Bendix

Instruments &
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Division

NASA CR 99536

Bendix Instruments & Life Support Division

DEVELOPMENT OF AN SPS/DPS HYDROGEN SHROUDED CRYOGENIC HELIUM STORAGE SYSTEM

CONTRACT: NAS9-7337

SUMMARY REPORT

PREPARED FOR:

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I. INTRODUCTION

Cryogenically stored supercritical helium gas is presently being used as the pressurant for on-board propellant tanks on the Apollo Lunar Module. The present system requires that the helium be transferred into the dewar in a sub-critical liquid state which involves sophisticated ground stand-by equipment to fill the unit. This transfer approach is also sensitive to atmospheric conditions which can effect the final helium state and the amount of usable pressurant stored.

An alternative approach to the above method is to store the helium gas at a higher temperature and pressure using a secondary cryogenic fluid. This concept can be achieved by adopting the Bendix developed integral shroud system whereby the secondary fluid is used as a refrigerant surrounding the primary fluid contained within the inner vessel.

By using the shroud tankage method, all the environmental heat leak is intercepted by the secondary fluid which vents to atmosphere leaving the primary helium unaffected by this standby period.

The objective of the NAS9-7337 contract was to develop and test a cryogenic, hydrogen shrouded helium storage and supply system. The system was sized for the Lunar descent and service module propulsion systems requirements.

The system described herein and shown in Figure 5 was successfully tested to approximate LM requirements and demonstrated the improved ground servicing and flight standby characteristics over the current SPS/DPS system.

This program was a follow on to contract NAS9-4634. Because of the significant improvement of the shroud concept and application potential to Propulsion Systems, it is recommended that this program be extended to include qualification for Lunar Module application.

II. STUDY OBJECTIVES

The overall objective of this development contract was to upgrade the integral shroud tank concept initially developed under a previous NAS9-4634 contract to meet the approximate LM descent propulsion system requirements. In this respect, the increased size of components compatible with the helium pressurant storage requirements was a major factor.

Study objectives also included the development of a dewar container with maximum reproducible and reliable heat leak characteristics to meet prolonged prelaunch and on-board standby requirements.

III. RELATIONSHIP TO OTHER NASA EFFORTS

The effectiveness of the shrouded dewar concept for both pre-launch and in-flight standby storage of various cryogens was clearly demonstrated by the results of NASA contract number NAS9-4634 carried out by The Bendix Corporation, Instruments & Life Support Division for the Propulsion & Power Division of NASA-MSC. Referring in particular to the primary storage of helium enshrouded by various subcritical refrigerants, Figures 1, 2, 3 and 4 reproduced from this report illu-

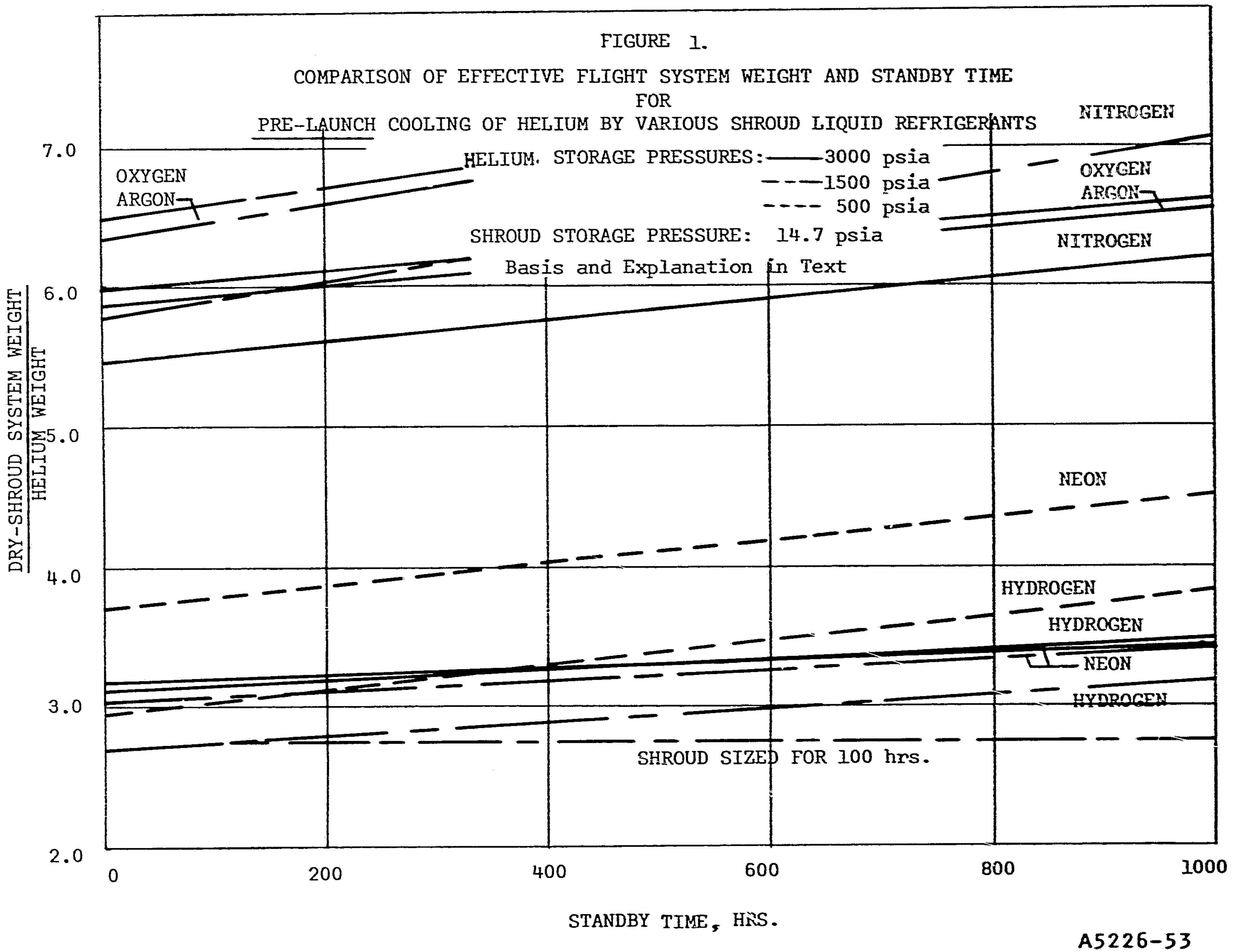

FIGURE 1.

COMPARISON OF EFFECTIVE FLIGHT SYSTEM WEIGHT AND STANDBY TIME
FOR
PRE-LAUNCH COOLING OF HELIUM BY VARIOUS SHROUD LIQUID REFRIGERANTS

