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EVALUATION OF A SPACECRAFT NITROGEN GENERATOR

ANNUAL STATUS REPORT

by

R. D. Marshall and J. D. Powell

September, 1976

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Prepared Under Contract NAS2-8732

by

Life Systems, Inc.
Cleveland, Ohio 44122

for

AMES RESEARCH CENTER

National Aeronautics and Space Administration

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LIFE SYSTEMS, INC.
Cleveland, Ohio 44122

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AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

The development work described herein was conducted by Life Systems, Inc. during the period February 1, 1975 to January 31, 1976. The Program Manager was Richard D. Marshall. Support was provided as follows:

Personnel	Area(s) of Responsibility
J. David Powell	Electrical Design
Fred C. Jensen	Mechanical Design
Franz H. Schubert	System Design Support
John W. Shumar	Product Assurance
Richard A. Wynveen, PhD	Program Administration

The Contract Technical Monitor was P. D. Quattrone, Chief, Environmental Control Research Branch, NASA Ames Research Center, Moffett Field, California.

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ACRONYMS

ARS	Air Revitalization System
CRS	CO_2 Reduction Subsystem
EC/LSS	Environmental Control/Life Support System
MSS	Modular Space Station
NGM	Nitrogen Generation Module
NGS	Nitrogen Generation System
NSS	Nitrogen Supply Subsystem
SSP	Space Station Prototype
TCCS	Trace Contaminant Control Subsystem
TSA	Test Support Accessories

SUMMARY

A research and development program is presently being conducted at Life Systems, Inc. to develop a method of generating nitrogen for cabin leakage makeup aboard space vehicles having longer duration missions. The nitrogen generation concept is based on using liquid hydrazine as the stored form of nitrogen to reduce the higher tankage and expendables weight associated with high pressure gaseous or cryogenic liquid nitrogen storage. The hydrazine is catalytically dissociated to yield a mixture of nitrogen and hydrogen. The nitrogen/hydrogen mixture is then separated to yield the makeup nitrogen. The excess supply of hydrogen would be available for use in the reduction of metabolic carbon dioxide.

A detailed comparison was completed of Palladium/Silver and Polymer Electrochemical-based Nitrogen Generation Systems. Preliminary system designs were defined, including flow and packaging schematics, detailed design specifications, component weight, volume, power and reliability characteristics, definition of system controls and critical parameters, and calculation of system launch and expendable weights. The Palladium/Silver-based Nitrogen Generation System would have a basic system equivalent launch weight of 69.0 kg (152 lb), excluding expendables and spares. The Polymer Electrochemical Nitrogen Generation System would have a basic system equivalent launch weight of 60.4 kg (133 lb), excluding expendables and spares. The palladium/silver-based system was judged better than the Polymer Electrochemical Nitrogen Generation System because of lower expendable weight and palladium/silver nitrogen/hydrogen separation represents "off-the-shelf" technology.

A laboratory breadboard Nitrogen Generation System has been designed, fabricated and assembled. The Nitrogen Generation System integrates a hydrazine catalytic dissociator and two-stage palladium/silver separator. The system is designed to operate at a nominal 3.63 kg/d (8.0 lb/day) nitrogen generation rate and recovers 94% of the hydrogen by-product formed in the catalytic dissociation of hydrazine. The hydrogen concentration in the product nitrogen is less than 0.2%.

The Test Support Accessories required to test the Nitrogen Generation System have been designed, fabricated, assembled and integrated with the Nitrogen Generation System. The primary function of the Test Support Accessories is to supply hydrazine to the Nitrogen Generation System at a controlled flow rate. The Test Support Accessories also provides for hydrazine storage, simulates process gas interfaces and supplies power to the Nitrogen Generation System.

The hydrazine dissociator and palladium/silver separator checkout tests have been completed. The efficiency of the hydrazine dissociator at the designed flow rate was 95% which corresponds to an ammonia concentration of 2.1% in the product nitrogen/hydrogen from the reactor. The product nitrogen from the palladium/silver separator contained less than 0.2% hydrogen and 94% of the feed hydrogen was recovered at 172 kN/m^2 (25 psia).

Supporting technology studies were completed in the areas of palladium/silver separator improvements, use of hydrazine hydrate instead of hydrazine as the stored form of nitrogen and ammonia removal. Separator performance can best be

improved by manifolding the nitrogen/hydrogen mixture through the inside of the palladium/silver tubes as opposed to over the outside of the tubes as is done in commercial separators. A 50% reduction in the number of palladium/silver tubes required is possible. Use of the less expensive hydrazine hydrate is not possible since condensation in the product nitrogen lines would occur at water concentrations greater than 0.05%. The ammonia removal analyses resulted in a staging process using alternate ammonia dissociation and hydrogen separation stages. The technique is capable of giving very low ammonia concentrations (less than 50 ppm) in the product nitrogen.

INTRODUCTION

Future long-term manned spacecraft missions will utilize an atmosphere of nitrogen (N_2) and oxygen (O_2). Space vehicle gas leakage and cabin depressurization requirements necessitate on-board storage of the primary cabin atmospheric constituents N_2 and O_2. The N_2 component of air can be stored as liquid hydrazine (N_2H_4) and the N_2H_4 catalytically dissociated to an N_2 and hydrogen (H_2) mixture. The N_2/H_2 mixture is then separated to yield the makeup N_2. The excess supply of H_2 would be available for use in the reduction of metabolic carbon dioxide (CO_2).

A research and development program has been established to evolve the capability for generating N_2 for cabin leakage makeup aboard a space vehicle of mission duration requiring regenerative methods for reprocessing the crew's metabolic products. The development program is focused on the Nitrogen Supply Subsystem (NSS) for a regenerative Environmental Control/Life Support System (EC/LSS).

Background

During the previous program(1) Life Systems, Inc. (LSI) identified two attractive N_2 generation systems based on the catalytic dissociation of N_2H_4. In the first system, liquid N_2H_4 is catalytically dissociated to yield a N_2/H_2 gas mixture. Separation of the gas mixture to yield N_2 and a supply of H_2 is accomplished using a Polymer Electrochemical N_2/H_2 Separator. In the second system, the N_2/H_2 product gas from the dissociator is separated in a two-stage Palladium/Silver (Pd/Ag) N_2/H_2 Separator.

The program culminated in the successful design, fabrication and testing of a N_2H_4 Catalytic Dissociator, a Polymer Electrochemical N_2/H_2 Separator and a two-stage Pd/Ag N_2/H_2 Separator. Based on the results of this program, it was recommended that a N_2 Generation System (NGS) be developed by integrating the N_2H_4 Catalytic Dissociator and the two-stage Pd/Ag Separator.

Program Objectives

The objectives of the present program are to develop and evaluate

1. a laboratory breadboard of a NGS based on the catalytic dissociation of N_2H_4,

(1) References cited are listed at the end of the report.

2. a Nitrogen Generation Module (NGM) to reduce ammonia (NH_3) concentrations in the product N_2 and

3. an engineering model of a NSS which incorporates the NGM and is integratable within an Air Revitalization System (ARS).

The NGS consists of the N_2H_4 Catalytic Dissociator and the two-stage Pd/Ag Separator developed on the previous contract (NAS2-7057). The NGM consists of an advanced Pd/Ag separator design and N_2H_4 dissociator design to lower NH_3 concentrations in the product N_2. The NSS incorporates the N_2H_4 storage and feed mechanism, the NGM and the advanced instrumentation required to control and monitor NSS performance and to interface with other ARS subsystems and controls.

Program Organization

The program was organized into five tasks whose specific objectives were to:

1. Design, fabricate, assemble and functionally check out the Laboratory Breadboard NGS, the NGM and the NSS.

2. Design, fabricate, asssemble and functionally check out the Test Support Accessories (TSA) required for the NGS and the NSS testing.

3. Establish, implement and maintain a Product Assurance Program throughout the contractual performance period to search out quality weaknesses and to define appropriate corrective measures.

4. Conduct an extensive test program on the NGS to establish the quantitative effects of key engineering parameters.

5. Conduct supporting technology studies to support NSS technology development.

Program Status

The following activities were completed during the present reporting period:

- Detailed comparison of N_2 generation systems
- Laboratory Breadboard NGS design and fabrication
- TSA for NGS design and fabrication
- N_2H_4 Dissociator and Pd/Ag Separator Checkout Tests
- Supporting technology activities in the area of Pd/Ag Separator performance improvements, use of hydrazine hydrate ($N_2H_4.H_2O$) as the stored form of N_2 and NH_3 removal.

DETAILED COMPARISON OF NITROGEN GENERATORS

A detailed comparison of the Pd/Ag and Polymer Electrochemical-based N_2 generators for flight application was completed. The comparison included determination of N_2 generation requirements, detailed system designs and comparison of the system designs for quantitative, semi-quantitative and qualitative evaluation criteria.

Nitrogen Generation Requirements

The N_2 generated by the NGS will be used for cabin leakage make up only. Nitrogen required for emergency repressurizations will be stored separately since N_2 flow rates up to 0.15 kg/s (20 lb/min) may be required to repressurize the cabin to 69 kN/m^2 (10 psia) in 20 minutes.

The projected space vehicle EC/LSS N_2 generation requirements for cabin leakage makeup are shown in Table 1. As a result of this study a nominal N_2 generation rate of 3.63 kg/d (8 lb/day) was selected. The NGS would be designed for a maximum 6.81 kg/d (15 lb/day) to provide for a performance derating based on the 3.73 to 5.71 kg/d (8.21 to 12.57 lb/day) projected for space vehicle EC/LSS requirements.

The criticality associated with N_2 generation is depicted in Figures 1 and 2 which show cabin pressure as a function of time without N_2 generation for N_2 leakage rates of 3.73 and 5.71 kg/d (8.21 and 12.57 lb/day), respectively. Depending on cabin volume, the allowable down-time for the NGS before cabin atmospheric pressure reaches 69 kN/m^2 (10 psia) is between 12 and 95 days. By comparison, if the water removal, CO_2 removal or O_2 generation subsystems are continuously inoperative, the relative humidity (RH) reaches 100% in less than two hours, the partial pressure of CO_2 (pCO_2) reaches 2 kN/m^2 (15 mm Hg) in 14 hours and the partial pressure of O_2 (pO_2) reaches the emergency limit in 60 hours. The NGS, therefore, is the least critical of the primary ARS subsystems.

The NGS interfaces are presented in Table 2. The NGS will integrate directly with the Trace Contaminant Control Subsystem (TCCS). The N_2 product stream will pass directly into the TCCS to insure that no H_2 or NH_3 enters the cabin. This direct integration results in the elimination of a cooling blower to cool the product gas streams in the NGS. The heat removed in the heat exchangers is then used to reduce TCCS power requirements and reduce NGS heat rejection to ambient.

Palladium/Silver-Based Nitrogen Generation System

The Pd/Ag-based NGS consists of an integrated N_2H_4 Catalytic Dissociator and Pd/Ag N_2/H_2 Separator, and the peripheral mechanical and electronic components necessary to control system operation and monitor performance. The dissociator and separator are packaged as a single unit to minimize insulation requirements since both operate at elevated temperatures.

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TABLE 1 PROJECTED SPACE VEHICLE EC/LSS N_2 GENERATION REQUIREMENTS

N_2 Generation Rate, kg/d (Lb/Day)	Vehicle	Comment
0.91 (2.0)[2]	MSS[a]	Projected from 48.3 to 55.2 kN/m^2 (7 to 8 Psia) to 101.4 kN/m^2 (14.7 Psia) NASA Contract NAS1-7905
3.13 (6.9)[3]	Skylab	Projected to 101.4 kN/m^2 (14.7 Psia) based on actual data at 34.5 kN/m^2 (5.0 Psia)
3.63 (8.0)[4]	-----	NASA Contract NAS9-13051
3.73 (8.21)[5]	MSS	Initial Station NASA Contract NAS9-9953
5.71 (12.57)[5]	MSS	Growth Station NASA Contract NAS9-9953
5.95 (13.1)[6]	SSP[b]	NASA Contract NAS9-10273
6.81 (15.0)[i,7,8]	-----	NASA Contract NAS2-7057

(a) Modular Space Station
(b) Space Station Prototype

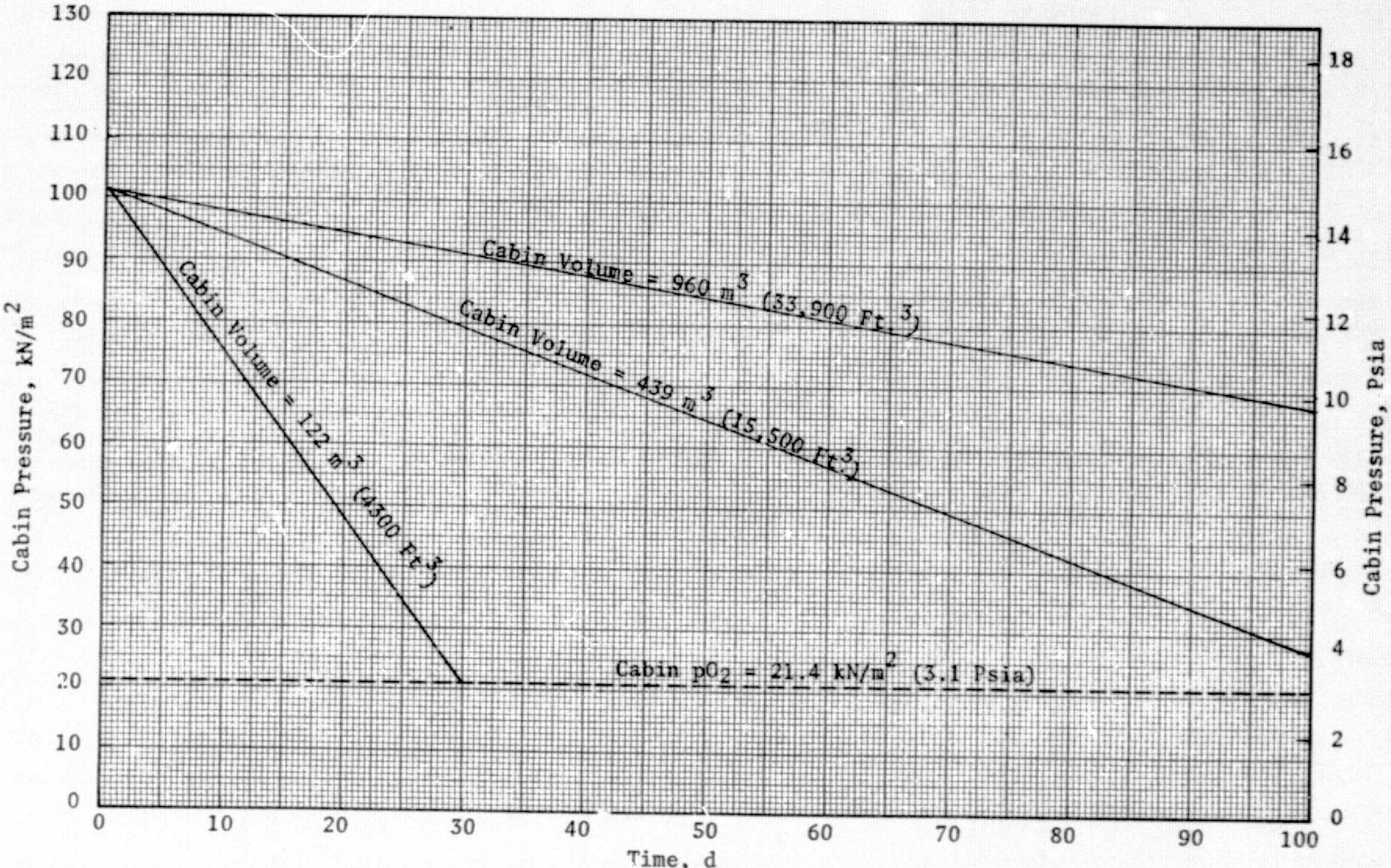

FIGURE 1 CHANGE IN CABIN PRESSURE WITHOUT N_2 GENERATION (N_2 LEAKAGE RATE OF 3.73 kg/d (8.21 LB/DAY))

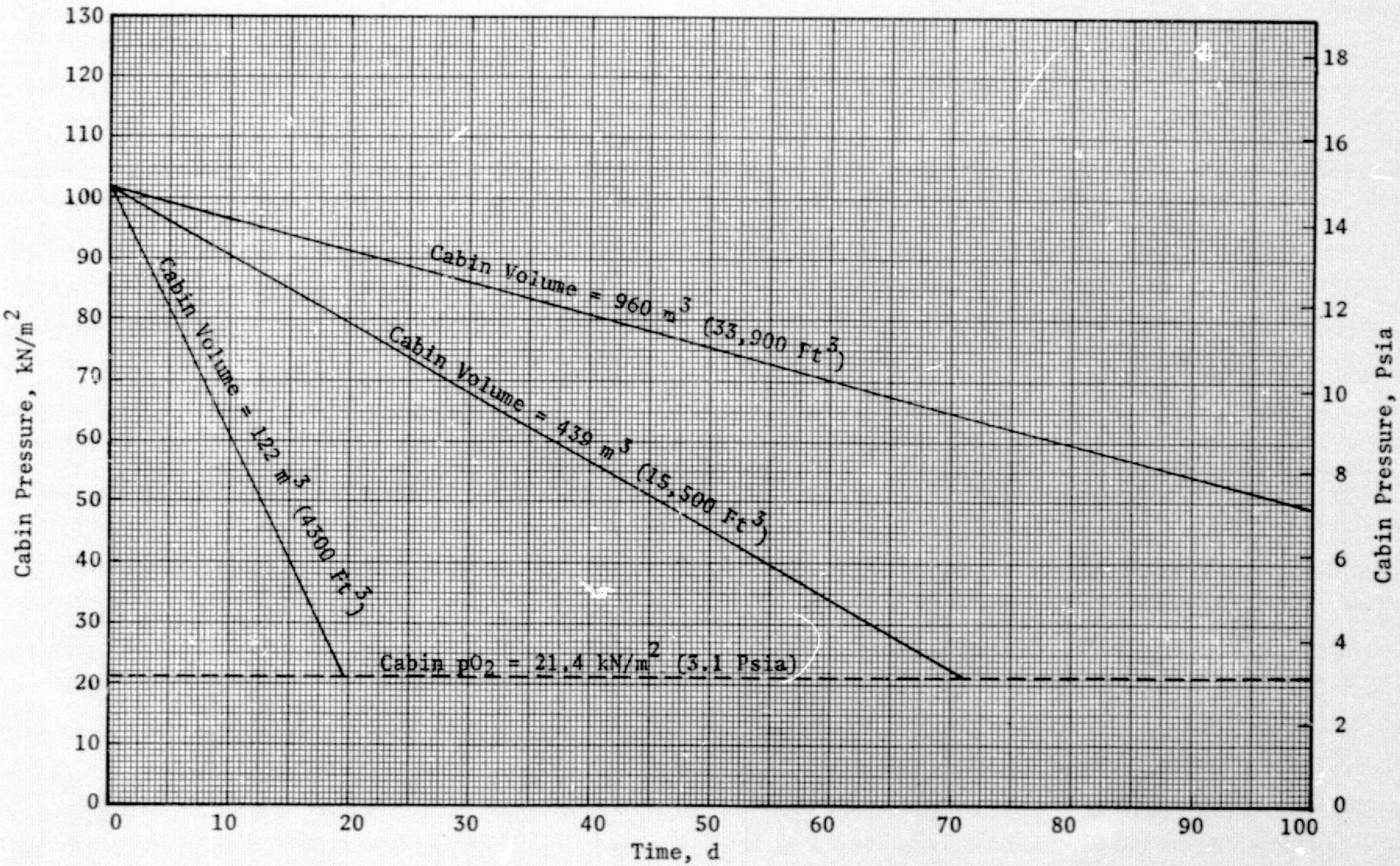

FIGURE 2 CHANGE IN CABIN PRESSURE WITHOUT N_2 GENERATION
(N_2 LEAKAGE RATE OF 5.71 kg/d (12.57 LB/DAY))

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TABLE 2 NITROGEN GENERATION SYSTEM INTERFACES

1. N_2H_4 Storage and Feed
2. Purge Gas
3. Trace Contaminant Control Subsystem (TCCS)
4. Cabin Air
5. Power Supply Subsystem
6. Heat Rejection Subsystem
7. CO_2 Reduction Subsystem (CRS)
8. Purge Vent (Polymer Electrochemical-Based NGS Only)
9. Vacuum (Pd/Ag-Based NGS Only)

System Operation

A schematic of the Pg/Ag-based NGS is presented in Figure 3. The detailed design specification is located in Appendix 1.

