and Test	
Valves	TBD	0.0	0.0	64	928.2	160	2320.0	400.0	5800.0	2.5		240.0	3490.9	1.5	Simularity or Test	
Pressure Sensors	PT Sensor Housing Stainless Steel 316L	.0005	.0011	64.0	928.2	160.0	2320.0	400.0	5800.0	2.5		240.0	3490.9	1.5	Simularity or Test	
Hudraulic Connectors	RES 386 (15-5PH)	.0005	.0011	64	928.2	160.0	2320.0	827.4	12000.0	2.5	5.2	240	3480.9	1.5	Spec.	
TTCS Accumulator	A316LN CRES	.720	1.587	64	928.2	160	2320.0	614	8914	2.5	3.8	240	3480.9	1.5	Analysis and Test	
Condensers	Inconel 718	.0613	.1352	64.0	928.2	3009	43642	13962.0	202501.7	2.5	TBD	240	3480.9	1.5		
Heat Exchanger	ANSI 316L Stainless Steel	.056	.1235	64	928.2	160	2320	400.0	5800.0			240	3480.9	1.5	Analysis and Test	
TTCS Accumulator Heat Pipe	316L					~~29.5~~57[4]	~~427.6~~826.7[4]	1323	19158	4.0	~~44.8~~23.2	481	6966	~~16.3~~8.4	Analysis and Test	
TTCS Accumulator Heat Pipe inside Accumulator	316L					160[4]	23~~19/0~~20	6570.0	95232.0	3.0	41.1	240	3480	1.5	Analysis and Test	
		0.0	0.0	0.0	0.0	0.0	0.0	1323	19158	4.0	22	481	6966	8		

Notes:

1) MDP has been established based on worst case thermal profile and where applicable (with mechanisms to fail) worst case two fault condition.

2) Burst Safety Factor is calculated from the material allowable stress and pipe geometry
3) Heat pipes are part of a pressurized system and are not isolated. Burst Factor of 4.0 is used.

4) Ref TCS Hardware Design Report AMS-OHB-DER-001 issue 2, March 1, 2005

5) Condenser MDP is based on more detailed CO2 melting line data (NIST) at -5 C (3009 bar). The burst pressure is calculated with

$$p_u = \frac{2\sigma_y}{\sqrt{3}}(2-\frac{\sigma_y}{\sigma_u})\ln\frac{r_o}{r_i}$$

6) HP MDP pressure based on ~~60~~ 65 C maximum HP temperature
7) The burst pressures of the Pumps valves, Pressure sensors and HX are design values. Pump design and HX designers have performed preliminary FEM analyses. Documents need to be written and delivered.

8) The TTCS Accumulator heat pipe inside the accu numbers are from AMS-02-CAST-TTCS-HP-SF-001 Issue 1, 10-03-2006 p8.

Tracker Radiator Heat Pipes Pressure System Components

Description	Material Of Construction	Mass Of fluid		Operating Pressure[6])		MDP[1]		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	bar	psid	bar	psid	bar	psid	Req[3]	Actual	bar	psid			
Embedded Heat Pipes	AL 6063	Note 5		4.0	58.0	20.0	290.0	174.7	2534.0	4.0	8.7	30.0	435.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C

Notes:

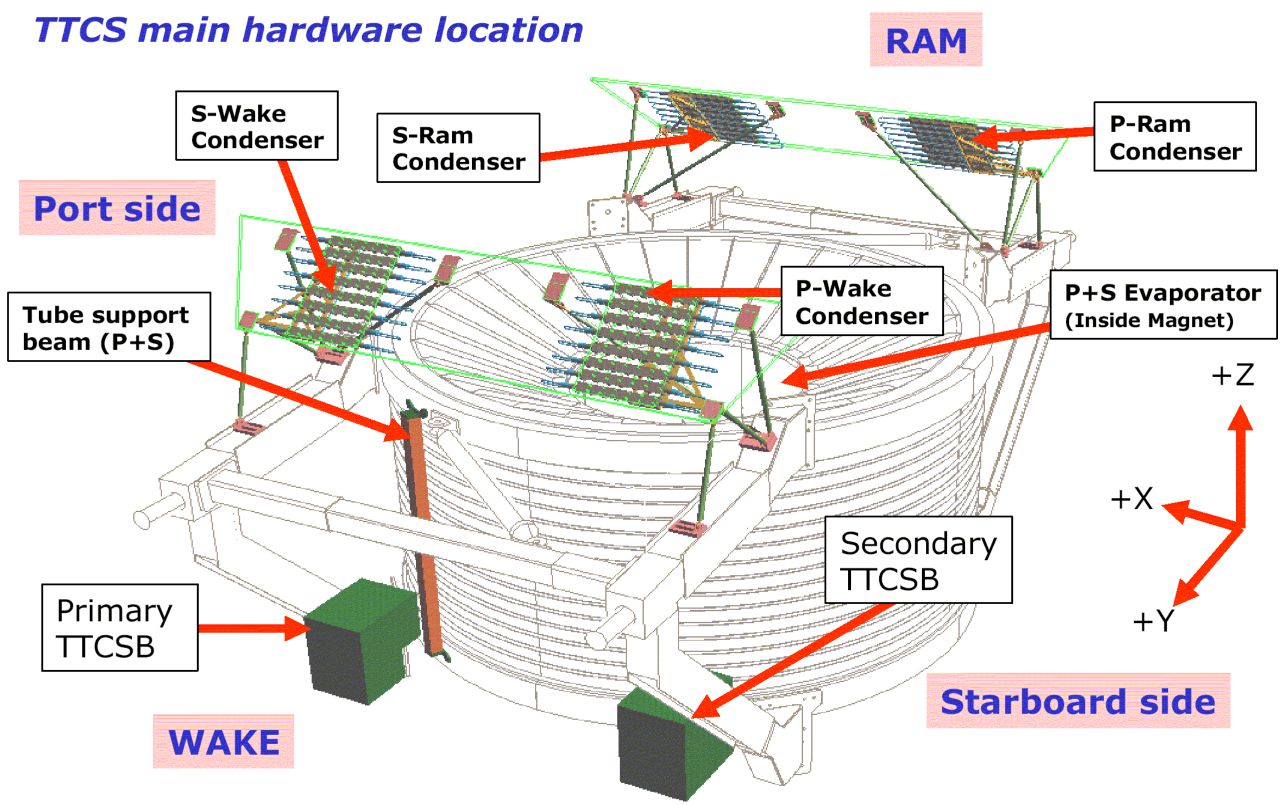
1) MDP has been established based on worst case thermal profile (50°C) and where applicable (with mechanisms to fail) worst case two fault condition.
2) Burst Safety Factor is calculated from the material allowable stress and pipe geometry
3) Heat pipes single components and not a part of a greater pressure system. Burst Factor of 4.0 is used (2.5 could be used for heat pipes as components.).
4) Ref TCS Hardware Design Report AMS-OHB-DER-001 Issue 2, Revision A, May 5, 2005
5) There are 7 embedded heat pipes with different lengths, mass of fluid (ammonia) ranges from 44.6 grams for the shortest to 52.6 grams for the longest
6) Calculated at 0°C, typical working temperature of the tracker cooling loop

TTCS Oscillating Heat Pipe Experiment

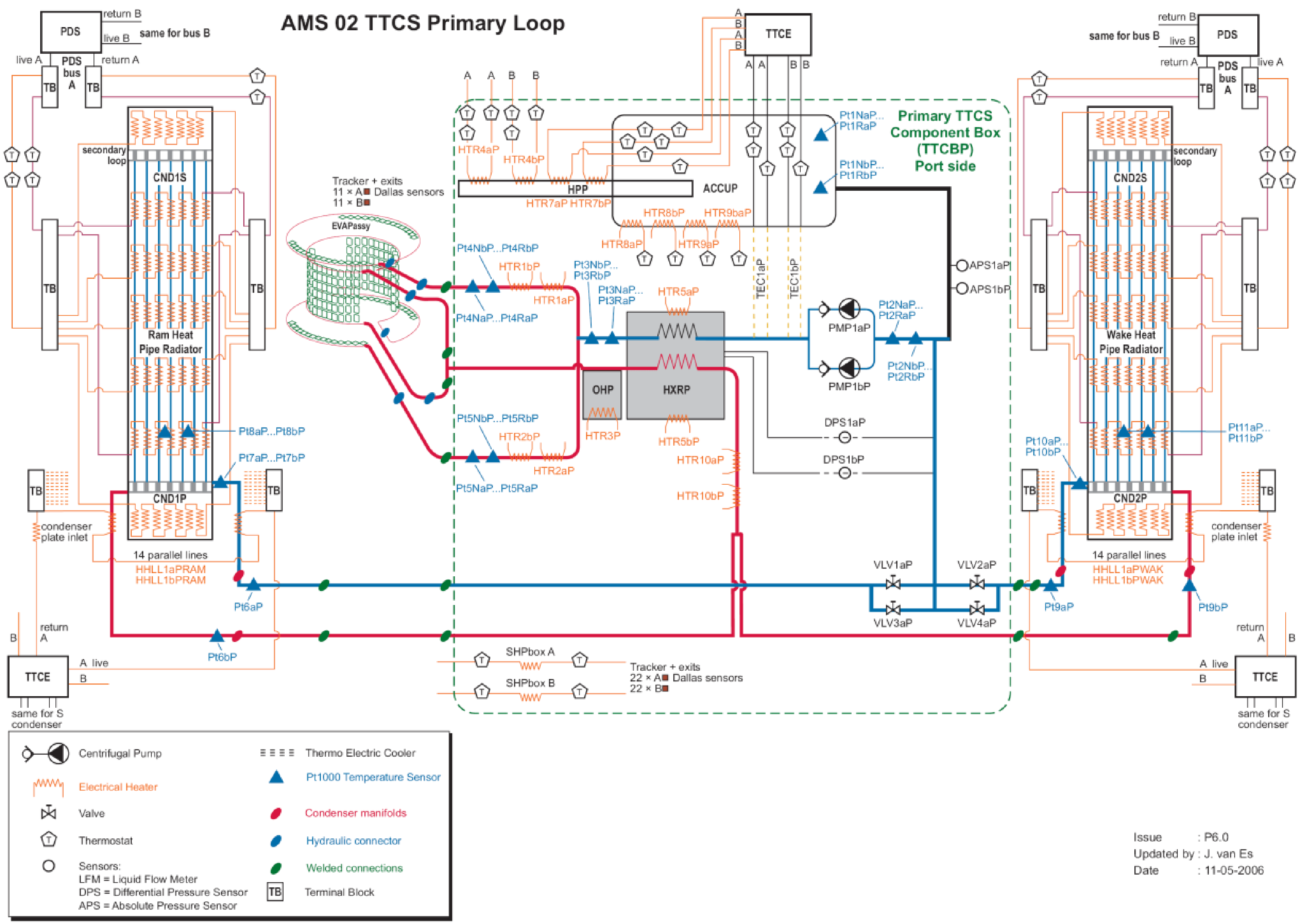
Description	Material Of Construction	Mass Of fluid		Operating Pressure		MDP[1]		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	Bar	psid	bar	psid	bar	psid	Req[3]	Actual	bar	psid			
TTCS Heat Pipe[2]	Stainless Steel	.0074	.0163	1.43	20.74	8.95	129.8	1471	21335	4	164.36	13.425	194.71	1.5	Analysis and Test	

Notes:

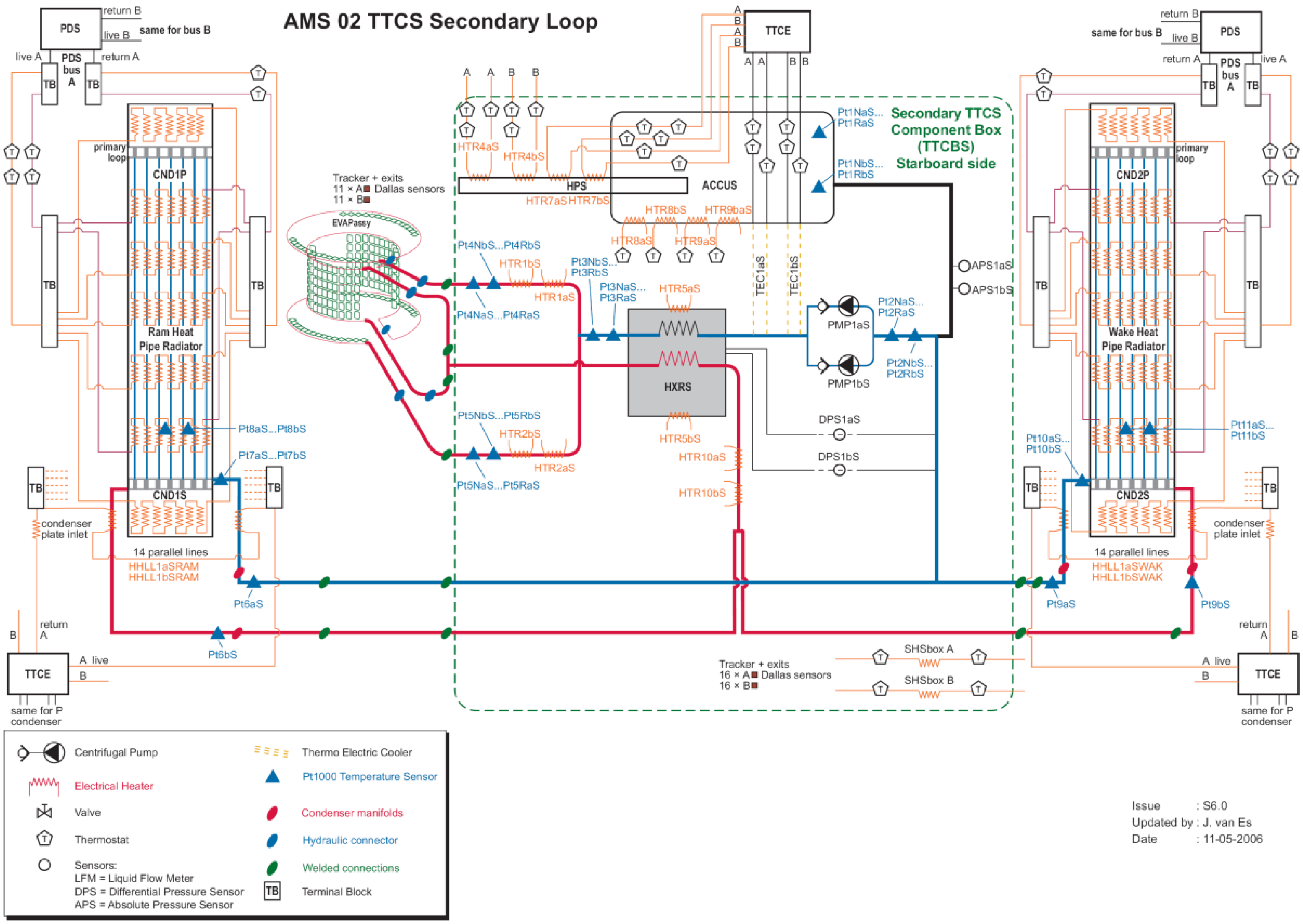
1) MDP has been established based on worst case thermal profile (most extreme,100°C, 40°C nominal)
2) Inner Radius of tube .5 mm, thickness .1 mm



