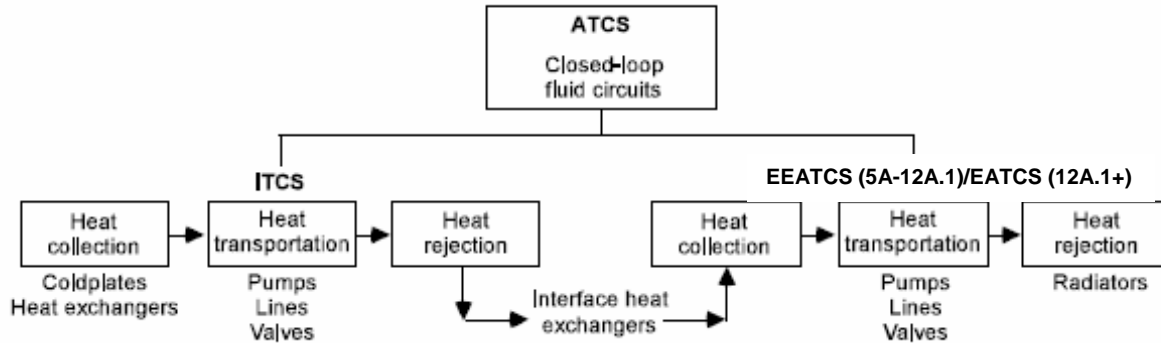




IDS Business Support,  
Communications and  
Community Affairs  
P.O. Box 516  
St. Louis, MO 63166

## Active Thermal Control System (ATCS) Overview



*Active Thermal Control System Architecture*

Most of the Station's many systems produce waste heat, which needs to be transferred from the ISS to space to achieve thermal control and maintain components at acceptable temperatures. An Active Thermal Control System (ATCS) is required to achieve this heat rejection function when the combination of the ISS external environment and the generated heat loads exceeds the capabilities of the Passive Thermal Control System to maintain temperatures. An ATCS uses a mechanically pumped fluid in closed-loop circuits to perform three functions: heat collection, heat transportation, and heat rejection. Waste heat is removed in two ways, through cold plates and heat exchangers, both of which are cooled by a circulating ammonia loops on the outside of the station. The heated ammonia circulates through large radiators located on the exterior of the Space Station, releasing the heat by radiation to space that cools the ammonia as it flows through the radiators.

The ATCS consists of the Internal Active Thermal Control System (IATCS), External Active Thermal Control System (EATCS), the Photovoltaic Thermal Control System (PVTCS) and the Early External Active Thermal Control System (EEATCS). The IATCS consists of loops that circulate water through the interior of the U.S. Destiny Laboratory module to collect the excess heat from electronic and experiment equipment and distributes this heat to the Interface Heat Exchangers for transfer to the EATCS. At assembly complete, there will be nine separate ITCS water loops in the U.S. and International Partner pressurized modules.

The Photovoltaic Thermal Control System (PVTCS) consists of ammonia loops that collect excess heat from the Electrical Power System (EPS) components in the Integrated Equipment Assembly (IEA) on P4 and eventually S4 and transport this heat to the PV radiators (located on P4, P6, S4 and S6) where it is rejected to space. The PVTCS consist of ammonia coolant, eleven coldplates, two Pump Flow Control Subassemblies (PFCS) and one Photovoltaic Radiator (PVR).

The External Active Thermal Control System (EATCS), activated for the first time on this mission, consists of ammonia loops to collect heat from the Interface Heat Exchangers and external electronic equipment mounted on coldplates and transports it to the S1 and P1 radiators where it is rejected to space. In lieu of using the EATCS initially, the station hardware has been cooled by the Early External Active Thermal Control System (EEATCS). The EEATCS has provided heat rejection capability for the U.S. Laboratory Interface Heat Exchangers (IFHX) since assembly flight 5A through 12a.1.

The EEATCS is the temporary system used to collect, transport, and reject waste heat from habitable volumes on the International Space Station (ISS). The EEATCS collects heat from the Interface Heat Exchangers (IFHX) located on the U.S. Laboratory module, circulates the working fluid, anhydrous ammonia, via the Pump and Flow Control Subassembly (PFCS), and rejects heat to space via two orthogonally oriented stationary radiators.

### **Internal Active Thermal Control System (IATCS)**

The purpose of the U.S. Destiny Laboratory ITCS is to maintain equipment within an allowable temperature range by collecting, transporting, and rejecting waste heat. The ITCS uses water because it is an efficient thermal transport fluid and is safe inside a habitable module. The IATCS is a closed loop system that provides a constant coolant supply to equipment, payloads and avionics to maintain proper temperature.

The U.S. Laboratory contains two independent loops, a Low Temperature Loop (LTL) and a Moderate Temperature Loop (MTL). This approach allows for segregation of the heat loads, simplifies heat load management, and provides redundancy in case of equipment failure. The LTL is designed to operate at 40° F (4° C) and service systems equipment requiring low temperatures, such as the Environmental Control and Life Support System (ECLSS) Common Cabin Air Assembly (CCAA) and some payload experiments. The LTL contains approximately 16.64 gallons (63 liters) of fluid. The MTL nominally operates at 63° F (17° C) and provides most of the cooling for systems equipment (i.e. avionics) and payload experiments. The MTL contains approximately 52.83 gallons (200 liters) of fluid. The IATCS loops can be configured and operated as a single loop. This capability is used for a variety of purposes, including the reduction of wear on the pumps, reduction of pump power usage, or to compensate for a pump failure.

### **Photovoltaic Thermal Control System (PVTCS)**

The PVTCS consist of ammonia coolant, eleven coldplates, two Pump Flow Control Subassemblies (PFCS) and one Photovoltaic Radiator (PVR). The coldplate subassemblies are an integral part of IEA structural framework. Heat is transferred from the IEA orbital replacement unit (ORU) electronic boxes to the coldplates via fine interweaving fins located on both the coldplate and the electronic boxes. The fins add lateral structural stiffness to the coldplates in addition to increasing the available heat transfer area. The PFCS is the heart of the thermal system. It consists of all the pumping capacity, valves and controls required to pump the heat transfer fluid to the heat exchanges and radiator, and regulate the temperature of the thermal control system ammonia coolant. The PVTCS can dissipate 6,000 Watts of heat per orbit on average and is commanded by the IEA computer. Each PFCS consumes 275 Watts during

normal operations and measures approximately 40 inches (101.6 cm) by 29 inches (73.7 cm) by 19 inches (48.3 cm), weighing 235 pounds (106.7 kilograms).

The PVR – the radiator – is deployable on orbit and comprised of two separate flow paths through seven panels. Each flow path is independent and is connected to one of the two PFCSs on the IEA. In total, the PVR can reject up to 14 kW of heat into deep space. The PVR weighs 1,633 pounds (740.7 kilograms) and when deployed measures 10.24 feet (3.12 meters) by 44.62 feet (13.6 meters). When the ISS assembly is complete, there will be a total of four PVRs, one for each PV module (S4, P4, P6, S6).

