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PREPROTOTYPE BOSCH CO₂ REDUCTION SUBSYSTEM FOR THE RLSE EXPERIMENT

FINAL REPORT

by

D. B. Heppner, R. A. Wynveen
and F. H. Schubert

December, 1977

Prepared Under Contract NAS8-32492

by

Life Systems, Inc.
Cleveland, Ohio 44122

for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
National Aeronautics and Space Administration
Marshall Space Flight Center, AL 35812



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FOREWORD

This report was prepared by Life Systems, Inc. for the National Aeronautics and Space Administration's (NASA) Marshall Space Flight Center in accordance with the requirements of Contract NAS8-32492, "Study of Bosch Carbon Dioxide Reduction Subsystem for Implementation into the Regenerative Life Support Evaluation." The period of performance for the study was June 2, 1977 to December 2, 1977. Analytical support was provided by Dr. R. A. Wynveen and F. H. Schubert. The study was directed by Dr. D. B. Heppner.

Appreciation is expressed to Mr. David C. Clark, Technical Monitor for the NASA George C. Marshall Space Flight Center, Huntsville, AL 35812.

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ACRONYMS

| | |
|--------|--|
| ARS | Air Revitalization System |
| B-CRS | Bosch Carbon Dioxide Reduction Subsystem |
| C/M I | Control/Monitor Instrumentation |
| EC/LSS | Environmental Control/Life Support System |
| EDC | Electrochemical Depolarized CO ₂ Concentrator |
| IARS | Independent Air Revitalization Subsystem |
| OGS | Oxygen Generation Subsystem |
| ORS | Oxygen Recovery System |
| RLSE | Regenerative Life Support Evaluation |
| SSP | Space Station Prototype |
| WES | Water Electrolysis Subsystem |
| WMS | Water Management System |

SUMMARY

Regenerative processes for the revitalization of spacecraft atmospheres are needed to sustain man in space for extended periods of time. A major step in this revitalization process is the Oxygen Recovery System, i.e., the collection of carbon dioxide and water vapor and the recovery of oxygen from these metabolic products. Various programs to develop the hardware subsystems to perform this and other life support functions have been sponsored by the National Aeronautics and Space Administration over the past few years. One current program is the Regenerative Life Support Evaluation experiment. This program is being conducted at NASA Johnson Space Center and has, as one of its major objectives, to demonstrate that regenerative life support processes are ready for manned space flight application.

The major components of the Regenerative Life Support Evaluation experiment's Oxygen Recovery System are an Electrochemical Depolarized Carbon Dioxide Concentrator Subsystem for collecting and concentrating the metabolically-produced carbon dioxide, a Sabatier Carbon Dioxide Reduction Subsystem for recovering the oxygen in the form of water, and a Water Electrolysis Subsystem for generating oxygen.

The work reported summarizes a study of the alternate Bosch Carbon Dioxide Reduction Subsystem for the experiment. Development of such an alternative technique might result from a Shuttle or Spacelab-imposed requirement to minimize the overboard venting of gases or to reduce equivalent launch weight for extended duration missions. The Sabatier reaction products are gaseous while the Bosch product is solid carbon which can be stored on-board.

A major objective of the study was to develop a preliminary design of a Bosch Subsystem for the Regenerative Life Support Evaluation experiment. The requirements of the Bosch Subsystem, including crew size, feed gas sources and rates, packaging constraints, among other interfaces, were the same as for the baseline Sabatier subsystem.

The results of the study established the Bosch Carbon Dioxide Reduction Subsystem requirements. A detailed design is presented including a schematic, components list and characteristics, requirements summaries, and complete definition of Life Systems' advanced Control/Monitor Instrumentation applied to the Bosch Subsystem. Design information needed to proceed with the final design and fabrication of a preprototype system is presented.

The study showed that a preprototype Bosch Subsystem can readily interchange with the baseline Sabatier subsystem. It is recommended that such a parallel development be initiated to insure the hardware is available. Inclusion of a Bosch subsystem within the Regenerative Life Support Evaluation experiment will allow competitive trade-off of the two concepts. The technology resulting from the development will give mission designers the choice of the optimum Carbon Dioxide Reduction Subsystem for future manned long-duration missions.

STUDY ACCOMPLISHMENTS

Key study accomplishments were:

- Definition of a Bosch Carbon Dioxide (CO₂) Reduction Subsystem (B-CRS) for National Aeronautics and Space Administration's Regenerative Life Support Evaluation (RLSE) experiment.
- Definition of an advanced Control/Monitor Instrumentation (C/M I) for operating the B-CRS.
- Preliminary design information required to commit the preprototype B-CRS to final design and fabrication.
- Evaluation of NASA's "cold-seal" Bosch reactor for the RLSE application.

INTRODUCTION

Providing oxygen (O₂) to the cabin atmosphere of a manned spacecraft is an important function of a regenerative Environmental Control/Life Support System (EC/LSS). Within an EC/LSS, various subsystems of the Air Revitalization System (ARS) are responsible for the removal and concentration of the metabolically-generated CO₂ from the atmosphere and regeneration of metabolically-consumed O₂. For long-duration manned space missions, launch and supply requirements can be materially reduced and simplified by inflight reclamation of O₂ from the recovered CO₂ and water. The Shuttle/Spacelab era both provides an opportunity for extensive testing of such regenerative systems and marks the beginning of the time period when they will be required.

Background

Three life support subsystems are highly qualified to perform the function of reclaiming O₂ within an ARS. They are an Electrochemical Depolarized CO₂ Concentrator (EDC), a Bosch CO₂ Reduction Subsystem (B-CRS), and a water-electrolysis O₂ Generation Subsystem (OGS). Figure 1 is a simplified block diagram of such a closed loop integrating these subsystems with the spacecraft's atmosphere. Carbon dioxide is stripped from the cabin atmosphere by the CO₂ concentrator and sent pre-mixed with hydrogen (H₂) to the Bosch Subsystem. The Bosch Subsystem converts the CO₂ and H₂ to form solid carbon and water. The water is returned to the OGS where the O₂ and H₂ are generated through the electrolysis of water.

Combining the three subsystems results in an integrated O₂ Recovery System (ORS). The B-CRS offers an advantage over the Sabatier-based CO₂ reduction concept where O₂, in the form of unreacted CO₂, is vented overboard. This loss in O₂ implies increased storage of O₂ or water (for electrolysis) resulting in an increase in spacecraft launch weight.

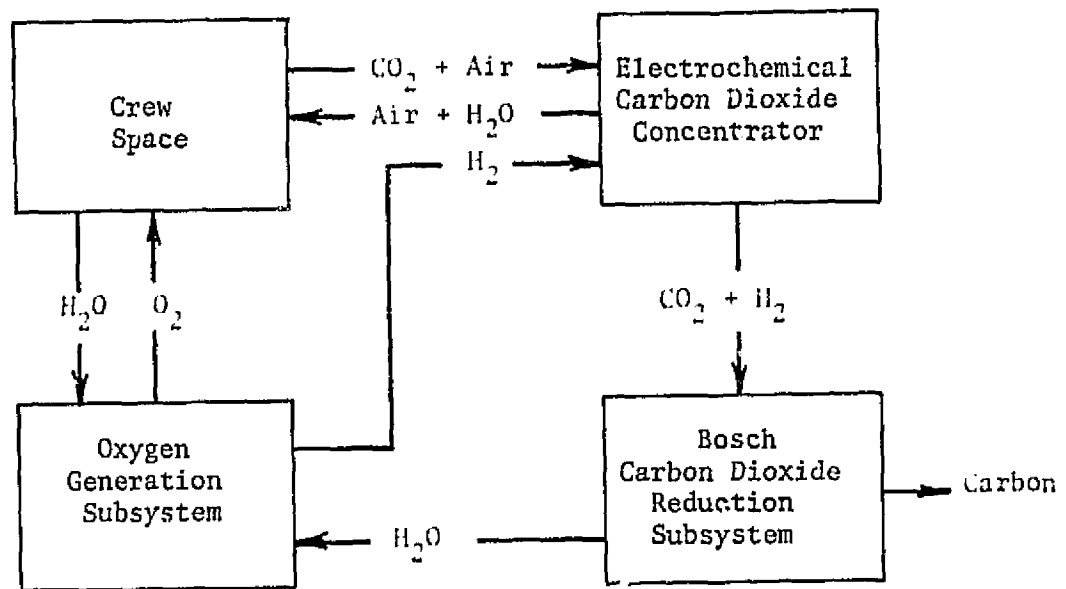


FIGURE 1 CLOSED-LOOP OXYGEN RECOVERY SYSTEM

Under NASA-sponsored development programs, EDC, (1-5)(a) OGS, (6-13) Sabatier, (14,15) and Bosch (16-22) technology has been developed and evaluated for application to spacecraft air revitalization systems. Various subsystem integration considerations have also been included as part of these activities. Such considerations must be included sufficiently early in each development to identify potential problems and to guide future subsystem design and testing. One such program being conducted presently at NASA Johnson Space Center (JSC) is a continuation of the integration and testing of these subsystems. This program is called the RLSE experiment.

NASA'S Regenerative Life Support Evaluation Experiment

The RLSE program is an important step in the overall plan to fully develop and demonstrate the flight readiness of regenerative EC/LSS equipment. The program evolved from the Phase B Space Station studies of the late 1960's and the Space Station Prototype (SSP) testing program of the early 1970's. The RLSE program development plan is scheduled so prototype/flight hardware can be available for evaluation in the Spacelab by 1983.

The RLSE program consists of two phases:

Phase I - Preprototype Hardware Development and Test

Phase II - Prototype/Flight Hardware Development and Manned Testing

Phase I has been underway since early 1976. This phase consists of the development of numerous preprototype subsystems followed by the integration and system test of these subsystems. Successful completion of this test will provide a firm basis for detailed definition of the prototype/flight hardware (Phase II). The preprototype subsystems are scheduled to be completed by the end of 1978 and integrated into the RLSE system and tested during 1979.

Regenerative Life Support Evaluation Experiment Description

The complete RLSE system consists of ten individual subsystems grouped into an air revitalization portion and a water/waste management portion. Included in these two groupings are two independent experiments: (1) an Independent Air Revitalization Subsystem (IARS) and (2) an Independent Waste Water Processing experiment.

The RLSE system requirements include:

- Provide regenerative life support for three persons.
- Support a 30-day mission.

(a) All references cited are listed at the end of this report.

- Package to fit within Spacelab.
- Utilize no more than 50% of the available Spacelab payload (weight, volume, power).
- Operation must not interfere with other Spacelab experiments.

The design philosophy for RLSE preprototype hardware (Phase I) stresses that the technology which is the heart of the subsystem (e.g., B-CRS reactor) be sound and require no modification when prototype/flight hardware is fabricated. Ancillary components not associated with the heart of the subsystem are more subject to RLSE program design philosophy concerning maintainability, commonality, etc., and do not follow this guideline. Therefore, on a system level, the preprototype B-CRS will not be optimized with respect to parameters such as weight and power. That optimization will be performed in Phase II.

The baseline RLSE system design was selected as a result of extensive evaluations conducted by NASA. It provides sufficient regeneration to eliminate the need for expendable supplies of O₂ and water for crew use and normal O₂ leakage and minimize the use of expendables. This degree of regeneration is expected to meet the requirements for the next generation long-duration manned space missions as presently foreseen. The baseline RLSE, however, does not include temperature and humidity control, solid waste management or state-of-the-art items for which this long-range development is not required. The three-person crew was selected as being representative of expected applications and at the same time, stays within the limitations of typical Spacelab payload requirements.

A detailed description of RLSE is contained in the literature sources. (23-24) Therefore only the baseline ORS will be described. The cabin atmosphere is passed through an EDC where CO₂ ionically defuses from the cabin air through an aqueous electrolyte to the H₂ provided from the OGS. The mixed stream of H₂ and CO₂ is transported to the CO₂ Reduction Subsystem where methane (CH₄) and water are produced in a Sabatier reactor. The water is condensed and separated from the residual gases (which include H₂, CO₂ and CH₄) which are then vented overboard. The water is fed to a water sterilization subsystem and then to a potable water storage. Water is removed from the storage to the OGS on demand where it is electrolyzed into the O₂ and H₂. The O₂ is returned to the cabin and the H₂ is supplied to the CO₂ Reduction Subsystem, thus completing the recovery process.

Study Objective

The objective of this study was to prepare a preliminary design of an alternative to the Sabatier CO₂ Reduction Subsystem. Its performance must satisfy the RLSE design requirements established for the Sabatier subsystem.

Study Guidelines

Design guidelines used throughout the study were:

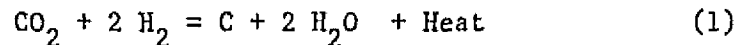
1. Packaging of the subsystem would be dictated by the RLSE allowance for the CO₂ Reduction Subsystem.
2. The RLSE maintainability concept would be followed.
3. The RLSE instrumentation approach minimizing provisions for man-tending would be used.
4. The "cold-seal" reactor would be evaluated for potential application for RLSE.
5. Operational options which tend to make the entire RLSE subsystem compatible with the Spacelab power availability would be considered. Generally, this refers to cyclic operation of the RLSE subsystems.
6. Consider that the H₂/CO₂ interface can come from either a central or an independent CO₂ collection subsystem (IARS).

BOSCH CO₂ REDUCTION

Detailed descriptions of the Bosch system, its theory of operation, specific hardware and performance have been discussed elsewhere. (16²²²) The following subsections summarize the Bosch process and hardware status.

