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Design of Components for the NASA OCEAN Project

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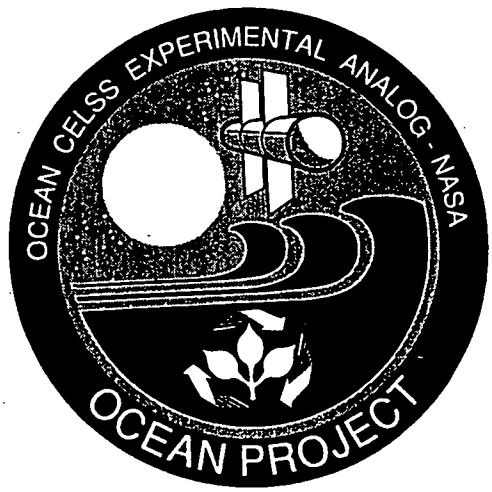

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SUMMARY

The goal of the Fall 1993 semester of the EGM 4000 class was to design, fabricate, and test components for the "Ocean CELSS Experimental Analog NASA" Project (OCEAN Project) and to aid in the further development of NASA's Controlled Ecological Life Support System (CELSS). The OCEAN project's specific aims are to place a human, Mr. Dennis Chamberland from NASA's Life Science Division of Research, into an underwater habitat off the shore of Key Largo, FL for three months. During his stay, he will monitor the hydroponic growth of food crops and evaluate the conditions necessary to have a successful harvest of edible food. The specific designs chosen to contribute to the OCEAN project by the EGM 4000 class are in the areas of hydroponic habitat monitoring, human health monitoring, and production of blue/green algae.

The hydroponic monitoring system focused on monitoring the environment of the plants. This included the continuous sensing of the atmospheric and hydroponic nutrient solution temperatures. Methods for monitoring the continuous flow of the hydroponic nutrient solution across the plants and the continuous supply of power for these sensing devices were also incorporated into the design system.

The human health monitoring system concentrated on continuously monitoring various concerns of the occupant - Mr. Dennis Chamberland - in the underwater living habitat of the OCEAN project. These concerns included monitoring the enclosed environment for dangerous levels of carbon monoxide and smoke, high temperatures from fire, and the ceasing of the continuous airflow into the habitat.

The blue/green algae project emphasized both the production and harvest of a future source of food. This project did not interact with any part of the OCEAN project. Rather, it was used to show the possibility of growing this kind of algae as a supplemental food source inside a controlled ecological life support system.

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The EGM 4000 Engineering Design class expresses it sincere gratitude to the personnel of the National Aeronautical and Space Administration, particularly to the following persons:

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Finally, the members of the class extend a special thanks to Dr. Gale E. Nevill, Jr. for his assistance and guidance throughout the Fall semester.

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INTRODUCTION

During the Fall 1993 semester, the students of the EGM 4000 Engineering Science Design class at the University of Florida prepared design components for NASA's OCEAN project. The design systems created for this controlled ecological life support system would assist in the efforts to demonstrate the ability for a human to fully operate and collect data on a hydroponic system established in an extreme underwater ocean environment. Several areas of concern emerged from the OCEAN project such as the well-being of the plants and the human - Mr. Dennis Chamberland. The hydroponic monitoring system includes monitoring the continuous power supply, continuous flow of the hydroponic liquid nutrient system, and the atmospheric and nutrient-solution temperatures. Another design component was created to aid in the development of producing and harvesting a future food stock - blue/green algae. This design will research the success of growing an algae food source in this type of controlled environment. Finally, the human health monitoring system will detect dangerous amounts of carbon monoxide, extreme heat and smoke percentage in the air, and the continuous flow of air supply into the underwater habitat.

Each of these systems were designed, fabricated and tested during the Fall 1993 semester. The Spring 1994 semester was utilized for further testing and refinement of the three design components for the three month underwater OCEAN project mission scheduled for November 1994. The concept designs, detail design, construction, and testing results for each of the three projects are described separately in the following report.

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HYDROPONIC HABITAT MONITORING SYSTEM

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ABSTRACT

A Hydroponic Habitat Monitoring System (HHMS) was developed to observe the hydroponic habitat of the OCEAN project located in an underwater laboratory. The four environmental parameters that the HHMS monitors are atmospheric temperature, nutrient-solution temperature, nutrient-solution flow rate, and electrical power. Signals from the sensors are connected to a central processing unit and then sent across twenty meters of sea water by an electrical cable. The signals are received by an alarm unit in the human living quarters (also located in an underwater habitat).

Both atmospheric temperature and nutrient-solution temperatures are measured by Radio Shack's Archer TL83969 modules which are located in the central processing unit. Probes attached by electrical wires to the central processing unit take sample temperatures every fifteen seconds. Nutrient-solution flow rate is measured by a flow-rate sensor (State Instruments) consisting of a piston attached to a magnet. The piston is displaced by flow of a liquid medium. The magnet then activates a hermetically-sealed reed switch isolated within the body of the sensor. When flow falls below 0.1 L/min, an opposing magnet is used to return the piston which deactivates the switch connected to the central processing unit. Electrical power is monitored by sensing a voltage signal directly from an AC/DC converter. When the voltage signal is no longer detected (power outage), a 4.5 V signal is produced by an invertor that is housed in the alarm unit and powered by a 9 V battery.

The output from the hydroponic habitat sensors are communicated to the human living quarters via a nine-lead underwater cable from Aqua-Tech. It contains seven 18-gauge conductors and one RG59 coaxial cable. The cable's diameter measures 1.43 cm, and each conductor is surrounded by a polyurethane jacket in order to protect it from the sea water.

The alarm unit consists of two sets of LEDs: four green and four red. Each LED represents the status of the parameters being monitored: green signifies acceptable conditions and red signifies harmful conditions. If one or more of the red LEDs are turned on, an audible alarm also sounds. A momentary reset button will disengage the alarm unit until acceptable conditions in the hydroponic habitat are restored. The alarm unit then resets itself automatically.

Testing has proven that the Hydroponic Habitat Monitoring System will significantly improve the quality of hydroponic plant production by ensuring that the scientist is immediately informed if any environmental conditions reach harmful levels.

INTRODUCTION

The major objective of the OCEAN project is to explore the plant production aspect of a Closed Ecological Life-Support System (CELSS). The OCEAN project will be conducted in two underwater habitats: one used for growing crops and the other providing human living quarters. Because a CELSS will eventually be utilized in microgravity, the plants will be grown hydroponically (without soil). In the hydroponic plant growth habitat, soil will be replaced by a nutrient solution that flows through the plants' roots in troughs.

Because of the sensitive nature of cultivating hydroponic crops, the environment in which the plants are growing is of extreme importance. However, the OCEAN project is being conducted by only one crew member, and that crew member will not be present in the hydroponic habitat continuously. During the night, the scientist may be away from the hydroponic habitat for hours. During that time, the environmental conditions in the hydroponic habitat may exceed acceptable limits - for example, the atmospheric temperature may get too high - which would result in detrimental effects to the hydroponic crops and the entire OCEAN project.

The solution to this problem was the goal of our design team. A Hydroponic Habitat Monitoring System (HHMS) was developed to continuously observe the environment and determine any potentially harmful conditions. Because the human living quarters are separate from the hydroponic habitat, the HHMS will also provide communication between the hydroponic habitat and the human living quarters. This communication link will ensure a quick response by the crew member to any conditions that might damage the crops.

Our design team was successful in designing, manufacturing, and testing a HHMS without exceeding a budget of one thousand dollars. The HHMS will accompany NASA into the underwater habitats of the OCEAN project.

DESIGN SPECIFICATIONS

Performance

After a careful evaluation of what environmental factors would significantly affect hydroponic plant growth, the following proved to be the most important and were presented to NASA:

Temperature of the atmosphere
Carbon dioxide concentration of the atmosphere
Flow of the nutrient solution
Power supply to the hydroponic habitat

Although all of the above elements are important, Mr. Dennis Chamberland stated that any failure of the pumps providing the carbon dioxide would also be indicated by monitoring the power supply [1]. In addition, Dr. Gary Stutte stressed a need for sensing the temperature of the nutrient solution because it frequently overheats [1]. The surrounding ocean will not allow either the atmospheric or nutrient solution temperatures to reach any harmful lower limit.

The following is a revised list of potentially harmful environmental factors the HHMS was specified to monitor:

Temperature of the atmosphere	> 95 ± 1°F
Flow of the nutrient solution	off
Temperature of the nutrient solution	> 95 ± 1°F
Power supply to the hydroponic habitat	off

Environment

The HHMS will operate under the following environmental conditions:

Temperature	90°F
Humidity	80%
Pressure	2 Atm
Corrosives	Salt water

The communication subsystem will be submerged 8.23 m into salt water.

Size

The HHMS must be designed so that it (dismantled if necessary) will fit into a 30.48 X 40.64 X 10.16 cm^3 briefcase [1]. The briefcase, provided by NASA, is

waterproof and will be used for transport between the surface and the underwater habitats.

Power

The HHMS can either be self-contained or may obtain power from standard wall outlets (110 V) in the underwater habitats.

DEVELOPED IDEAS

Temperature Sensors

The HHMS requires two temperature sensors, one designed to monitor the atmosphere and one designed to monitor the nutrient solution. The performance specifications for the two sensors are similar; the only difference is the environment in which the sensor will be placed. The atmospheric temperature sensor will be located in a gaseous environment, while the nutrient-solution temperature sensor will reside in a liquid medium. The systems that were considered included a thermocouple and two sensors that incorporated thermistors.

Thermocouple. A thermocouple consists of two dissimilar metals that are connected at both ends to create a circuit. When one of the ends is heated, the thermocouple generates a measurable current. The current can be analyzed to determine any change in temperature [2]. The main advantage of a thermocouple is that it does not require any power source to create the current. However, a thermocouple requires complex adaptive circuitry to ensure that the only current produced is due to the change in temperature at the point being monitored. In addition, a thermocouple may create noise and leak current into the circuit because of its highly sensitive nature. Another disadvantage is that the current produced is not linearly related to the change in temperature.

Thermistors. A thermistor is a variable resistor that changes resistance as the temperature changes. Adaptive circuitry is considerably less complicated than that required by a thermocouple. A thermistor, existing alone, does not change resistance with a temperature change. It requires a simple circuit (Wheatstone bridge) consisting of matching resistors allowing the thermistor to vary its resistance [2].

The first sensor employing a thermistor is a simple circuit custom-designed by our design team. It involves utilizing two thermistors in the medium being monitored. Instead of measuring current through just one thermistor, the currents through both thermistors of a specific sensor would be measured and compared. The

advantage of this design is that it would not demand complex adaptive circuitry. However, this design would require extensive testing in order to produce a calibrated temperature sensor.

The other thermistor system is prefabricated by Radio Shack. This system became the sensor of choice because of its many advantages. Prefabrication meant that it had already been tested and calibrated. This sensor also has an added benefit: a visual display of the current temperature that flashes when temperatures ranges are exceeded. Most importantly, it comes with plastic-covered probes that can be used in both the atmosphere and the nutrient solution with little chance of corrosion.

Flow Rate Sensor

The primary requirements of the HHMS flow rate sensor were specified by NASA. The flow rate sensor's input/output ports had to be 1.27 cm or 1.90 cm inches in diameter so that it could be installed in-line with NASA's system. In addition, the flow rate sensor must be sensitive to flow rates below the standard nutrient-solution flow rate: 0.1 L/min [1]. Three flow rate sensors were investigated, two custom-designed by our team members and one prefabricated by State Instruments in Tampa (Figure 1.1).

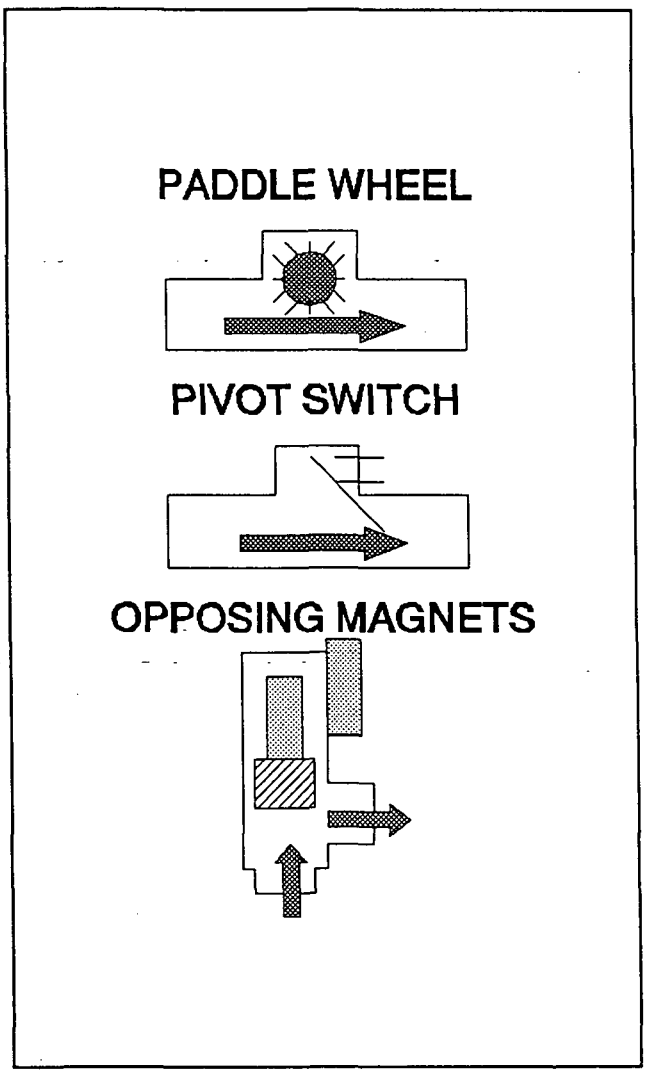

Figure 1.1 Flow Rate Sensors

Paddle Wheel. One of the flow rate sensors designed by our team consisted of a paddle wheel enclosed in the outer housing. A small current generator would be attached to the axle of the paddle wheel. The current generator would be in series with a relay switch and a power source. Flow of the nutrient solution turns the paddle wheel which generates a current. When the flow stops, the relay switch closes a circuit that would send a signal indicating that flow has ceased.

Pivoting Stem. The second custom-designed flow rate sensor employs a pivoting stem which would have one end in the nutrient solution and the other acting as a switch. The switch would be held in the closed position by a light spring. The presence of flow would force the switch to open. Without flow, the spring would close the circuit, and a signal would be generated.

Opposing Magnets. The flow rate sensor manufactured by State Instruments utilizes a pair of opposing magnets that close a switch in order to send a signal. One of the magnets is fixed while the other is mobile. The mobile magnet is attached to a piston which is located in the path of the flow. When a medium is flowing through the sensor, the piston magnet is forced upward against the opposing field of the second magnet. When the flow stops, the magnetic field of the fixed magnet drives the piston magnet downward. The magnetic field of the piston magnet closes the hermetically-sealed reed switch [3].

The most significant problem with both the paddle wheel and pivoting stem would be designing water-sealed switches without interfering with the movement of the wheel or stem. The flow rate sensor developed by State Instruments solves this problem by using magnetic fields to close its circuits. It has no metal parts in contact with the nutrient solution, resulting in minimal corrosion. This dual-magnet design was chosen for the HHMS.

Communication Link

The output from the hydroponic habitat sensors must be communicated to the human living quarters through twenty meters of sea water. Three conceptual designs were considered: sonar, light, and electric signals.

Sonar Signals. A sonar communication system would require encoding the information obtained from the sensors. After the signals have traveled to human living quarters, they would then be decoded. The main advantage of this design is that it does not require any hardware that would have to run between the habitats through sea water. Disadvantages include the complexity of encoding and decoding the signals and the interference of background noise. The cost of sonar equipment is also beyond the budget of our project [4].

Light Signals. A design similar to the sonar method incorporates a laser that would send information in the form of coded light pulses. A disadvantage of this design is that light can only travel a short distance in water before it is considerably scattered. During periods of turbulent water conditions, the range of the laser pulses would be further reduced. Fiber optics would solve the range problem, but is also cost prohibitive [4].

Electrical Signals. The third method of communication investigated would be the use of a multi-lead electrical cable. The major disadvantage of a cable is the possibility of water seeping into the cable and causing a short in the circuit. However, a cable has significant benefits over the other two designs considered. The design would be simple enough to complete during the semester time constraint, and it could be purchased within the scope of our budget [5].