## **Early External Active Thermal Control System (EEATCS)**

### **Function**

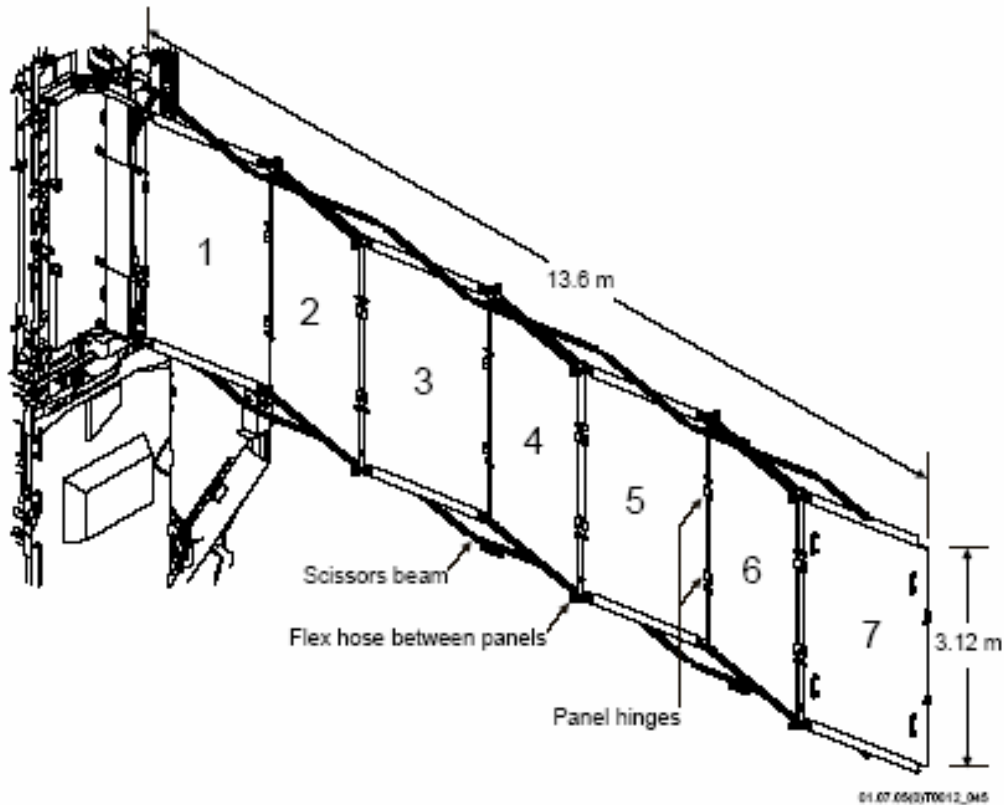
Since the U.S. Laboratory became operational before the permanent External Active Thermal Control System (EATCS) was assembled, a temporary external cooling system was needed. External cooling from the Russian segment is not possible because there are no operational interfaces between the U.S. On-orbit Segment (USOS) and the Russian On-orbit Segment (ROS) thermal systems. Instead, a modified version of the Photovoltaic Thermal Control System (PVTCS) called the Early External Active Thermal Control System (EEATCS) acts as a temporary thermal system. The EEATCS consists of two independent, simultaneously operating ammonia cooling loops (ACL). These loops transport heat loads from the Interface Heat Exchanger (IFHX) located on the Laboratory module's aft endcone to the radiators located on truss segment P6. The EEATCS is needed until the permanent EATCS is activated. Once the permanent EATCS becomes operational on mission, the EEATCS will be deactivated. After deactivation, portions of the EEATCS will be used as spare components for the PVTCS loops.

### **Hardware**

#### **Pump & Flow Control System (PFCS)**

Each external loop contains a Pump & Flow Control System (PFCS) which contains most of the controls and mechanical systems that drive the EEATCS. There are 2 pumps per PFCS which circulate ammonia throughout the external coolant loops and a Flow Control Valve (FCV) which mixes cold radiator flow and warm IFHX return flow to regulate the temperature of the ammonia in the loop. The PFCS also contains the primary ammonia accumulator, which provides limited ammonia leakage makeup, protection against thermal expansion of the ammonia, and a net positive suction head greater than the minimum required to prevent pump cavitations. Additionally, all manner of pressure, temperature, flow, and quantity sensors used by the EEATCS are part of the PFCS.

#### **Radiators**

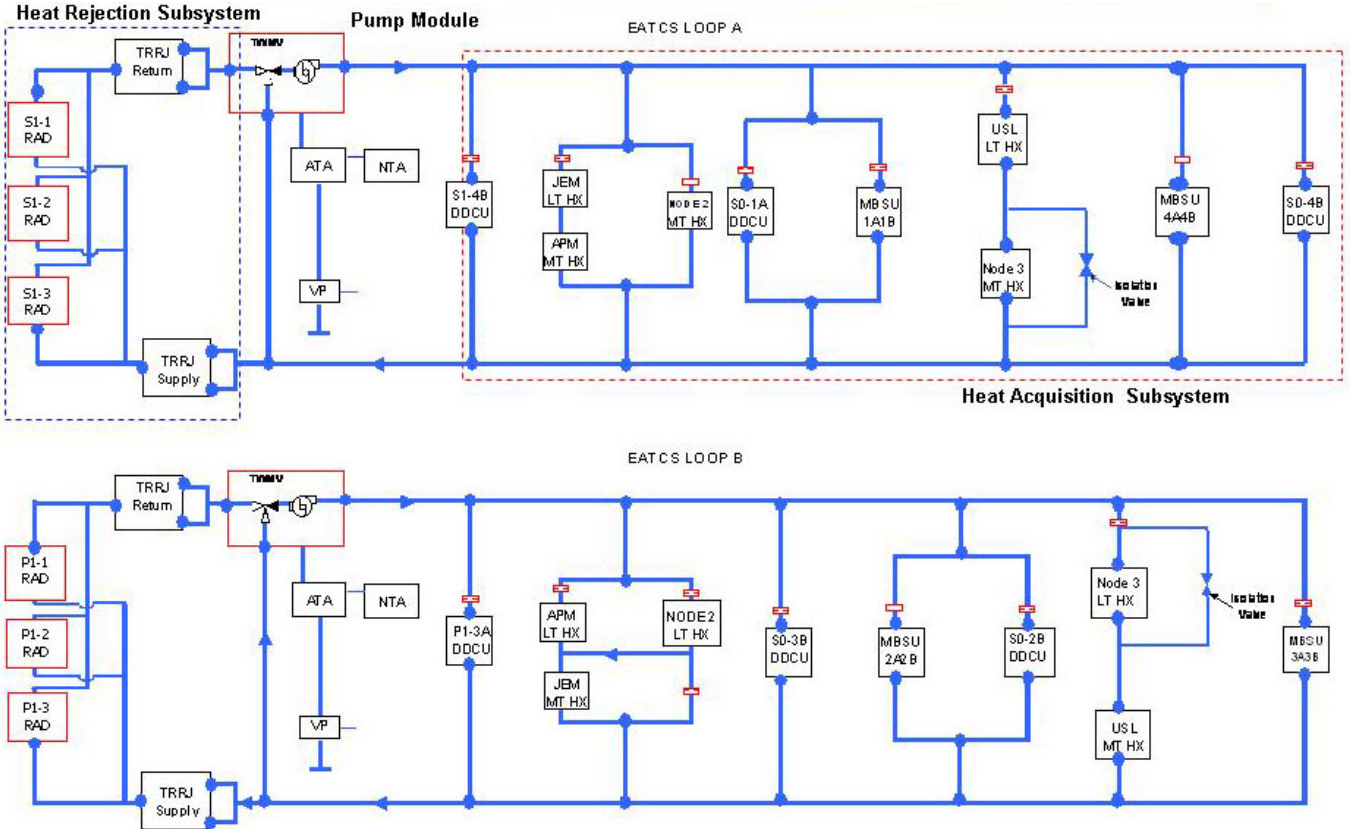


The EEATCS radiator ORU is a direct flow, deployable and retractable radiator system with two independent cooling loops. The EEATCS radiator consists of seven radiator panels, the deploy/retract mechanism, support structure, and the necessary plumbing. The EEATCS radiator has two channels (A & B) that acquire heat from the Lab Low Temperature (LT) and Moderate Temperature (MT) Loop Interface Heat Exchanger (IFHX) via liquid anhydrous ammonia. The ammonia flows from the PFCS to the associated IFHX, to the EEATCS radiator manifold tubes, across the radiator panels and back to the PFCS. The radiator panels reject the excess heat to space via two non-articulating EEATCS radiator ORUs: one AFT (Trailing) and one Starboard (Normal). The two radiator ORUs are located on the P6 Long Spacer Truss Segment. The radiator measures 10.24 feet (3.12 meters) by 44.62 feet (13.6 meters).

