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HELIUM TECHNOLOGY ISSUES

Peter Kittel
NASA Ames Research Center
Moffett Field, California

A number of future space missions require liquid helium for cooling scientific payloads. These missions will require the long term storage and resupply of liquid helium at temperatures of 1.4 - 2.1 kelvin. In addition, some of the proposed instruments will require refrigeration to temperatures as low as 50 mK. A variety of liquid helium based refrigerator systems could provide this subkelvin cooling. The status of helium storage and refrigeration technologies and of several alternative technologies is presented here along with areas where further research and development are needed. (Helium resupply technologies are the topic of another presentation at this symposium.) The technologies covered include passive and dynamic liquid helium storage, alternatives to liquid helium storage, ^3He refrigerators, $^3He/^4He$ dilution refrigerators, and alternative sub-kelvin coolers.

BACKGROUND

A number of planned missions will require temperatures below 2 kelvin. These low temperatures are needed for cooling infrared detectors for long wavelength background limited astrophysical observations and for cooling novel x-ray and gamma-ray astrophysics instruments. The low temperatures are also required for a number of high sensitivity physics experiments and for the helium resupply kit. A partial list of these experiments is given in the chart below.

MISSIONS REQUIRING LIQUID HELIUM

Mission	Liquid Helium Storage	Sub-kelvin Cooling
ASTRONOMY		
SIRTF	x	x
AXAF	x	x
LDR	x	x
Astromag	x	
Small IR telescopes	x	?
PHYSICS		
GP-B	x	
Lambda point	x	
Tricritical point	x	x
OTHER		
SHOOT	x	
Helium resupply kit	x	

LIQUID HELIUM STORAGE

Superfluid helium ($T<2.17K$, $P<5kPa$) is used on space missions because of its ease of containment and other physical properties. Such stored helium systems can provide cooling down to about 1-1.2 K. Future missions will require longer storage times, higher heat loads, and probably have more stringent ground operational requirements than in the past. These requirements can be summarized as:

- 2+ Year on orbit operational lifetime (except for shuttle based missions)
- Heat loads up to 1 watt
- 72+ Hours of ground hold between last service and launch

Technology issues relating to these requirements can be divided into several categories. These are passive storage techniques, dynamic storage techniques, extended ground hold techniques, and alternative approaches.

PASSIVE STORAGE TECHNOLOGY

Technology	Status	Issues
Supports	PODS-III demonstrated on ground up to x10 lower orbital conductivity PODS-IV improved side load capability	Interaction between low orbital resonant frequency and bulk fluid motion mission dependent trade-off between PODS and straps
Insulation	Double aluminized polymers with spacers in vacuum is SOA	Optimum packing for low boundary temperatures is unknown; performance is highly dependent on lay-up technique
Bulk fluid motions	Preliminary experiments (SFHE) were inconclusive	Unknown location of fluid, slosh modes, slosh damping