Process Description

The Bosch reaction occurs at 900 to 1000 K (980 to 1340 F) in the presence of an iron catalyst. Carbon dioxide combines with H₂ and produces carbon and water vapor as indicated in the overall reaction:



One mole of CO₂ combines with two moles of H₂ to form one mole of carbon and two moles of water vapor. In practice, single pass efficiencies through the Bosch reactor are less than 10%. Complete conversion is obtained only by recycling the processed gases with continuous deposition of carbon and removal of water vapor. The recycled gas mixture contains CO₂, H₂, water vapor, carbon monoxide (CO) and CH₄. These latter components are formed by intermediate reactions such as:



and



An equilibrium condition for the gas mixture is reached based on the specific operating temperatures, pressures and relative proportions of the primary reactants, CO₂ and H₂. Since all the reactants entering the subsystem are eventually converted to the products carbon and water, the stoichiometric ratio of two moles of H₂ to one mole of CO₂ must be maintained. This prevents a buildup of the rich constituent. Small deviations over short periods of time from stoichiometry are permitted.

Figure 2 is a simplified flow schematic of the B-CRS identifying the major subsystem components. Shown is a dual reactor system which is required for continuous operation since the subsystem operates in a batch mode.

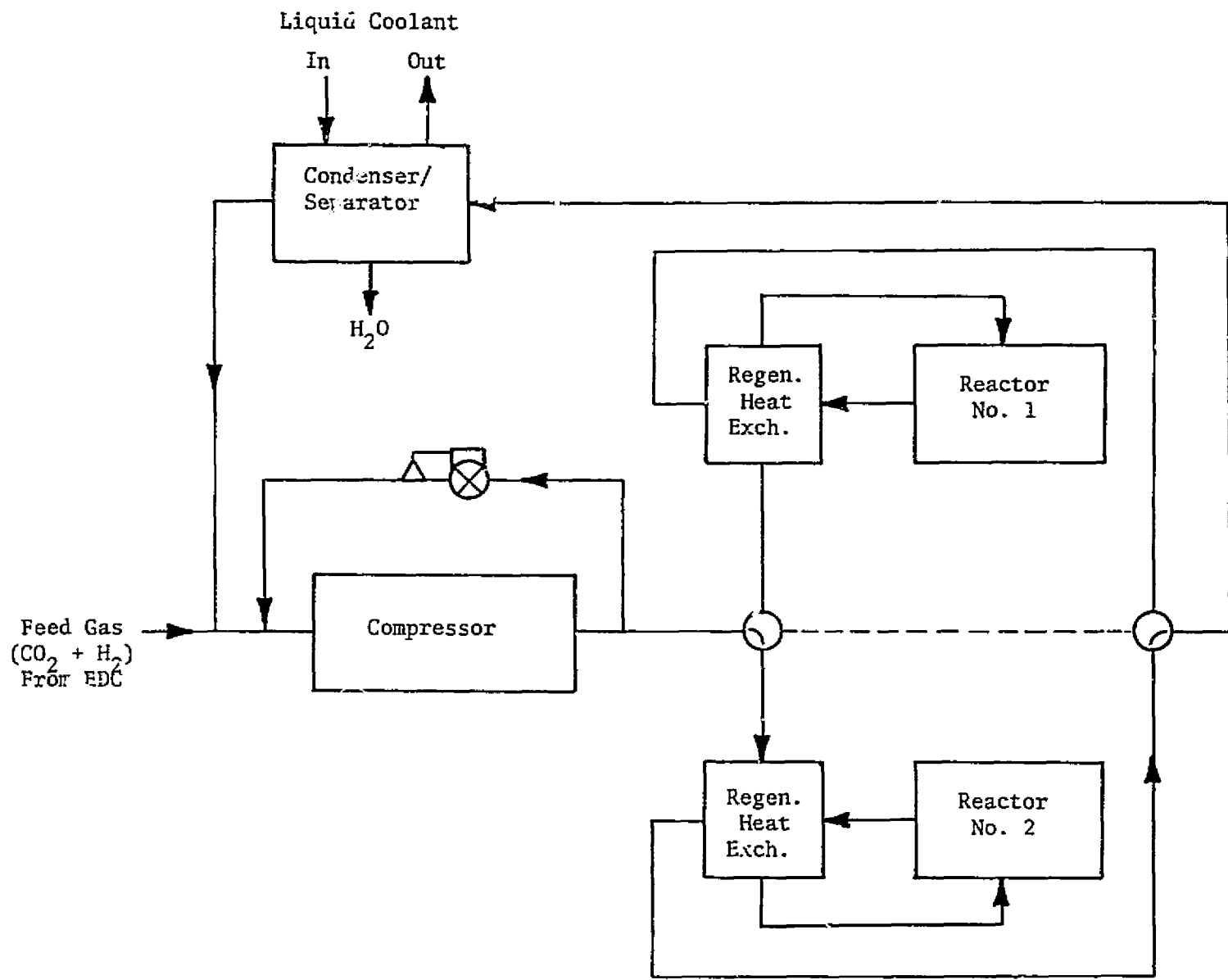
Gases are continually circulated through the recycle loop by a compressor. The gases leaving the compressor are diverted by a valve to either of the two regenerative heat exchanger/reactor units. The gases are preheated in the heat exchanger prior to entering the reactor. Within the reactor, CO_2 and H_2 react over an iron catalyst in the volumetric ratio of 2:1 ($\text{H}_2:\text{CO}_2$) to form carbon and water vapor. The recycled gases, partially depleted in CO_2 and H_2 , leave the reactor at a temperature near 222 K (1200 F) to exchange heat with the incoming gases in the regenerative heat exchanger. The mixture then flows through the second selector valve to a condenser/separator where the water vapor is condensed and separated. The recycle loop gas mixture then returns to the compressor. The feed gas from the EDC is added to the loop upstream of the compressor. This allows the feed gas pressure to remain at a minimum. The ratio of recycled gas flow rate to feed gas flow rate is about 15 to 1 indicating that conversion efficiency per pass in the reactor is about 6%.

The carbon is collected in expendable cartridges within the reactor. A dual reactor system is used to enable continuous operation. It allows collection of carbon in one reactor while the other one remains dormant until the first reactor is filled with carbon. Figure 3 shows a typical carbon collection cartridge. Figure 4 shows the various internal parts of the cartridge and Figure 5 shows a cartridge filled with carbon.

The performance of a B-CRS can be indicated by its CO_2 reduction process rate or efficiency. Figure 6 shows typical B-CRS performance characteristics given in terms of CO_2 conversion rate as a function of four different parameters. These four parameters are the recycle flow rate to feed rate ratio, reactor temperature, temperature of the coolant supplied to the condenser/separator and recycle loop composition in terms of H_2 percent. These curves are empirically derived from accumulated test data generated during many Bosch development programs. The overall trends are indicative of the anticipated performance of a three-person RLSE B-CRS.

Bosch Hardware Status

State-of-the-art technology and hardware for the B-CRS has been advanced primarily under the cognizance of NASA Marshall Space Flight Center (MSFC). Over the past few years, NASA has funded General Dynamics Convair Division, to develop various versions of Bosch reactors and Life Systems to integrate and optimize the process. The objective of the reactor developmental programs has been to investigate and develop materials compatible with the environment and optimize the reactor design for minimum heat loss. The most recent advance in reactor technology has been the "cold-seal" reactor. The major feature of this configuration is a low temperature sealing surface which permits the use of elastomeric seals. This approach simplifies the removal and replacement of the carbon collection cartridge. To date, approximately 9,000 operating hours have been accumulated on this configuration.



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FIGURE 2 B-CRS SIMPLIFIED FLOW SCHEMATIC

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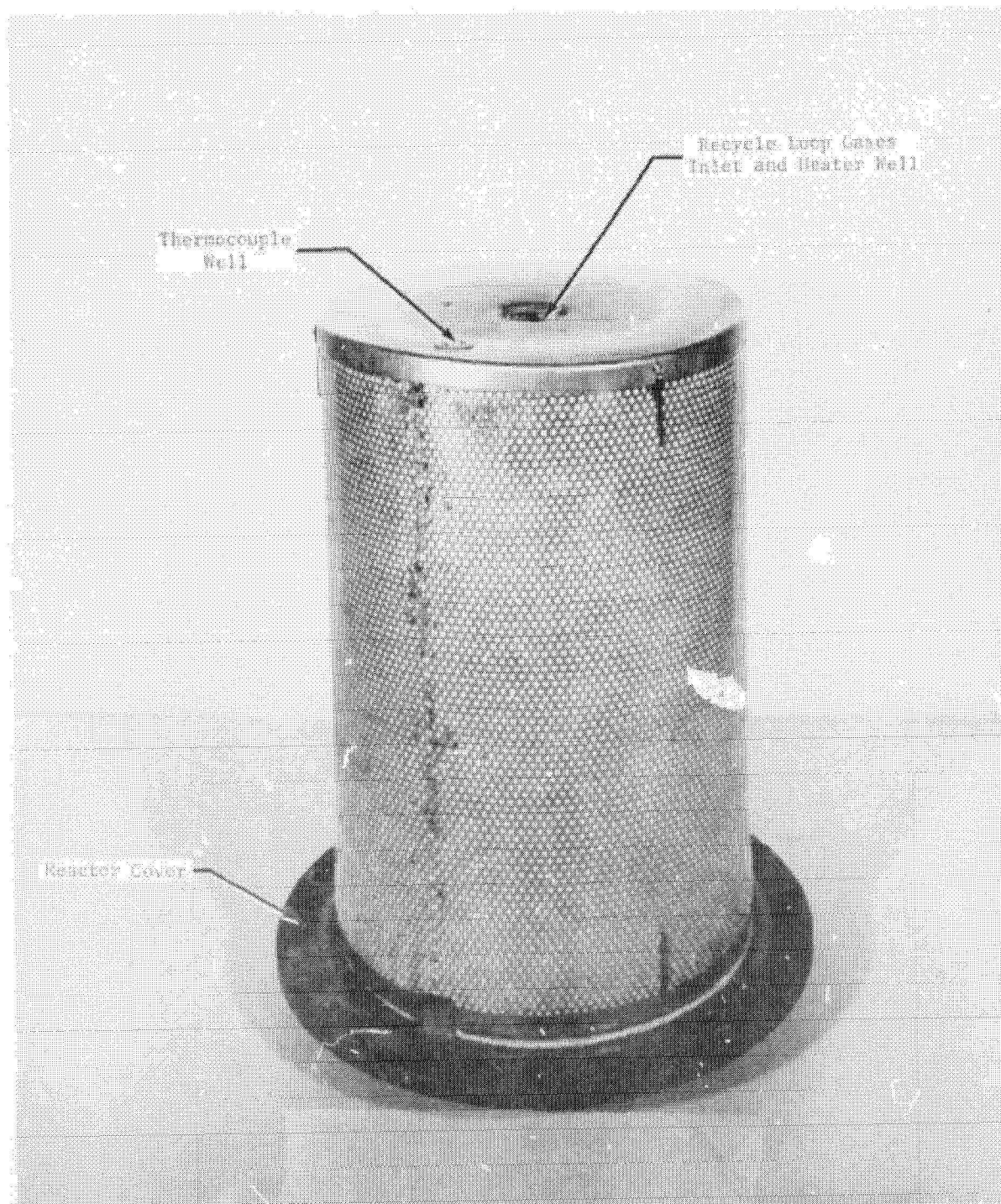
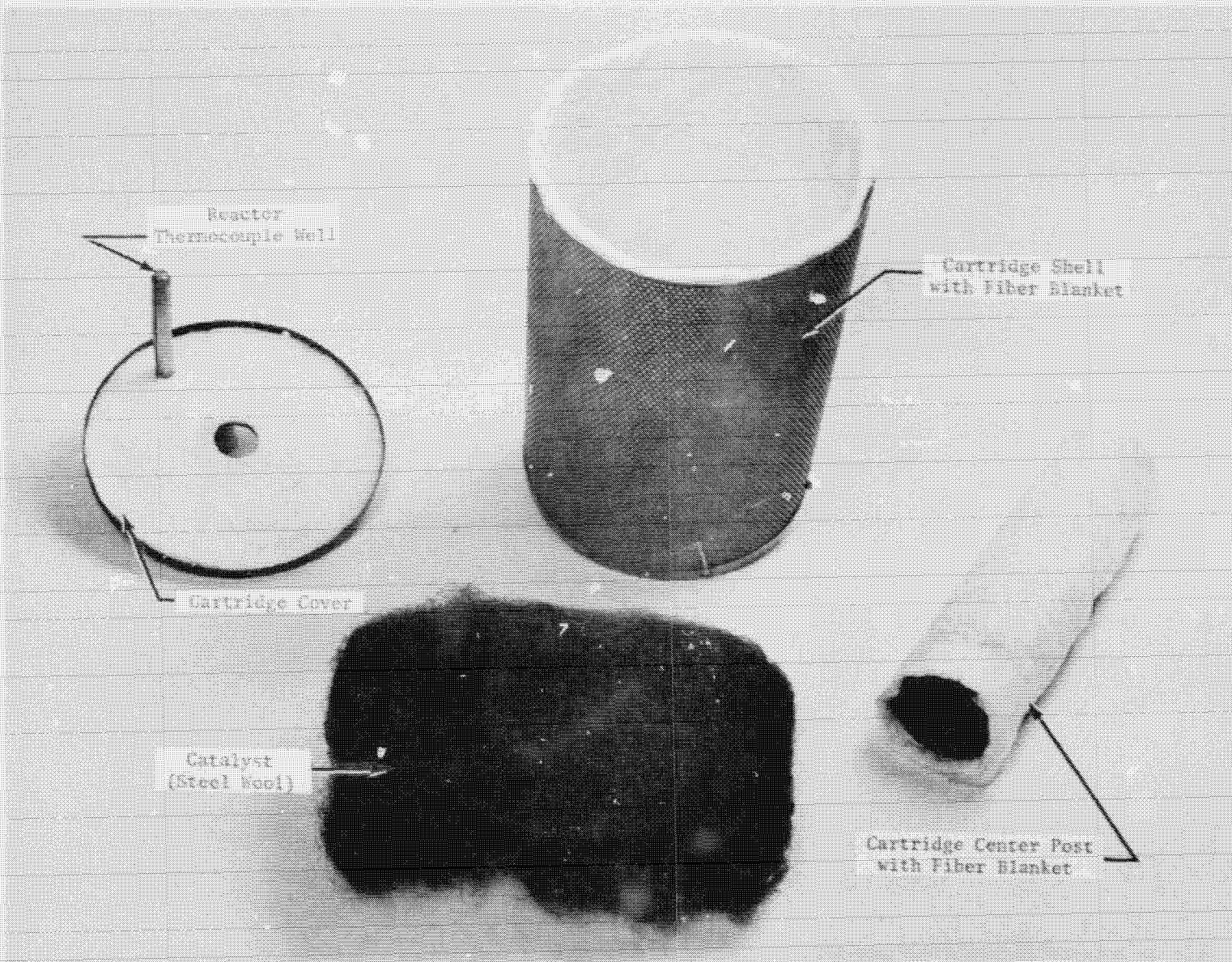