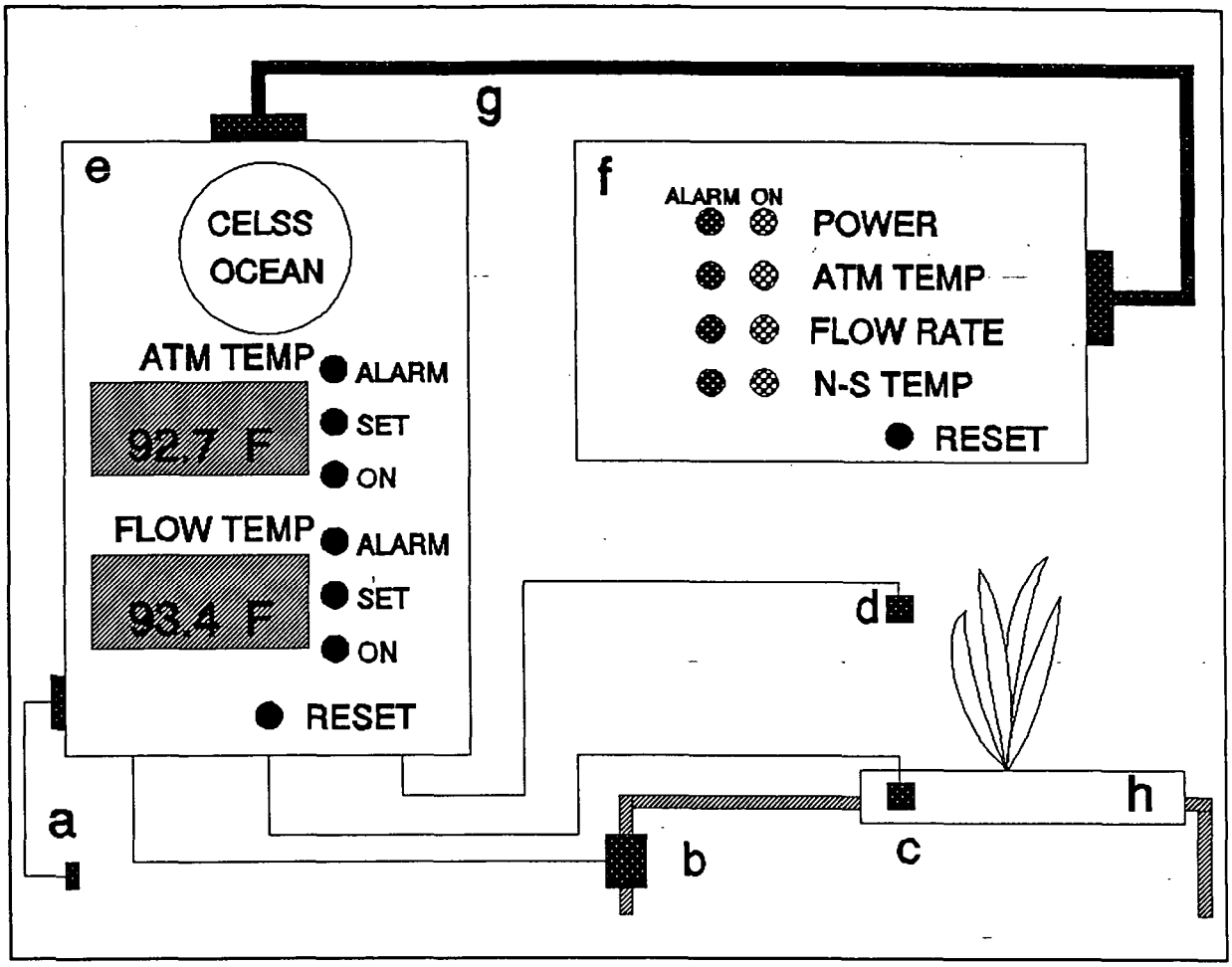

Fig 1.2 HHMS: a. power source; b. flow rate sensor; c. nutrient-solution temp sensor; d. atmospheric temp sensor; e. central processing unit; f. alarm unit; g. underwater cable; h. nutrient solution

The final design is illustrated in Figure 1.2. The atmospheric temperature sensor probe will be placed in close proximity of the plants. The probe of the nutrient-solution temperature sensor will be positioned directly in the nutrient solution flowing in the troughs underneath the plants. The flow rate sensor will be installed in-line with NASA's flow rate sensors.

Temperature Sensors

The sensor chosen to monitor both the atmosphere and the nutrient solution is the Archer TL83969 module. This module has a measuring range of 68°F to 230°F

with a resolution of 0.1°F. At 1.5 V while using a 3 meter cable, the temperature sensor is accurate to ± 1°F within the range of 95°F to 167°F. Sample temperatures can be sensed either every second or every fifteen seconds. The alarm output is 2 kHz for one minute. Working voltage is set at 1.5 V with an average current of approximately 10 mA. The battery life is approximately one year.

The Archer TL83969 also includes a visual digital display of the temperature (Figure 1.2). At the left of the digital display are three buttons that are used to set the temperature alarm and turn on the sensor. The sensor is designed to flash the digital display when preset temperature ranges are exceeded.

The module has eighteen pins which are used for such tasks as setting high and low temperature thresholds, sending alarm signals, turning off alarm signals, and resetting switches. Our design uses seven of the pins:

Pin 1- Connected to a ground.
Pin 2- Closes switch to set or reset the temperature alarm.
Pin 3- Closes switch to set high temperature; must press and hold the button connected to this pin to set.
Pin 4- Closes switch for the temperature display.
Pin 6- Sends alarm signal of 1.5 V.
Pin 14- Changes the units of temperature display from °C to °F and visa-versa.
Pin 16- Connected to 1.5 V source.

Flow Rate Sensor

The flow rate sensor, prefabricated by State Instruments, consists of a piston attached to a magnet (Figure 1.3). The piston is displaced by flow of a liquid medium. The magnet then activates a hermetically-sealed reed switch isolated within the sensor's body. When flow falls below 0.1 L/min, an opposing magnet is used to force the piston downward, which deactivates the switch. Any pressure drop is low because the flow-sensing element moves out of the flow path after actuation [3].

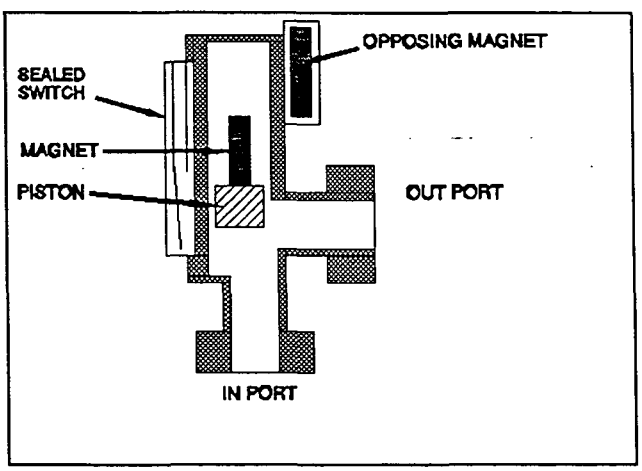

Figure 1.3 HHMS Flow Rate Sensor

Central Processing Unit

The central processing unit will be located in the hydroponic habitat (Figure 1.2). Its function is to processes all of the information obtained from the sensors. When the specified parameter ranges are exceeded it sends the appropriate signals through the communication cable and sounds its own audible alarm. Corrosion of internal parts in the central processing is prevented by silicon seals.

Face. The temperature displays for both the atmospheric and nutrient-solution temperature sensors are mounted on the face of the central unit. A reset button that turns off the audible alarm is located below the temperature displays.

Temperature Sensor Adaptation. The output voltage of the temperature sensors is too low to send to the alarm unit located in the human living quarters. To adapt the temperature sensors to our system, photoelectric transistors were inserted between the modules and the central unit. The output from the transistors close the corresponding circuits allowing a voltage source to send the signals to the alarm unit (Figure 1.4) [6,7].

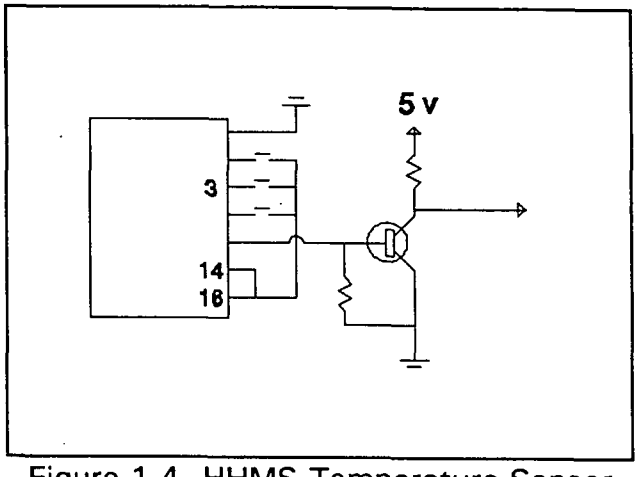

Figure 1.4 HHMS Temperature Sensor Adaptation

Alarm Unit

The alarm unit (located in the human living quarters) will provide both visual and audible warnings to the scientist when environmental conditions are potentially harmful (Figure 1.2). It receives signals from the central processing unit by the communication cable. Like the central processing unit, it is sealed with silicon to prevent corrosion.

Face. The face of the alarm unit consists of two sets of LEDs: four green and four red. An LED from each set represents one parameter being monitored. A green LED indicates acceptable ranges while a red LED indicates a potentially harmful condition. An audible alarm (that sound when ever any of the red LEDs are turned on) is also mounted on the alarm unit.

Power Sensor. The electrical power sensor is incorporated into the alarm unit. Electrical power is monitored by sensing a voltage signal directly from the AC/DC converter discussed in the power supply section. When a voltage signal is no longer detected (power outage), a 4.5 V signal is produced by an invertor powered by a 9 V battery which is part of the backup power supply discussed later.

Reset Circuit. The reset button on the alarm unit is a momentary switch that shuts off both the audible alarm and out of range LEDs immediately. When the momentary switch returns to the open position, the alarm and LEDs remain off. This is accomplished by a circuit consisting of one D-flip-flop chip, one three-input OR gate, and two two-input AND gates [7]. Figure 1.5 is a schematic of the reset circuit.

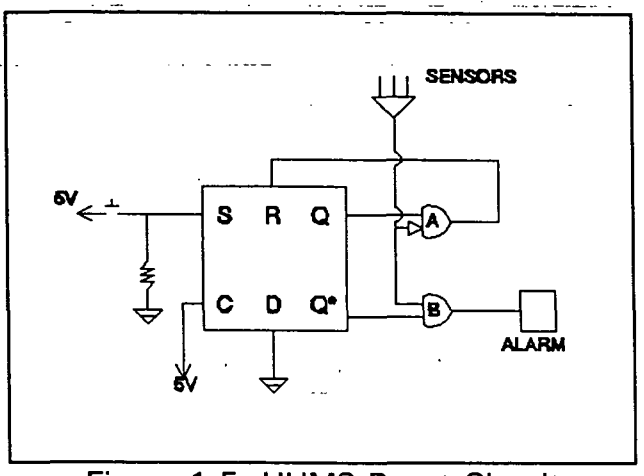

Figure 1.5 HHMS Reset Circuit

The D-flip-flop chip has six pins:

S - Set (high or low)
R - Reset (high or low)
C - Clock (high)
D - Data (low)
Q - Output to reset (high or low)
Q* - Output to audible alarm and LED (high or low)

The three sensor signals enter the reset circuit through the three-input OR gate. Whenever one of the sensors sends a high signal, the signal is split into two signals and sent to the two AND gates. The signal that arrives at the "A" AND gate is inverted and compared with the signal from the Q pin of the D-flip-flop chip. Depending on the combination of signals the "A" AND gate sends out a high or low signal to the R pin of the D-flip-flop.

The signal that arrives at the "B" AND gate is compared with the signal from the Q* pin of the D-flip-flop. If both of the signals are high, the "B" AND gate sends a high signal to the audible alarm and the out-of-range red LED.

Communication Subsystem

Cable. Signals will be communicated between the two habitats by a nine-lead underwater cable purchased from Aqua-Tech. Specifically, it contains seven 18-gauge conductors and one RG59 coaxial cable. It is 1.43 cm in diameter, 100 yards in length and has a resistance of approximately 1 Ohm. Each conductor is surrounded by a polyurethane jacket in order to protect it from the sea water [8].

Signalling. One lead of the communication cable is responsible for each of the four sensors. The temperature sensors and the flow rate sensor send a 5 V signal when their preset parameters are exceeded. The power sensor, on the other hand, sends a constant signal; a power outage is indicated when the signal stops. Any

signal below 1.5 V is considered an open circuit. This adaptation prevents any accidental triggering of the leads in the underwater cable caused by possible noise.

Power Supply

The power for the central processing unit is a standard wall outlet: a 110 V AC source that supplies power to the entire hydroponic habitat. An AC\DC converter changes the 110 V AC power to 9 V DC with a 800 mA current. The alarm unit is also powered by this AC\DC converter (Figure 1.6).

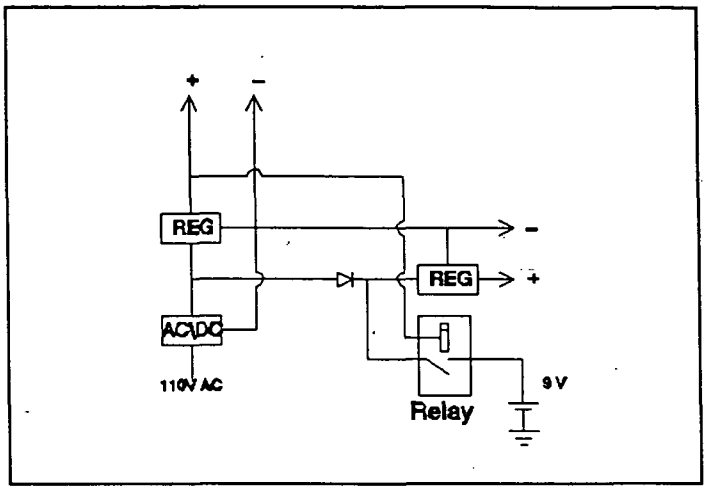

Figure 1.6 HHMS Power Supply Circuit

TESTING PROCEDURE AND RESULTS

Procedure

Atmospheric Temperature Sensor. The atmospheric temperature sensor was tested by simulating the threshold temperature (95°F). The sensor probe and a thermometer were enclosed in a glass container. The temperature of the system was slowly raised by blowing the glass with a hot-air source. Once the threshold temperature was established as read from the thermometer, the sensor had one minute to set off the appropriate light and the audible alarm.

Nutrient-Solution Temperature Sensor. The nutrient-solution temperature probe was placed in a bowl of hot tap water that was 3°F below the threshold temperature (95°F). A thermometer was used to measure the temperature of the water. Additional hot tap water was slowly added to increase the temperature to the threshold. Once the threshold was reached, the sensor was allowed one minute to set off the appropriate light and the audible alarm.

Flow Rate Sensor. The flow rate sensor was attached to a water pump. The pump was turned on to represent the normal flow status. When the pump was turned off to simulate no flow, the sensor was given ten seconds to detect the lack of flow and set off the appropriate light and audible alarm.

Power Supply Sensor. The power supply monitor was tested by plugging in the monitor to a wall outlet to establish the standard condition. It was unplugged to fabricate a power outage. The power supply monitor had ten seconds to set off the appropriate light and audible alarm.

Results

Each sensor was tested by its appropriate procedure twenty-five times for four days. The results were as follows:

	DAY 1	DAY 2	DAY 3	DAY 4
ATM TEMP	100%	96%	100%	100%
N-S TEMP	100%	100%	92%	96%
FLOW RATE	100%	100%	100%	100%
POWER	100%	100%	100%	100%

CONCLUSION

Testing suggests that the Hydroponic Habitat Monitoring System will significantly improve the quality of hydroponic plant production by ensuring that the scientist is immediately informed if any environmental conditions reach harmful levels. An additional advantage of the HHMS is that the scientist may use his time more efficiently during the day because tasks such as monitoring temperature are automated. The presence of HHMS will also increase the quality of the research by providing a means of monitoring experimental variables that cannot be detected by the scientist while he in the human living quarters.

In the future, a HHMS may be essential to the survival of crew members during extended space missions. During these missions, the space available to grow crops will be very limited as well as the total biomass of the system and the amount of man-hours allocated to food production. Under such extreme conditions, crop yield must reach its maximum potential. A HHMS, providing early warnings to crew members when potentially harmful situations arise, would indirectly help maximize the available resources.

RECOMMENDATIONS

Suggestions for further improvement of the HHMS are as follows:

1. Adapt the HHMS for communication with more information than just warning signals, such as current temperatures and flow rate panel readings.

2. Incorporate a memory (in the alarm unit) to store information, such as how often the parameters exceed their limits and the date and time of those warnings.

3. Monitor additional environmental parameters such as humidity, oxygen content, carbon dioxide content, nutrient-solution salt concentration, and nutrient-solution pH.

4. Monitor plant physiology parameters such as chlorophyll production, nutrient uptake, and gas exchange.

5. Design a Hydroponic Habitat Control System (HHCS) that could adjust any out of range environmental conditions.

HUMAN HEALTH MONITORING SYSTEM

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ABSTRACT

In order to insure the safety of the crew member - Mr. Dennis Chamberland - in the underwater, controlled ecological life support system at Key Largo, Florida, a health monitoring system must be integrated into the living habitat to monitor essential atmospheric parameters. This system must continuously monitor these parameters and promptly alert Mr. Chamberland if they could physically harm him. Because these proper parameters are crucial for the success of current and future exploration of space by mankind, this human health monitoring system must be reliable and accurate.

The most important health issues include carbon monoxide, smoke, fire, and airflow. Air will be pumped down to the underwater living habitat - the Jules - from the atmosphere above. Mr. Chamberland expressed concerns about a carbon monoxide build-up as well as an accidental halt of his continuous air supply. Therefore, a First Alert CO detector and a Rotron Model 2A airflow switch and vane were incorporated into the health monitoring system. In addition, Mr. Chamberland was worried about fire and smoke in the Jules. An ordinary dryer thermostat to sense heat and a First Alert smoke detector were also integrated into the health monitoring system.

To reduce the complexity of the four different detectors and alarms, a signalling system was designed to unite all four alarm signals into one unit. This signalling system will send both audio and visual warnings to Mr. Chamberland and alert him to any of the four sensing devices setting off the alarm.

After preliminary testing in the Fall 1993 semester, the results showed a high rate of reliability for each individual sensor along with the central processing unit and signalling system. A three month test period in Spring 1994 further investigated the performance of the whole system and allowed time to modify and refine the design to maximize its dependability during the three month underwater experiment beginning November 1994.

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INTRODUCTION

For any type of Controlled Ecological Life Support System (CELSS), the presence of humans and other living organisms requires a continuous monitoring of certain physical, chemical, and other environmental factors that could potentially harm the health of the inhabitants. The underwater OCEAN project sponsored by NASA, requires the occupant - Mr. Dennis Chamberland - to stay in an underwater habitat for three months. Because of the length of time and type of environment Mr. Chamberland will be exposed to, concerns about his well-being are of the utmost importance. The four major areas of importance are carbon monoxide, smoke, fire, and continuous airflow.