LONG-LIFETIME HELIUM DEWAR

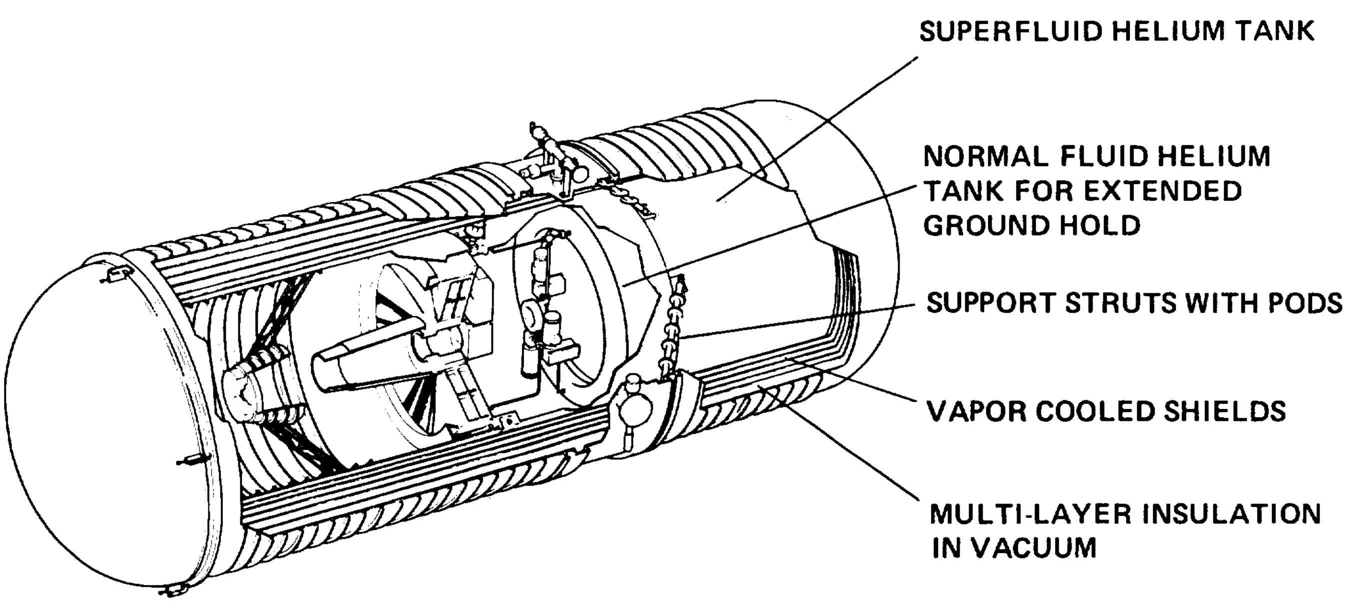
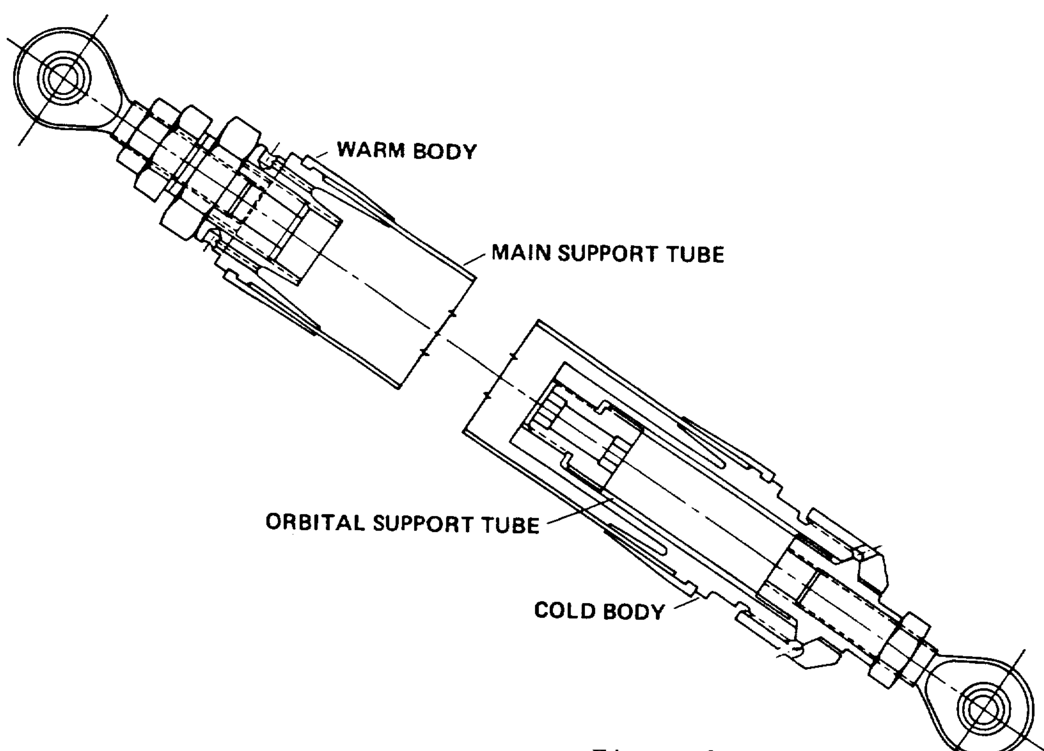