### **Interface Heat Exchanger (IFHX)**

The Interface Heat Exchanger (IFHX) units accomplish heat transfer from the IATCS water coolant loops to the external ammonia coolant loops. At assembly complete configuration of the ISS, 10 interface heat exchangers will be in operation to provide heat transfer from the IATCS loops of the various habitable modules to the two external ammonia coolant loops. The IFHX units are located on the U.S. Laboratory, Node 2, and Node 3.

## External Active Thermal Control System (EATCS) Overview



The EATCS provides heat rejection capabilities for all U.S. pressurized modules and the main power distribution electronics on S0, S1 and P1. The system uses a single-phase anhydrous ammonia as its working fluid for its high thermal capacity and wide range of operating temperatures. Ammonia has an extremely low freezing point of -107 degrees ° F (-77 °C) at standard atmospheric pressure. The EATCS is comprised of two independent loops labeled loop A on S1 (Starboard) and Loop B on P1 (Port). The independent loops were designed so that a failure in one would not take down the entire EATCS system. Both loops are physically separated to prevent orbital debris from taking out the lines and the fluid transport lines are buried within the truss structure. If a loop does go down, the EATCS operates at a reduced capacity. Each loop collects heat from up to five Interface Heat Exchangers (IFHXs) mounted on the Node 2, U.S. Destiny Laboratory, and Node 3 as well as externally mounted coldplates. Most of the cold plates and plumbing to the pressurized modules are located on the S0 center truss. The EATCS is designed to provide 35 kW of heat rejection per loop for a total capability of 70 kW. The EATCS also provides ammonia re-supply capability to the Photovoltaic Thermal Control Systems (PVTCS) located on P4, P6, S4 and S6. All EATCS components are located outside the pressurized volumes to prevent crew contact with ammonia.

At assembly complete, each ammonia loop will supply coolant to five Interface Heat Exchangers (IFHX) and five cold plates (three Direct Current-to-Direct Current Units (DDCUs) and two Main Bus Switch Units (MBSUs)). Two MBSU cold plates, each designed to remove 495 watts at 80 lbs/hr. Three DDCU cold plates are each designed to remove 694 watts at 125 lbs/hr. The cold plate interfaces with the component base-plate via radiant fins. IFHXs transfer thermal

energy from the Internal Thermal Control System's (ITCS) water based coolant to the ETCS anhydrous ammonia coolant. Ammonia supply temperature is currently set at 37 °F (2.8 °C)

The ITCS supply temperature varies as a function of the modules' thermal load. IFHX can isolate and bypass the IFHX core on the ammonia side in the event a cold slug is detected at the pump outlet to prevent ITCS coolant from freezing.

### **Key Components:**

The External Active Thermal Control System (EATCS) is the primary permanent active heat rejection system on ISS. It acquires, transports, and rejects excess heat from all U.S. and International Partner modules except the Russian modules. The EATCS contains two ammonia coolant loops, which cool equipment on the S0, S1, and P1 truss segments. Capable of rejecting up to 70kW, the EATCS provides a substantial upgrade in heat rejection capacity from the 14kW capability of the Early External Active Thermal Control System (EEATCS).

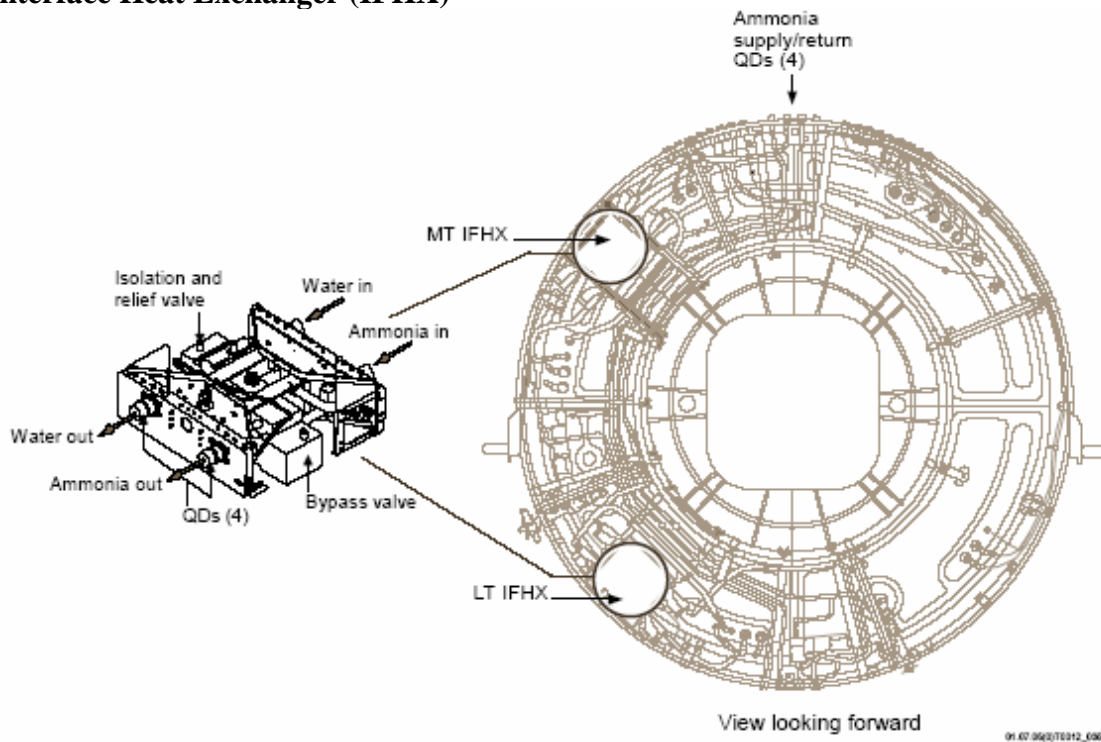
### **Heat Acquisition Subsystem (HAS)**

The HAS consists of the Interface Heat Exchanger (IFHX) Orbital Replacement Units (ORU), Main Bus Switch Unit (MBSU) and DC-to-DC Converter Unit (DDCU) cold plates ORU.

### **Heat Rejection Subsystem (HRS)**

The HRS consists of the radiator ORU, which is a deployable, eight-panel system that rejects thermal energy via radiation. The HRS also consists of the Radiator Beam Valve Module (RBVM) that provides radiator isolating or venting, radiator beam which carries three radiators and connects to the Thermal Radiator Rotary Joint (TRRJ), which rotates to the radiator beam to provide radiator articulation. The EATCS allows the flow of ammonia through heat rejection radiators that constantly rotate to optimize cooling for the station.

## Interface Heat Exchanger (IFHX)



*Interface Heat Exchanger (IFHX) provide the interface between the ITCS and the EATCS*

The Interface Heat Exchanger (IFHXs) provide the interface between a module's internal TCS and the EATCS. The IFHXs transfer heat from the internal loops of the USOS modules to the EATCS ammonia loops. IFHXs are used to collect heat from USOS modules. There are five IFHXs for each EATCS loop. Some IFHXs are plumbed in series such that the cool ammonia flows through a module's Low Temperature Loop (LTL) IFHX prior to flowing through another module's Moderate Temperature Loop (MTL) IFHX.

The IFHX units accomplish heat transfer from the IATCS water coolant loops to the external ammonia coolant loops. Each IFHX core utilizes a counterflow design with 45 alternating layers. IATCS water flows through 23 of the layers, while EATCS ammonia flows through the 22 alternate layers in the opposite direction. These alternating layers of relatively warm water and relatively cold ammonia help to maximize the heat transfer between the two fluids via conduction and convection. The heat exchanger core is a simple flow through device with no command or telemetry capability. IFHXs are mounted on the Node 2, U.S. Laboratory, and Node 3. The U.S. Laboratory IFHXs have been connected to the EEATCS, until this flight, when the EEATCS ammonia fluid line quick-disconnect will be disconnected and reconnected to the EATCS. When Node 2 arrives on Assembly Flight 10A, it is equipped with six IFHXs designed to provide cooling for itself, the Columbus and Japanese Experiment Module. Node 3 also contains a set of IFHXs, which are connected to the EATCS when it arrives on Assembly Flight 20A.