Hydrazine is dissociated in the catalytic reactor in two consecutive reactions at an elevated temperature (1000K (1340F)):

$$N_2H_4 = NH_3 + 1/2N_2 + 1/2H_2 \quad (1)$$

$$NH_3 = 1/2N_2 + 3/2H_2 \quad (2)$$

The overall reaction is exothermic:

$$N_2H_4 = N_2 + 2H_2 + 325\ kJ/kg\ (678\ Btu/Lb\ N_2H_4) \quad (3)$$

The N_2/H_2 gas mixture from the dissociator at an elevated temperature (644K (700F)) and pressure (1725 kN/m^2 (250 psia)) is separated in the Pd/Ag Separator. Approximately 90% of the feed H_2 removed in the separator is available for spacecraft usage. The remaining 10% of the feed H_2 is removed to vacuum to attain the required N_2 product gas purity.

The product N_2 is brought to ambient temperature in a heat exchanger prior to entering the cooling air stream which interfaces directly with the TCCS. Combustible gas sensors located in this air stream serve to insure proper N_2 product purity prior to leaving the NGS. A backpressure regulator is used to maintain system pressure at 1725 kN/m^2 (250 psia) to obtain the proper N_2/H_2 separation in the Pd/Ag separator.

The by-product H_2 and H_2 "vent-to-vacuum" streams are reduced to ambient temperature using heat exchangers prior to leaving the subsystem. The pressure level of the by-product H_2 stream is controlled by the interface with the CRS. Heaters are provided on the dissociator and separator for preheating prior to system startup. The system is purged with N_2 during startup and shutdown mode transitions to insure that no air is present in the Pd/Ag Separator or H_2 lines prior to startup and that all H_2 is removed following shutdown. A combustible gas sensor located on the system frame is used to detect possible internal-to-external H_2 leakage.

Component Power, Weight, Volume and Reliability

The Pd/Ag-based NGS components are listed in Table 3, including number required, weight, volume and power. The system has 27 major components having a total weight of 19.7 kg (43.4 lb), a component volume of 0.023 m^3 (0.8 Ft^3) and a total power requirement of 94W.

A reliability analysis goal used was 0.99975. The results of the analysis are summarized in Table 4. A total of 21 spares would be required to meet the

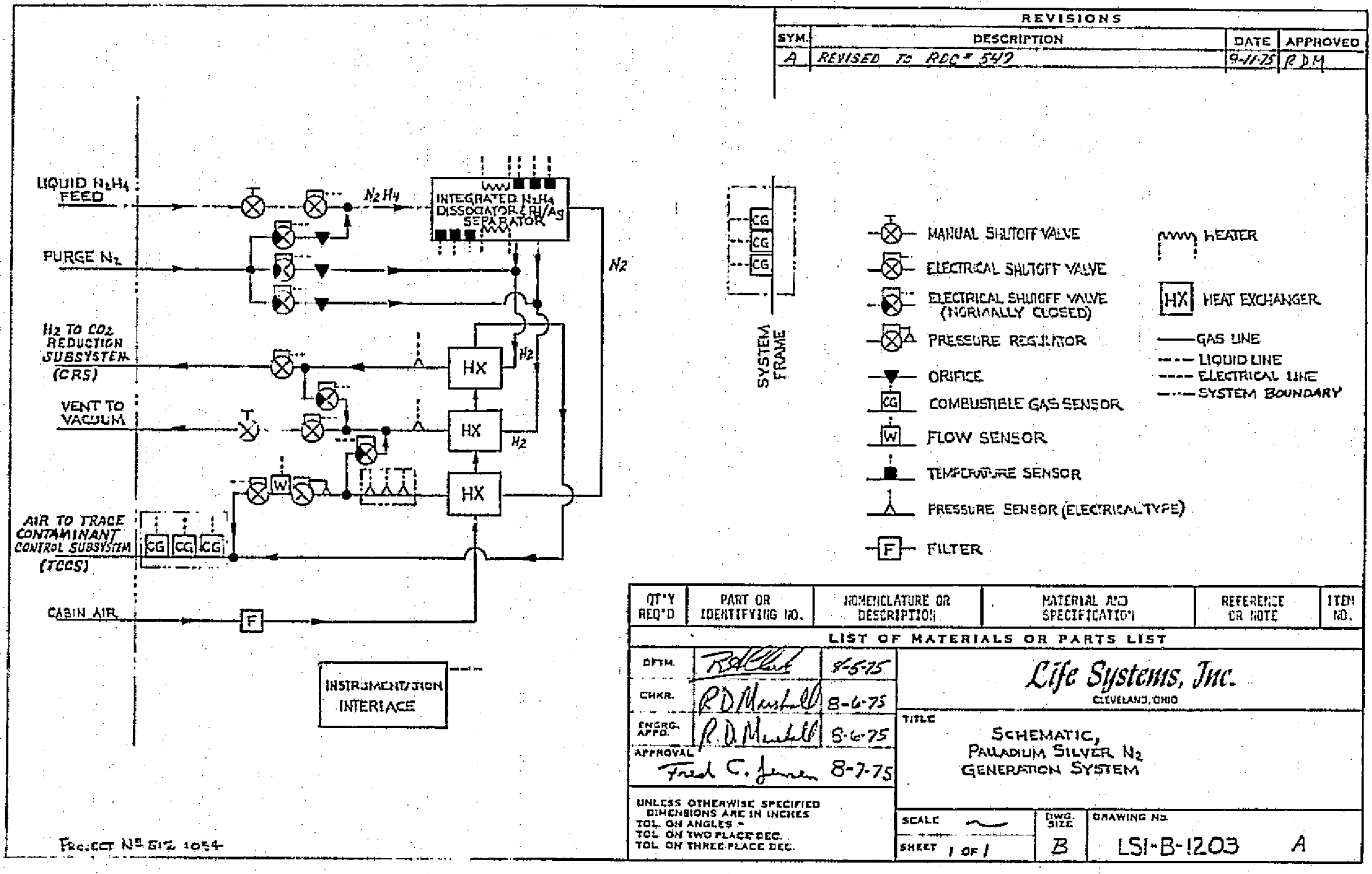

FIGURE 3 PALLADIUM/SILVER-BASED NGS SCHEMATIC

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TABLE 3 PALLADIUM/SILVER-BASED NGS COMPONENT CHARACTERISTICS

Component	Number Required	Weight,[a] kg (Lb)	Volume,[b] dm^3 (In^3)	Power,[c] W
Module, N_2 Generator	1	6.3 (13.9)	13.0 (794)	54
Heat Exchanger	3	0.4 (0.8)	0.4 (24)	--
Valve, Shutoff, Electrical	9	0.4 (0.8)	0.2 (11)	--[d]
Valve, Shutoff, Manual	2	0.5 (1.0)	0.3 (16)	--
Sensor, Pressure	2	0.2 (0.4)	0.1 (4)	5
Sensor, Pressure, Triple Redundant	1	0.4 (0.9)	0.3 (16)	5
Sensor, Combustible Gas, Triple Redundant	2	1.5 (3.3)	0.7 (40)	5
Sensor, Flow	1	0.2 (0.4)	0.1 (4)	5
Orifice	3	0.1 (0.2)	0.0 (0)	--
Regulator, Backpressure	1	1.2 (2.6)	9.8 (49)	--
Filter, Air	1	0.5 (1.0)	0.1 (8)	--
Instrumentation, Interface	1	2.3 (5.0)	3.4 (210)	10

(a) Basic System Weight = 19.7 kg (43.4 Lb)
(b) Basic System Volume - 22.7 dm^3 (0.8 Ft^3)
(c) Basic System Power = 94W
(d) Requires power on actuation only

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TABLE 4 PALLADIUM/SILVER-BASED NGS RELIABILITY CHARACTERISTICS[(a)]

Component	No. Required (N)	Failure Rate (λ) $x10^6$, Hr^{-1}	Total Failures (Nλt)	No. of Spares	Weight,[(b)] kg (Lb)	Volume,[(c)] dm^3 (In^3)
Module, N_2 Generator	1	0.90	0.00389	1	6.3 (13.9)	13.0 (794)
Heat Exchanger	3	0.34	0.00441	1	0.4 (0.8)	0.4 (24)
Valve Shutoff, Electrical	9	6.10	0.23717	4	1.5 (3.2)	0.7 (44)
Valve Shutoff, Manual	2	0.46	0.00397	1	0.5 (1.0)	0.3 (16)
Sensor, Pressure	2	4.79	0.04139	2	0.4 (0.8)	0.1 (8)
Sensor, Pressure, Triple Redundant	1	4.79	0.02069	2	0.8 (1.8)	0.5 (32)
Sensor, Combustible Gas, Triple Redundant	2	5.00	0.04320	2	3.0 (6.6)	1.3 (80)
Sensor Flow	1	4.79	0.02069	2	0.4 (0.8)	0.1 (8)
Orifice	3	0.01	0.0013	1	0.1 (0.2)	0.0 (0)
Regulator, Backpressure	1	3.21	0.01387	2	2.4 (5.2)	1.6 (98)
Filter, Air	1	0.30	0.00013	1	0.5 (1.0)	0.1 (8)
Instrumentation, Interface	1	5.30	0.02290	2	4.5 (10.0)	6.9 (420)

(a) System Reliability Goal = 0.99975 for t = 180-day duration
(b) Total Spares Weight = 20.6 kg (45.3 Lb)
(c) Total Spares Volume = 25.5 dm^3 (0.9 Ft^3)

system reliability goal. The mean-time-between-failure for the Pd/Ag-based NGS was estimated at 10,807 hours.

Control/Monitor Instrumentation Requirements

The Pd/Ag-based NGS has three primary control functions in addition to normal valve sequencing required during mode transitions. They are:

1. Dissociator temperature
2. Pd/Ag temperature
3. N_2 pressure

Monitoring instrumentation is required for the system's six critical parameters. They are:

1. Dissociator temperature
2. Pd/Ag temperature
3. N_2 pressure
4. N_2 Flow
5. H_2-in-N_2 concentration
6. H_2 leakage (internal to external)

Advantages and Disadvantages

The primary advantages and disadvantages of the Pd/Ag-based NGS are summarized in Table 5. The major advantage for comparison purposes is that the Pd/Ag separator is "off-the-shelf" technology. The primary disadvantage is that air containing O_2 must be excluded from the unit. The Pd/Ag tubes act like an H_2 sponge and adsorbed H_2 remains in the Pd/Ag metal. Sufficient purging with N_2 at elevated temperatures must be provided prior to maintaining the unit.

Polymer Electrochemical-Based Nitrogen Generation System

The Polymer Electrochemical-based NGS consists of an N_2H_4 Catalytic Dissociator, a Polymer Electrochemical N_2/H_2 Separator and the peripheral mechanical and electronic components necessary to control system operation and monitor performance. The dissociator and separator cannot be packaged as a single unit since the dissociator operates at 1000K (1340F) and the separator operates at room temperature.

System Operation

The Polymer Electrochemical-based NGS schematic is presented in Figure 4. The detailed design specification is located in Appendix 2.

Hydrazine is dissociated in the catalytic dissociator by the reactions shown in equations (1), (2) and (3). The N_2/H_2 mixture leaves the dissociator at approximately 1000K (1340F) and is cooled in a heat exchanger to room temperature before entering the N_2/H_2 separator. Approximately 80% of the feed H_2 (with <2% N_2) is removed in the polymer diffusion unit. The remaining 20% of

TABLE 5 PD/AG-BASED NGS: ADVANTAGES AND DISADVANTAGES

Advantages

1. Low system weight and volume
2. Ultrapure H_2 by-product
3. "Off-the-shelf" technology
4. Simple system control and operation

Disadvantages

1. High temperature operation
2. Approximately 10% of the H_2 by-product is lost to vacuum
3. Additional insulation and heat rejection to ambient
4. Oxygen must be excluded from the unit
5. Requires a vacuum to attain desired N_2 product purity

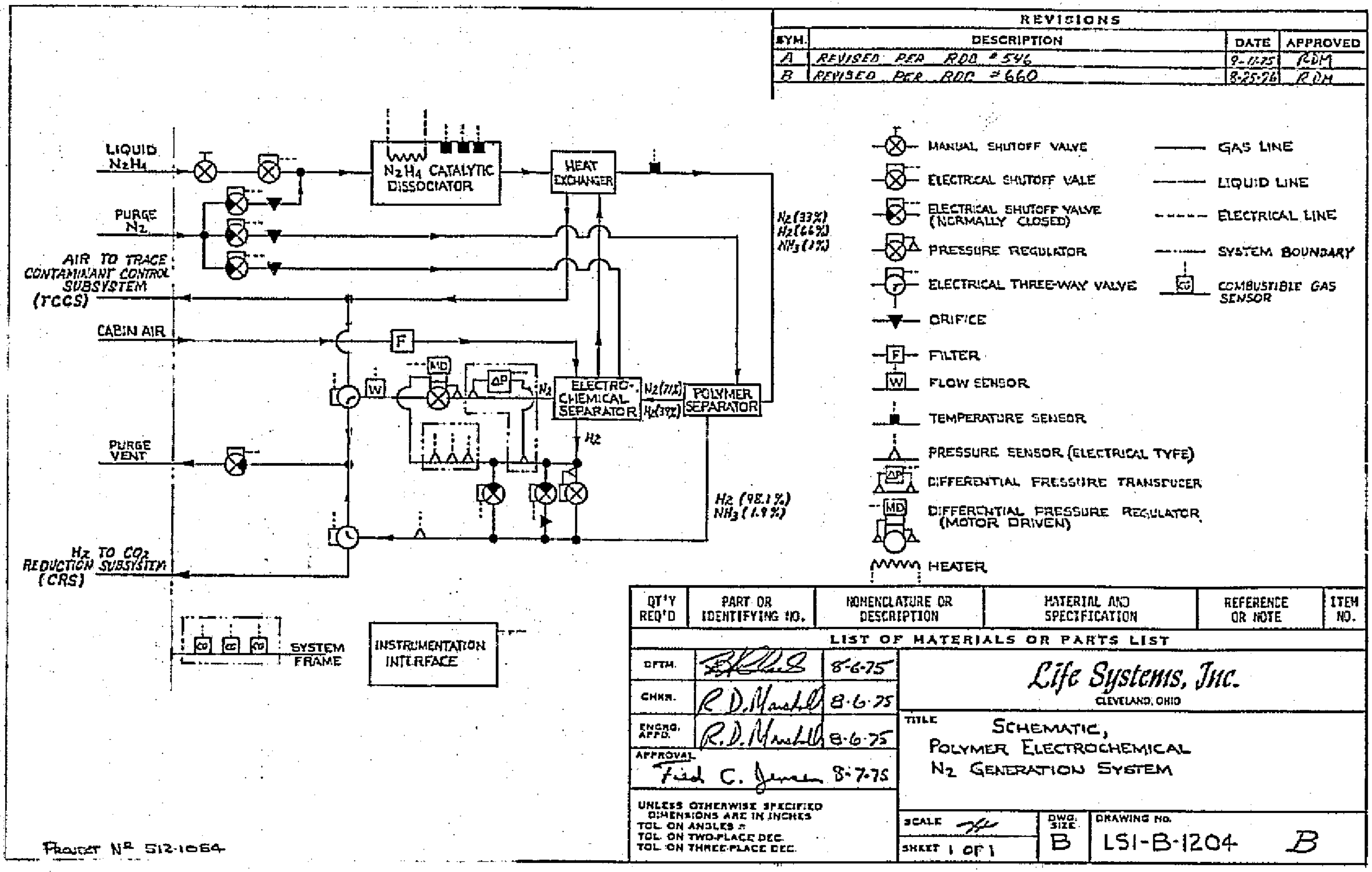

FIGURE 4 POLYMER ELECTROCHEMICAL-BASED NGS SCHEMATIC

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the feed H_2 in the product N_2 stream is removed in two stages in a nine-cell, electrochemical N_2/H_2 separator module.[7] Approximately 19% of the initial feed H_2 is removed in the first eight cells at a constant current. The N_2 product from these eight cells is manifolded internally to the last cell which is operated at a constant voltage of 1.0V. The last cell acts as the final stage to remove the remaining 1% of the H_2 and as a H_2 sensor to indicate the final N_2 product purity. All H_2 removed in the polymer and electrochemical separators is available for spacecraft usage.