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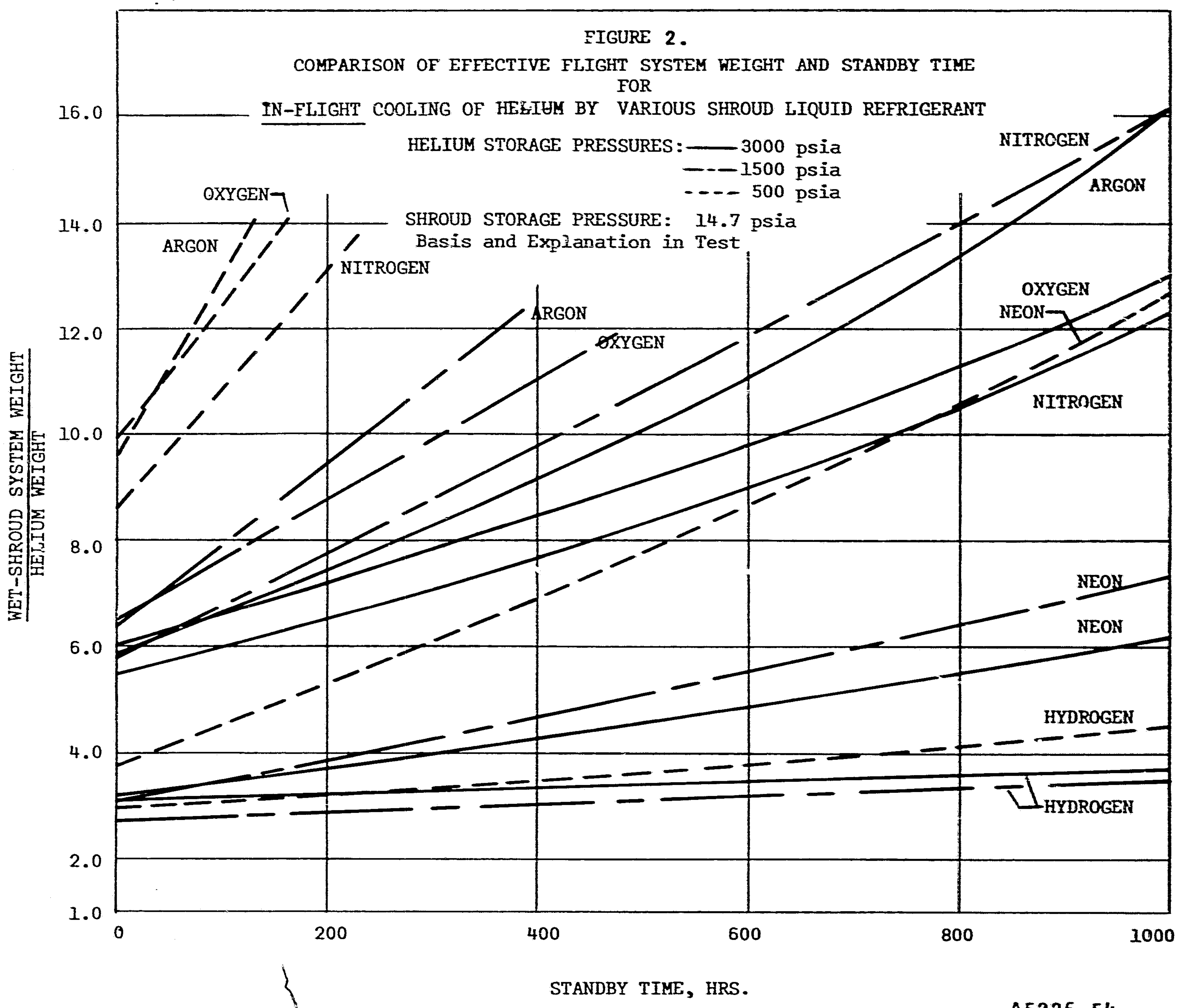
FIGURE 2.

COMPARISON OF EFFECTIVE FLIGHT SYSTEM WEIGHT AND STANDBY TIME FOR IN-FLIGHT COOLING OF HELIUM BY VARIOUS SHROUD LIQUID REFRIGERANT



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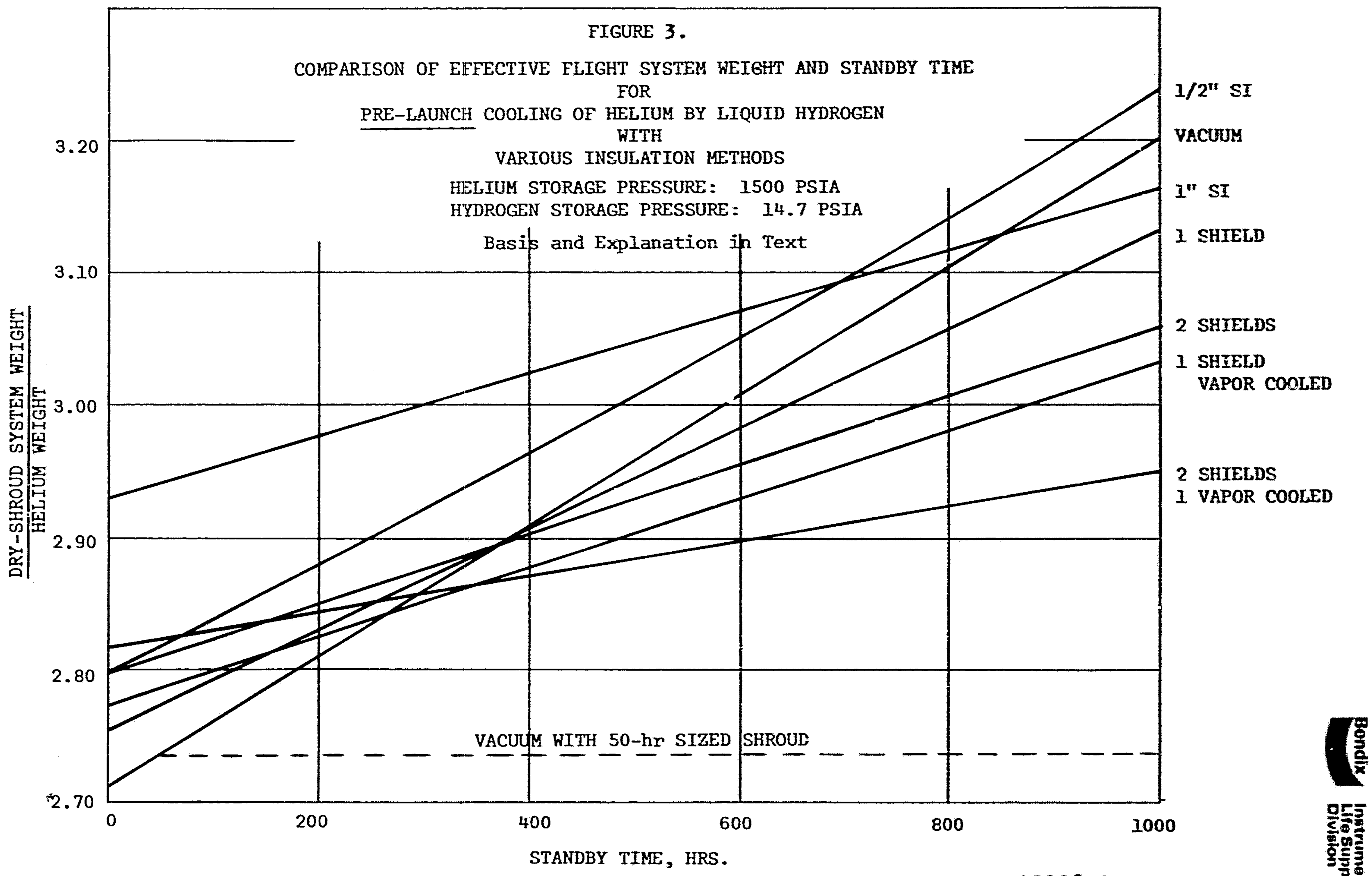

FIGURE 3.

