X. APPENDICES

APPENDIX A

EVALUATION OF INSTRUMENTATION

A. HELIUM FLOWMETER

(1) Measure upstream and downstream pressures independently and on a continuous basis using electrical transducers; compute ΔP and flow manually. Considering only the transducer system, this method involves the inaccuracies of only the primary sensors, amplifiers, and recorders. Frequency response can be made high to resolve fast transients, but data reduction can be made on a selected basis in the time domain.

(2) Measure upstream pressure and ΔP independently and on a continuous basis using electrical transducers; compute flow manually. In addition to the general inaccuracies mentioned in (1), this method would also involve vagaries unique to typical ΔP transducers which are apt to introduce considerable error in transient measurements because of their usual asymmetry of construction.

(3) Use transducers (sensors) with a penumatic output combined with mechanical function generators to produce a pneumatic output proportional to flow; make a second conversion to electrical output, amplify and record. Here, in addition to inaccuracies of the electrical portion of the system mentioned in (1), there are the inaccuracies of the pneumatic and mechanical elements. Frequency response will probably be quite low, and important transients may not be faithfully transcribed.

(4) Use a sensing system described in (1) or (2) combined with electronic units for logarithmic and/or square-law operations to yield an electrical output directly proportional to flow. It has possibilities for good over-all accuracy with the advantage of good frequency response. Although probably not available as a packaged system, it is worthy of consideration.

(5) Recommendations by instrument manufacturers to use a 2-inch minimum diameter line section in conjunction with the flowmeter orifice arrangement are apparently based on practical, rather than theoretical, considerations. This allows wider tolerances on orifice size

specifications and the use of larger B ratios to minimize pressure drop without danger of undesirable influence from possible turbulent flow conditions in the vicinity of the inner pipe wall. A 2-inch minimum diameter will also permit easier installation of straightening vanes if they should be required. By furnishing a recommended length of 2-inch section as part and parcel of the flowmeter section, the manufacturer is also able to exercise control over interior finish of the line for a length of run dictated by good engineering practice. Too small a minimum diameter would increase the difficulty of providing good interior finish.

B. TURBINE FLOWMETER

1. Introduction

The following paragraphs discuss the turbine type flowmeter recommended for measuring liquid oxygen flow in the topping lines to Stage I and Stage II liquid oxygen missile tanks.

2. Flow Sensing Element

The Potter flow-sensing element incorporates a high-efficiency rotor designed so that fluid flow past it establishes thrust components in an upstream direction which slightly exceed the downstream drag forces. In operation, the rotor spins freely within a venturi cavity in a no-slip manner. Because of this, the fluid viscosity, pressure, temperature, specific gravity, etc., have only a very slight effect on the indicated volumetric rate of flow. All units, regardless of operating range, are designed on the basis of a maximum pressure drop of about 6 psi at maximum flow rate. Physical size is a function of maximum flow capacity, and it appears that the probable size of units necessary to accommodate the maximum flow rates of about 2000 and 3000 gpm in the Fuel and Liquid Oxygen Systems, respectively, would be compatible with line size if there is some choice as to exact location.

Also related to the maximum capacity of these sensors is their useful linear operating range which is of the order of 25 to 1 for the larger units. This is adequate to extend operation of 2000- and 3000-gpm units down to minimum flow rates of 80 gpm for fuel and 120 gpm for liquid oxygen. Within the operating span, volumetric flow rate accuracies of ±0.5% of reading are easily realized. Standard housings permit operation from -450°F to more than ±500°F and at pressures of more than 5000 psi. Various installation fittings are available, and only three diameters of straight-run piping are required on the upstream side.

In special applications where sensors may be subjected to reverse flow, a stainless steel ball is added to the upstream rotor seat. This does not affect accuracy for normal flow operation and allows reverse flow to persist indefinitely at rates up to 80% of maximum normal flow capacity without injury to the unit. With the application of reverse flow for shorter periods, higher rates may be tolerated. Thus, for durations of the order of 3-4 minutes, the reverse flow rate may go to as high as 150% of the maximum of the linear range for forward flow.

In other respects, the units are extremely rugged and will withstand severe "water hammer" and hydraulic shock without damage or change in characteristics.

TABLE A-1

SIZES AND CAPACITIES OF STANDARD POTTER SENSING ELEMENTS

Sensing Element Size (in.)	Tube Size (in.)	Range (gpm)
1/8	1/2	0.07 - 0.63
3/8	1/2	0.44 - 3.00
1/2	1/2	0.62 - 9.5
3/4	3/4	1.75 - 27.5
1	1	2.5 - 50
2	2	11 - 250

3. Instrumentation

The output of the Potter flow-sensing element is an a-c voltage whose frequency is proportional to the speed of rotation of the rotor and, hence, proportional to volumetric flow rate. The signal from these units is normally fed to an electronic frequency converter which converts the a-c signal to a continuous d-c output whose voltage magnitude is proportional to the pulse rate of the a-c input. This d-c output can in turn be monitored by a suitable d-c indicator or recorder.

The basic Potter Electronic Frequency Converter is a single-channel unit designed to operate into a 50-ohm potentiometric recorder such as the Brown Electronik. Also available are multichannel units, compensated gravity models which yield outputs directly in weight units and counter models for total flow registration. All units are equipped with an integral calibrating network permitting calibration checks without requiring a disconnect of the sensing element.

