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FINAL REPORT
PRELIMINARY DESIGN TRADE-OFFS FOR A MULTI-MISSION STORED CRYOGEN COOLER

LMSC/D630389
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FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION GODDARD SPACE FLIGHT CENTER

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1.0 INTRODUCTION

This study was performed to determine the preliminary design trade-offs for a multi-mission stored solid cryogen cooler which will have application to both shuttle sortie and free flyer missions. This study was in response to the statement of work, generated by NASA Goddard Space Flight Center on May 1977.

Extensive studies were performed in this program. They fell into two main categories:

1) Trade studies which determined the optimum characteristics of various coolers for specific temperatures, heat loads and lifetimes.
2) Selection of a baseline design from these studies (i.e. fixed geometry) and an analysis of the instrument cooling capability of this baseline when loaded with various cryogen combinations.

The computer program which was utilized for these studies was modified at the start of the study and validated by comparison with the weights and heat rates of coolers which had previously been built and tested. A plotting routine was also developed for the trade studies.

Some studies were performed to determine the requirements of proposed instruments to aid in selecting a baseline cooler, but this activity was limited, and existing data was utilized for the most part.

2.0 SUMMARY

Preliminary design studies have been performed for a multi-mission solid cryogen cooler which has a wide range of application for both the shuttle sortie and free flyer missions. This multi-mission cooler (MMC) is designed to be utilized with various solid cryogens to meet a wide range of instrument cooling from 10°K (with solid hydrogen) to 90°K. The cryogens which may be utilized and their associated temperature capability is shown in Fig. 2-1.

The baseline cooler utilizes two stages of solid cryogen and incorporates an optional, higher temperature third stage which is cooled by either a passive radiator or a Thermoelectric cooler. The general configuration is shown in Fig. 2-2.

The MMC has an interface which can accommodate a wide variety of instrument configurations. A shrink fit adapter is incorporated which allows a "drop-in" instrument integration, as shown in Fig. 2-2.

The baseline system is 83 cm in diameter by 113 cm in length. Its weight varies depending upon the cryogens utilized and is a minimum of 154 Kg when loaded with solid H_2 and solid ammonia. When loaded with the heaviest cryogens; Argon and carbon dioxide, the loaded weight is 416 Kg. The dry weight of the cooler is 99 Kg.

The cooling capability of the system is indicated in Fig. 2-3 which shows the instrument cooling capability as a function of the instrument temperature for one and three year lifetimes. This capability is compared with the

FIGURE 2-1 TEMPERATURE RANGE OF SOLID CRYOGENS

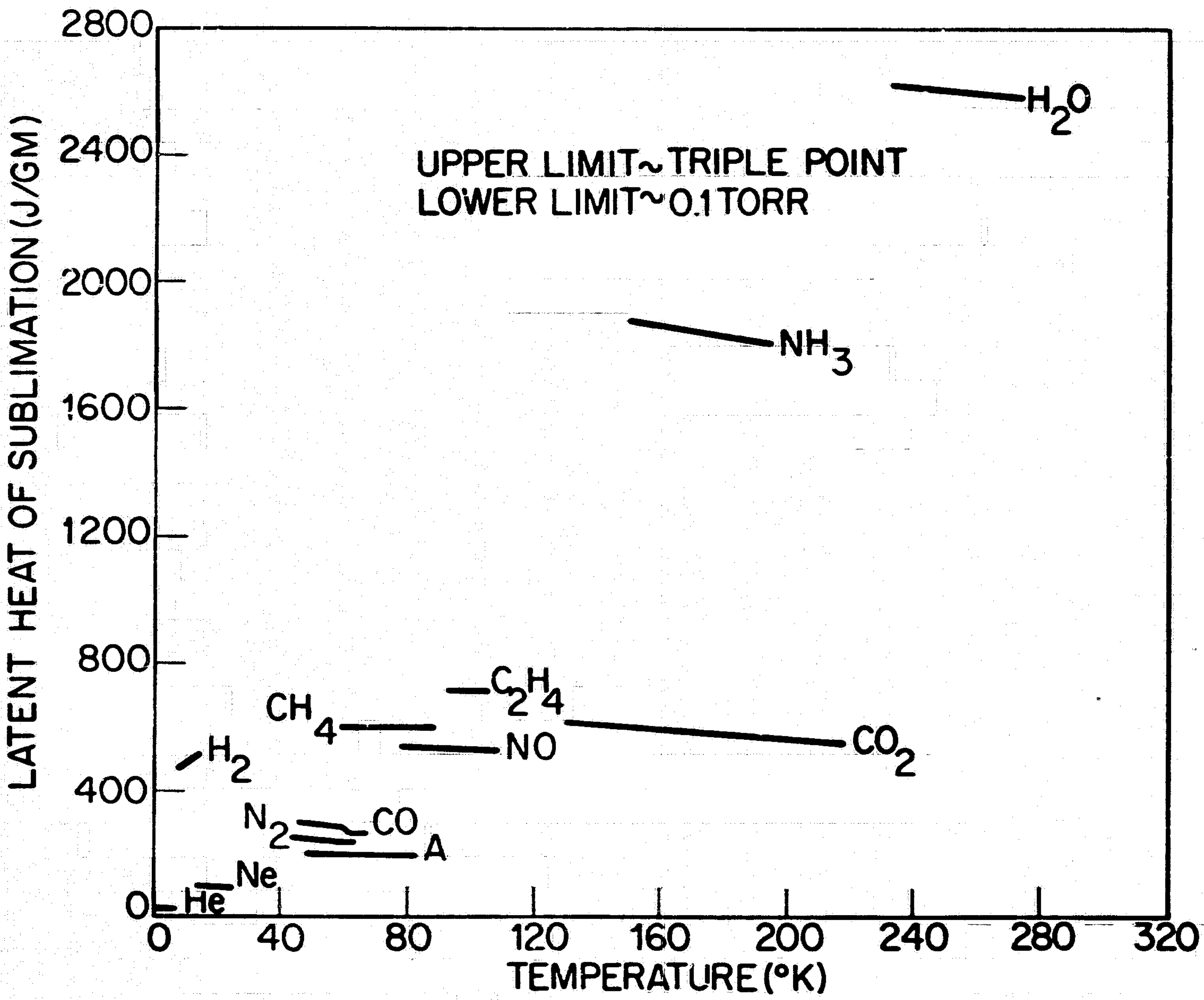

FIGURE 2-2 MULTI-MISSION COOLER CONFIGURATION

MULTI-MISSION-COOLER CONCEPT

"DROP IN" EXPERIMENT INTEGRATION CONCEPT

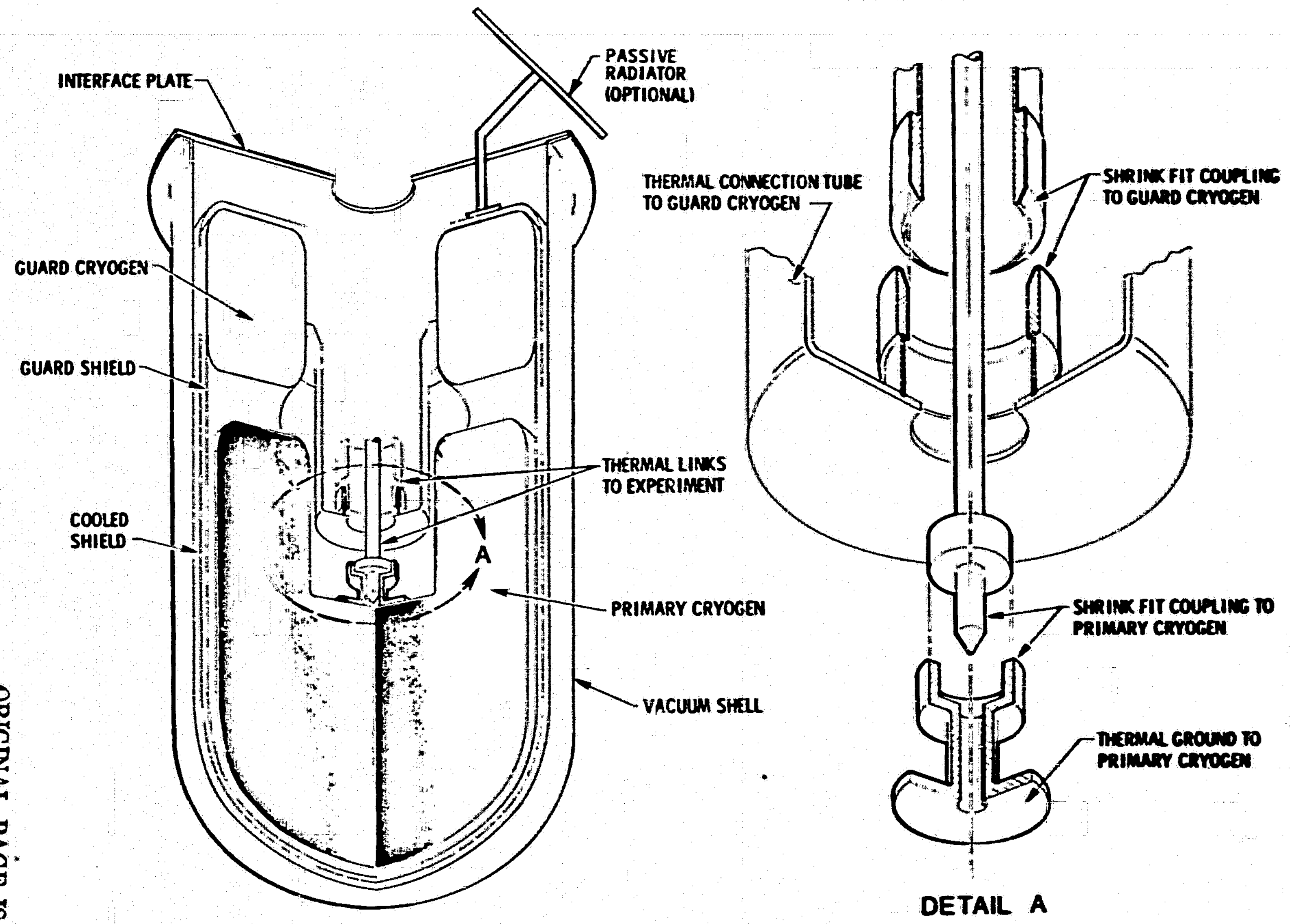

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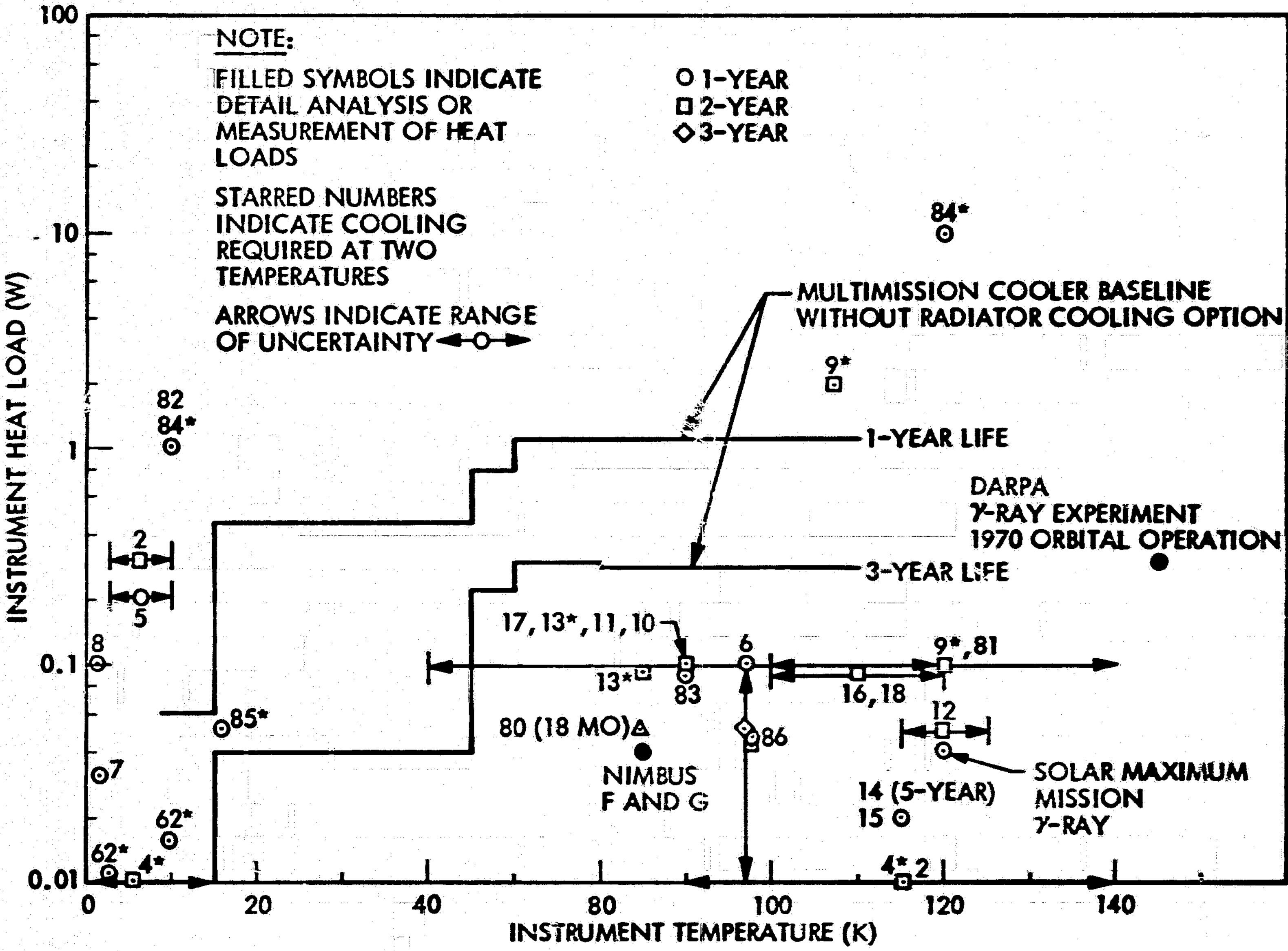
FIGURE 2-3. INSTRUMENT COOLING CAPABILITY OF BASELINE COOLER



requirements of various instruments which are described in Section 3.0.

The baseline design provides cooling of approximately 1 watt over a 60-100°K temperature range and about 0.5 watts from 15 to 60°K for a one year lifetime. For low cooling loads ($\approx$ 0.1W) and with use of the optional radiator shield, cooling lifetimes as great as 8 years are predicted.

The capability of the MMC is based on state of the art technology and does not incorporate any features which have not been previously demonstrated. The utilization of solid hydrogen in the cooler has not been extensively demonstrated, however, it is not expected that any new technology will be required for its use.

The MMC should demonstrate excellent versatility for the instruments under consideration and should lead to a substantial cost savings when compared to coolers which are uniquely designed for each mission and instrument.

3.0 PAYLOADS REVIEW

The cryogenic requirements of many proposed instruments are not established in much detail in the preliminary design phase. Temperature requirements are generally known to a fair degree for the instruments, but quite often the investigator does not recognize the impact of 5 or 10°K on the cooling system requirements. This is particularly significant for a solid cryogen cooler where 5 or 10°K change in temperature requirement may allow the use of an alternate, much more efficient cryogen.

In addition, many times other elements of the instrument such as optics, baffles or electronics may be operated at a separate, higher temperature than the primary or lowest temperature requirement. Consideration should also be given to provisions for intermediate temperature shields for the sole purpose of reducing the heat load to the primary. These shields may derive their cooling from the secondary temperature shield or from attachment to a passive radiator shield. The working curves which have been developed (Section 6.2) allow the investigator to determine the trade-offs associated with various temperatures.

Heat rates for proposed instruments are often estimated from the detector heat dissipation alone, which often underestimates the total heat input due to parasitic heat loads.

Instrument thermal design cannot be effectively accomplished without a thorough knowledge of how the instrument may be cooled and what the available interfaces and thermal shielding options with the instrument are. This study provides much of the required information in these areas to aid in establishing efficient instrument thermal design.

A partial list of parameters which are necessary or helpful in establishing the most efficient instrument design and cooling means are presented below.

- Primary Temperature Requirement and Cooling Load
- Secondary Temperature Requirement and Cooling Load
- Instrument Duty Cycle
- Vibration Environment
- Hold Time Prior to Launch
- Instrument Size and Distance from Cooler
- Required Overall Life of Cooler
- Orbital Characteristics (when Passive Radiator Option is Considered

Published documents and in-house instrument designs were reviewed, to determine the principal requirements for future instrument requirements.

Ref. 3-1 contained data on many instruments and was used extensively. It was apparent from the indicated data spread that the heat rates in many cases were not known better than a factor of three or four or even an order of magnitude in some cases.

Figs. 3-1 and 3-2 list the instruments for both the sortie and automated payloads along with their identification numbers which are summarized in Figs. 3-3 and 3-4.

These figures provide a convenient way to compare the MMC cooling capability with the instrument requirement.

Additional points in which detail thermal designs have been made or which have been built and tested are shown as filled points.

Although the data in these figures must be regarded as very approximate, it forms a rough guide to the cooling requirements for a wide range of instruments, and was utilized in sizing the baseline cooler parameters.

FIGURE 3-1. CRYOGENIC PAYLOAD REFERENCE
(AUTOMATED PAYLOADS)

*SSPDA	#1	LARGE SPACE TELESCOPE
	#2	LARGE X RAY TELESCOPE FACILITY
	#3	SYNCHRONOUS EARTH OBSERVATION SATELLITE (HE)
	#4	LARGE HIGH ENERGY OBSERVATORY D
	#5	COSMIC RAY LABORATORY
	#6	LARGE SOLAR OBSERVATORY
	#7	GRAVITY AND RELATIVITY SATELLITE (LEO)
	#8	GRAVITY AND RELATIVITY SATELLITE (SOLAR)
	#9	LANDSAT - D
	#10	SYNCHRONOUS EARTH OBSERVATION SATELLITE (EO)
	#11	APPLICATIONS EXPLORER
	#12	TIROS O
	#13	OPERATIONAL ENVIRONMENTAL SATELLITE
	#14	FOREIGN SYNCH. MET. SATELLITE
	#15	GEOSYNCH. OPERATIONAL ENV. SATELLITE
	#16	GEOSYNCH. EARTH RESOURCES SATELLITE
	#17	EARTH RESOURCES SURVEY OPERATIONS
	#18	FOREIGN SYNCHRONOUS EOS
	#19	SEASAT B
	#20	GLOBAL EARTH AND OCEAN MON. SYSTEM
	#21	ENCKE BALLISTIC FLYBY
	#22	PIONEER SATURN/URANUS/TITAN PROBE
	#23	MARINER MARS POLAR ORBITER
*SSPDA	#24	LUNAR ORBITER
OTHER	#80	Limb SCANNING IR RADIOMETER (LSIR)
	#81	HIGH RES. X RAY SPECTROSCOPY
	#82	IR TELESCOPE
	#83	IR TELESCOPE (GSFC)
	#84	EARTH RES. SENSOR (GSFC)
	#85	IRAS
OTHER	#86	POLLUTION MONITORING (LRC)

*SPACE SHUTTLE PAYLOADS DESCRIPTION ACTIVITY

FIGURE 3-2. CRYOGENIC PAYLOAD REFERENCE (Sorties)

*SSPDA	#25	1 m SHUTTLE IR TELESCOPE FACILITY
↑	#26	DEEP SKY UV SURVEY TELESCOPE
	#27	COMETARY SIMULATION
	#29	METEOROID SIMULATION
	#30	1 m UNCOOLED IR TELESCOPE
	#31	3 m AMBIENT TEMP. IR TELESCOPE
	#32	1.5 Km IR INTERFEROMETER
	#33	2.5 m CRYOGENICALLY COOLED IR TELESCOPE
	#34	COMBINED PAYLOAD EXPERIMENT
	#35	COMBINED PAYLOAD EXPERIMENT
	#36	ATTACHED FAR IR SPECTROMETER
	#37	COMBINED IR PAYLOAD
	#38	COMBINED UV PAYLOAD
	#39	ATTACHED FAR IR PHOTOMETER
	#40	MAGNETIC SPECTROMETER
	#41	HIGH RESOLUTION X RAY TELESCOPE
	#42	ANTIPROTON MEASUREMENTS
	#43	LIQUID "X" DETECTOR
	#44	SOLAR FAR IR TELESCOPE, AMBIENT TEMPERATURE
	#45	FLARE COARSE MONITORING PACKAGE
	#46	SOLAR ACTIVITY EARLY PAYLOAD
	#47	ATM. MAG. AND PLASMAS IN SPACE (AMPS)
	#48	SCANNING SPECTRORADIOMETER
	#49	SPACE SHUTTLE CALIBRATION FACILITY
	#50	ACTIVE AND PASSIVE CLOUD RADIANCE EXPERIMENT
	#51	STD. EARTH OBSERVATION PACKAGE (SEOPS)
↓	#52	MULTISPECTRAL SCANNER - COASTAL ZONE
*SSPDA	#53	LIQUID HELIUM RESEARCH FACILITY
OTHER	#54	LASER HETERODYNE EXPERIMENT
↓	#55	IR DETECTOR (MIT)
	#56	HX - II DETECTOR

*SPACE SHUTTLE PAYLOADS DESCRIPTION ACTIVITY

FIGURE 3-3 **COOLING REQUIREMENTS FOR AUTOMATED PAYLOADS**

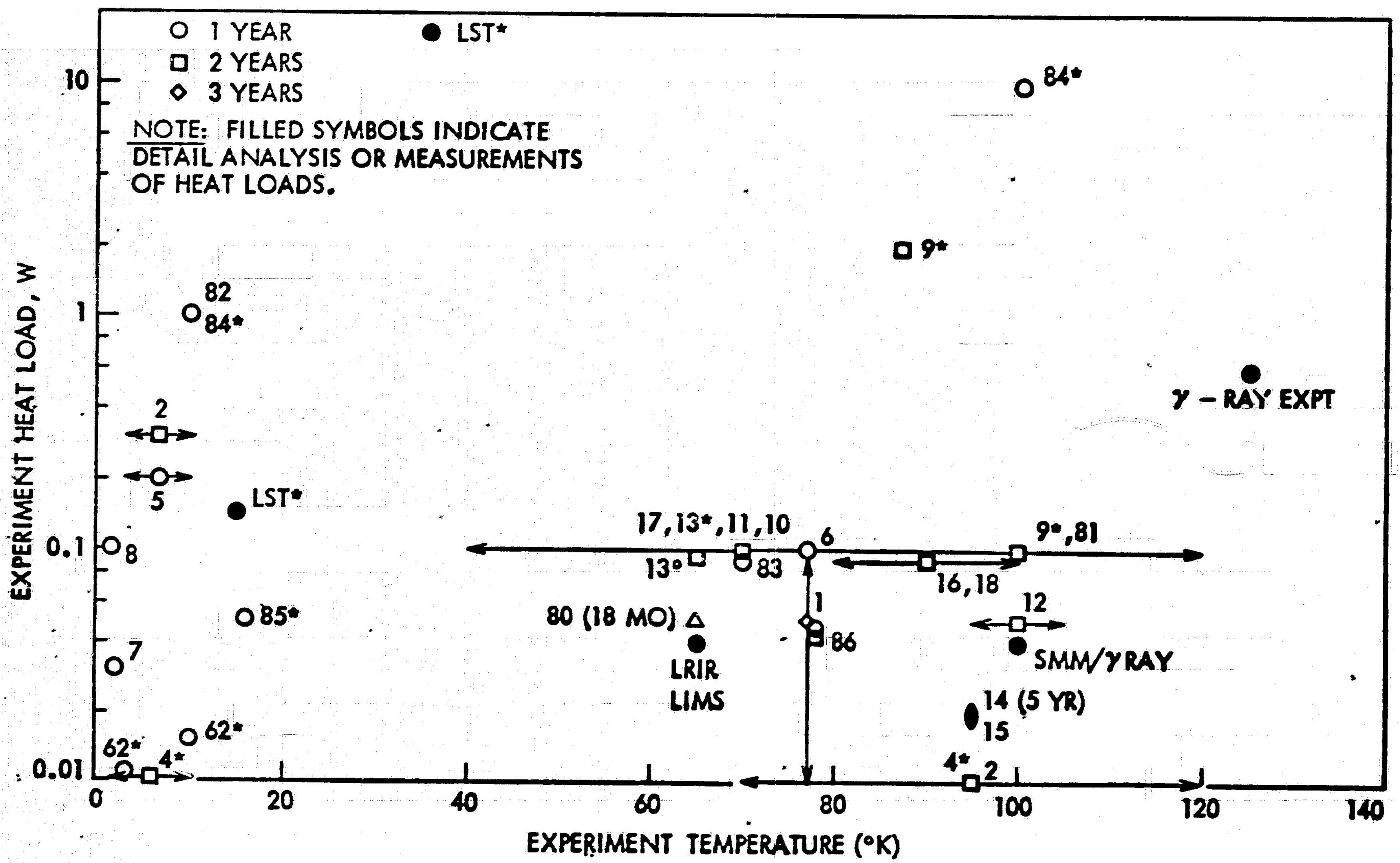
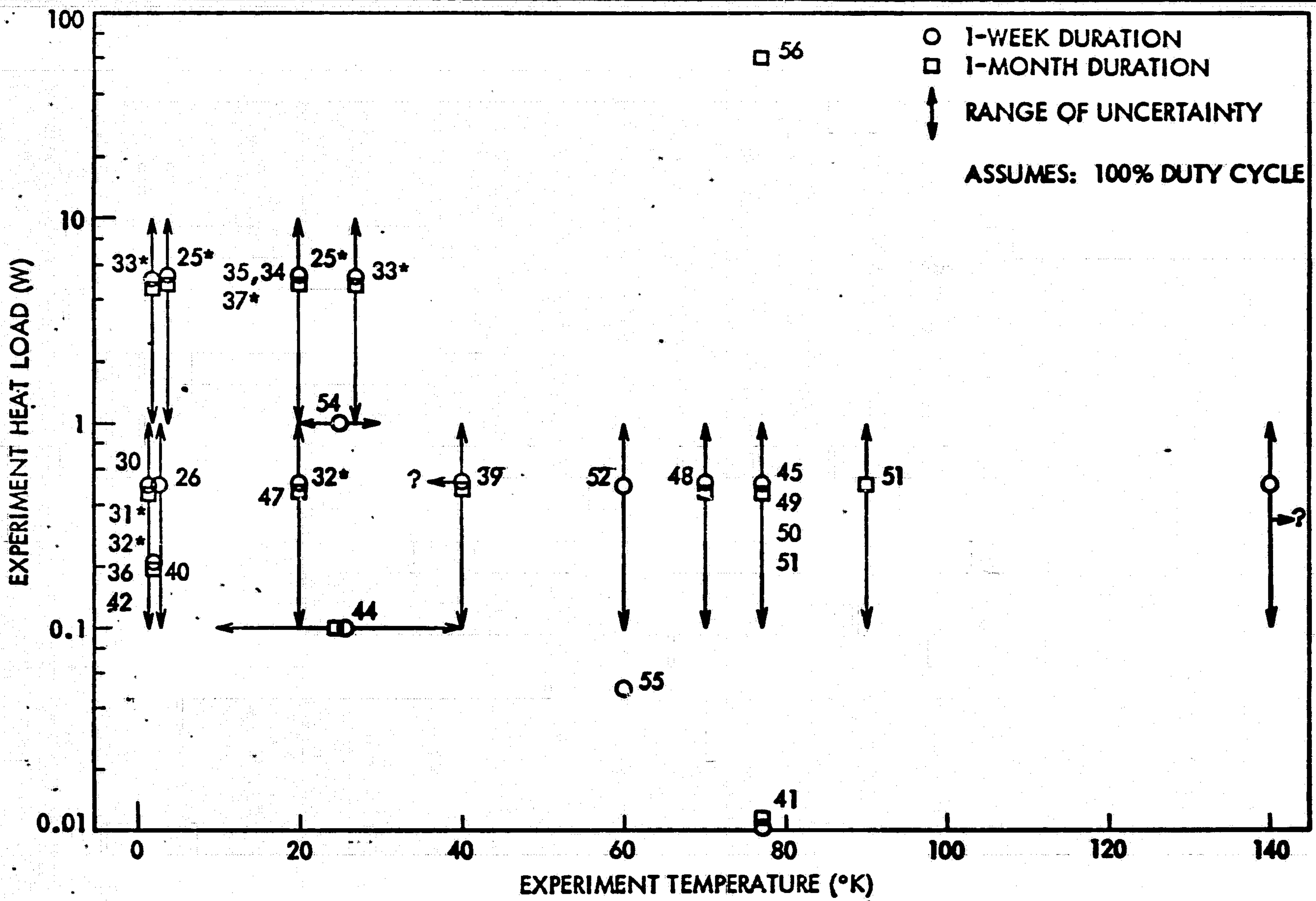


FIGURE 3-4. COOLING REQUIREMENTS FOR SPACE SHUTTLE SORTIE PAYLOADS



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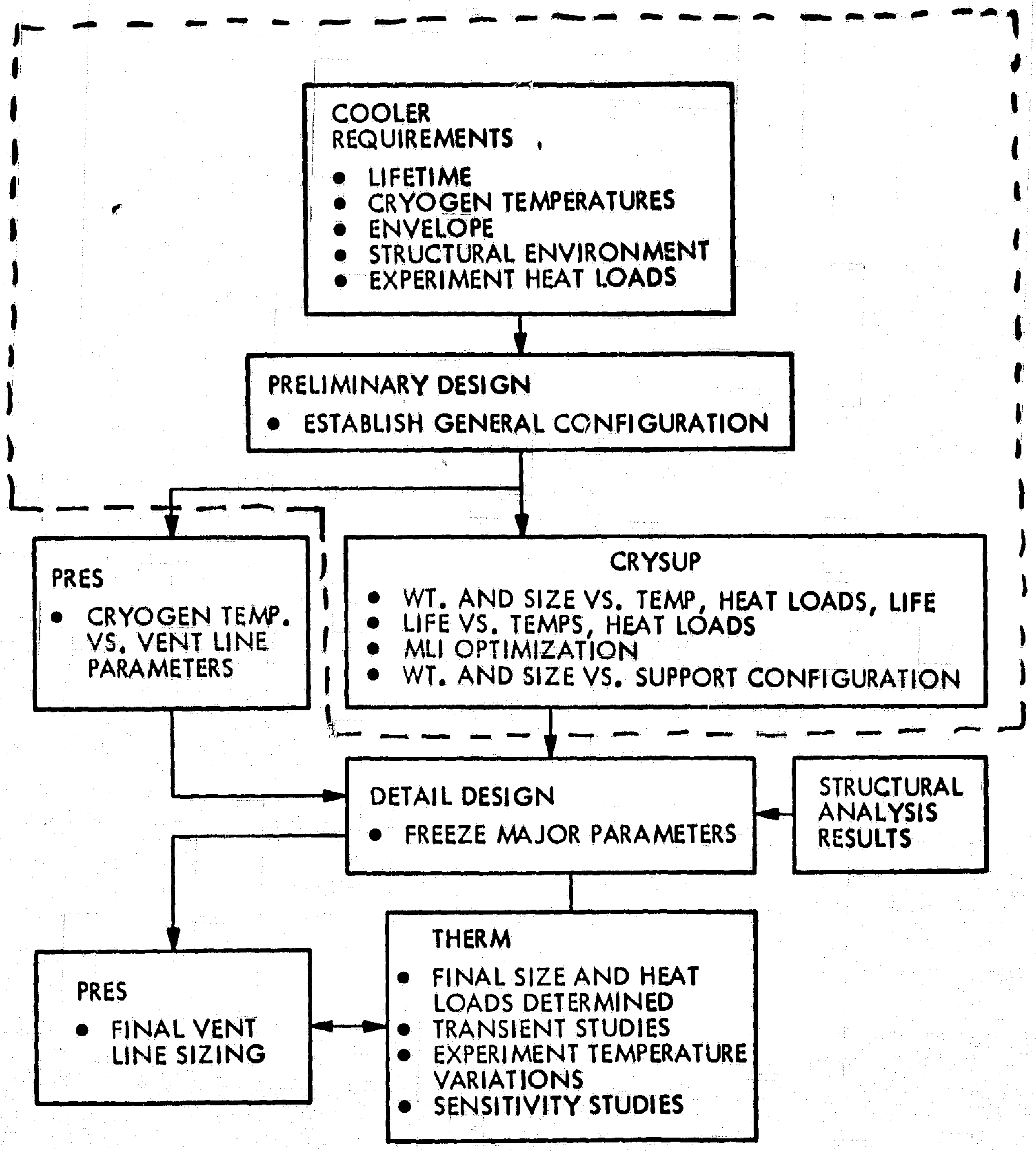

FIGURE 4.1-1 INTERRELATION OF COMPUTER PROGRAMS FOR SOLID COOLER THERMAL

Since PRES was not used during this work effort, the cryogen temperature at a pressure of 0.1 torr was used as input to the CRYSUP program for all cryogens investigated.

