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DESIGN GUIDE FOR PRESSURIZATION SYSTEM EVALUATION LIQUID PROPULSION ROCKET ENGINES

VOLUME I - USE OF DESIGN GUIDE, GENERAL DESIGN DATA

30 September 1962

Aerojet-General Report No. 2334
(Design Guide)

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AEROJET-GENERAL CORPORATION

The Space Propulsion Division
of the Liquid Rocket Plant
Azusa, California

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DESIGN GUIDE FOR PRESSURIZATION SYSTEM EVALUATION LIQUID PROPULSION ROCKET ENGINES

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General Design Data

Contract No. NAS 7-169

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Azusa, California

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FOREWORD

This report, a liquid-propellant pressurization system design guide, is published in partial fulfillment of NASA, Office of Advanced Research and Technology, Contract No. NAS 7-169. It includes, in a design guide format, all of the pressurization system design criteria made available by NASA Contract No. 5-1108. It is intended to make readily available the present state of the art in pressurization system design and selection.

The design guide consists of three volumes which cover the following subjects:

Volume I, Usage and General Data
Volume II, Component Analyses - Detailed
Volume III, Component Design Data

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Report No. 2334
Volume I

CONTENTS

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

I. INTRODUCTION

A. PURPOSE

This design guide has been prepared to provide a systematic and rapid procedure for the selection of the most suitable liquid rocket pressurization system on the basis of specific mission requirements.

The selection of a pressurization system depends on many factors. The evaluation of these factors can be quite time consuming. The design guide provides, in three volumes, both a method and the necessary data for the selection of the most suitable liquid rocket pressurization system.

Each of the four design parameters or rating factors which are now covered by the design guide is given a numerical function which is based on the mission requirements. These rating factors are reliability, weight, volume, and cost. The numerical functions are called influence coefficients, and each system is evaluated by the product of its four influence coefficients. Thus, each system considered receives a numerical rating. The system receiving the highest numerical rating is the best suited for the mission. The method is objective in that the influence coefficient curves are chosen directly from the mission objectives and prior to the consideration of any system.

The choice of systems to be submitted for evaluation is, of necessity, less objective. The user must provide several systems for evaluation. Presumably, these systems are selected because they appear promising enough to justify a detailed evaluation. The design guide can be used to select the most suitable system from those presented, but if the systems are not appropriately chosen, the result may not be satisfactory.

New systems may be created by a morphological approach. This method consists of choosing an array of components and then generating new systems by using combinations and permutations of these components. The morphological approach is explained in detail in Section II.

B. SCOPE

The design guide does not develop detailed pressurization system designs; rather, it guides in the selection of the most suitable system based on the candidate systems and parameters considered.

1. Rating Factors

Presently, the design guide can rate candidate systems by the following design parameters or "rating factors":

a. Reliability

b. Weight

c. Volume

d. Cost

The rating factors are plotted in a general manner so that they may be used with a minimum amount of calculation. As opportunity permits, more rating factors can be added to increase the scope and value of the guide.

2. Propellants

The following thrust-chamber propellant combinations are considered in the design guide:

a. LO_2/LH_2

b. OF_2/LH_2

c. LF_2/LH_2

d. N_2O_4/N_2H_4

e. N_2O_4/Aerozine-50 (50% N_2H_4 - 50% UDMH b.w.)

f. ClF_3/Hydrazoid [23.3% N_2H_4 - 76.7% ($3CH_3N_2H_3$ + $N_2H_5NO_3$)b.w.]

In addition to these, two solid propellants and N_2H_4 as a monopropellant are considered as part of the pressurization systems.

Not all of the propellants are covered in each part of the "Component Design Data," Volume III. The sections of Volume III in which the various propellant combinations are discussed are shown in the following chart.

Propellant Combinations	Sections of Volume III which Discuss Various Propellant Combinations: Injected Propellants	Liquid Propellant Gas Generator	VaPak
LO_2/LH_2	x	x	x
OF_2/LH_2		x	
LF_2/LH_2		x	x
N_2O_4/N_2H_4		x	x
N_2O_4/Aerozine-50	x	x	x
ClF_3/Hydrazoid	x	x	x
N_2H_4/Monopropellant		x	

3. Components

Component design data for the four rating factors have been compiled for the following items, using functional groupings.

a. Energy Supplies

Batteries

Heat exchangers

Injected propellant

Liquid-propellant gas generators (LPGG)

Solid-propellant gas generators (SPGG)

Stored gas and containers

VaPak

b. Initiators/Terminators

Igniters

Solenoid valves

c. Charge and Recharge Connectors

Disconnects

d. System Controls

Jet pump
Motors
Orifices
Pressure regulators
Pressure switches

e. Transmission Systems

Ball screws
Bellows tankage

f. Safety Devices

Check valves
Bladders
Relief valves

g. Reliability for all components

C. USE OF THE GUIDE

The design guide implements a more rigorous and objective procedure for evaluating the candidate systems. This procedure consists of the following steps.

1. The mission must be defined in the following terms:

a. Propellants to be used

b. I_{sp}

c. Mixture ratio

d. Thrust

e. Chamber pressure

f. Total impulse

g. Restarts and throttling

2. Propellant pressurization system requirements are calculated using Section III of this design guide. The calculations included: (a) propellant tank pressure, (b) volume of propellant expelled, (c) expulsion work, and (d) pressurant flow rate.

3. Using the data of 1 and 2 above, determine the influence coefficient curves. The determination technique is described in Section III of Volume I of this design guide.

4. Calculate the sizes of the components indicated by the choice of candidate pressurization systems. Sizing calculations for each component are shown in Section IV of Volume I of this design guide.

5. Summarize the rating factors for the sized components as noted in Section III of Volume I of this design guide.

6. Summarize the influence coefficients as noted in Section III of Volume I of this design guide.

7. Evaluate candidate pressurization systems as noted in Section V of Volume I of this design guide.

To aid in an understanding of the steps involved, a sample evaluation is made in Section VI of Volume I of this design guide. In the example, the above seven steps are restated with the appropriate calculations appearing immediately following each step.

II. MORPHOLOGICAL APPROACH*

A. CONCEPT OF THE MORPHOLOGICAL APPROACH

The selection of an optimum pressurization system is dependent both on the ability to select systems to evaluate and on the method used to establish the relative merit of the systems selected. In this section the first aspect, that of determining possible systems to evaluate, will be discussed.

The ultimate in widening the scope of the systems considered for any mission would be the morophological approach. The concepts underlying this approach are as follows:

1. Establish the list of components of which any pressurization system may be composed.

2. Generate all combinations which can be formed by the component array.

3. Generate all permutations which can be formed by the component combinations.

It is, therefore, a systematic procedure which will generate a vast number of candidate pressurization systems. For the components considered, the system has the potential of generating all possible pressurization systems for any mission. The difficulty encountered by this approach is that if enough components are included to make the method useful, more candidate systems are generated than can possibly be evaluated. This causes a great deal of time to be spent culling out obviously inoperative "systems." Some method of avoiding the vast number of inoperative systems must be implemented before this approach is practical.

B. MODIFIED MORPHOLOGICAL APPROACH

Intuitively, one can recognize that all component groupings which could truly qualify as pressurization systems are subject to further limitations. These are functional operations which must be performed by the components in order for the system to "pressurize" at all. Thus, we wish to restrict ourselves to the component associations which are capable of delivering pressurizing media.

*This section will also appear in Aerojet Report No. 2335.

In the process of developing this approach, grouping of the components that perform similar functions was found to be highly advantageous. This modified morphological approach reduces the number of possible combinations and leads to a selection technique that is more easily handled.

1. Modified Morphological Approach

The application of this modification is accomplished as follows:

a. Establish the ordered set of performance functions of which a generalized pressurization system is composed.

b. Establish the list of components which are to be considered in each functional set.

c. Generate all possible component combinations which can be formed by placing components only in the positions reserved for the functional sets to which they belong.

d. Examine the resulting systems for practicality and component compatibility.

2. Component Categories

It was found that all pressurization system components could be grouped into six ordered-function categories, Figure II-1. Any number of components, from none to several, may be selected from each category. The six categories are as follows:

a. Energy Supplies

This category includes all primary energy sources and their containers. High-pressure stored gases, liquid-propellant gas generators, solid-propellant gas generators, thrust-chamber heat exchangers, and batteries are covered in this section. The properties of gases and products of combustion will be included, together with the analysis of associated flow processes, such as the use of gas from a high-pressure storage container.

b. Initiators/Terminators

This section will cover the design of devices for commencing or terminating system operations such as igniters, electrical switches, solenoid-operated valves, explosive valves, and burst diaphragms. The size and weight of these items is dependent upon the energy demand and the operating conditions.

c. Charge and Recharge Connectors

Electrical connectors and fluid-line disconnects will be discussed under this heading. Design and evaluation data will be given in terms of the desired charging rate.

d. System Controls

In most propellant pressurization systems the energy-converting component is the "heart" of the system.

The task of maintaining a constant energy supply under varying load conditions often requires a complex component. This section will cover the design of pressure regulators and orifices.

e. Transmission Systems

The energy required to feed propellants to the engine must be transmitted from the supply to the propellant by one or more "conductors." Electric sources require wiring, mechanical sources require gears, and pressure sources require tubing to transmit energy. The transmission components will be described as a function of the energy supply rate.

f. Safety Devices

Most propellant feed systems employ safety devices to increase reliability and reduce operating hazards. Check valves prevent interflow between propellant tanks, electrical relays and relief valves prevent overload, and bladders prevent hot gases from coming in direct contact with the propellant. The design of safety devices and reasons for their use will be presented under this category.

C. EXAMPLE OF COMPONENT COMBINATIONS

The modified morphological approach, described above, was employed to select 16 workable component combinations. One or two components were selected from each of the performance categories described above, and the tabulation is shown in Table II-I.* These 16 systems, which are used as the examples of the evaluation technique, represent but a small percentage of the workable systems which could be formed using this approach.

In an attempt to maintain the objective of the program for unbiased system evaluation, the systems were formed without consideration of a particular mission. Every component being evaluated in this study is included in one or more of the systems. Schematic diagrams of the 16 systems have been prepared and are shown in Figures II-2 through II-17.

Component Combinations 8, 15, and 16 show that at least three basic types of hybrid propellant pressurization systems can be created. Component Combination 8 employs two energy supplies (high-pressure gas and a heat exchanger). functioning simultaneously to expel the propellant. Combination 15 employs two energy supplies, one for expelling each propellant. In Component Combination 16 two energy supplies are used consecutively, one being employed after depletion of the other. Component Combination 14 is an even more complex hybrid incorporating the features of both Combinations 8 and 10.

The formation of novel hybrid propellant pressurization systems appears to be a very promising area for the application of the modified morphological approach. With anticipated space missions being composed of several maneuvers, it is possible that propellant pressurization systems powered by two or more energy supplies, each functioning when it best suits the maneuver, could prove to be the lightest in weight or the most reliable.

*Tables and figures pertaining to a particular section may be found at the end of that section.

D. FUTURE POTENTIAL OF THE MORPHOLOGICAL APPROACH

Due to the large number of possible component combinations, an approach such as a modified morphological development appears to be the only practical technique that will permit all the alternative systems to be appraised. Presently, the designer tends to limit himself to variations of the relatively few systems with which he is familiar, and does not make full utilization of the components available to him. This is a result of the designer being discouraged by the number of components available and the geometric nature of the combining process.

This situation leads to the possible introduction of computer usage as a practical and expedient method of both generating and appraising a large number of possible systems. This would basically increase the breadth of the designers investigation and consequently permit a more thorough analysis of the possible systems.

The usefulness of computers in this particular application would depend primarily on the extent that factors, such as component compatibility, mission limits, and a weighting for the preference of proven systems over new untested systems could be incorporated into the program.

Moreover, once such a program is developed, it would have the potential of being used by designers regardless of their project or company affiliation and/or by a project administrator for the appraisal of pressurization systems that must meet certain design features. The future of such an undertaking is unlimited. Over a period of time,refinements would evolve that would continually increase the sophistication of the methodology and, therefore, the program's overall usefulness.

TABLE II-1

COMPONENT COMBINATIONS

	1	2	3	4	5	6	7	8
ENERGY SUPPLY	High Press. Gas	High Press. Gas	High Press. Gas	Preconditioned Propellant	Battery Vaporized Propellant	Propellant High Press. Gas	Propellant High Press. Gas	High Press. Gas TCA Heat Xchgr.
INITIATORS/TERMINATORS	Solenoid Valve	Squib Valve	Solenoid Valve	None	Electrical Switch	Solenoid Valve	Solenoid Valve	Solenoid Valve
CHARGE & RECHARGE CONNECTORS	Pressure Line Disconnect	Pressure Line Disconnect	Pressure Line Disconnect	Propellant Line Disconnect	Propellant Line Disconnect	Pressure Line Disconnect Propellant Line Disconnect	Pressure Line Disconnect Propellant Line Disconnect	Pressure Line Disconnect
SYSTEM CONTROL	Press Regulator	Orifice	Orifice	None	Pressure Regulator Pressure Switch	Press. Regulator	Press. Regulator	Press. Regulator
TRANSMISSION SYSTEM	Tubing	Tubing	Tubing	Tubing	Tubing/Wires	Tubing	Tubing	Tubing
SAFETY DEVICES	Check Valves Relief Valves	Check Valves Relief Valves	Check Valves Relief Valves	Relief Valve	Relief Valve	Check Valve Relief Valve	Relief Valve Filter	Check Valve Relief Valve
TYPE OF SYSTEM	Stored Gas	Stored Gas	Stored Gas	Vāpak	Secondary Vāpak	MTI	MTI	Heated Stored Gas

TABLE II-1 (cont.)

COMPONENT COMBINATIONS (CONT.)

	9	10	11	12	13	14	15	16
ENERGY SUPPLY	Battery	LGG High Pressure Gas	SGG	SGG	High Pressure Gas TCA Heat Exchgr.	High Pressure LGG Heat Exchanger	High Press. Gas Evaporated Fuel Heat Exchanger	High Pressure Gas SGG
INITIATOR/TERMINATOR	Electrical	Solenoid Valve	Ignitor Burst Diaphragm	Ignitor Burst Diaphragm	Solenoid Valve	Solenoid Valve	Solenoid Valve 3-Way Solenoid Valve	Solenoid Valve Igniter
CHARGE & RECHARGE CONNECTORS	None	Press. Line Disconnect Propellant Line Disconnect	None	None	Propellant Line Disconnects Pressure Line Disconnect	Propellant Line Disconnects	Pressure Line Disconnect Propellant Line Disconnect	Pressure Line Disconnect
SYSTEM CONTROL	Electric Motor	Pressure Regulator	Orifice	Orifice	Jet Pump	Variable Orifice Pressure Regulator	Pressure Regulator	Pressure Regulator Pressure Switch
TRANSMISSION	Wires, Gears Bellows	Tubing	Tubing	Tubing	Tubing	Tubing	Tubing	Tubing, wires
SAFETY DEVICES	Check Valve	Check Valves Relief Valves	Filter Check Valves Relief Valve	Filter Check Valve Relief Valve Bladder	Relief Valve	Relief Valve	Check Valve Relief Valve	Check Valves Relief Valves
TYPE OF SYSTEM	Mechanical Bellows	Liquid Propellant Gas Generator	Solid Propellant Gas Generator	Solid Propellant Gas Generator	Jet Pump	Hybrid LGG/Line Heated Stored Gas	Hybrid Line Heated Stored Gas/EP	Hybrid Stored Gas/SGG

MORPHOLOGICAL OUTLINE

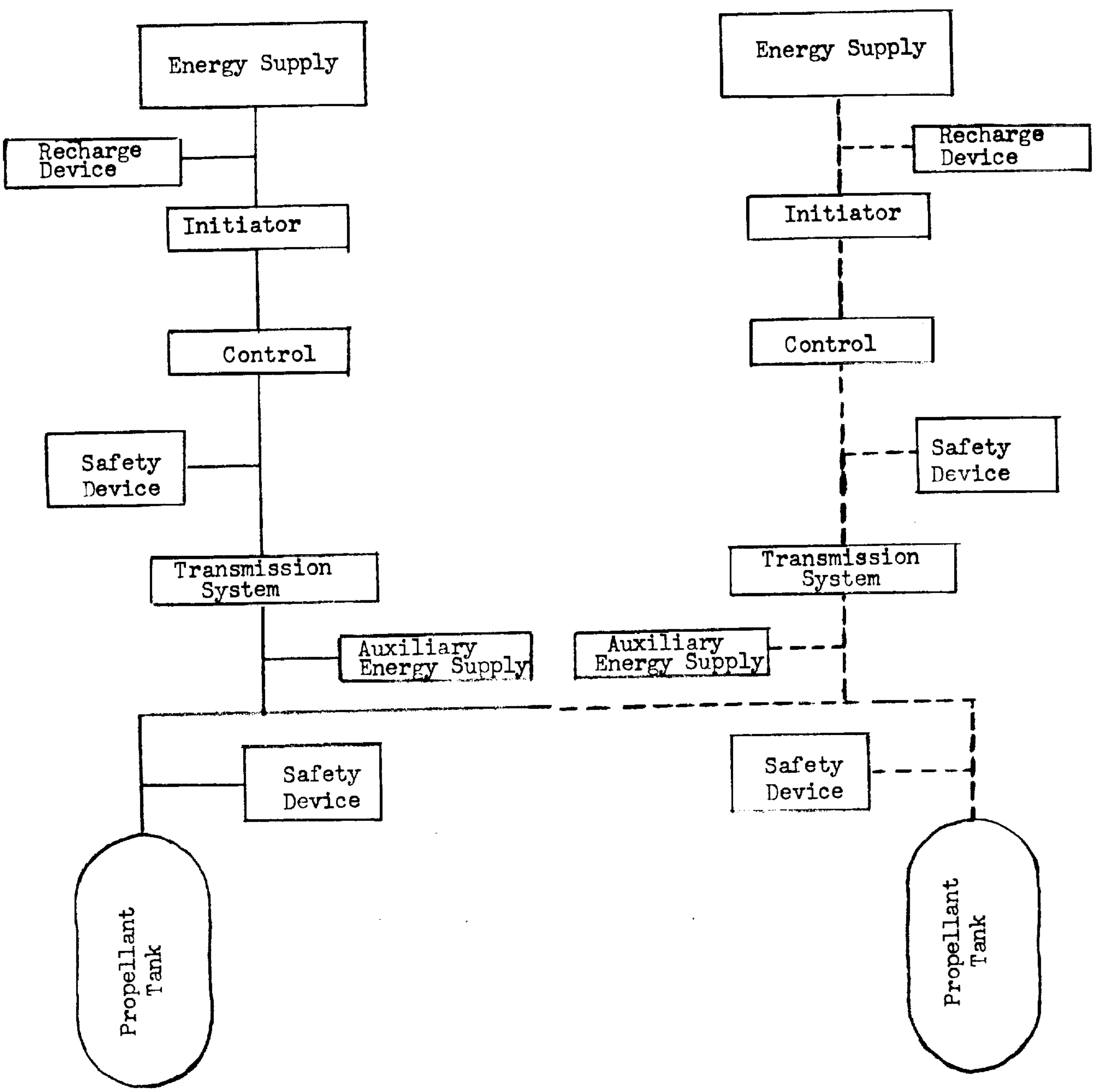
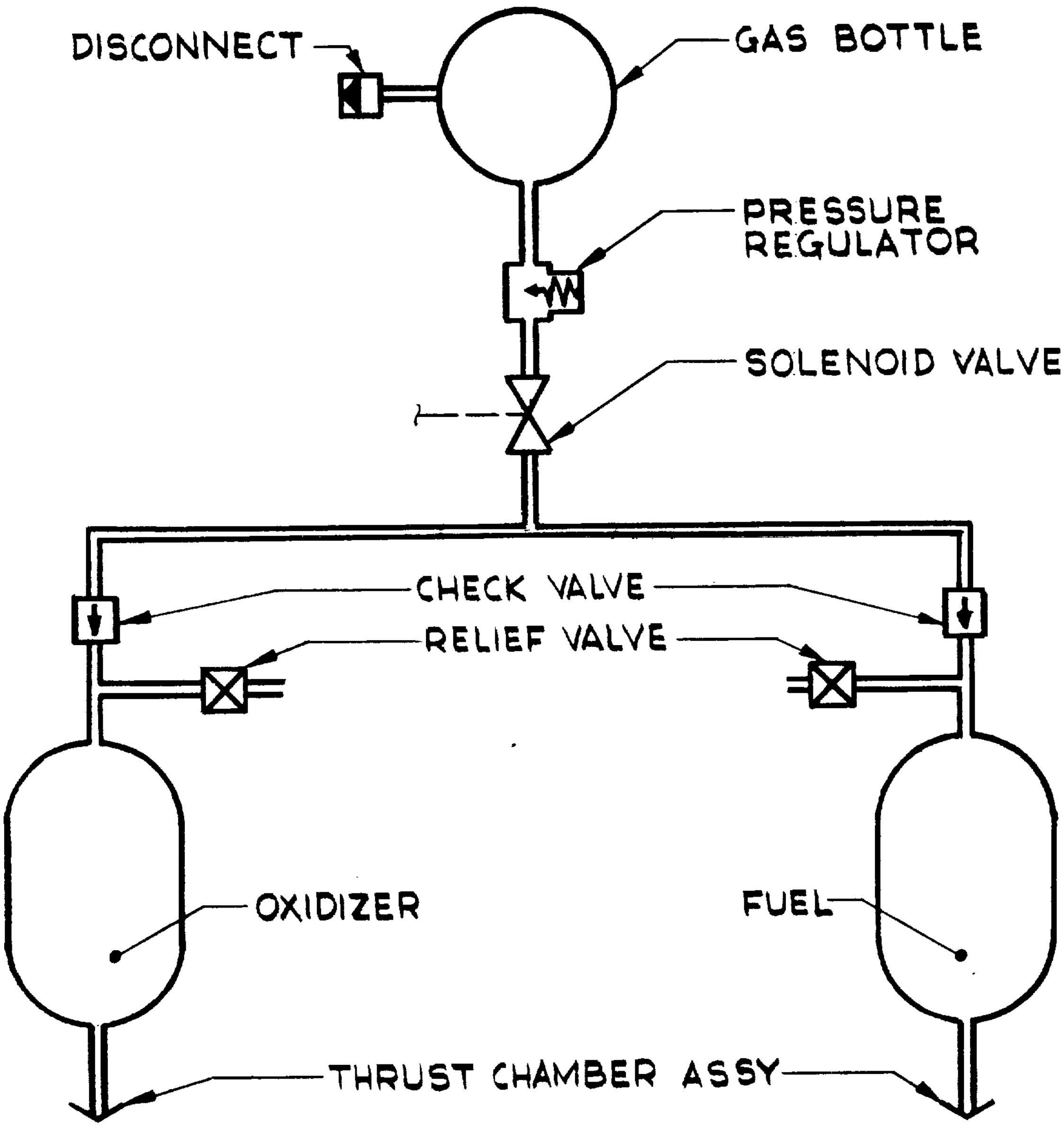
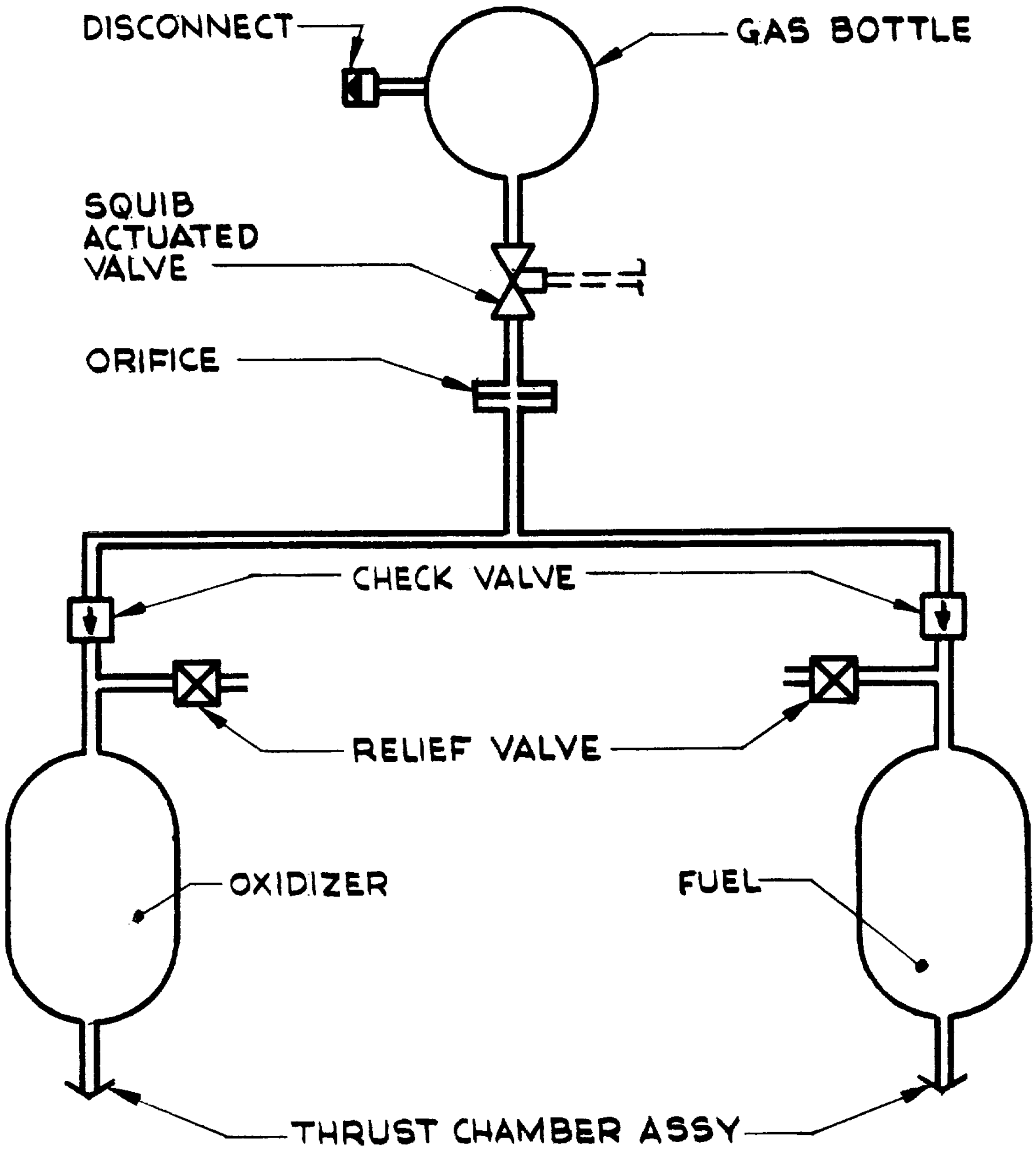