At the assembly complete configuration of the ISS, 10 interface heat exchangers will be in operation to provide heat transfer from the IATCS loops of the various habitable modules to the two external ammonia coolant loops. The IFHX units will be located on the U.S. Laboratory, Node 2, and Node 3. Because of the highly toxic nature of ammonia, IFHX ORUs are mounted



external to the pressurized modules as a safety precaution. Each IFHX measures 25 inches (63.50 cm) by 21 inches (53.34 cm) by 8 inches (20.32 cm) and weighs about 91 pounds (41.28 kilograms).

## Heaters

Each EATCS loop has electrically powered heaters wrapped around the supply and return fluid lines on the S0 Truss to maintain the minimum operating temperature. These heaters are used during low heat load conditions and are turned on and off by software in the Multiplexer/Demultiplexer (MDMs). These heaters can be operated in closed-loop mode (temperature based) or open-loop mode (time based). Numerous heaters are located on the EATCS plumbing on the S1 (Loop A) and P1 (Loop B) truss segments to prevent ammonia freezing and flexible hose damage during nonoperational periods. These heaters are thermostatically controlled and have no software interface.

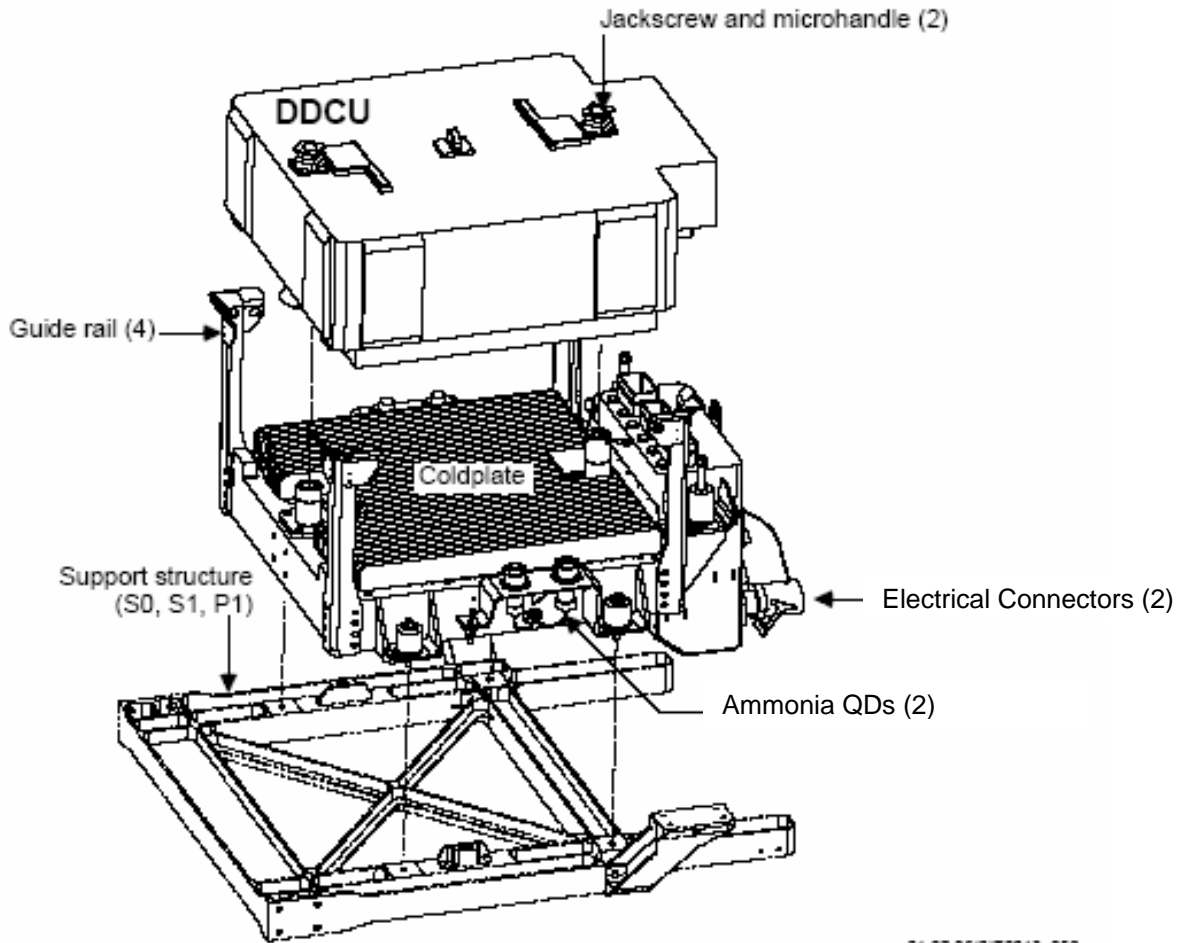
## Cold Plate

Each ETCS loop provides cooling to externally mounted coldplates located on the S0, S1 (Loop A), and P1 (Loop B) truss segment. These coldplates contain Electrical Power System (EPS) equipment used to convert and distribute power to downstream ISS loads. Each ammonia loop contains four coldplates, two attached to Direct Current-to-Direct Current Converter Units (DDCUs) and two attached to Main Bus Switching Units (MBSUs). Each MBSU coldplate measures 37 inches (93.98 cm) by 33 inches (83.8 cm) by 20 inches (50.8 cm) and weighs about 109 pounds (49.4 kilograms).



*Main Bus Switching Unit (MBSU) Coldplate*



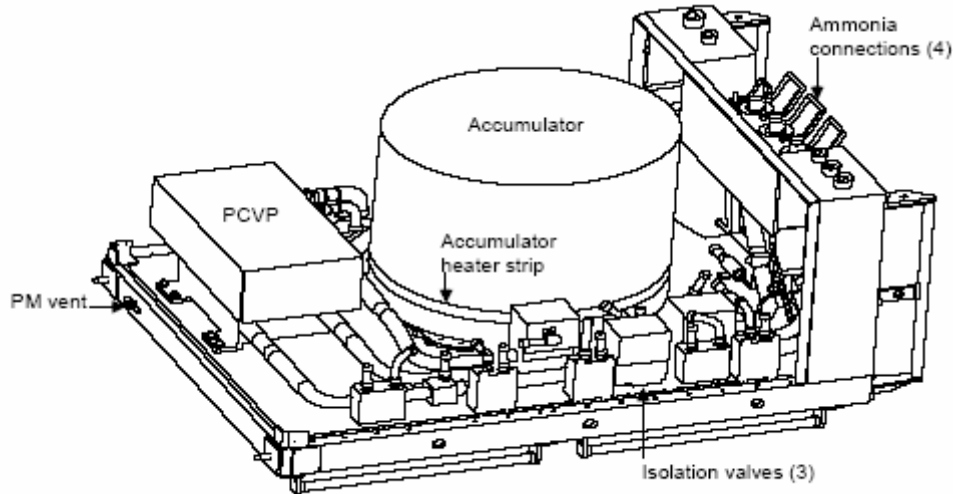


*Direct Current-to-Direct Current Converter Units (DDCU) Cold Plate*

Each coldplate ORU is connected to the EATCS ammonia loop by self-sealing quick disconnect (QD) couplings and contains a finned coldplate, two or three strip heaters and temperature sensor. The coldplates are installed such that the fins of the coldplate are positioned adjacent to corresponding fins on either the DCU or the MBSU to facilitate heat transfer by radiation between the cooled equipment and the coldplate. Each DCU coldplate measures 35 inches (88.9 cm) by 28 inches (71.12 cm) by 31 inches (78.74 cm) inches and weighs about 96 pounds (43.54 kilograms).