FIGURE 3 CARBON COLLECTION CARTRIDGE



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FIGURE 4 DISASSEMBLED CARBON COLLECTION CARTRIDGE

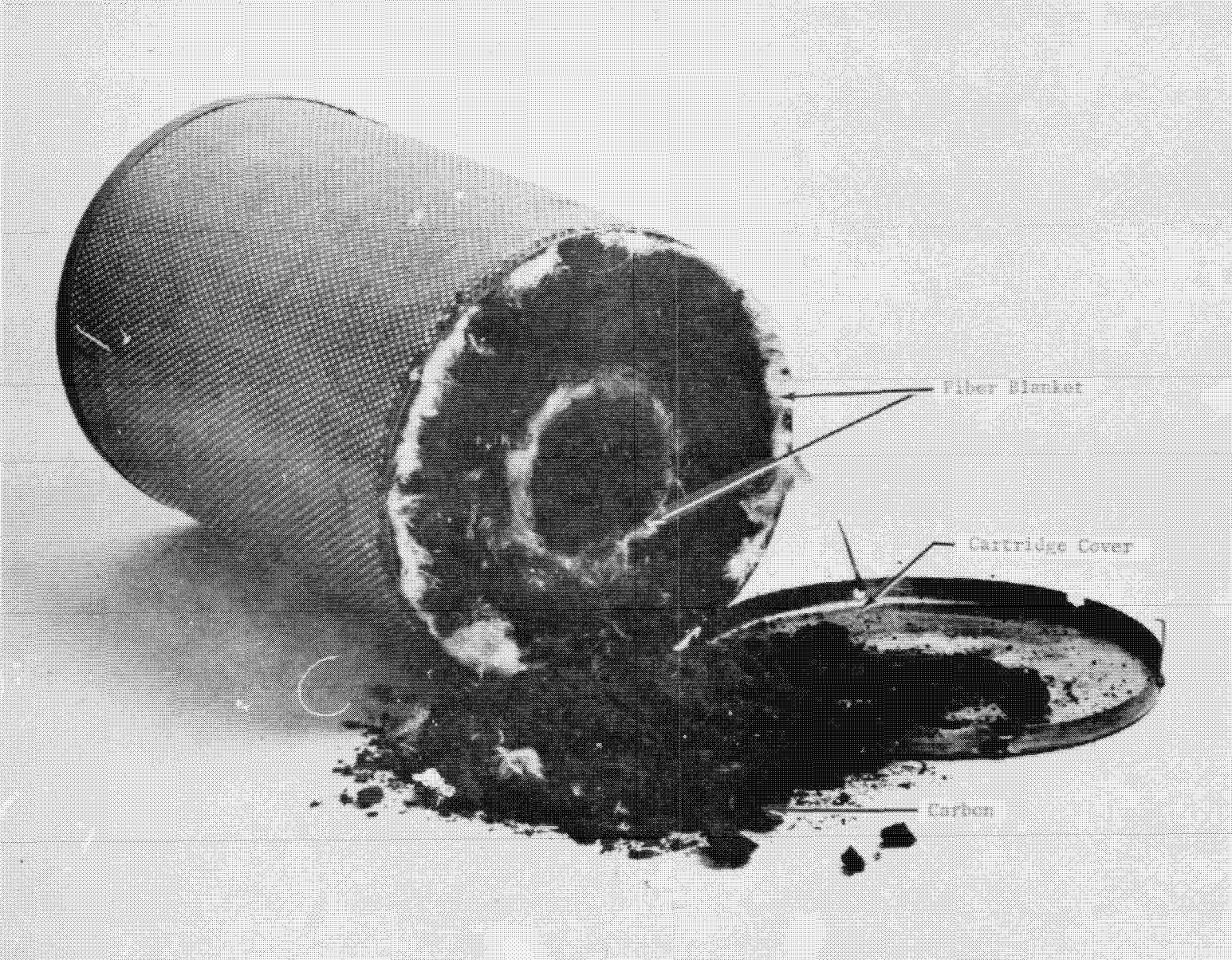


FIGURE 5 FILLED CARBON COLLECTION CARTRIDGE

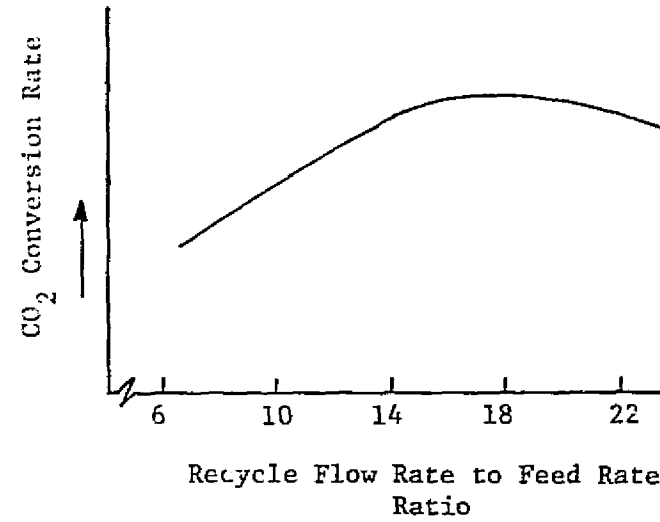
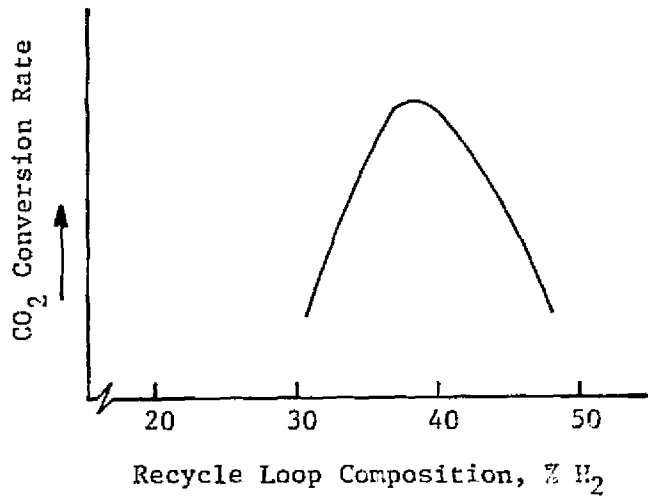
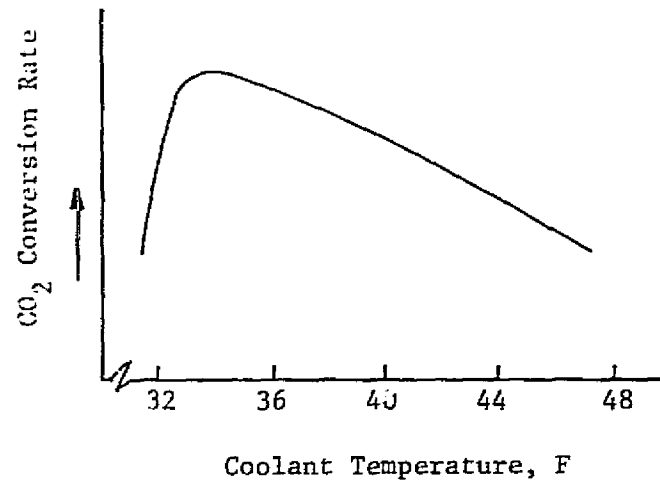
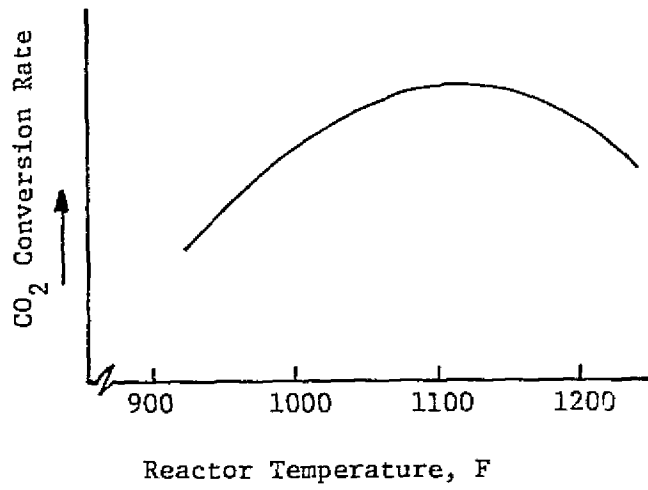


FIGURE 6 B-CRS PERFORMANCE CHARACTERISTICS

Since 1975, Life Systems has developed hardware for and conducted tests of the integration of the Bosch with the EDC⁽²¹⁾ and of the combined B-CRS/EDC with the Water Electrolysis Subsystem (WES).⁽²²⁾ Over 3300 hours of Bosch operation has been logged at Life Systems. To date, the integration and development tests have removed all technical and operational problems involved with introducing the B-CRS into an ORS. The testing results demonstrated the B-CRS is ready for development as a part of the RLSE experiment.

RLSE B-CRS DESIGN

This section discusses the subsystem design and specific technical design considerations for the preprototype B-CRS development for RLSE.

Subsystem Design Requirements/Interfaces

The function of the B-CRS is to generate water (liquid) through the reduction of metabolically-produced CO₂ with H₂ and subsequent condensation and separation of the water vapor formed during the reduction process. The H₂/CO₂ reactant mixture, dew point less than 288 K (60 F), from the CO₂ removal subsystem (EDC) enters the Bosch recycle loop. An additional H₂ stream directly from the OGS will also enter the loop. This latter stream is used to control the net feed ratio of H₂ to CO₂ to insure that it remains at the stoichiometric ratio (2:1). The recycled gases enter the heat exchanger/reactor combination where the overall reaction takes place. The reaction generates heat which is removed by the product gases and which is further exchanged with the incoming gases. The exhaust gas, partially depleted in CO₂ and H₂, enters the condenser/separator. The water vapor is condensed and removed from the gas stream and is stored in an accumulator. The accumulator is periodically emptied to the Water Management System (WMS). Liquid cooling at a temperature of approximately 277 K (40 F) is used to ensure that sufficient vapor is removed from the circulating gas stream to maintain the required reaction rate. The carbon remains in a collection cartridge within the reactor and is removed when required.

Table 1 lists the O₂ consumption and CO₂ production rates for the RLSE crew. The design assumes the preprototype hardware systems will operate in a Spacelab-like environment. The Spacelab vehicle parameters are also given in Table 1. The RLSE subsystems will be located in an earth-like environment of ambient temperature and pressure. To sustain the Shuttle launch environment, certain vibration and shock/acceleration requirements are also imposed. These are given in Table 2.

The overall design requirements of the B-CRS are summarized in Table 3. The B-CRS will be independent in operation requiring only electrical energy, a H₂ supply, a H₂/CO₂ supply, a N₂ purge supply, a liquid coolant and a vacuum interface. It will be capable of being tested in 1-g and 0-g as an independent subsystem and also as part of the RLSE where it will interface with either the central EDC or the IARS. It will be capable of being rack-mounted as would be required for flight application.

The B-CRS will provide its own C/M I, capable of automatic shutdown provisions for its own self-protection and provisions for monitoring critical parameters. The primary subsystem parameter status will be displayed on an operator/sub-

TABLE 1 RLSE CREW/VEHICLE DATA

Crew

Metabolic O₂ Consumption,
kg/man-day² (lb/man-day)

| | |
|---------|-------------|
| Nominal | 0.84 (1.84) |
| Minimum | 0.80 (1.77) |
| Maximum | 1.0 (2.20) |

CO₂ Production,
kg/man-day (lb/man-day)

| | |
|---------|-------------|
| Nominal | 1.0 (2.20) |
| Minimum | 0.91 (2.00) |
| Maximum | 1.2 (2.64) |

Vehicle

| | |
|-------------------------------------|----------------------|
| Cabin Total Pressure, kPa (psia) | 101 ±1.4 (14.7 ±0.2) |
| Cabin pO ₂ , kPa (psia) | 22 ±1.7 (3.2 ±0.25) |
| Cabin pCO ₂ , Pa (mm Hg) | |

| | |
|-----------|-----------|
| Design | 400 (3.0) |
| Emergency | 670 (5.0) |

| | |
|------------------------------------|-----------------------|
| Cabin Temperature, K (F) | 291 to 300 (65 to 80) |
| Cabin Minimum Dew Point, K (F) | 279 (42.5) |
| Cabin Maximum Relative Humidity, % | 70 |

| | |
|----------------------------------|-----------|
| Maximum Touch Temperature, K (F) | 318 (113) |
|----------------------------------|-----------|

| | |
|------------------------------------|----|
| Maximum Continuous Noise Level, db | 50 |
|------------------------------------|----|

Electrical Power

| | |
|---------------|--------------|
| Type, Vac | 115/200 ± 5% |
| Frequency, Hz | 400 |
| Phase | 3 |

Power and Heat Rejection Penalties
kg/W (lb/W)

| | |
|-------------------------------|-------------|
| AC Power | 0.32 (0.71) |
| DC Power | 0.27 (0.59) |
| Heat Rejection to Cooling Air | 0.20 (0.44) |

TABLE 2 VIBRATION AND SHOCK/ACCELERATION LEVELS

A. Random Vibration

| <u>Frequency, Hz</u> | <u>Level, g²/Hz</u> |
|----------------------|--------------------------------|
| 20 | 0.010 |
| 20 to 42 | +3 db/octave |
| 42 to 650 | 0.021 |
| 650 to 2000 | -6 db/octave |
| 2000 | 0.6022 |

B. Sinusoidal Vibration

| <u>Frequency, Hz</u> | <u>Level</u> |
|----------------------|------------------------------|
| 5 - 8.5 | 20 mm (0.80 in) peak to peak |
| 8.5 - 35 | 3g 0 to peak |
| 35 - 50 | 1g 0 to peak |

C. Shock/Acceleration (Landing) - Vertical Direction

| <u>Acceleration and Peak</u> | <u>Duration, ms</u> | <u>No. of Occurrences</u> |
|------------------------------|---------------------|---------------------------|
| 0.23 | 170 | 1 |
| 0.28 | 280 | 1 |
| 0.35 | 330 | 1 |
| 0.43 | 360 | 1 |
| 0.56 | 350 | 1 |
| 0.72 | 320 | 1 |
| 1.50 | 260 | 1 |

TABLE 3 B-CRS PREPROTOTYPE DESIGN REQUIREMENTS

Independent Operation as a Subsystem for Testing
Integrated Operation as part of an ARS
Compatible with Zero- and One-g
Capable of being rack mounted as required for Spacelab
Separate Control and Monitor Instrumentation
Computer-Based Instrumentation
CRT Type Display on Front Panel
Performance Trend Analysis and Status Display
Normal Operation at Derated EDC and IARS Levels
Flight Replaceable Unit Concept
All Materials Flight Qualifiable^(a)
Compatible with NASA Test Facility
Incorporate RLSE Design Specifications^(b)
Shelf Life \geq 1 Year^(c)

(a) Or flagged if not used in preprototype

(b) Hamilton Standard Specification No. SVHS7216, Revision B, 1976.