THERM: Detailed design analyses are done with the thermal analyzer computer program, THERM, on the UNIVAC 1110 computer. The cooler is divided into a three-dimension nodal network by the analyst and finite difference solutions to the heat transfer equation are determined at each node. THERM has the capacity to handle well over 1000 nodes for both steady-state and transient analyses. THERM also has subroutine capability which may be used to calculate temperature dependent properties before each iteration, call for heat maps of selected nodes, or in general perform a wide variety of tasks required by the analyst.

CRYSUP: The CRYSUP program uses the UNIVAC 1110 computer to initially size the support tube bundle to meet the cooler structural requirements and then determine the cryogen tank dimensions and system weight. The inputs are experiment and plumbing heat loads, MLI type, layer density and thickness, required lifetime, cryogens and boundary temperature, cryogen properties, tank wall densities and thicknesses, vacuum tank radius, the support tubes' radii and length, their structural properties and the structural loads on the system. For the MMC, lifetimes of 1, 2 and 3 years were investigated at primary experiment heat loads of 0.02, 0.1, 0.3, and 1.0 watt. Secondary experiment heat loads were assumed to be such that $Q_{Secondary} = 2 \times Q_{Primary}$ for all cases.

and tisuglas was used For each cryogen, the temperature was taken to be the temperature where the vapor pressure over the solid is 0.1 torr, and boundary temperatures considered were 100°K, 160°K, 200°K and 300°K. The following major assumptions were made:

- overall cooler L/D = 1.5
- cavity dimension to be

  $L_{cavity} = 40\%$ of $L_{Primary}$

  $D_{cavity} = 23\%$ of $D_{Primary}$

- fiberglas support tubes sized to survive 5.45g lateral static acceleration (includes 1.65 safety factor)
- design for 20% lifetime contingency

The program performs an iterative process in which the thickness of each tube, its deflection, and the clearance between tubes is calculated based on the equations for a cantilevered beam. With this information the support tube heat load is determined, and the size, weight and center of gravity location for the cryogens are calculated. With the recalculated weight and c.g., the support tubes are resized. The process continues until the difference in c.g. location between iterations is small. To do the tank sizing, the heat loads to the primary cryogen are first calculated and thereafter the tank size. The conductivity of the support tubes and MLI is curve fit from data measured at LMSC.[4-1,4-2] The sizing of the secondary is begun only after the sizing of the primary is completed since the net heat load to the secondary consists of both the secondary heat load inputs less the cooler heat loads to the primary and less the heat removed by the primary vent gas.

A summary of the CRYSUP program is shown in Figure 4.1-2. As seen, weight and heat rates as well as cooler geometry are output as the final results. Data on the degree of reliability that one can derive from the output, is indicated in Figures 4.1-3 and 4.1-4.

In figure 4.1-3, predicted system weights are compared to actual weights, and in figure 4.1-4 predicted heat rates are compared with actual heat rates for an in-house,prototype, two stage cooler having a 200°K cooled radiator shield. This cooler was selected because of its similarity in size and construction to the baseline cooler. As can be seen, excellent agreement in the cooler weights was acheived - a difference of only 3%. The agreement achieved between actual and predicted heat rates was 24% (predicting low by 105 mW). This disparity would be all but eliminated with the 20% lifetime contingency which is utilized in the MMC. This table also indicates the comparison with THERM which is 13%.

By way of summary, the cooler design methodology produces a preliminary design concept from the initial cooler requirements. From these, CRYSUP will size the cooler tank and support tube assembly, determine weight and heat leaks into each cryogen. In parallel, PRES would determine the vent plumbing sizes required and together with the CRYSUP results and a further input from a detailed structure analysis (see Section 4.2) a final design is selected. From these THERM is used to perform a detailed thermal analyses.

FIGURE 4.1-2 SOLID COOLER OPTIMIZATION PROGRAM

- DETERMINES OPTIMUM CONFIGURATION FOR FOLLOWING OPTIONS:
  - a) WILL OPTIMIZE SINGLE STAGE, OR DUAL STAGE COOLERS FOR ANY BOUNDARY TEMPERATURES
  - b) LIFETIME FOR SPECIFIC GEOMETRY AND INSTRUMENT COOLING REQUIREMENT
  - c) SIZE AND WEIGHT FOR SPECIFIED COOLING REQUIREMENT
- INCLUDES FOLLOWING SUBROUTINES
  - a) DETERMINES INSULATION THICKNESS FOR MINIMUM WEIGHT
  - b) DETERMINES DIMENSIONS OF SUPPORT STRUCTURE FOR STRUCTURAL LOADS
  - c) VENT GAS COOLING OF SUPPORT STRUCTURE, INSULATION, OR CRYOGEN TANKS MAY BE INCLUDED IN ANY REQUIRED COMBINATION
- OUTPUT
  - a) GEOMETRY OF ALL ELEMENTS, i.e. SUPPORT TUBES, INSULATION, CRYOGEN TANKS, VACUUM SHELL
  - b) WEIGHT OF ABOVE COMPONENTS AND CRYOGENS
  - c) ALL HEAT LOADS INCLUDING VENT GAS COOLING EFFECTS WHERE APPLICABLE
- PROGRAM VALIDATED BY COMPARISON WITH DEVELOPED FLIGHT COOLERS

Fig. 4.1-3
COMPARISON OF ACTUAL COOLER HARDWARE WEIGHTS WITH COMPUTER MODEL PREDICTED WEIGHTS

Item	Actual Weight of Prototype Cooler		Predicted Weight for Actual Geometry
Mounting Plate	48.8		30.11
Primary Cryogen Tank, Including Foam Heat Exchanger	80.8		73.2
Secondary Cryogen Tank	14		5.6
Primary Tank Insulation	8.1		8.1
Secondary Tank Insulation	6.5		6.2
Secondary Cooled Shield	16		15.1
Radiator Cooled Shield	20.7	23.9	24.3
Radiator Cooled Shield Insulation	3.2		
Outer Vacuum Shell	56.2		42.2
Fiberglas Support Bundle, Including Flanges	38.6		32.4
Dry Weight w/o 20% Misc	29.3		23.7
20% Dry Weight For Miscellaneous	0		47.4
TOTAL DRY WEIGHT	293		284.6
Primary Cryogen (Methane)	235		233.7
Secondary Cryogen (Ammonia)	30		26.1
TOTAL LOADED WEIGHT	558 LBS		544 LBS

Fig. 4.1-4. COMPARISON OF PREDICTED AND MEASURED HEAT LOADS

Item	Measured	Predicted by CRYSUP	Predicted by Thermal Analyzer THERM)
Loads to Primary:			
Support Tubes		292	301
Insulation		133	146
Plumbing		12	11
Miscellaneous			21
PRIMARY TOTAL HEAT LOAD	542	437	479

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4.2 Structural Analysis

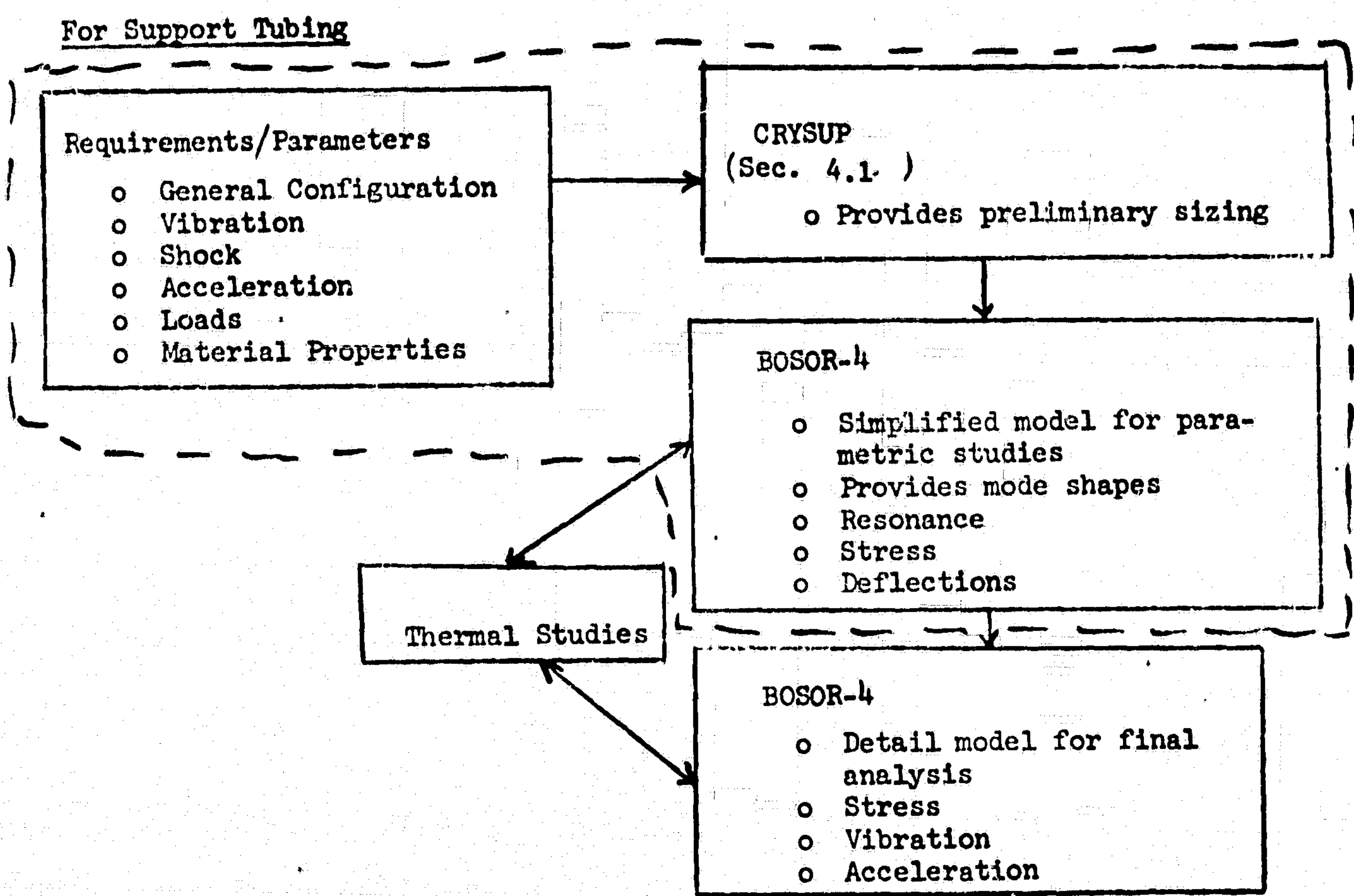
The dynamic vibration analysis was performed with the BOSOR4 computer program [4-3]

The flow

the thermal design requiring several iterations before all system requirements are satisfied is necessary. The extent of the studies performed here are shown by the dotted region.

The support tubes are sized initially with the combined thermal/structural program CRYSUP (Section 4.1) which determines the required wall thickness. This support configuration is incorporated into a simplified version of BOSOR4, and vibration and buckling studies are performed in a parametric manner. When the parametric studies are completed and consistent with thermal requirements, a detail model of the complete cooler is made, and final analyses are performed. These final analyses include the vibration and acceleration in both the lateral and axial direction.

FIGURE 4.2-1 STRUCTURAL ANALYSIS FLOW



5.0 TRADE STUDY RESULTS

Trade studies were conducted to determine the characteristics of various cryogen combinations as a function of heat load and lifetime. These studies were performed as an aid in determining the desirable characteristics of the baseline cooler. They also provide information on the required weight and size for cooler systems outside the scope of the multi-mission cooler (MMC) and may be used to compare the performance of the MMC with a cooler optimized for a particular cooling requirement.

The studies that follow show the characteristics of solid cryogen coolers each of which is optimized for a specific cooling requirement. The optimum insulation thickness is determined by a subroutine in the computer program for each cooling condition investigated.

In order to limit the number of parameters which must be investigated certain assumptions were made regarding the parameters of the cooler. These assumptions were based largely on prior experience in providing coolers for instrument cooling and in fabricating these coolers. The major assumptions are summarized in Table 5-1. One of the primary assumptions was that the net instrument cooling to the secondary instrument stage was twice the cooling required for the primary.

It was also assumed that the ratio of cooler length to diameter was 1.5 and this ratio corresponds with systems developed in the past. Experience has indicated that the diameter of the cooler is the critical dimension, while the length restraint is less severe. As mentioned before a 20% lifetime contingency has been incorporated into the calculations to account for uncertainties in predicting the heat rates.

The fiberglas support tubes were sized by a subroutine in the program and were treated structurally as cantilevered tubes with a static acceleration load equivalent to the dynamic environment. A check on the baseline cooler configuration indicated very close agreement between the static and equivalent dynamic loading. A lateral load of 5.45 g's was utilized, and this includes the 1.65 safety factor.

FIGURE 5-1. ASSUMPTIONS FOR COOLER TRADE STUDIES

o Equivalent Acceleration:	5.45 g's
o Length to Diameter Ratio:	1.5
o Insulation Type:	Tissue/Double Aluminized Mylar for Secondary Stage and Cooled Shield, Double Silk Net/ Double Aluminized Mylar for Primary Stage.
o Lifetime Contingency:	20%
o Instrument Heat Rates:	Secondary Cooling is Twice Primary Cooling
o Vapor Cooling:	The secondary cryogen is cooled with the primary vent gas, the supporcs are also cooled with both primary and secondary vent gas
o Cavity (Internal Instrument) Dimensions:	Cavity length is 40% of the Primary Tank Length. Cavity Diameter is 23% of the Primary Tank Dia.

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The principal result of this trade study is presented in Figures 5-2 thru 5- 20. In these figures the total weight of the system is presented as a function of primary instrument heat load for lifetimes of 1 year, 2 years and 3 years. Each curve corresponds to a particular primary cryogen selection, and shows the weights for various secondary cryogens and radiator temperatures. Although the CO_2 (125°K) and ethylene (95°K) fall somewhat above the stated temperature limits for the study, they were included for completeness and for possible consideration for use with gamma-ray instruments which may operate in this temperature range. It should be understood that the heat load to the secondary is twice the heat-load indicated to the primary and in most cases this increases the system weight substantially over the weight for cooling with the primary only.

Figure 5- 21 shows a summary of the cooler weights for various primary cryogens utilizing ammonia as the secondary for 1 year and 3 year lifetimes. The results for a cooled radiator shield is not shown, it is assumed the shield temperature is 300°K.

Figure 5-22 shows the diameter variation for the various cases. The length as previously stated is 1.5 times the indicated diameter.

The diameters shown in Fig. 5-22 do not include the insulation thickness required on the radiator shield. This thickness may be in the order of 0.76 to 2 cm, and requires further analysis to define. The overall system diameter will therefore increase above the values indicated in the figure.

