Pumped Fluid Loop Heat Rejection & Recovery Systems For Thermal Control Of The Mars Science Laboratory

Pradeep Bhandari

Gajanana Birur, Mauro Prina, Brenda Ramirez, Anthony Paris, Keith Novak, and Michael Pauken

Jet Propulsion Laboratory
California Institute of Technology

March 16, 2006
17th Spacecraft Thermal Control Workshop
The Aerospace Corporation, El Segundo, CA, USA

Outline

- Mars Science Laboratory Mission Overview
- Overall Architecture for Thermal Control
- Operations on Surface of Mars
  - Mechanically Pumped Loops
  - Harvest Heat From MMRTG
  - Reject Heat From Rover
- Operations During Cruise and Entry Descent & Landing
- Performance of Thermal Systems During Various Phases
- Development Tests
- Conclusions

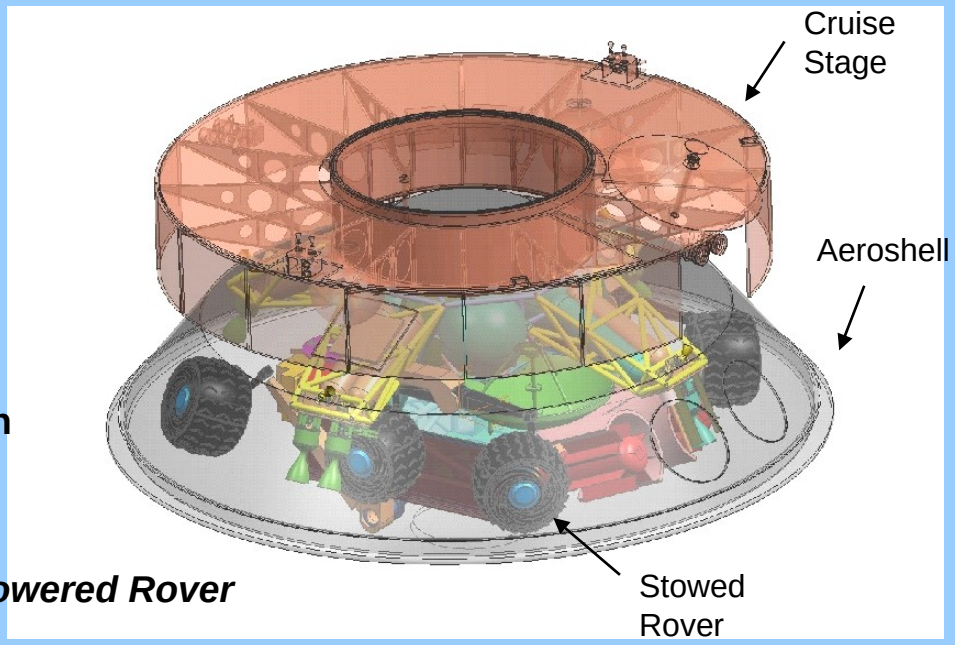
MSL Mission Overview

- 2009 Launch opportunity
- Sky Crane would land Rover on Martian Surface
  - Parachutes, Heat Shields and Retro-Rockets
- Rover capable of traversing large distances on Mars
- Rover has Onboard In Situ Laboratory would conduct extensive science
  - Soil sampling and processing
  - Atmospheric analysis
- *As currently conceived*, Rover Would Use A Radioisotope Power System
  - *Multi Mission* Radioisotope Thermo-electric Generator
- 110 W of Electric Power Output
  - Would allow operation without Solar Power
  - Extreme latitudes mission requirement
    - 60 S to 60 N
- 2000 W of Waste Heat Generation
  - Waste heat could be usefully harvested for rover thermal control

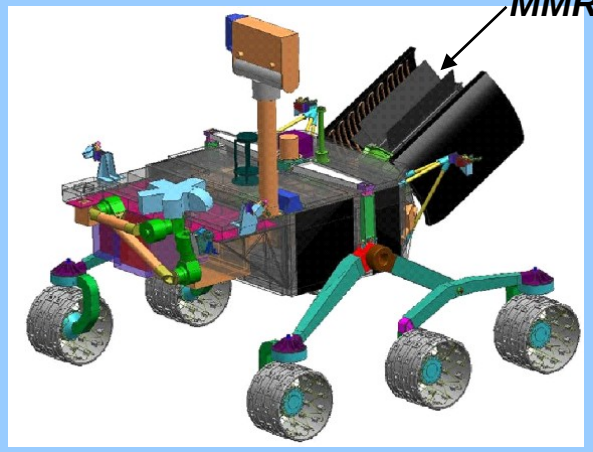
NASA Mars Science Laboratory (MSL) Mission (2009)

- **MSL is a landed rover mission**
- **Proposed Power source for the MSL Rover would be a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)**
- **Rover electronics and MMRTG would be stowed within an insulated aeroshell enclosure**
- **MSL duration would be much longer than that of MER**
  - **9-12 month cruise, 2 year surface operation**