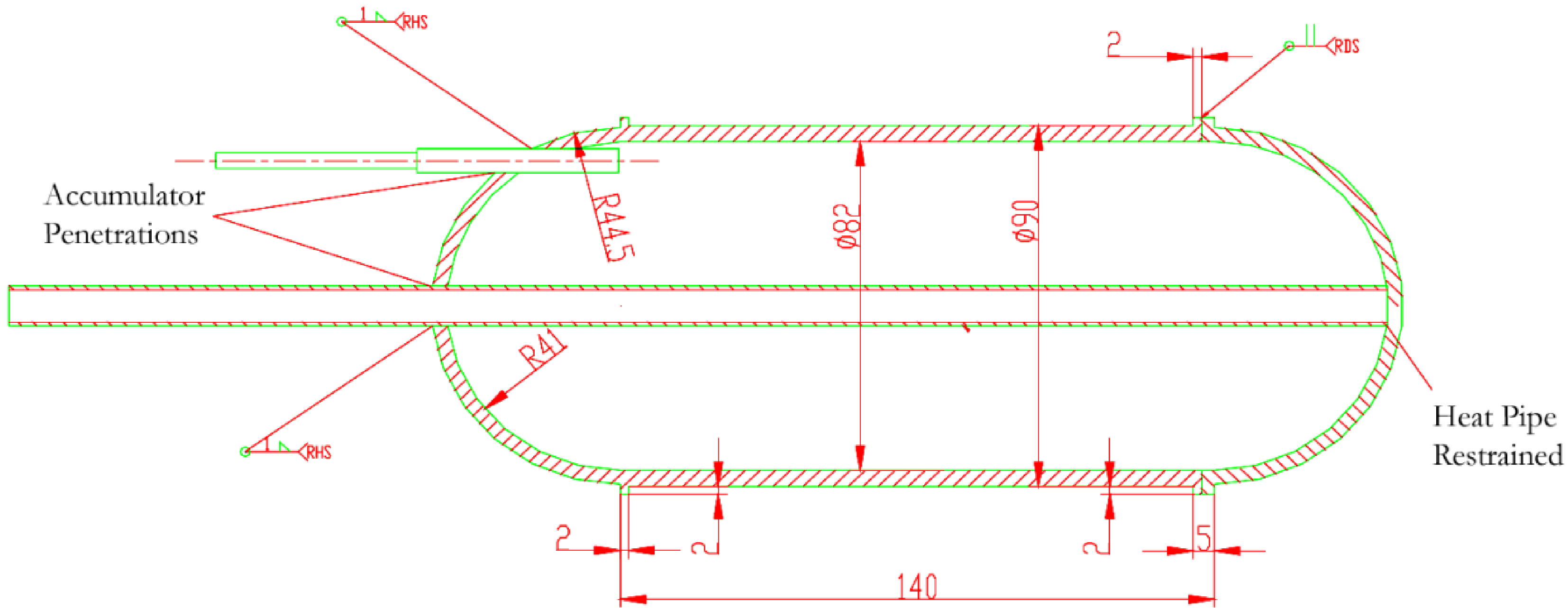
Components of the Tracker Thermal Control System (new Condenser configurations not shown)



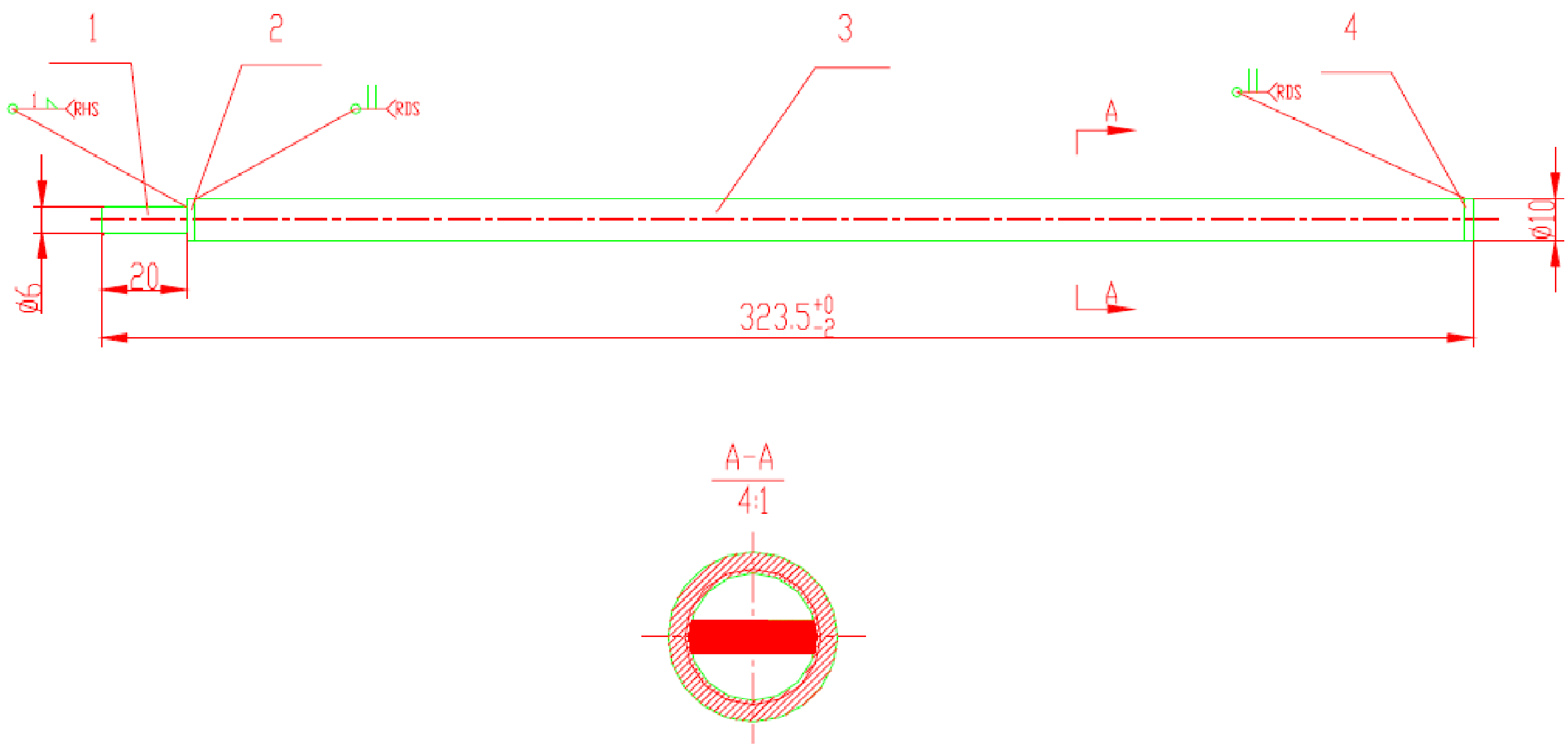
TTCS Primary Loop



TTCS Secondary Loop

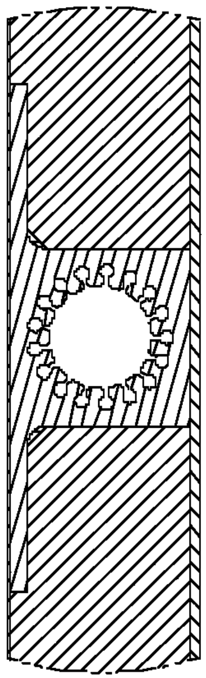


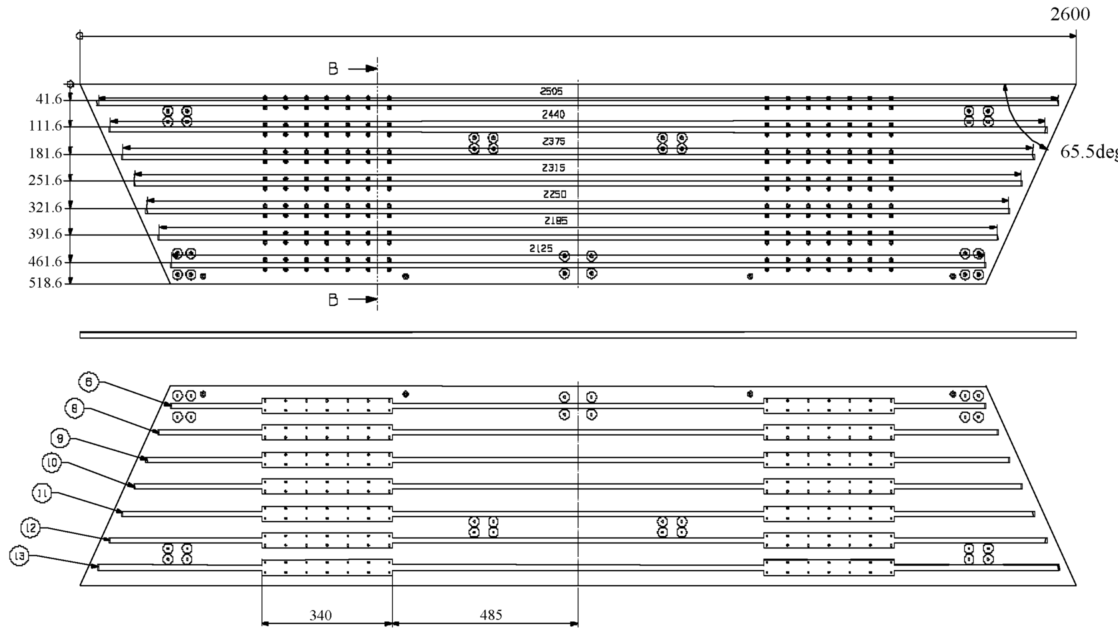
TTCS Accumulator Cross Section with Accumulator Heat Pipe.