FIGURE 5-2. TRADE STUDIES - CARBON DIOXIDE PRIMARY - 1 YEAR LIFE

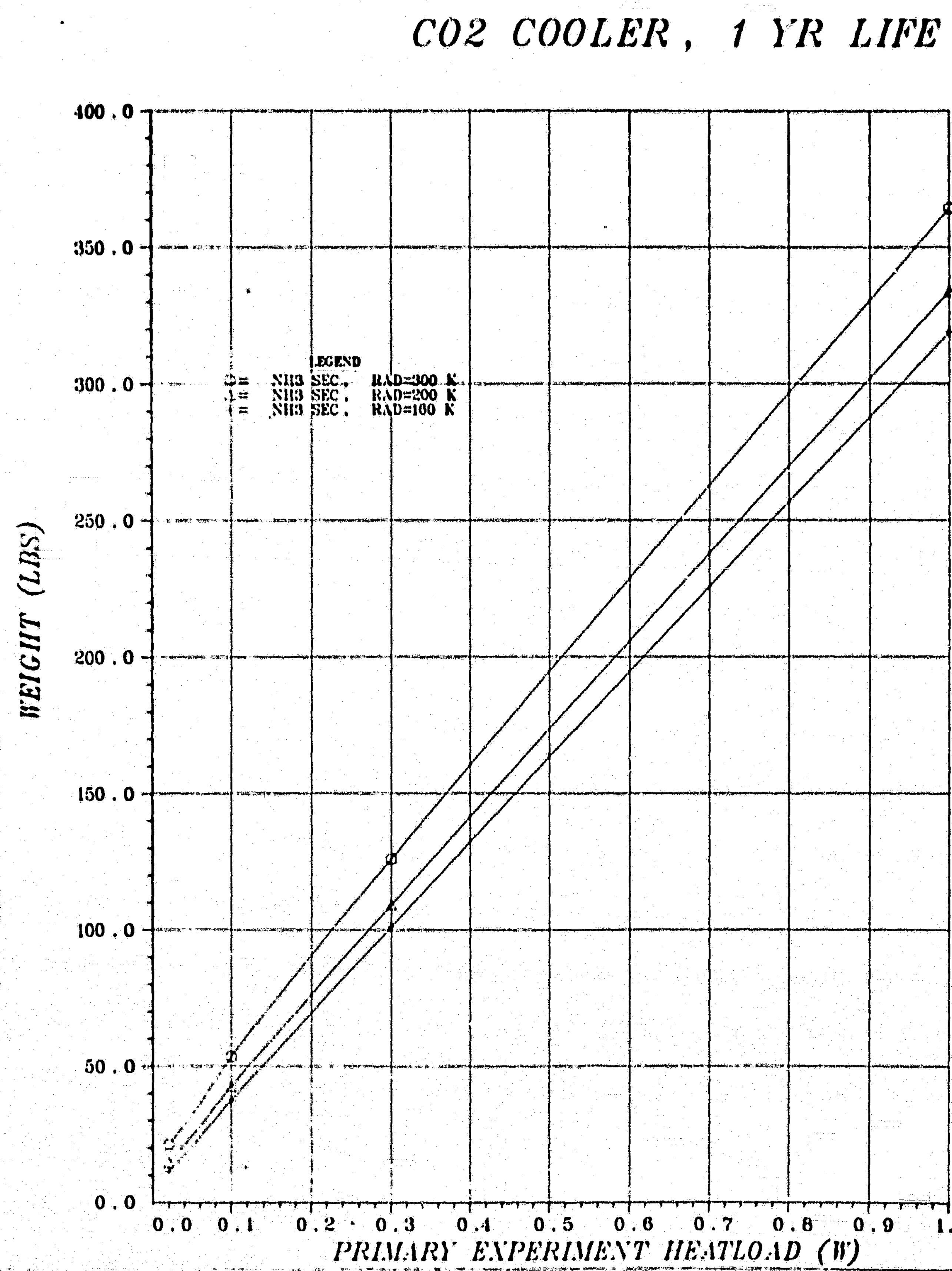

FIGURE 5-3. TRADE STUDIES - ETHYLENE PRIMARY - 1 YEAR LIFE

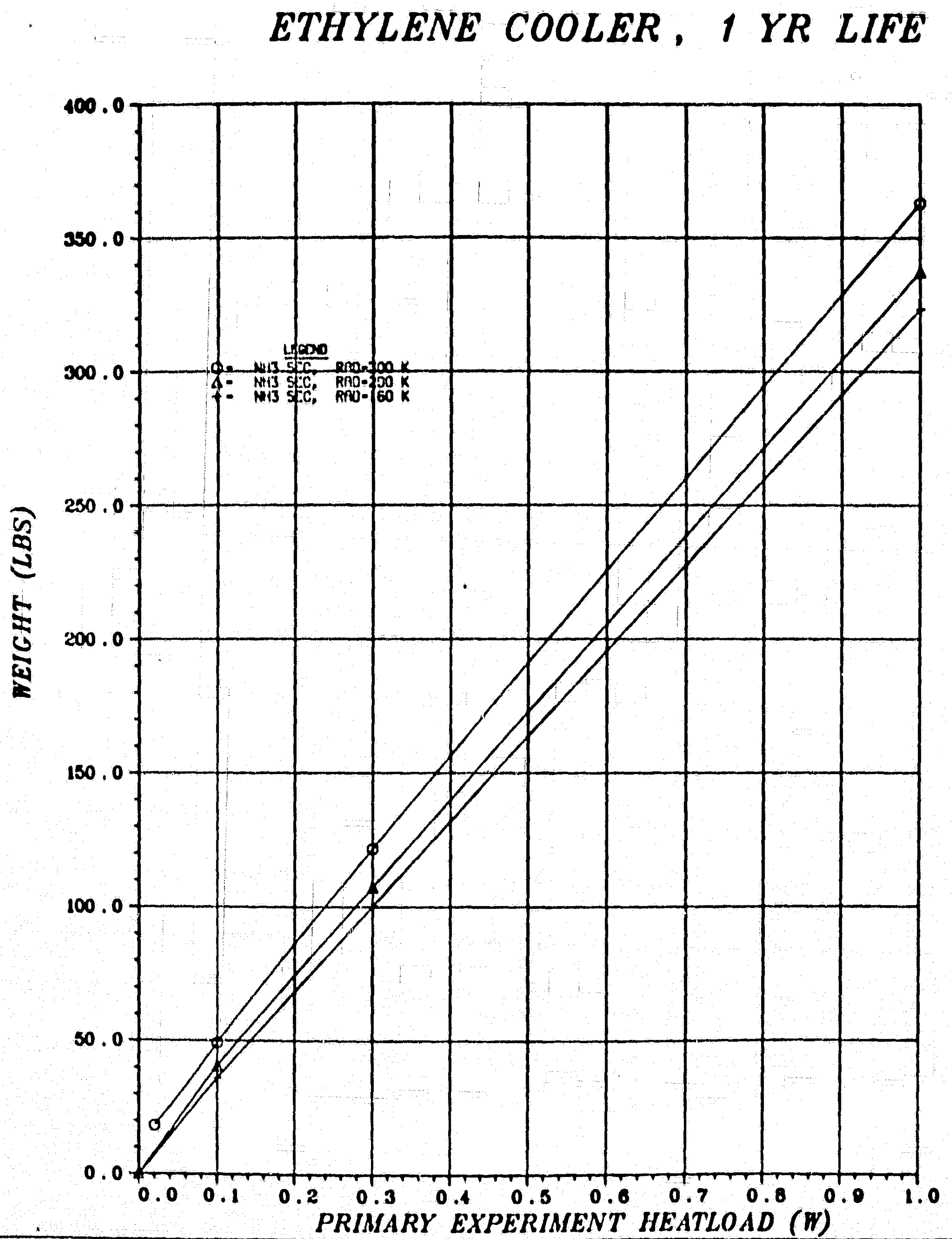

FIGURE 5-4. TRADE STUDIES - METHANE PRIMARY - 1 YEAR LIFE

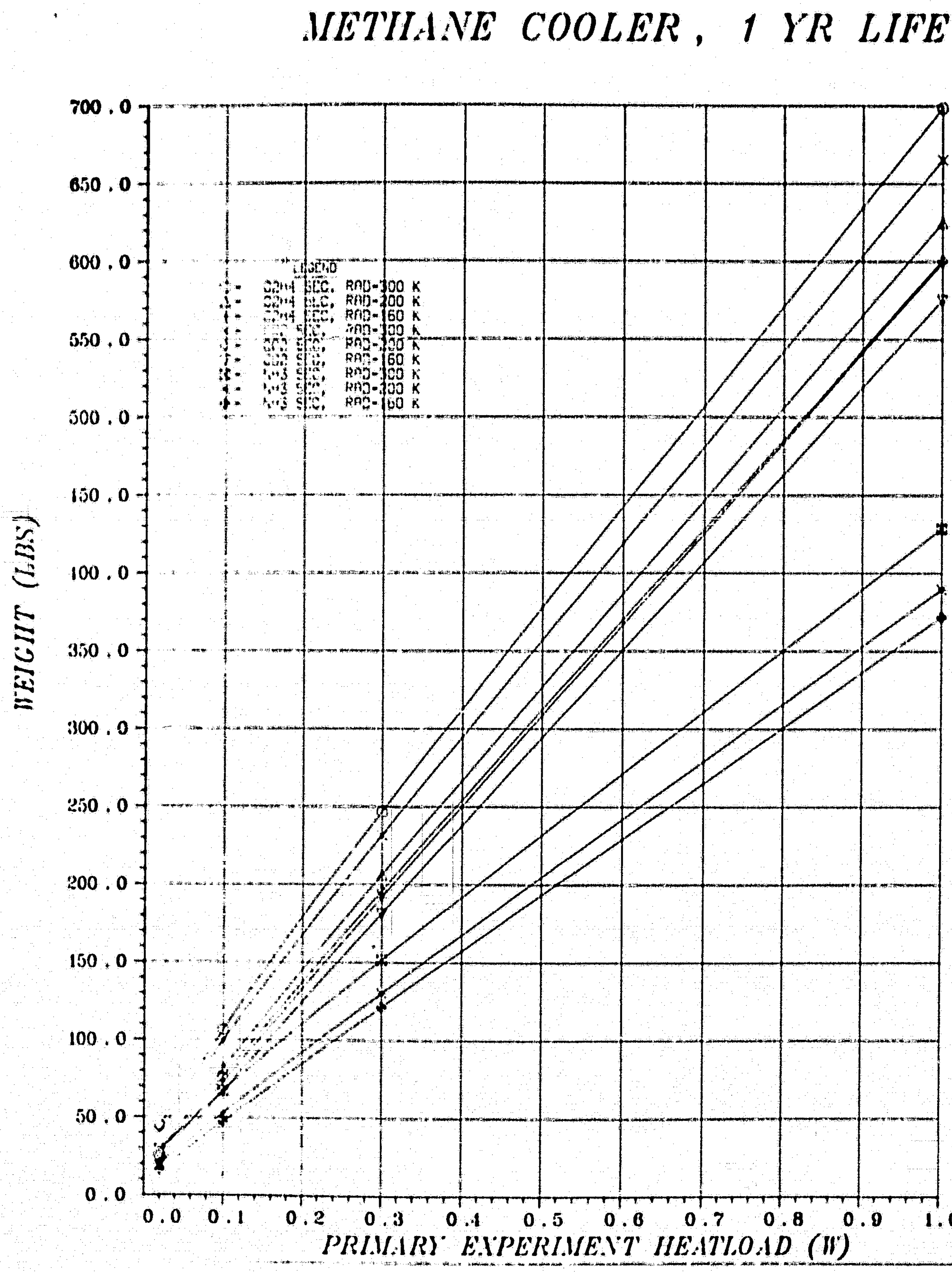

FIGURE 5-5. TRADE STUDIES - NITROGEN PRIMARY - 1 YEAR LIFE

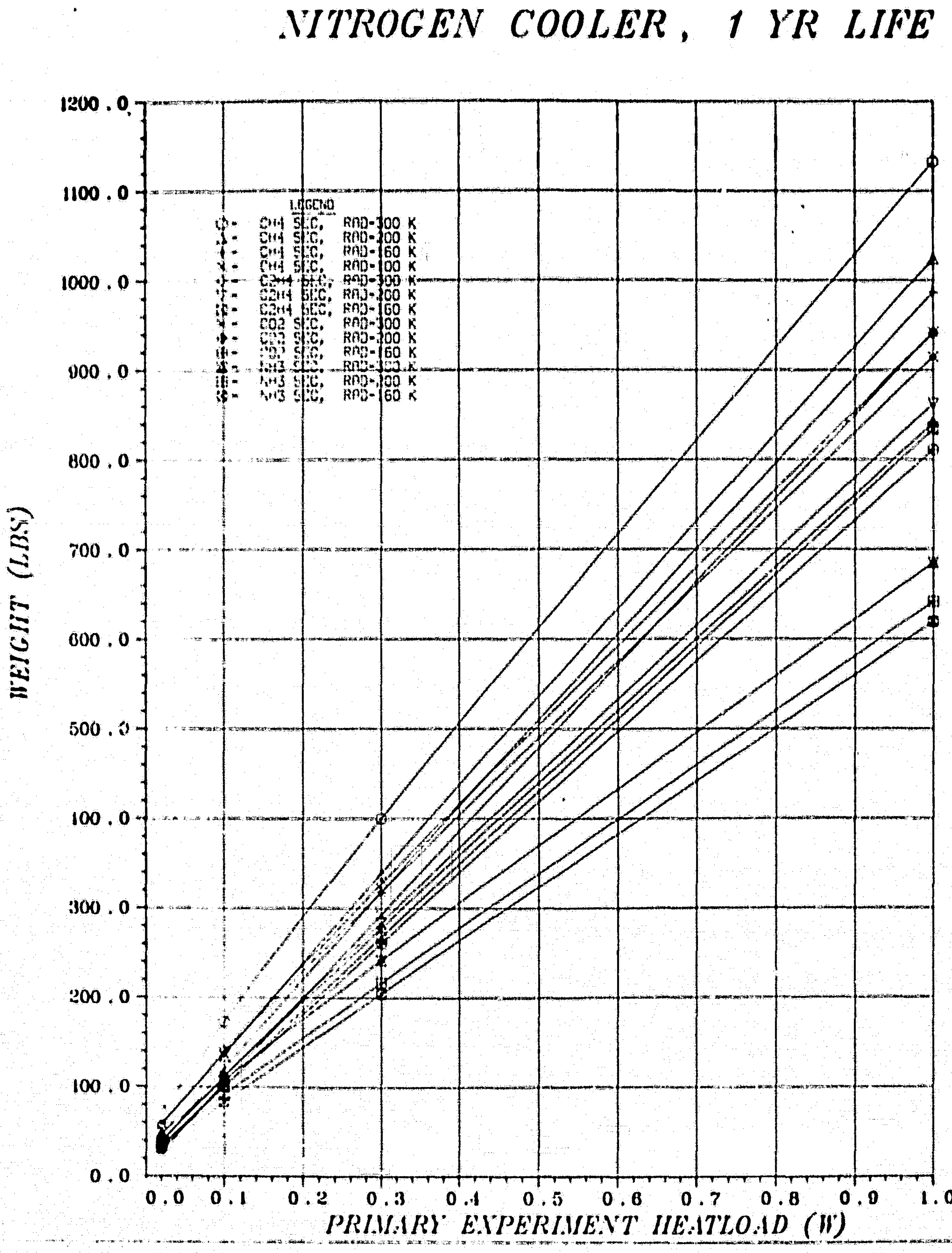

FIGURE 5-6. TRADE STUDIES - ARGON PRIMARY - 1 YEAR LIFE

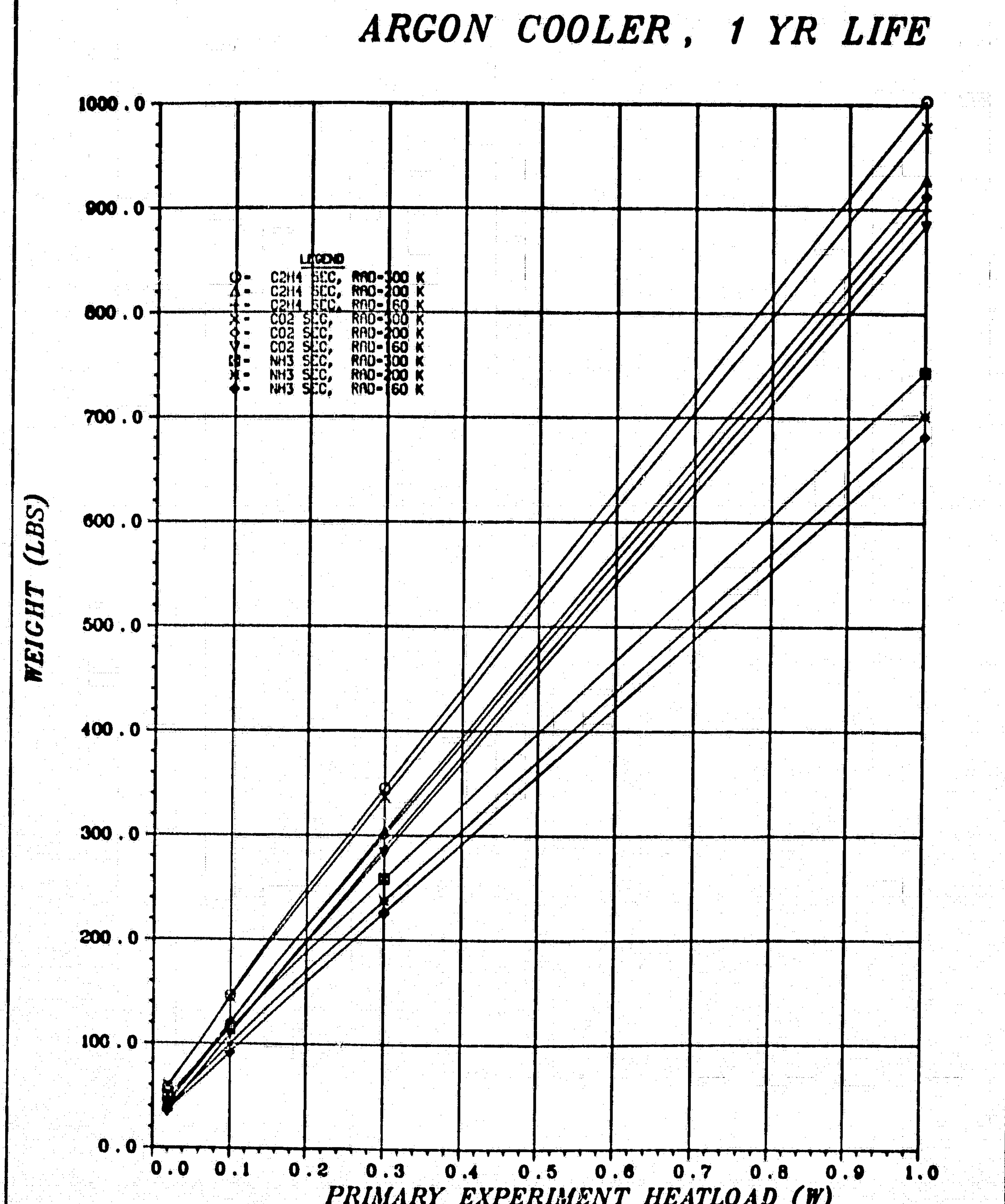

FIGURE 5-7. TRADE STUDIES - NEON PRIMARY - 1 YEAR LIFE

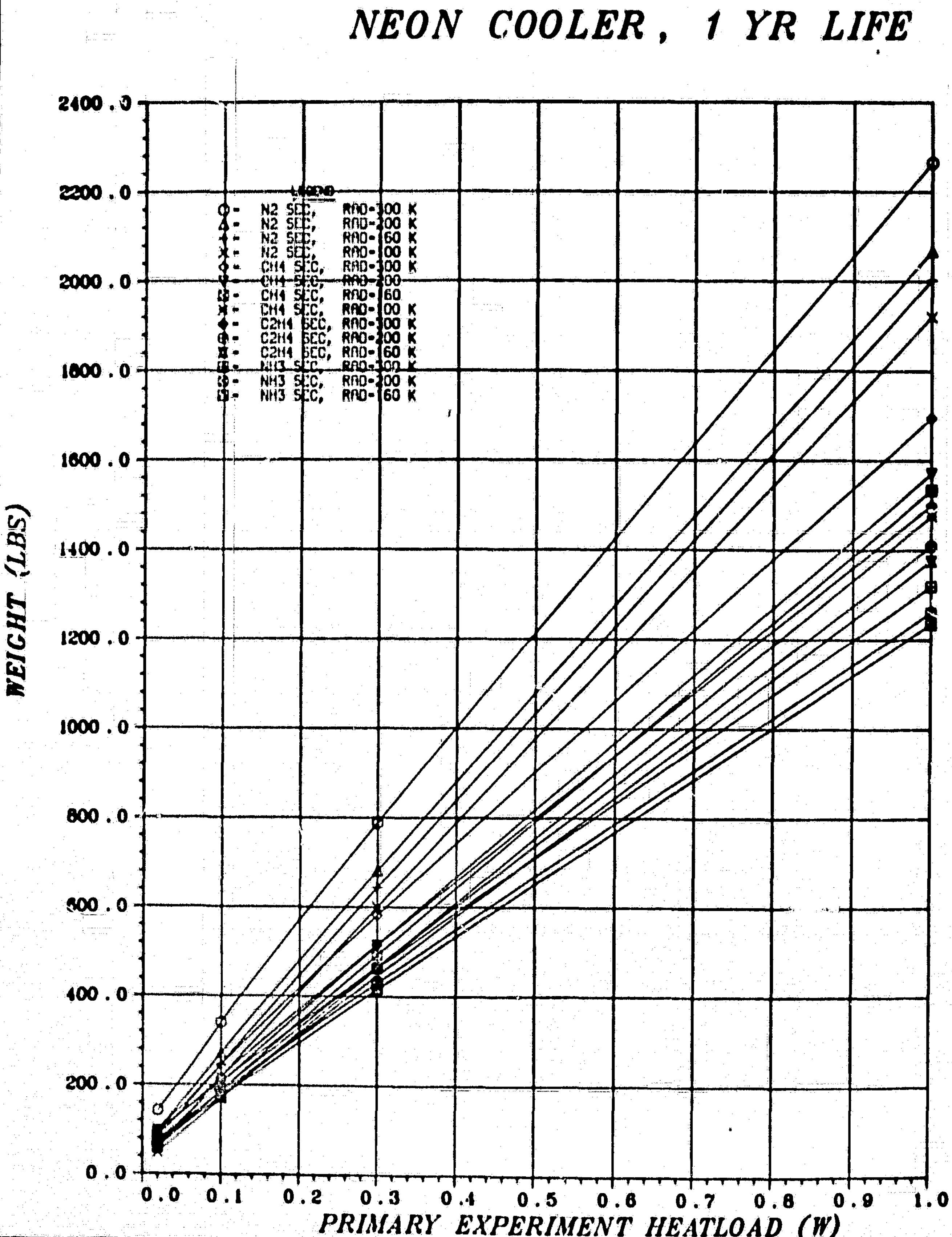

FIGURE 5-8. TRADE STUDIES - HYDROGEN PRIMARY - 1 YEAR LIFE

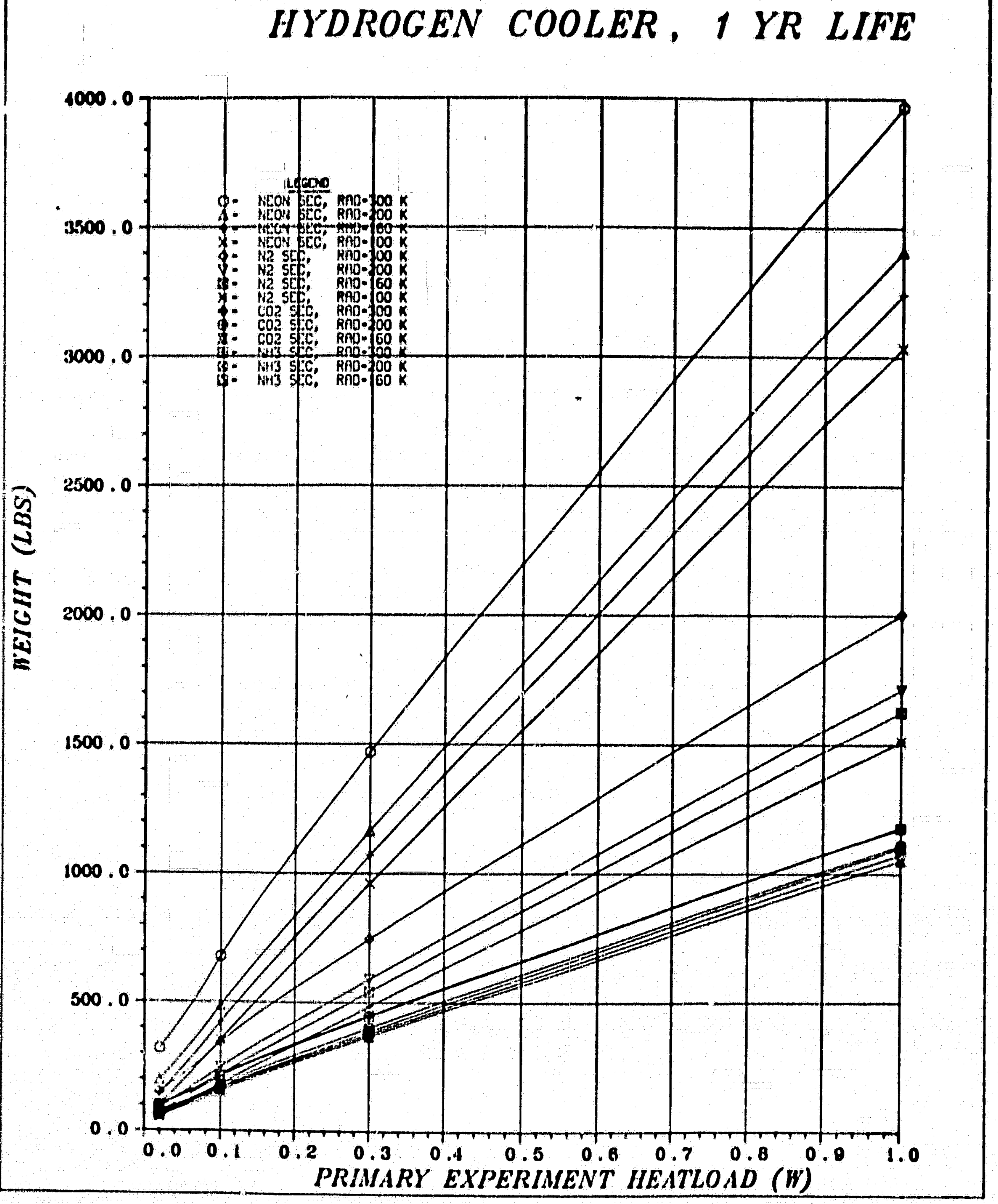

FIGURE 5-9. TRADE STUDIES - CARBON DIOXIDE PRIMARY - 2 YEAR LIFE

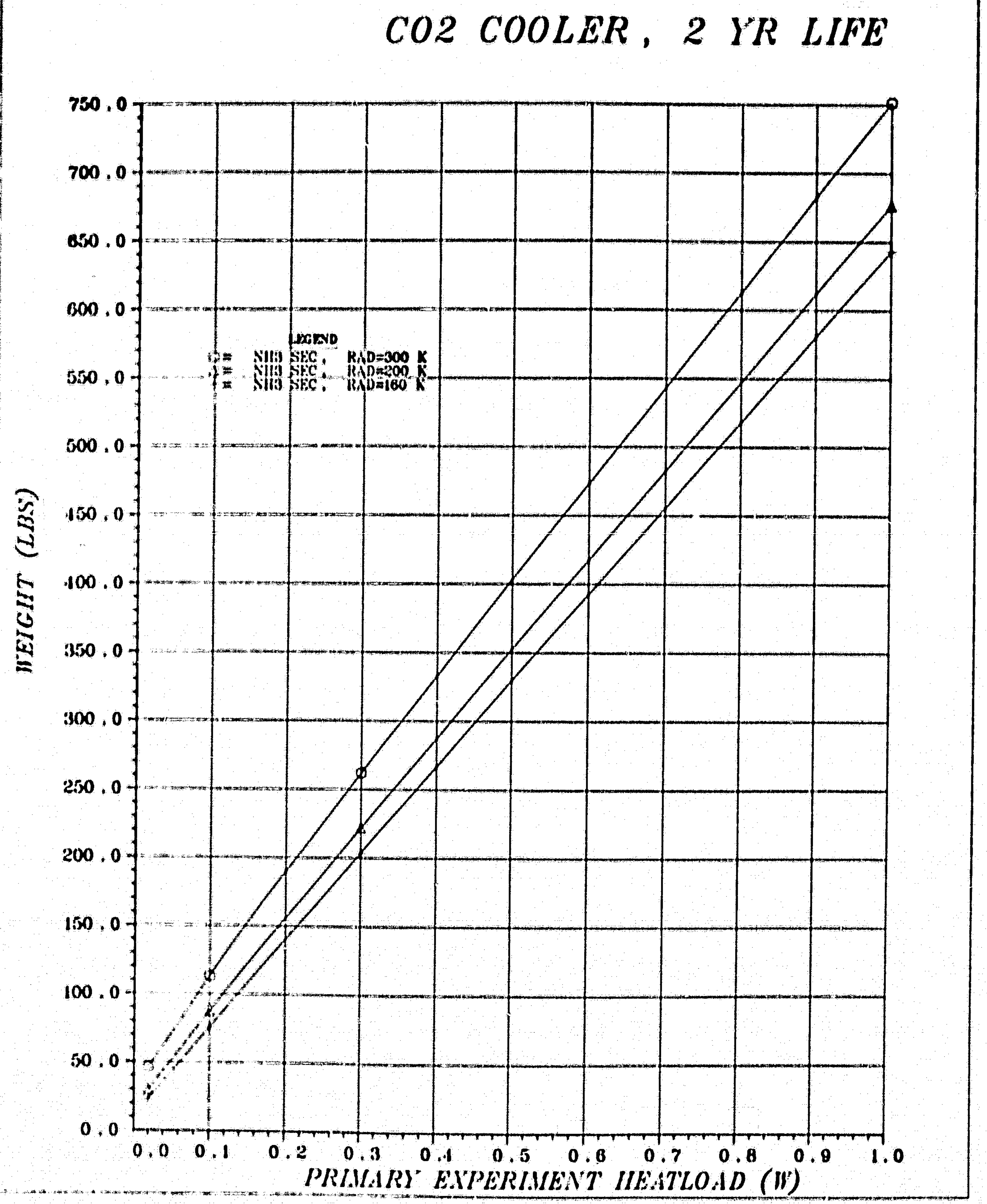

FIGURE 5-10. TRADE STUDIES - ETHYLENE PRIMARY 2 YEAR LIFE

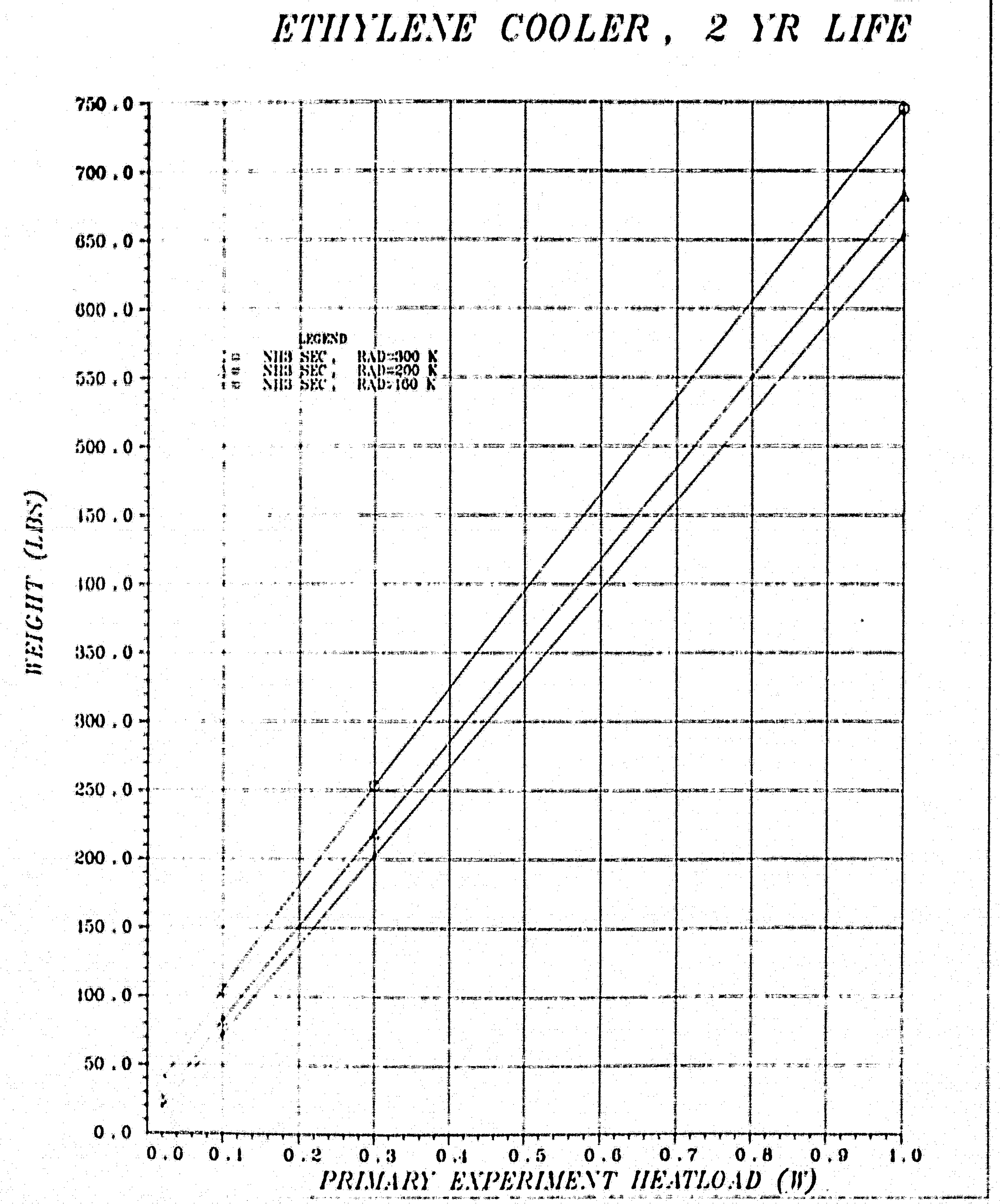

FIGURE 5-11. TRADE STUDIES - METHANE PRIMARY - 2 YEAR LIFE

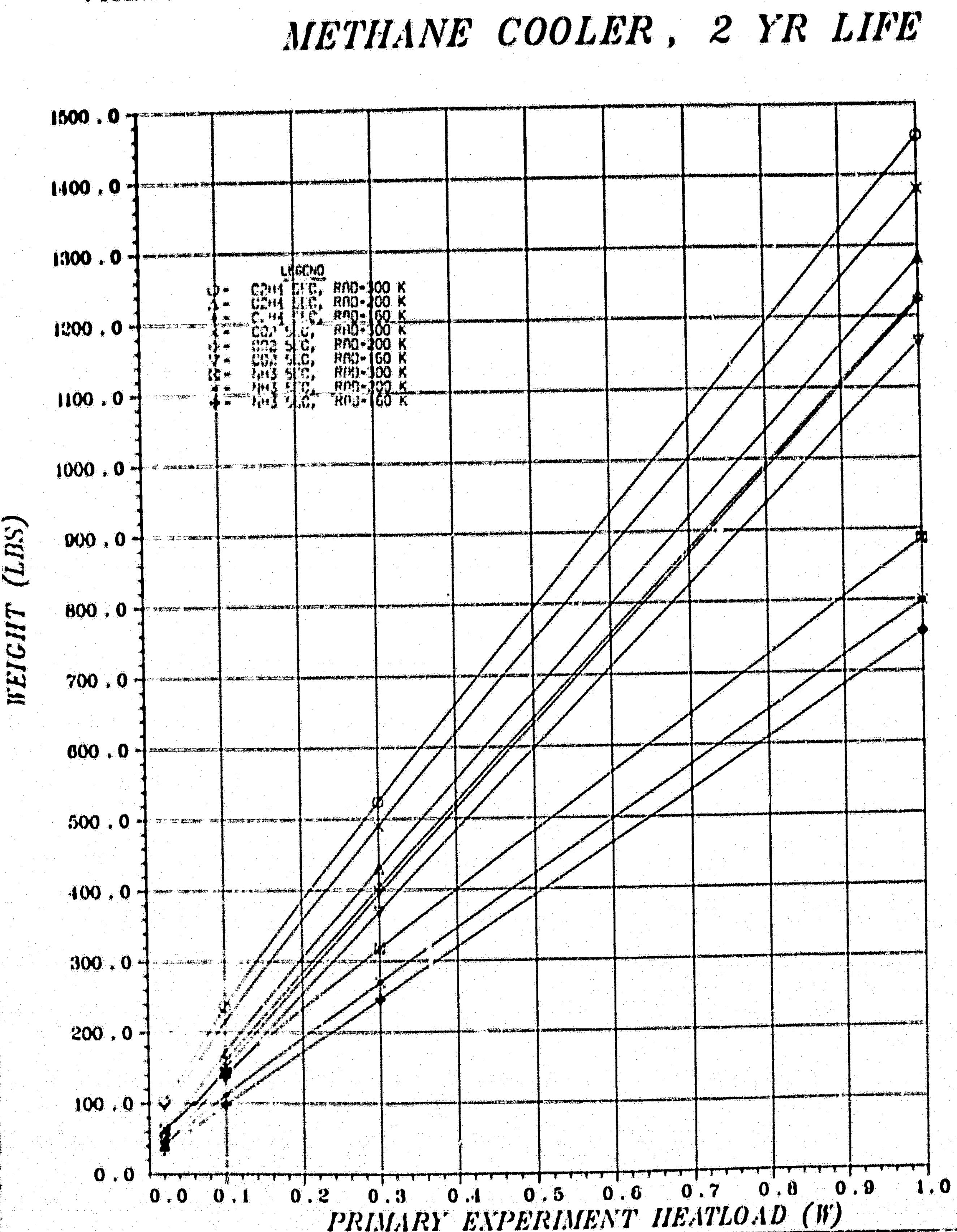

