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ENERGY DEPOT CRYOGENIC FUEL STORAGE AND DISTRIBUTION SYSTEM
PHASE I - CONCEPTUAL DESIGN STUDY (U)

QUARTERLY PROGRESS REPORT NO. 3

by

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Air Products and Chemicals, Inc.
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FOREWORD

This is the third of a series of written quarterly technical progress reports which proceed the final technical report. This report summarizes the work performed by Air Products and Chemicals, Inc. under Phase I of the Atomic Energy Commission Contract Number AT (30-1)-3129 for the period October - December, 1963.

The authors wish to express appreciation to: E. S. Tyminski for his contributions to the materials study, and to J. J. Gehringer and J. Tierney for their contributions to the Systems Study.

ABSTRACT

This third quarterly technical report, prepared under USAEC Contract No. AT(30-1)-3129, covers the work performed during the period October to December, 1963. The following is a brief summary of the program status.

Work Package I. - Vessel Conceptual Design Study
This effort was completed during the first reporting quarter.

Work Package II. - Materials Study
Welding procedures have been established and physical testing of weldments is nearing completion for the series of high strength steel and aluminum alloys considered to be promising for lightweight liquid hydrogen vessels.

Work Package III. - Boiler-Plate 50-Gallon Vessel Test
The test vessel has been fabricated and the developmental testing is nearing completion.

Work Package IV. - Lightweight 50-Gallon Vessel Test
The design of the lightweight vessel is completed. Sufficient materials and components have been received that vessel fabrication can be started.

Work Package V. - Conceptual Design of the Storage and Distribution System
This effort was initiated during this quarter. The conceptual design of the integrated fuel storage and distribution system has been established.

Work Package VI. - Final Technical Report
This effort will start during the last reporting quarter.

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I. INTRODUCTION

In Quarterly Technical Report No. 1 (1), Air Products and Chemicals, Inc. made general recommendations concerning revisions to the program. It was recommended that the design, fabrication, and test of a lightweight 5-gallon vessel, originally proposed, be replaced by the design, fabrication, and test of a boiler-plate 50-gallon vessel. The boiler-plate vessel is to be designed as a full-scale thermodynamic mock-up of the lightweight 50-gallon vessel and is to provide the opportunity to study the heat leak problem independently from the shell weight problem.

As reported in Quarterly Technical Report No. 2 (2) the Atomic Energy Commission gave Air Products limited approval to proceed with the revised program. The effort during this third quarter has continued according to the amended program. It is anticipated that the appropriate modifications to the contract will be negotiated early in the fourth quarter.

This third Quarterly Technical Report covers Air Products and Chemicals, Inc. activities under Contract USAEC Contract AT(30-1)-3129 during the period October through December, 1963.

II. MATERIALS STUDY

A. Introduction

Two activities are in progress under the materials study. The first is to obtain sufficient information about the properties of the candidate inner vessel materials to allow a choice of the most promising materials for the future vessel test programs. The candidate materials are relatively new high-strength aluminum and steel alloys. The required strength properties at cryogenic temperatures are not available in the literature. Therefore tests are performed to provide the necessary but otherwise unavailable information to support a selection of the best material for this application. The second activity involves the experimental testing of various types of welding transition joint between aluminum and stainless steel. The lightweight vessel design will most probably call for such a transition joint because: (1) the inner vessel and therefore the mandrel for the inner vessel will most probably be made of an aluminum alloy for low weight, and (2) the vessel piping will be of thin-walled stainless steel tubing for low heat leak. The transition piece will provide a vacuum-tight, strong joint between these two materials which cannot readily be welded directly to each other. The tests are to evaluate five joint designs. Published information concerning actual operating experience with the commercial joints is scarce. The test results are to provide a basis for selecting a joint for the lightweight 50-gallon vessel to be built and tested under the contract and specifying items for future vessel tests.

The technical results generated under the inner shell study and the transition piece study during this quarter are presented below as parts B and C of this section.

B. Inner Shell Study

Materials selected for welding and low-temperature property investigations as high strength-weight ratio alloys were aluminum alloys 2219, X7006, 7039, and high-strength maraging steels of the 18% nickel type. It is well established that some of the titanium alloys offer favorable properties at -423° F, the temperatures of interest for this investigation, but it was decided to evaluate more easily fabricated high-strength materials. The maraging steels were included because the very limited low temperature data indicates that impact properties at -423° F are marginally acceptable. Historically the aluminum alloys have offered excellent cryogenic properties.

Aluminum alloy 2219 has been utilized in high-strength applications. Experimental alloys X7006 and 7039 have not had wide application. The 7039 magnesium-zinc alloy, however, has been utilized successfully for prototype ballistic vehicles. Limited data available for both these alloys strongly indicate desirable cryogenic properties. One characteristic limitation which severely limits the materials chosen for test is the necessity for providing high strength after welding in thin sections either without post-weld heat treatment or with a heat treatment which would be unlikely to distort a thin-shelled vessel.

1. Test

Initial evaluation of materials is based on welding procedure evaluation, utilizing the consumable electrode MIG (metal inert gas) process, since the process is economical and lends itself to low distortion of thin shells. Following establishment of the welding procedures, plates weldments utilizing these procedures were prepared for room temperature and cryogenic testing. Room temperature tensile and bend tests were conducted according to ASTM Procedures to verify that the proper welding procedures had been utilized. Appropriate notched tensile, unnotched tensile, Charpy-V notch specimens were machined for tests to be conducted at -320° F and -423° F.

The results of the weldability studies are presented in Table I.

2. Discussion of Welding Evaluation

Although we have not experienced the difficulty in the series of tests run, we have been informed that repair welding of the 2219 aluminum alloy frequently produces cracks. The cracking tendency of the 7039 is felt to be associated with a similar basic characteristic of these high-strength alloys,

TABLE I
RESULTS OF WELDABILITY STUDY-INNER SHELL MATERIALS

A. Aluminum Alloy 2219

1. Weld Joint Configuration

   a. Plate thickness: 1/2"
   b. Bevel: 60°, single, with 1/4" land
   c. Sequence: beveled side welded first, back gouged

2. Welding Variables

   a. Current: 270 - 275 amperes
   b. Voltage: 31.5 - 33 volts
   c. Travel Speed: 32 - 36 ipm
   d. Gas Shield: 50 cfh argon-helium (75-25 mixture)
   e. Filler wire: 2319, 1/16" dia.

3. Results - fine grain weldments of X-ray quality. Bend tests of as-welded samples broke at 15° on a 2T bend at the fusion line. Room temperature mechanical tests after artificially aging indicate average tensile strengths of 44,800 - 46,300 psi, yield strengths of 29,400 - 40,400 psi, and elongations of 4.0 to 4.5%. Typical literature values for the corresponding room temperature properties of the parent metal in the T87 condition are 71,000 psi, 58,000 psi and 5% respectively. On this basis the apparent weld efficiency is approximately 64%.

B. Aluminum Alloy X7006

1. Weld Joint Configuration

   a. Plate thickness: 1/2"
   b.q Bevel: 60°, single, with 1/4" land
   c. Sequence: beveled side welded first, back gouged

2. Welding Variables

   a. Current: 350 - 360 amperes
   b. Voltage: 30 - 31 volts
   c. Travel Speed: 32 - 36 ipm
   d. Gas Shield: 50 cfh argon-helium (75-25 mixture)
   e. Filler wire: Alcoa M760

TABLE I (Continued)

3. Results - minor porosity occurred on all tests run. Bend tests of as-welded samples failed at 45° on a 2T bend. Room temperature mechanical properties after artificial aging to produce the T6 condition indicate average tensile strengths across the weld of 39,000 - 40,000 psi with elongations of about 4%. Typical literature values for the corresponding room temperature properties of the parent metal in the T6 condition are 62,000 psi, 57,000 psi and 15% respectively. On this basis the apparent weld efficiency is approximately 64%.

C. Aluminum Alloy 7039

1. Weld Joint Configuration

a. Plate thickness: 1/2"
b. Bevel: 60°, single, with 1/4" land
c. Sequence: beveled side welded first, back gouged

2. Welding Variables

a. Current: 350 - 360 amperes
b. Voltage: 24 - 32 volts
c. Travel Speed: 32 - 36 ipm
d. Gas Shield: 50 cfh argon-helium (75-25 mixture)
e. Filler wire: X5039, 1/16" dia.

3. Results - Some cracking occurred during the initial procedure weld tests. Removal and rewelding cracked areas produced X-ray quality deposits. As-welded longitudinal bend tests were successful at 180° on a 2T bend radius. After artificial aging only to produce a condition approximating T6, average ultimate strengths of 45,800 - 49,100 psi, yield strengths of 33,600 - 36,500 psi, and elongations of 12 - 20% were obtained. Typical literature values for the corresponding room temperature properties of the parent metal in the T6 condition are 63,000 psi, 53,000 psi, and 13% respectively. On this basis the apparent weld efficiency is approximately 75%.

D. 18% Nickel Maraging Steel

1. Weld Joint Configuration

a. Plate thickness: 1/4"
b. Bevel: 60°, with 1/16" land, 3/32" gap

TABLE I (Continued)

2. Welding Variables

   a. Process manual metallic arc
   b. Current: 140 - 150 D.C.R.P.
   c. Voltage: 24 - 26 volts
   d. Electrode: Inco R-108, 5/32" dia.

3. Results - Slag removal between passes is extremely difficult, making X-ray quality welding a potential problem. Extreme magnetism of the base metal makes quality metal arc welding almost impossible.. We have been informed by the vendor performing the cryogenic tensile tests that machined and aged specimens prepared for testing have exhibited delayed cracking and will not be tested.

that grain boundary remelting in the heat-affected zone causes the cracking tendency and is to be avoided as much as possible by low heat input welds. The 7006 alloy did not appear to be as sensitive in this respect as the other aluminum alloys.

Room temperature properties of weldments indicate consistently high mechanical properties for both alloy 2219 and 7039, with some reduction in strength produced in alloy 7006.

Weldability of the maraging steels by the manual metal arc process appears to be questionable on the basis of the limited results obtained.

3. Cryogenic Tensile and Impact Testing

Notched and unnotched tensile testing at -320° F and -423° F has not been completed. As of this date Charpy-V impact tests at -423° F have not been performed.

C. Aluminum-Stainless Steel Welding Transition Piece Study

The occasional necessity of mechanically or metallurgically joining components of stainless steel and components of aluminum for cryogenic and/or vacuum uses makes an analysis of the methods by which this can be accomplished desirable. Mechanically joined pieces are generally considered undesirable because of the possibility of eventual leakage. This type of joint is rarely used since repairs in many instances are impossible. Metallurgically bonded piping joints, ranging in size from 1/2 inch to about 12 inches, have been on the market for several years. However, information about the specific applications and the success of the joints in actual use is not readily available.

Five types of samples were selected for testing under a high degree of restraint. These consisted of: two existing types of transition pieces; and three combinations of materials from which it appeared that useable transition pieces could be made or from which they had been made. These samples are identified below.

1. Bi-Braze Corporation, Brooklyn, New York. This type of joint which has been in use for several years, is presently undergoing tests at several installations, and utilizes a mechanical locking arrangement together with a brazed aluminum-stainless steel interface.

2. Reynolds Metals Company. A relatively new flash butt-welded transition piece, presently being evaluated by several users, is composed of essentially an aluminum-to-copper, and a copper-to-stainless steel flash butt-welded metallurgical joint. No operating performance has been accumulated on this joint.

3. Aluminum Company of America. A welded transition piece utilizing Duranel is a roll bonded sandwich material composed of alternate layers of aluminum and stainless steel. This study represents the first usage of this material for a cryogenic joint.

4. Silver sleeve transition utilizing a screwed mechanical joint and welds joining an external silver sleeve to both the aluminum and stainless steel pipes. A history of apparently successful performance has been accumulated on this type of joint, although no published information is available on the subject.

5. All-State Welding Alloys Inc. Aluminum-stainless steel soldered joint which utilizes a 509° F melting point solder. All-State has felt that their solder would satisfactorily wet both aluminum and stainless steel but were unaware of other efforts to utilize the solder for a joint.

Other cast and brazed transition assemblies which are available on the market may have value. However, the above five chosen assemblies offer (a) a wide range of possible successful manufacturing techniques; (b) the potentially simplest types of manufactured joints; and (c) joints for which in some cases have no available history.

1. <u>Test</u>

A test involves rigidly restraining the test specimen and temperature cycling it between ambient and -320° F. The original intent of the test was to test each joint to failure. The number of cycles to failure is the criteria for differentiating the samples as to usefulness. It is true that cycling to -420° F would have been somewhat more desirable, but an evaluation of the cost of this type of testing as compared to the possible information to be gained indicated that liquid nitrogen testing would be satisfactory. Due to the variation of the coefficient of thermal expansion with temperature, the stress placed on a restrained sample cycled to liquid hydrogen temperature is only slightly more than that incurred during cycling to liquid nitrogen temperature. The severity of test conditions is not likely to be met in actual service but the intent of the test was, again, to acquire a gradation of usefulness rather than specifically an acceptability of produce for a given application.

Transition joint test samples were chosen close to 7/8-inch pipe size to approximate the joint size to be utilized in the lightweight 50-gallon vessel.

Eight-inch long transition pieces were used for testing. Each piece had welded to each end a 2" x 2" x 1/2" machined block with a screwed coupling in one end block for helium leak check purposes. Transition pieces were placed in a rigid assembly constructed of 9% nickel steel. Figure 1 is a photograph of the assembly with a joint in the test position. Sheet metal dams were placed around each joint to be tested for liquid nitrogen immersion. Dial gages were utilized for determination of assembly shrinkage during test, since the test rig itself was found to cool to -30° to -40° F during testing. Because of the high stress level imposed on joints during testing, all joints eventually elongated substantially and shim stock was used ahead of the machined blocks to provide restraint. Helium leak tests were performed at five cycle intervals. In order to determine the net stress imposed on all pieces, each of the pieces was cycled unrestrained for one cycle. The total shrinkage less the assembly shrinkage was utilized for calculation of imposed stress.

2. Results

a. Bi-Braze Corporation Transition

Stress Imposed: 13,000 psi min.
Cycles to Failure: 15
Failure Location: braze

b. Reynolds Metals Company Transition

Stress Imposed: 8,900 psi min.
Cycles to Failure: sample has not failed
Present Status: (1) pc. 1 - 146 cycles - no failure
(2) pc. 2 - 144 cycles - no failure

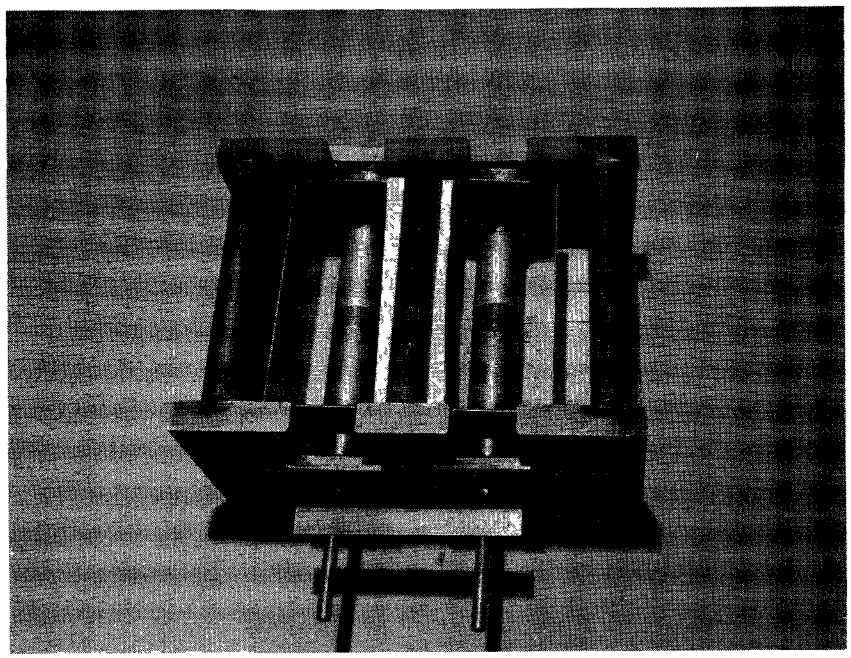

Figure 1. TRANSITION PIECE TEST FIXTURE

c. Aluminum Company of America, Duranel

Stress Imposed: 9,400 psi min.
Cycles to Failure: sample has not failed
Present Status: 130 cycles - no failure

d. Silver Sleeve Transition

Stress Imposed: 10,000 psi min.
Cycles to Failure: sample has not failed
Present Status: 44 cycles - no failure

e. Soldered Transition, All-State

No testing was accomplished on this joint. Several attempts to provide adequate solder flow and wetting were unsuccessful. Therefore no suitable test speciment was fabricated.