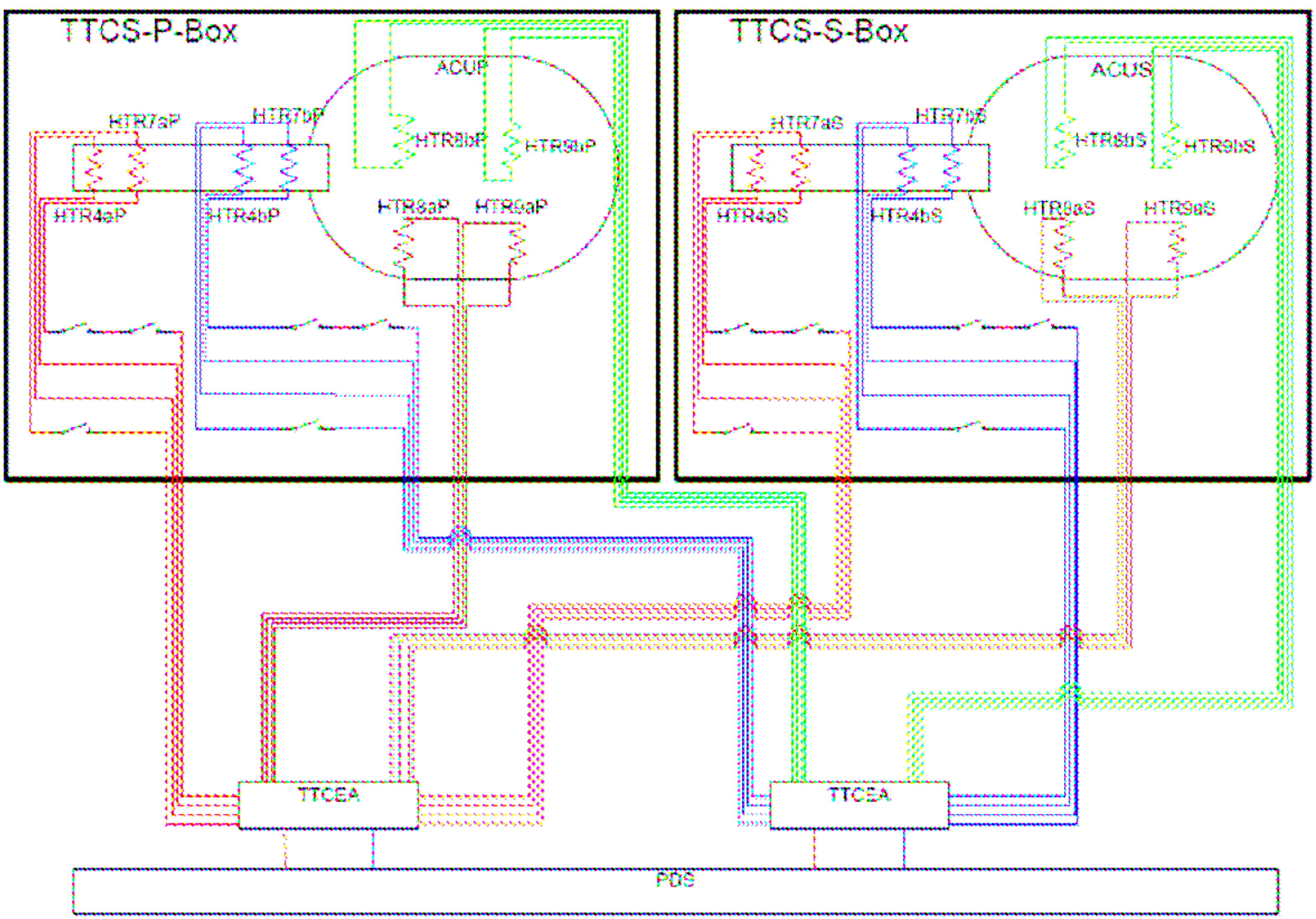
TTCE Accumulator Heat Pipe Design

Tracker
Heat
Pipe



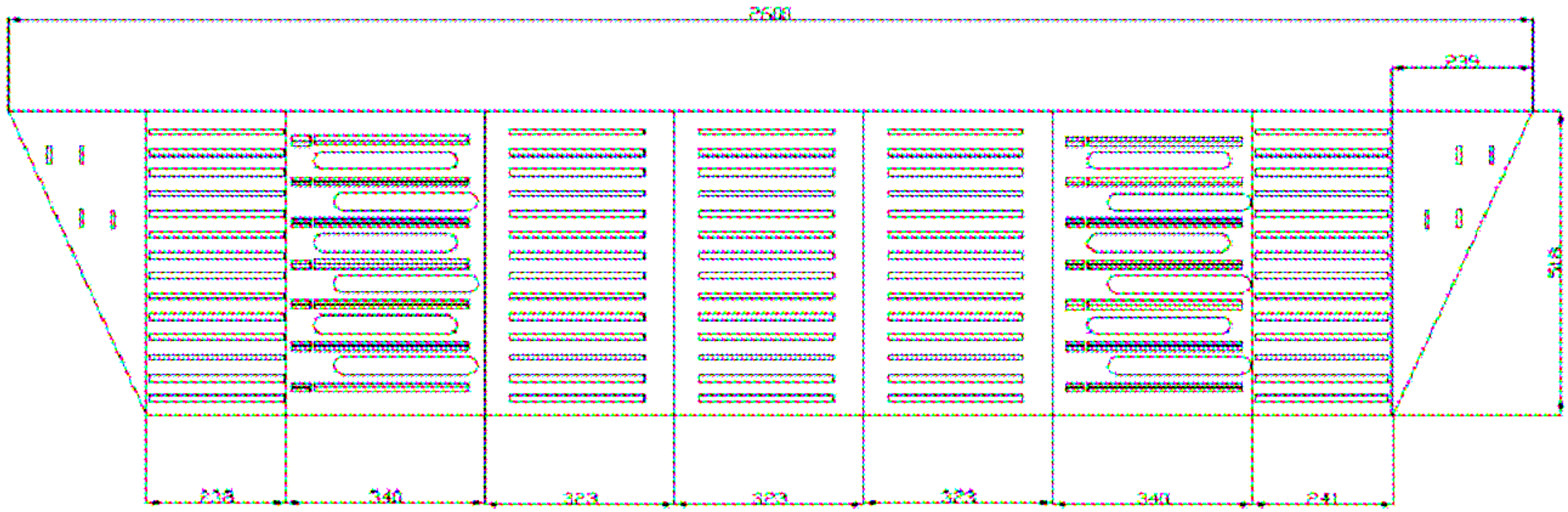


Tracker TTCS Radiators

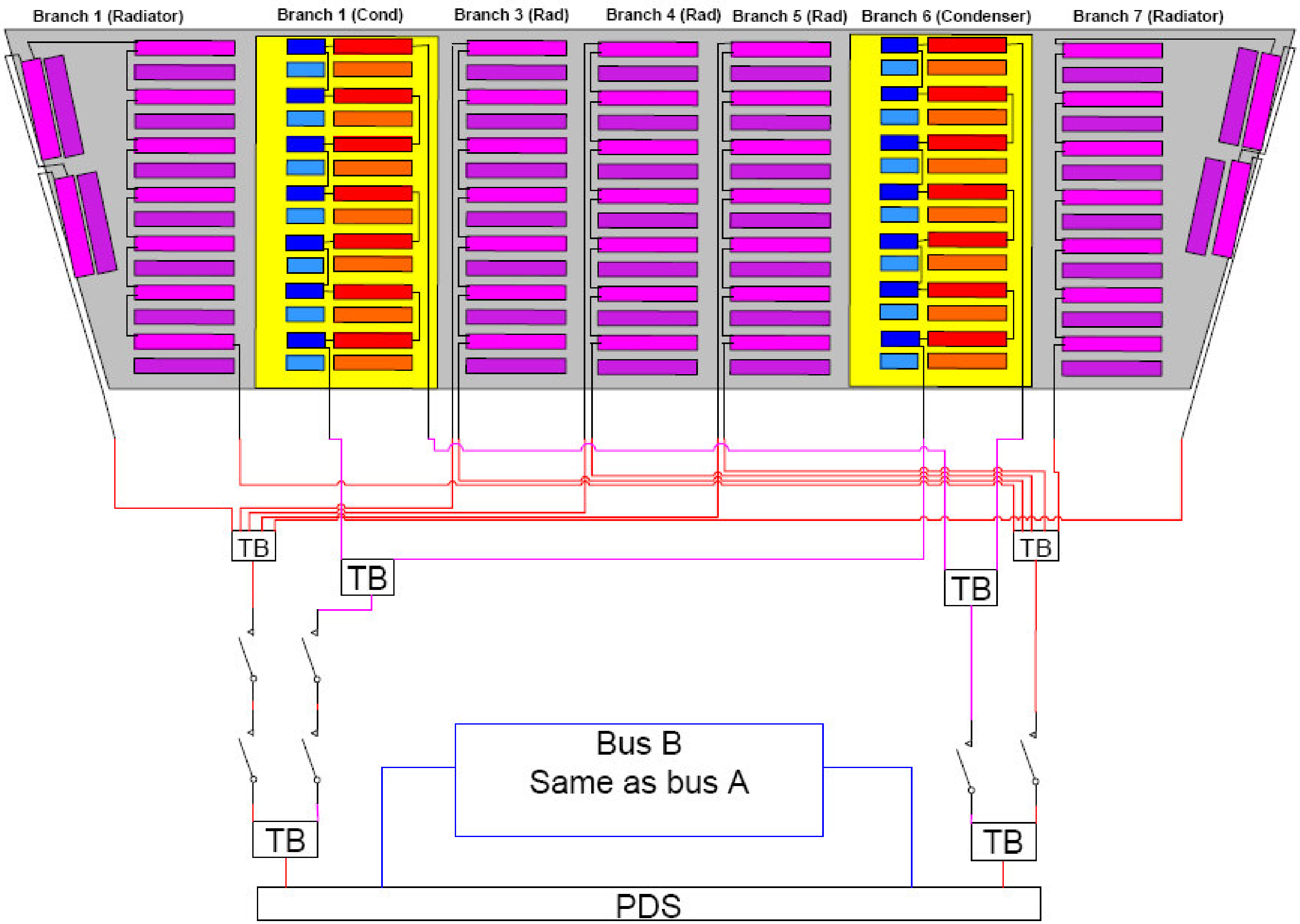


~~Tracter~~ Tracker TCS Accumulator Heater Circuit.

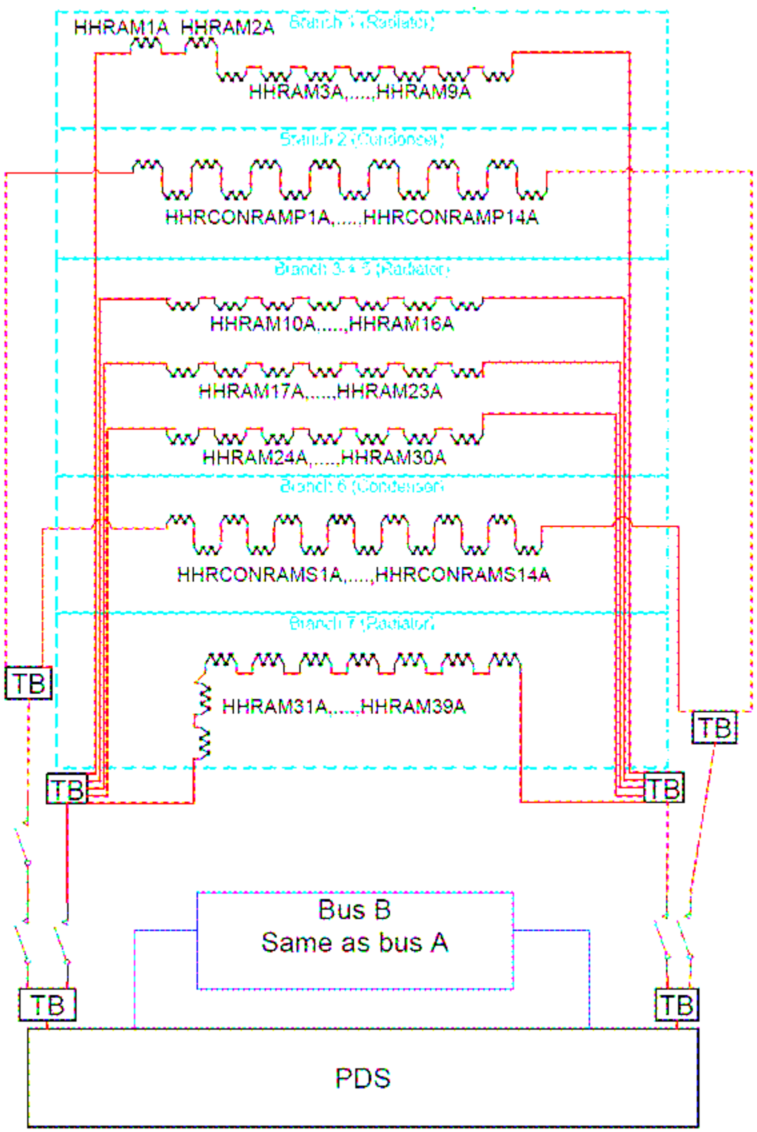
Note: Ground test heaters (HTR8xx) are not connected during flight.



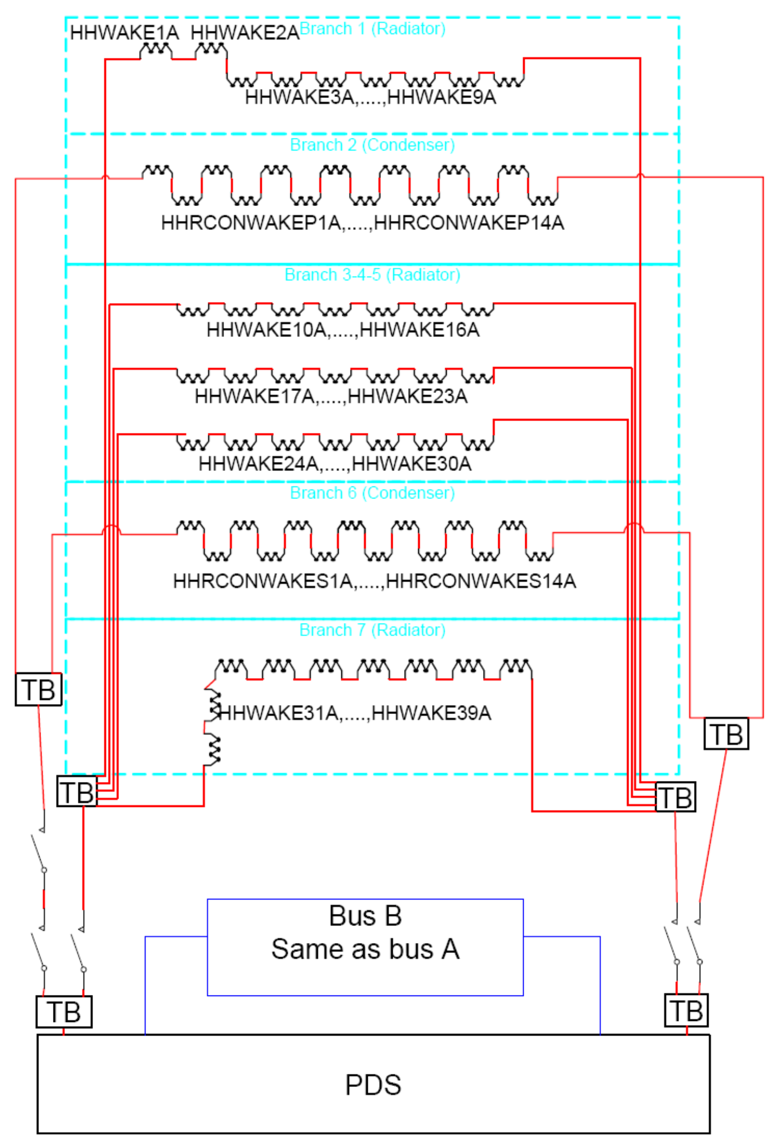
Tracker Radiator Heater Locations



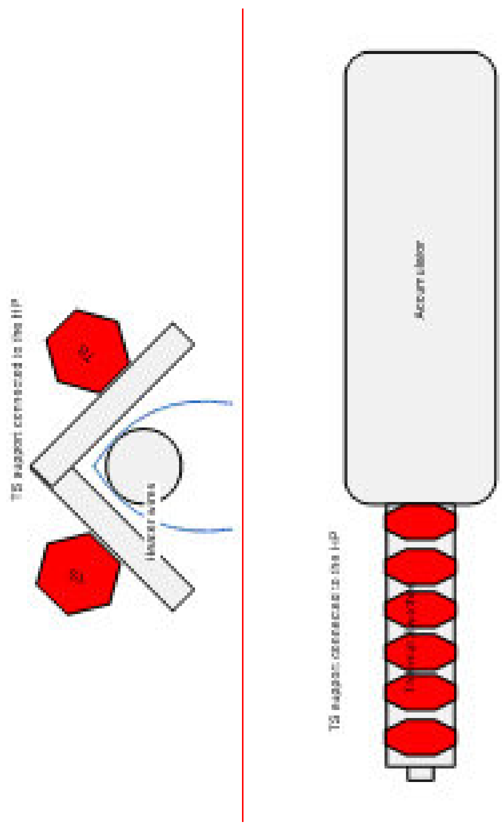
Tracker Radiator Heater Circuits with Thermal Switches.

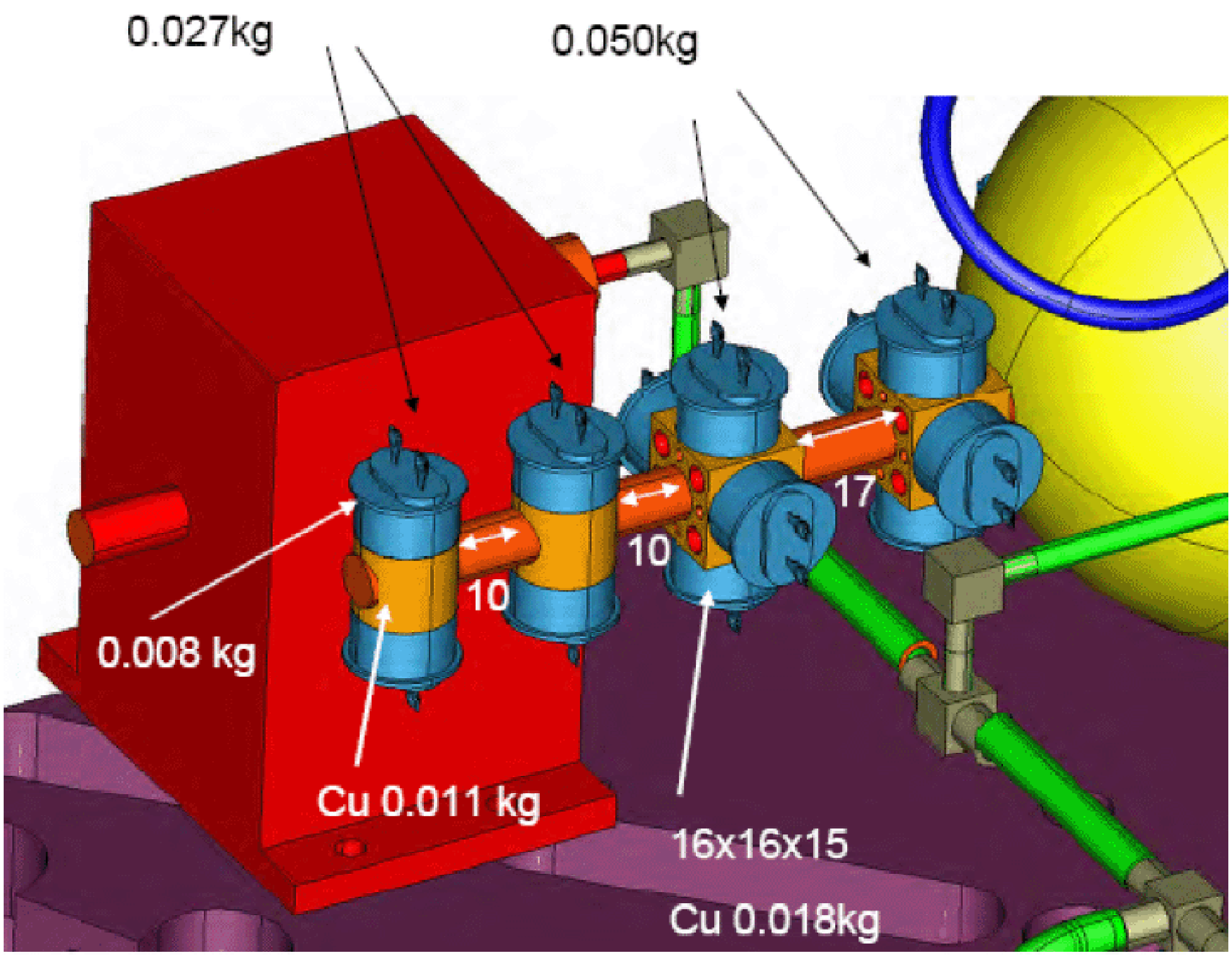


Tracker Radiator Heater Schematic (RAM)



Tracker Radiator Heater Schematic (Wake)