FIGURE 5-12. TRADE STUDIES - ARGON PRIMARY - 2 YEAR LIFE

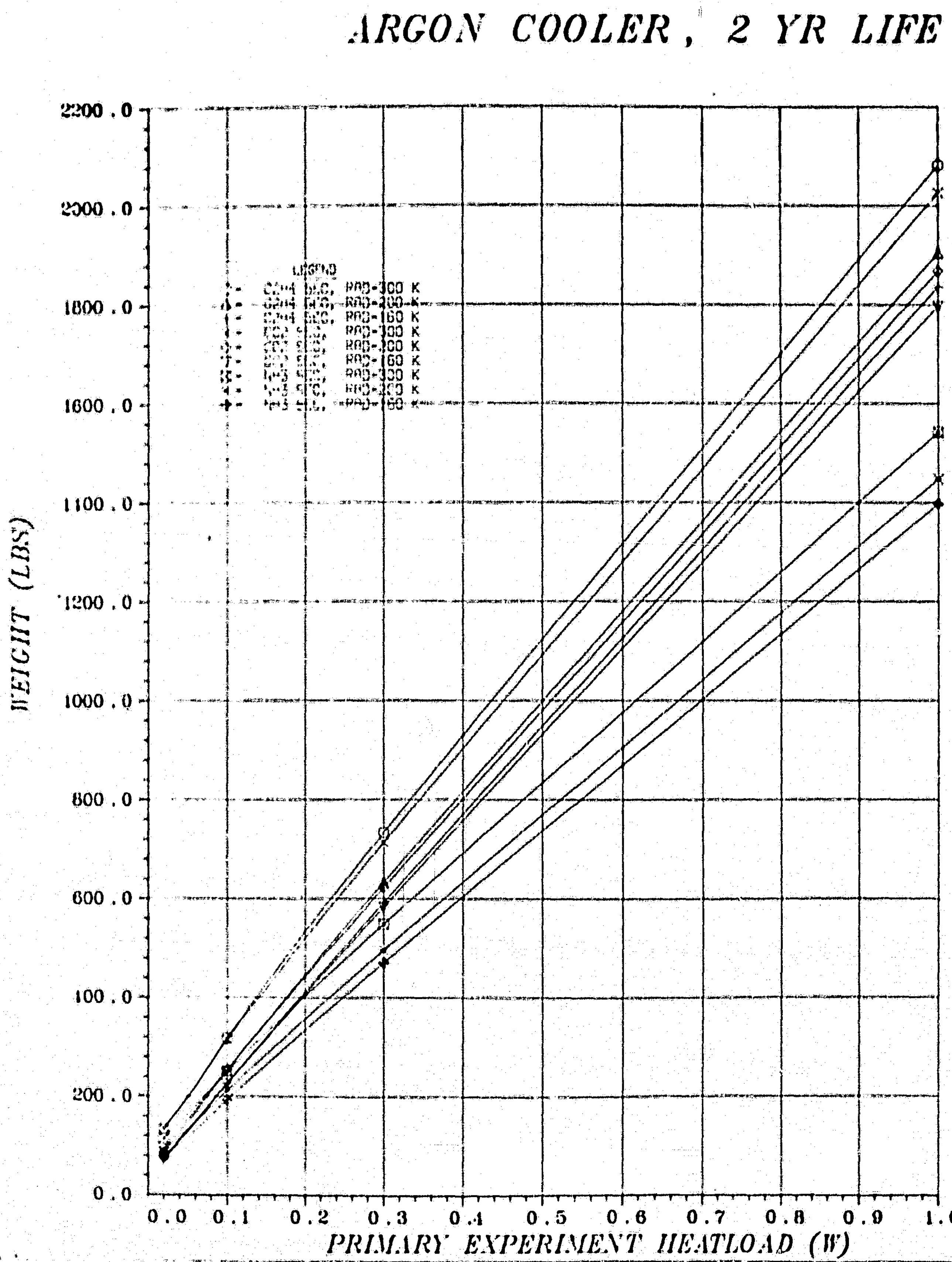

FIGURE 5-13. TRADE STUDIES - NEON PRIMARY - 2 YEAR LIFE

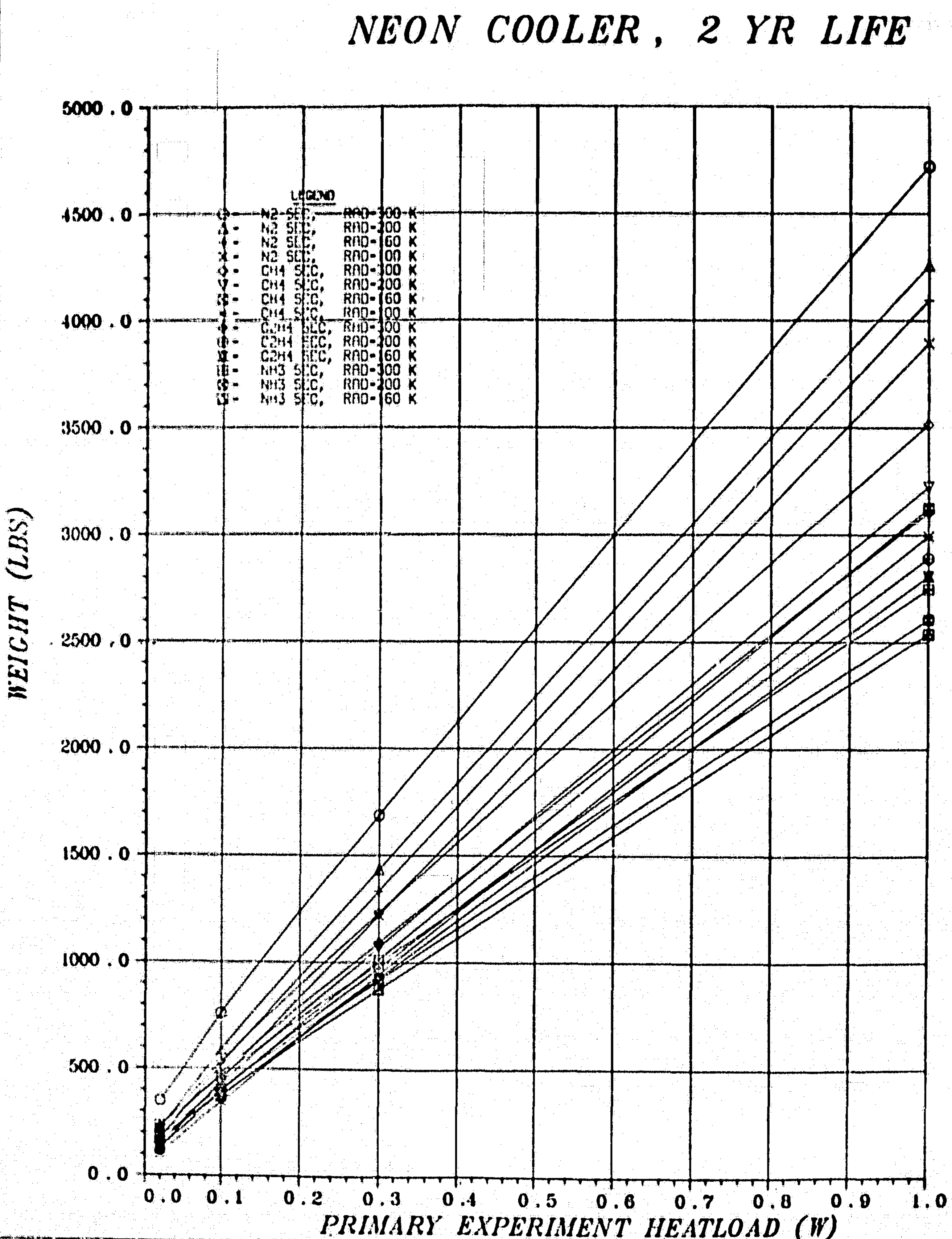

FIGURE 5-14. TRADE STUDIES - ETHYLENE PRIMARY - 2 YEAR LIFE

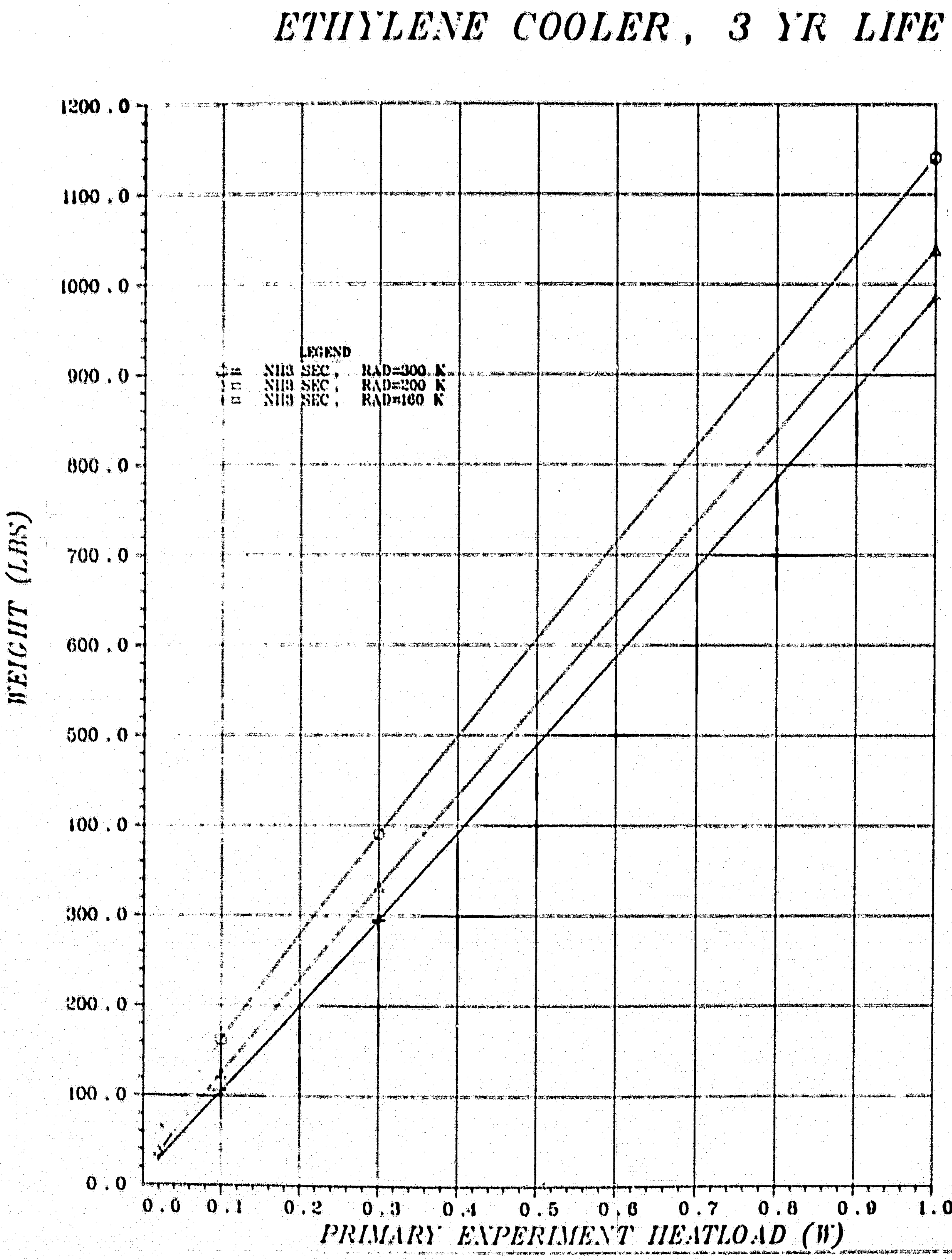

FIGURE 5-15. TRADE STUDIES - CARBON DIOXIDE PRIMARY - 3 YEAR LIFE

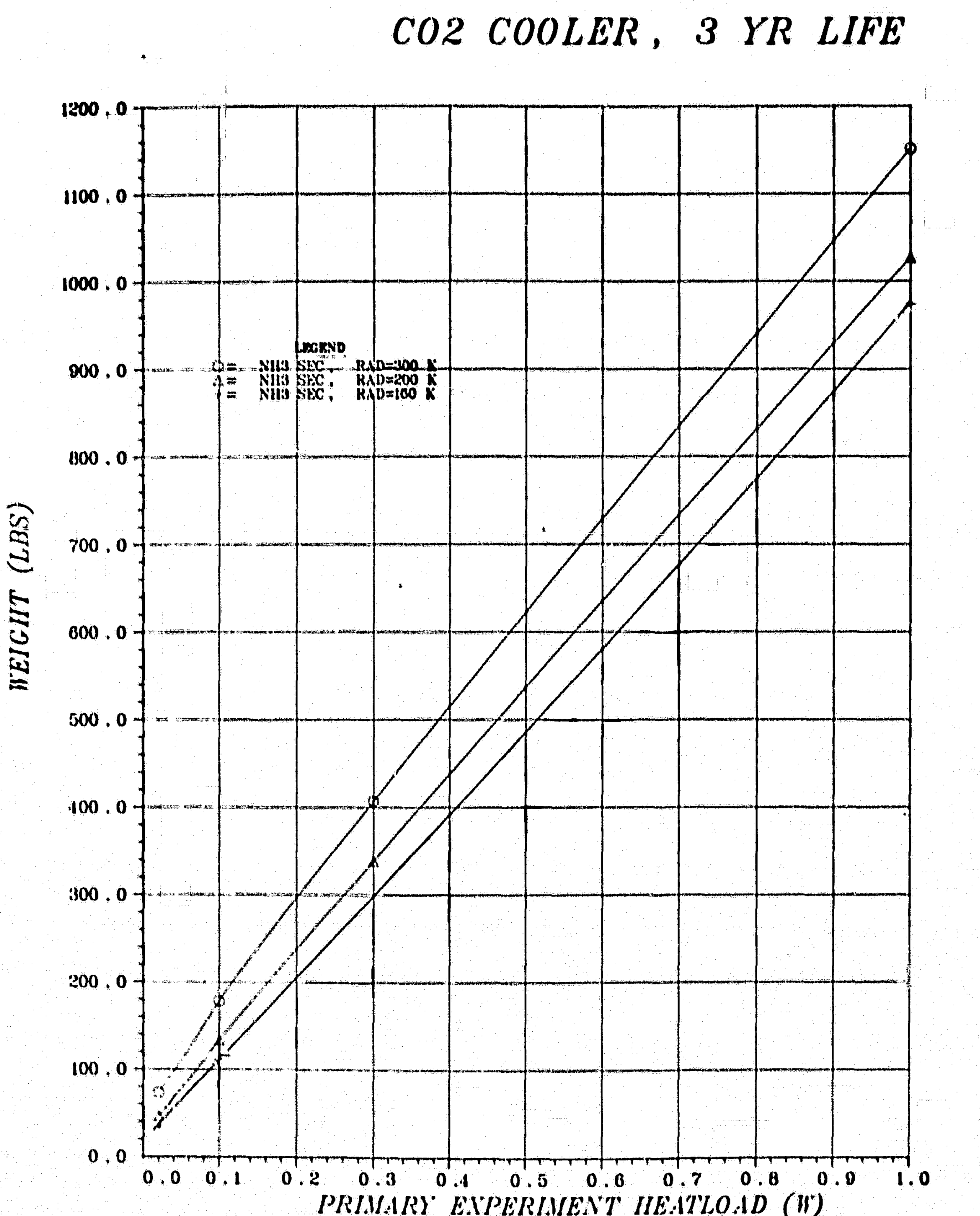

FIGURE 5-16. TRADE STUDIES - METHANE PRIMARY - 3 YEAR LIFE

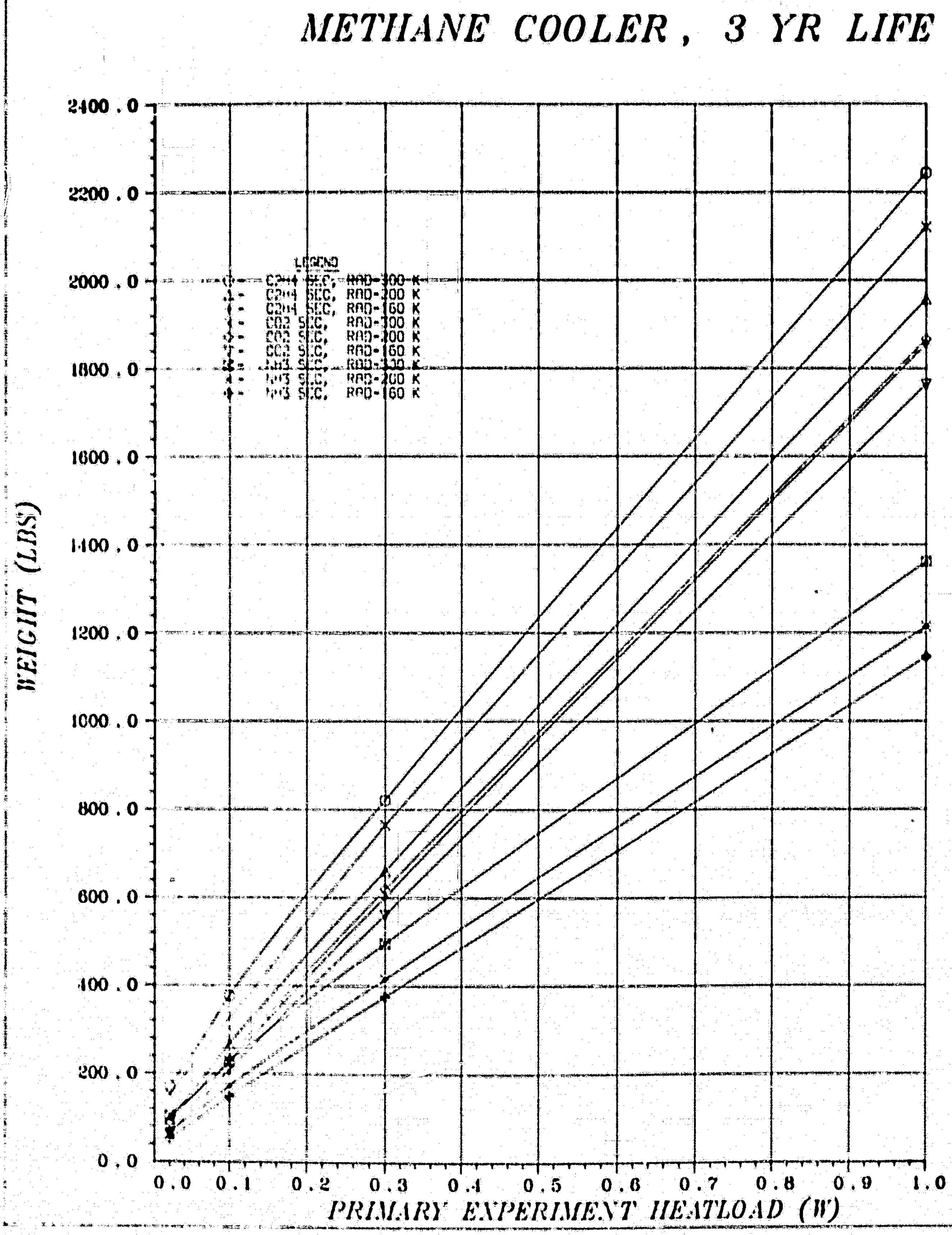

FIGURE 5-17. TRADE STUDIES - NITROGEN PRIMARY - 3 YEAR LIFE

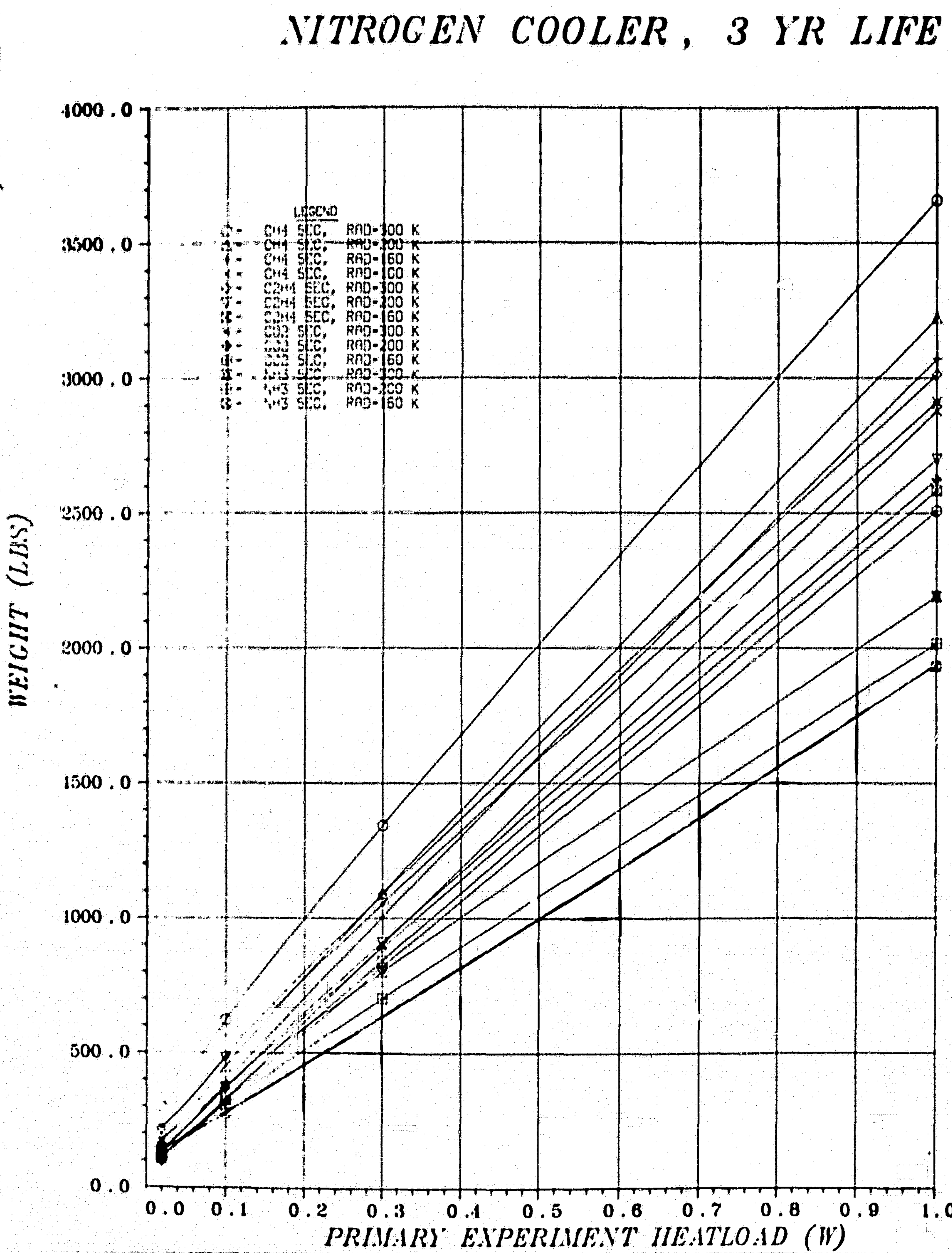

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FIGURE 5-18. TRADE STUDIES - ARGON PRIMARY - 3 YEAR LIFE

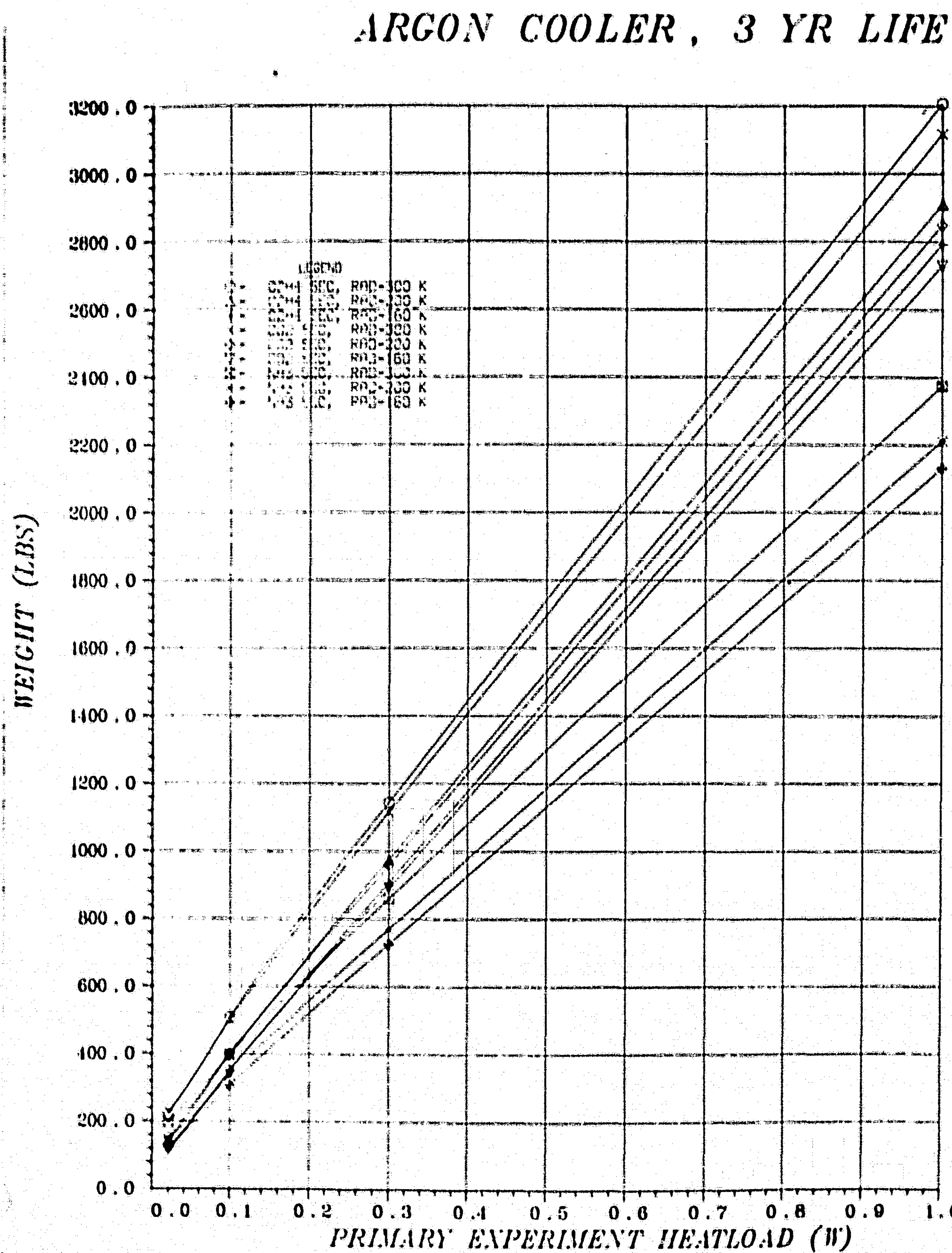


FIGURE 5-19. TRADE STUDIES - NEON PRIMARY - 3 YEAR LIFE

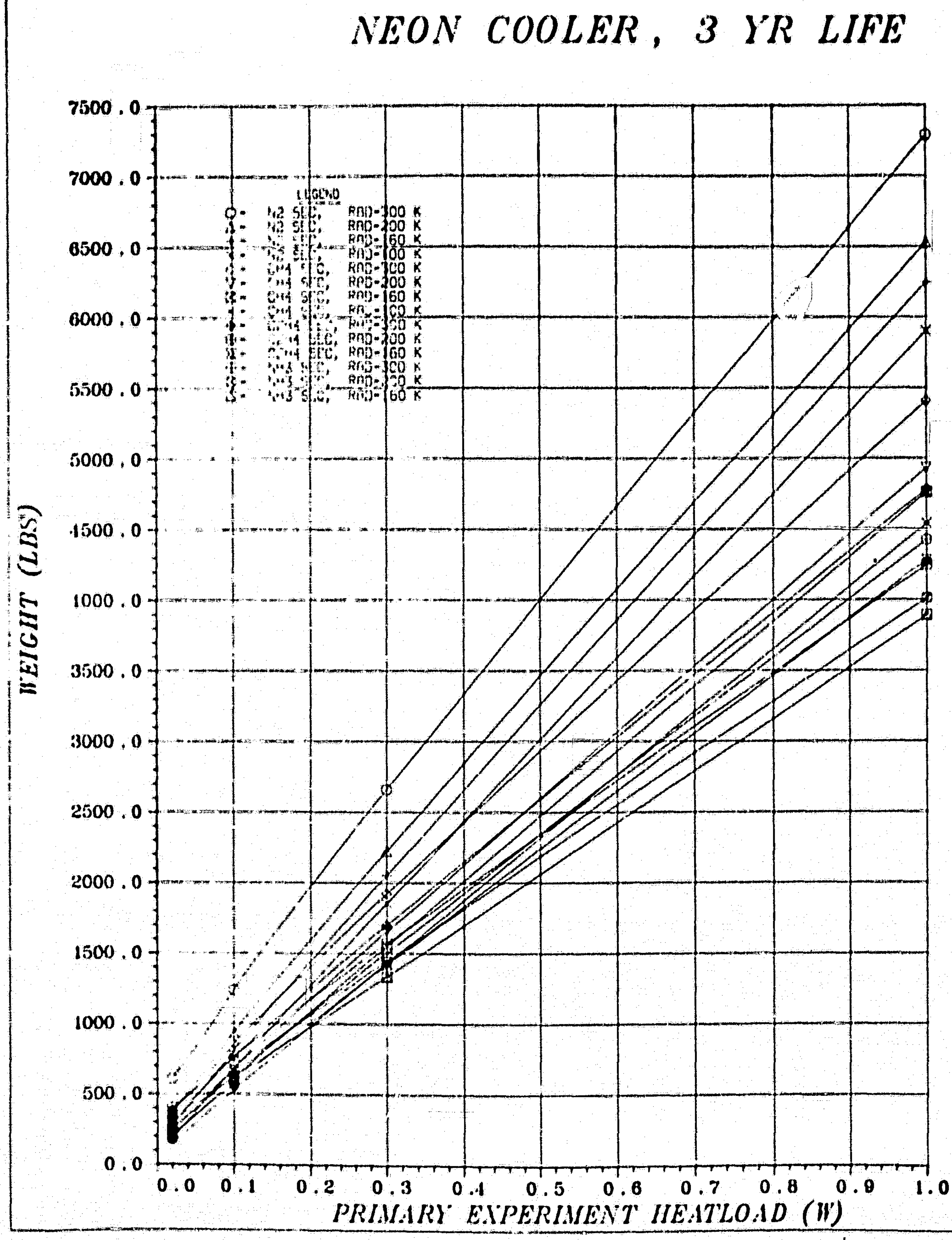


FIGURE 5-20. TRADE STUDIES - HYDROGEN PRIMARY - 3 YEAR LIFE

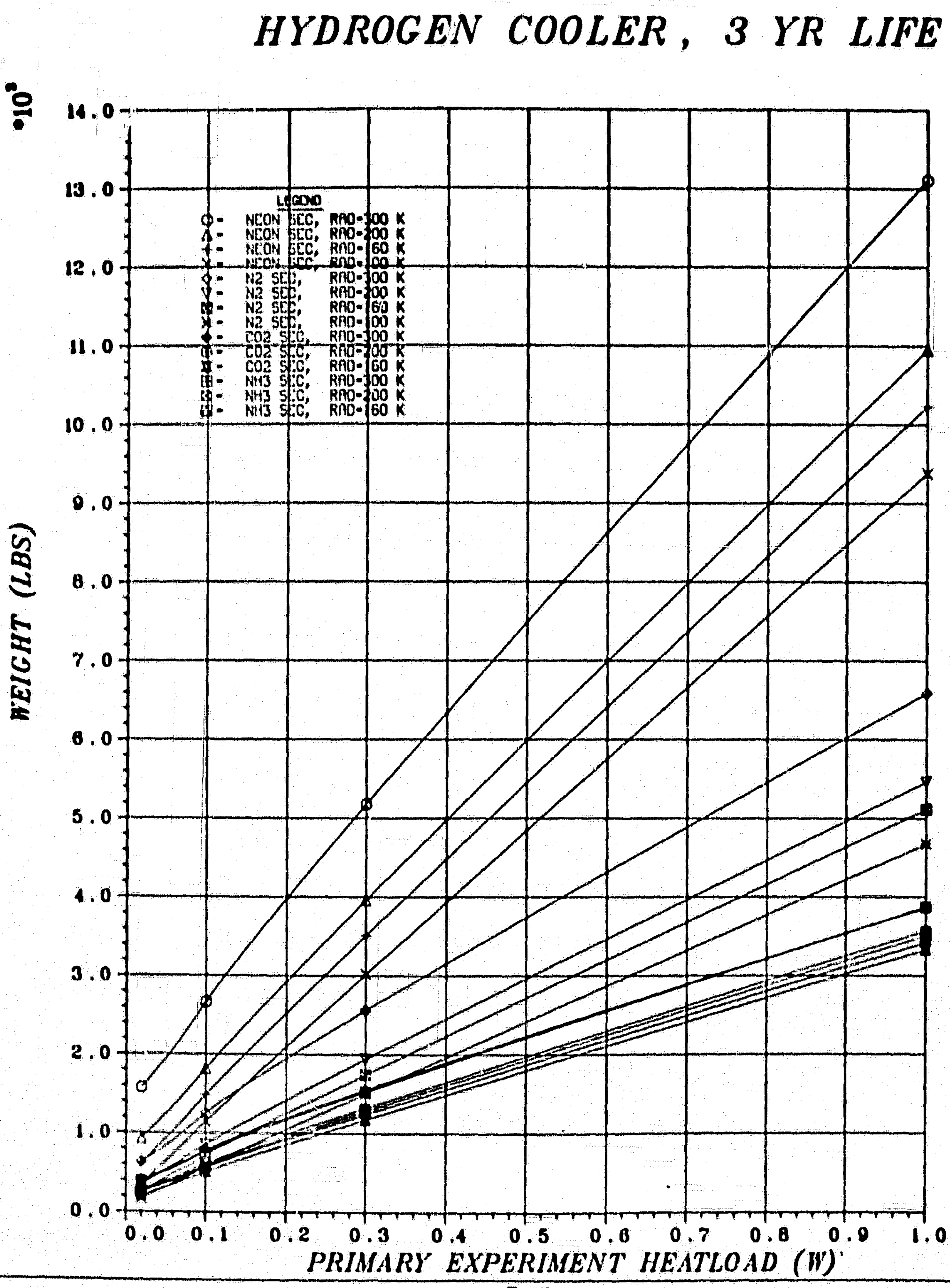
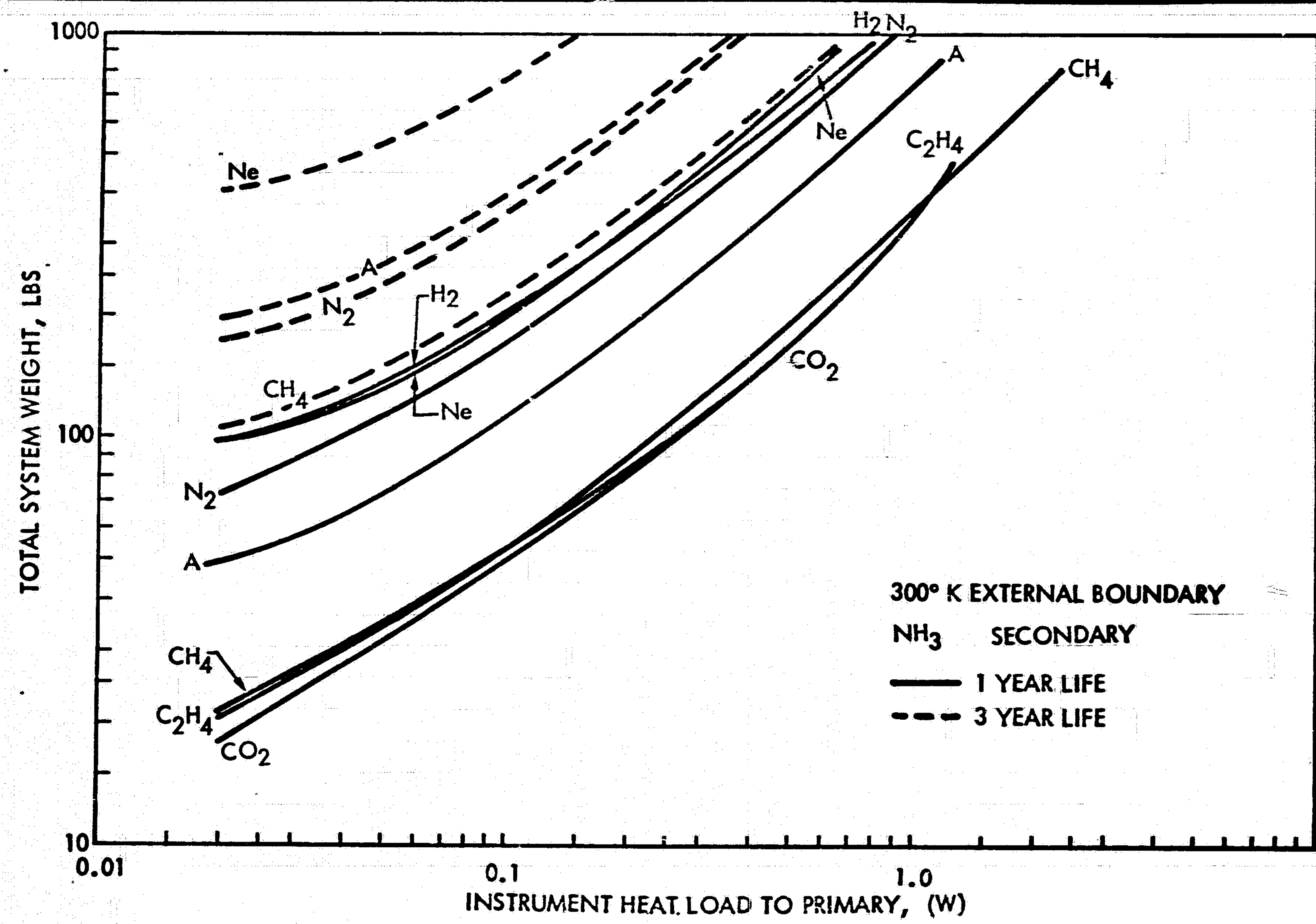