The purpose of this design project is to create a monitoring system that will detect dangerous levels of carbon monoxide and smoke, high temperatures from fire, and the ceasing of the continuous air supply. This paper presents several important areas of development of the human health monitoring system. First, the evaluation of several concept ideas are carried out to decide on a specific design concept. Second, the detail design and construction of each of the four sensors, central processing unit, and signalling system are described. Finally, the complete system is tested,results are recorded and recommendations are offered for future investigation into this type of human health monitoring system.

DESIGN SPECIFICATIONS

The following list are specifications describing the final design:

1. Environment
   - The system will function in these conditions:
     temperature range - 0°C to 85°C
     pressure range - 1 atm to 2 atm
     high humidity - approximately 80%, habitat is open to ocean
     dirty/dusty - blower system could contaminate habitat
     corrosion - exposure to ethylene and salt water
2. Performance
   - This system monitors CO levels in the air to alarm the inhabitant before dangerous levels become lethal. Depending on the concentration of the carbon monoxide and amount of time it is in the atmosphere, the monitor will set off the alarm. For instance, at 100 ppm of CO, the alarm will sound within 90 minutes.
   - This system monitors the air flow to make sure that some amount of air is constantly being pumped into the habitat.
     Note: The air flows in one of two ways:
     A. It is shunted from the plant habitat and 100% of it is blown into the living quarters (while he is present in the living quarters) producing a maximum flow rate of 35 ft/min.
     B. 50% is blown into the living quarters and 50% is blown into the plant habitat (while he is in the plant habitat) producing a minimum flow rate of 8 ft/min in the living quarters.
   - This system has a fire sensor (triggering at 120° F) and a smoke detector (triggering at 1.75% ± 0.6% particles/volume).
   - The performance of this system will be reliable for at least 100 days while Mr. Dennis Chamberland is in the underwater habitat.
3. Materials
   - The materials used in this project corrosion resistant such as plastic boxes, brass screws, and plastic coated telephone cables.
   - The electronics involved (i.e. alarms) are sealed off from the atmosphere by a silicone rubber sealant.
4. Weight
   - Central Processing Unit -- 8 lbs
   - Signalling System -- 2 lbs
   - Four sensors -- 3 lbs
5. Size
   - CO monitor -- 5.25"dia X 2.0"thickness
   - Flow meter -- 2.0" X 1.5" X 1.25"
   - Vane -- 2.69" in length
   - Fire/smoke detector -- 7.5" X 4.25" X 2.375"

- CPU -- 7.5" X 4.25" X 2.375"
- Signalling system -- 5.75" X 3.0" X 2.0"

DEVELOPED CONCEPT IDEAS

The main task is to construct a system that will effectively monitor the health of Dennis Chamberland in an underwater habitat. The following five concept designs were considered:

1. ARM SENSOR - an arm-mounted device to measure hazardous gas concentrations
2. BIOLOGIC - an animal physically weaker than a human that could be monitored for carbon monoxide poisoning
3. VITAL SIGNS - monitoring human expired air and vital signs
4. SENSORS/ALARM - CO, air flow, smoke and fire detectors with an alarm system
5. INTEGRATION - an alarm system integrated with detection equipment already present in the habitat such as the carbon dioxide monitor and oxygen monitor

Evaluation matrices were created to compare these designs against the product design specifications. Initially, the arm sensor was set as the datum against the other systems to be graded. The sensors and alarm system scored comparably with the integration system. Next, the integration concept was chosen as the datum and the matrix was reevaluated as shown in Table 2.1. The results indicated that the sensor and alarm system was rated the best. Therefore, the final system chosen to be designed was the sensor and alarm system based on research of Dennis Chamberland's specific requests for a CO monitor, airflow monitor, and fire and smoke detectors and the results of the matrix evaluations.

The primary reasons for rejecting the other concept ideas were the following:

1. ARM SENSOR - Dennis Chamberland must wear the device on his body 24 hours per day. In addition, to incorporate all the sensors into a single device which is small enough to be worn on the arm would be extremely difficult as well as costly.
2. BIOLOGIC - The animal must be given a certain amount of attention per day for feeding and cleaning.
3. VITAL SIGNS - Dennis Chamberland must set a certain amount of time aside per day to measure his vital signs.
4. INTEGRATION - No access to the monitoring equipment used by NASA.

TABLE 2.1 Matrix Evaluation

CONCEPTS SPECS	ARM SENSOR	BIOLOGIC	VITAL SIGNS	SENSORS/ ALARMS	(DATUM) NASA SYSTEMS
QUALITY	S	-	S	S	
MAINT.	S	-	S	S	
WEIGHT/SIZE	+	-	S	S	
CUSTOMER CONSTRAINT	-	-	-	+	
POLITICS	-	-	-	+	
MANUFACT. FACILITY	S	+	S	S	
SHIPPING	S	-	-	S	
COST	-	+	S	S	
PERFORM.	S	-	S	S	
LIFE IN SERVICE	S	-	S	S	
INSTALLING	+	+	S	S	
ERGONOMIC	S	-	S	S	
MATERIALS	S	-	S	S	
DISPOSAL	S	-	S	S	
TESTING	S	-	S	S	
ENVIRON.	S	-	S	S	
STANDARDS/ SPECS	-	-	-	S	
KNOWLEDGE	+	S	-	S	
TOTAL +	3	3	0	4	
TOTAL -	4	14	5	0	
TOTAL S	11	1	13	15	

(+) -- better than datum; (-) -- worse than datum; (S) -- same as datum

CO Monitor

The purpose of the carbon monoxide monitor is to continuously monitor the concentration of CO in Dennis Chamberland's living quarters. Dennis Chamberland expressed concern about the amount of CO that may be included in the air that will be pumped down into the living quarters.

The CO monitor is not set to alarm at a specific ppm of CO because it is rate dependent. Therefore, it will alarm at different ppm's within a certain amount of time. For example, at 100 ppm, the alarm will sound within 90 minutes.

Jeff Brown of Davis Instruments [1] offered information about what levels of CO may be harmful to the human body. Brown stated that the standard setting for CO monitors is at about 20 ppm. At 35 ppm of CO, a person can remain in this atmosphere for up to eight hours without harmful effects. However, a person can only stay in 200 ppm of CO for about two to three hours before he or she begins to feel symptoms of nausea, headache, and/or fainting. Some companies will set their CO monitors as low as 9 ppm depending on how long the employee stays in the quarters. When asked how long the average person should wait until returning to 35 ppm of CO after being exposed to 8 hours of it, Brown stated that since the body does not keep CO in its system, only an hour of fresh air would be enough to recuperate and re-enter the 35 ppm of CO.

Not convinced with what Jeff Brown had said about not requiring a detoxification for CO, a second opinion was investigated. Dr. Roger Berthols [2], a pathologist of toxicology, researched the topic and found that the half-life of carboxy-hemoglobin is about 3 - 4 hours. Therefore, taking into consideration that someone can stay in 35 ppm for 8 hours, then this person should breathe fresh air for four or five times the half-life. As a result, according to Dr. Robert Berthols, the toxicology expert, Jeff Brown is incorrect in his assessment regarding detoxification of carbon monoxide. Therefore, for the sake of using the most accurate information concerning the health of Dennis Chamberland, this design project will follow the information provided by Dr. Berthols.

Detailed Design. The First Alert CO detector senses dangerous levels of CO well before the conditions become lethal [3]. This particular CO detector requires a SensorPack module which consists of both a 9V battery as well as a CO sensor. The SensorPack should be replaced about every two years (required by UL) or when the alarm sounds once a minute. All the parts within this model have passed UL tests. The CO detector has a test switch button built into it in order to test the reliability of the detector without actually having to raise levels of CO within the

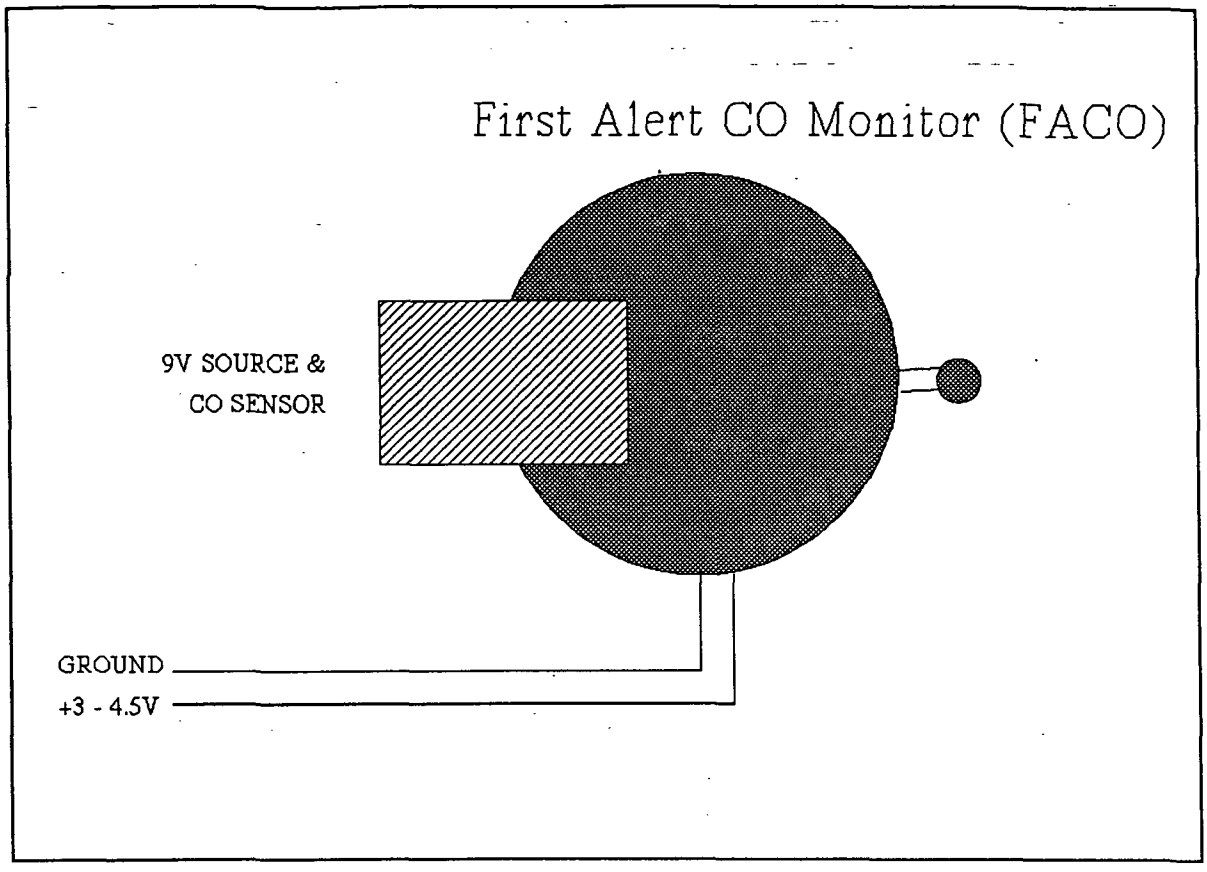

Figure 2.1 Carbon Monoxide Monitor.

living quarters. According to the manual, this monitor has not been investigated for detecting CO below 100 ppm. However, a conversation with a First Alert technician, Joanne Langstrom revealed that her First Alert CO detector installed at her home alarmed at 10 ppm [3].

Construction. The First Alert horn was disconnected permanently. Next, one of six wires inside a telephone cable was soldered to one of the First Alert buzzer leads. The other end of this telephone cable, was soldered at the number five pin in a female nine pin D connector. This connector was sealed with a silicone rubber sealant to keep any salt air from entering. Finally, the connector end of the cable was attached to the signalling system. Refer to Figure 2.1 for an illustrated view.

Airflow Switch and Vane

This device was discovered during a conversation with Dr. Hirko in the UF Aerospace, Mechanics & Engineering Sciences Department [3]. An airflow switch

without a vane was found in the machine shop at this department. Further research with the manufacturers of this device revealed the simplicity of the device and its easy adaptability to an alarm system circuit. Therefore, the decision was made to incorporate it into the human safety package for NASA's OCEAN Project. The specific device ordered was the Rotron Model 2A airflow switch and vane from the Rotron Manufacturing Company [4].

This device monitors the continuous airflow pumped into the living quarters of the underwater habitat. If the airflow ceases completely, the device will set off an alarm warning Dennis Chamberland to immediately investigate why the airflow stopped. If Dennis Chamberland is unable to solve the problem, he will have approximately (48 hours) before the air in the living chambers is no longer life-supporting. This should give him ample time to notify the scientists and technicians on land. However, if he cannot communicate to them, he will have enough time to make arrangements to leave the habitat.

Detail Design. The physical dimensions of the vane and airflow switch are shown in Figure 2.2. The direction and flow rate of the airflow allows a maximum change of 35° in the position of the vane. The socket screw will be utilized to mount the switch housing to the vertical downstream airflow duct.

The airflow switch and vane operates adequately in ambient temperatures of -35° to 85°C. The contact arrangement of the switch is single pole double throw and no other contacts are available. The closing contact will be obtained when the switch actuates. The rating for the switch is 1 amp at 28 volts DC.

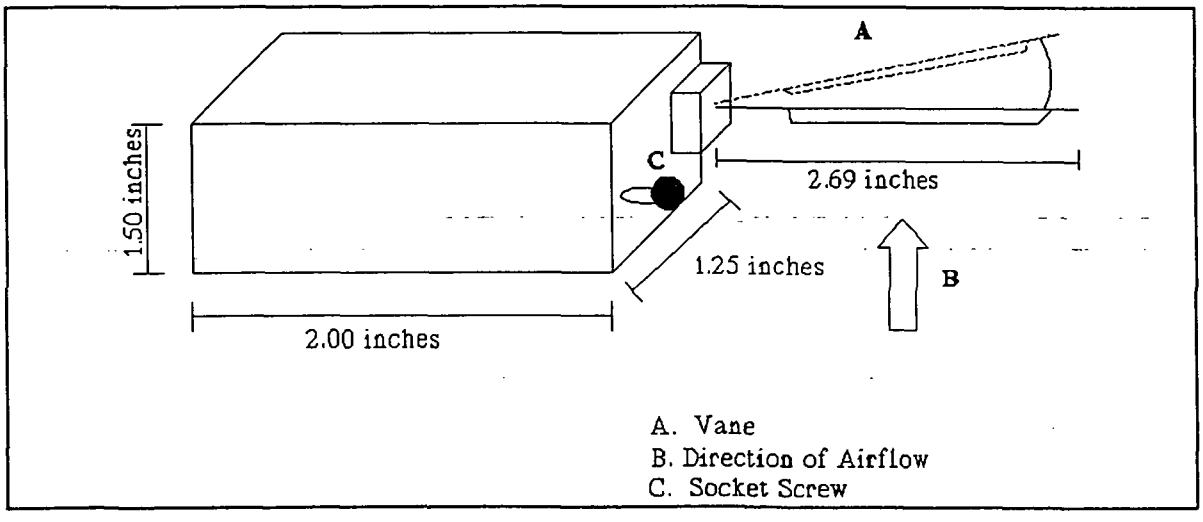

Figure 2.2 Rotron Model 2A Air Flow Switch and Vane.

The switch housing is made of glass-filled nylon and aluminum. The cover is a black enameled aluminum. The actuating arm and lightweight vane are made of stainless steel. The snap action switch mechanism is housed in a plastic enclosure. The spring material in the switch is berylium copper and the contacts are of pure fine silver.

The vertical-down airstream vane (type 1350) actuates at 720 ft/min ± 20% and deactuates at 685 ft/min ± 20%. These values were obtained by the manufacturer through a laboratory test set-up for controlled laminar flow conditions. These experimental results were used only as a guide for the human safety package requirements [4]. The exact requirements for the human safety package were determined through simulated airflow testing. The results are described in the testing procedure section of this report.

Construction. The major components involved in completing the construction of the airflow switch and vane to the central processing unit are shown in Figure 2.3. The electrical connection was developed by soldering two wires, one to the normal closed terminal (power out of the switch) and one to the common terminal (power into the switch) located inside the switch housing. The terminals each have a 0.06 inch diameter soldering hole. The two wires were fed through the nylon bushing at one end of the switch housing. The nylon bushing was coated with a silicone rubber sealant to aid in the stability of the wire attachment to the two terminals. These wires were two of six total wires enclosed in a telephone cable. The cable end opposite of the airflow switch has the two wires soldered to a 9-pin D-type subminiature connector at pins one and five.