3. Discussion

The yielding of the aluminum piping introduces some inaccuracies regarding the actual stress level imposed on the transition joint. However, comparison of these data with expected yield strengths at -320° F indicates that limiting stresses were the actual yield strengths of the aluminum piping.

Three test joints are still functional. Two of the three pieces have lasted over 100 cycles of testing. On the basis of these results, there can be a choice in the specification of a transition piece for the 50-gallon vessel.

III. 50-GALLON BOILER-PLATE VESSEL STUDY

A. Introduction

This effort is to fabricate and test a 50-gallon vessel to establish the validity of the thermal protection system which was conceptually designed during Work Package I. No attempt has been made to minimize the weight of these test shells. The vessel is to be considered a full-scale thermodynamic mock-up of the lightweight 50-gallon test vessel to be studied during Work Package IV.

In part B of this section, the test sequence and the pertinent results are presented. In part C the details of the test results are described. The conclusions to be drawn from the most recent results are discussed in part D.

B. Test Activity

Final assembly of the boiler-plate test vessel was completed early in October. After an unsuccessful attempt to attain a good vacuum, the tank was disassembled and a leak was discovered in one of the thin wall stainless lines. This leak was caused by weld splatter sticking to the tube during final assembly of the inner vessel. Because of this, it was necessary to cut open the inner vessel and replace the entire support assembly. The tank was reassembled without insulation, leak checked, and evacuated to a pressure level of 3×10^{-4} Torr on November 11. The tank was then filled with liquid nitrogen and the pressure was observed to drop to 2×10^{-5} Torr. After equilibrium was established in the liquid boil-off, the heat leak rate was 250 Btu/hour. The inner tank was then removed from the vessel and wrapped with 140 layers of aluminized Mylar. This insulation was applied in "packets" of 10 layers each and at an average density of 70 layers/inch. The activated charcoal adsorbent was put in place and the tank was reassembled, evacuated, and leak checked on November 20. When the pressure in the vacuum space reached 8 microns, the vessel was filled with liquid nitrogen and the pressure in the insulation space soon dropped to less than 10^{-5} Torr. A steady state heat leak rate of 28 Btu/hour was established after about 24 hours. The liquid level was dropped to half full and the heat leak was about 25 Btu/hour. At this point it was apparent that there existed a large deviation between the predicted heat leak of 10 Btu/hour and the test results of nearly 30 Btu/hour. A possible source of trouble was the electrical leads to the heater which were stranded wires with braided insulation. It was suspected that the wires were acting as capillary tubing and drawing liquid into a warm area; thereby causing a high apparent heat leak. To check this the tank was turned upside down so that the leads were out of the liquid. As a result the heat leak dropped several Btu/hour, indicating that this capillary action was occurring.

The vessel was then opened and the wires cut at the elbow in the cold end of the fill line. In addition, Teflon spacers were placed around the vent and fill lines to insure that they did not touch the support tube wall. The tank was then resealed and evacuated and filled with liquid nitrogen on November 30. The steady state heat leak was 24 Btu/hour. The vessel was then emptied, purged with gaseous hydrogen and refilled with liquid hydrogen. The steady state heat leak with hydrogen was 23 Btu/hour.

At this point it was apparent that there were still major problems to be solved. One very questionable area was the support discs. A calorimeter was built to measure the heat leak through these components independently and as a function of load. Figure 2 is a sketch of this apparatus. The vessel was disassembled and the support discs were tested in the calorimeter. The discs did show considerably higher heat leak than was anticipated. For example, at a load of 200 pounds/inch width the heat leak was 11 Btu/hour, while calculations based on the results presented in Reference 3 have resulted in a predicted heat leak of 1.8 Btu/hour. Thus the support discs were shown to be a major problem area. In an attempt to correct this high heat leak, new support discs were made which did not have an embossed or raised area but which did include a thin layer of 200 mesh MnO_2 dust between each layer. These discs were tested in the calorimeter and did show an improvement over the original discs. At a load of 200 pounds, the heat leak was 6.6 Btu/hour. Although these new discs do show an improvement in heat leak, the heat leak through them is still high. Furthermore, they were very poorly constructed, i.e. they had to be handled quite carefully to keep them from falling apart. The original discs with the embossing were much more rigid and were mechanically very similar to a solid disc of similar dimensions. Efforts are now underway to develop low heat leak support discs with high structural integrity.

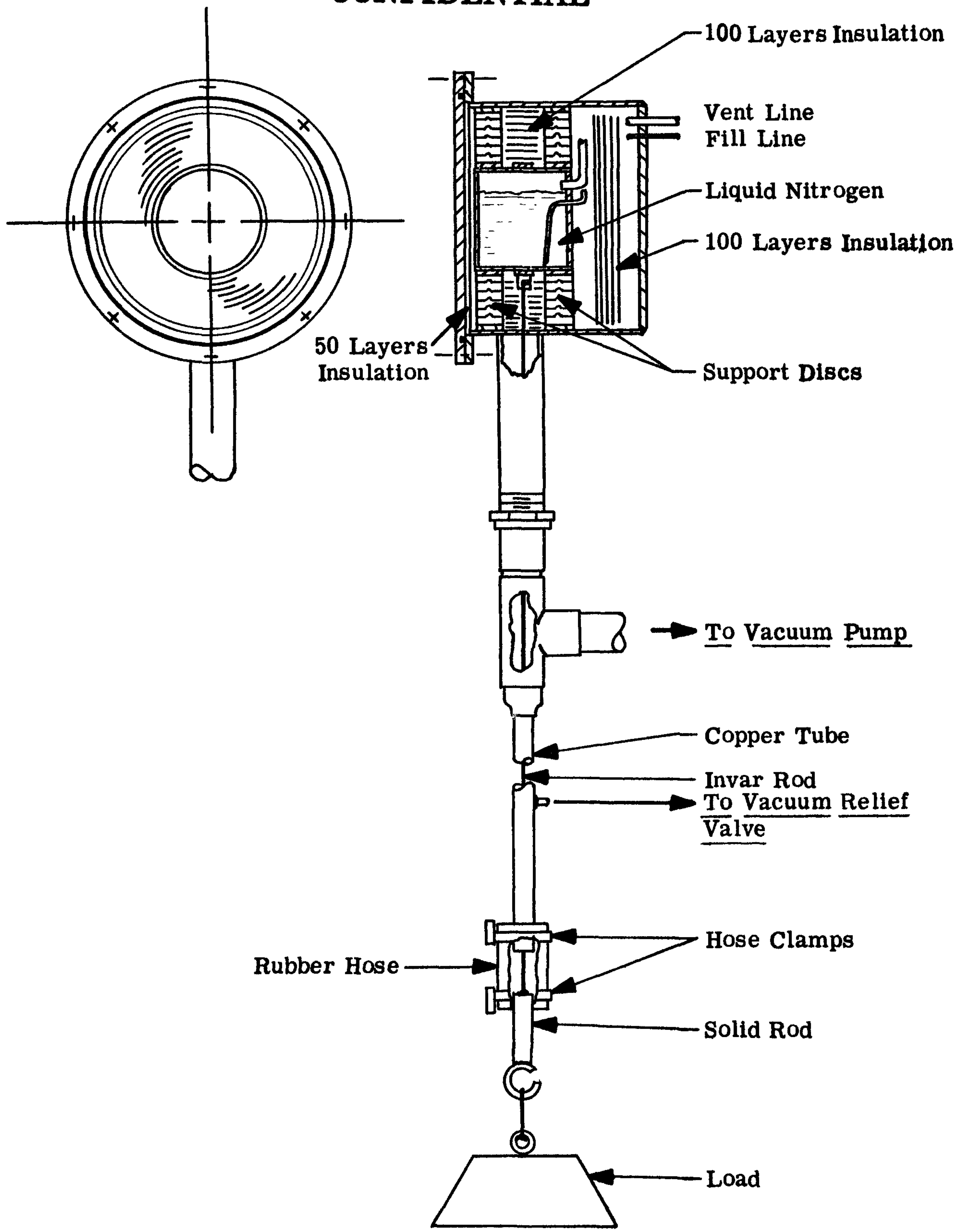

Figure 2. SKETCH OF CALORIMETER

The vessel was again disassembled on December 13 and carefully inspected. It was determined that a total of about 3-1/2 inches of the cold inner vessel support tube was not covered by the insulation and was exposed to the warm outer shell. In addition, there was a possibility that the joint between the insulation over the heads and the cylindrical wraps of insulation could be improved by using a wider insulation blanket on the cylindrical section to give a more uniform and wider overlap. For these reasons it was decided to rewrap the vessel. The wrapping technique was similar to that used before, except that 46-inch wide insulation was used instead of 42 inch and 50% additional layers were interleaved on the heads in order to completely fill the 3-inch insulation space between the inner and outer head sections. This additional thickness of insulation was to shield the cold support mandrel from the warm outer shell. The tank was then reassembled using the new, dusted support discs. After evacuation and cooldown, a steady state heat leak of 21 Btu/hour was obtained when the tank was 75% full and 19 Btu/hour when the tank was 20% full. Further testing is underway at this time and will be reported later.

C. <u>Detailed Test Results</u>

The data taken in each of the previously mentioned tests of the boiler plate vessel are shown graphically as Figures 3 through 7. The three quantities which are plotted as a function of time from start of test, are (a) instantaneous heat leak determined from flow rate of boil-off, (b) accumulated boil-off (integrated flow rate through the meter divided by the time interval), and (c) weight of tank contents. The quantity (a) has been corrected for gas density entering the meter but (b) has not been corrected. This was not corrected because it is a time average correction, and sufficient gas temperature data are not available to give an accurate temperature history. However, in general, temperature variations were within the range of 60 to 80° F and over a long period of time, the correction would tend to be small, on the order of 2% or less. No correction factor is applicable to (c).

It may be seen in the plotted data that there is some fluctuation in the instantaneous boil-off rate. It is believed that this may be due to changes in the outer shell temperature caused by changes in ambient temperature. Efforts to correlate these parameters have been unsuccessful so far, but work in this area will continue during the next quarter.

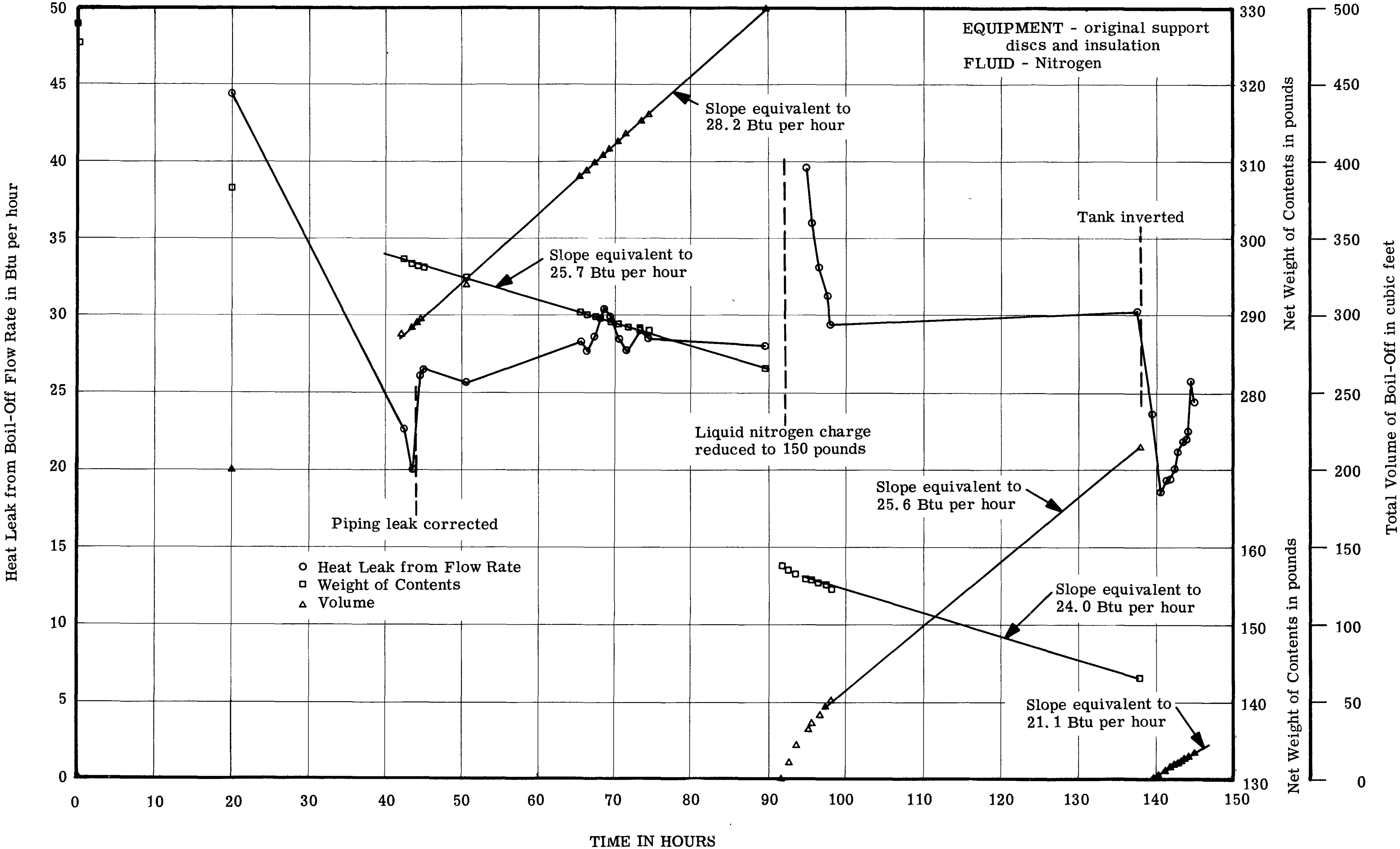

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Figure 3. BOILER-PLATE VESSEL TEST RESULTS, November 23 to November 29, 1963

