Bellcomm

955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

date: August 6, 1971

to: Distribution

B71 08017

from: A. S. Haron

subject: Pressure Rise Rates of the LM-10 Supercritical Helium (SHe) Tank - Case 320

ABSTRACT

A screening test conducted on the LM-10 supercritical helium tank in May 1971 indicated a significant increase in the pressure rise rates in comparison to rates measured on the same tank in June 1970. This caused enough concern to warrant an investigation as to whether or not the tank should be replaced prior to Apollo 15 flight. The investigation included two re-tests of the LM-10 tank, in addition to tests of two other tanks of similar construction.

The investigation resulted in a decision not to replace the LM-10 tank. This decision was based on:

1. The conclusion that it is highly unlikely that the tank pressure will exceed its redline value of 1780 psia prior to fulfilling its mission, whether normal or abort.

2. The possible adverse effects of replacing the tank on other LM hardware.

(NASA-CR-121316) PRESSURE RISE RATES OF THE LM-10 SUPERCRITICAL HELIUM /SHE/ TANK (Bellcomm, Inc.) 12 p

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MEMORANDUM FOR FILE

I. INTRODUCTION

Helium, which is essential for pressurizing the LM-DPS propellant tanks, is stored as a supercritical fluid in a spherical tank insulated by an evacuated annulus 2.75" thick. The annulus is normally evacuated to below 10^{-5} TORR to eliminate convective heat transfer, and packed with 173 layers of aluminized mylar to minimize radiative heat transfer from the environment to the helium. For tanks which are well-insulated the normal heat leak results in pressure rise rates of approximately 8, 6 and 4 psi/hr at full, 50% and 20% loads, respectively.

Special screening tests have been devised to check-out the SHe tanks prior to each Apollo flight. The LM-10 tank, which is to be carried on Apollo 15, was tested in May 1971 and found to possess pressure rise rates significantly higher than those measured during a similar test conducted in June 1970. This variance caused enough concern to warrant an investigation by GAEC, MSC, and NASA Headquarters as to whether or not the tank should be replaced prior to the flight. This memorandum summarizes the findings and conclusions of that investigation.

II. SCREENING TESTS' RESULTS

Figure (1) charts the results of the two screening tests referred to above. Also, Table (1) lists the results of all LM-10 tank tests and compares them with similar tests

performed on other SHe tanks. The following salient observations can be made:

1. The LM-10 tank exhibited a noticeable increase in pressure rise rate, which can be attributed to degradation of the effectiveness of the insulation having occurred over a period of one year. On the other hand, no further degradation could be detected through tests conducted between May 28, 1971 and June 17, 1971.

2. Comparison of LM-10 tank with S/N 120 indicates the presence of a residual gas in the annulus of the former. The molecules of this residual gas are desorbed with temperature rise, causing the effective conductance, and hence the pressure rise rate, to increase. It is also of importance to emphasize the layout of the fill, vent and heat exchanger lines which wind their way within the annulus, as shown in Figure (2). These lines are subjected to higher extremes of temperature in the screening tests than in actual flight, due to the need for fast pressurization from 200 psi to 1200 psi. This pressurization is accomplished during the screening tests by circulating helium at room temperature through the heat exchanger lines. Consequently, the desorption of any residual gas in the annulus is aggravated during the screening tests, leading to the expectation that the flight pressure rise rate will be less severe. In flight, the only tank pressurization by flowing hotter helium in the heat exchanger is done simultaneously with mass removal from the tank.

III. THERMODYNAMICS CONSIDERATIONS

The pressure rise rate in the cryogenic helium storage tank during standby is caused by the heat leak through the tank insulation. The mathematical representation (neglecting the thermal mass of the tank shell) is:

$$\dot{p} = \frac{\phi}{V} Q = \frac{\phi}{V} \frac{A}{\ell} K(\Delta T) \quad \ldots\ldots \qquad (1)$$

where

$\dot{p}$ = pressure rise rate, psi/hr

$\phi = \frac{1}{\rho} \left(\frac{\delta P}{\delta U}\right)_{\rho}$, psi · ft^3/Btu

A = tank surface, ft^2

K = effective thermal conductivity of tank insulation, Btu/hr ft °R

ℓ = thickness of insulation, ft

V = volume of tank, ft^3

ΔT = temperature difference between the ambient and the helium bulk, °R

The variation of ϕ and ΔT with quantity of helium remaining in the tank is shown in Figure (3).* Substituting the physical constants for V = 5.9, A = 15.8 and ℓ = .229, equation (1) is reduced to:

$$\dot{p} = 11.7\ K\phi(\Delta T) \quad \ldots\ldots \qquad (2)$$

From equation (2), it is possible to calculate the effective insulation conductance (K) for each phase of the screening tests. Such calculations, taking into consideration the tank shell thermal mass, resulted in the plot shown in Figure (4). Examination of this plot shows succintly how the contaminant gas in the annulus is acting to produce the results manifested by the screening.