Figure 1

The Passive Orbital Disconnect Strut (PODS)[1] is the only significant advance in dewar support structures. The PODS is a variable strength, variable thermal conductance tank support. It has two configurations. A high strength configuration for launch loads and a low thermal conductance configuration for orbital and ground operations. These supports change passively from the orbital configuration to the launch configuration by the application of the launch load. Upon the removal of this load, the configuration changes reversibly back to the orbital configuration. Extensive ground testing of the thermal and mechanical properties of the PODS have been carried out. These tests include measurements of the thermal conductivity, of thermal contraction effects, of loads in excess of Shuttle loads, of fatique strength, and of the effect of side loads. In all cases they have met or exceeded expectations. They are ready for use in space missions.

The only remaining issues are the mission dependant trade-off studies between PODS and conventional straps and the effect of the interaction between the lower orbital resonant frequency of PODS and the bulk motions (sloshing) of the fluid. The latter is only expected to be significant in missions that require high accuracy pointing; such as SIRTF and LDR. Unfortunately, it is difficult to simulate low-g sloshing motions on the ground, so a study of this interaction needs to be done in space.

DEWAR SUPPORT WITH PASSIVE ORBITAL DISCONNECT (PODS)



PODS III

- HIGH LAUNCH STRENGTH
- LOW ORBITAL CONDUCTANCE
- FLIGHT READY

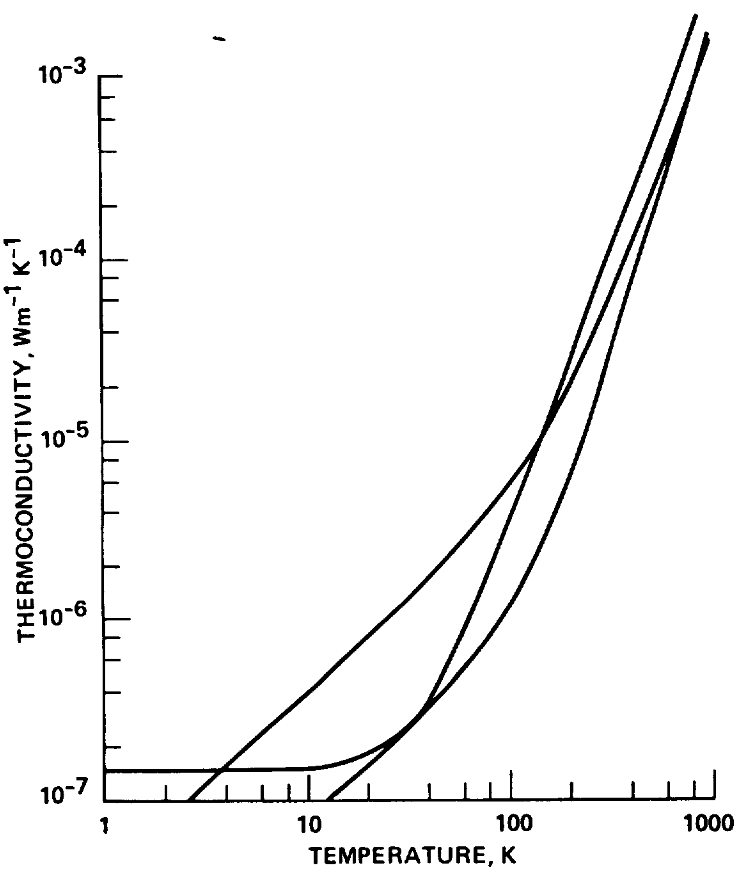
PODS IV

- INCREASED SIDE LOAD CAPACITY

Figure 2

The state of the art insulation systems is multi-layer blankets of double aluminized mylar separated by spacers (such as silk net). These blankets operate best in vacuum. Unfortunately, the performance of the insulation is very dependent on the care taken in preparing and applying the blankets. Another factor in their performance is the packing density of the layers. The effect of the packing density is reasonably well known at high temperatures. At issue is the optimum packing in the 2-20 K range where measurements are very difficult to make.