COMPARISON OF EFFECTIVE FLIGHT SYSTEM WEIGHT AND STANDBY TIME
FOR
PRE-LAUNCH COOLING OF HELIUM BY LIQUID HYDROGEN
WITH
VARIOUS INSULATION METHODS

HELIUM STORAGE PRESSURE: 1500 PSIA
HYDROGEN STORAGE PRESSURE: 14.7 PSIA

Basis and Explanation in Text

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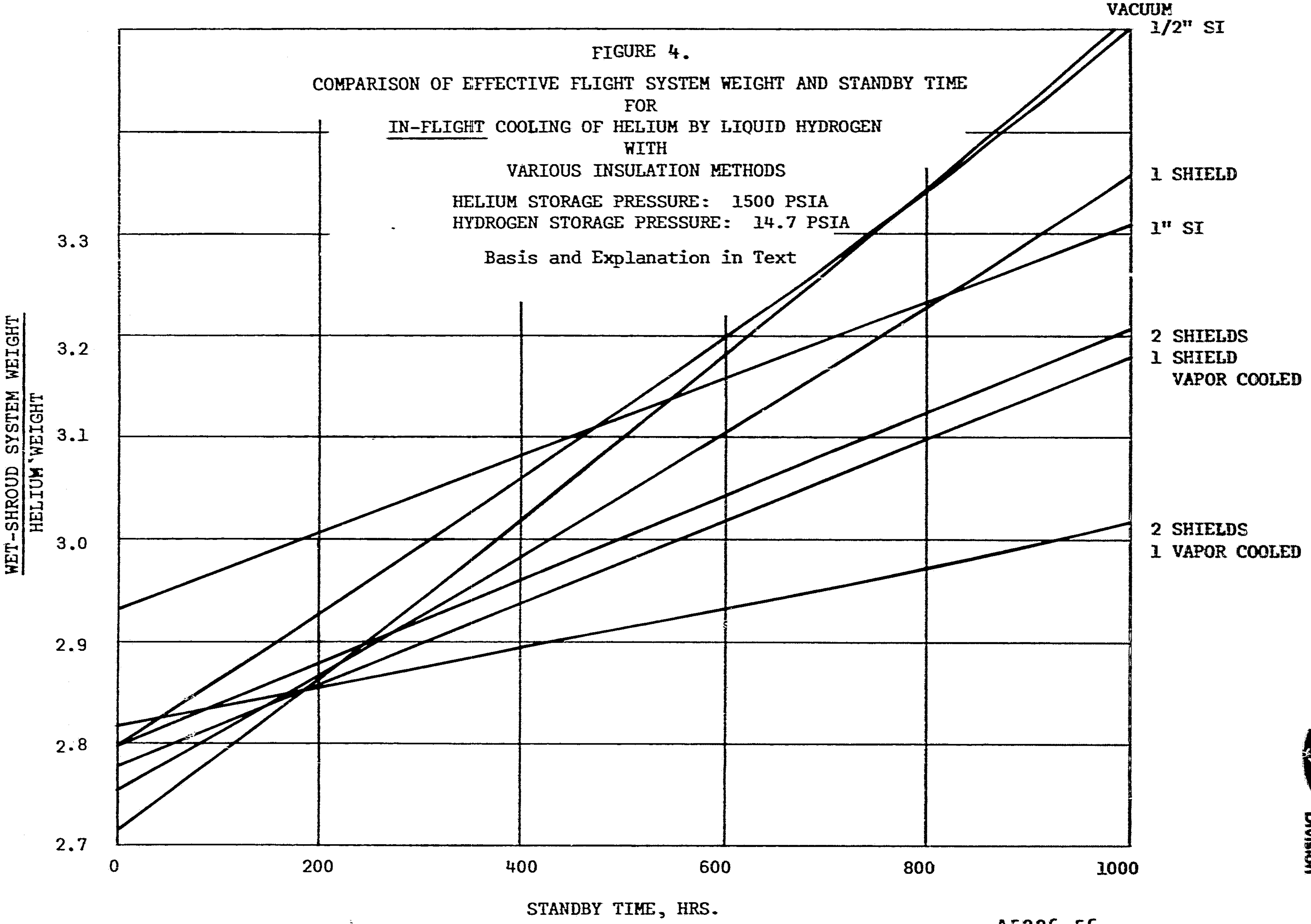

FIGURE 4.

COMPARISON OF EFFECTIVE FLIGHT SYSTEM WEIGHT AND STANDBY TIME
FOR
IN-FLIGHT COOLING OF HELIUM BY LIQUID HYDROGEN
WITH
VARIOUS INSULATION METHODS

HELIUM STORAGE PRESSURE: 1500 PSIA
HYDROGEN STORAGE PRESSURE: 14.7 PSIA

Basis and Explanation in Text

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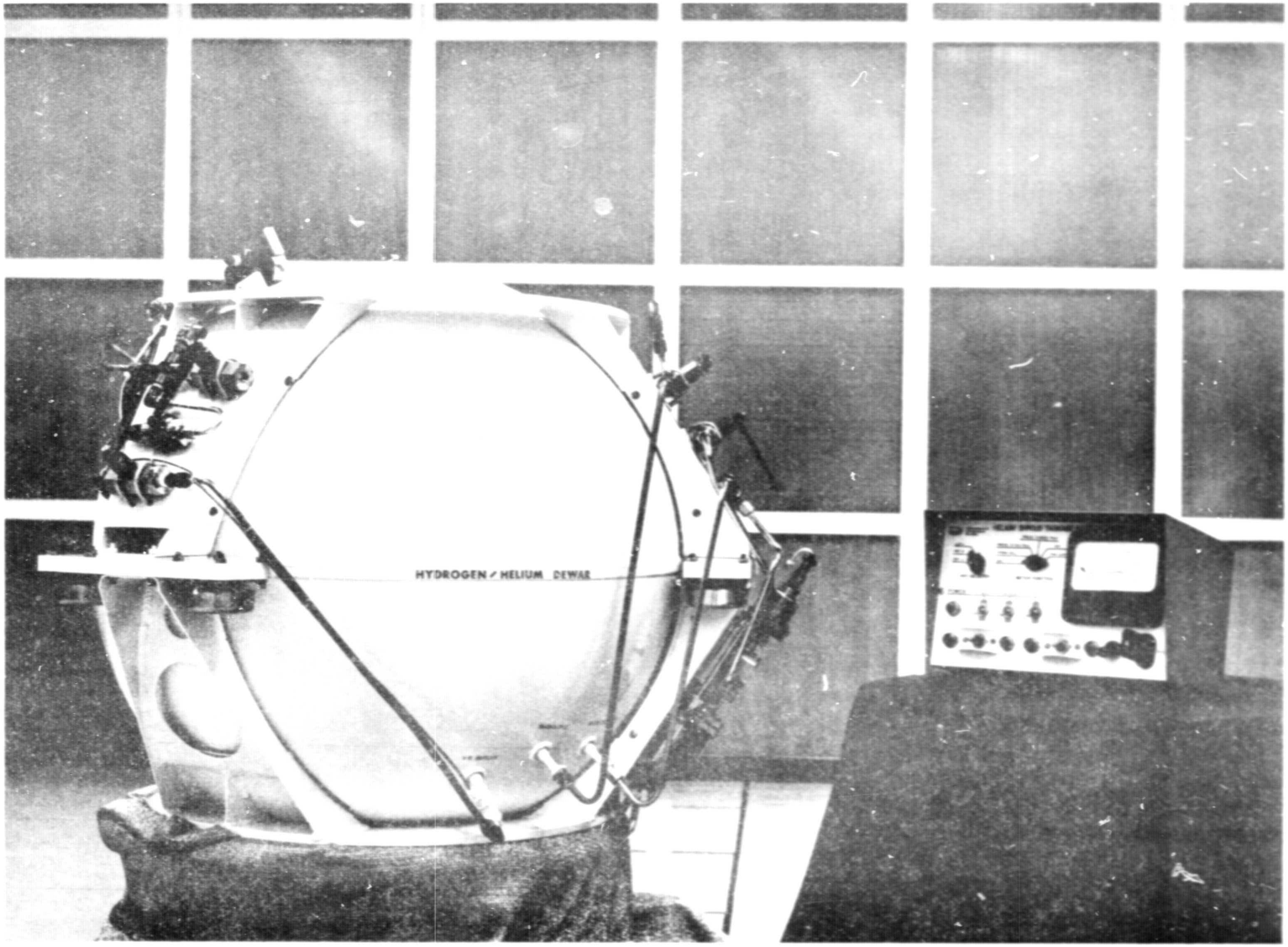


FIGURE 5 Helium Shroud Tankage System

strate the advantages of using hydrogen as the secondary fluid. These curves showed that a hydrogen shrouded helium system operating at about 2000 psia provides the best weight optimized storage system for both pre-launch and on-board standby The curves also showed that a dewar design which incorporates two discrete radiation shields with the inner shield being vapor cooled by the evaporated shroud fluid provides optimum design capabilities.