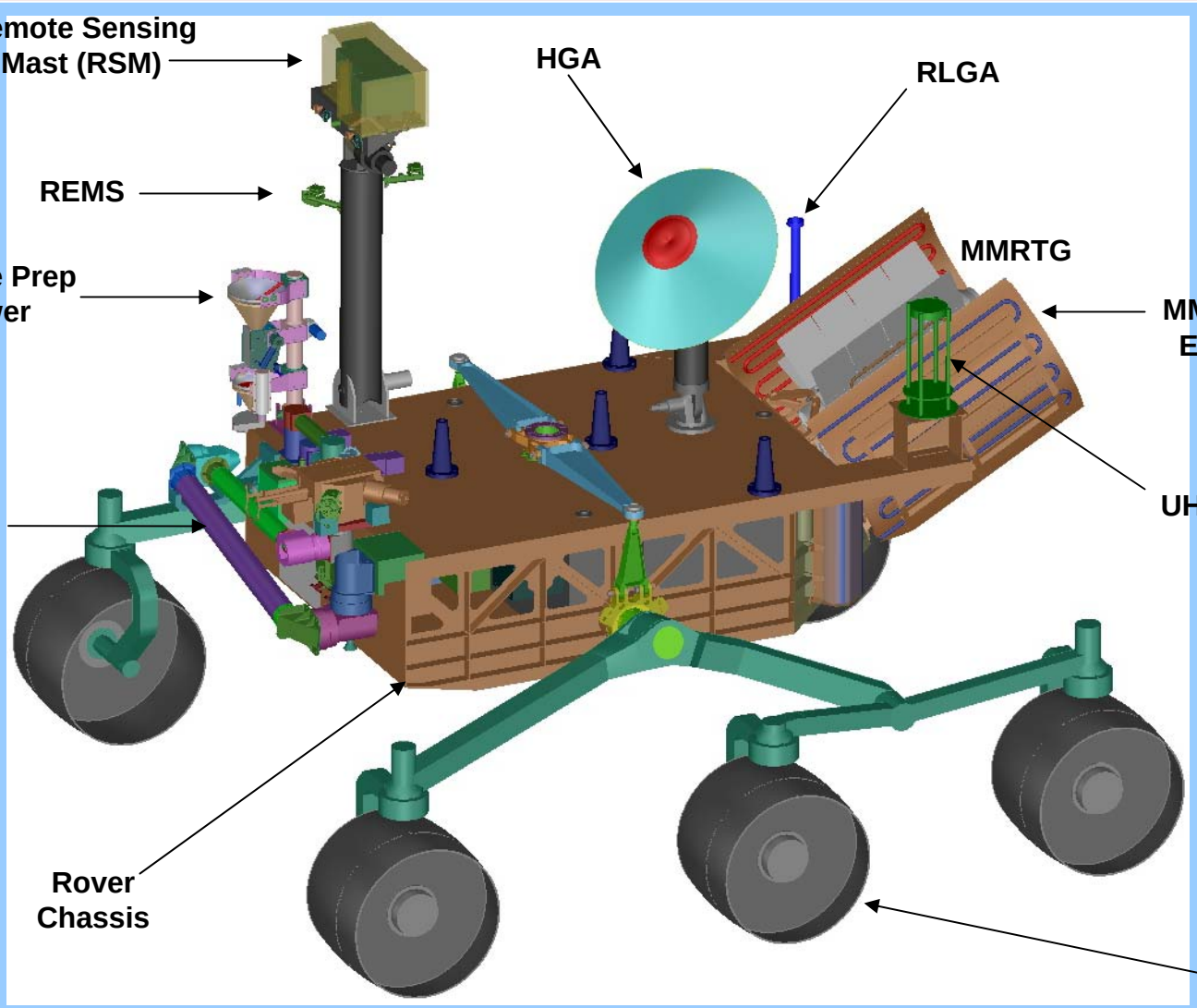
MSL Cruise Configuration Concept



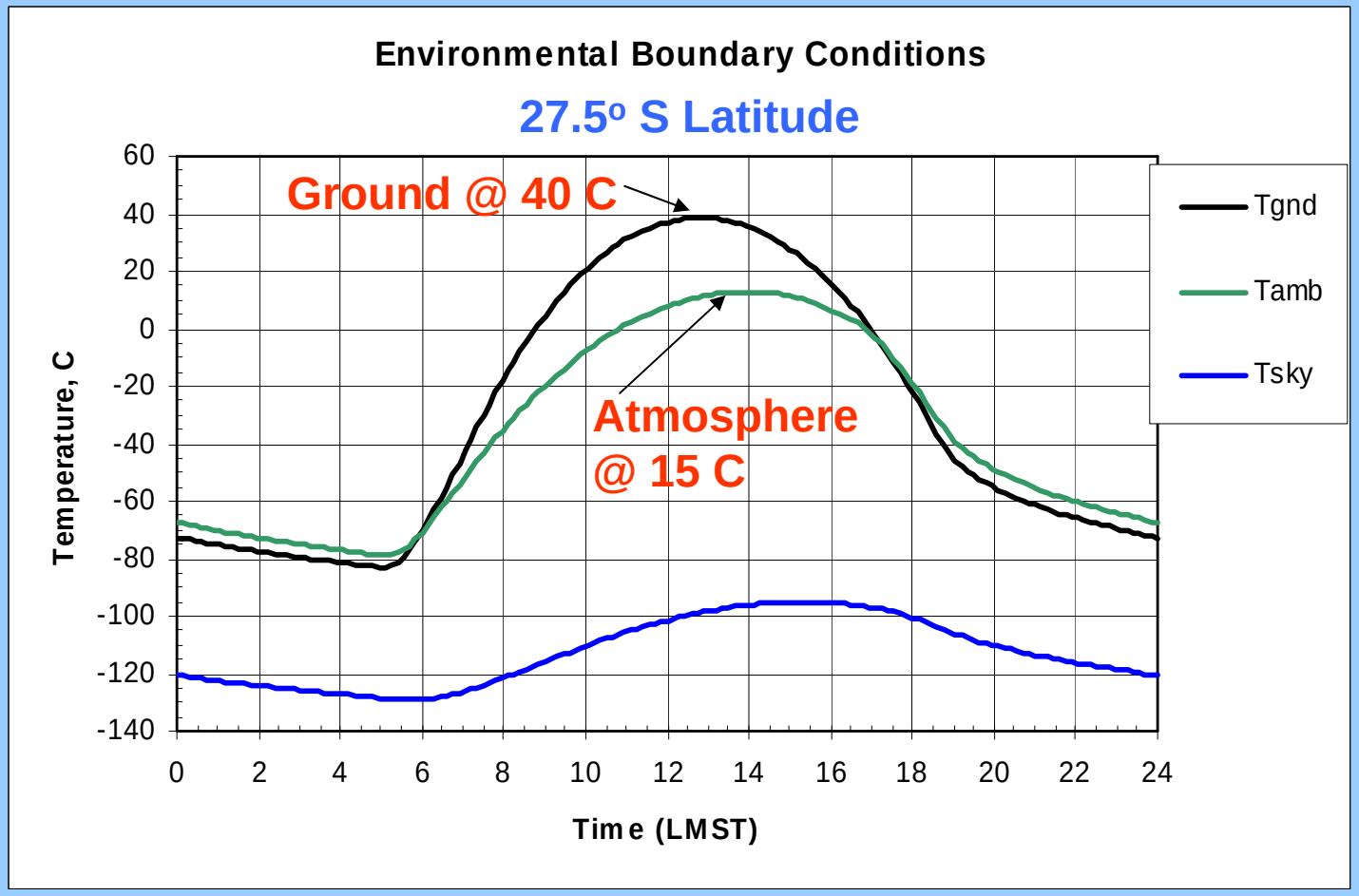
MMRTG Powered Rover



MSL Rover Design Concept



Worst Case Hot Martian Surface Environments



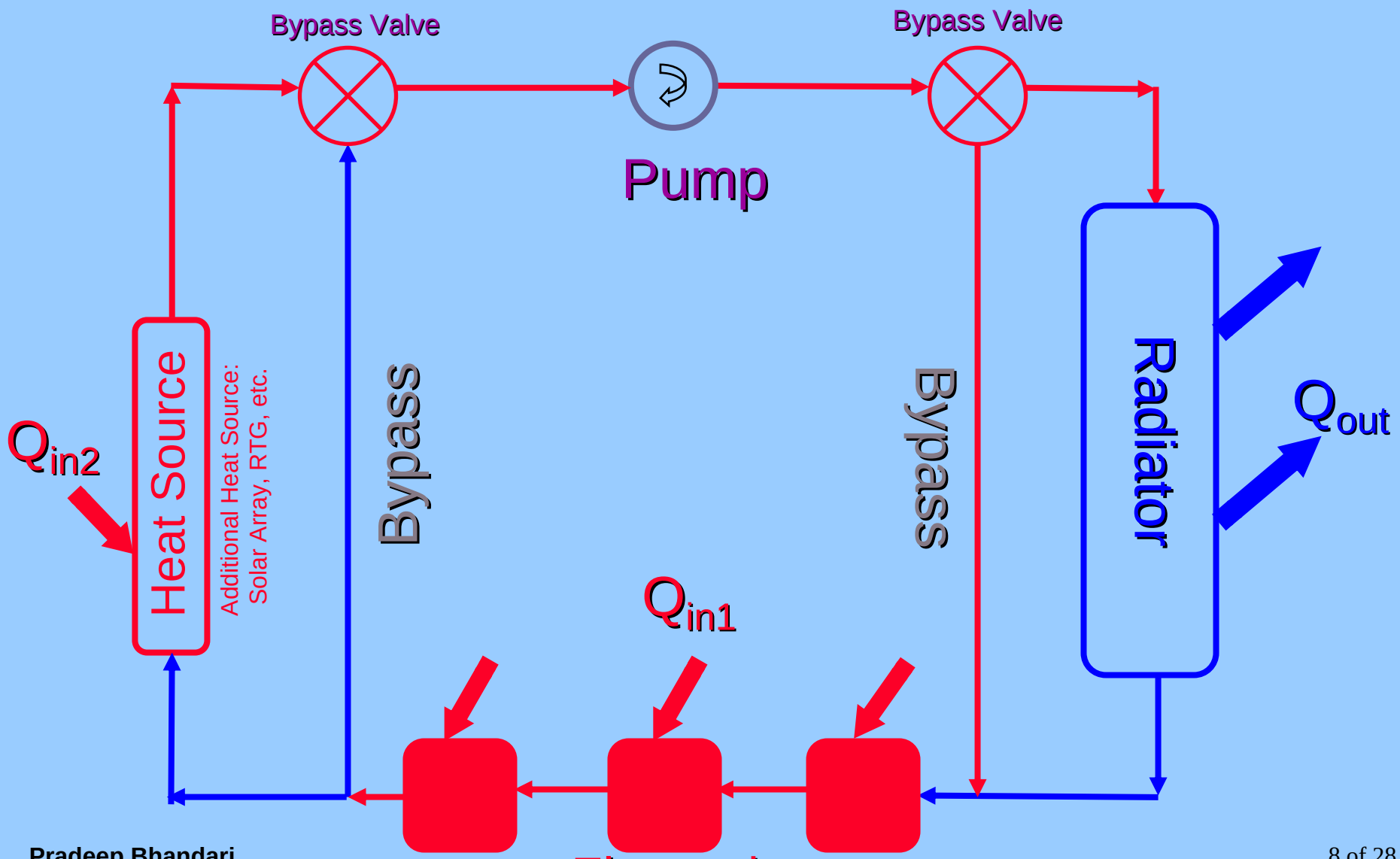
Peak Worst Case Hot Solar Insolation:

600 W/m2 (Direct); 100 W/m2 (Diffuse)

Worst Case Cold Martian Surface Environment

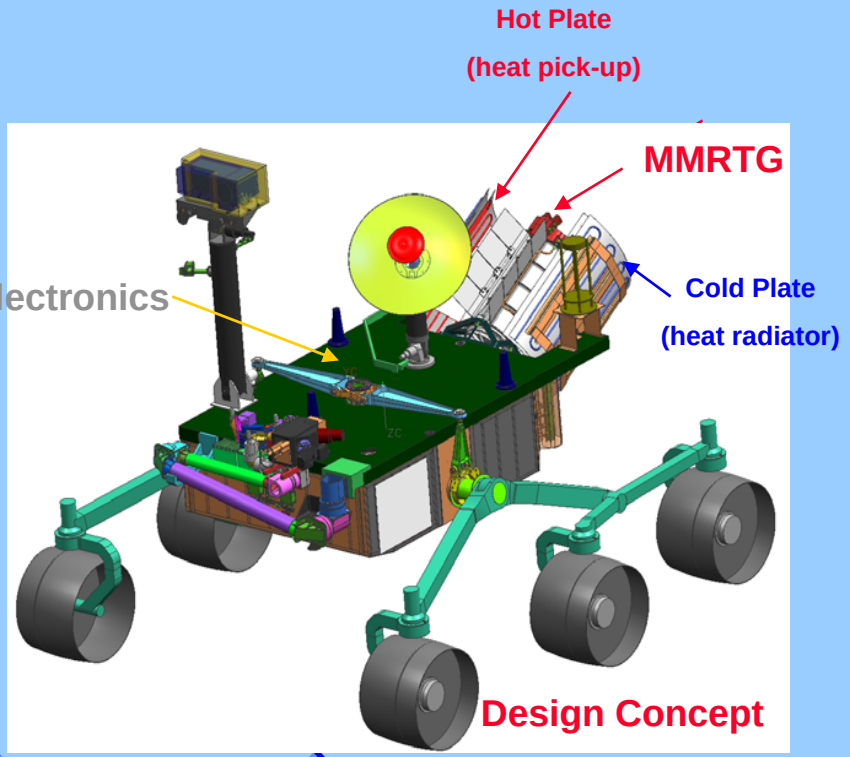
- **60º S Latitude**
- **Flat profile throughout day & night**
  - **No Sun**
  - **Ground/Air Temp: -127º C**
  - **Sky Temp: -192º C**
- **15 m/s wind speed**

Thermal *Bus* Architecture
(*Supply* *as well* as *Reject* Heat)

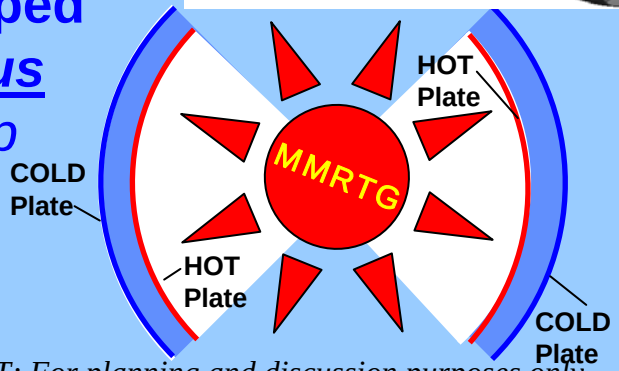


MPFL Rover *Thermal Bus* Concept for MSL *(Surface)*

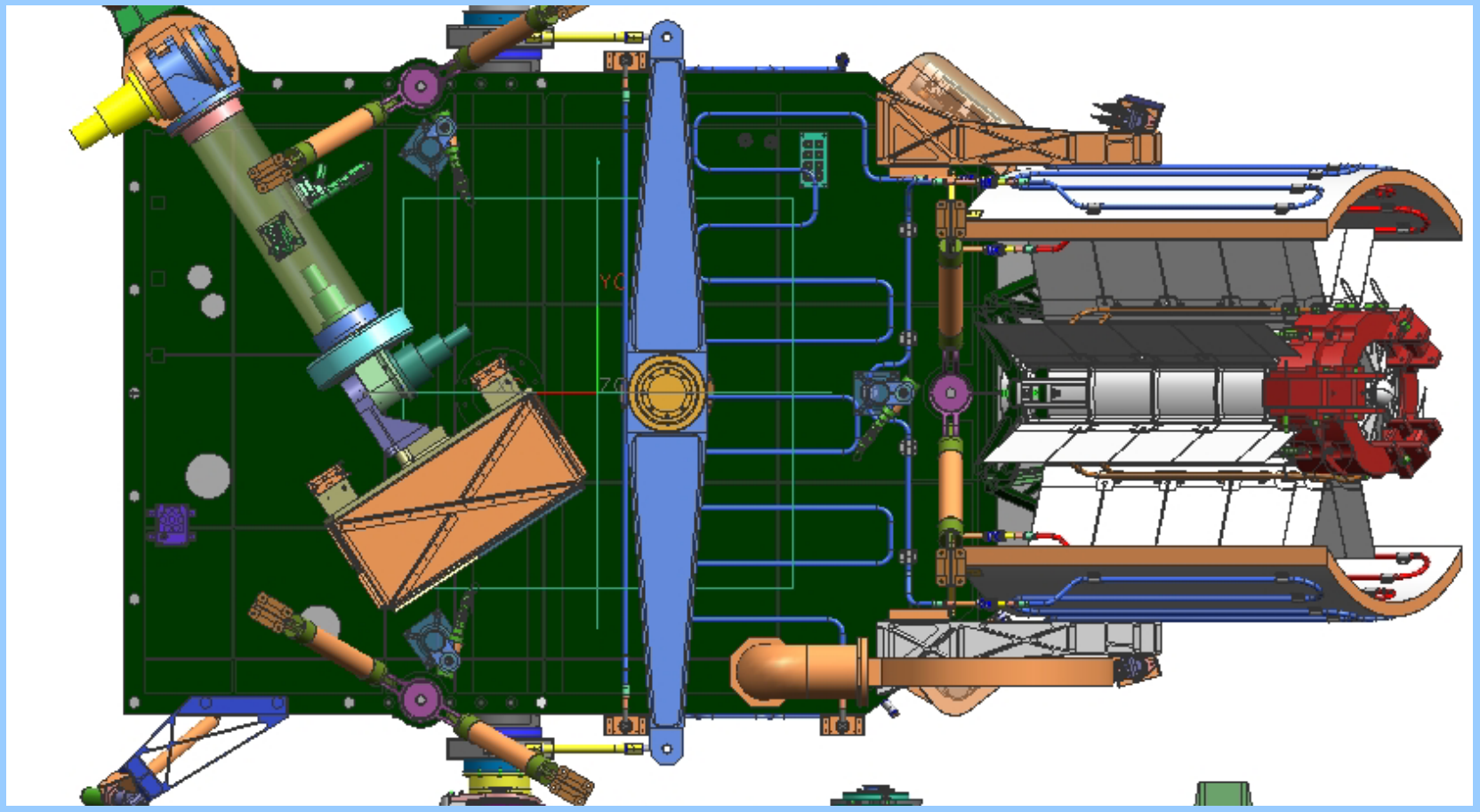
- **For thermal control of the rover during *Surface* Operations**
  - **For *both* heating and cooling**
  - **Harvests up waste heat from the MMRTG for cold conditions**
  - **Uses radiators to maintain rovers temperatures during hot conditions**



- **1st instance of using pumped fluid loop as a *Thermal Bus* to *supply* as well as *pick-up* heat from electronics**



Differential / Stowed RSM Changes



Design Concept

Internal Config – Bottom View

IMU

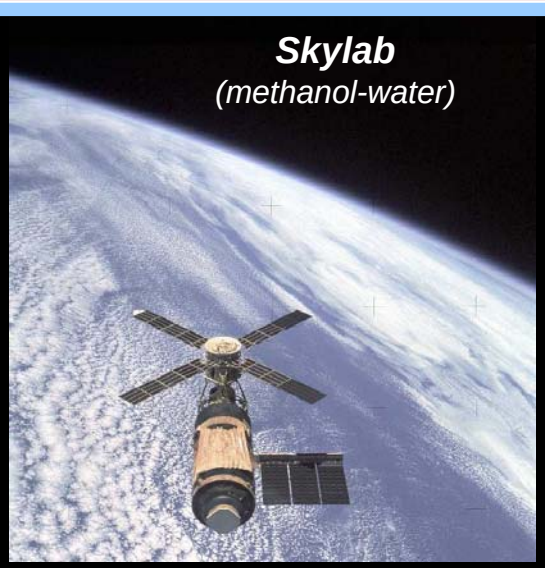
Cable tunnel volume – 250 mm unsupported length

Thermal Control Architecture Concept on Mars Surface

- ***Rover designed to be an "all terrain and all seasons" vehicle***
- **Harvested waste heat from MMRTG would be used to overcome heat losses during cold conditions**
  - **Minimal survival electric power used for thermal control**
    - **Precious electric power directed towards rover science, electronics & mobility**
- **Utilize single phase mechanically pumped fluid (Freon-11) loop to pick up heat from RTG and deliver to various components in Rover**
- **During Hot Conditions, use same fluid loop to pick up heat from Rover Electronics and reject it to Radiators**
- **Fluid Loop thermally couples all components at nearly the same temperature (isothermal)**
  - **Acts like a heat pipe**
  - **No local hot spots**
- **Use passive thermal control valves to automatically modulate heat pick up and insertion**
- **Usage of fluid loop greatly simplifies the thermal/mechanical design**
  - **Robust to design and environmental changes**
  - **Simplified testing and surface operations**
- **Survival Electrical Power used only for thermal control of remotely mounted instruments**
  - **Where it is not practical to use fluid loop**