4. Conclusion

This discussion is based on the Pottermeter manufactured by the Potter Aeronautical Corporation of Union, N. J. However, there are other similar turbine type flowmeters in the field with equal experience in the measurement of liquid oxygen flows.

C. COMMENTS ON CHOICE OF PRESSURE TRANSDUCERS

The choice of a pressure transducer for general application requires a judicious compromise among many factors. In a specific application, the requirements are more clearly defined. If frequency response is the first consideration, the freedom of choice may be considerably narrowed. Thus, if static measurements are involved, self-generating transducers are immediately eliminated. This automatically eliminates that class of transducers exhibiting the best high-frequency response, the piezoelectric gage. If reasonably fast transients must be subject to analysis, the more sluggish class of transducer such as bourdon-tube potentiometer units need not be considered. This narrows the field of selection to capacitance, inductance and resistance strain-gage devices. Of these, the capacitance units probably excel in the majority of characteristics, except characteristic impedance, which make them and their immediate circuitry extremely vulnerable to extraneous "noise" pickup; this, in view of their relatively small output, leads to undesirable or even intolerable signal-to-noise ratios, depending upon the environment.

For long-line transmission use, however, both capacitance and inductance gages are readily adaptable to frequency-modulation systems which have definite advantages despite somewhat increased circuit complexity. Inductance and resistance strain-gage units are typically low-impedance devices and the least subject to extraneous electrical influence in long-line applications. The inductance units require more careful shielding, which usually adds to their bulk and physical size. Although inductance units produce a significantly larger signal than strain-gage units, the latter hold the edge in a significant number of other respects to warrant their choice if the economics of additional signal amplification is not a limiting factor. By and large, strain-gage units are usually the best compromise in the average application.

D. STATIC CHARGE MEASUREMENT

If charge is being carried by a fluid in a pipeline, the charge can be sensed with the apparatus shown in Figure A-1. The potential generated between the probe and ground by the charge which impinges on the probe is measured with an electrometer. The electrometer suggested is useful from 80 microvolts to 20 kilovolts.

If the potential developed is too little to measure, a short section of line might be electrically isolated from the normally grounded pipeline. In this case, the charge would accumulate on the pipewall and develop a higher potential because of the higher capacitance of the pipe. A relocation of the electrometer connections will allow one to read the potential between the pipewall and ground.

In the configuration shown in Figure A-1, the probe would integrate the charge which impinges over its full length. If the charge at a point were desired, an uninsulated conductive sheath should be installed around, but not touching, the probe. Since there would be no flow in the fluid between the sheath and the probe, the only charge accumulation would be from the fluid stream which would pass over the exposed end of the probe. An insulating sheath should not be used, since the fluid passing over the insulator would give rise to extraneous charge which would complicate the situation.

There is no present requirement for static charge measurement at OSTF. This article has been retained for reference only.