With the exception of the extreme right data point of the May 28, 1971 test, which can be attributed to measurement inaccuracy, there is a steady increase in K with tank surface temperature. This can be logically attributed to the fact that the contaminant gas is being progressively desorbed. The highest rate of desorption appears to occur between 47°R and 63°R. It is suspected from this behavior that the majority of the residual gas is hydrogen, although other less likely contaminants might produce the same result.

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*J. A. Saxton, "Supercritical Helium Tank Presentation to R. A. Petrone", Memorandum for File, B71 06036, June 23, 1971.

Regardless of the composition of the residual gas in the annulus, it can be assumed with confidence that the upper operating limit for K in the LM-10 tank is of the order of 9×10^{-4} Btu/hr ft °R. This value of K corresponds to a pressure rise rate in phase C, which simulates the period between a first and second DPS-burn, of less than 20 psi/hour.

IV. MISSION CONSIDERATIONS

1. Normal Mission

In a normal mission, the SHe tank will remain full, i.e., as in phase A, until PDI which occurs at 104 hours GET. With on-time launch pressure being 550 psia, and redline pressure at PDI of 1780 psia, the allowable pressure rise rate is 11.8 psi/hr. Should launch be delayed 24 hours, causing the pressure at launch to increase to 780 psia, the allowable pressure rise rate to PDI would be 9.6 psi/hr. In both cases, the allowable rate is comfortably higher than the phase A rates measured in any of the screening tests conducted on LM-10 tank. Therefore, it can be concluded that there is no risk involved in flying this tank on a normal Apollo 15 mission.

2. Abort Missions

Of the abort missions requiring DPS burns, there are those requiring only one DPS burn (Abort Modes I and III) and those requiring two DPS burns (Abort Mode II):

a. Abort Modes I and III: Since both of these modes require only one DPS burn, occurring prior to scheduled PDI, the SHe tank pressure would be more favorable (lower) than in a normal mission. Therefore, these modes should present no special concern.

b. Abort Modes II: The risk involved in this abort mode is based on the need for two DPS burns, thus having to live with a helium pressure rise rate corresponding to that of phase C of the screening tests during the coast time between the two burns. By restricting this coast time to not more than 15 hours, the allowable pressure rise rate is 26 psi/hr. This is comfortably higher than any of the phase C rates measured during the screening tests. Therefore, it appears that the risk involved even in this worst abort mode is minimal.

3. Other Alternatives

The above-described abort modes can be carried out by the astronauts without help from Mission Control, e.g., with multiple failures of SPS and all modes of communication. With communications intact, there are several means whereby an excessive SHe tank pressure rise rate between burns can be alleviated, when detected, such as supplying real-time instructions for helium venting procedures.

It should be emphasized that a failure of SPS at LOI, necessitating abort, is highly unlikely. Also, failure of SPS between 145 and 198 seconds of SPS burn, necessitating Mode II abort, is even more unlikely.

V. DECISION

The decision was made not to replace the LM-10 SHe tank, based on the following arguments:

1. As explained above, the risk involved in flying with this tank is minimal and can be aggravated only through simultaneous multiple failures involving several different spacecraft systems, which are highly unlikely.

2. Replacement of the SHe tank would have required SLA cutout and repair, possibly damaged other hardware in the vicinity of the tank and could have delayed the Apollo 15 launch date.

VI. UNRESOLVED MATTERS

In spite of the decision to retain the LM-10 SHe tank on Apollo 15, there remains some questions as to why the tank behaves the way it does. These questions are academic as far as Apollo 15 flight is concerned. However, effort is being continued to develop a better understanding of the following:

1. The exact composition of the residual gas in the annulus.

2. The mechanisms causing the observed changes in the effective conductance of the insulation.

3. The effect on pressure performance of such matters as double evacuation, shelf life, helium loading procedures and screening test procedures.