(c) Anticipated shelf life can be \geq 5 years.

system display panel to confirm proper operation. The C/M I will also have the capability for operating the B-CRS at less than the three-person baseline level for extended periods of time. This derated or reduced capacity operation is a normal operating mode for all of the RLSE subsystems.

The subsystem design has addressed the subject of maintainability and will include maintainability features for those components most likely to require maintenance during any continuous 180-day operational period. If required, scheduled maintenance including replacement of individual parts will be used for achieving the required B-CRS operational life. The operational lifetime of the B-CRS will be more than two years and would be demonstrated to NASA within three years of hardware delivery. The B-CRS will be compatible with the NASA JSC test facilities.

Table 4 lists the system design specifications of the B-CRS. As these specifications indicate, the B-CRS is primarily designed to meet the needs for reduction of the CO_2 from three persons in a Spacelab cabin environment. As such, it is designed to reduce the CO_2 at a three-person rate corresponding to 0.125 kg/h (0.275 lb/h). The corresponding amount of H_2 to be processed is 0.011 kg/h (0.025 lb/h). The water and carbon production rates are 0.102 and 0.034 kg/h (0.225 and 0.075 lb/h), respectively.

The principal interface of the B-CRS is with the RLSE EDC. The operating range of the EDC is shown as the rectangle in Figure 7 along with its nominal operating point. Also shown is the stoichiometric ratio curve. It is seen that if the total feed to the B-CRS comes from the baseline EDC, there would be an eventual build-up of H_2 in the subsystem. However, if the EDC was operated with slightly reduced H_2 inflow (and therefore reduced outflow) the operating point would be below the stoichiometric line but still within its operating range. Then excess H_2 from the OGS can be supplied to the Bosch to maintain the proper mole ratio.

Table 5 further defines the fluid, power and other interfaces of the B-CRS. A vacuum vent and a N_2 supply are required for purging and repressurizing the H_2 lines and reactor cavities following a subsystem shutdown. This procedure would also be used during a routine carbon collection cartridge changeover.

The power required by the B-CRS will be 115/200 VAC, 400 Hz, 3 ϕ . Other power levels required within the subsystem will be provided by internal power supplies.

Mechanical Subsystem Design

The B-CRS mechanical subsystem design includes discussion of the schematic, sensors and physical characteristics.

B-CRS Schematic

The mechanical subsystem consists of the reactors, compressor, condenser/separator, ancillary components, tubing and frame. It will be connected to the C/M I by electrical cabling.

TABLE 4 B-CRS DESIGN SPECIFICATIONS^(a)

| | |
|--|-----------------------|
| Crew Size | 3 |
| CO ₂ Reduction Rate, kg/h (lb/h) ^(b) | 0.125 (0.275) |
| Processed H ₂ Flow Rate, kg/h (lb/h) ^(b) | 0.011 (0.025) |
| Feed Gas Pressure, kPa (psia) | 130 (18.7) |
| Feed Gas Temperature, K (F) ^(c) | 291 to 300 (65 to 80) |
| Feed Gas Humidity | |
| Relative Humidity Range, % | 50 to 84 |
| Dew Point Temperature, K (F) | 289 (60) |
| Liquid Coolant Temperature, K (F) | 277 (40) |
| Purge Gas | N ₂ |
| Purge Gas Pressure, kPa (psia) | 310 (45) |
| Electrical Power, Vac | 115/200, 400 Hz, 3Ø |
| Gravity | 0 to 1 |

(a) Does not include values for interfacing with derated (1-person) operation of the EDC and IARS.

(b) For the reaction $\text{CO}_2 + 2 \text{H}_2 = \text{C} + 2 \text{H}_2\text{O}$

(c) Same as cabin temperature range

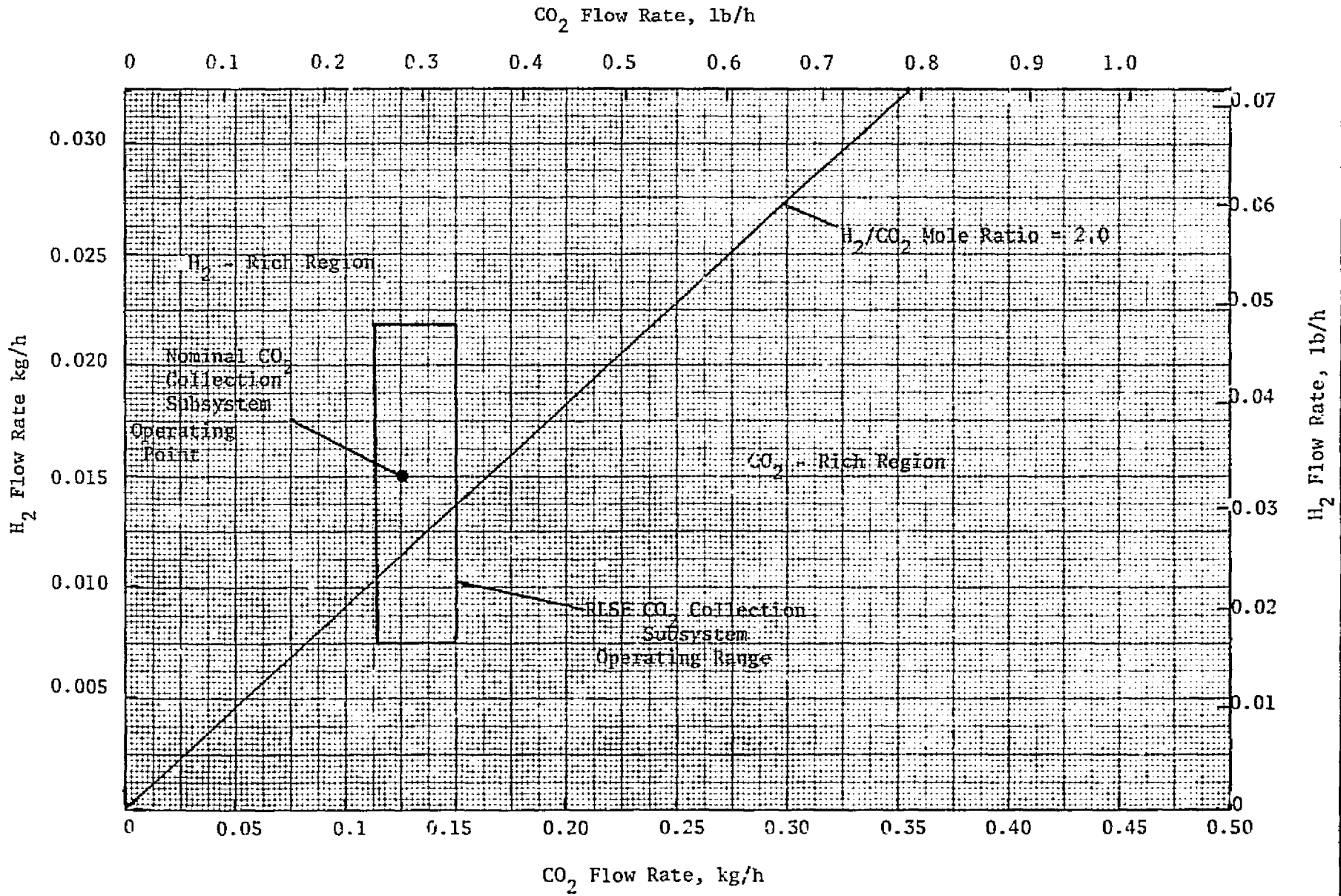


FIGURE 7 B-CRS OPERATING RANGE

TABLE 5 B-CRS INTERFACES

| | |
|--|----------------|
| From CO ₂ Collection Subsystem (EDC) ^(a) | |
| H ₂ Flow Rate, kg/h (lb/h) | |
| Nominal | 0.150 (0.033) |
| Minimum | 0.0072 (0.016) |
| Maximum | 0.0218 (0.048) |
| CO ₂ Flow Rate, kg/h (lb/h) | |
| Nominal | 0.125 (0.275) |
| Minimum | 0.114 (0.250) |
| Maximum | 0.150 (0.330) |
| To Water Management System ^(b) | |
| H ₂ O Flow Rate, kg/h (lb/h) | |
| Nominal | 0.102 (0.225) |
| Minimum | 0.093 (0.205) |
| Maximum | 0.122 (0.269) |
| Carbon Generation Rate, kg/h (lb/h) | |
| Nominal | 0.034 (0.075) |
| Minimum | 0.031 (0.068) |
| Maximum | 0.041 (0.090) |
| N ₂ Purge Gas | |
| Pressure, kPa (psia) | 310 (45) |
| Purge Flow, kg/h (lb/h) | 0.27 (0.60) |
| Purge Duration, min | 2 |
| Vent | |
| Type | Vacuum |
| Flow, kg/h (lb/h) | 0.5 (1.1) |
| Coolant Supply | |
| Temperature K (F) | 277 (40) |
| Flow Rate, kg/h (lb/h) | 57.8 (125) |
| Electrical Power Supply | |
| Type, Vac | 115/200 |
| Frequency, Hz | 400 |
| Phase | 3 |
| Level, W ^(c) | 239 |

(a) Based on RLSE requirement for Sabatier interface.

(b) Does not include the water coming into the subsystem through the process gases (maximum \leq 3% of the total).

(c) Mechanical subsystem only.

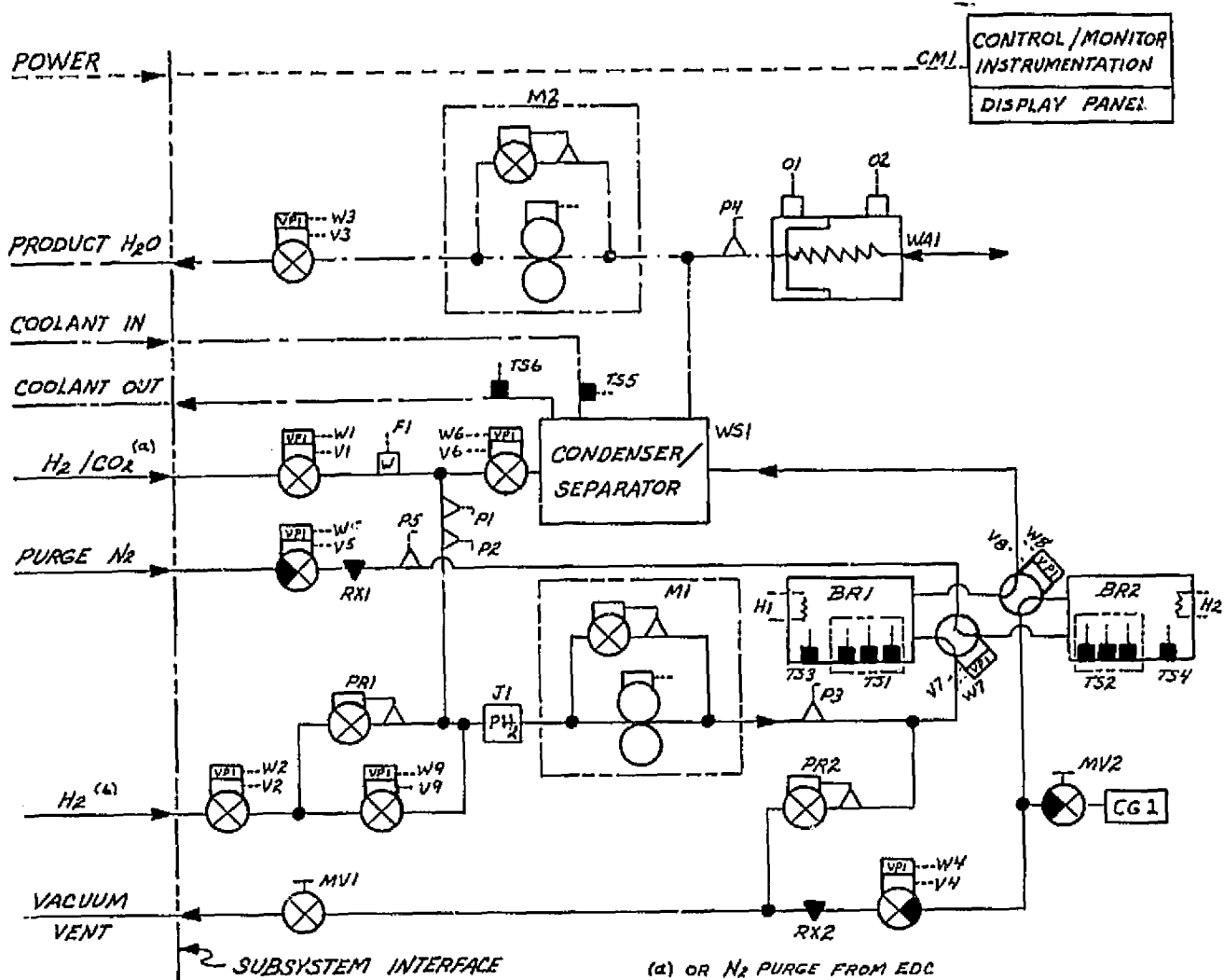
The schematic of the preprototype B-CRS is shown in Figure 8. The H_2/CO_2 mixture from the EDC enters the B-CRS through an electrical shutoff valve (V1). This valve is only required for independent subsystem operation and is not required when integrated with the EDC. The H_2/CO_2 mixture enters the recycle loop, passes through the compressor (M1), and enters the reactor where the CO_2 reduction process takes place. For convenience, the regenerative heat exchangers and the reactors themselves have been grouped into BR1 and BR2. The two four-way valves (V7 and V8) permit selection of the operating reactor. The water vapor formed along with excess reactants and intermediate products of reaction exhausts the reactor at an elevated temperature (approximately 338 K (150 F)). The hot product gases then pass through the condenser/separator where the gases are cooled and the water vapor is condensed and removed from the gas stream. The remaining gases then join with the incoming stream to pass through the compressor and into the reactor.