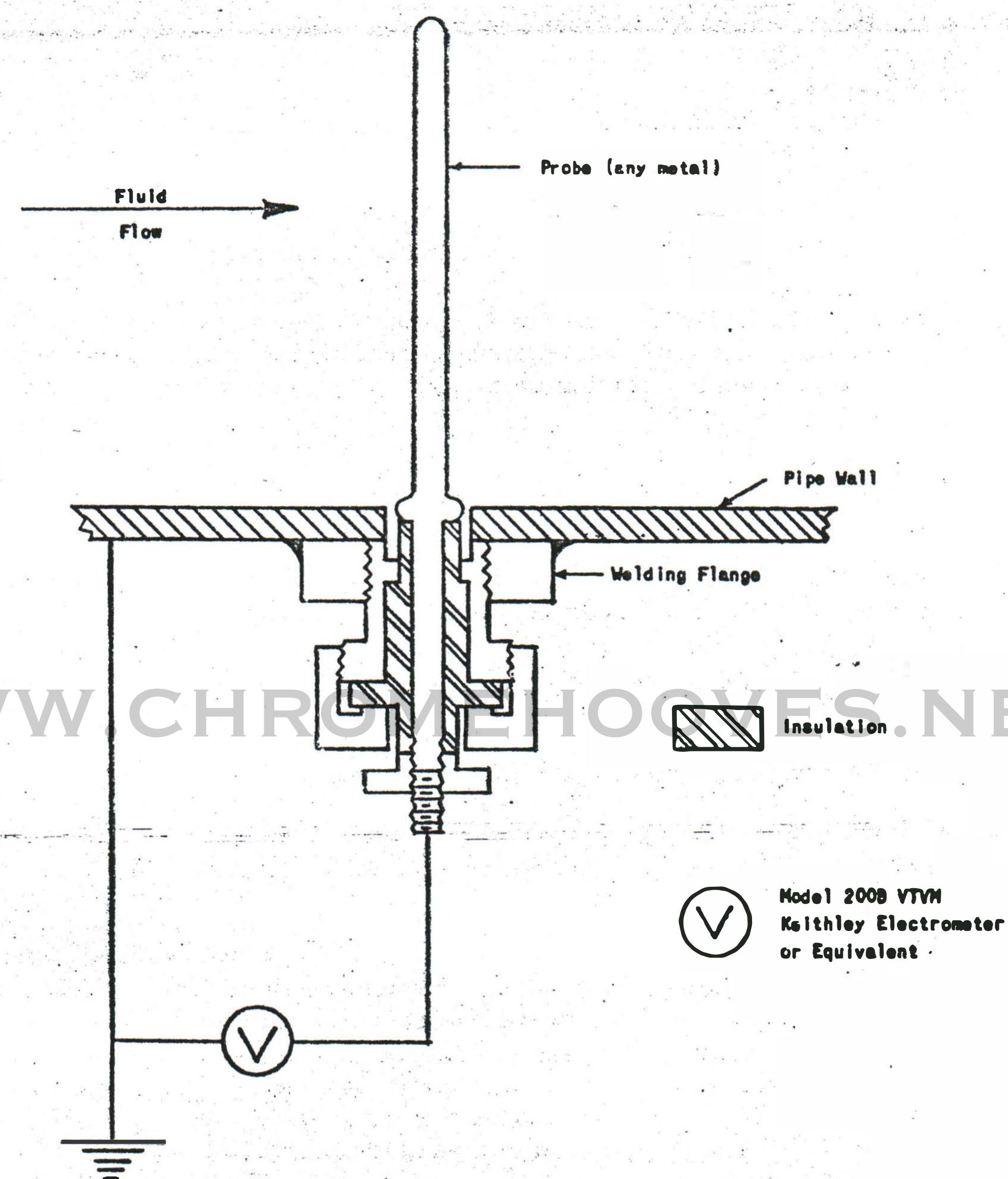

Figure A-1

PROBE TO MEASURE STATIC CHARGE IN FLUIDS IN PIPELINES

E. TEMPERATURE MEASUREMENT

1. Thermocouples

a. Relation of EMF-Temperature Characteristic to Choice of Reference Junction Temperature

For any thermocouple having junctions composed of metallic conductors, the emf-temperature characteristic can be represented to a very good approximation by the following second degree equation:

$$E = a\,(t_m - t_r) + \frac{b}{2}\,(t_m^2 - t_r^2) \qquad (1)$$

where the constants "a" and "b" are the thermoelectric coefficients unique to the particular combination of junction materials.

A graph of E versus t_m for various values of t_r will be a family of parabolas oriented as shown in Figure A-2 when "a" and "b" are positive. There are two values of t_m for which $E = 0$, corresponding to the roots of equation 1. These values of t_m are

$$t_m = t_r \text{ and } t_m = -\left(\frac{2a}{b} + t_r\right)$$

where the latter, for no good reason, is called the inversion temperature, t_i. Of more importance is the temperature for which $dE/dt_m = 0$. This temperature is called the neutral temperature, t_n, and has a value $-a/b$. A line through t_n and parallel to the E axis will be the axis of symmetry for all parabolas of a particular family, since t_n is a function of "a" and "b" only. Therefore, for a particular thermocouple, the choice of reference junction temperature merely defines the location of the emf-temperature curve along the t_n axis. It is inherent, then, that for a temperature range between any given limits, the total differential emf output will be a constant regardless of the choice of reference junction temperature. Only the values of the emfs' corresponding to the limits of the differential range will be altered.