TS support connected to the HP
TS support connected to the HP



TTCS Accumulator Proposed location of Thermoswitches

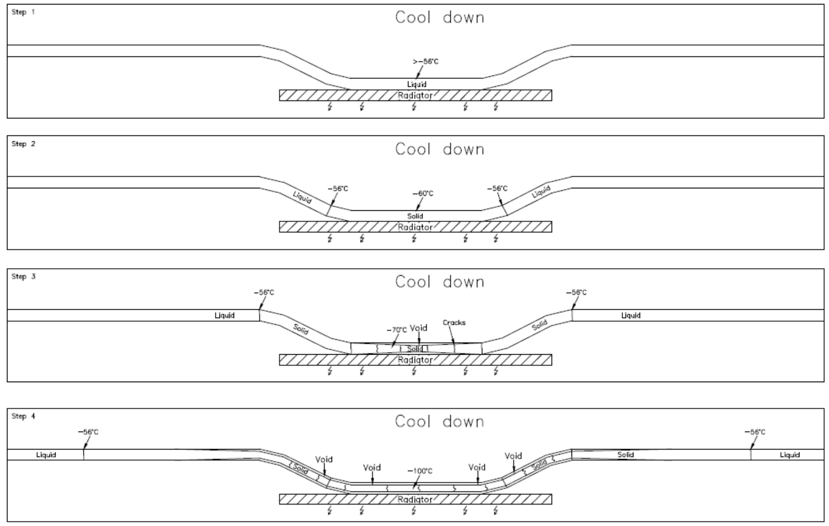


Figure 4-1: Condenser cool down sequence

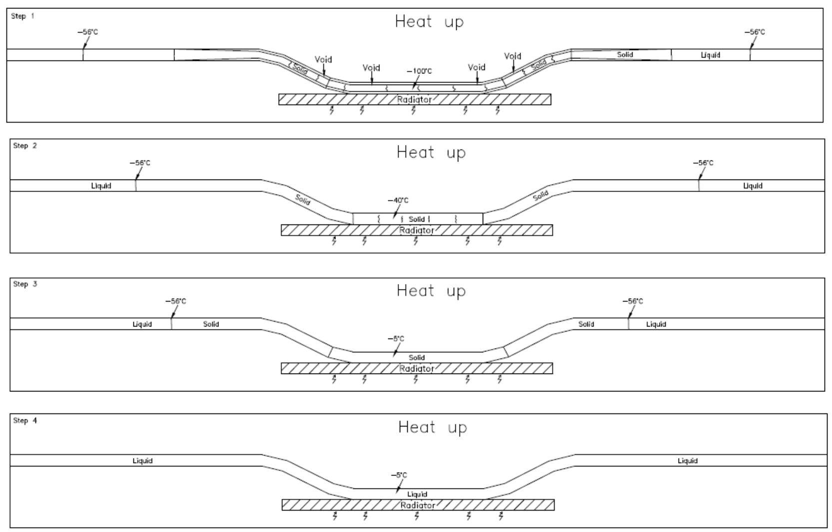
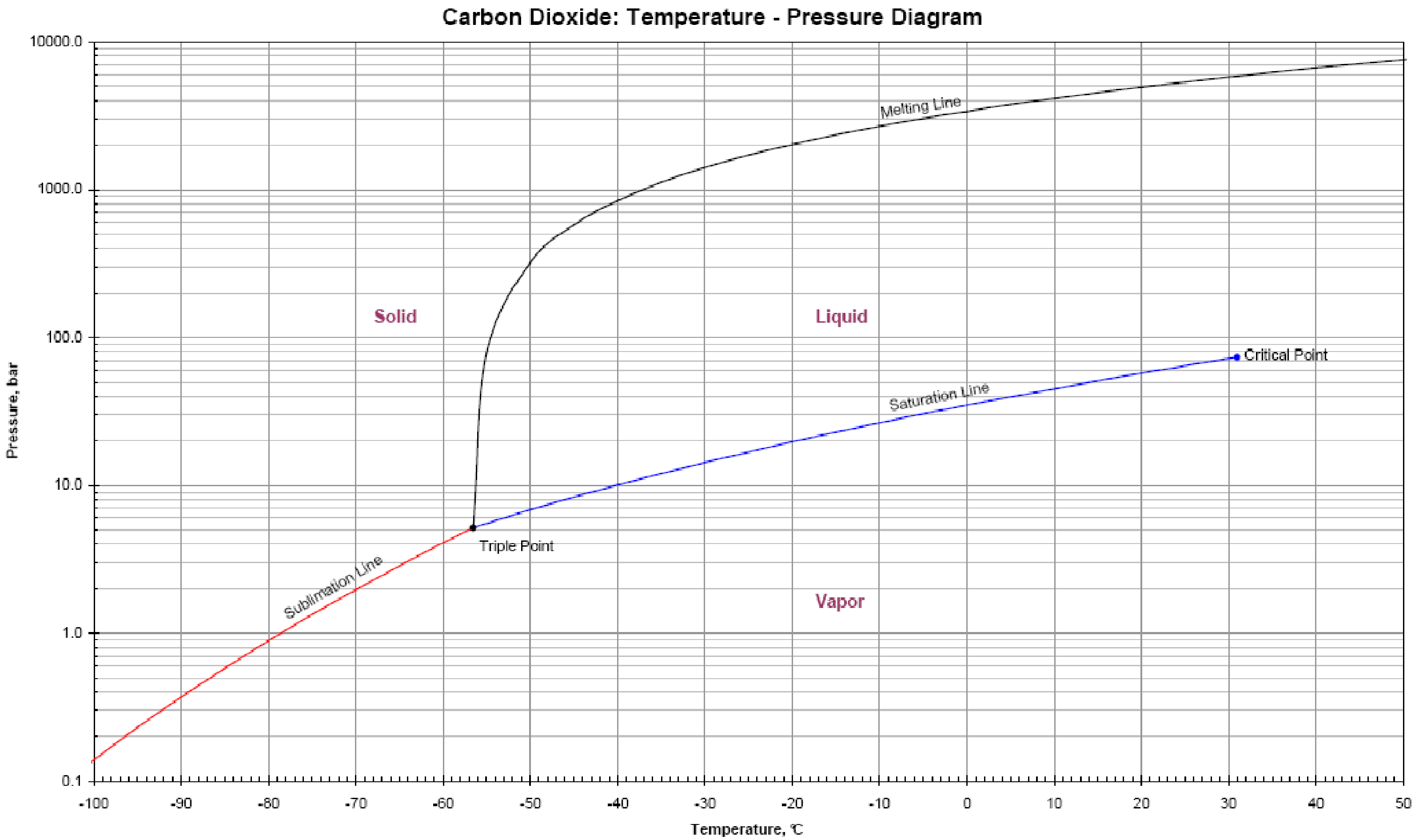
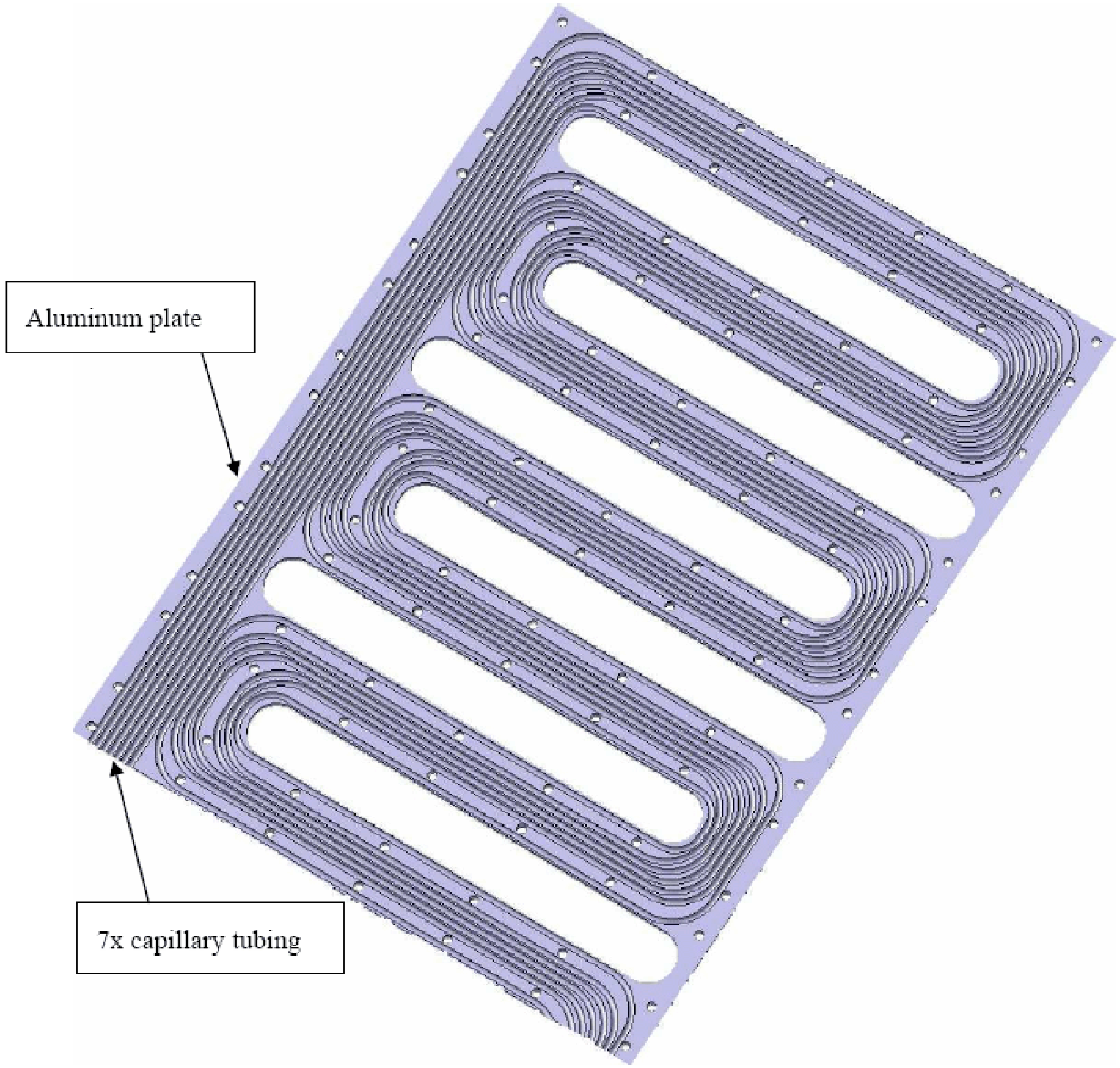


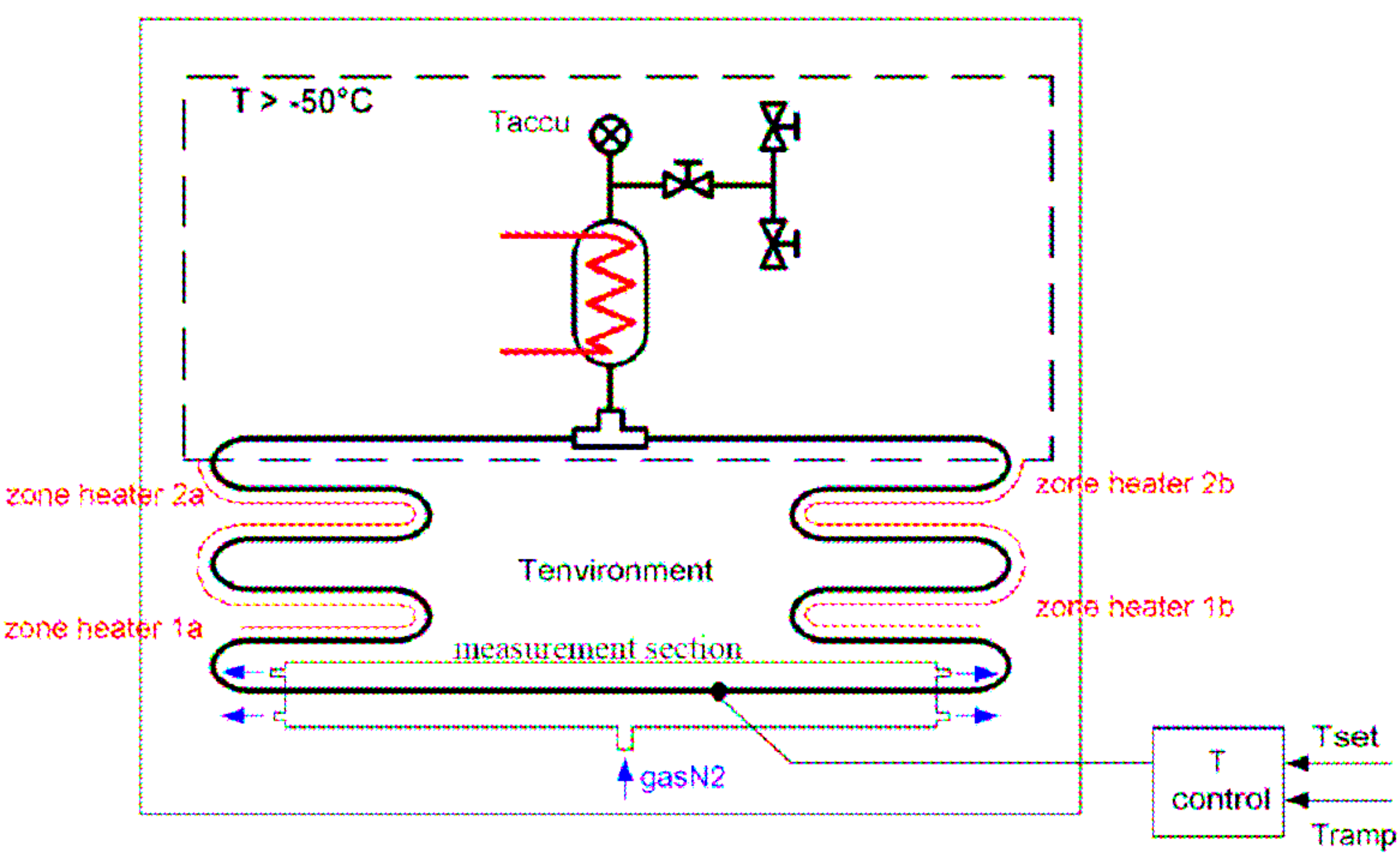
Figure 4-2: Condenser heat up sequence



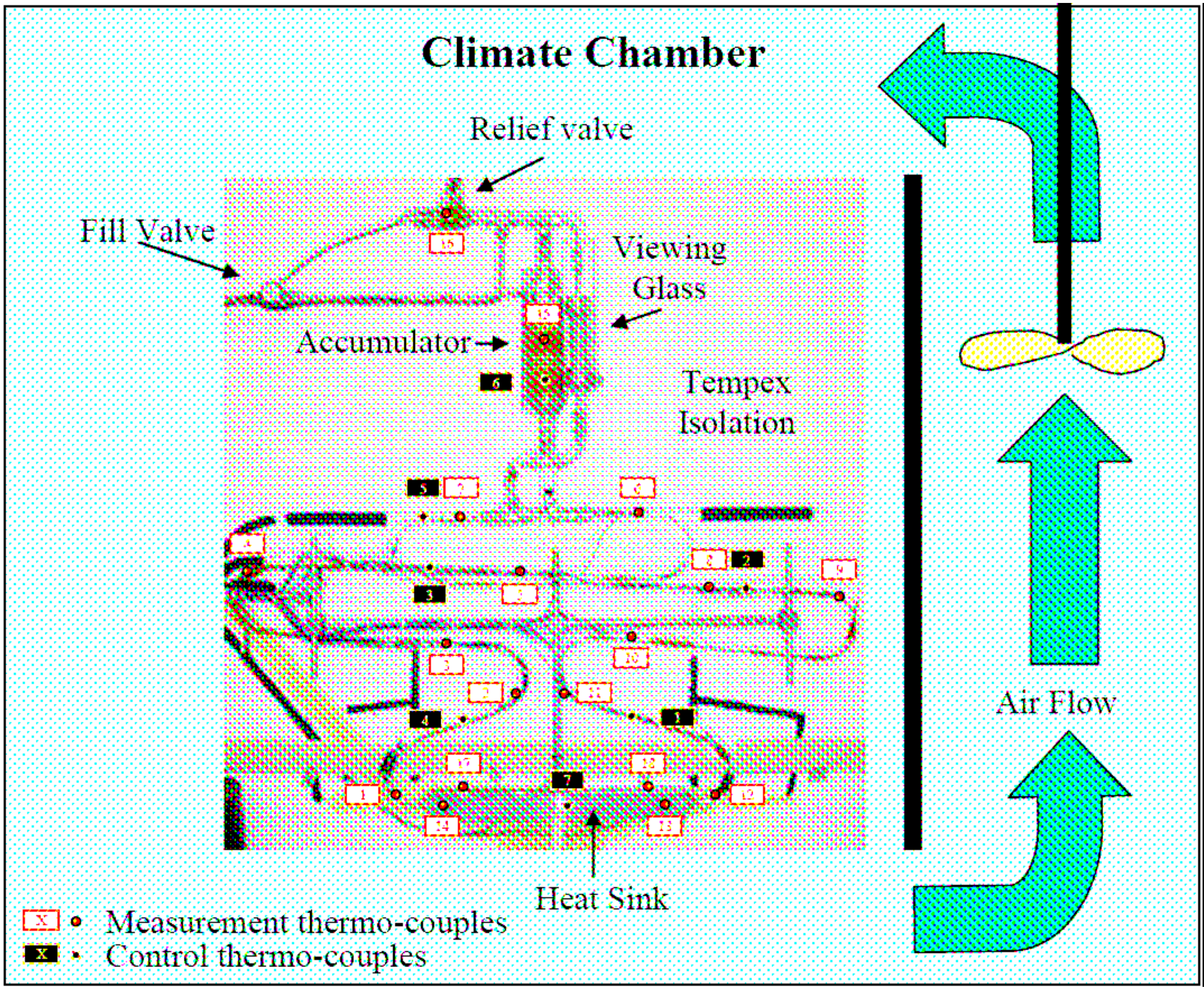
Carbon Dioxide Temperature-Pressure Diagram