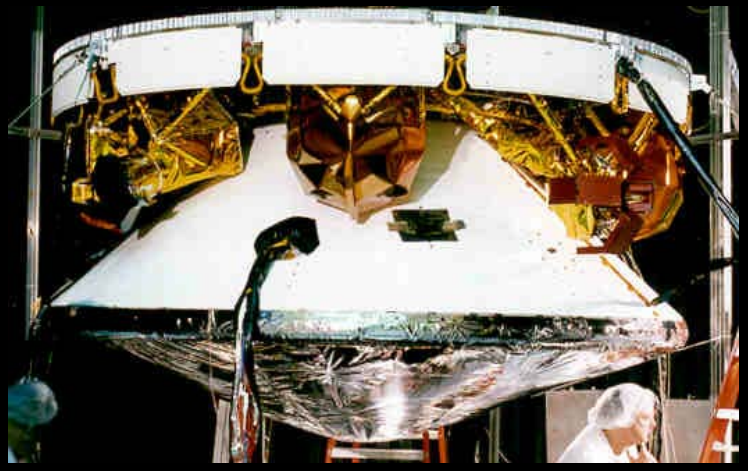
Mechanically Pumped Fluid Loops on NASA Missions

Skylab
(methanol-water)



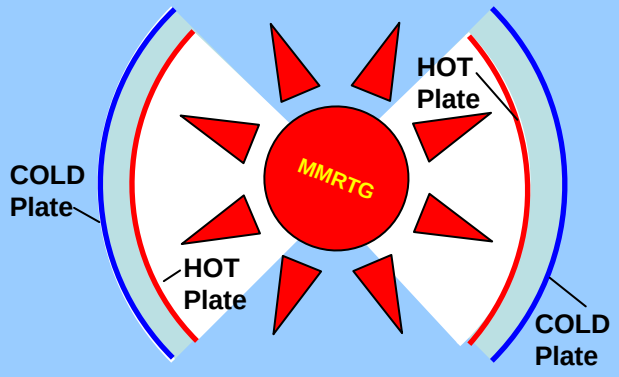
NSTS (Space Shuttle)
(water/CFC-21)

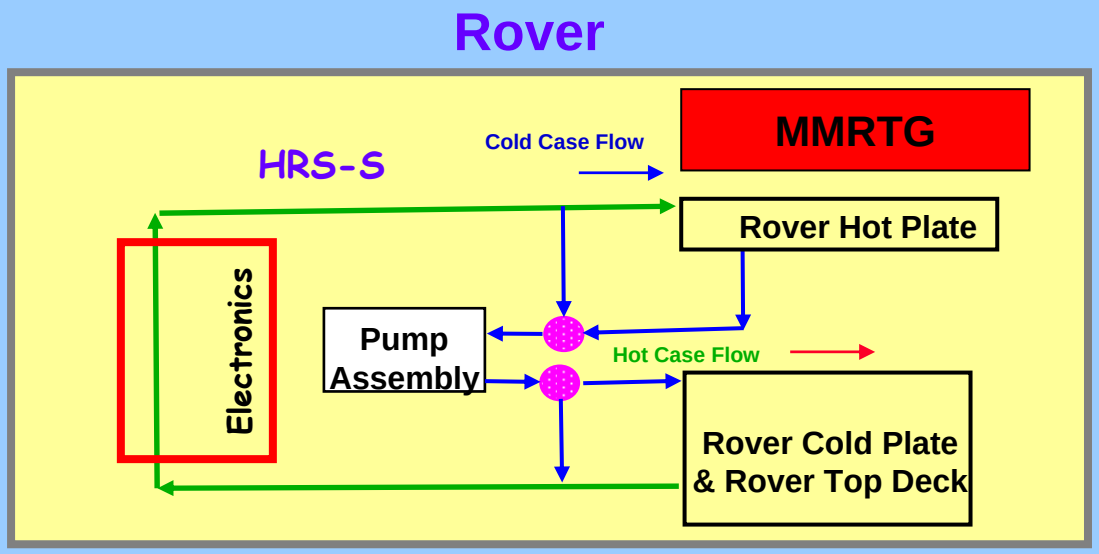
Mars Pathfinder &
Mars Exploration Rovers
(CFC-11)



International
Space
Station
(water/ammonia)

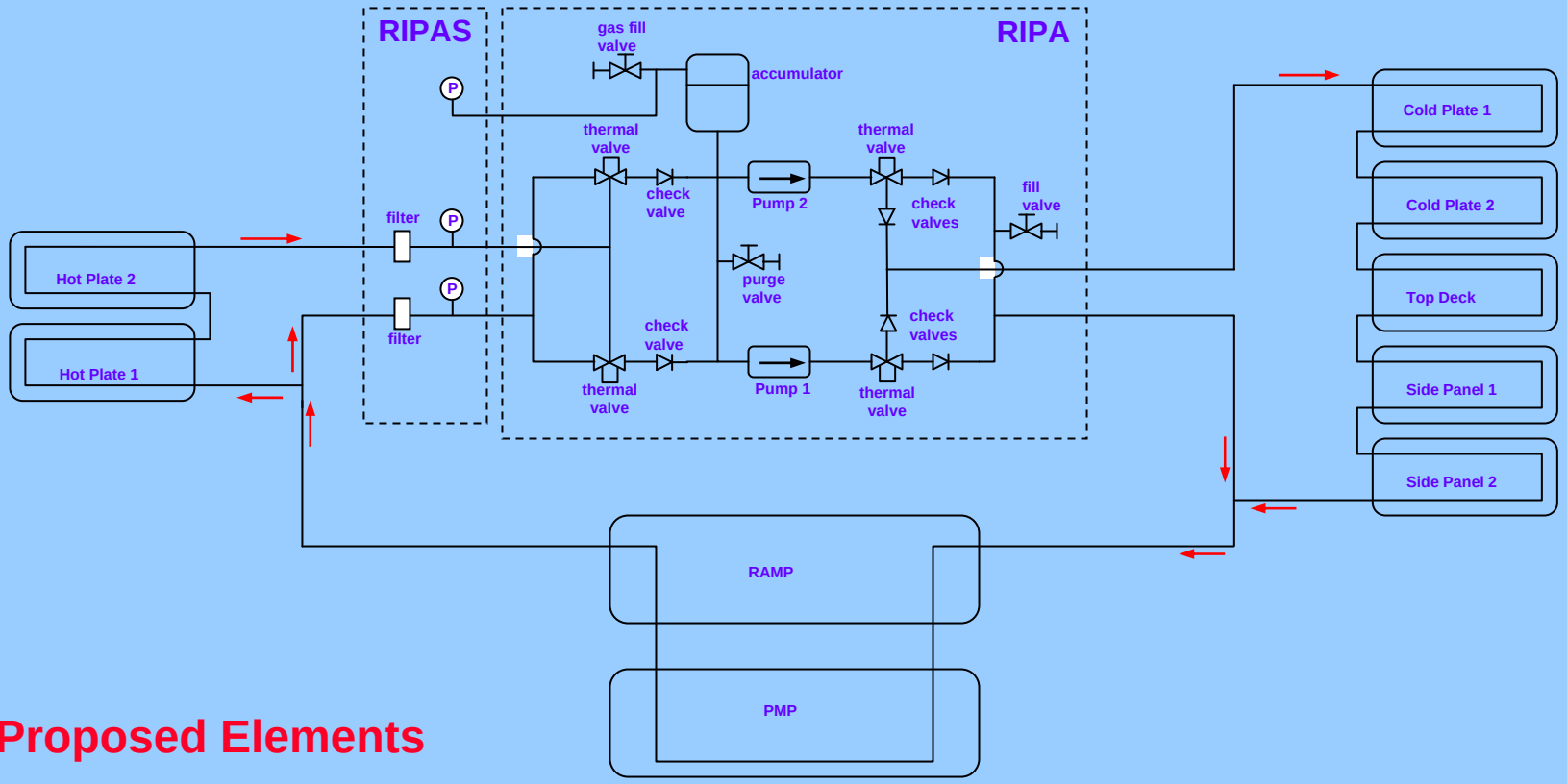
Surface Fluid Loop Concept





- The surface HRS system would consist of CFC-11 fluid loop with following elements
  - Pump assembly with redundant pumps/electronics
  - Thermal control mixing/splitting valves to bypass Cold Plate or Hot Plate