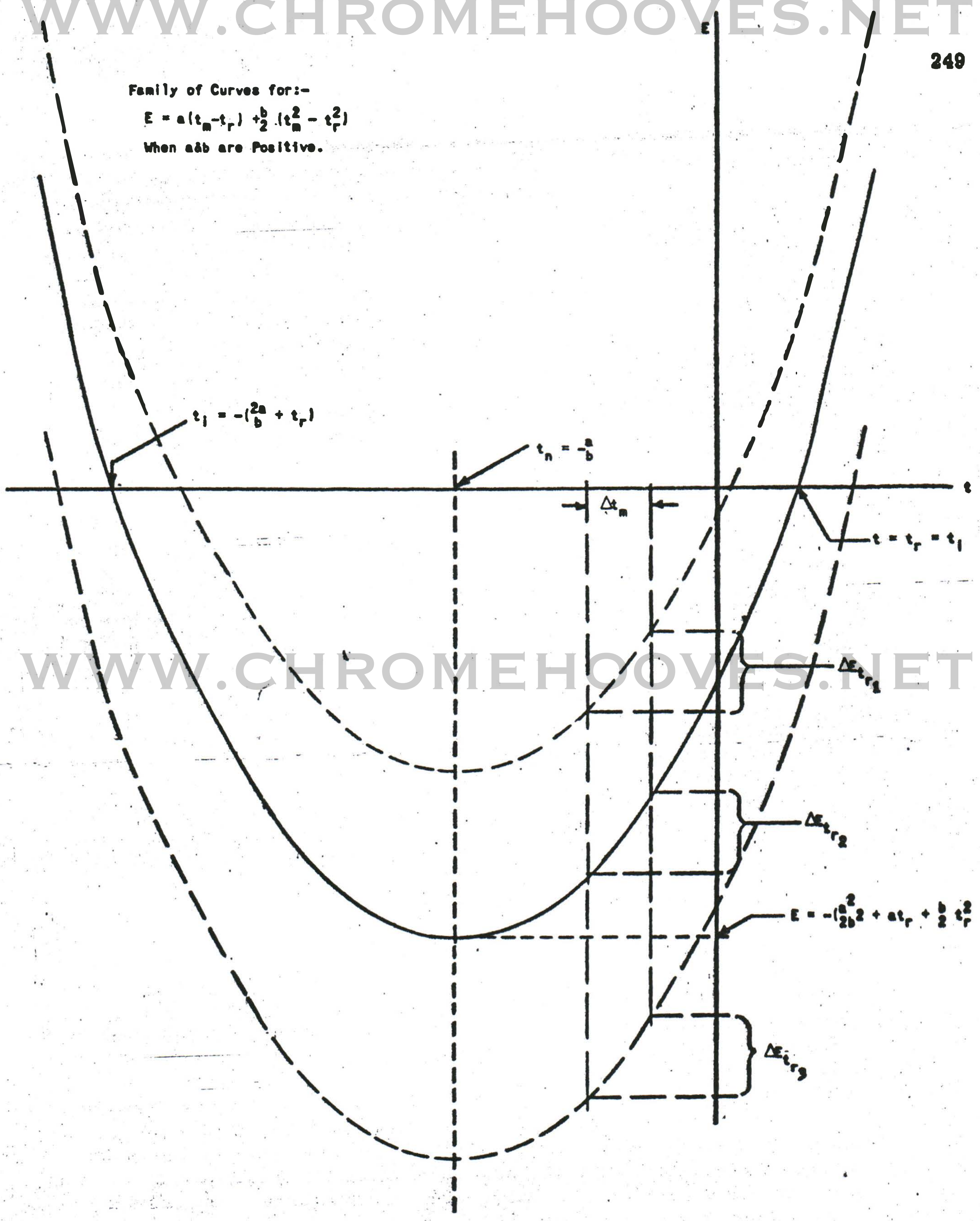

Figure A-2

THERMOCOUPLE EMF VS TEMPERATURE

It is true that in practice the shape of a thermocouple emf-temperature curve as determined experimentally may not be in precise agreement with equation 1. This is immaterial, however, because regardless of the exact shape of the emf-temperature characteristic for a particular couple, neither it nor the value of "a" or "b" will change no matter what the temperature environment of either junction. Thus, unless there is a change in the composition of the thermojunctions, the neutral-temperature axis will remain parallel to and at a particular distance from the E axis and the sensitivity of the couple for a given operating range will be independent of reference junction temperature.

As a matter of academic interest, the values of "a," "b," and "t_n" for a couple composed of copper-constantan junctions are +40.81, +0.0484, and -727.6°F, respectively.

b. Re Mr. McEnery's Comment on Use of Thermocouples at Low Temperatures

According to a memo by M. O. Hoenig, 1/7/59, re phone call from McEnery of Martin on December 22, 1958, the latter would rule out the use of thermocouples at low temperatures because the 0.03-mv output per 3°F increment would provide an intolerable signal-to-noise ratio with an amplifier having a noise level, presumably referred to the input, of 0.07 mv. On the same basis, then, one must also rule out thermocouples for any temperature level if a resolution of 3°F is required, for even at a temperature level of +75°F the output for a copper-constantan couple would only be about 0.05 mv per 3°F increment. A seemingly possible solution, therefore, would be a better choice of amplifier. Kaylab, for example, offers chopper stabilized d-c amplifiers having voltage gains of 1000 with an rms noise level of only 0.005 mv for bandwidths to 750 cps. Hewlett-Packard produces model 425A D.C. Micro Volt-Ammeter, usable as a voltage amplifier, with a maximum gain of 100,000 for a bandwidth of 0.2 cps and noise level of less than 0.0002 mv. The bandwidth for this same instrument increases to 1 cps for gains of 30,000 and less. Instruments of this type are rather expensive, however, and the extremely narrow bandwidth of the higher gain units may rule them out in many instances, although an amplifier having a 1-cps bandwidth should be satisfactory in most thermocouple applications where the thermocouple time-constant would be the limiting factor. The amplifier alone, however, may not be the major contributor of noise, particularly in installations involving long signal lines where thermoelectric and other stray electrical effects may be encountered. It is logical, then, to consider the possibility of selecting a transducer of greater sensitivity. This leads at once to the resistance-wire and semiconductor types of devices discussed below.

2. Resistance Thermometers

a. Resistance-Wire Types

The classical device to measure low temperatures between ambient and, say, -340°F is the platinum resistance thermometer, whose behavior can be accurately described by the Callendar-VanDusen equation. Although other wire materials such as nickel are commonly employed, the platinum units are undoubtedly superior from the standpoint of linearity, accuracy, and stability. Contrary to popular belief, resistance-wire thermometers can be designed to have quite low thermal inertias, and the thermal impedance of the installation is usually the determining factor. Typical values of attainable time constants range from 0.005 second (for surface temperature grids) to 2.5 seconds (for enclosed bulbs). Their sensitivity is normally around 1000 times as great as that of thermocouples, and by use of time-sharing techniques in the application of excitation voltage, another factor of 10 can easily be realized. Another advantage they offer over thermocouples is the variety of circuits in which they may be employed. Being a passive element, a-c, as well as d-c, excitation is possible. This allows use of a-c amplifiers which are inherently more stable than their d-c counterparts.