Figure II-1



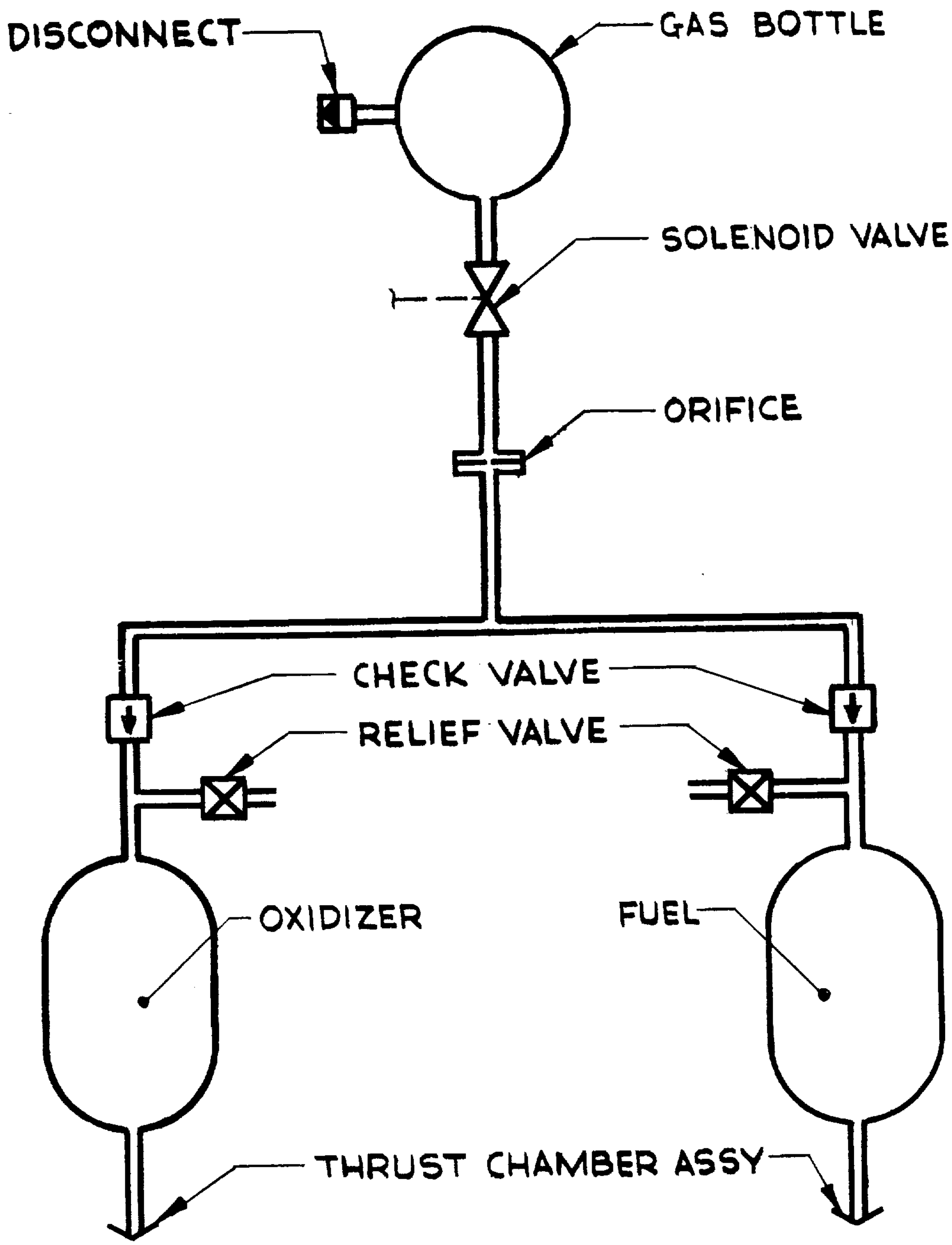
COMPONENT COMBINATION I

Figure II-2



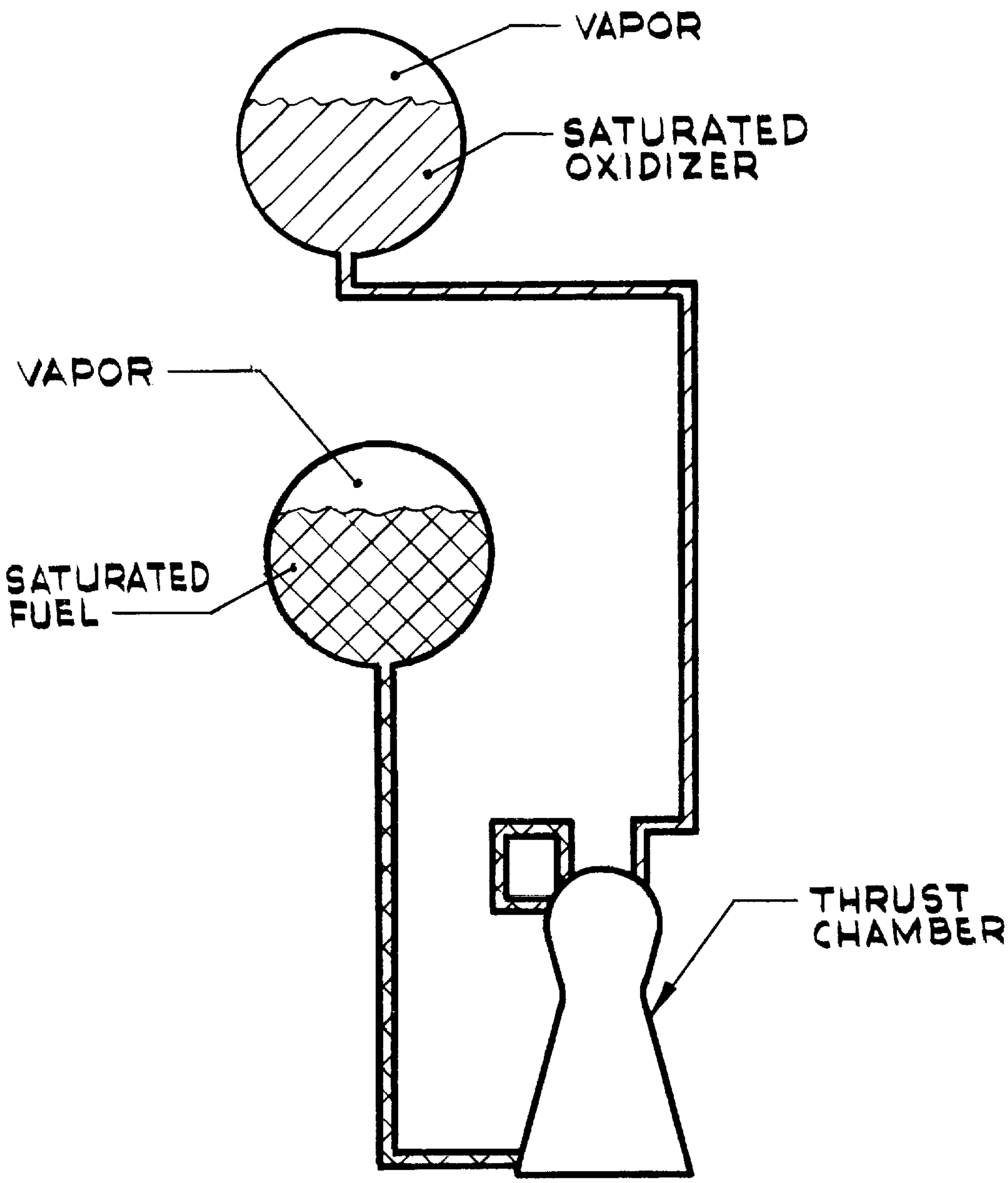
COMPONENT COMBINATION 2

Figure II-3



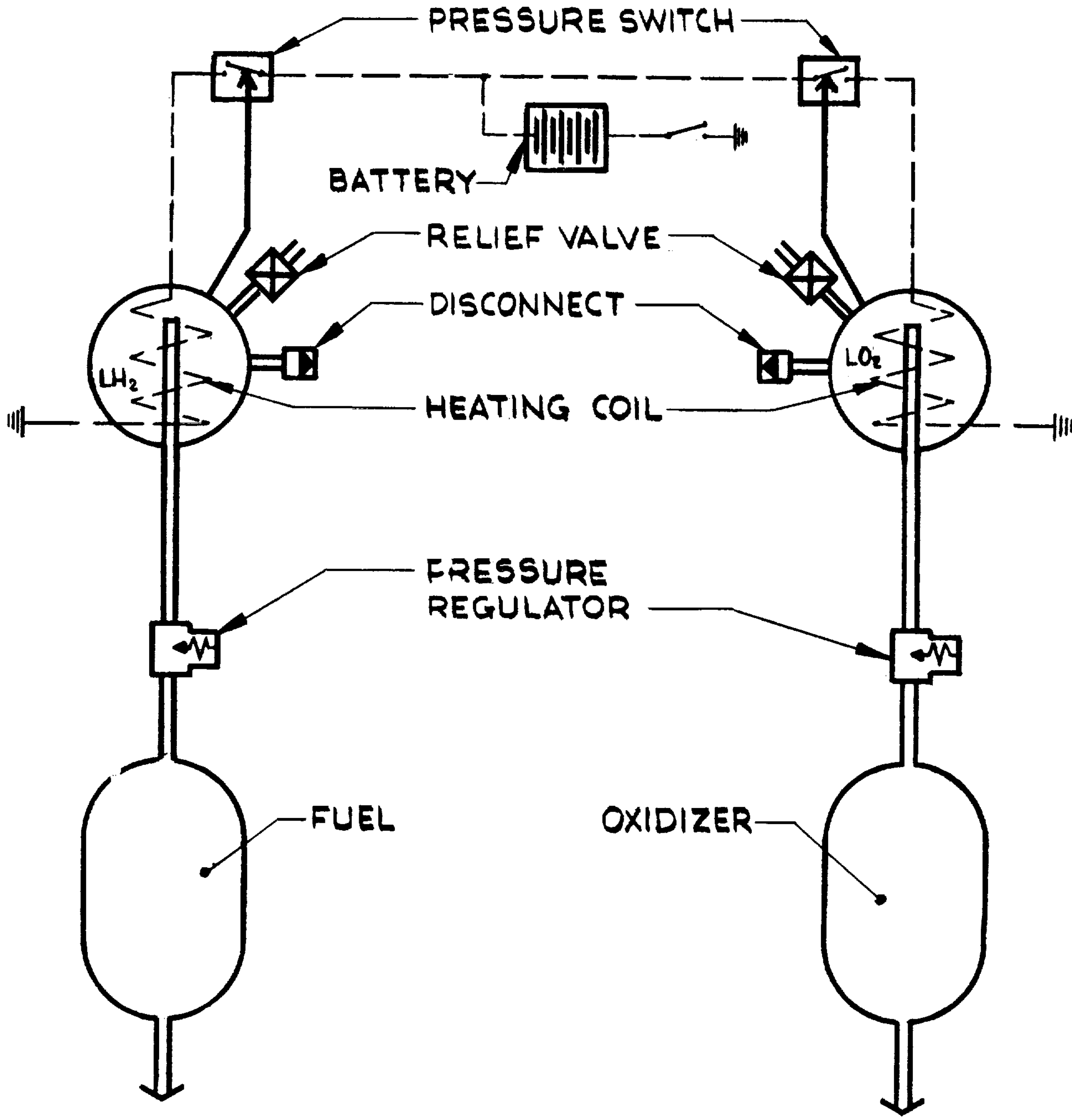
COMPONENT COMBINATION 3

Figure II-4



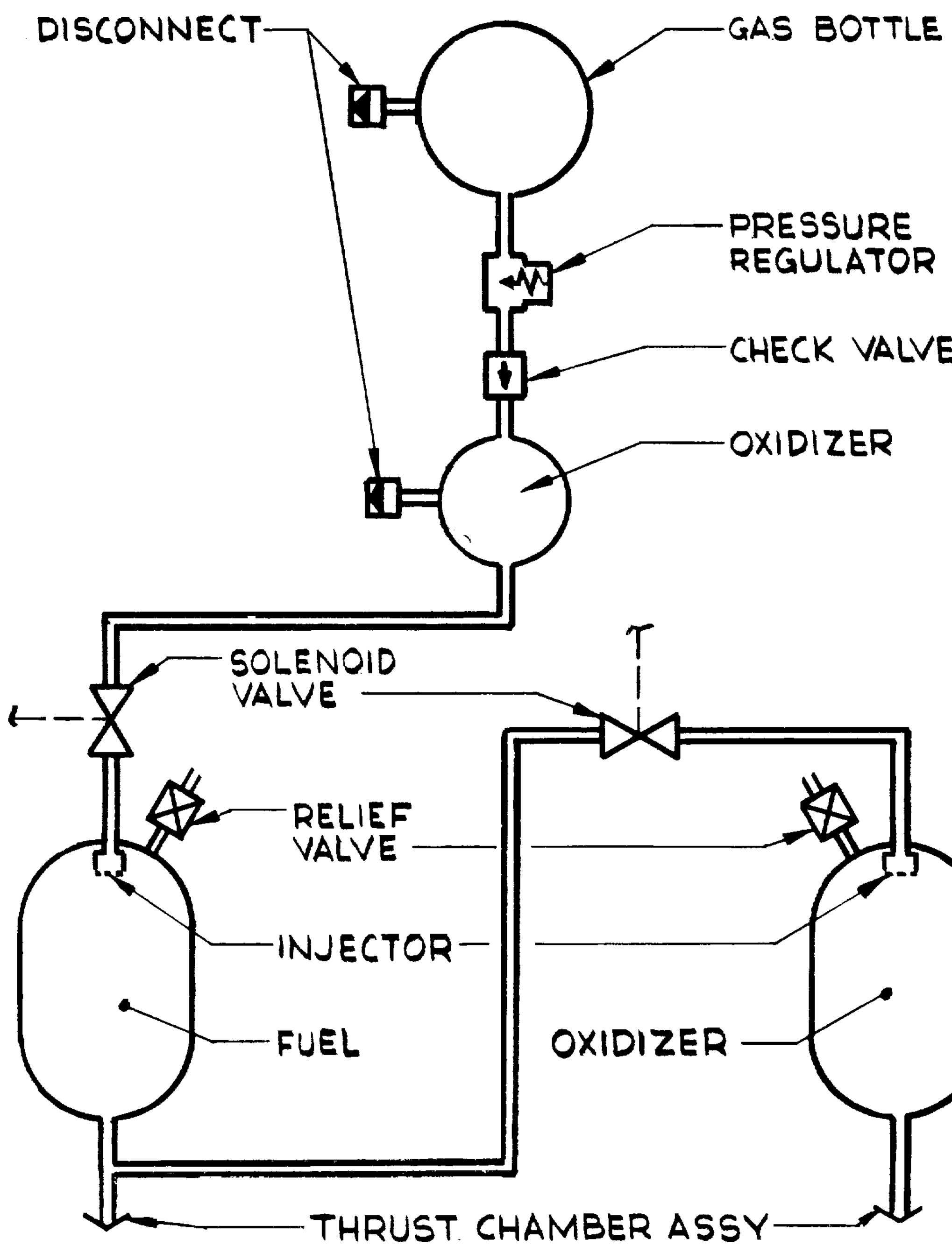
COMPONENT COMBINATION 4

Figure II-5



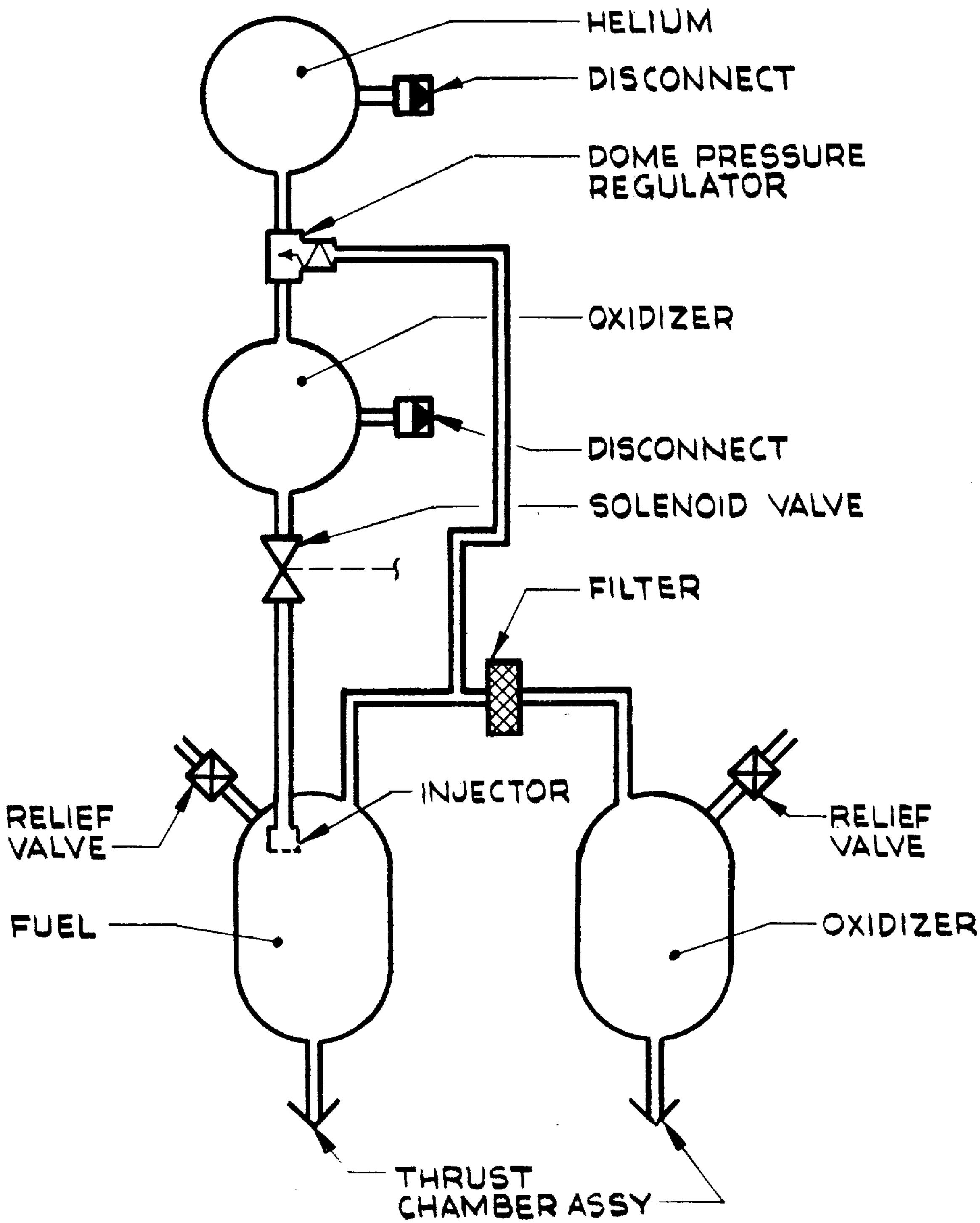
COMPONENT COMBINATION 5

 Figure II-6



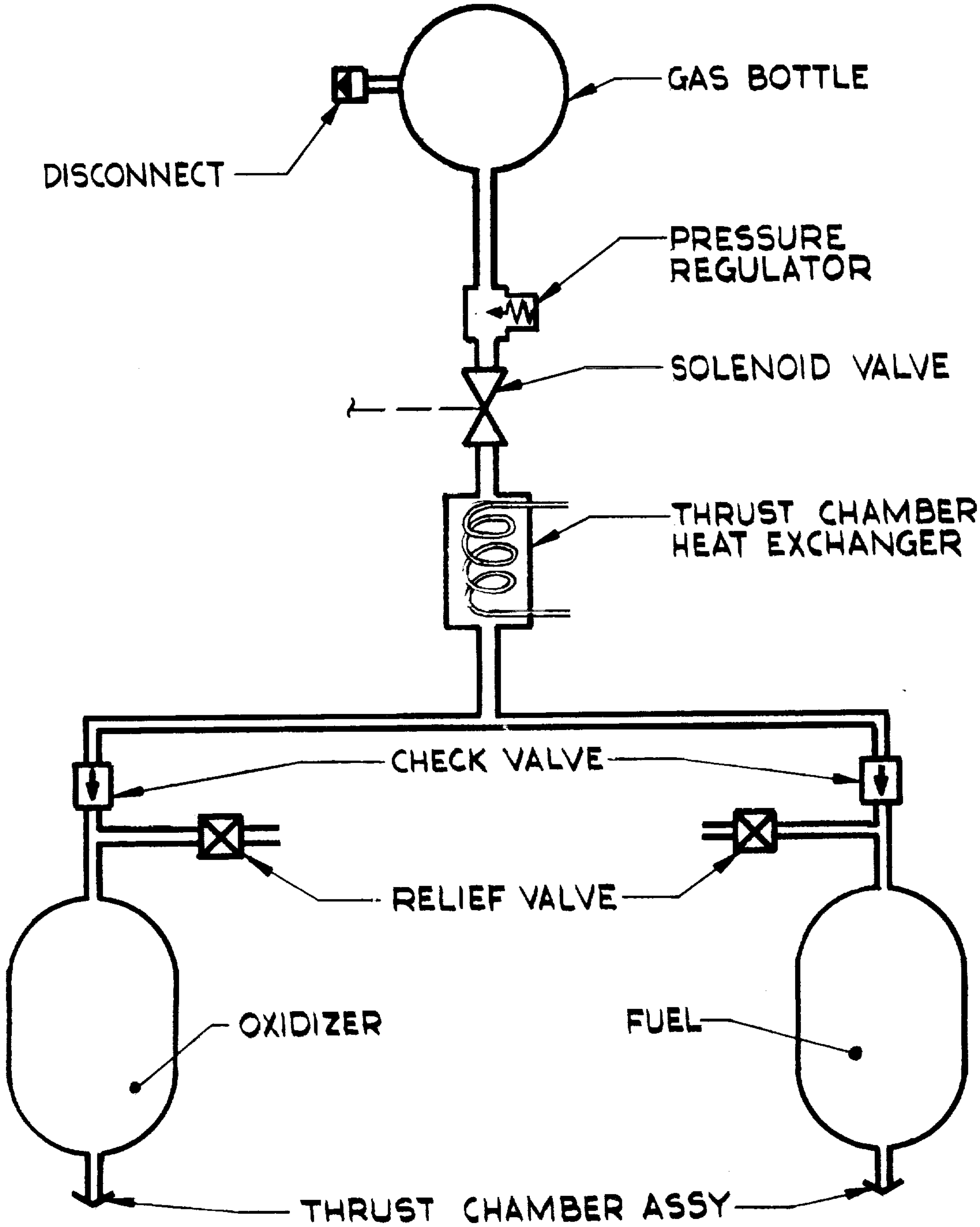
COMPONENT COMBINATION 6

Figure II-7



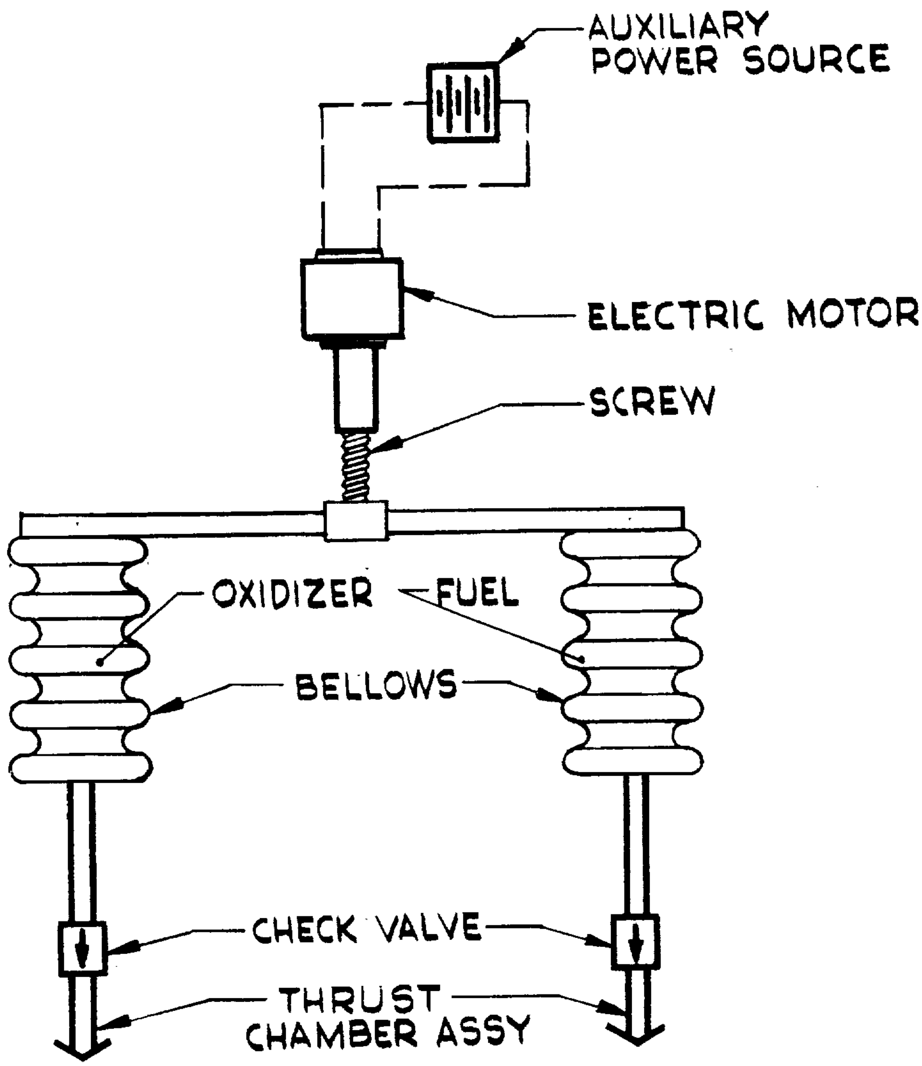
COMPONENT COMBINATION 7

Figure II-8



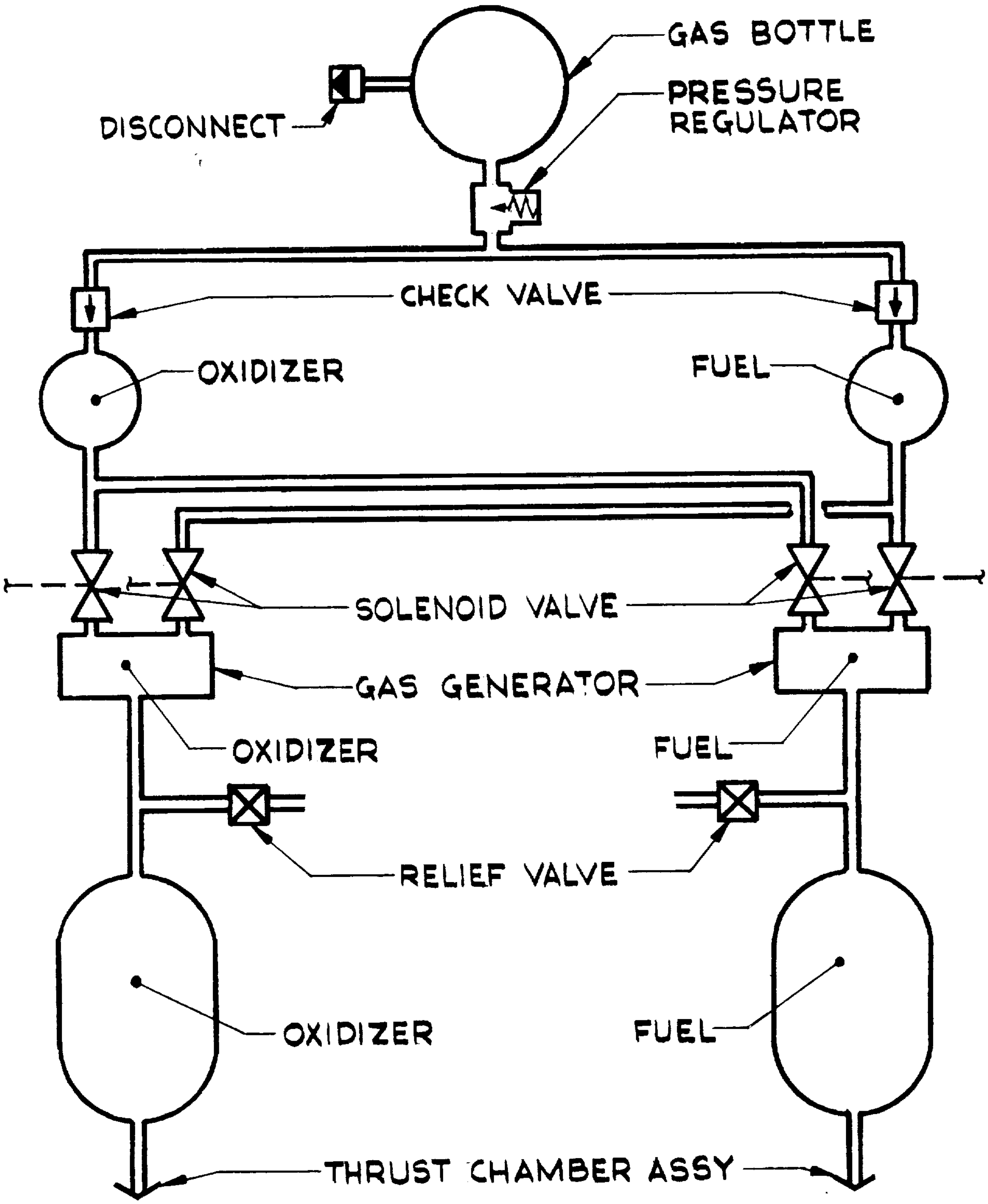
COMPONENT COMBINATION 8

Figure II-9



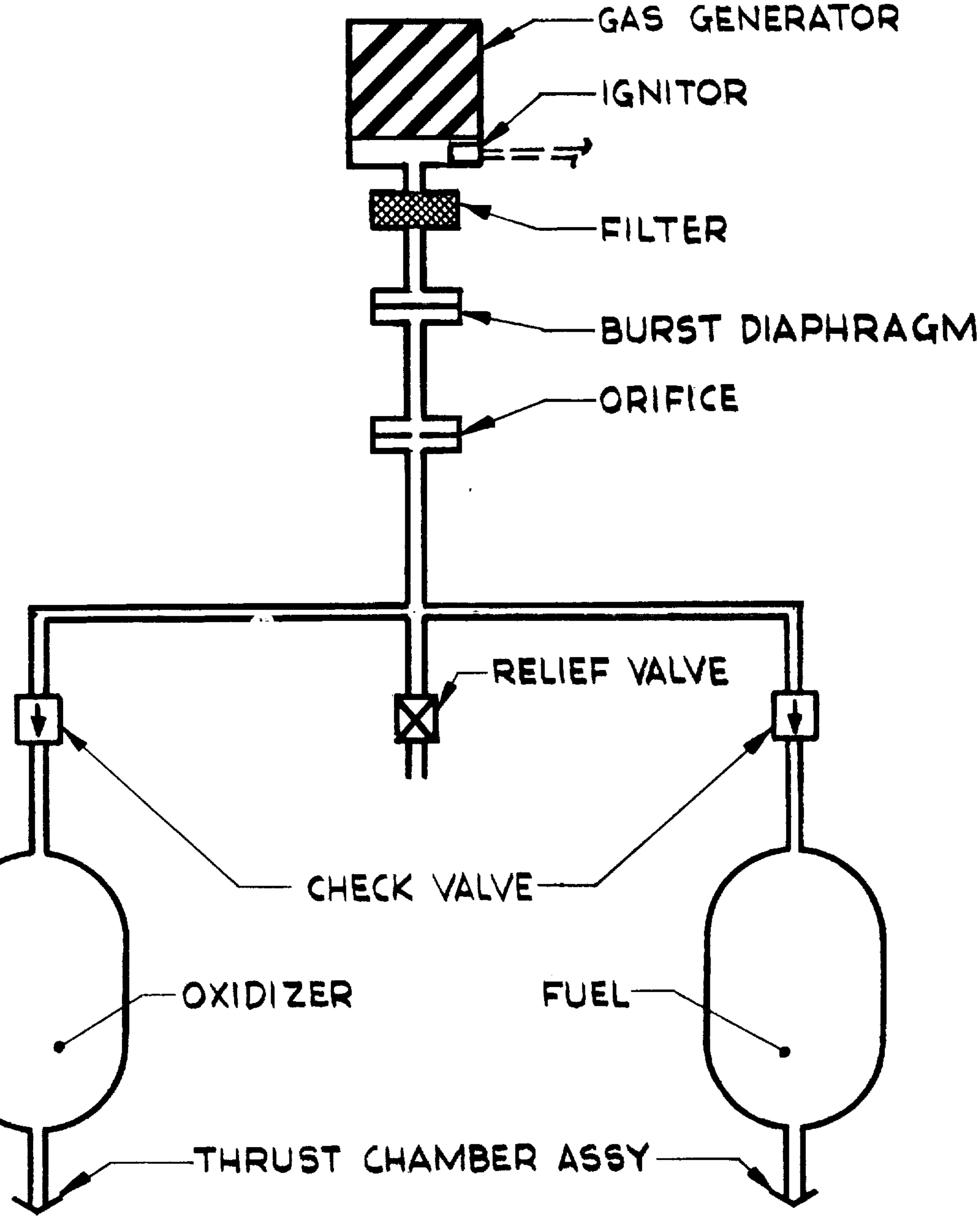
COMPONENT COMBINATION 9

Figure II-10



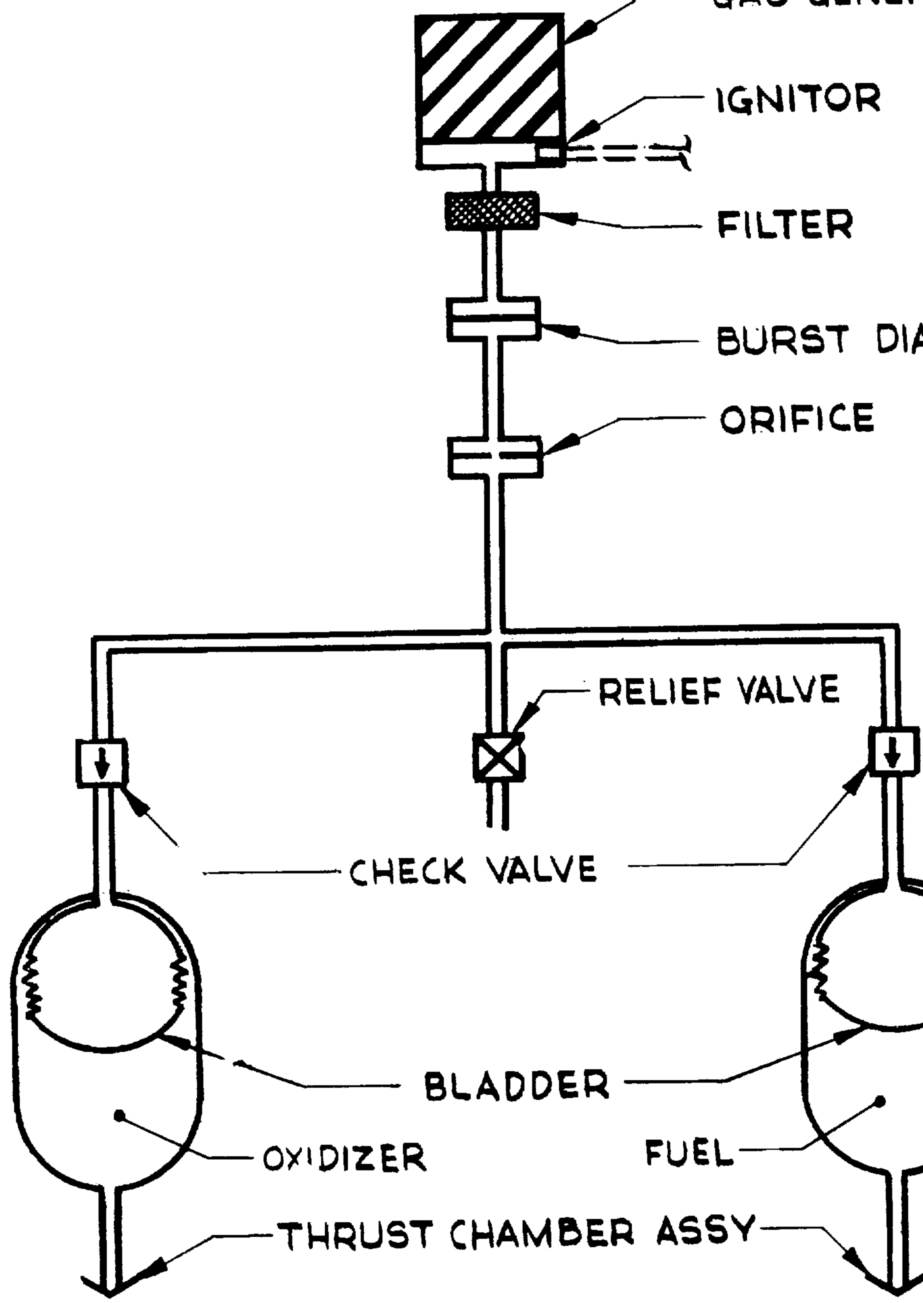
COMPONENT COMBINATION 10

Figure II-11



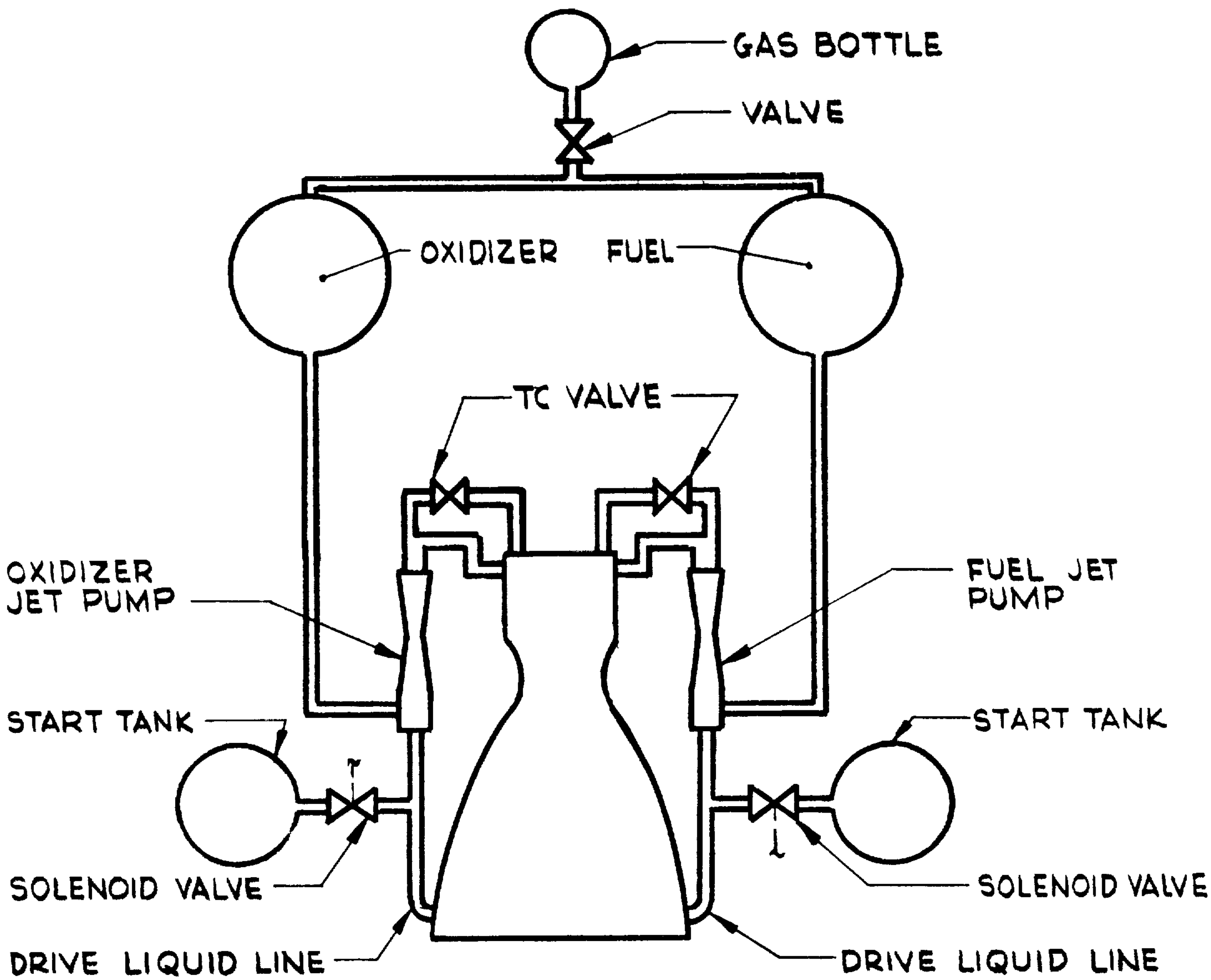
COMPONENT COMBINATION II

 Figure II-12



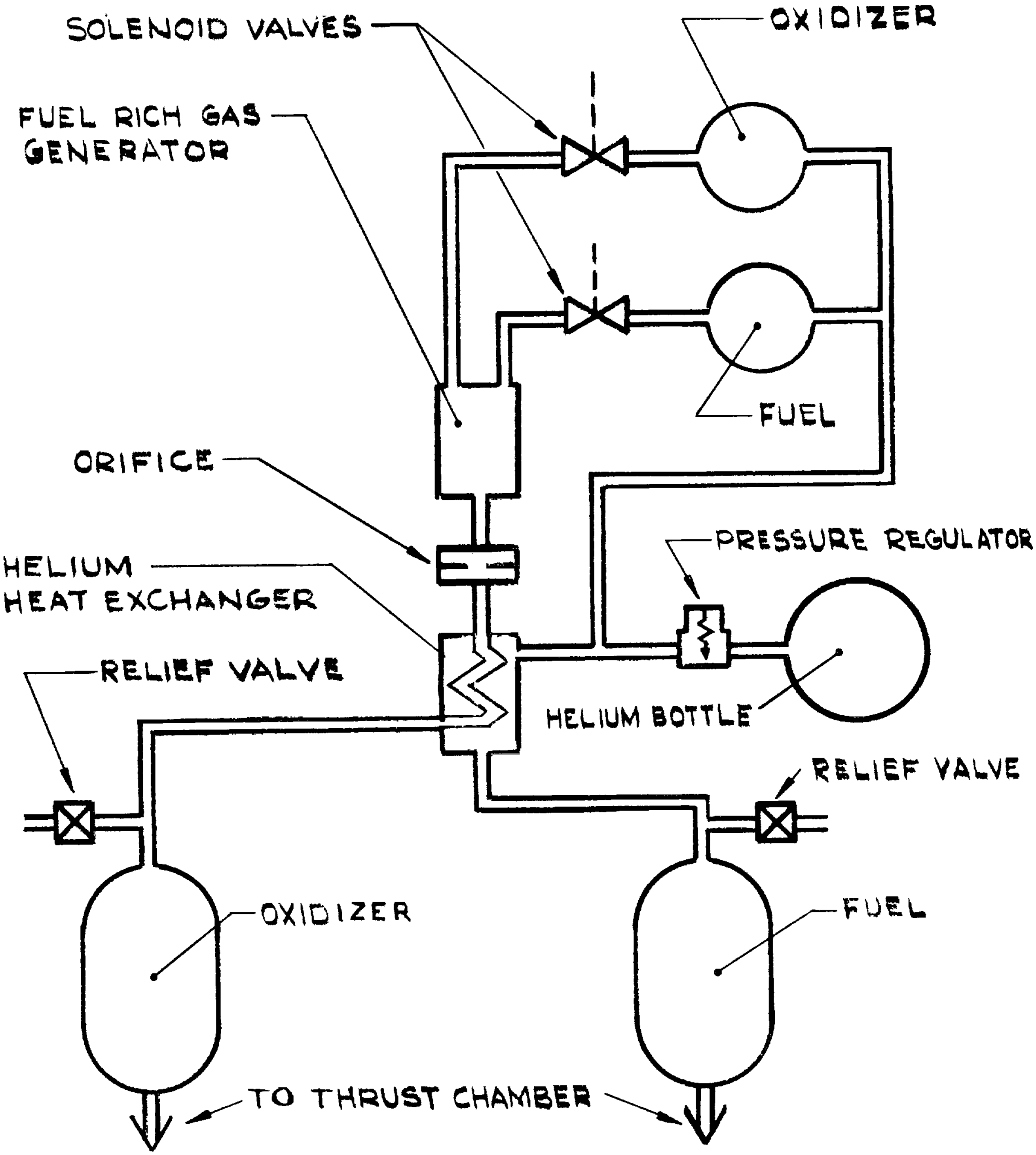
COMPONENT COMBINATION 12

Figure II-13



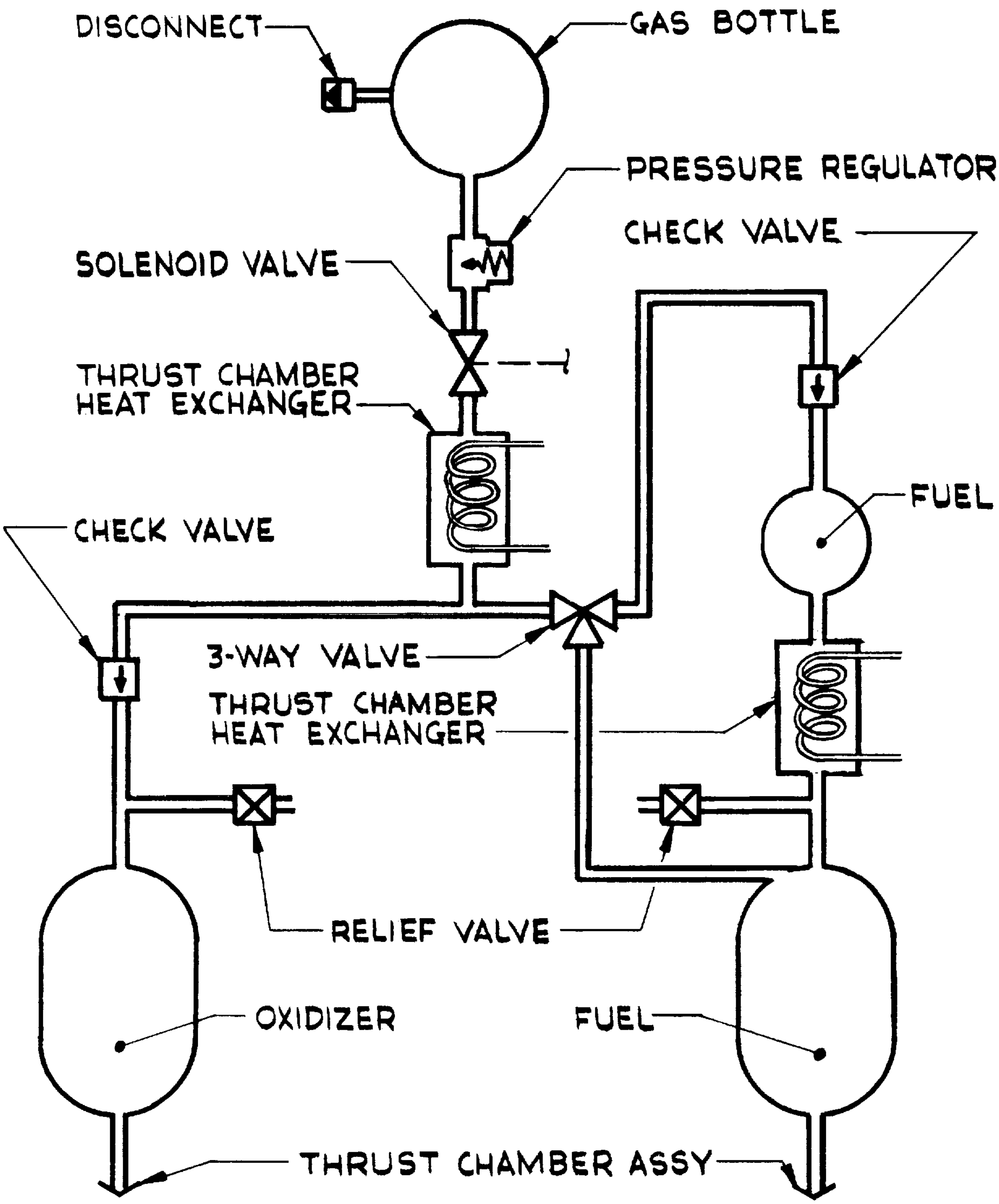
COMPONENT COMBINATION 13

Figure II-14



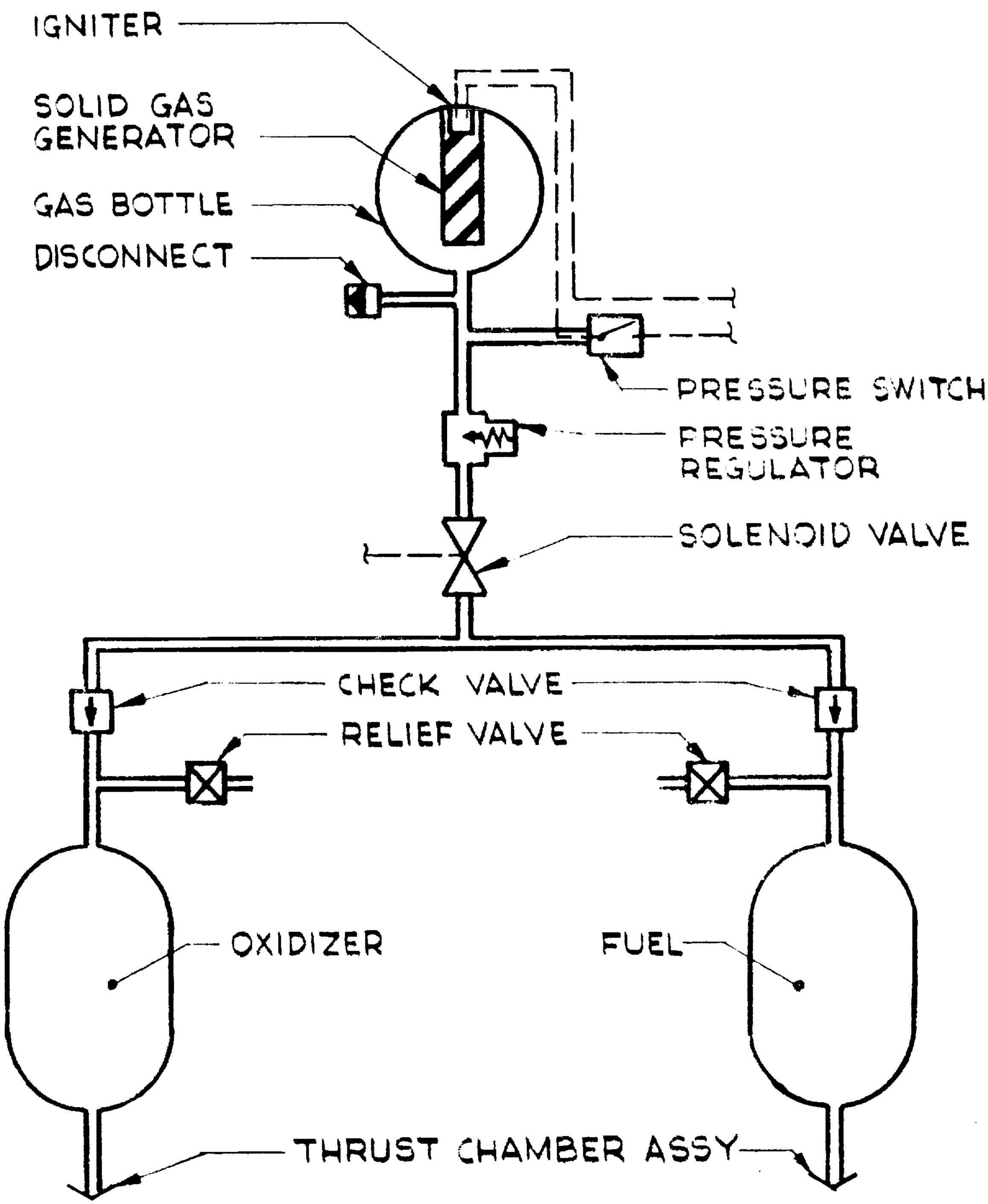
COMPONENT COMBINATION 14

 Figure II-15



COMPONENT COMBINATION 15

Figure II-16



COMPONENT COMBINATION 16

Figure II-17

III. SYSTEM EVALUATION TECHNIQUE*

For any given mission, several propellant pressurization systems may be capable of meeting the performance requirements to a greater or lesser extent. The following rating technique has been devised to provide an objective means of comparing and selecting the most suitable pressurization systems for any mission.

A numerical rating, based upon performance factors, is determined for each candidate pressurization system. The final rating of each system is computed by multiplying a base value by the rating factors for that system. Two types of rating factors are established; qualitative factors, which systems must meet to be acceptable, and quantitative factors, which systems can fulfill to varying degrees. Examples of the two categories are shown below:

Qualitative Factors	Quantitative Factors
Restart capability	Reliability
Variable-thrust capability	Weight
Propellant compatibility	Size
200-day storability	Cost
	Control accuracy

Some rating factors can be both qualitative and quantitative depending upon the mission requirements. For example, if a minimum reliability of 97% were a requirement, all systems having reliabilities below this value would be eliminated from consideration; however, those systems with reliabilities above 97% would be rated quantitatively over the range of 97 to 100%.

This evaluation is maintained as an objective technique by establishing the rating factors (or influence coefficients) independently of and previous to the evaluation of system performance. Influence coefficient curves and tables are prepared to reflect the desired propellant pressurization system configuration, and the rating technique serves as a measure of how closely each candidate system approaches these desired values.

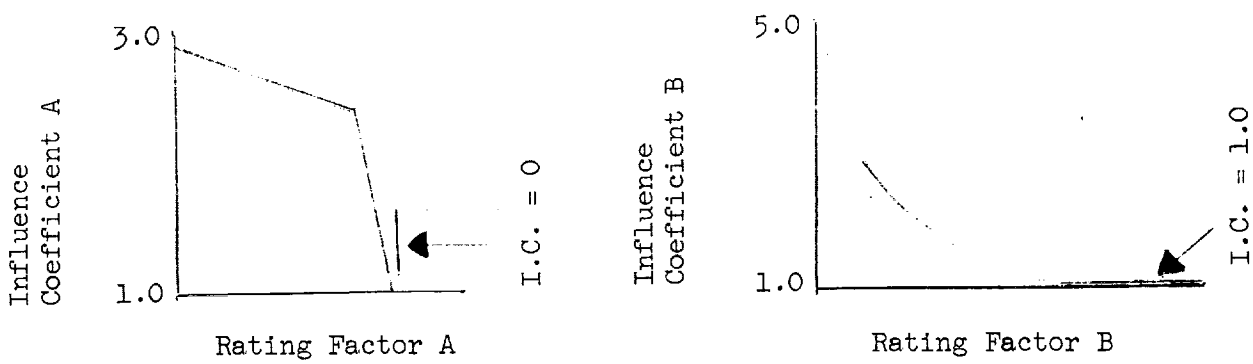
*This section will also appear in Aerojet Report No. 2335.

A. QUALITATIVE EVALUATION FACTORS

Qualitative factors are those rating parameters which are "go, no-go" measurements. If a system can meet a requirement it will rate 1.0, if not, it will rate 0. Since the final numerical rating of the system is the product of the coefficients, a zero rating of any coefficient will eliminate that system from further consideration. The effect of this initial screening will be to reduce the number of candidate systems to a workable group.

B. QUANTITATIVE EVALUATION FACTORS

The remaining candidate systems are all capable of satisfying the mission requirements to varying extents. The quantitative evaluation factors will be presented as influence coefficient curves like those shown below:



The shape of the influence coefficient curves is a measure of the absolute importance that is placed upon an increase or decrease in the value of each rating factor. The rating factors may carry different weights in the over-all evaluation; thus, the relative importance of each factor can be adjusted by varying the range of the influence coefficients on the ordinate of the curve. Rating factor A may have a range of influence coefficient from 1.0 to 3.0 while factor B may have a range of influence coefficient from 1.0 to 5.0, indicating that factor B has more influence on the selection of the system than factor A.

The value of the influence coefficient is defined as zero for rating factor values beyond the point where the value of the influence coefficient drops below 1.0. Thus, qualitative influence coefficient curves may be extended to represent both qualitative and quantitative considerations.

C. INFLUENCE COEFFICIENT USAGE

To illustrate the method of preparing the influence coefficient curves, a selection of a system for a manned, lunar mission will be demonstrated. Reliability, weight, and size will be the factors used in rating the systems.

Minimum allowable reliability - 98.5%

Desired weight - 120 lb or less

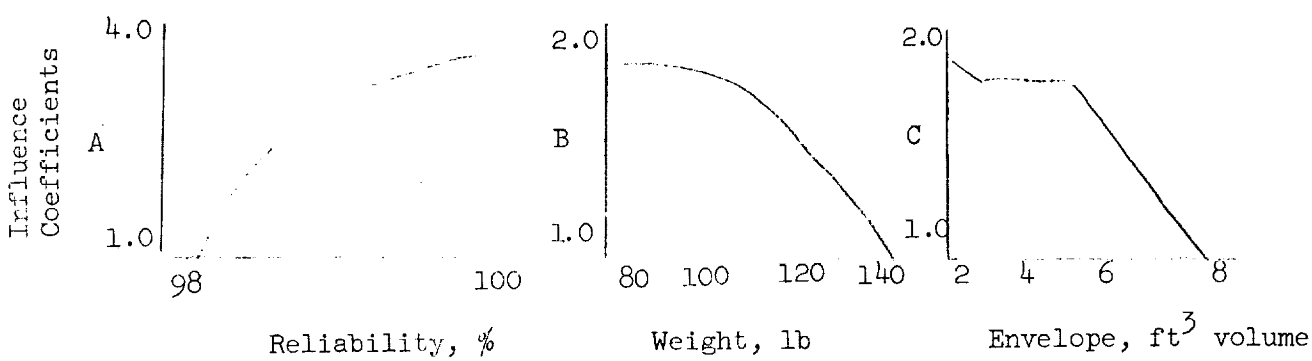
Desired size - 6 ft^3 or less

1. Selection of Coefficient Ranges

Of the three rating factors, reliability is the most important for this manned mission, with weight and size being of lesser importance. The coefficient ranges are selected as follows:

Reliability	1.0 - 4.0
Weight	1.0 - 2.0
Size△	1.0 - 2.0

2. Determination of Influence Curves



With the coordinates determined, the shape of the influence coefficient curves becomes a function of desired performance. A small improvement in reliability is highly desirable so the curve will exhibit a steep slope above the minimum value of 98.5%.

Variations in weight immediately above and below the desired value of 120 lb have a severe effect on the weight influence coefficient; however, a further decrease in weight below 100 lb is of little importance and the curve levels out sharply at this point. A weight of 140 lb is the maximum which can be accepted and a quantitative cutoff is made in the curve.

An envelope of 6 ft^3 has been allotted to the system in one area of the vehicle. If it is larger than this, other equipment can be moved to provide a maximum of 8 ft^3. However, there is no advantage to a 4 ft^3 system since it would still occupy the same location. Below 4 ft^3, the system can be installed in several unused areas and there is an advantage to small-size systems. The volume curve slopes sharply from 8 ft^3 down to 6 ft^3; then, it is flat from 6 to 4 ft^3 and slopes sharply again below 4 ft^3.

3. Final Evaluation and System Selection

With the rating curves prepared, the reliabilities, weights, sizes, etc. of each system are determined using the data presented in Volume III, Report No. 2334. These values are applied to the influence coefficient charts and the resulting coefficients are tabulated as shown below.

	Base	Influence Coefficients A	B	C	Point Rating
System 1	10	3.2	1.7	1.6	87
System 2	10	1.8	1.8	1.2	39
System 3	10	3.0	1.1	1.6	53
System 4	10	2.4	1.8	1.8	78

The numerical rating of each candidate system is determined by multiplying a base value of 10.0 by the product of the influence coefficients. The system with the highest point rating is the one most suitable for the mission.

In the sample case, System 1 with a point rating of 87 would be the best system to accomplish the mission. Viewing the tabulation reveals the strong and weak points of each system. It should be noted that System 1 rated highest only under Factor A; however, Factor A was of high final rating. This might be typical of the reliability factor on a man-rated vehicle.

Use of the influence coefficient method for evaluating systems, organizes the thought behind system selection and removes evaluation from the realm of intuition. The influence coefficient curves permit a review and discussion of the factors attendent to the final selection without considering a particular pressurization system. The curves, themselves, are the result of a subjective definition of the mission which, once established, provide a valuable tool for the objective selection of the most suitable system.

IV. PRESSURIZATION SYSTEM DESIGN CRITERIA

Several propulsion system operating characteristics must be established before the preliminary design of a propellant pressurization system can be performed. The design criteria for propellant pressurization systems can be determined through calculations performed with the following items of information:

- Thrust, F
- Total impulse, I_t
- Propellant combination
- Mixture ratio, $\dot{W}_o/\dot{W}_f$ = M.R.
- Specific impulse, I_{sp}
- Combustion chamber pressure, P_c
- System operating time, T_o
- System coast time, T_c
- Vehicle environment (s)
- Thrust variation requirements

A. PROPELLANT-TANK PRESSURE

Propellant-tank pressure for a pressure-fed vehicle must equal the combustion-chamber pressure plus the drop in pressure through the propellant lines, valves, and injector.

The pressure drop across the injector must be large enough to provide sufficient fuel-oxidizer mixing for good combustion efficiency and to prevent feedback of thrust-chamber-pressure variation to the pressurization system. The necessary injector pressure drop may range from about 20 psia for H_2-O_2 propellant to 50 psia for N_2O_4 - Aerozine 50.

Total pressure drop from the propellant tank to the combustion chamber will depend on both the injector pressure drop and the length of lines, line sizes, and number of valves used in the system. Since these variables involve design choices on the part of the rocket engine designer, the total pressure drop cannot be accurately specified until the actual location of system components is considered.

B. VOLUME OF PROPELLANT EXPELLED

The total volume of propellant expelled is a function of total impulse, specific impulse, and propellant density. The volume of oxidizer and fuel expelled may be calculated using the equations below:

$$v_o = \frac{I_t}{I_{sp}\left(1 + \frac{1}{M.R.}\right)\rho_o}$$

$$v_f = \frac{I_t}{I_{sp}\,(1 + M.R.)\,\rho_f}$$

Figures IV-1 and IV-2 are plots of these equations for some common propellant combinations. The plots of the equations for v_o and v_f were made with I_{sp}, M.R., ρ_o and ρ_f constant as shown in the following chart. Propellant densities were chosen at their normal boiling points.

Oxidizer - Fuel	I_{sp}	M.R.	ρ_o (gm/cc)	ρ_f (gm/cc)
OF_2 - LH_2	411	0.5	1.90	0.07
LO_2 - LH_2	440	4.5	1.15	0.07
LF_2 - LH_2	460	11.0	1.50	0.07
N_2O_4-N_2H_4	329	1.4	1.40	0.90
N_2O_4-A-50	337	2.1	1.40	0.85
CIF_3-Hydrazoid	319	2.4	1.85	1.09

C. EXPULSION WORK

The total amount of energy which the propellant pressurization system must supply is the product of the propellant-tank pressure and the volume of propellant expelled.

$$E = P \times V$$

Ullage volume may be accounted for through addition of a percentage of the PV term.

Size and weight of propellant pressurization systems are largely a function of this parameter.

D. PRESSURANT FLOW RATE

Line sizing and valve selection are dependent upon the rate of pressurant flow. The volumetric flow rate of pressurant into the tank must equal the volumetric flow rate of propellant to the engines. Once the propellant-tank ullage pressures and temperatures have been computed the volumetric gas flow rate can be converted into a mass flow rate. This mass flow rate will be constant throughout the system, from source to delivery point, for steady-state operation.

1. Propellant Flow Rates

total weight flow rate, $\dot{W}_T = \frac{F}{I_{sp}}$

fuel flow rate, $\dot{W}_f = \frac{\dot{W}_T}{M.R. + 1}$

oxidizer flow rate, $\dot{W}_o = \frac{\dot{W}_T}{\frac{1}{M.R.} + 1}$

volumetric flow rates, $\dot{Q}_f = \frac{\dot{W}_f}{\rho_f}$; $\dot{Q}_o = \frac{\dot{W}_o}{\rho_o}$

2. Pressurant Flow Rates

Pressurant volumetric flow rate at the tank equals the propellant volumetric flow rate:

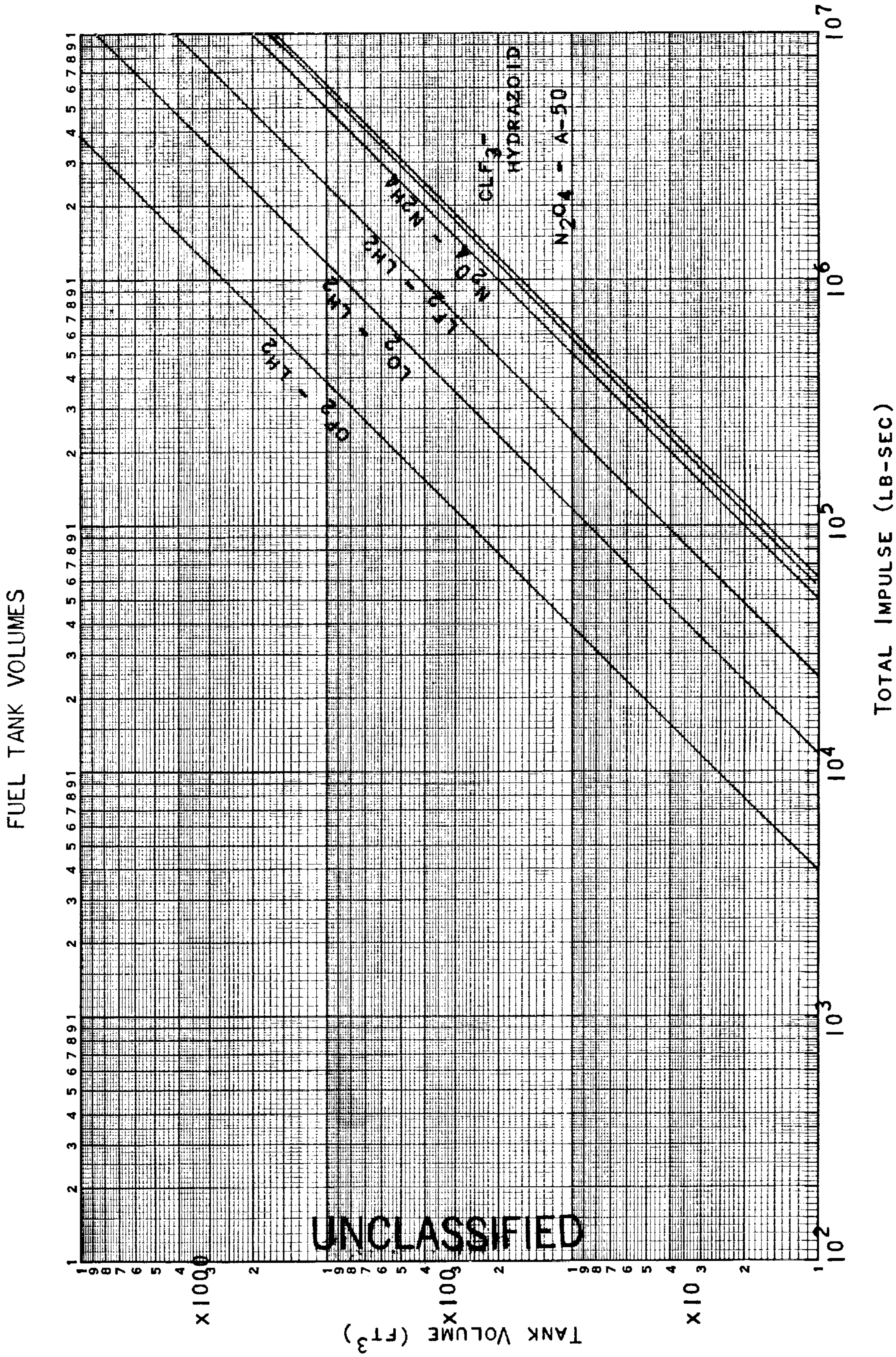
$$\dot{Q}_f = \frac{\dot{W}_f}{\rho_f} = (\dot{Q}_\rho)_f$$

$$\dot{Q}_o = \frac{\dot{W}_o}{\rho_o} = (\dot{Q}_\rho)_o$$

Pressurant mass flow rate = $Q_{propellant} \times \rho_{gas}$ at final ullage temperature and pressure.

"Properties of Pressurants," Section V,B of this volume shows densities of some of the common pressurants.

Determination of the final ullage temperature of the pressurizing gas is dependent on the type of pressurization system being evaluated, and it is covered in Volume III.



UNCLASSIFIED

 Figure IV-1

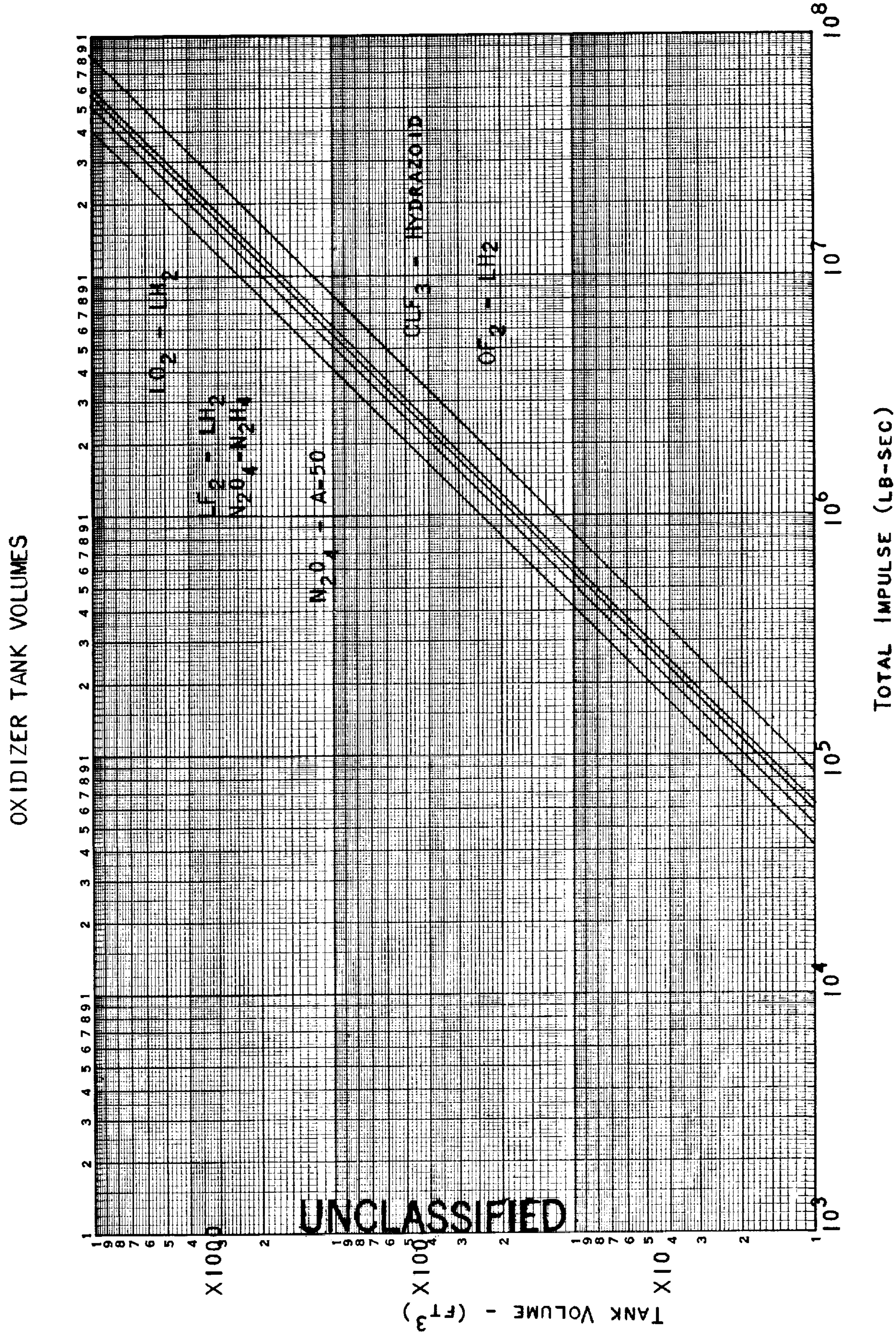

OXIDIZER TANK VOLUMES
LO2 - LH2
LF2 - LH2
N2O4 - N2H4
N2O4 - A-50
CLF3 - HYDRAZOID
OF2 - LH2
TOTAL IMPULSE (LB-SEC)
TANK VOLUME - (FT3)
X1000
X100
X10
UNCLASSIFIED

 Figure IV-2

V. GENERAL DESIGN INFORMATION

A. PROPERTIES OF PROPELLANTS

This study has covered propellant pressurization systems based upon, but not limited to, the following six propellant combinations, three cryogenic and three storable:

Cryogenic	Storable
LO_2/LH_2	ClF_3/Hydrazoid
LF_2/LH_2	N_2O_4/Aerozine-50
OF_2/LH_2	N_2O_4/N_2H_4

Knowledge of the physical properties of the above liquid propellants is necessary in evaluating pressurization systems. Such data as heat of vaporization, vapor pressure, heat of formation, and specific heats must be known for the propellants in order to evaluate the main tank injection system. Transport properties are of primary concern when designing a heat exchanger. Critical temperatures and pressures are of importance when working with cryogenic propellants.