The N_2 product stream leaving the electrochemical separator joins with the cooling air which interfaces directly with the TCCS. Combustible gas sensors in the air stream are not required since the electrochemical separator acts as an H_2 sensor. The H_2 by-product stream from the electrochemical separator and the polymer separator are joined and interfaced with the CO_2 Reduction Subsystem (CRS).

A backpressure regulator is used to control the pressure level of the electrochemical and polymer separators at 1035 kN/m^2 (150 psia) to attain the desired N_2/H_2 separation. A heater is provided on the catalytic dissociator for preheating prior to startup. Since the catalytic dissociation reactions are exothermic, the heater is not used during normal operation. The system is purged with N_2 during startup and shutdown mode transitions to insure no H_2 remains in the system prior to or after maintenance. A combustible gas sensor located on a system frame is used to detect possible internal-to-external H_2 leakage.

Component Power, Weight, Volume and Reliability

The Polymer Electrochemical-based NGS components are listed in Table 6, including number required, weight, volume and power. The Polymer Electrochemical-based NGS has 28 major components, a component weight of 22.0 kg (48.5 lb), a component volume of 0.028 m^3 (1.0 ft^3) and a total power requirement of 94W.

The results of the reliability analysis completed are presented in Table 7. A total of 34 spares would be required to meet the system reliability goal of 0.99975 for a 180-day mission. The mean-time-between-failure for the Polymer Electrochemical-based NGS would be 9,325 hours.

Control/Monitor Instrumentation Requirements

The Polymer Electrochemical-based NGS requires four primary controls in addition to normal valve sequencing required during mode transitions. They are:

1. N_2H_4 dissociator temperature
2. Electrochemical cell current/voltage
3. N_2-to-H_2 differential pressure
4. H_2 pressure

The Polymer Electrochemical-based NGS has seven critical parameters that must be monitored. They are:

TABLE 6 POLYMER ELECTROCHEMICAL-BASED NGS COMPONENT CHARACTERISTICS

Component	Number Required	Weight,(a) kg (Lb)	Volume,(b) dm^3 (In^3)	Power,(c) W
Dissociator, Catalytic	1	2.0 (4.4)	1.6 (99)	29
Separator, Polymer	1	2.7 (6.0)	5.6 (339)	--
Separator, Electrochemical	1	4.5 (10.0)	11.8 (720)	25
Heat Exchanger	1	0.4 (0.8)	0.4 (24)	--
Valve, Shutoff, Electrical	7	0.4 (0.8)	0.2 (11)	--(d)
Valve, Shutoff, Manual	1	0.5 (1.0)	0.3 (16)	--
Valve, Three-Way, Electrical	2	0.4 (0.8)	0.2 (11)	11(d)
Sensor, Pressure	1	0.2 (0.4)	0.1 (4)	5
Sensor, Pressure, Triple Redundant	1	0.4 (0.9)	0.3 (16)	5
Sensor, Pressure, Differential	1	0.2 (0.4)	0.1 (4)	5
Sensor, Combustible Gas, Triple Redundant	1	1.5 (3.3)	0.7 (40)	5
Sensor, Flow	1	0.2 (0.4)	0.1 (4)	5
Sensor, Temperature, Triple Redundant	1	0.3 (0.7)	0.1 (9)	5
Filter, Air	1	0.5 (1.0)	0.1 (8)	--
Orifice	4	0.1 (0.2)	0.0 (0)	--
Regulator, Differential Backpressure, Motor-Driven	1	1.6 (3.6)	0.9 (54)	--(e)
Regulator, Backpressure	1	1.2 (2.6)	0.8 (49)	--
Instrumentation, Interface	1	2.3 (5.0)	3.4 (210)	10

(a) Basic System Weight = 22.0 kg (48.5 Lb)
(b) Basic System Volume = 28.3 dm^3 (1.0 Ft^3)
(c) Basic System Power = 94W
(d) Requires power on actuation only.
(e) Power required to control differential pressure on start-up only.

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TABLE 7 POLYMER ELECTROCHEMICAL-BASED NGS RELIABILITY CHARACTERISTICS[a]

Component	No. Required (N)	Failure Rate (λ) x 10^6, Hr^{-1}	Total Failures ($N\lambda t$)	No. of Spares	Weight,[b] kg (Lb)	Volume[c] dm^3 (In^3)
Dissociator, Catalytic	1	0.90	0.00389	1	2.0 (4.4)	1.6 (99)
Separator, Polymer	1	5.71	0.02467	2	5.4 (12.0)	11.1 (678)
Separator, Electrochemical	1	5.71	0.02467	2	9.1 (20.0)	23.6 (1440)
Heat Exchanger	1	0.34	0.00147	1	0.4 (0.8)	0.4 (24)
Valve, Shutoff, Electrical	7	6.10	0.18446	4	1.5 (3.2)	0.7 (44)
Valve, Shutoff, Manual	1	0.46	0.00199	1	0.5 (1.0)	0.3 (16)
Valve, Three-Way, Electrical	2	6.10	0.05270	3	1.1 (2.4)	0.5 (33)
Sensor, Pressure	1	4.79	0.02069	2	0.4 (0.8)	0.1 (8)
Sensor, Pressure, Triple Redundant	1	4.79	0.02069	2	0.8 (1.8)	0.5 (32)
Sensor, Pressure, Differential	1	4.79	0.02069	2	0.4 (0.8)	0.1 (8)
Sensor, Combustible Gas, Triple Redundant	1	5.00	0.02160	2	3.0 (6.6)	1.3 (80)
Sensor, Flow	1	4.79	0.02069	2	0.4 (0.8)	0.1 (8)
Sensor, Temperature, Triple Redundant	1	0.50	0.00216	2	0.6 (1.4)	0.3 (18)
Filter, Air	1	0.30	0.00130	1	0.5 (1.0)	0.1 (8)
Orifice	4	0.01	0.00017	1	0.1 (0.2)	0.0 (0)
Regulator, Differential Backpressure, Motor-Driven	1	5.71	0.02467	2	3.3 (7.2)	1.8 (108)
Regulator, Backpressure	1	3.21	0.01387	2	2.4 (5.2)	0.1 (98)
Instrumentation, Interface	1	5.30	0.02290	2	4.5 (10.0)	6.9 (420)

(a) System Reliability Goal = 0.99975 for t = 180-day duration
(b) Total Spares Weight = 36.1 kg (79.6 Lb)
(c) Total Spares Volume = 50.1 dm^3 (1.8 Ft^3)

1. Dissociator temperature
2. N_2/H_2 temperature
3. H_2 pressure
4. N_2-to-H_2 differential pressure
5. N_2 flow
6. H_2-in-N_2 concentration
7. H_2 leakage (internal-to-external)

Advantages and Disadvantages

The advantages and disadvantages of a Polymer Electrochemical NGS are summarized in Table 8. The major advantage is that all the by-product H_2 is collected and an overboard vent to vacuum is not required. The major disadvantage of the system, for comparison purposes, is that further polymer membrane development is required for the application. Presently used membranes are not compatible with trace quantities of NH_3 present from the dissociation of N_2H_4. Unlike the Pd/Ag technology base, then, the polymer membranes do not represent "off-the- shelf" technology.

Systems Comparison

The Pd/Ag-based NGS and the Polymer Electrochemical-based NGS were compared using the comparison evaluation criteria shown in Table 9. The criteria were divided into quantitative, semiquantitative and qualitative criteria.

Quantitative Criteria Comparison

The comparison of quantitative criteria (i.e., those that relate directly to equivalent launch weight and volume) are presented in Table 10. The Pd/Ag NGS would have a basic system equivalent launch weight of 69.0 kg (152 lb), excluding expendables and spares. The Polymer Electrochemical NGS would have a basic system equivalent launch weight of 60.4 kg (133 lb), excluding expendables and spares. The equivalent weight calculations were based on a power penalty of 0.268 kg/W (0.591 lb/W) and a heat rejection penalty for heat rejected to cabin air of 0.198 kg/W (0.127 lb/Btu/hr).

Semiquantitative Criteria Comparison

A comparison of semiquantitative criteria is presented in Table 11. The semiquantitative criteria favors the Pd/Ag NGS since the Pd/Ag system has one less control, one less critical parameter and one less major component.

Qualitative Criteria Compairson

A comparison of qualitative criteria indicated that the Pd/Ag NGS will be available for a flight program beginning in 1978 that would culminate in an actual flight experiment in the early 1980s. The Polymer Electrochemical NGS, however, requires additional technology development in the area of polymer fiber technology and would not be available to begin a flight program until the early 1980s. The actual flight experiment would take place in the mid-1980s.

TABLE 8 POLYMER ELECTROCHEMICAL-BASED NGS:
ADVANTAGES AND DISADVANTAGES

Advantages

1. Low temperature operation
2. All H_2 by-product is collected
3. Low system weight and volume

Disadvantages

1. Polymer fiber technology development required (2 to 5 years development time commercially)
2. Some N_2 (<4%) diffuses with the H_2 through the polymer
3. Some N_2 lost as NH_3 that diffuses through the polymer

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TABLE 9 COMPARISON EVALUATION CRITERIA

Quantitative Criteria

1. Basic system launch weight
2. Basic system launch volume
3. System power requirements
4. Expendable weight (logistics costs)
5. Expendable volume
6. Spares weight
7. Spares volume
8. Heat rejection

Semiquantitative Criteria

1. Number of interfaces
2. Number of control functions
3. Number of critical parameters
4. Number of major system components
5. Allowable downtime for maintenance (system criticality)

Qualitative Criteria

1. Availability for flight program
2. Operating life
3. Flexibility to change in mission requirements

TABLE 10 COMPARISON OF QUANTITATIVE CRITERIA

	Pd/Ag	Polymer Electrochemical
Basic System Launch Weight, kg (Lb)	19.7 (43.4)	22.0 (48.5)
Basic System Launch Volume,[a] m^3 (Ft^3)	0.05 (1.7)	0.08 (3.0)
System Power, W	94	94
Heat Rejection,[b] W (BTU/Hr)	121 (415)	67.0 (229)
Expendables Weight for 180 days,[c] kg (Lb)	812 (1789)	852 (1877)[d]
Spares Weight, kg (Lb)	20.6 (45.3)	36.1 (79.6)
Spares Volume, m^3 (Ft^3)	0.03 (0.9)	0.05 (1.8)

(a) Includes packaging
(b) Does not include heat rejected in heat exchangers since cooling air used in TCCS
(c) Includes tankage weight at 0.1 kg/kg (Lb/Lb) of N_2
(d) Includes N_2 and NH_3 that diffuses into polymer H_2 product stream

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TABLE 11 COMPARISON OF SEMIQUANTITATIVE CRITERIA

	Pd/Ag	Polymer Electrochemical
Interfaces	8	8
Controls	3	4
Critical Parameters	6	7
Major Components	27	28
Downtime, Day[a]	$\geq$12	$\geq$12

(a) Depends on cabin volume and minimum allowable cabin pressure.

Both systems have an envisioned operating life after full development of 5 to 20 years and both systems would be flexible to a change in mission N_2 generation requirements.

Conclusions

The following conclusions are a direct result of the comparison study completed:

1. Both systems are basically equal in total system equivalent launch weight and volume.

2. Present Pd/Ag Separator technology is adequate for the application. Polymer fiber technology, however, requires an additional two years or more to develop. A NGS development based on the Polymer Electrochemical concept, therefore, would be postponed approximately two years.

3. Operating experience with a Pd/Ag Separator and a Polymer Electrochemical Separator indicate that although the Pd/Ag unit operates at a higher temperature, operation is much simpler than the Polymer Electrochemical Separator.

4. It is recommended that the Pd/Ag NGS be developed at the present time since the Polymer Electrochemical Separator offers no direct system advantages and the polymer diffusion unit is not fully developed. A low level of effort, however, should be maintained on the Polymer Electrochemical concept to review polymer fiber technology as it develops commercially. The Polymer Electrochemical NGS is a viable alternative to the selected Pd/Ag NGS.

NITROGEN GENERATION SYSTEM DEVELOPMENT

A laboratory breadboard of a Pd/Ag-based NGS has been designed, fabricated and assembled. The NGS consists of a N_2H_4 Catalytic Dissociator, a two-stage Pd/Ag N_2/H_2 Separator, and the peripheral mechanical and electrical components required to control and monitor system performance.

Design Requirements

The laboratory breadboard NGS is capable of delivering N_2 at a rate of 3.18 to 6.18 kg/d (7 to 15 lb/day) at pressures less than or equal to 1725 kN/m^2 (150 psia). The nominal N_2 generation rate is 3.63 kg/d (8 lb/day). The detailed design specifications for the NGS are listed in Table 12.

System Description

The primary components of the NGS are the N_2H_4 Catalytic Dissociator and the Pd/Ag Separator.

TABLE 12 NITROGEN GENERATION SYSTEM DESIGN SPECIFICATIONS

Leakage Data	
Air Leakage Rate	
Minimum, kg/d (Lb/Day)	4.15 (9.13)
Maximum, kg/d (Lb/Day)	8.88 (19.56)
N_2 Leakage Rate	
Minimum, kg/d (Lb/Day)	3.18 (7.0)
Maximum, kg/d (Lb/Day)	6.81 (15.0)
O_2 Leakage Rate	
Minimum, kg/d (Lb/Day)	0.97 (2.13)
Maximum, kg/d (Lb/Day)	2.07 (4.56)
Cabin Atmosphere Data	
Operational Gravity, m/s^2 (G)	0 to 9.8 (0 to 1)
Total Pressure, kN/m^2 (Psia)	101.4 (14.7)
O_2 Partial Pressure, kN/m^2 (Psia)	21.4 (3.1)
Diluent	N_2
Volume	
Initial, m^3 (Ft^3)	439 (15,500)
Growth, m^3 (Ft^3)	960 (33,900)
Ventilation Rate	
Minimum, cm/s (Ft/Min)	7.6 (15)
Maximum, cm/s (Ft/Min)	20.3 (40)
H_2 Concentration, Volume %	0.2
NH_3 Concentration, Volume %	5.0×10^{-4}
Temperature, K (F)	291 to 297 (65 to 75)
Surface Temperature Guidelines, K (F)	$\leq$322 (120)
Acoustical Guidelines	NC-65

Hydrazine Catalytic Dissociator

Hydrazine catalytically dissociates to form N_2 and H_2 in a packed bed reactor. The schematic of the N_2H_4 Catalytic Dissociator is presented in Figure 5. Figure 6 is a photograph of the assembled dissociator.

Dissociator Operation. The reactor is heated to approximately 1000K (1340F). Liquid N_2H_4 at a pressure of approximately 2070 kN/m^2 (300 psia) is injected into the dissociator through a capillary orifice in the header assembly. The diameter of the capillary opening is smaller than the quenching diameter for N_2H_4 to prevent propagation of the dissociation reaction back to the feed tanks.

A platinum (Pt) screen is placed at the end of the capillary feed tube. Hydrazine decomposes spontaneously over the screen catalyst to NH_3 and N_2. Approximately 20 to 40% of the NH_3 formed decomposes instantaneously to N_2 and H_2.[9] Due to the highly exothermic decomposition of N_2H_4 this zone is at the highest temperature in the reactor. The decomposition reactions can be summarized as follows:

Pt Screen: $$N_2H_4 = NH_3 + 1/2N_2 + 1/2H_2 \quad (4)$$

Catalyst Bed: $$NH_3 = 1/2N_2 + 3/2H_2 \quad (5)$$

Overall: $$N_2H_4 = N_2 + 2H_2 \quad (6)$$

The Pt catalyst screen also acts as a retaining screen for the packed catalyst bed and therefore prevents plugging of the feed tube.

As product gases (NH_3, N_2 and H_2) now flow down the central tube NH_3 is dissociated to N_2 and H_2 in the endothermic step described in equation (5). At the end of the central tube the flow pattern of the product gases is reversed in direction. The product gases flow in the annular housing concentric with the central tube and exit at the hottest zone in the reactor. The decomposition of NH_3 into N_2 and H_2 is favored kinetically and thermodynamically at higher temperatures.[10] The "hairpin" type reactor will therefore result in higher NH_3 conversion efficiency. The catalyst retaining screen prevents catalyst particles from being removed by the product gases.

Dissociator Hardware Description. At 1000K (1340F) there are very few materials which are compatible with N_2H_4 and its decomposition products. This incompatibility is manifested in H_2 embrittlement, nitridification or NH_3 corrosion, and results in reduced material properties and operating life.