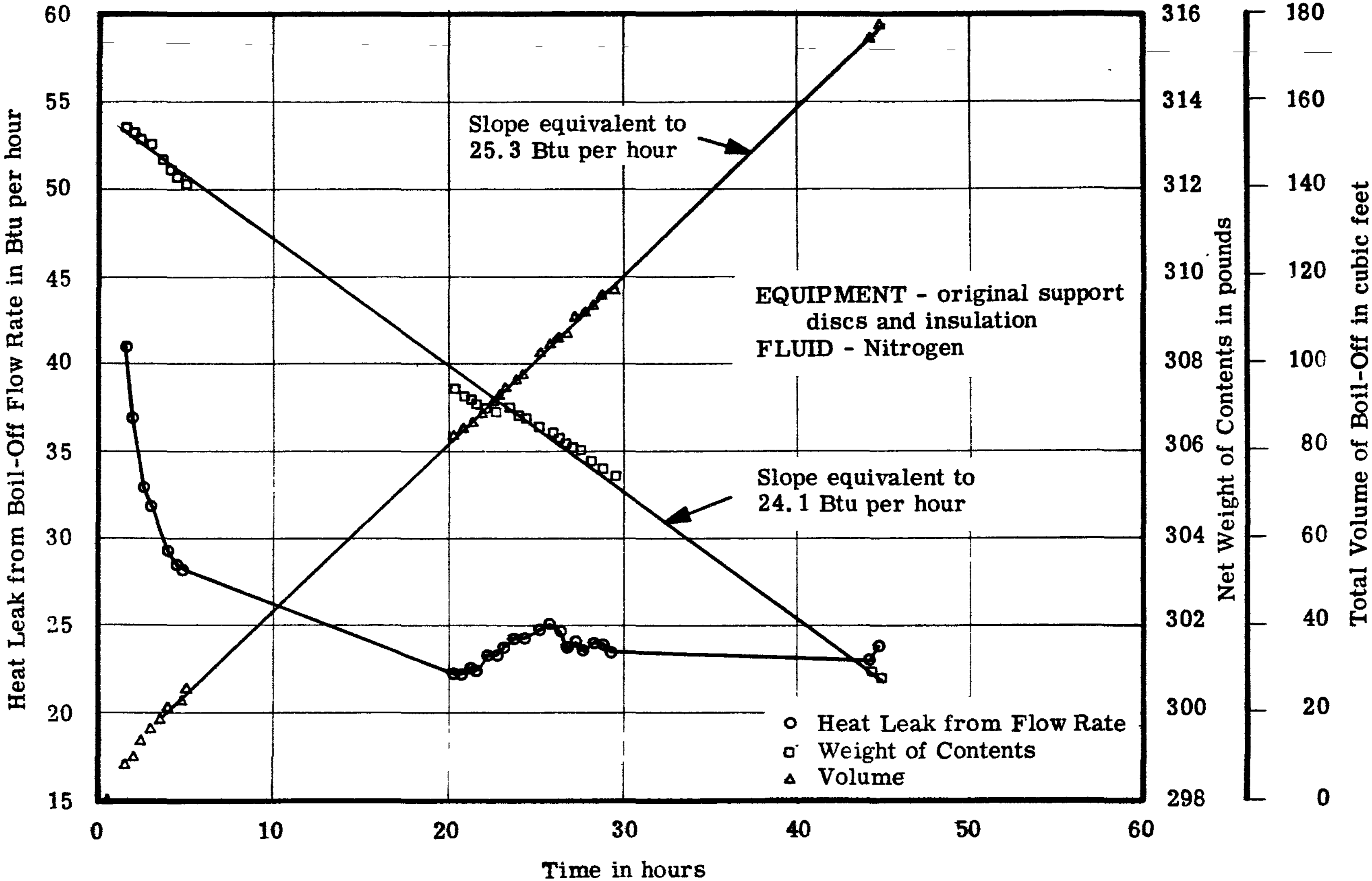

Figure 4. BOILER-PLATE VESSEL TEST RESULTS, December 3 to December 6, 1963

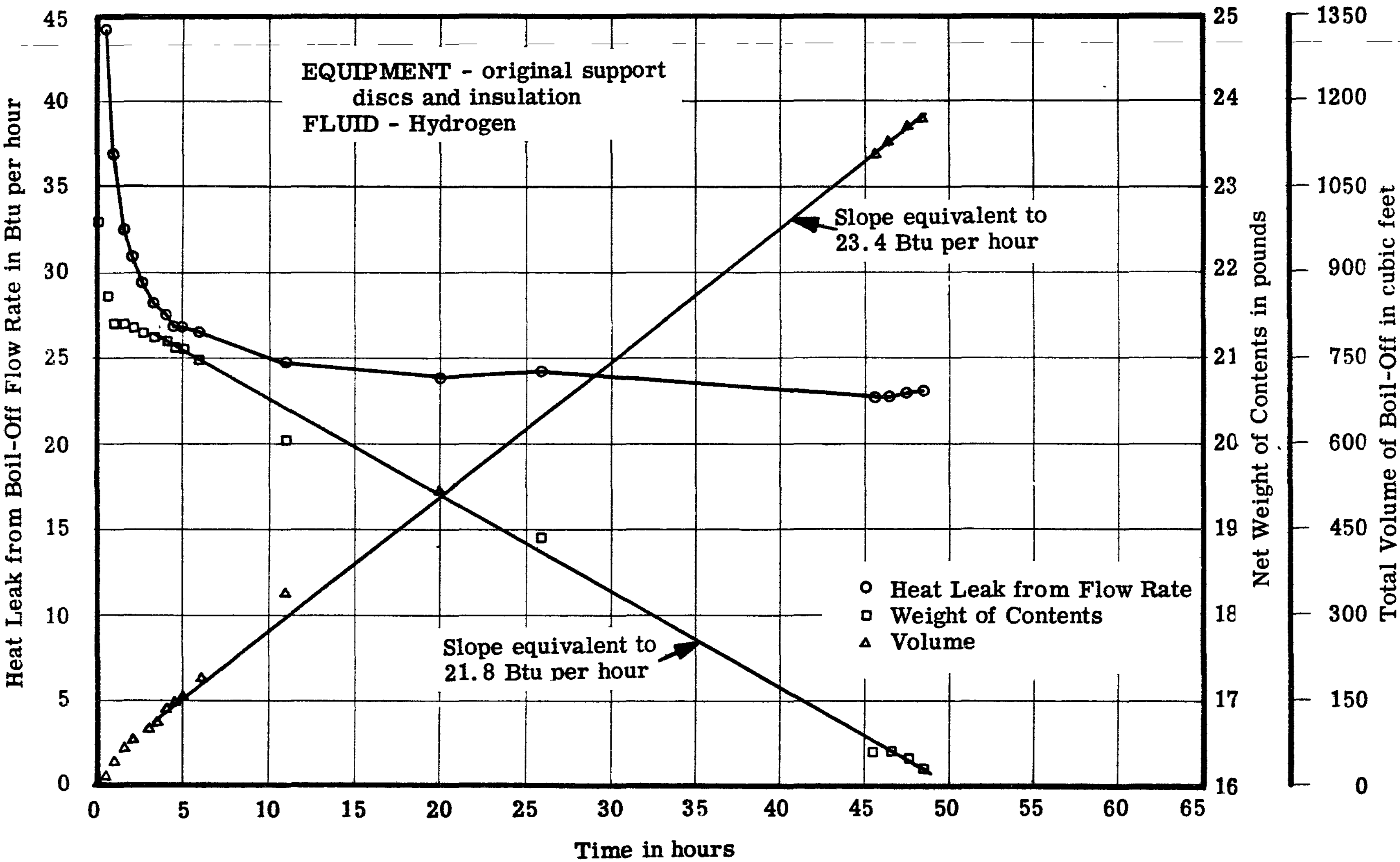

Figure 5. BOILER-PLATE VESSEL TEST RESULTS, December 7 to December 9, 1963

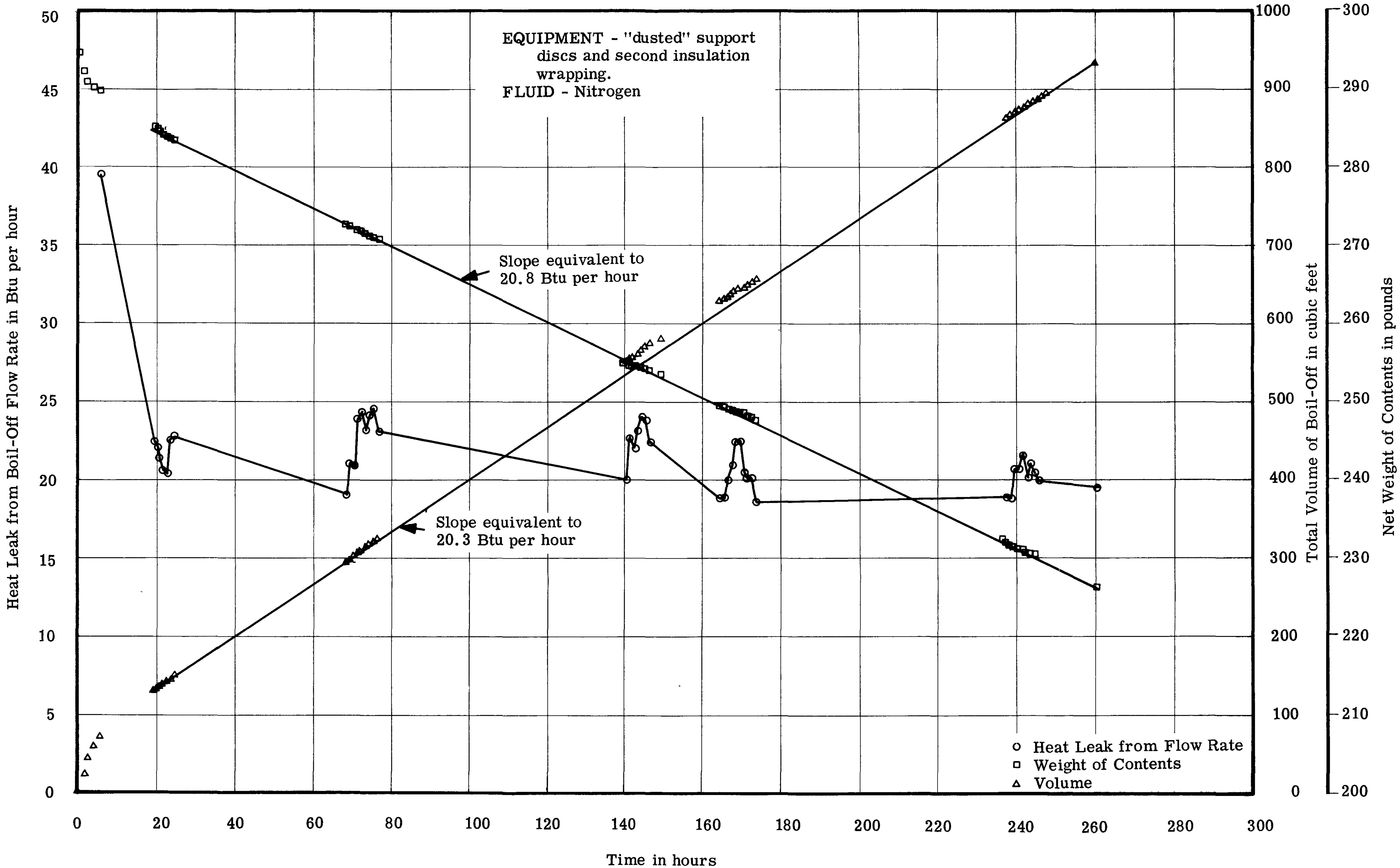

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Figure 6. BOILER-PLATE VESSEL TEST RESULTS, December 20 to December 31, 1963

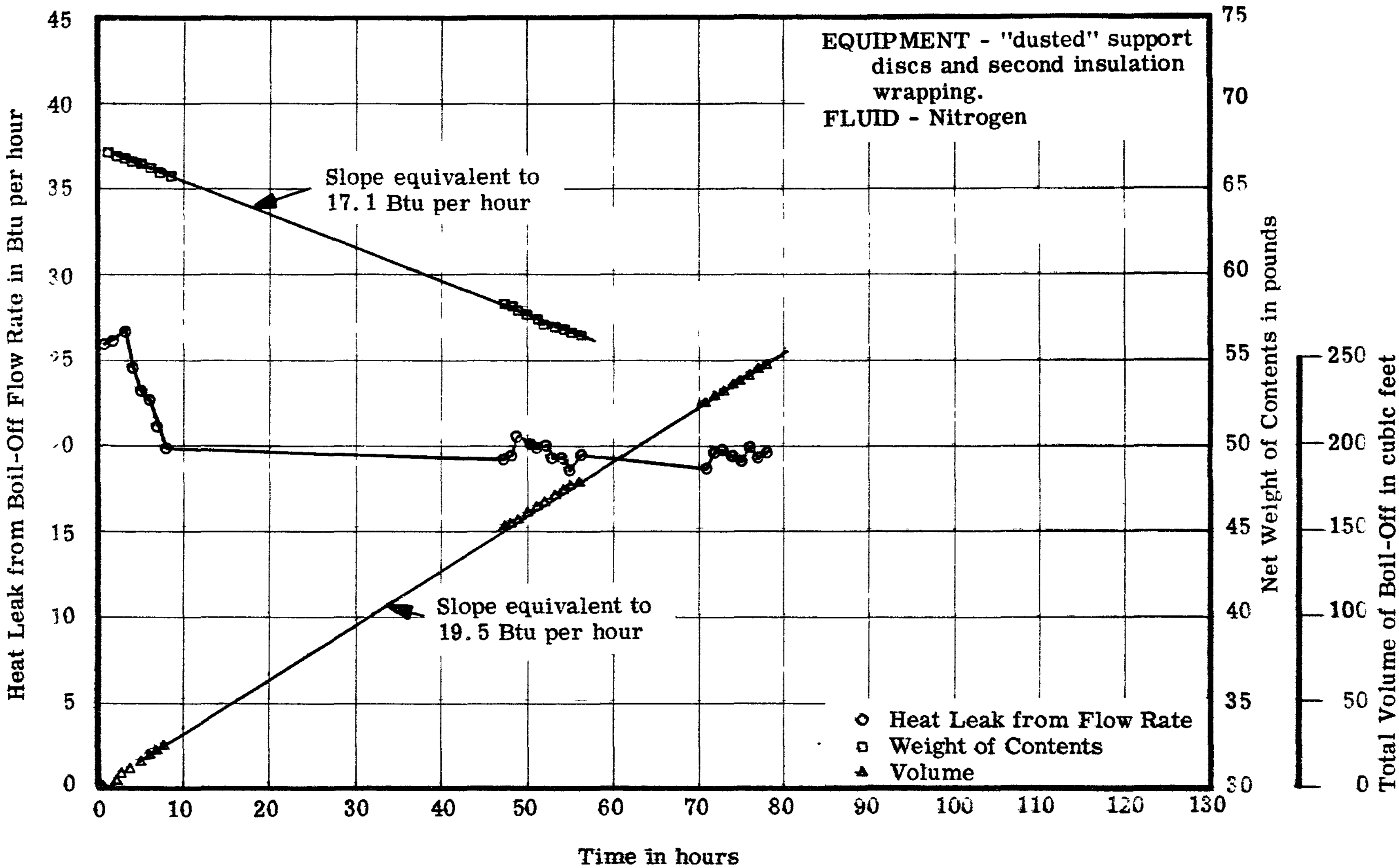

Figure 7. BOILER-PLATE VESSEL TEST RESULTS, December 31 to January 3, 1964

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It may be seen by comparing results shown in Figures 4 and 5 that the heat leak obtained with liquid hydrogen is very similar to that obtained with liquid nitrogen. The conductive type heat leaks were higher with hydrogen but this effect was offset by the decreased load on the support discs. Heat leak by radiation would be unaffected by this difference in sink temperature except for changes in the emissivity of the various vessel components.

The heat leak data for the various support discs are shown as a function of load in Figure 8. Figures 9 and 10 are photographs of an original support disc and the calorimeter assembly, respectively. The "background" heat leak of the calorimeter apparatus was determined to be 2.3 Btu/hour by measuring heat leak with no discs in the chamber. This value has been assumed to be constant and the data shown in Figure 8 have had this amount subtracted from the original data.

D. Analysis of Results

Based on the test results to date and a careful reanalysis of the heat leak calculations, the heat leak distribution listed below has been estimated. The conditions used are those that existed during the test conducted from December 31 to January 3. Three values are listed for each component, the maximum and minimum establishing the extreme range possible, and the middle value represents the best estimate.