b. Semiconductor Types

At temperatures below ambient, practically every semiconductor can be used as a thermal sensing element. Most are ruled out, however, because of exceedingly high resistivity at temperatures in the vicinity of -250°F and lower. Recently a new group of thermistors exhibiting resistive characteristics as low as 300 ohm-cm and temperature coefficients as high as 35% per degree in the vicinity of LO_2 temperatures has been produced. The range of temperatures over which thermistors have high sensitivity is rather limited, however, because of their logarithmic characteristic. Thus, thermistors having the characteristics noted above would, at room temperature, have specific resistivities of the order of 0.03 to 1.0 ohm-cm and a temperature coefficient of about 1% per degree. Semiconductor transducers are nevertheless commercially available, but recommended for use only over a limited span of temperatures such as for an investigation of temperature stratification in a LO_2 tank.

3. Recommendations

On the basis of over-all performance and versatility, the resistance-wire thermometer has definite advantages over other types of thermal sensing devices; for field applications involving the continuous dynamic measurement of temperature over extended ranges, they are a logical choice. Although the investment in sensing units may be considerably higher than that in the alternative thermocouples, the cost of auxiliary instruments to obtain accurate measurements with a high degree of resolution may more than offset this. I concur with Martin's judgment in their selection.

F. PRESSURE AND TEMPERATURE TAPS IN PIPING

The following paragraphs from the A. D. Little, Inc., Propellant Loading System Specifications are enclosed for reference.

1. Pressure Tap and Orifice Connections

a. General Pipe on which connection is to be attached shall be free of any fittings or connections for a straight length of eight to ten diameters on the upstream side and two to three diameters on the downstream side. Location of connections shall be in accordance with the piping drawings.

b. Material Connection shall be a 3000#, for pressures up to 3000#, and 6000#, for pressures above 3000#, 1/2-inch IPS Thredolet as manufactured by Bonney Forge & Tool Works, Allentown, Pennsylvania, or equal, of the same material and circumferential contour as the line on which it is being welded.

c. Cleaning Pipes or pipe subsections having connections welded to them, shall be cleaned after all fabrication has been performed.

d. Fabrication Thredolet shall be welded perpendicular to the axis of the pipe line. After welding, a .182 diameter (#14 Drill) hole shall be drilled through the pipe within the Thredolet and shall be concentric with the Thredolet within 1/8" and perpendicular to the axis of the pipe line. If the hole is not free of burrs, subsequent drilling or reaming operations shall be performed until the burrs have been removed. The maximum size of the tool used shall not exceed .191 diameter (#11 Drill).

e. Sealing Thredolet shall be sealed with an external square headed pipe plug.

2. Well Type Temperature Tap Connections

a. General The location of connections shall be in accordance with the piping drawings.

b. Material Connection shall be a 3000#, for pressures up to 3000#, and 6000#, for pressures above 3000#, 1/2" IPS Thredolet as manufactured by Bonney Forge & Tool Works, Allentown, Pennsylvania, or equal, of the same material and circumferential contour as the line on which it is being welded.

c. Cleaning Pipes or pipe subsections having connections welded to them, shall be cleaned after connections have been welded to pipe and all fabrication has been performed.

d. Fabrication Thredolets shall be welded perpendicular to the axis of the pipe line. After welding, a hole 1/2-inch diameter shall be drilled through the pipe within the Thredolet and shall be concentric with the Thredolet.

e. Sealing Thredolet shall be sealed with an external square head pipe plug.

G. VALVE MOTION TRANSDUCERS RECOMMENDATIONS

Requirements for motion transducers to provide valve stem position readout are as follows:

1. Have resistance valves (ohms per inch travel) compatible with recorders.

2. To be explosion proof. (Class I, Division II, Group D)

3. To be compatible with control valves.

   a. Mounting Brackets

   b. Stem Extensions

In order to preserve the cleanliness, integrity, and leakage characteristics of the valves, the valve manufacturer should provide the mounting brackets and stem extensions for the transducers selected. It might be desirable to consider having the transducers shipped to the valve manufacturer for final fitting and testing before the control valves are shipped.

It should be noted that a change in the OSTF Corps of Engineers specifications would have to be made if the latter recommendations were accepted.

Since such a change appears unlikely, it is felt that the instrument contractor (The Martin Company) should try to make some typical assembly tests at the manufacturer's plant, even though the transducers would have to be removed again.

