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MARS TRANSIT VEHICLE THERMAL PROTECTION SYSTEM: ISSUES, OPTIONS, AND TRADES

Norman Brown PD22
NASA-MSFC

ABSTRACT

A Mars mission is characterized by different mission phases. The thermal control of cyrogenic propellant in a propulsive vehicle must withstand the different mission environments. Long term cryogenic storage may be achieved by passive or active systems. Passive cryo boiloff management features will include multilayer insulation (up to 4 in.), vapor cooled shields, and low conductance structural supports and penetrations. Active boiloff management incorporates the use of a refrigeration system. Key system trade areas include active verses passive system boiloff management (with respect to safety, reliability, and cost) and propellant tank insulation optimizations. Technology requirements include refrigeration technology advancements, insulation performance during long exposure, and cryogenic fluid transfer systems for mission vehicle propellant tanking during vehicle buildup in LEO.

INTRODUCTION

The manned Mars missions are characterized by different mission phases. They are low Earth orbit (LEO) buildup, vehicle transit, and Mars orbit and surface. The thermal environment in each phase presents varied challenges to maintain thermal control of stored cryogenic propellants. For example, during LEO buildup, the vehicle is in a severe environment in which propellants must be stored for periods of months. This situation presents unique problems requiring a high performance and reliable thermal control system (TCS). Likewise, in the mission transit phase and Mars orbit, degraded insulation performance and system reliability become major factors when analyzing thermal environments. The thermal control options include active and passive type systems. The TCS and fluid acquisitions system must withstand each environment. Mission trades, issues, and technology requirements have been identified in order to determine the feasibility of the TCS options.

PASSIVE THERMAL PROTECTION

Advanced passive thermal control systems for cryogenic propellant tanks include the following: multilayer insulation (MLI), vapor cooled shields (VCS), thermodynamic vent system (TVS), low heat leak support struts, and a para-ortho hydrogen converter.

Multilayer insulation consists of thin radiation shields separated by low-conducting material. Coatings have been developed which provide environmental protection for the radiation shields with minimal performance loss. Cryogenic storage will require multiple layers of MLI with fabrication/assembly techniques that minimize seam heat leaks. Currently, there is no significant experience in installing or testing MLI in thicknesses over 4 in.

Another subsystem of passive thermal control is the vapor cooled shield (VCS). A VCS is similar in design to a conventional cross flow heat exchanger. Cryogenic fluid is routed across a metallic shield to intercept part of the heat leak which would otherwise reach stored cryogens. Assuming a LH_2/LO_2, propellant combination, the VCS system is most efficient when utilizing a coupled tank configuration (See Figure 1). Liquid or vapor may be drawn from the LH_2 tank for VCS use; however, studies have shown that saturated vapor (boiloff) may be the more feasible choice. After the vented fluid leaves the LH_2 heat exchanger, it is routed to the LO_2 tanks, in the coupled tank configuration, to perform the same function. Study results have shown approximately 50% reduction in heat leaks when using an optimally located VCS. Optimal location of a VCS is estimated to be 40%-50% of distance through the MLI measured from the tank wall.

The thermodynamic vent system performs a dual function. The primary function is to regulate tank pressure through controlled escape of saturated vapor (boiloff). The TVS is an effective pressure control device for any system (active or passive). Additionally, when used in conjunction with a VCS, the TVS provides the saturated vapor from the tank. Utilizing both the TVS and VCS and an effective insulation system, relatively long term storage of cryogens is possible.

Tank support struts are a key element in thermal design of cryogenic tanks. Heat leaks due to structural supports have been estimated at approx. 30% of the total environmental heat leak. Various composite materials with high strength and low conductivity properties are under investigation for use as support structures. Other options include

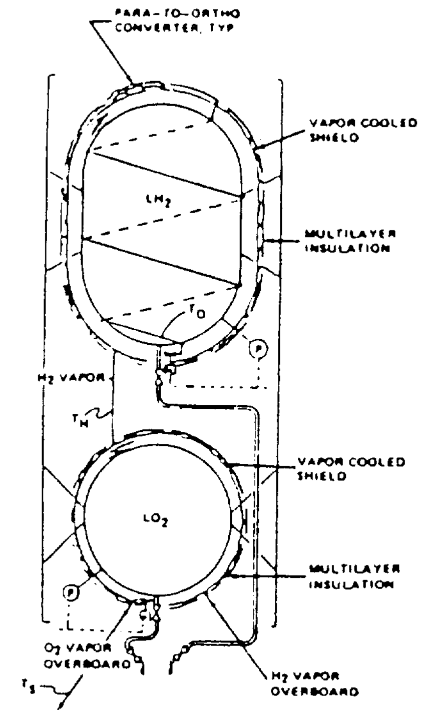

FIGURE 1. TYPICAL PASSIVE TPS (COUPLED TANK DESIGN)