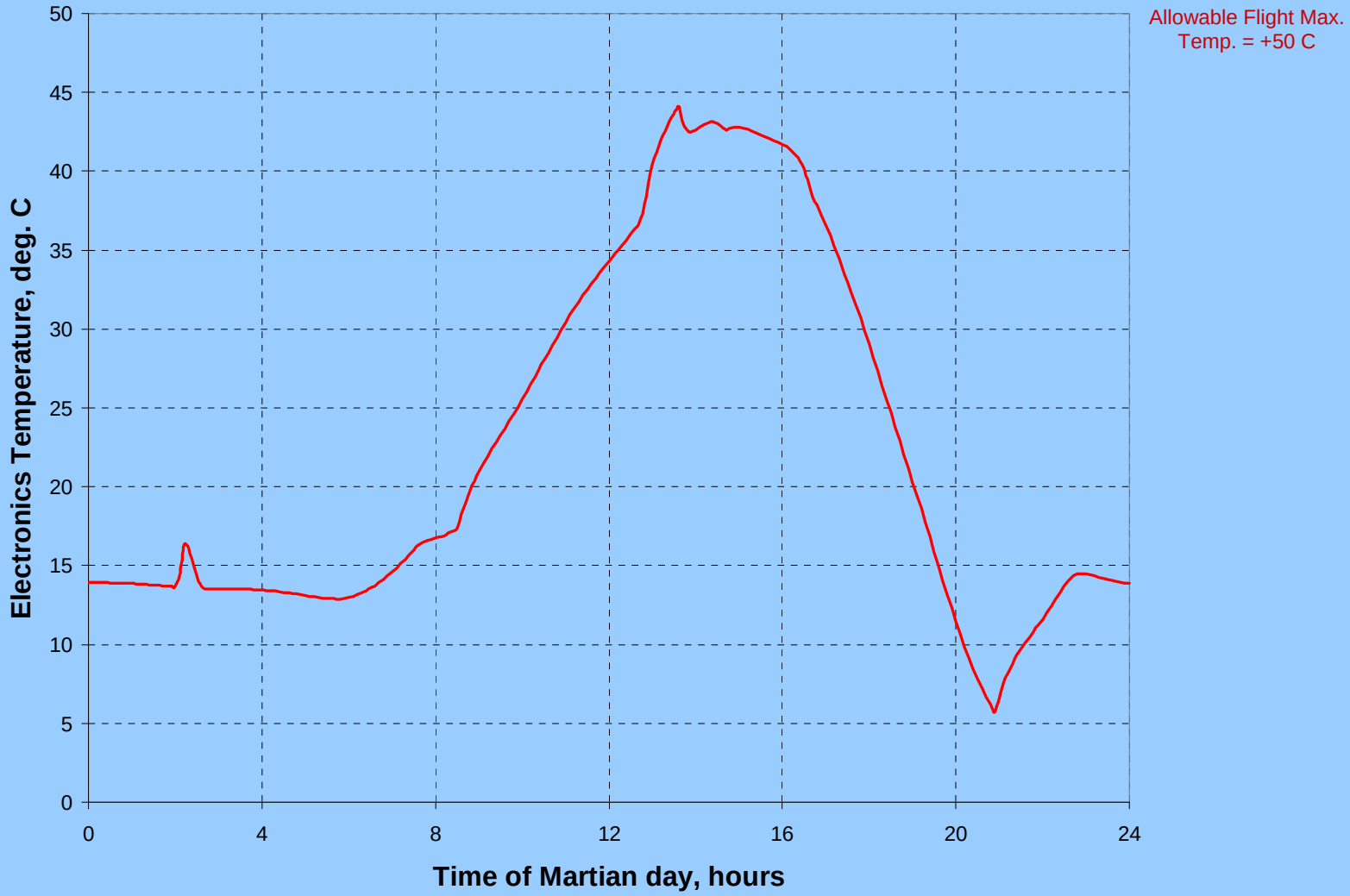
Surface System Fluid Loop RIPA & Thermal Valves Concept



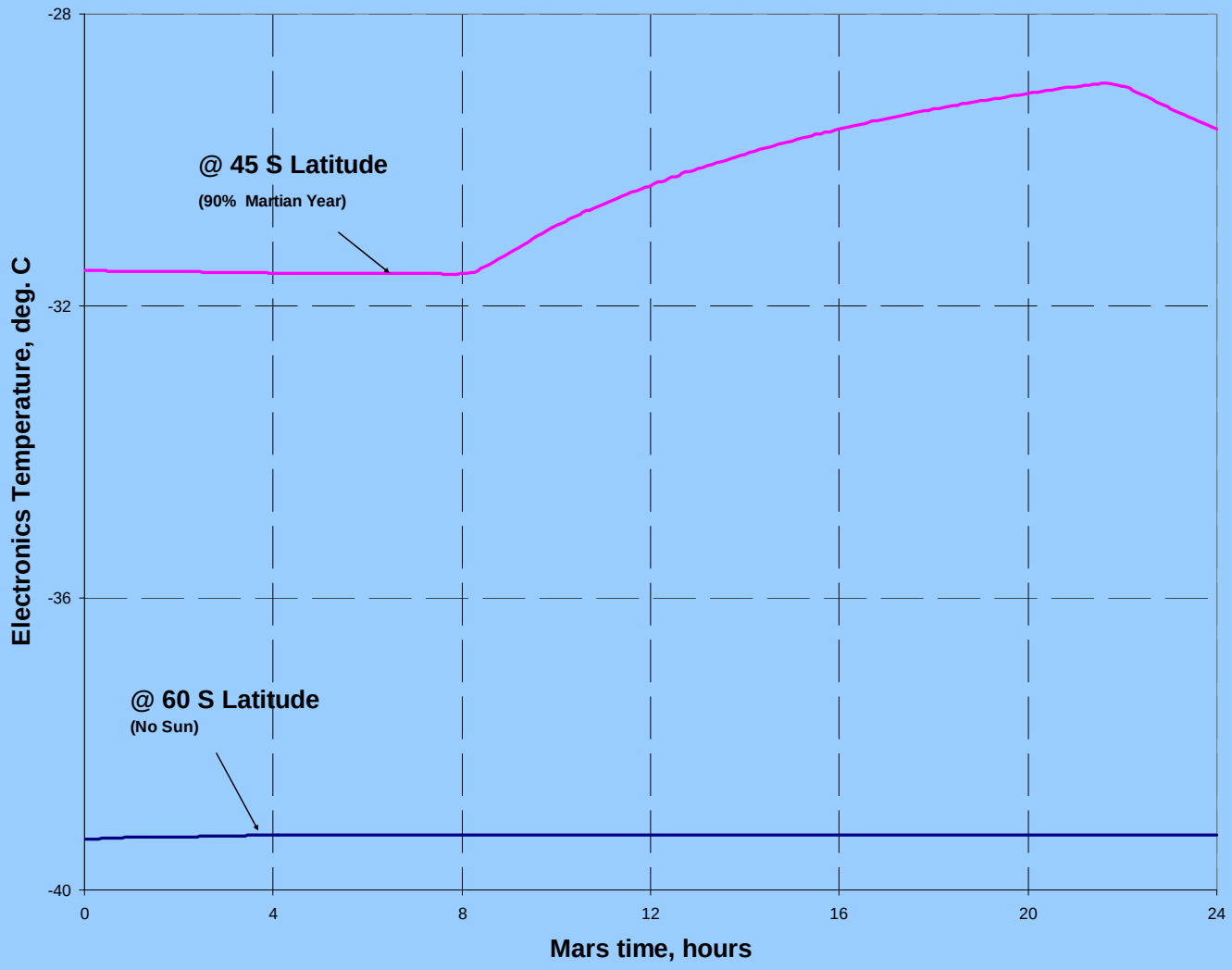
Proposed Elements

•The pump assembly is of the same heritage as the Mars Pathfinder and MER HRS Integrated Pump Assembly (IPA), pump/motor/electronics are fully block redundant (primary and backup pumps)
• The working fluid is CFC-11 and the flow rate approximately 0.75 liters/min
• The pumps are centrifugal pumps using brushless dc motors
• Only one pump will be operating at any time when HRS is on - it draws ~10 W power
• Each leg of the IPA/MV system is independent and overall system is single-fault tolerant

Predictions for Worst Case *Hot* Temperatures of Rover Electronics @ 27 S Latitude

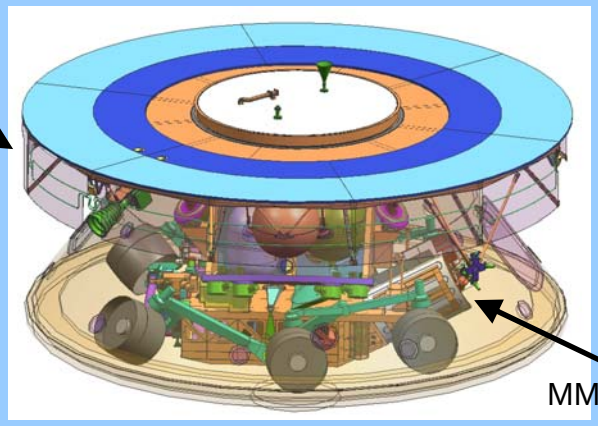


Predictions for Worst Case *Cold* Temperatures of Rover Electronics @ 45 & 60 S Latitude