A. S. Haron

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TABLE (1)

SHe TANK SPECIAL SCREENING TEST RESULTS

	LM-8*		LM-9*		LM-10*				LM-11**	S/N 120***	
TEST NO.	KSC	KSC	1ST	2ND	1ST	2ND	3RD	4TH			
ACCEPT. DATE	8/12/57		10/3/67		9/23/68				10/19/68		
TEST DATE	5/11/70	11/27/70	5/16/70	6/6/71	6/70	5/28/71	6/10/71	6/17/71		1/71	6/9/71
INITIAL LOAD	44 LBS	44 LBS	44 LBS	51 LBS	44 LBS	51 LBS	44 LBS	44 LBS	44 LBS	44 LBS	51 LBS
PHASE A	8.0	8.0	7.6	8.83	8.5	9.45	8.7	8.4	8.2	7.72	9.0
PHASE B	9.9	10.4	9.8	14.25	10.5	15.8	12.6	12.8	7.8	7.24	7.4
PHASE C	15.0	15.65	14.7	18.33	14.5	19.3	18.2	17.2	6.4	5.27	6.06
PHASE D	11.7	12.02	9.3	9.9	9.9	11.3	13.75	12.15	4.1	3.65	4.3

LM-9 WORST CASE ABORT SIMULATION WITH 51 LBS	
PHASE A	8.8
POST DPS-1	15.5
POST DPS-2	19.0

*SINGLE EVACUATED TANK
**DOUBLE EVACUATED TANKS
***SINGLE EVACULATION FOR INSULATION AND OUTER SHELL.