	Minimum	Probable	Maximum
Insulation	1.4	4.1	---
End Radiation	.5	2.8	8.8
Piping	1.4	3.1	4.3
Support Rod	.5	.8	1.0
Support Discs	---	6.6	---

The minimum values shown for the insulation represents published (4) data multiplied by an "experience" factor of three. The range shown for end radiation, piping, and support rod is due to the uncertainty always present in estimating surface emissivity. The emissivities used for calculation of the "minimum", "most probable",

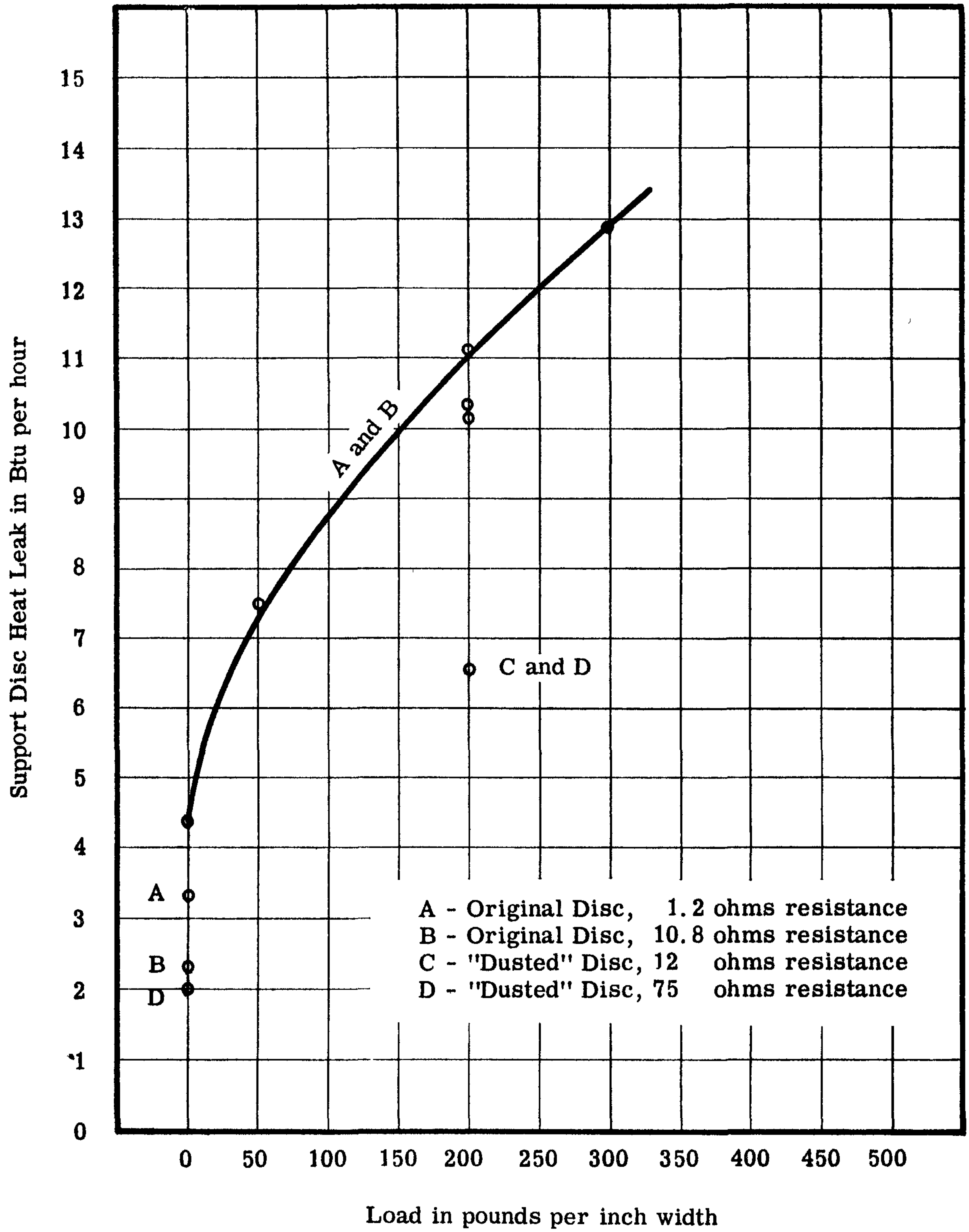


Figure 8 SUPPORT DISC TEST RESULTS

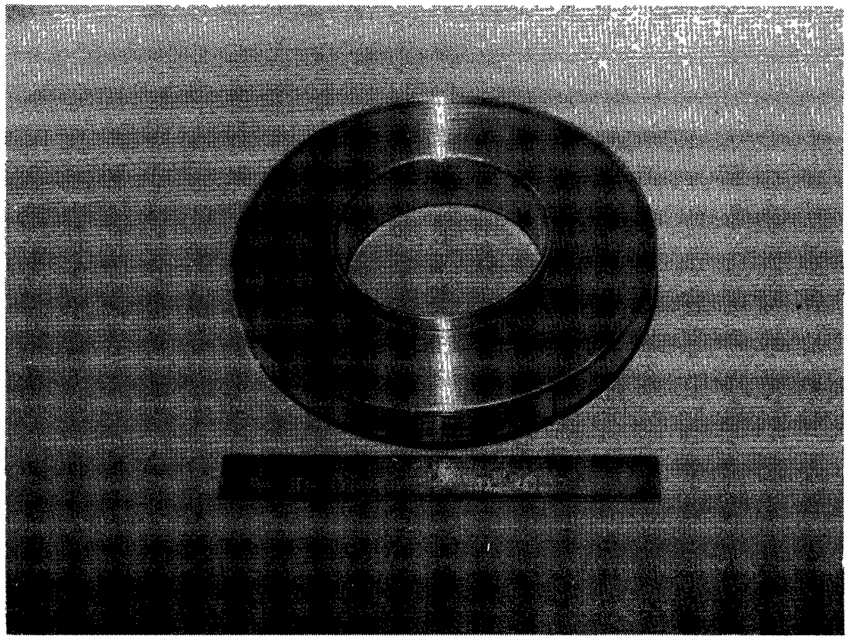


Figure 9. ORIGINAL SUPPORT DISC

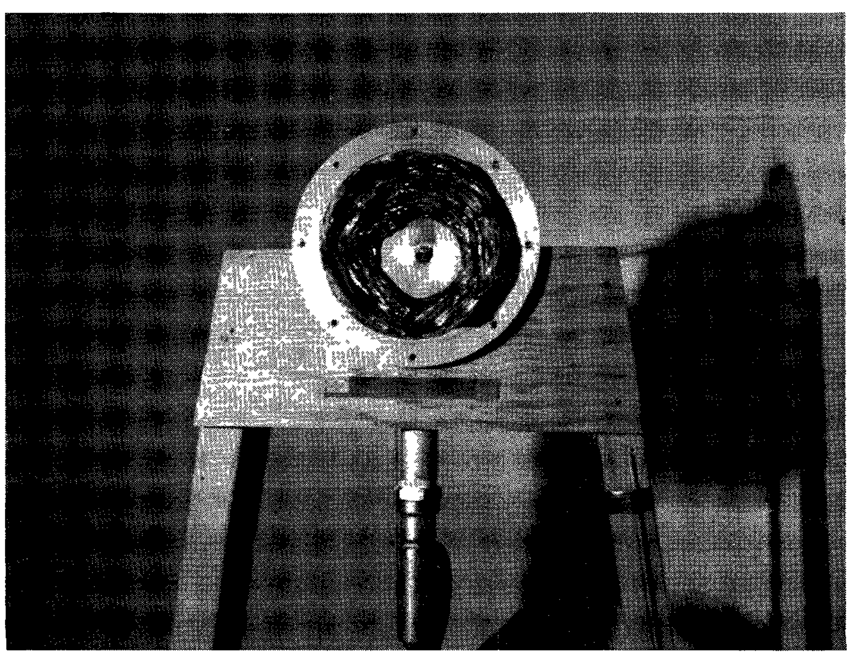


Figure 10. CALORIMETER FOR TESTING SUPPORT DISCS

and "maximum" heat leak due to radiation interchange between the mirrors which is the dominant part of the end radiation are 0.03, 0.1, and 0.3 respectively, The corresponding emissivity values assumed for the piping and support rod calculations are 0.1, 0.5, 1, and 0.3, 0.6, 1.0, respectively. The value shown for the support discs was obtained experimentally.

Analysis of the tabulated results have lead to modifications in the design of the lightweight vessel to reduce the heat leak through the ends, the support discs and the piping.

IV. 50-GALLON LIGHTWEIGHT VESSEL STUDY

A. Introduction

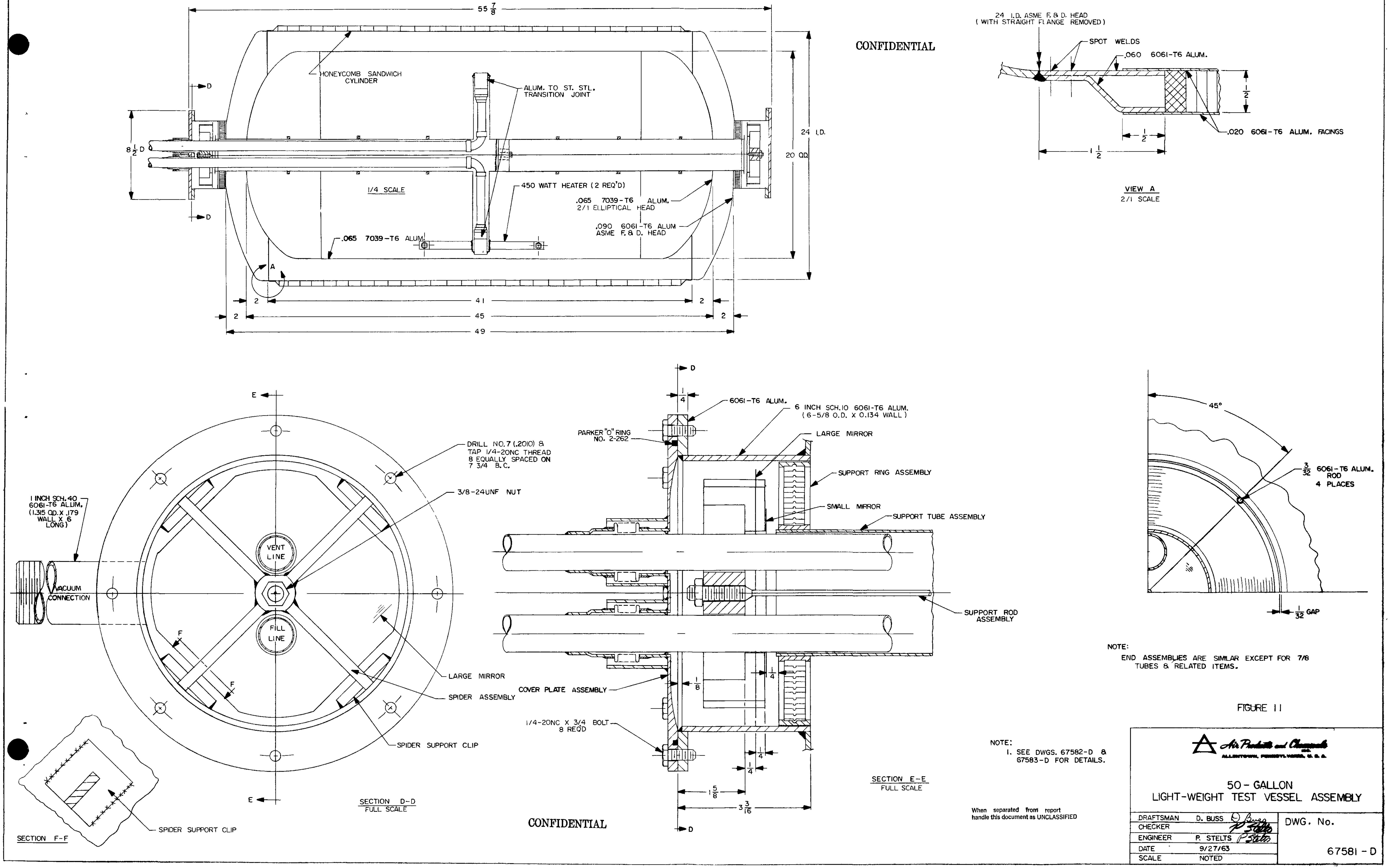
This study involves the design, fabrication, and heat leak testing of a liquid hydrogen vessel which embodies the advanced concepts developed earlier in the contract. The thermodynamic aspects of the design were studied in the boiler-plate test vessel, which was the object of Work Package III. The lightweight vessel study is to demonstrate that the thermodynamic properties predicted on the basis of the boiler-plate vessel tests can be obtained with a vessel which is also of very light weight. This demonstration of low weight and low heat leak built into one ruggedly designed vessel will constitute proof of feasibility of the basic design concept.

B. Vessel Design

The vessel design, as shown in Figure 11, 12, and 13, consists of three primary structural components; the outer shell, inner shell, and support members. Figure 11 is the assembly drawing, and Figure 12 and 13 give additional details of the design. This design is essentially the same as was discussed in detail in a previous report (1). It is very similar to the boiler-plate vessel from the standpoint of thermal design, however some modifications have been made, based on experience gained testing the boiler-plate vessel. The major modifications to the original design include a redesign of the support discs and plating of the vent and fill lines and the lining of the interior of the end caps with aluminum foil to reduce their emissivity. In addition, Teflon-coated solid core wire will be used to supply power to the inside heater, thus eliminating the possibility of capillary flow of liquid into warm areas.

Based on the results of the transition piece study, this vessel will use two aluminum-to-copper-to-stainless steel flash butt-welded joints. These joints are shown in Figure 14. These pieces have been leak checked both before and after welding into the piping to insure their integrity in the assembled vessel.

In Quarterly Progress Report No. 2 (2) it was stated that the aluminum alloy 2219 would be used for the inner vessel. It developed however, that this alloy was unavailable in the thickness range of interest. A new and very promising alloy, 7039 was available. Because of the availability and also its somewhat better mechanical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55 7/8
HONEYCOMB SANDWICH CYLINDER
ALUM. TO ST. STL. TRANSITION JOINT
8 1/2 D
1/4 SCALE
450 WATT HEATER (2 REQ'D)
.065 7039-T6 ALUM. 2/1 ELLIPTICAL HEAD
.090 6061-T6 ALUM ASME F. & D. HEAD
.065 7039-T6 ALUM.
24 I.D.
20 OD.
A
2
41
45
49
24 I.D. ASME F. & D. HEAD (WITH STRAIGHT FLANGE REMOVED)
SPOT WELDS
.060 6061-T6 ALUM.
.020 6061-T6 ALUM. FACINGS
1/2
1 1/2
VIEW A
2/1 SCALE
E
DRILL NO. 7 (.2010) & TAP 1/4-20NC THREAD 8 EQUALLY SPACED ON 7 3/4 B.C.
3/8-24UNF NUT
1 INCH SCH. 40 6061-T6 ALUM. (1.315 OD. X .179 WALL X 6 LONG)
VENT LINE
FILL LINE
VACUUM CONNECTION
LARGE MIRROR
SPIDER ASSEMBLY
SPIDER SUPPORT CLIP
F
SECTION D-D
FULL SCALE
SECTION F-F
SPIDER SUPPORT CLIP
D
6061-T6 ALUM.
6 INCH SCH. 10 6061-T6 ALUM. (6-5/8 O.D. X 0.134 WALL)
PARKER "O" RING NO. 2-262
LARGE MIRROR
SUPPORT RING ASSEMBLY
SMALL MIRROR
SUPPORT TUBE ASSEMBLY
SUPPORT ROD ASSEMBLY
COVER PLATE ASSEMBLY
1/4-20NC X 3/4 BOLT 8 REQ'D
1/4
1/8
1 5/8
3 3/16
SECTION E-E
FULL SCALE
CONFIDENTIAL
45°
3/32 6061-T6 ALUM. ROD 4 PLACES
1/32 GAP
NOTE:
END ASSEMBLIES ARE SIMILAR EXCEPT FOR 7/8 TUBES & RELATED ITEMS.
NOTE:
1. SEE DWGS. 67582-D & 67583-D FOR DETAILS.
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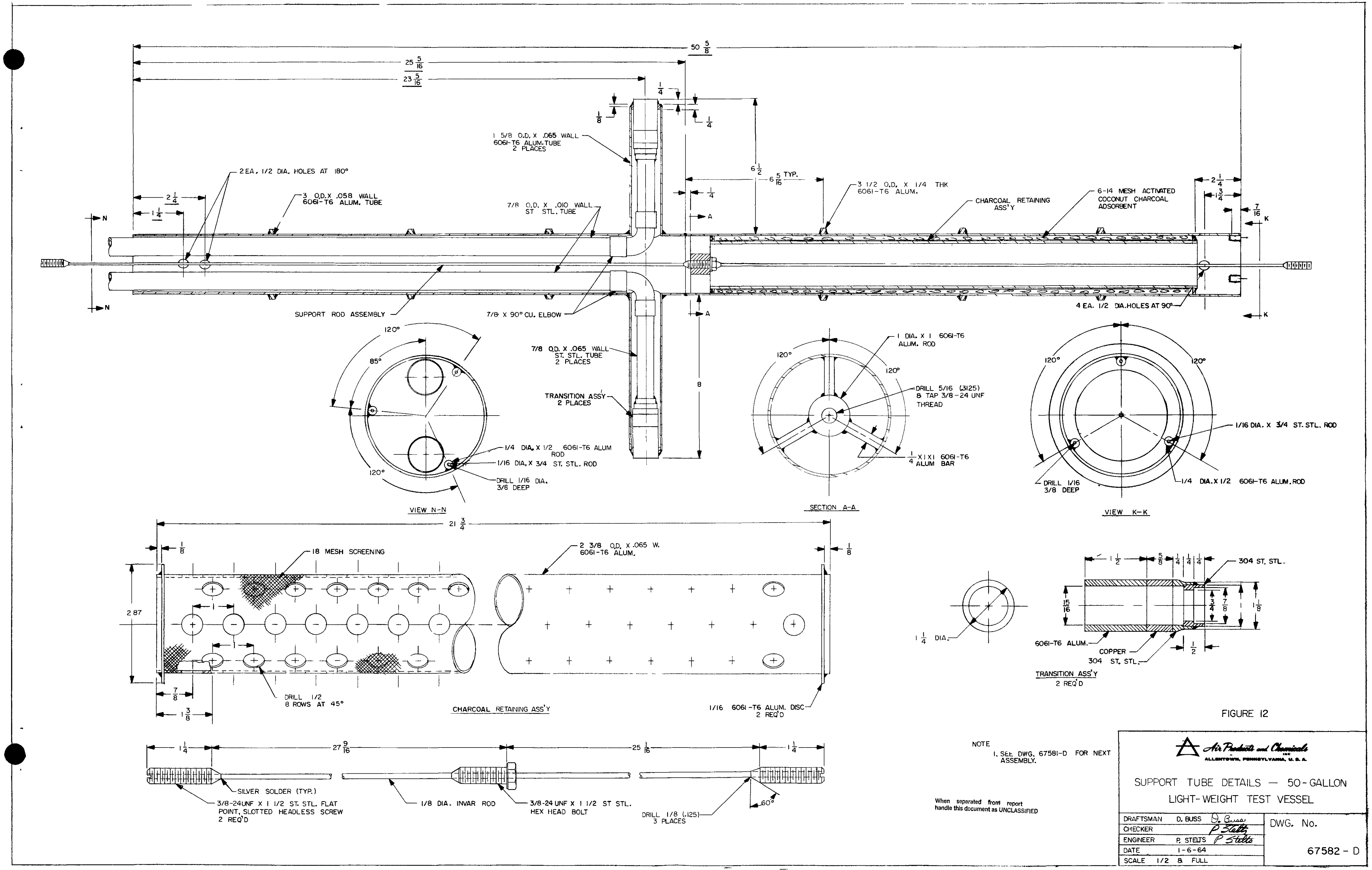
Air Products and Chemicals Inc.
ALLENTOWN, PENNSYLVANIA, U.S.A.
50-GALLON
LIGHT-WEIGHT TEST VESSEL ASSEMBLY
DRAFTSMAN D. BUSS
CHECKER
ENGINEER P. STELTS
DATE 9/27/63
SCALE NOTED
DWG. No.
67581-D