The data shown in Figures V-1 through V-9 were obtained by various empirical and semi-empirical techniques which were used to extrapolate the existing narrow-range experimental data. This approach provides data which represents a compromise between accuracy, completeness, and simplicity. A discussion of the individual methods used and a list of the appropriate references may be found in Aerojet Report No. 8160-6S.

B. PROPERTIES OF PRESSURANTS

Pressurizing gases included in this study are divided into two general categories: (1) stored gases, and (2) products of combustion.

1. Stored Gases

The stored gases are helium, nitrogen, and hydrogen. Helium and nitrogen are particularly attractive for pressurization because of their being inert; thus, not reacting with the propellants being pressurized. Nitrogen is the more practical of the two, being easy to work with, readily available from the atmosphere, and easily stored under high pressure for long periods of time without leakage. Helium on the other hand has the advantage of being seven times lighter than nitrogen, and it is used extensively for pressurization. Hydrogen, being the lightest gas, is also attractive for pressurization. However, since it is an active gas, its use is limited to the propellants with which it will not react. Thermodynamic properties of these gases are shown in Figures V-10 through V-16.

2. Products of Combustion

a. Theoretical

(1) Bipropellant

The propellant combinations considered here can be used in a gas generator and the products of combustion can be used for pressurizing the propellant. A very low mixture ratio (oxidizer-to-fuel weight ratio) is used to generate low temperatures and low-molecular-weight pressurant gases. High mixture ratios will also generate low temperatures; however, the molecular weights become quite large. The primary use for this type of pressurization is to use the fuel-rich combustion products to pressurize the fuel tank. With proper filtration and separation, the fuel-rich gases also may be used to pressurize the oxidizer tank. Theoretical products of combustion, temperatures, etc., are shown for several propellant combinations in Table V-1.

(2) Hydrazine Monopropellant

Hydrazine monopropellant, as a gas generant, undergoes exothermic decomposition and forms ammonia, nitrogen, and hydrogen. This thermal decomposition may be represented by the following equations (Report No. JPL 20-77):

$$3\ N_2H_4 = 4\ NH_3 + N_2 + 144{,}300\ \text{Btu} \qquad (1)$$

$$4\ NH_3 = 2N_2 + 6H_2 - 79{,}200\ \text{Btu} \qquad (2)$$

Because of variations in the decomposition reaction with catalysts and temperature, it is difficult to specify the exact stoichiometry in any given system. Therefore, (1) and (2) have been combined to give the following expression, where X represents the fraction of the ammonia which is dissociated:

$$3\ N_2H_4 = 4(1-X)\ NH_3 + (1+2X)\ N_2 + 6\ H_2 + (144{,}300-79{,}200X)\ \text{Btu}$$

With this equation the following parameters were computed and their variation with X is shown in Figure V-7;

M_g = average mol wt of decomposition gases

I_{sp} = specific impulse (sec)

T_c = reaction temperature (^oF)

C^* = characteristic velocity (ft/sec)

% = mol gas composition of NH_3, H_2 and N_2

Volume III of this design guide, section titled "Liquid Propellant Gas Generators," describes the design of a N_2H_4 monopropellant gas generator.

b. Experimental

Theoretical results of 2a(1) and 2a(2) above show a large deviation from experimental results. Report No. JPL 32-212 presents the experimental data from a nitrogen tetroxide-hydrazine propellant system under both oxidizer-rich and fuel-rich conditions. The relationship of the actual performance data obtained in each region with those predicted from thermochemical performance calculations is presented in Figures V-7 and V-8.

The results of this experimental work emphasize the significance of the kinetic effects in low-temperature combustion systems, as well as the necessity for using caution in the application of thermochemical equilibrium performance calculations. In the oxidizer-rich region, experimental combustion temperatures obtained were considerably lower than predicted because of the lack of exothermic dissociation on the part of the nitrogen oxides; in the fuel-rich region, the measured temperatures were higher than predicted because of the lack of endothermic dissociation of ammonia.

Further, the test results indicate that over the mixture ratio investigated in the oxidizer-rich region, the effect of varying L^* over wide limits is of little significance in altering the resultant nature of combustion products.

c. Comparison

The conclusions drawn from the experimental data, that is, a stable gas mixture at combustion-gas temperature and characteristic exhaust velocity versus mixture ratio, closely approximate the theoretical data. For design purposes, in the fuel-rich region, the use of the experimental data developed is suggested up to a mixture ratio of approximately 0.3. Above this mixture ratio, the use of theoretical data appears to be more suitable.

C. MATERIALS

The following lists indicate materials that are compatible with the specified chemical systems. These data are a result of the extensive experience Aerojet-General has accumulated over the years in developing liquid-propellant systems. The tables are intended to provide the general background information for the eight categories of chemicals and indicate the variety of materials needed to satisfy a particular system's requirements.

As new and improved materials are continually being developed, constant attention must be given to the aspect of optimum material selection.

1. <u>Material Lists</u>

Materials that are acceptable for various functional uses with the following chemical systems:

liquid fluorine
oxygen difluoride
chlorine trifluoride

liquid oxygen
liquid hydrogen
nitrogen tetroxide
hydrazine, and
hydrazine-UDMH blends

Also presented is a list of materials which are suitable for hot-gas service and a list of materials which is suitable for space-environment electrical systems. The last two lists contain temperature operating ranges and propellant compatibility data for several expulsion bladder and bellows materials.

a. Materials for use in Liquid Fluorine, Oxygen Difluoride,* and Chlorine Trifluoride

Valve Bodies: Stainless steels 304ELC, 321, and 347; Monel; K-Monel; and aluminum alloys 356T6, M 517, 359T6, 6061, 5052, 3001 and Tens 50

Springs: Inconel, Inconel-X, Inconel-W, K-Monel; and stainless steels 304ELC, 321, and 347

Stems: Hardenable stainless steels 410, 403, and 422; K-Monel and Rene 41

Bellows: K-Monel; Monel; stainless steels 304ELC, 321, and 347; and aluminum

Bearings: Cold-worked stainless steels 301 and 301N; aluminum 6061, and hard anodize copper

Seats: Nitrided hardenable stainless steels 410, 403, 422, and 347; Monel; copper; aluminum; brass and gold-plated silver

Seals: Beryllium-copper, aluminum, brass, copper, lead, 50-50 tin indium alloy, tin and boron carbide

Packing: Copper and pure tin

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*Compatibility data for oxygen difluoride is not available. Since an unstable gas exists above its boiling point at -230°F, it is assumed the materials recommended for liquid fluorine are applicable to OF_2. OF_2 is liquid between -370°F and -230°F.

Bolts, nuts and screws:	Monel, K-Monel, stainless steels 304, 321, and 347; and Inconel-X
Thread sealants and antiseize compounds:	Unsintered Teflon and Permatex No. 2 and 3 applied to all but the first two threads of the male fitting.
Lubricants:	Molybdenum disulfide
Coatings:	Hard nickel plate, chrome plate, and anodized (aluminum)

b. Materials for Use in Liquid Oxygen and Liquid Hydrogen

Valve bodies:	Stainless steels 304, 321, 347 and 310; N-155, K-Monel, Hastalloy B, aluminum alloys 2014T6, 6061T6, 5456H-24, 5154, 5052 and 5086
Springs:	K-Monel, Inconel, Inconel-X, and stainless steels 321 and 347
Stems:	A286, Haynes No. 25, stainless steels 321 and 347; and Inconel-X
Bellows:	K-Monel, Inconel-X, and stainless steels 321 and 347
Bearings:	440C and 52100
Seats:	Teflon, Kel-F 300, aluminum 110, Monel, and stainless steels 321 and 347
Seals:	Teflon, Kel-F 300, aluminum 1100, stainless steels 321 and 347, Buna-N*, Mylar*, Lexan*, and Polyproplene*, Neoprene
Packing:	Teflon, Kel-300
Bolts, nuts and screws:	A286, Inconel-X, and stainless steels 321 and 347

*Materials so noted will not be used in contact with liquid oxygen.

Thread sealants:	LOX Safe
Lubricants:	Teflon coatings and molybdenum disulfide; halogenated oils may be used for installation only
Coatings:	Do not use except for special requirements, then use hardchrome and nickel.

c. Materials for Use in Nitrogen Tetroxide

Valve bodies:	Aluminum alloys 6061, 3003, and 2024 and stainless steels 304, 321, and 347
Springs:	Stainless steels 301, 321 and 347 and alloy steels 17-4PH, 17-7PH and 8630
Bellows:	Stainless steels 303, 321 and 347 and Inconel X
Bearings:	Stainless steels 410, 440C, 403 and cold-worked 301 and 301N
Seats:	Teflon, Kel-F 300, aluminum 1100 and stainless steels 303 and 347
Seals:	Teflon, Kel-F 300 and aluminum 1100
Packing:	Teflon, Kel-F 300 and impregnated asbestos
Bolts, nuts and screws:	Stainless steels 303, 321 and 347 and alloy steels 17-4PH and 17-7PH
Thread sealants and antiseize compounds:	Unsintered Teflon, Redel N_2O_4 thread sealant and LOX Safe
Lubricants:	Teflon coatings, carbon-graphite, and molybdenum disulfide
Coatings:	Chrome plate, rhodium undercoatings.

d. Materials for Use in Hydrazine and Hydrazine-UDMH Blends

Valve bodies:	Aluminum alloys 6061, 3003 and 2024 and stainless steels 304, 321 and 347

Springs:	Stainless steels 301, 321 and 347; alloy steels 17-4PH, 17-7PH, and A-286
Stems:	Stainless steels 321, 347, 410 and 403; and alloy steels 17-4PH, 17-7PH and 8630
Bellows:	Stainless steels 303, 321 and 347; and Inconel-X
Bearings:	Stainless steels 410, 440C, 403; and cold-worked 301 and 301-N
Seats:	Teflon; aluminum 1100; stainless steels 303 and 347; butyl rubber compounds 823-70 (Parco), B480-7 (Parker), and 9257 (Precision), and Polypropylene
Seals:	Teflon, aluminum 1100; butyl rubber compounds 823-70 (Parco), B480-7 (Parker) and 9257 (Precision); and Polypropylene
Packing:	Teflon
Bolts, nuts and screws:	Stainless steels 303, 321 and 347; and alloy steels 17-4PH and 17-7PH
Thread sealant and antiseize compounds:	Unsintered Teflon, Redel UDMH Sealant and LOX Safe (exterior use only)
Lubricants:	Teflon coatings and carbon graphite
Coatings:	Chrome plate

e. Materials for Use in Hot-Gas Service

Valve bodies:	Stainless steels 321, 347; N-155, GMR 2350, Inconel 713, Nicrotung, Haynes No. 151, DCM and Udimet 700
Springs:	Inconel-X and Inconel-W
Stems:	A-286, Waspaloy, AF 1753, Refractalloy 26, N-155 and Udimet 500

Bellows:	Inconel-X
Bearings:	440C, DBL 2, AM 350 and AM 355
Seats:	Aluminum oxide and tungsten carbide overlaid on base metal (e.g., 347 SS)
Packing:	Dynamic-static design to eliminate use of packing at 1500°F
Seals:	Carbon-graphite, mineral-filled Teflon
Bolts, nuts and screws:	A-286, Waspaloy, AF 1753, Rene 41
Thread sealants:	Fel-Pro C5a, Led-Plate
Lubricants:	Graphite
Coatings:	Do not use except for special requirements, then use thermal-sprayed refractory metals.

f. Materials for Use in Space-Environment Electrical Systems

Conductors:	Copper
Insulation:	Vacuum degassed ceramics, silicone rubber and shielded Teflon
Permanent magnets:	Alnico alloys
Electrical steels:	AISI Types M-6, M-14, M-19, M-22, M-27, M-36, M-43 and M-50
Potting:	Epoxies, silicones and polyurethanes
Structural non-magnetic materials:	Aluminum and aluminum alloys; quench-annealed stainless steels 304, 321, 347; copper; austenitic iron and nickel-base alloys
Lubricants:	Teflon coatings, molybdenum disulfide, and graphite
Terminal boards:	Phenolic-inorganic fiber laminate

Solder: Precious metal

g. Operating Temperature Ranges for Positive Expulsion Bellows and Bladders

Material	High Temperature, °F	Low Temperature, °F
Buna S	250	-60
Neoprene	300	-60
Natural rubber	250	-40
Silicone rubber	400	-120
Mylar	300	-400
Nylon	285	-40
Teflon	500	-400
Kel-F-81	400	-400
Polyethylene	200	-65
Viton A	800	-40
Stainless steel 321-347	1000	-423
Butyl	250	-65

h. Bladder Material Propellant Compatibility

Propellant	Acceptable
N_2O_4	Teflon TFE Teflon FEP Stainless steel 321-347 Mylar unsuitable
UDMH	Teflon TFE Teflon FEP
N_2H_4	Teflon Butyl rubber SBR

Propellant	Acceptable
LH_2	Mylar Teflon
ClF_3	K-Monel Monel Stainless steels 304 ELC, 321, and 347
Aerozine-50	Teflon Butyl rubber
LF_2	K-Monel Monel Stainless steels 304 ELC, 321, and 347
LO_2	Teflon Stainless steels 321 and 347

2. Metals

The Aerojet-General Structural Materials Division has furnished the following information for high-strength alloys currently used in missile applications, plus alloys that look superior for future applications.

a. Curves

(1) Yield strength vs temperature

(2) Ultimate strength vs temperature. A safety factor of (2) (ultimate strength) should be used in calculations.

(3) Yield strength/weight vs temperature

(4) Ultimate strength/weight vs temperature

b. Data

(1) Corrosion data

(2) Specific heats

(3) Compatibility data

c. Classes of Alloys

(1) Heat resistant steels

(2) Titanium

(3) Aluminum

Data collected are shown on the following curves:

The specific heats of aluminum 2014, titanium 6Al/4V, and 17-7PH stainless steel from 50 to 700°R are given in Figure V-19.

Figure V-20 is a comparison of the yield strength of titanium 6Al/4V and 17-7PH stainless steel from 100 to 800°R.

Figure V-21 through V-24 show ultimate and yield strength vs temperature (-400 to 60°F) for aluminum alloys. Also included is elongation and ductility.

Figure V-25 through V-28 show ultimate and yield strength vs temperature (-400 to 60°F) for titanium alloys. Also included is elongation and ductility.

Figure V-29 through V-32 show tensile strength density ratio vs temperature.

Figure V-33 and V-34 present a comparison of the yield strength-density ratio vs temperature (-400 to 60°F) for selected materials.

Figure V-35 shows yield strength-density ratio vs temperature (-400 to 90°F) for heat-resistant and stainless steels.

Figure V-36 through V-38 show yield strength-density ratio vs temperature (60 to 1600°F) for various alloys.

Figure V-39 shows specific heats vs temperature (0 to 1600°F) for titanium alloys and Inconel X.

D. SPACE ENVIRONMENT

A space vehicle's pressurization system will encounter a wide variety of environmental conditions during the vehicle mission. The behavior of material in outer space is effected by the presence and absence of matter, i.e., ultra-high vacuum, wide variation in radiant heat flux, and bombardment by radiation. While much information has been gained on the nature of space environment and its effects on materials, large gaps in our knowledge still remain.

Materials considered here are those to be used in space vehicle pressurization systems. They include metals, plastics, and elastomers. Not included are living material, grease, paint, oils, or ceramics.

Environmental conditions produced by the spacecraft are not included in this discussion. These include vibration and shock at launching, temperatures associated with propulsion combustion and utilization of cryogenic propellants, and other vehicle-produced environments.

1. Vacuum of Space

The degree of vacuum encountered in space is shown in Figure V-40. Gas pressure falls from approximately 3.5×10^{-9} mm Hg at 400 miles altitude to less than 10^{-12} mm Hg beyond 4000 miles. At the surface of the earth, the atmospheric pressure is 10^{3} mm Hg.

a. Loss of Inorganic Material

The rate at which material leaves a surface in a vacuum is given by the Langmuir equation

$$W = (P/17.14)\ (M/T)\ 1/2$$

where

W = rate of sublimation, gm/cm^2-sec

P = vapor pressure of material, mm Hg

M = molecular weight of material in gas phase

T = temperature, $^{\circ}K$

Results of calculations for metals of interest in this study are given in Figure V-41. It will be noted that the loss of aluminum, in inches per year, is negligible below $1000^{\circ}F$ as is the loss of ferrous materials below $1350^{\circ}F$, and of titanium below $1600^{\circ}F$.

b. Loss of Organic Materials

Organic materials being considered for use in spacecraft are long-chain compounds which go off into a vacuum by the breakdown of the compounds into smaller, more volatile fragments rather than by evaporation. The molecular weights of the fragments and the vapor pressure of the polymers are not known; therefore, the Langmuir equation cannot be used to give decomposition rates. For this reason, it is necessary to make laboratory measurements of weight loss per unit time for various materials and configurations. These measurements are made in a vacuum at controlled surface temperature conditions. To date, few polymers of practical interest have been studied under these controlled conditions. In general, loss rates appear to decrease with time when surface temperature is kept constant. Results indicate that some polymers lose less than 10% of their weight per year at temperatures of less than 200°F. More experimentation and application studies are required in this area of interest.

2. Effects of Temperature

Although the approximate temperature of gas in space is 10^3 to 10^5 °F, it has no significant effect on the temperature of a spacecraft because the concentration of molecules is extremely low. Spacecraft temperature must be determined by a heat-balance calculation. The balance is dependent upon heat received by solar radiation. Heat is also received from the earth, moon, and other solar bodies. Heat generation and dissipation within the spacecraft system is another factor of heat balance. All these sources of heat flux must be considered in determining the quantity of heat to be transferred from the vehicle.

Figure V-42 shows the values of heat flux, Btu/hr-ft^2, received by the surface of a spacecraft at altitudes of 10^2 to 10^5 miles. The curves indicate a flux of direct solar radiation of 440 Btu/hr-ft^2 up to 10^7 miles. In addition, depending upon the position of spacecraft, the curves indicate the heat flux received from other sources.

Internal heat generated and dissipated by the spacecraft is dependent upon the design, and must be calculated separately.

3. Radiation Damage in Space

Mechanical property changes are caused in plastics and metals by irradiation of high-energy particles in the space environment. Figure V-43 indicates the location of various radiation belts and further describes the radiation dosage expected by direct exposure of metals and non-metals (plastics, polymers, propellant). The Area A radiation belt of the earth starts at 300 to 700 miles depending on longitude. It extends up to approximately 12,000 miles. Area B also starts from 300 to 700 miles and extends to 24,000 miles altitude on a quiet day and to 48,000 miles on an active day. As noted on Figure V-43, Area A extends from approximately 40° North magnetic latitude to 40° South magnetic latitude and Area B extends from 60° North to 60° South magnetic latitude. The Area C not encompassed by the torus of Area B is also indicated on Figure V-43.

Radiation damage occurs through two mechanisms, ionization and atomic displacement. Ionization is the removal of electrons from the atoms of the material and is associated with the mechanism of damage to plastics and polymers. The ionization flux energy, ERG per gram-year, does its damage to a definite depth. The depth is commonly expressed in terms of grams per square centimeter through which the damage will penetrate. Atomic displacement consists of knocking atoms from their position in the crystal lattice by collision with high-energy particles. The damage of displacement is measured in terms of atoms displaced per year. Figure V-43 tabulates the expected radiation dosage in the various environments.

Table V-2 is a tabulation of the estimated life of materials in a direct radiation space environment. Results indicate a life of one year for polymers and three years for metals.

TABLE V-1

Properties of Combustion Products

LO_2/LH_2

P_c = 300

			Composition of Gases, % Mole								
MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	C_p	C*	I_{sp}
.5	958	3.02	6.30	93.70	-	-	-	-	-	5808	248.7
1.0	1821	4.03	12.60	87.40	-	-	-	-	7.6	6985	299.3
1.5	2598	5.04	18.90	81.10	-	-	-	-	8.4	7543	323.8
2.0	3292	6.05	25.20	74.79	.01	-	-	-	9.0	7819	336.8
2.5	3915	7.05	31.48	68.42	.09	-	-	-	-	7955	343.8
3.0	4448	8.05	37.67	61.89	.38	.04	-	-	10.1	8003	347.1
3.5	4919	9.01	43.61	55.12	1.05	.20	-	-	-	8014	348.3
4.0	5272	9.95	49.16	48.30	1.94	.56	.01	.02	10.9	7957	347.4
5.0	5786	11.69	58.26	35.37	3.83	2.26	.11	.17	11.4	7767	342.5
6.0	6064	13.25	64.19	24.87	4.77	4.89	.63	.65	11.7	7510	334.0
7.0	6179	14.62	67.21	17.39	4.65	7.42	1.97	1.35	11.9	7237	323.1
8.0	6203	15.77	67.63	12.58	4.08	9.35	4.29	2.07		6981	312.0
9.0	6160	16.87	67.98	9.00	3.26	10.11	7.14	2.51	11.9	6729	300.6
10.0	6107	17.76	66.58	6.89	2.66	10.59	10.47	2.81		6526	291.3
12.0	5950	19.36	63.97	4.04	1.64	10.10	17.40	2.85		6164	274.6
15.0	5661	21.29	59.76	1.87	.73	8.03	27.37	2.23		5716	253.7
16.0	5602	21.78	57.89	1.56	.61	7.58	30.26	2.11		5620	249.1
20.0	5252	23.48	52.20	.63	.21	5.06	40.63	1.27		5216	229.7

P_c = 500

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	C_p	C*	I_{sp}
.5	958	3.02	6.30	93.70	-	-	-	-	-	5809	260.9
.8	1488	3.63	10.08	89.91	-	-	-	-	7.3	-	-
1.0	1821	4.03	12.60	87.40	-	-	-	-	7.6	6985	314.1
1.5	2598	5.04	18.90	81.10	-	-	-	-	8.3	7542	340.2
2.0	3293	6.05	25.20	74.79	.01	-	-	-	9.0	7818	354.4
2.5	3919	7.05	31.49	68.44	.07	-	-	-	-	7955	362.3
3.0	4469	8.05	37.70	61.95	.31	.04	-	-	10.8	8010	366.5
3.5	4922	9.06	43.71	55.29	.82	.16	-	-	10.6	8001	367.9
4.0	5312	9.97	49.36	48.52	1.62	.48	-	.01	11.0	7967	367.9
4.5	5625	10.88	54.44	41.85	2.53	1.10	.02	.05	11.2	7893	366.7
5.0	5886	11.73	58.61	35.56	3.44	2.15	.09	.15		7809	364.7
5.25	5982	12.14	60.44	32.64	3.78	2.75	.16	.22		7753	363.2
5.3	5981	12.24	61.06	32.06	3.74	2.75	.16	.22		7723	362.4
5.5	6047	12.56	62.42	29.83	3.96	3.25	.23	.30	11.7	7678	361.0
6.0	6189	13.30	64.72	24.95	4.37	4.81	.58	.58		7566	357.4
6.5	6259	14.05	67.14	20.59	4.36	5.99	1.05	.86	11.9	7419	352.1
7.0	6315	14.68	67.85	17.32	4.28	7.43	1.88	1.24		7292	347.0
8.0	6326	15.93	69.51	11.93	3.61	9.06	4.03	1.85	12.0	7015	334.4
9.0	6284	16.98	69.23	8.56	2.89	10.02	6.99	2.30	12.0	6767	322.5
10.0	6226	17.88	67.70	6.48	2.34	10.50	10.39	2.58		6563	312.3
12.0	6054	19.47	64.89	3.72	1.41	9.99	17.45	2.59		[illegible]	293.8
15.0	5741	21.38	60.42	1.67	.60	7.78	27.55	1.98		5739	270.7
16.0	5677	21.86	58.49	1.38	.50	7.31	30.45	1.87		5641	265.5
20.0	5304	23.54	52.59	.54	.17	4.78	40.83	1.09		5228	244.0
60.0	2737	28.73	23.36	-	-	.01	76.63	-	9.3	-	149.7
80.0	2152	29.48	18.05	-	-	-	81.95	-	8.9	-	129.8
100.0	1759	29.94	14.71	-	-	-	85.29	-	8.5	-	115.5
120.0	1477	30.27	12.41	-	-	-	87.59	-	8.2	-	104.7
140.0	1264	30.50	10.73	-	-	-	89.27	-	8.0	-	-

TABLE V-1 (cont.)

Properties of Combustion Products

LO_2/LH_2

P_c = 1000

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	$C_p^{\#}$	C*	I_{sp}
			Composition of Gases, % Mole								
.5	958	3.02	6.30	93.70	-	-	-	-	-	5809	274.2
.8	1488	3.63	10.08	89.91	-	-	-	-	7.3	-	-
1.0	1821	4.03	12.60	87.40	-	-	-	-	7.6	6987	330.3
1.5	2598	5.04	18.90	81.10	-	-	-	-	8.3	7544	358.2
2.0	3293	6.05	25.20	74.79	-	-	-	-	9.0	7818	373.8
2.5	3919	7.05	31.49	68.46	.05	-	-	-	-	7955	382.8
3.0	4465	8.05	37.71	62.02	.22	.04	-	-	10.2	8007	387.8
3.5	4967	9.04	43.78	55.43	.64	.14	-	-	-	8016	390.5
4.0	5360	9.99	49.60	48.76	1.25	.37	-	.01	11.0	7975	391.0
4.5	5697	10.92	54.89	42.15	2.01	.90	.01	.03	11.3	7912	390.5
5.0	5966	11.81	59.55	35.81	2.74	1.73	.06	.09	11.6	7818	388.8
5.5	6172	12.65	63.43	29.97	3.32	2.88	.17	.22	11.8	7718	386.4
5.8	6269	13.13	65.35	26.77	3.56	3.68	.30	.33	11.9	7649	384.6
6.0	6322	13.44	66.48	24.78	3.66	4.23	.42	.42	11.9	7595	383.2
6.5	6420	14.17	68.71	20.35	3.74	5.62	.88	.69	12.1	7471	378.9
7.0	6478	14.86	70.18	16.68	3.63	6.91	1.58	1.00	12.1	7335	374.3
8.0	6502	16.08	71.36	11.33	3.08	8.85	3.78	1.60	12.2	7068	361.9
9.0	6455	17.15	71.01	7.91	2.43	9.83	6.79	2.02	12.2	6821	348.6
10.0	6388	18.03	69.28	5.91	1.93	10.32	10.29	2.27		6609	337.1
12.0	6192	19.61	66.15	3.28	1.13	9.64	17.54	2.26		6231	316.3
15.0	5844	21.49	61.29	1.42	.46	7.39	27.79	1.67		5766	290.1
16.0	5774	21.96	59.28	1.16	.37	6.90	30.72	1.56		5664	284.4
20.0	5368	23.61	53.08	.44	.12	4.39	41.10	.88		5242	260.3
62.0	2669	28.83	22.69	-	-	.01	77.30	-	9.3	3237	155.7
78.0	2202	29.42	18.47	-	-	-	81.53	-	8.9	2898	138.7
94.0	1866	29.82	15.57	-	-	-	84.43	-	8.6	2639	125.9
110.0	1611	30.12	13.46	-	-	-	86.54	-	8.4	2433	115.7

TABLE V-1 (cont.)

Properties of Combustion Products
LF_2/LH_2

P_c=300

MR	T, °R	M/W	H_2	H	HF	F_2	F	C_p	C*	I_{sp}
			Composition of Gases, % Mole							
1	1691	3.83	89.91	-	10.08	-	-	7.2	6866	293.8
3	4208	6.95	72.34	.22	27.43	-	-	8.4	8216	352.6
4	5066	8.25	63.73	1.52	34.74	-	-	8.6	8384	360.7
5	5674	9.37	54.88	4.03	41.06	-	.03	8.7	8415	364.0
6	6123	10.32	46.37	7.05	46.47	-	.10	8.7	8375	364.6
8	6781	11.89	31.53	12.83	55.15	-	.48	8.5	8247	362.1
10	7277	13.15	20.10	16.96	61.46	-	1.48	8.4	8138	358.4
12	7671	14.23	12.11	18.75	65.59	-	3.54	8.2	8052	355.1
14	7959	15.17	7.19	18.30	67.63	-	6.88	8.1	7967	352.2
16	8139	15.99	4.37	16.42	68.13	-	11.08	8.1	7865	348.7
18	8236	16.70	2.75	13.98	67.71	-	15.56	8.0	7746	344.1
19	8259	17.02	2.19	12.72	67.30	-	17.79	7.9	7685	341.5
20	8270	17.31	1.75	11.46	66.80	-	19.98	7.9	7621	338.6

P_c=500

MR	T, °R	M/W	H_2	H	HF	F_2	F	C_p	C*	I_{sp}
.5	904	2.95	94.82	-	5.17	-	-	6.9	-	-
.8	1387	3.48	91.84	-	8.14	-	-	7.1	-	-
1	1691	3.83	89.91	-	10.08	-	-	7.2	6868	308.1
3	4213	6.95	72.38	.17	27.44	-	-	8.4	8218	370.7
4	5097	8.26	63.95	1.25	34.79	-	-	8.7	3387	379.7
5	5740	9.39	55.33	3.46	41.18	-	.03	8.7	8431	384.1
6	6220	10.37	46.99	6.24	46.68	-	.09	8.7	8406	385.7
8	6923	11.96	32.32	11.71	55.50	-	.47	8.6	8292	385.0
10	7448	13.25	20.92	15.69	61.94	-	1.45	8.4	8191	382.2
12	7861	14.33	12.84	17.51	66.20	-	3.45	8.3	8109	379.3
14	8162	15.28	7.73	17.19	68.42	-	6.66	8.2	8025	376.6
16	8353	16.11	4.72	15.48	69.07	-	10.73	8.1	7928	373.5
18	8455	16.82	2.96	13.16	68.74	-	15.13	8.1	7810	369.1
19	8480	17.14	2.35	11.95	68.36	-	17.34	8.0	7748	366.3
20	8490	17.43	1.87	10.73	67.87	-	19.52	8.0	7686	363.2
40	5748	19.49	-	-	47.15	.09	52.75	6.8	-	252.2
60	3364	21.24	-	-	34.55	9.99	55.46	6.4	-	200.1
80	2951	24.46	-	-	29.96	27.18	42.86	6.9	-	177.3
100	2732	27.09	-	-	26.61	41.18	32.22	7.3	-	162.8
120	2570	29.15	-	-	23.90	52.18	23.92	7.6	-	152.1

P_c=1000

MR	T, °R	M/W	H_2	H	HF	F_2	F	C_p	C*	I_{sp}
4	5132	8.28	64.20	.95	34.85	-	-	8.7	8389	400.5
5	5820	9.43	55.87	2.77	41.33	-	.02	8.8	8451	405.9
6	6343	10.42	47.77	5.20	46.94	-	.08	8.8	8439	408.8
8	7112	12.06	33.37	10.20	55.98	-	.44	8.7	8350	410.2
10	7681	13.38	22.03	13.96	62.62	-	1.39	8.6	8260	409.1
12	8122	14.48	13.83	15.79	67.09	-	3.29	8.4	8183	407.2
14	8445	15.44	8.47	15.65	69.55	-	6.33	8.3	8106	405.0
16	8652	16.28	5.21	14.15	70.42	-	10.22	8.3	8010	402.5
18	8763	16.99	3.24	12.01	70.23	-	14.51	8.2	7895	398.8
19	8789	17.31	2.56	10.86	69.89	-	16.68	8.1	7835	396.0
20	8799	17.61	2.02	9.71	69.42	-	18.84	8.1	7773	392.2

TABLE V-1 (cont.)

Properties of Combustion Products

OF_2/LH_2

ΔH_f OF_2 = -7 kcal/mole.

P_c = 500

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	HF	F_2	F	C_p	I_{sp}
			Composition of Gases, % Mole										
.5	904	2.97	1.83	94.49	-	-	-	-	3.67	-	-	7.0	-
1	1714	3.89	3.60	89.19	-	-	-	-	7.20	-	-	7.3	308.4
2	3114	5.63	6.95	79.14	-	-	-	-	13.90	-	-	8.2	351.6
3	4253	7.24	10.05	69.61	.19	.01	-	-	20.12	-	-	8.9	368.2
4	5130	8.71	12.83	59.98	1.30	.08	-	-	25.80	-	-	9.3	375.4
6	6208	11.12	16.59	41.23	5.80	.95	.01	.09	35.25	-	.07	9.5	377.7
8	6780	12.99	17.46	26.79	9.23	2.94	.16	.66	42.45	-	.30	9.4	372.7
10	7088	14.45	16.10	17.42	10.25	5.04	.65	1.89	47.95	-	.69	9.3	364.8
12	7255	15.61	13.72	11.60	9.84	6.46	1.52	3.46	52.19	-	1.19	9.1	355.9
14	7350	16.57	11.15	7.88	[illegible]	7.13	2.65	5.04	55.49	-	1.77	9.0	347.7
16	7406	17.36	8.75	5.39	7.73	7.22	3.91	6.48	58.09	-	2.44	8.8	340.4
18	7440	18.04	6.64	3.67	6.58	6.90	5.19	7.73	60.09	-	3.21	8.7	334.3
20	7457	18.62	4.86	2.45	5.46	6.30	6.46	8.76	61.58	-	4.12	8.6	329.2
40	6321	21.69	.01	-	.03	.17	17.60	3.81	52.25	.01	26.10	7.8	263.1
60	3840	22.28	-	-	-	-	20.29	.01	36.24	1.48	41.98	7.1	203.1
80	3027	24.67	-	-	-	-	22.57	-	30.22	12.83	34.38	7.2	177.4
100	2726	27.09	-	-	-	-	24.84	-	26.61	24.19	24.36	7.6	161.5
120	2518	28.99	-	-	-	-	26.62	-	23.77	33.12	16.48	7.9	149.5

P_c = 1000

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	HF	F_2	F	C_p	I_{sp}
5	5827	10.04	15.19	50.83	2.68	.29	-	.01	30.97	-	.02	9.5	399.9
7	6692	12.21	17.81	34.03	6.64	1.68	.04	.22	39.42	-	.15	9.6	400.3
9	7165	13.91	17.73	22.01	8.74	3.87	.30	.99	45.87	-	.49	9.6	395.8
12	7495	15.81	14.67	11.67	8.66	6.48	1.42	3.03	52.80	-	1.25	9.3	384.2
12.5	7525	16.07	14.02	10.55	8.46	6.75	1.69	3.41	53.72	-	1.39	9.3	381.9
13	7552	16.32	13.37	9.55	8.24	6.96	1.97	3.78	54.58	-	1.54	9.3	379.8
13.5	7574	16.55	12.72	8.65	8.00	7.13	2.27	4.15	55.38	-	1.70	9.2	377.5
14	7593	16.78	12.07	7.84	7.74	7.26	2.58	4.50	56.14	-	1.86	9.2	375.2

ΔH_f OF_2 = -12 kcal/mole.

P_c = 500

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	HF	F_2	F	C_p	I_{sp}
.5	881	2.97	1.83	94.49	-	-	-	-	3.67	-	-	7.0	-
1	1669	3.89	3.60	89.19	-	-	-	-	7.20	-	-	7.3	304.2
2	3041	5.63	6.95	79.14	-	-	-	-	13.90	-	-	8.2	347.2
3	4156	7.25	10.05	69.65	.15	.01	-	-	20.13	-	-	8.8	363.4
4	5032	8.72	12.86	60.16	1.08	.06	-	-	25.84	-	-	9.2	370.8
6	6125	11.17	16.79	41.60	5.23	.84	.01	.07	35.39	-	.06	9.5	373.4
8	6711	13.06	17.93	27.03	8.59	2.73	.14	.56	42.74	-	.26	9.5	369.0
10	7026	14.55	16.73	17.46	9.64	4.84	.61	1.71	48.37	-	.63	9.4	361.5
12	7191	15.74	14.42	11.52	9.23	6.31	1.49	3.20	52.73	-	1.10	9.2	352.9
14	7281	16.71	11.81	7.75	8.25	7.02	2.67	4.71	56.14	-	1.64	9.0	344.5
16	7331	17.52	9.32	5.26	7.12	7.14	4.00	6.08	58.84	-	2.24	8.9	337.1
18	7358	18.21	7.09	3.55	6.00	6.83	5.39	7.25	60.95	-	2.94	8.8	331.0
20	7370	18.80	5.20	2.35	4.93	6.23	6.76	8.21	62.54	-	3.77	8.7	325.6
40	6058	21.83	.01	-	.01	.10	18.34	2.66	52.70	.02	26.16	7.9	254.6
60	3499	22.68	-	-	-	-	20.65	-	36.88	3.28	39.18	7.1	194.9
80	2850	25.68	-	-	-	-	23.49	-	31.46	17.45	27.60	7.4	169.3
100	2541	28.28	-	-	-	-	25.93	-	27.78	29.66	16.62	7.8	151.9
120	2282	30.25	-	-	-	-	27.78	-	24.80	38.90	8.52	8.1	137.0

TABLE V-1 (cont.)

Properties of Combustion Products

OF_2/LH_2

P_c = 1000

Composition of Gases, % Mole

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	HF	F_2	F	C_p	I_{sp}
5	5725	10.06	15.28	51.10	2.31	.24	-	.01	31.04	-	.01	9.5	394.9
7	6590	12.39	18.13	34.34	6.04	1.50	.03	.17	39.63	-	.13	9.6	395.7
9	7092	14.00	18.29	22.12	8.16	3.64	.27	.88	46.22	-	.44	9.6	391.8
12	7424	15.94	15.38	11.56	8.09	6.31	1.38	2.79	53.34	-	1.15	9.4	380.8
12.5	7454	16.20	14.73	10.42	7.89	6.58	1.66	3.15	54.28	-	1.28	9.4	378.6
13	7479	16.45	14.07	9.40	7.66	6.81	1.95	3.50	55.17	-	1.42	9.3	376.2
13.5	7500	16.69	13.41	8.49	7.42	6.99	2.27	3.85	56.00	-	1.56	9.3	373.9
14	7518	16.92	12.74	7.67	7.17	7.13	2.59	4.19	56.79	-	1.71	9.2	371.8

TABLE V-1 (cont.)

Properties of Combustion Products

N_2O_4/Aerozine-50

Composition of Gases, % Mole

$P_c = 300$

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	NH_3	NO	N_2	CO	CO_2	C/S	CH_4	C_p-F	C_p-G	C*	I_{sp}
0	2007	12.62	-	48.74	-	-	-	-	.12	-	30.14	-	-	4.78	16.24	9.2	9.4	4222	184.2
[illegible]	2078	12.53	.97	[illegible]	-	-	-	-	.10	-	28.99	2.05	.03	5.17	12.41	8.9	8.6	4307	189.7
.08	2099	12.54	1.15	50.69	-	-	-	-	.09	-	28.74	2.79	.05	5.03	11.45	8.8	8.5	4331	191.0
.10	2121	12.56	1.28	51.12	-	-	-	-	.09	-	28.51	3.56	.07	4.82	10.56	8.8	8.5	4353	192.1
.20	2223	12.82	1.45	52.87	-	-	-	-	.07	-	27.84	7.57	.13	2.85	7.22	8.5	8.6	4443	196.4
1.0	4513	17.22	21.75	33.59	.33	.04	-	-	-	-	29.96	13.01	1.31	-	-	9.7	9.7	5488	237.8
1.4	5402	19.70	32.74	19.02	1.53	.79	.03	.05	-	.12	32.06	11.12	2.54	-	-	10.4	10.4	5715	249.2
1.8	5781	21.62	38.02	9.38	1.96	2.82	.63	.41	-	.71	33.22	8.49	4.35	-	-	10.8	10.8	5722	252.7
2.2	5815	23.01	38.66	4.84	1.48	4.25	2.74	.91	-	1.51	33.64	5.97	6.00	-	-	11.0	11.0	5582	248.6
2.6	5720	24.06	37.58	2.73	.97	4.59	5.95	1.15	-	2.11	33.81	4.04	7.08	-	-	11.0	11.0	5413	240.8

$P_c = 500$

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	NH_3	NO	N_2	CO	CO_2	C/S	CH_4	C_p-F	C_p-G	C*	I_{sp}
.10	2192	12.96	1.36	49.52	-	-	-	-	.11	-	29.40	3.62	.07	3.46	12.46	9.1	8.9	-	205.4
.30	2383	13.37	1.77	53.12	-	-	-	-	.07	-	27.92	11.25	.20	-	5.67	8.6	8.6	-	213.9
.50	2721	13.65	4.42	53.72	-	-	-	-	.04	-	26.69	14.46	.45	-	.23	8.2	8.2	-	221.3
.70	3516	15.09	11.46	45.76	.01	-	-	-	.01	-	27.98	13.98	.79	-	-	8.9	8.9	-	233.5
1.0	4528	17.23	21.74	33.65	.26	.03	-	-	-	-	29.97	12.99	1.34	-	-	9.7	9.7	5489	251.0
1.4	5446	19.74	32.98	19.08	1.28	.68	.02	.03	-	.01	32.14	11.15	2.54	-	-	10.4	10.4	5721	263.9
1.8	5867	[illegible]	[illegible]	9.22	1.71	2.62	.54	.34	-	.68	33.37	8.46	4.44	-	-	10.9	10.9	5744	268.8
2.0	5923	22.48	39.34	6.43	1.56	3.52	1.34	.58	-	1.11	33.65	7.03	5.44	-	-	[illegible]	11.0	-	268.7
2.2	5911	23.12	39.30	4.66	1.29	4.10	2.57	.80	-	1.55	33.79	5.82	6.20	-	-	11.0	11.0	5610	266.1
2.6	5808	24.16	38.13	2.52	.82	4.44	5.79	1.02	-	2.19	33.92	3.84	7.33	-	-	11.1	11.1	5437	257.4
4.0	5226	26.35	32.14	.41	.13	2.73	18.34	.62	-	2.68	34.18	.74	8.03	-	-	10.8	10.8	-	228.2
6.0	4378	27.72	25.13	.03	.01	.73	31.25	.11	-	1.70	34.45	.05	6.54	-	-	10.3	10.3	-	198.5
8.0	3696	28.38	20.25	-	-	.15	38.96	.01	-	.83	34.54	-	5.24	-	-	9.9	9.9	-	177.6
10.0	3186	28.78	16.86	-	-	.03	43.88	-	-	.38	34.50	-	4.35	-	-	9.5	9.5	-	162.2
12.0	2794	29.06	14.41	-	-	.01	47.29	-	-	.16	34.41	-	3.72	-	-	9.2	9.2	-	150.1
15.0	2361	29.35	11.83	-	-	-	50.81	-	-	.05	34.26	-	3.05	-	-	8.9	8.9	-	136.3
20.0	1871	29.65	9.14	-	-	-	54.48	-	-	.01	34.06	-	2.35	-	-	8.4	8.4	-	119.6
25.0	1545	29.84	7.40	-	-	-	56.76	-	-	-	33.93	-	1.91	-	-	8.1	8.1	-	-
30.0	1320	29.97	6.23	-	-	-	58.32	-	-	-	33.84	-	1.61	-	-	7.9	7.9	-	-
35.0	1146	30.07	5.39	-	-	-	59.46	-	-	-	33.77	-	1.39	-	-	7.7	7.7	-	-
40.0	1016	30.14	4.74	-	-	-	60.32	-	-	-	33.72	-	1.22	-	-	7.6	7.6	-	-

$P_c = 1000$

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	NH_3	NO	N_2	CO	CO_2	C/S	CH_4	C_p-F	C_p-G	C*	I_{sp}
0	2163	13.63	-	44.59	-	-	-	-	.22	-	32.50	-	-	1.19	21.49	10.1	10.1	4282	207.1
.10	2284	13.50	1.48	47.34	-	-	-	-	.18	-	30.59	3.72	.07	1.61	15.01	9.5	9.6	4438	220.5
.20	2386	13.68	1.83	49.38	-	-	-	-	.15	-	29.67	7.78	.15	-	11.04	9.2	9.2	4527	226.5

TABLE V-1 (cont.)

Properties of Combustion Products

P_c=1000 (cont.) N_2O_4 / AEROZINE-50 **Composition of Gases, % Mole**

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	NH_3	NO	N_2	CO	CO_2	C/S	CH_4	C_p-T	C_p-G	C*	I_{sp}
1.0	4529	17.24	21.79	33.67	.19	.02	-	-	.01	-	29.98	13.03	1.31	-	-	9.7	9.7	5488	265.9
1.2	5083	18.56	27.95	26.10	.55	.15	-	-	-	.02	31.18	12.19	1.85	-	-	-	-	5639	274.5
1.4	5498	19.79	33.26	19.15	.99	.54	.01	.02	-	.08	32.23	11.18	2.54	-	-	10.5	10.5	5728	280.4
1.6	5818	20.87	36.99	13.40	1.35	1.38	.10	.10	-	.29	33.02	9.85	3.51	-	-	-	-	5782	284.8
1.8	5979	21.83	39.40	9.00	1.40	2.34	.42	.25	-	.64	33.58	8.41	4.56	-	-	11.0	11.0	5771	287.1
2.0	6054	22.59	40.00	6.23	1.29	3.35	1.18	.48	-	1.12	33.82	6.92	5.61	-	-	-	-	5729	288.3
2.2	6039	23.70	40.18	4.25	1.05	3.87	2.33	.66	-	1.58	33.99	5.59	6.51	-	-	11.1	11.1	5645	286.6
2.4	6003	23.80	39.44	3.14	.85	4.25	3.87	.80	-	1.98	34.01	4.49	7.16	-	-	-	-	5566	282.1
2.6	5925	24.31	38.87	2.23	.65	4.22	5.57	.85	-	2.30	34.07	3.54	7.69	-	-	11.2	11.2	5469	276.4
2.8	5854	24.70	37.83	1.72	.51	4.21	7.43	.88	-	2.52	34.07	2.83	7.99	-	-	-	-	5386	271.2

TABLE V-1 (cont.)