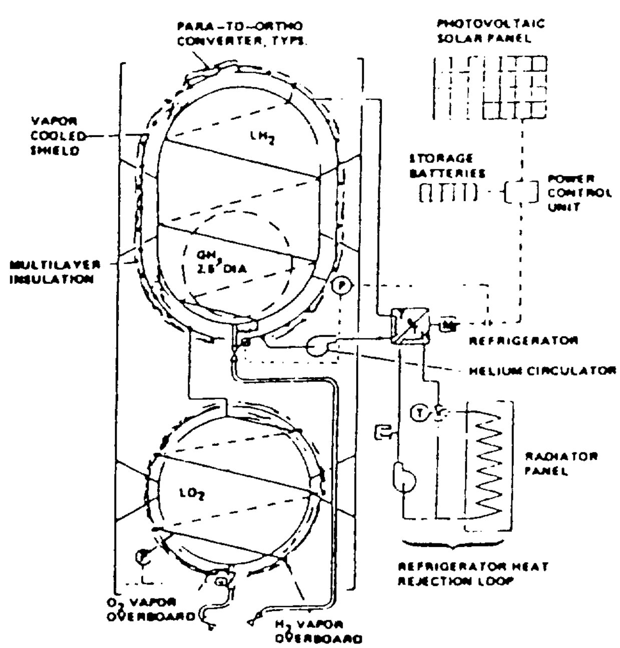

FIGURE 2. TYPICAL ACTIVE TPS

configurations of orbital disconnect struts where highly efficient struts are complemented by larger struts for support during launch loads.

A para-ortho hydrogen converter exploits the endothermic reaction of transforming para hydrogen into a para-ortho mixture. Feeding the para hydrogen saturated vapor (boiloff) over a catalyst bed allows additional heat adsorption. Development is continuing on improved catalysts and the converter efficiency.

ACTIVE THERMAL CONTROL

Primarily, there are two methods of active thermal control; refrigeration and reliquefaction. A refrigeration system design would intercept a large portion of the total heat load into the tanks. A reliquefaction system would be designed to reliquefy the boiloff of propellants. Elements in a spacecraft refrigeration system include the refrigerator, a power supply, power conditioning equipment, and a heat rejection system. (See Figure 2) A number of different refrigerator cycles have experienced various degrees of development. Current technology refrigerator cycles (such as Brayton, Claude, Stirling) have the potential to provide cooling in the range of 10K to 100K in capacities ranging up to a few hundred watts.

Reliquefaction would eliminate the need for any tank venting by reliquefying the boiloff vapor. The efficiences associated with reliquefaction are lower than those using refrigeration systems. Reliability, along with power, weight, and volume requirements are areas of development for space based reliquefaction systems.

FLUID TRANSFER

An important part of the propellant tankage design is fluid transfer. All transfers must be accomplished with minimum waste and ullage venting. The primary fluid transfer subsystems of concern are zero-g liquid acquisition devices, pressure control systems, and mass gauging systems. Currently, significant progress in liquid acquisition devices for storable propellants has been achieved. However, progress has been very slow in developing similar devices for cryogenics. Cryogenic tank pressures must be maintained within a specified range. Control of the pressure during engine burn may be maintained by inert gas or autogenous pressurization, that is, pumping liquid to a higher pressure, vaporizing and heating it, and then returning the heated vapor back into the tank. Thermodynamic venting (required with VCS) can be utilized to control pressure during storage periods. Mass gauging of cryogenic liquid in a tank under zero-g conditions has yet to be demonstrated. Currently, work is being conducted in this area. The potential use of subcooled or slush LH_2/LO_2 appears to be feasible to enhance propellant storage during vehicle buildup. The subcooled liquids will provide a limited thermal sink to absorb heat leaks. It is estimated that propellant with up to 60% solids content can still be transferred using state-of-the-art fluid lines.