FIGURE 11


50 5/8
25 5/16
23 5/16
1 5/8 O.D. X .065 WALL 6061-T6 ALUM. TUBE 2 PLACES
2 EA. 1/2 DIA. HOLES AT 180°
3 O.D. X .058 WALL 6061-T6 ALUM. TUBE
7/8 O.D. X .010 WALL ST STL. TUBE
6 1/2
6 5/16 TYP.
3 1/2 O.D. X 1/4 THK 6061-T6 ALUM.
CHARCOAL RETAINING ASS'Y
6-14 MESH ACTIVATED COCONUT CHARCOAL ADSORBENT
4 EA. 1/2 DIA. HOLES AT 90°
SUPPORT ROD ASSEMBLY
7/8 X 90° CU. ELBOW
7/8 O.D. X .065 WALL ST. STL. TUBE 2 PLACES
TRANSITION ASS'Y 2 PLACES
1/4 DIA. X 1/2 6061-T6 ALUM ROD
1/16 DIA. X 3/4 ST. STL. ROD
DRILL 1/16 DIA. 3/8 DEEP
VIEW N-N
1 DIA. X 1 6061-T6 ALUM. ROD
DRILL 5/16 (.3125) & TAP 3/8-24 UNF THREAD
1/4 X 1 X 1 6061-T6 ALUM BAR
SECTION A-A
1/16 DIA. X 3/4 ST. STL. ROD
DRILL 1/16 3/8 DEEP
1/4 DIA. X 1/2 6061-T6 ALUM. ROD
VIEW K-K
21 3/4
18 MESH SCREENING
2 3/8 O.D. X .065 W. 6061-T6 ALUM.
DRILL 1/2 8 ROWS AT 45°
CHARCOAL RETAINING ASS'Y
1/16 6061-T6 ALUM. DISC 2 REQ'D
1 1/4 DIA.
304 ST. STL.
6061-T6 ALUM.
COPPER
304 ST. STL.
TRANSITION ASS'Y 2 REQ'D
27 9/16
25 1/16
SILVER SOLDER (TYP.)
3/8-24UNF X 1 1/2 ST. STL. FLAT POINT, SLOTTED HEADLESS SCREW 2 REQ'D
1/8 DIA. INVAR ROD
3/8-24 UNF X 1 1/2 ST STL. HEX HEAD BOLT
DRILL 1/8 (.125) 3 PLACES
60°
NOTE
1. SEE DWG. 67581-D FOR NEXT ASSEMBLY.
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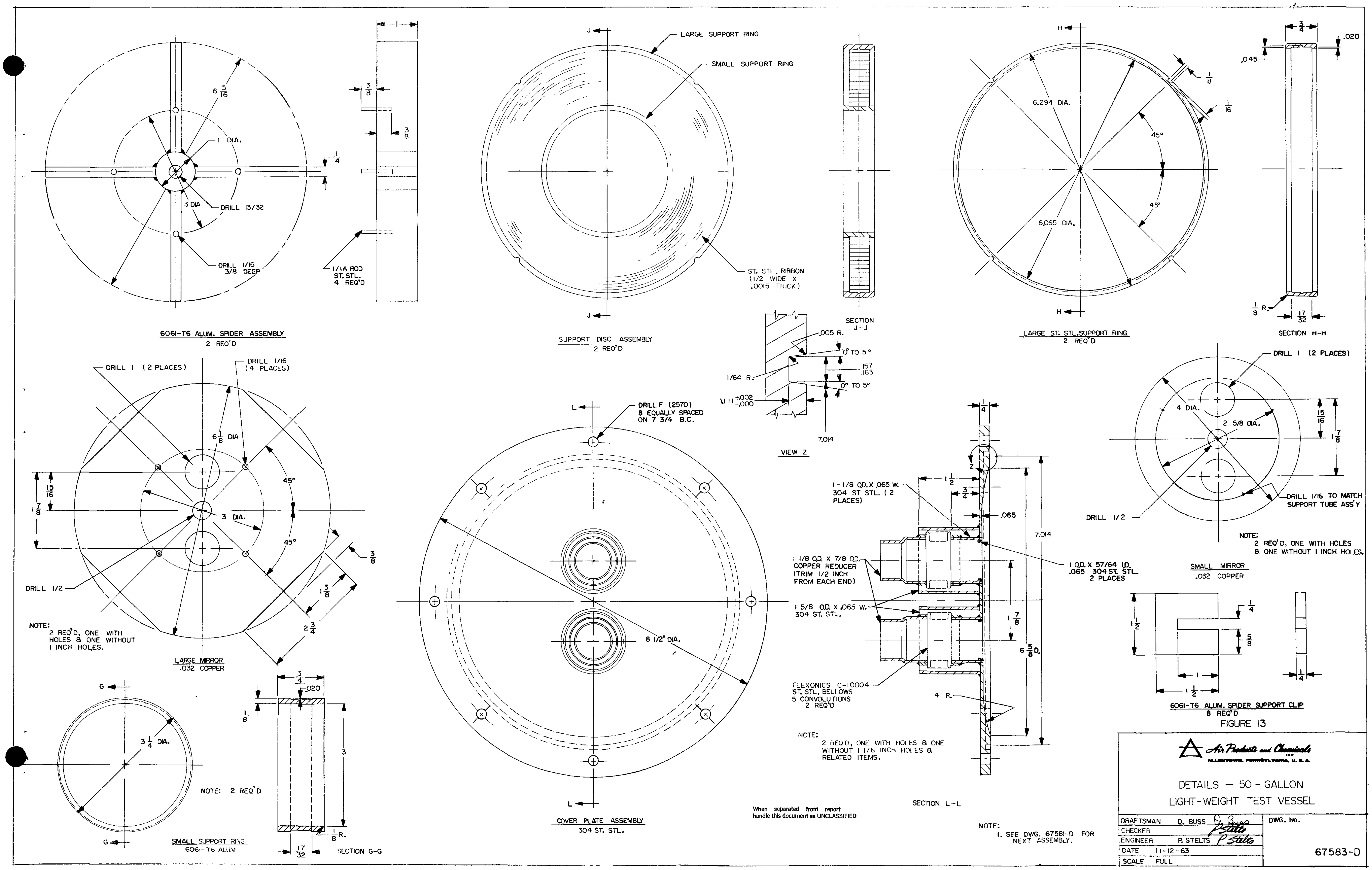
Air Products and Chemicals INC
ALLENTOWN, PENNSYLVANIA, U. S. A.
SUPPORT TUBE DETAILS — 50-GALLON LIGHT-WEIGHT TEST VESSEL
DRAFTSMAN D. BUSS
CHECKER P. Stelts
ENGINEER P. STELTS
DATE 1-6-64
SCALE 1/2 & FULL
DWG. No. 67582-D

FIGURE 12



6061-T6 ALUM. SPIDER ASSEMBLY
2 REQ'D
1 DIA.
3 DIA
DRILL 13/32
DRILL 1/16
3/8 DEEP
1/16 ROD
ST. STL.
4 REQ'D
LARGE SUPPORT RING
SMALL SUPPORT RING
ST. STL. RIBBON
(1/2 WIDE X
.0015 THICK)
SUPPORT DISC ASSEMBLY
2 REQ'D
SECTION
J-J
.005 R.
0° TO 5°
1/64 R.
.157
.163
VIEW Z
6.294 DIA.
6.065 DIA.
45°
LARGE ST. STL. SUPPORT RING
2 REQ'D
SECTION H-H
DRILL 1 (2 PLACES)
DRILL 1/16
(4 PLACES)
6 1/8 DIA
3 DIA.
DRILL 1/2
NOTE:
2 REQ'D, ONE WITH
HOLES & ONE WITHOUT
1 INCH HOLES.
LARGE MIRROR
.032 COPPER
DRILL F (2570)
8 EQUALLY SPACED
ON 7 3/4 B.C.
8 1/2" DIA.
COVER PLATE ASSEMBLY
304 ST. STL.
1-1/8 OD. X .065 W.
304 ST STL. (2
PLACES)
1 1/8 OD. X 7/8 OD.
COPPER REDUCER
(TRIM 1/2 INCH
FROM EACH END)
1 5/8 OD. X .065 W.
304 ST. STL.
1 OD. X 57/64 ID.
.065 304 ST. STL.
2 PLACES
FLEXONICS C-10004
ST. STL. BELLOWS
5 CONVOLUTIONS
2 REQ'D
4 R.
7.014
6 5/8 D.
NOTE:
2 REQ'D, ONE WITH HOLES & ONE
WITHOUT 1 1/8 INCH HOLES &
RELATED ITEMS.
SECTION L-L
4 DIA.
2 5/8 DIA.
DRILL 1/16 TO MATCH
SUPPORT TUBE ASS'Y
DRILL 1/2
NOTE:
2 REQ'D, ONE WITH HOLES
& ONE WITHOUT 1 INCH HOLES.
SMALL MIRROR
.032 COPPER
6061-T6 ALUM. SPIDER SUPPORT CLIP
8 REQ'D
3 1/4 DIA.
NOTE: 2 REQ'D
SMALL SUPPORT RING
6061-T6 ALUM
SECTION G-G
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NOTE:
1. SEE DWG. 67581-D FOR
NEXT ASSEMBLY.
Air Products and Chemicals INC
ALLENTOWN, PENNSYLVANIA, U.S.A.
DETAILS — 50 - GALLON
LIGHT-WEIGHT TEST VESSEL
DRAFTSMAN D. BUSS
CHECKER
ENGINEER P. STELTS
DATE 11-12-63
SCALE FULL
DWG. No.
67583-D

FIGURE 13

properties, 7039 was chosen for the inner vessel, and fabrication is well underway with this material. This material is received in the fully hard or T6 condition (solution heat treat followed artificial age) and is formed in this temper. Welding reduces the heat affected area to about the fully annealed or "-0" level of mechanical properties. To regain the full strength (T6) condition through the joint, it is necessary to solution heat treat and then artificially age either the whole vessel or just the heat affected zone. Solution heat treatment consists of heating to about 900° F followed by a cold water quench, as a result of which distortion can be a major problem in a thin walled vessel. For small vessels it is very difficult to treat the joint areas only. Because of this, it was decided to age the welded vessel artificially and therefore not attain the highest mechanical properties through the joint area. Aging consists of holding the vessel at 325° F for 48 hours. Experimental values attained in welded aged joints in Work Package II indicate joint efficiencies of 75%. In order to fully utilize this material's potential, the joint area has been reinforced. This was accomplished by starting with a sheet thicker than required and by chemically milling away material from the non-joint areas. In the finished vessel, the joint (and one inch on either side) will be 0.063 inch thick, while the main part of the cylindrical section will be 0.045 inch thick. The minimum head thickness after forming is 0.067 inch. The chemically milled area has been etched away an equal amount on both sides so that the centerline of the thickness is not displaced. Surface finish of this area is less than 125 rms. Figure 15 is a photograph of a typical weld and chemically milled portion.

The burst pressure of this vessel at room temperature should be about 300 psi. Maximum working pressure, based on criteria listed in the first progress report is 110 psi.

The 7039 alloy is somewhat preferable to the 2219 alloy because it develops the high strength condition (T6) by heat treatment alone, while 2219 needs some cold work to attain the high strength (T87) condition, and so 2219 can never achieve the full strength condition through the weld, but 7039 can if proper jigs or fixtures are used to prevent distortion during the solution heat treatment. In production such measures could easily be taken, hence eliminating the need for chemical milling to achieve the full potential of the material. Both alloys have equivalent properties in their high strength condition.