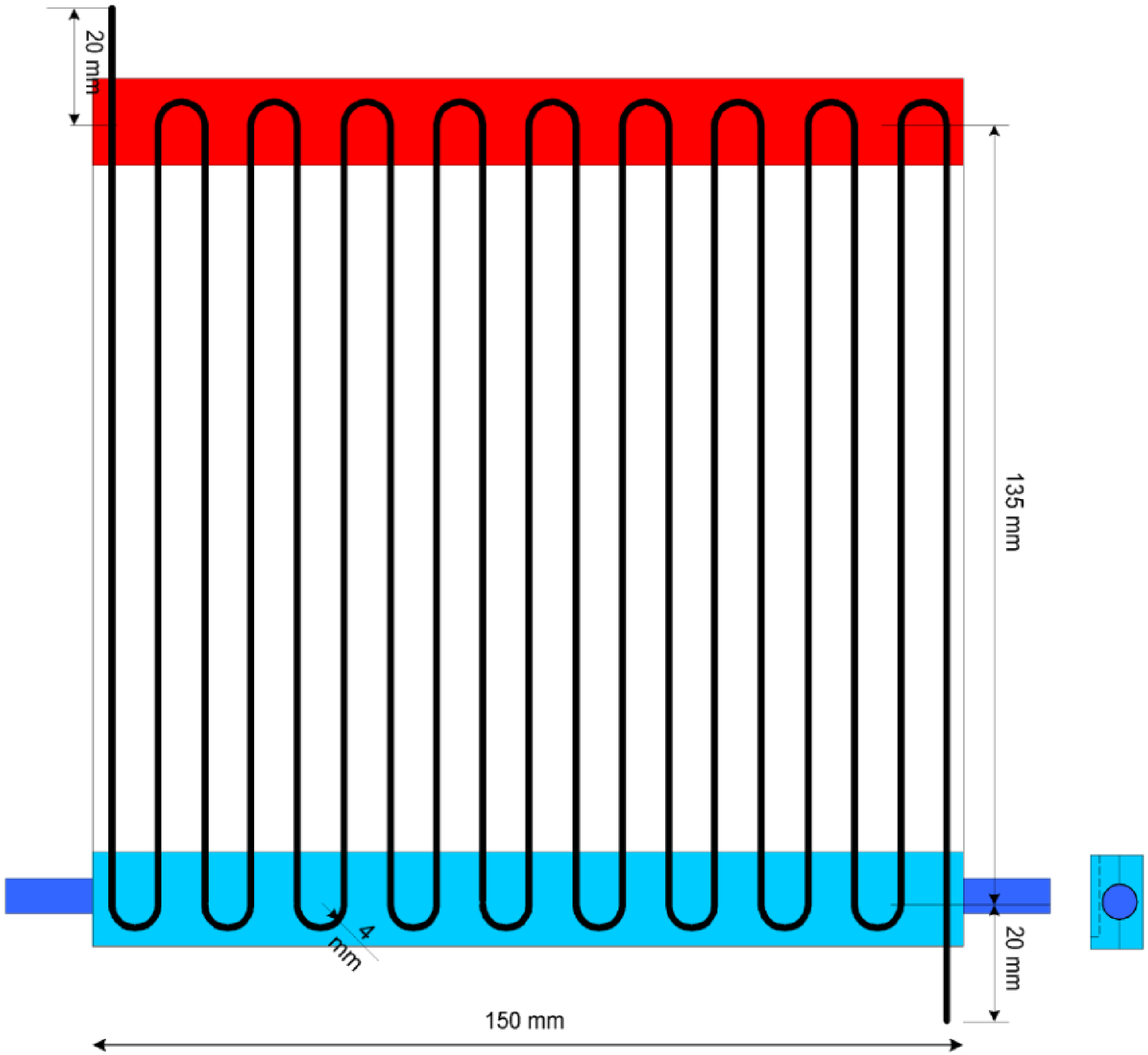
Capillary Tube Mounting Plate for Condenser



TTCS Freeze/Thaw Test Configuration (Extracted from NLR Memorandum AMSTR-NLR-TN-039 Issue 02)



Physical Test Setup for TTCS CO_2 Freeze/Thaw Testing



Oscillating Heat Pipe (open bore)

D. Thermal Control System

Cryomagnet Avionics Box Loop Heat Pipe Pressure System Components

Description	Material Of Construction	Mass Of fluid		Operating Pressure[6])		MDP[1]		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	bar	psid	bar	psid	bar	psid	Req[3]	Actual	bar	psid			
Loop heat pipe evaporator	AISI 321 stainless steel			15.0	217.6	20.3	294.0	208.5	3024.0	4.0	10.3	30.4	441.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Loop heat pipe reservoir[5]	AISI 321 stainless steel	0.055	0.121	15.0	217.6	20.3	294.0	165.5	2400.0	4.0	8.2	30.4	441.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Loop Heat pipe vapor tubes	AISI 321 stainless steel			15.0	217.6	20.3	294.0	672.4	9753.0	4.0	33.2	30.4	441.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Loop Heat pipe liquid tubes	AISI 321 stainless steel			15.0	217.6	20.3	294.0	924.0	13401.0	4.0	45.6	30.4	441.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Loop Heat pipe condenser tubes	Al 6063			15.0	217.6	20.3	294.0	450.5	6534.0	4.0	22.2	30.4	441.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Bypass valve gas bellow – Argon[7]	AISI 321 stainless steel			6.0	87.0											
Bypass valve liquid side – Ammonia	AISI 321 stainless steel			6.0	87.0											

Notes:
1) MDP has been established based on worst case thermal profile and where applicable (with mechanisms to fail) worst case two fault condition.
2) Burst Safety Factor is calculated from the material allowable stress and pipe geometry
3) Heat pipes are part of a pressurized system and are not isolated. Burst Factor of 4.0 is used (2.5 could be used for heat pipes as components.)
4) Ref TCS Hardware Design Report AMS-OHB-DER-001 Issue 2, Revision A, May 5, 2005
5) Mass of working fluid is allocated to reservoir for accounting purposes.
6) Calculated at 40°C; maximum operating temperature of CAB
7) Operating Pressure calculated at 20°C

Cryomagnet Avionics Box Heat Pipes Pressure System Components

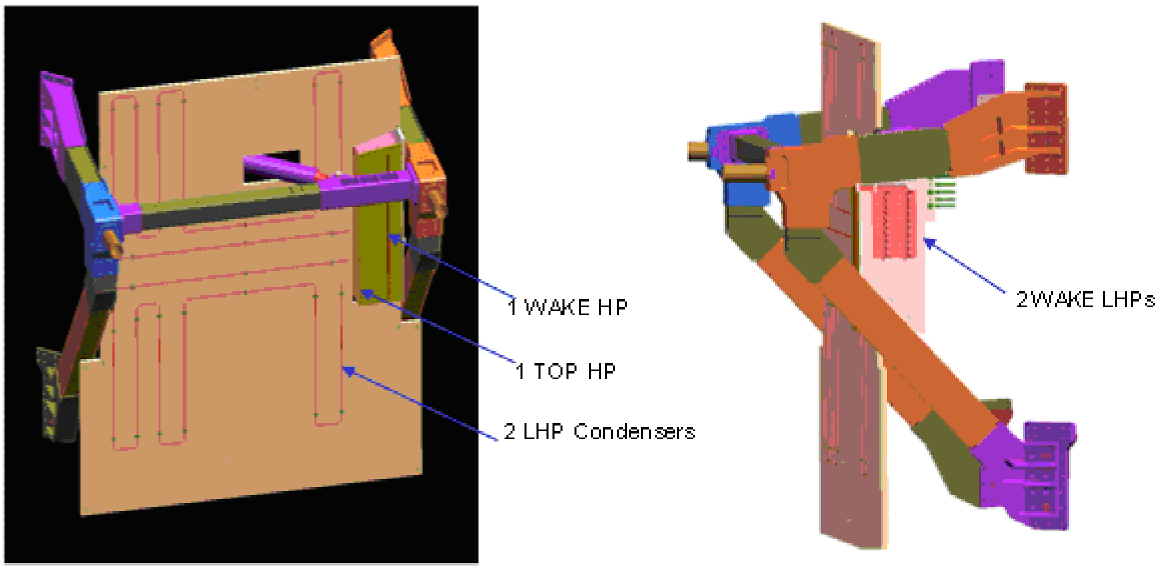
Description	Material Of Construction	Mass Of fluid		Operating Pressure[6])		MDP[1]		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	Bar	psid	Bar	psid	bar	psid	Req[3]	Actual	bar	psid			
Body mounted Heat Pipes	AL 6063	Note 5		15.0	217.6	20.0	290.0	174.7	2534.0	4.0	8.7	30.0	435.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C

Notes:
1) MDP has been established based on worst case thermal profile and where applicable (with mechanisms to fail) worst case two fault condition.
2) Burst Safety Factor is calculated from the material allowable stress and pipe geometry
3) Heat pipes single components and not a part of a greater pressure system. Burst Factor of 4.0 is used (2.5 could be used for heat pipes as components.)
4) Ref TCS Hardware Design Report AMS-OHB-DER-001 Issue 2, Revision A, May 5, 2005
5) There are 2 heat pipes with different lengths, mass of fluid (ammonia) is 5 grams for the shortest and 7 grams for the longest
6) Calculated at 40°C; maximum operating temperature of CAB

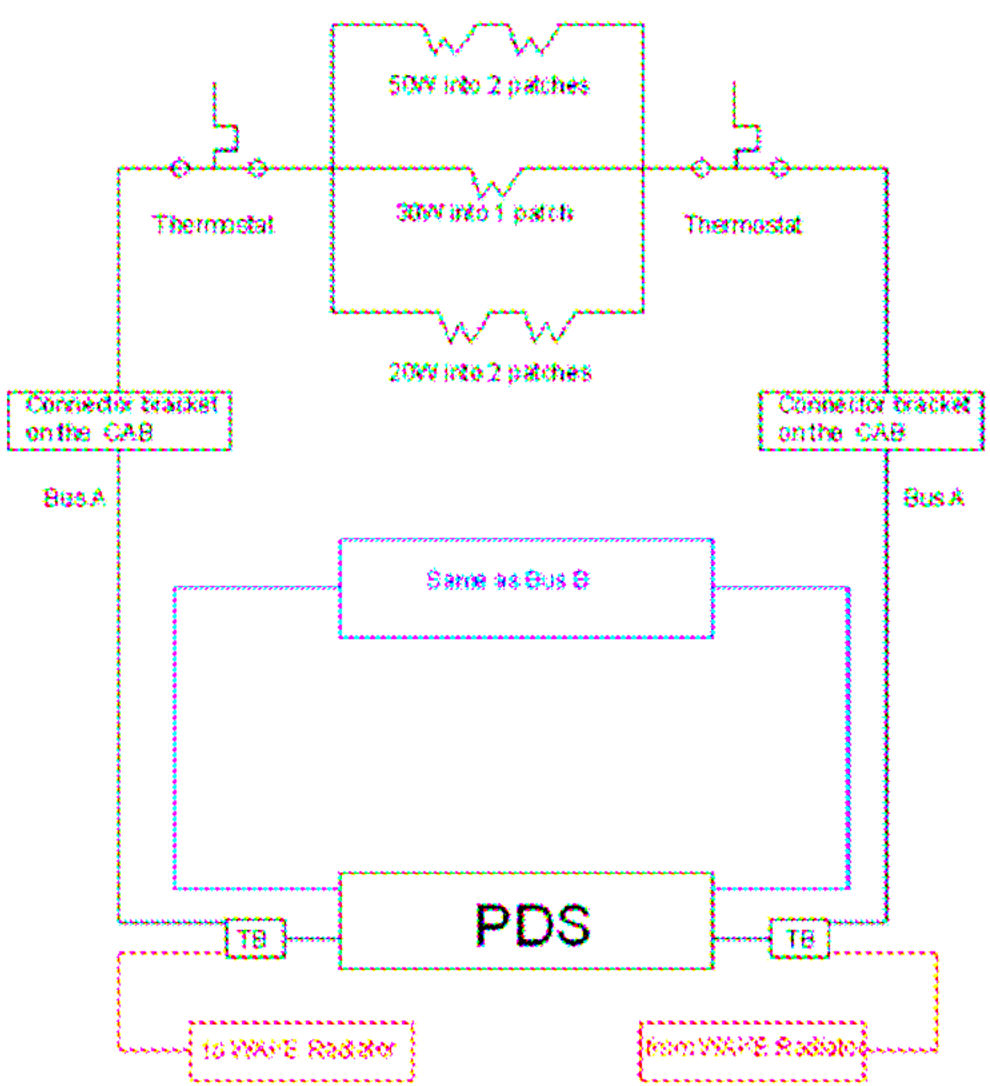
USS-02 Structure Heat Pipes Pressure System Components

Description	Material Of Construction	Mass Of fluid		Operating Pressure[6])		MDP[1]		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	Bar	psid	bar	psid	bar	psid	Req[3]	Actual	bar	psid			
USS Mounted HP	Al 6063	Note 5		15.0	217.6	20.3	294.0	174.7	2534.0	4.0	8.6	30.4	441.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C

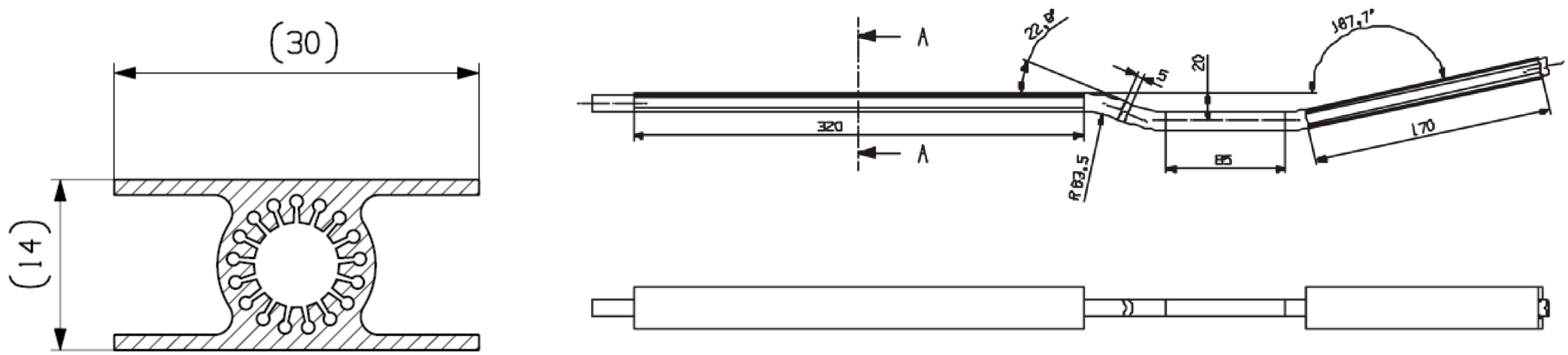
Notes:
1) MDP has been established based on worst case thermal profile and where applicable (with mechanisms to fail) worst case two fault conditions.
2) Burst Safety Factor is calculated from the material allowable stress and pipe geometry
3) Heat pipes single components and not a part of a greater pressure system. Burst Factor of 4.0 is used (2.5 could be used for heat pipes as components.)
4) Ref TCS Hardware Design Report AMS-OHB-DER-001 Issue 2, Revision A, May 5, 2005
5) The USS-02 Structure Heat Pipes consist of three non-embedded heat pipes that each contains 6.8 grams of ammonia.
6) Calculated at 40°C; maximum operating temperature of CAB



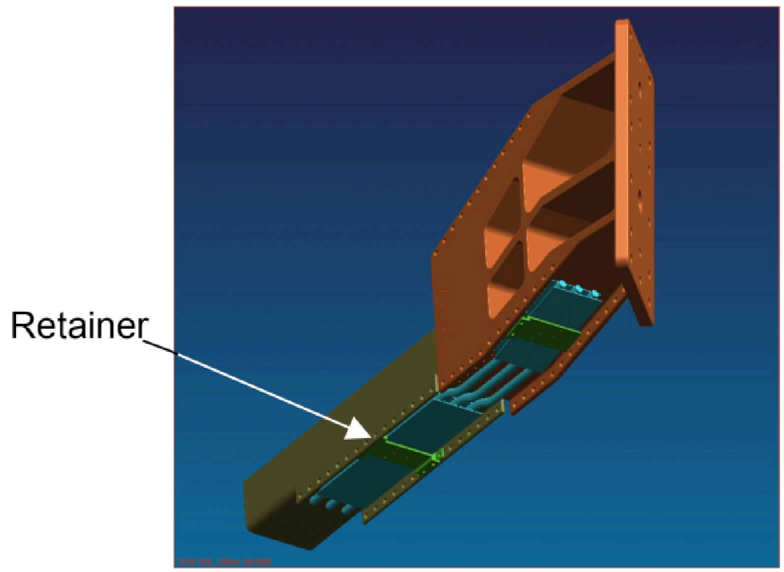
CAB Loop Heat Pipe



CAB (Avionics Box) Heater Layout, Computer Control of Heaters Not Shown.



