

A Lightweight, Freeze Tolerant Radiator for an EMU

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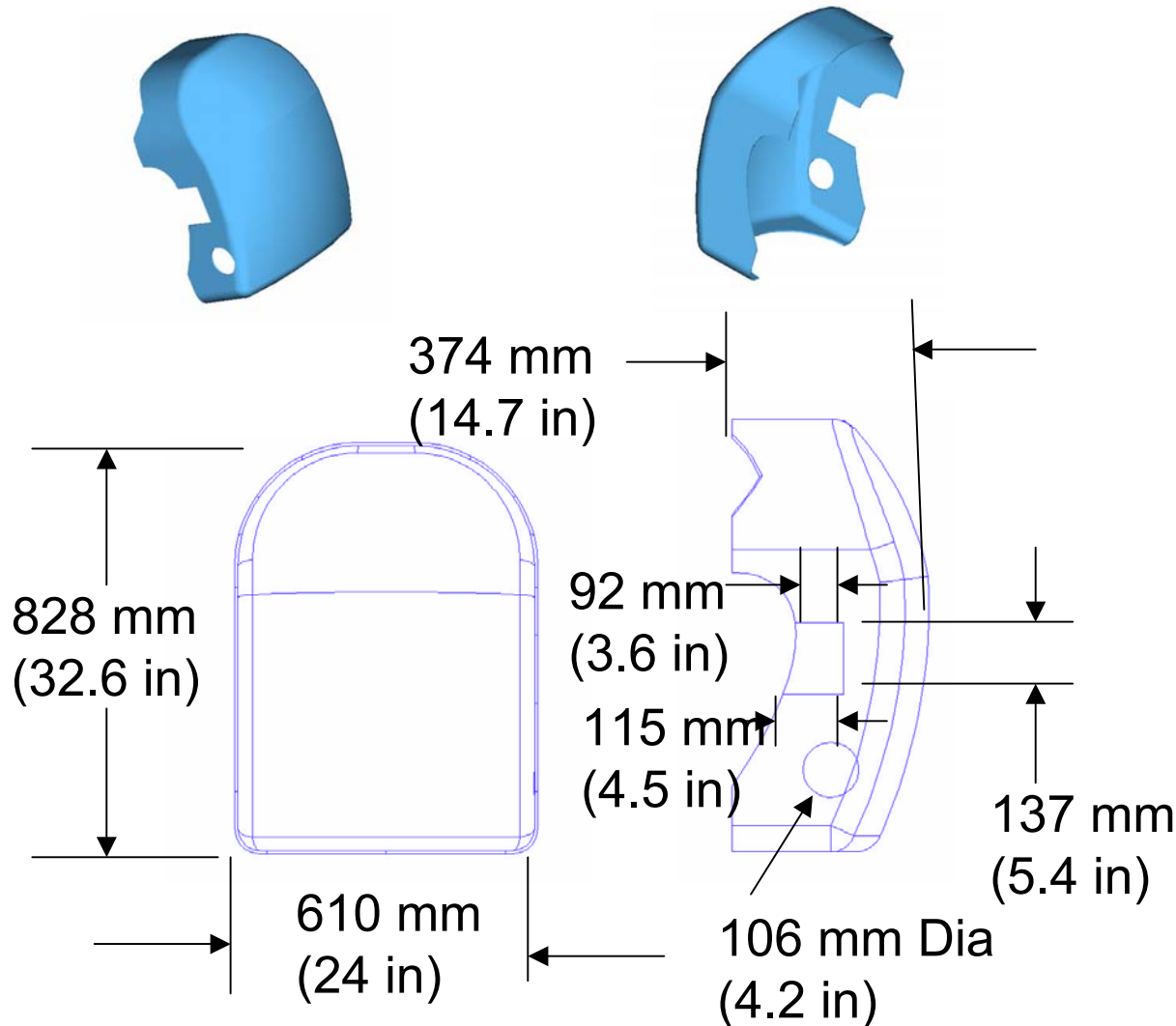
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Freeze Tolerant Radiator

- **Current sublimator removes all heat loads**
 - Highly variable metabolic loads
 - Highly variable environmental loads
 - Largest expendable in PLSS
- **Radiators can provide heat rejection without expendables**
- **This research to develop an advanced, freeze tolerant radiator**
 - Freezable to meet variable heat loads
 - Lightweight – near the weight of a sublimator only

Advanced Flex PLSS Design



**~9.2 ft²
Available
for
Radiation**

EVA Thermal Environment

	Hot	Nominal Cold	Cold
Mars Atmosphere	65 to 80 F	-120 to -50 F	-180 to -155 F
Mars Radiation*	15 to 25 F (suit) -5 to 20 F (rad.)	-80 to -50 F (suit) -150 to -90 F (rad.)	-190 to -100 F (suit) -190 to -140 F (rad.)
EMU ISS	110 F		-169 F (night pass)
EMU Shuttle PLB	220 F (PLB-Sun)	-60 to 30 F PLB-Earth)	-130 F (PLB-space)
EMU Experience	No hot cases	Typical	Several cold night passes

* Baseline surface optics.