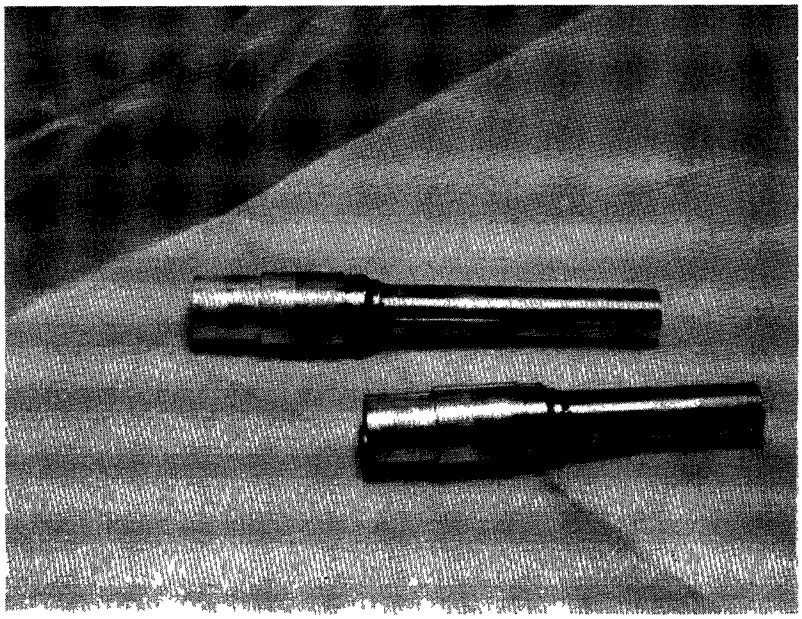

Figure 14. ALUMINUM-STAINLESS STEEL TRANSITION PIECE

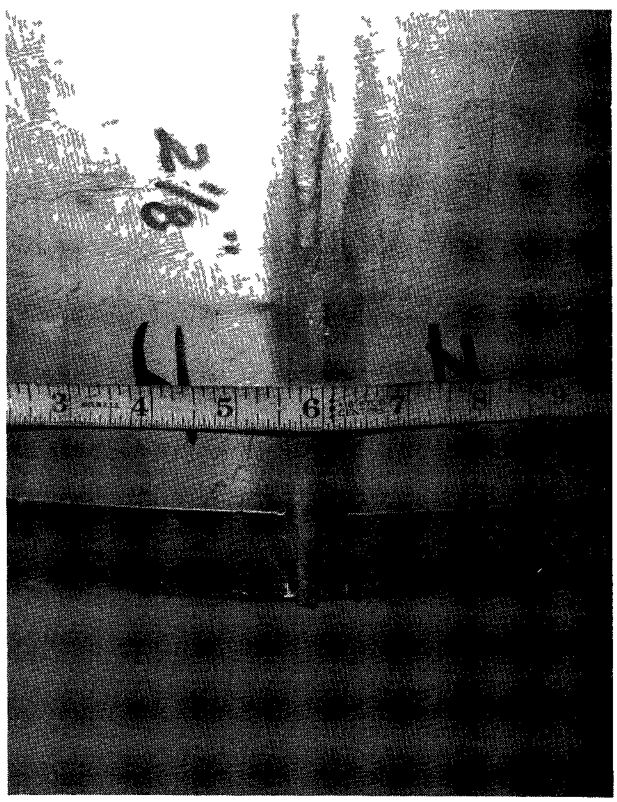

Figure 15. TYPICAL JOINT ON LIGHTWEIGHT INNER VESSEL

It is of interest to note that this vessel is the first pressure vessel to be constructed from this material. It was necessary to develop welding procedures for this material in this thickness range because nearly all the previous work had been with much thicker gages. As a result, this program is a major contribution to the development of the 7039 alloy.

The aluminum-honeycomb outer shell has been fabricated by the Goodyear Aerospace Corporation, Akron, Ohio, and has been received. On this basis, all materials required for the fabrication of the inner and outer vessels have been procured.

C. Test Stand Design

The test stand equipment for the experimental work on the lightweight vessel will be the same as that used in the boiler-plate study. This test stand design was discussed in detail in the second quarterly progress report (2). For convenience, the flow diagram is shown as Figure 16. Since this test stand functioned satisfactorily during the testing of the other vessel, no significant changes have been made.

D. Test Program

The main objectives of the test program for the 50-gallon lightweight vessel are as follows:

1. To demonstrate the structural integrity of a vacuum-jacketed vessel using lightweight construction.

2. To determine the weight of this vessel in final form.

3. To determine heat leak into this vessel, using both liquid nitrogen and hydrogen.

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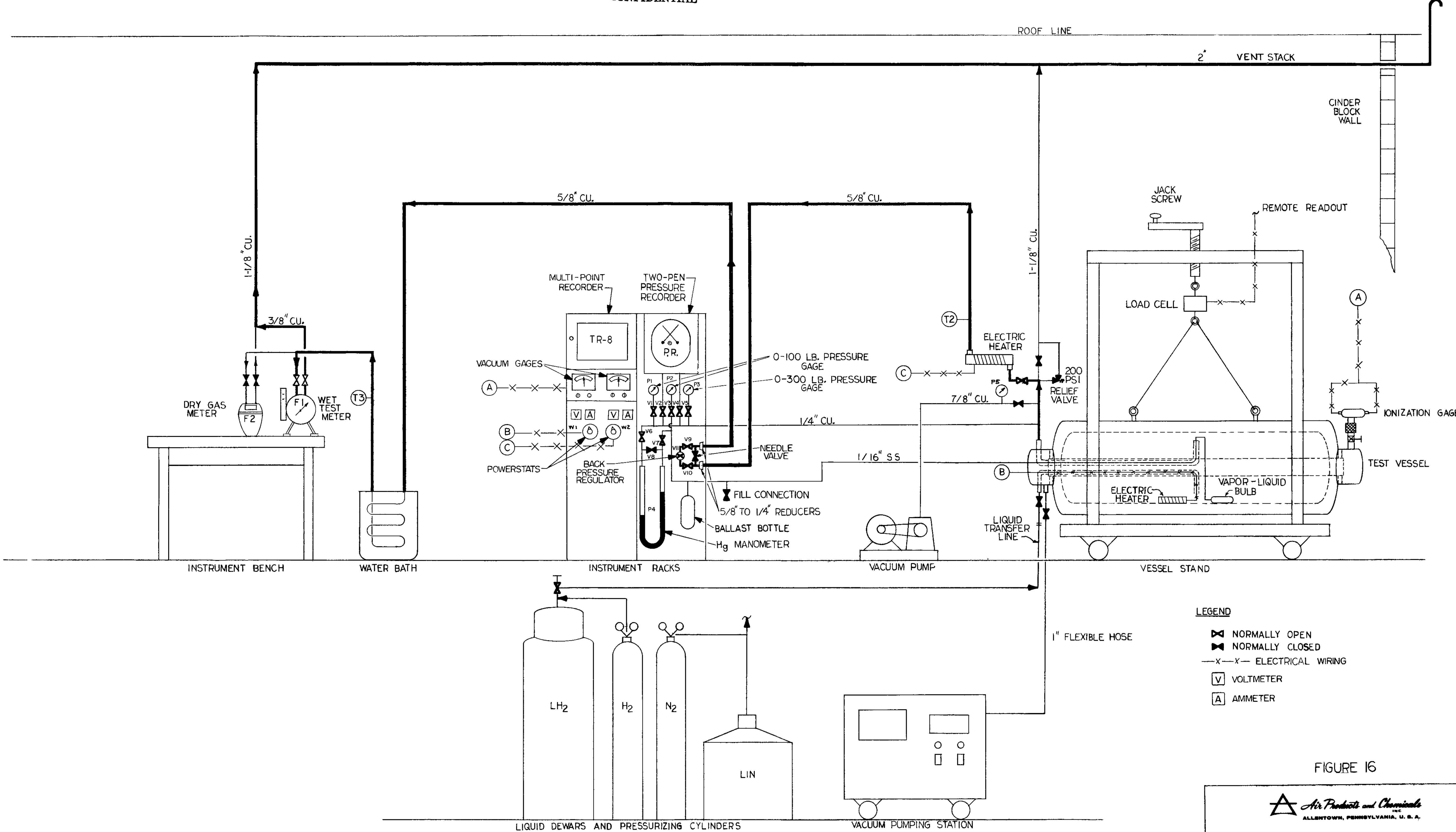

FIGURE 16

Air Products and Chemicals Inc.
ALLENTOWN, PENNSYLVANIA, U. S. A.

FLOW DIAGRAM FOR 50-GALLON VESSEL STUDY

DRAFTSMAN	B J Buss
CHECKER	P Stalz
ENGINEER	E M Flounders
DATE	9/4/63
SCALE	NONE

DWG. No. 67586-D

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V. STORAGE AND DISTRIBUTION SYSTEM STUDY

A. Introduction

This study is to arrive at a conceptual design of the liquid hydrogen Storage and Distribution System for the Energy Depot. The basis of the present study is the result of the preliminary conceptual design study performed by Air Products as sub-contractor to Allis-Chalmers Mfg. Co. under Energy Depot System Study, Phase IIA, Contract AT(30-1)-3133 (4). The work during this third reporting quarterly has been to establish the design criteria for the fuel system, the conceptual design of a flow system to meet these criteria, and the availability of equipment suitable for this application.

The storage and distribution of hydrogen to user vehicles have been limited to liquid storage and transfer. Some thought was given to gaseous hydrogen storage and transfer. The storage bulk and weight for a gas system presents a serious transportation problem. The storage of one pound of hydrogen as a gas at ambient temperature and a pressure of 2000 psig will occupy a volume 6.7 times as great as one pound of liquid hydrogen at 15 psia. A storage vessel containing 100 pounds of gaseous hydrogen at 2000 psig would weigh approximately 2000 pounds and have a diameter of 3 ft and an over-all length of 23 ft. Typical properties for an insulated container for storing 100 pounds of liquid hydrogen would be 200 pounds of vessel with an over-all diameter of 2-3/4 ft and a length of 5 ft. Since the vessel weight and size is substantially lower for liquid transport, the conceptual design was limited to a liquid system.

The problems associated with the production and handling of subcooled liquid or slush hydrogen have been identified in another report (5). The results of that study showed that the lower fuel loss during transfer (due to the increased refrigeration available) is essentially balanced by the lower production capacity of the fuel generation depot (due to the higher process energy). Therefore, the use of subcooled hydrogen will not significantly increase the quantity of hydrogen which is deliverable to the fuel users. In addition, the use of subcooled hydrogen will increase the safety problems due to the necessity of storing a cryogenic fuel at below atmospheric pressure. Based on these conclusions, subcooled hydrogen was not given further consideration during the present study.

Once the selection of a liquid hydrogen system had been established, two basic alternatives for liquid storage and distribution are possible:

1. Bulk liquid storage and individual transfer to user vehicles.

2. Containerized liquid with container transfer to user vehicles.

Direct filling of user vehicles at the Depot is not recommended by the Strategic Planning Group. The traffic and scheduling problems at the Depot and the large inventory of vehicles required tend to make such a system impractical.

The method of bulk liquid storage and individual transfer to user vehicles is most promising because:

1. Larger payload capability with bulk storage as compared to containerized storage.

   a. For a given volume of liquid, the gross storage volume required is larger for a containerized system.

   b. For a given storage volume, the total container weight is larger for a containerized system.

2. The manual handling of a containerized (jerry can) system limits the net liquid in a container to 25 to 40 gallons (considering maximum full container weight of 80 pounds). Both economically and logistically, the maintenance of the required large inventory of the relatively expensive individual containers does not appear to be attractive to the Army.

3. The bulk liquid system has a lower vessel boil-off loss than the containerized (jerry can) system.

4. A bulk storage system requires a single safety system for each primary and secondary unit, while the jerry cans of a containerized system require either an individual safety system for each container or a manifold safety system for each primary and secondary unit. In each case, the total weight of a containerized safety system would be greater than for a bulk storage system.

5. A bulk storage system has greater flexibility in handling varying quantities of liquid. A containerized system limits transfer to container multiples.

In view of the foregoing reasons and with the concurrence of the AEC at an early stage of this study, a bulk liquid storage system with individual liquid transfer to secondary (user) vehicles was selected as the system which holds the greatest potential for the Army. This choice is reflected in the established criteria for the fuel storage and distribution system. (See Appendix B)

The design criteria for the Energy Depot as a whole and the Fuel Storage and Distribution System in particular are documented as Appendixes A and B, respectively. Within the framework of these criteria, the following assumptions and working decisions have been made during the conceptual design of the Fuel Storage and Distribution System:

The normal operation of the system will be highly automatic. Very little training, attention, or activity will be required of the operator during primary or secondary fuel transfer, fuel storage and fuel utilization.

It is assumed that the primary vehicle and the larger secondary vehicles (e.g. Armored personnel carriers) will involve an air brake system and that pressurized air will be available for activation of control valves. Smaller secondary vehicles (e.g. jeeps) may not involve pneumatic brakes and the control valves can be operated from a small cylinder of pressurized air located on the vehicle. It is envisioned that this cylinder will have to be recharged about once a month during secondary fuel transfer by means of a small compressor on the primary vehicle. It is therefore decided that the control valves for fuel handling will be pneumatically operated. It is considered that this will offer a smaller, lighter and more reliable control system then one based on electrically driven valves.

Some redundancy has been designed into the primary system. The system can be operated manually under emergency conditions to deliver the fuel to another primary unit or to a secondary unit in the event that the main transfer or the pressure-raising (PR) coil valves jam shut. A primary unit which has lost its electrical power and/or air supply can perform its transfer mission through interconnection with the power and/or air system of an adjacent vehicle.

B. Reference System

1. Description of Systems

As presently conceived, there are two major subsystems comprising the fuel storage and distribution system: a primary storage and distribution unit and a secondary storage unit. The primary unit is a mobile bulk storage vessel which will be filled at the Depot. It will provide bulk storage at the Depot, and will serve to transport the fuel to the user vehicles.

The primary system is made mobile by mounting it on an 8-ton GOER, a transport vehicle being developed by the Army. The GOER is being designed in such a manner as to be adaptable to perform many transport duties, such as hauling earth, food, troops, materiel or liquid. During this study the GOER was considered a flat bed truck which will accommodate the primary system.

The secondary unit is the fuel storage and handling system on board the user vehicle. The secondary storage capacity will generally be an order-of-magnitude smaller than the primary capacity and will be determined by the characteristics of the vehicle. For the purpose of this study the general fuel loading, storage arrangement and delivery rate characteristics of the M-113 Armored Personnel Carrier have been assumed to be representative for all user vehicles (5).

2. Description of Operation

Before filling the primary liquid hydrogen container, the vessel and transfer lines must be cooled if a high boil-off rate is to be avoided during the early period of storage. Cool-down of the primary storage system is achieved by gradually cooling the equipment with liquid hydrogen from the plant. During normal usage, the primary vessel is cold at subsequent filling operations. All liquid hydrogen vaporized during cool-down is returned to the plant for reliquefaction. The cool-down is performed under automatic control and normally needs no manual correction.

Once the unit has cooled to liquid hydrogen temperature, vaporization will gradually cease and liquid will begin filling the GOER. During the filling of a primary vessel, liquid hydrogen flows from the plant to a delivery manifold. The manifold is arranged so that an empty GOER can connect to it while another is being filled. The purpose of this arrangement is to keep the plant in continuous operation until all primary storage units have been filled, and to decrease the total time required to complete filling operations.

During the 17 hour filling period, friction and heat leak into the transfer lines causes liquid to vaporize. This vapor, like the cool-down vapor, is returned to the plant for reliquefaction.

After the storage vessel on the GOER is filled, the main transfer valves on the plant and the primary vessel automatically operate halting liquid flow to the full GOER and divert the flow to an empty GOER which was previously connected to the fill manifold.

It is assumed that a small quantity of liquid remains at all times in the secondary storage tanks, therefore maintaining a cold vessel, and only the transfer lines are cooled at each transfer. The initial cool down of the transfer lines is accomplished in approximately one minute. Losses during subsequent fillings are a function of the time elapsed since the previous transfer.

When the temperature of the secondary inlet reaches -350° F, the main transfer valves are automatically opened, initiating liquid filling of the secondary. The liquid transfer between primary and secondary storage tanks is effected by a predetermined pressure differential between the two tanks. During the filling operation this pressure differential is maintained with a vaporizing coil located on the primary. The flow rate from the primary is controlled automatically from 50 to 100 gpm depending upon the size of, and time required to fill the secondary vessel.

Some consideration was given to the possibility of using a pump as a means of transferring liquid from the primary unit to secondary units. A two horsepower, 100 gpm capacity pump would require approximately eight gallons of liquid hydrogen for cool-down. The utilization of a pump would require some additional equipment necessary in maintaining a positive liquid pressure at the inlet of the pump. This could be accomplished by adding a small pressure raising coil, or an electric resistance heater with a minimum power out-put of 3.9 kilowatts. Coupled with its power requirement for adequate operation, and the amount of hydrogen lost in cooling it down and the decreased system reliability, the pump is not considered the most promising means of effecting liquid transfer. Consequently a pressure raising coil was selected for liquid hydrogen transfer.

The user vehicle stores hydrogen in liquid form because of savings in storage weight and space. The hydrogen will be used as a gas in a fuel cell and consequently the liquid must be vaporized. Electric resistance heaters supply the heat of vaporization. Although a separate vaporizer and a pressure-raising coil were briefly considered for this purpose, the response time of an ambient vaporizer is more sluggish than an electric heater. Less responsive control and greater weight and volume make a vaporizer and pressure raising coil less attractive than an electric heater.