ISSUES

Support structure requirements form the main issues in the LEO buildup phase. Assembly time should be minimized and propellant loading scheduled to optimize cryogenic control. With the relatively high boiloff rates in LEO, long term refrigeration of propellant tanks may be required. The main issue associated with active thermal protection systems is the power to performance ratio. A normalized range of required input power for refrigeration systems operating at LH_2/LO_2 temperatures are shown in Figures 3 and 4, respectively. The estimated refrigeration input range due to mission vehicle propellant boiloff is well above any current state-of-the-art system. Current systems are generally providing refrigeration capability of less than 50 watts, whereas this system will be required to have a capability in excess of 400 Watts. Additional issues when utilizing long term active systems include weight and volume requirements and reliability concerns. The passive TCS will experience thermal cycling, long term exposure, degraded insulation, and potential micro-meteoriod impact. The propellant transfer/resupply issues include transfer methods, advanced technology systems, and minimum leak joints for safety considerations.

The vehicle transit mission phase is characterized by relatively low boilff due to an efficient passive TCS and reduced environmental heating. An important point to make is the issue of preferred vehicle orientation. The preferred orientation of the space vehicle can be represented as the longitudinal axis of the vehicle "pointing" toward the sun. This orientation results in minimum tank area being exposed to direct solar flux. Any deviation of the longitudinal axis of the vehicle will expose greater surface area to solar flux and result in increased environmental heating.

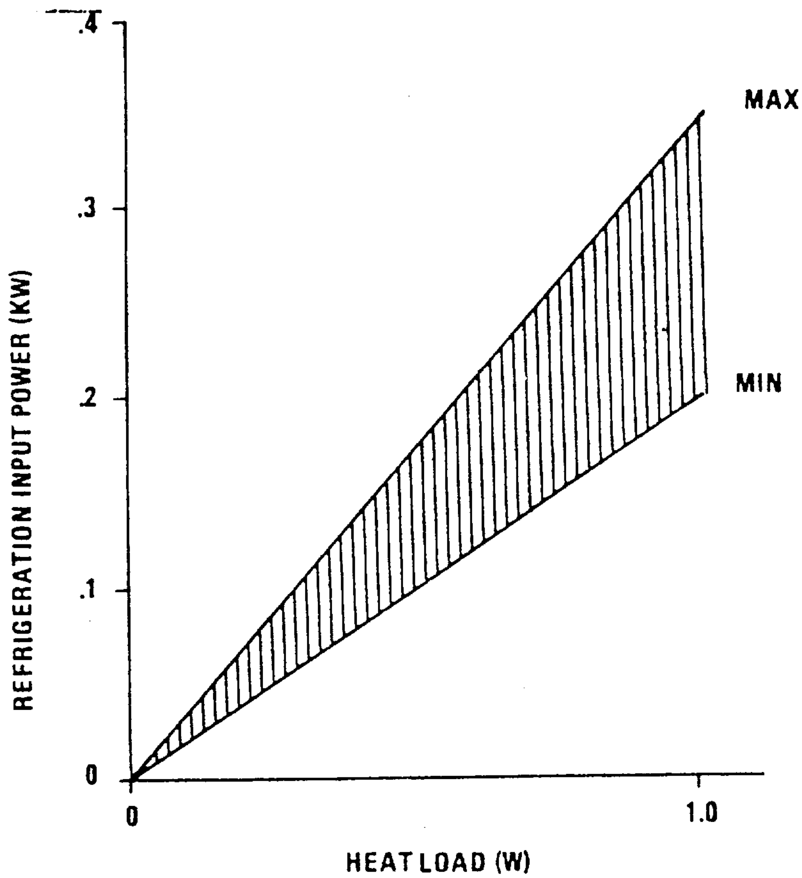

FIGURE 3. REFRIGERATION REQUIREMENTS @ LH_2 TEMPERATURE (38^oR)