Properties of Combustion Products

N_2O_4 / .5 N_2H_4 + .4825 UDMH + .0175 H_2O

Composition of Gases, % Mole

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	NH_3	NO	N_2	CO	CO_2	C/S	CH_4	C_p-T	C_p-G	C*	I_{sp}
P_c = 300																			
.025	2006	12.95	1.08	48.39	-	-	-	-	.12	-	30.13	1.46	.03	3.01	15.78	9.2	9.1	4217	184.9
.050	2035	12.90	1.42	49.10	-	-	-	-	.11	-	29.65	2.33	.06	3.18	14.16	9.1	8.9	4251	187.3
.085	2073	12.89	1.72	49.99	-	-	-	-	.10	-	29.12	3.63	.10	3.09	12.26	8.9	8.8	4295	189.4
.100	2089	12.90	1.80	50.34	-	-	-	-	.09	-	28.94	4.21	.12	2.95	11.55	8.9	8.7	4313	190.3
1.60	5651	20.89	37.27	12.52	1.86	1.86	.22	.20	-	.38	32.79	9.33	3.56	-	-	10.7	10.7	5730	251.4
1.70	5723	21.34	38.26	10.41	1.90	2.41	.43	.31	-	.56	33.03	8.64	4.04	-	-	10.8	10.8	5722	251.9
1.80	5769	21.76	38.91	8.67	1.85	2.93	.74	.44	-	.76	33.22	7.95	4.52	-	-	10.9	10.9	5703	252.0
1.87	5787	22.03	39.19	7.65	1.79	3.25	1.03	.53	-	.91	33.32	7.48	4.84	-	-	10.9	10.9	5681	251.8
2.01	5802	22.53	39.40	6.02	1.62	3.79	1.77	.72	-	1.20	33.47	6.58	5.43	-	-	11.0	11.0	5633	250.6
2.10	5797	22.83	39.38	5.19	1.50	4.04	2.34	.82	-	1.38	33.54	6.04	5.78	-	-	11.0	11.0	5597	249.1
2.20	5784	23.13	39.22	4.43	1.36	4.25	3.05	.91	-	1.56	33.60	5.48	6.12	-	-	11.0	11.0	5555	247.3
2.30	5765	23.41	38.99	3.81	1.22	4.40	3.82	.99	-	1.73	33.65	4.96	6.43	-	-	11.0	11.0	5512	245.3
P_c = 500																			
1.60	5722	20.96	37.72	12.46	1.60	1.68	.17	.15	-	.36	32.92	9.34	3.60	-	-	10.8	10.8	5745	266.8
1.70	5802	21.43	38.82	10.28	1.64	2.21	.35	.25	-	.53	33.18	8.63	4.11	-	-	10.9	10.9	5742	267.7
1.80	5856	21.85	39.51	8.49	1.61	2.74	.64	.36	-	.74	33.37	7.91	4.61	-	-	10.9	10.9	5725	268.3
1.87	5878	22.13	39.82	7.44	1.56	3.07	.90	.45	-	.90	33.48	7.41	4.96	-	-	11.0	11.0	5706	268.3
2.01	5895	22.64	40.06	5.78	1.41	3.62	1.61	.62	-	1.21	33.63	6.47	5.60	-	-	11.0	11.0	5659	267.7
2.10	5892	22.93	40.02	4.94	1.30	3.89	2.17	.71	-	1.40	33.69	5.90	5.97	-	-	11.1	11.1	5623	266.6
2.20	5878	23.24	39.87	4.18	1.17	4.10	2.87	.80	-	1.60	33.75	5.32	6.34	-	-	11.1	11.1	5582	264.7
2.30	5857	23.52	39.61	3.56	1.05	4.25	3.65	.87	-	1.79	33.79	4.78	6.66	-	-	11.1	11.1	5538	262.5
P_c = 1000																			
.085	2235	13.80	2.05	46.20	-	-	-	-	.18	-	31.15	3.68	.10	-	16.64	9.7	9.7	-	-
1.60	5807	21.05	38.32	12.37	1.28	1.42	.12	.10	-	.31	33.08	9.34	3.65	-	-	10.8	10.8	5761	284.2
1.70	5903	21.54	39.57	10.08	1.33	1.94	.26	.18	-	.49	33.34	8.60	4.21	-	-	10.9	10.9	5765	285.6
1.80	5968	21.97	40.33	8.24	1.32	2.46	.50	.27	-	.70	33.58	7.84	4.75	-	-	11.0	11.0	5753	286.6
1.87	5997	22.26	40.67	7.15	1.28	2.80	.74	.35	-	.87	33.69	7.31	5.14	-	-	11.1	11.1	5738	287.1
2.01	6021	22.78	40.95	5.44	1.15	3.37	1.39	.49	-	1.21	33.84	6.30	5.85	-	-	11.1	11.1	5695	287.2
2.10	6021	23.09	40.93	4.59	1.07	3.65	1.93	.58	-	1.41	33.88	5.64	6.31	-	-	11.1	11.1	5659	286.7
2.20	6004	23.38	40.73	3.84	.95	3.88	2.63	.66	-	1.65	33.94	5.08	6.65	-	-	11.2	11.2	5617	285.1
2.30	5980	23.66	40.44	3.23	.84	4.02	3.40	.72	-	1.85	33.97	4.52	6.99	-	-	11.2	11.2	5572	282.6

TABLE V-1 (cont.)

Properties of Combustion Products

N_2O_4 / N_2H_4

P_c = 300

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	NH_3	NO	N_2	C_p	C*	I_{sp}
			Composition of Gases, % Mole											
.20	2678	12.53	9.08	56.05	-	-	-	-	.03	-	34.84	-	4853	208.3
.40	3602	14.29	17.75	45.93	.02	-	-	-	.01	-	36.29	-	5326	229.7

P_c = 500

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	NH_3	NO	N_2	C_p	C*	I_{sp}
.20	2678	12.53	9.08	56.03	-	-	-	-	.05	-	34.84	-	4854	219.0
.40	3603	14.29	17.75	45.93	.02	-	-	-	.01	-	36.29	-	5327	241.8
1.20	5697	20.11	44.35	10.96	1.44	2.05	.30	.19	-	.50	40.20	-	5860	272.6
1.28	5745	20.53	45.40	8.81	1.39	2.57	.57	.29	-	.71	40.26	-	5838	272.9
3.00	4816	24.80	37.62	.20	.04	1.70	19.57	.26	-	2.12	38.49	-	4807	221.9
4.00	4250	25.88	31.95	.03	-	.63	27.94	.07	-	1.47	37.91	-	4382	201.3
5.00	3782	26.60	27.55	-	-	.22	33.83	.02	-	.91	37.47	-	4054	185.4
6.00	3398	27.12	24.14	-	-	.07	38.16	-	-	.53	37.09	-	3786	172.8
8.00	2816	27.84	19.30	-	-	.01	44.05	-	-	.17	36.46	-	3382	153.8
10.00	2403	28.32	16.06	-	-	-	47.90	-	-	.05	35.98	-	3084	139.8
12.00	2095	28.66	13.76	-	-	-	50.61	-	-	.02	35.62	8.6	-	129.1
14.00	1857	28.91	12.03	-	-	-	52.63	-	-	.01	35.34	8.4	-	120.4
16.00	1667	29.11	10.68	-	-	-	54.20	-	-	-	35.11	8.2	-	113.2
20.00	1381	29.39	8.73	-	-	-	56.48	-	-	-	34.79	7.9	-	-
25.00	1134	29.63	7.11	-	-	-	58.37	-	-	-	34.52	7.6	-	-
30.00	959	29.79	6.00	-	-	-	59.67	-	-	-	34.33	7.4	-	-
35.00	829	29.91	5.19	-	-	-	60.62	-	-	-	34.20	7.3	-	-
40.00	727	30.00	4.57	-	-	-	61.34	-	-	-	34.09	7.2	-	-

P_c = 1000

MR	T, °R	M/W	H_2O	H_2	H	OH	O_2	O	NH_3	NO	N_2	C_p	C*	I_{sp}
.05	1887	11.24	2.33	63.28	-	-	-	-	.81	-	33.59	7.6	-	207.1
.10	2157	11.66	4.61	61.01	-	-	-	-	.34	-	34.04	7.8	-	215.4
.20	2680	12.54	9.09	55.98	-	-	-	-	.10	-	34.83	-	4588	231.1
.40	3604	14.29	17.75	45.92	.01	-	-	-	.02	-	36.29	-	5326	255.2

TABLE V-1 (cont.)

Properties of Combustion Products

ClF_3 / HYDRAZOID

P_o = 300

									Composition of Gases, % Mole			
MR	T, °R	M/W	H_2O	H_2	H	OH	O	HF	F_2	F	HCl	Cl_2
1.6	5942	21.35	.06	13.91	3.02	-	-	42.52	-	.11	12.39	-
2.0	6333	22.58	.04	7.18	3.64	.01	-	48.46	-	.39	12.15	.01
2.4	6567	23.54	.02	2.92	3.08	.01	.01	52.89	-	1.03	10.55	.02
2.8	6605	24.24	[illegible]	.75	1.63	.01	.01	55.66	-	2.30	7.88	.04
3.2	6305	24.58	-	.06	.33	-	.01	56.26	-	4.52	4.48	.12

P_o = 500

MR	T, °R	M/W	H_2O	H_2	H	OH	O	HF	F_2	F	HCl	Cl_2
0	2166	13.43	6.05	51.07	-	-	-	-	-	-	-	-
.1	2327	13.64	3.28	51.78	-	-	-	4.02	-	-	1.34	-
.2	2545	13.96	1.44	51.35	-	-	-	7.55	-	-	2.52	-
.3	2839	14.48	.55	49.45	-	-	-	10.85	-	-	3.62	-
.5	3543	15.81	.12	43.46	.01	-	-	17.10	-	-	5.70	-
.8	4485	17.71	[illegible]	34.24	.24	-	-	25.54	-	-	8.47	-
1.0	4992	18.82	.07	28.52	.68	-	-	30.53	-	-	10.01	-
1.6	6017	21.42	.06	14.04	2.61	[illegible]	-	42.67	-	.10	12.67	-
2.[illegible]	6435	22.68	.04	7.23	3.21	.01	-	48.68	-	.37	12.61	.01
2.4	6680	23.65	.03	2.86	2.68	.01	[illegible]	53.19	-	.01	11.11	.02
2.8	6704	24.34	[illegible]	.67	1.34	.01	.01	55.94	-	2.25	8.33	.06
3.2	6347	24.63	-	.05	.23	-	.01	56.40	-	4.49	4.60	.19
4.0	5039	24.93	-	-	-	-	-	51.69	.01	19.00	.45	2.17
6.0	3216	27.89	-	-	-	-	-	41.67	4.11	27.69	-	12.04
8.0	2543	32.49	-	-	-	-	-	37.75	20.94	14.07	-	15.51
10.0	2001	36.11	-	-	-	-	-	34.33	34.76	2.67	-	17.75
12.0	1987	37.80	-	-	-	-	-	30.41	41.38	.06	-	18.87

P_o = 1000

MR	T, °R	M/W	H_2O	H_2	H	OH	O	HF	F_2	F	HCl	Cl_2
1.6	6110	21.51	.06	14.20	2.11	-	-	42.86	-	.09	13.01	-
2.[illegible]	6566	22.81	.04	7.27	2.66	.01	-	49.01	-	.33	13.21	.01
2.2	6724	23.34	.04	4.71	2.56	.01	-	51.51	-	.57	12.74	.02
2.4	68[illegible]	23.81	.03	2.75	2.20	.01	.01	53.59	-	.94	11.86	.03
2.6	6871	24.18	.02	1.39	1.63	.01	.01	55.22	-	1.46	10.58	.06
2.8	6826	24.46	.01	.55	.98	.01	.01	56.31	-	2.18	8.90	.09
3.0	6668	24.63	-	.16	.44	.01	.01	56.78	-	3.16	6.86	.17
3.2	6398	24.69	-	.03	.14	-	.01	56.59	-	4.47	4.71	.34

TABLE V-1 (cont.)

Properties of Combustion Products

ClF_3 / HYDRAZOID

P_c = 300

Composition of Gases, % Mole (cont.)

MR	Cl	NH_3	NO	N_2	CO	CO_2	C/S	CH_4	C_p-T	C_p-G	C*	I_{sp}
1.6	1.81	-	-	18.11	8.07	-	-	-	8.7	8.7	5712	247.8
2.0	4.11	-	-	16.60	7.39	.01	-	-	8.6	8.6	5760	251.3
2.4	7.39	-	-	15.27	6.80	.01	-	-	8.5	8.5	5756	252.2
2.8	11.35	-	.01	14.06	6.26	.01	-	-	8.4	8.4	5672	245.6
3.2	15.53	-	.01	12.90	5.74	.02	-	-	8.1	8.1	5420	235.4

P_c = 500

MR	Cl	NH_3	NO	N_2	CO	CO_2	C/S	CH_4	C_p-T	C_p-G	C*	I_{sp}
0	-	.12	-	29.56	6.22	.52	-	6.46	8.6	8.6	-	204.6
.1	-	.08	-	27.30	8.40	.30	-	3.48	8.3	8.3	-	208.9
.2	-	.05	-	25.64	9.84	.12	-	1.47	8.1	8.1	-	213.2
.3	-	.03	-	24.56	10.42	.04	-	.50	8.1	8.1	-	217.5
.5	-	.01	-	23.24	10.30	.01	-	.05	8.3	8.3	-	227.5
.8	.04	-	-	21.70	9.67	-	-	-	8.6	8.6	-	241.5
1.0	.17	-	-	20.75	9.25	-	-	-	8.7	8.7	-	248.8
1.6	1.58	-	-	18.17	8.[illegible]	-	-	-	8.7	8.7	5726	261.7
2.0	3.73	-	-	16.67	7.43	.01	-	-	8.7	8.7	5782	266.2
2.4	6.91	-	-	15.34	6.83	.01	-	-	8.6	8.6	5782	267.8
2.8	10.95	-	.01	14.12	6.28	.01	-	-	8.4	8.4	5689	259.9
3.2	15.32	-	.01	12.93	5.74	.02	-	-	8.1	8.1	5424	249.7
4.0	16.77	-	-	11.00	4.86	.04	-	-	7.6	7.6	-	221.9
6.0	1.78	-	-	8.79	3.89	.03	-	-	7.3	7.3	-	170.4
8.0	.22	-	-	7.96	3.52	.03	-	-	7.8	7.8	-	141.3
10.0	.01	-	-	7.24	2.85	.20	.18	-	8.1	8.1	-	116.3
12.0	-	-	-	6.41	.12	1.38	1.36	-	8.1	8.0	-	90.7

P_c = 1000

MR	Cl	NH_3	NO	N_2	CO	CO_2	C/S	CH_4	C_p-T	C_p-G	C*	I_{sp}
1.6	1.29	-	-	18.24	8.13	-	-	-	8.8	8.8	5741	277.1
2.0	3.21	-	-	16.77	7.47	.01	-	-	8.7	8.7	5809	282.5
2.2	4.58	-	-	16.09	7.16	.01	-	-	8.7	8.7	-	284.3
2.4	6.25	-	-	15.44	6.88	.01	-	-	8.6	8.6	5815	285.2
2.6	8.20	-	.01	14.81	6.59	.01	-	-	8.6	8.6	-	281.3
2.8	10.41	-	.01	14.19	6.32	.01	-	-	8.5	8.5	5705	276.5
3.0	12.78	-	.01	13.57	6.03	.02	-	-	8.3	8.3	-	271.6
3.2	14.97	-	.01	12.96	5.75	.03	-	-	8.2	8.2	5433	266.7

TABLE V-1 (cont.)

Properties of Combustion Products

N_2H_4 MONOPROPELLANT

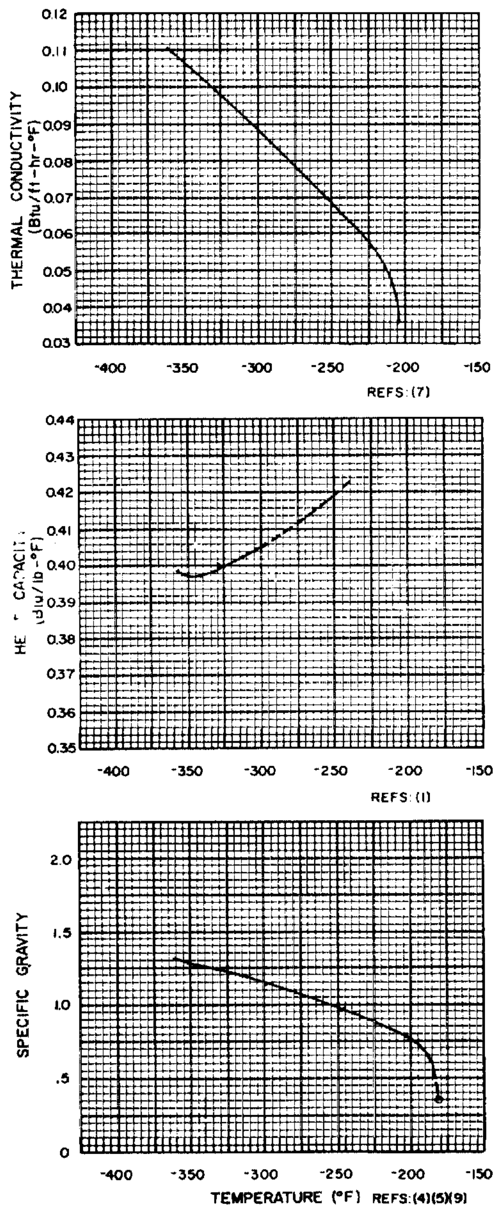
MR = .000

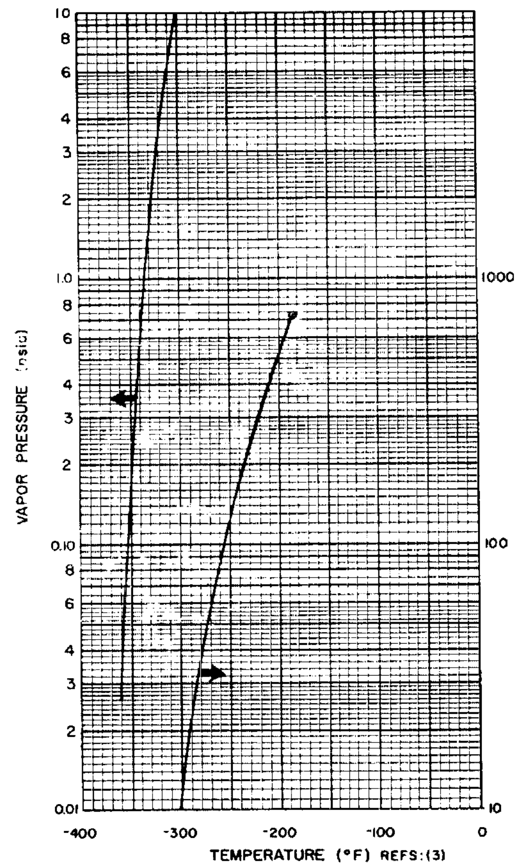
P_c	T, R	M/W	H_2	NH_3	N_2	C_p	C*	I_{sp}
			Composition of Gases, % Mole					
200	1573	10.75	66.15	.62	33.23	8.4	3985	164.4
300	1582	10.78	65.93	.88	33.19	8.1	3998	174.0
500	1597	10.83	65.53	1.36	33.11	8.4	4017	185.0
700	1610	10.87	65.18	1.78	33.04	8.7	4032	191.7
750	1613	10.88	65.10	1.87	33.02	9.4	4035	192.9
1000	1631	10.94	64.66	2.41	32.93	7.5	-	198.7

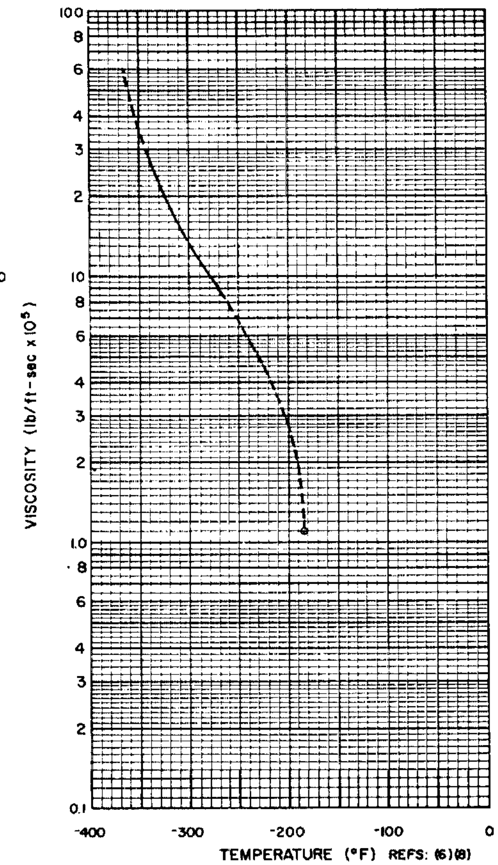
TABLE V-2

ESTIMATED LIFE OF MATERIALS IN
SPACE RADIATION ENVIRONMENT

Materials	Radiation Dosage: ERG/gram-yr through 1 gram/cm^2 — Expected Dosage by Direct Exposure	Required to Produce Appreciable Change to Engineering Properties	Estimated Life (Years)
Polymers	$10^6 - 10^8$	$10^6 - 10^7$	1
Metals	$10^{-13} - 10^{-9}$	$10^{-4} - 10^{-3}$	3





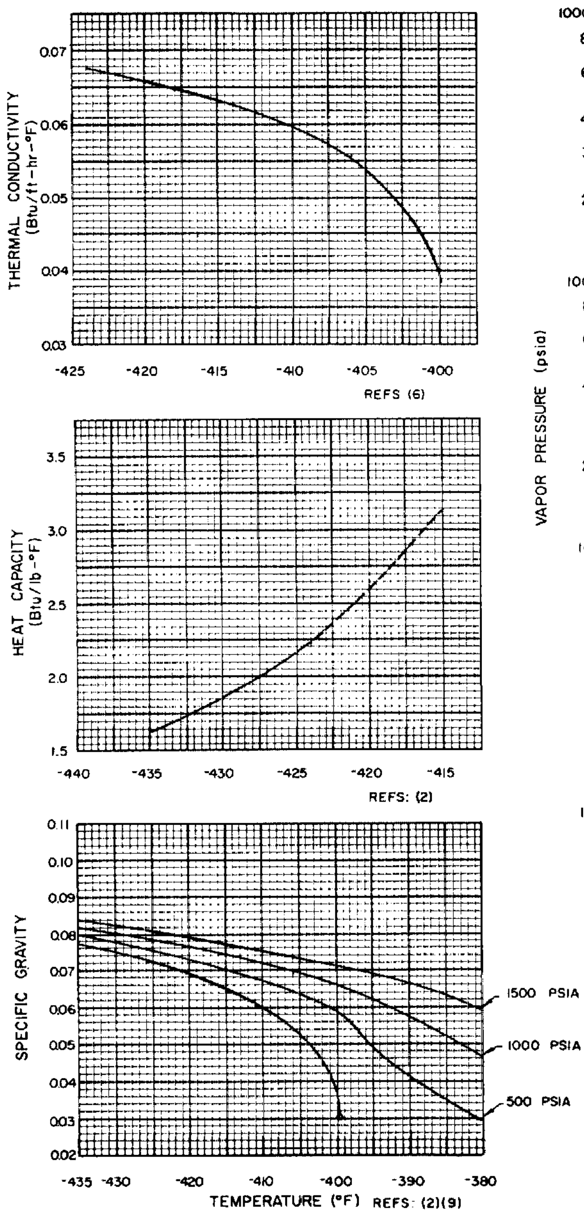


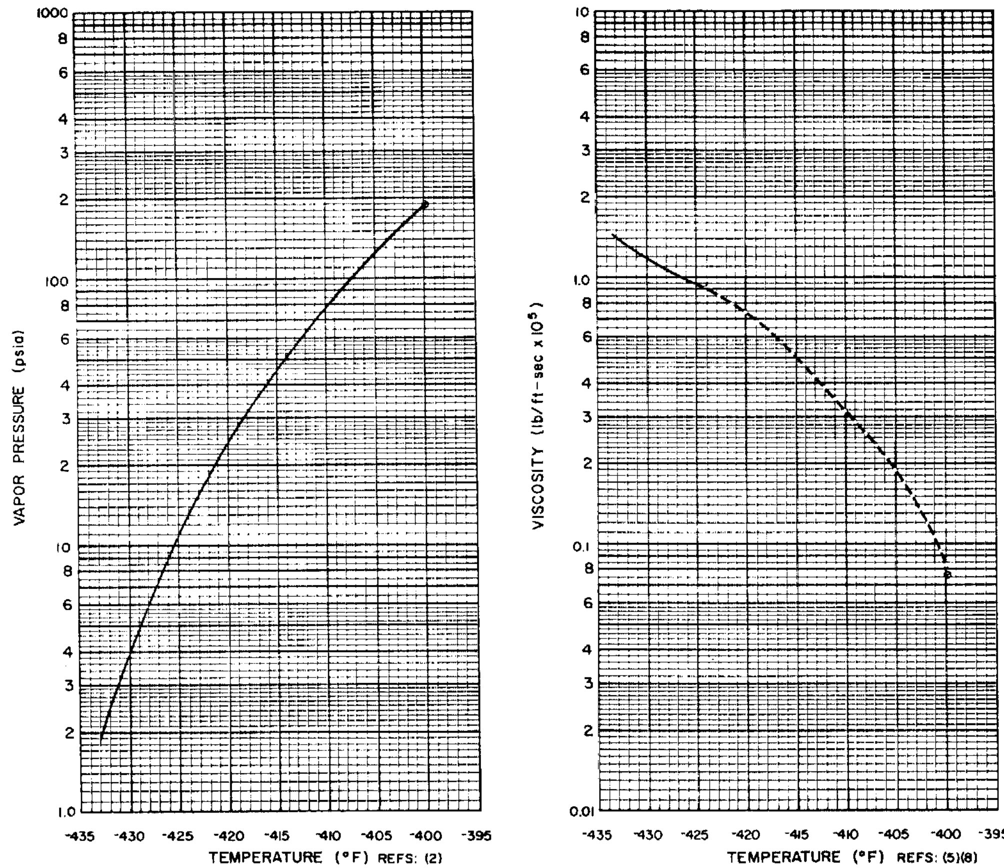
PHYSICAL PROPERTIES OF OXYGEN - O_2

MOLECULAR WEIGHT	32.000
FREEZING TEMPERATURE (°F)	-362 (1)
NORMAL BOILING POINT (°F)	-297 (1)
CRITICAL TEMPERATURE (°F)	-182.0 (2)
CRITICAL PRESSURE (psia)	730.6 (2)
HEAT OF FORMATION (cal / mole liq@nbp)	-2896
HEAT OF VAPORIZATION (Btu / lb)	91.62

REFERENCE DATA ———
EXTRAPOLATED DATA - - - - - -
CRITICAL POINT o

Figure V-1



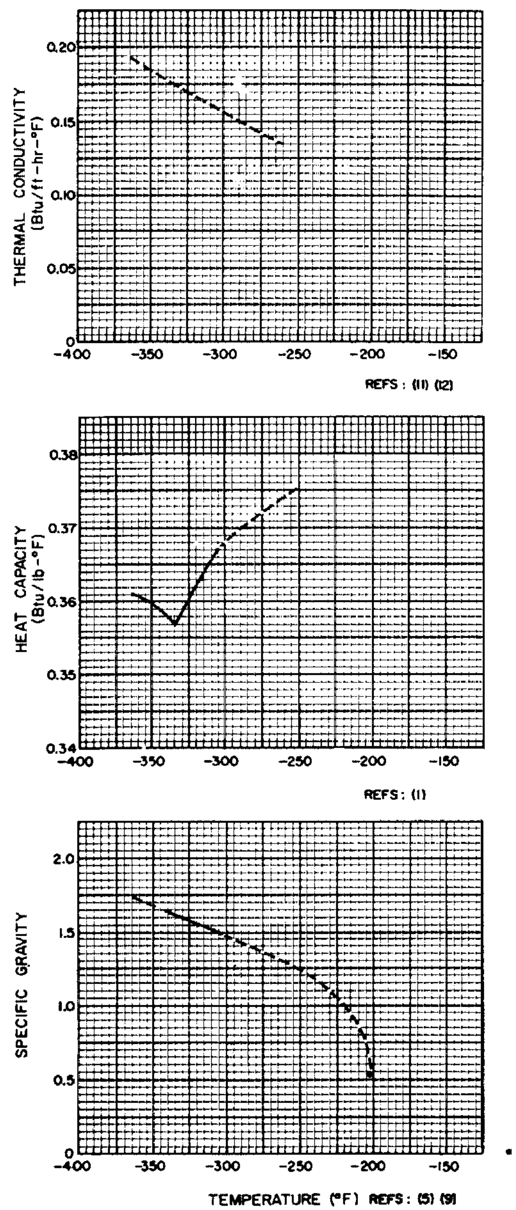


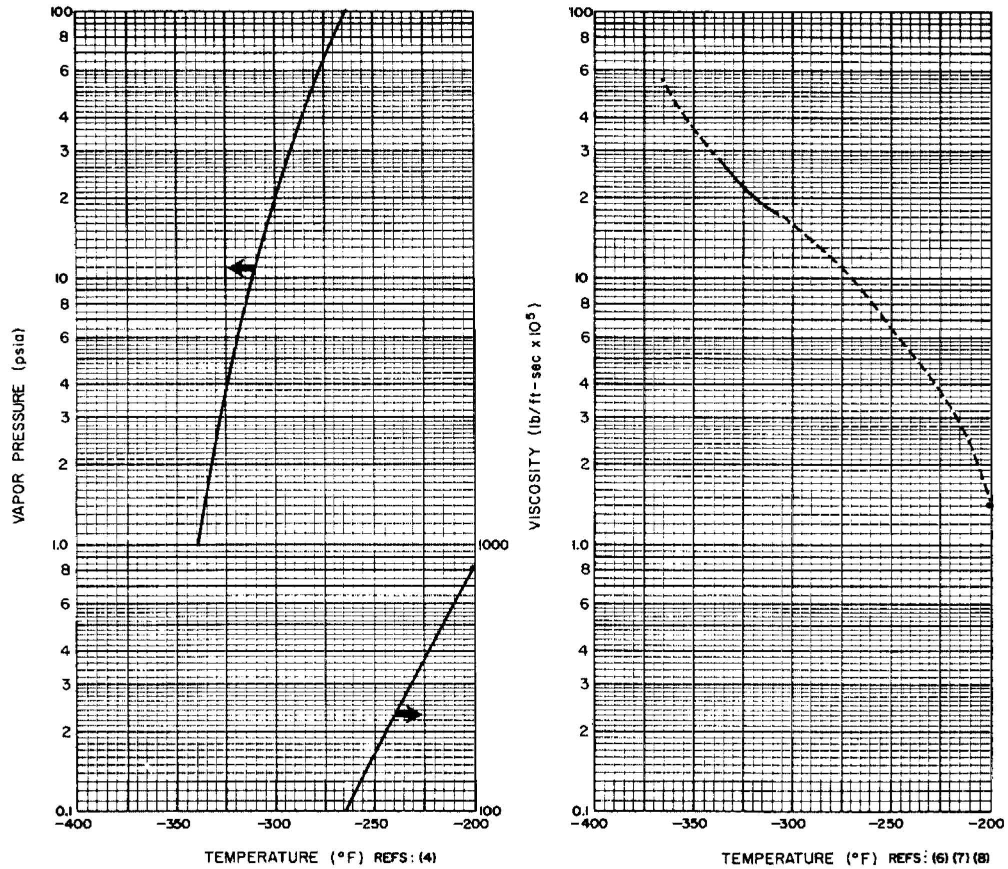
PHYSICAL PROPERTIES OF LIQUID HYDROGEN-H_2

MOLECULAR WEIGHT	2.016
FREEZING TEMPERATURE (°F)	-434.8 (1)
NORMAL BOILING POINT (°F)	-423.3 (2)
CRITICAL TEMPERATURE (°F)	-399.9 (3)
CRITICAL PRESSURE (psia)	188 (3)
HEAT OF FORMATION (cal / mole liq nbp)	-1895 (4)(7)
HEAT OF VAPORIZATION (Btu / lb)	195.3 (4)

REFERENCE DATA ————
EXTRAPOLATED DATA - - - - - -
CRITICAL POINT o

Figure V-2



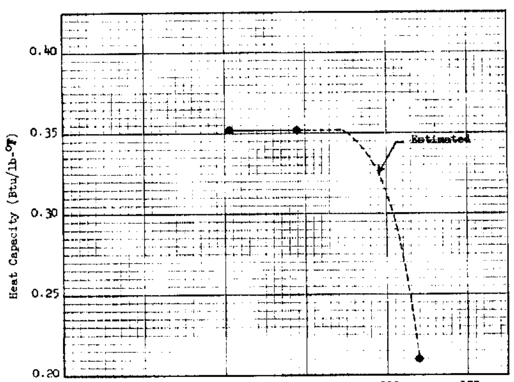


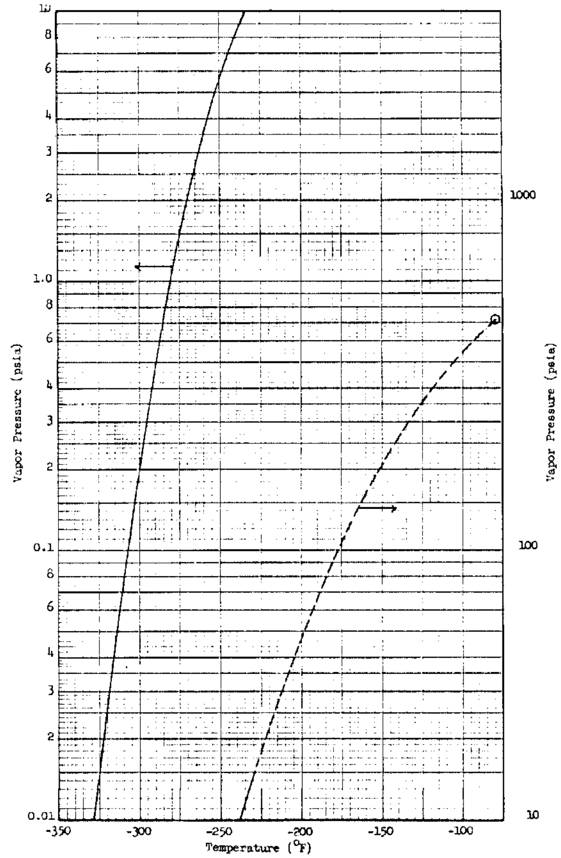
PHYSICAL PROPERTIES OF FLUORINE – F_2

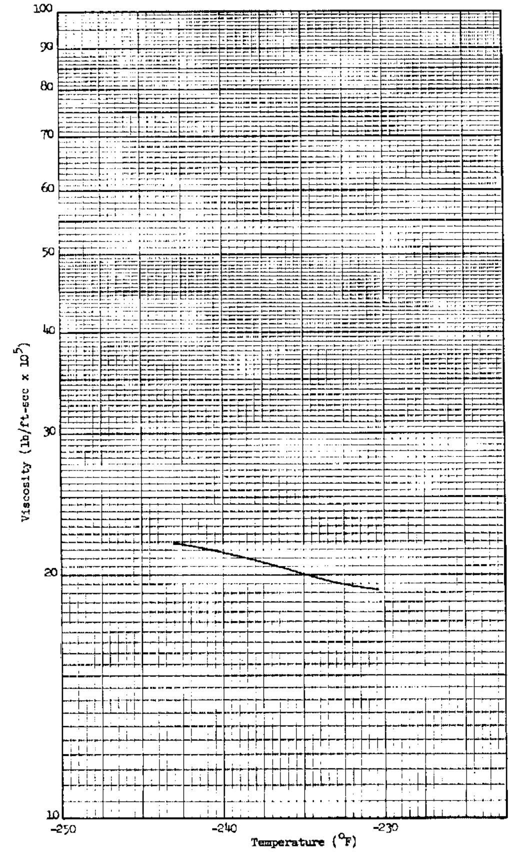
MOLECULAR WEIGHT	38.000
FREEZING TEMPERATURE (°F)	–365 (1)
NORMAL BOILING POINT (°F)	–307 (2)
CRITICAL TEMPERATURE (°F)	–201 (2)
CRITICAL PRESSURE (psia)	808.5 (2)
HEAT OF FORMATION, (cal / mole liq @ nbp)	–3056 (3) (10)
HEAT OF VAPORIZATION (Btu / lb)	71.5 (3)

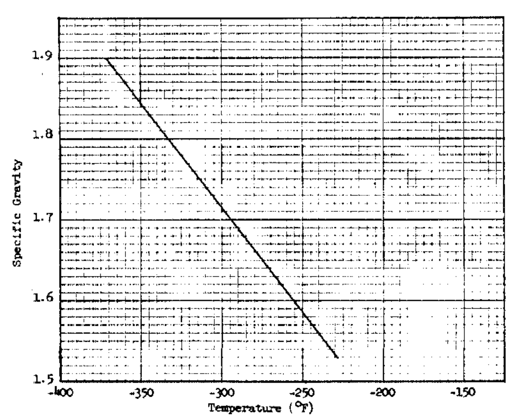
REFERENCE DATA ———
EXTRAPOLATED DATA - - - - -
CRITICAL POINT o

Figure V-3







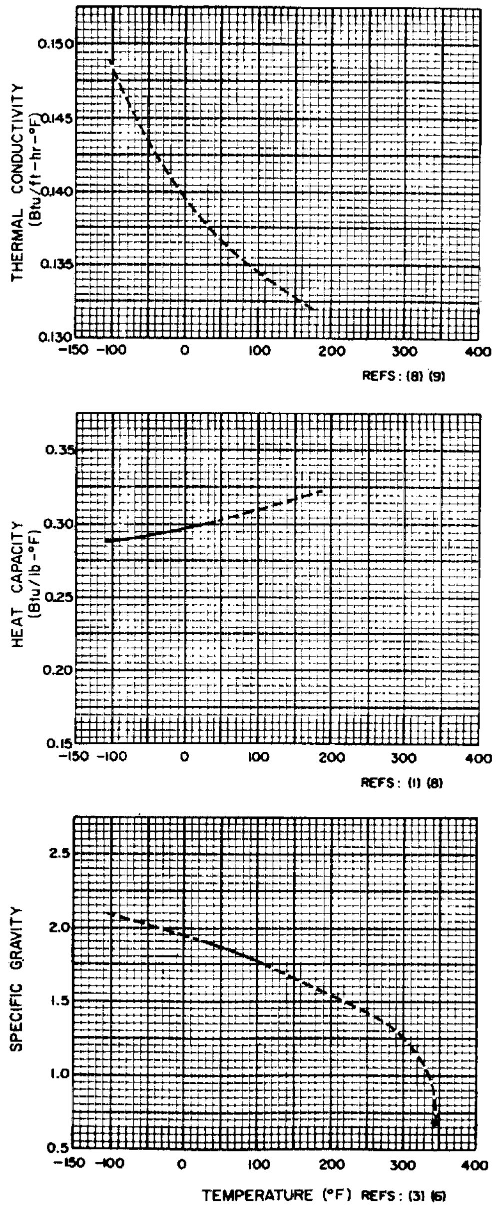


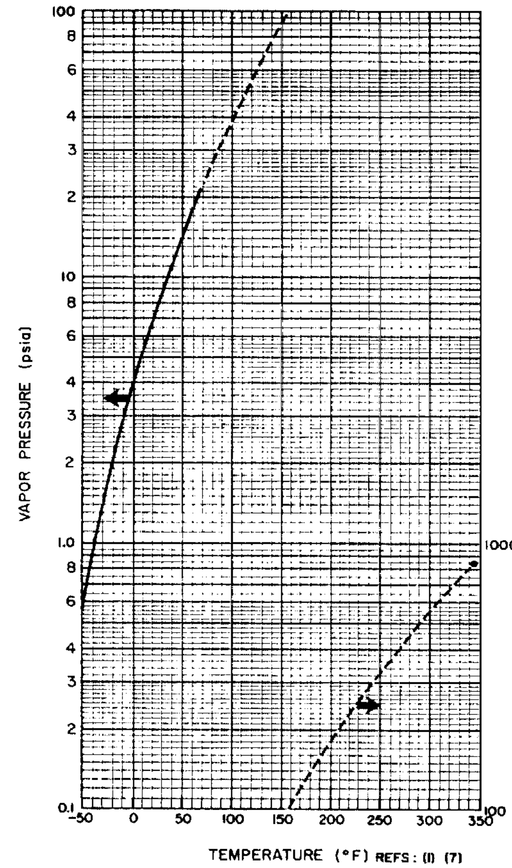
PHYSICAL PROPERTIES OF OXYGEN DIFLORIDE - (OF_2)

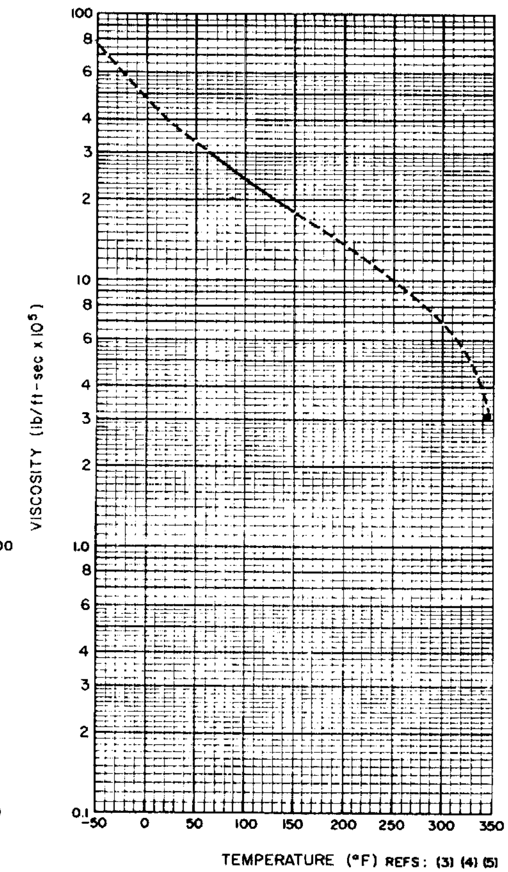
MOLECULAR WEIGHT	54
FREEZING TEMPERATURE (°F)	-371
NORMAL BOILING POINT (°F)	-228
CRITICAL TEMPERATURE (°F)	-72.4
CRITICAL PRESSURE (psia)	719
HEAT OF FORMATION (cal/mole liq @ nbp)	5200
HEAT OF VAPORIZATION (Btu/lb)	86.6

EXPERIMENTAL DATA ———
EXTRAPOLATED DATA - - - -
CRITICAL POINT ⊙

Figure V-4





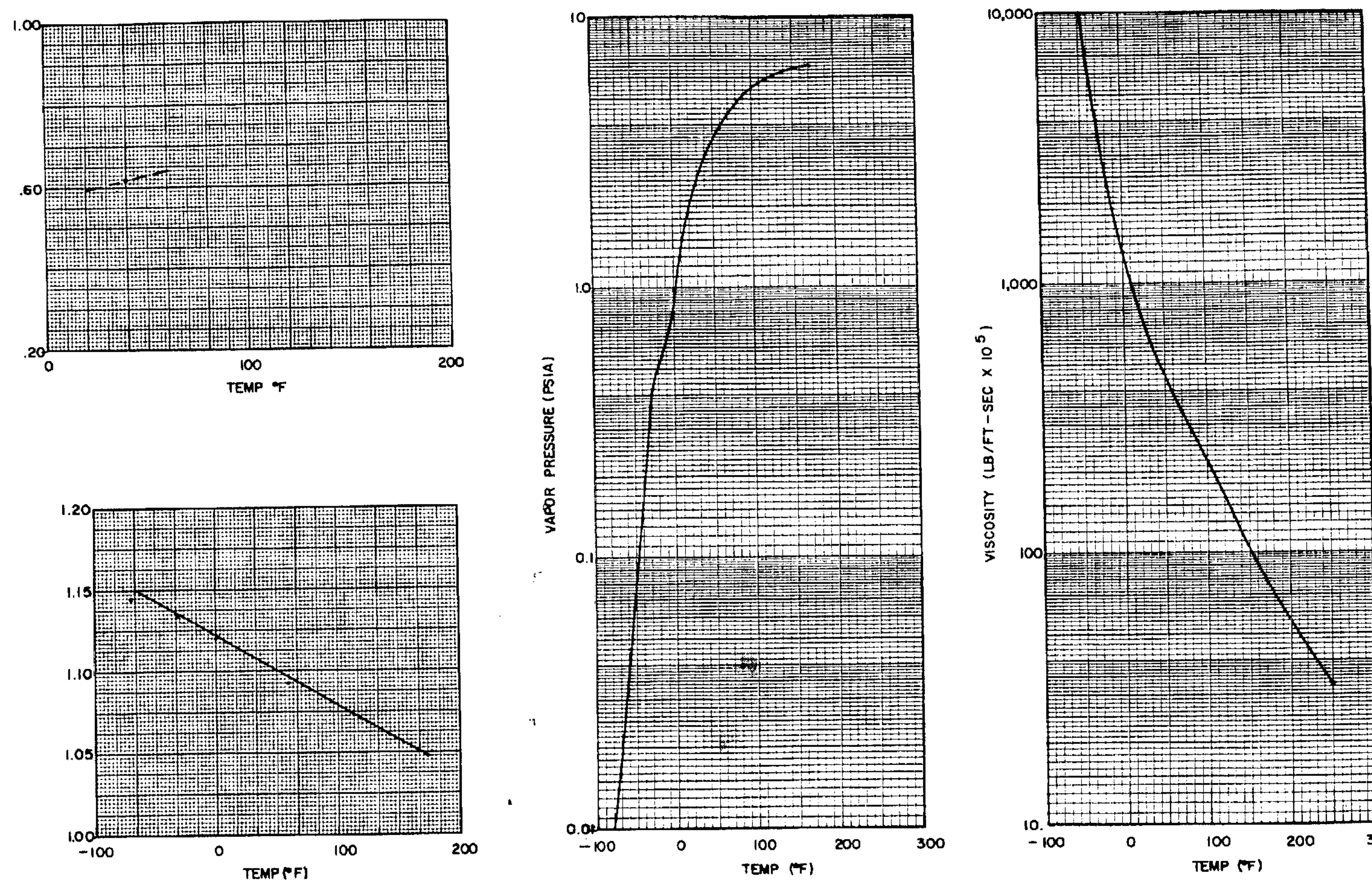


PHYSICAL PROPERTIES OF CHLORINE TRIFLUORIDE— ClF_3

MOLECULAR WEIGHT	92.46
FREEZING TEMPERATURE (°F)	-105 (1)
NORMAL BOILING POINT (°F)	53 (1)
CRITICAL TEMPERATURE (°F)	345 (1)
CRITICAL PRESSURE (psia)	838 (1)
HEAT OF FORMATION (cal / mole liq @ nbp)	-43,100 (2)
HEAT OF VAPORIZATION (Btu / lb)	128 (1)

REFERENCE DATA ————
EXTRAPOLATED DATA - - - - - -
CRITICAL POINT o

Figure V-5

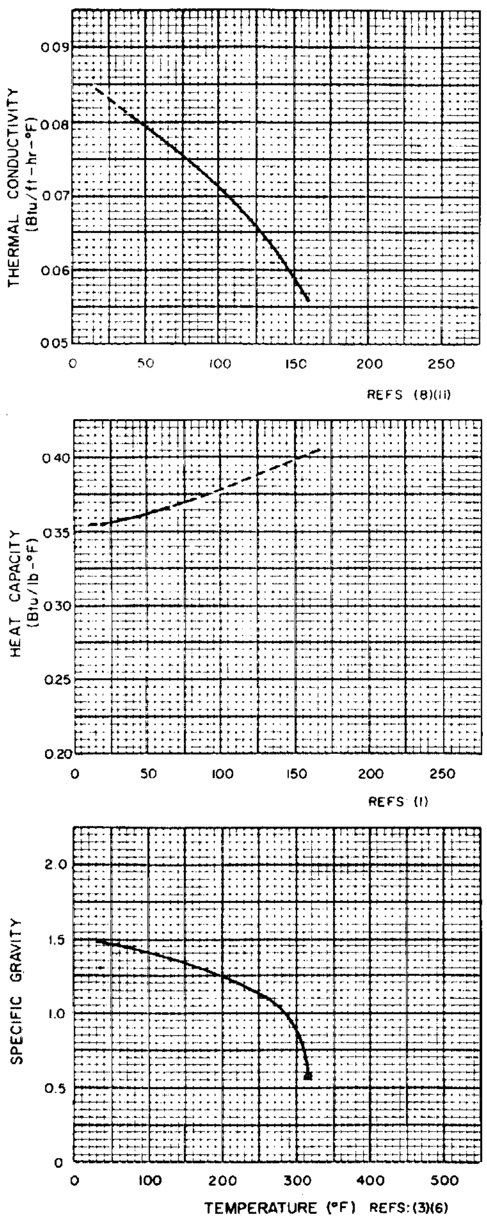


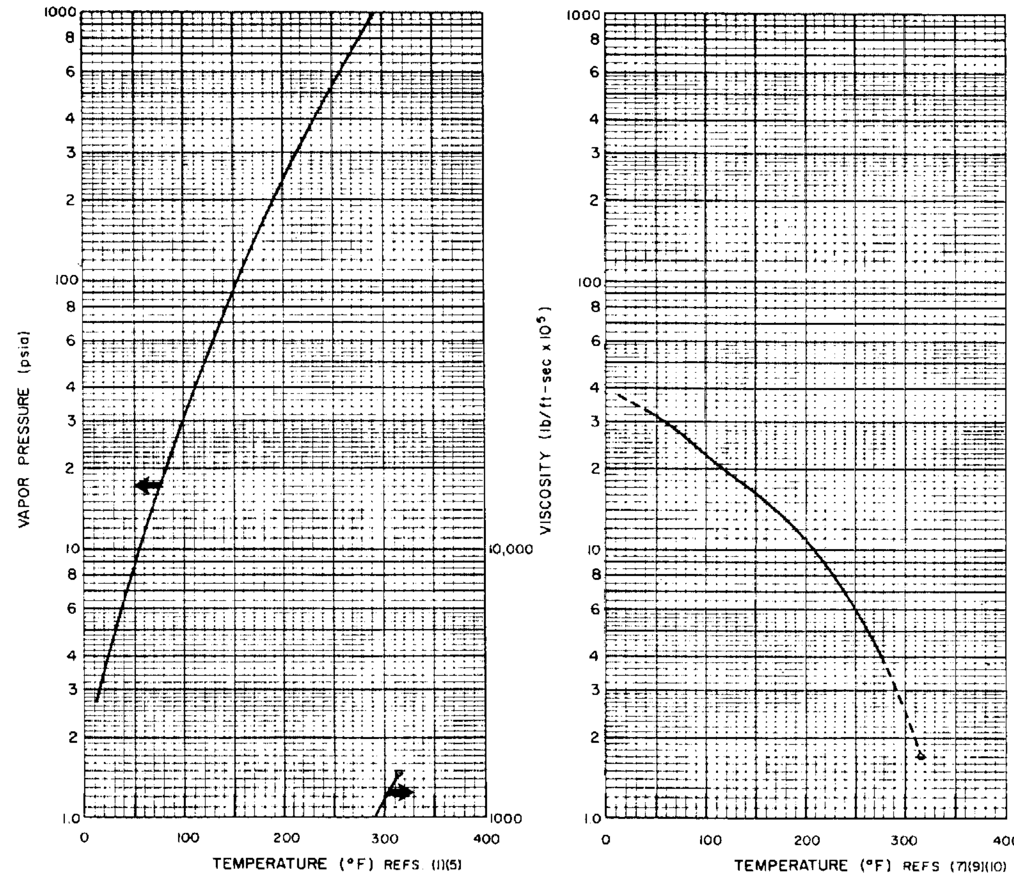
MOLECULAR WEIGHT — 49.0
FREEZING TEMPERATURE — -68 °F
NORMAL BOILING POINT — 200 °F
CRITICAL TEMERATURE —

CRITICAL PRESSURE —
HEAT OF FORMATION — +1.07 K CAL/g MOLE
HEAT OF VAPORIZATION —

PHYSICAL PROPERTIES OF HYDRAZOID

 Figure V-6

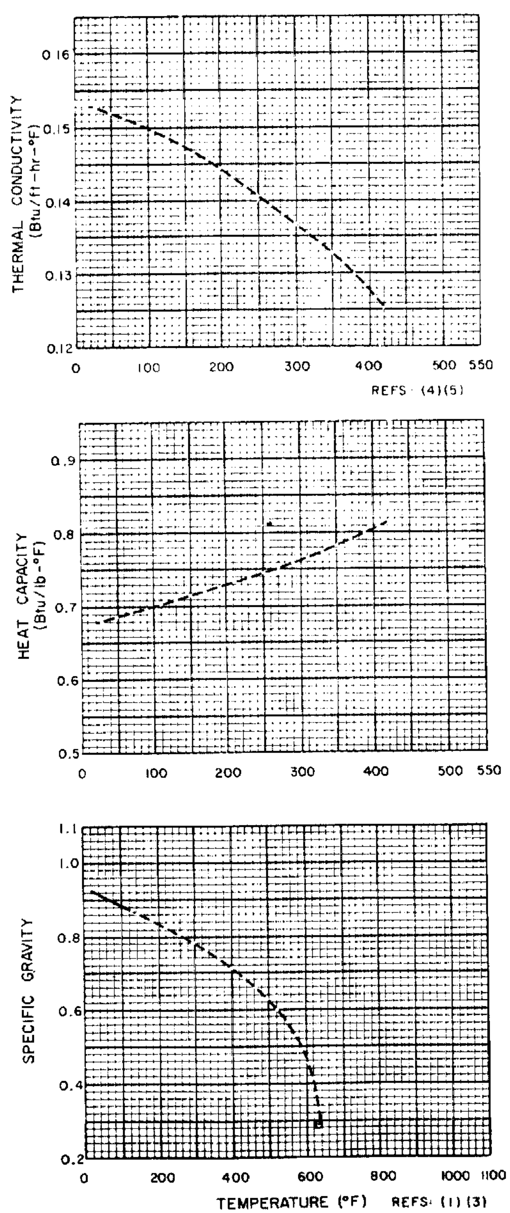


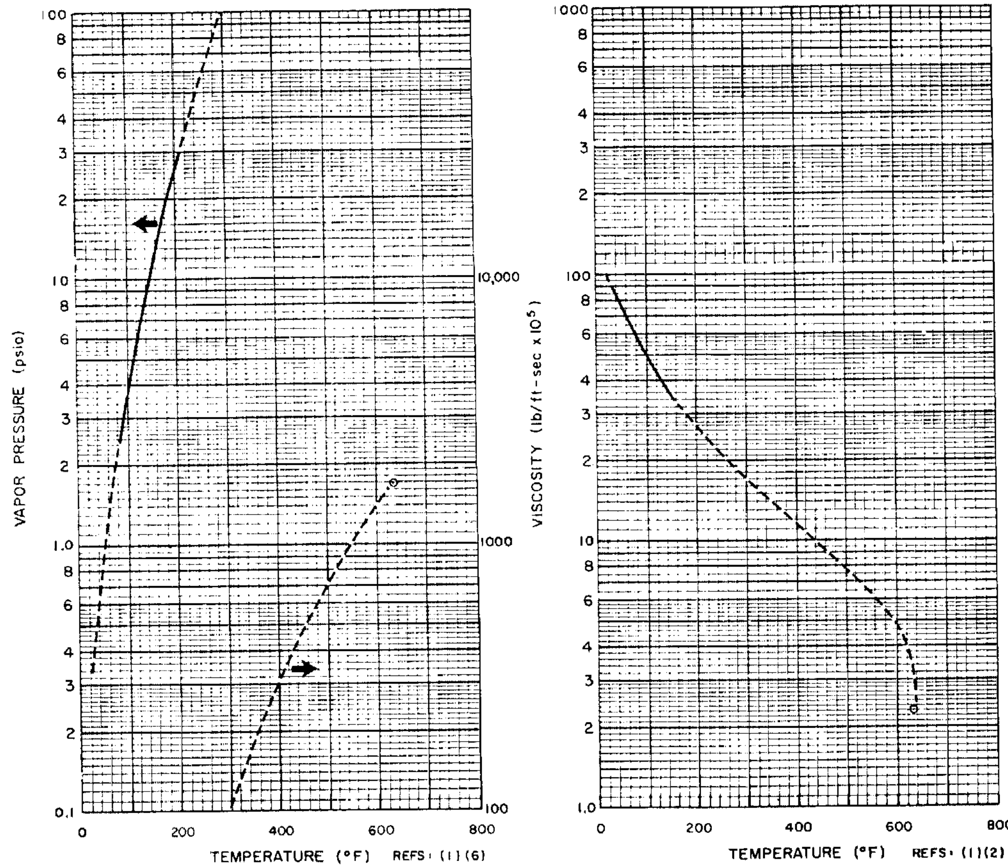


PHYSICAL PROPERTIES OF NITROGEN TETROXIDE - N_2O_4

MOLECULAR WEIGHT	92.016	REFERENCE DATA	———
FREEZING TEMPERATURE (°F)	11.8 (1)	EXTRAPOLATED DATA	- - - - - -
NORMAL BOILING POINT (°F)	70 (1)	CRITICAL POINT	o
CRITICAL TEMPERATURE (°F)	316 (2)		
CRITICAL PRESSURE (psia)	1470 (3)		
HEAT OF FORMATION (cal / mole liq @ 298.16°K)	-6800 (4)		
HEAT OF VAPORIZATION (Btu / lb)	178.2 (1)		

Figure V-7





PHYSICAL PROPERTIES OF AEROZINE - 50

(50% HYDRAZINE - 50% UDMH b. w.)