A pH_2 sensor (J1), is used to monitor the loop composition and to control the makeup valve (V9), permitting H_2 to enter the recycle loop. The shutoff valve (V2), interfaces the subsystem with the OGS. A backpressure regulator (PR1) is provided to insure that the recycle loop will not go subatmospheric but rather will admit sufficient H_2 to keep the loop pressure at or near atmospheric conditions.

The water collected in the condenser/separator is stored in a water accumulator (WA1). A spring and pressure reference to the atmosphere maintains the water collection pressure (measured by P4) below that of the system pressure (a differential pressure of greater than 20.7 kPa (3 psig)). This negative pressure differential is required to prevent the condensate from being carried out with gases exhausting the separator. The water accumulator is periodically emptied when full by energizing water pump M2 and opening electrical shutoff valve (V3) to the WMS.

Pressure in the H_2 -carrying lines is maintained at greater than or equal to 108 kPa (14.7 psia) during operation (the design point is 122 kPa (17.7 psia)) to insure that any possible H_2 leakage would be internal to external and would be detected by the combustible gas sensor (CG1) located on the subsystem frame. During shutdown for maintenance, however, the above ambient pressure in the H_2 lines which contain N_2 after purge will be relieved prior to maintenance. Manual valve MV2 is used for this purpose and vents the pressure past the combustible gas sensor to insure that the vacuum venting and/or N_2 purge adequately removes H_2 from the subsystem. Also, opening MV2 prior to cartridge removal will insure equalization of pressure, internal and external at the reactor cover.

Nitrogen purge is provided through an electrical valve (V5) and is flow controlled by a flow restrictor (RX1). Pressure transducer P5 is used for sensing the level of the N_2 purge following vacuum vent. The shutoff valve V4 is used to expose the system to vacuum vent. A restrictor (RX2) controls the flow during the venting process. An inline, redundant manual valve (MV1) is used to isolate the subsystem from space vacuum for maintenance. A backpressure regulator (PR2) is used to insure that the subsystem does not go above a preset pressure level.



(a) OR N₂ PURGE FROM EDC
(b) OR N₂ PURGE FROM CGS

| Item No. | Dwg. Ref | Component |
|----------|----------|---|
| 1 | BR1, BR2 | Reactor, Bosch (with heater) |
| 2 | WS1 | Condenser/Separator |
| 3 | WA1 | Accumulator (with level switches) |
| 4 | M1 | Compressor (with flow control) |
| 5 | M2 | Pump, Water (with internal relief) |
| 6 | V1-V9 | Valve, Solenoid (with valve position indicator) |
| 7 | PR1, PR2 | Regulator, Pressure |
| 8 | RX1, RX2 | Restrictor, Flow |
| 9 | P1-P5 | Sensor, Pressure |
| 10 | F1 | Sensor, Flow |
| 11 | J1 | Sensor, Composition |
| 12 | TS1, TS2 | Sensor, Temperature Triple Redundant |
| 13 | TS3-TS6 | Sensor, Temperature |
| 14 | O1, O2 | Sensor, Level |
| 15 | MV1, MV2 | Valve, Manually Actuated |
| 16 | CG1 | Sensor, Combustible Gas |
| 17 | CMI | Instrumentation, Control/Monitor |

FIGURE 8 B-CRS SCHEMATIC

Sensors

Various sensors located throughout the subsystem are used to control subsystem operation and monitor critical parameters for fault detection and isolation. Under- and over-pressurization protection of the recycle loop is provided using pressure sensors P1, P2, and P3. Pressure sensor P4 insures that the liquid collection pressure remains lower than the ambient pressure. Pressure sensor P5 monitors the N₂ purge pressure. Level sensors O1 and O2 are used to cycle the water pump (M2). Temperature sensors TS1 and TS2 are triple redundant thermistor type sensors which are used to monitor the reactor temperature. Temperature sensors TS3 and TS4 monitor the heater (H1 and H2) temperatures and are used in the temperature controller circuits. Sensors TS5 and TS6 monitor the inlet and outlet temperatures of the coolant flow through the condenser/separator. The flow sensor (F1) located on the inlet H₂/CO₂ gas line is used to monitor for reduced capacity or off-nominal design operation. Finally, each of the valves has a valve position indicator for determining the operational state of the valve.

Mechanical Subsystem Summary

A list of all of the components of the B-CRS is shown in Figure 8 below the schematic. A summary of the component weight, power, and heat rejection is given in Table 6 for the mechanical components. The weight and power for the Bosch reactors have been estimated for modifications made to the "cold-seal" reactor. The components' weight subtotal is 79 kg (173 lb). With allowances for packaging, including ducting, insulation, mounting plates, brackets, fittings, tubing and wiring, the mechanical portion of the B-CRS will weigh approximately 102 kg (225 lb). Except for the heat rejected to the coolant fluid by the condenser/separator, the remaining heat must be rejected as waste to the cabin air.

Table 6 shows that both AC and DC power will be required. The DC power is required for the solenoid valves which were selected for the preprototype to insure a fail-safe condition following a power failure. For the prototype/flight B-CRS, motor-driven valves and an emergency controller would be used. Since power for motor-driven valves is only required upon actuation, the total power requirements for the prototype/flight unit will be reduced by approximately 99 W.

The heater power represents steady-state operation. Power for startup from room temperature has not been included. Since the carbon collection cartridge has been sized for 20 man-days and the B-CRS is operating at the three-person level, there is ample time to heat up the dormant reactor to reaction temperature without imposing an excessive power demand. Heatup over a 6-hour time span would require a 200 W heater.

The overall characteristics of the B-CRS mechanical subsystem are summarized in Table 7. The expendable estimate shown is based on a 20 man-day carbon collection cartridge. Characteristics of the cartridge are more fully defined in Table 8.

TABLE 6 PREPROTOTYPE B-CRS MECHANICAL COMPONENT WEIGHT, POWER AND HEAT REJECTION SUMMARY

| Item No. | Component | No. Req'd | Weight kg (lb) | Total Wt, kg (lb) | AC Power, W | DC Power, W | Total Heat Rej., W |
|----------------------|---|-----------|----------------|-------------------|-------------------|-------------|--------------------|
| 1 | Reactor, Bosch (with heat exchanger and heater) | 2 | 27.3 (60.0) | 54.6 (120.0) | 60 ^(a) | --- | 60 ^(d) |
| 2 | Condenser/Separator | 1 | 1.4 (3.0) | 1.4 (3.0) | --- | --- | 74 |
| 3 | Accumulator (with level switches) | 1 | 1.4 (3.0) | 1.4 (3.0) | --- | --- | --- |
| 4 | Compressor (with flow control) | 1 | 5.2 (11.5) | 5.2 (11.5) | 80 | --- | 80 |
| 5 | Pump, Water | 1 | 1.6 (3.5) | 1.6 (3.5) | (b) | --- | --- |
| 6 | Valve, Solenoid (with VPI) | 9 | 1.0 (2.2) | 9.0 (19.8) | --- | 99 | 99 |
| 7 | Regulator, Pressure | 2 | 1.0 (2.3) | 2.1 (4.6) | --- | --- | --- |
| 8 | Sensor, Pressure | 5 | 0.18(0.4) | 0.91(2.0) | --- | (c) | --- |
| 9 | Sensor, Flow | 1 | 1.1 (2.5) | 1.1 (2.5) | --- | (c) | --- |
| 10 | Sensor, Temperature | 6 | 0.09(0.2) | 0.54(1.2) | --- | (c) | --- |
| 11 | Sensor, Composition | 1 | 0.23(0.5) | 0.23(0.5) | --- | (c) | --- |
| 12 | Sensor, Level | 2 | 0.09(0.2) | 0.18(0.4) | --- | (c) | --- |
| 13 | Sensor, Combustible Gas | 1 | 0.09(0.2) | 0.09(0.2) | --- | (c) | --- |
| 14 | Restrictor, Flow | 2 | 0.045(0.1) | 0.09(0.2) | --- | (c) | --- |
| 15 | Valve, Manually Actuated | 2 | 0.09(0.2) | 0.18(0.4) | --- | (c) | --- |
| Components Subtotal: | | | | 78.6 (172.8) | 140 | 99 | 313 |
| Packaging | | | | 23.5 (51.8) | | | |
| Hardware Total: | | | | 102.1 (224.6) | | | |

- (a) Assumed heater power to make up losses.
- (b) Requires power on actuation only.
- (c) Power included in instrumentation.
- (d) Assumed reactor heat losses.

TABLE 7 B-CRS MECHANICAL SUBSYSTEM CHARACTERISTICS

| | |
|---|--|
| Crew Size | 3 |
| Fixed Weight, kg (lb) | 102 (225) |
| Overall Dimensions, cm (in) | 94.0 x 61.2 x 98.6 (37.0 x 24.1 x 38.8) |
| Volume, m ³ (ft ³) | 0.57 (20.0) |
| Power Required, W | 239 |
| Heat Load, W | 313 |
| Expendables, ^(a) kg/d (lb/d) | 1.1 (2.4) |
| MTBF (Estimated), h | 1 x 10 ⁵ |

^(a) Includes catalyst, carbon and non-reused cartridge parts.

TABLE 8 B-CRS CARBON COLLECTION CARTRIDGE CHARACTERISTICS

| | |
|---|-------------|
| Man-Day | 20 |
| Size, cm (in) | |
| Diameter | 21.8 (8.6) |
| Length | 35.6 (14.0) |
| Carbon Capacity, kg (lb) | 5.46 (12.0) |
| Carbon Density, g/cm ³ (lb/ft ³) | 0.55 (34.3) |
| Catalyst Weight, kg (lb) | 0.20 (0.44) |
| Cartridge Weight, kg (lb) | |
| Empty | 1.7 (3.7) |
| Filled | 7.2 (15.8) |

Control/Monitor Instrumentation

The C/M I selected for the preprototype B-CRS is an advanced instrumentation design using minicomputer/software technologies. This C/M I, including an operator/subsystem interface panel, will be contained in a separate enclosure. The function of the C/M I is to provide:

- Automatic mode and mode transition control
- Automatic shutdown provisions for self-protection
- Provisions for monitoring typical subsystem parameters
- Provisions for interfacing with ground test instrumentation

Operating Modes and Transitions

The preprototype B-CRS has five operating modes: Shutdown, Normal, Purge, Standby and Unpowered. Table 9 defines these five operating modes. The allowable mode transitions are shown in Figure 9.

Table 10 defines the four B-CRS intermode controls: reactor temperature, accumulator empty, cyclic operation, and gas composition. All four controls are active during the normal operating mode and inactive during all other modes. The one exception to this is reactor temperature control which remains active during the Standby Mode. The reactor temperature, gas composition and accumulator empty controls are straightforward. The cyclic operation control is somewhat unusual in that it automatically determines the subsystem's steady-state operating mode, either normal or standby. The cyclic operation control uses two internal timers (Z1 and Z2) to determine the length of time the subsystem will be operating in each mode. The typical orbital duty cycle would correspond to 55 minutes in the Normal Mode and 39 minutes in the Standby Mode. For added testing flexibility, the internal timers can be programmed anywhere from 0 to 120 minutes so that, if desired, other than the nominal orbital duty cycle can be examined. The B-CRS control set points can be adjusted over the range indicated in Table 10 and the projected set points for the preprototype B-CRS are given. Control is accomplished by monitoring the parameter value using the sensor indicated and controlling the indicated actuator to achieve the desired set point. In the case of the cyclic operation control, the actuator is the C/M I itself. The steady state operating mode conditions for all actuators are given in Table 11.