Stainless steel 310 is used for the dissociator housing and all associated metal parts with the exception of the central feed tube. The central feed tube is made from tungsten because of its high melting point (approximately 3589K (6000F)). Temperatures in the central feed tube where the initial dissociation reaction (Equation 4) takes place can reach as high as 1144 to

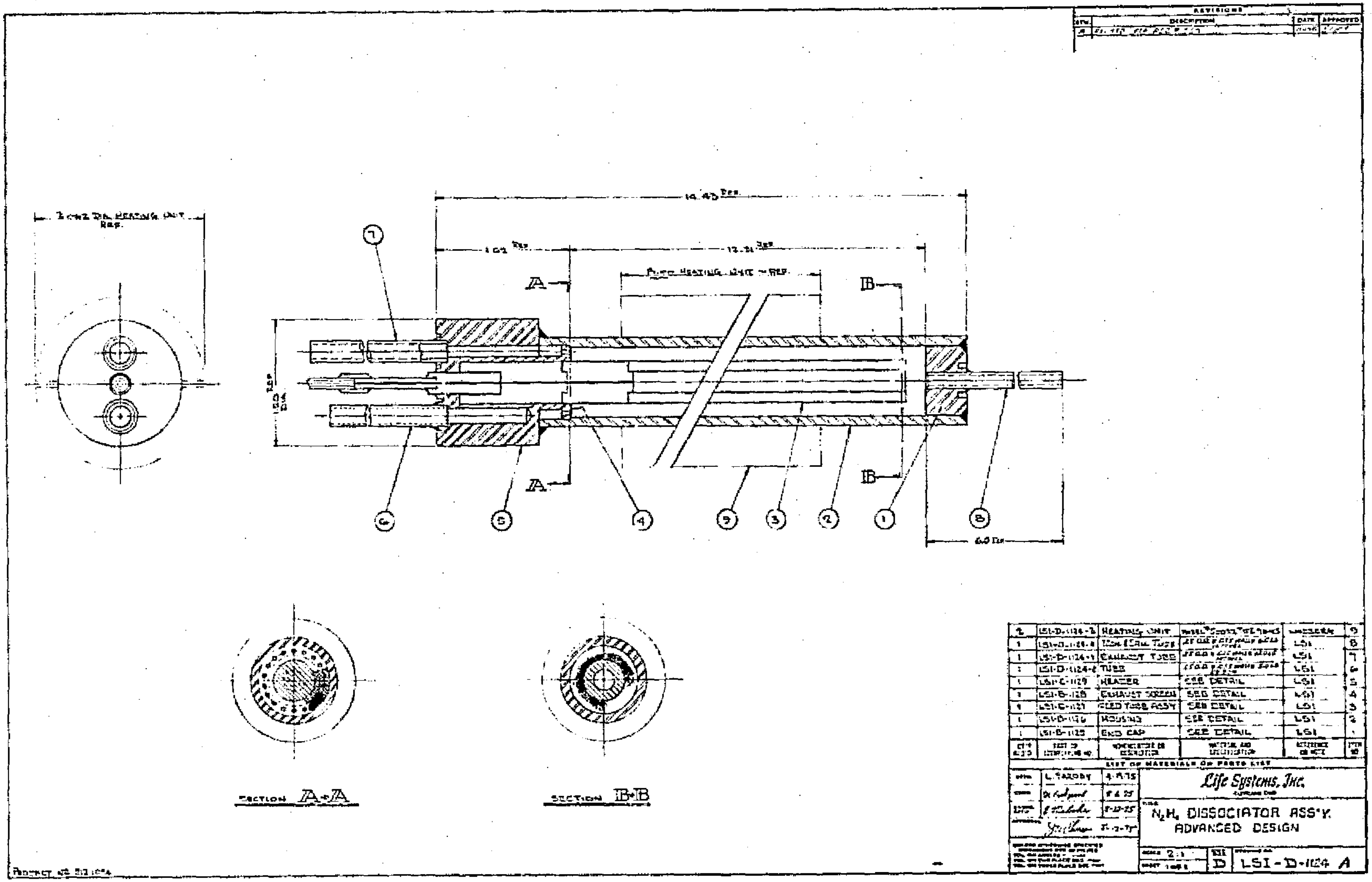

FIGURE 5 HYDRAZINE CATALYTIC DISSOCIATOR SCHEMATIC

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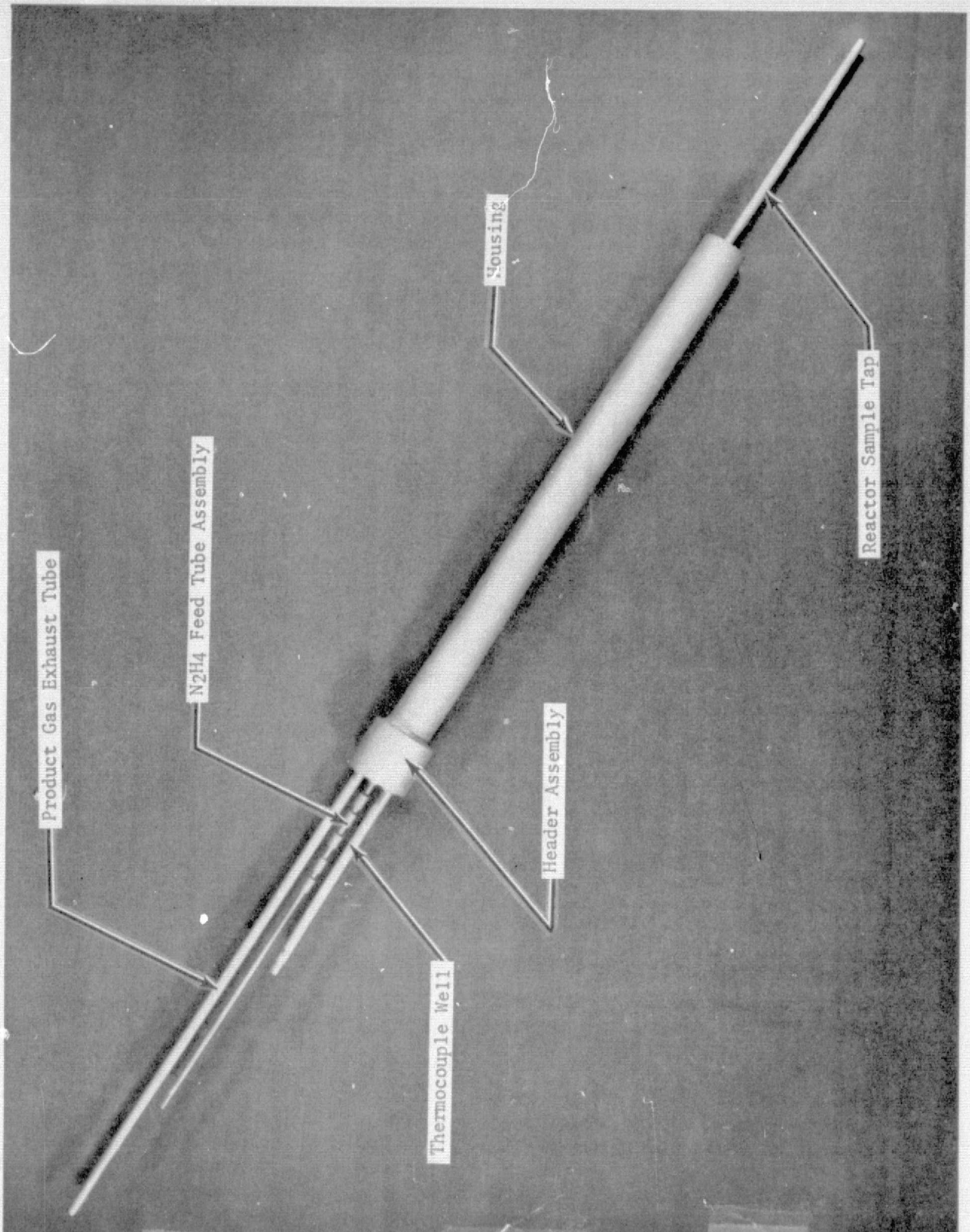

FIGURE 6 HYDRAZINE CATALYTIC DISSOCIATOR

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1366K (1600 to 2000F). Tungsten screen is also used as the catalyst retainer on the process gas out ports in the header assembly (see Figure 5).

A dual catalyst configuration was selected for use in the dissociator. The first catalyst is a Pt screen located at the N_2H_4 injection point. Hydrazine immediately dissociates into NH_3, N_2 and H_2 at the Pt screen. The remaining catalyst bed serves as a NH_3 dissociator. Non-noble metal NH_3 catalyst granules (10 to 20 mesh) are packed in the remainder of the central feed tube and in the annular housing concentric with the central feed tube.

Palladium/Silver Separator

The N_2/H_2 product stream from the dissociator is separated in a two-stage Pd/Ag N_2/H_2 Separator. The schematic of the separator is presented in Figure 7. Figure 8 is a photograph of a Pd/Ag Separator. Two separators like the one shown in Figure 8 are required for the NGS.

Separator Operation. The Pd/Ag Separator consists of two Pd/Ag separator units connected in series. Each unit represents a stage. The first stage recovers approximately 90% of the feed H_2 at a usable pressure. The second stage removes the remaining H_2 to vacuum.

The N_2/H_2 feed mixture enters the Pd/Ag Separator in the shell side of the first stage at 1725 kN/m^2 (250 psia) and 644K (700F). Hydrogen diffuses into the tubes under a H_2 partial pressure (pH_2) driving force and exhausts through the tube manifold plate at 172 kN/m^2 (25 psia) for spacecraft usage. The H_2-depleted mixture from the shell side of the first stage enters the shell side of the second stage. The remaining H_2 diffuses into the tubes of the second stage and is vented to vacuum. The purified N_2 from the shell side of the second stage is available for spacecraft usage at approximately the same pressure as the N_2/H_2 feed.

Separator Hardware Description. The Pd/Ag tubes are suspended from a manifold plate into the diffusion unit housing. The tubes are sealed at one end. The N_2/H_2 gas mixture enters the shell side traveling the length of the unit to preheat. Hydrogen diffuses into the Pd/Ag tubes and is manifolded from the Pd/Ag N_2/H_2 Separator. The H_2-depleted-N_2 product stream is manifolded from the shell side at the same end of the unit as the H_2 product.

System Operation

The NGS schematic is presented in Figure 9. Hydrazine is fed under pressure and at room temperature into the system through a pneumatic valve (PV1) and a flow control orifice (O1). Porous stainless steel filters (F1 and F2) are used to prevent the flow control orifice from clogging by particles contained in the feed N_2H_4 or possible catalyst dust from the dissociator. These filters also serve as flame arrestors to prevent propagation of the dissociation reaction back from the dissociator to the storage tanks located in the TSA. Flow to the dissociator is controlled by manually adjusting the N_2H_4 feed pressure from the TSA until the desired flow through the orifice is attained.

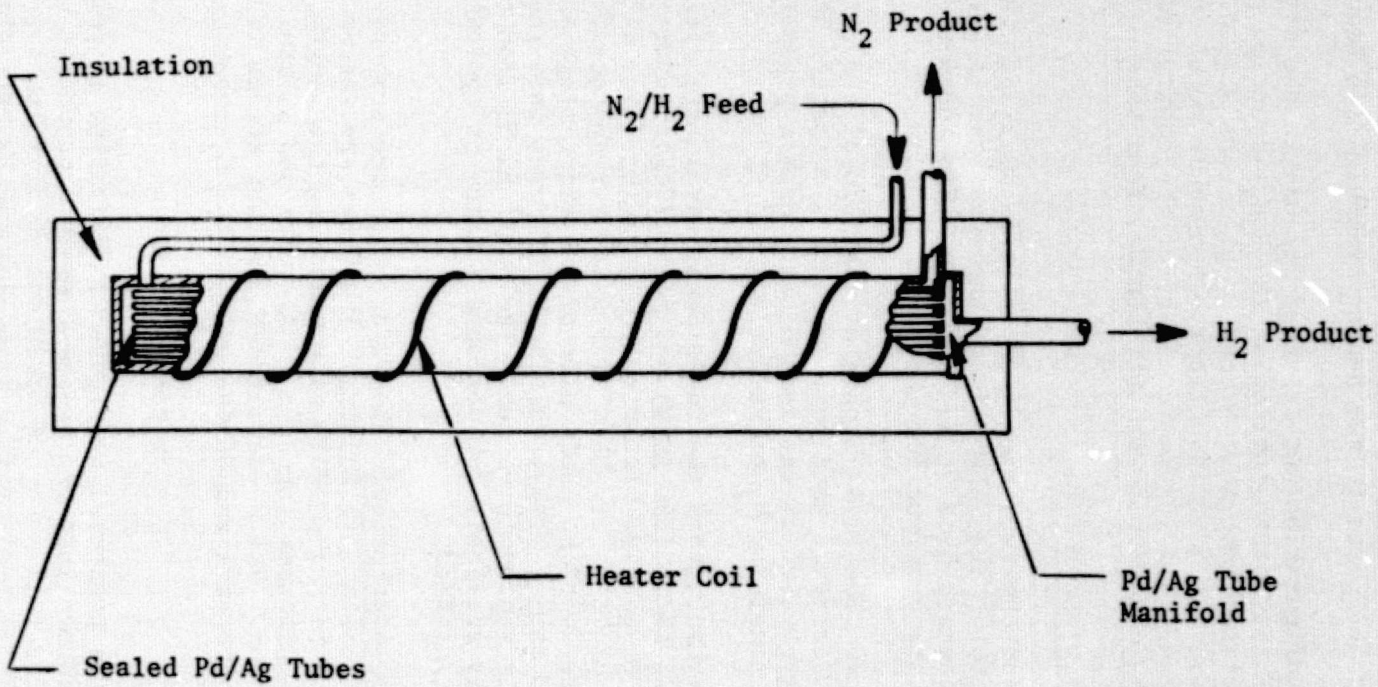

FIGURE 7 PALLADIUM/SILVER SEPARATOR SCHEMATIC

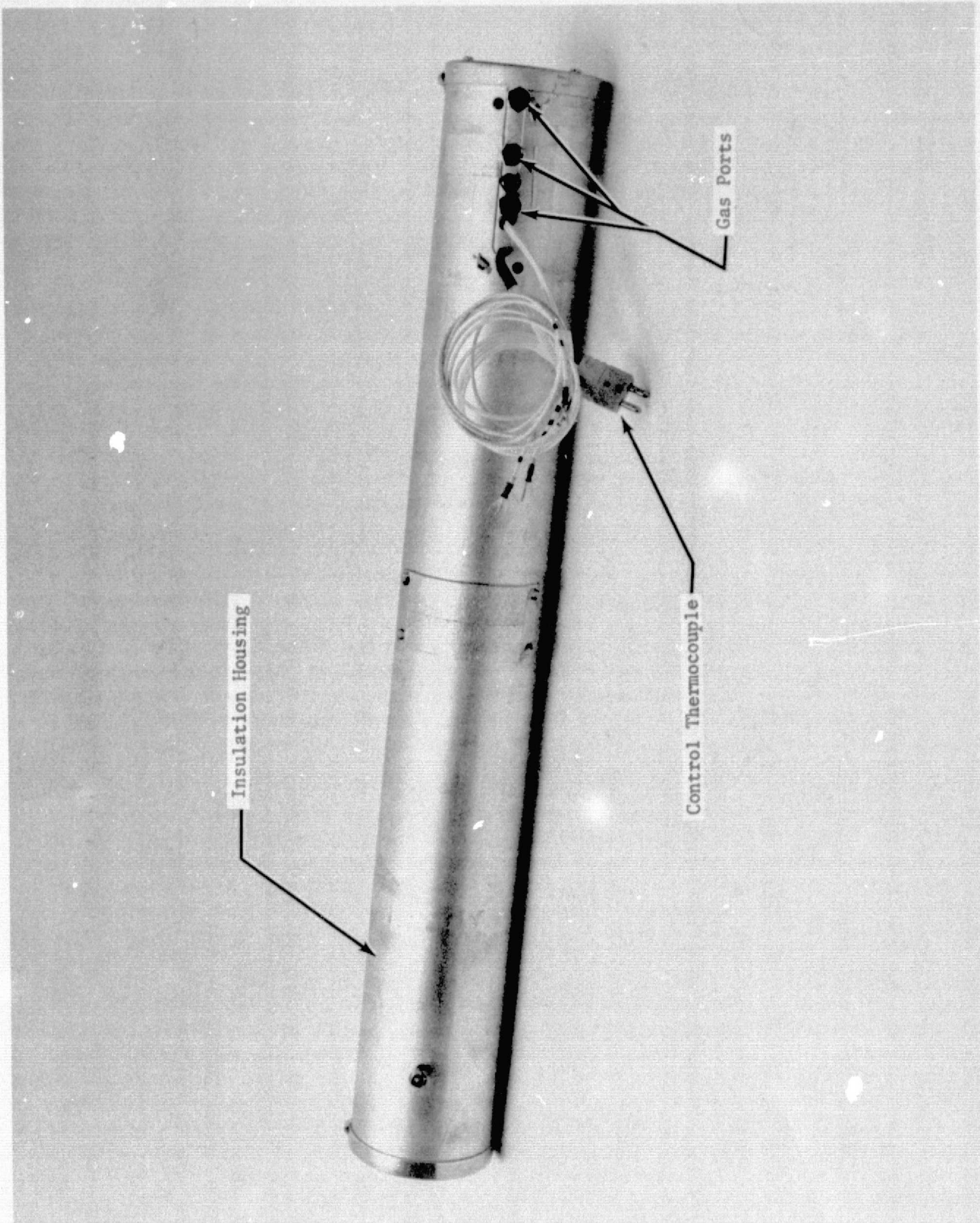

FIGURE 8 PALLADIUM/SILVER SEPARATOR

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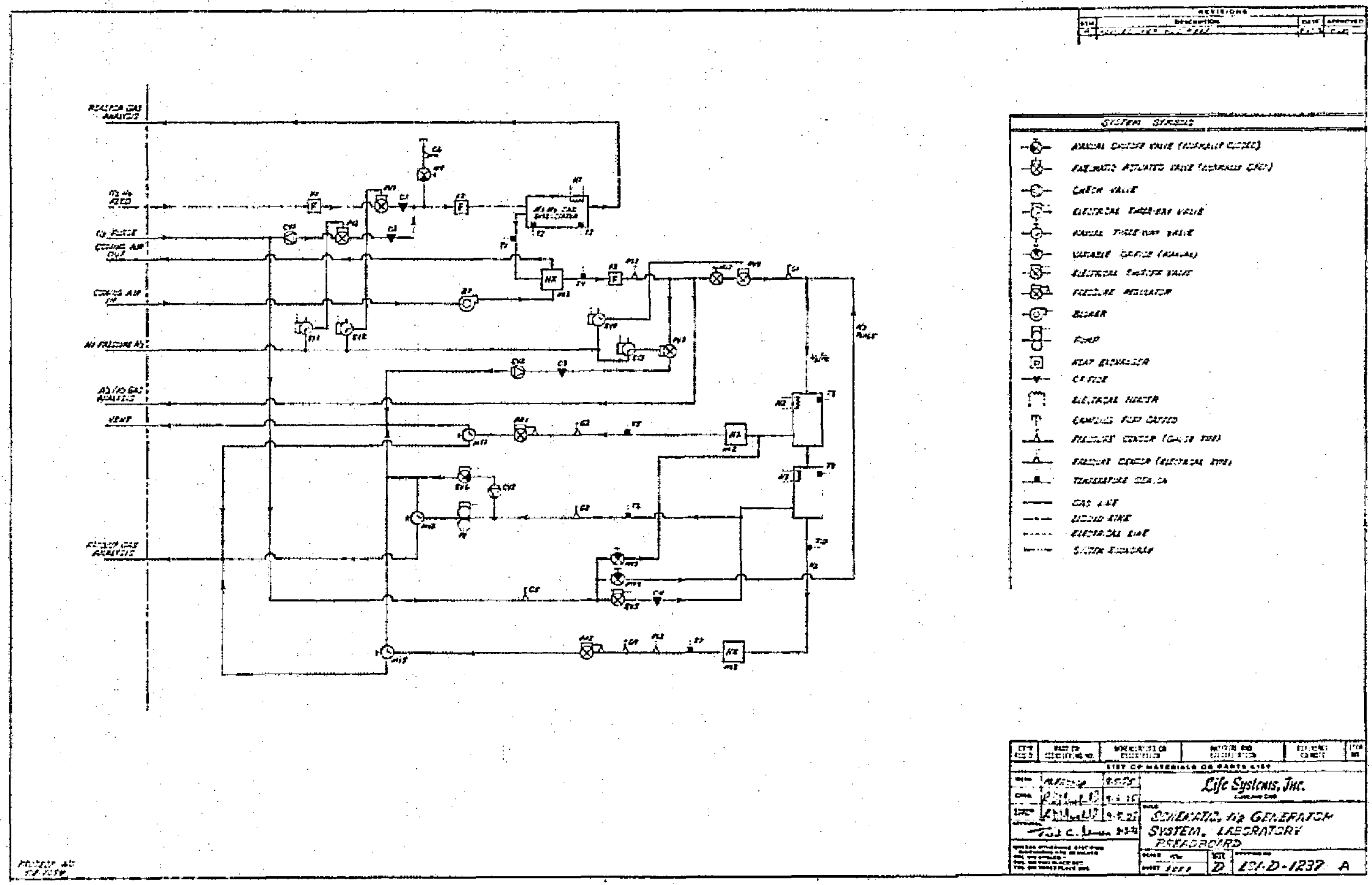