FIGURE 5-21 SUMMARY OF COOLER WEIGHT VS. INSTRUMENT HEAT LOAD

MULTI-PURPOSE COOLER STUDIES – TRADE STUDIES



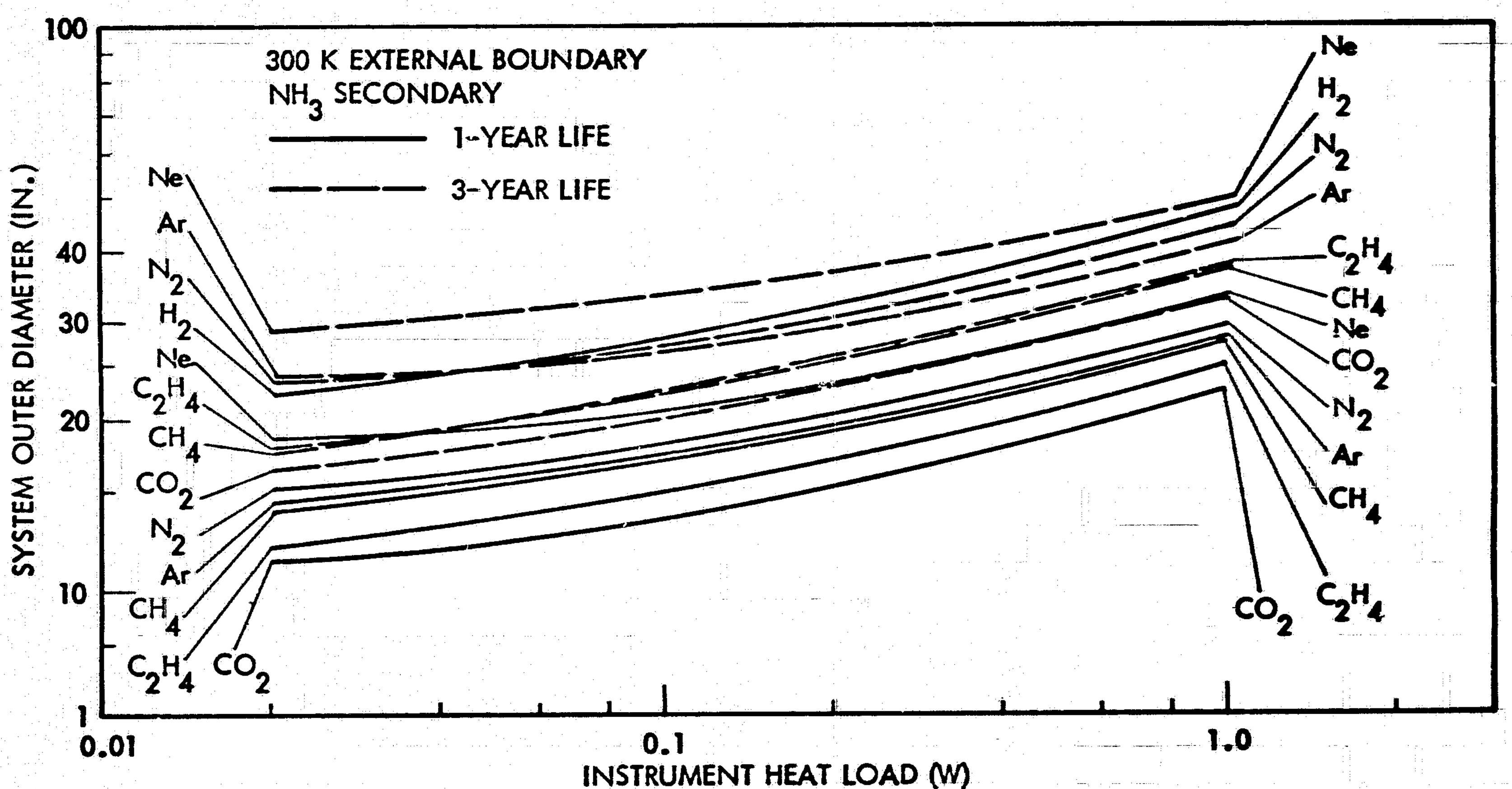


FIGURE 5-22. SUMMARY OF COOLER DIAMETER VS. INSTRUMENT HEAT LOAD

6.0 BASELINE COOLER

6.1 Baseline Cooler Description

6.1.1 Summary

The cooler trade studies described in Section 5, together with instrument cooling requirements presented in Section 3, were utilized to select a baseline configuration. The physical parameters of a cooler which provides 1W of primary and 2W of secondary cooling to the instrument for a lifetime of one year with a methane primary (60°K) and ammonia secondary (150°K) was selected for the baseline cooler studies.

A summary of the mechanical and thermal characteristics of this baseline cooler is presented in Figure 6.1-1. As can be seen, vapor cooling is used extensively to help reduce the heat load to the primary and secondary cryogens, as well as to reduce the heat load to the boundary temperature radiator shield.

The primary resonance is 7.2 Hz when loaded with neon and ammonia; which is substantially below the 50 Hz design goal.

To give the one year design lifetime for the CH_4/NH_3 cooler at a primary experiment heat load of 1.0 Watt and secondary load of 2 Watts, a 148.9 liter primary tank and 65.7 liter secondary tank is required. The dry mass of the cooler including a 10% margin is 99.2 Kg. A more detailed breakdown of the cooler mass by component is given in Figure 6.1-2. Included in this table is the mass of

Fig. 6.1-1. MULTIMISSION BASELINE COOLER SYSTEM SUMMARY

Mechanical

• Envelope (incl vacuum shell)	83.2 cm diameter by 112.7 cm long
• Primary tank volume	148.9 liter
• Secondary tank volume	65.7 liter
• Dry mass (incl 10% margin)	99.2 kg
• Primary resonance	7.2 Hz
• Support tubes design criteria	Survive qualification random level with 3 σ probability using neon as primary cryogen.

Thermal

- Vapor Cooling of Secondary with Primary Vent Gas
- Vapor Cooling of Primary Support Tubes
- Vapor cooling of Radiator Shield with both Primary and Secondary Cryogen Vent Gas
- Tissuglas/Double Aluminized Mylar over Secondary Tank and Radiator Shield
- Silk Net/Double Aluminized Mylar over Primary Tank

Fig. 6.1-2. MULTIMISSION COOLER MASS SUMMARY

Dry Cooler Mass

Item	Mass (kg)	Weight (lb)
Primary Cryogen Tank	21.0	46.3
Secondary Cryogen Tank	9.3	20.4
Secondary Shield	4.9	10.9
Radiator Shield	5.1	11.2
Vacuum Shell	12.9	28.5
Mounting Plate	15.4	34.0
Support Tubes	10.9	24.0
Multilayer Insulation	6.5	14.3
Plumbing	2.7	6.0
Vacion Pump (incl magnets)	0.5	1.0
Misc Hardware	1.0	2.2
Total Dry Mass	90.2	198.8
10% Margin	9.0	19.9
Dry Mass with 10% Margin	99.2	218.7

Cryogen Mass

	Primary		Secondary	
Cryogen	Mass (kg)	Weight (lb)	Mass kg	Weight (lb)
Hydrogen	12.0	26.6	5.3	11.7
Neon	193.2	425.9	85.3	188.0
Argon	217.0	478.5	95.8	211.1
Nitrogen	131.2	289.2	57.9	127.6
Methane	67.0	147.8	29.6	65.2
Carbon Dioxide			100.0	220.4
Ammonia			43.2	95.1
Ethylene			43.2	95.1

the various cryogens considered in this study in both the secondary, and, where applicable, the primary cryogen tank. The lightest system would be the H_2/NH_3 cooler which would have a loaded mass of 154.4 Kg. The heaviest system would be the Ar/CO_2 cooler which would have a mass of 416.2 Kg.

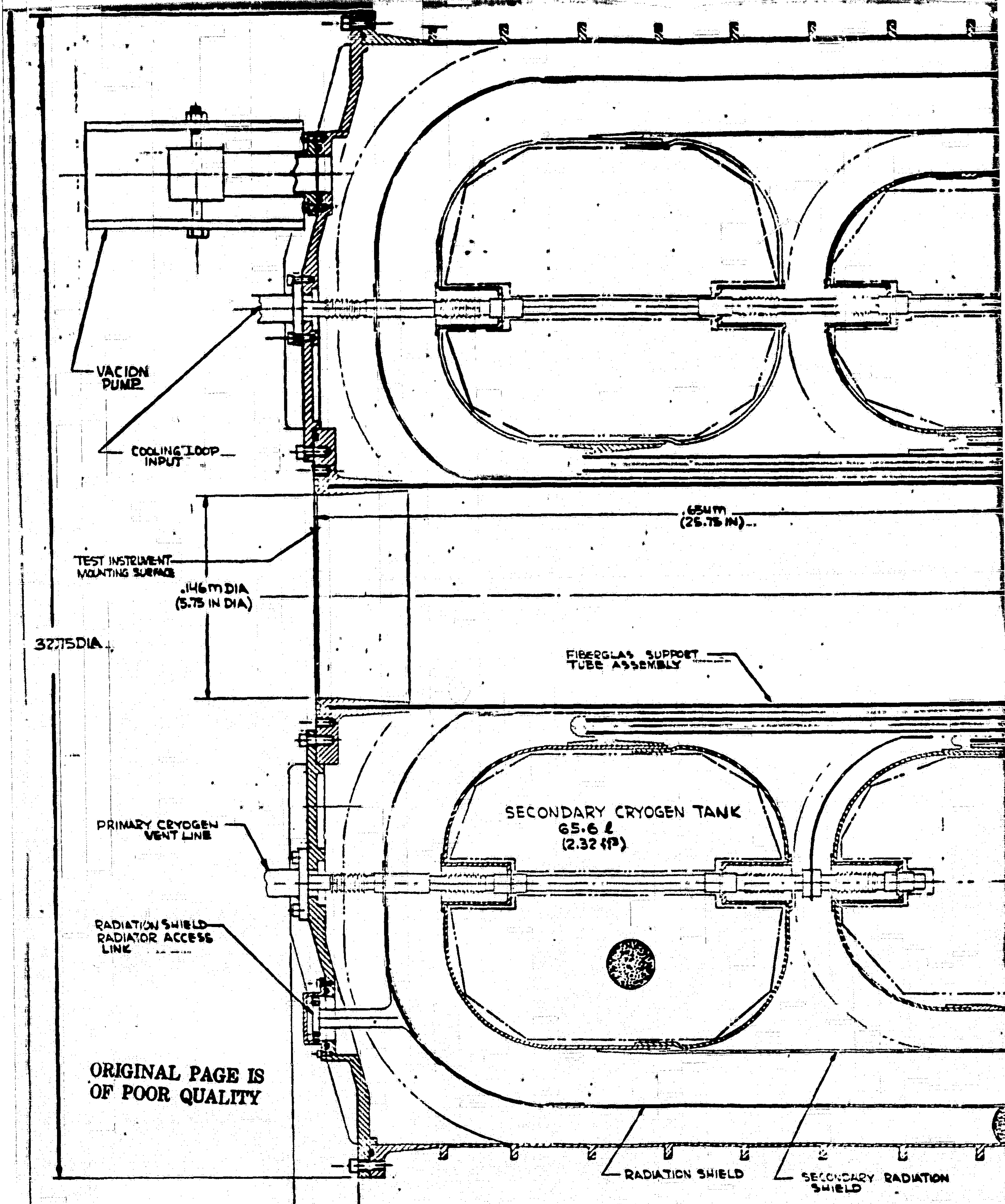
6.1.2 Component Description

A layout of the multimission cooler is shown in Figure 6.1-3. Each of the major cooler subassemblies shown in the layout is described in more detail in the following paragraphs.

6.1.2.a Experiment Interface

At the base of the cylindrical recession in the primary cryogen tank is the cooler/experiment interface. Instrument cooling at three distinct temperatures (primary, secondary, and radiator shield) is available, and for any given mission, any combination of one, two or three temperatures may be utilized. This flexibility in the design also allows for different combinations to be selected for any one cooler during different missions.

The interface at each of the temperatures, consists of a shrink fit assembly of dissimilar materials. The female member of each shrink fit is a removable "bolt-on" member which connects to the cooler assembly. The male member which slips into the shrink fit while at ambient temperature couples directly to the experiment. These types of shrink fit cooler interfaces have been used on previous flight cooler programs[6-1,6-2] and have proven to be an excellent structural and thermal interface with very small thermal resistance.



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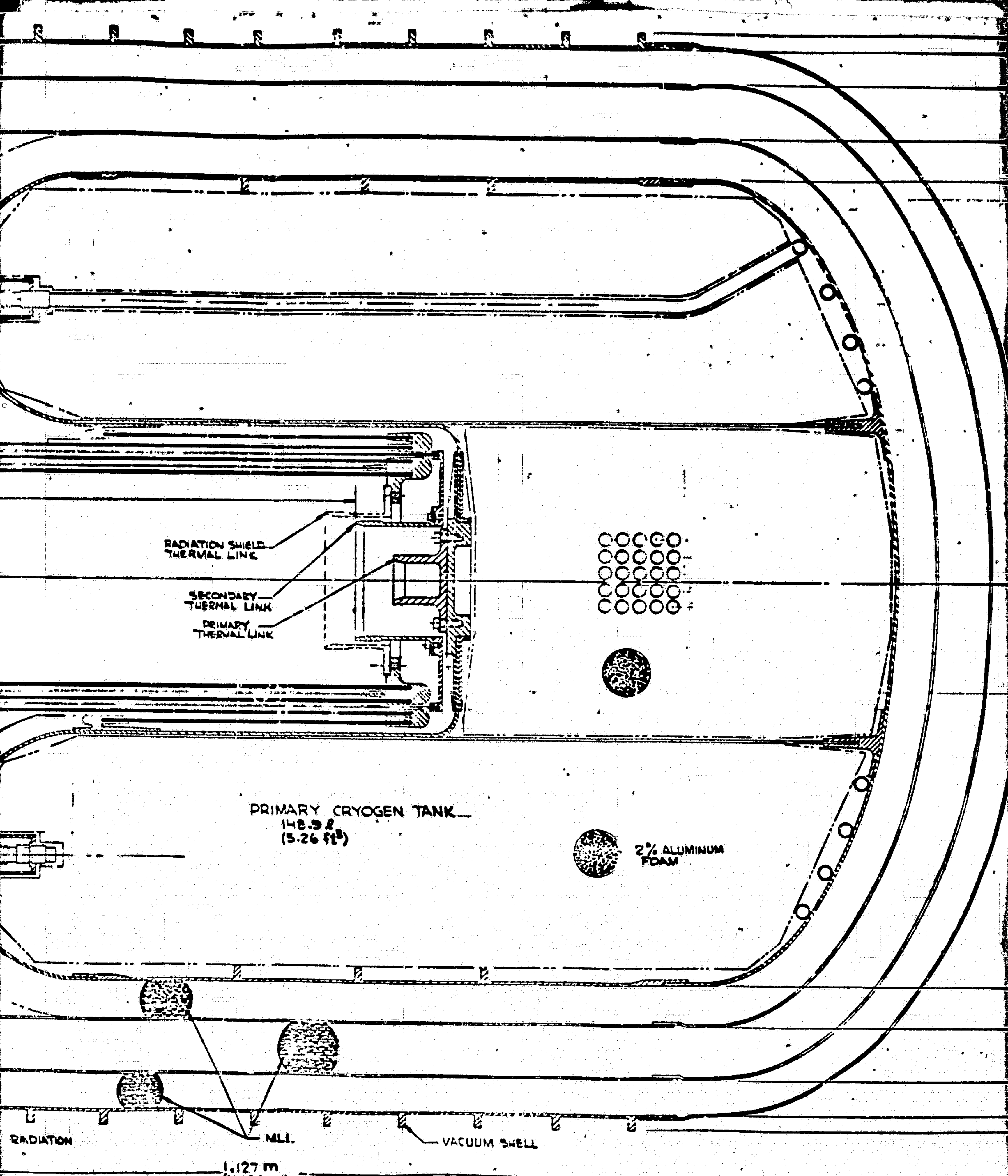
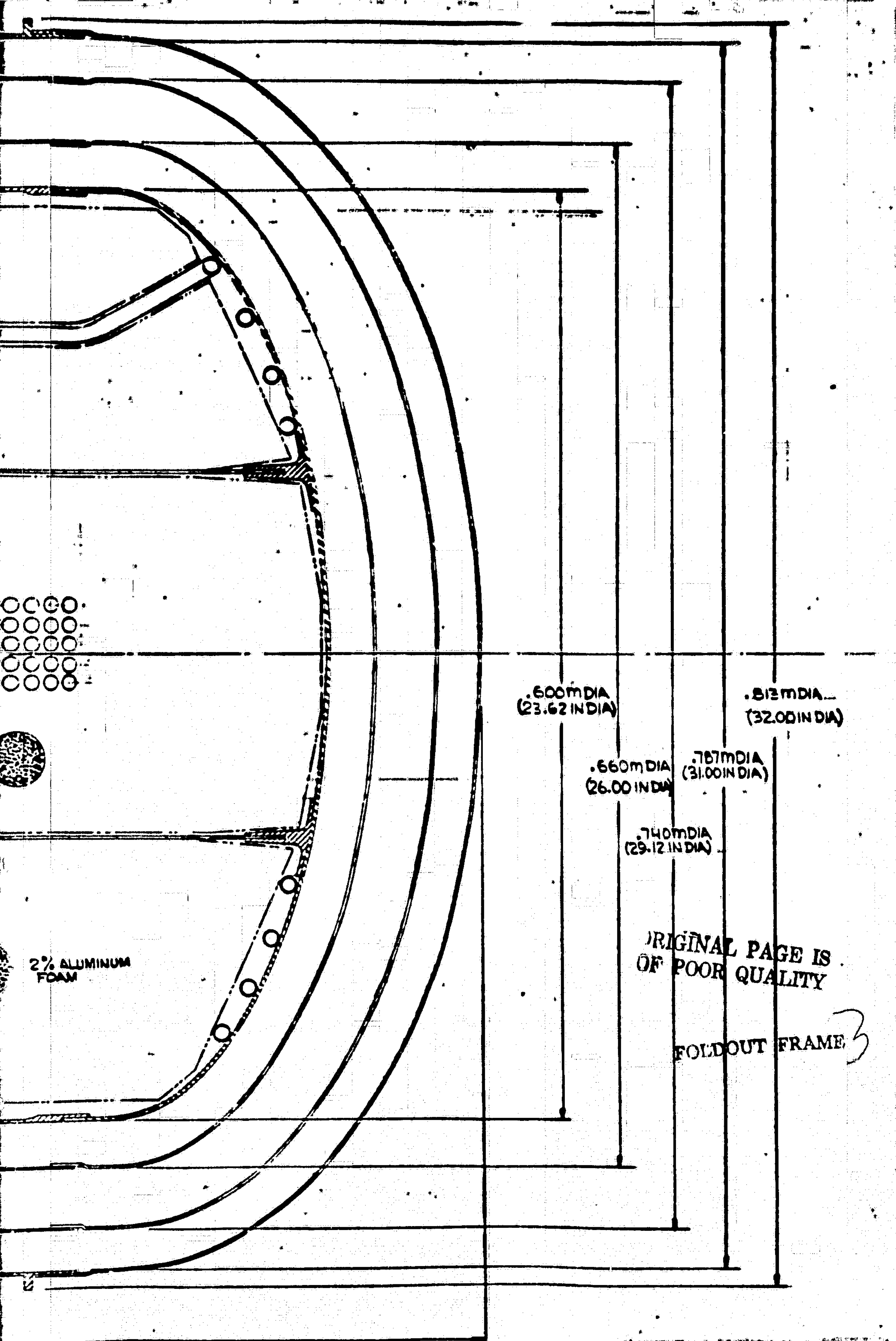
FOLDOUT FRAME



FOLDOUT FRAME 2



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FOLDOUT FRAME 3

FIGURE 6.1-3 MULTI-MISSION COOLER LAYOUT

The test instrument mounting surface located on the cooler main plate can be blanked-off to allow cooler testing without need of the experimentor's hardware. Likewise, the modular "drop-in" experimentors package can be cooled for testing independent of the cooler assembly. During integration, the experimentors package is "dropped in" the cooler while at ambient temperature. Alignment of the package is referenced to the test instrument mounting surface which is part of the experimentor's package. To maintain alignment when cold and also to mechanically decouple the cooler from the experiment during launch, a flexible braid is used on the experimentor side of the male shrink fit member. These braids which have been used in the past will transmit as little as 0.250 Kg per centimeter of relative motion (i.e., a negligible load) to the experiment.

6.1.2.b Aluminum Foam Heat Exchanger

Inside both the primary and secondary cryogen tanks is a heat exchanger, whose function is to provide good thermal contact between the heat transfer assembly and the solid cryogen. The heat exchanger used is a 2% dense aluminum foam which is machined to size and then bonded to the inner wall of both tanks. Without any heat exchanger in the tanks, the cryogen will sublime away from the conduction surfaces creating a vapor gap which supports an every increasing temperature gradient. This foam has been utilized on prior solid cooler programs at LMSC and has been found to be a most efficient design.

6.1.2.c Primary Cryogen Tank

The tank containing the primary cryogen is a vacuum tight, 148.9 liter, 6061 T6 aluminum enclosure. Manufacture of the tank is made in three separate components: a spun-formed spheroidal end and contoured top piece as well as a machined, central cylindrical section. Assembly of the tank is achieved by epoxy bonding along two lap joints at both ends of the cylindrical section.

Special features of the primary tank include the addition of three uniformly spaced 0.51 cm wide by 1.02 cm high integrally machined internal ring stiffeners along the crylindrical section and a 24.9 cm diameter by 36.3 cm long cylindrical recession in the top cover.

Along the recession, the folded fiberglas support tube assembly is bonded into place, and at the base, attachment to the experiment is made through a shrink fit union.

On the inside portion of the recession, an aluminum tube is bonded to the tank and extends down to the spheroidal end dome to provide support to the flat recession base.

Within the tank, the 2% dense aluminum foam heat exchanger and a cryogenic fluid (N_2 or He) cooling coil are attached to the tank walls.

Four feedthrus are provided on the top of the tank for the cryogen fill and vent lines and auxiliary cooling loop lines.

6.1.2.d Secondary Tank and Shield

The tank containing the secondary cryogen is a vacuum tight, 65.7 liter, 6061 T6 aluminum enclosure. The tank, which takes the form of a toroid, is spun-formed in two halves and assembled at a common lap joint with epoxy.

Attached to the outer diameter of the secondary tank is a 6061-T6 aluminum shield. This shield, located 3.02 cm from the primary tank shell, extends completely around the primary tank and insulation system to provide a uniform intermediate boundary temperature for reduction of the parasitic heat leak into the primary cryogen.

The cooling line is routed through the tank and thermally grounded to the secondary tank wall at the feedthru/tank interface. In total, four feedthrus are provided on the bottom of the tank and five on the tank top. Two each are used for the cooling loop line and two each are required for the primary fill and vent line. The extra feedthru on the tank top is required for the secondary fill/vent line. The 2% dense aluminum foam heat exchanger is also employed within the secondary.

6.1.2.e Radiator Shield

A shield which acts as the warm temperature boundary to the secondary cryogen system is provided. This shield can be left "uncoupled" to any outside temperature sinks, in which case it would act as a floating shield, maintaining an equilibrium temperature slightly less than the local ambient. Alternatively, an external cooling source such as a space radiator or thermoelectric cooler may be coupled to the thermal link which is attached to the top of the shield and drive the shield temperature lower. By lowering the radiator shield temperature, longer secondary lifetimes and/or higher secondary experiment heat loads can be realized. Heat rates to the primary cryogen would be unaffected by a change in the radiator shield temperature. The shield is supported by an aluminum cylinder which is bonded to the aluminum ring that connects support tubes number 1 and 2.

6.1.2.f Vacuum Shell

The vacuum shell consists of a 6061-T6 aluminum integrally machined-ring stiffened cylinder with spheroidal dome. The 0.51 cm wide by 1.02 cm high rings are spaced 5.5 cm apart along the entire 85.0 cm length of the crylindrical shell. On the base of the cylindrical section is a mounting flange which contains an O-ring groove and a mounting bolt hole pattern. The addition of the spheroid dome makes the total length of the vacuum shell 112.7 cm.

6.1.2.g Support Tubes

The support tube assembly consists of four concentric, folded, low conductivity, high strength fiberglas tubes. Tubes 1 and 2, 3 and 4, and at the opposite end tubes 2 and 3 are jointed at their ends by epoxy bonding to an aluminum machined end fitting.

The end of the tube 1 mounts to the main plate forming the warm temperature boundary. At the end of tube 2, where tubes 2 and 3 are coupled, the secondary tank is epoxy bonded in place. The primary tank is likewise epoxy bonded in place at the end of tube 4. The geometry of each tube is summarized as follows: (Dia = Inner Dia and Length = Unsupported Length).

Tube No.	Dia (cm)	Thickness (cm)	Length (cm)
1	15.67	0.254	61.39
2	17.70	0.191	46.86
3	19.69	0.191	46.86
3	21.13	0.152	18.97

6.1.2.h Insulation

About the primary tank, secondary tank and shield and radiator shield will be a multilayer insulation blanket of double-aluminized mylar. Spacer material used in the blanket about the primary tank will be silk net, while at all other locations - tisuglas will be used. Each layer of insulation will be wrapped individually, such that a layer density of 15 layers/cm results in the silk net system and 43 layers/cm in the tisuglas system will be achieved. The thickness of the wrap will be 3.02 cm about the primary, 3.96 cm about the secondary tank and 2.39 cm about the radiator shield.

6.1.2.i Vapor Cooling

Vent gas cooling will be utilized in various locations to help in reducing the parasitic heat load to the cooler. These techniques have been utilized in previous coolers and have been studied on company funded programs. At the first location, a thermal link will be attached to the primary cryogen vent line. This thermal link will be coupled to a point along the primary support tube #3. The primary vent line will also be grounded to the secondary tank so that vapor cooling will occur. An additional location where vent gas cooling will be utilized will be at the radiator shield. The primary and secondary vent lines will both be thermally grounded to the radiation shield so as to allow vent gas cooling of the shield from both cryogens.

6.1.2.j Cooler Plumbing

The cooler plumbing consists of both the primary and secondary fill/vent lines and the cryogenic fluid (LN_2 or LHe) cooling loop line.

Two identical fill and vent lines are provided to the primary to provide flexibility in either filling with a liquid (requiring two lines) or filling with gas (requiring a single line). A single fill/vent line is provided to the secondary tank.

All lines are 1.27 cm diameter convoluted stainless having a 0.013 cm wall thickness. Stainless was selected because of its low thermal conductivity, low permeability, and good flexibility in mechanically decoupling structures that will realize relative motion in a launch environment. In addition, coated fiberglas tube sections are utilized in series to reduce the heat loads.

The cryogenic fluid cooling loop line also employes the same convoluted stainless-fiberglas tubing wherever a temperature transition is encountered within the cooler. On the mounting plate, the vacuum feedthru includes a stainless steel tubing standoff to insure no cooling of the main plate occurs during the chilldown process.

A schematic of the cooler plumbing system is shown in Figure 6.1.-4.

6.1.2.k Main Plate

The main plate acts as the supporting structure for the cooler, as well as the vacuum interface for the vacuum shell. It is planned that the main plate also act as the primary support for the experiment and satellite vehicle interface.

On the plate will be four 2.5 cm dia Cryolab valves. Three valves will be the terminators for the fill/vent lines and the remaining one will be a vacuum access port for rough pumpdown. An interface to an 8ℓ/s Varian vacion pump is also provided for maintaining low pressure in the insulation space during ground testing.

Access to the radiator shield thermal link and to the cryogen fluid cooling loop is also provided on the main plate as is a hermetically sealed electrical feedthru for thermometry instrumentation.