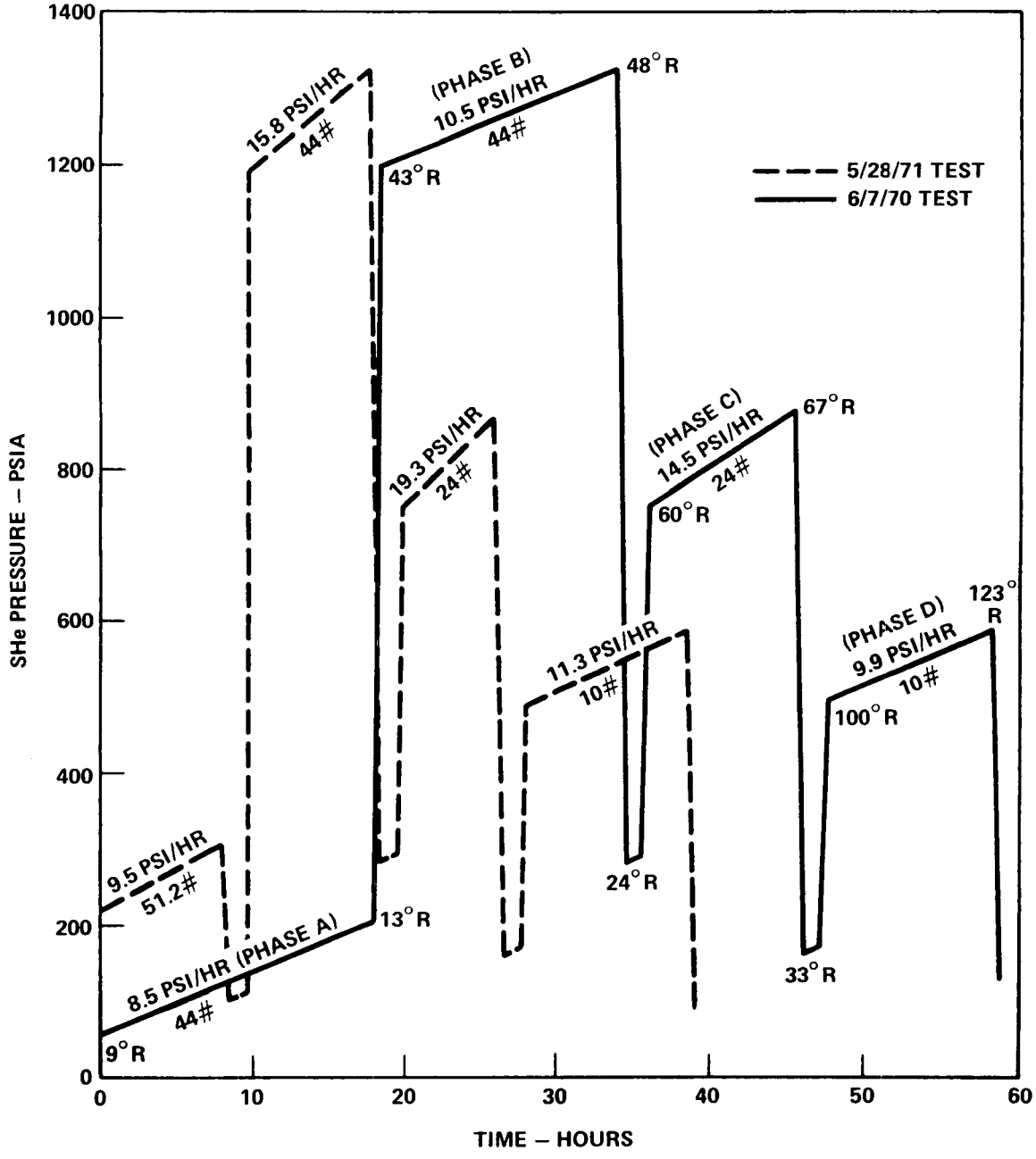

FIGURE 1 - LM-10 SHe TANK SCREENING TESTS

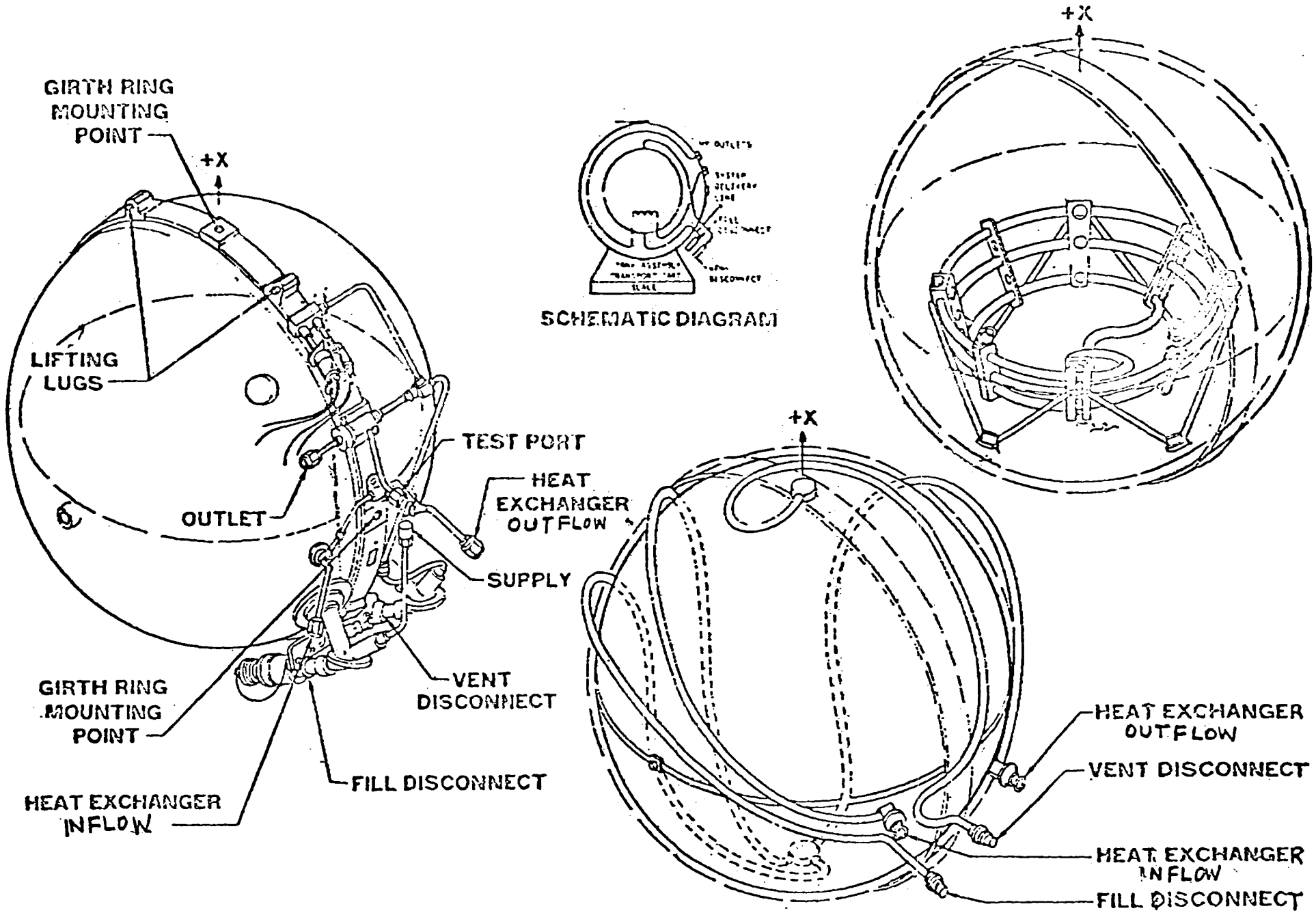