FIGURE 9 NITROGEN GENERATION SYSTEM SCHEMATIC

The N_2H_4 enters the dissociator and is catalytically dissociated into N_2, H_2 and a trace of NH_3. The product gas exits the dissociator at approximately 1000K (1340F). A gas-to-gas (air) heat exchanger is used to lower the temperature of the product gas to approximately ambient temperature. Sample taps are located (1) upstream of the dissociator to monitor feed pressure, (2) in the dissociator to monitor internal gas composition and temperature and (3) lownstream of dissociator to measure product gas composition. The N_2/H_2 product gas from the dissociator then passes through PV4 and enters the first stage Pd/Ag Separator.

Hydrogen is removed from the feed gas stream as it flows through the two successive H_2 removal stages. The temperature of the N_2 product gas is then reduced to ambient by a heat exchanger (HX3). The N_2 delivery pressure is controlled by a backpressure regulator (PR2) located downstream from HX3. The pressures of the gas stream before and after the Pd/Ag Separators are measured by gauges G1 and G4.

The H_2 removed in the first stage is cooled in a heat exchanger (HX2) and its pressure is controlled by a backpressure regulator (PR1). The H_2 is removed in the second stage to vacuum using a vacuum pump. No heat exchanger was required to cool the second stage H_2 because of the low mass and high volumetric H_2 flow rate in the vacuum line. The H_2 pressures for each stage are measured by pressure gauges G2 and G3.

The system is equipped with an automatic N_2 purge for the dissociator which is initiated following a shutdown. During actual running, the N_2 purge valve (PV2) is closed as is the purge vent valve (PV3). A shutdown causes PV2 and PV3 to open and PV4 to close. System pressure decays slowly across orifice O3 located downstream of PV3. When the pressure decays to below the purge pressure, check valve CV1 upstream of PV2 permits N_2 purge gas to enter the system. The purging operation continues until manually ended. Orifice O3 on the purge vent line maintains the system under positive pressure to prevent ambient air from entering the system.

Nitrogen purge for the Pd/Ag Separator is provided manually for the first stage H_2 lines and components, and automatically for the second stage H_2 lines and components. Valves MV3 and MV4 are used for the manual purge operation. Solenoid valves SV5 and SV6 are used to automatically purge the vacuum lines following a shutdown to prevent ambient air from leaking into the evacuated lines.

Control/Monitor Instrumentation

Instrumentation is provided to:

1. Control N_2H_4 Catalytic Dissociator temperature
2. Control Pd/Ag Separator temperature
3. Control solenoid valve and cooling fan operation
4. Provide automatic fail-safe shutdown when a critical parameter exceeds a preset level
5. Monitor system temperatures

Laboratory breadboard-style instrumentation was selected for maximum testing flexibility and direct readout of system parameters in engineering units.

Control Features

The following control features were incorporated:

1. Automatic fail-safe shutdown and N_2 purge initiated by excessive dissociator temperature and pressure, and excessive Pd/Ag Separator temperature and pressure

2. Startup accomplished by supplying power to the solenoid valves, the cooling fan and the heater/temperature controllers; shutdown is accomplished by removing power from these components

3. Fan speed (voltage) manually set by a digital potentiometer

4. Dissociator and separator stage temperatures maintained by individual, manually set temperature controllers

The electrical power sources required to operate the instrumentation are 115V AC, 60 Hz power, which is converted to 24V DC within the test stand to run the instrumentation, and 230V AC, 60 Hz power for the diffusion unit heaters.

Monitor Features

The following monitor features were incorporated:

1. Continuous monitoring and direct meter readout for system temperatures (TS1 to TS10) are provided

2. Temperature shutdowns are signaled by TS1, TS3 and TS9

3. Pressure shutdowns are signaled by PS1 and PS2

TEST SUPPORT ACCESSORIES

The function of the TSA is to provide the system interfaces required to test the NGS. The TSA designed and fabricated for the NGS Test Program provide:

1. N_2H_4 feed mechanism
2. N_2H_4 storage
3. Process gas interfaces
4. Power supply

The TSA schematic is presented in Figure 10.

Hydrazine Feed Mechanism

Hydrazine is fed by pressurizing the N_2H_4 feed tanks to the pressure level that gives the required flow rate through an orifice located in the NGS. Each

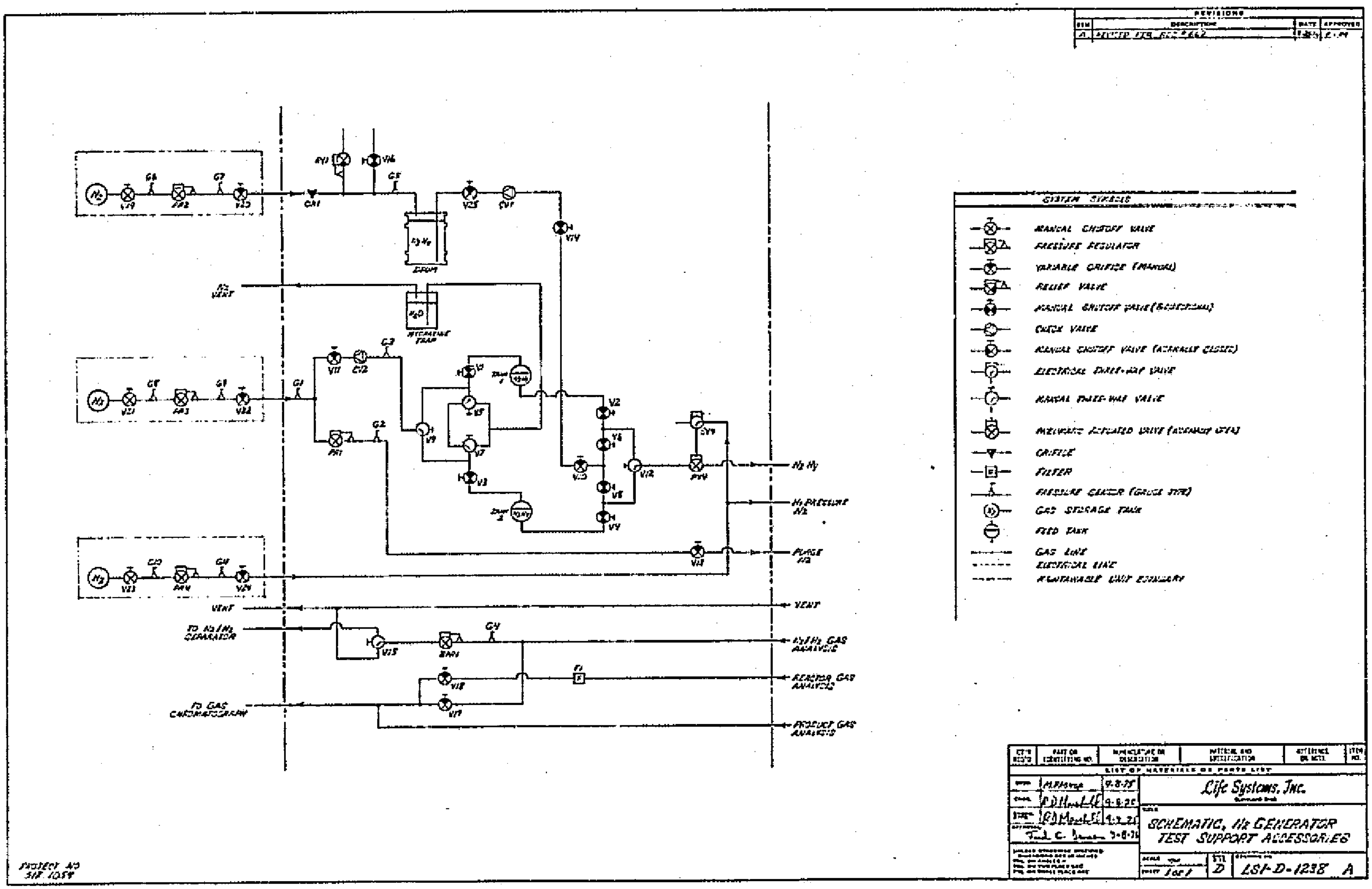

FIGURE 10 TEST SUPPORT ACCESSORIES SCHEMATIC

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tank has sufficient N_2H_4 to operate at a flow rate equivalent to 3.63 kg (8 lb) of N_2 per day for one day. Valving is provided to allow uninterrupted operation of the NGS by refilling one tank while the other tank remains operative.

The N_2H_4 feed line to the NGS also contains a pneumatic valve (PV4) which closes when the NGS is in shutdown. This valve provides in-line redundancy with its counterpart located in the NGS. This redundant valve insures fail-safe shutdown and shutoff of the N_2H_4 feed supply during NGS shutdown even if one of the two valves should fail.

Hydrazine Storage

Hydrazine is stored in a separate drum. The individual N_2H_4 feed tanks in the TSA are refilled by the storage drum. During refill one N_2H_4 feed tank is depressurized while the other tank continues to feed N_2H_4 to the NGS. The depressurized tank is then refilled by using pressure to transfer N_2H_4 from the storage drum into the feed tank. The overflow of N_2H_4 into the N_2H_4 water trap indicates that the tank is full. The refilled tank is then repressurized and can either be hooked back into the system in parallel with the other tank, or as is the case under normal operation, will be held in reserve until the other N_2H_4 tank is ready for refill.

Process Gas Interfaces

The TSA simulates the process gas interfaces with the NGS. The five process gas interfaces simulated are:

1. N_2 purge
2. High pressure N_2
3. Process gas vent
4. Gas analysis taps
5. Ambient air

Bottled N_2 purge gas is supplied to the NGS at 310 kN/m^2 (45 psia). The purge gas is taken from the same source as the N_2 used to pressurize the N_2H_4 feed tanks. The high pressure N_2 at 1,035 kN/m^2 (150 psia) used to operate the pneumatic valves is supplied from a separate N_2 source. A single gas vent line is provided to vent the N_2 and H_2 product gases from the NGS. Gas analysis taps are provided to analyze the N_2/H_2 product gas from the dissociator, the N_2 product gas from the Pd/Ag Separator and the internal gas composition within the dissociator. Analysis of the gas streams is provided using a gas chromatograph.

Power Supply

The TSA supplies 115V and 230V AC, 60 Hz, power to the NGS control/monitor instrumentation. No other power is required to operate the NGS.

TEST PROGRAM

The NGS Test Program is designed to define the present level of technology for NSS application. The experimental activities include:

1. N_2H_4 Dissociator checkout testing
2. Pd/Ag Separator parametric checkout testing
3. Shakedown testing
4. A Design Verification Test (DVT)
5. Parametric testing to determine the effect of N_2 delivery rate and pressure
6. Nominal endurance testing for 60 days at baseline operating conditions
7. Post-endurance test evaluation, including short-term post-parametric testing and component disassembly and inspection

The N_2H_4 Dissociator and Pd/Ag Separator checkout tests have been completed and the results are summarized below. The remaining NGS tests will be completed and reported during the next reporting period.

Hydrazine Dissociator Checkout Testing

The results of the N_2H_4 dissociator checkout testing are presented in Figure 11.

The NH_3 reaction rate, expressed as gNH_3/h/g catalyst, was used since the primary function of the catalyst bed is the dissociation of NH_3 formed by the reaction.

$$3N_2H_4 = N_2 + 4NH_3 \qquad (7)$$

The amount of NH_3 for the reaction is calculated from equation (7) and the N_2H_4 feed flow rate.

Figure 11 shows that the NH_3 reaction rate increases linearly with increasing flow rate. This linear relationship would indicate that the reactor is mass transfer limited and not reaction kinetics limited. A mass transfer limit, however, would not be expected, especially at the higher flow rates where linear flow velocities of up to 39.6 m/s (130 ft/sec) are attained. This apparent discrepancy can be explained by the fact that the temperature profile in the reactor changes with gas flow rate. Higher gas flow rates yield higher reactor bed temperatures which kinetically favor the dissociation of NH_3 and therefore yield a higher dissociation rate with flow than would be expected for a constant temperature profile.

Palladium/Silver Separator Checkout Testing

The results of the Pd/Ag Separator parametric checkout testing as a function of N_2 generation rate, delivery pressure and separator temperature are presented in Figures 12, 13 and 14 respectively. The baseline operating conditions for the test are presented in Table 13.