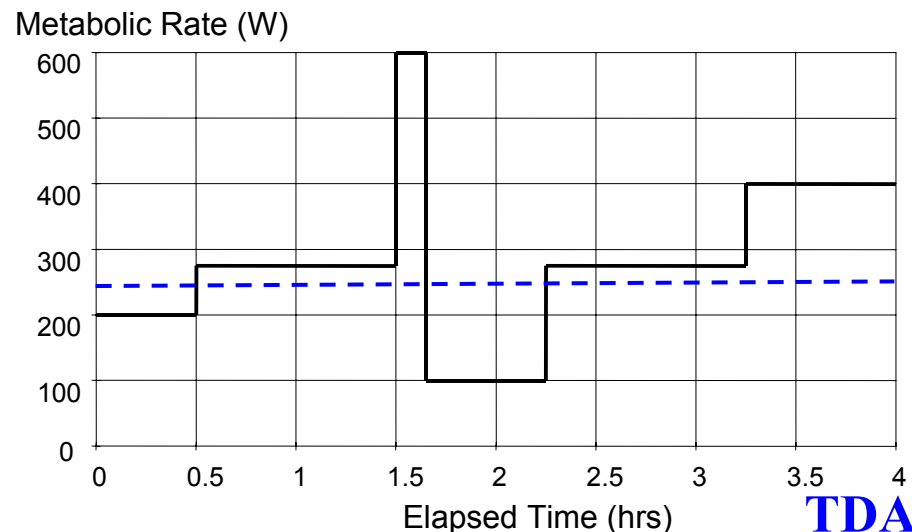
PLSS Heat Loads

Average heat load in the average environment*, 600 Btu/h

Maximum heat load in the coldest environment, 2,500 Btu/h

Minimum heat load in the coldest environment, 192 Btu/h

Nominal EVA Metabolic Profile



* 850 BTU/hr (249 W)
average metabolic
less EMU heat leak
plus electrical load

Freeze Tolerance

- **Highly variable heat load**
 - Something must freeze at low loads
- **Either a very small radiator**
 - Small savings in expendable
- **Large radiator**
 - Large savings in expendables
 - BUT must freeze to prevent chilling Astronaut
- **Must isolate radiator in hot environments**
 - Otherwise very large heat gains and
 - High impact on expendables