The main control valve handling liquid hydrogen on the primary unit, and the main control valves on the secondary unit are pneumatically operated valves. Pneumatically operated valves were chosen primarily because of their proven reliability in cryogenic service. Motor-operated valves were not considered adequate for this application due to their comparatively long response time and questionable reliability. Pilot operated solenoid valves depend on the flowing fluid for actuation and have developed repeated malfunctions when used with cryogenic fluids.

3. Operating Procedure

The conceptual design of the Storage and Distribution flow pattern system is best shown by Figure 17, which schematically represents both the primary and secondary systems.

Tables II and III contain the operating condition of each control component during each of seven basic operations.

In preparing the GOER for filling, the operator need only connect the couplings; EC-102, C-105, and C-101, in that order. The filling operation and shut-off will then commence automatically upon the initial signal from the plant. When the primary is full, the operator need only disconnect the above-mentioned couplings in reverse order. The unit can now be used for either long-term storage (operator opens V-112), or be driven to a rendezvous with a secondary unit.

When transferring from a primary to a secondary, the operator must first connect EC-102 and C-102 to the secondary. He then energizes the primary's system controller by flicking a switch. After a few seconds a light on the GOER's control console will notify him that the differential pressure between both units is at the desired transfer setting. The operator then connects coupling C-101 to the secondary. The cool down, filling, and shut-off will then be automatic. After shut-off the operator de-energizes the system controller on the primary and disconnects C-101, C-102, and EC-102, in that order.

C. Process Equipment Description

1. Primary System

The primary unit consists essentially of the six components described below.

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VALVE & INSTRUMENT LIST - PRIMARY VESSEL

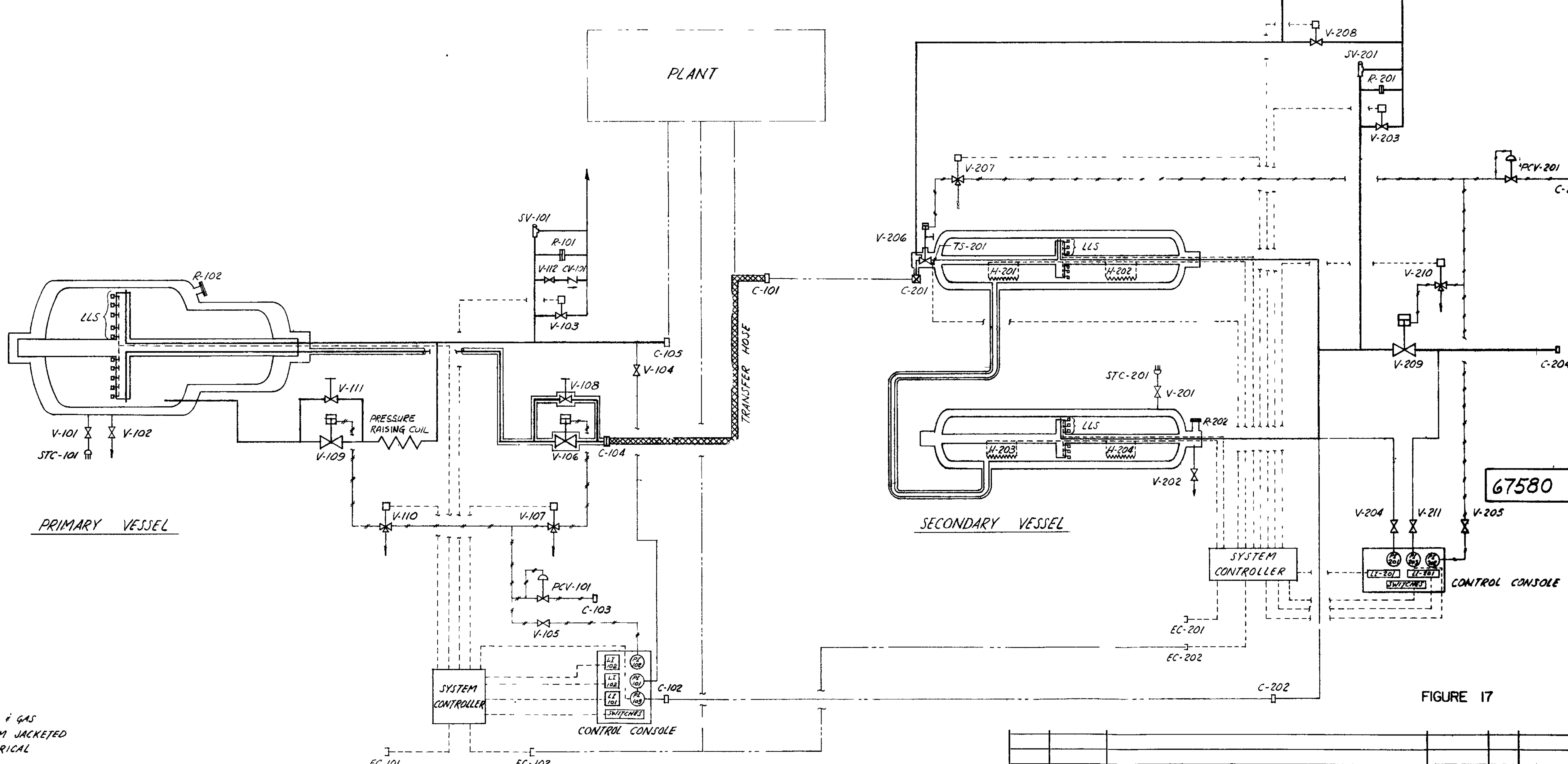
C-101	CPLG. - LH_2 TRANSFER
C 102	CPLG - GAS PHASE FROM SECONDARY
C-103	CPLG - AIR SUPPLY
C-104	CPLG. - TRANSFER HOSE ISOLATION
C-105	CPLG. - VAPOR RETURN TO PLANT
CV-101	CHECK VALVE (CONTINUOUS BLOWDOWN)
EC-101	ELECTRICAL CONNECTION (POWER SUPPLY)
EC-102	ELECTRICAL CONNECTION (PLANT OR SECONDARY
LI-101	LEVEL INDICATOR (PRIMARY VESSEL)
LI-102	LEVEL INDICATOR (SECONDARY VESSEL)
LLS	LIQUID LEVEL SENSORS
PCV-101	AIR REGULATOR
PI-101	PRESSURE INDICATOR (INNER VESSEL)
PI-102	PRESSURE INDICATOR (AIR TO V-107 & V-110)
PI-103	DIFFERENTIAL PRESSURE INDICATOR
R-101	RUPTURE DISC (INNER VESSEL)
R-102	RUPTURE DISC (JACKET)
STC-101	VACUUM SENSING CONNECTION
SV-101	SAFETY VALVE (INNER VESSEL)
V-101	SHUT-OFF VALVE (STC-101)
V-102	SHUT-OFF VALVE (VACUUM PUMP)
V-103	VENT VALVE
V-104	SHUT-OFF VALVE (PI-101)
V-105	SHUT-OFF VALVE (PI-102)
V-106	LH_2 TRANSFER VALVE
V-107	AIR VALVE (TO OPEN V-106)
V-108	BYPASS VALVE (V-106)
V-109	CONTROL VALVE (LH_2 TO PR COIL)
V-110	AIR VALVE (TO OPEN V-109)
V-111	BYPASS VALVE (V-109)
V-112	BLOCK VALVE (CV-101)

VALVE & INSTRUMENT LIST - SECONDARY VESSEL

C-201	CPLG - LH_2 TRANSFER
C-202	CPLG. - GAS PHASE FROM INNER VESSEL
C-203	CPLG. - AIR SUPPLY
C-204	CPLG. - GAS TO FUEL CELL
EC-201	ELECTRICAL CONNECTION (POWER SUPPLY)
EC-202	ELECTRICAL CONNECTION (TO PRIMARY)
H-201, H-202, H-203, H 204	ELECTRIC RESISTANCE HEATERS
LI-201	LEVEL INDICATOR (SECONDARY VESSEL)
LLS	LIQUID LEVEL SENSORS
PCV-201	AIR REGULATOR
PI-201	PRESSURE INDICATOR (INNER VESSEL)
PI-202	PRESSURE INDICATOR (AIR TO V-207 & V-210)
PI-203	INDICATING PRESSURE TRANSMITTER (GAS TO FUEL CELL)
R-201	RUPTURE DISC (INNER VESSEL)
R-202	RUPTURE DISC (JACKET)
STC-201	VACUUM SENSING CONNECTION
SV 201	SAFETY VALVE (INNER VESSEL)
SV-202	SAFETY VALVE (COOL DOWN GAS BYPASS LINE)
TS-201	TEMPERATURE SENSOR
V-201	SHUT-OFF VALVE (STC-201)
V-202	SHUT-OFF VALVE (VACUUM PUMP)
V-203	VENT VALVE
V [illegible]	SHUT-OFF VALVE (PI-201)
V-20[illegible]	SHUT-OFF VALVE (PI-202)
V-206	LH_2 TRANSFER VALVE
V-207	AIR VALVE (TO OPEN V-206)
V-208	VENT VALVE (WARM COOL DOWN GAS)
V-209	CONTROL VALVE (GAS TO FUEL CELL)
V-210	AIR VALVE (TO OPEN V-209)
V-211	SHUT-OFF VALVE (PI-203)

REVISIONS

NO	LETTER	ZONE	DESCRIPTION	DATE	MADE	CHK'D	APPR'D



LINE LEGEND

- LIQUID & GAS
- VACUUM JACKETED
- ELECTRICAL
- AIR
- CONNECTION PATH

FIGURE 17

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REQ'D	PART NO	NOMENCLATURE	MAT'L SPEC.	UNIT WT.	FINISH	ZONE

UNLESS OTHERWISE SPECIFIED DIM'S ARE IN INCHES
FRACTION ± DECIMAL ± ANGLES ±

FIRST USED ON

		DATE
DRAFTSMAN	J. R. Young	12/12/63
CHECKED	TVT & JJ	12/16/[illegible]
ENGINEER	[illegible]	12/17/63
	[illegible]	12/17/63
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TITLE FLOW DIAGRAM OF LIQUID HYDROGEN STORAGE AND DISTRIBUTION SYSTEM

SCALE ~ WT. ~

AIR PRODUCTS AND CHEMICALS, INC.
ALLENTOWN, PENNSYLVANIA U. S. A.

67580 D

TABLE II

STATE OF EQUIPMENT DURING OPERATION - PRIMARY UNIT

CONDITION (7) Vapor generation in secondary when in use
CONDITION (6) Secondary unit filled, or partially filled, and not in use
CONDITION (5) Transfer from primary to secondary
CONDITION (4) Primary unit cooling down transfer lines when coupled to secondary unit
CONDITION (3) Primary unit en route to rendezvous with secondary unit
CONDITION (2) Long-term liquid storage in primary unit
CONDITION (1) Filling of primary unit

		(1)	(2)	(3)	(4)	(5)	(6)	(7)
PRIMARY UNIT	V-101	C.	C.	C.	C.	C.		
	V-102	C.	C.	C.	C.	C.		
	V-103	C.	C.	C.	C.	C.		
	V-104	O.	O.	O.	O.	O.		
	V-105	C.	O.	O.	O.	O.		
	V-106	O.	C.	C.	C.	O.		
	V-107	E.C.ATM.	DE.O.ATM.	DE.O.ATM.	DE.O.ATM.	E.C.ATM.		
	V-108	C.	C.	C.	C.	C.		
	V-109	C.	C.	C.	O.	O.		
	V-110	DE.O.ATM.	DE.C.ATM.	DE.O.ATM.	E.C.ATM.	E.C.ATM.		
	V-111	C.	C.	C.	C.	C.		
	V-112	C.	O.	C.	C.	C.		
	C-101	CONN.	DSCONN.	DSCONN.	CONN.	CONN.		
	C-102	DSCONN.	DSCONN.	DSCONN.	CONN.	CONN.		
	C-103	CONN.	CONN.	CONN.	CONN.	CONN.		
	C-104	CONN.	CONN.	CONN.	CONN.	CONN.		
	C-105	CONN.	DSCONN.	DSCONN.	DSCONN.	DSCONN.		
	STC-101	DSCONN.	DSCONN.	DSCONN.	DSCONN.	DSCONN.		
	EC-101	CONN.	CONN.	CONN.	CONN.	CONN.		
	EC-102	CONN.	DSCONN.	DSCONN.	CONN.	CONN.		
	SYS. CONT. PR.	E.	DE.	DE.	E.	E.		

ABBREVIATIONS

O. - Open
C. - Closed
E. - Energized
DE. - De-energized
CONN. - Connected

DSCONN. - Disconnected
O.E. - Open and Energized
C.DE. - Closed and De-energized
DE.O.ATM. - De-energized and Open to Atmosphere
E.C.ATM. - Energized and Closed to Atmosphere

TABLE III

STATE OF EQUIPMENT DURING OPERATION - SECONDARY UNIT

CONDITION (7) Vapor generation in secondary when in use
CONDITION (6) Secondary unit filled, or partially filled, and not in use
CONDITION (5) Transfer from primary to secondary
CONDITION (4) Primary unit cooling down transfer lines when coupled to secondary unit
CONDITION (3) Primary unit en route to rendezvous with secondary unit
CONDITION (2) Long-term liquid storage in primary unit
CONDITION (1) Filling of primary unit

SECONDARY UNIT	Condition (1)	Condition (2)	Condition (3)	Condition (4)	Condition (5)	Condition (6)	Condition (7)
V-201				C.	O.	O.	O.
V-202				C.	C.	C.	C.
V-203				C.	C.	C.	C.
V-204				C.	C.	O.	O.
V-205				O.	O.	O.	O.
V-206				C.	C.	C.	C.
V-207				DE.O.ATM.	E.C.ATM.	DE.O.ATM.	DE.O.ATM.
V-208				O.E.	C.DE.	C.DE.	C.DE.
V-209				O.	O.	C.	C.
V-210				E.C.ATM.	E.C.ATM.	DE.O.ATM.	E.C.ATM.
V-211				O.	O.	C.	O.
C-201				CONN.	CONN.	DSCONN.	DSCONN.
C-202				CONN.	CONN.	DSCONN.	DSCONN.
C-203				CONN.	CONN.	CONN.	CONN.
C-204				CONN.	CONN.	CONN.	CONN.
ST -201				CONN.	CONN.	CONN.	CONN.
EC-201				CONN.	CONN.	CONN.	CONN.
EC-202				CONN.	CONN.	DSCONN.	DSCONN.
H-201				DE.	DE.	DE.	E.
H-202				DE.	DE.	DE.	E.
H-203				DE.	DE.	DE.	E.
H-204				DE.	DE.	DE.	E.
SYS. CONT. SEC.				E.	E.	DE.	E.

ABBREVIATIONS

O. - Open
C. - Closed
E. - Energized
DE. - De-energized
CONN. - Connected
DSCONN. - Disconnected
O.E. - Open and Energized
C.DE. - Closed and De-energized
DE.O.ATM. - De-energized and Open to Atmosphere
E.C.ATM. - Energized and Closed to Atmosphere

a. Vacuum-Jacketed Storage Vessel - The liquid hydrogen is contained in a single inner vessel with a net capacity of approximately 3200 gallons and made of a high strength aluminum alloy. The inner vessel is wrapped with a multi-layer reflective type insulation, and mounted in an evacuated jacket of aluminum honeycomb.

b. Pressure-Raising (PR) Coil - Pressure head required for transfer of liquid hydrogen from the primary vessel to a secondary vessel is obtained by allowing liquid hydrogen to flow from the bottom of the primary vessel into an ambient temperature PR coil located on the bed of the GOER. The liquid hydrogen is vaporized in the coil, and the resulting vapor is returned to the top of the primary vessel, thereby increasing the gas phase pressure. Flow of liquid hydrogen to the coil is automatically monitored by an air activated control valve, which operates on a signal from a differential pressure indicating transmitter. A manually operated bypass valve is located in the line for increased reliability, and is used only in the event of power failure or malfunction of the automatic control valve. The PR coil is capable of generating enough vapor to effect transfer rates of not less than 50 GPM and in excess of 100 GPM depending on the liquid head available.

c. Transfer Piping - The transfer line consists of a lightweight, vacuum-jacketed pipe and control valve, and an insulated flexible metal hose. The hose is highly flexible and equipped with valving on both ends. The valves are quick-connect double-check couplings providing positive shut-off, thus eliminating leakage of air or other contaminants into the transfer line. The control valve is an air activated valve which operates on a signal from a temperature sensor (to open) or a liquid level sensor (to close) located on the secondary unit. A small hole is drilled in the inner valve to permit a low quantity flow of liquid hydrogen during the cool down period. A manually operated bypass valve is located in the line for increased reliability, and is used only in the event of power failure or malfunction of the automatic control valve.

d. Vent System - The vent system consists of the following valves mounted in parallel:

(1) A spring loaded safety valve to prevent pressure in the inner vessel from exceeding the maximum allowable working pressure, (MAWP).