### **Pump Module (PM)**

Circulation, loop pressurization, and temperature control of the ammonia is provided by the Pump Module (PM). Each ammonia loop contains a Pump Module Assembly (PM) ORU to provide flow and accumulator functions and maintains proper temperature control at the pump outlet. Each PM consists of a single pump, a fixed charge accumulator, a Pump & Control Valve Package (PCVP) containing a firmware controller, startup heaters, isolation valves, and various sensors for monitoring performance. The accumulator within the PM works in concert with the Ammonia Tank Assembly (ATA) tanks to compensate for expansion and contraction of



Note: Enclosure removed for clarity.

*The Pump Module ORU circulates liquid ammonia at a constant flowrate to a network of coldplates and heat exchangers located on the external trusses and U.S. modules, respectively.*

ammonia caused by the temperature changes and keeps the ammonia in the liquid phase via a fixed charge of pressurized nitrogen gas on the backside of its bellows.

The Pump Module (PM) provides fluid pumping, fluid temperature control and system pressure control. The PCVP provides flow control. A single pump in the PCVP provides circulation of the ammonia. The Flow Control Valve (FCV) located within the PCVP regulates the temperature of the ammonia. The FCV mixes “cool” ammonia exiting the radiators with “warm” ammonia that has bypassed the radiators.

Nominally, loop A will operate at 8,200 lb/hr and loop B at 8,900 lb/hr at 14,000 and 14,700 revolutions per minute, respectively. For STS-116, initial activation with U.S. Laboratory IFHX where Loop A pump will run at 11,500 rpm, equivalent to 5,000 lb/hr while Loop B pump will run at 11,500 rpm which is equivalent to 5,200 lb/hr.

The accumulator located in the PM provides auxiliary pressure control. The accumulator resides upstream of the PCVP in each PM ORU. The accumulator keeps the ammonia in the liquid phase by maintaining the pressure above the vapor pressure of ammonia and provides makeup ammonia in case of a leak. The accumulator works in conjunction with the ATA to absorb fluctuations in the fluid volume due to varying heat loads through the expansion and contraction of its internal bellows.

Nominal operating pressure for the loops is 300 psia at the pump inlet; the pressure will be brought up to 390 psia for start up. The maximum system design pressure is 500 psia.

Each PM measures 69 inches (175.26 cm) by 50 inches (127 cm) by 36 inches (.91 cm) inches and weighs about 780 pounds (353.8 kilograms).

### **Low and High Pressure flow Control Monitoring**

Failure Detection, Isolation and Recovery (FDIR) for high and low pressure conditions are monitored and issued by the S1/P1 Multiplexer/Demultiplexers (MDMs). For an over pressure, gaseous nitrogen pressure is relieved down to 360 psia when pump inlet pressure reaches 415 psia (active control). The PVCP Inlet pressure, Radiator return pressure, and Bypass return pressure sensors are part of this system and two of three pressure readings are used to determine if an overpressure condition exists. The pump will shut down issued when the pump outlet pressure reaches 480 psia (active control). Various relief valves and burst disks at the IFHX, PM, and RBVM will relieve at approximately 70 psia (passive control)

Low pressure (current limit set at 170 psia) is monitored by two methods to determine a low pressure condition (chooses higher of the two values to determine the limit). Low pressure conditions are monitored using the PVCP inlet pressure, radiator return pressure, and bypass return pressure sensors.

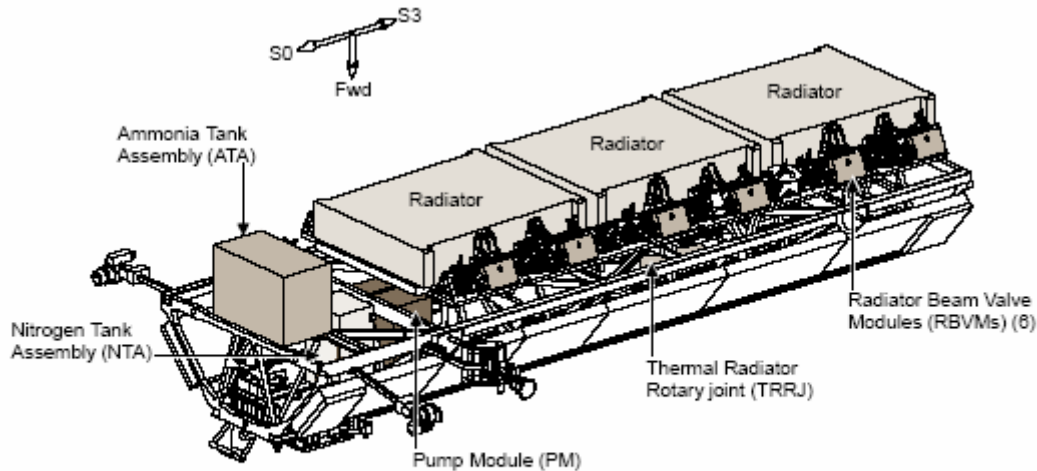
### **Temperature Control**

The PCVP also maintains temperature set point control of the ammonia supplied to the HAS. The PCVP has a temperature control capability of 36 °F (2.2 °C) to 43 °F (6.1 °C) and it will be set at 37 °F ± 2 °F (2.8 °C). The temperature control method is by three way mixing valve that mixes flow from the radiators and the HRS Bypass. Heaters on the HRS Bypass leg provide an additional level of control. Heaters are used to provide fluid conditioning in the event the thermal load on the loop is not sufficient to maintain set point control and to support temporary transient events. Total heater power of 1.8 kW is split across two heater strips mounted on the HRS bypass lines (900 watts each).

Pump outlet over temperature protection is provided by a Firmware Controller (FWC) in the PCVP that uses three PCVP outlet sensors to determine an over temp condition and issues zero pump speed. The S1/P1 MDMs use the PM outlet sensor to determine an over temp condition and pull power from the Solenoid Driver Output (SDO) card providing power to the PM.

Current limit is set at 65 °F (18.33 °C). Freeze Protection in the IFHX is detected by the PCVP firmware which shuts down the pump (first leg). When an under temperature condition is detected by the S1/P1 MDMs, it will pull power from the SDO card providing power to the PM (second leg). Under temperature detected by the S0 1,2 MDMs pulls power from the utility rail (third leg, leaves many things without power). The current limit is set at 35 °F (1.67 °C).

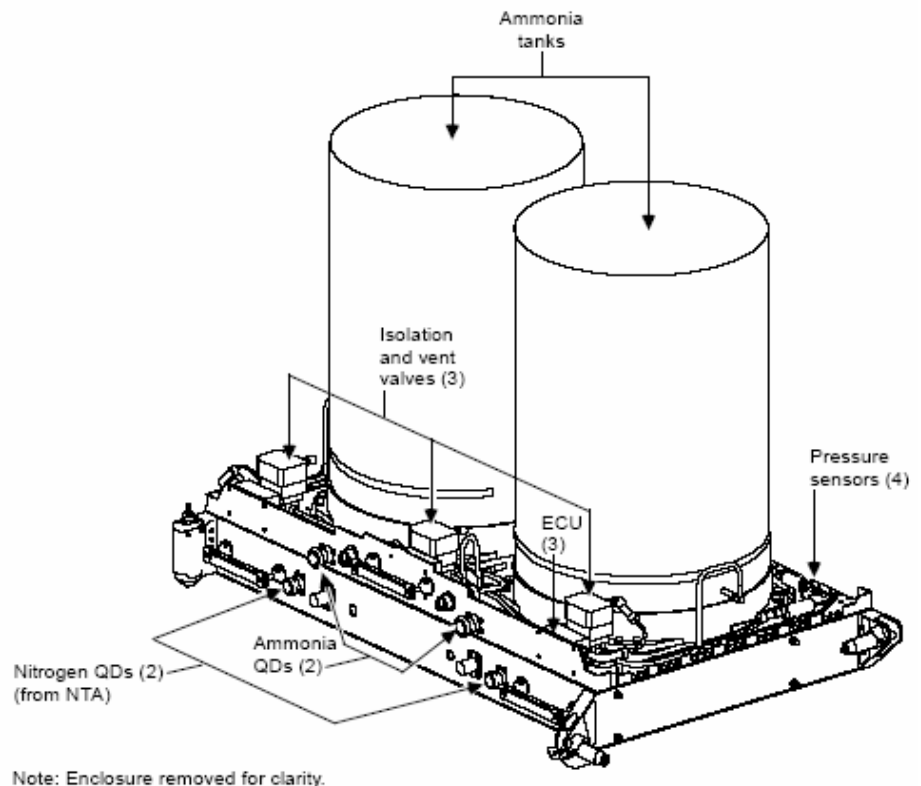
## Fluid Supply



Note: Loop A components on the S1 Truss segment shown. Loop B components on the P1 Truss segment are identical; however, the orientation is reversed. All three radiators are retracted.