APPENDIX B

PIPING AND INSTRUMENTATION

TEST FLOW DIAGRAMS

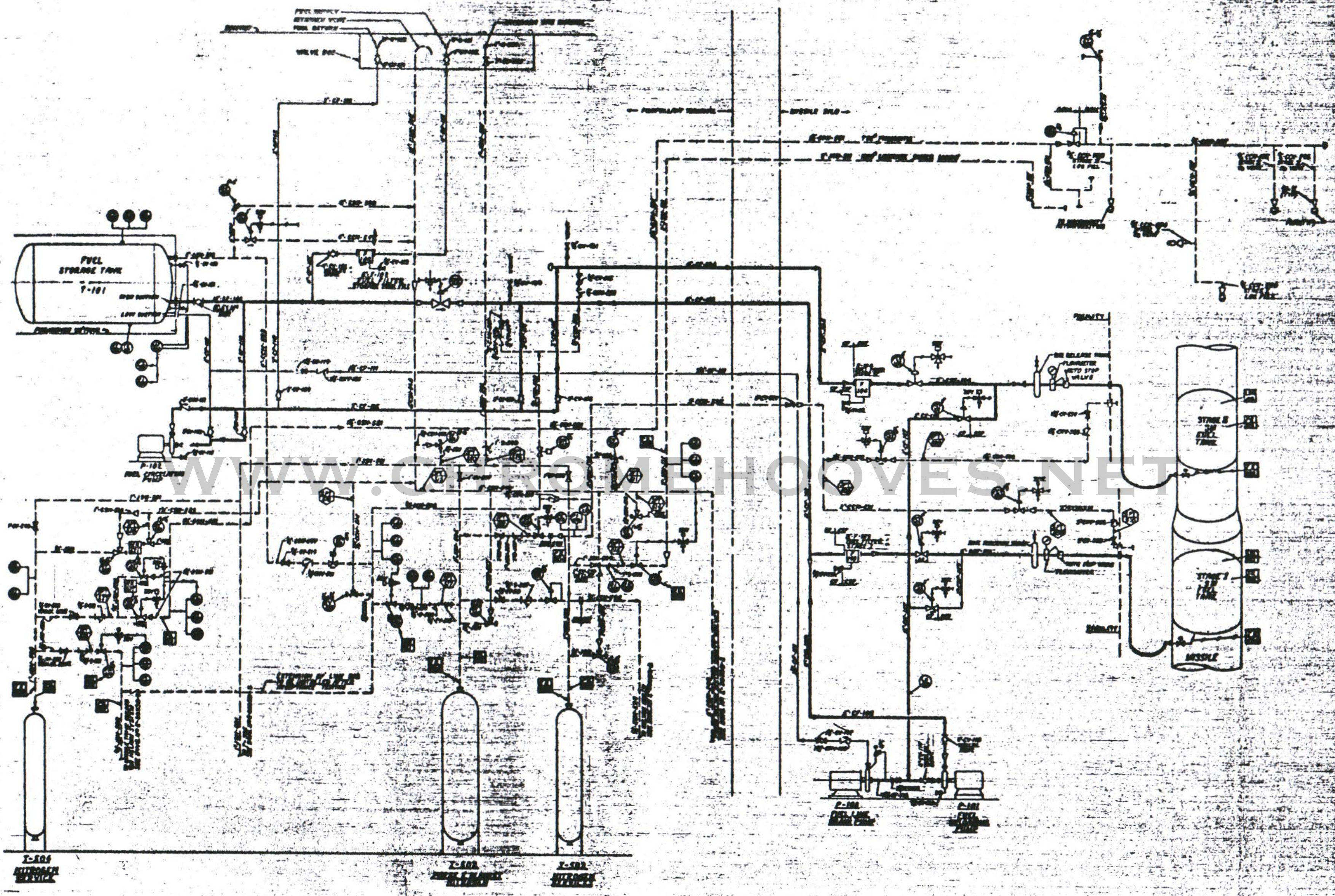

Figure B-I

(E-3039D-I)