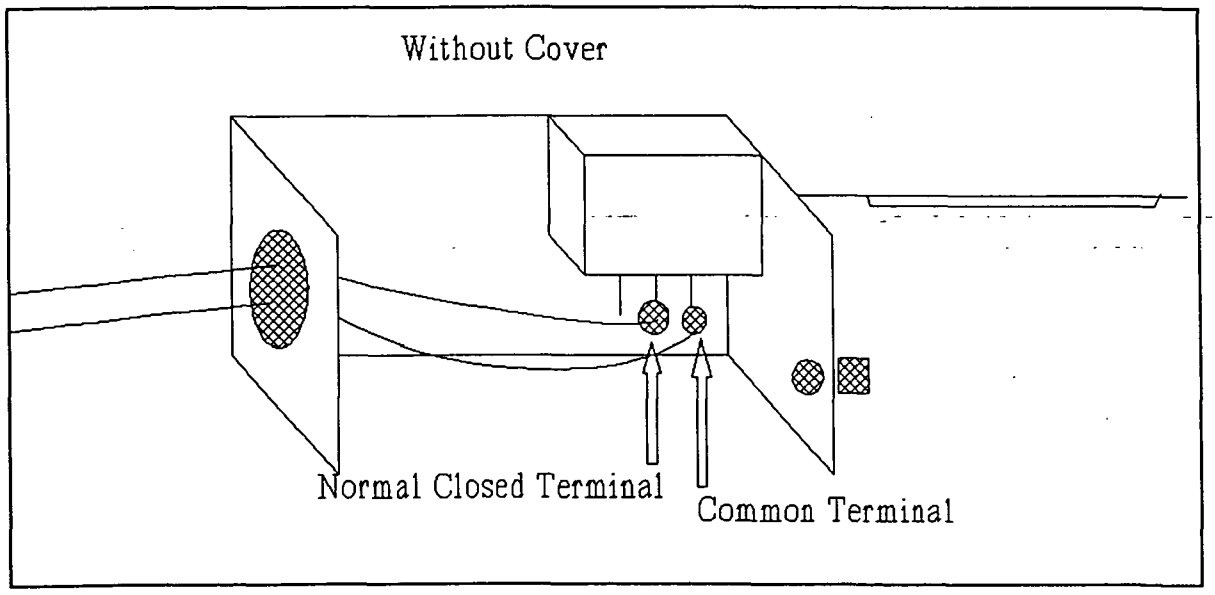

Figure 2.3 Wiring of Airflow Switch.

Fire and Smoke Detectors

A significant concern in the underwater habitat is fire. Dennis Chamberland relayed this concern to our group. Both fire and smoke detectors are utilized in our design. A sensor for elevated temperature and a sensor for smoke particles are both necessary for early detection.

Two types of smoke detectors are available commercially. They are classified by method of detection. One type is photoelectric. Normally a light source is directed to bypass a light-sensitive photocell. When smoke particles are present light is reflected into the photocell thus triggering the alarm. A second type of smoke detector is an ionization model. A small amount of radioactive material is encased in a chamber which ionizes the air in the chamber. This ionized air can then support current flow. As smoke enters the chamber the flow of current is interrupted and the alarm sounds.

Two types of fire detection methods were also considered. Both react to temperature, but one alarms at a predetermined temperature while the other alarms if a certain rate of increase of temperature is monitored. A fixed temperature detector consists of a single sensing element that closes a switch at a certain temperature. A rate-of-rise detector is more complicated often consisting of a sensor and processing circuitry.

Detail Design. The photoelectric detector was incorporated into the safety system. Speed of detection is the most important concern. Ionization models detect smoke from fast burning fires quicker, but only 3 to 4 seconds [6]. Photoelectric models respond 24 minutes earlier than ionization models to slow burning fires [6]. Photoelectric models are more expensive than their ionization counterparts, but their quicker response time is more important than the added cost.

Given the difference in complexity and ease of installation the fixed temperature model was used. A common dryer thermostat(LD 120) with a bimetallic element was purchased. It activates the alarm at 120°F and inactivates the alarm after the temperature drops by 15°F. The alarm threshold for temperature was determined by consulting Dennis Chamberland and considering fire safety guidelines [7].

Construction. Smoke and fire sensors have been installed in a plastic box (7.5" X 4.25" X 2.375"). Each sensor protrudes from the box lid with a maximum protrusion of 0.625". A 9-pin male D-type subminiature connector has been placed in the lower left corner of the unit. To install the fire sensor a hole was created with a hole saw and the sensor was then fastened to the lid with brass machine screws and nuts. The hole was sealed with silicone. The smoke sensor was installed in a layered manner. The smoke sensor is composed of a pc board and a smoke chamber. The chamber was disassembled and another hole was

made in the lid using a hole saw. The chamber was reassembled with the lid in between the upper and lower portion of the chamber. Ordinary super-glue was used to fix the layers together. Additionally, a hole was drilled to accommodate the test button for the smoke sensor. The hole was sealed with a rubber patch from a bicycle tube repair kit. Refer to Figure 2.4 for an illustrative view.

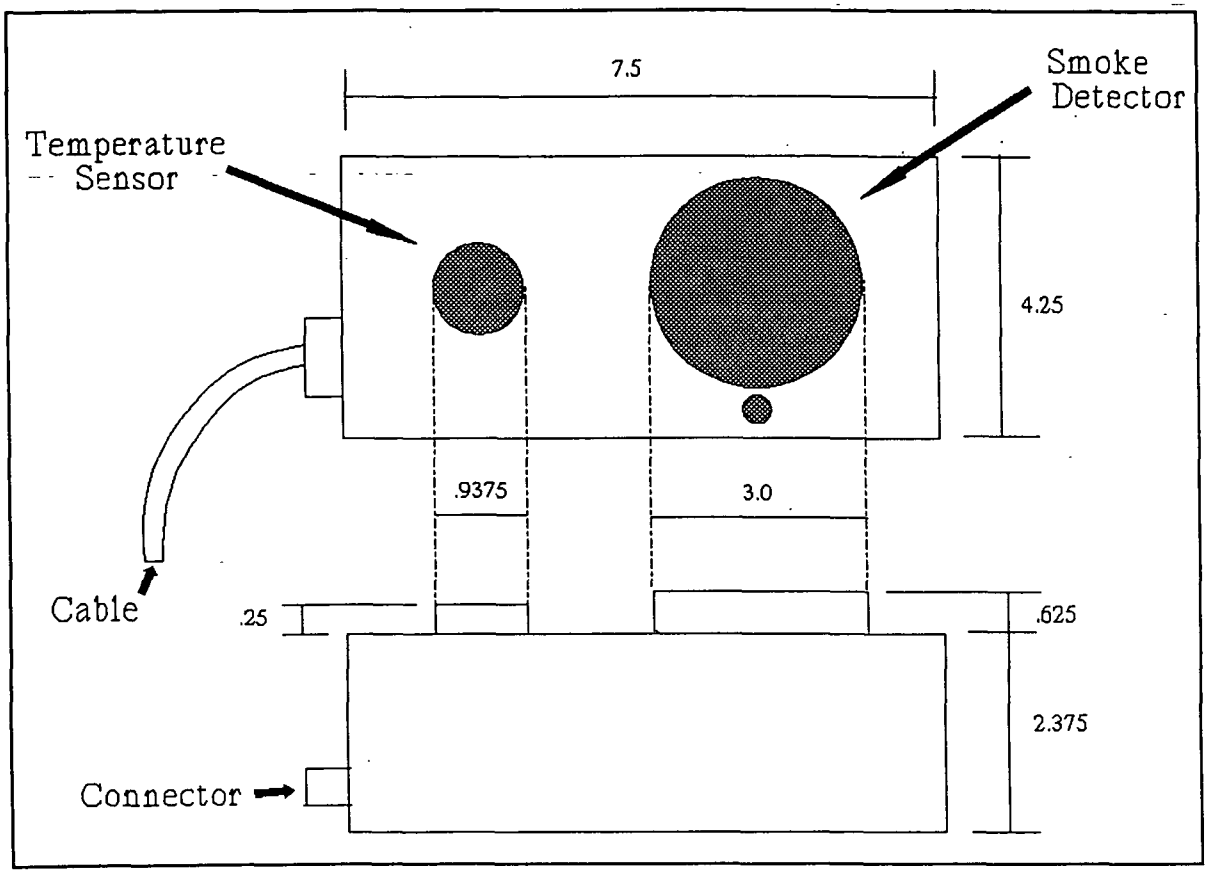

Figure 2.4 Smoke and Fire Sensor

Two electrical leads were required for the fire sensor. Each was soldered to the 9-pin connector. One inputs 5V DC to the sensor which acts as a normally open switch. When the temperature reaches 120°F the switch closes allowing the signal to pass through to the CPU. The smoke sensor is powered by a 9V battery (estimated life span = 1 year) secured in the box by a rubber strap. A single output to the 9-pin connector was wired. The output varies from 3V to 4.5V DC. The lid will be sealed to the box with silicone and secured with brass screws to prevent corrosion. Refer to Figure 2.5 for an illustrative view.

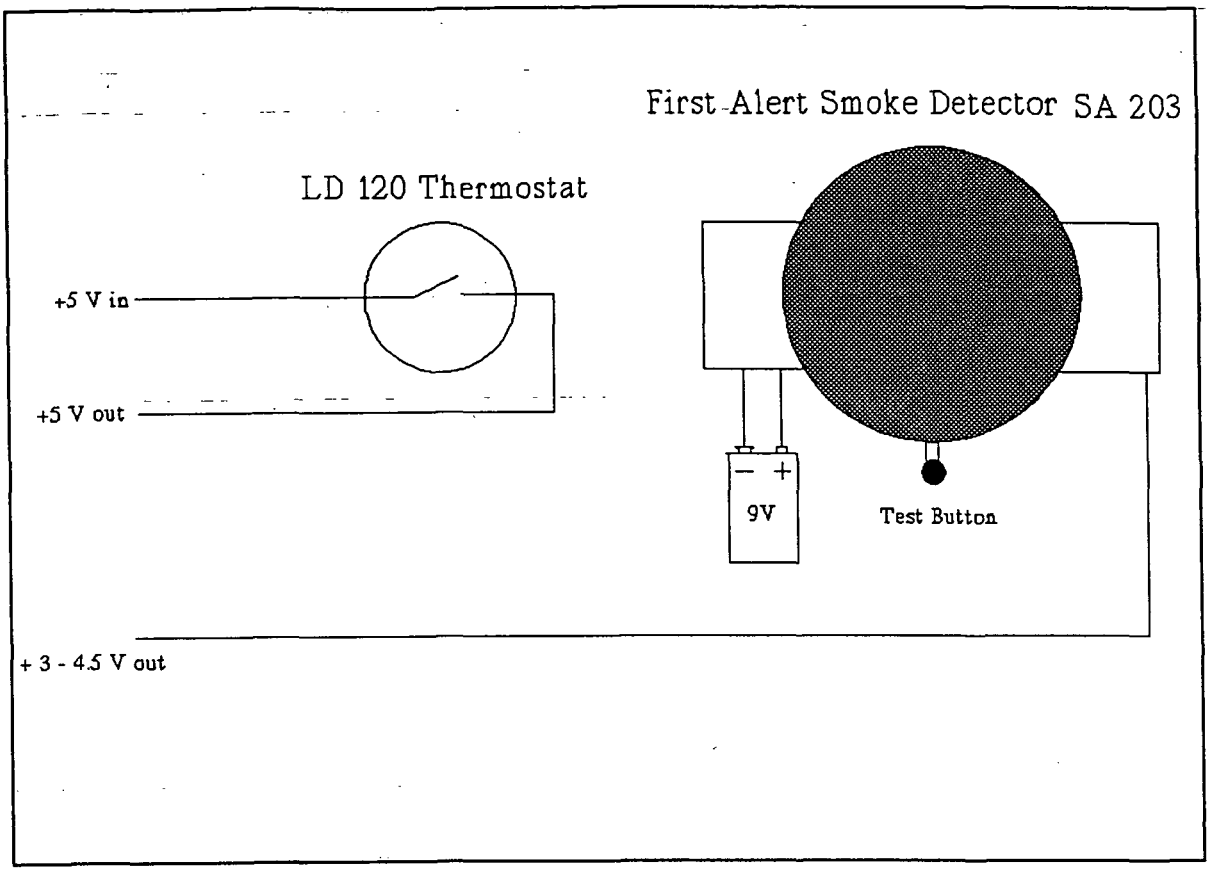

Figure 2.5 Wiring Diagram of Smoke and Fire Sensor.

Signalling System

The signalling device is an integral part of the human health monitoring system. The purpose of this device is to alert the user, Dennis Chamberland, if any of the sensing devices previously discussed are triggered. There will be a single safety unit placed in the living quarters. This unit has LED's for each of the different monitoring systems as well as a main buzzer and LED. This system must be able to wake Dennis Chamberland up if there is a problem, yet able to be silenced once he is aware of the problem. It will be placed near the sleeping area of Mr. Chamberland so that it may be easily heard.

Detail Design. The design of this device was created by the members of the group. The design incorporates visible signals for each of the different alarms as well as a main buzzer and LED that are powered when the CPU sends a signal to the device. Yellow LED's were used for each of the different sensing devices because of visibility. A green LED is mounted on the box for an indication that the power is on. A large red LED was used for the main signal. Each of the LED's has

the current regulated by a specific resistor. The yellow LED's utilize 2.2K ohm resistors and the green and large red LED's utilize 1.8K ohm resistors. The 6V DC buzzer was chosen because it would be functional with the voltage level that we were using as well as the sound level it provided. The connectors, 9-pin male D-type subminiature, were used because of the number of leads that were required for this device. Seven of the nine leads were used to run the signalling device.

The signalling device will be connected to the CPU via cable. The cable used is 6-conductor 24AWG telephone station wire. Two of these cables have been wound together so that seven leads are available. There are 9-pin female D-type subminiature type connectors on each end, one to connect with the signalling device, and one end to the CPU.

Construction. The signalling system is enclosed in a plastic box purchased from Radio Shack. The outer dimensions are 6" X 3.25" X 2". It is closed by using brass screws as well as silicone sealant. On the left hand side of the box, as shown in Fig 2.6, there is a 9-pin male D-type subminiature connector. Seven of these pins have wires soldered to them. On the top surface as shown in Fig 2.6, there are four yellow LED's, one for each of the different signalling devices. Holes approximately 0.25" in diameter were drilled. These holes were sealed once the LED's were mounted with silicone to prevent any leaks from the atmosphere. All of the LED's were mounted in this same manner. There is also a green LED to indicate if there is power to the system. The main buzzer and large red LED are located on the top surface as well. Additionally, a toggle switch was installed to disable the buzzer while any problems in the habitat are remedied. After the alert is over, it is necessary to flip the switch back to the ready position to prepare for the next signal.

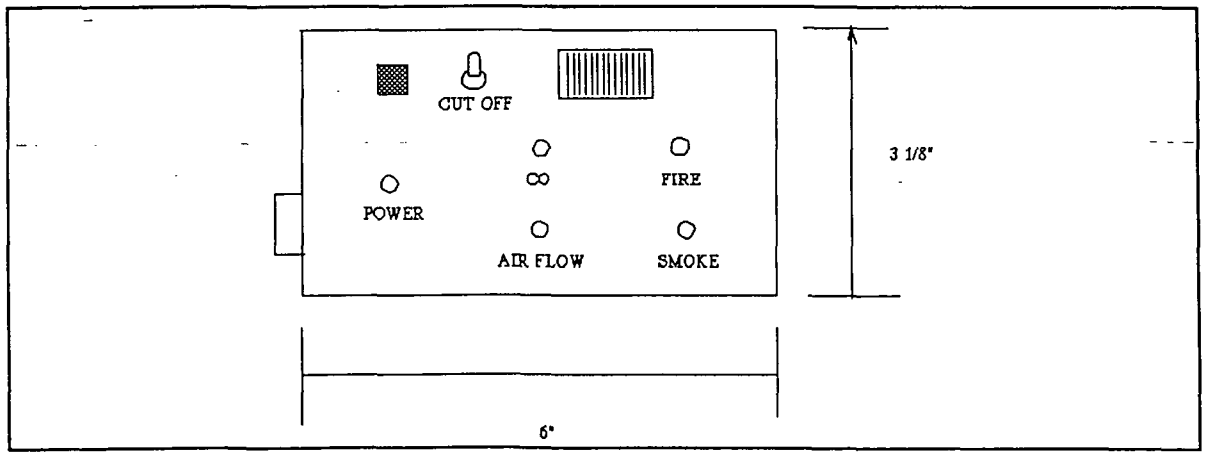

Figure 2.6 Signalling System.

The cable used to connect the signalling system to the CPU is approximately 15 feet. The two sets of the telephone wire were tie-wrapped together. Then seven wires were soldered to each of the 9-pin female D-type subminiature connectors. Four of the wires in one cable are used for the four different sensor LED's. In the other cable, three of the wires are used; one wire for the power indication LED, one ground wire, and a main signal wire to power the red LED and buzzer. The wiring diagram for the signalling system is shown in Fig 2.7.

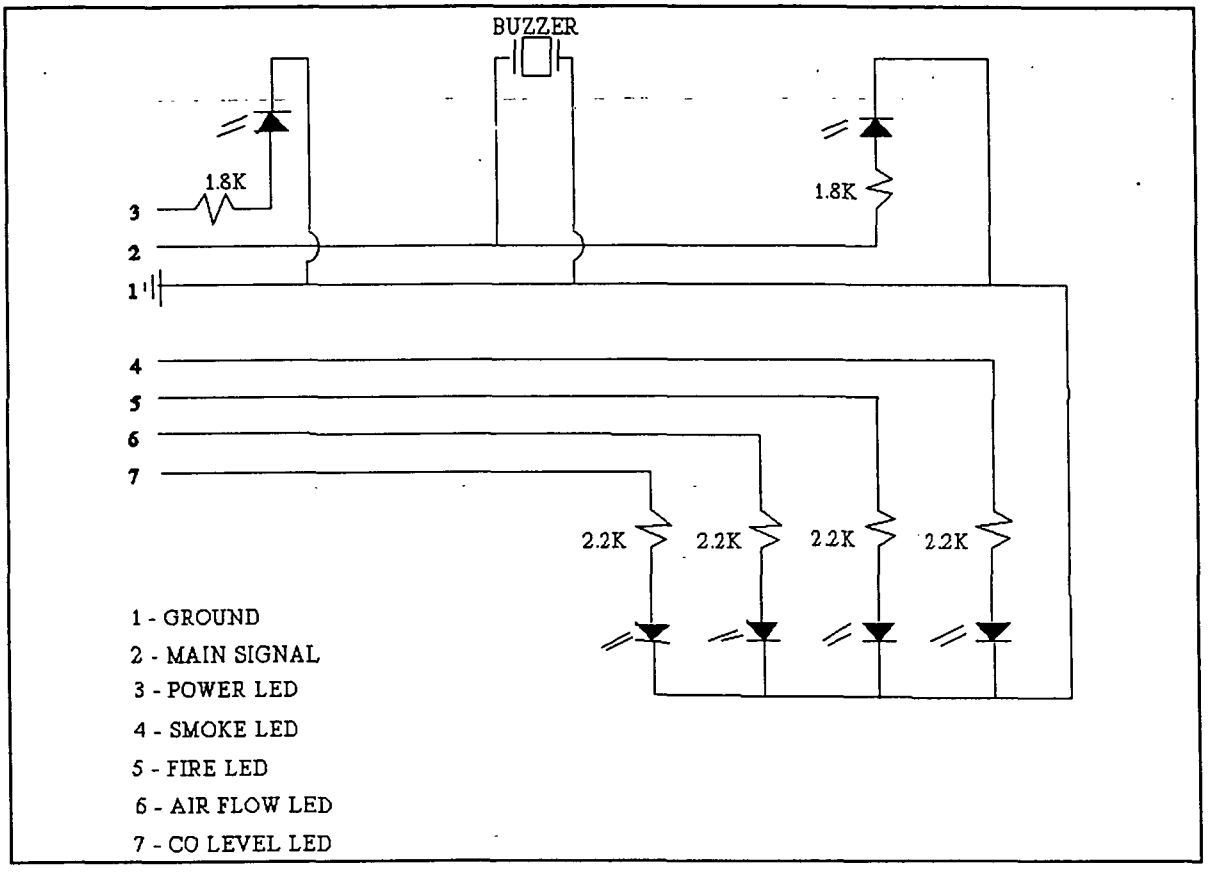

Figure 2.7 Wiring Diagram of Signalling System.