CAB-USS Heat Pipe Lay Out

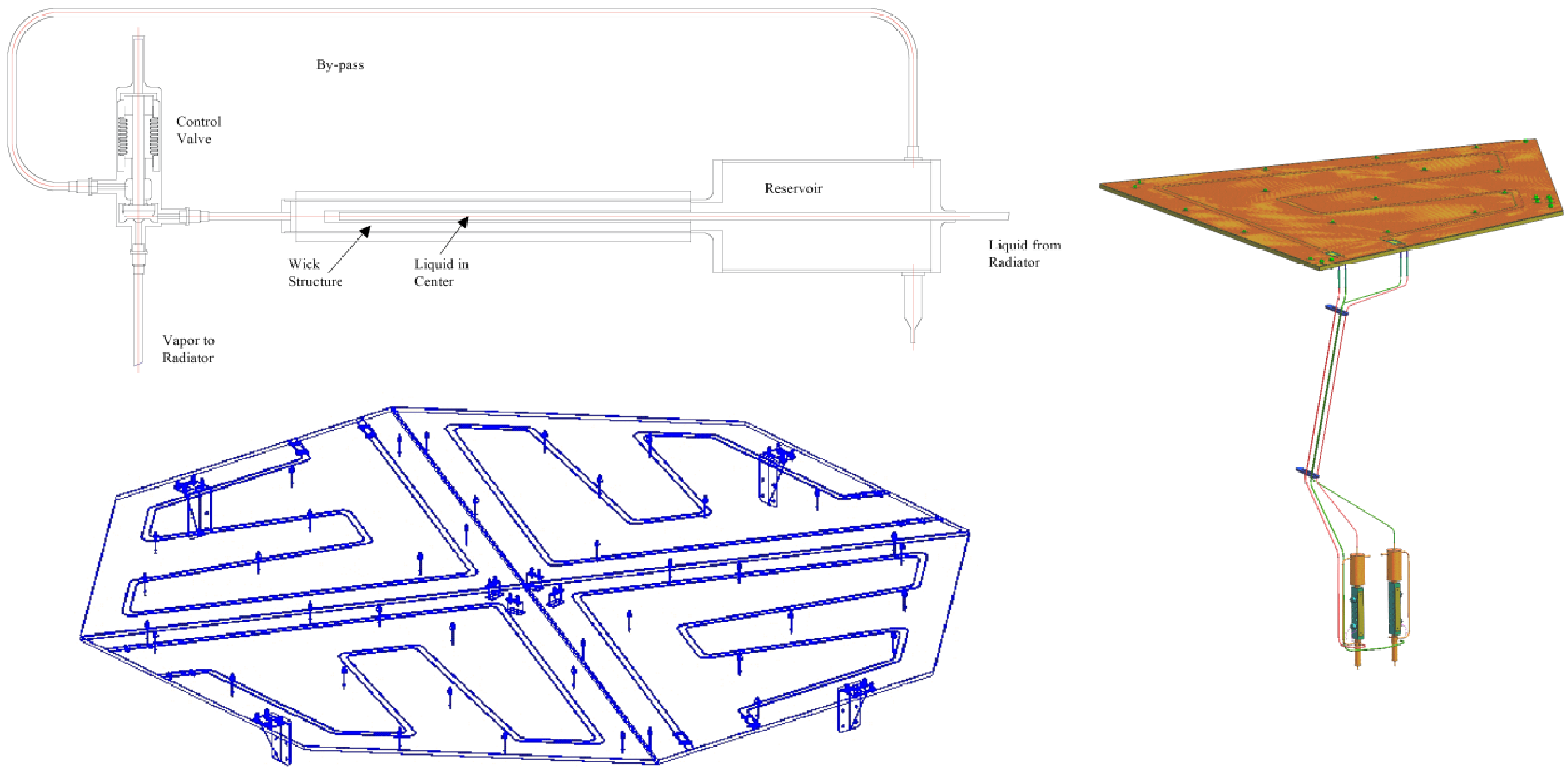


USS Heat Pipes (a.k.a CAB-USS Heat Pipes)

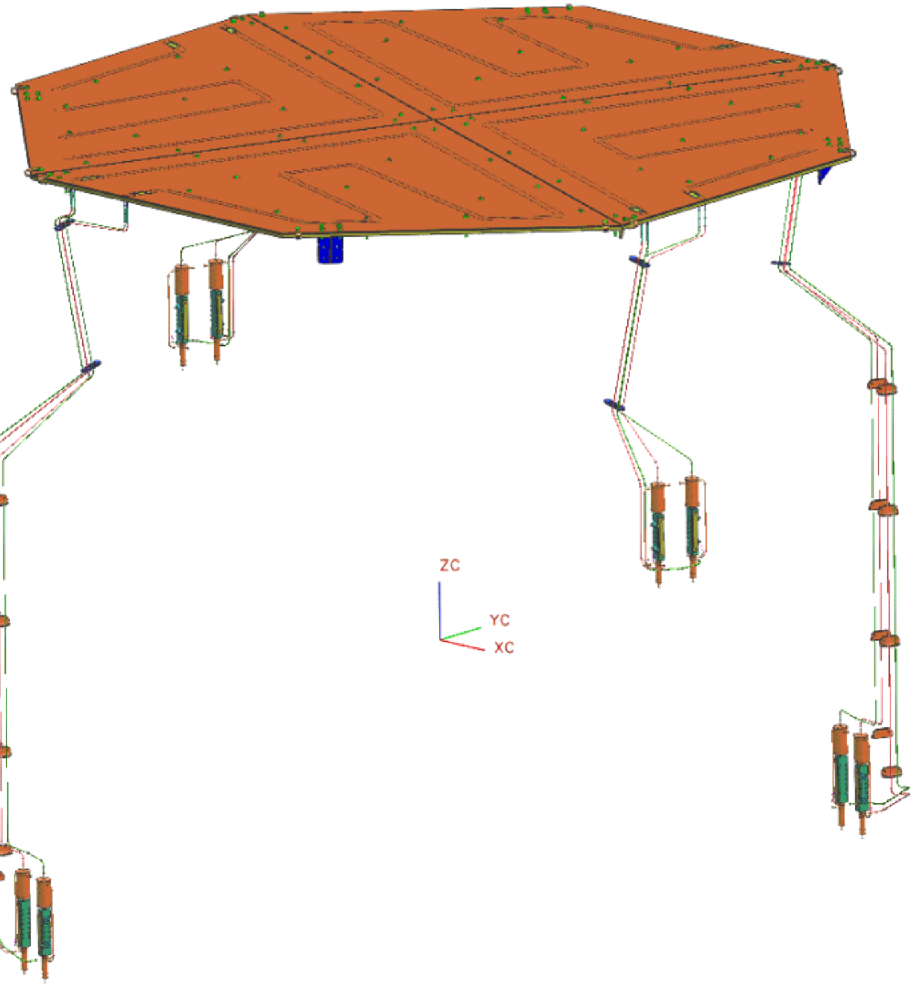
Cryocooler Loop Heat Pipe/Zenith Radiators Pressure System Components

Description	Material Of Construction	Mass Of Fluid		Operating Pressure[7]		MDP[1]		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	Bar	Psid	bar	psid	bar	psid	Req[3]	Actual	bar	psid			
Loop Heat Pipe Evaporator	AISI 321 stainless steel			4.0	58.0	18.0	261.0	165.4	2399.0	4.0	9.2	27.0	392.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Loop Heat Pipe Reservoir[5]	AISI 321 stainless steel	0.042	0.093	4.0	58.0	18.0	261.0	123.1	1785.0	4.0	6.8	27.0	392.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Loop Heat Pipe Liquid Tubes	AISI 321 stainless steel			4.0	58.0	18.0	261.0	924.0	13401.0	4.0	51.3	27.0	392.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Loop Heat Pipe Vapor Tubes	AISI 321 stainless steel			4.0	58.0	18.0	261.0	672.4	9753.0	4.0	37.4	27.0	392.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Loop Heat Pipe Valve	AISI 321 stainless steel			4.0	58.0	18.0	261.0	266.1	3859.0	4.0	14.8	27.0	392.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Loop Heat Pipe Condensor Tubes	AL 6063			<4.0	<58.0	18.0	261.0	252.2	3658.0	4.0	14.0	27.0	392.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C
Bypass valve gas bellow – ARGON (6)	AISI 321 stainless steel			6.0	87.0											
Bypass valve liquid side – Propylene	AISI 321 stainless steel			6.0	87.0											

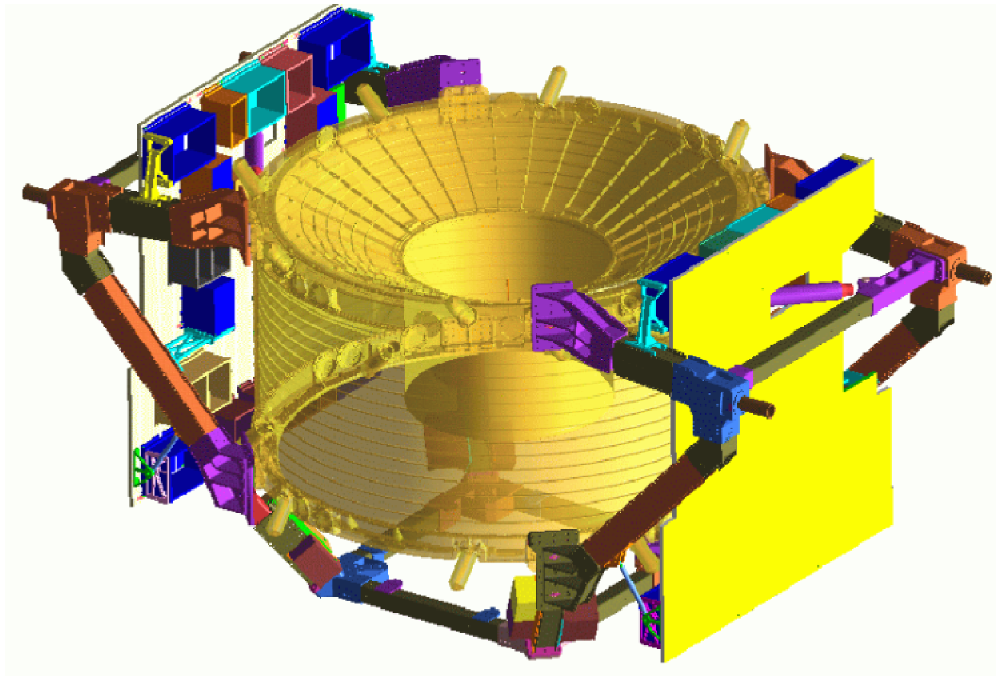
Notes:
1) MDP has been established based on worst case thermal profile and where applicable (with mechanisms to fail) worst case two fault condition.
2) Burst Safety Factor is calculated from the material allowable stress and pipe geometry
3) Listed Components are part of a pressurized system and are not isolated. Burst Factor of 4.0 is used (2.5 could be used for heat pipes as components.)
5) Mass of working fluid is allocated to reservoir for accounting purposes.
6) Operating Pressure calculated at 20°C
7) Calculated at 0°C, typical working temperature of the cryocoolers



Cryocooler Loop Heat Pipe System



Four Radiators of the Zenith Radiators/Cryocooler Loop Heat Pipe System



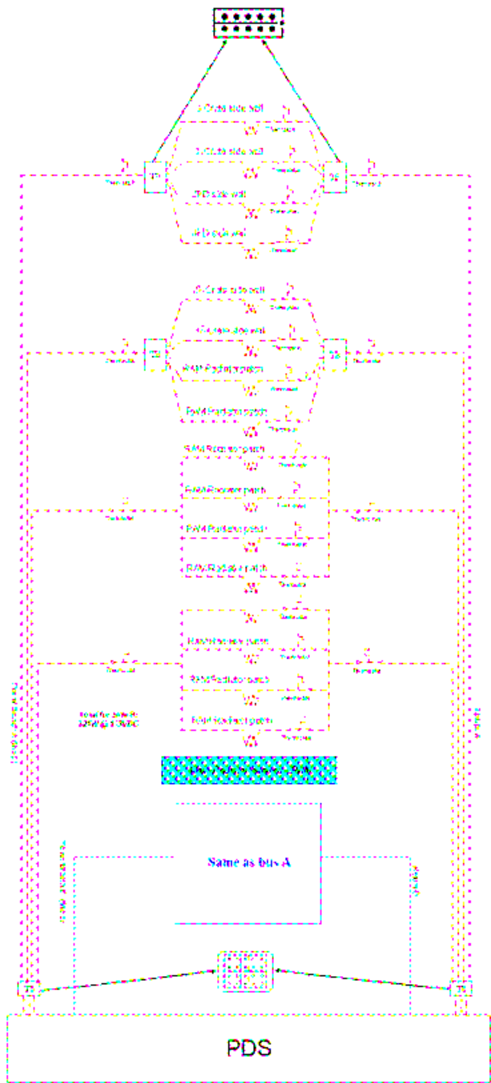
AMS-02 Wake and Ram Radiators

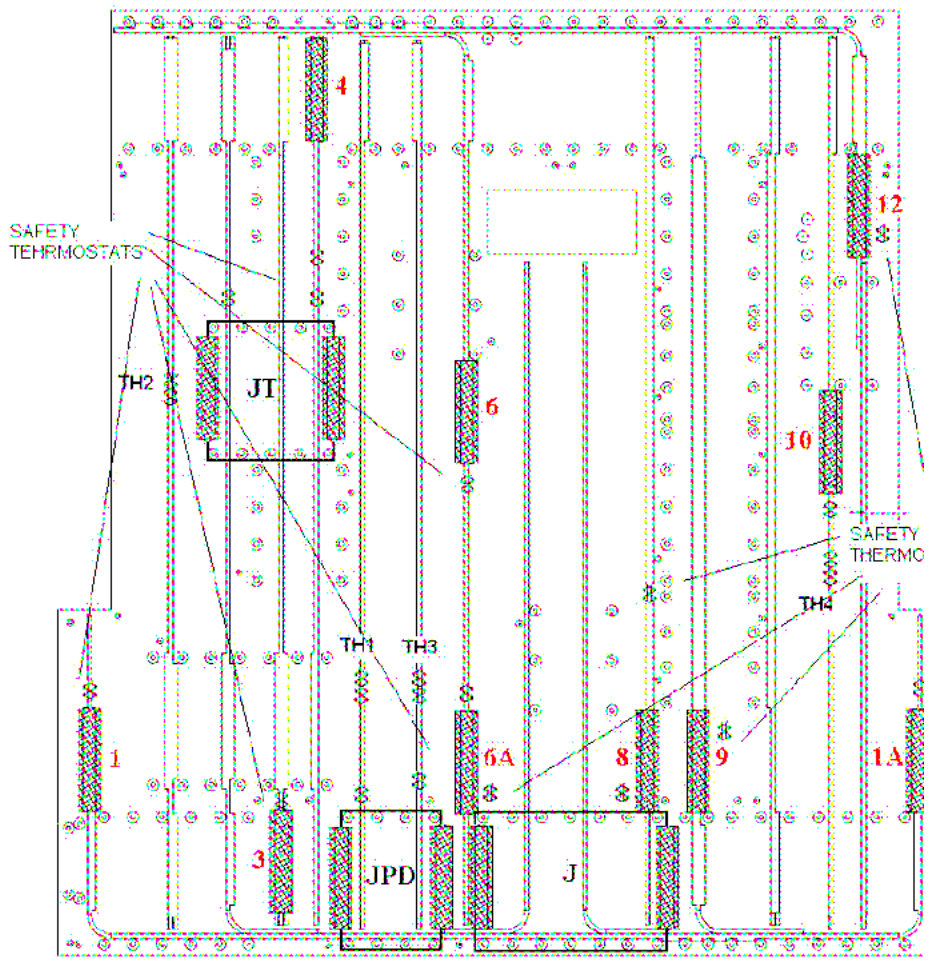
Wake and Ram Radiator (Crates) Heat Pipes Pressure System Components