Proposed MSL HRS Configurations

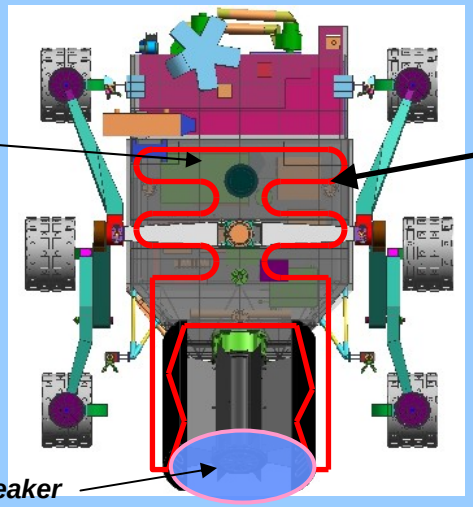
Cruise HRS Radiators



MMRTG

Surface System Fluid Loop (HRS-S)

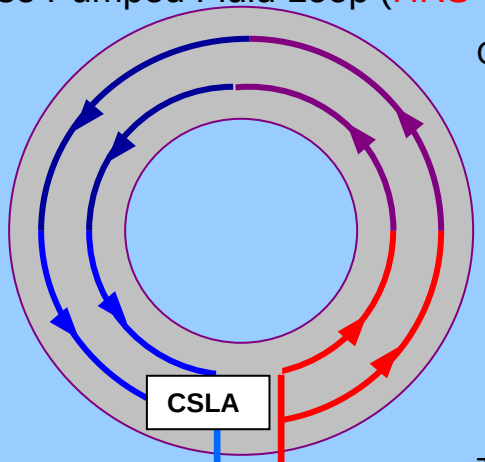
Loop controls ***both*** Avionics and Payload zones



Windbreaker

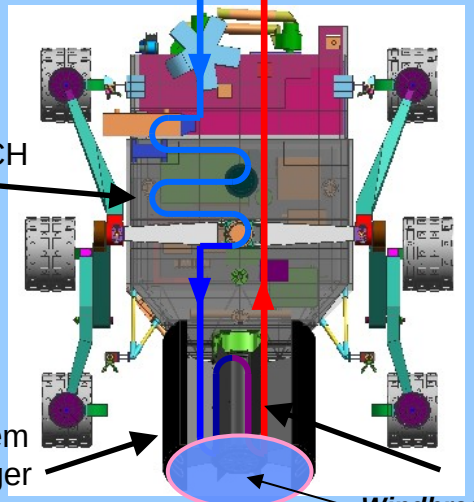
Cruise Pumped Fluid Loop (HRS-C)

Cruise Radiator (split flow)



Transfer Lines (8m)