Freezing with Ice

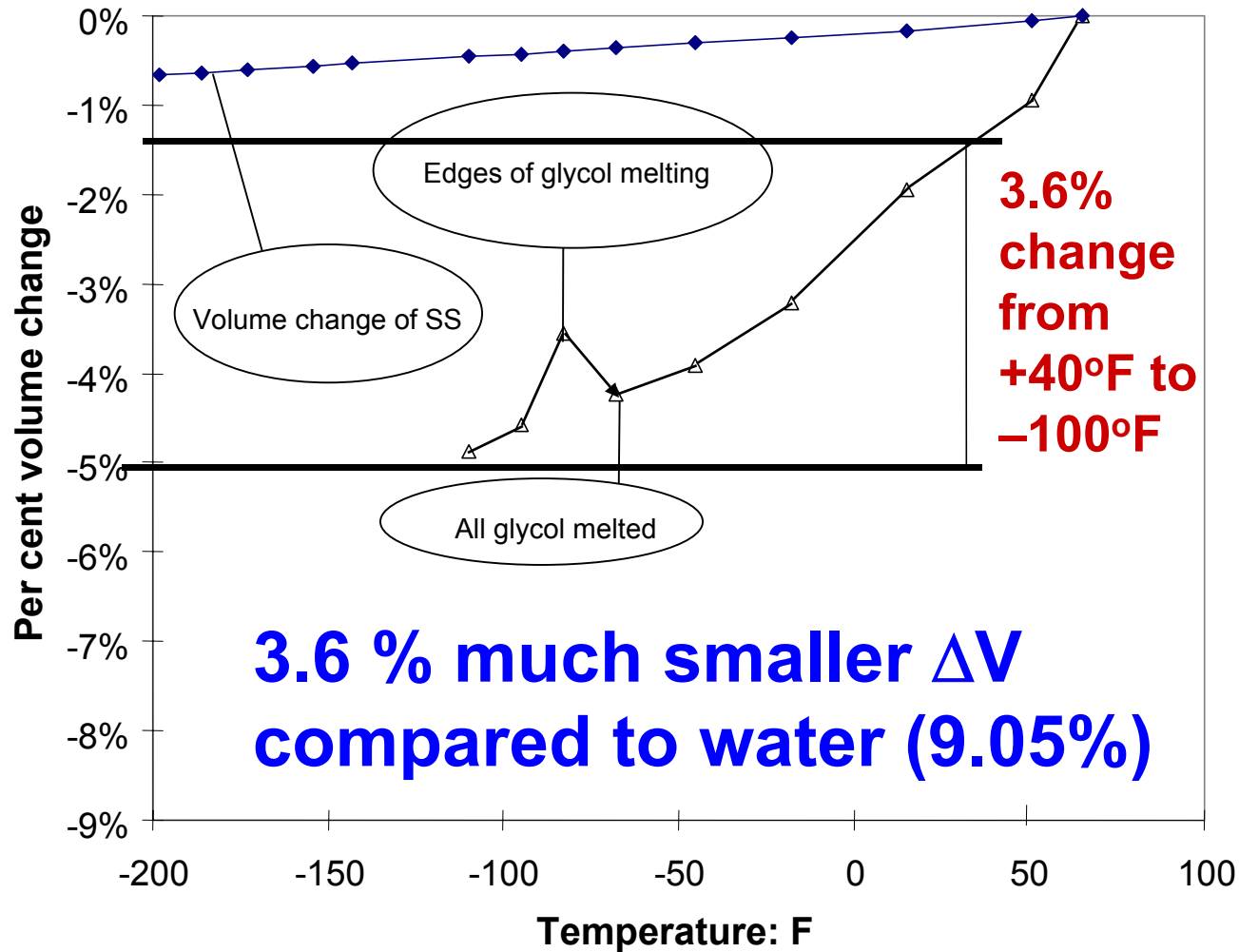
- **Water is the heat transport fluid in PLSS**
 - Safe, proven, understood, good thermal properties
- **BUT – High freezing point 32°F (0°C)**
 - With only ~70°F inlet to radiator, very close to freezing point
 - Environment can be as low as –174°F E.O. (-290 °F moon)
 - Water is difficult to thaw if frozen
 - Large volume change on freezing
 - Water = 1.0 g/cc versus (8.3 % increase)
 - Ice = 0.917 g/cc (9.05 % decrease)