6.1.3 Thermal Analysis

A heat map of the baseline cooler, utilizing CH_4/NH_3 at $Q_{primary}$ = 1.0 watt and $Q_{secondary}$ = 2.0 w is shown in Figure 6.1-5. Included are the effects

FIGURE 6.1-4 COOLER PLUMBING SCHEMATIC

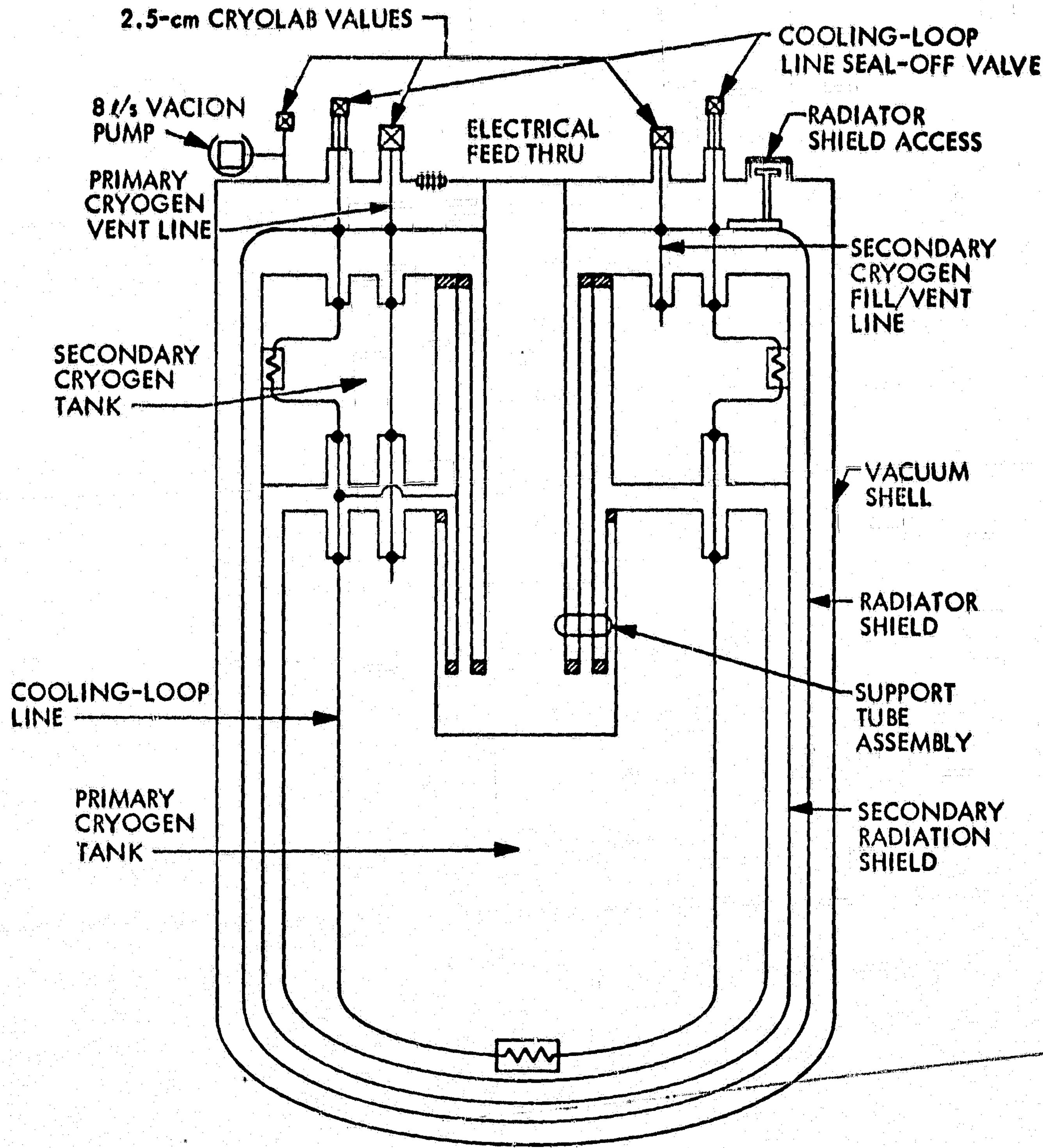
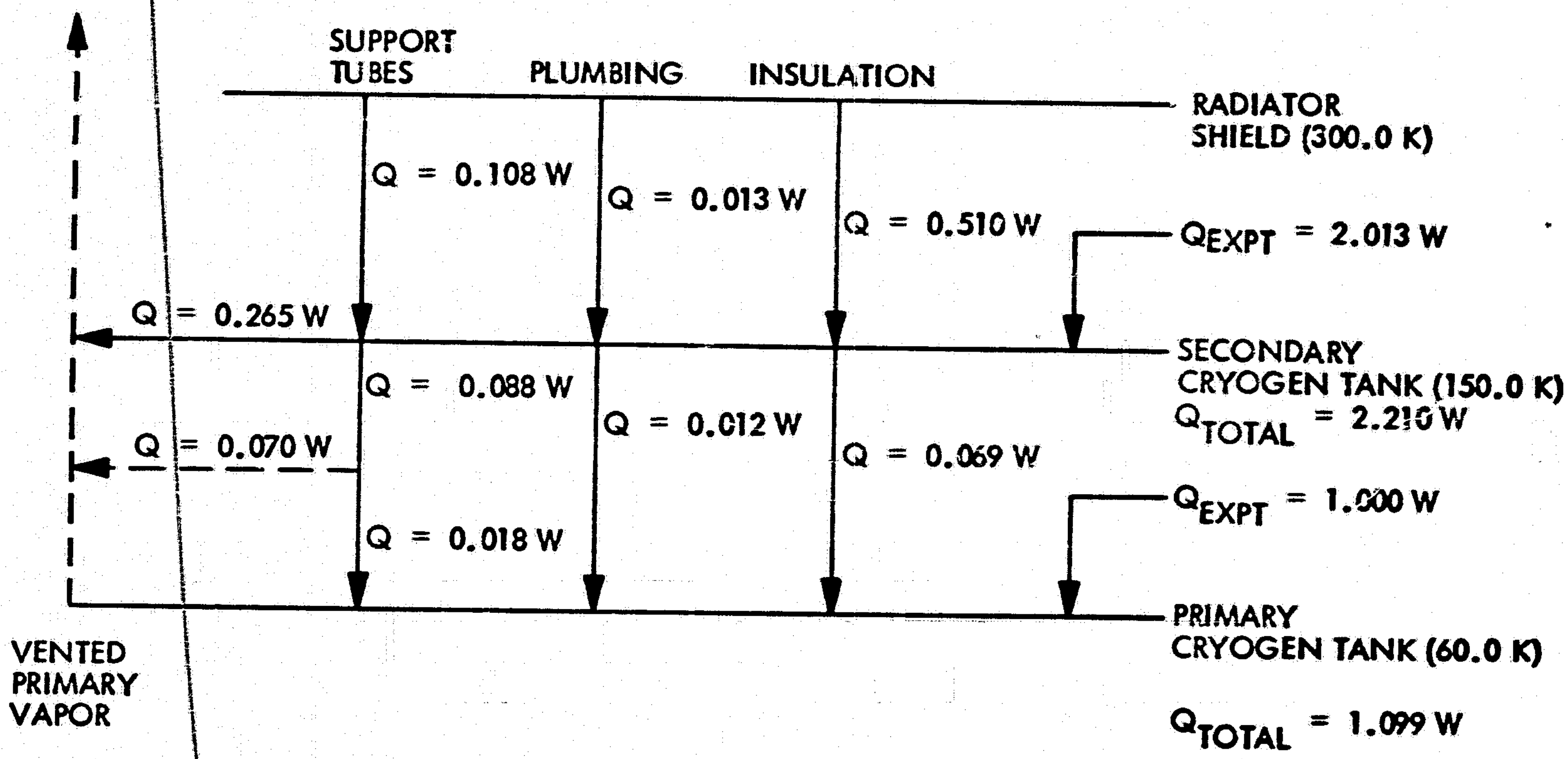


FIGURE 6.1-5 HEAT MAP OF COOLER



of double aluminized mylar insulation systems, miscellaneous cooler plumbing lines, and the primary and secondary support tube assembly.

No external cooling of the radiator shield was assumed, and for the baseline the temperature was fixed at 300°K, the local ambient. In actuality, the shield will maintain an equilibrium temperature somewhat less than the local ambient. This will occur because (1) both the primary and secondary vent lines are tied to the radiator shield providing some amount of vapor cooling and (2) the shield is supported from an intermediate point along the secondary support tubes. These effects were not considered in the analysis and will tend to make the predicted heat loads more conservative.

The multimission cooler utilizes vapor cooling at both the secondary cryogen tank and along the primary support tube. As shown in Figure 6.1.5, vapor cooling removes 265 mw from the secondary and an additional 70 mw along the support tubes. These figures represent a 42% reduction in the parasitic heat load to both stages of the cooler, but only 6.4% and 12.4% of the total primary and secondary heat load, respectively when the instrument load is included.

At lower primary experiment heat loads, the lower mass flow rates will decrease the absolute effect of the vent gas cooling at both locations, as well as the percentage change in the secondary cooling. The relative cooling effect at the support tube, however, will increase. For example, if the primary experiment heat load to the baseline cooler were dropped to 20 mW, the percentage of heat removed through the support tube compared to the total primary heat load will increase from 6.4% to 14%. At the same time, vapor cooling of the secondary when compared to the net secondary heat load will decrease from 12.4% to 5.3%.

The effect of vent gas cooling is greater when other cryogen combinations are utilized in the "baseline cooler". On a percentage basis, the largest benefit is seen to occur for a Ne/C_2H_4 cooler at a primary experiment heat load of 1.0 watt. In this cooler, 49% of the net secondary heat load of 1.68 watts is removed by the primary vent gas. Vent gas cooling of the support tubes removes only 6% of the total primary heat load in this cooler, but the heat leak realized through the support tubes is only 0.4% of the total primary heat load.

6.1.4 Structural Analysis

6.1.4.a Support Tubes

In designing the support tube assembly, it is found that use of different cryogens in the primary and secondary tanks leads to a support tube thickness which varies by as much as 50%. In selecting one particular design which accommodates all cryogens with no major penalty, two approaches were investigated. In the first approach, the supports are sized for a lighter cryogen and to survive launch stresses using the heavier cryogens, the cooler would only be partially filled. The second approach is to overdesign the supports to accommodate the heavier cryogens, accepting the higher heat loads over that from an optimum design with the less dense cryogens.

As a reference point, the baseline CH_4/NH_3 cooler is used. Support tubes were sized to survive a static 5.45g lateral acceleration including a safety factor of 1.65. Maximum fill percentage giving rise to equivalent static stresses within the tubes were then computed for cryogens having higher density than methane. In this analysis, two cases need to be investigated - that with the secondary above the primary during fill and that with the secondary below the primary during fill. These cases are distinct because of the location of the center-of-mass of the cryogen within the cooler during a partial fill condition. In figure 6.1-6 the maximum fill percentage of the primary tank as a function of the cryogen density is shown using methane as the reference cryogen.

As can be seen, neon (ρ = 1.44 kg/liter) can only be filled to between 28% to 43% of maximum capacity - depending on whether the tank is filled with the secondary above or below the primary, respectively. This reduction in fill percentage translates directly to a reduction in cooler lifetime.

To assess the influence of a support tube designed for the heaviest cryogen on cooler performance, a more rigorous analysis into the support tube sizing was performed. In this analysis, a dynamic vibration analysis considering both material and buckling failures were con-

FIGURE 6.1-6 EFFECT OF OFF-LOADING FOR VARIOUS CRYOGENS

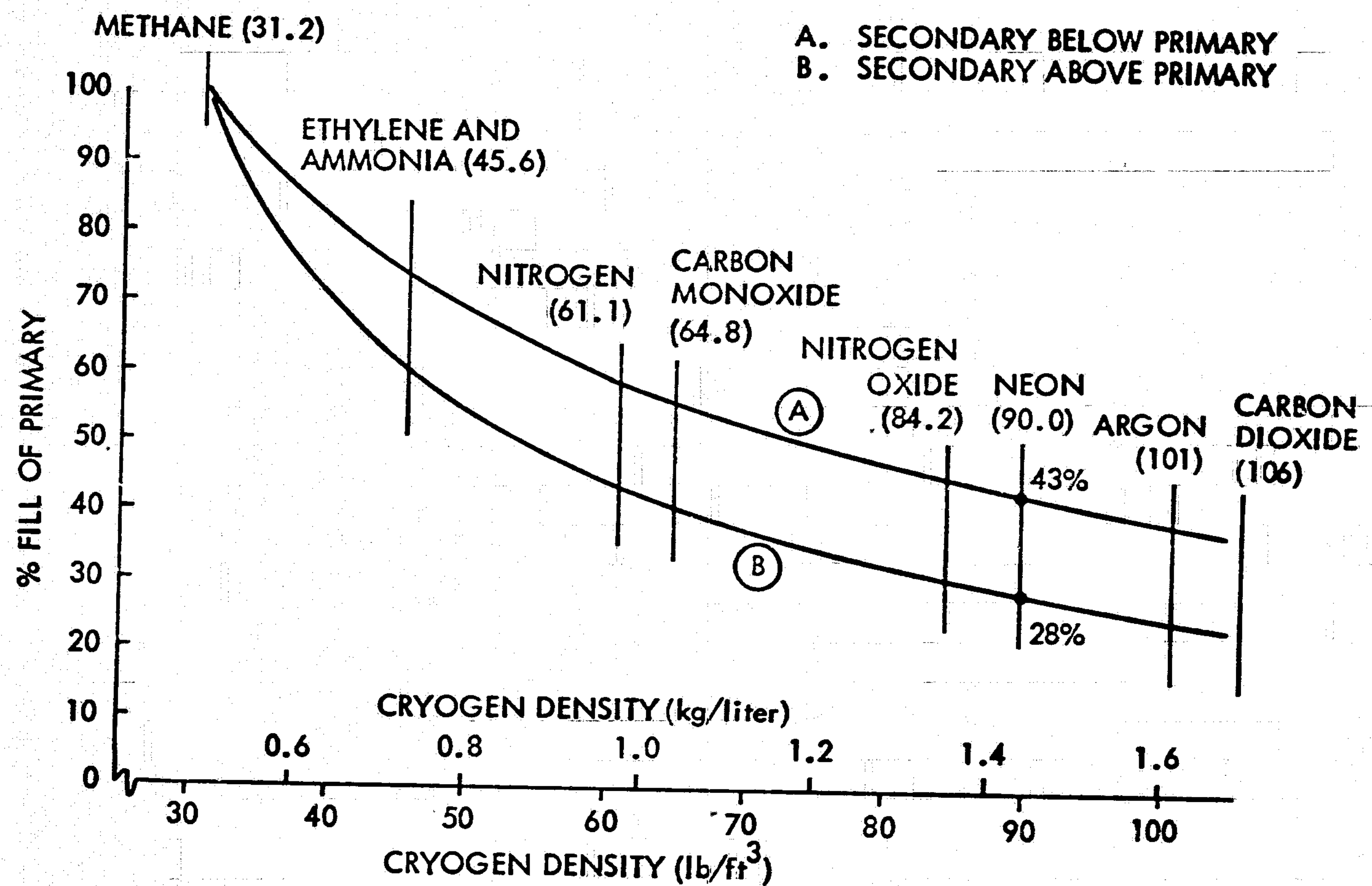


Fig. 6.1-7 MATERIAL PROPERTIES

Shear modulus:	$G = 750000$ psi
Shear modulus:	$G = 750000$ psi
Elasticity modulus:	
Axial:	$E_x = 2.14 \times 10^6$ psi
Circumferential:	$E_y = 5.55 \times 10^6$ psi
Poisson's ratio:	$\nu_{xy} = 0.0956$
Cloth thickness per layer:	0.010 in
Ultimate strength, axial direction:	26.4 ksi
Proportional limit, axial direction:	5.7 ksi
Ultimate strength, hoop direction:	119 ksi
Proportional limit, hoop direction:	72 ksi

ENVIRONMENT

Ultimate static lateral acceleration: 4 g

Lateral acceptance vibration level:

Frequency, Hz	Level, g-pk
5 – 40	0.5
40 – 80	0.0125 × Hz
80 – 200	1.0

Random vibration acceptance level:

Frequency, Hz	
20 – 130	6 dB/Oct
130 – 1000	0.18 g^2/Hz
1000 – 2000	-3 dB/Oct

Level: 16.7 g-rms

Fig. 6.1-8. STRUCTURAL ANALYSIS RESULTS

Required Support Tube Thicknesses (cm)

Tube	CH_4/NH_3 (Static Analysis)	CH_4/NH_3 (Vibration Analysis)	Ne/NH_3 (Vibration Analysis)
1	0.155 cm	0.178	0.254
2	0.132	0.132	0.191
3	0.132	0.132	0.191
4	0.094	0.102	0.152
Primary Resonance		9.5 Hz	7.2 Hz

sidered for a CH_4/NH_3 and Ne/NH_3 cooler. The baseline cooler support tube assembly was analyzed in addition to the Ne/NH_3 cooler to verify the statis analysis performed in the trade studies.

This dynamic vibration analysis was performed with the BOSOR computer program which is described in Section 4.2.

The material properties of the fiberglass epoxy tubes and the design environment is shown in Figure 6.1-7. The structural analysis results are shown in Figure 6.1-8. As can be seen, excellent agreement exists between the static and dynamic analysis sizing the tubes for the CH_4/NH_3 cooler. To support the Ne/NH_3 cooler, the required thicknesses are increased by $\sim$ 50% for all tubes.

To assess the impact that the thicker support tubes have on cooler lifetime, it is recalled that for a primary experiment heat load greater than 150 mW, the contribution of the support tubes to the total heat load is less than 10%. As a result, the maximum influence of increasing the thickness of tube #4 from 0.094 cm to 0.152 cm would be to reduce the lifetime a maximum of 6% from that achieved using the thinner support tube. The worst case occurs at the 20 mW primary experiment heat load case where an 18% maximum reduction in lifetime would result.

Comparing the two options, the data shows a better choice is to design the support tubes for a neon primary cryogen. This choice would result in a worst case 18% reduction in lifetime for off-design systems, as opposed to a 57% to 72% reduction in lifetime which would be experienced should the tubes be designed to support CH_4.

The lifetimes shown in figures 6.2-1 to 6. -5 are the lifetimes expected with tubes sized for neon. The very low percentage of the primary heat load that results from the support tube is true, in general, for all the cryogen combinations examined at a primary experiment heat load of 1.0 watt. It is also true, in general, that only until the primary experiment heat load is reduced to $\sim$ 150 mW does the contribution from the support tube begin to contribute as much as 10% of the total primary heat load, and 30% when the primary experiment heat load is 20 mW.

6.1.4.b Retractable Support

Figure 6.1-8 also shows the primary resonance of the Ne/NH_3 cooler to be 7.2 Hz, considerably less than the minimum 50 Hz desired. In an attempt to increase the primary resonance, a retractable support concept was analyzed. The retractable support consists of an actuator which slides into a recession of the cantilever side of the cooler primary tank. During launch this support is engaged to provide the cooler with a pin-type of support in addition to the fixed boundary cantilever support. Once in orbit, this actuator is removed to eliminate the heat leak from this relative short to ambient.

The results of the analysis showed the primary resonance to increase to 19 Hz still considerably less than the 50 Hz minimum. The additional complexity of this support coupled with the marginal gains indicates that either the constraint should be relaxed or other support mechanisms be analyzed.

6.2 Instrument Cooling Capabilities

In order to determine the multimission cooling capabilities for a particular instrument the following primary parameters of the instrument must be specified.

1) Temperature requirement of the coldest element of the instrument (primary temperature requirement)
2) Temperature requirement of other elements, if any (secondary temperature requirement)
3) Cooling load for the primary
4) Cooling load for the secondary
5) Desired system lifetime

The cooling capability curves which will be described allow the investigator to determine the utility of the MMC in terms of the above parameters.

Figures 6.2-1 thru 6.2-5 indicate the cooler lifetime as a function of the instrument primary heat load for various secondary cryogens. Although a unique choice of secondary cryogen will give the maximum cooler lifetime for a specific primary cryogen, other choices are shown since instrument requirements may dictate the use of a different secondary to attain the necessary temperature.

Figures 6.2-1 thru 6.2-5 also indicate the requirements or benefits of utilizing a passive radiator for cooling of the guard shield. Figure 6.2-1 which is for a methane primary indicates the radiator temperature "cut off" point as follows:

FIGURE 6.2-1 METHANE PRIMARY-LIFETIME VS. INSTRUMENT HEAT LOAD

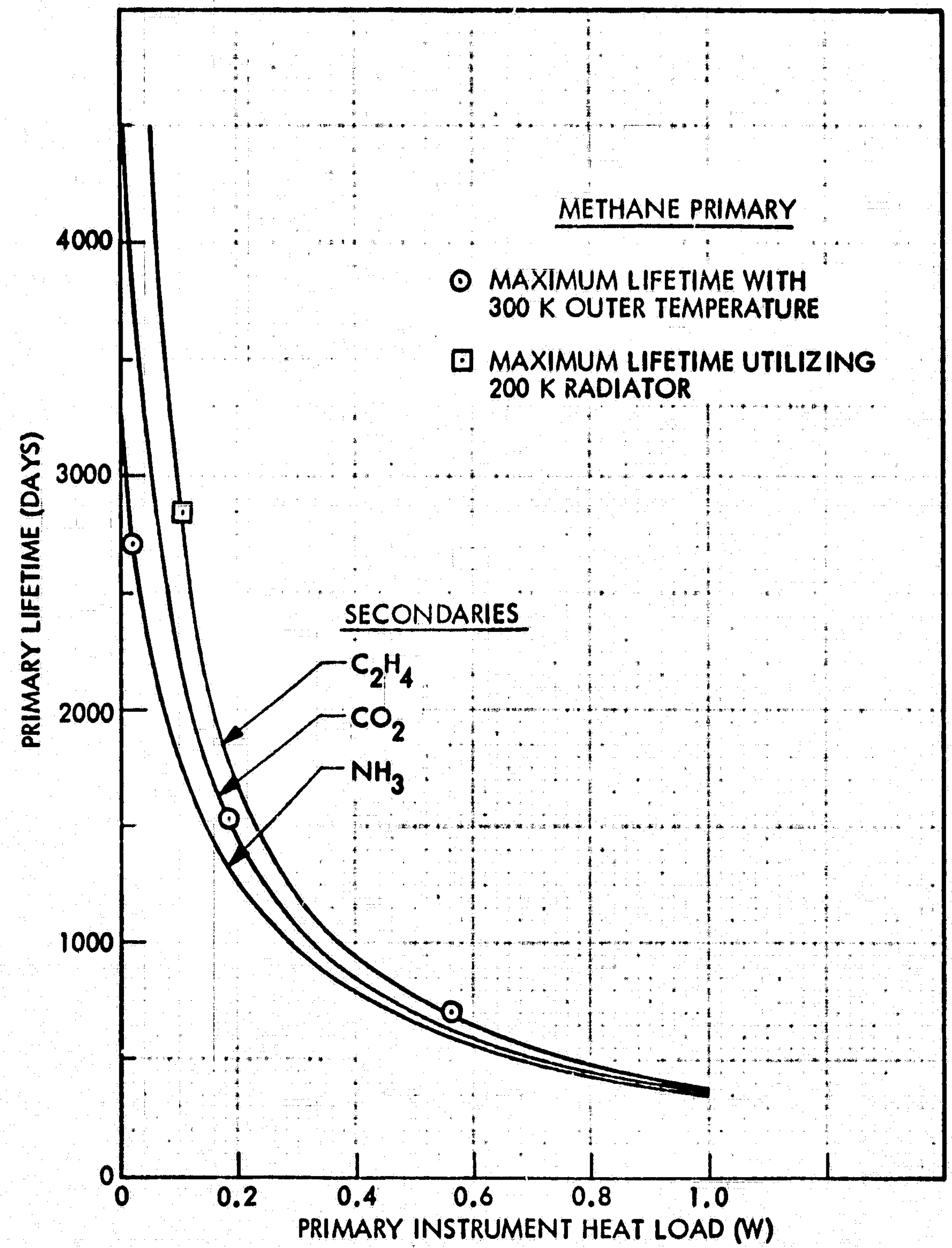


FIGURE 6.2-2 ARGON PRIMARY-LIFETIME VS. INSTRUMENT HEAT LOAD

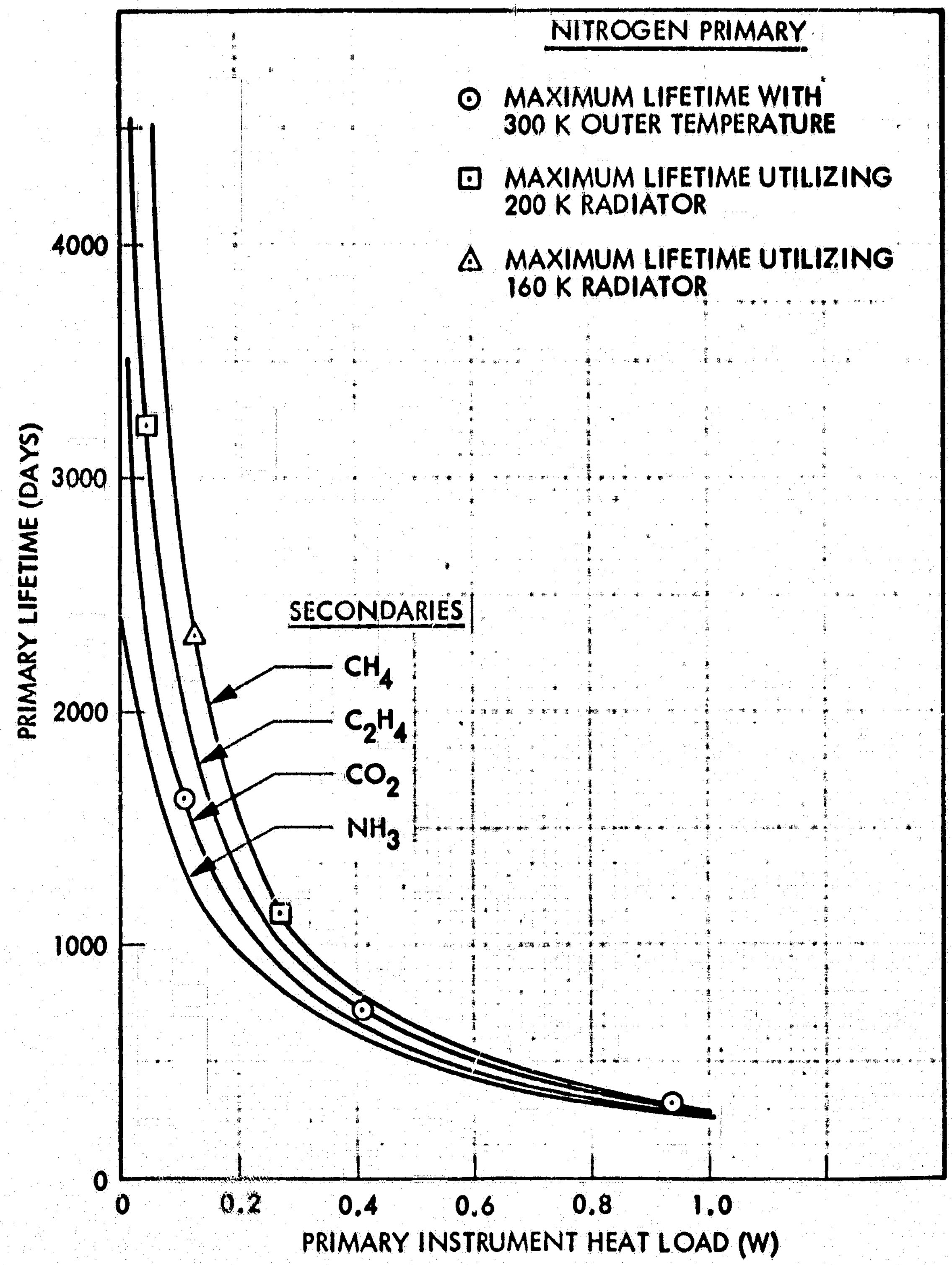


FIGURE 6.2-3 NITROGEN PRIMARY-LIFETIME VS. INSTRUMENT HEAT LOAD

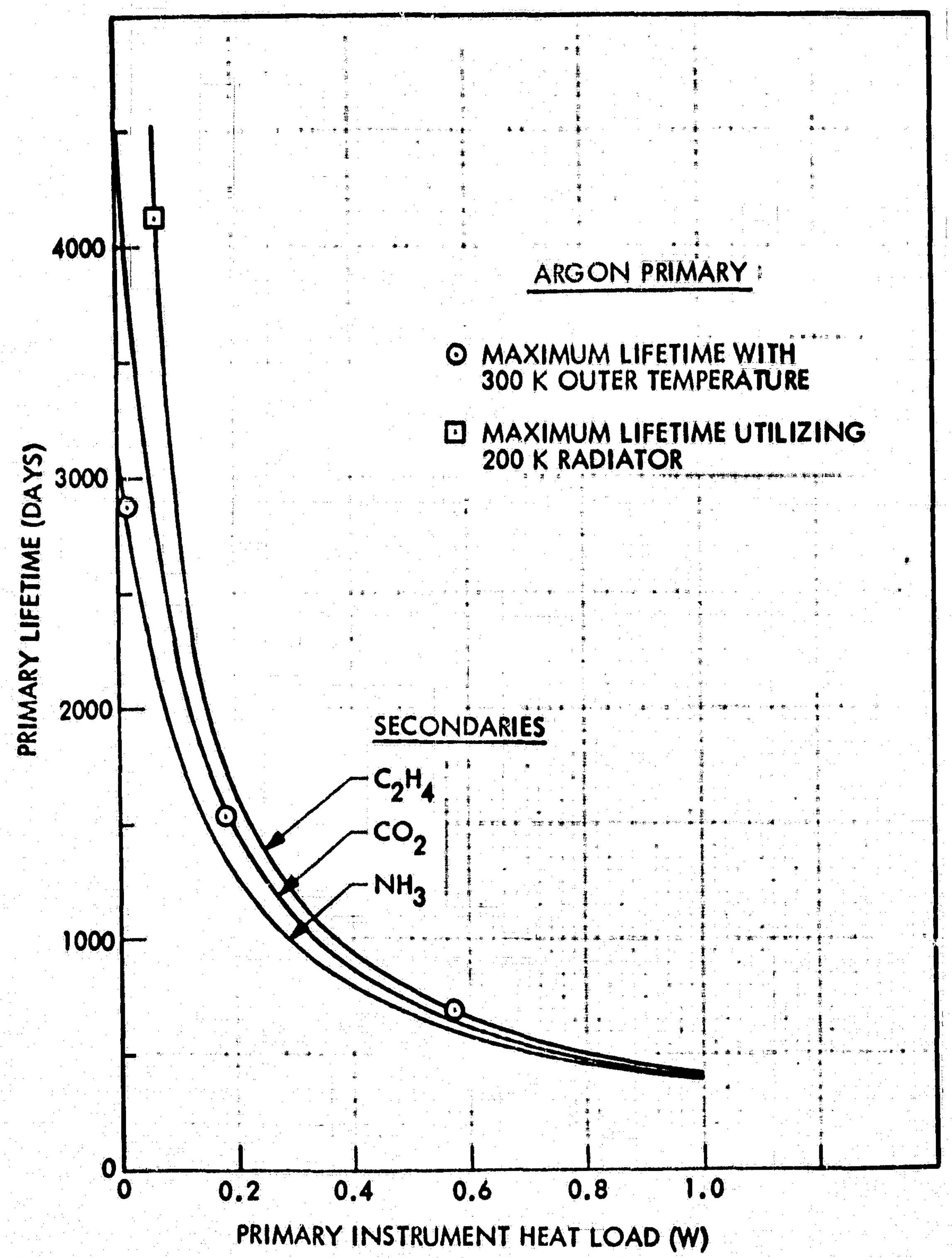


FIGURE 6.2-4 NEON PRIMARY-LIFETIME VS. INSTRUMENT HEAT LOAD

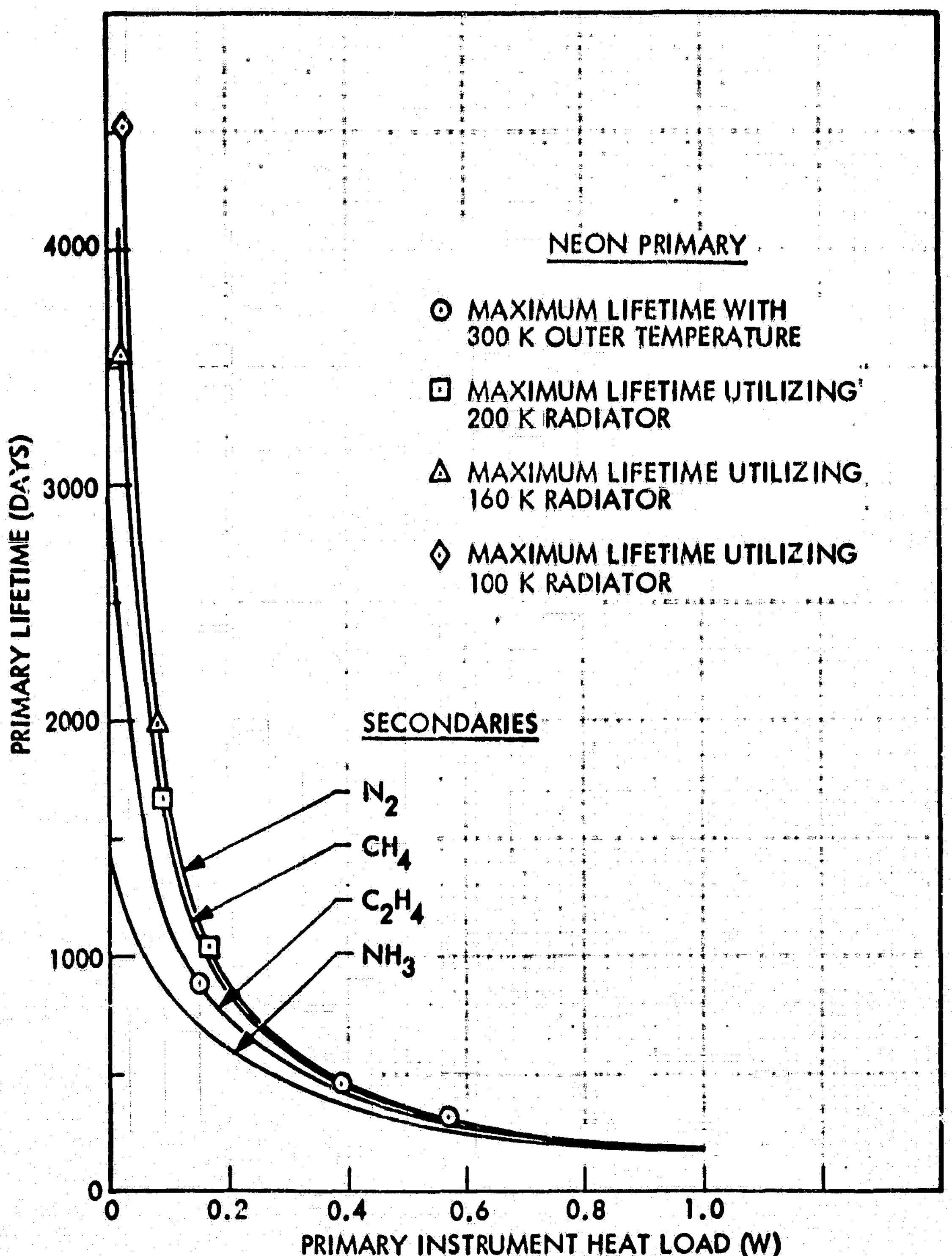
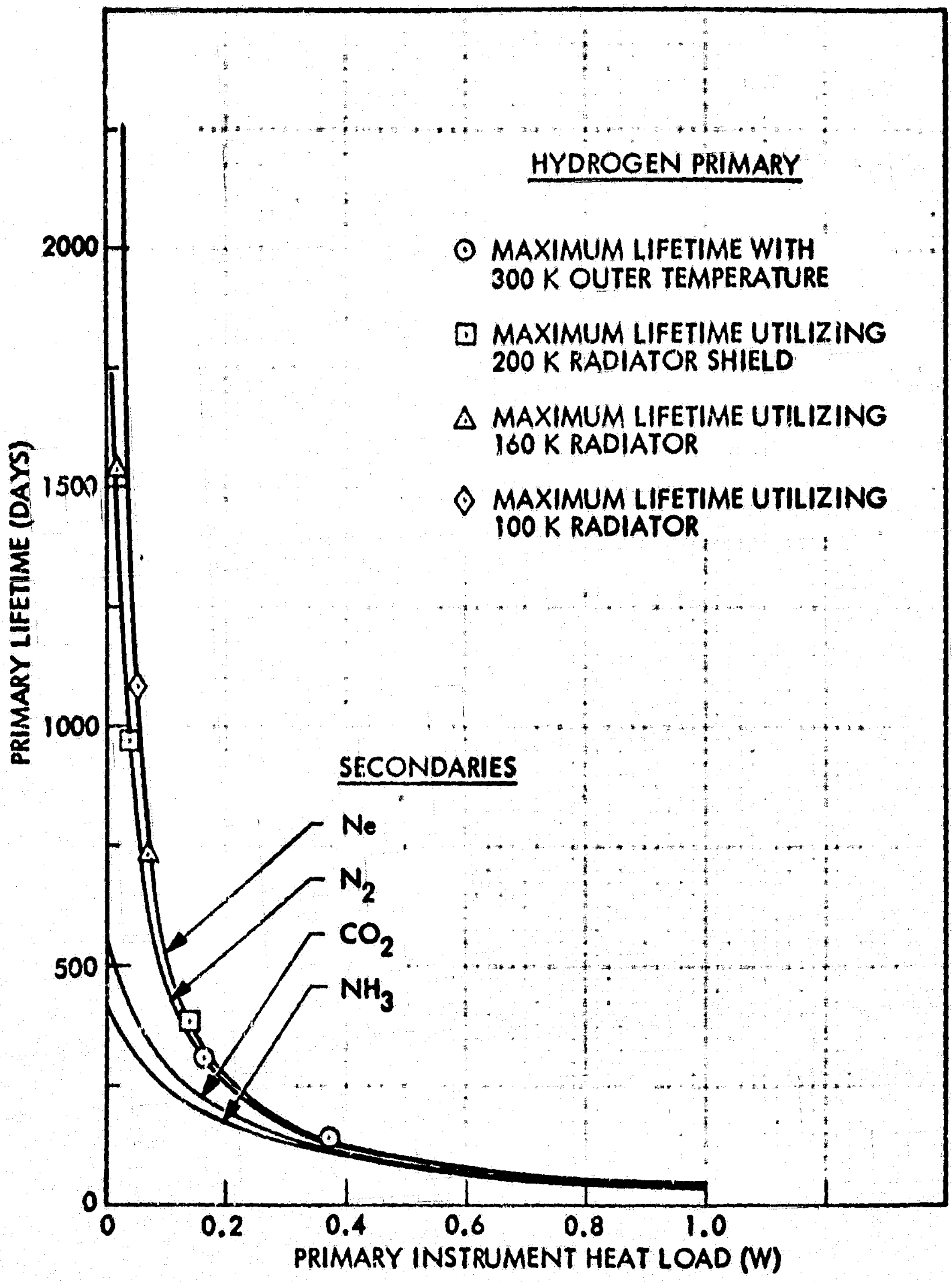


FIGURE 6.2-5 HYDROGEN PRIMARY-LIFETIME VS. INSTRUMENT HEAT LOAD



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At a primary instrument heat load of 0.56W with an ethylene (C_2H_2) secondary a lifetime of 700 days is indicated. This lifetime may be achieved with a 300°K external boundary as indicated by the symbol. To the left of this point the vent gas flow rate is lower, due to the lower heat load and this results in less vent gas cooling of the secondary cryogen and consequently reduces the secondary stage lifetime to less than the primary life (700 days). In order to increase the secondary lifetime to match the increased primary lifetime (at lower primary heat loads) it is necessary to reduce the secondary heat load. This may be done by reducing the cooled shield boundary temperature below 300°K by means of the passive radiator or thermo-electric cooler option. At 0.1W primary heat load with a C_2H_4 secondary a lifetime of 2800 days can be achieved for both primary and secondary cryogen stages by utilization of a 200°K radiator, as shown in Figure 6.2-1. For heat rates between the example points a radiator temperature between 300°K and 200°K is needed, the required value being obtained by interpolation. These radiator "cut-off" points are indicated for the various primary and secondary combinations in curves 6.2-1 thru 6.2-5.

These curves do not indicate the secondary cooling capacity which is available to the instrument if this is required. The curves 6.2-6 thru 6.2-10 can be utilized to determine the secondary stage cooling available. These curves indicate the conditions for matching the secondary cryogen life with the primary life, and allow the determination of the parameters which will satisfy a given secondary instrument cooling load. The following example illustrates the use of these curves.

FIGURE 6.2-6 SECONDARY COOLING CAPACITY - METHANE PRIMARY

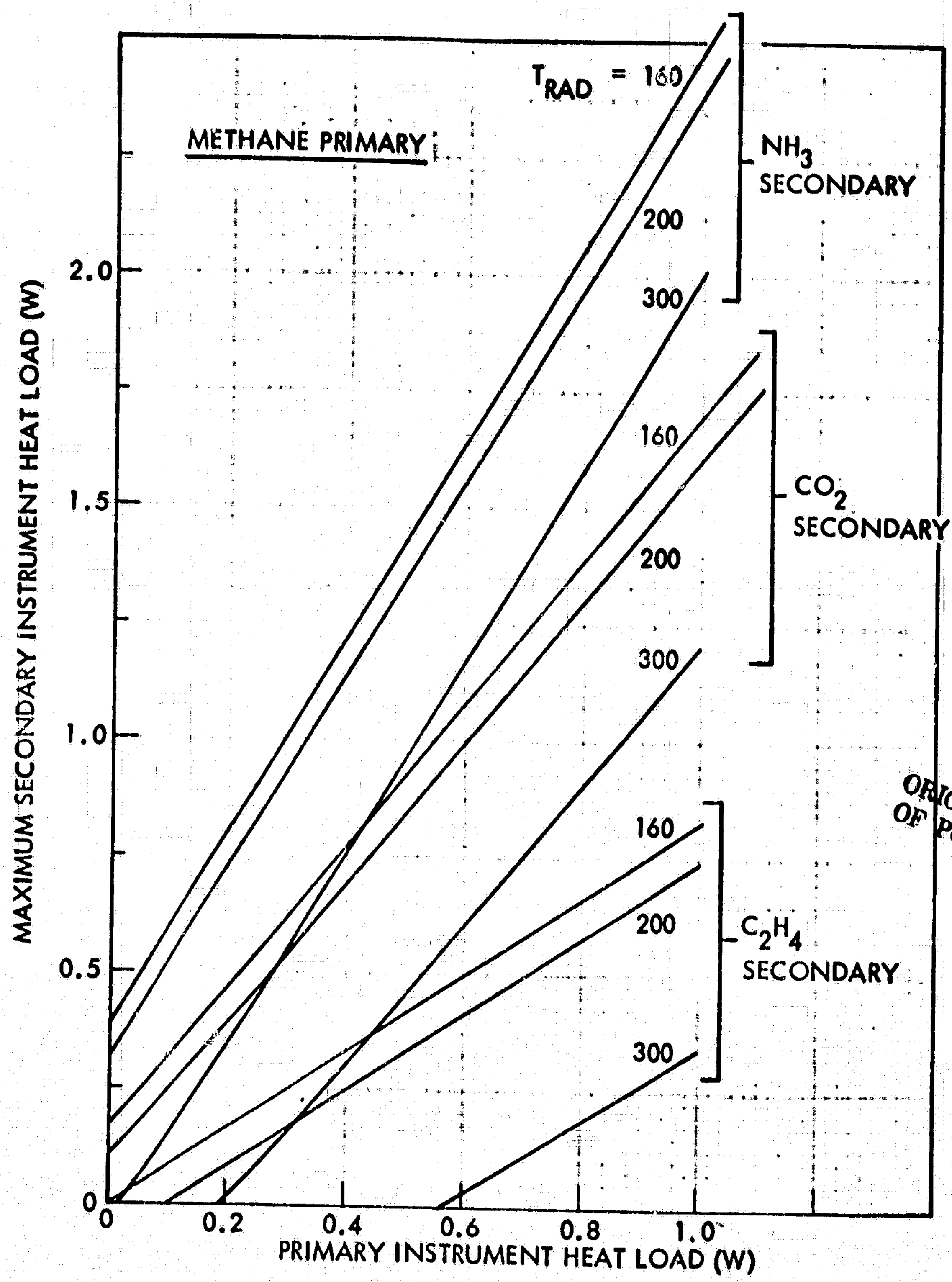


FIGURE 6.2-7 SECONDARY COOLING CAPACITY - ARGON PRIMARY

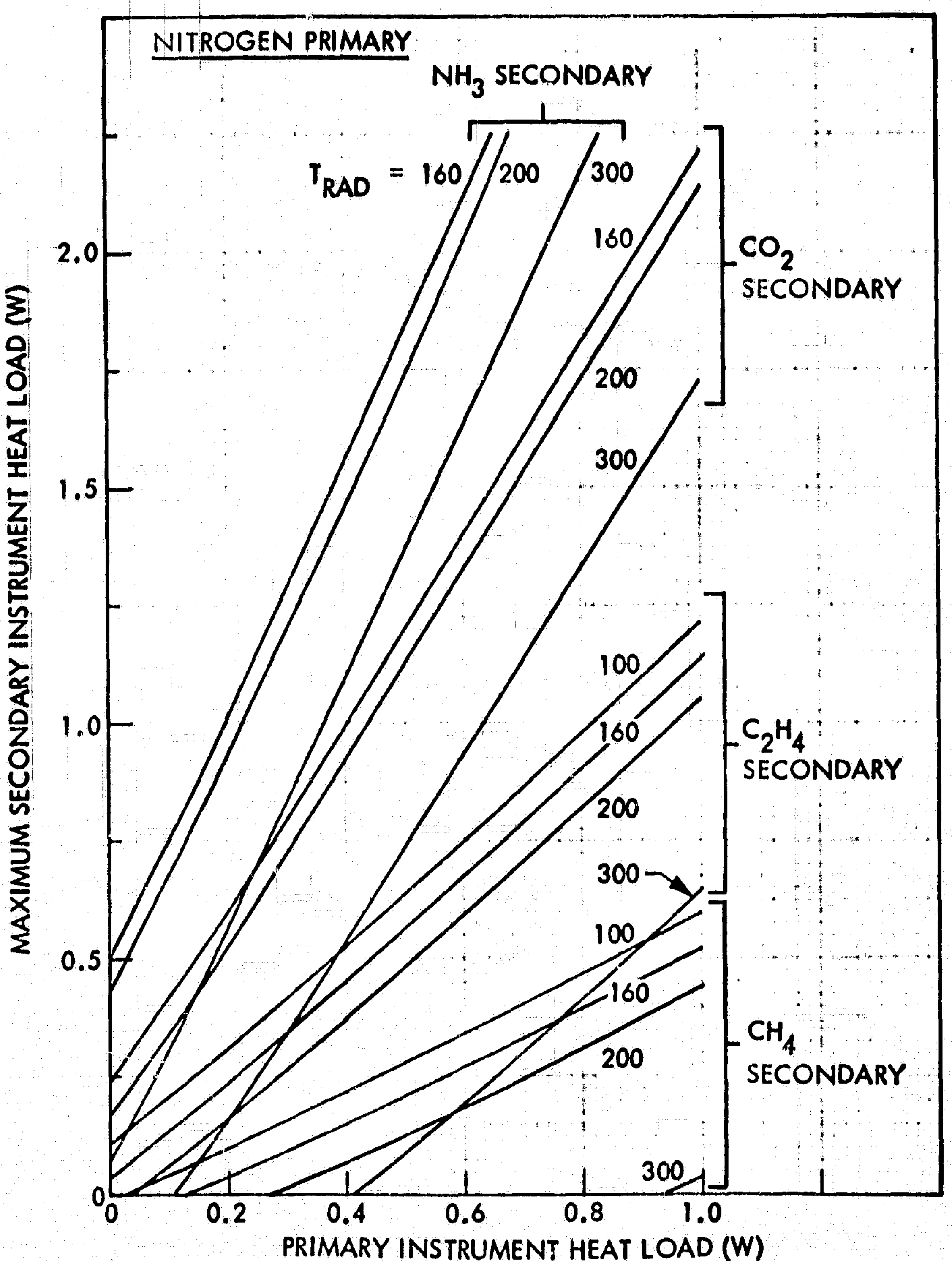


FIGURE 6.2-8 SECONDARY COOLING CAPACITY - NITROGEN PRIMARY

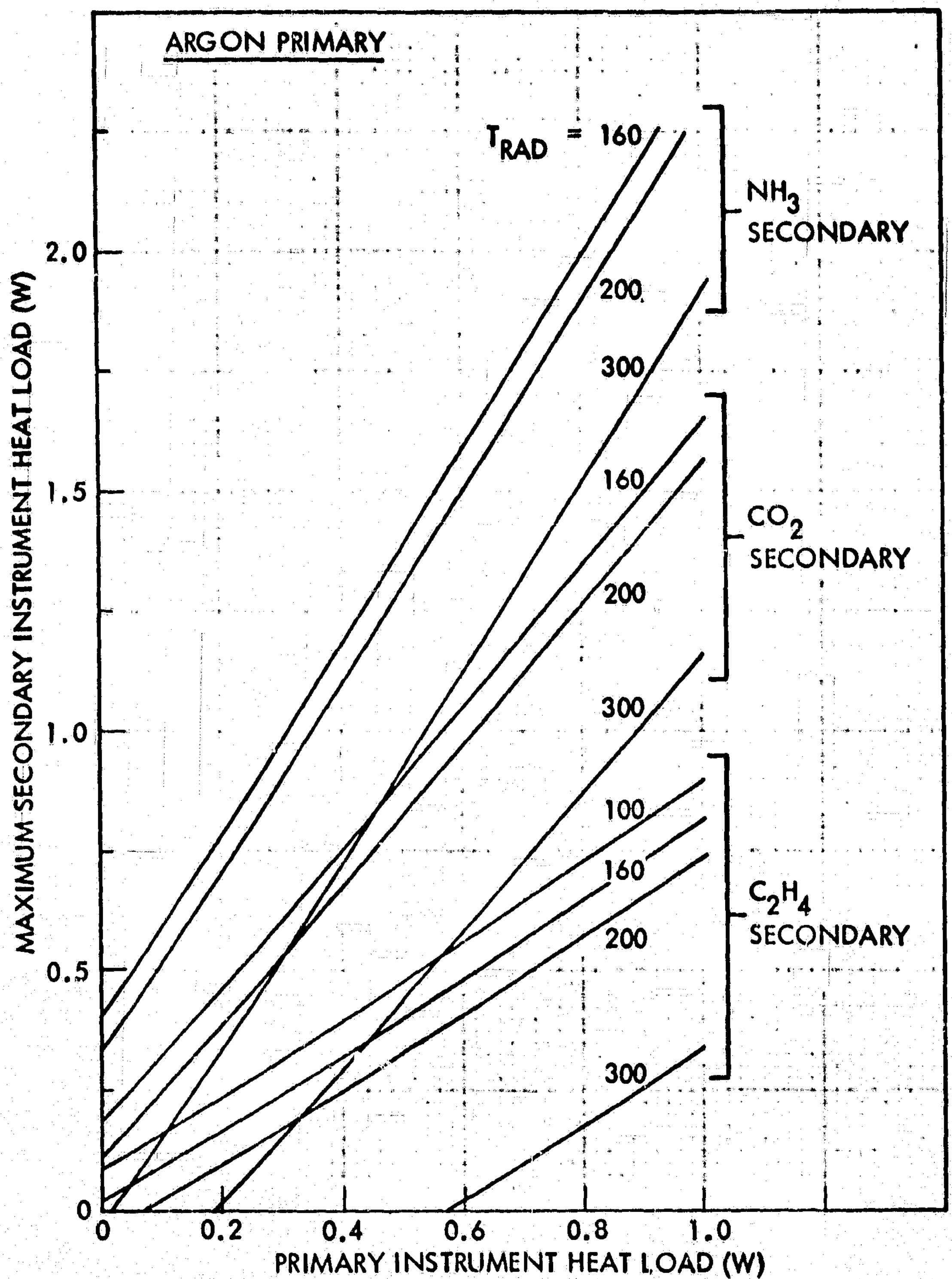


FIGURE 6.2-9 SECONDARY COOLING CAPACITY - NEON PRIMARY

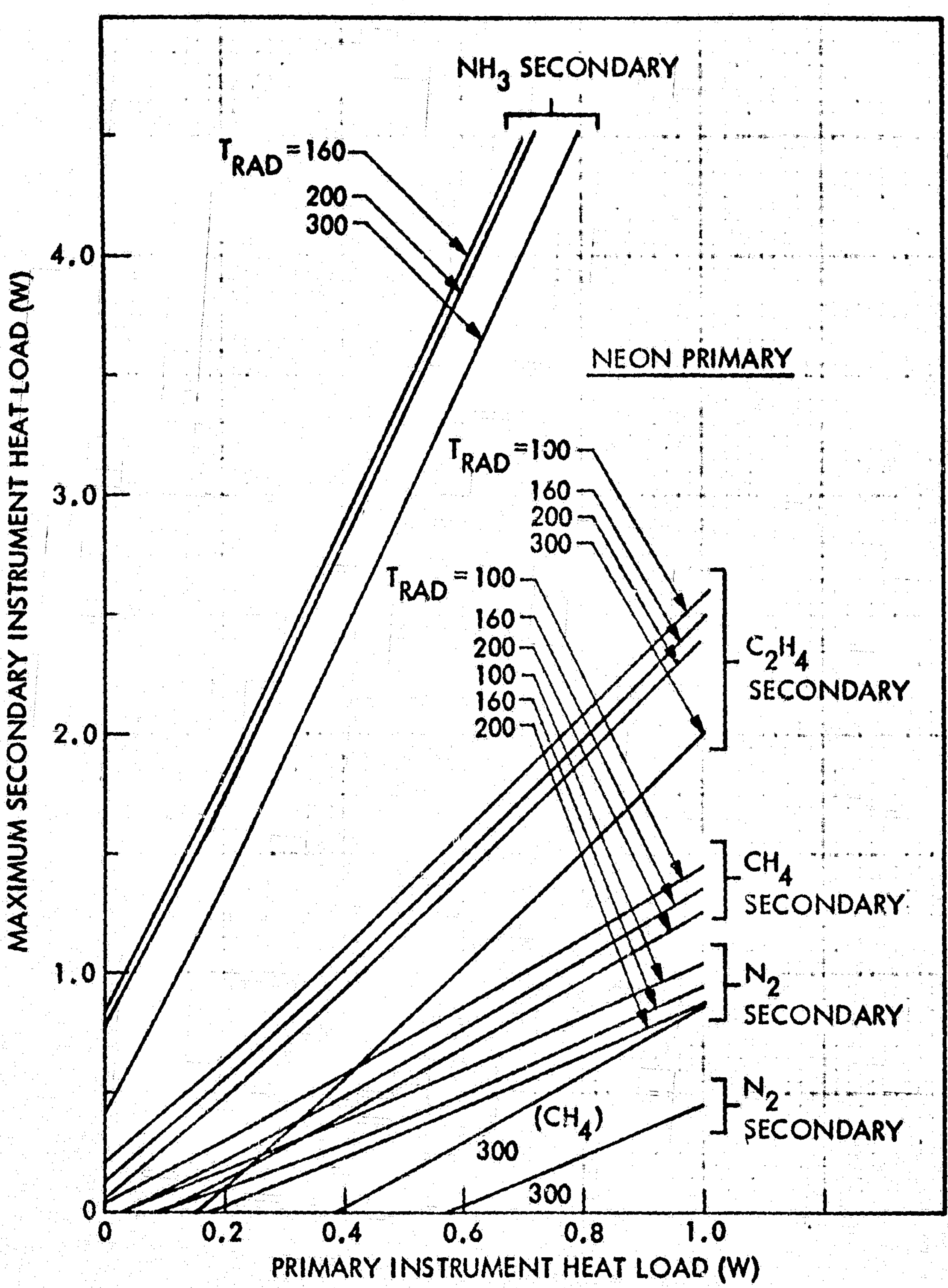
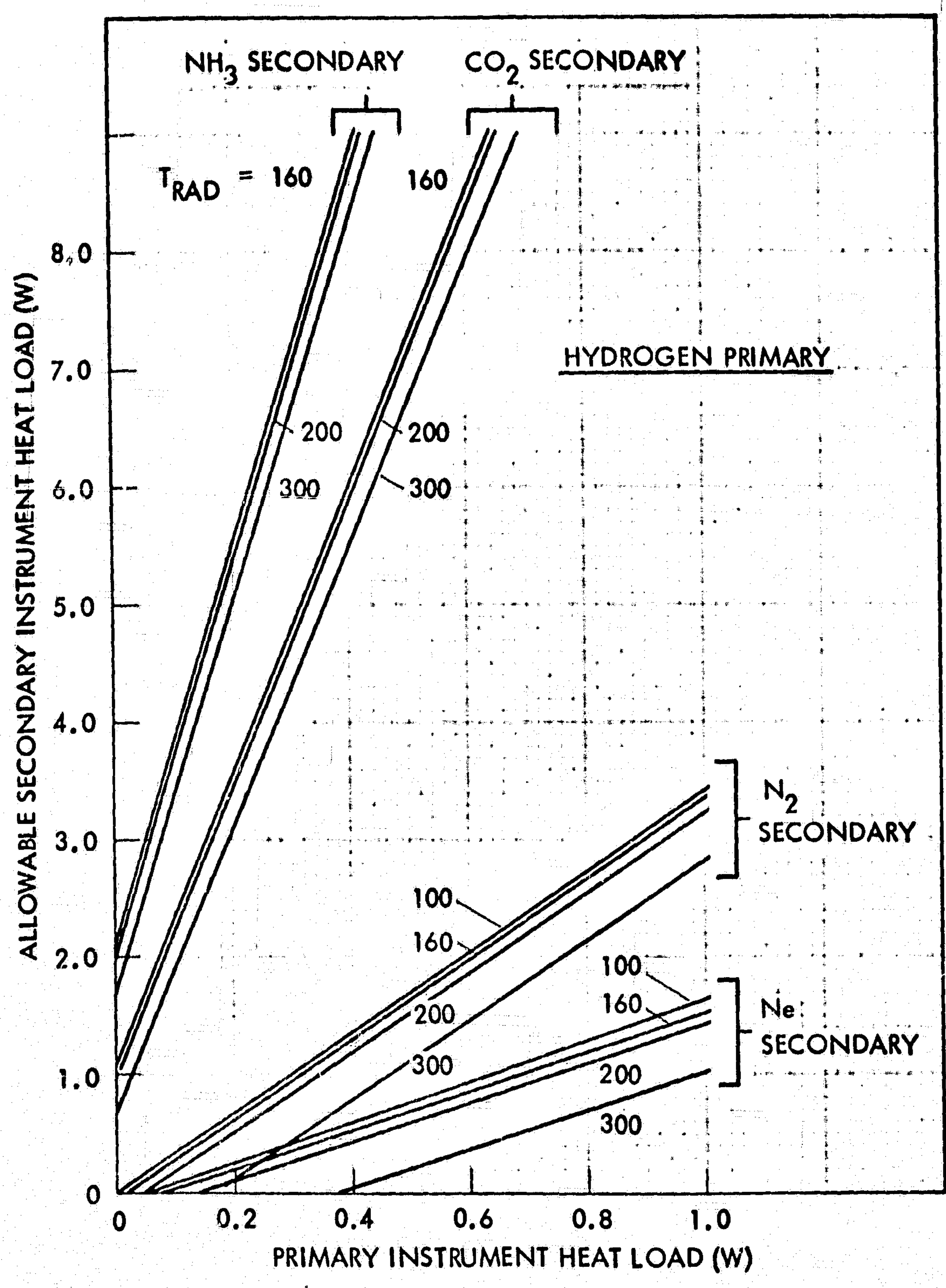


FIGURE 6.2-10 SECONDARY COOLING CAPACITY - HYDROGEN PRIMARY



For a primary cooling requirement of 0.56W with methane and the use of an ethylene secondary Figure 6.2-6 indicates a secondary cooling capability of zero for a 300°K shield temperature. At this condition the secondary cryogen will be depleted at the same time as the primary. In order to provide net instrument cooling for the secondary for the 0.56W primary load the outer shield must be cooled by radiator or T/E cooler. Fig. 6.2-6 shows that if the shield is cooled to 200°K then the instrument cooling by the secondary is 0.37W. If ammonia is used as the secondary then the secondary cooling available for a 300°K boundary and 0.56W primary cooling is 0.92W.

These two sets of curves for a particular primary cryogen selection may be utilized to determine the instrument cooling capability of the MMC in several different ways. For example, when the primary and secondary temperature requirements are selected the allowable cooling load for a specified lifetime may be determined. Or if the instrument cooling loads and temperature are established, the lifetime capability may be established. The effect of the instrument temperature requirements on cooler lifetime may be determined by comparing various secondaries and primary cryogen choices with their associated temperatures.

Figures 6.2-11 thru 6.2-13 were plotted from the previous curves to provide summaries of the cooling capabilities. In these curves the secondary which yields the largest system lifetime was selected and a set of curves was made for each radiator temperature studied. On each figure the secondary and primary cryogen along with and the associated weight of the loaded cooler is indicated. The discontinuities on the curve occur at the points where the optimum secondary changes from one to another. At these points the cooling capability of the secondary is zero while away from these points the secondary cooling is positive and can be determined from the curves 6.2-6 thru 6.2-10. The lower temperature capabilities of the primary cryogens are indicated on the figure.