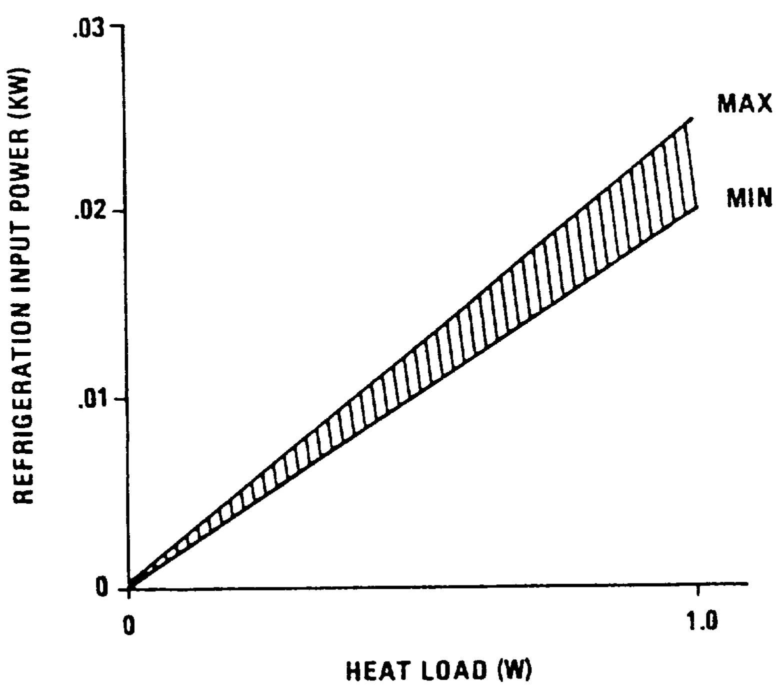

FIGURE 4. REFRIGERATION REQUIREMENTS @ LO_2 TEMPERATURE (162^oR)

Additional insulation or shields may be placed around tank bulkheads (in the all cryogenic stage configuration) to reduce environmental heating effects. Long-term space exposure effects, e.g. degraded performance of MLI/coatings, are areas of concern when trying to maintain very low heat leak rates.

The Mars orbit and surface mission phase is concerned with variable environmental conditions. The vehicle in orbit around Mars could experience medium environmental heating rates (compared to LEO) due to orientations dictated by mission requirements. If a preferred orbital orientation could be achieved (resulting in minimal surface area exposed to direct solar flux), environmental heating would be reduced. The TCS must maintain a high level of performance throughout the Mars mission duration. The insulation performance is common to other mission phases. The lander propellant tanks (LO_2) must have additional thermal control due to degraded insulation performance on the Martian surface resulting from increases in pressure (i.e. gas conduction in insulation). A Dewar type tank design may be used in order to minimize cryogenic boiloff during the surface stay time. Dewar tank sizing, along with weight are issues that impact the MEM vehicle.

KEY TRADES

In LEO, the cryogenic boiloff rate will be relatively high, potentially requiring a form of active thermal control. Refrigeration, reliquefaction, or a combination could be used. The support structure system would have to be sized for the time period required during LEO buildup. Key trades identified for active thermal control systems include: 1) performance versus power requirements, 2) performance versus weight/volume requirements, and 3) reliability issues. Additional analysis should evaluate the impact of providing an active system during the entire mission due to environments, driven by vehicle orientation, dictated by mission requirements.

Insulation optimization is another key trade in the long term control of cryogenic propellants. Preliminary estimates show the optimum range of tank insulation to be 2-4 in. (See Figures 5 and 6). Trades identified for insulation optimization include insulation performance, weight, and degraded characteristics.