Freeze Tolerant Round Tube



0.25" O.D. Round Tube

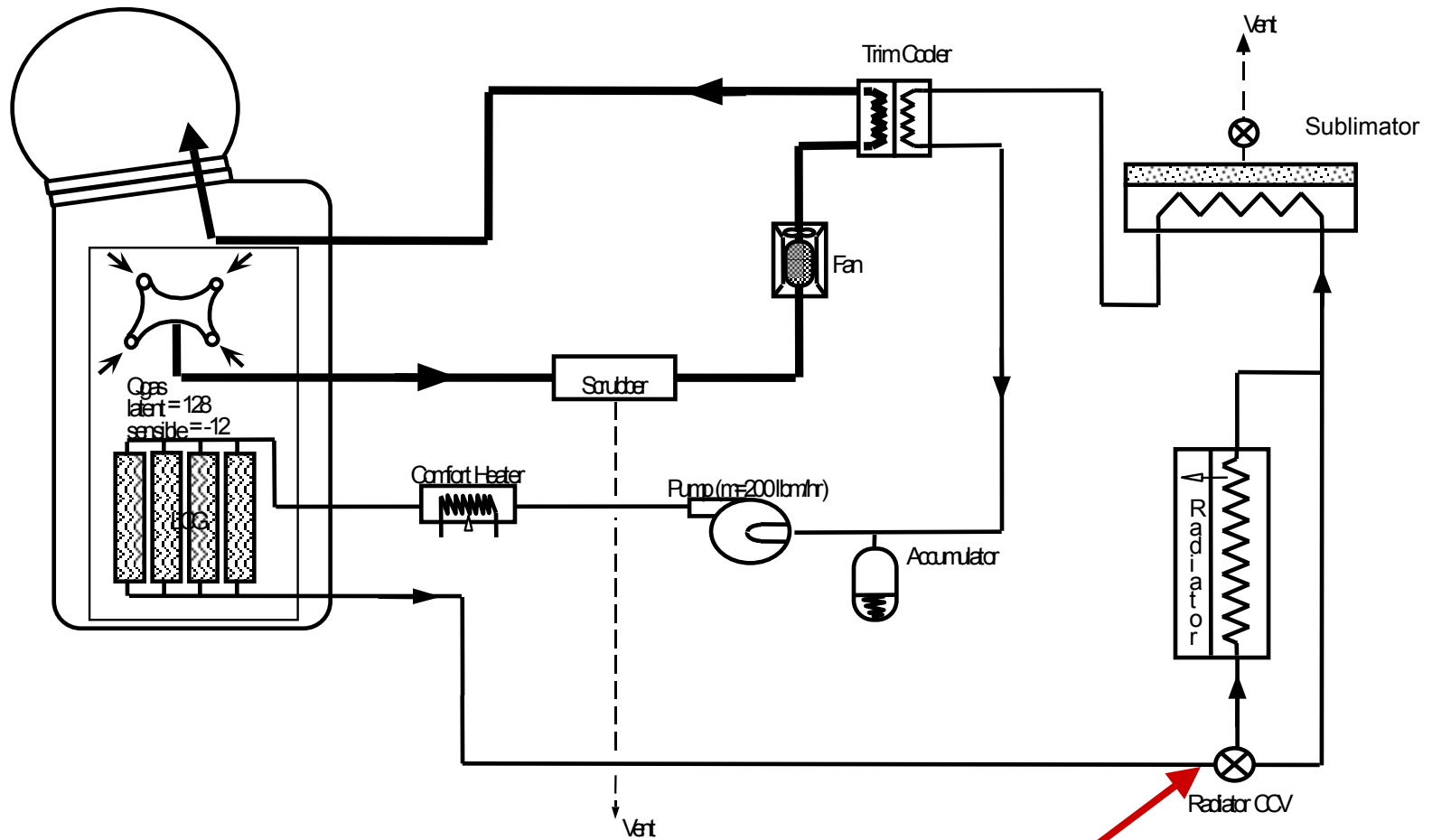
Volume Changes in Propylene Glycol (60%, wt) Water Solution