Rover **PMP & RAMP** HXCH

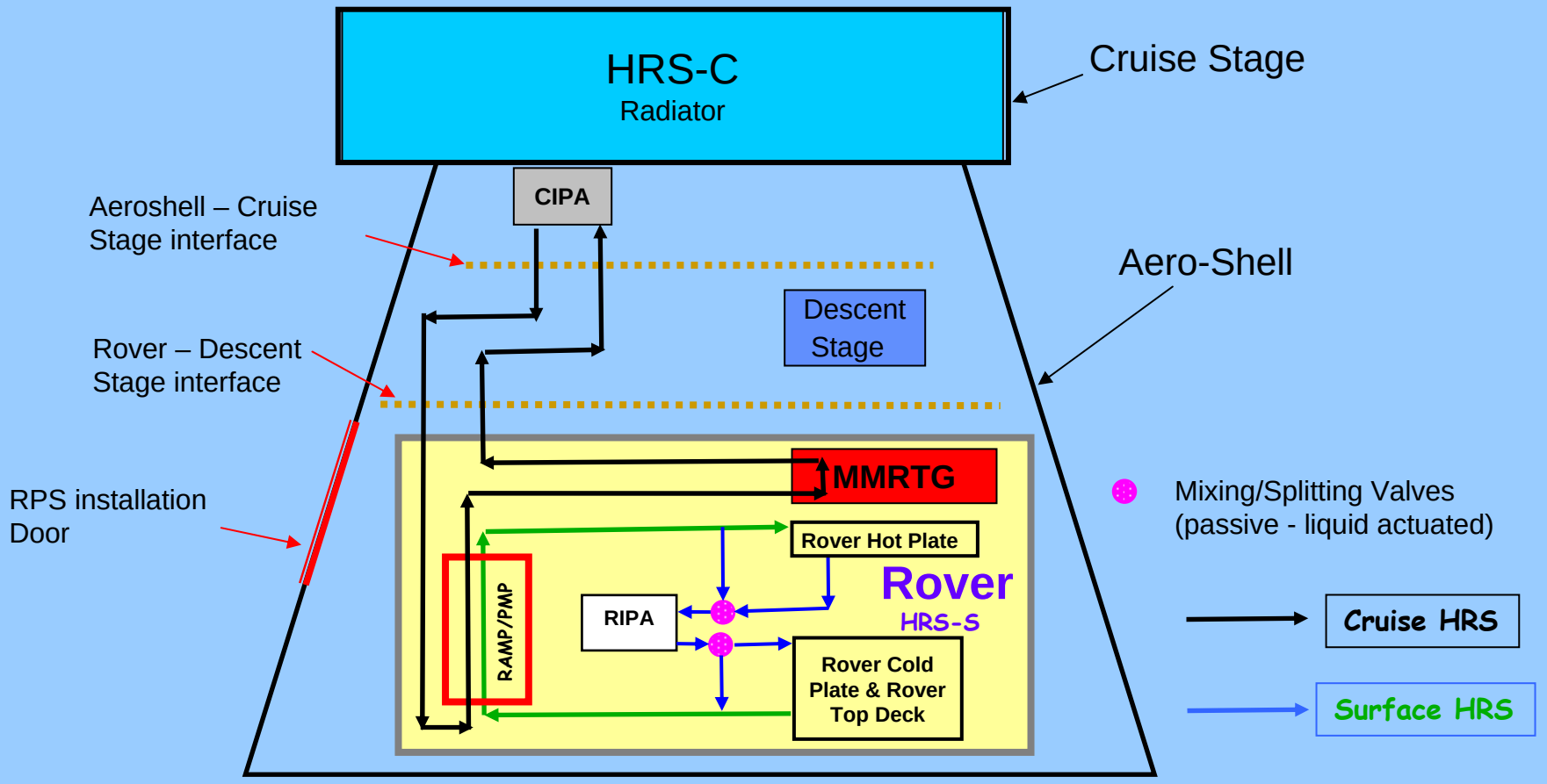


Surface System Heat Exchanger

MMRTG Heat Exch

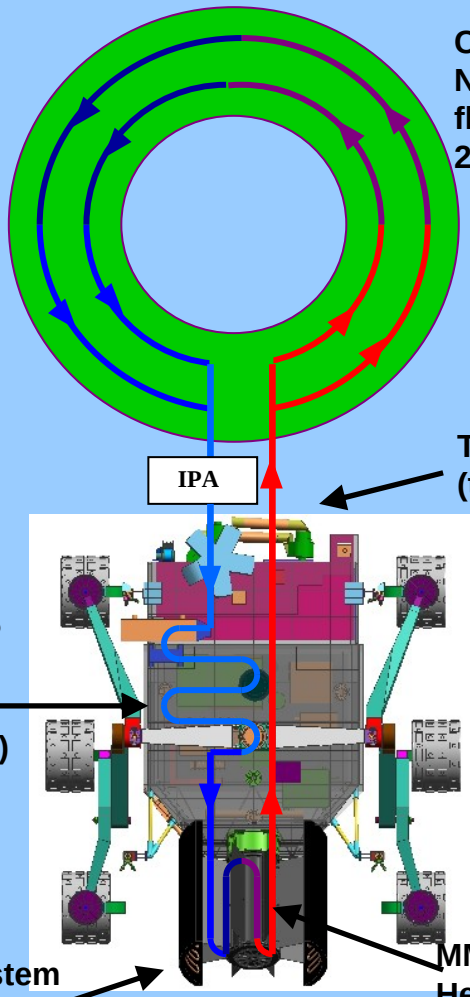
Windbreaker

Proposed MSL Fluid Loops for Cruise & Surface



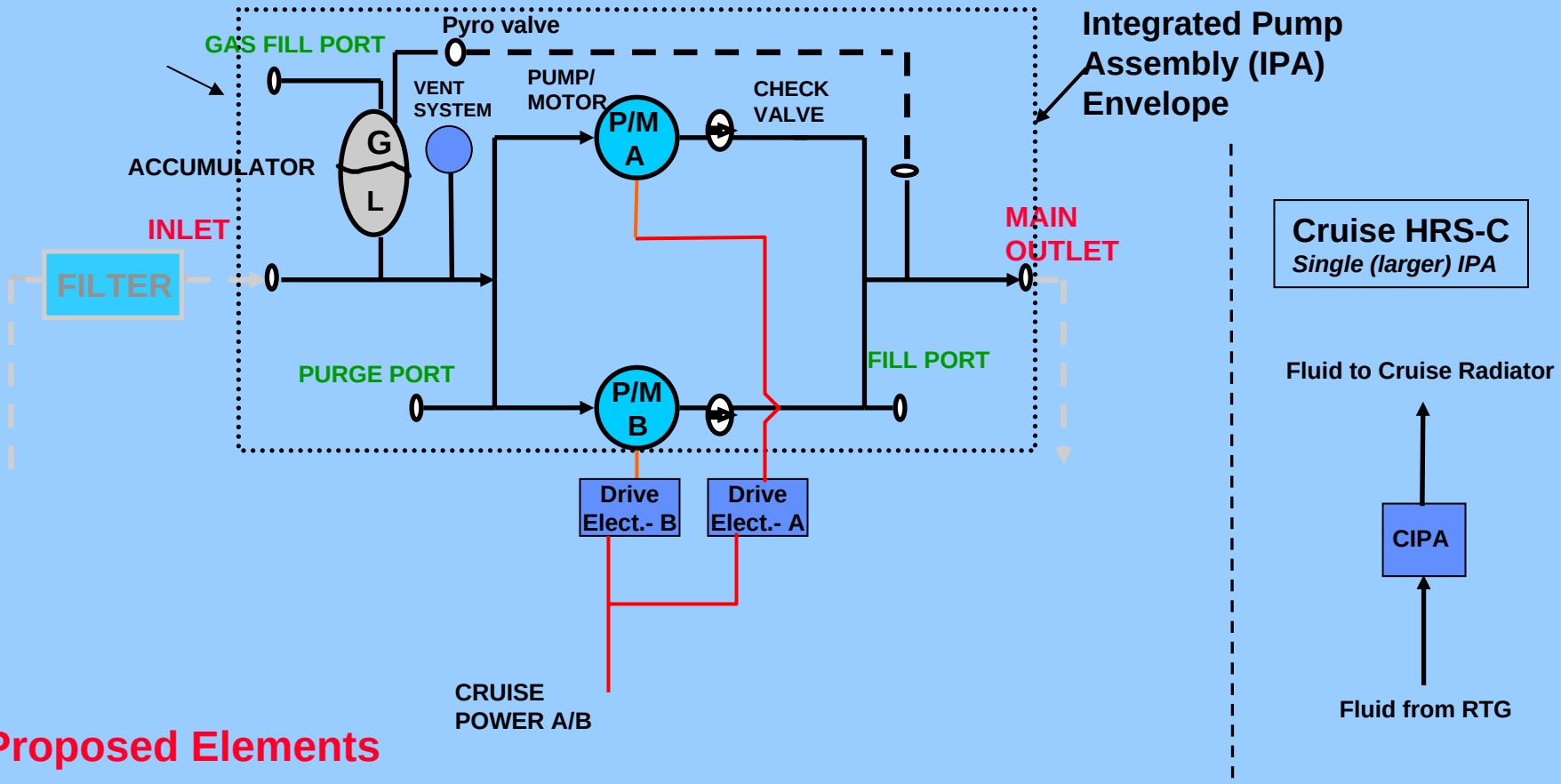
- The Surface System fluid loop (HRS-S) would use CFC-11 as the working fluid and has an operating temperature range of -100 to +100 C in various components of the system
- Cruise HRS (HRS-C) would use CFC-11 (in the 0 to 80 C range)

Thermal Control Architecture Design Concept for Cruise



- Cruise Fluid Loop thermally controls:
  - Rover (150 W)
  - Cruise electronics (50 W)
  - RTG (2000 W)
- Freon-11
- Silver/Teflon tape for Cruise Radiator (6 m^2)
- 1.5 liters/minute flow rate at 25 kPa delta-P
- 9.5 mm O.D. Aluminum/Stainless Steel Tubing
- Fluid picks up heat from cruise and rover electronics followed by RTG
- Fluid rejects heat to cruise radiator (6 m^2)

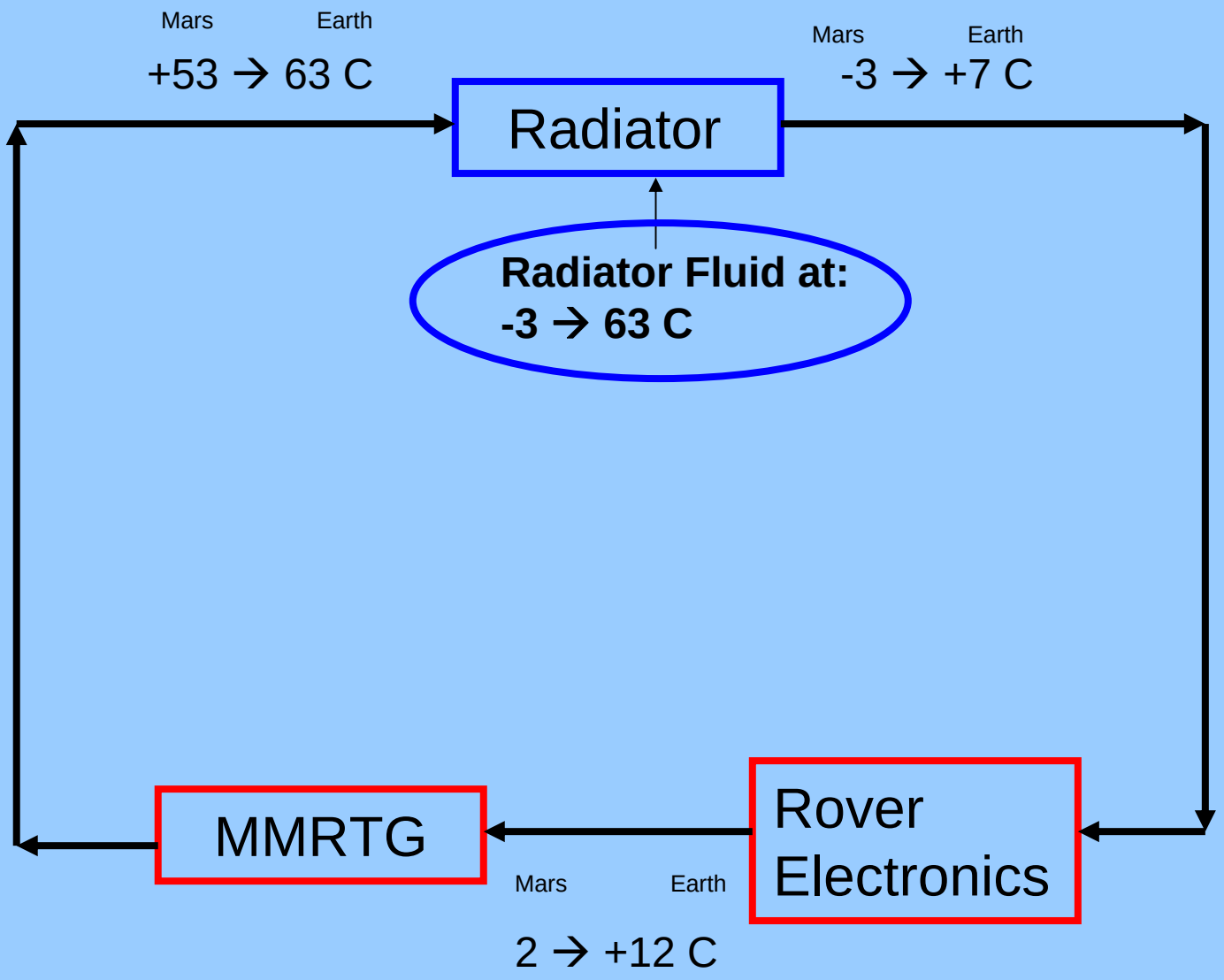
Cruise HRS System CIPA Concept



Proposed Elements

- IPA in the Cruise HRS system (HRS-C) has block redundancy in its pump/motor and the drive electronics
- The primary pump (Pump A) is on always while the back up pump (Pump B) is turned on by the fault-tolerant system in case of an anomaly
- The vent system shown for each IPA will be combined to result in a single vent valve assembly for the S/C