(2) A solid rupture disc to prevent pressure in the inner vessel from exceeding 1.50 MAWP.

(3) A solenoid operated vent valve to blow down the inner vessel.

(4) A spring loaded check valve to keep the inner vessel pressure between 15 and 16 PSIA during long term storage.

(5) A manually operated block valve to isolate the check valve during normal operation.

e. Instrumentation - All instruments are mounted on the control console and consist of the following:

(1) Primary vessel liquid level indicator - a panel of pin-point lights activated by a signal from a series of thermistors (solid state devices) located inside the vessel.

(2) Secondary vessel liquid level indicator - a panel of pin-point lights activated by an electrical signal from the secondary unit controller.

(3) Primary vessel pressure indicator - Bourdon-type connected to vapor space of primary vessel.

(4) Differential pressure indicating transmitter - bellows-type connected to vapor space of primary and secondary vessels.

(5) Air supply pressure indicator - Bourdon-type connected to air line downstream of air regulator.

(6) Switches - to energize controller and various valves.

f. Controls - All controls are housed in the system controller and consist of transmitters and relays necessary for automatic operation of the unit.

2. Secondary System

The secondary system consists essentially of the seven components described below:

a. Vacuum-Jacketed Storage Vessel - The liquid hydrogen is contained in either a single inner vessel or a combination of interconnected inner vessels depending on the capacity requirements and space limitations of the secondary unit in question. The inner vessel of a high-strength aluminum alloy will be wrapped with a multilayer reflective-type insulation, and mounted in an aluminum-honeycomb evacuated chamber.

b. Vaporizing Equipment - Hydrogen gas required to operate the fuel cell is supplied by vaporizing some of the liquid hydrogen in the storage vessel. The heat of vaporization is introduced to the liquid hydrogen through electric resistance heaters. The power to the heaters is controlled by a rheostat connected mechanically to a throttling device by which the operator varies the output of the fuel cell. A signal from a pressure indicating transmitter in the feed gas line will be used to modulate the heater current and insure sufficient hydrogen flow to the fuel cell. This arrangement provides immediate response to changing demands from the fuel cell. The heaters are capable of generating enough vapor to effect flow rates to the fuel cell over a range of 0.8 lb/hr to 26.6 lb/hr.

c. Transfer Line - The transfer line consists of a lightweight, vacuum jacketed pipe and control valve. The end of the pipe is equipped with a quick disconnect coupling, the mate of which is located on the transfer hose of the primary. The control valve is air activated and operates on a signal from a temperature sensor (open and close). A small hole is drilled in the inlet side of the valve body and is connected to the vent system through a length of tubing. Through this arrangement, the warm hydrogen gas generated in cooling down the transfer line is bypassed away from the cold secondary vessel.

d. Vent System - The vent system valves protecting the inner vessel are mounted in parallel and consist of the following:

(1) A spring loaded safety valve to prevent pressure in the inner vessel from exceeding the maximum allowable working pressure (MAWP).

(2) A solid rupture disc to prevent pressure in the inner vessel from exceeding 1.50 MAWP.

(3) A solenoid operated vent valve to blow down the inner vessel.

The vent system valves to protect the warm cool down gas bypass line are mounted in parallel and consist of the following:

(1) A spring-loaded safety valve to prevent pressure in the bypass line from exceeding MAWP.

(2) A solenoid operated vent valve to blow down the bypass line.

e. Fuel Cell Supply Line - The fuel cell supply line consists of uninsulated piping and a control valve. The control valve is air activated and operates on a signal from the starting mechanism of the secondary unit vehicle.

f. Instrumentation - All instruments are mounted on the control console and consist of the following:

(1) Secondary vessel level indicator - a panel of pin-point lights activated by a signal from a series of thermistors (solid state devices) submerged in the liquid.

(2) Secondary vessel pressure indicator - Bourdon-type connected to vapor space of inner vessel.

(3) Air supply pressure indicator - Bourdon-type connected to air line down stream of air regulator.

(4) Fuel cell supply pressure indicating transmitter - Bourdon-type connected to fuel cell supply line. By making use of a magnetic core, an electrical signal is transmitted to the secondary unit controller.

(5) Switches - to energize controller and various valves.

g. Controls - All controls are housed in the system controller and consist of transmitters and relays necessary for automatic operation of unit.

REFERENCES

1. Air Products and Chemicals, Inc., Allentown, Pennsylvania, Clark, R. G., E. M. Flounders and P. D. Stelts, "Energy Depot Cryogenic Fuel Storage and Distribution System Phase I - Conceptual Design Study (U)" Quarterly Progress Report 1, (July 1963).

2. Air Products and Chemicals, Inc., Allentown, Pennsylvania, Clark, R. G., E. M. Flounders and P. D. Stelts, "Energy Depot Cryogenic Fuel Storage and Distribution System Phase I - Conceptual Design Study (U)", Quarterly Progress Report 2, (October 1963)

3. Mikesell, R. P. and R. B. Scott, "Heat Conduction Through Insulating Supports in Very Low Temperature Equipment", Journal of Research of the National Bureau of Standards, 57:6, 371-378, (December 1956).

4. Hnilicka, M. P., R. D. Hay, and J. S. Sight, "Insulation of Liquid Hydrogen Vessels", (Paper presented at 50th National Meeting of AIChE, Buffalo, New York, May 5-8, 1963).

5. Allis-Chalmers Manufacturing Company, "Energy Depot System Study Summary Report: Conceptual Design of Hydrogen and Ammonia Energy Depot Systems (U)", ACNP 64501, USAEC Contract No. AT(30-1)-3133, (February 1964).

APPENDIX A

ENERGY DEPOT SYSTEM CRITERIA

1.0 General

1.1 A single Energy Depot system shall be designed to maximize the energy available to the user. Specific output goals will depend on both operational and technical feasibility as developed during the program. Equipment including the nuclear power plant contained within the depot will be minimized consistent with providing the required reliability.

1.2 The only raw materials available in quantity are air and water. It should be borne in mind that water may be scarce in particular world areas, therefore large volumes of cooling water are not available. Additives may be used provided the quantities are so small that no logistics burden is encountered in transporting a 30-day supply. The depot should be capable of either regenerating reactants or generating fuel from the available raw materials.

1.3 The Energy Depot system should not introduce nullifying safety, maintenance, or logistic problems, nor should it impose significantly unattractive characteristics on the vehicles or equipment that it supports.

1.4 For planning purposes, three reactor types are assumed to be available in the near future. Power output are 500 kwe, 3000 kwe, and 10,000 kwe. Degree of mobility roughly correspond to the ML-1, MCR, and MH-1A. The primary source of nuclear energy for Energy Depot use is considered to be the MCR which is suitably modified to generate the power required by processing equipment, i.e., 400 cycle alternators will be used if a significant weight advantage may be realized.

2.0 Operations and Applications

2.1 Modules of the system should have land mobility compatible with that of the units they support and be capable of operation in the fast moving, flexible environment required for mechanized task forces without requirement for elaborate or time consuming installation procedures. The energy utilization device should be as small, lightweight, reliable, and long-lived as practicable. It must be well adapted to vehicular propulsion.

2.2 The system shall be capable of refueling vehicles and equipment on short notice in a period equal to or less than that now required for petroleum refueling.

2.3 All equipment shall be capable of 24 hours per day operation, but production rates will be estimated using an average operating day of 16 hours. The remaining time is to be used for maintenance, relocation, shut-down time, and buildup of stored energy in the form of fuel.

2.4 Vehicle operational endurance with Energy Depot fuels or regenerated reactants will be at least equal to that afforded by conventional fuels.

2.5 There will be a minimum of operating personnel. Control systems should be centralized.

2.6 The use of air as an oxidant for Energy Depot fuels should be a goal for the energy utilization device development.

2.7 The preferred system will incorporate only one nuclear power plant per Energy Depot for ease of control and operational deployment.

3.0 <u>Maintenance, Lifetime, Reliability</u>

3.1 The system will be designed to have 95% reliability.

3.2 Major overhaul interval is 5000 operational hours with a unit lifetime of 25,000 operation hours. Units will be designed for minimum maintenance between major overhauls.

3.3 The system shall be capable of operation under conditions as specified in AR 705-15 "Operation of Material Under Extreme Conditions of Environment". The output of units shall not be downgraded to less than 75% of design values under an conditions listed in the AR above. "Cold weather kits" may be specified if required for low temperature operation.

3.4 Connections between packages shall permit easy, rapid assembly and disassembly; a minimum number of connections will be employed.

3.5 Maximum protection from small arms fire is to be incorporated without undue weight or size limitations.

3.6 Only a minimum of special tools and equipment will be available for field maintenance. All equipment required for movement or operation of the Energy Depot must be an integral part of the system. However, special equipment for reactor refueling will not normally be a part of the system.

3.7 Reactor core life shall be of the order of 5,000-10,000 full power hours.

4.0 Safety

4.1 Vulnerability of the Energy Depot shall not be greater than that of a conventional fuel depot or power generating equipment.

4.2 System shall be of fail-safe design.

4.3 Operating crew will not be subject to hazards (other than normal low radiation exposure from a reactor) in excess of a conventional chemical or power plant and associated fuel supplies.

5.0 Transportability

5.1 Components of the system should be compact and light weight and should be transportable in Phase III of airborne operations. The plant should consist of convenient modules or packages. The structures of the packages should provide adequate support and housing for plant equipment both during transport and operation. Modules should be designed for convenient handling and transport and may be either skid or wheel mounted, depending on final characteristics and application.

5.2 Module weight should not exceed 30,000 pounds. The dimensions should be a minimum but may not exceed 8-1/2 by 8-1/2 by 24 feet.

5.3 Applicable regulations include:

AR 705-8 Department of Defense Engineering for Transportability Program

AR 705-35	Criteria for Air Transportability and Air Delivery of Material
MIL-A-8421B (USAF)	Air Transportability

6.0 Cost

Equipment cost will be as low as possible consistent with other criteria.

APPENDIX B

DESIGN CRITERIA
ENERGY DEPOT
FUEL STORAGE AND DISTRIBUTION

I. General

This document supplements the general criteria for Energy Depot systems, "Nuclear Powered Energy Depot System Criteria", in the specific area of fuel handling and distribution. It is to be used as a guide in studies of anhydrous ammonia and liquid hydrogen storage, handling, and distribution. Since this criteria is applicable to conceptual design studies it is anticipated that contractor assumptions will be required within the general guidance of this document, the system criteria, and applicable regulations and specifications as therein quoted.

II. Operations

A. The philosophy of fuel distribution from Energy Depots to the user involves bulk transport directly from the production unit to the fuel tank at the user location. The following definitions apply:

1. Primary storage -- those vessels, vehicular mounted, which serve as bulk storage for depot output and transport vessels from depot to user.

2. Secondary storage -- those vessels designed to store fuel for the user at his location or in his equipment. These tanks are generally at least an order of magnitude less in capacity than primary storage units.

3. Primary transfer -- transfer of depot fuel from the production facility to the primary storage.

4. Secondary transfer -- transfer of fuel from the primary storage to the secondary storage.

B. No integral storage will be designed into depot equipment other than the tanks that may be required to insure continuous operation of the fuel producer. Primary storage will be accomplished through bulk storage transport vehicles. This does not preclude secondary storage of fuel in the vehicles required for Energy Depot mobility.

C. A sufficient number of primary storage units will be used with each depot fuel manufacturing plant to provide a capacity for storing the full output of 96 hours continuous operation. Primary storage units will be in the 3000-5000 gallon size range.

D. Loss rates from storage vessels and transfer lines for perishable fuels will be a minimum. The acceptable fuel retention rates for storage vessels are as follows:

1. Primary Storage -- 85% of an original full load of fuel will be deliverable to the secondary storage after seven days of storage.

2. Secondary Storage -- 75% of an original full load of fuel will be deliverable to the utilization device (engine, fuel cell, etc) after seven days of storage.

3. Conditions will be selected from AR 705-15 that will cause maximum loss rates when applying these limitations.

E. Storage vessels will not be designed solely to meet the criteria imposed by various codes and specifications not directly applicable to military equipment. Contractors should be cognizant of deviations from such codes or specifications (e.g. I.C.C. regulations) and aware of the possibility of later redesign within these restrictions.

F. Crew requirements for operation of Energy Depot Systems will be held to a minimum. Equipment for primary and secondary transfer should be capable of being operated by one man with only limited technical training.

G. Secondary transfer rates will be such that secondary storage of 50 gallons capacity and greater can be filled at a minimum rate of 50 gallons per minute. Secondary storage of less than 50 gallons will be filled in one minute or less.

H. Equipment shall be capable of operation under the extreme conditions of environment specified in AR 705-15.

III. Vulnerability

Systems and components will be designed for maximum protection from small arms fire and blast damage without undue weight or size penalties. Armor plating is not required specifically for this purpose.

IV. Transportability

A. Typical shock and vibration data as experienced by military vehicles during various operating conditions is incorporated as an attachment. This information will be used as a guide in designing any vehicular or vehicular mounted components for depot fuel storage and distribution equipment.

B. All components of depot systems, when assembled, must not exceed 132 inches in height. (AR 705-8).

C. Shock and vibration protection for transport of Energy Depot components by various transportation methods will be consistent with the following:

1. Emergency landing shock loads during transit by air with not loss of servicability.

	Loading	Duration
Forward	4.5 g	0.1 Sec.
Sideward	1.5 g	0.1 Sec.
Vertical (up)	3.0 g	0.1 Sec.
Aft	2.0 g	0.1 Sec.

2. Emergency landing shock loads during transit by air with questionable servicability.

	Loading	Duration
Forward & Aft	8 g	0.1 Sec.
Vertical	4.5 g	0.1 Sec.
Sideward	1.5 g	0.1 Sec.

3. The data of the attachment pertaining to vibration will be used as guidance for design. Equipment must remain servicable under the conditions specified therein.

D. Gradeability and side slop criteria to be met by Energy Depot equipment will be correlated with the general specifications outlined below:

1. Combat and tactical vehicles must be capable of negotiating a 60 per cent grade of smooth, dry concrete and must be able to brake adequately on the same grade.

2. Wheeled vehicles with towed trailers must be able to negotiate and brake adequately on a 30 per cent slope.

3. Vehicles are required to operate on side slopes as follows:

   a. tactical vehicles - 20 per cent
   b. combat vehicles - 30 per cent
   c. jeep-type vehicles - 40 per cent

V. Maintenance

A. Energy Depot equipment should be so designed as to be capable of maintenance during severe military use by means of readily available skills, tools, and supplies wherever possible.

B. Routine maintenance required to maintain equipment at an acceptable level of performance should be done at the lowest echelon possible.

C. Maximum interchangeability of components and sub-components is desired to reduce repair parts supply, maintenance, etc.

VI. Safety

The nature of Energy Depot fuels dictates that a great deal of attention be given to the safety aspects of fuel storage, distribution, and utilization. In Energy Depot studies consideration will be given to but not be limited to the following:

1. Hazards associated with flammability of fuels.
2. Hazards associated with toxicity of fuels.
3. Safety valves and rupture disks on fuel tankage and other safety mechanisms as appropriate.
4. Interactions with other materials in the environment of intended use.
5. Special protection of personnel such as gloves, coats, goggles, respirators, etc.
6. Detection methods for leaks and fires.
7. Results of battle damage to various components of systems.
8. Venting of fuel to atmosphere and the hazards resulting from such action.

Air Products and Chemicals Inc

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