A special control is not required for the B-CRS to operate in the derated mode. The subsystem has been designed and sized to handle the requirements of up to a three-person crew. Operation at less than the three-person level for extended periods will not affect overall subsystem performance or require special control features. However, adjustments to the reaction rate need to be made to insure that system pressure does not go subatmospheric. This adjustment for operation at the one-person level can be automatic by reducing the reactor temperature making the reduction process less efficient but still in a range that converts at the incoming gas flow rate. Alternatively, H₂ could be added to the recycle loop through the interface control regulator

TABLE 9 B-CRS OPERATING MODES DEFINITION

| <u>Mode (Code)</u> | <u>Definition</u> |
|--------------------|--|
| Shutdown (B) | <p>The B-CRS is not reducing CO₂. The compressor is off, the Bosch reactor heater is off and all valves are closed. The subsystem is powered and all sensors are working. The Shutdown Mode is called for by:</p> <ul style="list-style-type: none">• Manual actuation• High reactor temperature• High system pressure• High condenser temperature• High combustible gas concentration• Low separator pressure• High separator pressure |
| Normal (A) | <p>The B-CRS is performing its function of depositing carbon and recovering water generated by the reaction of CO₂ and H₂. The Normal Mode is called for by:</p> <ul style="list-style-type: none">• Manual actuation |
| Purge (C) | <p>The B-CRS is being purged with N₂ through all H₂-carrying lines and out through V4 to the overboard vent. The Bosch reactor heater current and the compressor are off. This is a continuous purge until a new mode is called for. The Purge Mode is called for by:</p> <ul style="list-style-type: none">• Manual actuation |
| Standby (E) | <p>The B-CRS is standing by ready to reduce CO₂. The reactor is maintained at temperature by leaving the heater control on. The compressor is off and all valves are closed except valve V6. The subsystem is powered and all sensors are working. The Standby Mode is called for by:</p> <ul style="list-style-type: none">• Manual actuation• Low system pressure |
| Unpowered (D) | <p>No electrical power is applied to the B-CRS. Actuator positions can only be verified visually. There will be no recycle gas flow and the heater is off. The Unpowered Mode is called for by:</p> <ul style="list-style-type: none">• Manual actuation• Electrical power failure |

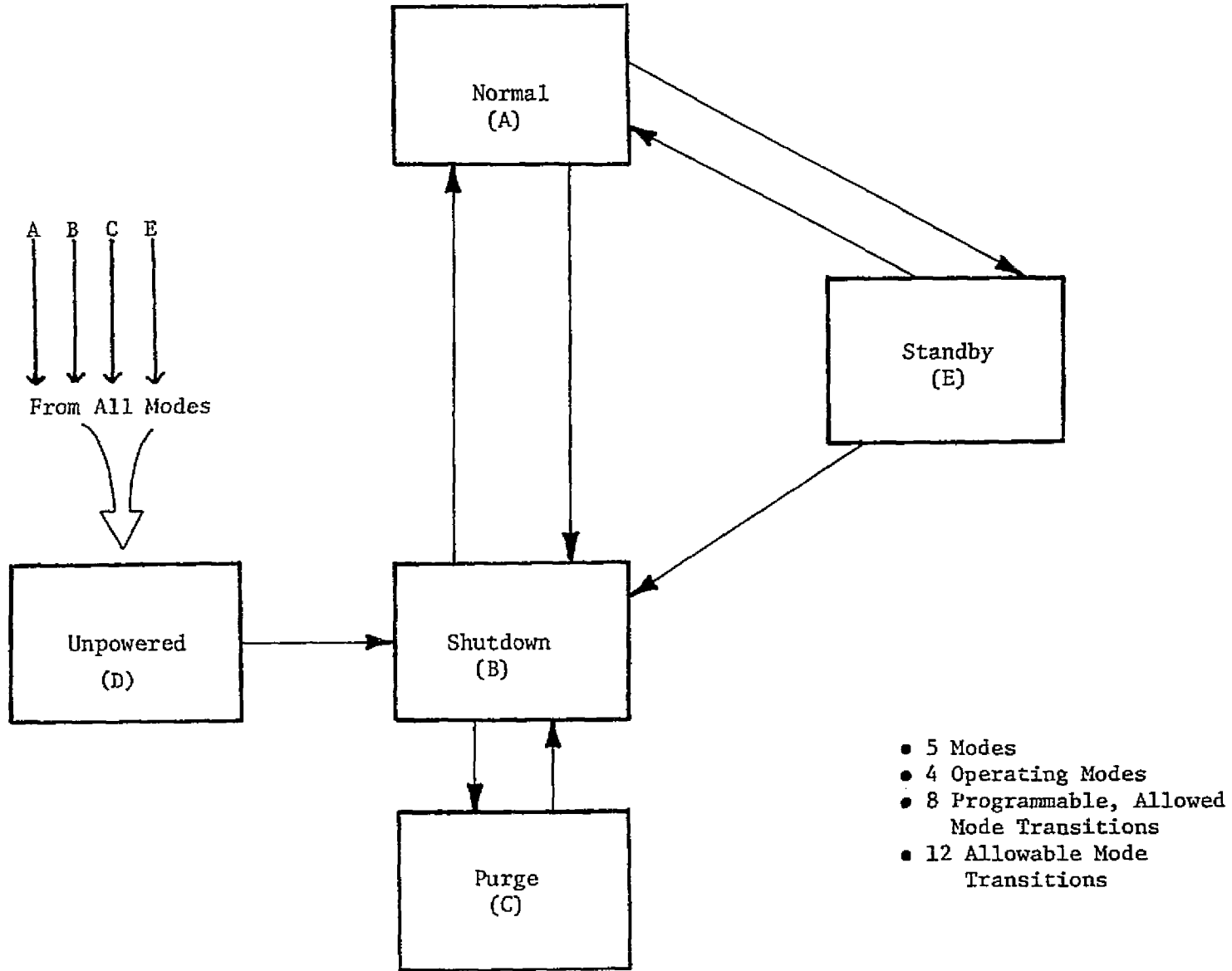


FIGURE 9 B-CRS MODES AND ALLOWABLE MODE TRANSITIONS

TABLE 10 B-CRS CONTROLS DEFINITION

| <u>Control</u> | <u>Controlled Parameter</u> | <u>Description</u> | <u>Actuator(s)</u> | <u>Sensor(s)</u> | <u>Set Point(s)</u> | <u>Set Point Adjustment Range</u> |
|----------------------|--|---|--------------------|------------------------|------------------------|-----------------------------------|
| 1. Reactor Temp. | Temperature | Maintain the temperature of the catalyst bed at the set point by increasing or decreasing heater current (proportional control) | H1 (or H2) | TS1 (or TS2) | 894 K (1150 F) | 839-923 K (1050-1200 F) |
| 2. Accumulator Empty | Liquid level in Accumulator | Empties water accumulator when full by opening valve V3 and energizing the pump until the accumulator is empty | M2, V3 | 01, 02 | 01-Empty 02-Full | N/A |
| 3. Cyclic Operation | Subsystem Operating Mode (Normal or Standby) | Change B-CRS operating mode during the cyclic duty cycle using timers to determine the length of time in Normal Mode (Z1) and the length of time in Standby Mode (Z2) | CM1 | Internal Timers Z1, Z2 | Z1=55 Min Z2=39 Min | 0-120 Min |
| 4. Gas Composition | Recycle Loop pH_2 | Maintain stoichiometric ratio of reactants H_2 and CO_2 in response to recycle loop gas composition variations | V9 | J1 | 35% | 30-40% |

TABLE 11 STEADY-STATE ACTUATOR CONDITIONS FOR B-CRS OPERATING MODES

| <u>Mode</u> | <u>Valves</u> | | | | | | |
|---------------|---------------|-----------|-----------|-----------|-----------|-----------|---------------|
| | <u>V1</u> | <u>V2</u> | <u>V3</u> | <u>V4</u> | <u>V5</u> | <u>V6</u> | <u>V7, V8</u> |
| Shutdown (B) | Closed | Closed | Closed | Closed | Closed | Closed | (a) |
| Normal (A) | Open | Open | Open | Closed | Closed | Open | (a) |
| Purge (C) | Closed | Closed | Closed | Open | Open | Closed | (a) |
| Standby (E) | Closed | Closed | Closed | Closed | Closed | Open | (a) |
| Unpowered (D) | Closed | Closed | Closed | Closed | Closed | Closed | (a) |

| | <u>Heater H1 or H2</u> | <u>Compressor M1</u> | <u>Pump M2</u> | <u>H₂ Makeup V9</u> |
|---------------|----------------------------|--------------------------|--------------------|------------------------------------|
| Shutdown (B) | Off | Off | Off | Closed |
| Normal (A) | On | On | Off ^(b) | Closed ^(b) |
| Purge (C) | Off | Off | Off | Closed |
| Standby (E) | On | Off | Off | Closed |
| Unpowered (D) | Off | Off | Off | Closed |

(a) Position of four-way valves dependent on which reactor is operating.

(b) Actuator condition controlled by C/M I intermode sequence.

(PRI) to maintain system pressure. This H₂ enrichment of the recirculating gases again will help to lower conversion efficiency to prevent subatmospheric operation. During operation at off-design conditions, therefore, the B-CRS will remain in the Normal Mode and the off-design condition displayed on the operator/subsystem interface panel.

Performance monitoring is accomplished using sensors located throughout the subsystem. There are six critical parameters that are monitored and will cause the subsystem to shut down should the parameter exceed a preset level. These seven parameters are: high reactor temperature, high recycle loop pressure, high combustible gas concentration, high condenser/separator coolant temperature, and high and low separator differential pressure. There are a total of 29 sensors located in the subsystem. The sensors are listed in Table 12. All sensors are monitored and their values expressed in engineering units on the operator/subsystem interface panel. Non-critical parameters, however, will not cause the subsystem to shut down and are provided for increased testing flexibility and performance monitoring during preprototype development and testing.

Operator/Subsystem Interface Panel

The preprototype B-CRS operator/subsystem interface panel is shown in Figure 10 with the access panel in the lower right hand corner removed to show the manual controls provided. During automatic operation, the access panel remains in place. Control of four operating modes (Normal, Shutdown, Purge and Standby) is provided in the upper right hand corner of the panel. The controls automatically prevent the operator from initiating an illegal mode transition, e.g., Normal to Purge. The subsystem will not respond to an illegal mode transition command. Located directly below the operating mode controls is a split legend control indicating which reactor is operating. The operator has the capability for switching reactors with this control. Alternatively, the C/M I will automatically switch reactors in response to a built-in timer signal or when the pressure differential across the cartridge is such that a changeover is required.

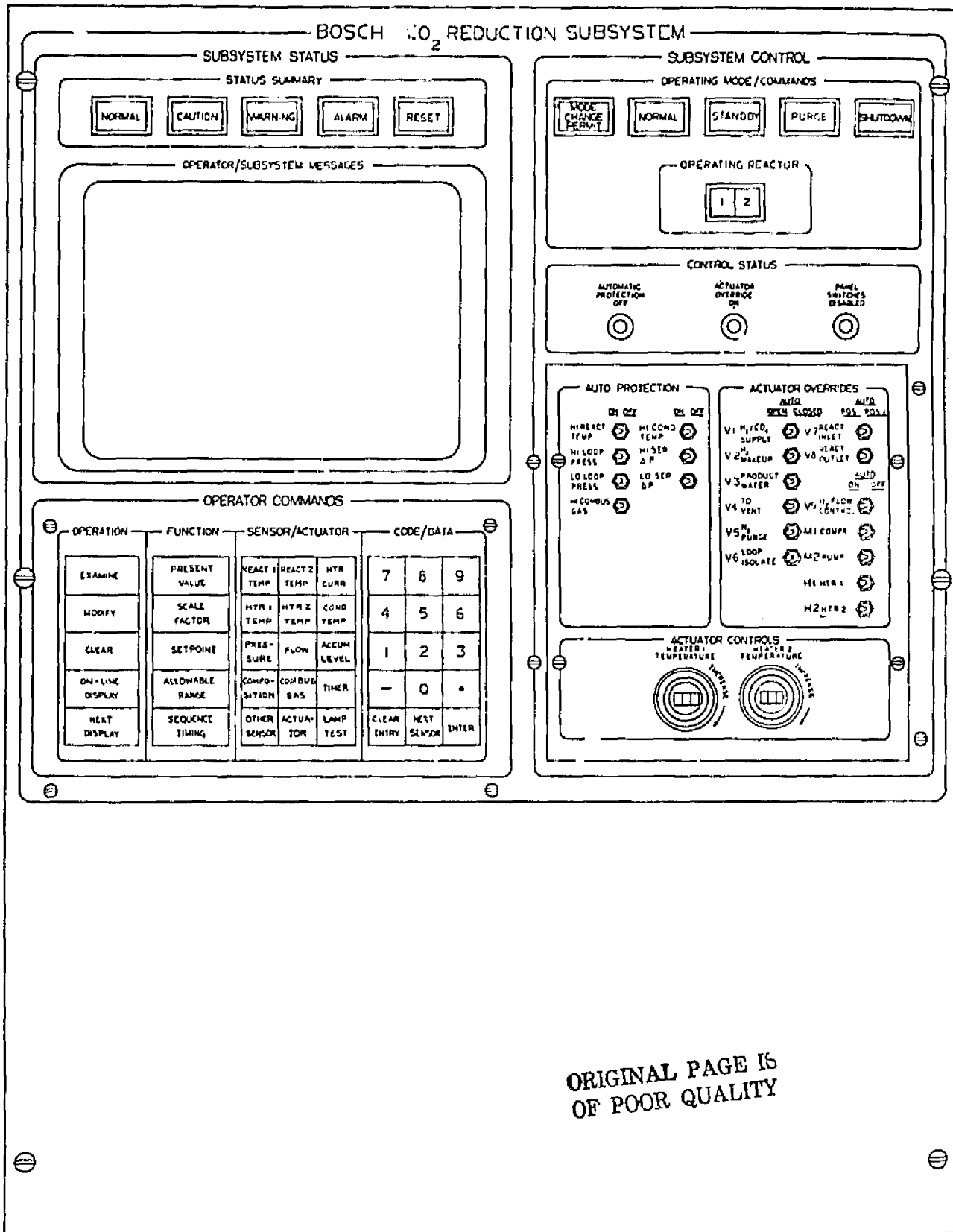
The control status is located directly below the operating mode/commands section. Three lights are provided to indicate whether one of the automatic protection overrides has been turned off or an actuator override has been taken out of automatic control. A light is also provided to indicate when the panel switches have been disabled.

Manual controls are provided behind the access panel located immediately below the control status indicator lights. Overrides are provided for all automatic shutdown circuits and actuators. The actuator overrides must be placed in an automatic position for the subsystem to operate normally. A manual adjustment is provided for setting the heater temperature of each reactor.