MULTI-LAYER INSULATION



- HIGH-TEMPERATURE PERFORMANCE KNOWN
- PERFORMANCE LAY-UP DEPENDENT
- LOW TEMPERATURE BEHAVIOR UNKNOWN

Figure 3

The final technology area in passive systems relates to the bulk behavior of the stored fluid. There are three issues here. The first is the distribution of the bulk liquid within the tank. Theory predicts that, in space, in a partially full helium dewar, the liquid will completely cover the wall while the vapor will reside in a single bubble. Sounding rocket experiments by the Japanese tend to confirm this. A more extensive experiment (SFHE) produced inconclusive results[2]. The knowledge of where the helium resides is critical to missions, such as GP-B, that are extremely sensitive to the location and stability of the center of mass of the liquid. The second issue is to understand the slosh modes and their damping. The viscosity of superfluid helium has an unusual behavior. At low velocities it exhibits no viscosity and thus sloshing can be expected to persist for longer times than it would in ordinary fluids. (In low-g, sloshing of ordinary fluids damps out rapidly.) Previous attempts to measure these effects were limited to the last 10% of fill on IRAS. Thus, they did not measure the region where slosh is expected to be the greatest (50% full). Large slosh effects would affect the pointing stability of helium cooled telescopes such as SIRTF, AXAF, GP-B and LDR. A knowledge of the amplitude and damping of the slosh modes will be needed to design baffles to suppress the slosh and to design the fine pointing control system to react against the slosh in these telescopes. The final issued is an extension of the first two. It is to develop fluid management devices to control the location and slosh of the fluid. A variety of missions will require this additional liquid control. These include GP-B which has a particularly stringent requirement on the control of the liquid's center of mass. Another mission is the liquid helium resupply kit where a liquid management device is required to keep the liquid at the pump inlet during adverse accelerations[3]. While a variety of management devices have been used in space to control different liquids, they have not been used to control saturated liquids (as will be required for liquid helium systems). Also, they have not been used with superfluid helium which has a thick creeping film, no viscosity (at low velocities), and a low surface tension (an order of magnitude lower than previously used fluids).

An alternative to the purely passive storage, is the hybrid technique of dynamic storage. In dynamic storage systems, some of the parasitic heat loads on the stored cryogen are intercepted by refrigerated shields. This approach has several advantages: 1) the refrigerators need not run at the ultimate system operating temperature; as cooling just the higher temperature shields can significantly reduce the quantity of liquid needed; and 2) the refrigerators need not survive the whole mission; as the stored liquid will remain for a while after the refrigerator has failed. This comes with the disadvantages of increased complexity. Whether or not the resulting system is lighter and smaller will be mission dependent. In general, there are two issues with dynamic systems. The first is the lifetime of the coolers. The more important issue is how to optimize a dynamic storage system. Such an optimization must consider such factor as thermodynamics, mass, volume, and cost among other considerations[4].

DYNAMIC STORAGE TECHNOLOGY

Technology	Status	Issues
Closed-cycle coolers		Lifetimes, system system optimization
- Magnetic stirling	Single-stage demonstrated	
- adsorption/ JTX	8 K unit under development	
- pulse tube	single-stage brassboard	