Central Processing Unit

The central processing unit (CPU) is the main device in this project. This will continuously be functioning to insure the safety of the occupant. It takes the signals from each of the four different sensors, decides which is triggered, and sends a signal to the signalling device indicating which of the devices has been triggered. For the two devices that need power to the circuit, the CPU will send power to them. It transforms the power from the outlet provided in the living

quarters to the 5V DC power that runs the system.

Detail Design. The CPU is powered by a 110V supply from within the habitat. An AC/DC converter is used to power the system by DC power. The converter used transforms 110V AC power to 12V DC power at one amp. A voltage regulator to change the 12V power to 5V power has been installed. A 5V DC relay has been installed to be triggered if the power ceases. This relay will set off the main LED and buzzer using an internal power supply (9V battery) if the power fails. The DC power from the input is divided among two of the different sensors, the air flow switch and the fire detector, as well as the alarm system. When the circuit closes on one of these two devices, the 5V signal returns to the CPU then triggering one of the signalling system's sensor specific LED's. When there is power to the system, the green LED is lit. The smoke detector and CO detector send signals of 3-4.5 V to the CPU. These signals then are sent to the signalling system and each of the individual LED's.

Construction. The CPU has been placed in a project box purchased from Radio Shack. The outer dimensions are 7.5" X 4.25" X 2.375". On the left hand side of the box are three 9-pin male D-type subminiature connectors; one for the CO monitor, one for the air flow detector, and one for the fire and smoke detector. On the right hand side of the box is another 9-pin male D-type subminiature connector for the signalling system. Also on the right side of the box is the power input wire. This is shown in Figure 2.8.

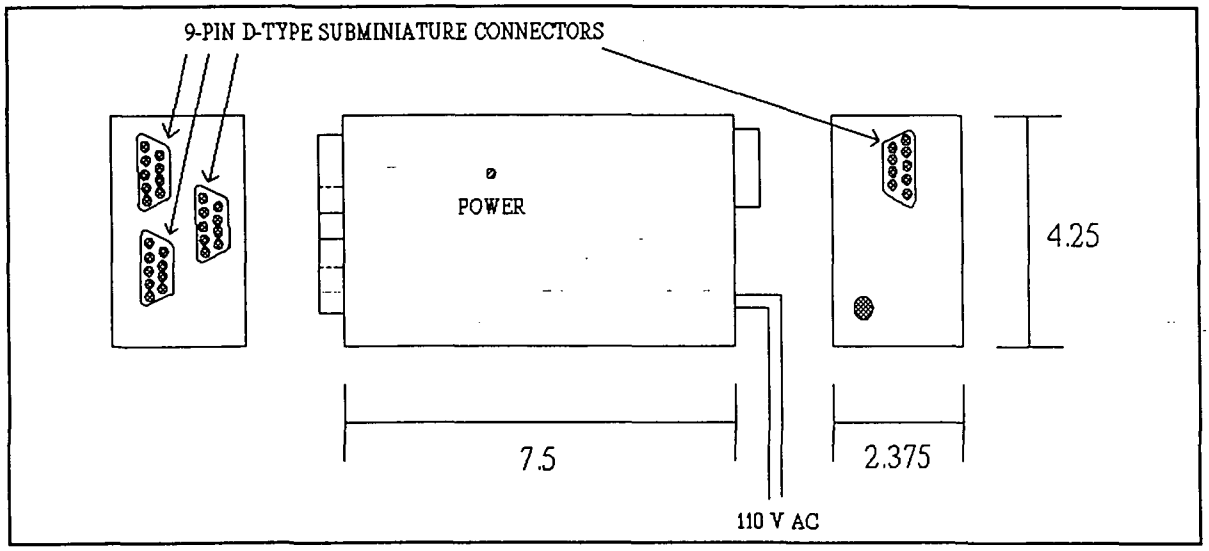

Figure 2.8 Central Processing Unit.

This power goes into the box directly and then into the AC/DC converter. The power that comes out of the converter is reduced from 12V to 5V with a voltage regulator. This regulator has a heat sink attached to dissipate accumulated heat. There is a 5V DC relay that will switch if the power goes off. This will allow the power signal from the internal 9V battery source to be sent to the signalling device if needed. The 5V power is then run into a breadboard which is where most of the circuitry is located. A power signal is run through a 1.8K ohm resistor then to a green LED to indicate that the power is on. There are two leads that run 5V output to the air flow switch and fire detector. All the connections to the four different sensors and the signalling device are through 9-pin male D-type subminiature connectors. All the voltage inputs from the sensors are run in a series of diodes to function as OR gates. These voltage signals are then sent to the main LED and buzzer and to each of the sensor specific LED's. The wiring diagram is shown in Figure 2.9.

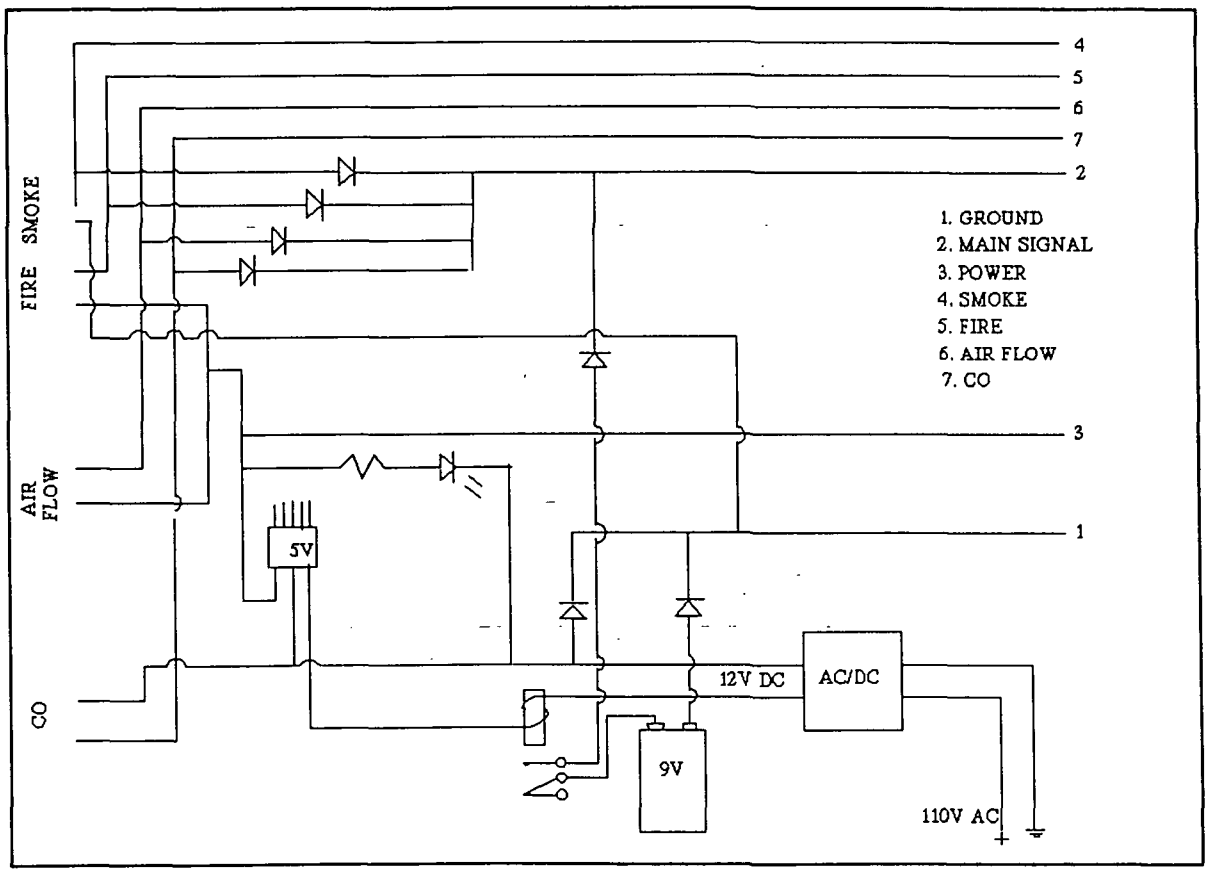

Figure 2.9 Wiring Diagram of Central Processing Unit.

TESTING PROCEDURES

Preliminary Tests - December 1993

Preliminary testing of the performance of the human health system included the following criteria:

1. Tested system over a period of three days.
2. Ran two tests per hour for five hours.
3. Kept the system plugged in during the five hour periods.

Each of the four sensors were triggered per test run. (See Appendix 2.1 for instructions on assembly of the components of the human health monitoring system). The results for the three days of testing were collected to assess the performance and reliability of the system. This data is shown in tables 2.2, 2.3, 2.4. If a triggered sensor successfully set off the alarm, a plus sign was marked in the data table. Otherwise, a minus sign was reported in the data table. Note: the first day of testing excluded the fire detector because it was not functioning properly.

The following list describes how each sensor was tested per experimental run.

1. CO MONITOR - A test button already incorporated into the design of this monitor was used to test the performance of this sensor. The button was pressed down until a signal was sent to the central processing unit and signalling system. The button, when pressed for 20 seconds, simulated the reaction of the CO monitor to a dangerous percentage of carbon monoxide that would be in the air.
2. AIRFLOW SWITCH AND VANE - A blow dryer was held six inches away from the airflow switch and vane such that the air was flowing in a vertical down direction at an air-speed of approximately 90 ft/min based on the underwater habitat air duct area of 3" by 5". (Note: the surface area of the vane was increased in order to trigger at this flow rate). This velocity was measured by an air flow meter that was obtained from a local air conditioning company [9]. When the velocity from the blow dryer was less than 90 ft/min, the vane returned to the horizontal position opening the circuit and sending a signal to the central processing unit and the signalling system.
3. FIRE DETECTOR - A blow dryer and thermometer were used to produce heat up to 120°F. Once the temperature reached 120°F, the device sent a signal to the central processing unit and signalling system simulating an actual warning that there was a fire.
4. SMOKE DETECTOR - Similar to the CO monitor, this detector also has a

test button incorporated into the design. The button was pressed until a signal was sent to the central processing unit and signalling system simulating a dangerous percentage of smoke was in the air.

5. SIGNALLING - The visual and audio alarms were tested as each sensor was triggered. The performance of the light signals and audio signal were noted as each sensor sent a signal to this system. Next, the main power to the system was tested by unplugging the power supply. If the red LED and audio alarms were triggered, then the signalling system was working properly. Finally, the green LED on the signalling system box was tested for staying on continuously during the six hour periods.
6. CENTRAL PROCESSING UNIT - This system was tested to be sure the green LED stayed on continuously during a six hour period.

Final Tests - Spring 1994

The final tests included keeping the whole system powered from the end of the Fall semester (December 17,1993) to the end of the 1994 Spring semester. Beginning January 4, 1994, the four sensors and alarms were tested twice a day by the above list of testing procedures. All experimental runs were 100% successful.

The vane on the airflow switch will be altered after January 31, 1994 such that its surface area is increased in order to trigger the alarm if the airflow is as low as 90 ft/min. This velocity is not the slowest speed air will flow into the underwater habitat. However, based on how experimental runs on the reaction of the vane by a blow dryer, the minimum 8 ft/min air flow that will flow through the air duct of the underwater habitat could not be simulated. (Recall from the Design Specifications of this report that when Dennis Chamberland is in the plant habitat, 50% of the air will be blown in there and the other 50% will flow through the human habitat causing a minimum flow rate of 8 ft/min through a 3 in.by 5 in. air duct). If he is in the human habitat, the air flow will reach a maximum rate of 35 ft/min. Therefore, based on the limitations of the vane even with the increased surface area, Dennis Chamberland should only use the airflow switch and vane while he is occupying the human habitat.

Table 2.2 Testing Data Day 1

December 5, 1993

		1	2	3	4	5	6	7	8	9	10
Audio	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	-	-	-	-	-	-	-	-	-	-
	Airflow	+	+	+	+	+	+	+	+	+	+
Red LED	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	-	-	-	-	-	-	-	-	-	-
	Airflow	+	+	+	+	+	+	+	+	+	+
Yellow LED	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	-	-	-	-	-	-	-	-	-	-
	Airflow	+	+	+	+	+	+	+	+	+	+
Reset Switch	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	-	-	-	-	-	-	-	-	-	-
	Airflow	+	+	+	+	+	+	+	+	+	+

(+) -- success
(-) -- failure

Table 2.3 Testing Data Day 2

December 6, 1993

		1	2	3	4	5	6	7	8	9	10
Audio	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	+	+	+	+	+	+	+	+	+	+
	Airflow	+	+	+	+	+	+	+	+	+	+
Red LED	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	+	+	+	+	+	+	+	+	+	+
	Airflow	+	+	+	+	+	+	+	+	+	+
Yellow LED	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	+	+	+	+	+	+	+	+	+	+
	Airflow	+	+	+	+	+	+	+	+	+	+
Reset Switch	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	+	+	+	+	+	+	+	+	+	+
	Airflow	+	+	+	+	+	+	+	+	+	+

(+) -- success
(-) -- failure

Table 2.4 Testing Data Day 3

December 7, 1993

		1	2	3	4	5	6	7	8	9	10
Audio	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	+	+	+	+	+	+	+	+	+	+
	Airflow	+	+	+	+	+	+	+	+	+	+
Red LED	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	+	+	+	+	+	+	+	+	+	+
	Airflow	+	+	+	+	+	+	+	+	+	+
Yellow LED	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	+	+	+	+	+	+	+	+	+	+
	Airflow	+	+	+	+	+	+	+	+	+	+
Reset Switch	CO	+	+	+	+	+	+	+	+	+	+
	Smoke	+	+	+	+	+	+	+	+	+	+
	Fire	+	+	+	+	+	+	+	+	+	+
	Airflow	+	+	+	+	+	+	+	+	+	+

(+) -- success
(-) -- failure

CONCLUSION

The results of the preliminary (December 1993) and continuing (Spring 1994) testing show promise in the human health monitor. The recorded data from the tests indicates a 100% reliability except for the fire detector on the first day of testing. However, after the fire alarm was repaired, the device also produced 100% reliability. A continuation of testing in the Spring 1994 semester was vital in establishing more information on how durable and effective this design product will be to insure the safety of Dennis Chamberland and the success of NASA's OCEAN project. The Spring semester also allowed additional time to modify and refine this monitoring system for the finished product.

Although this particular human health monitoring system only measures four areas of concern (carbon monoxide, continuous airflow, fire, and smoke), other human health monitoring systems are certainly not limited to these four aspects. NASA has already integrated a carbon dioxide monitor and oxygen monitor of their own into the OCEAN project. Applications of this type of health monitoring system in future space and underwater missions is an absolute necessity. Without these kinds of monitoring devices, the safety of humans and other living organisms can not be guaranteed in these closed ecological life support systems.

RECOMMENDATIONS

Design Improvements

One problem with the signalling system and central processing unit was distinguishing between the weak visual light signals from the various green, yellow, and red LED's when the alarm was triggered to go off. One suggestion is to purchase colored LED's that can produce a brighter visual signal. Also, incorporating lower resistors into the signalling system and central processing unit circuit design would allow more voltage to reach the LED's, hence producing a brighter signal. Another improvement could be made in the size of cable used to connect the sensors to the central processing unit. At most, only two out of the six wires inside the cable were integrated into the connections between the units. Therefore, a smaller cable could easily replace the current cable size providing more space and easier adaptability with the system.

Testing Procedure

The current design of the smoke and carbon monoxide detectors only allows testing by an experimental button already incorporated into the device. If possible,

obtain smoke and carbon monoxide detectors that can be tested with actual smoke and carbon monoxide particles. This will increase the percentage of accuracy and dependability for a device to detect these dangerous environmental hazards in the underwater habitat. If actual smoke and carbon monoxide is used, completely sealed test boxes will need to be built or purchased, to insure the safety of the humans testing the detectors.