Overall subsystem status is provided in the upper left portion of the panel. The status summary is given as Normal, Caution, Warning or Alarm and is determined by the worst condition for any critical parameter. A reset button is provided to clear the status summary and reset the subsystem monitoring functions. Messages and information concerning the subsystem are displayed visually on the

TABLE 12 B-CRS SENSOR LIST

| <u>Description</u> | <u>Quantity</u> | <u>Redundancy Level</u> |
|---------------------------------|-----------------|-------------------------|
| Feed Gas Flow | 1 | 1 |
| Reactor Temperature | 2 | 3 |
| Heater Temperature | 2 | 1 |
| Condensor/Separator Temperature | 2 | 1 |
| Inlet Gas Pressure | 2 | 2 |
| Reactor Gas Pressure | 1 | 1 |
| Water Accumulator Pressure | 1 | 1 |
| N ₂ Purge Pressure | 1 | 1 |
| Combustible Gas Sensor | 1 | 3 |
| Recycle Loop Composition | 1 | 1 |
| Accumulator Level | 2 | 1 |
| Cyclic Operation Timers | 2 | 1 |
| Valve Position Indicators | 9 | 1 |
| Heater Current | 2 | 1 |



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FIGURE 10 B-CRS OPERATOR/SUBSYSTEM INTERFACE PANEL

cathode ray tube (CRT) located below the status summary lights. Operator/subsystem messages include display of all parameters, in engineering units, not within the normal range and a periodic display of all of the monitored parameters.

Shown in the lower left portion of the operator/subsystem interface panel is a keyboard for entering operator commands. The capability exists for performing various operations on different functions of the subsystem parameters. Present values can be examined, set points can be modified, or the other indicated functions performed. The keyboard provides flexibility to the user in operating the B-CRS.

B-CRS C/M I Summary

Table 13 lists the design characteristics of the B-CRS C/M I. The C/M I package will be contained within a separate enclosure and connected to the mechanical hardware through cabling. One feature of the C/M I is that it will operate on 400 Hz power. Any additional power requirements of it or the mechanical subsystem will be derived from internal power supplies. The central processor is a Computer Automation LSI-4/10 minicomputer. Characteristics of this machine are listed in Table 14. Table 15 summarizes the instrumentation component size, weight, and power. All of the hardware, including signal conditioning, power supplies, computer input/output boards, CRT, CRT controller and front panel are contained in one 53 cm x 53 cm x 73 cm (21 in x 21 in x 28.6 in) enclosure. Allowances for expanding the system by adding circuit cards have been made.

The moderate power requirements (508 W) for the preprototype C/M I will be greatly reduced for the prototype/flight subsystem. The preprototype C/M I has been designed to allow maximum operator flexibility and information interchange during the RLSE development and testing phases. The prototype/flight B-CRS C/M I will require less of this capability and, coupled with the state-of-the-art instrumentation technology (e.g., microprocessors, CMOS) and a centralized EC/LSS control philosophy, will use much less power.

Packaging/Volume Considerations

Figures 11 and 12 show the projected RLSE envelope for the CO₂ Reduction Subsystem. This envelope was selected assuming a Sabatier subsystem. The envelope consists of the top two-thirds of a double side-by-side Spacelab mounting rack. The CO₂ Reduction Subsystem would be located directly above the IARS and next to the OGS. Analysis has shown that a dual reactor B-CRS could be designed to fit within this allotted envelope. Figure 13 shows a concept of the B-CRS in a double Spacelab rack. Shown is the projected prototype or flight version which most probably will be a "hot-seal" reactor. The two reactors are shown side-by-side and access for cartridge removal is from the front. In this configuration, the B-CRS would easily fit within the allotted space and not be required to project into the Spacelab aisleway for cartridge removal. A "cold-seal" reactor would have this disadvantage. The drawing also indicates that the maintainability concept of line replaceable units has been included. All sensors and components are maintainable from the front of the rack with the exception of the reactors.

TABLE 13 B-CRS CONTROL/MONITOR INSTRUMENTATION
DESIGN CHARACTERISTICS

| | |
|---|--|
| Dimensions (Depth x Width x Height), cm (in) | 53.0 x 53.0 x 73.0 (21.0 x 21.0 x 28.6) |
| Weight, kg (lb) | 95 (209) |
| Power Consumption, W | 508 |
| Line Voltage, Vac | 115/200, 3Ø |
| Line Frequency, Hz | 400 |
| Input Sensor Signal Range, Vdc | 0 to 5 |
| Output Actuator Signal Range, Vdc | 0 to 5 |
| Processor | |
| CPU | LSI-4/10 |
| Word Size, bits/word | 16 |
| Memory Size, words | 16,000 |
| Memory Speed, ns | 3,000 |
| Instruction Cycle Time, ns | 2,000 |
| Input/Output | |
| Number of Analog Inputs | 22 |
| Number of Analog Outputs | 2 |
| Number of Digital Inputs | 11 |
| Number of Digital Outputs | 13 |
| Transfer Rate, Megawords/s | 1.67 |
| Front Panel | |
| Command Inputs | Pushbutton Switches |
| Message Display | (a) Color-coded Indicators and (b) 23 cm (9 in) CRT Display |
| Display CRT Capacity, characters | 1,920 (80 x 24) |
| Number of Manual Overrides | 20 |
| Operating Modes | |
| Number of Operating Modes | 5 |
| Number of Allowable Mode Transitions | 8 |

TABLE 14 B-CRS INSTRUMENTATION COMPUTER CHARACTERISTICS

| <u>Item</u> | <u>Description</u> |
|---------------------------|--|
| Type of Computer | CAI LSI-4/10 Minicomputer |
| Word Size | 16 bits |
| Memory Size | 16 K Core |
| Memory Speed | 3000 ns |
| Instruction Cycle Time | 2000 ns |
| I/O Transfer Rate | 1.67 Megawords/s |
| Priority Interrupt Levels | 6 |
| Other Important Features | <ul style="list-style-type: none">• Real Time Clock• Direct Memory Access Channels• Hardware Multiply/Divide• Stack processing• Automatic and Blocked I/O• Power Fail Restart |

TABLE 15 B-CRS CONTROL/MONITOR INSTRUMENTATION COMPONENT SIZE, WEIGHT, AND POWER SUMMARY

| Component | H x W x D, in | Volume, dm ³ (ft ³) | Weight, kg (lb) | Power, (a) W |
|---|----------------------------------|---|--------------------|-----------------|
| Instrumentation Enclosure | 28.6 x 21.0 x 21.0 | 207 (7.30) | 22.7 (50) | -- |
| LSI-4/10 Computer and Accessories | 8.7 x 10.0 x 19.6 | 28 (0.99) | 9.1 (20) | 150 |
| CRT Display | 7.0 x 9.0 x 10.0 | 10 (0.36) | 13.6 (30) | 24 |
| Display Controller | 5.3 x 19.0 x 11.8 | 19 (0.68) | 8.6 (19) | 66 |
| Front Panel Interface | 5.0 x 9.0 x 3.0 | 2.3 (0.08) | 2.3 (5) | 20 |
| Front Panel Switches | 0.8 x 1.2 x 1.3 | 1.1 (0.04) | 2.3 (5) | 5 |
| Total 71 | each (max) | | | |
| Front Panel Lamps | ----- | --- | 0.45(1) | 30 |
| Total 15 | | | | |
| Intelligent Cables | 9.0 x 4.0 x 1.0 ea. | 0.6 (0.02) | 0.91(2) | 8 |
| Total 2 | | | | |
| Power Supplies (5 V, ±12 V, ±15 V, 28 V) | 6.0 x 6.0 x 19.0 | 11 (0.40) | 13.6 (30) | 120 |
| Signal/Power Conditioners | 6.0 x 6.0 x 15.0 | 8.8 (0.31) | 13.6 (30) | 25 |
| Recessed Override Switch Panel | 7.5 x 9.0 x 4.0 | 4.5 (0.16) | 2.3 (5) | -- |
| Connectors and Harness | ----- | --- | 4.5 (10) | -- |
| Fans, Total 3 | 5.0 x 5.0 x 2.0 ea | --- | 0.91(2) | 60 |
| Total | 28.6 x 21.0 x 21.0 (Envelope) | 207 (7.30) (Envelope) | 95 (209) | 508 |