Description	Material Of Construction	Mass Of fluid		Operating Pressure[6])		MDP[1]		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	bar	psid	bar	psi	bar	psid	Req [3]	Actual	bar	psid			
Embedded Heat Pipes	AL 6063	Note 5		15.0	217.6	25.0	362.5	155.4	2254.0	4.0	6.2	30.0	435.0	1.5	Analysis[2]	NSTS 1700.7B SSP 30559C

Notes:
1) MDP has been established based on worst case thermal profile and where applicable (with mechanisms to fail) worst case two fault conditions with a relevant MDT of 60°C.
2) Burst Safety Factor is calculated from the material allowable stress and pipe geometry

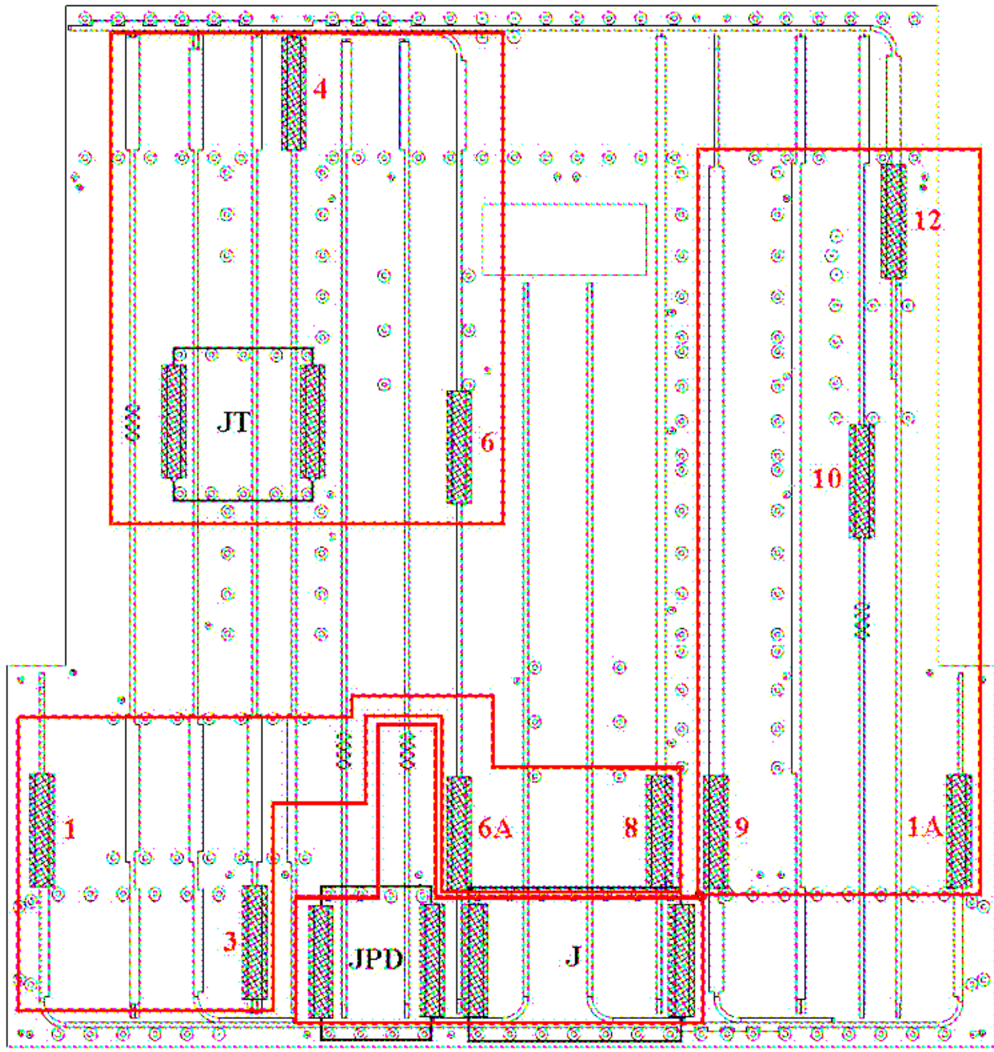
3) Heat pipes single components and not a part of a greater pressure system. Burst Factor of 4.0 is used (2.5 could be used for heat pipes as components.)
4) Ref TCS Hardware Design Report AMS-OHB-DER-001 Issue 2, Revision A, May 5, 2005
5) There are 20 embedded heat pipes with different lengths on the Wake Radiator, 16 heat pipes on the Ram Radiator, mass of fluid (ammonia) ranges from 7.6 grams for the shortest to 29.6 grams for the longest
6) Calculated at 40°C, maximum working temperature of the electronic



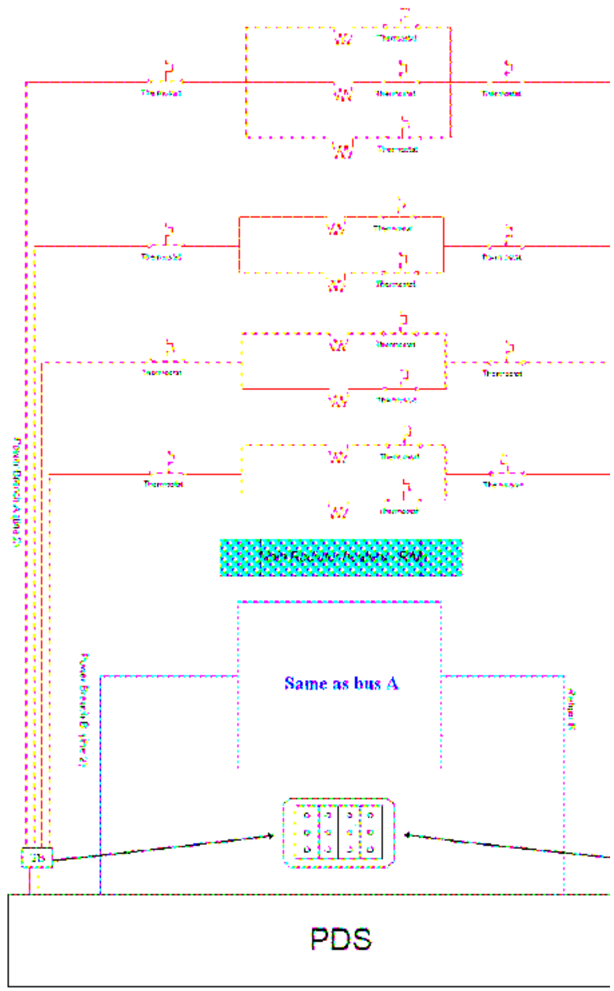


RAM Radiator Heater Set 1 Schematic

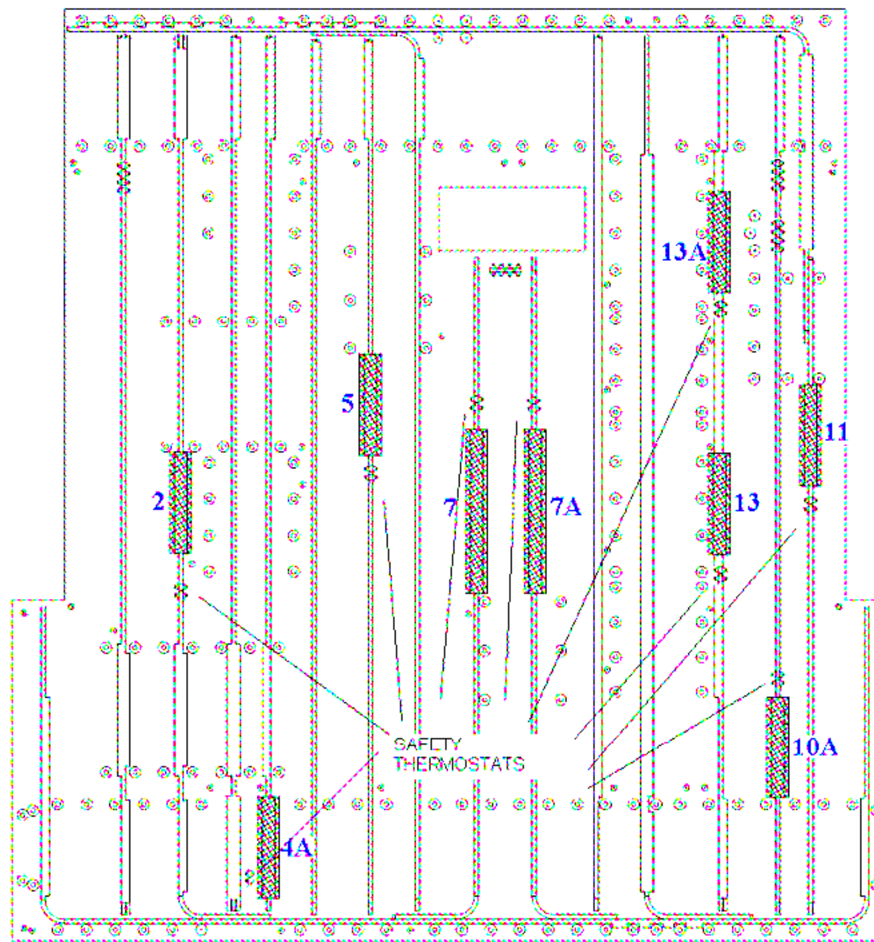
RAM Radiator Heater and Thermostatic Switch Locations (Set 1)



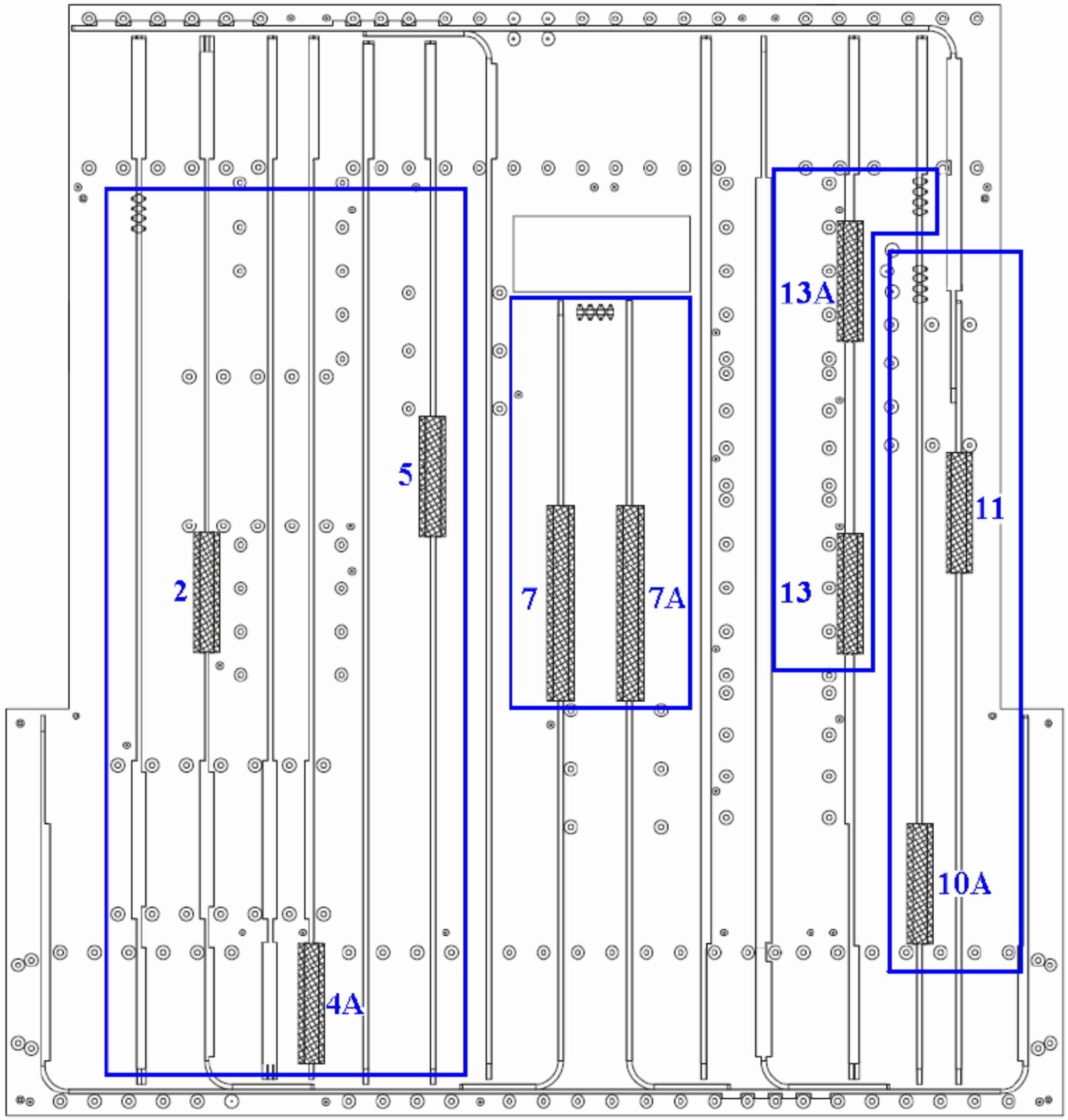
Ram Heater Set 1 Control Zone Layout with Heater Locations



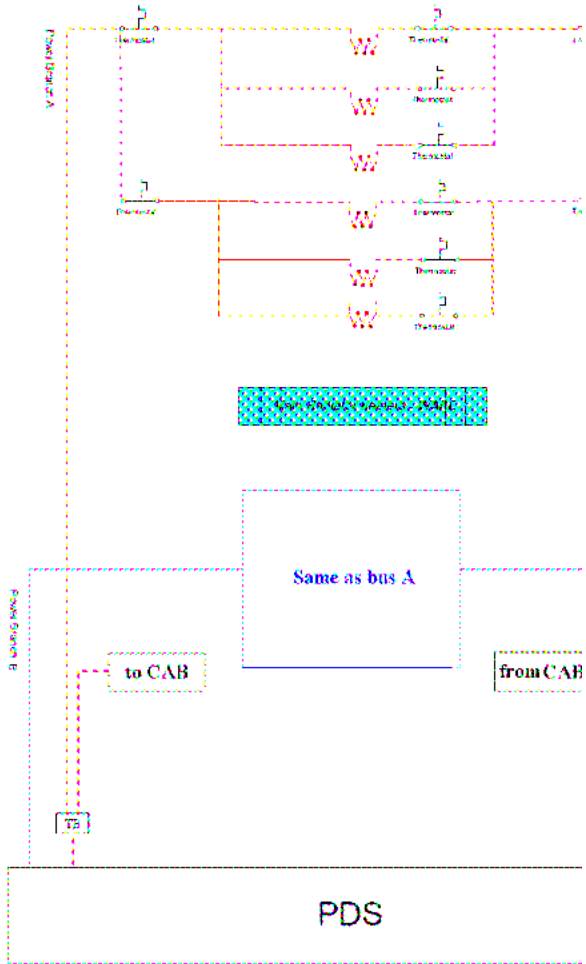
Ram Radiator Heater Set 2 Schematic



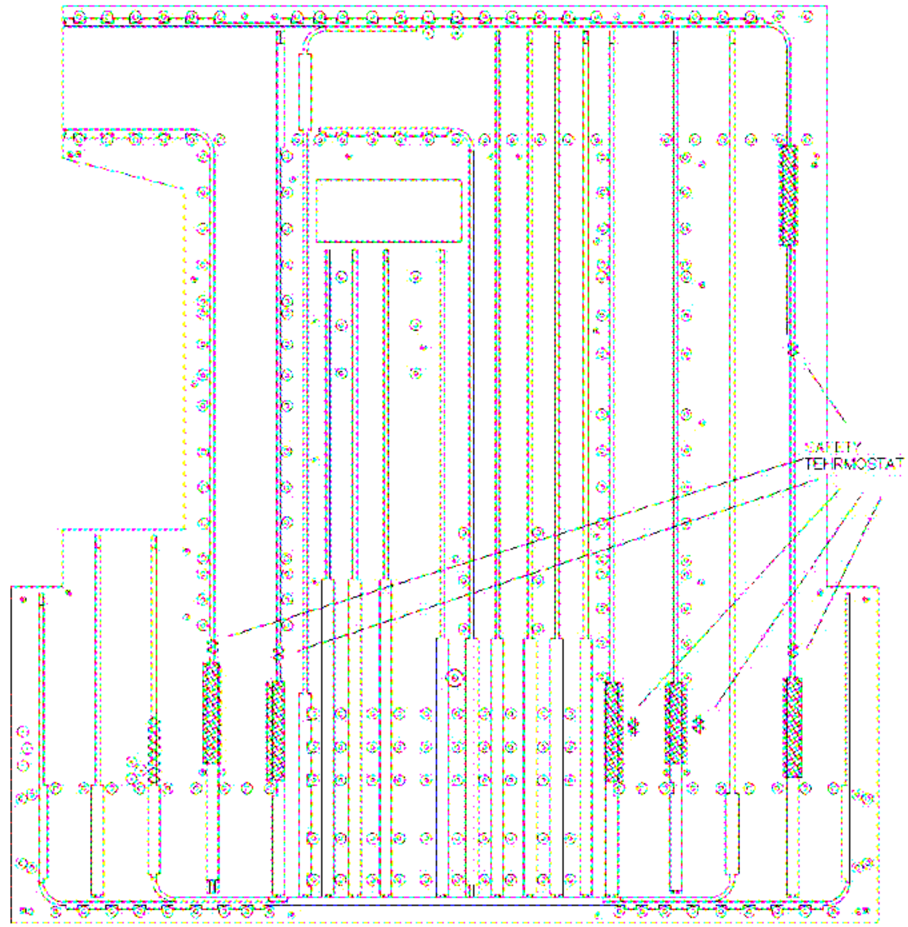
Ram Radiator Heater and Thermostatic Switch Locations (Set 2)