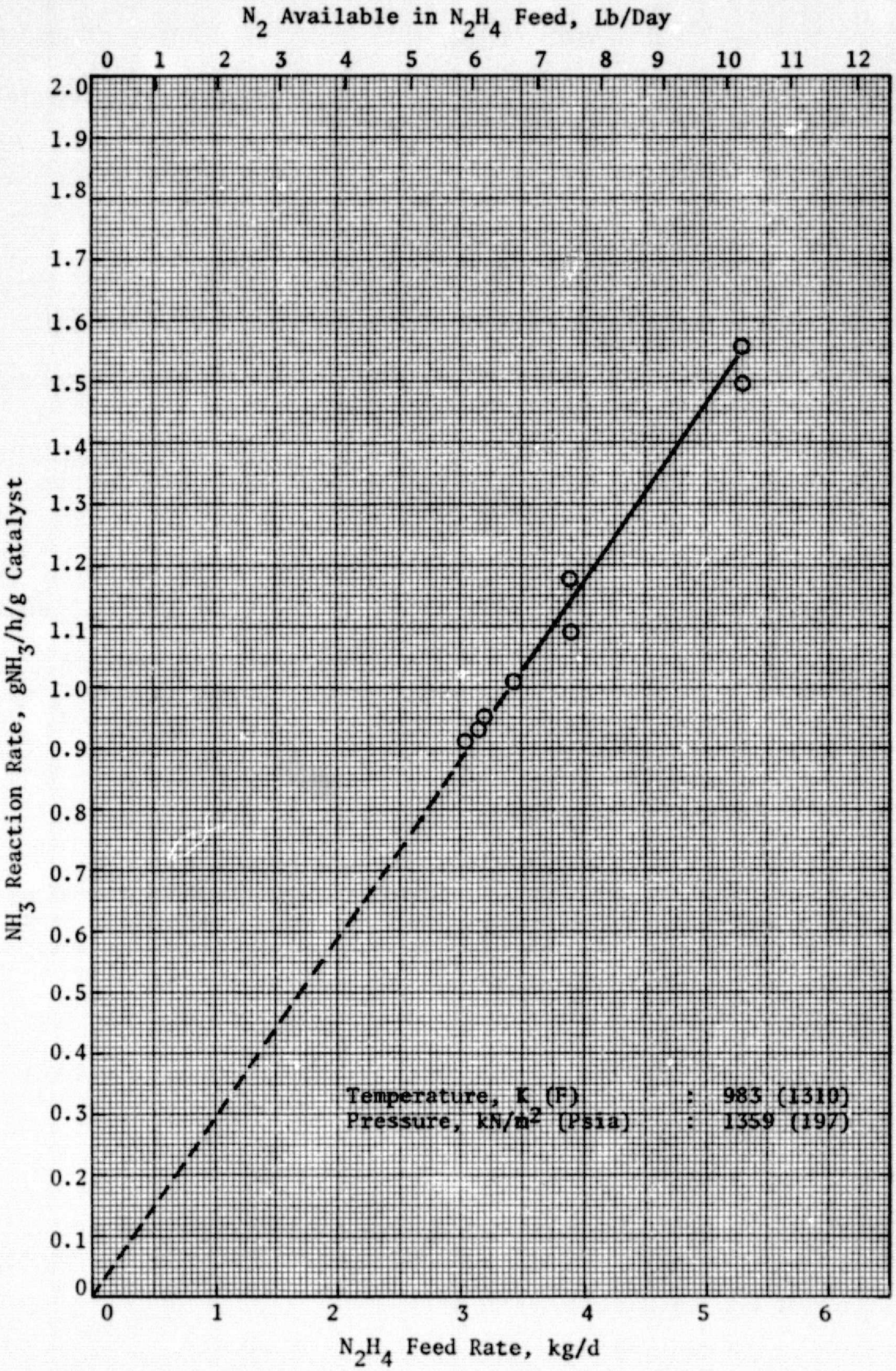

FIGURE 11 HYDRAZINE DISSOCIATOR CHECKOUT TEST

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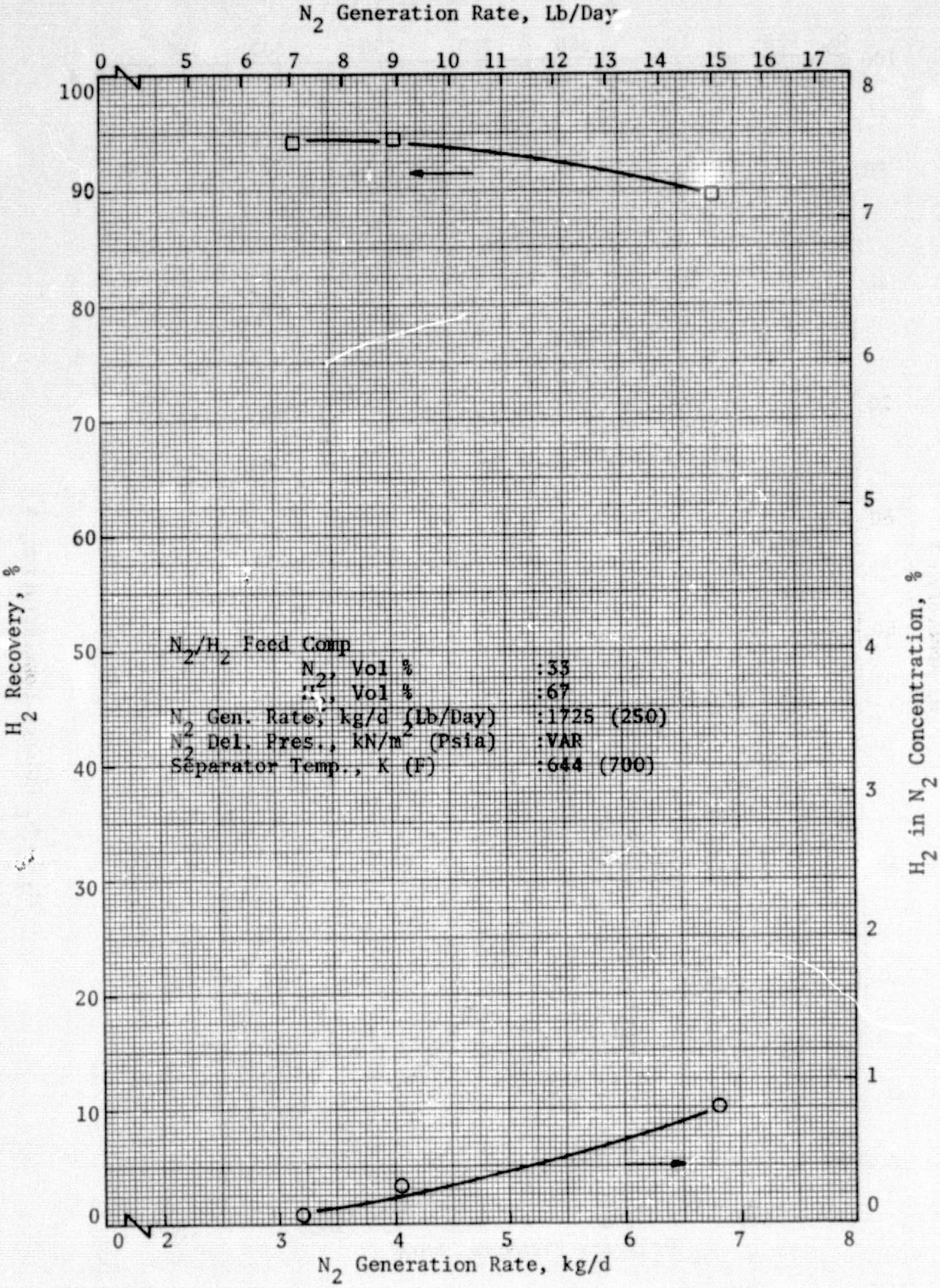

FIGURE 12 EFFECT OF N_2 GENERATION RATE ON PD/AG SEPARATOR PERFORMANCE

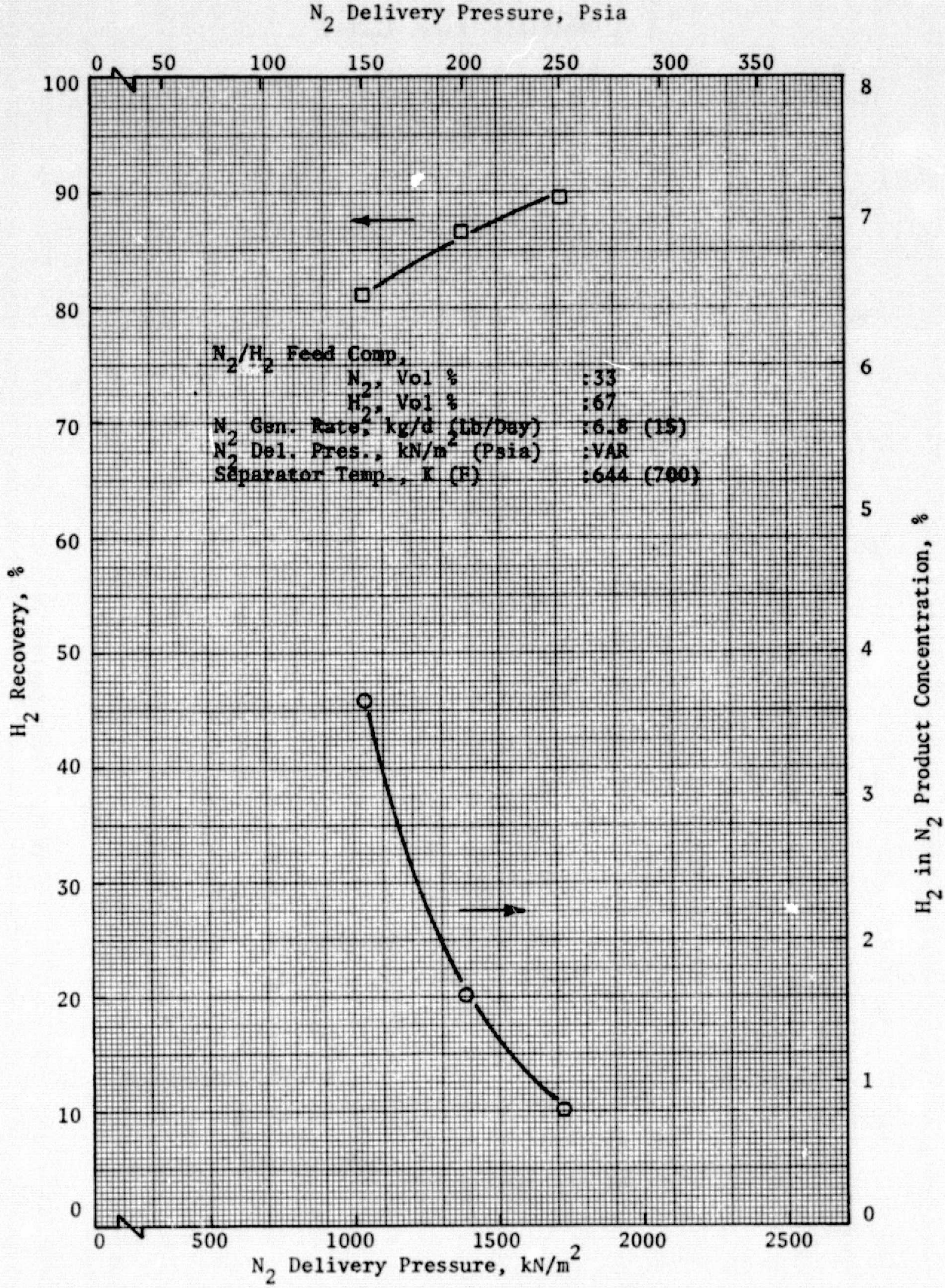

FIGURE 13 EFFECT OF N_2 DELIVERY PRESSURE ON PD/AG SEPARATOR PERFORMANCE

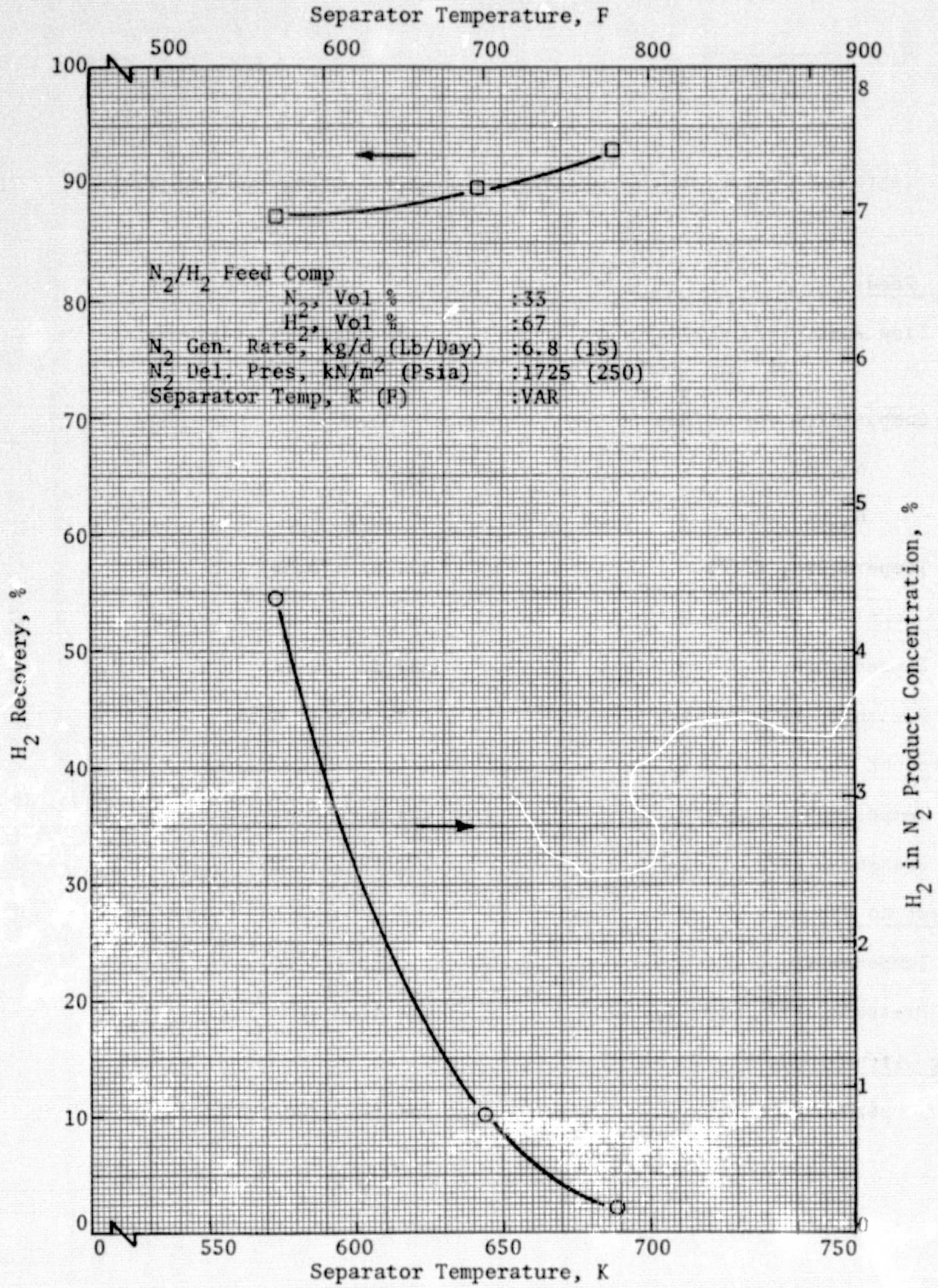

FIGURE 14 EFFECT OF SEPARATOR TEMPERATURE ON PD/AG SEPARATOR PERFORMANCE

TABLE 13 PALLADIUM/SILVER SEPARATOR BASELINE OPERATING CONDITIONS

<u>N_2/H_2 Feed</u>	
Flow Rate, kg/d (Lb/Day)	7.78 ±0.23 (17.14 ±0.5)
dm^3/min (Scfm)	12.2 ±0.04 (0.43 ±0.01)
Composition (by volume)	
N_2, %	33 ±0.5
H_2, %	67 ±0.5
Temperature, K (F)	294 ±2 (70 ±4)
<u>N_2 Product</u>	
Temperature, K (F)	294 ±2 (70 ±4)
Pressure, kN/m^2 (Psia)	1725 ±35 (250 ±5)
<u>H_2 Product</u>	
Temperature, K (F)	294 ±2 (70 ±4)
Pressure, kN/m^2 (Psia)	172 ±7 (25 ±1)
<u>H_2 Vent to Vacuum</u>	
Temperature, K (F)	294 ±2 (70 ±4)
Pressure, kN/m^2 (mm Hg)	0.3 ±0.3 (2 ±2)
<u>Pd/Ag Diffusion Unit</u>	
Temperature, K (F)	644 ±14 (700 ±25)

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The Pd/Ag Separator performance increases with increasing delivery pressure, increasing separator temperature and decreasing N_2 generation rate. At normal operating conditions the H_2 and N_2 product concentration will be less than 0.2% and approximately 94% of the H_2 feed will be recovered for use in a CRS.

SUPPORTING TECHNOLOGY ACTIVITIES

Three analyses were completed to support NSS technology development:

1. Pd/Ag Separator performance improvements
2. Use of hydrazine hydrate ($N_2H_4 \cdot H_2O$)
3. NH_3 removal techniques

Palladium/Silver Separator Improvements

Analytical studies to improve Pd/Ag Separator performance were completed in the areas of N_2/H_2 manifolding, alternate Pd alloys, surface treatment of the diffusion tubes and operation at higher temperatures.

Nitrogen/hydrogen manifolding techniques were evaluated. The most promising technique can theoretically yield a 50% or greater volume and weight reduction of the Pd/Ag Separator by flowing the process gases through the inside of the tubes. The tubes are closely spaced in a straight bundle and manifolded at both ends. The H_2 permeates through the tube walls and is collected from the spaces between the tubes. The length/diameter ratio of the flow path is increased so that the stagnant gas layer is reduced and plug flow is improved.

Alternate Pd alloys were identified. The Pd/Ag/gold (Au) alloys are reputed to be an improvement over the standard 75/25 Pd/Ag alloy. The improvement appears to be marginal, however, and little life data is currently available. Therefore, until additional data is available, 75/25 Pd/Ag remains the recommended alloy.

Surface treatment of the Pd alloy tubes has been used to improve H_2 absorption and desorption kinetics in ambient temperature applications. At high temperatures, however, the literature indicates that the H_2 transfer rate is limited not by surface phenomena but by diffusion through the metal itself. For this reason surface treatment will not be considered further for the present high temperature application.

Operation of the Pd/Ag units at higher temperatures (700K (800F)) compared to baseline (644K (700F)) would not change system power or heat rejection significantly since the process gases are available at higher temperatures. Hydrogen transfer would increase but the reliability of the units would be adversely affected, more than offsetting the gains. Therefore, the recommended operating temperature range remains 616 to 644K (650 to 700F).

Hydrazine Hydrate Analysis

A study was completed to determine if $N_2H_4 \cdot H_2O$ can be used to replace the more expensive anhydrous N_2H_4 as the storable form of N_2. The study concluded that $N_2H_4 \cdot H_2O$ could not be used to replace N_2H_4 for the following reasons:

1. The addition of water to N_2H_4 would require that water be removed from the N_2 product stream to prevent condensation in the N_2 product lines and pressure regulator. At 1725 kN/m^2 (250 psia), the operating pressure of the N_2 generator, only 0.05% water in the feed N_2H_4 would result in an N_2 product gas dew point of 287K (57F).

2. The addition of water to the N_2H_4 feed shifts the equilibrium concentration of NH_3 (i.e., the lowest concentration of NH_3 that can be reached in the reactor) to higher concentrations of NH_3.

3. There are no safety advantages to diluting the feed N_2H_4 with a small amount (less than 10%) of water, and, in fact, the corrosive nature of the product gas stream is worsened by the addition of water vapor.

Ammonia Removal Analysis

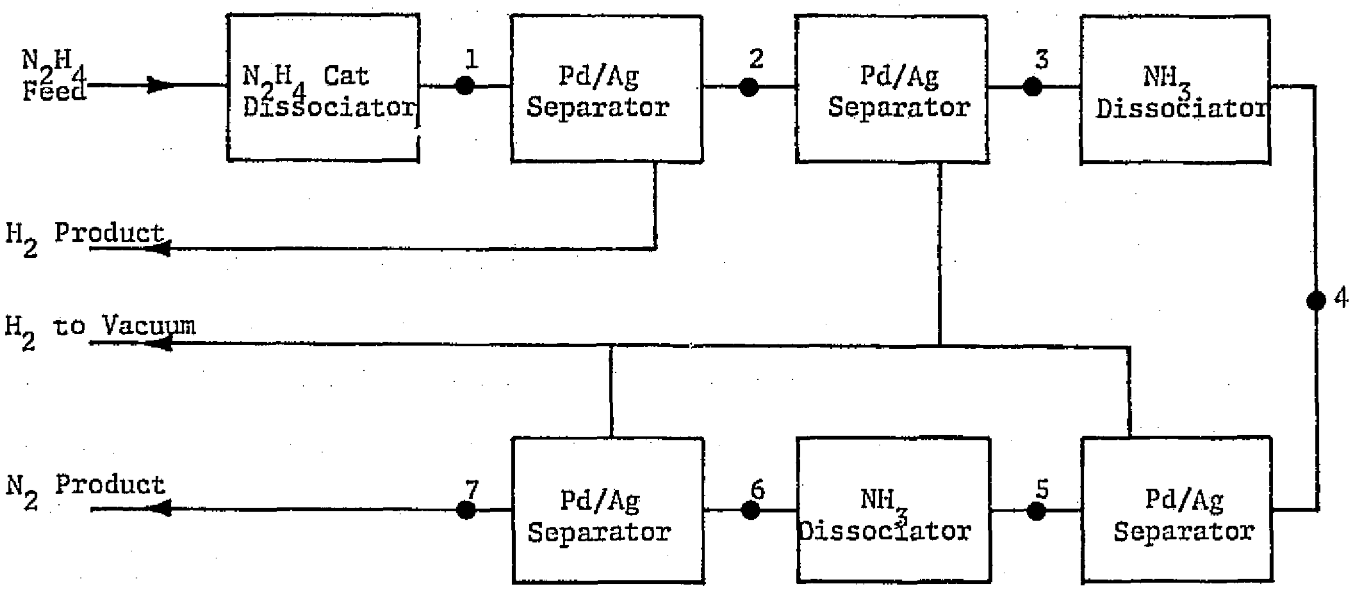
The N_2H_4 Catalytic Dissociator produces between three and twenty times the normal crew metabolic NH_3 production. A method of removing the NH_3 produced is, therefore, required.