PIPING AND INSTRUMENTATION OF FUEL AND GN_2 SYSTEMS

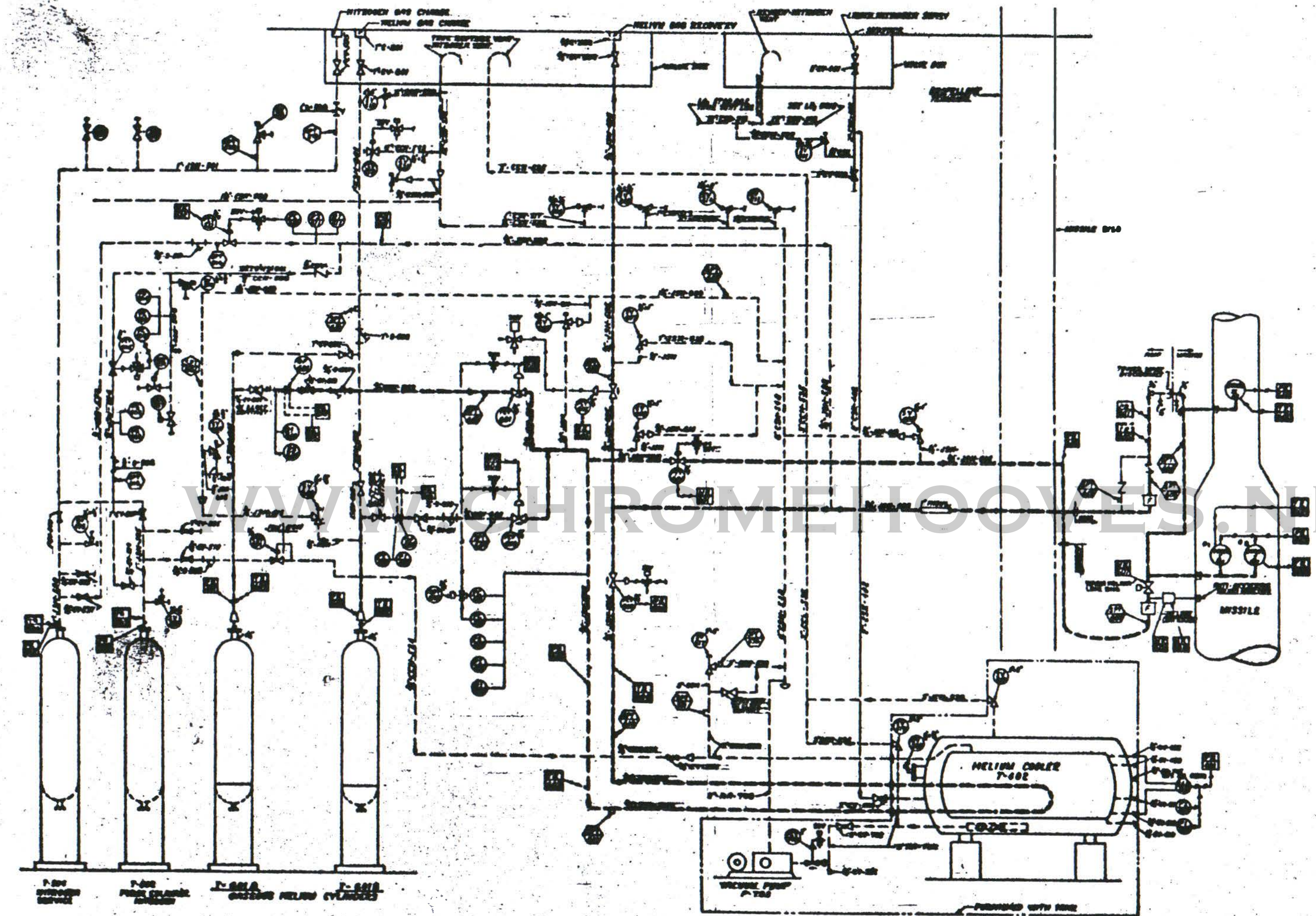

Figure B-2
(E-3039D-2)

PIPING AND INSTRUMENTATION OF HELIUM SYSTEM

Arthur D. Little, Inc.