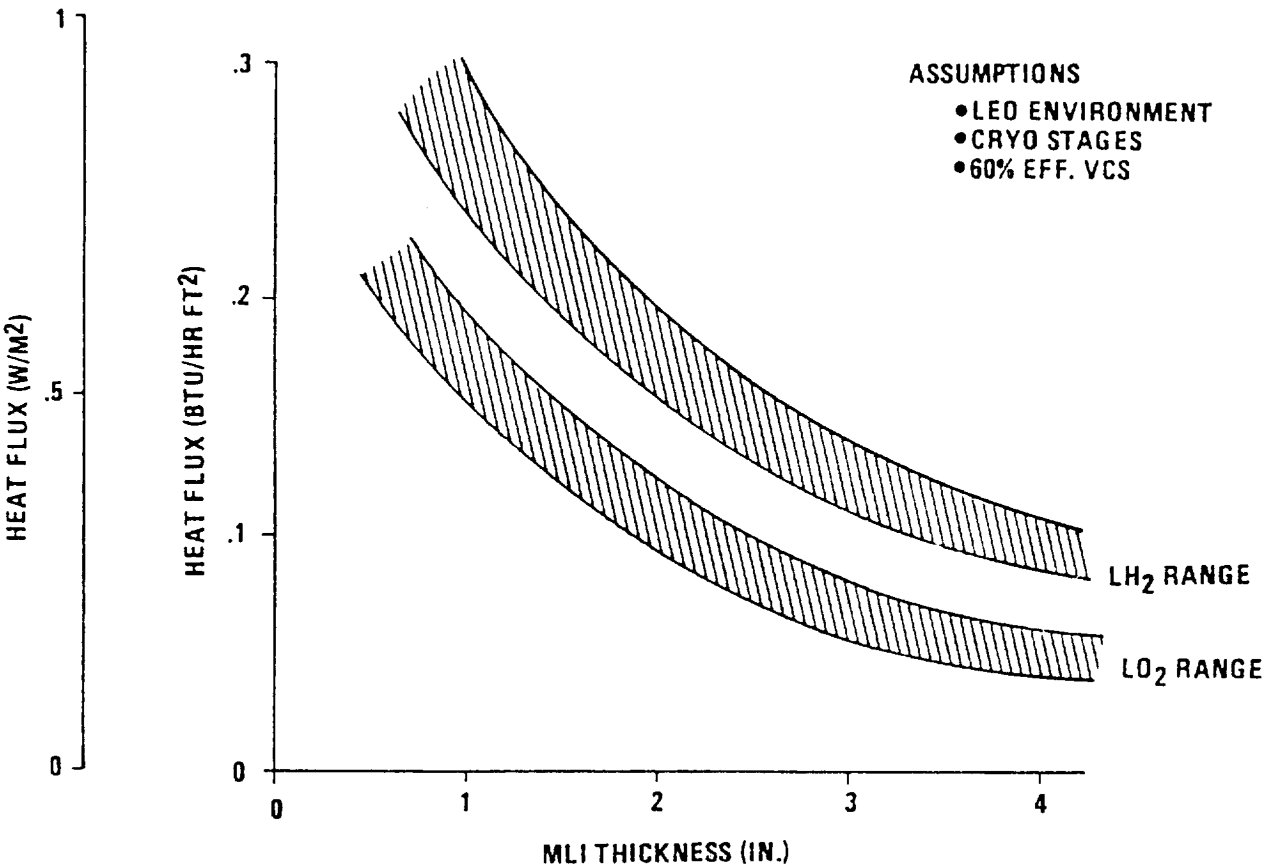

FIGURE 5. MARS TRANSIT VEHICLE HEAT FLUX VS. MLI THICKNESS

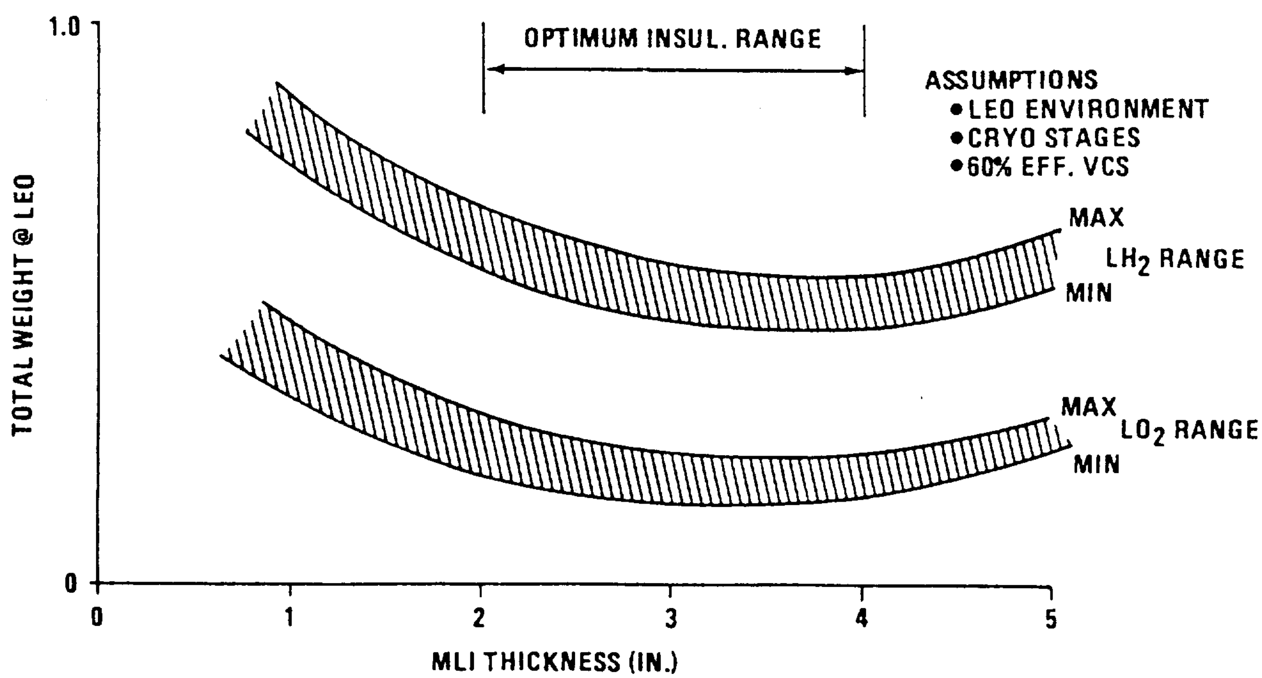

FIGURE 6. MARS TRANSIT VEHICLE TYPICAL INSULATION OPTIMIZATION

A third trade area is propellant transfer methods (mainly concerned with LEO operations). The option of zero-g versus induced artificial-g transfer should be evaluated. Artificial-g fluid transfer may be achieved by thruster firing, rotation of tethered vehicles, etc. Liquid acquisition devices for zero-g cryogenic fluids must be developed and tested. Systems trades should include various acquisition systems and fluid transfer systems.

TECHNOLOGY

Refrigeration system technology advancement could be required for utilization on Mars missions. Due to the vehicle tank sizes and duration in LEO, the anticipated refrigeration power input range could approach a megawatt (MW), using current efficiencies. The current capacities of refrigeration systems are well below the MW range. Additionally, support structure weight and volume restraints will place restrictions on any form of active thermal protection system. Another technical concern is the system's reliability during long term exposure. Factors affecting reliability and performance of active systems include the retention of the working fluid, the contamination of internal components, and the need for advanced electronic controls.

High insulation performance requirements are common to all mission phases. Current state-of-the-art multilayer insulation properties have been shown to degrade during long term exposure. Improvement in thermal protective coatings will be required for the Mars mission. Support structure heat leaks must be minimized using advanced composite materials or deployable struts.