Ammonia re-supply capability for the EATCS and the eight PVTCS located on P6, P4, S4 and S6 is provided by the **Ammonia Tank Assembly (ATA)**.

Each ammonia loop contains an ATA ORU to contain the heat transfer fluid (liquid ammonia) used by the EATCS loops. There is one ATA per loop located on the zenith side of the S1 (Loop A) and P1 (Loop B) truss segments. The ATA ORU will be used to fill the EATCS loop on startup, to supply makeup fluid to the system, to act as an accumulator in concert with the PM accumulator and provide the capability to vent the ammonia loops by way of a connection to an external non-propulsive vent. Each ATA primarily consists of two bellows ammonia tanks pressurized by an external nitrogen source, two internal survival heaters and two sets of quantity, differential pressure, absolute pressure and temperature sensors. The ATAs are isolatable and replaceable on orbit. Multilayer Insulation (MLI) applied to the exterior surfaces of the ORU is provided to guard against excessive heat loss. The ATA ORU is protected against Micro-Meteoroid/Orbital Debris (MM/OD) by shielding on the exterior of each tank and the ORU itself. Each ATA measures 79 inches

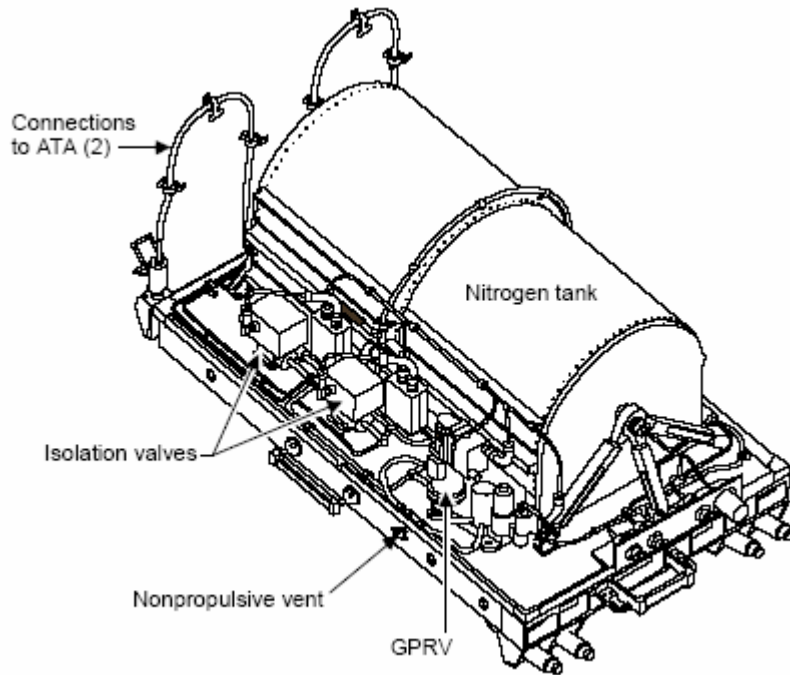


Note: Enclosure removed for clarity.

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(200.66 cm) by 46 inches(116.84 cm) by 55 inches (139.7 cm) inches and weighs about 1,120 pounds (508.02 kilograms).

The ATA in combination with the **Nitrogen Tank Assembly (NTA)** provide fluid supply and primary system pressure control. A single ATA was launched on Flights 9A and 11A (ITS S1 and P1) with approximately 640 lbm ammonia in each ATA, 320 lbm per tank. ATA provides necessary plumbing connection to the ammonia vent system via the vent panel. Supply to outboard trusses is provided through the vent panel. The ATA acts as the primary accumulator for the EATCS in concert with the NTA. If required, it can also be used to replenish the PVTCS fluid lines.



Note: Enclosure removed for clarity.

Each ammonia loop contains a NTA ORU to provide storage for the high pressure nitrogen used for controlled pressurization of the ATA. The NTA mounts to the S1 (Loop A) and P1 (Loop B) truss segments and is connected to the ATA by self-sealing QDs. Each NTA ORU primarily consists of a nitrogen tank, a gas pressure regulating valve (GPRV), isolation valves and survival heaters. The nitrogen tank provides a storage volume for the

high-pressure gaseous nitrogen, while the GPRV provides a pressure control function as well as nitrogen isolation and over pressure protection of downstream components. The NTA provides the necessary pressure to move the ammonia out of the ATA. The single high-pressure tank containing nitrogen at 2,500 psia (@70 °F, ground fill) and uses the GPRV to supply continuous pressure up to 390 psia in one psia increments. A back-up mechanical valve limits the maximum nitrogen pressure to 416 psia. The GPRV provides pressure control as well as high-pressure nitrogen isolation and overpressure protection of downstream components. The NTA has venting capabilities and over pressure controls. Each NTA measures 64 inches (162.56 cm) by 36 inches (91.44) by 30 inches (76.2 cm) inches and weighs about 460 pounds (208.65 kilograms).

### **Fluid Lines and Quick Disconnects (QD):**

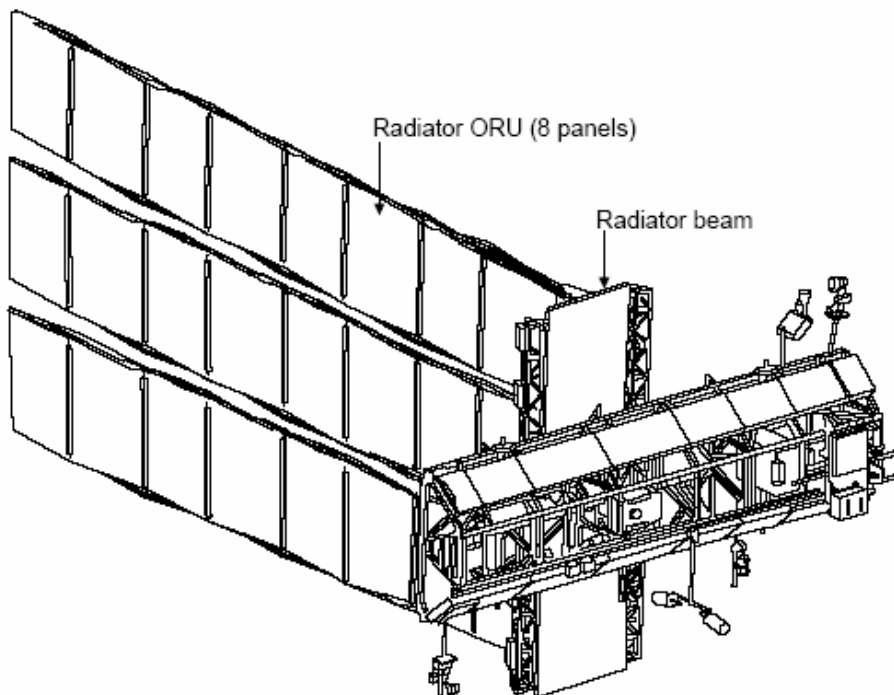
Fluid lines and external QDs provide the transportation path from the truss segments to the IFHXs. Connections between segments are made with flex hoses and QDs. There are flex hoses and QDs between each truss, and between the S0 truss and the various IFHXs.