MOLECULAR WEIGHT	41.797	
FREEZING TEMPERATURE (°F)	18	(1)
NORMAL BOILING POINT (°F)	170	(1)
CRITICAL TEMPERATURE (°F)	634	(5)
CRITICAL PRESSURE (psia)	1696	(5)
HEAT OF FORMATION (cal / mole liq @ 298.16°K)	11,789	
HEAT OF VAPORIZATION (Btu / lb)	425.8	

REFERENCE DATA ———
EXTRAPOLATED DATA - - - -
CRITICAL POINT o

Figure V-8

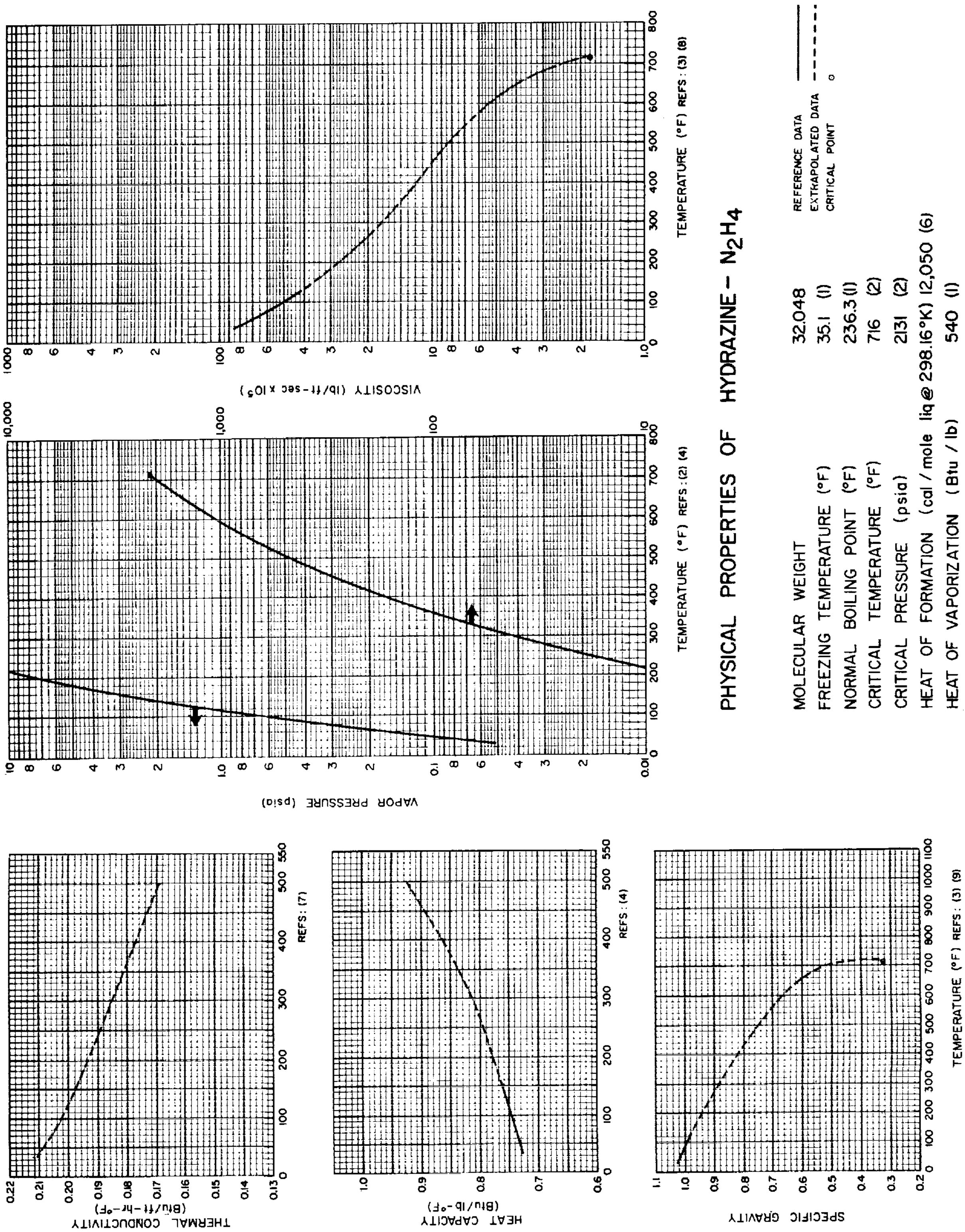

PHYSICAL PROPERTIES OF HYDRAZINE – N_2H_4
MOLECULAR WEIGHT 32.048
FREEZING TEMPERATURE (°F) 35.1 (1)
NORMAL BOILING POINT (°F) 236.3 (1)
CRITICAL TEMPERATURE (°F) 716 (2)
CRITICAL PRESSURE (psia) 2131 (2)
HEAT OF FORMATION (cal / mole liq @ 298.16°K) 12,050 (6)
HEAT OF VAPORIZATION (Btu / lb) 540 (1)
REFERENCE DATA
EXTRAPOLATED DATA
CRITICAL POINT
VISCOSITY (lb/ft-sec x 10⁵)
TEMPERATURE (°F) REFS: (3) (8)
VAPOR PRESSURE (psia)
TEMPERATURE (°F) REFS: (2) (4)
THERMAL CONDUCTIVITY (Btu/ft-hr-°F)
REFS: (7)
HEAT CAPACITY (Btu/lb-°F)
REFS: (4)
SPECIFIC GRAVITY
TEMPERATURE (°F)

Figure V-9

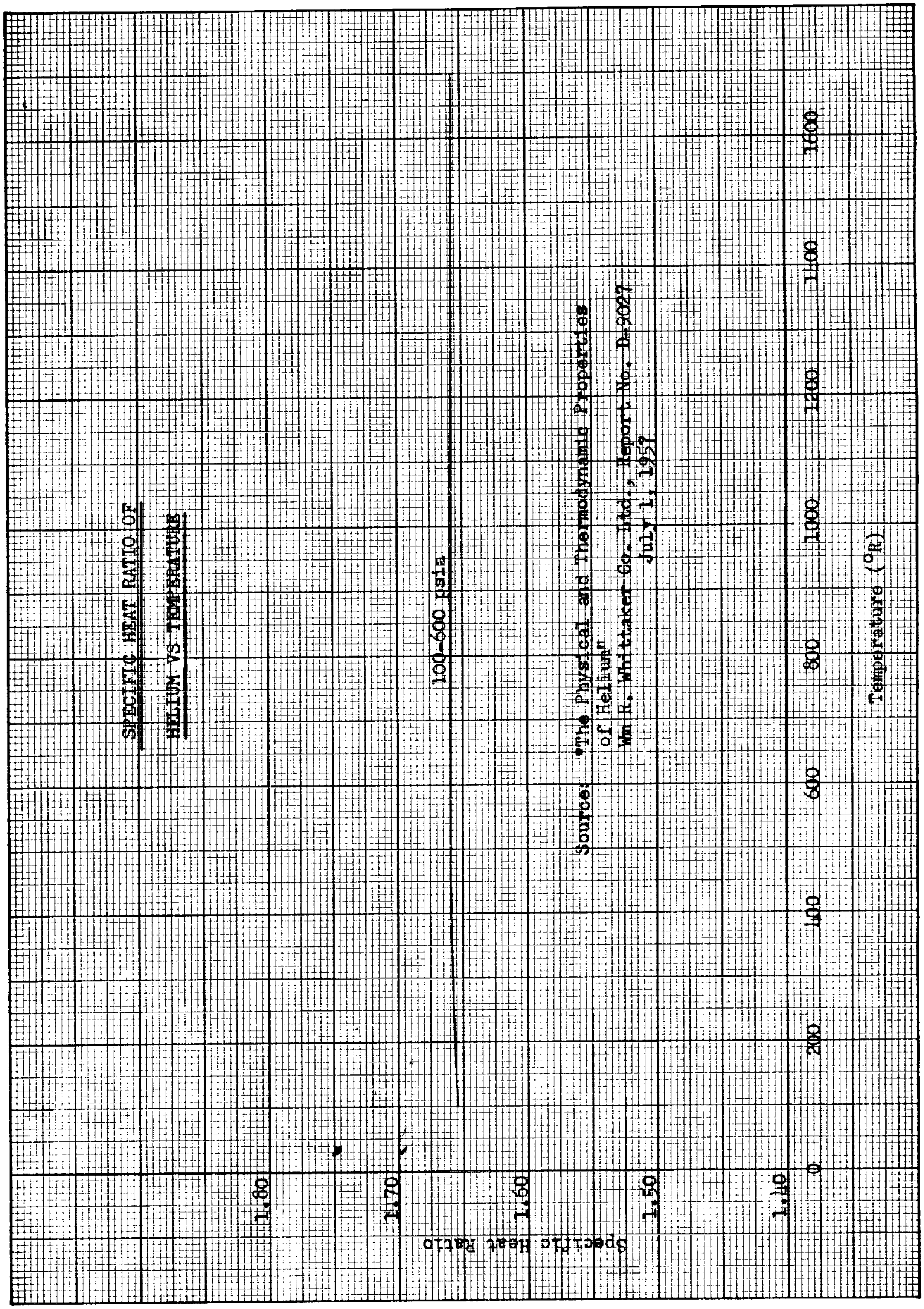

SPECIFIC HEAT RATIO OF
HELIUM VS TEMPERATURE
100-600 psia
Source: "The Physical and Thermodynamic Properties
of Helium"
Wm R. Whittaker Co. Ltd., Report No. D-9027
July 1, 1957
1.80
1.70
1.60
1.50
1.40
Specific Heat Ratio
0
200
400
600
800
1000
1200
1400
1600
Temperature (°R)

Figure V-10

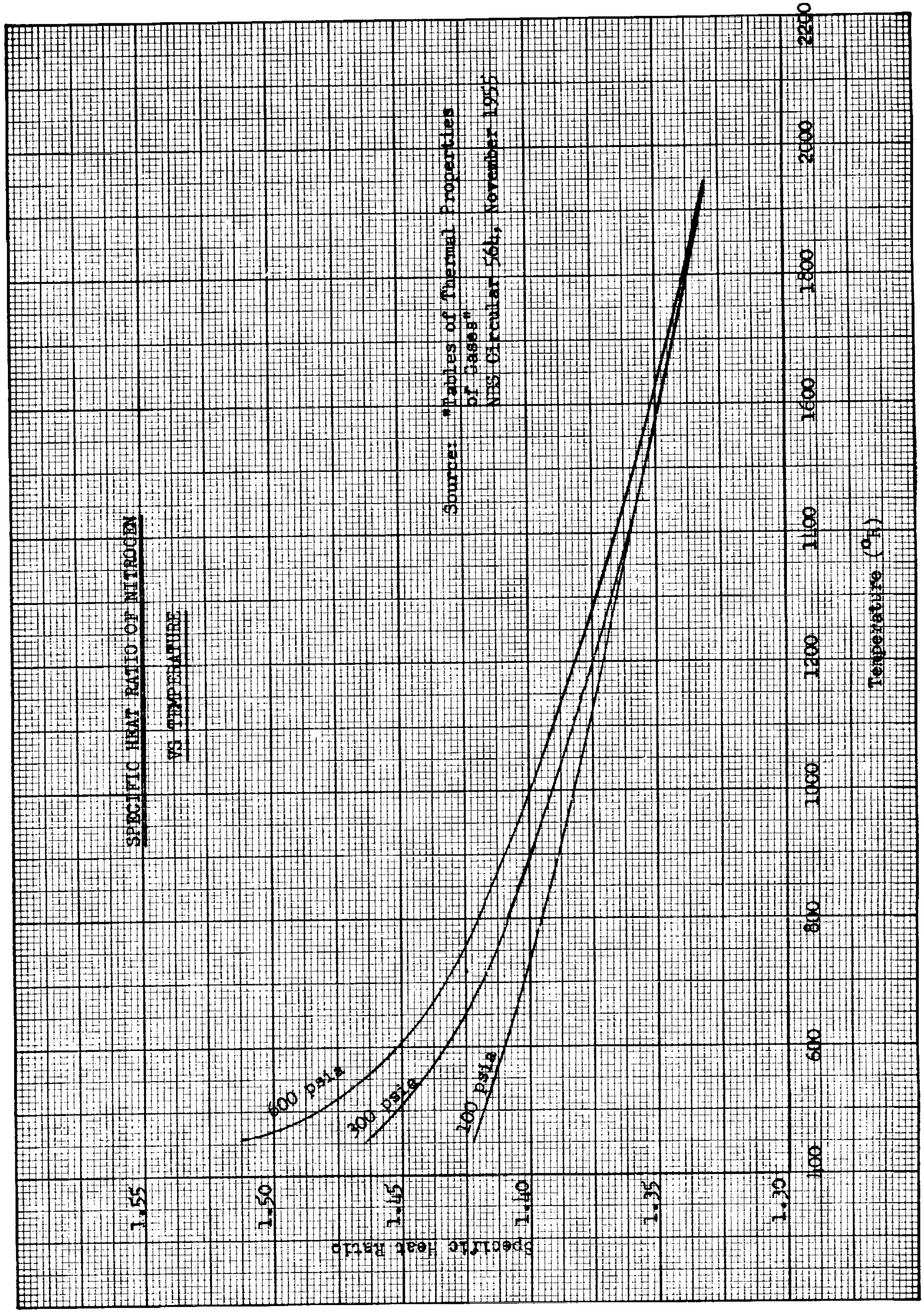

SPECIFIC HEAT RATIO OF NITROGEN
VS TEMPERATURE
Source: "Tables of Thermal Properties of Gases"
NBS Circular 564, November 1955
600 psia
300 psia
100 psia
Specific Heat Ratio
1.55
1.50
1.45
1.40
1.35
1.30
Temperature (°R)
400
600
800
1000
1200
1400
1600
1800
2000
2200

Figure V-11

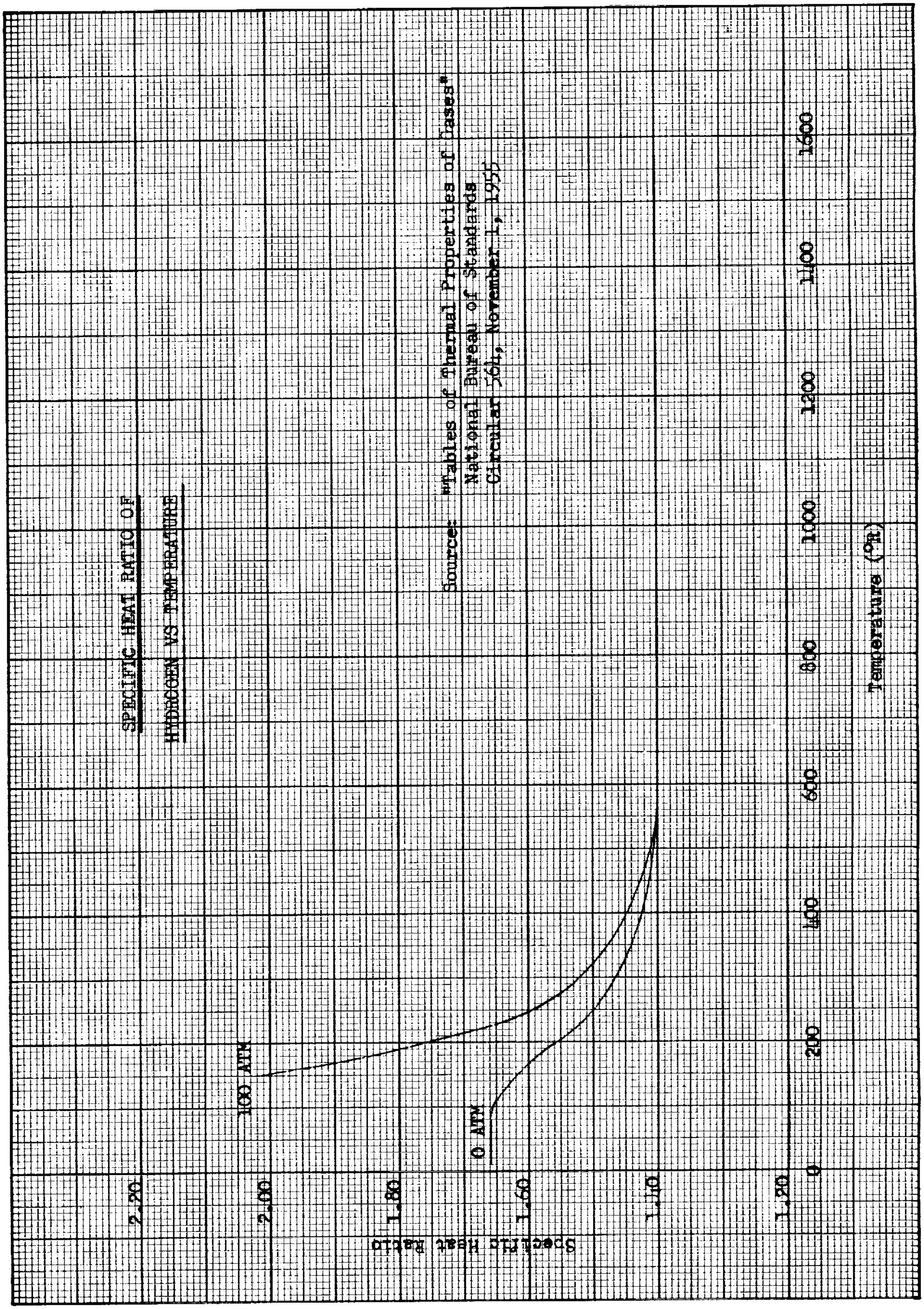

SPECIFIC HEAT RATIO OF
HYDROGEN VS TEMPERATURE
Source: "Tables of Thermal Properties of Gases"
National Bureau of Standards
Circular 564, November 1, 1955
100 ATM
0 ATM
Specific Heat Ratio
2.20
2.00
1.80
1.60
1.40
1.20
Temperature (°R)
0
200
400
600
800
1000
1200
1400
1600

Figure V-12

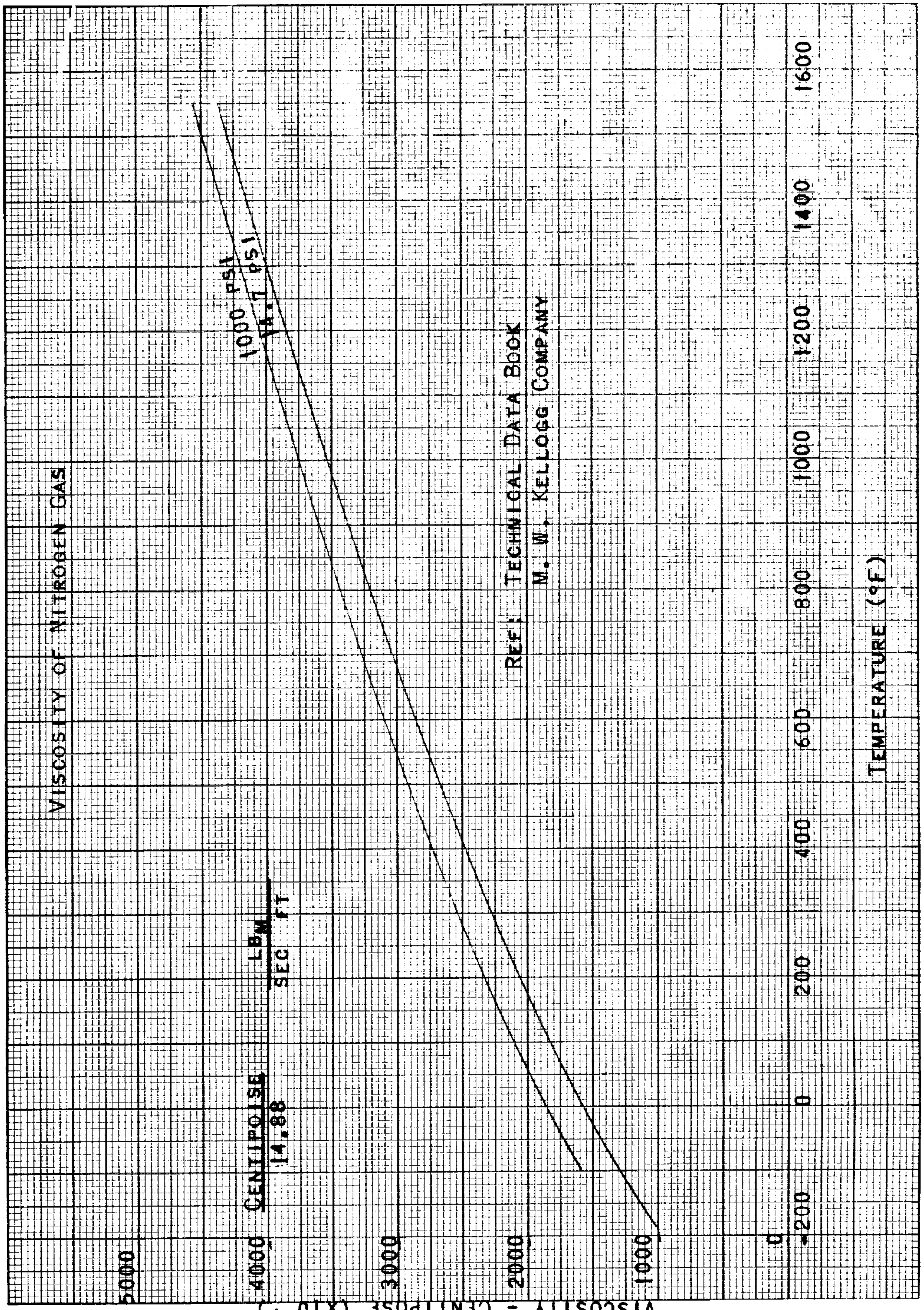
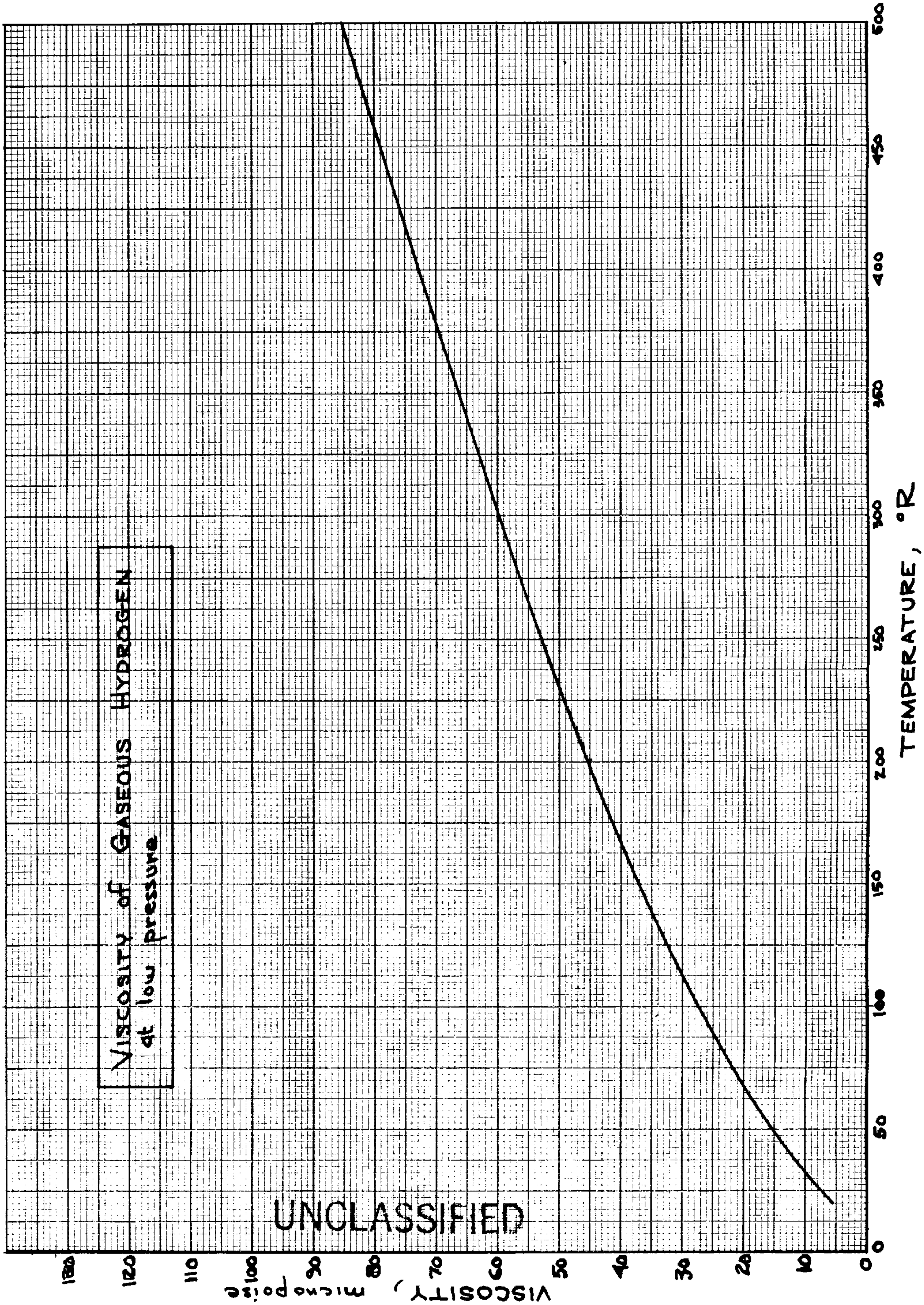

VISCOSITY OF NITROGEN GAS
1000 PSI
14.7 PSI
REF: TECHNICAL DATA BOOK
M. W. KELLOGG COMPANY
CENTIPOISE / 14.88 = LB_M / SEC FT
TEMPERATURE (°F)
-200
0
200
400
600
800
1000
1200
1400
1600
VISCOSITY - CENTIPOISE (x10^-7)
0
1000
2000
3000
4000
5000

Figure V-13



UNCLASSIFIED

Figure V-14

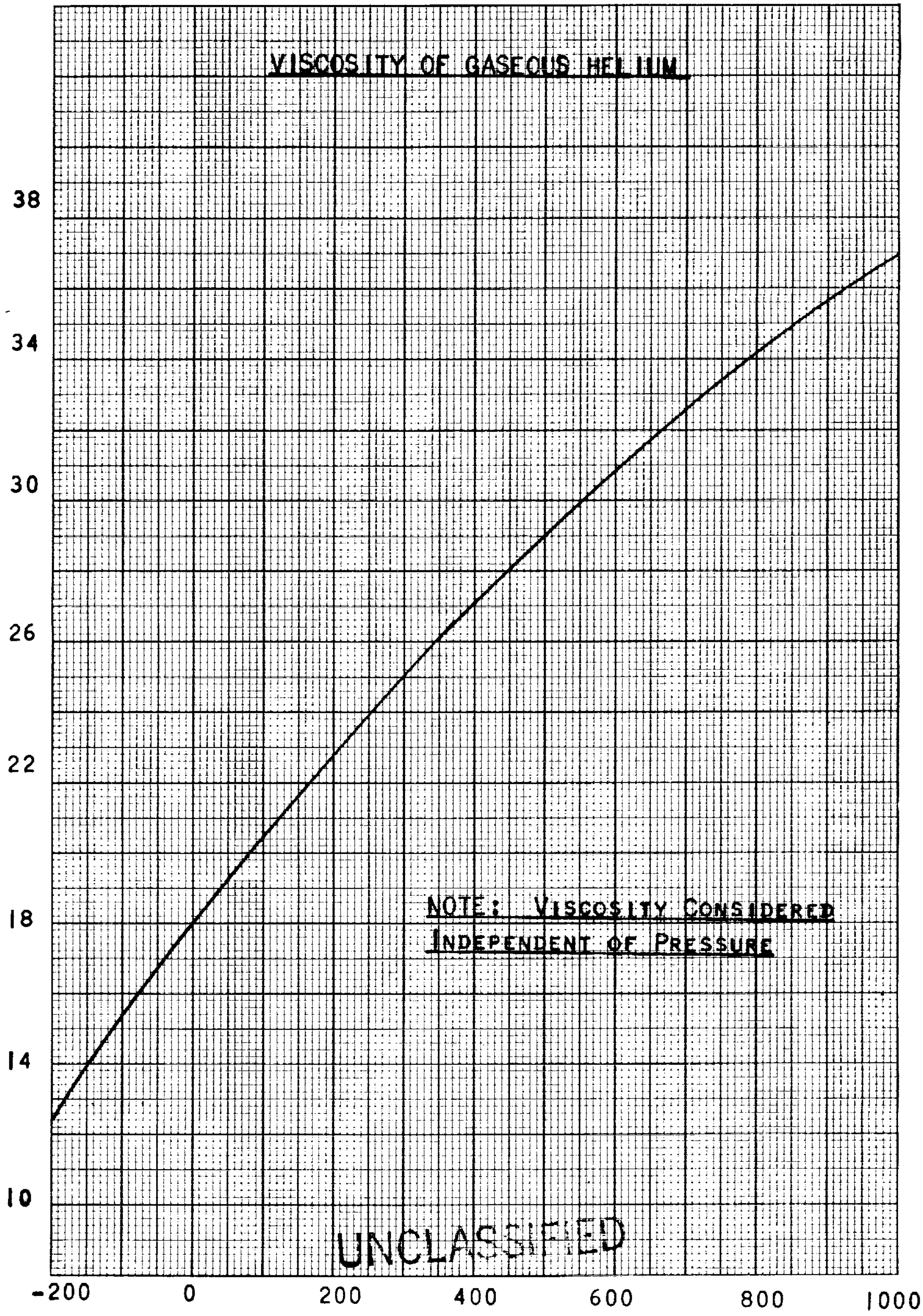

VISCOSITY OF GASEOUS HELIUM
38
34
30
26
22
18
14
10
NOTE: VISCOSITY CONSIDERED INDEPENDENT OF PRESSURE
-200
0
200
400
600
800
1000
TEMPERATURE -°F

 Figure V-15

CALCULATED PERFORMANCE OF HYDRAZINE

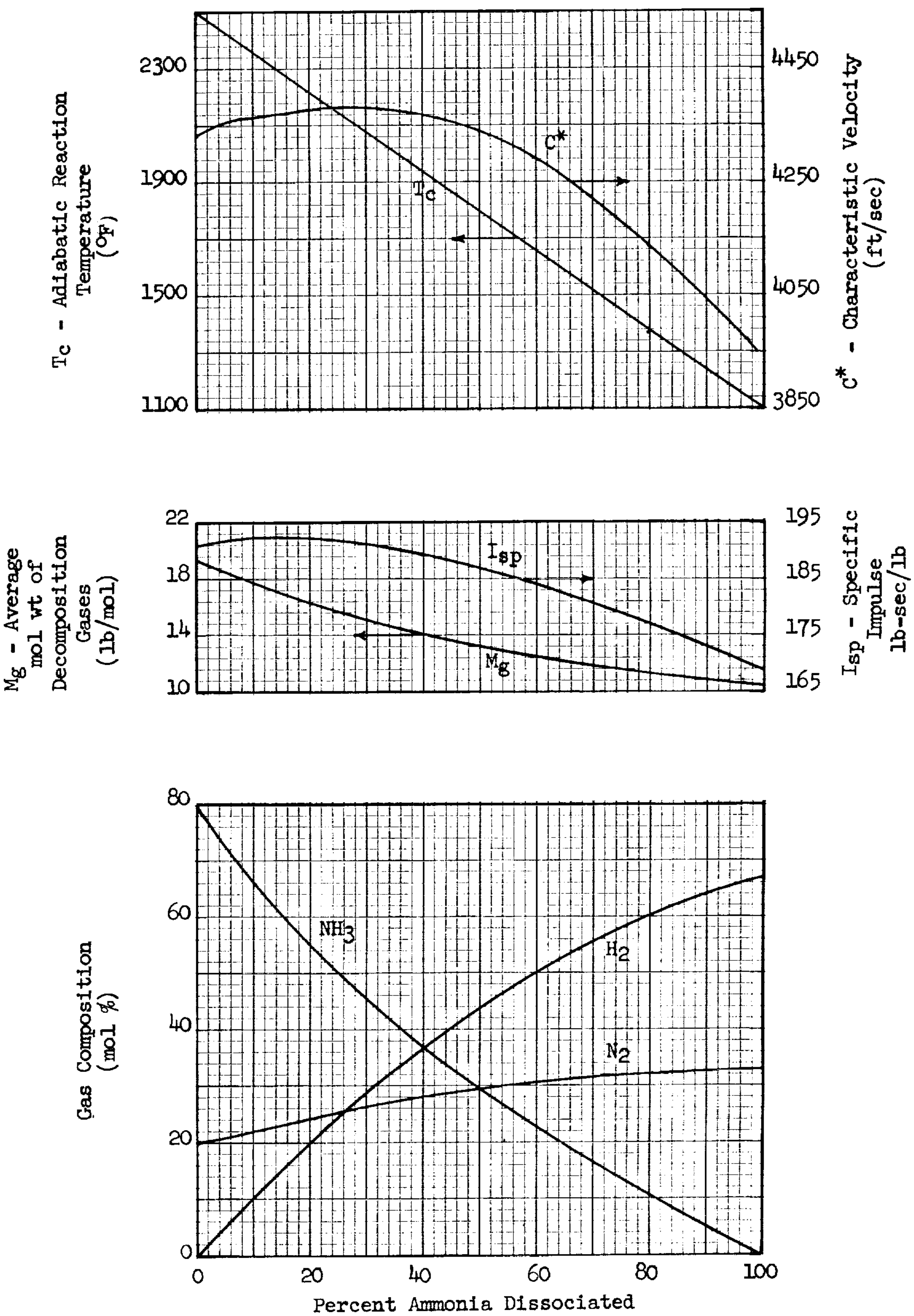


Figure V-16

MIXTURE RATIO (FUEL RICH) VS
CHARACTERISTIC VELOCITY & GAS TEMPERATURE

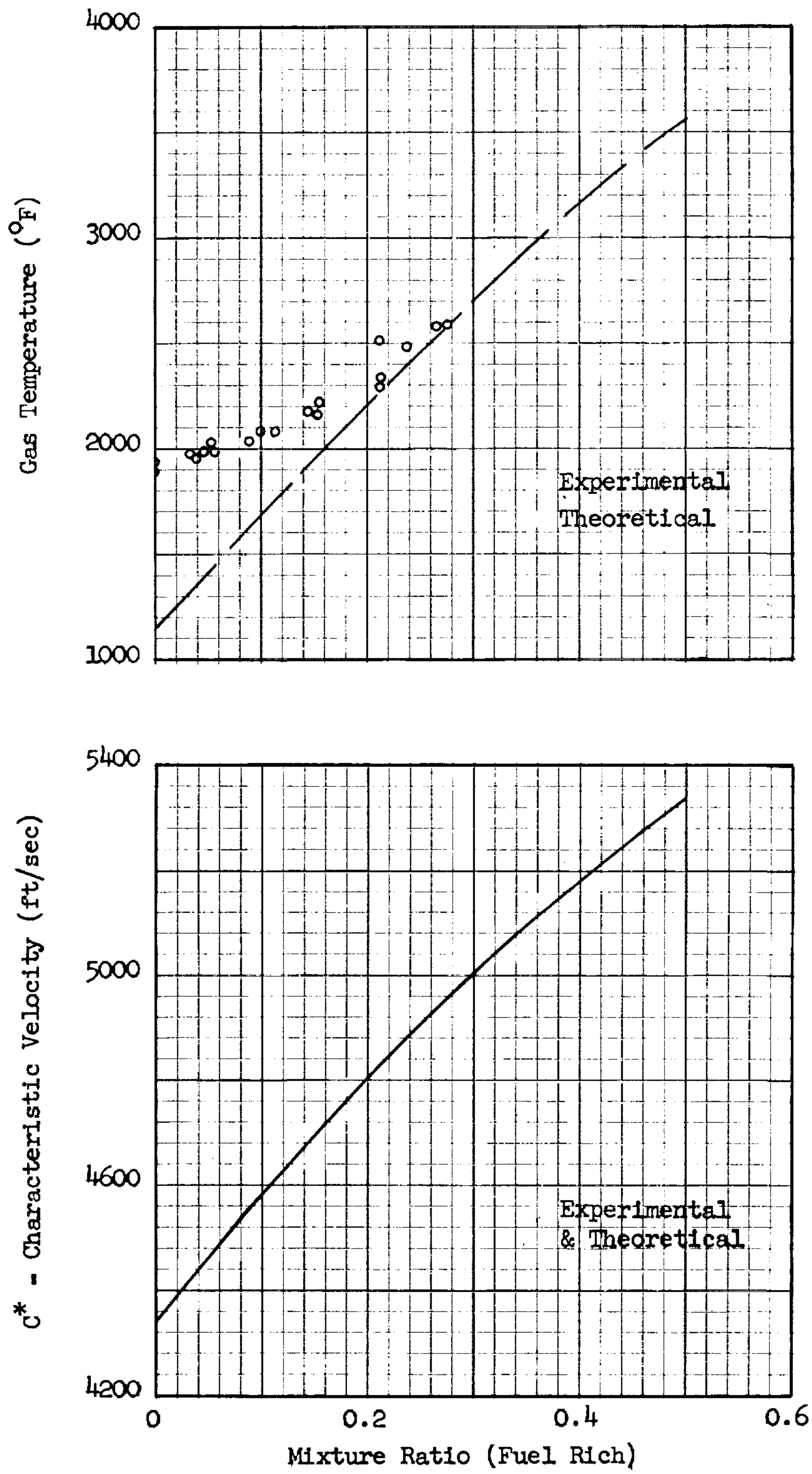


Figure V-17

MIXTURE RATIO (OXIDIZER RICH) VS
CHARACTERISTIC VELOCITY & GAS TEMPERATURE

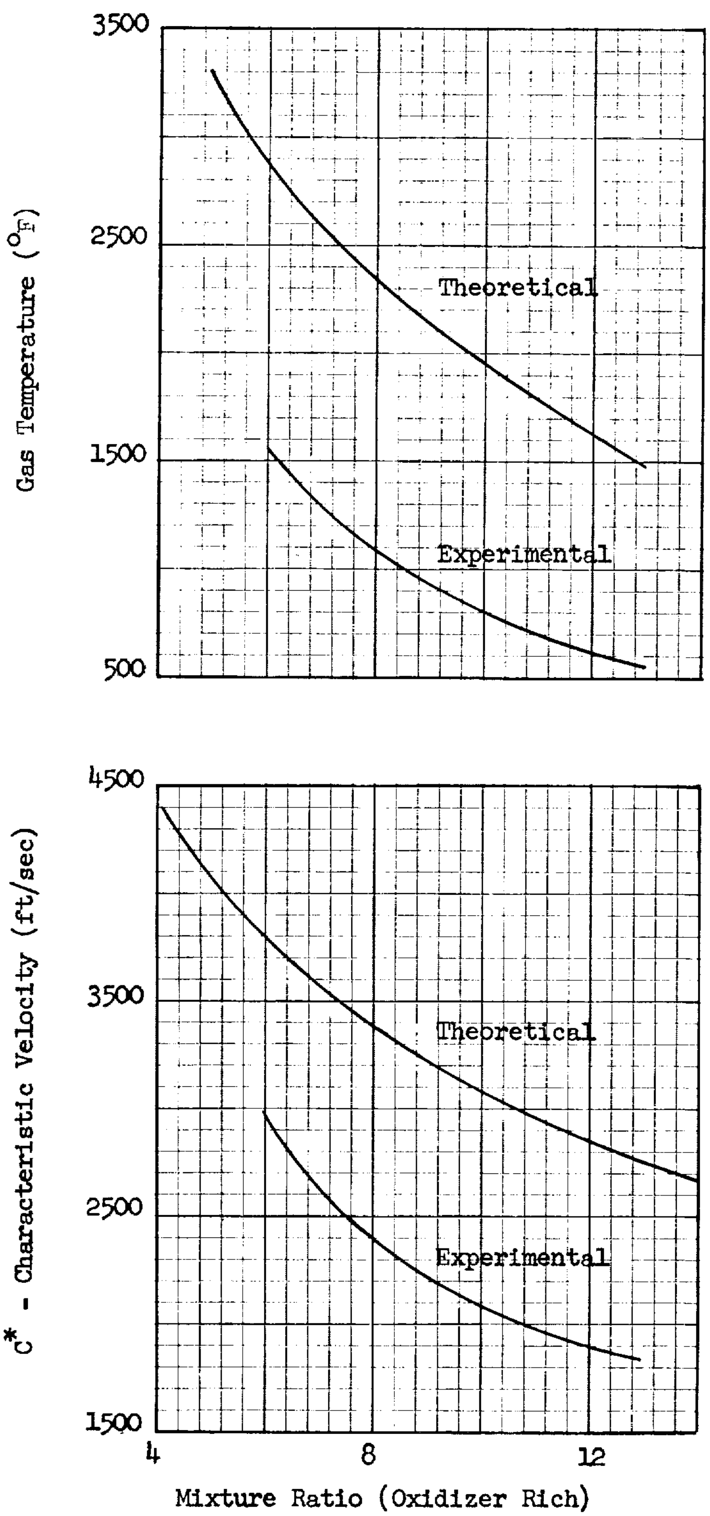


 Figure V-18

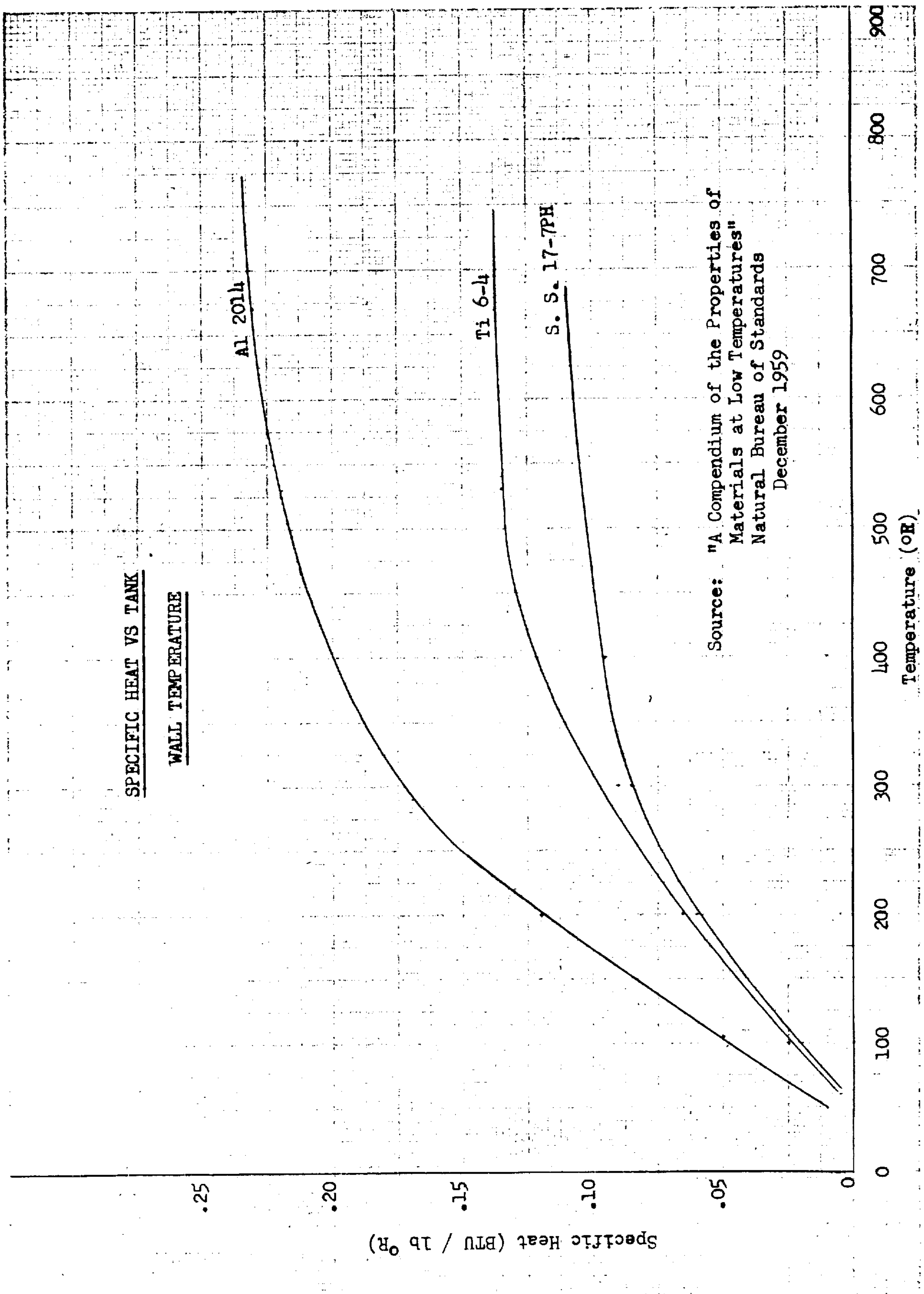

SPECIFIC HEAT VS TANK
WALL TEMPERATURE
Al 2014
Ti 6-4
S. S. 17-7PH
Source: "A Compendium of the Properties of
Materials at Low Temperatures"
Natural Bureau of Standards
December 1959
Specific Heat (BTU / lb °R)
.25
.20
.15
.10
.05
0
Temperature (°R)
0
100
200
300
400
500
600
700
800
900