IV. METHOD OF APPROACH & PRINCIPLE ASSUMPTIONS

The helium tankage assembly designed and constructed under the present contract employs the recommendations contained in the NAS9-4634 final report.

The basic design of Figure 6 is a dual wall vacuum dewar employing the Bendix developed discrete radiation shielded concept using two shields with the inner shield being vapor cooled by the vented hydrogen.

The dewar is designed to store 50.0 pounds of helium at 2000 psia and 37°R by enshrouding the helium gas with liquid hydrogen at standard atmospheric conditions.

By employing the integral shroud design concept, the vacuum void exists between the shroud and enclosing outer shell thus reducing the environmental heat leak to a mainly radiative heat transfer mode.

The Bendix developed radial bumper suspension system is used to suspend the inner vessel and shroud assembly concentric within the enclosing spherical outer shell.

Wrapped around the inner vessel outer surface and contained within the shroud annulus is 1/8" thick Teflon felt which is aimed at providing a "wicking action" for the liquid hydrogen in the shroud and thus improve system standby capabilities.

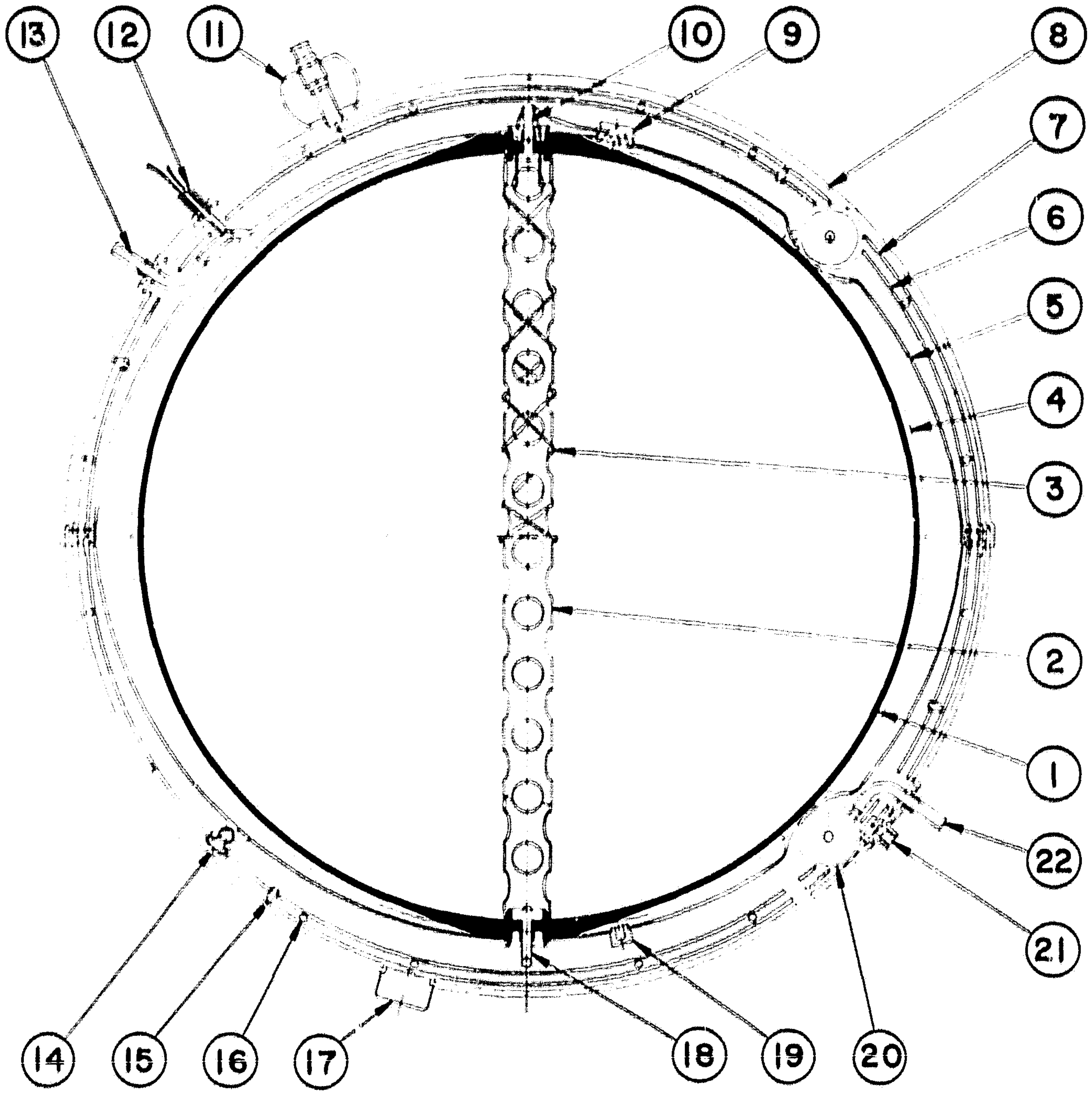
Because of tooling availability and the possibility of overall size reduction, a tapered shroud annulus which tapers from the poles to the equator is used in the design. This also provides a comparison between the concentric annulus shroud geometry used on the NAS9-4634 unit and a tapered geometry.

The basic dewar assembly is mounted in a cradle-type mount carriage which provides six point center plane attachment between the tankage assembly and the vehicle or propellant cascade system.

External components and valves used to operate the system of Figure 7 are conveniently attached to the mount carriage arms and a remotely operated control panel is supplied which can control the operation of the valves or monitor temperatures and pressures from a distant location.

V. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

Section III of the main report discusses in detail the theoretical analysis performed within the scope of the contract. This work includes a structural analysis of the mount carriage which supports the dewar, an investigation into the dynamical characteristics of the radial bumper suspension system and an outline of the heat transfer equations used to predict the thermal performance of the unit.