FIGURE 2 - HEAT EXCHANGER AND TUBING DETAIL

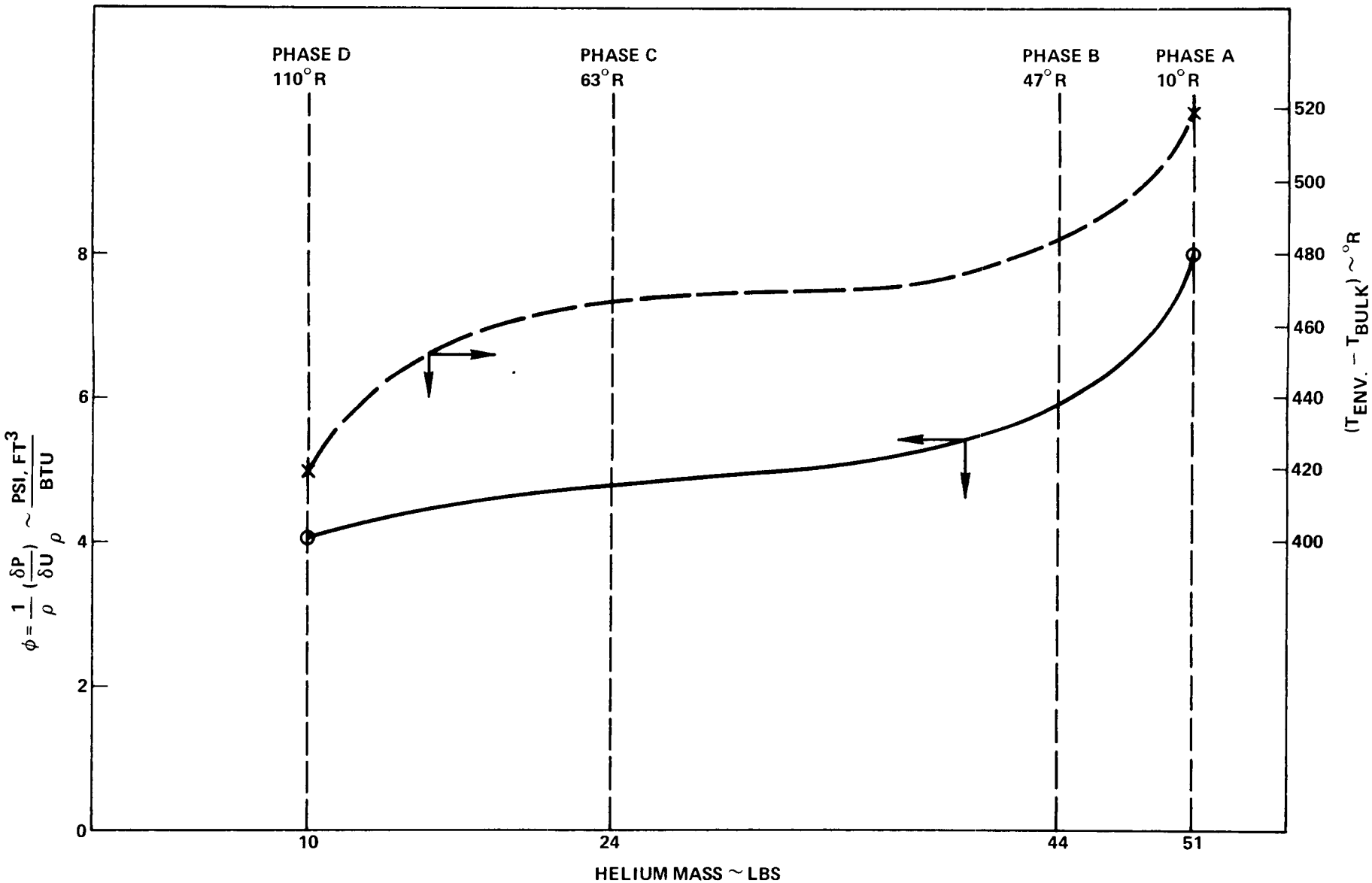

FIGURE 3 - VARIATION OF ϕ AND ΔT WITH HELIUM QUANTITY IN TANK