Figure V-19

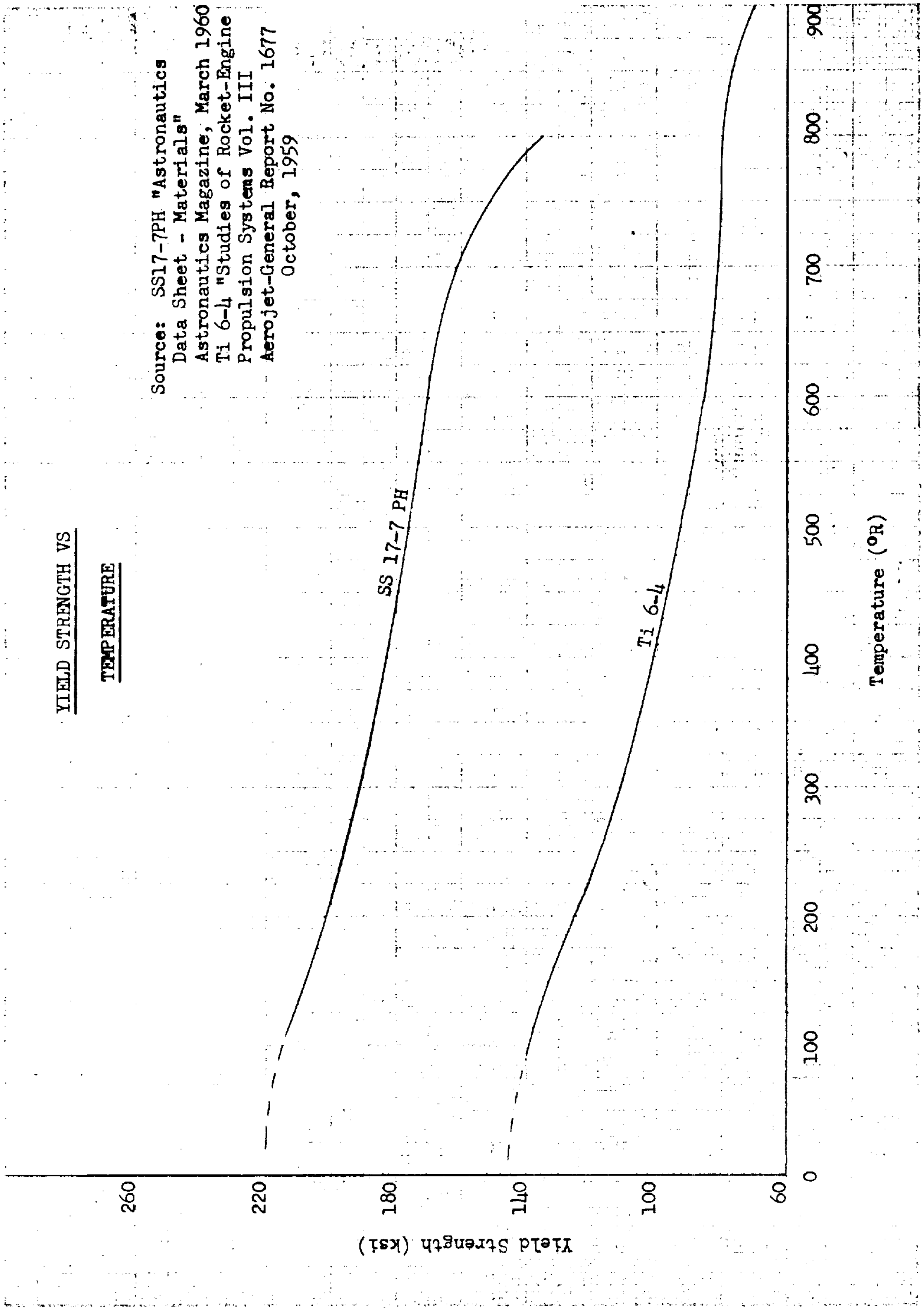

YIELD STRENGTH VS
TEMPERATURE
Source: SS17-7PH "Astronautics Data Sheet - Materials" Astronautics Magazine, March 1960
Ti 6-4 "Studies of Rocket-Engine Propulsion Systems Vol. III Aerojet-General Report No. 1677 October, 1959
SS 17-7 PH
Ti 6-4
Yield Strength (ksi)
260
220
180
140
100
60
Temperature (°R)
0
100
200
300
400
500
600
700
800
900

Figure V-20

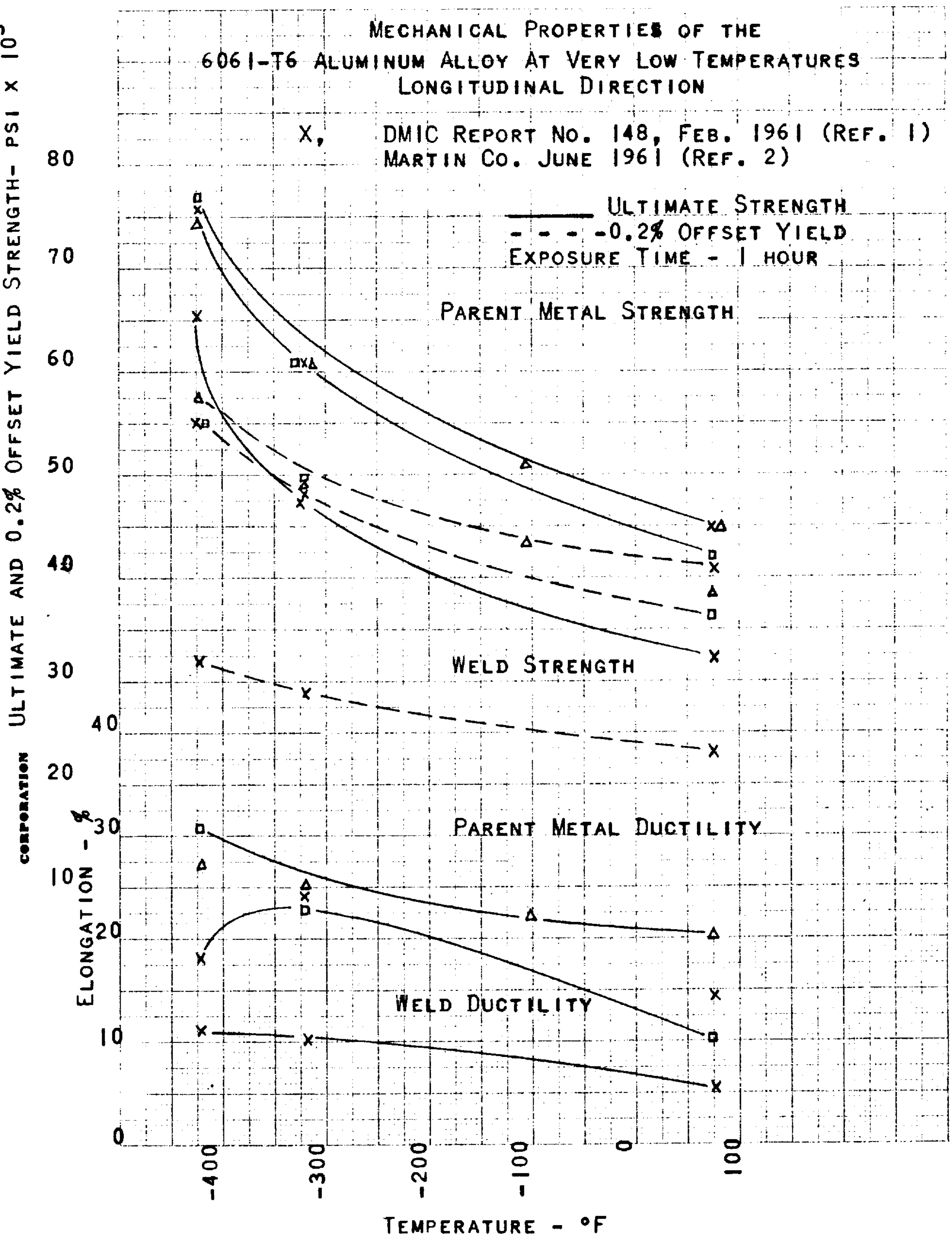

MECHANICAL PROPERTIES OF THE
6061-T6 ALUMINUM ALLOY AT VERY LOW TEMPERATURES
LONGITUDINAL DIRECTION
X, DMIC REPORT NO. 148, FEB. 1961 (REF. 1)
MARTIN CO. JUNE 1961 (REF. 2)
ULTIMATE STRENGTH
-0.2% OFFSET YIELD
EXPOSURE TIME - 1 HOUR
PARENT METAL STRENGTH
WELD STRENGTH
PARENT METAL DUCTILITY
WELD DUCTILITY
ULTIMATE AND 0.2% OFFSET YIELD STRENGTH- PSI x 10^3
ELONGATION - %
TEMPERATURE - °F
80
70
60
50
40
30
20
10
0
-400
-300
-200
-100
0
100

 Figure V-21

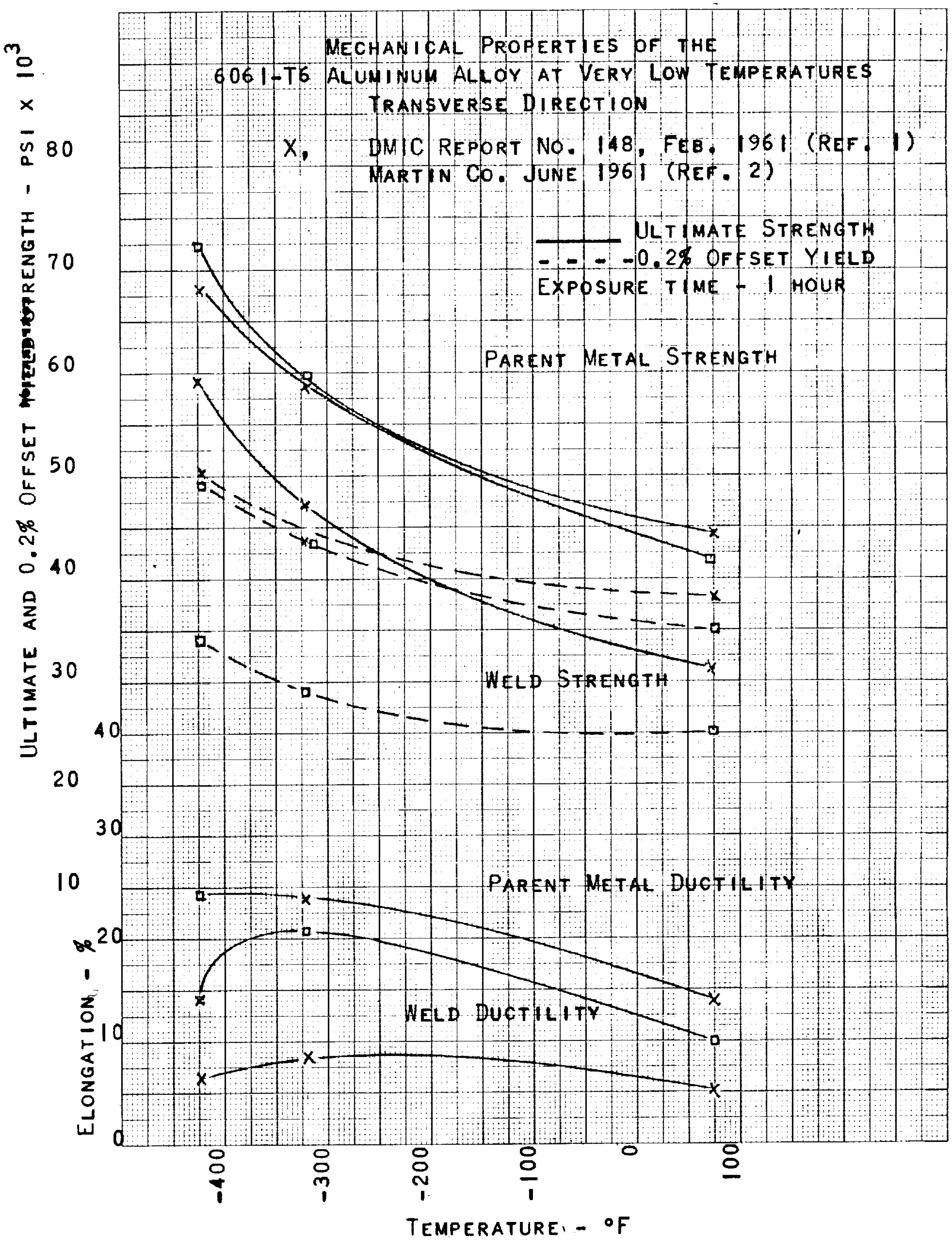
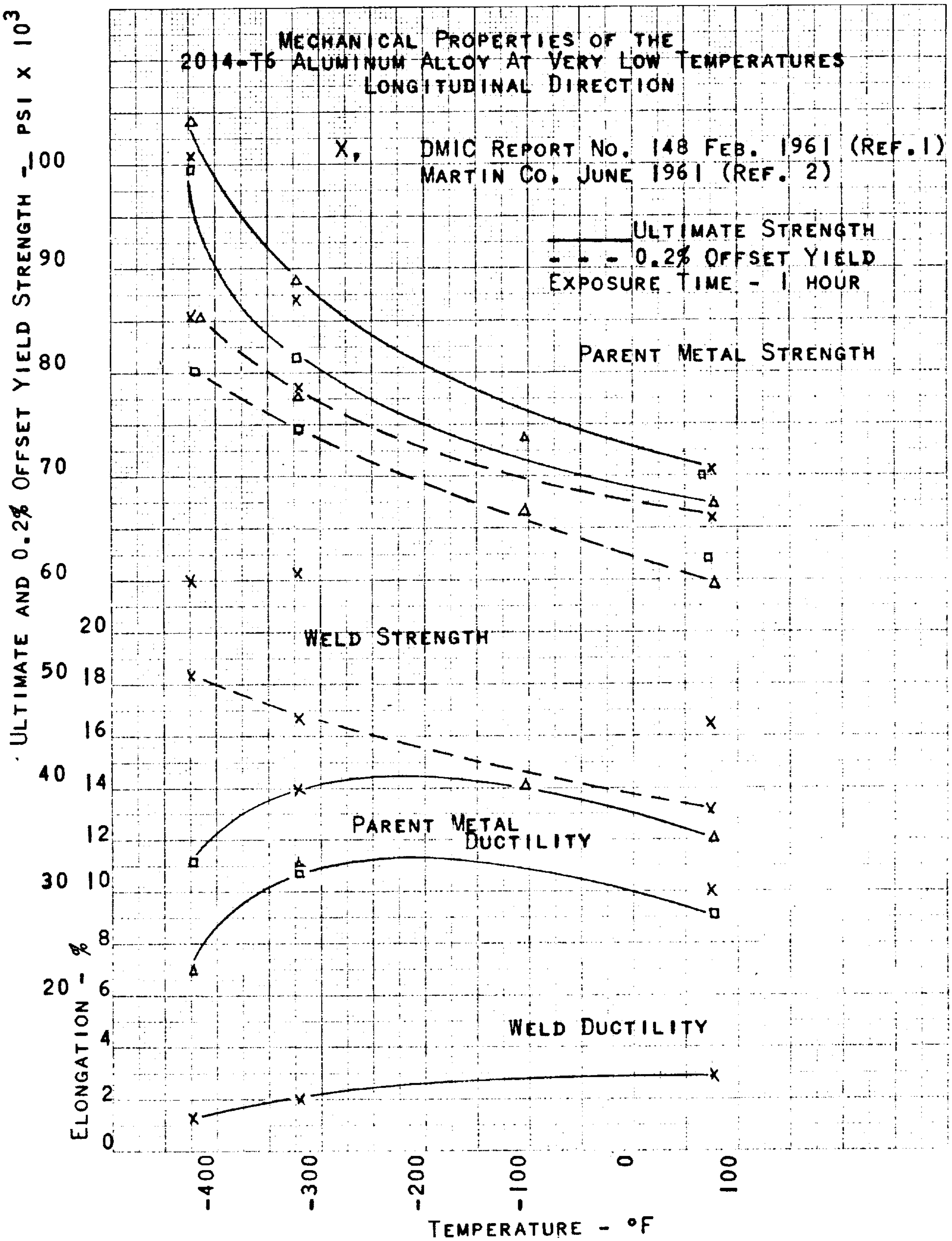

MECHANICAL PROPERTIES OF THE
6061-T6 ALUMINUM ALLOY AT VERY LOW TEMPERATURES
TRANSVERSE DIRECTION
X, DMIC REPORT NO. 148, FEB. 1961 (REF. 1)
MARTIN CO. JUNE 1961 (REF. 2)
ULTIMATE STRENGTH
0.2% OFFSET YIELD
EXPOSURE TIME - 1 HOUR
PARENT METAL STRENGTH
WELD STRENGTH
PARENT METAL DUCTILITY
WELD DUCTILITY
ULTIMATE AND 0.2% OFFSET STRENGTH - PSI x 10³
80
70
60
50
40
30
20
10
ELONGATION - %
40
30
20
10
0
-400
-300
-200
-100
0
100
TEMPERATURE - °F

Figure V-22


Mechanical Properties of the
2014-T6 Aluminum Alloy At Very Low Temperatures
Longitudinal Direction
X, DMIC Report No. 148 Feb. 1961 (Ref. 1)
Martin Co. June 1961 (Ref. 2)
Ultimate Strength
0.2% Offset Yield
Exposure Time - 1 hour
Parent Metal Strength
Weld Strength
Parent Metal Ductility
Weld Ductility
Ultimate and 0.2% Offset Yield Strength - psi x 10^3
Elongation - %
Temperature - °F
-400
-300
-200
-100
0
100

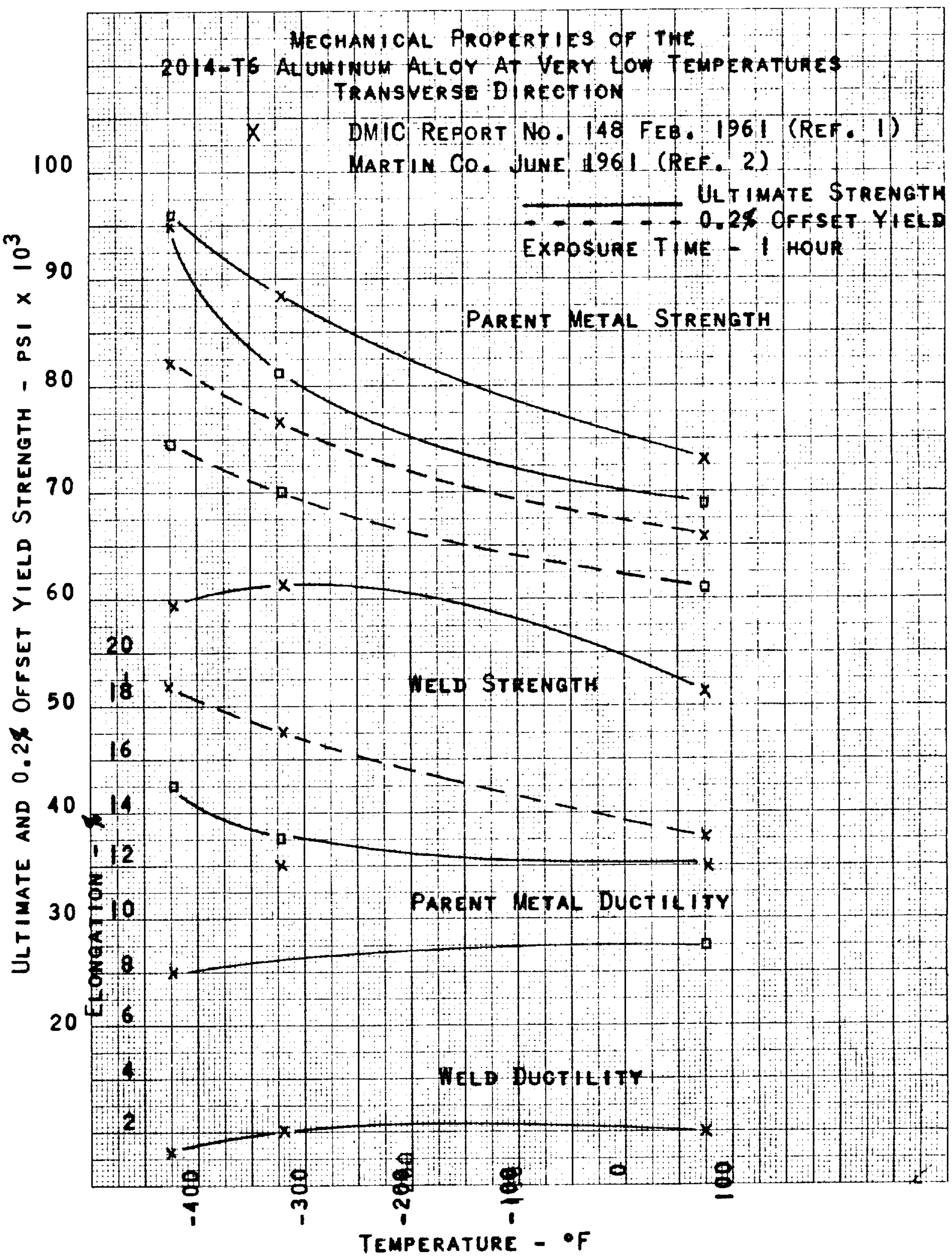

Mechanical Properties of the
2014-T6 Aluminum Alloy At Very Low Temperatures
Transverse Direction
X DMIC Report No. 148 Feb. 1961 (Ref. 1)
Martin Co. June 1961 (Ref. 2)
Ultimate Strength
0.2% Offset Yield
Exposure Time - 1 hour
Parent Metal Strength
Weld Strength
Parent Metal Ductility
Weld Ductility
Ultimate and 0.2% Offset Yield Strength - psi x 10^3
Elongation - %
100
90
80
70
60
50
40
30
20
20
18
16
14
12
10
8
6
4
2
-400
-300
-200
-100
0
100
Temperature - °F

 Figure V-24

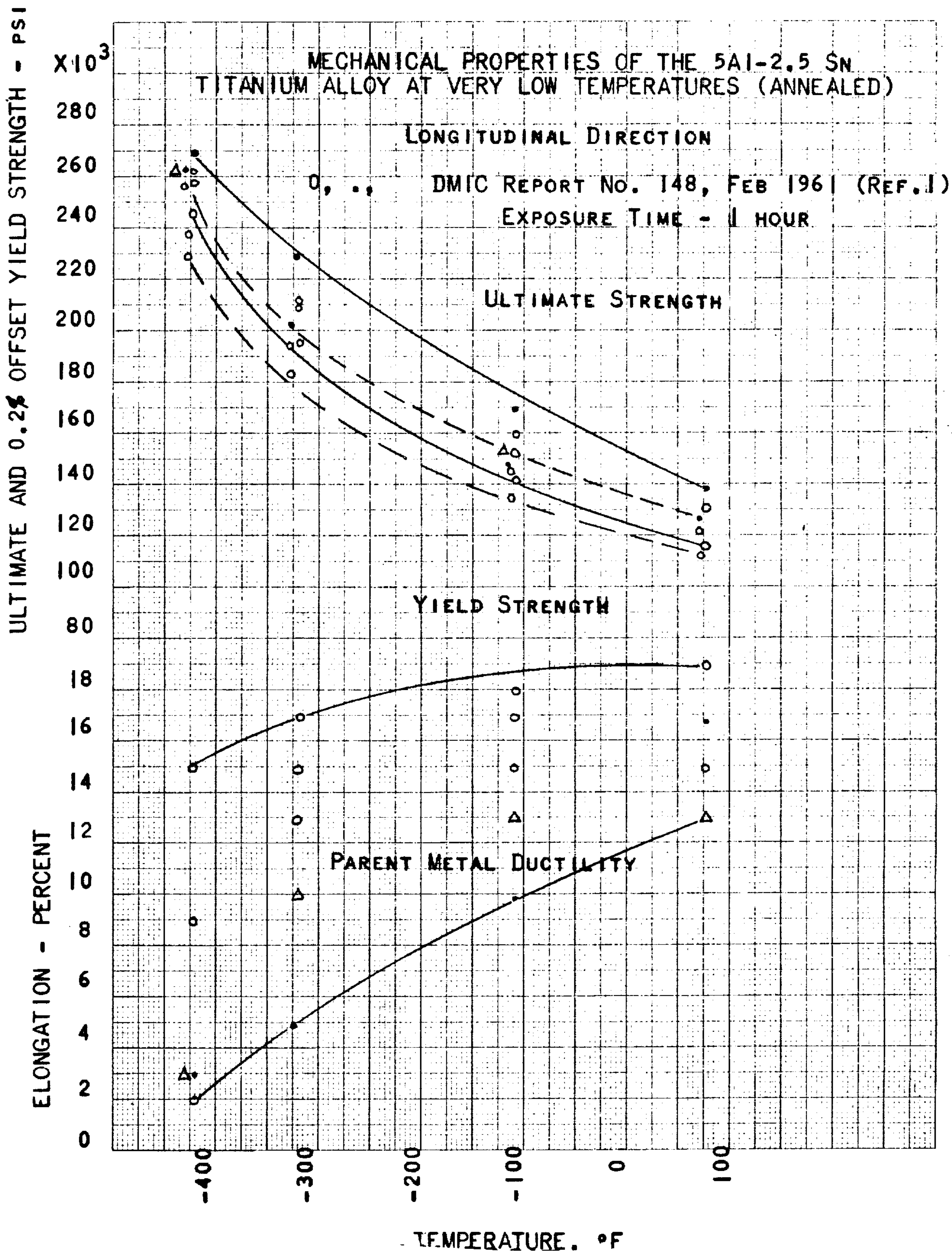

MECHANICAL PROPERTIES OF THE 5Al-2.5 Sn TITANIUM ALLOY AT VERY LOW TEMPERATURES (ANNEALED)
LONGITUDINAL DIRECTION
O, ., DMIC REPORT NO. 148, FEB 1961 (REF. I)
EXPOSURE TIME - 1 HOUR
ULTIMATE STRENGTH
YIELD STRENGTH
PARENT METAL DUCTILITY
ULTIMATE AND 0.2% OFFSET YIELD STRENGTH - PSI
X10^3
280
260
240
220
200
180
160
140
120
100
80
ELONGATION - PERCENT
18
16
14
12
10
8
6
4
2
0
-400
-300
-200
-100
0
100
TEMPERATURE, °F

Figure V-25

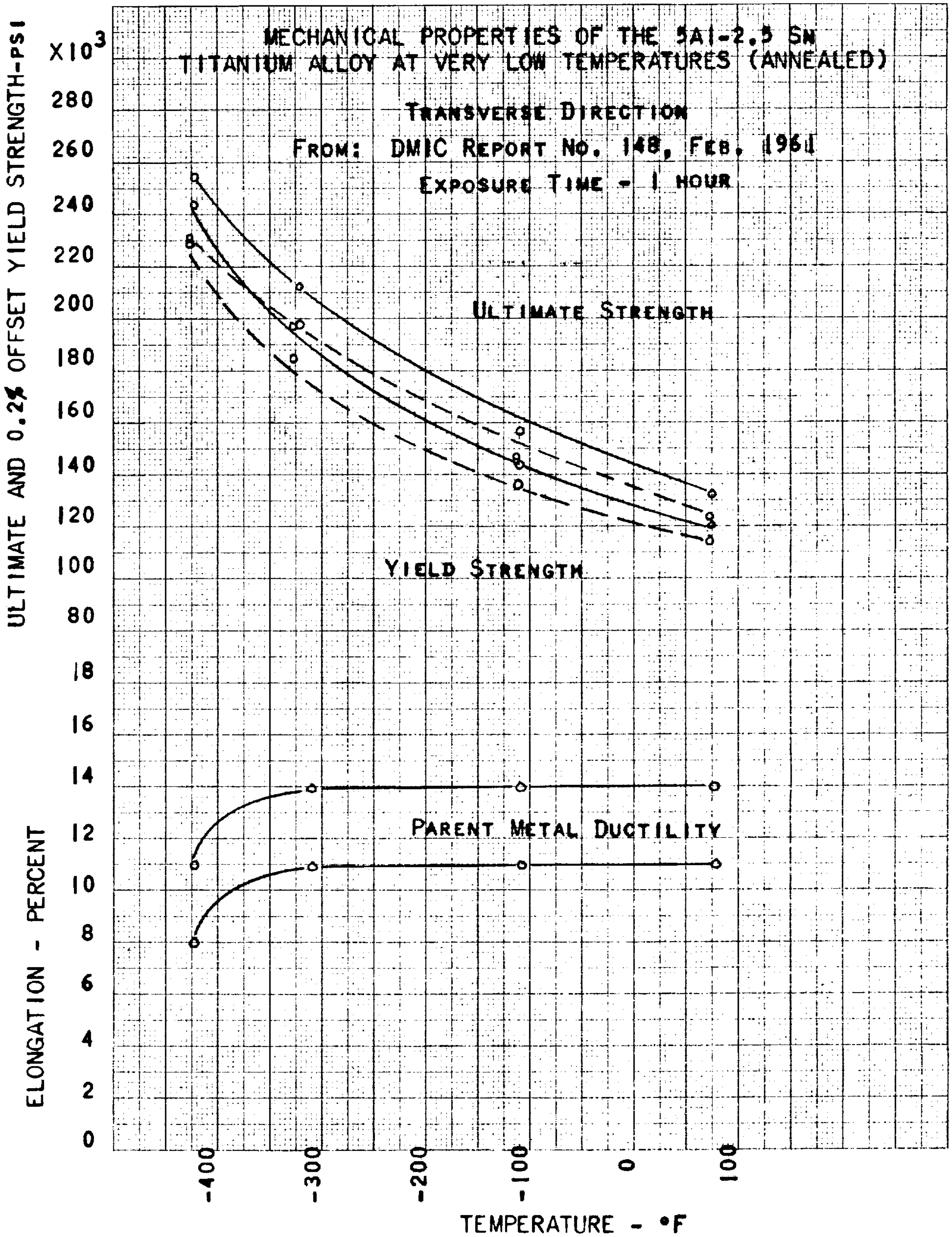

MECHANICAL PROPERTIES OF THE 5Al-2.5 Sn TITANIUM ALLOY AT VERY LOW TEMPERATURES (ANNEALED)
TRANSVERSE DIRECTION
FROM: DMIC REPORT NO. 148, FEB. 1961
EXPOSURE TIME - 1 HOUR
ULTIMATE STRENGTH
YIELD STRENGTH
PARENT METAL DUCTILITY
ULTIMATE AND 0.2% OFFSET YIELD STRENGTH-PSI
X10^3
280
260
240
220
200
180
160
140
120
100
80
ELONGATION - PERCENT
18
16
14
12
10
8
6
4
2
0
-400
-300
-200
-100
0
100
TEMPERATURE - °F

Figure V-26

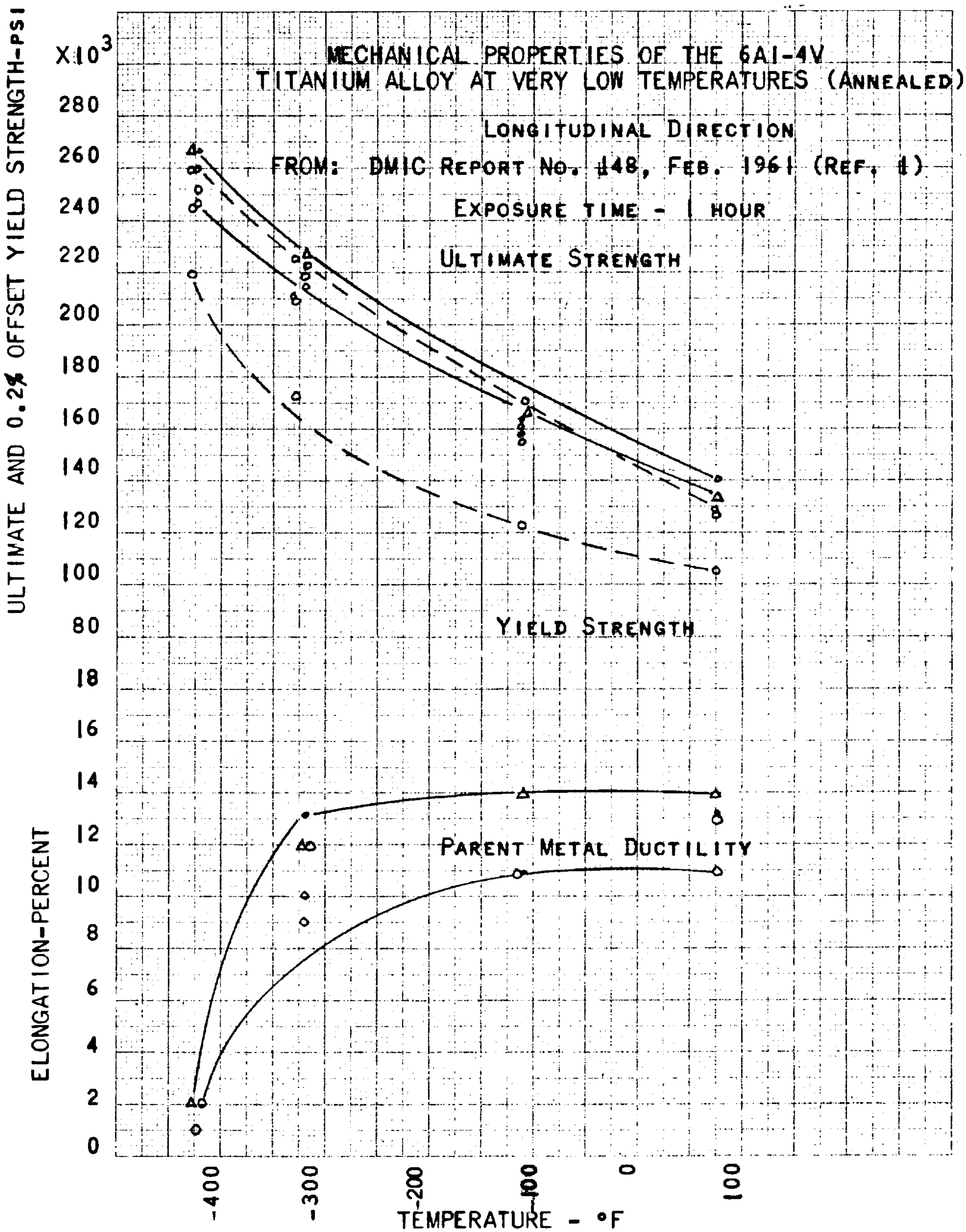

MECHANICAL PROPERTIES OF THE 6Al-4V
TITANIUM ALLOY AT VERY LOW TEMPERATURES (ANNEALED)
LONGITUDINAL DIRECTION
FROM: DMIC REPORT NO. 148, FEB. 1961 (REF. 1)
EXPOSURE TIME - 1 HOUR
ULTIMATE STRENGTH
YIELD STRENGTH
PARENT METAL DUCTILITY
ULTIMATE AND 0.2% OFFSET YIELD STRENGTH-PSI
X10^3
280
260
240
220
200
180
160
140
120
100
80
18
16
14
12
10
8
6
4
2
0
ELONGATION-PERCENT
-400
-300
-200
-100
0
100
TEMPERATURE - °F

Figure V-27

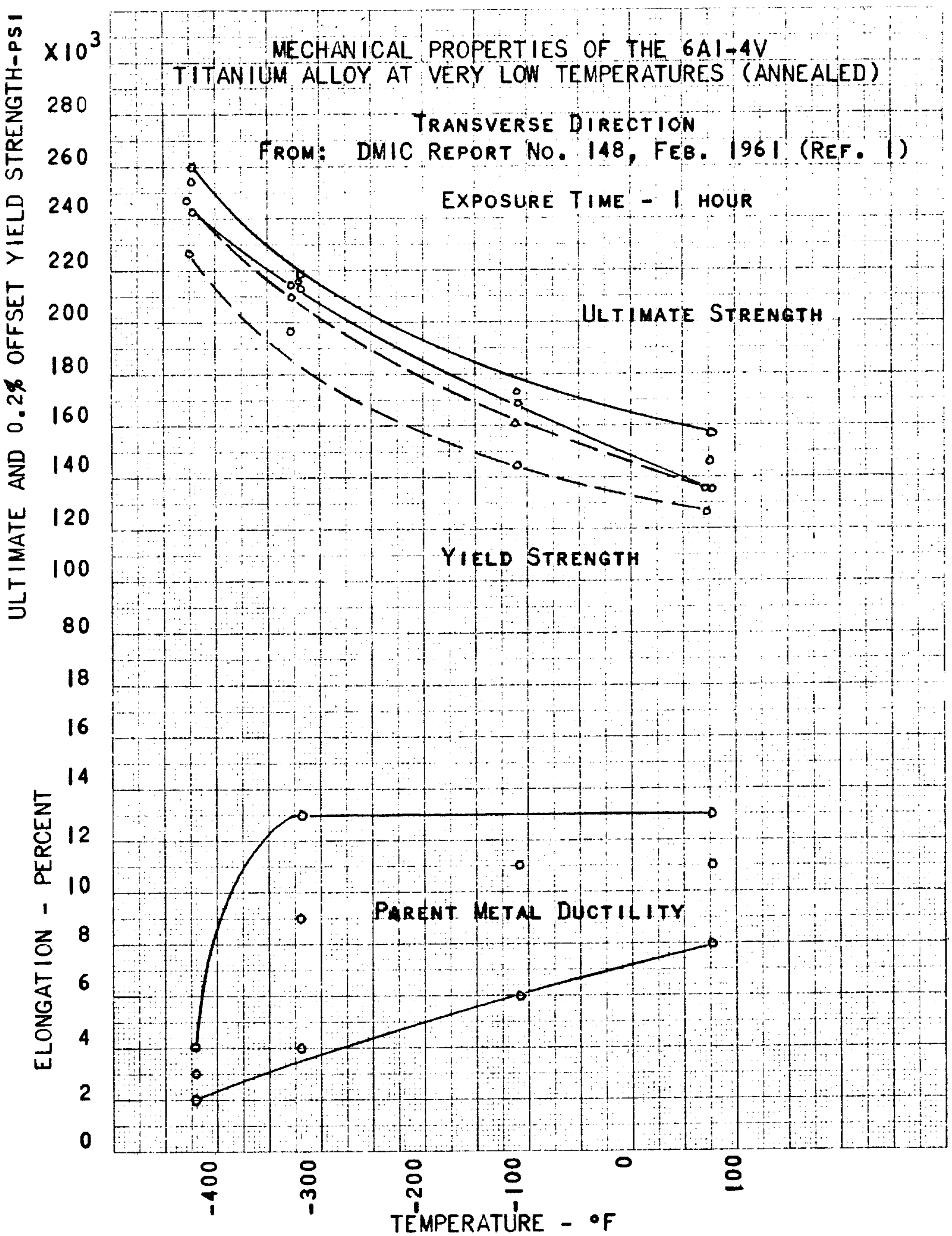

MECHANICAL PROPERTIES OF THE 6Al-4V
TITANIUM ALLOY AT VERY LOW TEMPERATURES (ANNEALED)
TRANSVERSE DIRECTION
FROM: DMIC REPORT NO. 148, FEB. 1961 (REF. 1)
EXPOSURE TIME - 1 HOUR
ULTIMATE STRENGTH
YIELD STRENGTH
PARENT METAL DUCTILITY
X10^3
ULTIMATE AND 0.2% OFFSET YIELD STRENGTH-PSI
280
260
240
220
200
180
160
140
120
100
80
ELONGATION - PERCENT
18
16
14
12
10
8
6
4
2
0
-400
-300
-200
-100
0
100
TEMPERATURE - °F

 Figure V-28

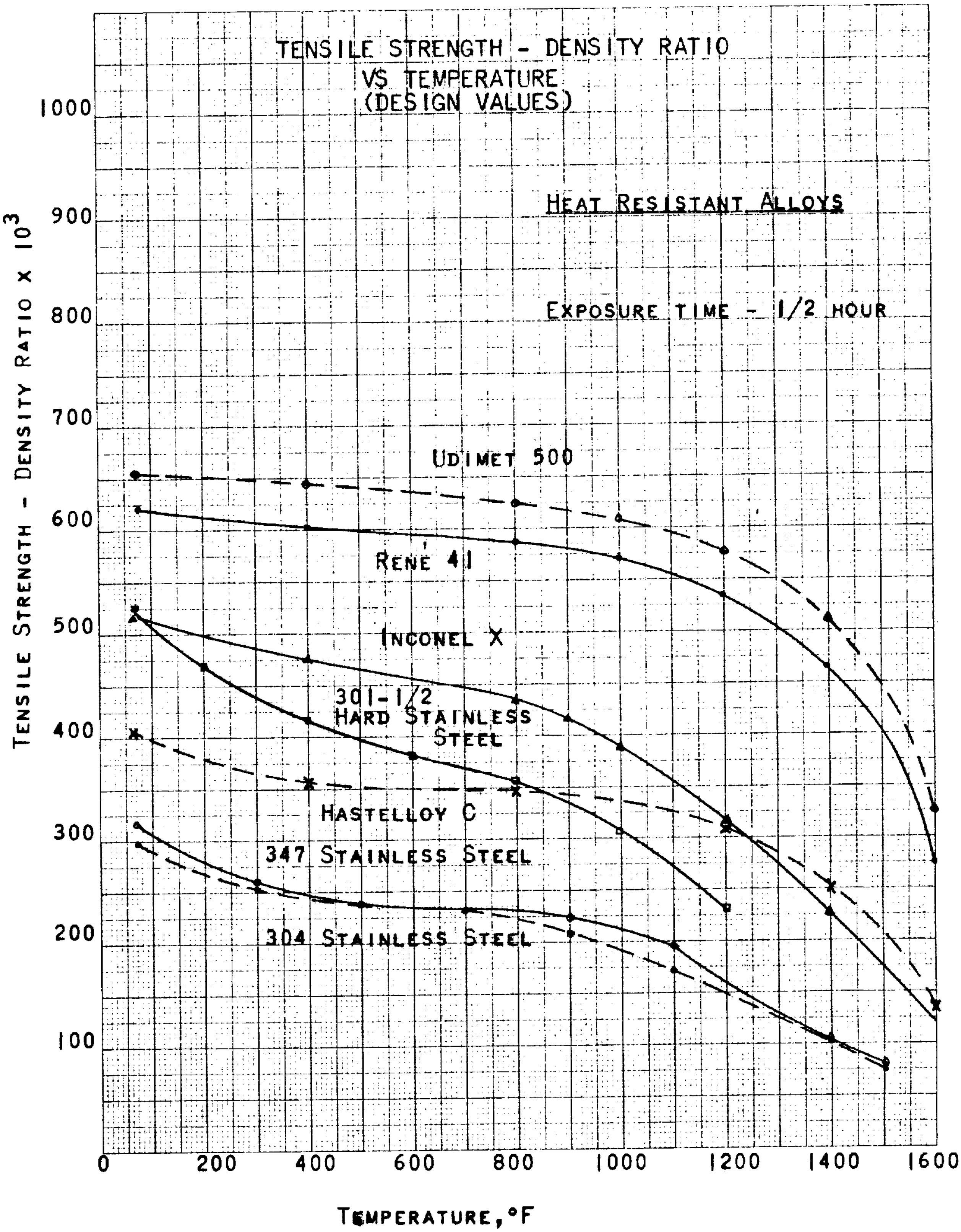

TENSILE STRENGTH - DENSITY RATIO
VS TEMPERATURE
(DESIGN VALUES)
HEAT RESISTANT ALLOYS
EXPOSURE TIME - 1/2 HOUR
UDIMET 500
RENE 41
INCONEL X
301-1/2
HARD STAINLESS
STEEL
HASTELLOY C
347 STAINLESS STEEL
304 STAINLESS STEEL
TENSILE STRENGTH - DENSITY RATIO x 10^3
1000
900
800
700
600
500
400
300
200
100
0
200
400
600
800
1000
1200
1400
1600
TEMPERATURE, °F

 Figure V-29

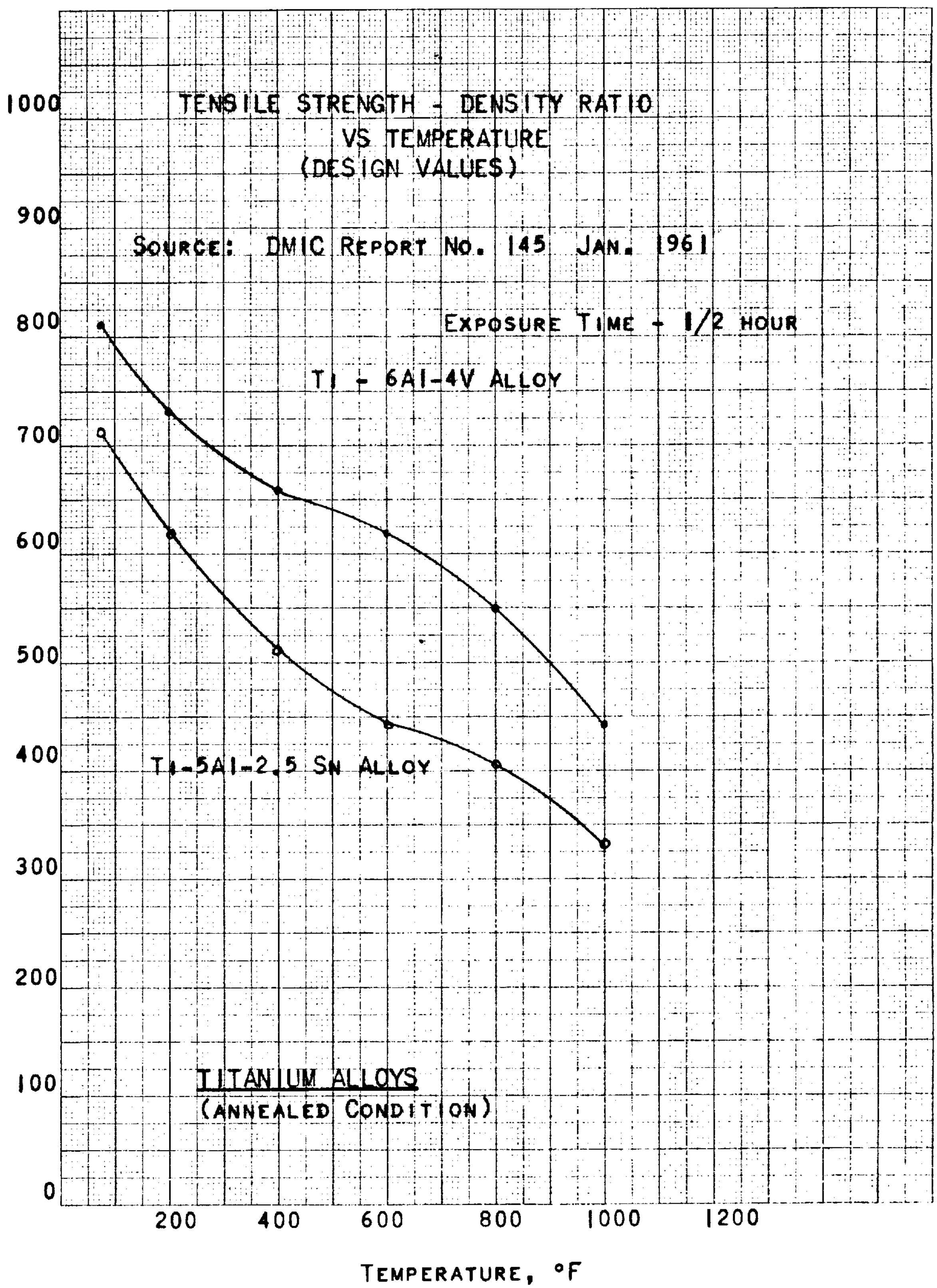

TENSILE STRENGTH - DENSITY RATIO
VS TEMPERATURE
(DESIGN VALUES)
SOURCE: DMIC REPORT NO. 145 JAN. 1961
EXPOSURE TIME - 1/2 HOUR
TI - 6AI-4V ALLOY
TI-5AI-2.5 SN ALLOY
TITANIUM ALLOYS
(ANNEALED CONDITION)
1000
900
800
700
600
500
400
300
200
100
0
200
400
600
800
1000
1200
TEMPERATURE, °F