1. INNER PRESSURE VESSEL
2. TEMPERATURE SENSOR SUPPORT TUBE
3. TEMPERATURE SENSOR LEADS
4. TEFLON FELT
5. SHROUD
6. INNER VAPOR COOLED RADIATION SHIELD
7. OUTER RADIATION SHIELD
8. OUTER SHELL
9. SHROUD VENT FITTING
10. INNER VENT TUBE
11. ION PUMP
12. ELECTRICAL LEAD FITTING
13. FLUID OUTLET VENT FITTINGS
14. SHIELD HANGER ASSEMBLY
15. SHIELD TO SHIELD SPACER
16. VAPOR COOL TUBING
17. RUPTURE DISC
18. INNER FILL & SUPPLY TUBE
19. SHROUD FILL FITTING
20. RADIAL BUMPERS
21. VAPOR COOL OUTLET FITTING
22. FLUID INLET FILL FITTINGS

FIGURE 6

HELIUM SHROUD TANK DEWAR ASSEMBLY

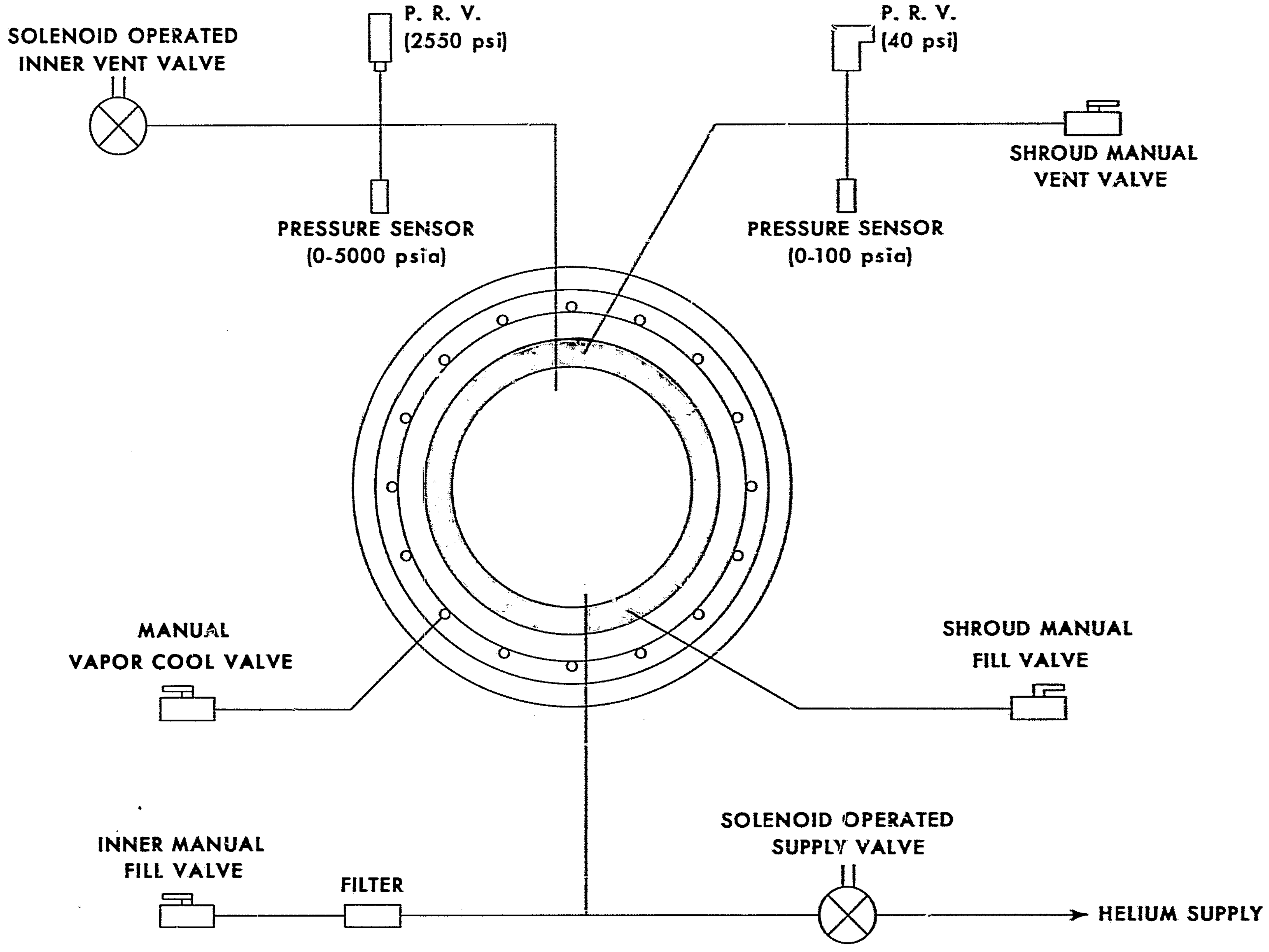


FIGURE 7.

HELIUM SHROUD TANKAGE SYSTEM SCHEMATIC

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An extensive testing program was carried out on the completed unit to verify its structural and thermal capabilities.

A series of LN_2 and LH_2 vented heat leak tests were carried out which resulted in the equilibrium heat leak values listed in the attached Table I. These values are compared with the NAS9-4634 unit on a heat leak/unit area of shroud surface basis. It can be concluded from these results that the heat leak performance of the NAS9-7337 unit compares favorably with the performance of the original shrouded dewar.

The plots of all the vented heat leak tests illustrate the reduction in shroud heat interception as the liquid level in the shroud decreased. This occurs in conjunction with a rise in the heat leak into the inner vessel. Figure 8 shows typical experimental results obtained from the vented heat leak tests.

Vapor cooled and non-vapor cooled GH_e pressure build-up tests were performed on the unit with LH_2 in the shroud. These tests indicated a maximum standby capability of 101 hours for the unit without replenishing the hydrogen in the shroud.

A significant factor resulting from the thermal tests on the unit was the increase in total equilibrium heat leak which occurred between the LH_2 vented heat leak data and the pressure build-up data. This was attributed to increased bumper contact caused by pressure expansion of the inner vessel but is a design aspect which requires further investigation.

A system flow and pressure decay test were performed on the tankage assembly when it reached maximum operating pressure conditions. This resulted in a maximum GH_e mass flow capability of 0.8 lbs/sec.

The completed helium storage system was subjected to modified LM spectrum random and sinusoidal vibration inputs along the three principal axes of the unit. These tests resulted in full compliance with the specified levels of random input excitation and showed the need for further study in certain areas of the sinusoidal input spectrum. Theoretically predicted resonance points were in good agreement with the measured output response of the unit.

Vented heat leak tests performed on the tankage assembly after vibration testing showed that the thermal performance was unaffected by the dynamical loadings.

VI. LIMITATIONS

Two basic limitations are inherent in the NAS9-7337 design in relation to the Apollo LM descent propulsion system requirements.

A design upgrading from a structural standpoint is necessary to meet the present LM sinusoidal vibration input levels. This can be accomplished by suitable pre-loading of the bumper suspension system during assembly of the unit.

TABLE I

VENTED HEAT LEAK DATA

DEWAR	INNER VESSEL FLUID	SHROUD FLUID	MEAN AMBIENT TEMP. °F	EQUILIBRIUM HEAT LEAK [BTU/HR] INNER VESSEL	SHROUD	TOTAL	TOTAL HEAT LEAK/UNIT AREA OF SHROUD SURFACE [BTU/(FT^2 HR]	REMARKS
NAS9-4634	---	LN_2	70	---	9.79	9.79	1.24	Non-Vapor Cooled
NAS9-7337	LN_2	LN_2	80	6.25	10.0	16.25	1.0	Non-Vapor Cooled
NAS9-4634	---	LN_2	70	---	8.87	8.87	1.12	Vapor Cooled
NAS9-7337	LN_2	LN_2	80	5.0	8.0	13.0	0.8	Vapor Cooled
NAS9-4634	---	LH_2	70	---	8.6	8.6	1.09	Non-Vapor Cooled
NAS9-7337	LH_2	LH_2	--	3.3	9.3	12.6	0.774	Non-Vapor Cooled
NAS9-4634	---	LH_2	70	---	5.11	5.11	0.65	Vapor Cooled
NAS9-7337	LH_2	LH_2	70	1.4	7.3	8.7	0.534	Vapor Cooled