The normal method of NH_3 removal in a spacecraft atmosphere is using the fixed carbon bed impregnated with phosphoric acid which is located in the TCCS. The removal of the NH_3 generated by the NGS, however, would severely penalize the TCCS by increasing the size of the fixed activated carbon removal bed. Development of an alternate NH_3 removal technique was, therefore, required.

The study of possible NH_3 removal methods resulted in selection of a staging technique to remove NH_3 generated in the N_2H_4 catalytic dissociation process. The staging technique takes advantage of the principle that removing H_2 from the product stream favors further NH_3 dissociation. The lowest NH_3 concentration possible, based on thermodynamic equilibrium, is approximately 0.3% in the product N_2 and H_2 from the dissociator. After removal of the H_2 in the process stream, however, further NH_3 dissociation can be attained.

Subsequent dissociation and H_2 separation stages were selected as a feasible means of removing the NH_3 generated. A typical staging scheme is presented in Figure 15. The gas concentrations following each dissociation and H_2 separation stage are also presented to demonstrate how low concentrations of NH_3 can be attained. Use of the staging technique offers the following advantages:

1. Lower than "theoretical" NH_3 concentrations
2. Approximately 63.6 kg (140 lb) equivalent weight savings over fixed activated carbon bed removal (TCCS)
3. Less NGS expendables since nearly all of the N_2H_4 goes into the production of N_2 and H_2 and is, therefore, not lost as NH_3
4. Lower interface sensitivity since the product N_2 can be dumped directly into the cabin



Stream	% N_2	% H_2	% NH_3	Efficiency %	Temp K (F)
1	33.1	65.5	1.4	97	1000 (1340)
2	86.2	10.2	3.5	94	644 (700)
3	95.9	0.2	3.9	98	644 (700)
4	94.2	5.7	0.1	97	800 (981)
5	99.78	0.12	0.12	98	644 (700)
6	99.70	0.29	36 ppm	97	800 (981)
7	99.99	59 ppm	36 ppm	98	644 (700)

FIGURE 15 BLOCK DIAGRAM OF STAGING CONCEPT

CONCLUSIONS

Based on the program activities completed, the following conclusions were reached:

1. The Hydrazine Catalytic Dissociator and the Palladium/Silver Separator can be integrated into a single Nitrogen Generation Module to take advantage of the heat generated in the hydrazine dissociation reaction. The Nitrogen Generation Module would contain alternate dissociation and hydrogen separation stages to reduce the ammonia concentration in the product nitrogen stream to less than 50 ppm.

2. Alternate ammonia dissociation and hydrogen separation stages are the most effective and lowest equivalent method of reducing the ammonia concentration in the product nitrogen. The equivalent weight savings over using the Trace Contaminant Control Subsystem for ammonia removal would be approximately 63.6 kg (140 lb).

3. The Palladium/Silver Separator performance can be improved by manifolding the nitrogen/hydrogen gas mixture through the inside of the diffusion tubes. A 50% reduction in the number of tubes required is possible.

4. Hydrazine hydrate cannot be used to replace the more expensive anhydrous hydrazine as the stored form of nitrogen. Condensation in the product gas nitrogen lines, reduced ammonia dissociation efficiency and increased ammonia corrosion problems would result from its use.

5. The Palladium/Silver-based Nitrogen Generation System is preferred over the Polymer Electrochemical-based Nitrogen Generation System. The palladium/silver diffusion tube technology is "off-the-shelf" technology and the polymer separator membrane technology is not. The Polymer Electrochemical Nitrogen Generation System could not easily be staged for low ammonia concentrations in the product nitrogen since the polymer separator cannot be subjected to high temperatures. Higher expendable weight would result since nitrogen would be lost as undissociated ammonia.

RECOMMENDATIONS

The following recommendations are a direct result of the program activities completed:

1. A Nitrogen Generation Module should be developed and tested to demonstrate the staging process and integration into a single unit containing the dissociation and separation stages.

2. An engineering prototype of a Nitrogen Supply System should be developed which incorporates the Nitrogen Generation Module, automatic hydrazine feed control and the control and monitor instrumentation required for totally self-contained, automatic subsystem operation as part of a total Air Revitalization System.

3. Future Palladium/Silver Separator designs should manifold the nitrogen/hydrogen mixture through the inside of the diffusion tubes to reduce unit weight and volume.

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10. Smetana, Frederick O., Fairchild II, Howard H. and Martin, Glenn L., "Equilibrium Concentrations of N_2H_4 and its Decomposition Products at Elevated Temperatures and Pressures," Department of Mechanical and Aerospace Engineering, School of Engineering, North Carolina State University, Raleigh, NC.

APPENDIX 1

DESIGN SPECIFICATION FOR PD/AG-BASED NGS

Life Systems, Inc. CLEVELAND, OHIO 44122	SPECIFICATION	NO. 200	REVISION LTR. A
	Project 512-1054	PAGE 1 OF 6	DATE 4/2/75
TITLE N_2 GENERATION SYSTEM (PD/AG-BASED) - FLIGHT VERSION		R. D. Marshall	

FUNCTION:

The function of the Nitrogen (N_2) Generation System is to generate sufficient N_2 to replace the N_2 component of air that is lost from a space vehicle through cabin air leakage. Nitrogen is stored on board the spacecraft as liquid hydrazine (N_2H_4) and is fed at a controlled flow rate to the N_2 Generation System which generates the makeup N_2 and a supply of by-product hydrogen (H_2).

DESCRIPTION:

The N_2 Generation System consists of an integrated N_2H_4 Catalytic Dissociator and Palladium/Silver (Pd/Ag) N_2/H_2 Separator and the peripheral mechanical and electronic components necessary to control system operation and monitor performance. The system schematic is presented in Figure 1. The dissociator and separator are packaged as a single unit to minimize insulation requirements since both operate at elevated temperatures.

Hydrazine is dissociated in the catalytic reactor in two consecutive reactions:

$$N_2H_4 = NH_3 + 1/2N_2 + 1/2H_2 \quad (1)$$

$$NH_3 = 1/2N_2 + 3/2H_2 \quad (2)$$

The overall reaction is exothermic:

$$N_2H_4 = N_2 + 2H_2 + 325 \text{ kJ/kg } (678 \text{ Btu/Lb } N_2H_4) \quad (3)$$

The N_2/H_2 gas mixture from the dissociator at an elevated temperature and pressure is separated in the Pd/Ag Separator. Approximately 90% of the feed H_2 removed in the separator is available for spacecraft usage. The remaining 10% of the feed H_2 is removed to vacuum to attain the required N_2 product gas purity.

DESIGN DATA:

Design Specifications

Leakage Data	
Air Leakage Rate	
Minimum, kg/d (Lb/Day)	4.15 (9.13)
Maximum, kg/d (Lb/Day	8.88 (19.56)
N_2 Leakage Rate	
Minimum, kg/d (Lb/Day)	3.18 (7.0)
Maximum, kg/d (Lb/Day)	6.81 (15.0)
O_2 Leakage Rate	
Minimum, kg/d (Lb/Day)	0.97 (2.13)
Maximum, kg/d (Lb/Day)	2.07 (4.56)

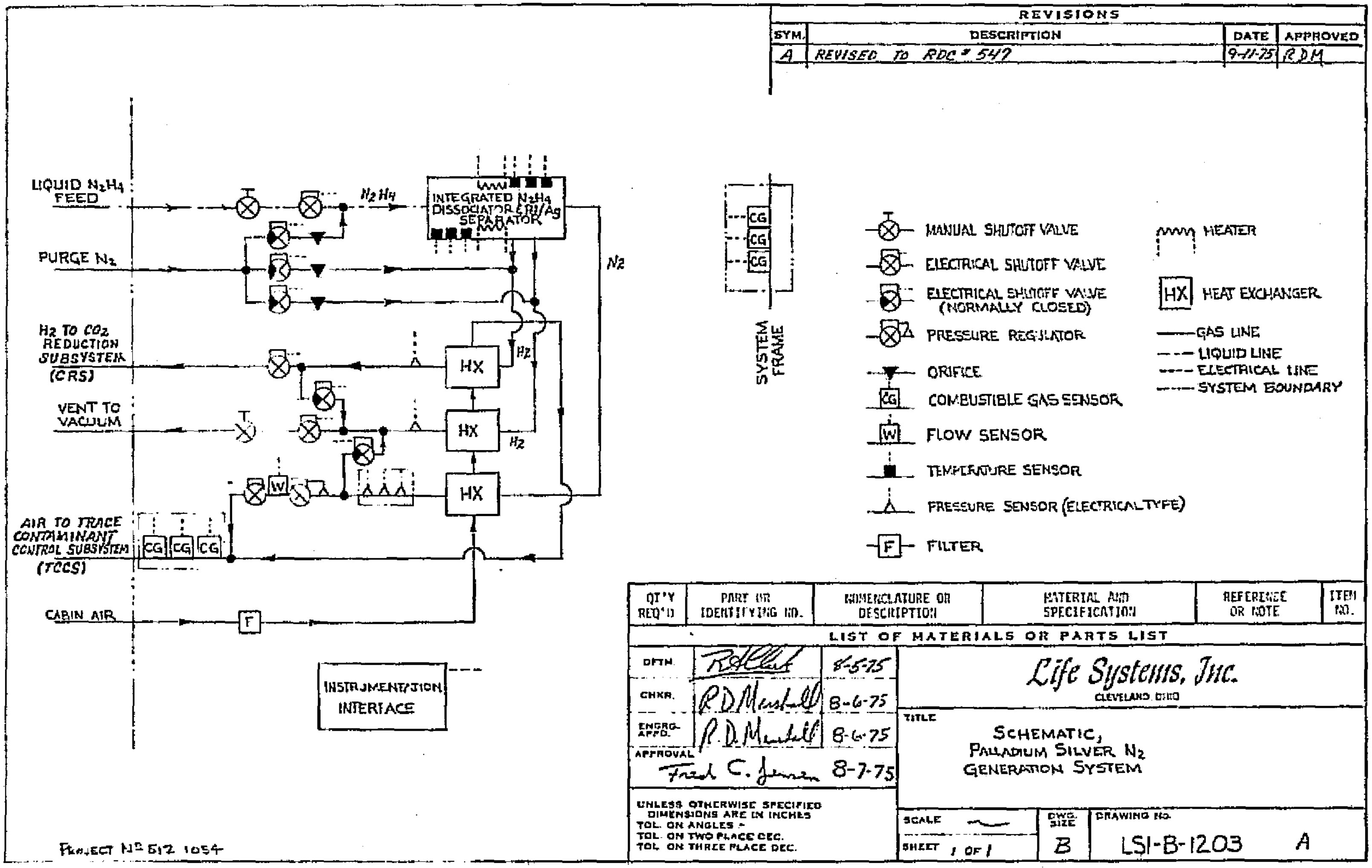

FIGURE 1 PALLADIUM/SILVER-BASED NGS SCHEMATIC

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Cabin Atmosphere Data	
Operational Gravity, m/s^2 (G)	0 to 9.8 (0 to 1)
Total Pressure, kN/m^2 (Psia)	101.4 (14.7)
O_2 Partial Pressure, kN/m^2 (Psia)	21.4 (3.1)
Diluent	N_2
Volume	
Initial, m^3 (Ft^3)	439 (15,500)
Growth, m^3 (Ft^3)	960 (33,900)
Ventilation Rate	
Minimum, cm/s (Ft/Min)	7.6 (15)
Maximum, cm/s (Ft/Min)	20.3 (40)
H_2 Concentration, Volume %	0.2
NH_3 Concentration, Volume %	5.0×10^{-4}
Temperature, K (F)	291 to 297 (65 to 75)
Surface Temperature Guidelines, K (F)	$\leq$322 (120)
Acoustical Guidelines	NC-65

Nominal Operating Conditions

Catalytic Dissociator Temperature, K (F)	1000 (1340)
Pd/Ag Separator Temperature, K (F)	644 (700)
N_2H_4 Feed	
Source	Liquid N_2H_4
N_2H_4 Flow Rate, kg/d (Lb/Day)	4.15 (9.14)
cm^3/min	2.9
Composition (Weight)	
N_2H_4, %	99.5 to 100
Water, %	0 to 0.5
Temperature, K (F)	293 to 298 (63 to 77)
Pressure, kN/m2 (Psia)	1773 to 1794 (257 to 260)
N_2 Product	
Flow Rate, kg/d (Lb/Day)	3.63 (8.0)
dm^3/min (Slpm)	2.2 (2.2)
Composition	
H_2, Volume %	<0.2
NH_3, Volume %	5×10^{-4}
Water, Volume %	<0.1
Temperature, K (F)	293 to 298 (68 to 77)
Pressure, kN/m^2 (Psia)	1725 (250)
H_2 Product	
Flow Rate, kg/d (Lb/Day)	0.43 (0.94)
dm^3/min (Slpm)	3.6 (3.6)
Purity, Volume %	99.9999 to 100
Temperature, K (F)	293 to 298 (68 to 77)
Pressure, kN/m^2 (Psia)	173 (25)
H_2 Vented	
Flow Rate, kg/d (Lb/Day)	0.03 (0.06)
dm^3/min (Slpm)	0.23 (0.23)
Temperature, K (F)	293 to 298 (68 to 77)
Pressure, N/m^2 (mm Hg)	0 to 1.33 (0 to 10)

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Coolant Supply	
Type	Ambient Air
Temperature, K (F)	293 to 298 (68 to 77)
Flow Rate, m^3/min (Scfm)	2.8 (100)

Performance Characteristics

N_2 Generation Rate, kg/d (Lb/Day)	3.18 to 6.81 (7 to 15)
dm^3/min (Slpm)	1.9 to 4.0 (1.9 to 4.0)
NH_3 Conversion Efficiency, %	<96
H_2 Recovery, %	89 to 94
NH_3 Generated, kg/d (Lb/Day)	0[a]
Water Generated	0.02 to 0.04 (0.04 to 0.09)
Power Required, W	94
Heat Rejected, J/s (Btu/Hr)	121 (415)
Reliability Data	
Goal	0.999750
MTBF, Hr	10,807
Mission Length, Day	180

Physical Characteristics See Figure 2

Weight	
Basic System, kg (Lb)	19.7 (43.4)
Spares, kg (Lb)	20.6 (45.3)
Total, kg (Lb)	40.3 (88.7)
Volume	
Basic System, m^3 (Ft^3)	0.05 (1.7)
Spares, m^3 (Ft^3)	0.03 (0.9)
Total, m^3 (Ft^3)	0.07 (2.6)
Basic Dimensions, m (In)	0.03 x 0.5 x 0.3 (12 x 20 x 12)

Material Characteristics

A. Nonmetallic	EPR, TFE
B. Metallic	310 SS, Tungsten, 302 SS, 304 SS, 316 SS, Inconel

Electrical Characteristics

Supply Voltage, VAC	230 ±20
, Hz	60 or 400
Supply Voltage, VDC	28 ±4

(a) NH_3 concentration in product N_2 is equal to cabin ambient concentration; hence, the NH_3 that is removed through cabin leakage equals what is produced by the NGS; i.e., no net NH_3 concentration increase.