## Heat Rejection System



*Heat Rejection System (HRS) Radiator during deployment testing at Lockheed Martin Missiles and Fire Control.*

Heat collected by the EATCS ammonia loops is radiated to space by two sets of rotating radiator wings—each composed of three separate radiator ORUs. Each radiator ORU is composed of eight panels, squib units, squib unit firmware controller, Integrated Motor Controller Assemblies (IMCAs), instrumentation, and QDs. Each Radiator ORU measures 76.4 feet (23.3 meters) by 11.2 feet (3.4 meters) and weighs 2,475 pounds (1,122.64 kilograms)



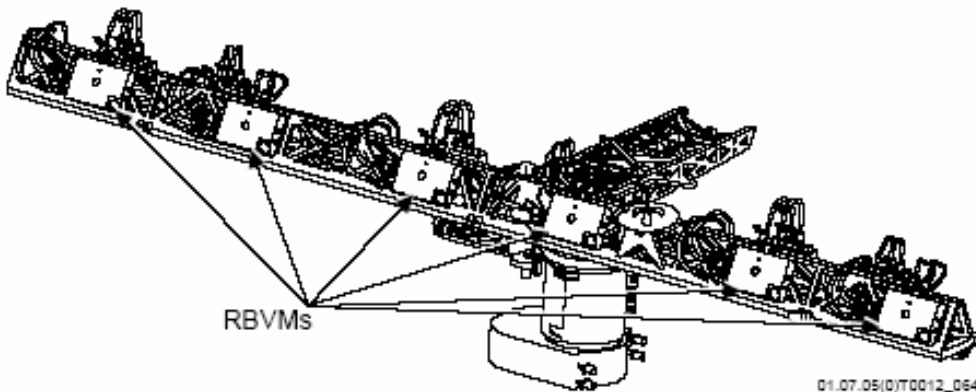
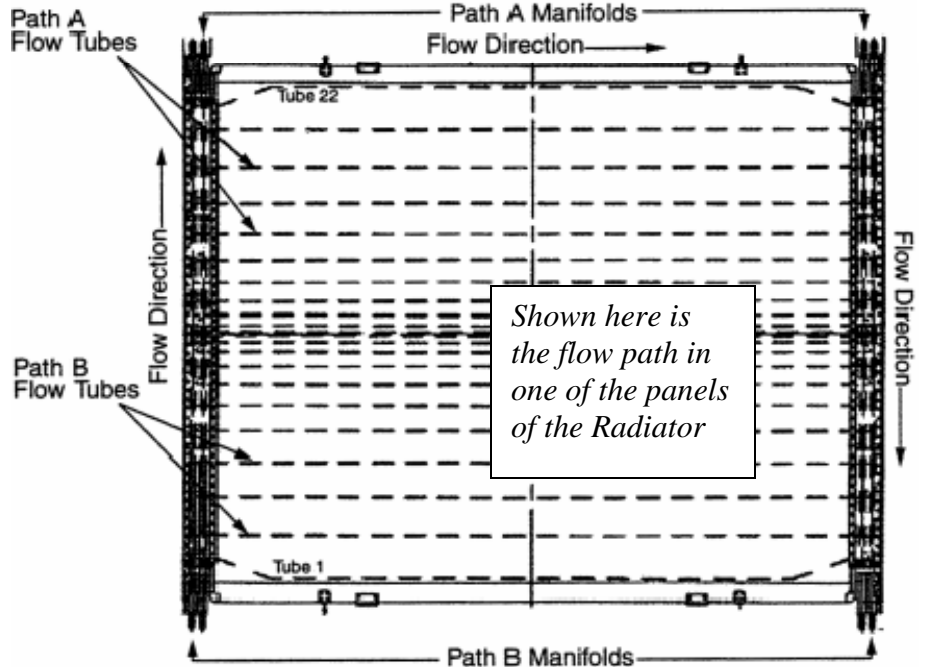
Note: All three radiators shown deployed.

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Each ammonia loop contains one radiator wing comprised of three Radiator ORUs mounted on the Radiator Beam and six Radiator Beam Valve Modules (RBVM) and one Thermal Radiator Rotary Joint (TRRJ). The Radiator ORUs utilize anhydrous ammonia to reject heat from the EATCS. Each Radiator ORU contains a deployment mechanism and eight radiator panels. The deployment

mechanism allows the Radiator ORU to be launched in a stowed configuration and deployed on orbit. Each radiator ORU can be remotely deployed and retracted.

Each individual radiator has two separate coolant flow paths. Each flow path flows through all eight radiator panels. Each panel's flow path has eleven flow tubes for a total of 22 Inconel flow tubes or passages (11 passages per flow path) per radiator panel; flow tubes are freeze tolerant. Flow tubes are connected along the edge of each panel by manifolds. Flex hoses connect the manifold tubes between panels. Each panel has a white (Z-93) coating which provides optimum thermo-optical properties to maximize heat rejection. Flow tube arrangement is designed to minimize ammonia freezing in the radiator.



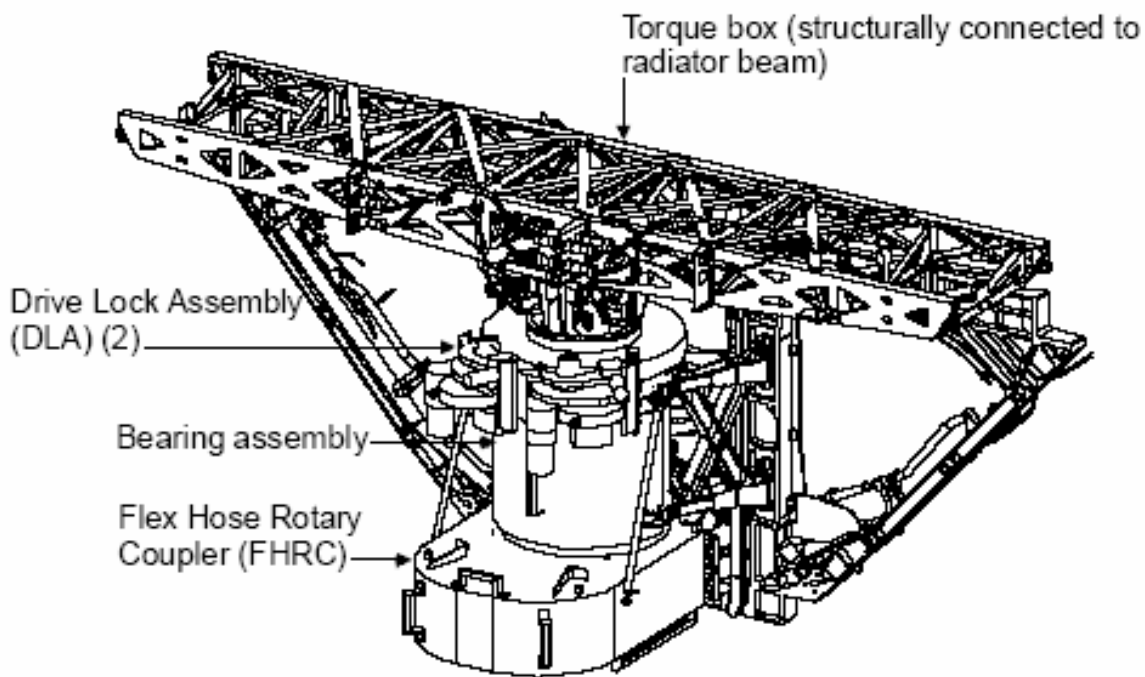
*There are two RBVMs (one per flow path) that allow or prevent the transfer of ammonia to and from the radiator panels.*