(a) 115/200 VAC, 400 Hz, 3Ø Power

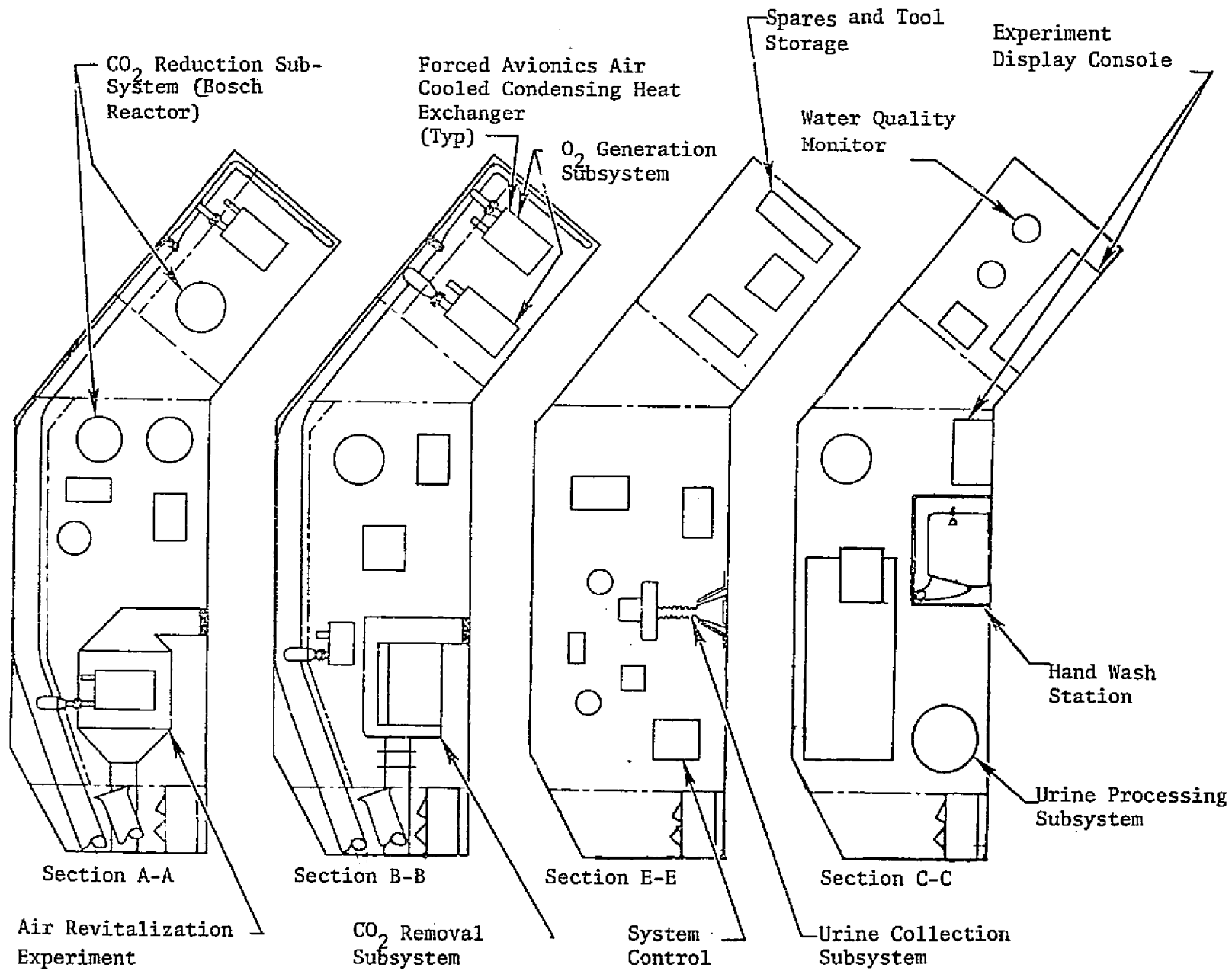


FIGURE 11 RLSE SUBSYSTEMS IN SPACELAB

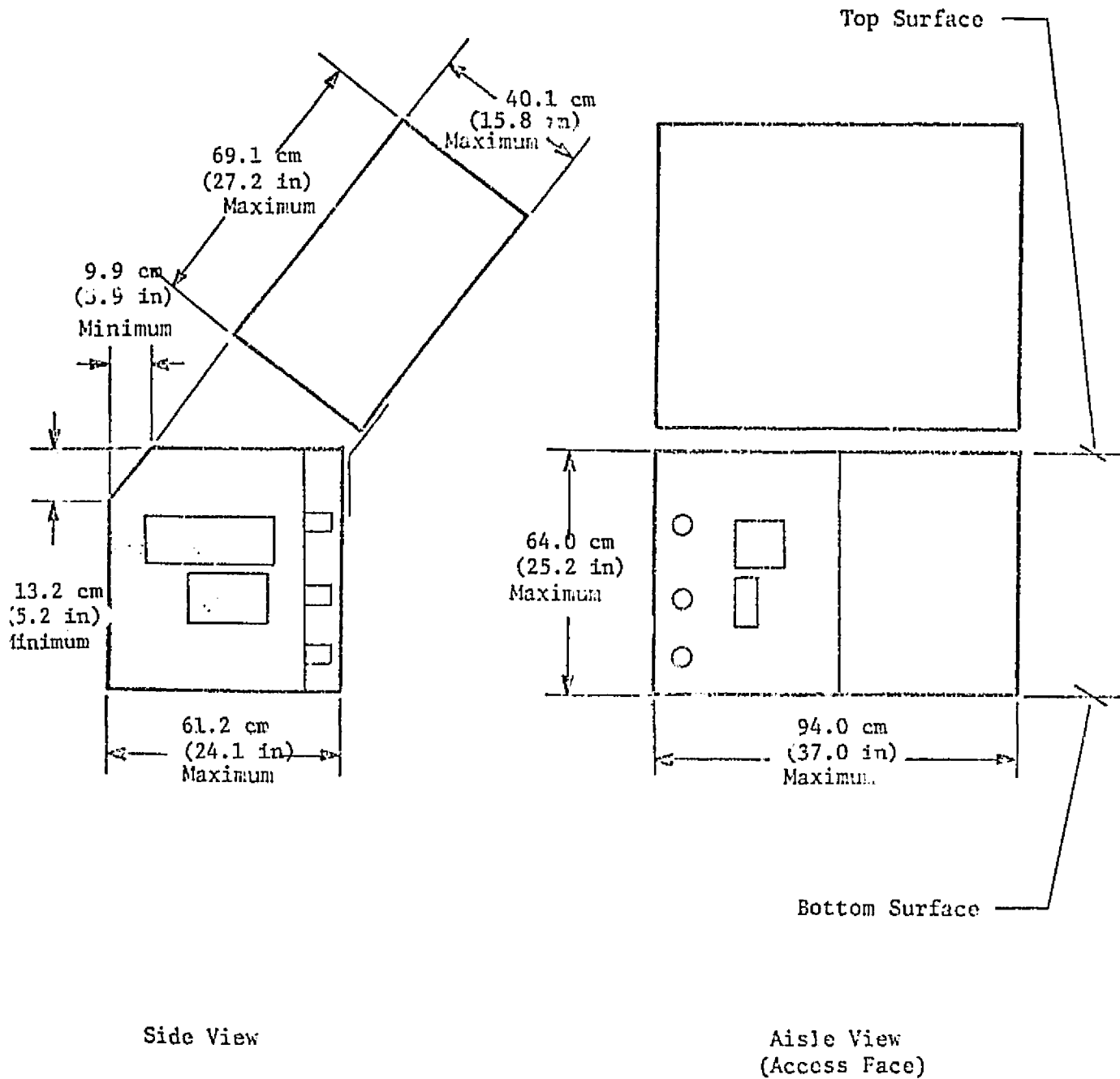


FIGURE 12 CO₂ REDUCTION SUBSYSTEM PACKAGING ENVELOPE FOR RLSE

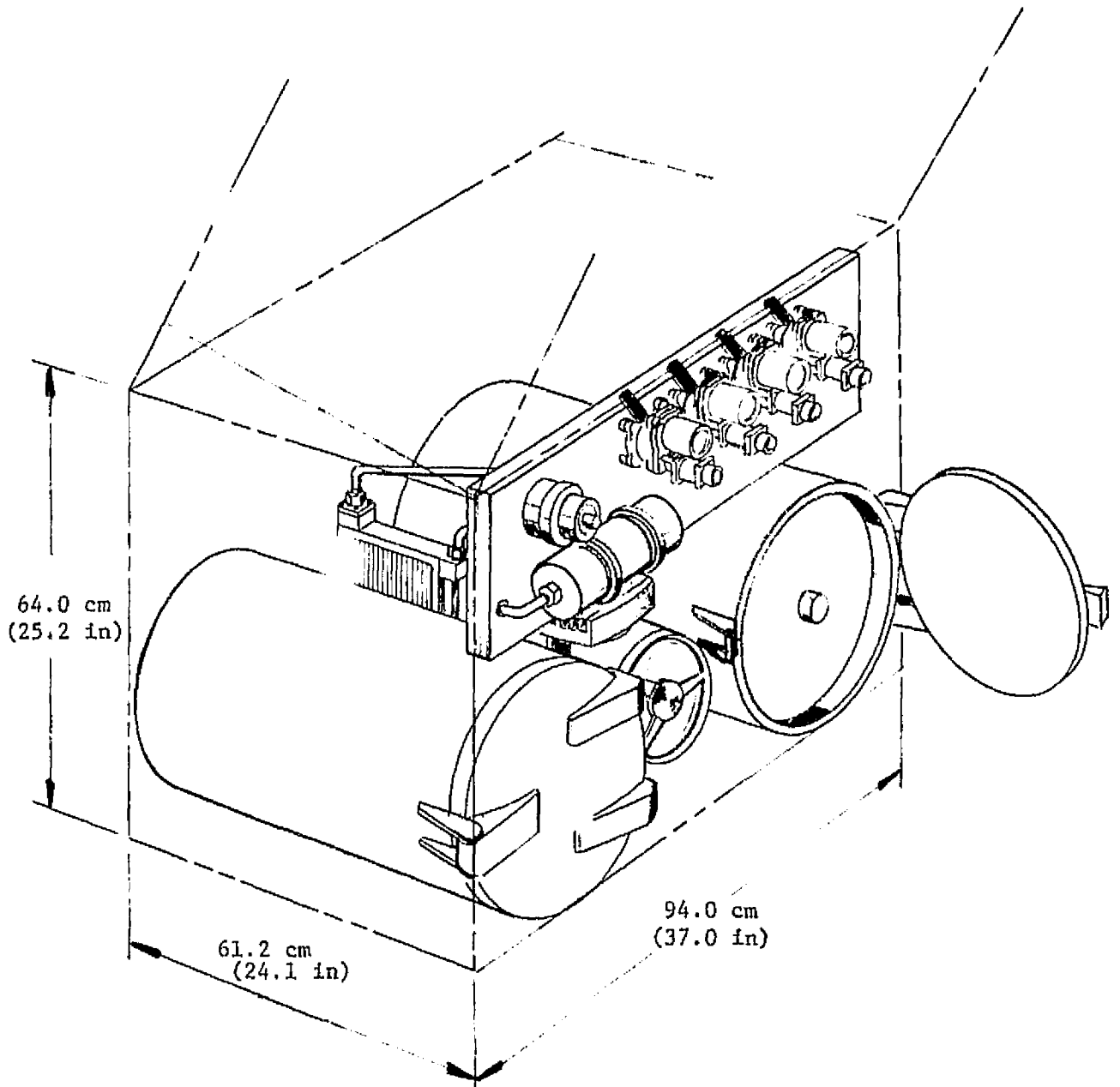


FIGURE 13 CONCEPT OF B-CRS IN SPACELAB RACK

RLSE B-CRS DEVELOPMENT

The development of a B-CRS as an alternative to the Sabatier CO₂ Reduction Subsystem for RLSE requires an assessment of the Bosch hardware maturity. In addition, the development period must correspond with the overall RLSE test schedule. This section discusses these considerations.

B-CRS Hardware Readiness

The major component of the B-CRS is the reactor/heat exchanger combination. It has been noted above that the current Bosch technology employs a "cold-seal" reactor. While it is an optimized Bosch reactor from a thermodynamic and heat loss point of view, it has several disadvantages. First, the present ceramic heat exchanger does not have the structural integrity to withstand the Shuttle launch shock, vibration and acceleration environment. Second, the heat exchanger and cartridge is not structurally supporting in any orientation other than the vertical. In other words, a vertical stackup is required and there can be no side loads. Third, packaging a "cold-seal" reactor within the Spacelab racks requires extension of the reactor into the aisleway in order to facilitate cartridge removal. This is because the entire reactor shell/vacuum jacket needs to be removed to gain access to the carbon collection cartridge. This procedure is not desirable. Therefore, it is recommended that the "hot-seal" reactor with a quick-opening access to the cartridge be employed. Vacuum insulation is used to minimize heat loss. This configuration was pictured in Figure 13.

Another component under evaluation is the loop composition sensor, J1. In the past, a thermoconductivity flow-control type sensor has been used. However, this sensor has certain disadvantages, including an orientation sensitivity and a large size. Work at Life Systems has progressed to a point where a pH₂ sensor, consisting of a palladium/silver (Pd/Ag) H₂ separation tube and pressure detector, is both feasible and desirable because of small size and insensitivity to orientation. It is recommended that this sensor be employed in the B-CRS.

The condenser/separator must be compatible with 0-g operations. The condenser/separators used with present Bosch systems are not. However, Life Systems has identified a technique and has developed a breadboard model of a 0-g compatible water vapor condenser/separator. Continuation of a prototype development of this hardware is recommended.

Integration Into RLSE

For the B-CRS to be integrated within the RLSE, changes in the interface hardware are required. First, the gas mixture coming from the EDC will have to be at an H₂ to CO₂ ratio of less than two. This requires operating the EDC with less H₂ flow than is presently specified. Currently, all the H₂ from the OGS passes directly to the EDC. It will be required to bypass some H₂ around the EDC directly to the B-CRS. A control concept has been used in the past at Life Systems to permit integrating an OGS an EDC and a B-CRS. (21,22) Figure 14 is a block diagram and flow schematic showing the major components required to implement this control concept.

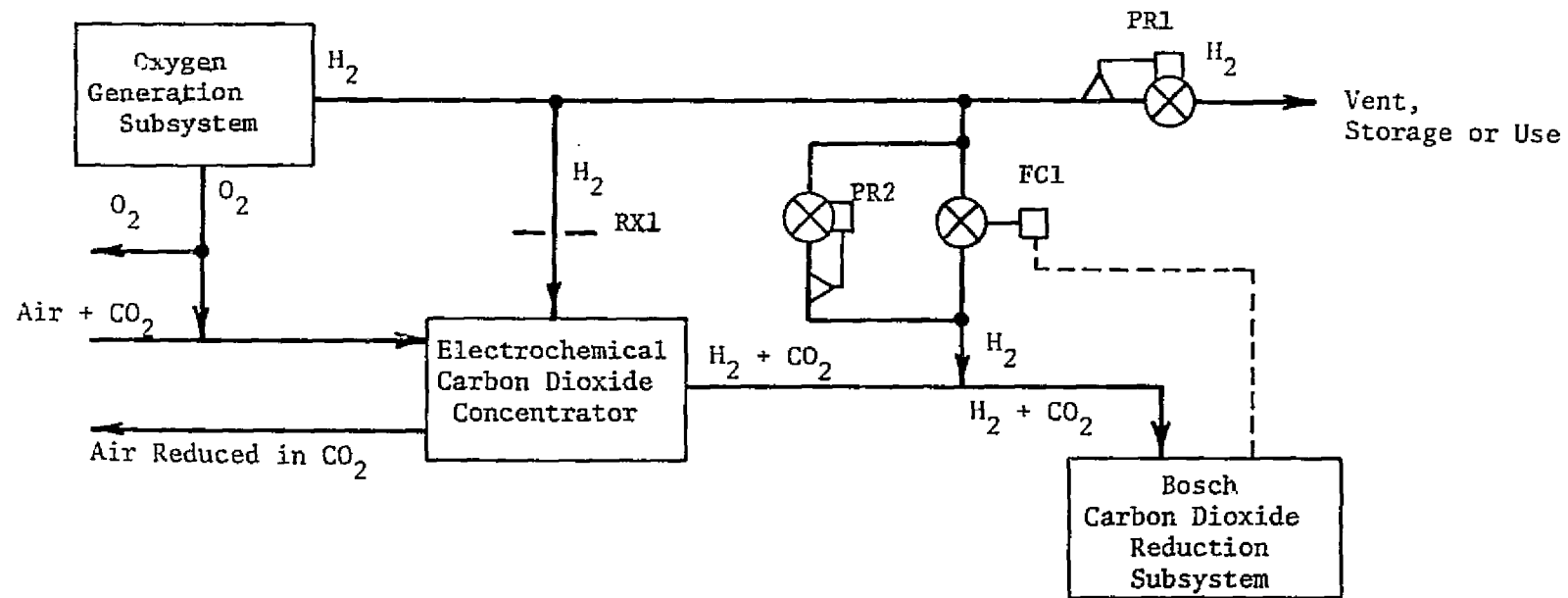


FIGURE 14 INTEGRATION SCHEMATIC FOR AN EDC, BRS AND OGS

Pressure regulator PR1 maintains a constant upstream H_2 pressure from the OGS resulting in a constant H_2 flow rate to the EDC as controlled by flow restrictor RX1. This flow restrictor is fixed in size and has the capacity to supply a constant flow of H_2 to the EDC sufficient to satisfy the stoichiometric requirements of the EDC but always less than that required for the H_2 -to- CO_2 ratio of the EDC anode exhaust gas to reach a level of 2:1. Thus, H_2 must always be added to the B-CRS feed gas through FC1 as sensed by the B-CRS recycle loop gas composition sensor.

Pressure regulator PR2 prevents the B-CRS recycle loop pressure from going subatmospheric by adding H_2 to the loop to throttle CO_2 and H_2 conversion efficiencies at low CO_2 feed rates and/or when minimum recycle loop flow rates have been reached.

It is noted that provisions for storing or venting overboard excess H_2 produced by the OGS have been made. Under normal operation an ARS employing a B-CRS will produce approximately 14% excess H_2 . Therefore, under normal operation, this excess H_2 will have to be stored or vented overboard.

B-CRS Development Schedule

A preprototype B-CRS can be developed within 14 months after go-ahead. The RLSE Phase I testing schedule shows that complete system test is to be started during the first quarter of 1979. For the B-CRS to be included in this testing, a development start is required during early 1978 with shipment of the completed B-CRS to NASA JSC by mid-1979.

CONCLUSIONS

Based on the study activities, the following conclusions are drawn:

1. The B-CRS meets the requirements for the RLSE CO_2 Reduction Subsystem. It is a viable alternative to the Sabatier system, and essential when minimizing or eliminating overboard venting of gases.
2. A dual reactor B-CRS to demonstrate continuous operation and interface with the RLSE CO_2 collection subsystem is required.
3. A recycle loop composition sensor based on sensing directly the partial pressure of H_2 in the recycle loop is feasible.
4. Prior integrated testing of a B-CRS with an EDC and a WES demonstrated the compatibility of these subsystems. No integration problems associated with introducing the Bosch into the RLSE are anticipated.
5. The "cold-seal" reactor evaluation indicated modifications are needed to the present concept to satisfy the RLSE orientation, shock/vibration and packaging constraints.

RECOMMENDATION

The final detail design and fabrication of a preprototype B-CRS is recommended. The development effort should begin in early 1978 to insure timely incorporation of the B-CRS into the RLSE test program.

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