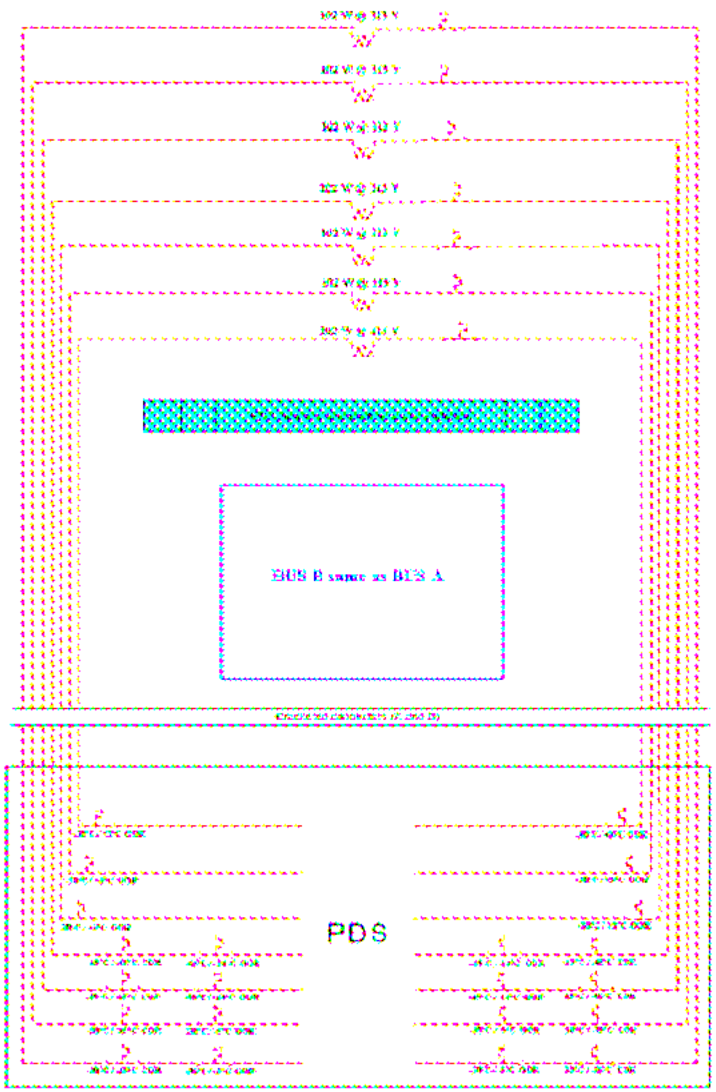
Ram Heater Set 2 Control Zone Layout with Heater Locations



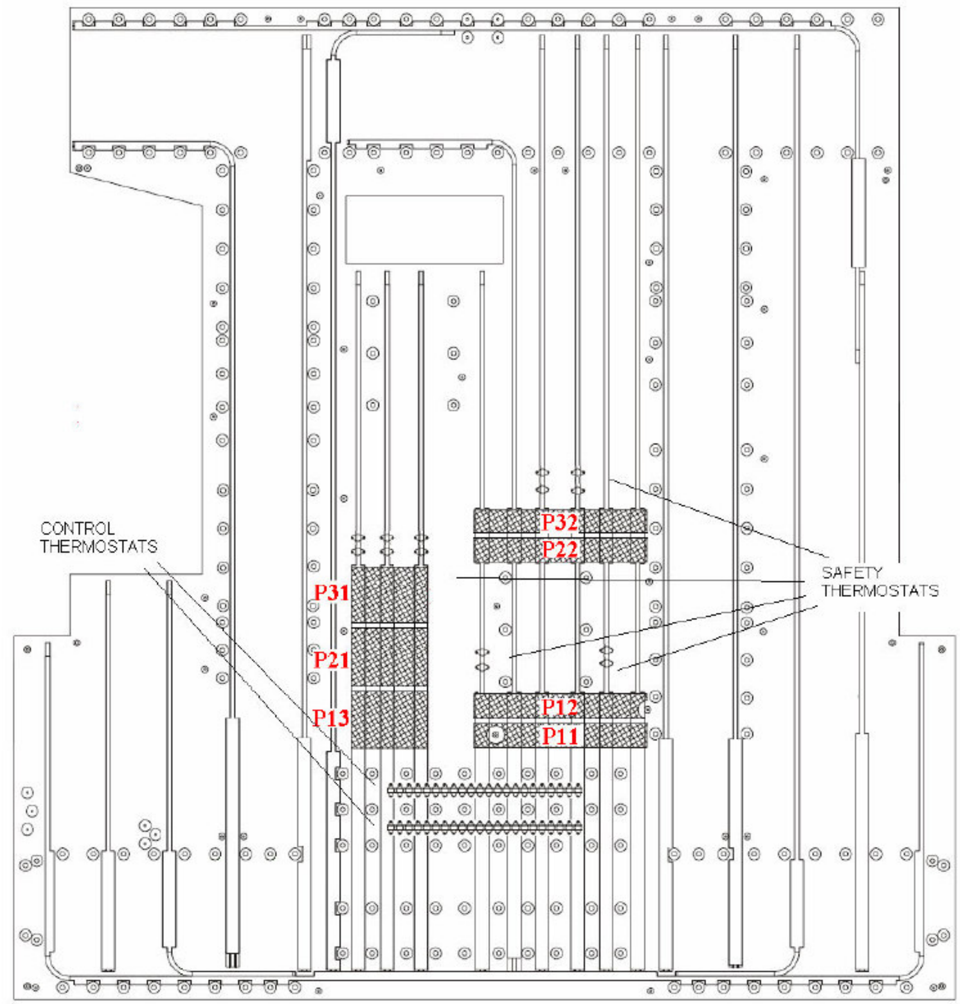
Wake Radiator Schematic



Wake Radiator Heater and Thermostatic Switch Locations



PDS Heaters Schematics



PDS Heaters Location with Thermostats

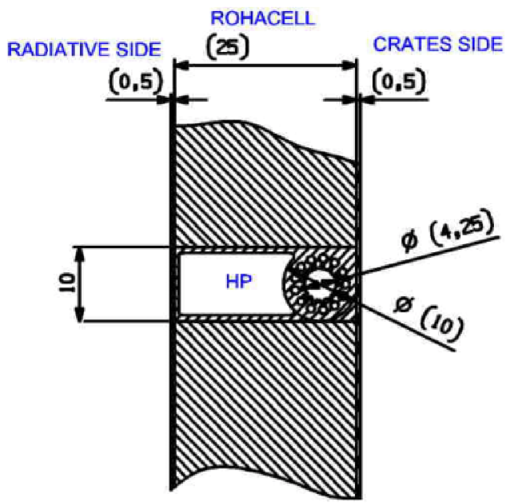
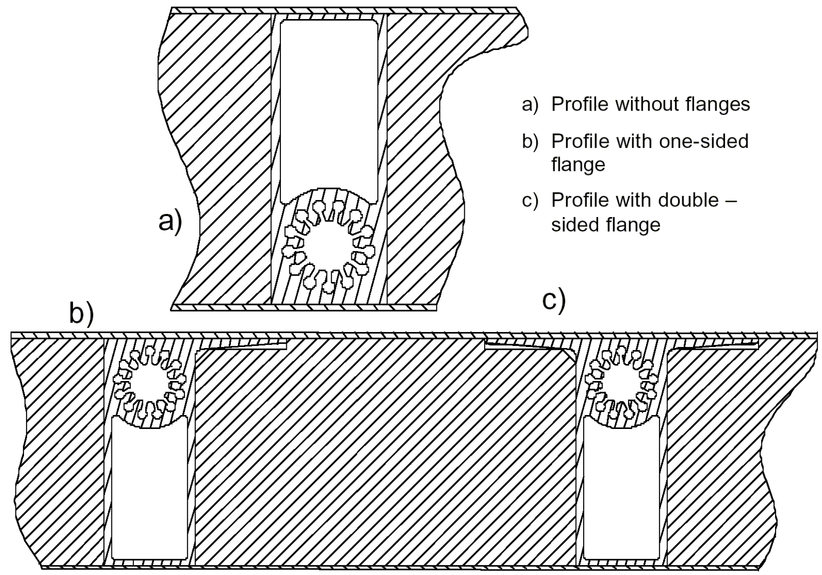


Figure 4-1: Main Dimensions Heat Pipe and Panel Layout



TCS Main Radiator Heat Pipe Cross Section with Mounting Profiles

E. Cryocoolers

Cryocoolers

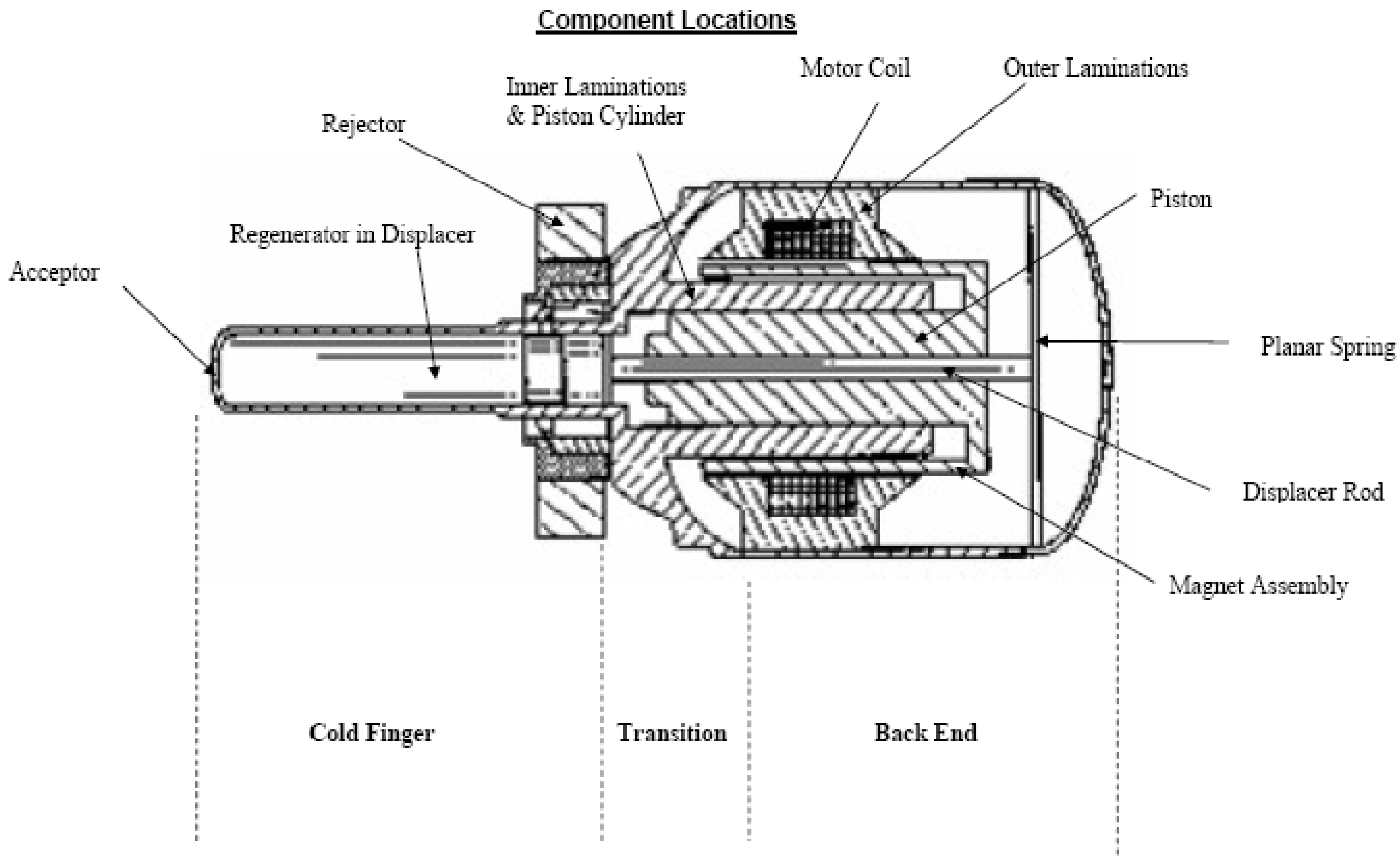
Description	Material Of Construction	Mass Of fluid		Operating Pressure		MDP		Burst Pressure		Burst SF		Proof Pressure		Proof SF	Analysis Test or Similarity	Reference Document
		kg	lbm	bar	psid	bar	psid	bar	psid	Req	Actual	bar	psid			
Sunpower Stirling cycle mechanical cryocoolers	Stainless Steel	7.20E-04	1.60E-03	Note 1	Note 1	20.3	294	124	1800	Note 2	6.1	Note 2	Note 2	Note 2	Leak Test	Note 3

Notes:

Note 1: The cryocoolers are filled with 275 cm^3 of helium gas at a pressure of 16 bar (232 psid) and ambient temperature. When operating, the helium in the compression space can reach a pressure as high as 20 bar (290 psid) at the maximum operating temperature of the cooler. This is very nearly the same as the MDP, which occurs with a non-operating cryocooler exposed to an 80°C environment. The MDP is derived from the increased pressure when raising 16 bar of helium at ambient temperature to a temperature of 80°C at constant volume.

Note 2: The measured burst pressure is 124 bar (1800 psid) in the compressor body and 152 bar (2200 psid) in the cold finger so the minimum Burst SF is 6.1. The cryocooler has been classified as a pressurized device by personnel on the ~~Fracutre~~Fracture Control Panel at JSC (see e-mail from N. Martinez to C. Balas, Subject: AMS Cryocoolers - Fracture Control), and we were not given a required Burst Safety Factor. Also, no proof pressure test is required, only a leak test to verify workmanship.

Note 3: We consulted NSTS 1700.7B, MIL STD 1522A, ANSI/AIAA S-080, and NPD 8710.5A (Draft) and did not find Pressurized Device listed.



CRYOCOOLER Functional Cross Section of Sunpower M87N cryocoolers