Each radiator path contains one **Radiator Beam Valve Module (RBVM)** as a part of the radiator wing. Six RBVMs are mounted on the radiator beams on the S1 and P1 truss segments. Two RBVMs service each radiator ORU. Each RBVM consists of an isolation relief valve, an isolation valve, an Integrated Motor Controller Assembly (IMCA), QDs, and pressure and temperature sensors. The RBVM controls the transfer of ammonia between the Radiator Assembly ORU and the rest of the EATCS loop. Each RBVM contains sensors to monitor absolute pressure, temperature and valve position within the ORU. Remote control venting of the radiator fluid loop is also available through the RBVM to facilitate radiator replacement and prevent freezing of the ATCS coolant during contingency operations. The RBVM provides flow path isolation in the event that a panel suffers micro-meteoroid damage. Leak isolation FDIR functions are controlled by the S1/P1 MDMs monitoring large leaks via the STR/PTR MDMs. Additionally, the RBVM provides automatic pressure relief when the EATCS is over



pressurized. Each RBVM weighs about 50 pounds (22.68 kilograms) and measures 24 inches (60.96 cm) by 20 inches (50.8 cm) x 5.4 inches (13.72 cm).

The rotation capability for each radiator assembly is provided through a **Thermal Radiator Rotary Joint (TRRJ)**. The TRRJ provides power, data, and liquid ammonia transfer to the rotating radiator beam while providing structural support for the radiator panels. Each TRRJ is composed of the following: a bearing assembly, two Rotary Joint Motor Controllers (RJMCs), two Drive Lock Assemblies (DLAs), a Flex Hose Rotary Coupler (FHRC), and a Power and Data Transfer Assembly (PDTA). The bearing assembly is the rotary interface and primary structural component of the TRRJ. The RJMCs provide control for the DLA system, which provides joint rotation and joint locking capability. The FHRC consists of four flex hoses, two supply and two return. The PDTA provides the data and power paths for transfer to and from the radiator beam.



Note: RJMC-1 and -2 not shown.

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*Thermal Radiator Rotary Joint (TRRJ) provides controlled rotation of the EATCS radiators, allows the transfer of power, data, and ammonia across the rotating interface, and provides the structural support between the SI/P1 truss segments and the associated radiator wing assembly.*

TRRJ ORU provides rotation capability to the Radiator Beam to optimize the thermal environment of the radiators and to maximize heat rejection capability and prevent freezing in the radiator manifolds. Rotation angles are determined via the Radiator Goal Angle Calculation (RGAC) algorithm which commands the Radiator Beam to put the radiators either “edge to the sun” during isolation phase of the orbit or “face to the Earth” during the eclipse phase. The RGAC ensures the radiators stay cold enough so the heat can be rejected but warm enough so that the ammonia does not freeze. There is a temperature goal of  $-40^{\circ}\text{F}$  at the radiator outlet. The FHRC provides the transfer of liquid ammonia across the rotary joint and is capable of rotating 230 degrees, at  $\pm 115$  degrees from its neutral position. (software command limit is  $\pm 105^{\circ}$ ); with a variable rotation speed of 0 to 45 degrees-per-minute. Each TRRJ measures

approximately 5.6 feet (1.7 meters) by 4.6 feet (1.4 meters) by 4.3 feet (1.3 meters) and weighs 927 pounds (420.5 kilograms),

## **System Performance Overview**

Loop A and B operate at slightly different flow rates mainly due to differing system hydraulic resistance layout. Actual heat rejection will need to be planned and coordinated between all modules so as not to exceed the EATCS total heat rejection capability of 70 kW (at assembly complete), including S1/P1/S0 mounted electrical equipment.

## **Software**

Thermal Control System (TCS) software is used to control and monitor the system. The TCS software executes actions such as system startup, loop reconfiguration, and valve positioning for flow and temperature control automatically or via commands from crew laptops or ground workstations. Telemetry from the various temperature, pressure, flow, and quantity sensors is monitored by TCS software and displayed on crew laptops or ground workstations. In addition, Fault Detection, Isolation, and Recovery (FDIR) software is used to monitor the performance of the TCS and, if there is a problem, alert the crew and flight controllers. In some cases, FDIR software initiates recovery actions.

## **EATCS Activation**

With the solar arrays attached by the shuttle Atlantis' crew in September, NASA is ready with STS-116 to start generating enough power so that the permanent cooling system can be brought on line. NASA will have to bring up the permanent electrical power distribution system on line first before activating EATCS. The goal is to power up the MBSUs, route power through them to the cooling system and gets that system activated before the MBSUs can overheat. The EATCS has never been tested as an entire integrated system in its on-orbit configuration. However, NASA and Boeing engineers did conduct an entire loop test, but it did not have a rotating Radiator.

During STS-116/Assembly flight 12A.1, during the second and third spacewalks, the EATCS is activated as part of the entire reconfiguration. There are two major power domains, 1/4 and 2/3. During EVA 2, the 2/3 power domain reconfiguration takes place and loop B is activated and then on EVA 3, the 1/4 power domain reconfiguration takes place and loop A is activated. Both power-on and power-off are major reconfigurations, when half the station power is turned off for periods of time. NASA has implemented a large number of procedures to account for the situation where they are zero-fault tolerate. The key to each EVA is activation of the pump modules and getting the system started for the first time. Assuming a nominal activation, there are approximately 24 procedure steps to activate the EATCS for the first time.

Preparations to activate the EATCS start when the ground filled nitrogen pad is vented from the center radiators and the rest of the system (to be vented after STS-116 reaches orbit). The system is presently pressured with about 80 psia of nitrogen. The next step will be to introduce ammonia into the system with only one radiator ORU per loop plumbed, which will take several hours. Filling and activating the system will be one of the major challenges that mission controllers and engineers will face. Activation will take about an hour for each loop. If there

were an anomaly during filling such as pressure begins to drop like a leak, then the entire reconfiguration would be interrupted. Mission controllers have thoroughly rehearsed their procedures to identify any potential leaks in the system. Some minor leaks are possible. Early activation will provide cooling to the MBSUs and DDCUs (their respective cold plates) on S1, S0 and P1. The activation sequence also allows for a through checkout of the EATCS loops prior to connecting the U.S. Destiny Laboratory IFHX to the EATCS. The US Laboratory IFHXs will continue to be cooled via the Early External Active Thermal Control System (EEATCS) located on P6 Long Spacer.

During the 12A.1 stage, EVAs will be conducted to connect the U.S. Laboratory IFHXs to the EATCS. After the IFHXs are connected to the EATCS, the EEATCS will enter a dormancy phase.

On Assembly Mission 10A/STS-120, the two remaining radiator ORUs per wing are deployed and filled. Node 2 end-cones are connected to the EATCS via the starboard and port, boom trays located on the forward end of S0. Pump shut down will be required. All six IFHXs on Node 2 receive cooling from the EATCS: two for Node 2, two for Attached Pressurized Module (APM-Columbus), and two for Japanese Experiment Module (JEM-Kibo). The APM and JEM IFHXs remain in a bypassed and isolated configuration to prevent accidental freezing of the water side core of the IFHXs.

On Assembly Flight 20A/STS-132, the Node 3 end-cone is connected to the EATCS via jumpers from the US Laboratory aft end-cone. A bypass line with an isolation valve on the US Laboratory Aft end-cone allows the fluid circuit to be completed prior to Node 3 arrival. Upon Node 3 arrival, the end-cone connection and activation the bypass-Isolation valves on US Lab end-cone are closed. This mission completes the EATCS loop architecture.

Boeing engineers in Huntington Beach, Calif. designed the EATCS as well as S0, S1 and P1 which contains most of the EATCS hardware. Major subcontractors to Boeing were Hamilton Sundstrand (PCVP, coldplates, core for heat exchanger), Honeywell (tanks, accumulator, RBVMs), Lockheed Martin (radiators) and Marotta (valves).