Propylene Glycol-Water Issues

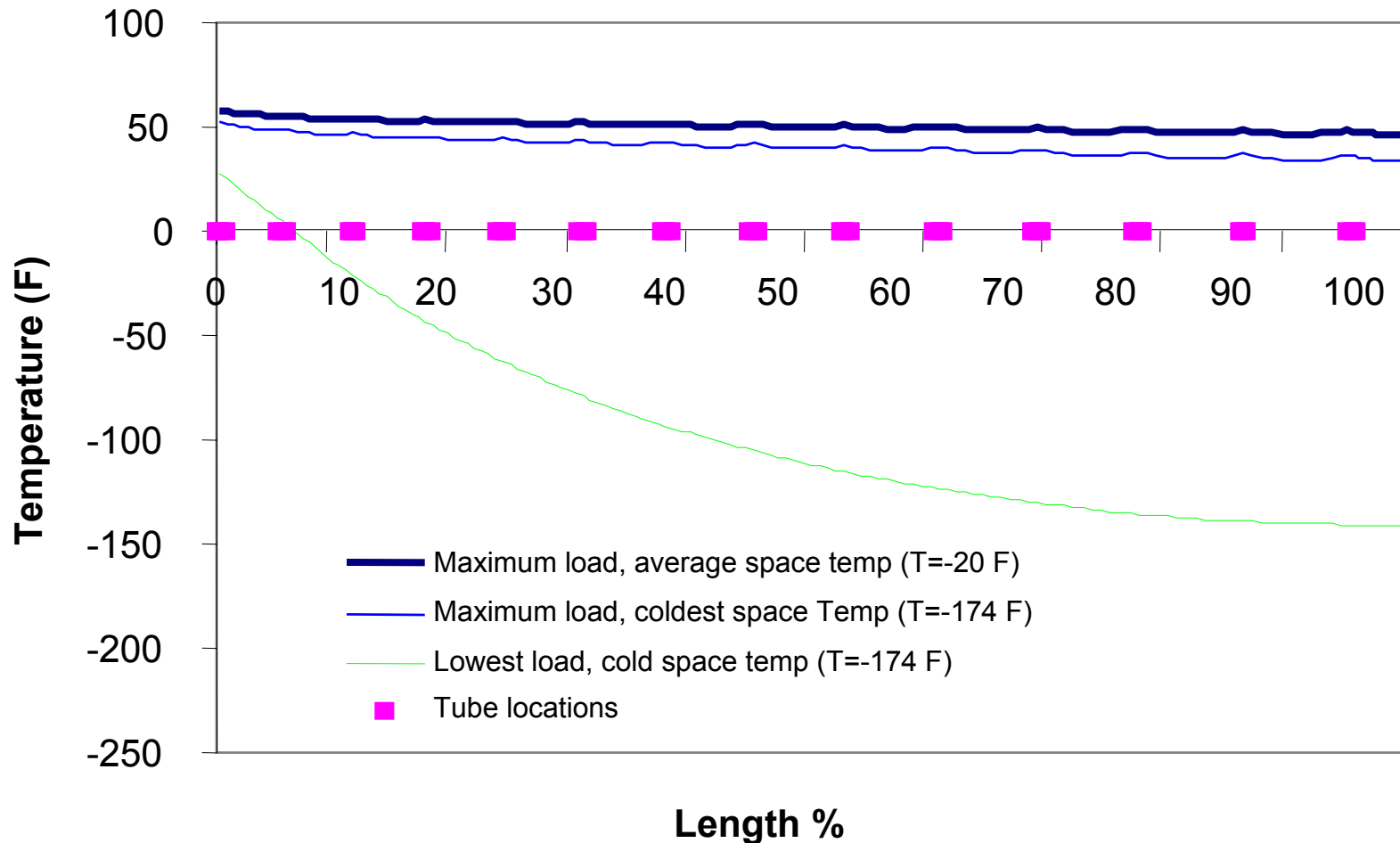
- **Smaller volume changes**
- **Lower freezing point ($\sim -60^{\circ}\text{F}$)**
- **Relatively not toxic**
- **Good thermal properties**
- **BUT impacts unknown**
 - Separation from sublimator water?
 - Removal of gas bubbles?
 - Compatibility?
 - Availability in airlock?

ATS MPLSS Model Flow Chart



Valve isolates radiator in hot environments

Propylene Glycol-Water Modeling (Sinda/Fluint Thermal model)



Radiator Performance with Propylene Glycol Solution

9.2 ft² radiator

Maximum heat rejection in the average environment, 448 Btu/h

Maximum heat rejection in the coldest environment, 804 Btu/h

Minimum heat rejection in the coldest environment, 127 Btu/h

Note: expendable water required only in the highest heat loads and hottest environments

Radiator EMU Weight Savings

- **~ 50% of the total heat rejection can be radiated**
 - 3 to 4 lbs of water saved per 8 hour EVA
- **Design EMU**
 - Tank big enough of the hottest mission
 - i.e., maximum water
 - Carry very little extra water on average or cold missions when radiator is known to be effective
- **~3.5 lbs of water saved on average or cold EVA missions**

Items in Current shuttle EMU NOT required with Radiator

Weight that could be removed:

SOP cover structure: 0.72 lbs.

Tank cover structure: 1.33 lbs.

Upper shield cover: 0.55 lbs.

TMG (for 5 sides): 3.41 lbs.

Total 6.0 lbs.

Since radiator provides all of the MMOD, impact, and thermal protection for the PLSS

Estimated weight for freeze tolerant radiators

Radiator Design Option	Gross Weigh, lbs	Net Weight, lbs
Water in round tube	27.6	21.6
Water in expanding tube radiator	16.1	10.1
PPG in round tube	10.5	4.5
PPG in expanding tube	10.0	4.0