NAS9-4634 Shroud Surface Area = 7.9 FT^2

NAS9-7337 Shroud Surface Area = 16.28 FT^2

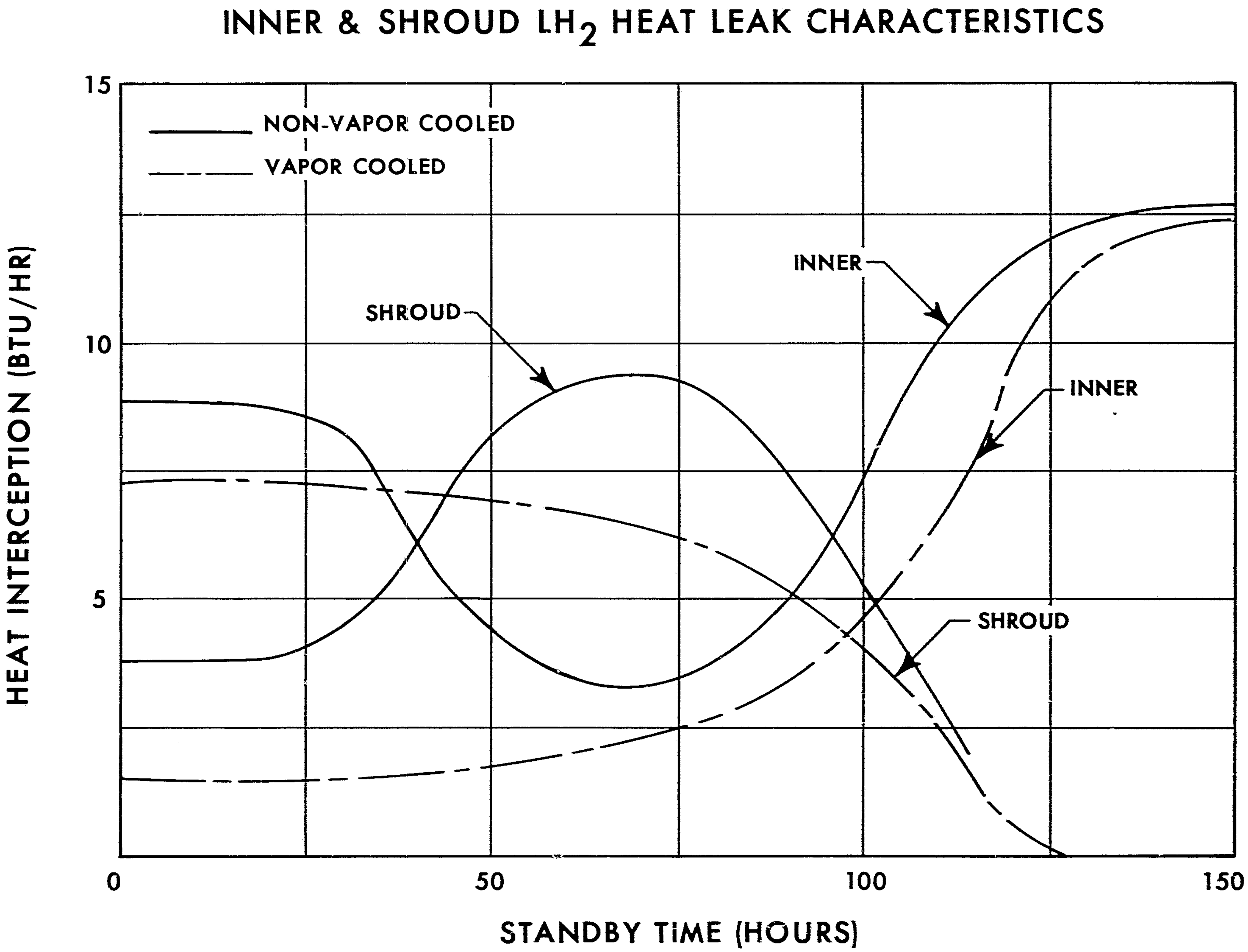
INNER & SHROUD LH_2 HEAT LEAK CHARACTERISTICS

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FIGURE 8

The tapered shroud geometry, chosen mainly on a basis of existing tooling, reduced the standby capabilities of the shroud design by a significant degree. The alternative shroud geometries shown on the attached Figure 9 can considerably extend the mission duration of a shrouded unit.

VII. IMPLICATIONS FOR RESEARCH

The work performed under this contract and described in the main report confirms the recommendations put forward in the NAS9-4634 contract. A hydrogen shrouded helium storage dewar can be designed and fabricated to store any quanitity of GH_e at densities greater than the present lunar module SH_e pressurization system. This increased density allows the storage of the same pressurant quantity in a smaller tankage envelope.

An indefinite pre-launch standby capability is available with a shroud tank without loss of primary stored fluid provided the shroud liquid is replenished at certain intervals. The unit constructed under the present contract to approximate LM descent propulsion system requirements would require LH_2 replenishment approximately every 100 hours of ground standby without loss of GH_e. This ground standby capability can be increased by a factor of 3 by adopting one of the shroud geometries shown in Figure 9.

Preliminary theoretical analysis of the alternative shroud geometries shown in Figure 9 produced the shroud heat interception curves of Figure 10 and the corresponding system standby curves of Figure 11. The extremely significant implications contained in these theoretical curves suggest the need for further research effort into the heat transfer mechanics between the primary and secondary fluids in relation to the shroud annulus geometry.

VIII. SUGGESTED ADDITIONAL EFFORT

The development work carried out on the NAS9-4634 and current programs have clearily shown the feasibility of an integral shrouded cryogenic storage system. Application of this type of unit to future space storage dewars should be seriously considered for life support and reactant supply systems in addition to propellant pressurization systems. In this respect, the shrouding of ignitible cryogens by inert gases during pre-launch standby is worth consideration.

It is recommended that the hydrogen shrouded helium pressurization system described in this report be upgraded to meet the present lunar module pre-launch and on-board propellant tankage standby requirements. This upgrading should adopt an approach similar to the task breakdown shown on page 15 concentrating particularily on providing a weight optimized unit which satisfies the anticipated LM vibration spectrum requirements.

To achieve this upgrading the adoption of one of the two alternative shroud geometries, shown by Figure 11 to considerably extend standby capabilities, is recommended.

Adoption of the concentric shroud annulus should be carried out in conjunction with the use of a cryoformed stainless steel inner vessel which would provide a 25% reduction of the pressure vessel weight. This annulus geometry would increase the overall tankage envelope from 29 3/4 inches to 31 inches resulting in an approximate overall tankage weight reduction of 20% and a mission standby capability of 125 hours.