DYNAMIC STORAGE

EXTENDED CRYOGEN LIFETIME BY SUB-COOLING SHIELDS

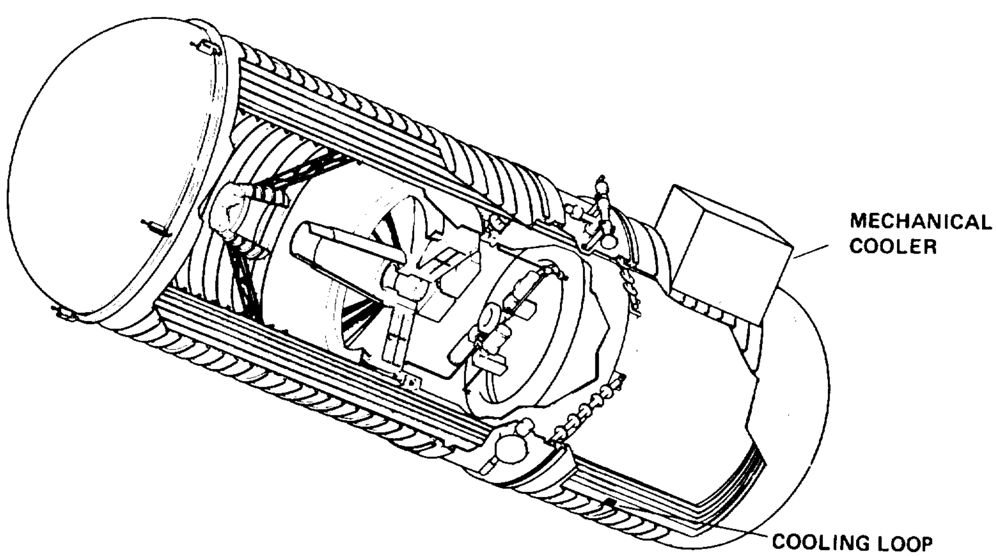


Figure 4

In recent years three novel refrigerators, that could be used in dynamic systems, have been under development at NASA. These are the Magnetic Stirling (GSFC), the Adsorption Joule-Thomson (JPL), and the Pulse Tube (ARC). The current status of these refrigerators will be reported in more detail at this years Cryocooler Conference (Easton MD, Sept. 25-26, 1986). Briefly, the magnetic stirling eliminates wear by using magnetic bearings. This is a complex system, but a considerable number of operating hours has been achieved on a single stage cooler. Multi-stage units should be able to reach temperatures down to approximately 10 K. A multi-stage adsorption cooler is under development. The current goal is a 8 K, although lower temperatures are possible. One advantage of this type of cooler is that the only moving part is a room temperature compressor. This greatly simplified the seals and bearings problem. However, the compressor must be a multi-stage device since a number of different gasses must be compressed with a high pressure ratio. Another refrigerator that has a room temperature compressor as its only moving part is the pulse tube refrigerator. Here, the compressor is a single stage unit with a low pressure ratio and a large displacement. A single stage brass-board has been built and has a performance similar to single stage stirling coolers. A multi-stage unit should be capable of temperatures below 20 K. Since the pulse tube is the least well known of these cycles, it is illustrated here.