Another presentation of the cooling capability of the MMC is shown in Figure 6.2-14 in which the primary cooling load is shown as a function of the primary temperature for various lifetimes of interest. This curve shows the effect of the radiator temperature on primary cooling load. It should be emphasized that the primary advantage of the radiator or cooled shield is increasing the cooling capability of the secondary stage. The curve shows a small benefit of the radiator temperature at the one year lifetime, however, as the lifetime increases to three and five years the benefits become substantial, in some cases more than doubling the primary cooling capability.

It is felt that the curves which have been presented will allow the instrument developer to determine all the parameters of interest which may be provided by the MMC. These predictions have been based on prior experience with coolers which have been developed and flown in orbit. As previously mentioned these predictions include a 20% lifetime contingency. It is anticipated that as the development of the MMC progresses measurements of the actual performance for several combinations of cryogens will be made and the predicted capability curves shown can be replaced by the actual measurements so the instrument developer will know the orbital performance to be expected with great confidence.

FIGURE 6.2-11 SUMMARY OF COOLING CAPABILITY FOR 300°K SHELL

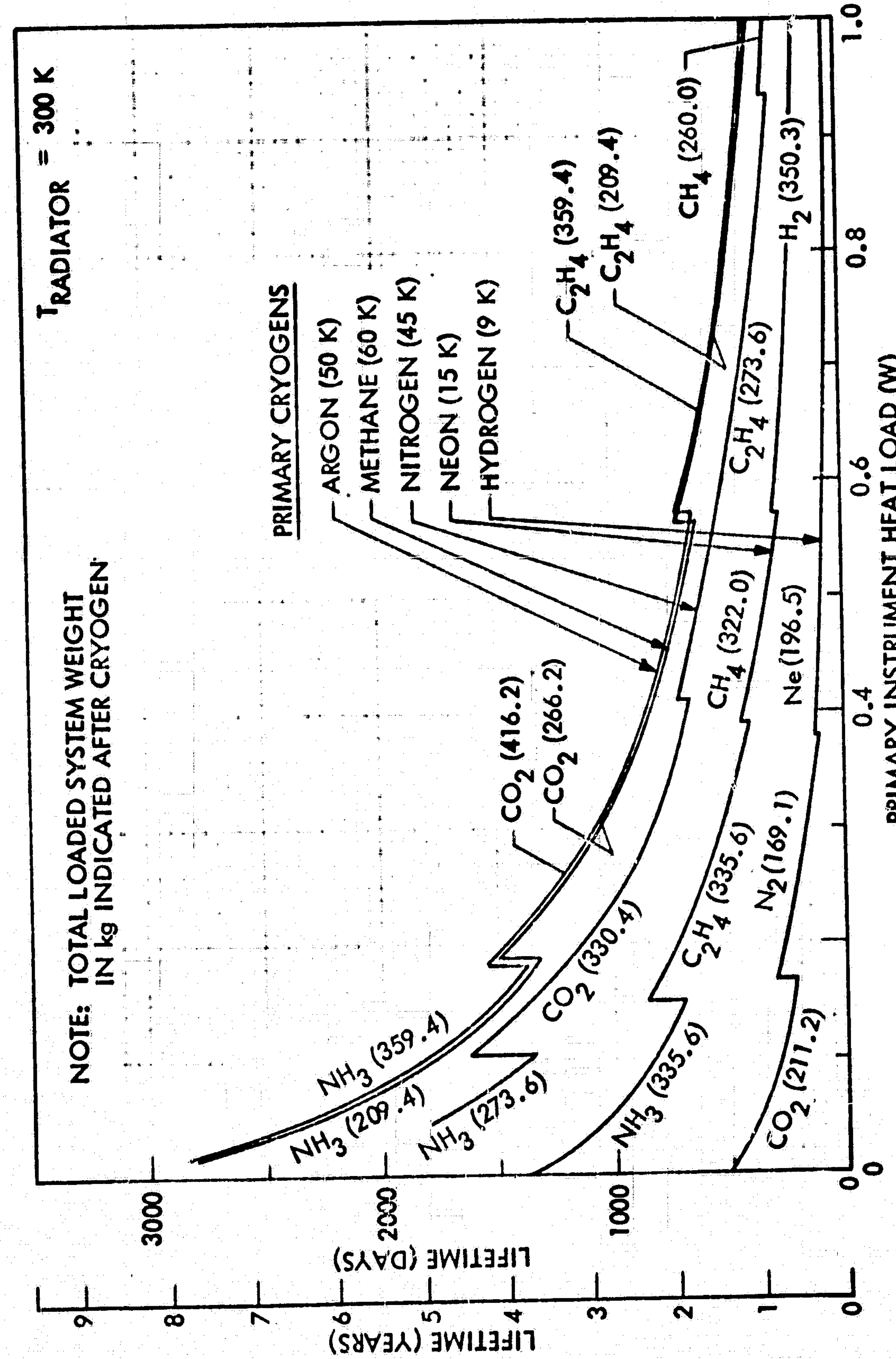


FIGURE 6.2-12 SUMMARY OF COOLING CAPABILITY FOR 200°K SHELL

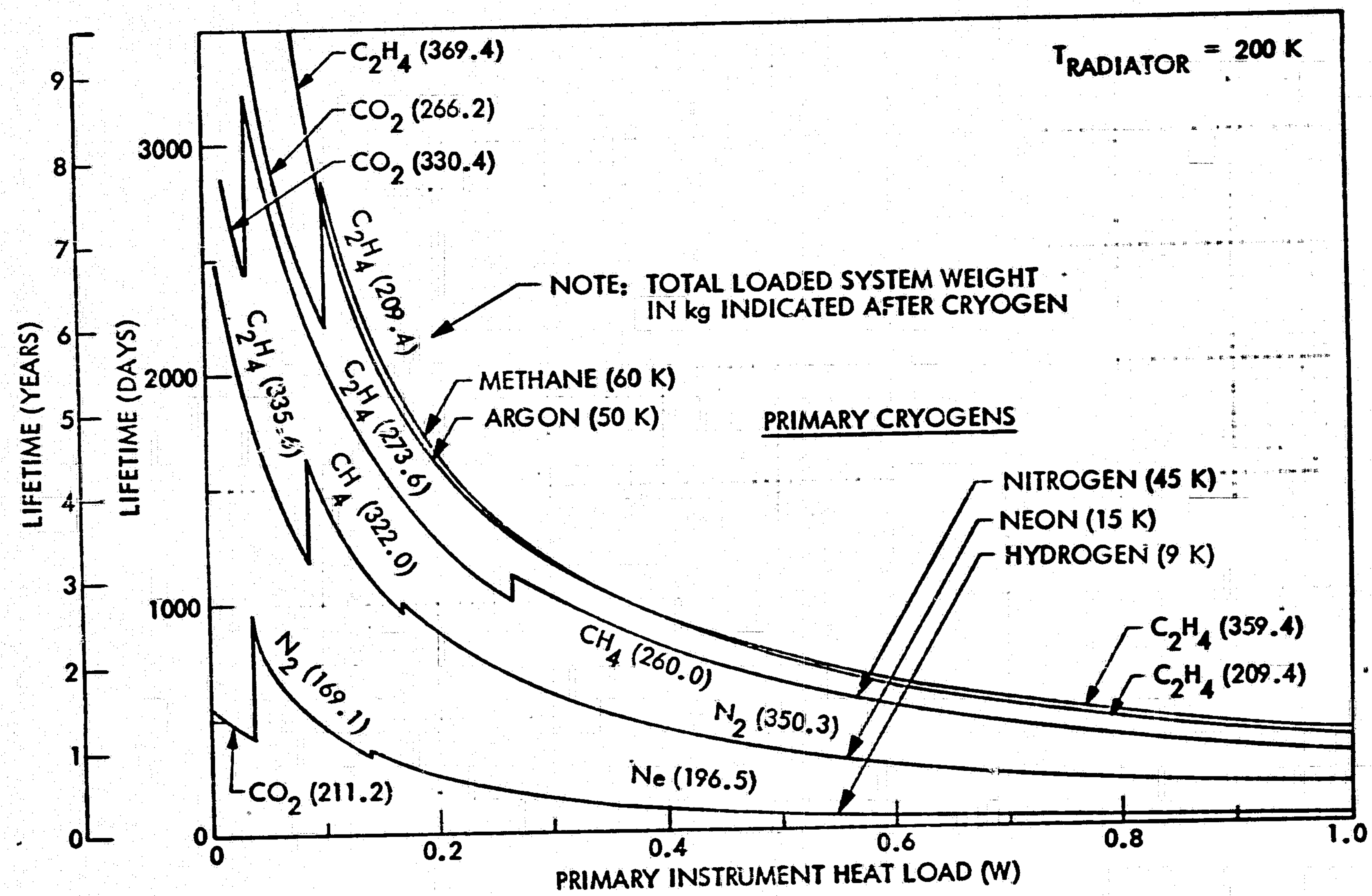


FIGURE 6.2-13 SUMMARY OF COOLING CAPABILITY FOR 160°K SHELL

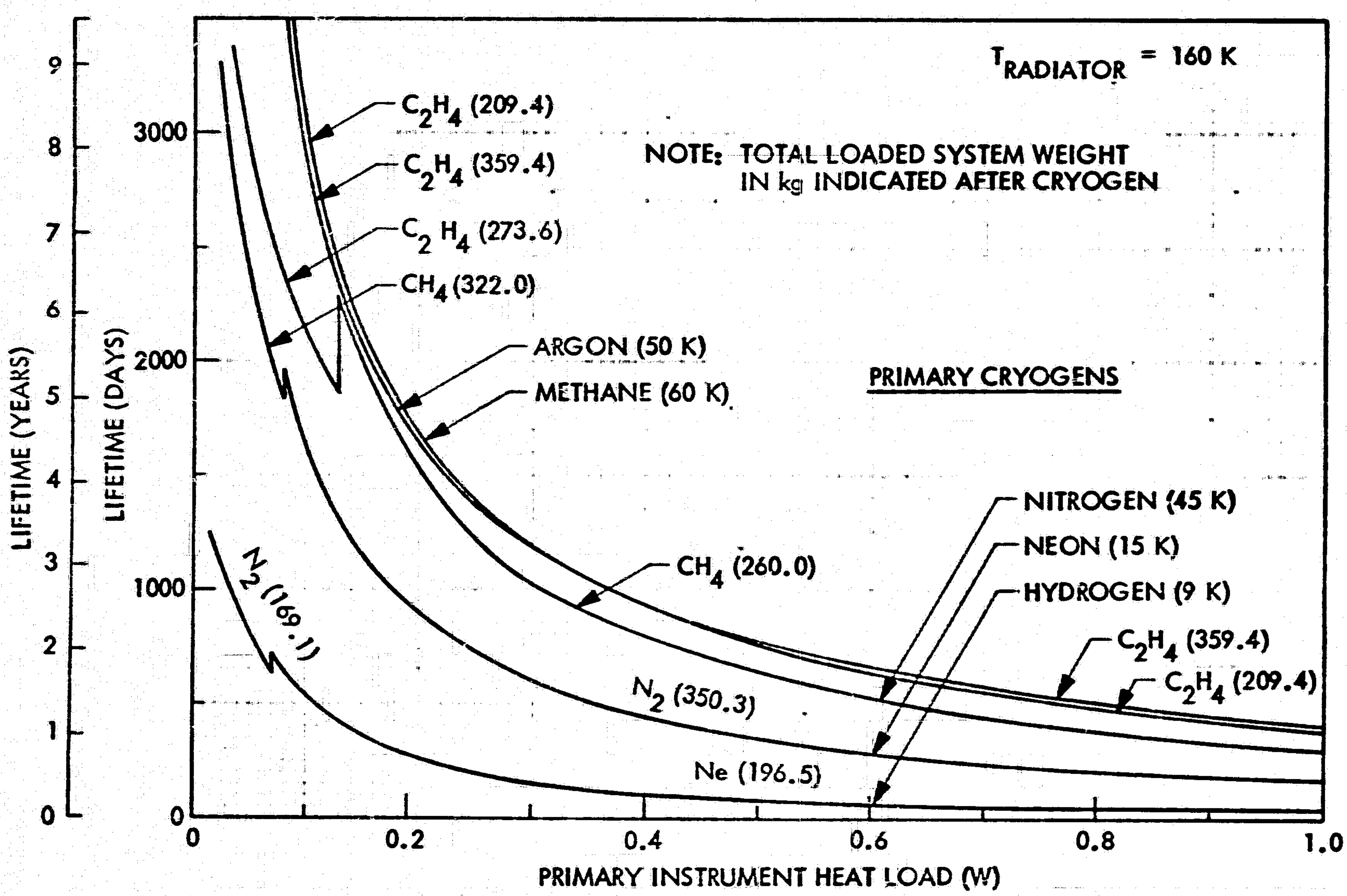
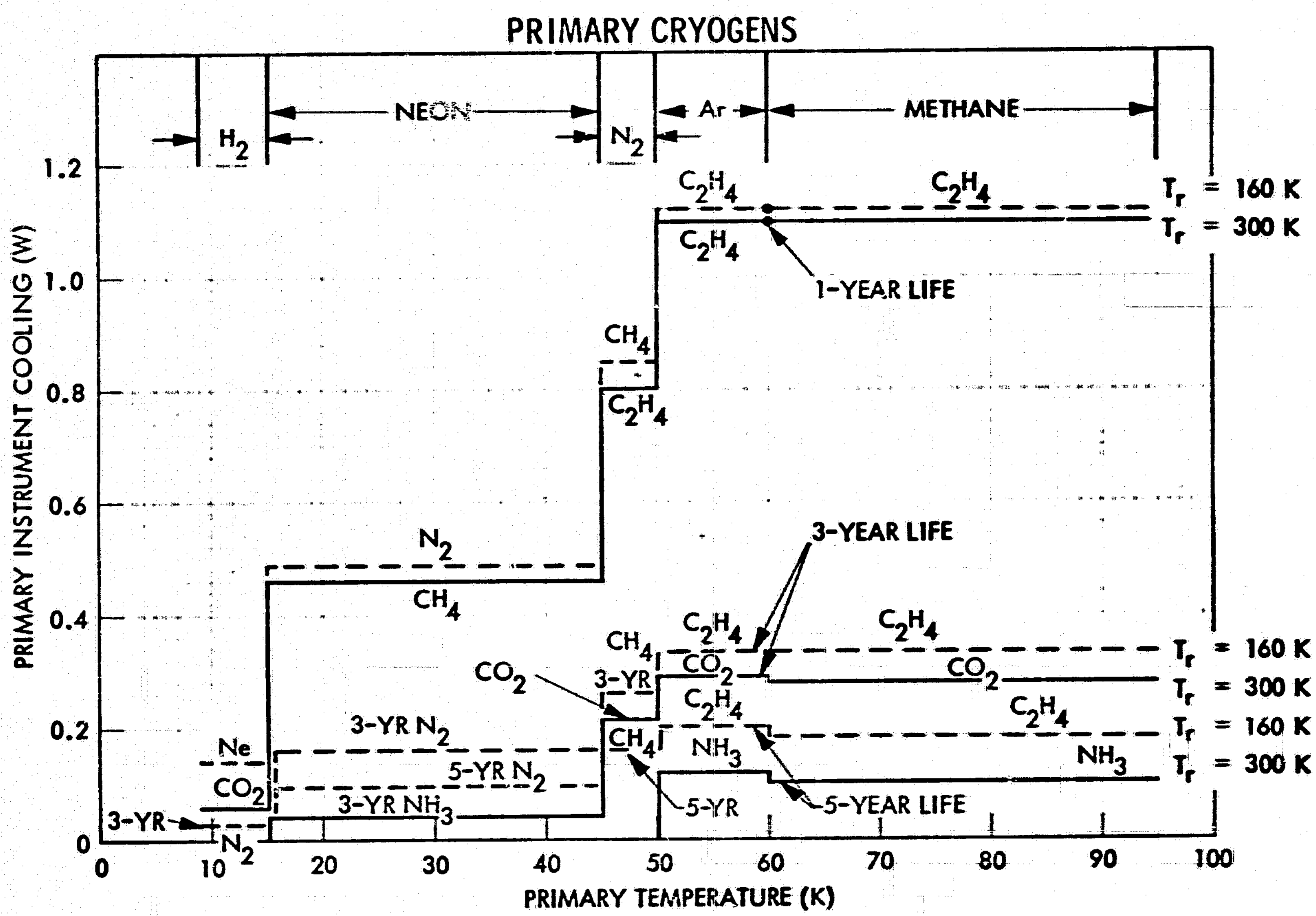


FIGURE 6.2-14 SUMMARY OF PRIMARY COOLING VS. PRIMARY TEMPERATURE

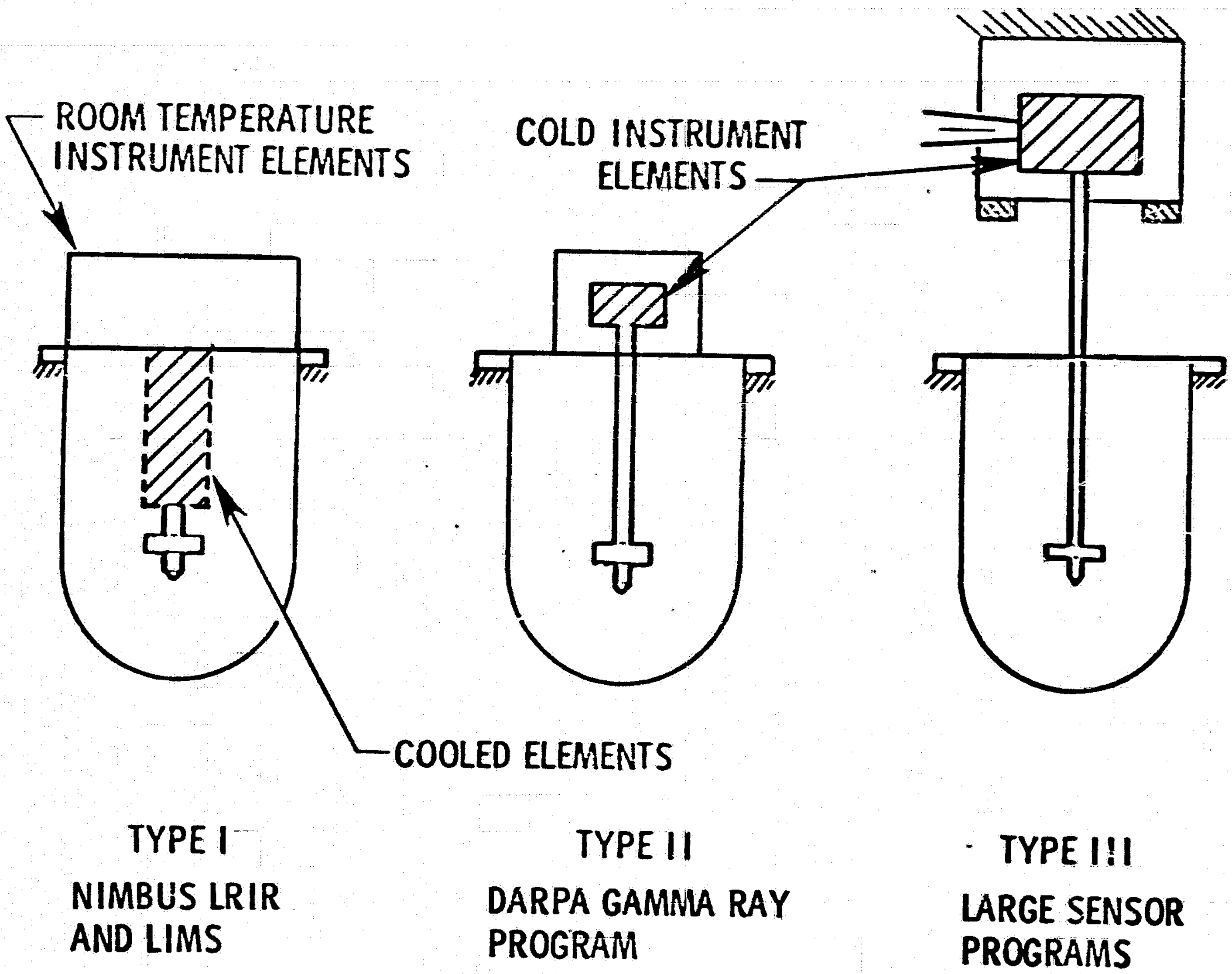


6.3 Instrument Integration and Flight Operation

It is believed that the MMC provides a very versatile approach for integrating a wide range of instruments. The thermal attachment to the cooler is made through shrink fit connections, whose configuration is described in Section 6.1. This type of connection has been demonstrated and proven on many coolers including flight qualified units and has proven to be a versatile and efficient coupling. The MMC may incorporate as many as three cooling links between the instrument and the cooler; one to the primary, one to the secondary and one to the cooled shield. Any combination of these links may be utilized depending upon instrument temperature and thermal shielding requirements.

Several basic arrangements of the instrument/cooler integration are possible and have been considered. The more ordinary types of integration are schematically indicated in Fig. 6.3-1. The three approaches are designated Type I, II and III. In the Type I approach the cooled elements are placed within the cooler instrument cavity and the room temperature instrument elements are located on the cooler mounting plate outside the cooler. These elements might be primary optical elements or electronics or any elements which may be conveniently located on the mounting plate. This approach is limited to the size of the instrument cavity, which for the present baseline configuration is 65 cm long by 14.6 cm in diameter. These dimensions can be altered to some extent in the final design if desirable and the instrument can extend outside

FIGURE 6.3-1 INSTRUMENT INTEGRATION WITH COOLER



the cooler if necessary. This approach has been utilized on the solid cryogen coolers utilized on the Nimbus 6 and Nimbus 7 satellites and is a proven approach.

In addition to the Type I integration the Type II and III approaches have been proven on actual hardware and can easily be incorporated. In these approaches the cooled instrument elements are located outside the cooler and are therefore not limited in size as the first approach was. The Type II approach consists of mounting the cooled elements on the mounting plate of the cooler and transferring the cooling to the cryogens by means of a thermal link which may consist of a metal rod or in extreme cases where heat loads are high and the instrument temperature is very close to the cryogen temperature by heat pipe. The Type II approach with a solid copper link was utilized on a single stage solid CO_2 cooler which provided orbital cooling of a γ-ray instrument in 1971. 6-1

Another approach which may be necessary because of instrument viewing requirements or unique physical parameters is illustrated as Type III. All of the instrument elements are located some distance away from the mounting plate and are attached to a separate structure. In this approach flexible connections in the thermal links and the outer vacuum tube may be required so that instrument alignment may be maintained separate from the cooler. In addition, it may be necessary to utilize a heat pipe to maintain small temperature gradients between the cooler and instrument. A cooler has been built and tested at LMSC which incorporated this approach utilizing an oxygen heat pipe to provide instrument cooling at a distance of 76 cm from the cooler.

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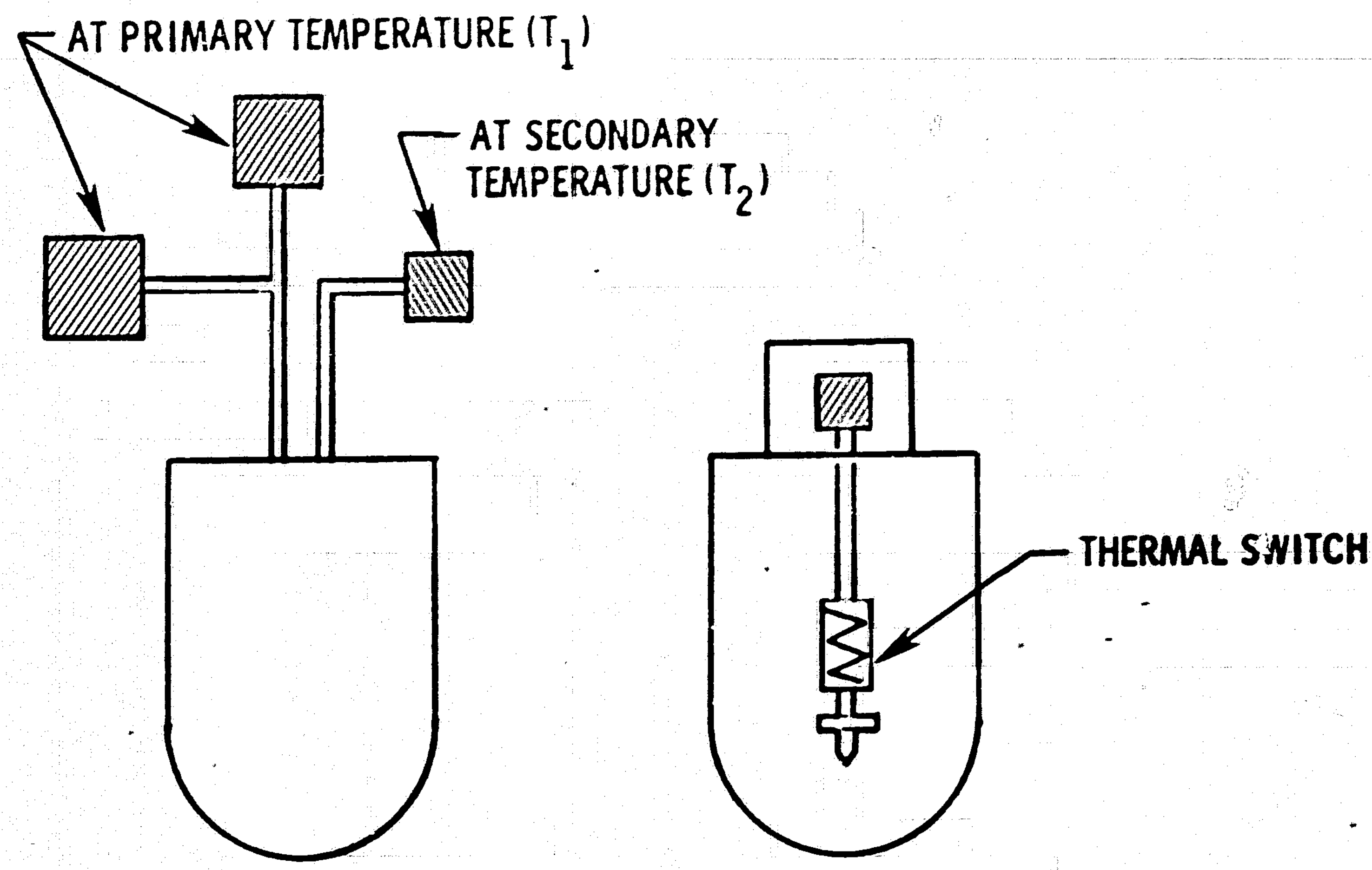
It is believed that these three types of instrument integration will satisfy the majority of instrument requirements, however, there are other options which appear to be perfectly feasible but have not been demonstrated completely with actual hardware. These are shown in 6.3-2.

The first approach illustrates multiple cooling of several instruments. It appears to be perfectly feasible to cool several instruments with the MMC by utilizing several thermal links. The instruments could be cooled to either the primary or secondary temperature. In cases where several instruments must be located at substantial distances it may again be necessary to utilize heat pipes. Many variations are possible.

The other illustration while not indicating a different type of integration indicates another option in utilizing the MMC. If the parasitic heat load from the instrument is quite high and the duty cycle is low, then a thermal switch could be incorporated to extend mission lifetime by reducing cryogen usage. A thermal switch has been developed at LMSC specifically for this use and could substantially reduce cryogen depletion rates for favorable duty cycles and high parasitic instrument heat rates.

In determining the instrument heat loads to the cooler the heat load associated with whatever thermal link configuration is utilized must be included. This heat load is not considered to be part of the cooler parasitic heat load, since each instrument configuration will have a unique link configuration, and hence unique heat load.

FIGURE 6.3-2 ADDITIONAL INSTRUMENT OPTIONS



MULTIPLE INSTRUMENT COOLING

THERMAL SWITCHING FOR LOW INSTRUMENT DUTY CYCLE

An additional consideration is that the cooled regions of the instrument must be vacuum sealed on the ground so that condensible gases do not cryopump. This can be achieved with a permanent vacuum window or by a vacuum cover which is removable in orbit for cases where a permanent window or cover is not feasible.

Venting of the gases in orbit is achieved in most cases by venting directly through a line which is opened in orbit by an explosive valve. The vent line sizes which are shown on the baseline cooler are of sufficient size to allow the cryogens to operate near their minimum temperature. The final temperature "trimming" for a particular instrument can be accomplished in a simple manner by simply "bolting" on the required external plumbing line size to provide the desired pressure above the cryogen. This pressure adjustment provides for a very sensitive adjustment of the cryogen temperature.

The vent gases in general do not contribute a significant thrust to the spacecraft, however, it is usually desirable to direct the vented gases away from the instrument field of view and normal to the roll axis of the vehicle to minimize any thrust effects from this source.

The cooler has been designed to the vibration specification provided in the work statement which is representative of the space shuttle. If more severe environments are encountered due to different boosters or other changes, it may be necessary to off-load the cryogen tanks somewhat to maintain stresses within safe limits. This can be easily incorporated.

Limited calculations were performed to determine the ground hold capability of the MMC. For the calculation it was assumed that the MMC was loaded with methane and ammonia and that the instrument provided heat loads of 1W to the methane and 2W to the ammonia. Calculations indicated that if the solid cryogens were cooled with LN_2 to 80°K and then cooling was discontinued, the methane would warm up to the melting point (90°K) in seventeen days and the ammonia would be well below the 195°K melting point (105°K) at the end of seventeen days.

The hold time for this case, that is the duration between re-cooling periods to maintain the cryogens solid, is therefore 17 days.

For lower instrument heat loads the hold time would be proportionately greater or if the instrument heat load consists of a significant fraction of heat generation, which could be turned off during ground hold, this period would be increased.

Several other options may be considered in extending the groundhold period . One is the use of cold helium gas for sub-cooling the cryogens to lower temperatures. The use of cold helium will be required for ground hold operations when hydrogen or neon are utilized, so that this cooling mode is consistent with the normal requirements.

A second option which is available for consideration is to provide LN_2 cooling of the radiator shield on a continuous basis during ground hold operations. If the instrument is shielded by a link to the radiator shield then the cryogens could be maintained indefinitely without a temperature increase. This operation is safer than cooling the cryogens directly because when cooling the cryogens directly, an interruption or depletion of the cooling fluid could result in rapid warming of the cryogens and possible unexpected venting. Although not considered a primary option for ground hold, it provides an additional degree of flexibility in the ground hold operations and may be used to advantage in some operations.

A third option is to utilize a mechanical refrigerator to provide cooling of the cooled shield on the ground, and also during orbit if desired The coupling flange to the cooled shield provides easy access for "bolting" on a mechanical refrigerator.

As these options show, the cooled shield adds an extra dimension to the versatility of the MMC.

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