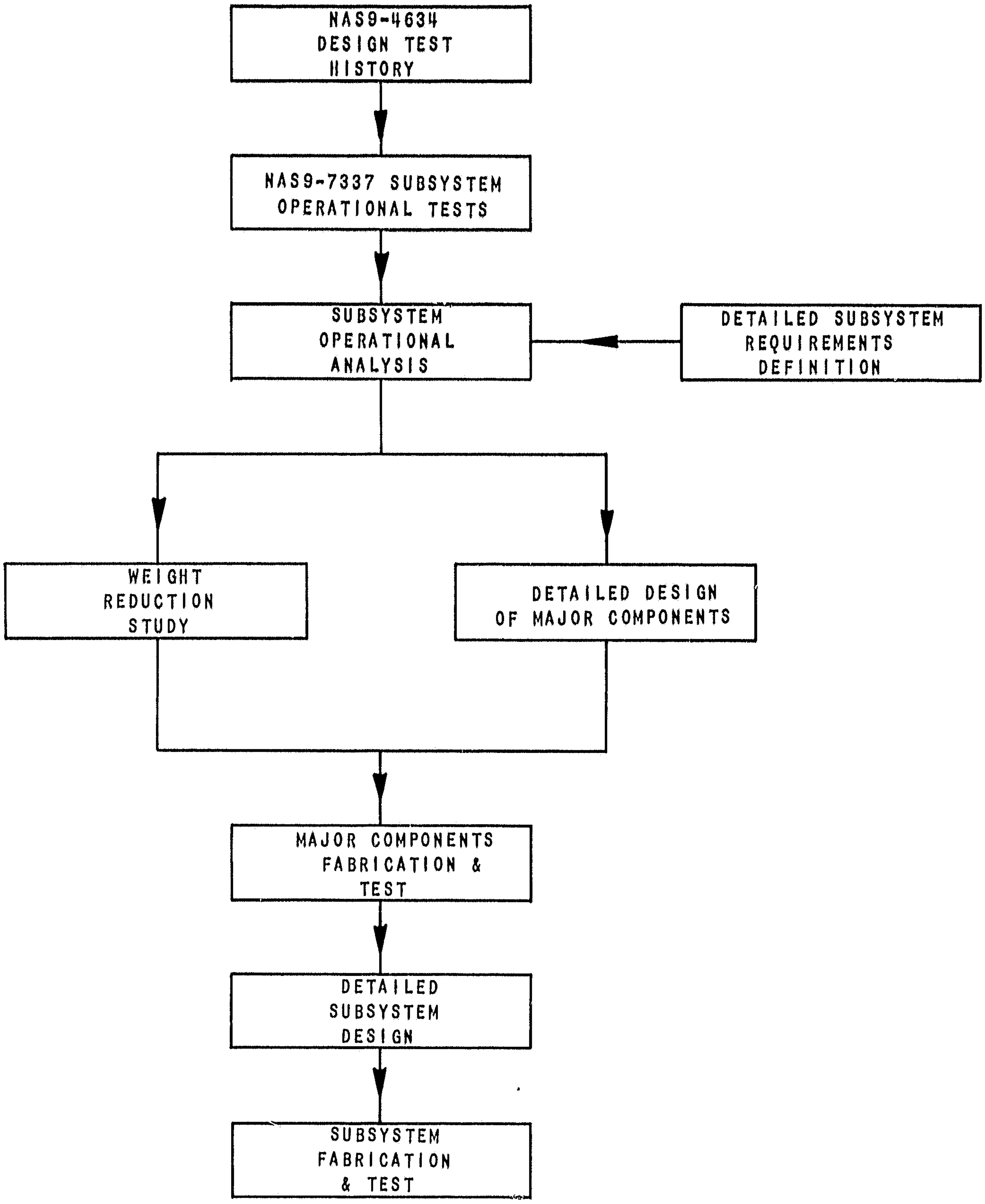
The glass-fiber reinforced (GFR) oblate spheroidal inner vessel with metal liner can provide an inner pressure vessel weight reduction of between 25 and 50% depending on the liner material. The possible disadvantages of vacuum outgassing and plating associated with the composite surrounding this type of vessel do not apply to the shrouded dewar concept.

Adopting aluminum for the GFR pressure vessel liner would allow the use of this material for the shroud which would save a further 30% in shroud weight.

The shroud annulus geometry associated with a GFR inner vessel would again increase the overall tankage envelope from 29 3/4 inches to 31 inches resulting in an overall tankage weight reduction of 30% and a mission standby capability of approximately 340 hours.

The above increased tankage envelope sizes compare favorably with the existing LM supercritical helium pressurant tanks which have an envelope of 33 inches.

It is further recommended that improved structural and dynamic performance of the shrouded unit should be pursued by extending the analysis contained in Section III of the main report. This would be specifically aimed at the effect of various pre-loading techniques on eliminating the non-linear shock loads experienced by the dewar during vibration.



RECOMMENDED TASK BREAKDOWN STRUCTURE

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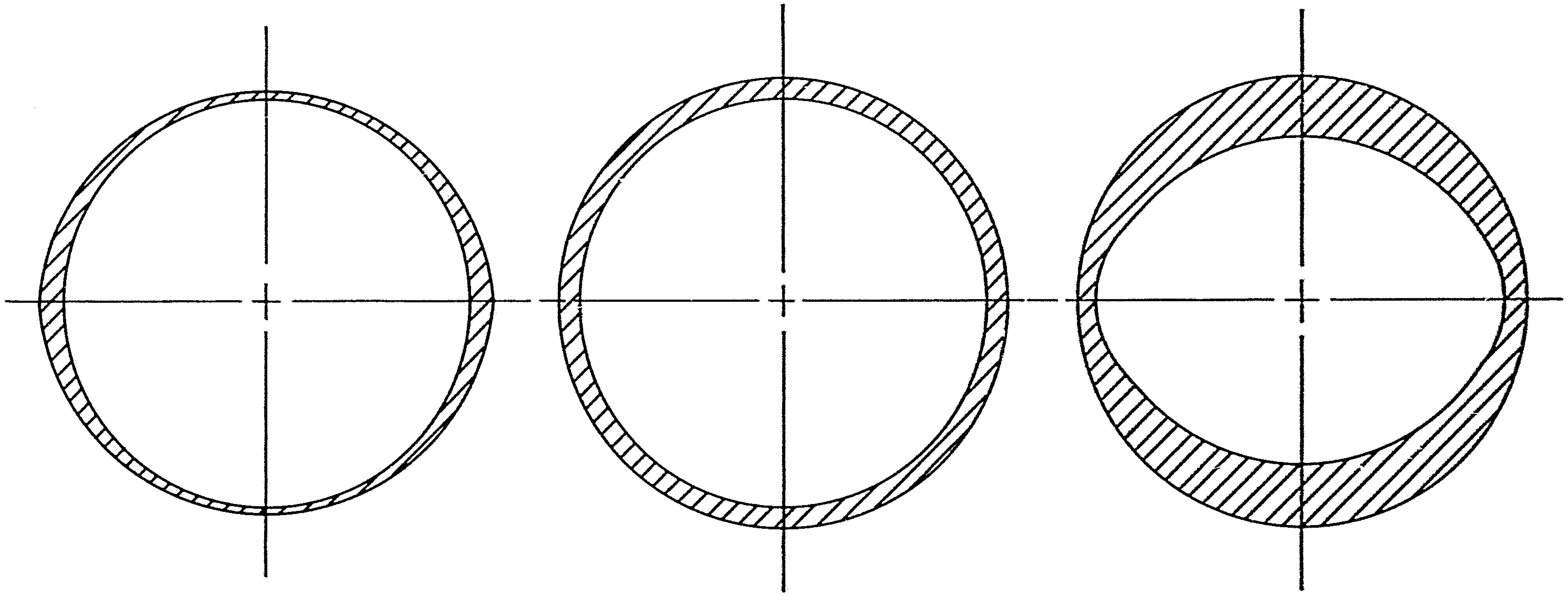
ALTERNATIVE SHROUD ANNULUS GEOMETRIES



NAS 9-7337 SHROUD GEOMETRY

NAS 9-4634 SHROUD GEOMETRY

GFR INNER VESSEL SHROUD GEOMETRY

FIGURE 9

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EFFECT OF SHROUD GEOMETRY ON SHROUD HEAT INTERCEPTION CHARACTERISTICS