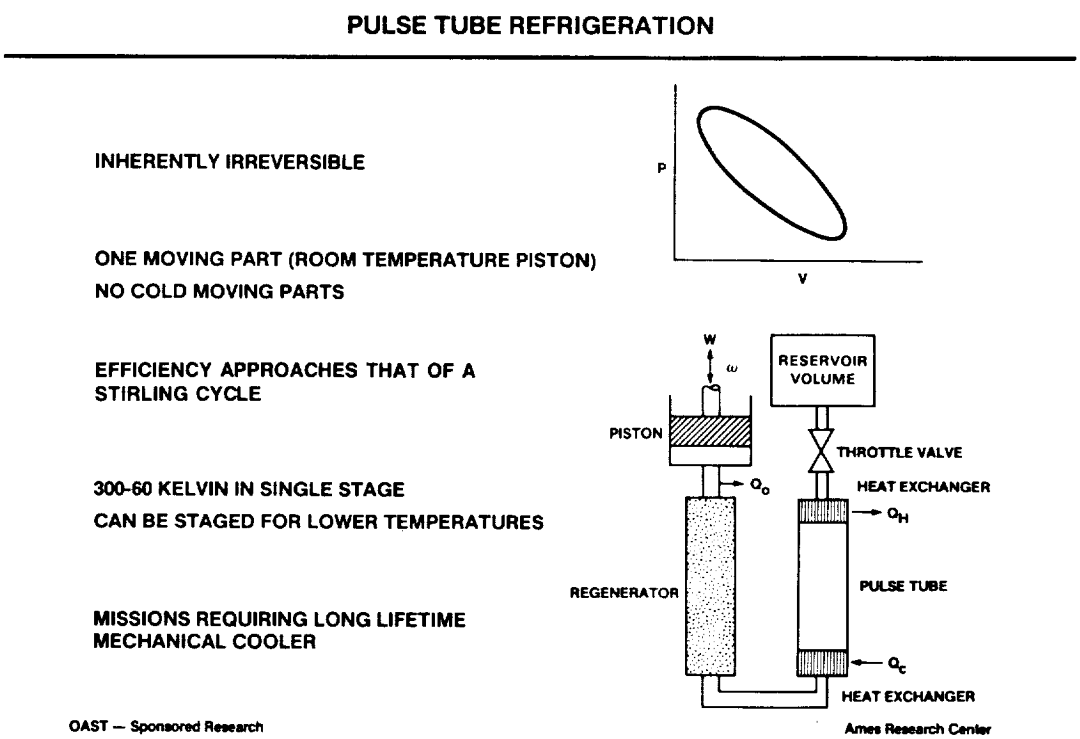


Figure 5

The limited ability to service spacecraft prior to launch has caused many difficulties with liquid helium systems. Missions such as GP-B and SHOOT are considering new approaches. GP-B is including a second helium tank. The tank holds only enough helium at atmospheric pressure (4.2K) to last during ground operations[5]. During which time it reduces the parasitic load on the main tank by subcooling the inner most shield.

SHOOT is taking another approach[6]. This is to launch with atmospheric helium and to pump down to the operating pressure on the way to orbit. This greatly simplifies ground operations at the expense of loosing 30-50% of the helium volume during the conversion process. At issue is how to contain the liquid during pump down in zero-g until the superfluid transition is reached (where upon existing techniques can be used to contain the helium). The technology to do this containment is only in the early stages of laboratory testing.

EXTENDED GROUND HOLD TECHNOLOGY

Technology	Status	Issues
Sacrificial tank	Concept only	Trade extra hold time for extra mass/ complexity
In-orbit conversion	Preliminary ground testing of one concept	Not yet demonstrated in flight

The alternative to storing liquid helium for instrument cooling is to replace it with a closed cycle refrigerator. Such a refrigerator would have to provide cooling to well below 2 K. Unfortunately, there are few refrigerators capable of doing this on the ground let alone in space. (Perhaps, the effort to develop the Superconducting Supercollider will improve things on earth.) For space applications, a suitable cooler could be made by adding an appropriate Joule-Thomson stage to a multi-stage version of any of the refrigerators discussed earlier. At present there is no effort to do this.

ALTERNATE TECHNOLOGIES

Technology	Status	Issues
Closed-cycle coolers	No suitable coolers	

SUB-KELVIN COOLERS

The general requirements for subkelvin coolers can be summarized as

- Operating temperatures:
  - various, over range 0.05-0.9 K
  - single cooler need not span entire range
- Heat load
  - 0 (absorb parasitic load only)
- Duty cycle
  - 85% to continuous
  - minimum time between recycling mission dependent
    - 20 min. for SIRTF (10-20 hr. preferred)

These requirements do not include single shot coolers that could operate only once per mission. Such coolers could be used on short missions or on missions where resupply were possible.

^{3}He refrigerators work by evaporative cooling of liquid ^{3}He. A problem of using this type of refrigerator in space is keeping the liquid near the detector while maintaining good thermal contact. A potential refrigerator has been tested on the ground in an inverted geometry where a high conductivity porous material was used to both confine the liquid and to conduct the heat from the bolometer to the liquid[7]. The effect of the larger pores on the heat transfer in low-g in the presence of both saturated liquid and vapor within the pores in unknown.