System Additions

This monitoring system was designed specifically for Mr. Chamberland's needs in this underwater habitat. The smoke, fire, carbon monoxide, and airflow monitors are only four of many other sensors that could be incorporated into the design system. Several other crucial concerns that could be implemented into this are a carbon dioxide monitor and an oxygen monitor. Mr. Dennis Chamberland had suggested adding a carbon dioxide monitor that he has already purchased from Honeywell Co. Because of time constraints, this monitor could not be included. However, for future design projects, this sensor could certainly be integrated into the human health monitoring system without much difficulty. Depending on the type of CELSS, priority of the monitors could be shifted to maximize the safety of the living habitants.

With the addition of other sensors into this type of monitoring system, larger boxes for the central processing unit and signalling system would be necessary to incorporate new electrical component connections, visual and audio alarms, and external cable connectors. A power supply providing a larger amount of power may need to be added in also. Finally, if the system increases in size and the physical environment changes, the mounting of the system on to the wall may need to be altered by placing the system on a console for easier adaptability to the surroundings.

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APPENDIX 2.1 Instruction Manual

I. MOUNTING AND ASSEMBLY

First, mount the components of the system. Each component is equipped with hooks for attachment to the carpeted walls. Estimate a central location for the central processing unit. It should be located so that each sensor is within reach of its cord. Choose a location based on the following requirements:

1) The air flow sensor must be located directly in the air flow from the air vent.

2) The combination smoke and fire sensor should be located as close to the ceiling as possible, but at least five feet away from air vents, cooking facilities, light sources and any other heat sources.

3) The carbon monoxide sensor should be located near the sleeping area, but at least five feet away from air vents, cooking facilities, and fluorescent lights.

4) The signalling system should be located near the sleeping area.

The power cord and the cords for each sensor are approximately five to six feet long while the cord for the signalling system is approximately 15 feet.

Once rough locations for each sensor have been located, the CPU may be mounted. Note: Mounting hooks are sharp and could cause injury. Next, mount each sensor within reach of its cord. Note: Each cord is numbered according to its sensor and CPU connections. Choose a location for the signalling system. Plug in the CPU and attach the cords as follows:

1) Attach the #1 cord from the CPU to the signalling system.

2) Attach the #2 cord to the CPU.

3) Attach the #3 cord to the CPU.

4) Attach the #4 cord from the smoke/fire sensor to the CPU.

II. TESTING THE SYSTEM

Unplug the system to check the power loss alarm. While the alarm is sounding flip the cut-off switch. The buzzer will stop, but the main LED will be lit. Reset the cut-off switch.

To check the air flow switch, move the switch against the air flow until the switch clicks and the alarm will sound.

To check the CO sensor, press and hold the test button. It will alarm in 10 to 20 seconds.

To check the smoke detector, press and hold the test button. It will also alarm in the range of 10 to 20 seconds.

To check the fire detector, warm the sensor with hot air or any available heat source. If a thermometer is available, check the temperature when the sensor alarms. It will alarm at 120 ± 10°F. It will stop alarming after the temperature drops 15°F.

If any part of the system does not function properly check the cable connections and repeat the above testing procedure.

If problems persist, replace the batteries in the system (CO detector, smoke detector, and Central Processing Unit). Repeat the testing procedure. This should alleviate any problems.

BLUE-GREEN ALGAE PRODUCTION

Prepared by:

Shannon Gardner

Elizabeth Phillips

Elizabeth Webb

TABLE OF CONTENTS

ABSTRACT

The purpose of this project was to grow Spirulina, a cyanobacteria, under artificial conditions. Spirulina can be used both for an supplemental food source and waste reclamation. The Blue-Green Algae Production design team, BGAP for short, consulted Mr. Dennis Chamberland about project constraints in order to assemble a list of product design specifications (PDS) for direction of the design and construction of this project. Then the team developed ideas and considered various designs for the growth of Spirulina in an artificial environment. A final design which best matched the PDS was selected for use in this project. Procedures were outlined for starting, maintaining, and harvesting a culture. Safety precautions were taken in the design construction, and testing was implemented to ensure the reliability of the design to grow cultures and endure steady operation for a required period of time. Conclusions were obtained from these results, and recommendations made for further study on promising choices for optimization.

INTRODUCTION

During the Fall 1993 semester, the EGM 4000 Engineering Design class at the University of Florida designed projects to be utilized in conjunction with the National Aeronautic and Space Administration's OCEAN Project. This project will be located in Key Largo, Florida for ninety days in the fall of 1994. It is a *Controlled Ecological Life Support System (CELSS) designed to study hydroponic* growth systems in a simulated closed environment for future NASA space projects. Our task was to design and implement systems to be used in this underwater environment.

The CELSS project will study the growth of five edible plants in a hydroponic environment to be incorporated in future space systems. The BGAP group designed and tested an incubator for the growth of Spirulina to supplement these crops. The unit consisted of an outer PVC shell, an inner cast acrylic guide unit, three cast acrylic algae growth tubes, an aeration pump, a fluorescent lamp, and miscellaneous plastic tubing. This incubator successfully grew Spirulina on Zarrouk, an artificial nutrient solution.

PRODUCT DESIGN SPECIFICATIONS

A complete product design specification for the Blue Green Algae Production Unit is as follows:

Performance	Continuous production of cyanobacteria for use both as a food source and a resource recovery system: optimal - 25 $g/m^3/day$.	
Environment	Temperature range:	optimal - 35 to 37°C total - 18 to 40°C
	pH:	optimal - less than 10.8 total - 8.3 to 11
	Salinity:	optimal - 20 to 70 grams/liter total - 2.5 to 270 grams/liter
Life in Service	90^+ days. Over design for 6 months of service.	
Maintenance	Initial start up procedure Routine harvest of the algae	
Target Product Cost	Less than $1000.	
Shipping	All components will be delivered to the CELSS site via the students involved. Pump and lighting unit will be dry boxed prior to submersion. All other components will not be packaged before being submersed underwater.	
Packing	Waterproof pouch for the algae inoculum. Dry box pump and lighting system. All other components will be open to water.	
Quantity	1	
Manufacturing Facilities	EGM 4000 Design Lab and University of Florida Facilities.	
Size	Maximum size: 18W x 18D x 26H (inches).	

Weight	Recommended maximum is the carrying capacity of one human: 50 pounds.
Aesthetics	Design is compact and fits size requirements. Design is visually pleasing: internal components are housed in an outer shell. No discontinuous parts, rough edges, extraneous members, are used in design.
Materials	PVC for outer housing with cast acrylic growth tubes, ends and inner housing. Plastic tubing, aerator, and fittings to facilitate gas exchange. Fluorescent lighting fixture to supply illumination for algae. pH meter as a sensory device. Secchi disk made from cast acrylic .
Product Life Span	90^{+} days of continuous production.
Standards and Specifications	See FINAL DESIGN section; NASA/USRA standards as described by Dr. Gale Nevill, Mike Hessel and Dennis Chamberland.
Ergonomics	Design is easy to transport, install, maintain, and disassemble.
Customer	Dennis Chamberland in conjunction with the NASA CELSS OCEAN project.
Quality and Reliability	Structure/design: 95% to 99% efficiency and effectiveness Algae production: 66% growth of three separate cultures
Time-scales	September--research, preliminary design October--design, begin construction November--continue construction December--final details, testing
Testing	Structure passed tests for leaks, durability, and water holding capabilities. Incubator growth tested to insure correct operation of unit as designed.
Safety	Project encased in PVC. 110v electrical wiring. Low watt fluorescent lighting for reduced heat and fire safety.

Company Constraints	Time commitments outside project for other classes.
Political and Social Implications	Potential to become an alternate or supplemental food source for extended space travel.
Installation	Installed by Dennis Chamberland at CELSS in Key Largo, Florida.
Documentation	Journal available upon request containing ideas, specifications, and assignments pertaining to experiment to date. Instruction manual for installation and operation of unit will accompany product to CELSS.
Disposal	Recycle unit components as necessary upon completion of project.

DEVELOPED IDEAS

Growth of Spirulina

The key objective of the CELSS project is to maintain the health of individuals and plants in a partially closed system over an extended period of time. Data collected will be utilized in making decisions pertaining to deep space travel and colonization. The optimal selection of plants for an adequate crop yield, crop success rate, and highest nutritional value is crucial to the success of these long range objectives. For a closed system, no one particular crop could satisfy all nutritional needs; therefore a complementary combination of crops should be carefully selected for this purpose [2,3]. Spirulina (blue-green algae) could be an integral part of the plants selected because of it's high protein, vitamin and mineral content [1]. An added benefit is digestibility: Spirulina's cell walls are made of peptidoglycan instead of cellulose [5]. This group's effort was centralized around designing an incubator to grow Spirulina under artificial circumstances.

The design of the incubator was sculpted around Spirulina's requirements for optimal growth [1]. The major factors taken into consideration include:

- growth medium
- light source
- temperature
- exclusion of other organisms
- mixing

Growth Medium. Spirulina, similar to plants, must receive carbon to grow. Two ways can be utilized in providing this element: bubbling carbon dioxide through the medium and seeding the medium with a carbon source such as sodium bicarbonate [5]. The incubator was designed to utilize the latter choice due to the problems associated with carbon dioxide delivery into the CELSS environment. The BGAP group conducted experiments at the University of Florida's Swine Research Unit to decide what artificial medium Spirulina thrived best in. Two mediums were tried in growing Spirulina: Zarrouk and a modified Hoagland solution. The Zarrouk solution called for 16 grams per liter of sodium bicarbonate; since the Hoagland solution had none of this compound, it was added to the medium at 16 grams per liter. It was thought that the utilization of NASA's Hoagland solution would simplify shipment of the incubator. Zarrouk, however provides essential trace elements critical for Spirulina's growth. The BGAP group's experiments indicate that the Zarrouk medium is more adept at growing blue green algae. Please refer to the TESTING section for actual data.

Light Source. Spirulina is a photosynthetic bacteria that uses light to fuel its metabolic machinery. Optimal lighting conditions for this organism could not be found in literature; in fact, conflicting reports on the feasibility of 24 hour light versus a dark period was noted. BGAP's experiments at the University of Florida's Swine Unit indicated that twenty-four hour light from a wide spectrum fluorescent bulb could be used to grow Spirulina effectively. Spirulina can thrive in as little as 100 W/m^2, one-tenth the intensity of full sun.

Temperature. Spirulina can survive at temperatures ranging from 18 to 40° C, with optimal temperatures ranging from 35° to 37°C [5]. As ambient temperature inside the underwater habitat was estimated at 35°C , the design team chose fluorescent lighting to minimize temperature increase inside the incubator.

Exclusion of Other Organisms. Medium control is a key to Spirulina growth. A pH range of 8.3 to 11 and a salinity of 20 to 70 grams per liter are optimal for growth of this particular blue green algae. In fact, Spirulina has been found thriving in alkali lakes in the upper ranges of pH range and salinity concentrations of 85 to 270 grams per liter [5]. In general, the nutrient solution guarantees that the Spirulina will experience the ranges of optimal pH and salinity for growth; these

conditions will exclude almost all other organisms and yield a vigorous culture of Spirulina.

Mixing. To make a dense, harvestable culture, Spirulina requires mixing. If left unmixed, Spirulina would congregate on the surface due to the dissolved oxygen it produces, and not utilize all the volume of the algae incubator. Mixing also helps circulate the Spirulina so that all parts of the culture receive light. Flotation of the algae is handy when harvesting blue green algae because a skimmer can be utilized to recover the product.

Design Considerations

Choice of Outer Housing. The design of the outer housing was dependent upon two of NASA's specifications: the dimensions of the overall unit and the requirement that excess light be contained within the incubator. The choice of opaque PVC pipe with end caps was made because a cylindrical unit would provide one seam, whereas a rectangular box would have multiple seams, ergo more places for leaks. Spherical designs were not considered due to high cost of production.

Choice of Growth Housing. Four structures with various component combinations were originally considered for the algae growth incubator: a sphere, a box, a bowl, and a tube. A box would leave unmixed areas around it's corners, and a bowl would evaporate too much. A sphere was deemed too expensive. The BGAP group chose the tubular design because of the need of easy access to the cultures. Heat transfer considerations were also taken into effect. Airflow around the growth housing could help to cool the unit by convection. Consequently the BGAP group chose a tubular design and cast acrylic due to temperature considerations.

Choice of Lighting. Lighting choices considered include: incandescent, fluorescent, mercury vapor, low pressure sodium and high pressure sodium. Incandescent was not picked due to temperature buildup inside the incubator. Mercury vapor, low pressure sodium, and high pressure sodium were eliminated due to cost constraints. Heat considerations played a major factor in the selection of the light. Fluorescent bulbs produce far less heat than incandescent bulbs, but house a ballast that regulates the voltage and produces heat. Fluorescent illumination was also selected due to illuminance factors and spectrum considerations.

Choice of Mixing Device. Both mechanical and aeration mixing were investigated. Mechanical mixing was eliminated because of the corrosive atmosphere within the CELSS environment. Aeration pumps were chosen because of proven reliability under similar environmental conditions. A down side of aeration is nitrogen

depletion of the medium via NH_4 production from NO_3, and will eventually become inhibitory. In conventionally stirred cultures, availability of carbon inhibits the culture [5].

FINAL DESIGN

The final algae incubator consists of a polyvinylchloride (PVC) outer housing equipped with intake and exhaust ports. The incubator contains three cast acrylic growth tubes, a fluorescent hand lamp, and a cast acrylic inner housing. An aeration pump external to the incubator will aerate the system via air tubes through the intake port.

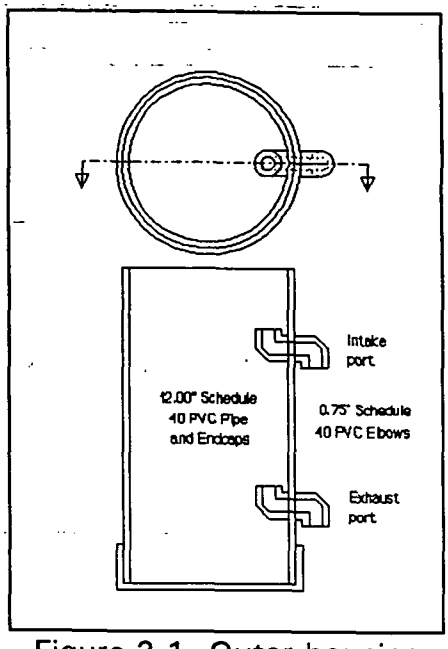

Figure 3.1 Outer housing with intake and exhaust ports.

Outer Housing. The outer housing is made of 12.00 in. diameter Schedule 40 polyvinylchloride (PVC) tubing, capped at the ends with a 12.00 in. diameter Schedule 40 end caps (Figure 3.1). The actual dimensions are given below:

Dimensions	Values
Pipe	
Inner diameter	11.88 in.
Outer diameter	12.75 in.
Height	24.00 in.
Dimensional tolerances	$\pm$0.06 in.
Total volume (with lid)	10,641.27 $in.^3$
End cap	
Inner diameter	12.75 in.
Outer diameter	13.50 in.
Height	4.06 in.
Dimensional tolerances	$\pm$0.06 in.

The housing is cylindrical with the bottom cap glued to the main body tube. The top cap is removable to allow access to the cultures housed inside.

Intake and Exhaust Ports. An intake and exhaust port interfaces the incubator with the CELSS environment. Both ports are made of two 0.75 in. Schedule 40 PVC elbows (Figure 3.1). The exhaust and intake ports are located vertically at 7.00

and 18.50 in. respectively, from the bottom of the capped PVC end. The actual dimensions for the elbows are as follows:

Dimensions	Values
Inner diameter	1.31 in.
Outer diameter	1.06 in.
Height (from center of joint)	1.44 in.

The intake port is designed to accept the power supply to the hand lamp and the air tubes from the pump while allowing fresh air to enter the unit. The exhaust port is designed to expel excess heat and stale air from the incubator. The inside of the exhaust port is also painted black to prevent light from escaping the incubator. An airflow diagram is provided in Figure 3.5.

Growth Tubes. The Spirulina culture will be grown in three cast acrylic tubes (Figure 3.2). Cast acrylic is a clear, durable plastic that can withstand a temperature range of 150 to 200°F (65.6 to 93.3°C). Lids cap the ends of each culture tube to minimize evaporation of water from the culture. The dimensions of the growth tubes are as follows:

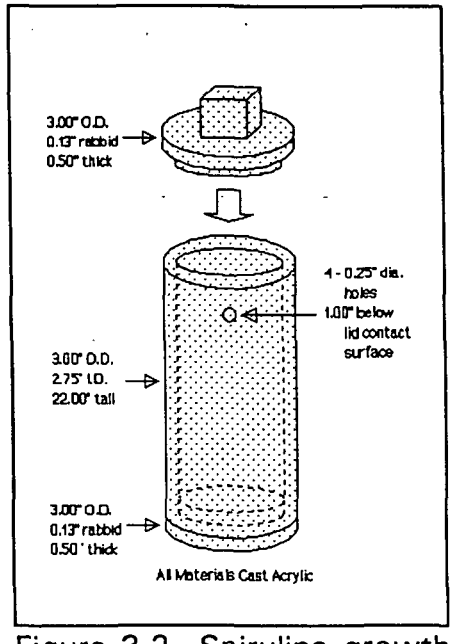

Figure 3.2 Spirulina growth tubes.

Dimensions	Values
Height (without lid)	22.00 in.
Outer diameter	3.00 in.
Inner diameter	2.75 in.
Dimensional tolerance	±0.03 in.
Total volume of tube	130.67 $in.^3$

In addition, each tube has four 0.25 in. diameter holes 1.00 in. down from the lid contact surface for culture aeration purposes.

The growth tubes provide an environment in which several cultures can be grown at one time. This allows for testing of different nutrient solutions and different nutrient concentrations if so desired. As an added benefit, if one culture does not survive, two others still remain. The tubes can also be removed from the incubator for data collection from the culture.