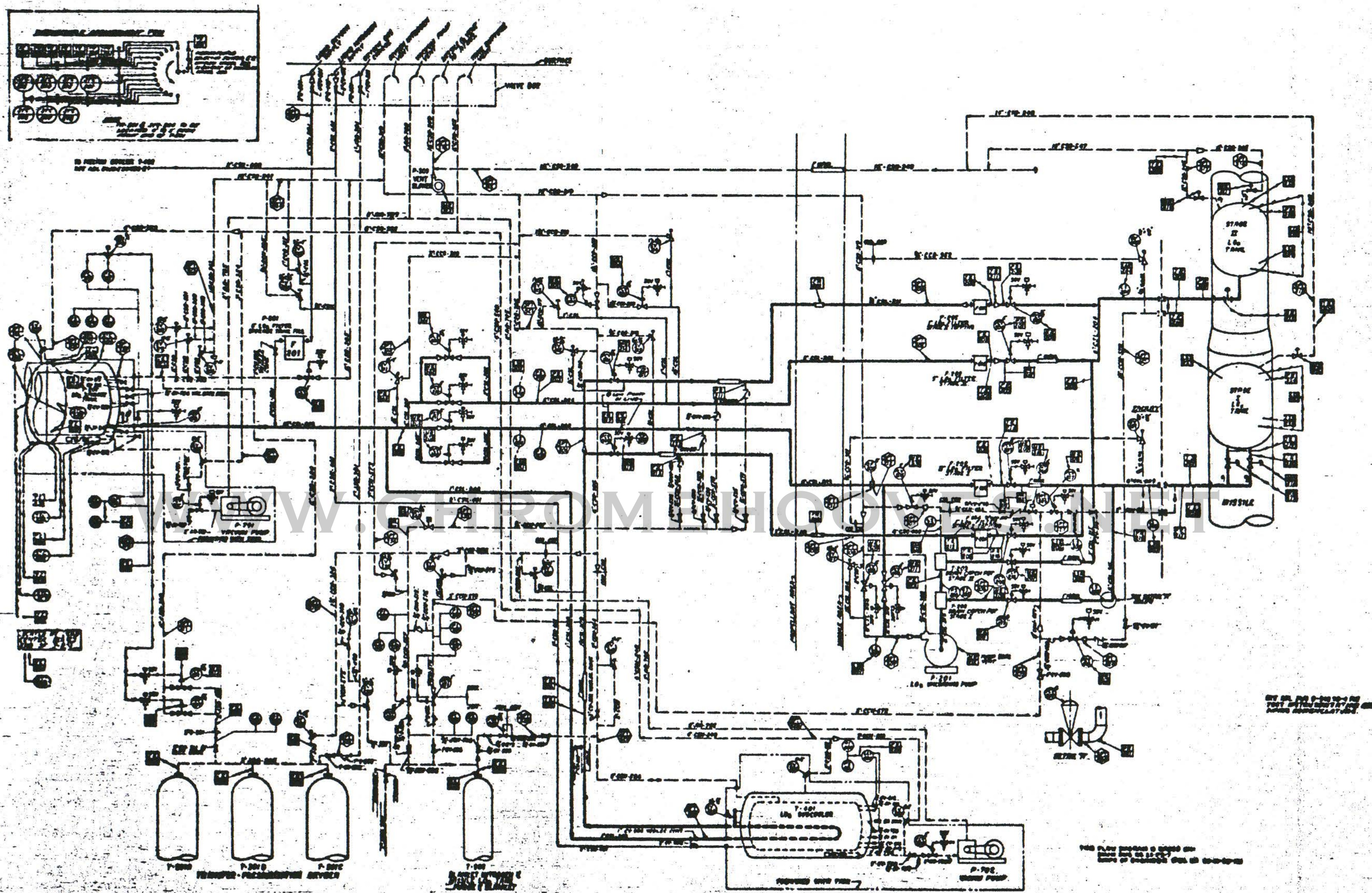

Figure B-3
(E-3039D-3)

PIPING AND INSTRUMENTATION OF LO_2 SYSTEM

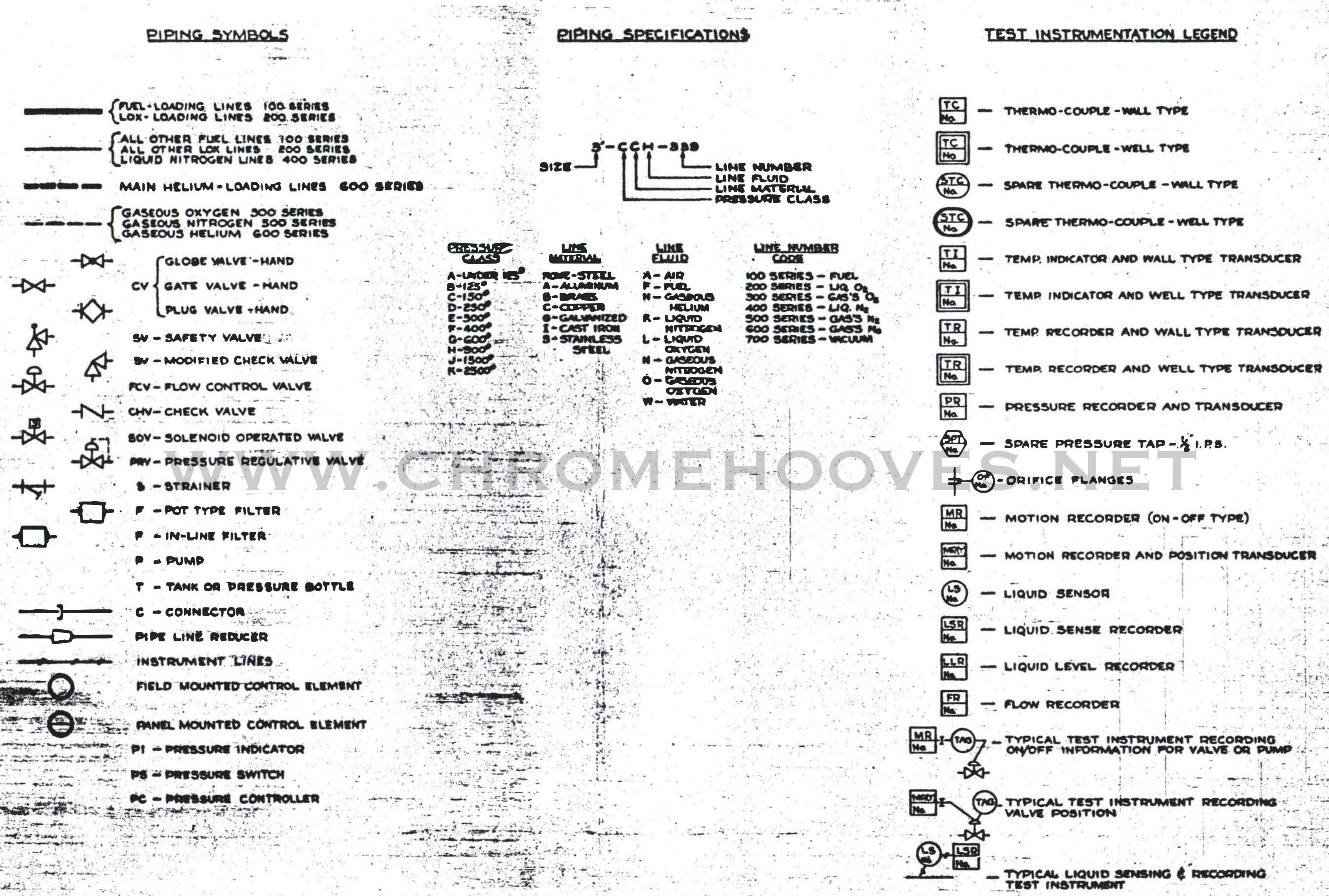

Figure B-4
(D-3039D-4)

TEST INSTRUMENTATION LEGEND FOR FIGURES B-1, B-2 AND B-3