Figure V-30

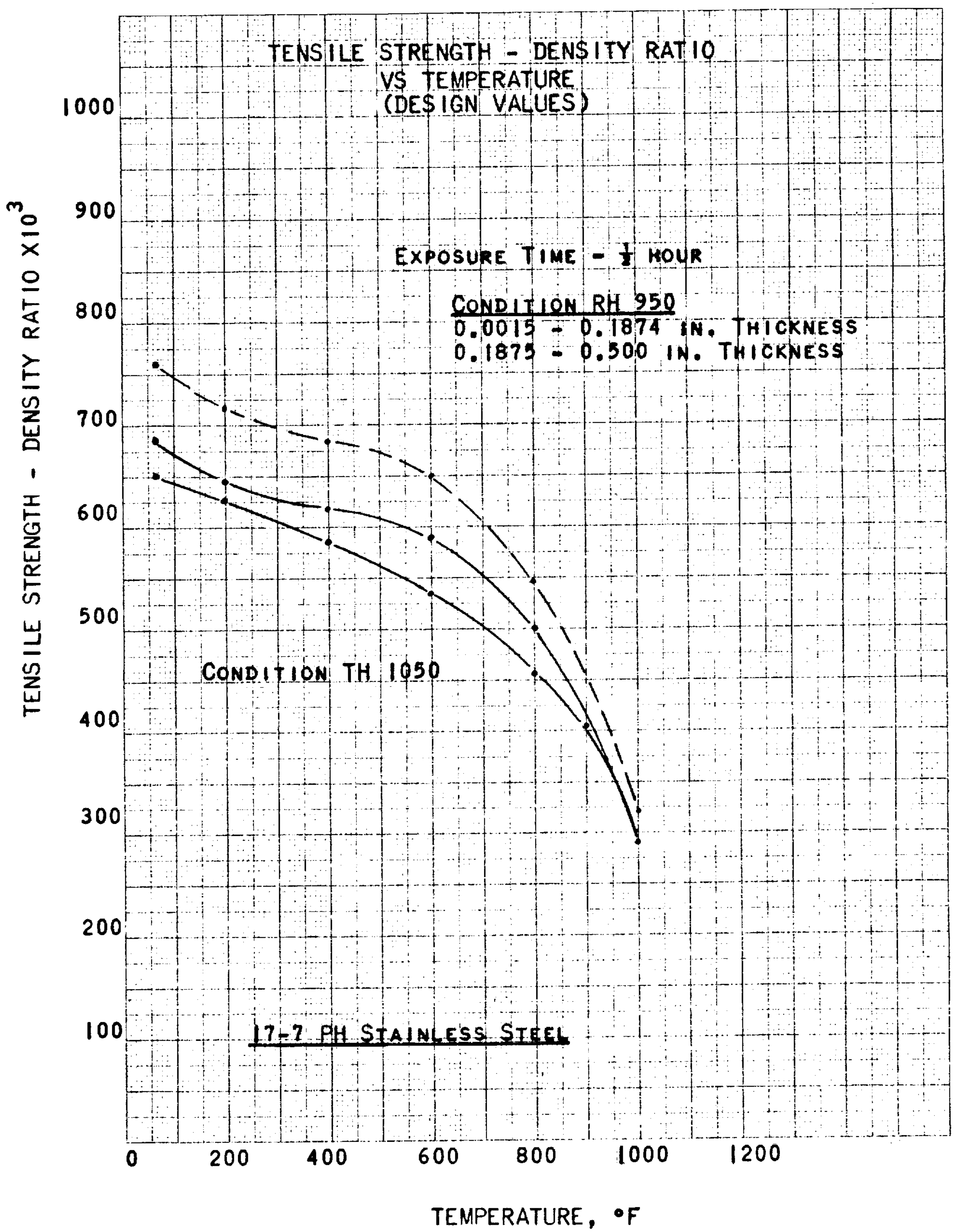

TENSILE STRENGTH - DENSITY RATIO
VS TEMPERATURE
(DESIGN VALUES)
EXPOSURE TIME - ½ HOUR
CONDITION RH 950
0.0015 - 0.1874 IN. THICKNESS
0.1875 - 0.500 IN. THICKNESS
CONDITION TH 1050
17-7 PH STAINLESS STEEL
TENSILE STRENGTH - DENSITY RATIO X10³
1000
900
800
700
600
500
400
300
200
100
0
200
400
600
800
1000
1200
TEMPERATURE, °F

Figure V-31

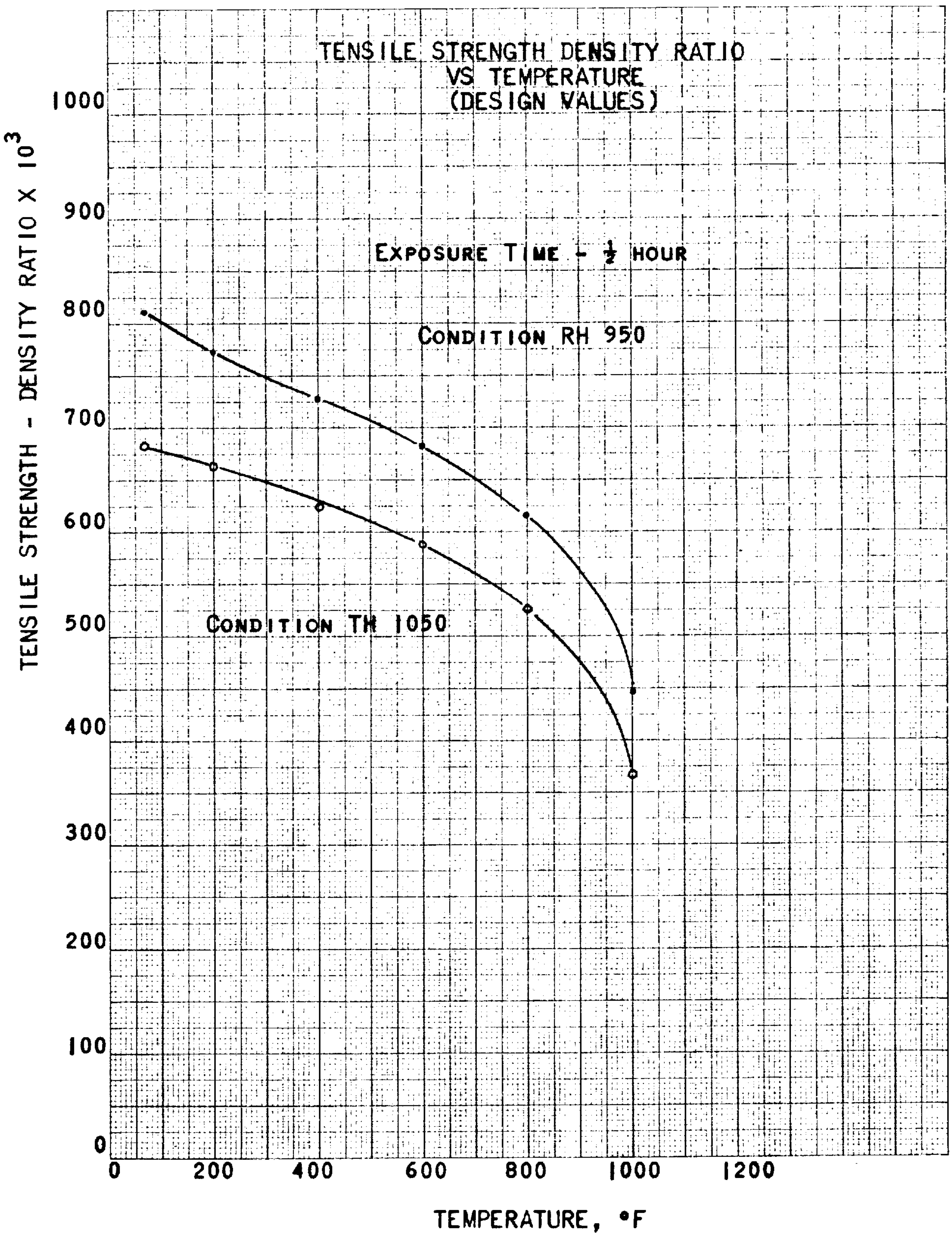

TENSILE STRENGTH DENSITY RATIO
VS TEMPERATURE
(DESIGN VALUES)
EXPOSURE TIME - ½ HOUR
CONDITION RH 950
CONDITION TH 1050
TENSILE STRENGTH - DENSITY RATIO X 10³
0
100
200
300
400
500
600
700
800
900
1000
0
200
400
600
800
1000
1200
TEMPERATURE, °F

Figure V-32

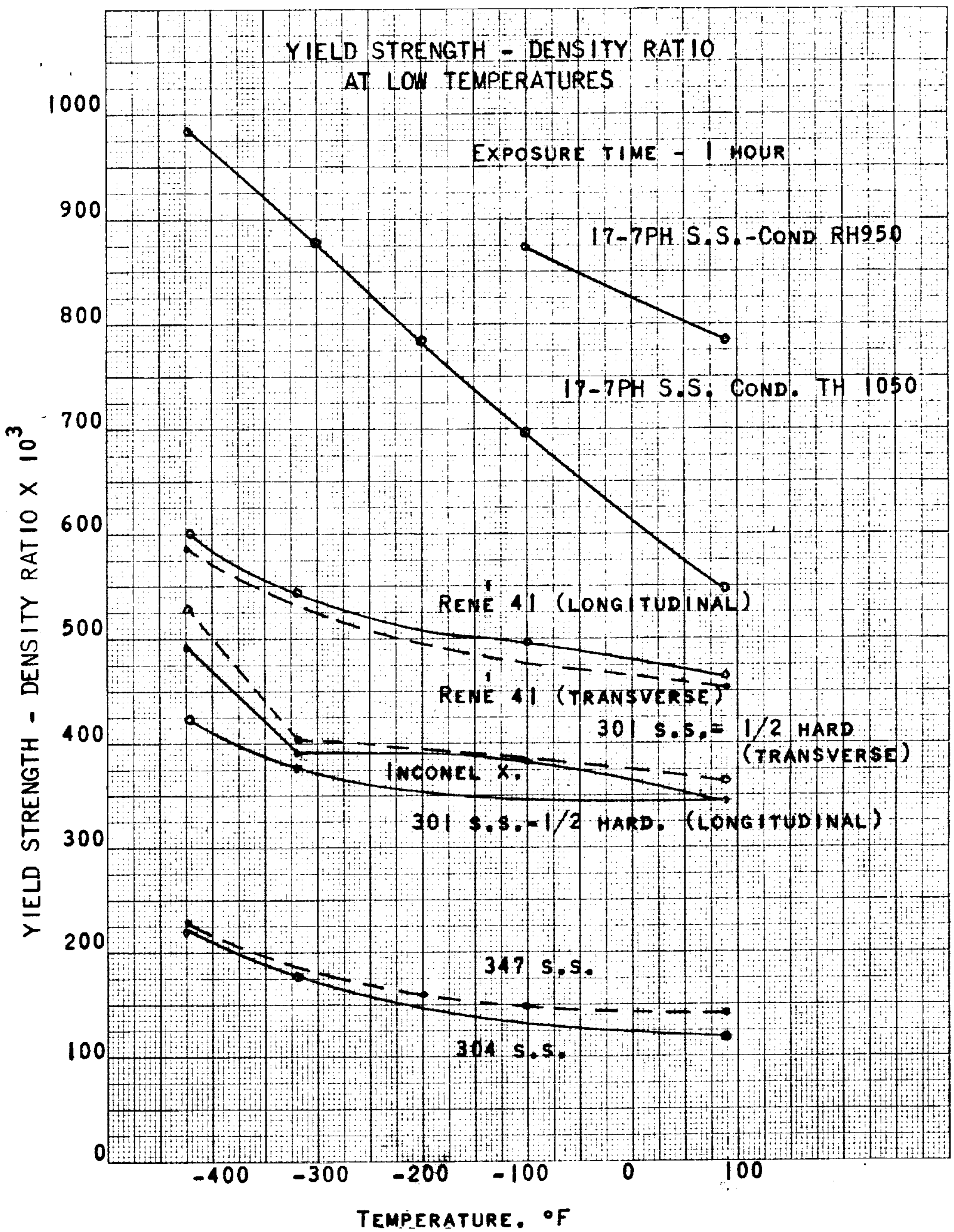

YIELD STRENGTH - DENSITY RATIO
AT LOW TEMPERATURES
EXPOSURE TIME - 1 HOUR
17-7PH S.S.-COND RH950
17-7PH S.S. COND. TH 1050
RENÉ 41 (LONGITUDINAL)
RENÉ 41 (TRANSVERSE)
301 S.S.-1/2 HARD
(TRANSVERSE)
INCONEL X.
301 S.S.-1/2 HARD. (LONGITUDINAL)
347 S.S.
304 S.S.
YIELD STRENGTH - DENSITY RATIO X 10^3
1000
900
800
700
600
500
400
300
200
100
0
-400
-300
-200
-100
0
100
TEMPERATURE, °F

 Figure V-33

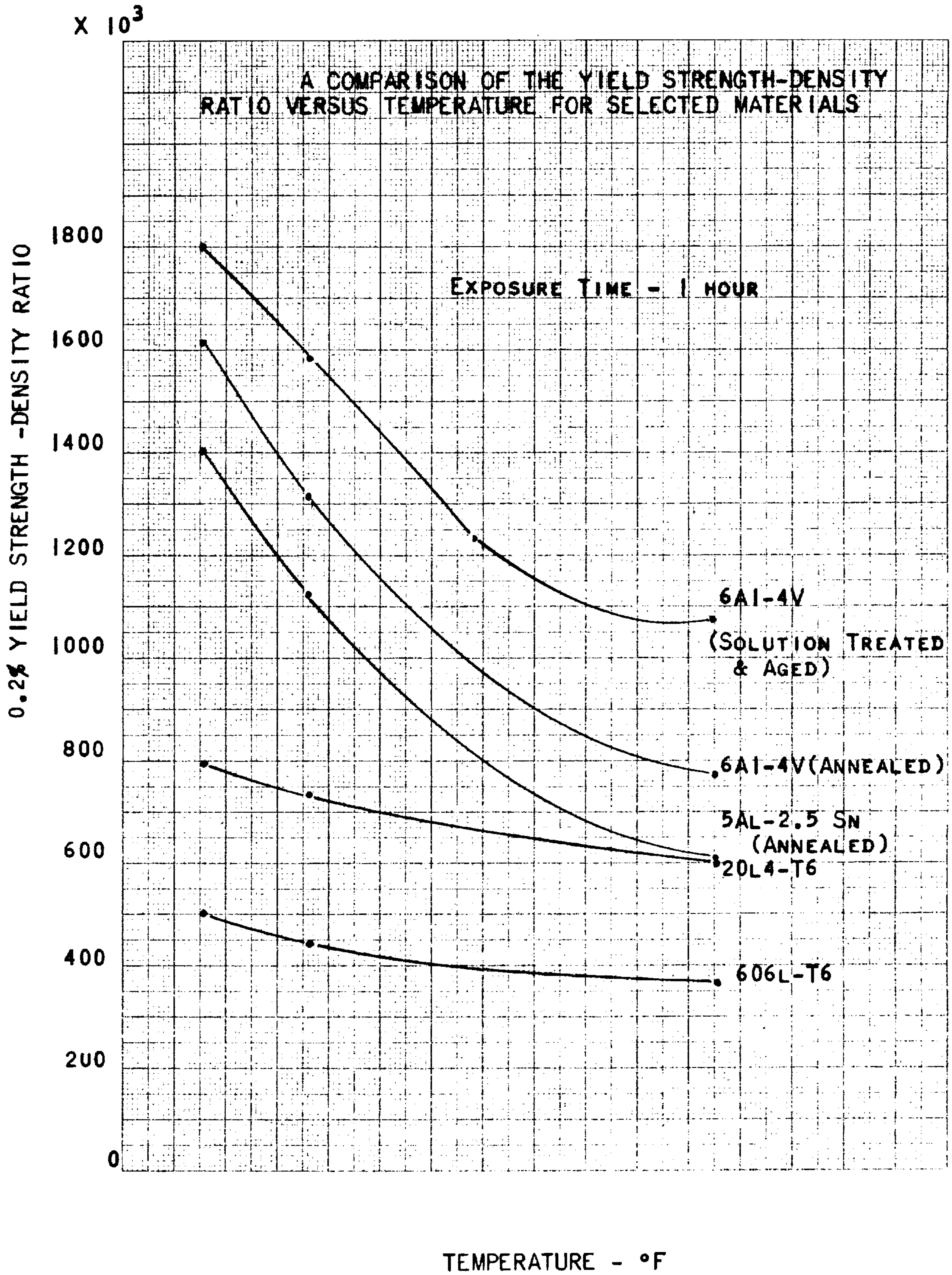

X 10^3
A COMPARISON OF THE YIELD STRENGTH-DENSITY RATIO VERSUS TEMPERATURE FOR SELECTED MATERIALS
EXPOSURE TIME - 1 HOUR
6Al-4V
(SOLUTION TREATED & AGED)
6Al-4V(ANNEALED)
5AL-2.5 SN
(ANNEALED)
2014-T6
6061-T6
0.2% YIELD STRENGTH -DENSITY RATIO
1800
1600
1400
1200
1000
800
600
400
200
0
TEMPERATURE - °F

Figure V-34

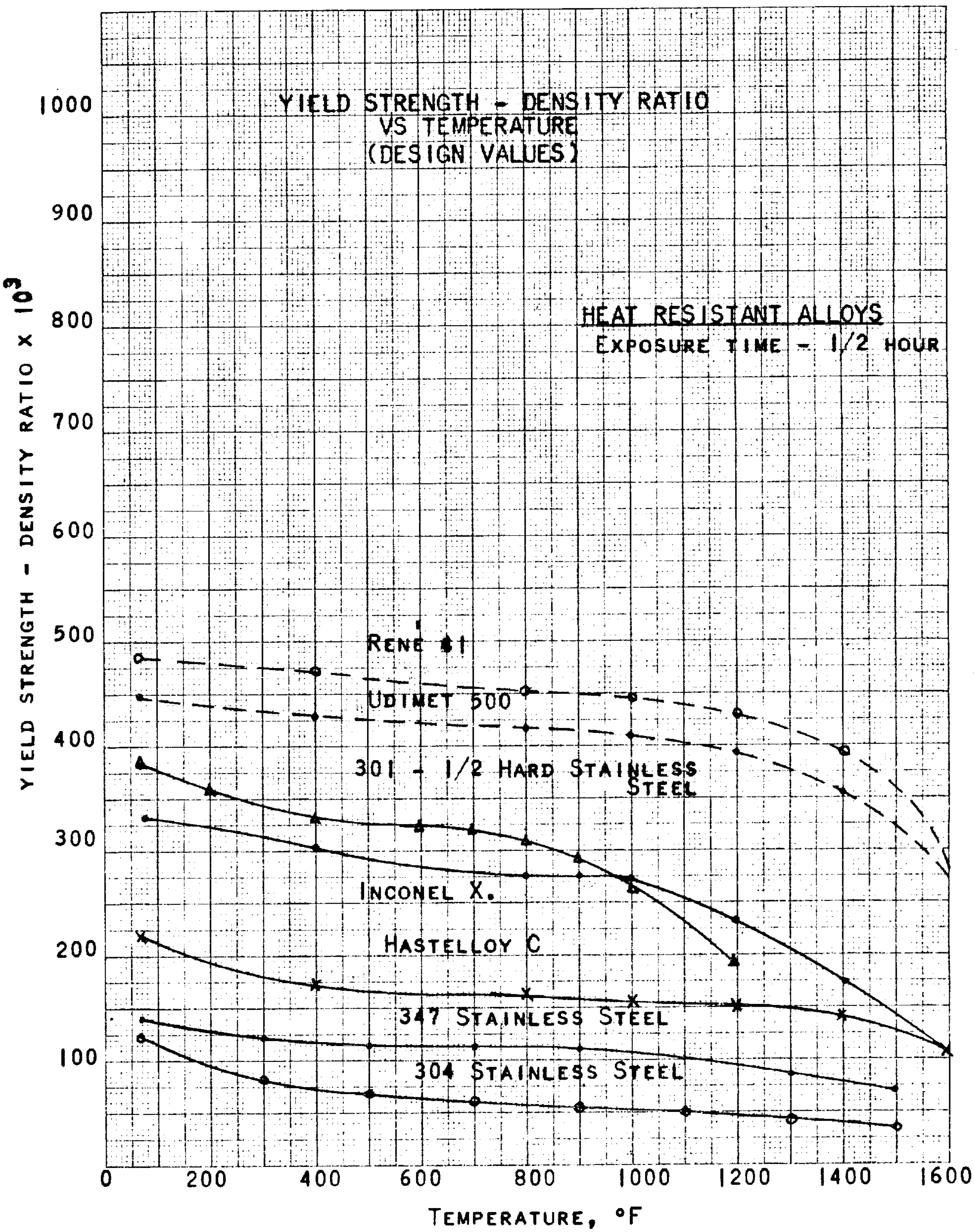

YIELD STRENGTH - DENSITY RATIO
VS TEMPERATURE
(DESIGN VALUES)
HEAT RESISTANT ALLOYS
EXPOSURE TIME - 1/2 HOUR
RENE 41
UDIMET 500
301 - 1/2 HARD STAINLESS STEEL
INCONEL X.
HASTELLOY C
347 STAINLESS STEEL
304 STAINLESS STEEL
1000
900
800
700
600
500
400
300
200
100
0
200
400
600
800
1000
1200
1400
1600
TEMPERATURE, °F
YIELD STRENGTH - DENSITY RATIO x 10^3

 Figure V-35

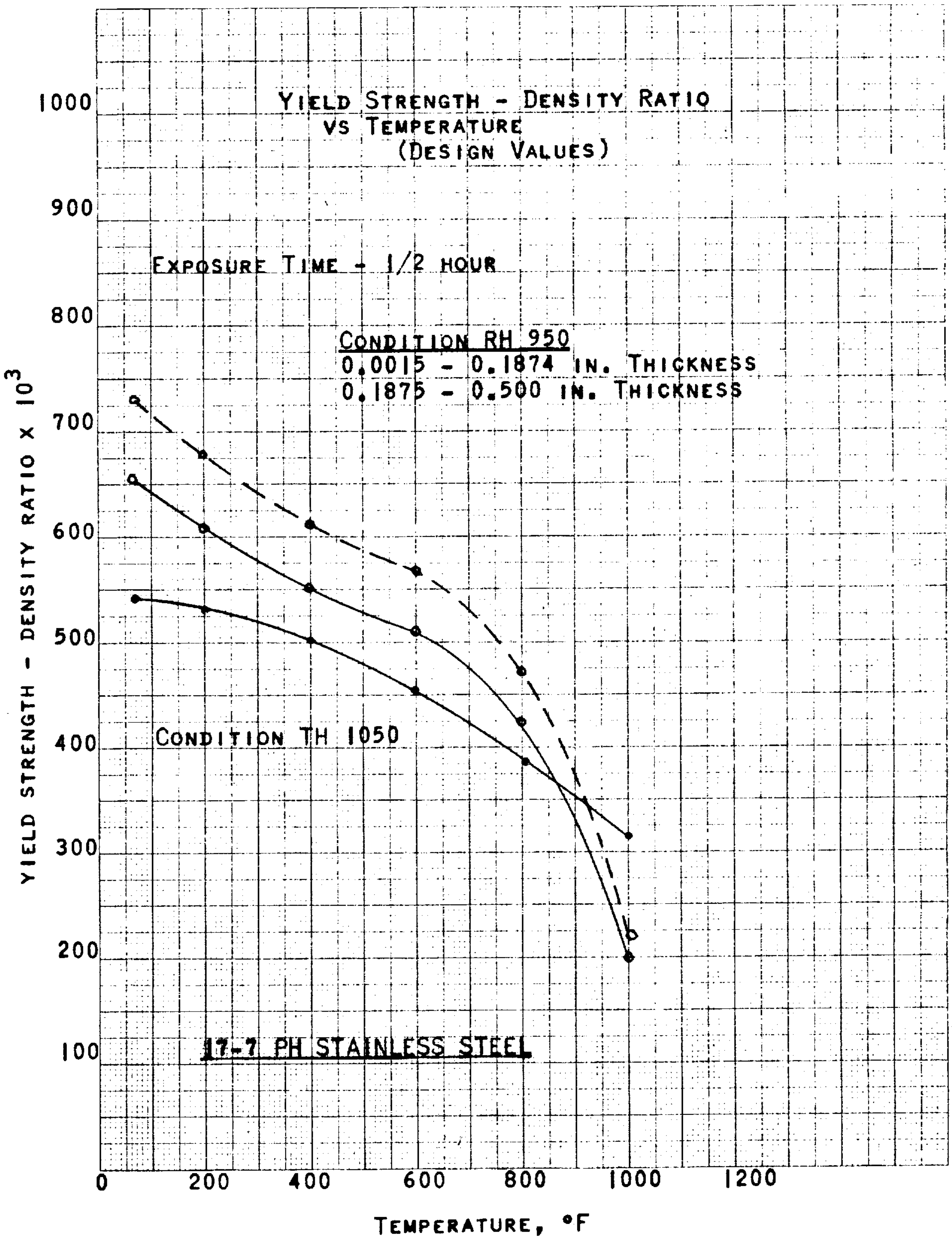

YIELD STRENGTH - DENSITY RATIO
VS TEMPERATURE
(DESIGN VALUES)
EXPOSURE TIME - 1/2 HOUR
CONDITION RH 950
0.0015 - 0.1874 IN. THICKNESS
0.1875 - 0.500 IN. THICKNESS
CONDITION TH 1050
17-7 PH STAINLESS STEEL
YIELD STRENGTH - DENSITY RATIO x 10³
TEMPERATURE, °F
1000
900
800
700
600
500
400
300
200
100
0
200
400
600
800
1000
1200

 Figure V-36

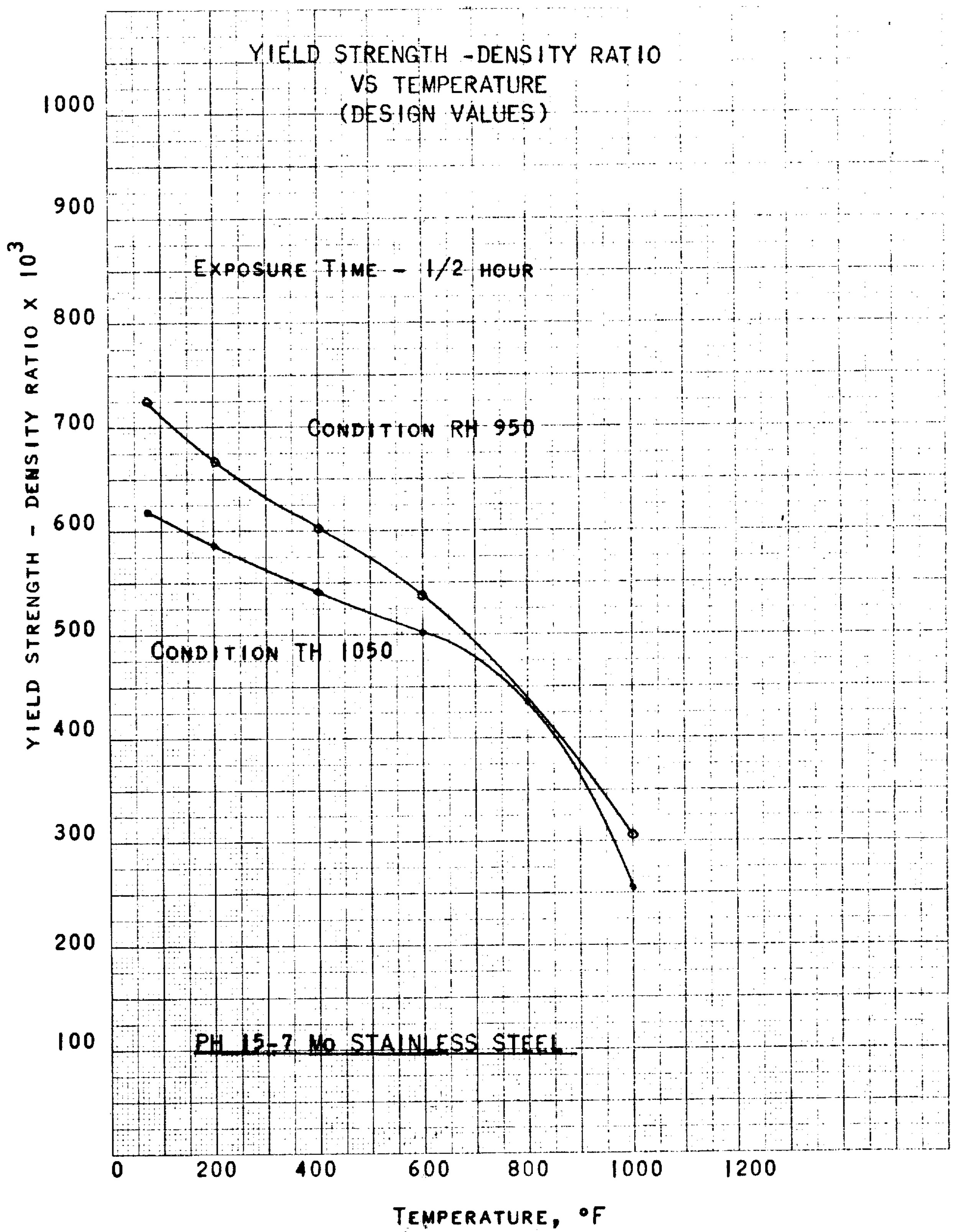

YIELD STRENGTH -DENSITY RATIO
VS TEMPERATURE
(DESIGN VALUES)
EXPOSURE TIME - 1/2 HOUR
CONDITION RH 950
CONDITION TH 1050
PH 15-7 Mo STAINLESS STEEL
YIELD STRENGTH - DENSITY RATIO X 10^3
1000
900
800
700
600
500
400
300
200
100
0
200
400
600
800
1000
1200
TEMPERATURE, °F

Figure V-37

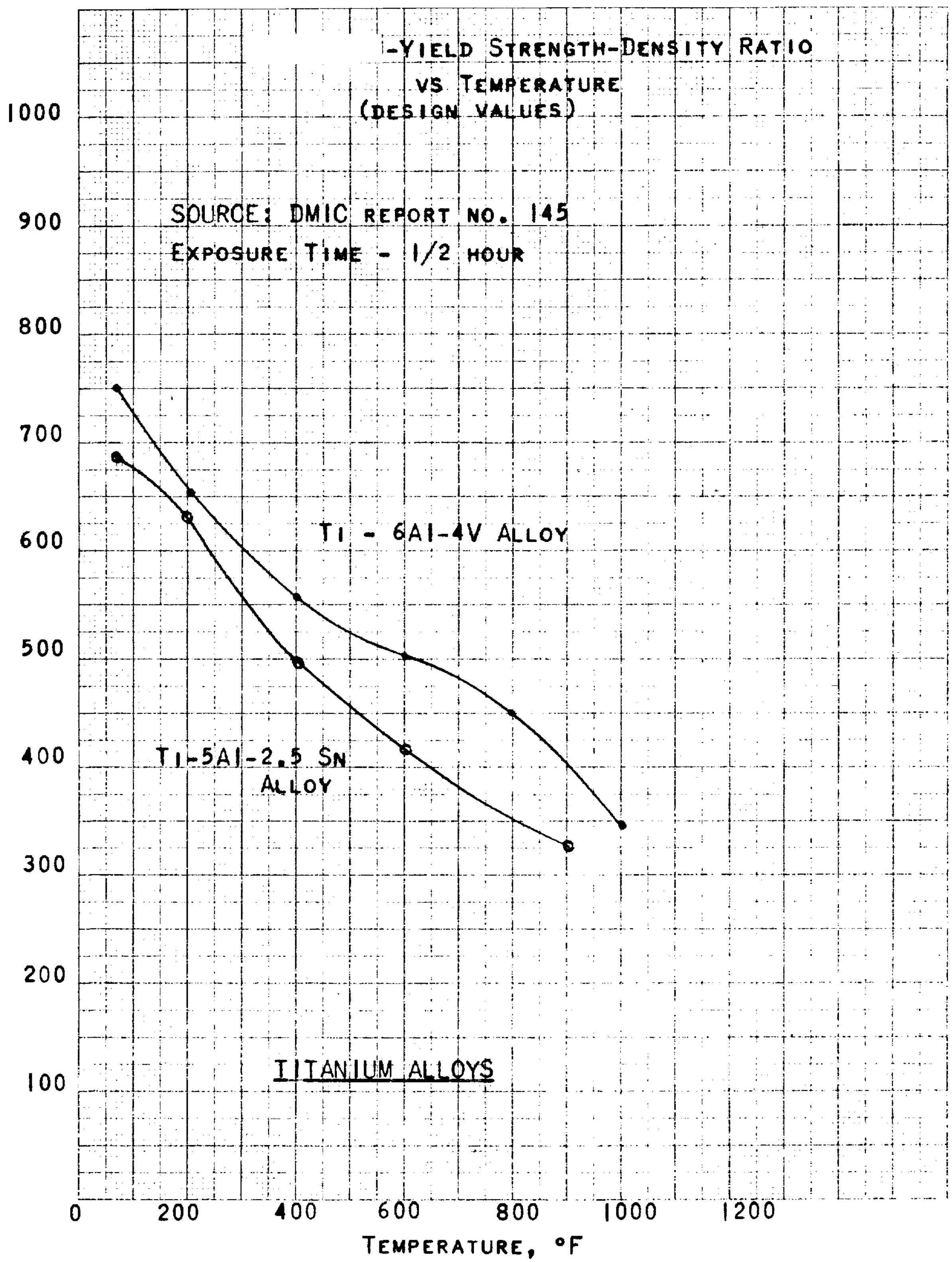

-Yield Strength-Density Ratio
vs Temperature
(design values)
Source: DMIC report no. 145
Exposure Time - 1/2 hour
Ti - 6Al-4V Alloy
Ti-5Al-2.5 Sn
Alloy
Titanium Alloys
1000
900
800
700
600
500
400
300
200
100
0
200
400
600
800
1000
1200
Temperature, °F

Figure V-38

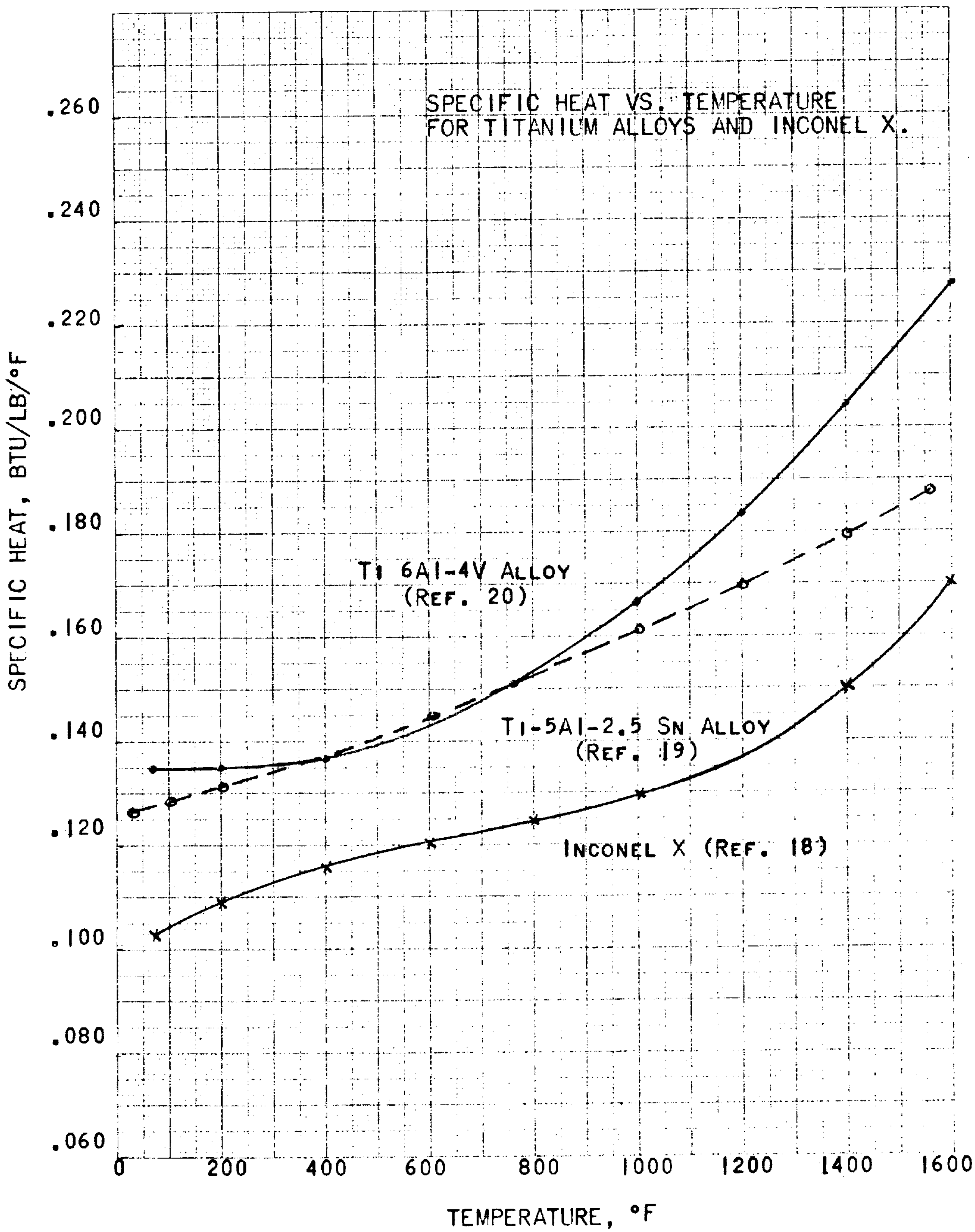

SPECIFIC HEAT VS. TEMPERATURE
FOR TITANIUM ALLOYS AND INCONEL X.
Ti 6Al-4V Alloy
(Ref. 20)
Ti-5Al-2.5 Sn Alloy
(Ref. 19)
Inconel X (Ref. 18)
SPECIFIC HEAT, BTU/LB/°F
.260
.240
.220
.200
.180
.160
.140
.120
.100
.080
.060
0
200
400
600
800
1000
1200
1400
1600
TEMPERATURE, °F

Figure V-39

SPACE ENVIRONMENT

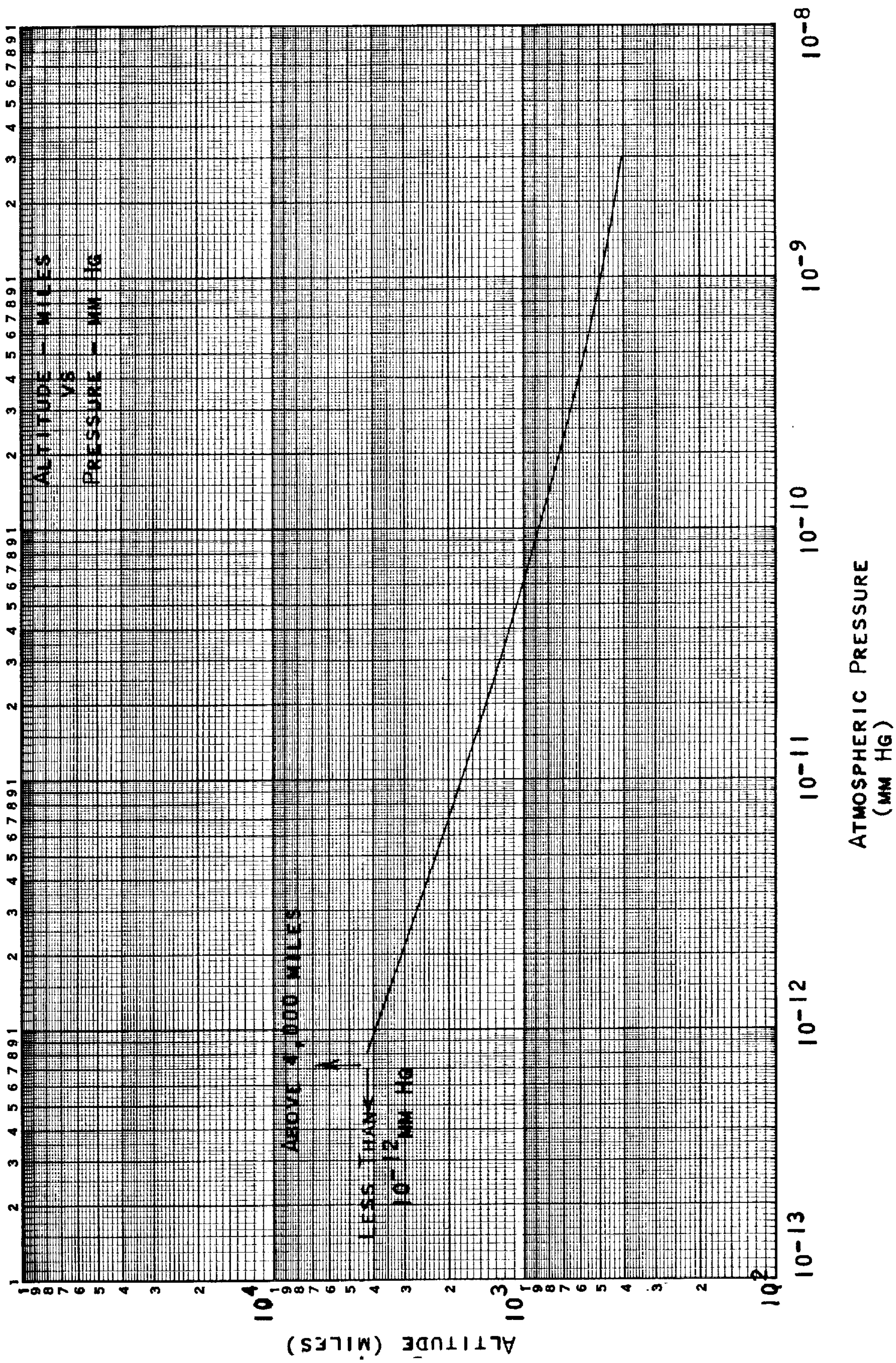


Figure V-40

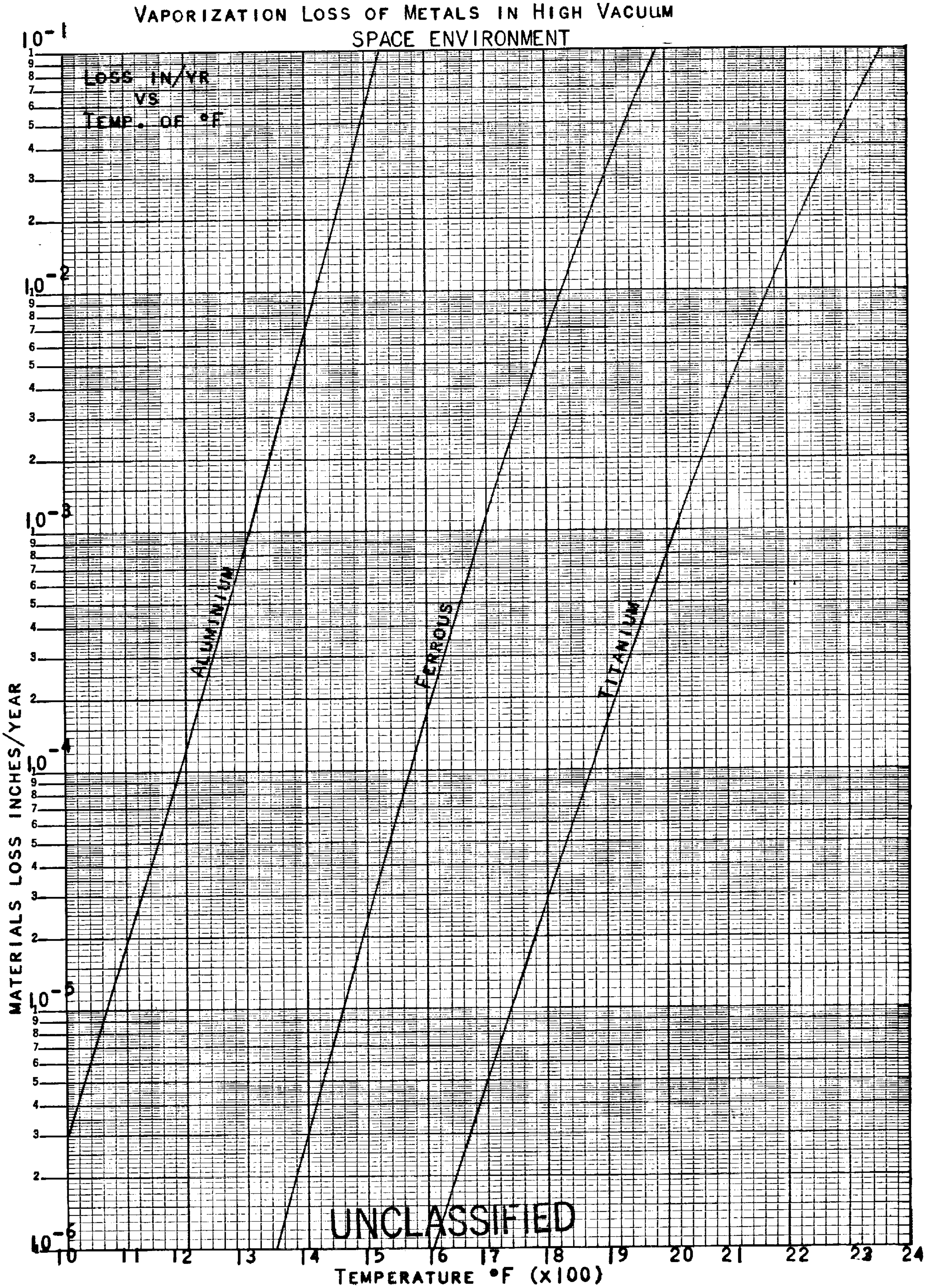

VAPORIZATION LOSS OF METALS IN HIGH VACUUM
SPACE ENVIRONMENT
LOSS IN/YR
VS
TEMP. OF °F
ALUMINIUM
FERROUS
TITANIUM
MATERIALS LOSS INCHES/YEAR
TEMPERATURE °F (x100)
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
UNCLASSIFIED

Figure V-41

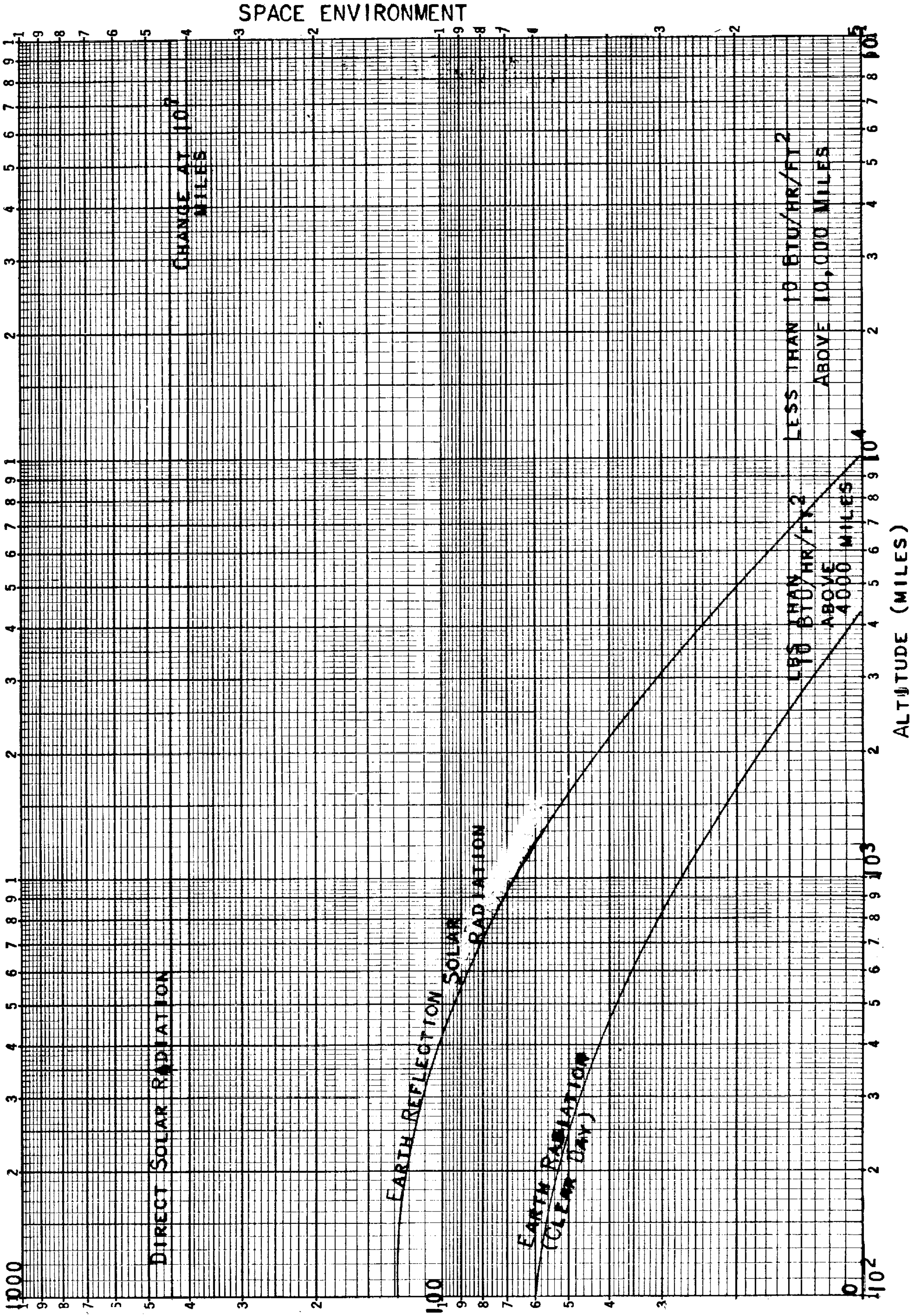
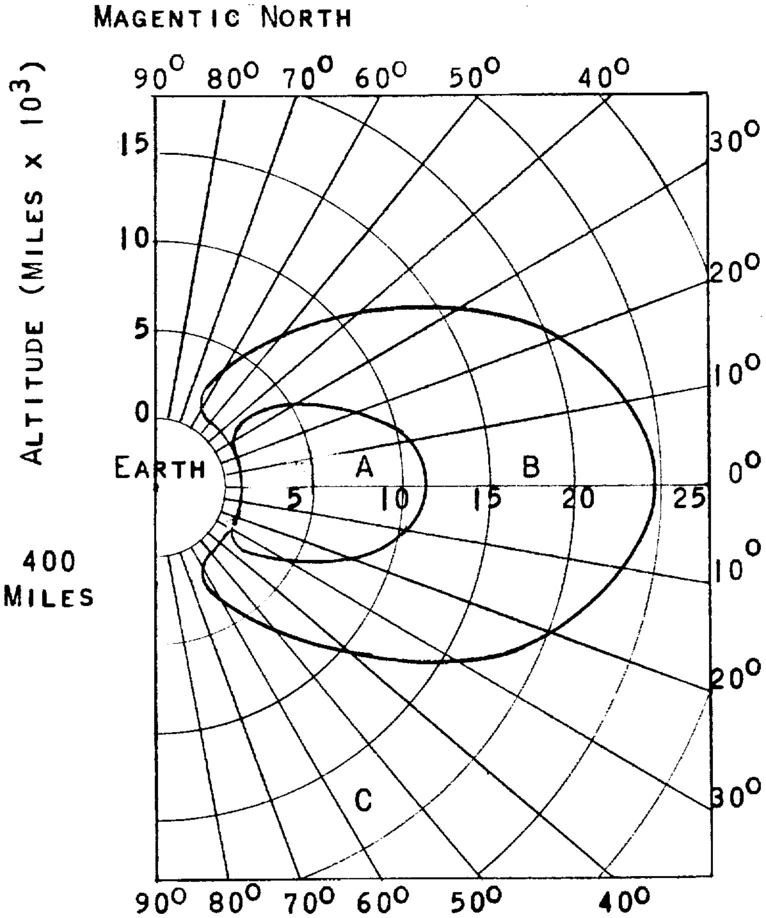

SPACE ENVIRONMENT
DIRECT SOLAR RADIATION
CHANGE AT 10^7 MILES
EARTH REFLECTION SOLAR RADIATION
EARTH RADIATION (CLEAR DAY)
LESS THAN 10 BTU/HR/FT^2
ABOVE 10,000 MILES
LESS THAN 10 BTU/HR/FT^2
ABOVE 4000 MILES
ALTITUDE (MILES)

Figure V-42

SPACE ENVIRONMENT



SPACE RADIATION DOSAGE (NON-METALS)

ERGS/GRAM-YEAR THROUGH L GRAM/CM^2

AREA "A" = 10^7 - 10^8

AREA "B" = 10^6 - 10^8 QUIET-DAY 24,000 MILES ALTITUDE
ACTIVE-DAY 48,000 MILES ALTITUDE

AREA "C" = 10^4 - 10^5

SPACE RADIATION DOSAGE (METALS)

FRACTION OF ATOMS DISPLACED/YR.