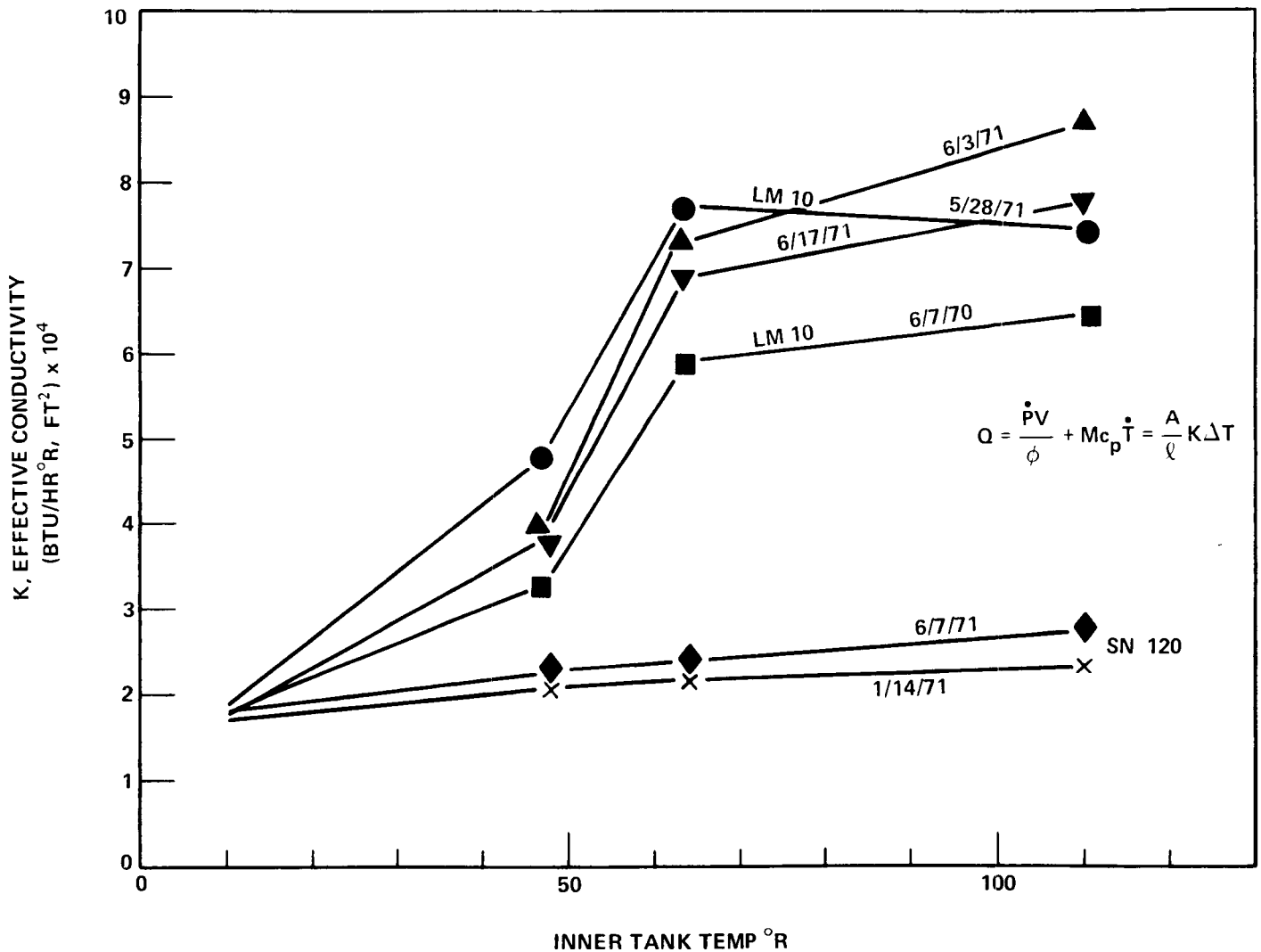

FIGURE 4 - EFFECTIVE CONDUCTIVITY – LM SHe TANK

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