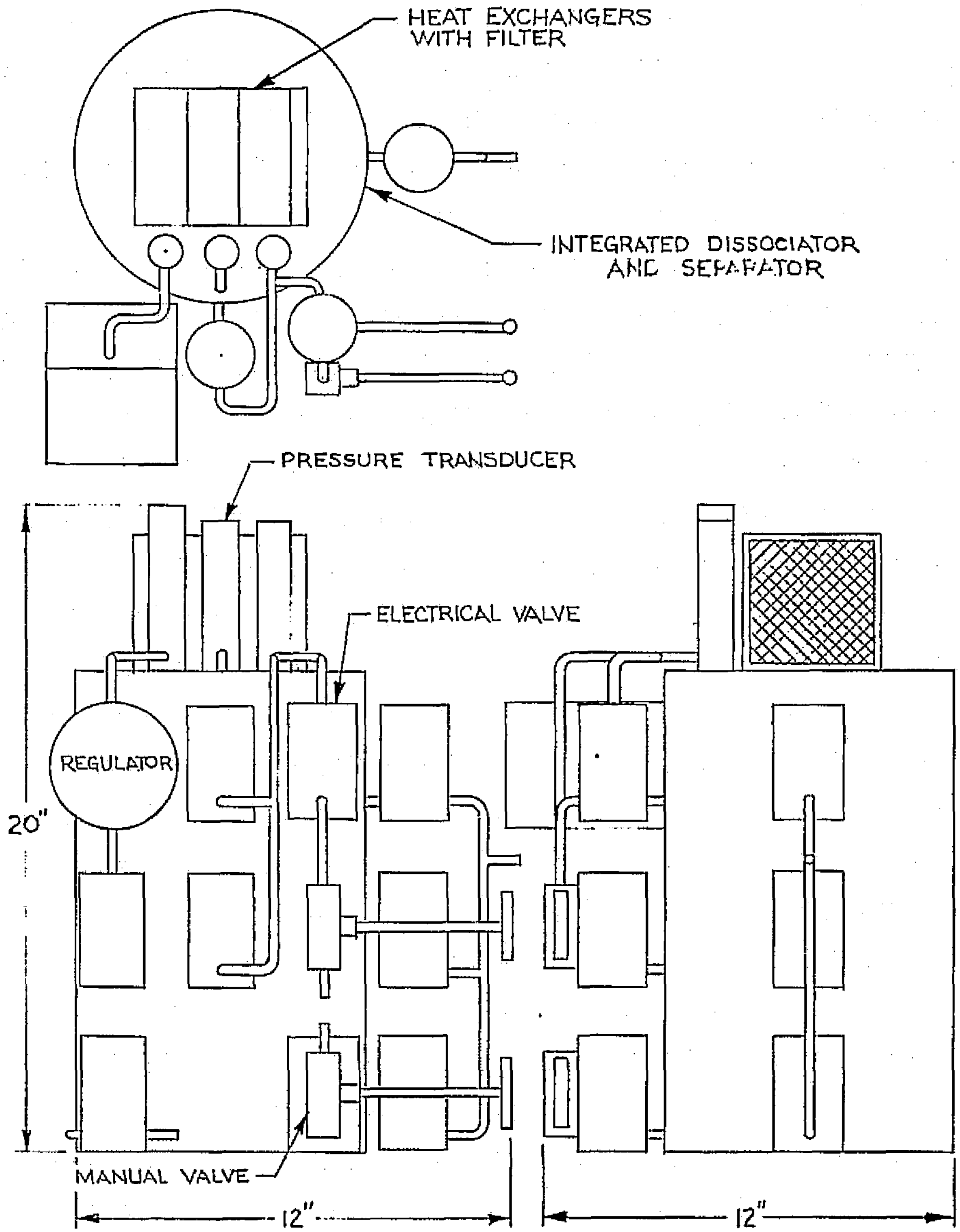

FIGURE 2 PD/AG-BASED N_2 GENERATION SYSTEM PACKAGING LAYOUT SCHEMATIC

INTERFACES

Mechanical

N_2H_4 Feed	1/4 In Tube
H_2 to CRS	1/4 In Tube
H_2 to Vacuum	1 In Flexible Vacuum Tube
Air to TCCS	2 In Flexible Duct
Purge Gas	
Type	N_2
Pressure, kN/m^2 (Psia)	310 (45)
Cabin Air	Ambient

Electrical

Connector	MIL-C-81511

Mounting

4-1/4 In x 20 NC Bolts

ENVIRONMENT:

Cabin Atmosphere

MAINTENANCE LEVEL AND METHOD:

First Level - Shut system down and go to backup
Second Level - Line Replaceable Components
Time Required - 8 Hours

APPENDIX 2

DESIGN SPECIFICATION FOR POLYMER ELECTROCHEMICAL-BASED NGS

Life Systems, Inc. CLEVELAND, OHIO 44122	SPECIFICATION Project 512-1054	NO. 250 PAGE 1 OF 6	REVISION LTR. DATE 4/29/75
TITLE N_2 GENERATION SYSTEM (POLYMER ELECTROCHEMICAL-BASED) - FLIGHT VERSION		R. D. Marshall	

FUNCTION:

The function of the Nitrogen (N_2) Generation System is to generate sufficient N_2 to replace the N_2 component of air that is lost from a space vehicle through cabin air leakage. Nitrogen is stored on board the spacecraft as liquid hydrazine (N_2H_4) and is fed at a controlled flow rate to the N_2 Generation System which generates the makeup N_2 and a supply of by-product hydrogen (H_2).

DESCRIPTION:

The N_2 Generation System consists of an integrated N_2H_4 Catalytic Dissociator and Polymer Electrochemical N_2/H_2 Separator and the peripheral mechanical and electronic components necessary to control system operation and monitor performance. The system schematic is presented in Figure 1. The dissociator and separator cannot be packaged as a single unit since the dissociator operates at 1000K (1340F) and the separator operates at room temperature.

Hydrazine is dissociated in the catalytic reactor in two consecutive reactions:

$$N_2H_4 = NH_3 + 1/2N_2 + 1/2H_2 \tag{1}$$

$$NH_3 = 1/2N_2 + 3/2H_2 \tag{2}$$

The overall reaction is exothermic:

$$N_2H_4 = N_2 + 2H_2 + 325 \text{ kJ/kg } (678 \text{ Btu/Lb } N_2H_4) \tag{3}$$

The N_2/H_2 gas mixture leaves the dissociator at approximately 1000K (1340F) and is cooled in a heat exchanger to room temperature before entering the N_2/H_2 Separator. Approximately 80% of the feed H_2 (with <2% N_2) is removed in the polymer diffusion unit. The remaining 20% of the Feed H_2 in the product N_2 stream is removed in two stages in a nine-cell electrochemical N_2/H_2 separator module. Approximately 19% of the initial feed H_2 is removed in the first eight cells at a constant current. The N_2 product from these eight cells is manifolded internally to the last cell which is operated at a constant voltage of 1.0V. The last cell acts as the final stage in the removal of the remaining 1% of the H_2 and as a H_2 sensor to indicate the final N_2 product purity. All H_2 removed in the polymer and electrochemical separators is available for spacecraft usage.

DESIGN DATA:

Design Specifications

Leakage Data
Air Leakage Rate

Minimum, kg/d (Lb/Day)	4.15 (9.13)
Maximum, kg/d (Lb/Day	8.88 (19.56)

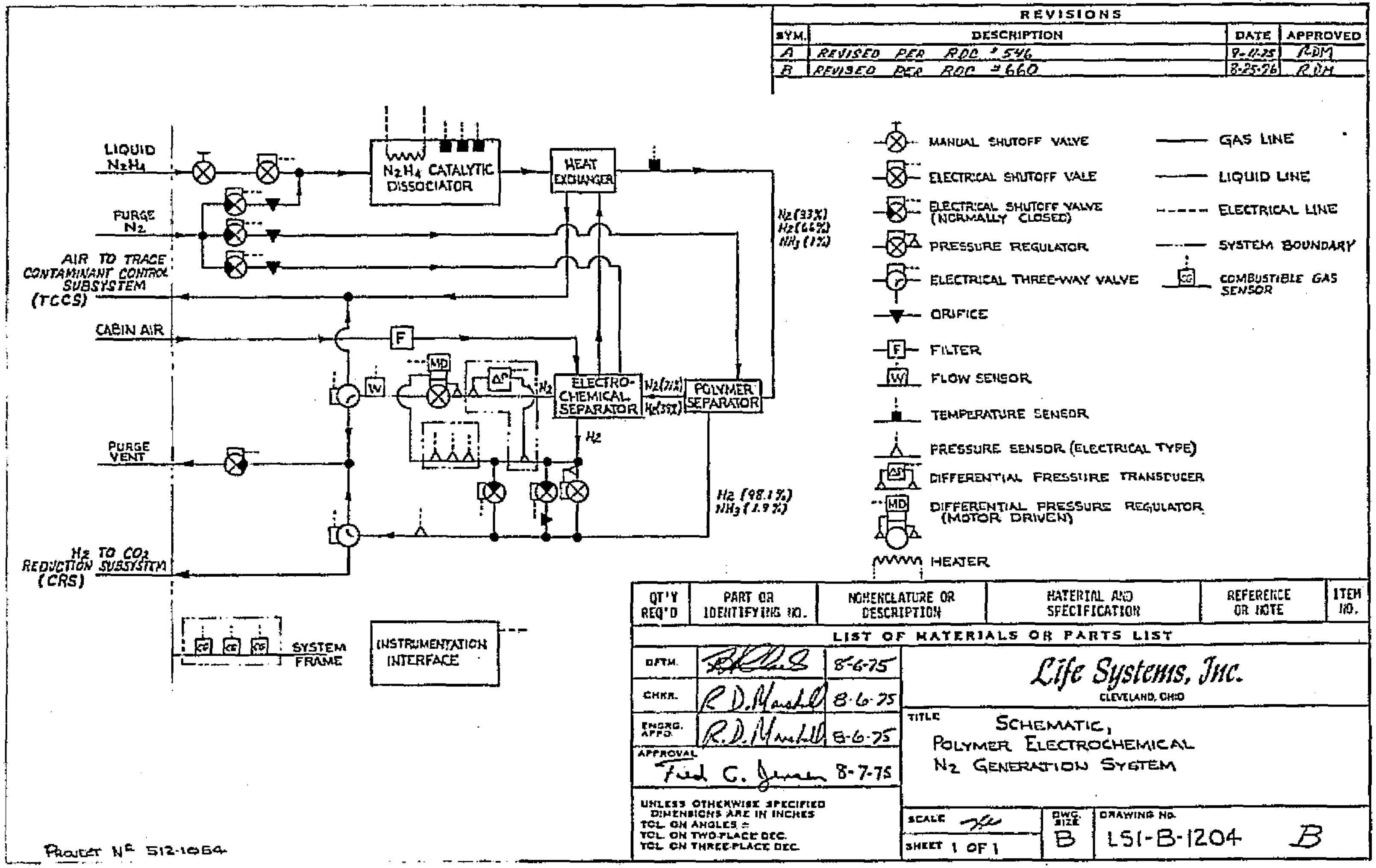

FIGURE 1 POLYMER ELECTROCHEMICAL-BASED NGS SCHEMATIC

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N_2 Leakage Rate	
Minimum, kg/d (Lb/Day)	3.18 (7.0)
Maximum, kg/d (Lb/Day)	6.81 (15.0)
O_2 Leakage Rate	
Minimum, kg/d (Lb/Day)	0.97 (2.13)
Maximum, kg/d (Lb/Day)	2.07 (4.56)
Cabin Atmosphere Data	
Operational Gravity, m/s^2 (G)	0 to 9.8 (0 to 1)
Total Pressure, kN/m^2 (Psia)	101.4 (14.7)
O_2 Partial Pressure, kN/m^2 (Psia)	21.4 (3.1)
Diluent	N_2
Volume	
Initial, m^3 (Ft^3)	439 (15,500)
Growth, m^3 (Ft^3)	960 (33,900)
Ventilation Rate	
Minimum, cm/s (Ft/Min)	7.6 (15)
Maximum, cm/s (Ft/Min)	20.3 (40)
H_2 Concentration, Volume %	0.2
NH_3 Concentration, Volume %	5.0×10^{-4}
Temperature, K (F)	291 to 297 (65 to 75)
Surface Temperature Guidelines, K (F)	$\leq$322 (120)
Acoustical Guidelines	NC-65

Nominal Operating Conditions

Catalytic Dissociator Temperature, K (F)	1000 (1340)
N_2/H_2 Separator Temperature, K (F)	Ambient
N_2H_4 Feed	
Source	Liquid N_2H_4
N_2H_4 Flow Rate, kg/d (Lb/Day)	4.74 (9.61)[a]
cm^3/min	2.9
Composition (Weight)	
N_2H_4, %	99.5 to 100
Water, %	0 to 0.5
Temperature, K (F)	293 to 298 (68 to 77)
Pressure, kN/m^2 (Psia)	1277 (185)
N_2 Product	
Flow Rate, kg/d (Lb/Day)	3.63 (8.0)
dm^3/min (Slpm)	2.2 (2.2)
Composition	
H_2, Volume %	<0.2
NH_3, Volume %	5×10^{-4}
Water, Volume %	<0.1
Temperature, K (F)	293 to 298 (68 to 77)
Pressure, kN/m^2 (Psia)	1035 (150)

(a) Includes additional N_2H_4 required to make up for losses caused by NH_3 generation of N_2 diffusion into H_2 in the polymer separator.

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H_2 Product	
Flow Rate, kg/d (Lb/Day)	0.52 (1.14)
dm^3/min (Slpm)	4.37 (4.37)
Purity, Volume %	98
Temperature, K (F)	293 to 298 (68 to 77)
Pressure, kN/m (Psia)	173 (25)
Coolant Supply	
Type	Ambient Air
Temperature, K (F)	293 to 298 (68 to 77)
Flow Rate, m^3/min (Scfm)	2.8 (100)

Performance Characteristics

N_2 Generation Rate, kg/d (Lb/Day)	3.18 to 6.81 (7 to 15)
dm^3/min (Slpm)	1.9 to 4.0 (1.9 to 4.0)
NH_3 Conversion Efficiency, %	<96
H_2 Recovery, %	100
NH_3 Generated, kg/d (Lb/Day)	0[a]
Water Generated	0.02 to 0.04 (0.04 to 0.09)
Power Required, W	94
Heat Rejected, J/s (Btu/Hr)	67 (229)
Reliability Data	
Goal	0.999750
MTBF, Hr	9325
Mission Length, Day	180

Physical Characteristics — See Figure 2

Weight	
Basic System, kg (Lb)	22.0 (48.5)
Spares, kg (Lb)	36.1 (79.6)
Total, kg (Lb)	58.1 (128.1)
Volume	
Basic System, m^3 (Ft^3)	0.08 (3.0)
Spares, m^3 (Ft^3)	0.05 (1.8)
Total, m^3 (Ft^3)	0.13 (4.8)
Basic Dimensions, m (In)	0.6 x 0.4 x 0.4 (25 x 15 x 14)

Material Characteristics

A. Nonmetallic	EPR, TFE
B. Metallic	310 SS, Tungsten, 302 SS, 304 SS, 316 SS, Inconel

(a) NH_3 concentration in product N_2 is equal to cabin ambient concentration; hence, the NH_3 that is removed through cabin leakage equals what is produced by the NGS; i.e., no net NH_3 concentration increase.

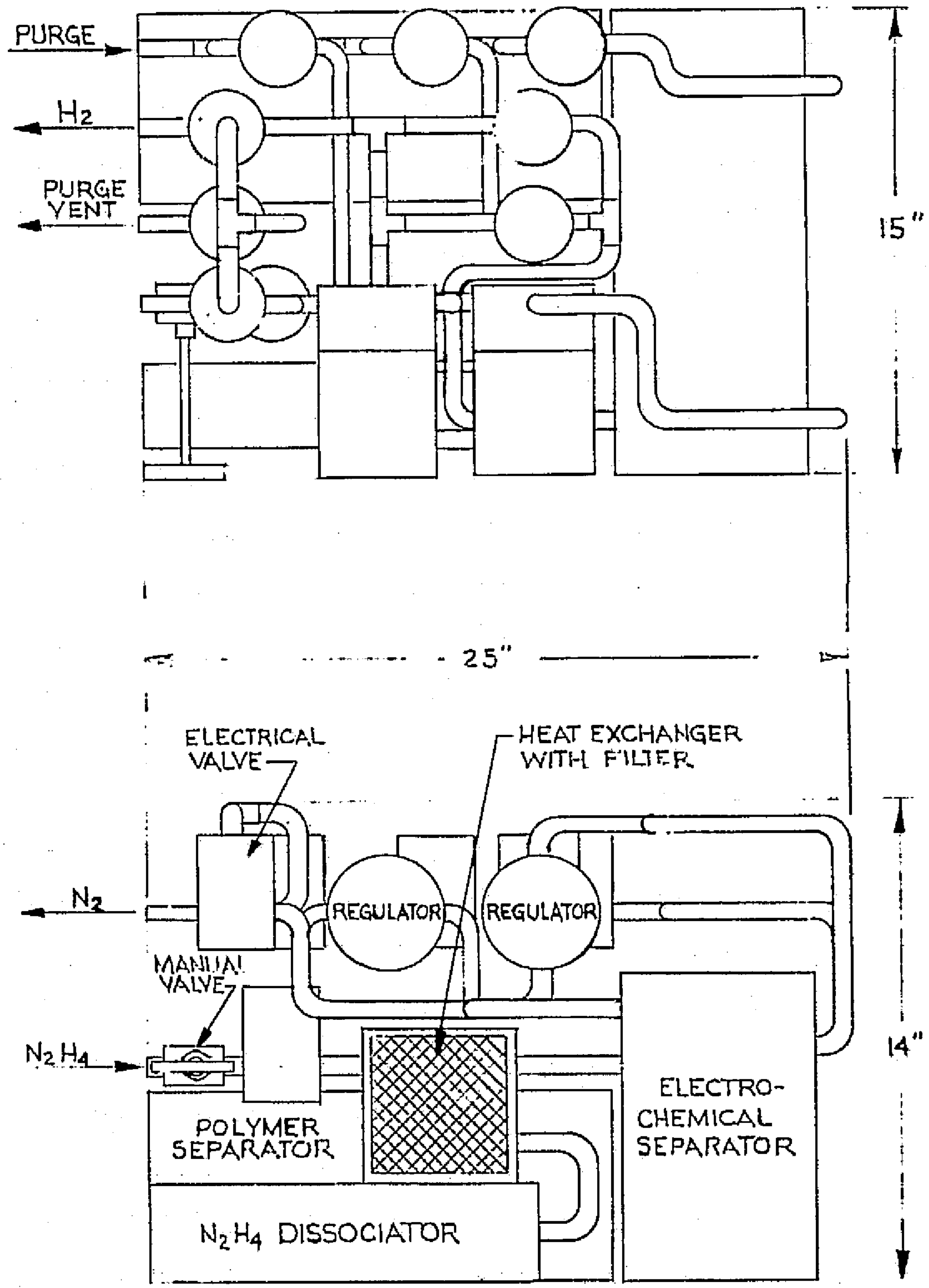

FIGURE 2 POLYMER ELECTROCHEMICAL-BASED N_2 GENERATION SYSTEM PACKAGING LAYOUT SCHEMATIC

Life Systems, Inc. CLEVELAND, OHIO 44122	NUMBER 250	REVISION LETTER	PAGE 6

Electrical Characteristics

Supply Voltage, VAC	230 ±20
, Hz	60 or 400
Supply Voltage, VDC	28 ±4

INTERFACES

Mechanical

N_2H_4 Feed	1/4 In Tube
H_2 to CRS	1/4 In Tube
Purge Vent	1/2 In Tube
Air to TCCS	2 In Flexible Duct
Purge Gas	
Type	N_2
Pressure, kN/m^2 (Psia)	310 (45)
Cabin Air	Ambient

Electrical

Connector	MIL-C-81511

Mounting	4-1/4 In x 20 NC Bolts

ENVIRONMENT:

Cabin Atmosphere

MAINTENANCE LEVEL AND METHOD:

First Level - Shut system down and go to backup
Second Level - Line Replaceable Components
Time Required - 8 Hours