Light. A fluorescent hand lamp manufactured by the Daniel Woodhead Company (Model #1049) was incorporated in the final incubator design. The dimensions of the hand lamp are as follows:

Dimensions	Values
Height	15.50 in.
Maximum diameter	1.31 in.
Cord length	18.00 ft.

The hand lamp selected has a ballast external to the light housing and is 24.50 in. from the end of the power cord. The lamp is completely sealed from environmental effects such as corrosion.

The hand lamp contains a Sylvania F8T5/GRO 8 Watt fluorescent grow bulb, which provides a wide spectrum of wavelengths while focusing prominently on the red end of the spectrum ($\approx$ 700 nanometers). The illuminance of this bulb can be measured by the equation:

$$E = I/d^2$$

where E is illuminance, I is intensity, d is distance from the source, and the units are Watts per meter squared (Figure 3.3). The illuminance measured 220.4 W/m^2, which is equivalent to one quarter of the midday sun's intensity (1000 W/m^2).

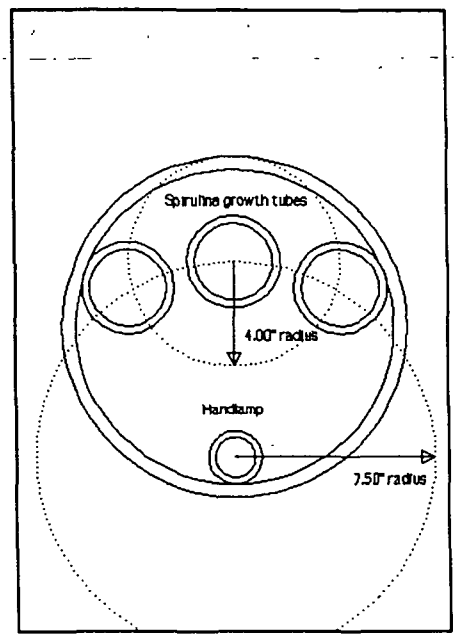

Figure 3.3 Illuminance diagram.

Inner Housing. The inner housing is made from cast acrylic and consists of two 11.75 in. diameter disks, three 3.50 in. outer diameter tubes, one 2.00 in. outer diameter tube, and one 0.13 in. thick rectangular component (Figure 3.4). The dimensions of these components are as follows:

Dimensions	Values
Disks	
Diameter	11.75 in.
Thickness	0.30 in.
Tubes (3.50 in.)	
Inner diameter	3.25 in.
Outer diameter	3.50 in.
Height	15.88 in.
Tube (2.00 in.)	
Inner diameter	1.75 in.

Outer diameter	2.00 in.
Height	15.88 in.
Rectangle	
Length	4.56 in.
Height	0.56 in.
Thickness	0.13 in.
Tolerances	±0.30 in.

A 2.375 in. long by 1.813 in. wide notch was cut from both disks to allow the inner housing to slip into the outer housing, past the intake/exhaust ports. Also, a 0.283 in. hole was drilled in the top disk to allow placement of a thermometer to measure temperature data.

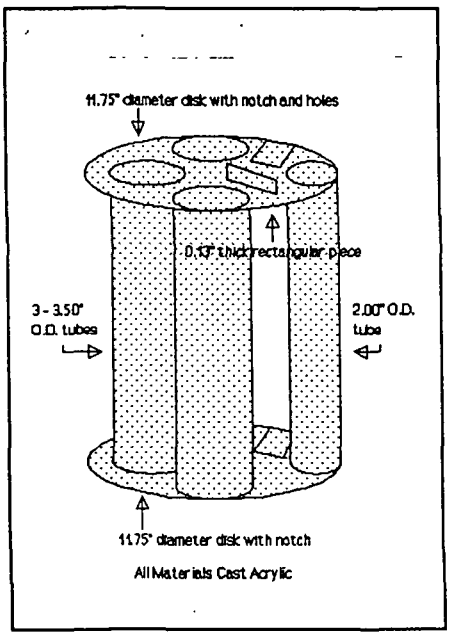

Figure 3.4 Fully assembled inner housing.

The inner housing stabilizes the growth tubes, hand lamp, and pump components within the outer housing as described later in the assembly instructions (Figure 3.6). The housing is removable if needed and in the event one of the growth tubes leaks, will contain the rupture within one of the housing tubes. It is also made of cast acrylic to allow light through to the culture.

Pump.

The growth tubes are aerated by a Whisper 800 air pump. The pump consists of two smaller Whisper 400 models contained in one housing and has an adjustable air flow dial designed to aerate 10 to 135 gallons of water. This component utilizes a dual out take exhaust system. All dimensions of the Whisper 800 are provided below and are measured from the bottom of the air pump:

Dimensions	Values
Length	5.38 in.
Width	4.13 in.
Height	3.13 in.

The dual out take exhaust system of the Whisper 800 provides circulation to both the tubes and the entire incubator. Two separate air control valves were purchased to accomplish this task. The first air control valve provides three outputs from one out take. These outputs were installed directly into the three Spirulina growth tubes. The second air control valve provides two outputs from

the other out take. These outputs were installed to circulate air around the tubes, past the hand lamp, and out the exhaust port (Figure 3.5).

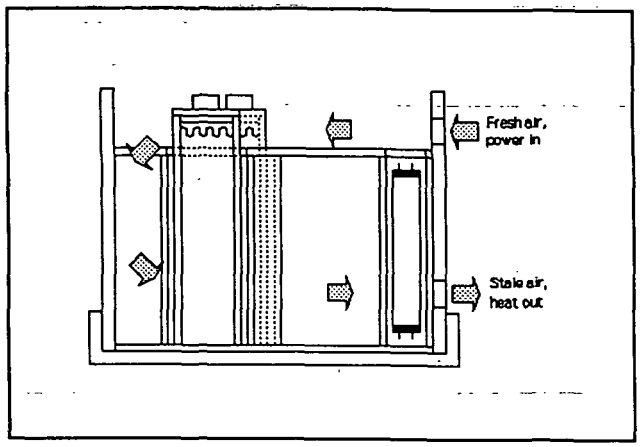

Figure 3.5 Incubator airflow diagram.

Assembly

The following paragraphs provide a parts list of the major components and instructions for their assembly.

Parts list. The following is a list of the major components of the incubator (Figure 3.6):

A) Woodhead Handlamp
B) Cast Acrylic GrowthTubes
C) Cast Acrylic Inner Housing
D) PVC Outer Housing
E) Slots for Growth Tubes
F) Slot for Handlamp
G) Intake Port
H) Exhaust Port

Assembly instructions. The following provides step-by-step instructions for assembly of the major components of the incubator (Figure 3.6):

1) Insert (C) into (D), aligning the notches to pass (G) and (H)

2) Insert (A) into slot (F)

3) Insert each (B) into slots (E)

4) Arrange (A) in slot (F) so that it will radiate light towards each (B)

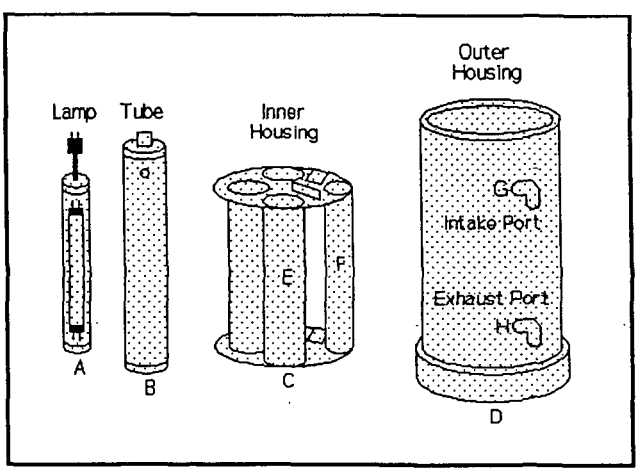

Figure 3.6 Assembly diagram.

Support Equipment

Additional instruments were required to monitor and maintain an ongoing Spirulina

culture. Included are the following:

- pH meter and indicator paper
- Thermometer
- Harvester/bioscum remover
- Secchi disk

pH meter. The HI1270 pH meter was chosen for monitoring the alkalinity of the Spirulina culture. This meter has a range of 0-14 pH, a $\pm$0.01 resolution, $\pm$0.20 accuracy, two point calibration, operating temperature of 0 to 50°C, power requirement of two 1.4 volt batteries with 3000 hour lifetime, and 2.40 x 2.00 x 1.00 in. dimensions. Color indicator pH paper was also provided as a backup to this meter.

Thermometer. A thermometer was needed to measure the temperature of the algae culture as an indicator of algal growth. It was assumed that the temperature of the ambient air was the temperature of the algae medium. The thermometer was mounted in a hole drilled through the inner housing and made easily accessible for daily measurements.

Harvester/bioscum remover. The algae harvester/bioscum remover designed for this project consists of very fine netting on a hoop with a round sponge at the other end of a 23.00 in. handle. The handle is made of plastic tubes around twisted metal wire all coated with liquid plastic in order to prevent corrosion. See Harvest section for implementation of this instrument.

Secchi disk. A secchi disk was fashioned from a long piece of cast acrylic to the bottom of which a circular disk was glued. This disk was divided into four quadrants and painted alternately black and white. A ruler was butted against the base of the disk and glued to the cast acrylic handle. Please see Harvest section for culture measurement instructions.

ALGAE START-UP AND MAINTENANCE

Initial Startup

1) Fill growth tubes to 1/4 full line with algae inoculum

2) Top off clear tube, to full line, with Zarrouk medium solution

3) Start aeration pump. Pump should be aerating enough so that the culture is stirred, but not so that the algae experience vigorous bubbling

(vigorous bubbling promotes nitrogen loss = NOT DESIRED). A good bubbling rate looks like a slowly bubbled fish tank. Remember to adjust the other pump output for cooling of chamber.

4) Turn on light.

Daily Maintenance

1) Measure algae culture density with secchi dish and record. To take a reading of algae culture density, lower the apparatus into the Spirulina medium until the line between the black and white portions of the disk is indiscernible. Take a measurement of the water line on the ruler. Smaller measurements mean a denser culture. If secchi disk measurement exceeds 0.7 inches, proceed to Harvest section. Use the equation

$$\frac{750}{inches\ visibility} = \frac{mg}{\ell}\ dryweight$$

to predict algal culture density and yield.

2) Measure pH, temperature and fill level of algae and record.

3) Look at algae and note color.

4) Adjust pump aeration speed. The denser the culture, the more vigorous the culture should be aerated.

Harvest

Harvest one tube per day, even if more than one tube becomes "ripe" at a time. Algae will wait without experiencing detrimental effects.

1) Sink harvest screen apparatus in culture.

2) Turn off aeration pump.

3) After 30 minutes to 1 hour, harvest algae by scooping organisms with the inserted harvest screen apparatus.

4) Take secchi disk reading. Figure out how much water should be added to make secchi disk read in the 2.5 to 3.0 inch range. Pour out appropriate amount of old nutrient solution.

5) Clean sides with cleaning apparatus provided.

6) Renourish by adding Zarrouk solution to fill line.

7) Add sodium bicarbonate in proportion to how much algae is harvested. Every 2 grams of algae harvested contains 1 gram of carbon. For every 2 grams of algae harvested add 7 grams of sodium bicarbonate. Remember to account for bicarbonate added in fresh nutrient solution. (16 grams/liter)

SAFETY AND TESTING

Safety

The major safety considerations of the Spirulina culture are as follows:

- Culture integrity
- Human consumption
- Toxicity

Culture Integrity. As mentioned in the specifications, Spirulina grows well at a pH range of 8.3 to 11.0. In fact, almost all other microorganisms are inhibited by such a high pH, therefore ensuring a virtual monoculture [5]. This elimination of other cultures ensures that the harvested biomass will not contain other microorganisms that could prove toxic to humans.

Human consumption. As a precaution, Spirulina should be incorporated into human diets slowly, so as not to cause gastric upset. Consumption of the Zarrouk grown Spirulina is looked upon with caution, as no testing of this culture has been performed by the BGAP group.

Toxicity. Humankind has consumed Spirulina since ancient times. Accounts of Aztec Indians consuming a green scum that abounded on Lake Texcoco were reported by the Spanish conquistadors [1]. This green scum was Spirulina, and still thrives on Lake Texcoco today. The Mayan culture constructed ponds explicitly for the growth of Spirulina. The Kanembu tribe to this day consumes Spirulina from Lake Chad. Commercial production of Spirulina today takes place in Mexico, Taiwan, Thailand, California, Japan and Israel. Worldwide production of Spirulina for human consumption spans 35.6 hectares of area with an output of 850 tons of dry product per year [5]. With so many people eating Spirulina, it is the authors' opinion that if this particular cyanobacteria were toxic, someone would have heard of it by now.

An additional concern about Spirulina and gout was expressed during conversations with NASA scientists. Gout can be induced by the excessive consumption of purine chemicals which make up half the bases of DNA and RNA. There have been reports of microbial single cell proteins causing this condition. Bacterial single cell proteins and Spirulina have approximately the same length DNA and RNA; however since a Spirulina cell is physically much larger than single cell proteins, it is thought that the ratio of nucleic acids to cell mass is much less in Spirulina than in single cell proteins. In other words, because there are fewer cells per unit volume, one ingests less nucleic acids eating Spirulina. Nucleic acids comprise 4.5% of the chemical composition of this particular organism [1,5]. Please refer to the Chemical Analysis Appendix for a detailed compositional breakdown.

Testing

Medium Test. Results of the growth test of Spirulina using a modified Hoagland solution and Zarrouk medium are reported as follows:

Table 3.1 Test results for growth of Spirulina in Zarrouk and Hoagland media

Date	Day	Zarrouk (in)	Hoag (in)
10/23	1	1.90	1.60
10/24	2	1.90	3.10
10/25	3	1.90	3.00
10/26	4	1.50	2.40
10/27	5	1.10	1.80
10/28	6	0.80	1.20
10/30	8	0.70	0.80
10/31	9	0.60	0.75
11/01	10	0.60	0.75
11/02	11	0.50	0.75
11/03	12	0.50	0.60
11/07	16	0.38	0.50
11/11	20	0.38	0.50
11/14	23	0.30	0.35
11/15	24	0.38	0.44
11/16	25	0.35	0.40

Zarrouk was better suited at growing Spirulina that the modified Hoagland solution. This is probably due to increased amounts of molybdenum and copper in the Hoagland solution. These compounds are inhibitory to Spirulina.

Light Leak Test. The unit was tested for light leakage by turning off the lights and checking for light radiation. No light leakage was detected.

Immersion Test. Each cast acrylic component was immersed in water to check for leaks in the material and at surface junctions. Specific areas of interest included prevention of water leakage into the wires of the lighting system, the culture growth containers, and the pump housing. These areas were also tested to insure stability of the structure and indicated no chemical breakdown within and between (i.e. bonding at seams) materials.

Model Test. The Spirulina incubator was filled with water and plumbed in accordance to design plans. The aeration pump and the light were subsequently turned on and operated for approximately five days with no ill effects observed.

Algae Growth Test. Utilizing Zarrouk medium, a Spirulina culture was started and maintained for 41 days. At the end of this time period, the three tubes were harvested with a combined yield of 5.61 grams. Both the aeration pump and the fluorescent hand lamp performed without failing and no leaks were detected in the growth tubes. Algae visibility can be found in Table 3.2 on the following page.

CONCLUSIONS

The nutrient solution growth experiment conducted at the Swine Unit showed Zarrouk rather than the modified Hoagland solution as the superior nutrient solution for the growth of Spirulina.

The BGAP unit has performed to specifications with no malfunctions. In addition, the resent algae culture growth experiment currently shows an increase in density of the Spirulina which indicates a positive reaction to the incubator's physical structure, even though the culture is experiencing a lower than optimal temperature.

Table 3.2 Algae visibility using Zarrouk medium in BGAP unit

Date	Day	Tube 1 Visibility (in)	Tube 2 Visibility (in)	Tube 3 Visibility (in)
12/04	1	3.57	3.10	3.19
12/05	2	3.06	2.63	2.63
12/06	3	2.88	2.88	2.63
12/07	4	2.72	2.97	2.82
12/09	6	1.94	2.44	2.50
12/10	7	1.94	2.31	2.25
12/11	8	2.00	2.00	2.19
12/12	9	2.00	2.25	1.94
12/13	10	2.00	2.25	2.13
12/14	11	1.94	2.00	2.00
12/17	13	1.63	1.56	1.56
01/04	31	0.81	0.88	0.75
01/06	33	0.81	0.88	0.75
01/07	34	0.81	0.84	0.75
01/10	37	0.68	0.75	0.75
01/11	38	0.68	0.75	0.75
01/12	39	0.68	0.75	0.75
01/13	40	0.68	0.68	0.68
01/14	41	0.68	0.68	0.68

RECOMMENDATIONS

General

From the results presented here, Spirulina production could be a valuable asset as a food source in NASA's continued efforts to further space exploration. Therefore further research would be highly recommended for optimizing the yield of Spirulina cultures and investigation into making this blue green algae more palatable for humans.

Lighting

Spectra. Very little is known about the effects of various wavelengths of light on the growth of Spirulina. Our growth studies have been executed using wide

spectrum fluorescent light. The recommended spectra for further study include cool white and gro-lux fluorescent. In addition, combinations of lights could be used in experiments to further simulate the changing wavelengths of light throughout the course of the day.

Illuminance. The level of illuminance for this project was chosen to approximate a suggested value of 15 watts per square foot for low energy growing plants. Larger or smaller levels of illuminance could be examined along with fluctuations of these levels. Furthermore, the increase of light intensity at the beginning and the decrease at the end of a 12 hour period could better simulate the natural cycle of a day.

Position. As mentioned earlier, one of the designs which was considered included the light in the center of the cultures. This design may be further studied with an outer housing of larger diameter.