AREA "A" & "B" - 10^{-9} AT SURFACE ONLY

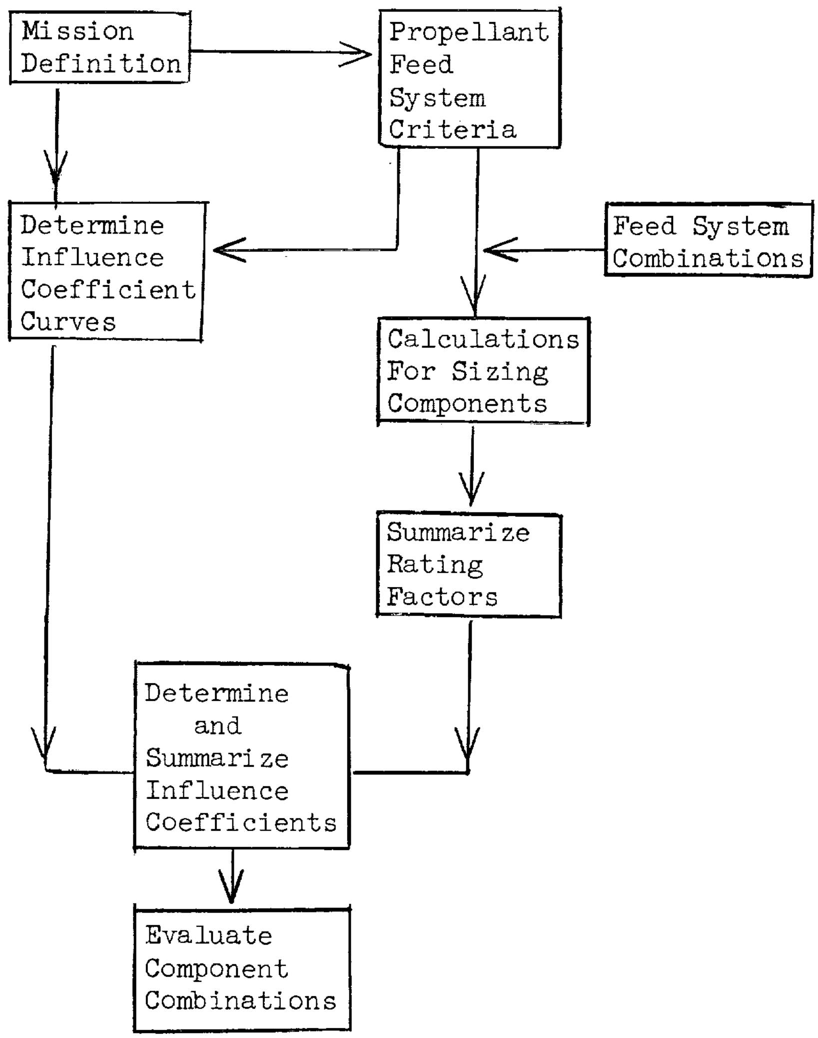
AREA "C" - 10^{-13} AT SURFACE ONLY

Figure V-43

VI. DESIGN EVALUATION

A. EXAMPLE

A design evaluation of various component combinations which may be selected for a given mission can proceed as follows:



B. SAMPLE MISSION

1. Mission is defined in terms of:

Propellants to be used

I_{sp}

Mixture ratio

Thrust

Chamber pressure

Total impulse

Restarts

Sample Mission:

Manned vehicle, upper stage

Propellants LO_2/LH_2

$I_{sp} = 420$ sec

MR = 5.0

Fixed 10,000-lb thrust

2 restarts, 2-day coast

$P_c = 200$ psia

Total impulse = 2.5×10^6 lb/sec

2. Propellant pressurization system requirements are calculated utilizing Section IV, Volume I of this design guide. The calculations include:

Propellant tank pressure

Volume of propellant expelled

Expulsion work

Pressurant flow rate

Sample Mission:

Propellant pressurization system criteria

$\dot{\omega}_t = 23.8$ lb/sec

$\dot{\omega}_f = 3.97$ lb/sec; $\rho_f = 4.3$ lb/ft^3; $Q_f = 0.924$ ft^3/sec

$\dot{\omega}_o = 19.80$ lb/sec; $\rho_o = 70.6$ lb/ft^3; $Q_o = 0.280$ ft^3/sec

Burning time = 250 sec

Propellant tank pressure = 270 psia

Tank volumes; LO_2 = 70 ft^3

LH_2 = 231 ft^3

Total 301 ft^3

Expulsion work;

LO_2 = 131 ft/lb

LH_2 = 433 ft/lb

3. Utilizing the data of 1 and 2 above determine influence coefficient curves. The determination technique is described in Section III, Volume I of this design guide.

The influence coefficient curves of a sample mission and a sample candidate pressurization system will be evaluated on the basis of reliability, weight, and size. Figures VI-1, VI-2 and VI-3 show the influence coefficient vs influence factor size.

4. Calculate the sizes of the components indicated by the choice of candidate pressurization systems. Sizing calculations are shown in Volume III of this design guide.

The sample mission candidate systems chosen are shown in Figures VI-4 through VI-8. Calculations for sizing the components are completed, e.g. check valves

$$Q_o = Av \qquad\qquad Q_o = 0.280\ ft^3/sec$$

$$0.280 = \frac{\pi D^2}{4} \times 436 \qquad\qquad A = \frac{D^2}{4}$$

$$v = 436\ ft/sec$$

$$D = 0.027\ ft$$

$$D = 0.32\ in.$$

5. Summarize the rating factors as noted in Section III, Volume I of this design guide.

Summaries of the rating factors are tabulated in Tables VI-1 and VI-2. Table VI-1 summarizes the reliabilities and Table VI-2 summarizes the weights and volumes.

6. Summarize the influence coefficients as noted in Section III, Volume I of this design guide.

A summary of the influence coefficients is tabulated in Table VI-3. The final rating is the product of the numbers appearing in columns; basic, reliability, weight and size. The basic column gives 10 points to all systems. This factor increases all ratings by a factor of 10 to allow for a more apparent numerical evaluation.

7. Evaluate candidate pressurization systems as noted in Section III, Volume I of this design guide.

For the sample mission, the numerical evaluation of the candidate systems by Table VI-3 indicates candidate System 4, bipropellant gas generator, to be the most suitable way to pressurize the propellants.

RATING FACTOR SUMMARY RELIABILITY
Candidate Pressurization Systems

COMB 1					COMB 2					COMB 3					COMB 4					COMB 5				
Component Name	Hours Oper.	Hours Coast	Reliability Oper.	Reliability Coast	Component Name	Hours Oper.	Hours Coast	Reliability Oper.	Reliability Coast	Component Name	Hours Oper.	Hours Coast	Reliability Oper.	Reliability Coast	Component Name	Hours Oper.	Hours Coast	Reliability Oper.	Reliability Coast	Component Name	Hours Oper.	Hours Coast	Reliability Oper.	Reliability Coast
Discon-nect	.5	48	.9999	.9998	Discon-nect	.5	48	.9999	.9998	Mono G.G.	.07	48	.9999	.9998	Aux. Oxi-dizer	48	—	.9993	—	Disconnect (G)	.5	48	.9999	.9998
																				Disconnect (F)	.5	48	.9999	.9998
Gas Bottle	48	—	.9993	—	Pressure Regulator	.07	48	.9998	.9997	Solenoid Valve	.07	48	.9996	.9992	Aus. Fuel	48	—	.9993	—	Gas Bottle	48	—	.9993	—
Solenoid Valve	.07	48	.9996	.9992	Solenoid Valve	.07	48	.9996	.9992	Orifice	.07	48	.9999	.9999	Solenoid (oxi.)	.07	48	.9996	.9992	Pressure Regulator	.07	48	.9998	.9997
Orifice	.07	48	.9999	.9999	T/C Ht X' Chgr	.07	48	.9999	.9999	Check Valve	.07	48	.9999	.9986	Solenoid (Fuel)	.07	48	.9996	.9992	Solenoid Valve	.07	48	.9996	.9992
Check Valve	.07	48	.9999	.9986	Check Valve	.07	48	.9999	.9986	Check Valve	8 x 10^4	48	.9999	.9986	G.G.-4Q	.07	48	.9999	.9998	T/C Ht X' Chgr	.07	48	.9999	.9999
Check Valve	.07	48	.9999	.9986	Check Valve	.07	48	.9999	.9986	Relief Valve	8 x 10^4	48	.9999	.9993	Orifice	.07	48	.9999	.9999	Check Valve	.07	48	.9999	.9986
Relief Valve	8 x 10^4	48	.9999	.9993	Relief Valve	8 x 10^4	48	.9999	.9993	G.G. Fuel Tank	48	—	.9993	—	He Bottle	48	—	.9993	—	3-Way Valve	.07	48	.9996	.9995
Relief Valve	8 x 10^4	48	.9999	.9993	Relief Valve	8 x 10^4	48	.9999	.9993	Discon-nect	.5	48	.9999	.9998	Pressure Regulator	.07	48	.9998	.9997	Check Valve	.07	48	.9999	.9986
					Gas Bottle	48	—	.9993	—	Pressure Regulator	.07	48	.9998	.9997	He - Ht X' chgr	.07	48	.9999	.9999	Aux. Fuel	48	—	.9993	—
										Gas Bottle	48	—	.9993	—	Relief Valve	8 x 10^4	48	.9999	.9999	T/C-Ht X' chgr	.07	48	.9999	.9999
										Disconnect	.5	48	.9999	.9998	Relief Valve	8 x 10^4	48	.9999	.9993	Relief Valve	8 x 10^4	48	.9999	.9993
															Discon-nect (AO)	.5	48	.9999	.9998	Relief Valve	8 x 10^4	48	.9999	.9993
															Discon-nect (AF)	.5	48	.9999	.9998					
															Discon-nect	.5	48	.9999	.9998					
Reliability			.9983	.9947				.9981	.9944				.9973	.9947				.9961	.9957				.9968	.9936
Reliability (Oper.+ Coast) Non-Redundant			.9930					.9925					.9920					.9918					.9904	

Table VI-1

TABLE VI-2

RATING FACTOR SUMMARY - WEIGHTS AND VOLUMES

COMBINATION 1

Component	Quantity	Weight (lb)	Volume (in.^{3})
Disconnect	1	0.13	1.0
Gas bottle (4500 psi)	1	306.0	31,200.1
He (in bottle)		3.0	
Solenoid valve	1	0.6	2.0
Orifice	1	0.1	0.2
Check valve	2	0.24	2.1
Relief valve	2	0.4	0.6
Totals		310.47	31,206.0

COMBINATION 2

Component	Quantity	Weight (lb)	Volume (in.^{3})
Disconnect	1	0.13	1.0
Gas bottle (4500 psi)	1	150.0	15,500.0
He (in bottle)		1.8	
Pressure regulator	1	0.5	2.0
Solenoid valve	1	0.6	2.0
TC heat exchanger	1	1.0	20.0
Check valve	2	0.24	2.1
Relief valve	2	0.4	0.6
Totals		154.67	15,527.7

COMBINATION 3

Component	Quantity	Weight (lb)	Volume (in.^{3})
Disconnect	2	0.26	2.0
Auxiliary fuel tank (500 psi)	1	5.0	4,200.0
N_2H_4 (in bottle)		120.0	

TABLE VI-2 (cont.)

COMBINATION 3 (cont.)

Component	Quantity	Weight (lb)	Volume (in.^{3})
Solenoid valve	1	0.6	2.0
Mono gas generator (450 psi)	1	1.8	2.5
Orifice	1	0.1	0.2
Relief valve	1	0.2	0.3
Check valve	2	0.24	2.1
Gas bottle (4500 psi)	1	4.5	4,300.0
He (in bottle)		0.04	
Pressure Regulator	1	0.5	2.0
Totals		133.24	8,511.1

COMBINATION 4

Component	Quantity	Weight (lb)	Volume (in.^{3})
Disconnect	3	0.39	3.0
Auxiliary fuel tank (500 psi)	1	1.6	1,100.0
He (in bottle)		2.4	
Auxiliary oxygen tank (500 psi)	1	0.1	14.0
O_2 (in bottle)		0.2	
Solenoid valve	2	1.2	4.0
Pressure regulator	1	0.5	2.0
Gas bottle (4500 psi)	1	38.0	4,000.0
He (in bottle)		0.5	
Gas generator (450 psi)	1	1.5	1.5
Orifice	1	0.1	0.2
Helium heat exchanger	1	1.0	20.0
Relief valve	2	0.4	0.6
Totals		47.8	5,145.3

Table VI-2
Sheet 2 of 3

TABLE VI-2 (cont.)

COMBINATION 5

Component	Quantity	Weight (lb)	Volume (in.^{3})
Disconnect	2	0.26	2.0
Gas bottle (4500 psi)	1	38.0	4,000.0
He (in bottle)		0.5	
Auxiliary fuel tank (300)	1	2.0	1,350.0
H_2 (in bottle)		3.0	
Pressure regulator	1	0.5	2.0
Relief valves	2	0.4	0.6
Solenoid valve	1	0.6	2.0
Check valves	2	0.24	2.1
Three-way valve	1	0.7	2.5
TC heat exchanger	2	2.0	40.0
Totals		48.2	5,401.2

TABLE VI-3

INFLUENCE COEFFICIENT SUMMARY

Candidate Combination	System	Influence Coefficient: Basic	Reliability	Weight	Size	Final Rating
1	Ambient helium	10	2.76	1.00	1.11	30.6
2	Heated helium	10	2.50	1.32	1.55	51.5
3	Mono gas generator	10	2.24	1.45	1.98	64.5
4	Bipropellant gas generator	10	2.12	2.32	1.97	97.0
5	Hybrid He/vaporized H_2	10	1.30	2.30	1.95	58.5

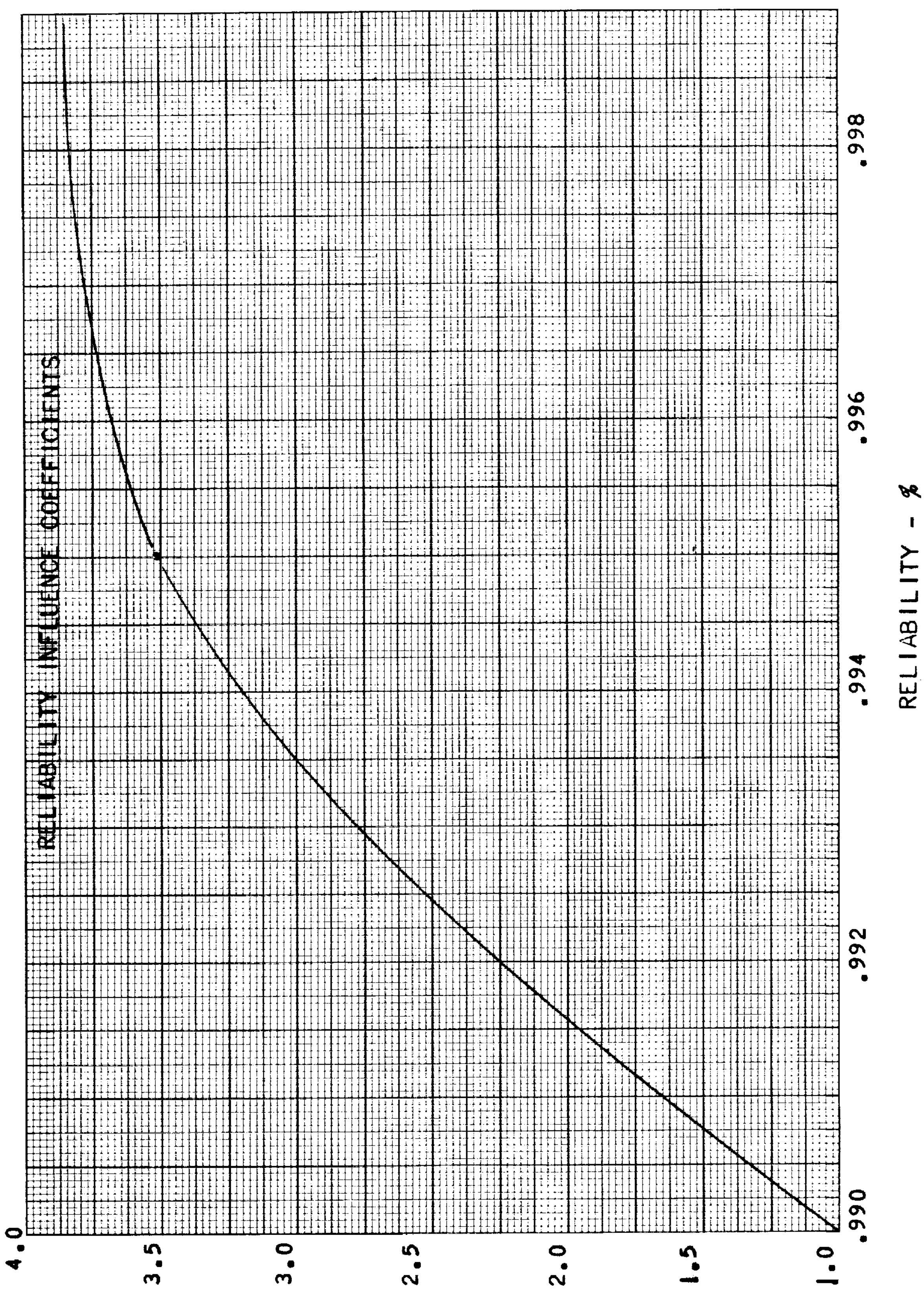

RELIABILITY INFLUENCE COEFFICIENTS
RELIABILITY - %
.990
.992
.994
.996
.998
1.0
1.5
2.0
2.5
3.0
3.5
4.0

 Figure VI-1

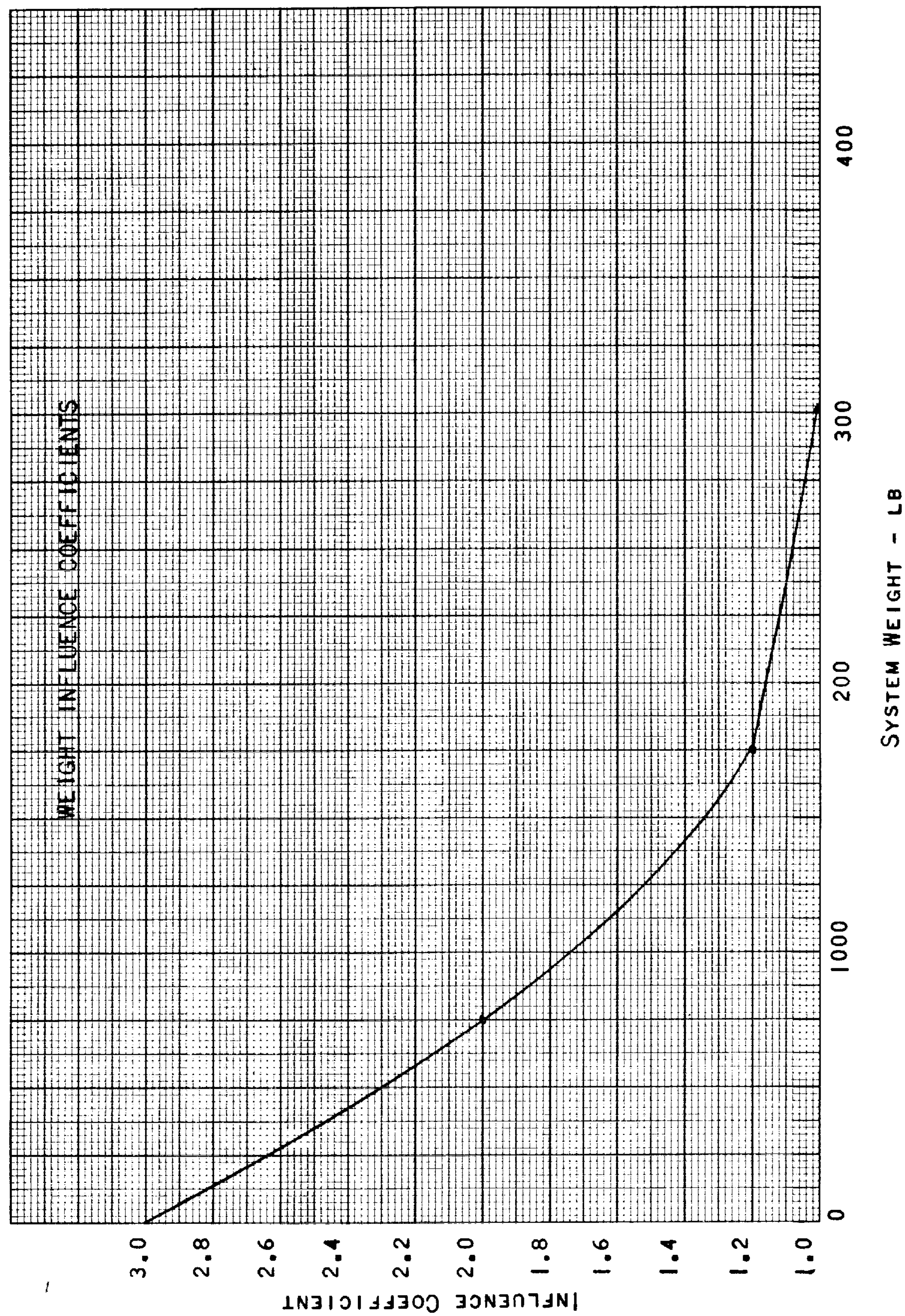

WEIGHT INFLUENCE COEFFICIENTS
SYSTEM WEIGHT - LB
INFLUENCE COEFFICIENT
0
1000
200
300
400
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0

 Figure VI-2

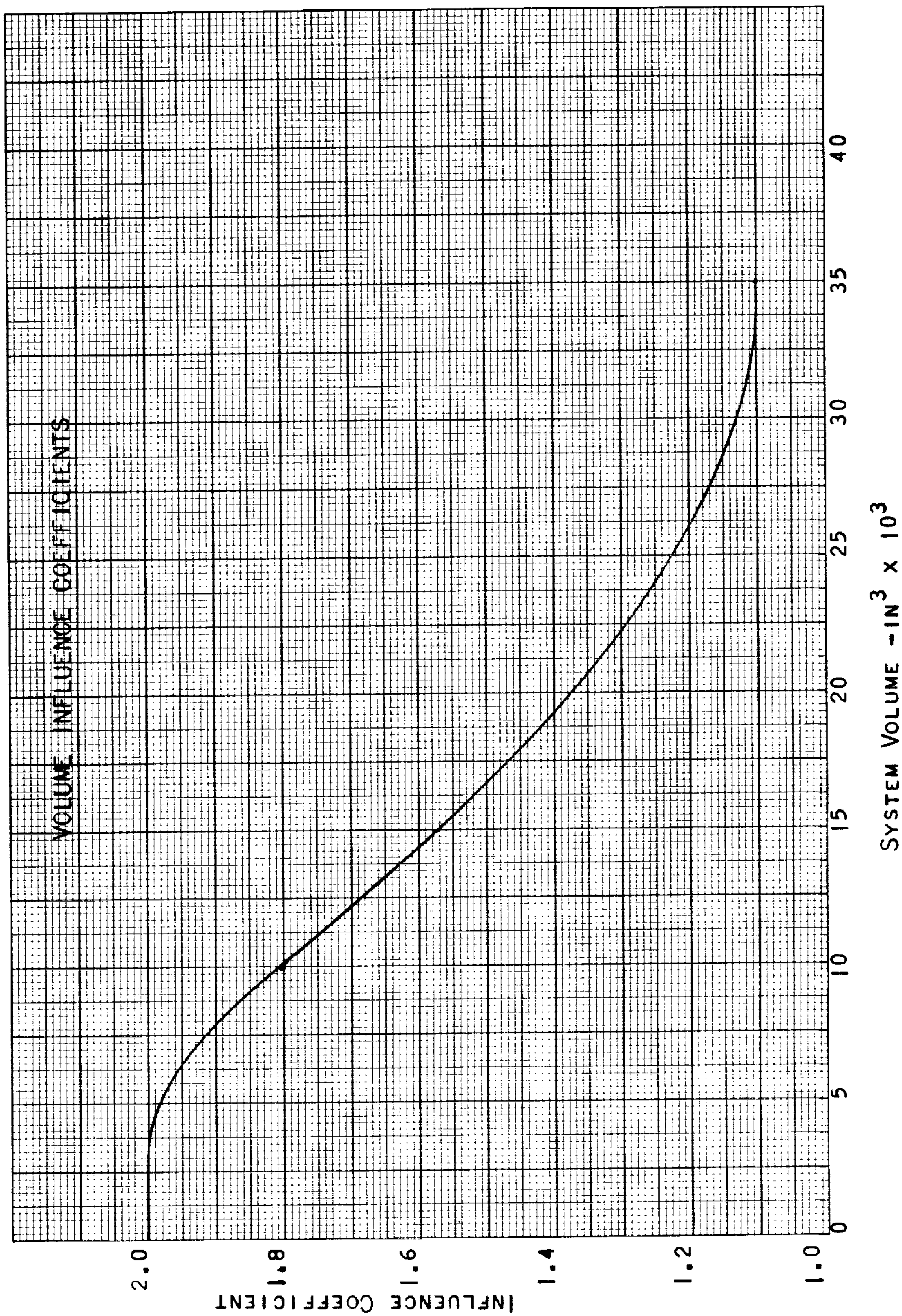
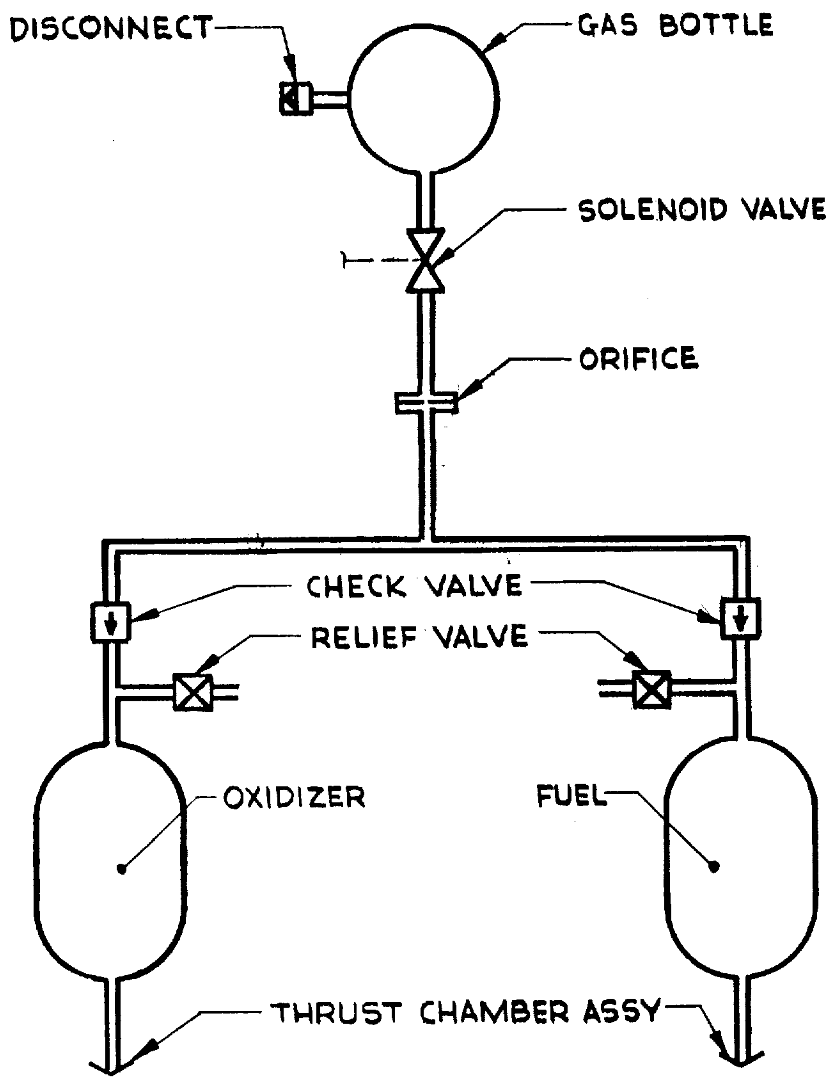
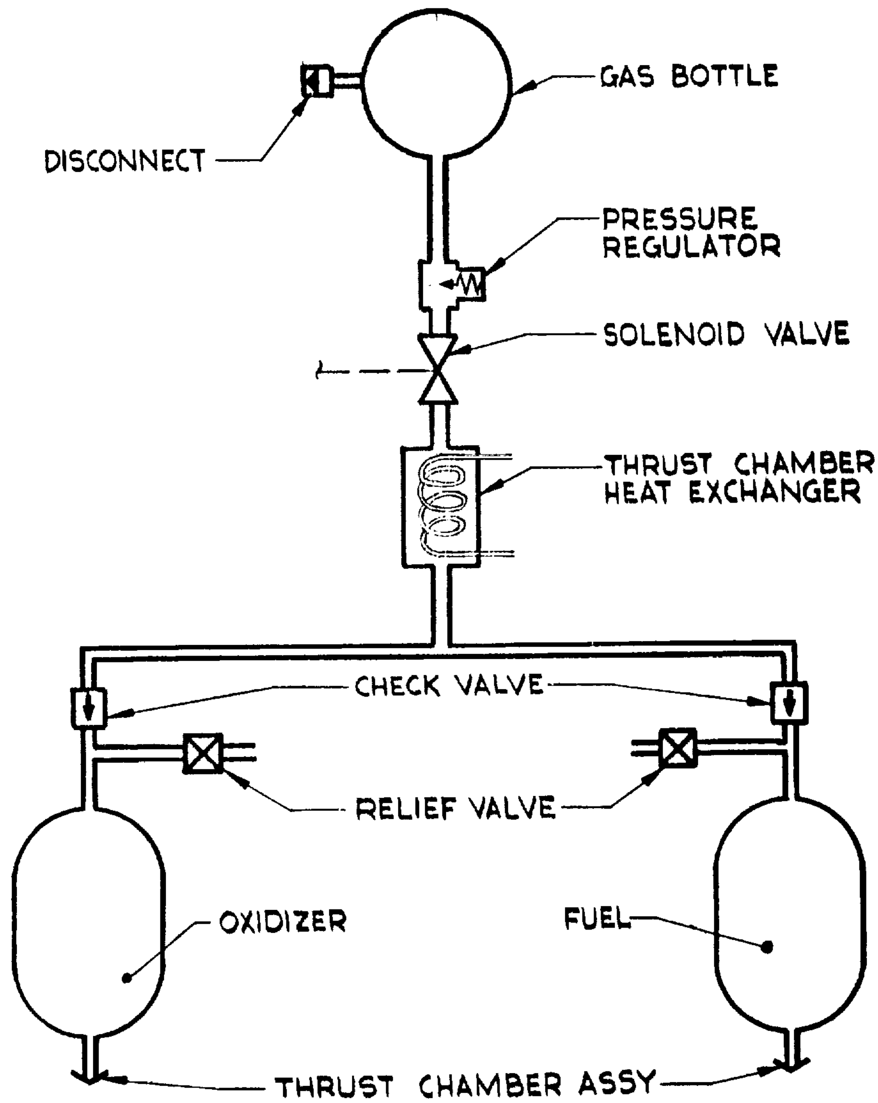

VOLUME INFLUENCE COEFFICIENTS
INFLUENCE COEFFICIENT
2.0
1.8
1.6
1.4
1.2
1.0
SYSTEM VOLUME -IN^3 x 10^3
0
5
10
15
20
25
30
35
40

Figure VI-3



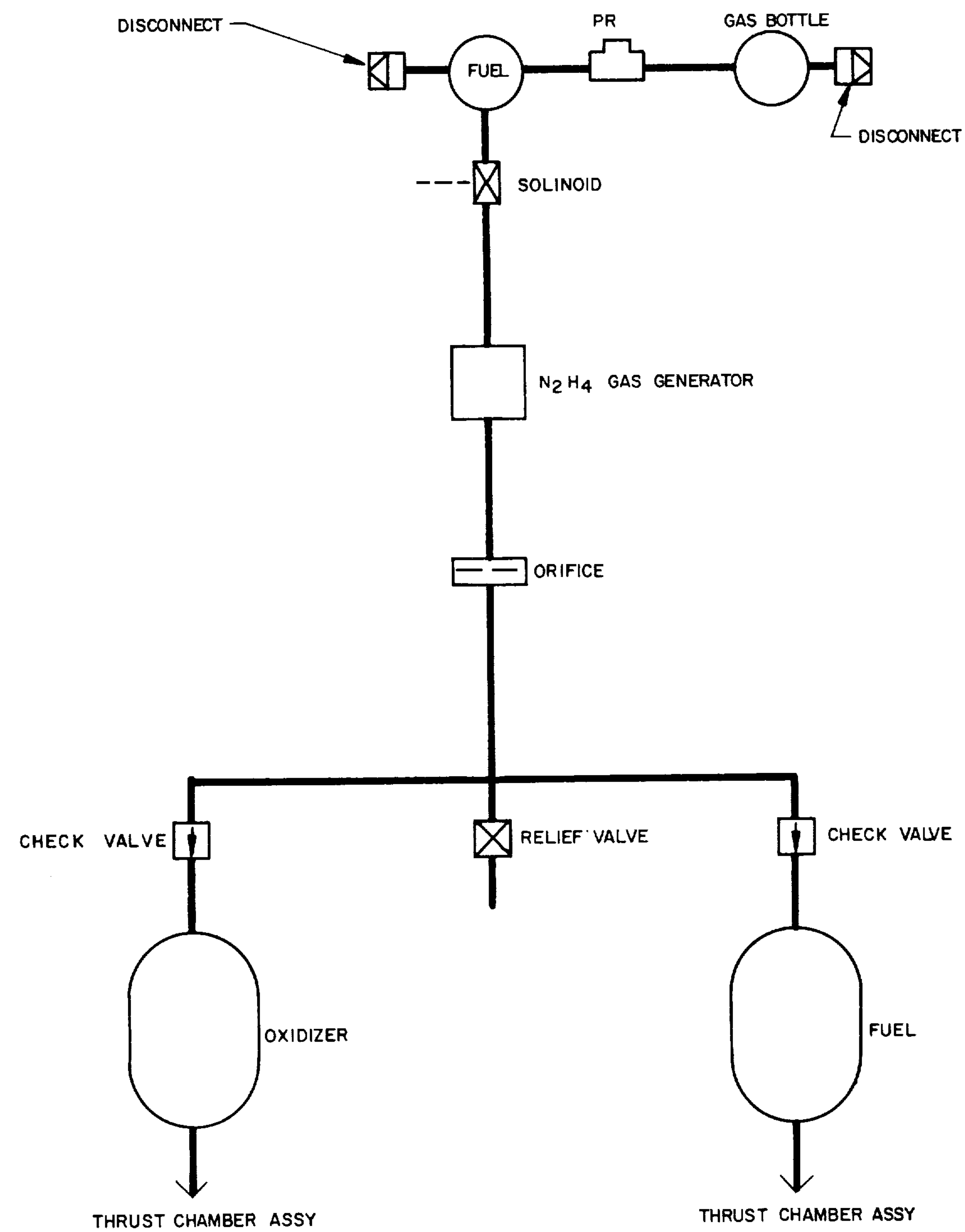
COMPONENT COMBINATION I
COLD HELIUM PRESSURANT

Figure VI-4



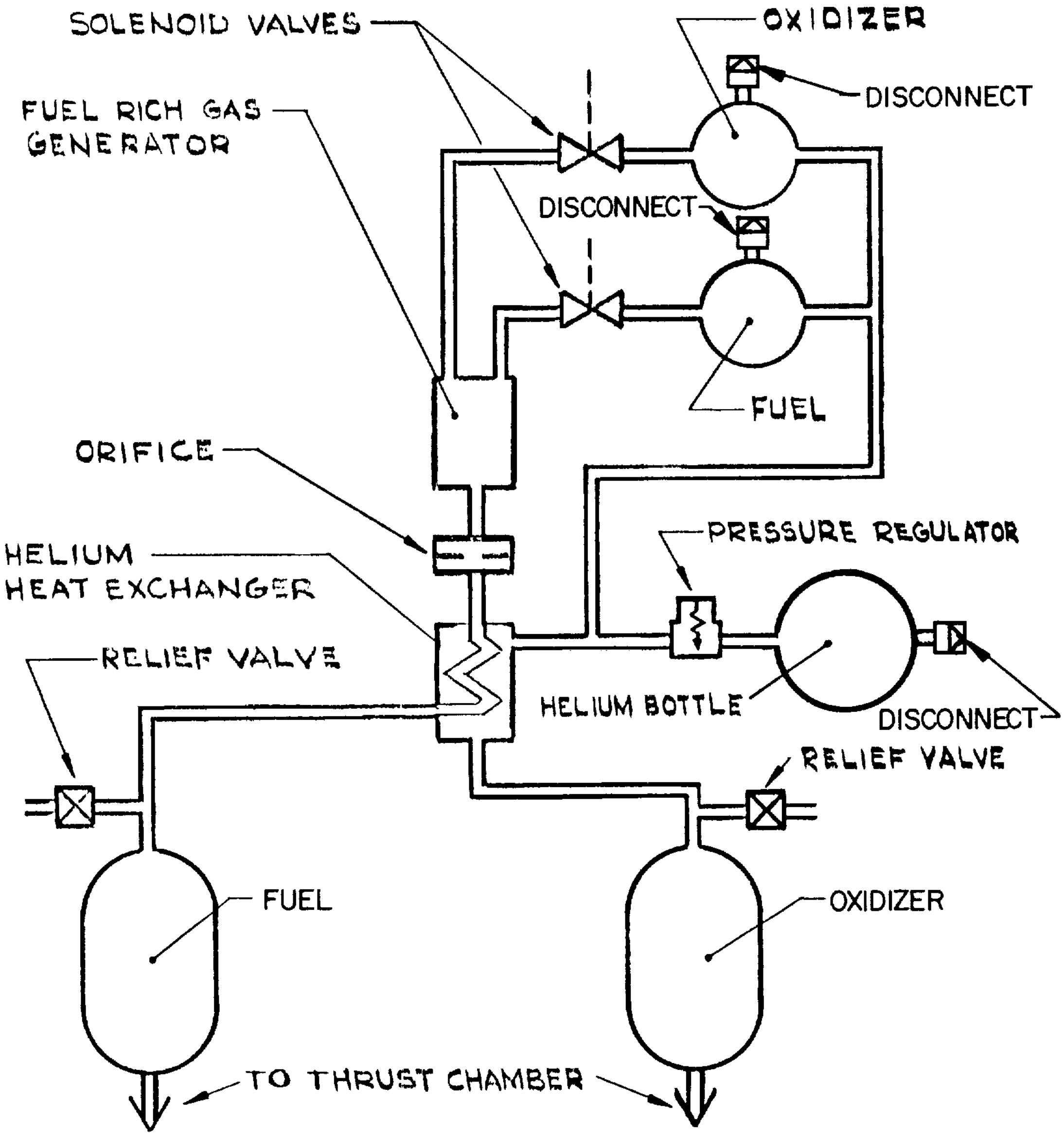
COMPONENT COMBINATION 2
HEATED HELIUM PRESSURANT

Figure VI-5

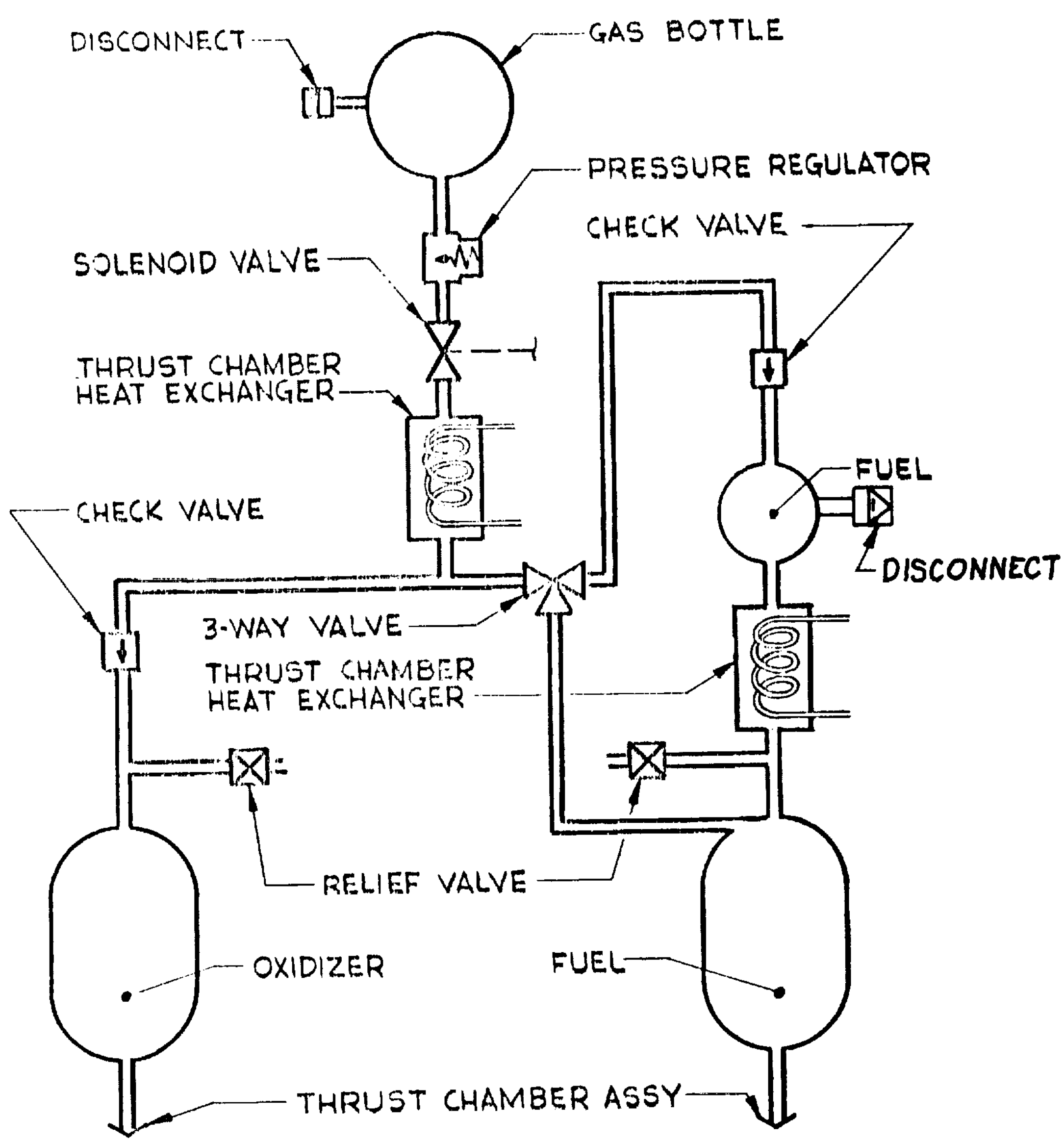


COMPONENT COMBINATION 3
MONO-PROPELLANT GAS GENERATOR

Figure VI-6



COMPONENT COMBINATION 4
BI-PROPELLANT GAS GENERATOR



COMPONENT COMBINATION 5
HYBRID PRESSURANT SYSTEM