SUB-KELVIN COOLERS

Technology	Status	Issues
^{3}He refrigerators	Demonstrated on ground	Fluid retention with heat transfer in space
Dilution refrigerator	Conceptual only	Phase separation

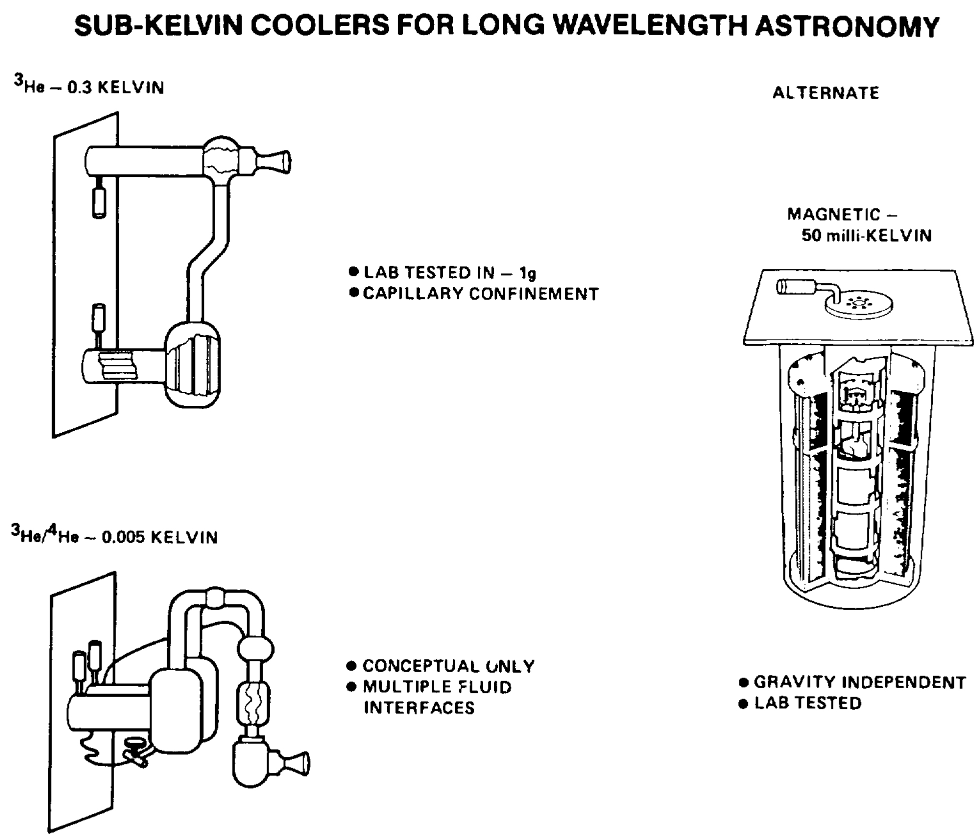


Figure 6

The preferred method to reach temperatures in the 0.005-0.5 K range in the laboratory is with dilution refrigerators. They are preferred because they can provide continuous cooling over the entire operating range. Two types of dilution refrigerators exist; ^3He circulating and ^4He circulating. Adapting the former to space requires the physical control of three fluid interfaces[8]: two vapor-liquid interfaces and a liquid-liquid interface in the mixing chamber. The ^4He circulating type has similar difficulties. In both types liquid-liquid interface presents the biggest problem because the surface tension is extremely low.

There is an alternative technology to liquid based sub-kelvin coolers. These are demagnetization coolers. These coolers are inherently gravity independant. Small units of the size and power suitable for space use have been ground tested in various laboratories and a full IR detector/magnetic cooler system has been tested at Mt. Palomar[9]. The remaining issues relate to developing light weight, compact shielding, to prevent the degradation of the solid refrigerants, and to developing techniques to fabricate a space qualifiable cooler while keeping the parasitic heat loads small[10].

ALTERNATE TECHNOLOGIES

Technology	Status	Issues
Demagnetization coolers	Ground demonstrated	Magnetic shielding, interactions with neighboring experiments, parasitic heat, space qualification

SUMMARY

Many of the issues raised here can be resolved by a ground based development program. There are, however, a few items that are difficult or impossible to adequately demonstrate on the ground. These items all relate to the behavior of liquid helium in the low gravity environment of space. These are summarized in the chart below.

SUMMARY
LIQUID HELIUM MICRO-G FLUID MANAGEMENT ISSUES

Technology	Issue
Storage	Bulk fluid behavior and interactions with pointing; liquid management devices; in space conversion to superfluid
^{3}He refrigerators	Liquid retention with heat transfer
Dilution refrigerators	Phase separation of multiple fluid interfaces

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