Toxicity

Identification of the chemical composition of the culture grown in the BGAP incubator would indicate potential toxins which could be harmful to humans.

Palatibility and Psychological Aspects

Spirulina has traditionally been passed over for food because it is not a culturally familiar product. This apprehension can be minimized by simply including Spirulina as a supplement to other foods. It can be mixed with flour, added to soy bean powder, prepared in bars or cakes or any number of other creative methods of introducing algae to food. Additional research needs to be done into methods for progressively introducing this blue green algae into humankind's diet.

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2. Haas, Elson M., M.D. Staying Healthy with Nutrition. Celestial Arts Publishing. Berkeley, California. 1992.

3. Leviton, Richard. Tofu, Tempeh, Miso and Other Soyfoods. Keats Publishing, Inc. New Canaan, Connecticut. 1982.

4. "Ocean CELSS Experimental Analog - NASA." Kennedy Space Center. Cape Canaveral, Florida. 1993.

5. CRC, Handbook of Microalgal Mass Culture., CRC Publishing, 1988.

APPENDIX 3.1 Zarrouk Medium for Spirulina Culture

Compound	Grams/Liter
Macronutrient Solution	
$NaHCO_3$	16.0
K_2HPO_4	0.5
$NaNO_3$	2.5
K_2SO_4	1.0
NaCl	1.0
$MgSO_4 \cdot H_2O$	0.20
$CaCl_2$	0.04
$FeSO_4 \cdot 7H_2O$	0.01
Ethylene Diamino Tetracetic Acid (EDTA)	0.08
Solution A_5	
H_3BO_3	2.86
$MnCl_2 \cdot 4H_2O$	1.81
$ZnSO_4 \cdot 7H_2O$	0.22
$CuSO_4 \cdot 5H_2O$	0.08
★MoO_3	0.01
Solution B_6	
NH_4VO_3	229×10^{-4}
★$K_2Cr_2(SO_4)_4 \cdot 24H_2O$	960×10^{-4}
★$NiSO_4 \cdot 7H_2O$	478×10^{-4}
★Na_2WO_4	179×10^{-4}
▲$Ti_2(SO_4)_3$	400×10^{-4}
★$Co(NO_3)_2 \cdot 6H_2O$	44×10^{-4}

Directions

Add 1 ml each of solutions A_5 and B_6 per liter of macronutrient solution.

▲ This compound was indicated to be nonessential and was subsequently deleted.

★Substitutions

Working laboratory did not have all of necessary ingredients. Group was instructed to measure the correct amount of metal ions that were called for in the original solution, because the metals will disassociate in water.

Ingredient (grams)	Substitution (grams)
MoO_3 (0.01)	$(NH_4)_6Mo_7O_{24}\bullet 4H_2O$ (0.01)
$K_2Cr_2(SO_4)_4\bullet 24H_2O$ (960×10^{-4})	$K_2Cr_2O_7$ (0.0282)
$NiSO_4\bullet 7H_2O$ (478×10^{-4})	$NiCl_2\bullet 6H_2O$ (0.0398)
Na_2WO_4 (179×10^{-4})	H_2WO_4 (0.0152)
$Co(NO_3)_2\bullet 6H_2O$ (44×10^{-4})	$Co(Cl_2)_2\bullet 6H_2O$ (0.0037)

APPENDIX 3.2 Hoagland Medium for Spirulina Culture

Stock Solution	Compound	Grams/Liter
#1	KH_2PO_4	27.22
#2	KNO_3	101.11
#3	$Ca(NO_3)_2 \cdot 4H_2O$	236.15
#4	$\star MgSO_4 \cdot 7H_2O$	98.59
Trace Elements		
#5	H_3BO_3	0.57
	$MnCl_2 \cdot 4H_2O$	0.36
	$ZnSO_4 \cdot 7H_2O$	0.04
	$CuSO_4 \cdot 5H_2O$	0.016
	$\star H_2MoO_4 \cdot H_2O$	0.004
Iron Solution		
#6	Ferric Citrate	1.00

Directions

Add 16 grams of $NaHCO_3$ plus 5 ml of each stock solution to 1 liter of water.

★ Substitutions

Because of limited resources, certain chemical substitutions were made.

Ingredient (grams)	Substitute (grams)
$MgSO_4 \cdot 7H_2O$ (98.59)	$MgSO_4$ (48.15)
$H_2MoO_4 \cdot H_2O$ (0.004)	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ (0.0048)

APPENDIX 3.3 Parts List

PARTS LIST

Description	Quantity	Price	Source
3" O.D. 1/8" thick cast acrylic tube, 6 ft length	1	$39.48	Faulkner, Inc.
3 1/2" O.D. 1/8" thick cast acrylic tube, 1 ft length	1	$10.85	"
3" O.D. 1/2" thick cast acrylic cap 1/8" rabbid	3	$22.75	"
3" O.D. 1/2" thick cast acrylic cap 1/8" rabbid, with handles	3	$28.75	"
11 3/4" disc 1/4" thick	2	$15.50	"
12" Schedule 40 P.V.C. pipe, 2 ft length	1	$88.00	"
12" Schedule 40 P.V.C. endcap	2	$78.86	Hughes Supply, Inc.
Grow bulb Part# SF8T5GRO	3	$20.28	"
Woodhead hand lamp Part# 1049	1	$107.00	Daniel Woodhead Co., Inc.
Whisper 800 air pump	1	$25.00	The New Zoo
Checker pH meter	1	$31.50	PGC Scientific

APPENDIX 3.4 Chemical Analysis of Spirulina

Chemical Analysis of Spirulina (Average)

Component	Percent
Protein	71.00
Crude Fiber	0.90
Carbohydrates	16.90
Fat	7.00
Cholesterol - less than	.05
Moisture	7.00

Vitamin Analysis of Spirulina (Average)

Nutrient	mg/kg
Biotin	0.4
Vitamin B12	2.0
d-Ca-Pantothenate	11.0
Folic Acid	0.5
Inositol	350.0
Nicotinic Acid	118.0
Vitamin B6	3.0
Vitamin B2	40.0
Vitamin B1	55.0
Vitamin E	190.0

Essential Amino Acids

Amino Acid	Percent
Isoleucine	4.1
Leucine	5.8
Lysine	4.0
Methionine	2.2
Phenylalanine	4.0
Threonine	4.2
Tryptophane	1.1
Valine	6.0

Non-Essential Amino Acids

Amino Acid	Percent
Alanine	5.8
Arginine	6.0
Aspartic Acid	6.4
Cysteine	0.7
Glutamic Acid	8.9
Glycine	3.5
Histidine	1.1
Proline	3.0
Serine	4.0
Tyrosine	4.6

Mineral Analysis of Spirulina (Average)

Mineral	mg/kg
Calcium	1315.0
Phosphorus	8942.0
Iron	580.0
Sodium	412.0
Magnesium	1915.0
Manganese	25.0
Zinc	39.0
Potassium	15400.0
Selenium	0.4

Other Components of Spirulina (Average)

Component	Percent
Nucleic Acids	4.5
Carotenoids	0.4
Chlorophyll	0.8

Crude Protein on Average (%N x 6.25) = 71%

APPENDIX 3.5 Lake Chad Recipe for Dihe

Ingredients

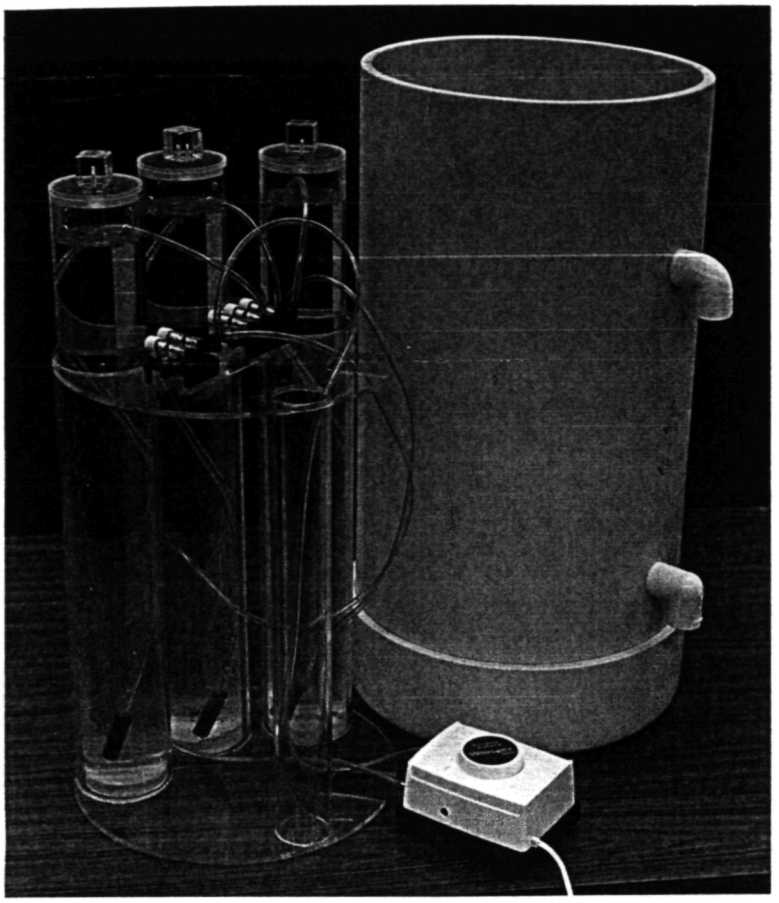
1 T. Spirulina
1 clove garlic, finely chopped
1/4 c. pimento, chopped
1/2 c. red and green bell peppers, chopped
1/4 c. onion, chopped
1/2 c. vegetable stock or water
1 c. millet, raw

Directions

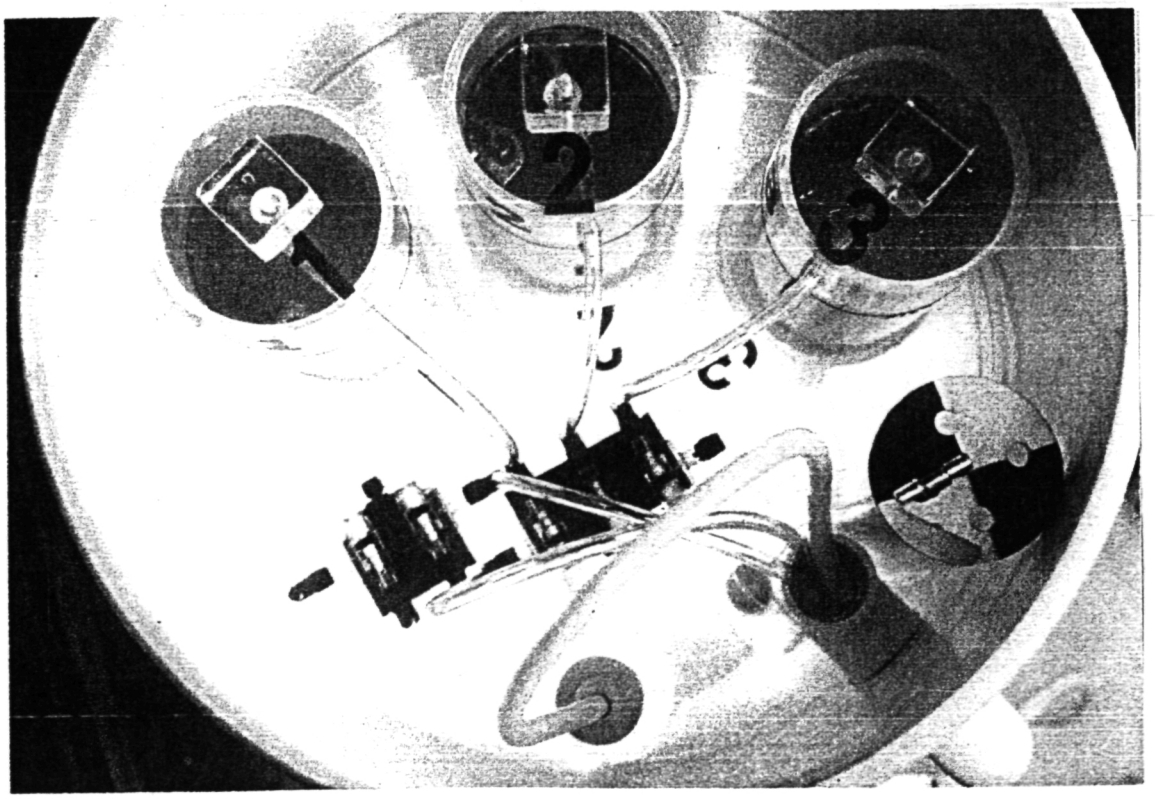
Gently boil the millet in a covered pan with 3 cups of water for 30 minutes or until all liquid is dissolved. Remove and drain if necessary. Premix vegetable stock or water with Spirulina powder in a blender separately. In a separate saucepan, saute the onions and garlic in oil. Add pimentos and red and green bell peppers to the saute, and after a few moments pour in the Spirulina mix and stir until it has a uniform sauce consistency. Ladle sauce over individual servings of steaming millet. Salt and pepper to taste.

Serves 4.

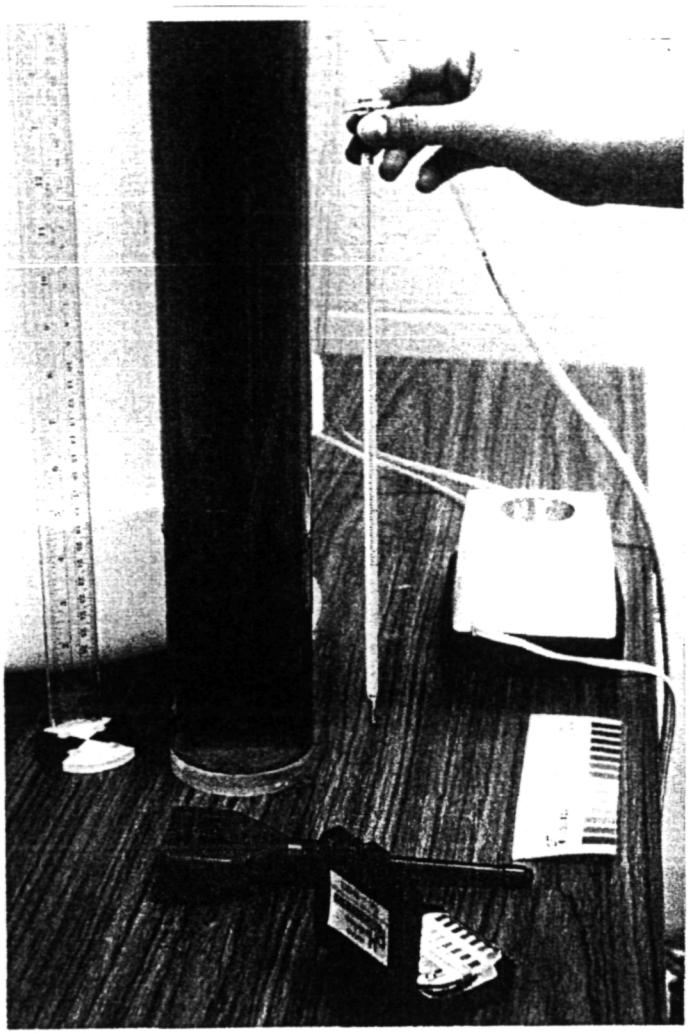
APPENDIX 3.6 Photographic Documentation of BGAP Unit



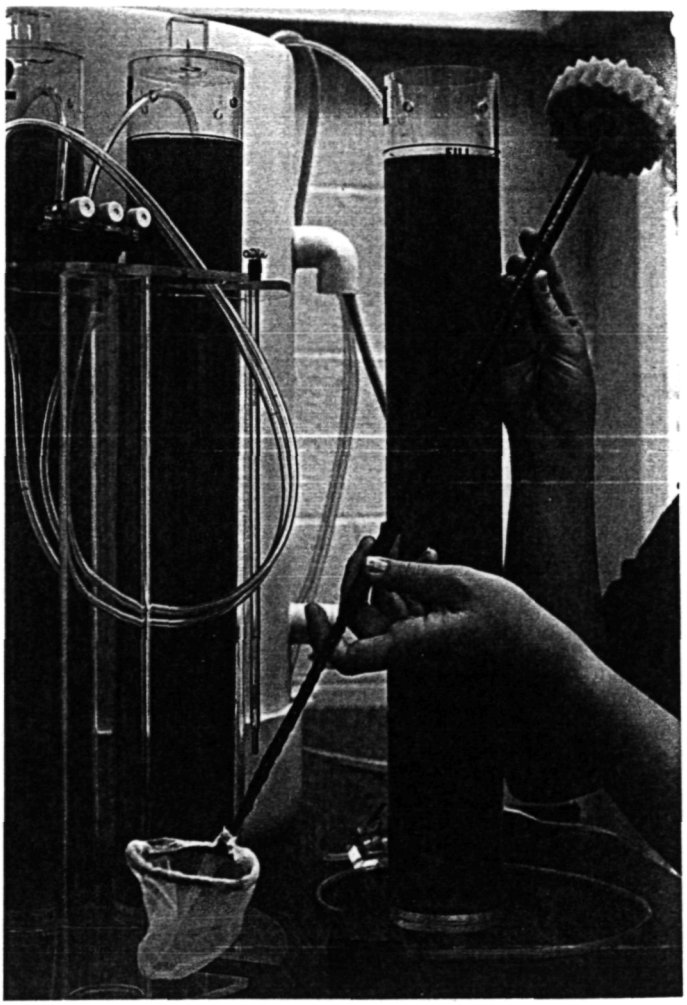
P1. Incubator and inner housing with aeration pump



P2. Top view of fully assembled BGAP Unit



P3. Measuring instruments including secchi disk, pH meter and paper, and thermometer



P4. Harvester/bioscum remover