Cruise Loop Performance Prediction

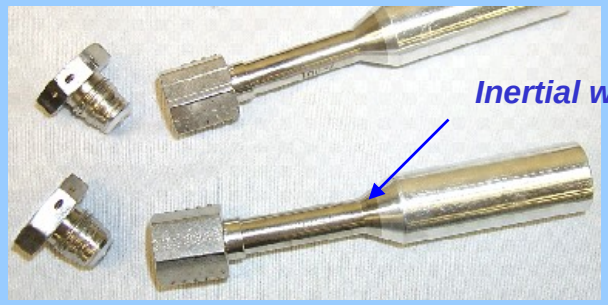


Development Tests

- **Component Tests**
  - **Tubing interacting with Freon-11 at high temperature**
    - **Aluminum and Stainless Steel**
    - **Interface weld material combinations**
- **High Temperature operation of Pump flowing Freon-11**
  - **Use same kind of pump as base-lined for flight**
  - **Long term reliability of pump**
- **Long Term Life test to simulate *synergistic* effect of all components and subsystems in loops**
  - **Tubing, Valves, Pumps, Heat Exchangers, filter, etc. simulated**
  - **Removable tubing coils to periodically sample**
    - **Tube degradation**
    - **Freon**
      - **Particles**
      - **Halides**

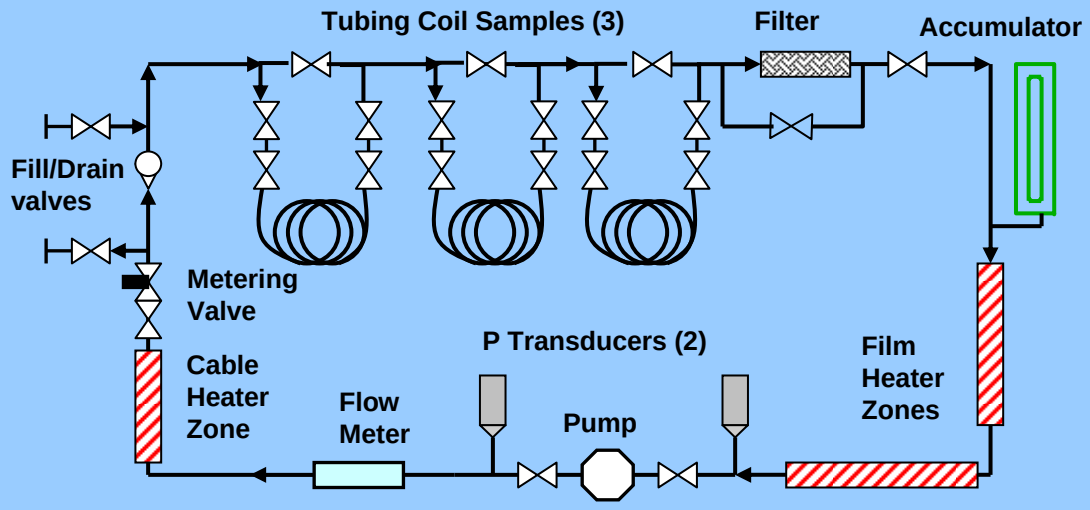
Material Compatibility Coupon Tests

- Stainless steel and Aluminum tubing samples have been fabricated and filled with Nanopure water
- Sample types include stainless steel and aluminum orbital welds, stainless steel to aluminum inertial welds, and aluminum coupons within stainless steel tubing.
- Samples are sealed and baked in a 150°C oven
- A member of each sample type will be opened and inspected at 30 day intervals

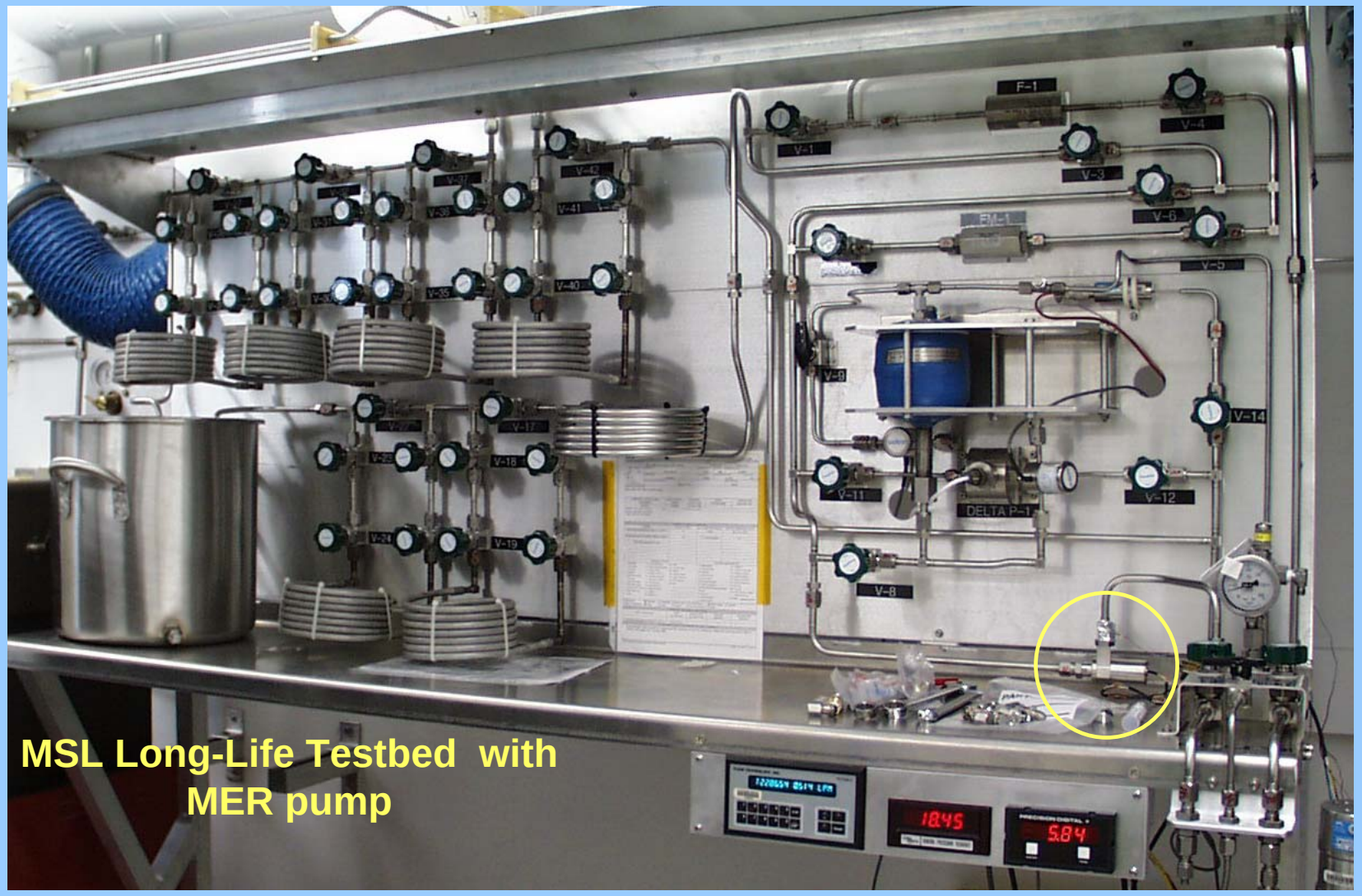


High Temperature Pump Testbed

- Designed to maintain pump and Freon at 100°C
- System pressure of approximately 200 psia (1.4 MPa)
- Wetted Flow path: 300 series stainless steel
- Filled with pure Freon
- In-line filter removes particles greater than 25 microns
- Thermocouples monitor loop temperatures, pressure transducers monitor pressure drops



Long-Life Test-bed (Freon-11) Tests



Conclusions

- MSL mission would utilize mechanically pumped fluid loop based architecture for thermal control of the spacecraft and rover
  - During all phases of its mission (Cruise & Surface)
- The architecture is designed to harness waste heat from an MMRTG during Mars surface operations for thermal control during cold conditions
- It would also safely reject heat from the MMRTG during cruise
- Several development tests are being conducted to retire any risks associated with this architecture
- This architecture is well suited for any future interplanetary missions utilizing radioisotope power systems for power generation
- The development and successful implementation of these advanced technologies for MSL would serve as pathfinders for similar future missions

Acknowledgements

- The research described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

- The authors wish to thank NASA's Mars Technology Program for funding the research and development a high temperature mechanically pumped single-phase fluid loop.

- Pacific Design Technologies, Inc is acknowledged for their work on developing the high temperature, long-life pump technology used in our development tests.