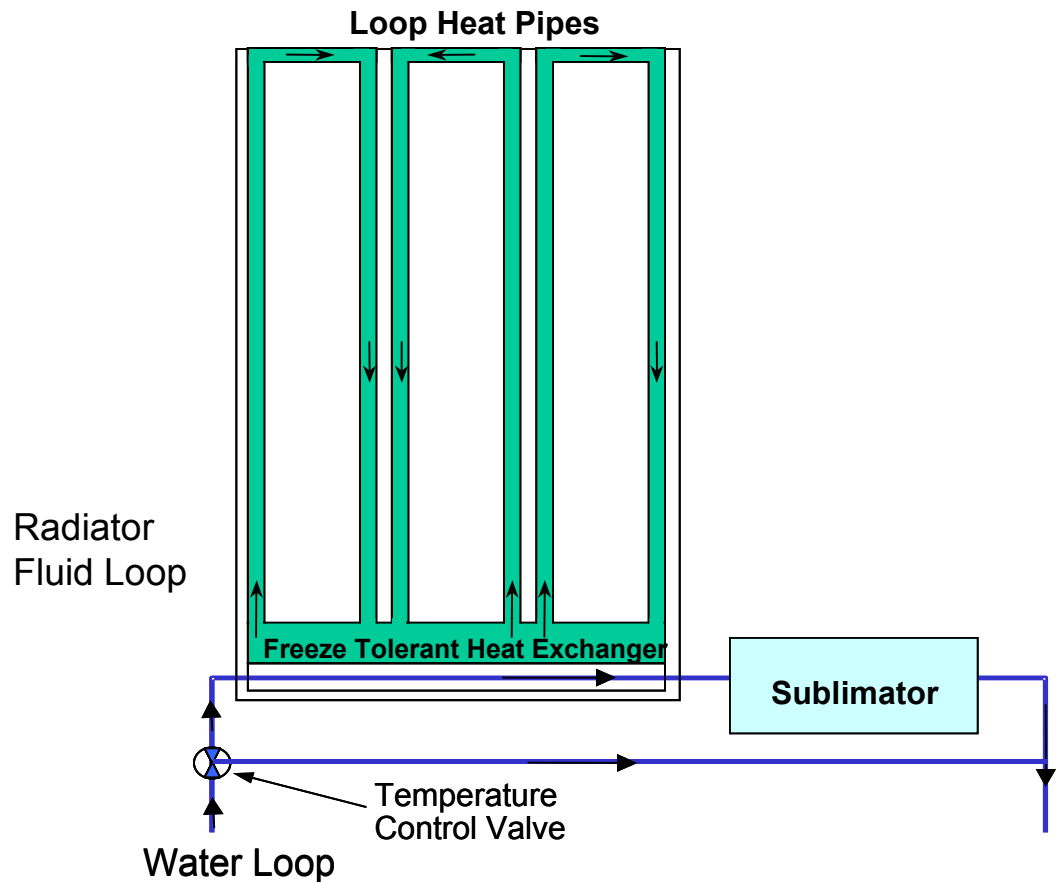
Net weight due to savings in MMOD, impacts, thermal insulation, and optical coating

Net Radiator Weight Estimates

- **Water with freeze tolerant round tube**
 - ~21.6 lbs (9.8 kg)
 - But ~18.1 lbs extra without un-needed water
- **Propylene Glycol/water solution with freeze tolerant round tube**
 - ~4.5 lbs (2.1 kg)
 - But only ~1.0 lbs extra without un-needed water
- **PPG radiator is lightweight**
- **Technical issues associated with changing to PPG.....**

Separate Fluid Loop for Radiator

- Freeze tolerant heat exchanger removes heat from cooling water loop
- Loop heat pipes (5) moves heat from heat exchanger to radiator fin
- Completely passive system, no moving parts



Advantages of Freeze Tolerant HX/LHP Approach

- **Separate fluid loop in radiator means damage to radiator pipe is not a life threatening emergency**
- **Heat transfer fluid for radiator can be selected without concerns of impacting the LCG or other components of the PLSS**
- **Freeze tolerant HX still allows turndown of the system in low heat loads**
- **Lighter weight because heat pipe tubes do not have to be freeze tolerant (we choose a very low freezing point fluid)**
- **Estimated system weight only 8.5 lbs gross weight, 2.5 lbs net weight**

Weight Savings Summary

Radiator Design Option	Gross Weight, lbs	Net Weight, lbs	Weight with unneeded sublimator water removed*, lbs
Water expanding tube radiator	16.1	10.1	6.6
PPG expanding tube radiator	10.0	4.0	0.5
Heat exchanger/ loop heat pipe	8.5	2.5	-1.0

*Heat rejection by radiation saves 3.5 lbs of sublimator water

New Approach Saves Expendables and Overall Weight

Closure

- **Freeze tolerant radiator has potential**
 - Relatively light weight
 - Saves substantial expendables
- **Work is in progress**
 - Better approach with a freeze tolerant heat exchanger in combination with a loop heat pipe
 - Lighter weight than water or PPG freeze tolerant radiators