Technology drivers in the fluids transfer area include; 1) minimal waste transfer, 2)advanced liquid acquisition devices, and 3) mass gauging techniques. Current estimated fluid transfer losses are less than 5 percent. Liquid acquisition systems must be developed and tested for use in a zero-g environment. Mass gauging of cryogenic propellants must be successfully demonstrated. In order to utilize a no vent transfer system, leak proof joints/fluid interfaces must be developed.

SUMMARY

The Mars mission transit vehicle TCS options include active and passive systems. Insulation performance, active TCS support structure requirements, and propellant transfer highlight the vehicle issues while in LEO. During vehicle transit and Mars orbit, reduction of environmental heating through preferred vehicle orientation is a key issue. Vehicle orientation may be affected by mission requirements, thus varying the environment the vehicle experiences. The transit vehicle trades are identified as active TCS utilization, insulation optimization, and propellant transfer methods. Advanced active TCS, advanced MLI and other passive TCS options, and fluid transfer systems for zero-g resupply are recommended for technology development.

REFERENCES

1. D. Elliott, "Advanced Thermal Control Technology For Cryogenic Propellant Storage," NASA-OAST, FY85 Quarterly Report No.1.
2. T.J. Kramer, E.W. Brogren, and B.L. Siegel, "Evaluation of Propellant Tank Insulation Concepts for Low Thrust Chemical Propultion Systems," Boeing Aerospace Company, March 1984.
3. "Long Term Cryogenic Storage," Martin Marietta, July 1982.
4. J.W. Robinson, R.T. Giellis, and D.A. Fester, "Long Term Cryogenic Storage Study," Martin Marietta, December 1984.

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