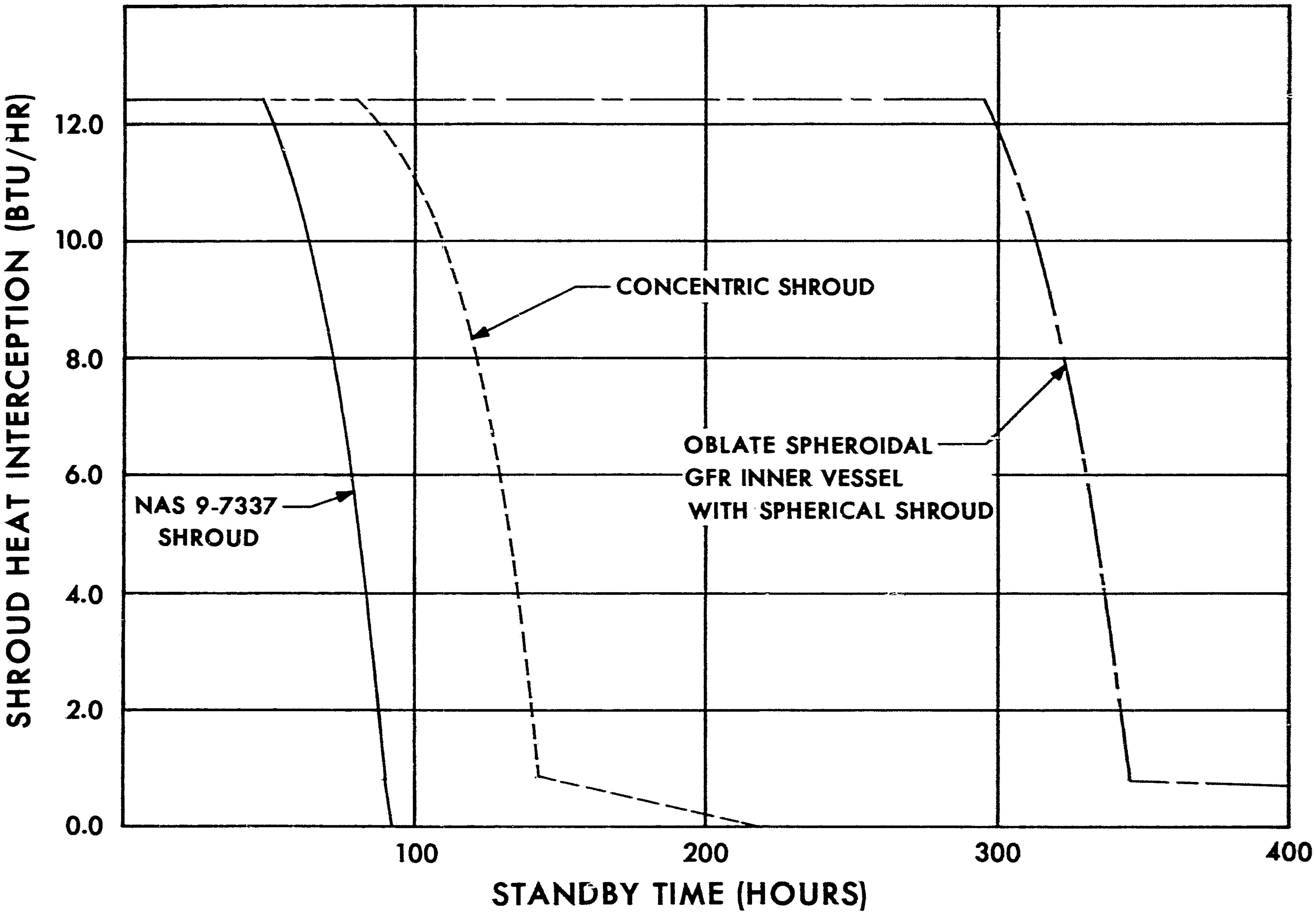

FIGURE 10

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EFFECT OF SHROUD GEOMETRY ON GHe PRESSURE BUILD-UP AND TANKAGE STANDBY CAPABILITIES

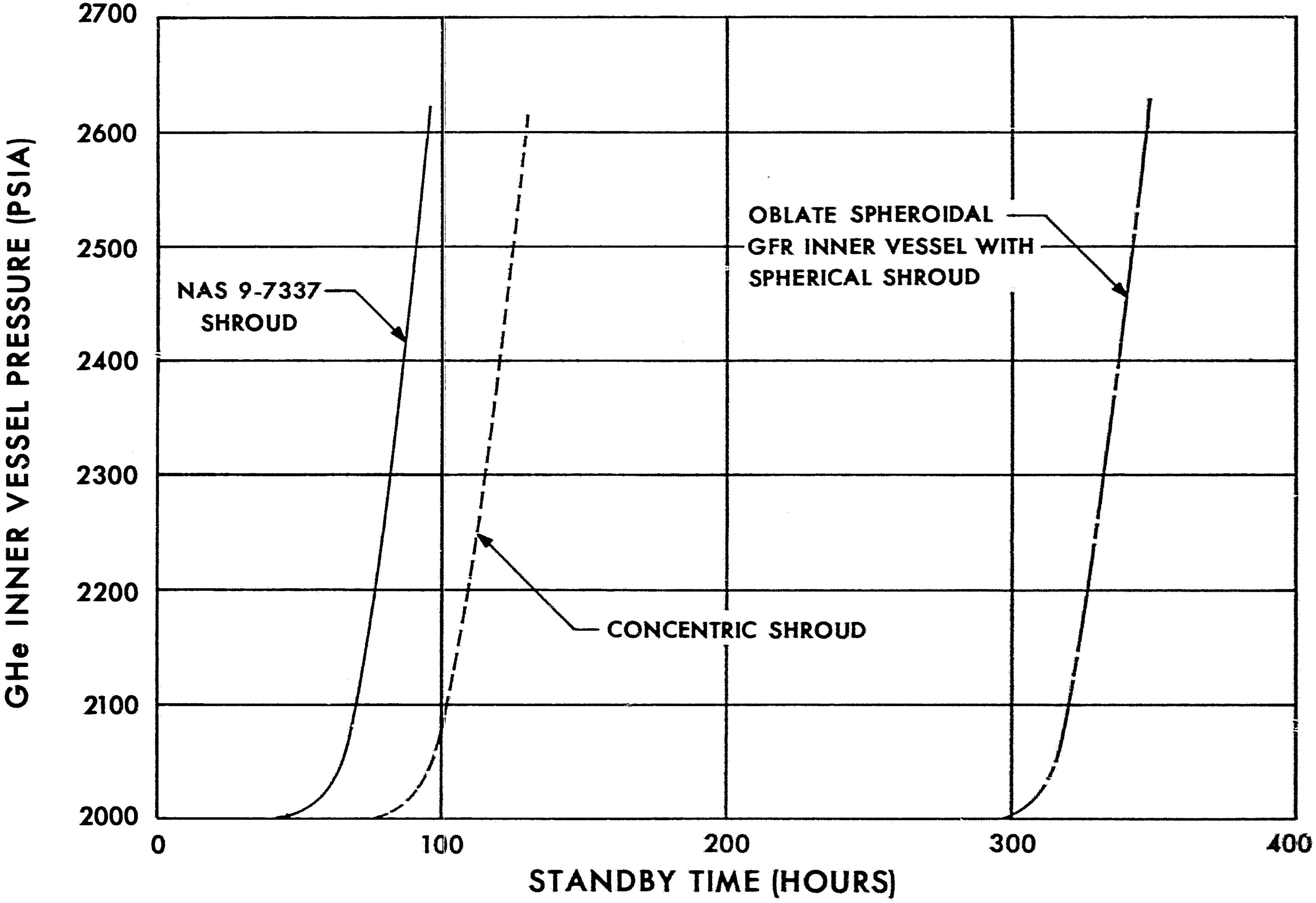

FIGURE 11

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