N88-13855

-- SECTION III: --

# PLANT GROWTH MODULE (PGM)

## - CONCEPTUAL DESIGN -

Steven H. Schwartzkopf and Daryl Rasmussen

April 1985

## INTRODUCTION

To support the CELSS research program, construction of a laboratory-sized (2-3 $m^2$) plant growth module (PGM) at the NASA-Ames Research Center has been proposed. This PGM will be fully closed, and capable of maintaining the strictly controlled environmental conditions necessary to answer basic science questions related to growing plants in closed systems.

This section contains a conceptual view of the PGM design. The design requirements were gleaned from the recommendations made at the PGM Workshop reported in Section II, and the subsystem descriptions were formulated to fulfill those requirements. The subsystem descriptions will serve as a starting point from which the PGM design will be refined and developed. What follows, then, is the framework upon which the design and construction of the Ames Plant Growth Module will be based.

## REQUIREMENTS

The PGM Workshop held at NASA-Ames in September, 1984 began the design definition phase for the development of the Ames PGM. Each of the topics discussed at that meeting was viewed individually, without a concentrated effort at system integration. As a result, some of the requirements for the PGM were contradictory, while there were no specific requirements decided for some of the topics. With that in mind, the design requirements as they are presently understood are listed in the following tables: Table 1 for the shoot zone, and Table 2 for the root zone of the PGM.

Table 1

Nominal and control ranges for shoot zone environmental variables

| Variable | Nominal Range Min | Nominal Range Max | Control Range Min | Control Range Max | Units | Comments |
|---|---|---|---|---|---|---|
| Carbon Dioxide | 350 | 1500 | 25 | $10^4$ | ppm | |
| Oxygen | 5 | 21 | 5 | 40 | % | No information is available on $[O_2] > 21\%$ |
| Temperature | 15 | 30 | 5 | 40 | $^oC$ | |
| Relative Humidity | 50 | 80 | 35 | 90 | % | |
| Irradiance | 400 | 700 | 0 | 1000 | $uM/m^2/sec$ | Measured at top of plant canopy |
| Air Flow | 0.4 | 0.5 | 0.2 | 0.9 | m/sec | |
| Volatiles | TBD | | TBD | | ppm, ppb | |
| Bacteria | TBD | | TBD | | $cells/m^3$ | |
| Pressure | TBD | | TBD | | mm Hg | |

Table 2

Nominal and control ranges for root zone environmental variables

| Variable | Nominal Range Min | Nominal Range Max | Control Range Min | Control Range Max | Units | Comments |
|---|---|---|---|---|---|---|
| Carbon Dioxide | TBD | | TBD | $10^4$ | ppm | |
| Oxygen | TBD | | TBD | | % | Little data is available, but zone must be aerobic. |
| Temperature | 15 | 30 | 5 | 40 | $^oC$ | |
| pH | 4.0 | 7.0 | TBD | | pH | |
| Conductivity | 0.7 | 0.9 | 0.6 | 1.8 | mS | |
| Volatiles | TBD | | TBD | | ppm, ppb | |
| Bacteria | 100 | $10^4$ | TBD | | cells/ml | Estimates from studies at Ames |
| Pressure | TBD | | TBD | | mm Hg | |

# DESIGN

## PGM FUNCTIONAL DESCRIPTION

The Plant Growth Module (PGM) will be a tightly sealed, low leakage device with a computer control system which will closely monitor and regulate the PGM's internal environment. In essence, the PGM will serve as a life support system for higher plants, such as wheat, soybeans, and potatoes. Since the chief purpose of the Ames PGM will be to conduct scientific research on a variety of crops, the design will incorporate a maximum degree of flexibility in the number of growing configurations available. Additionally, the design will emphasize accurate control over the PGM environment and will provide, to the maximum possible extent, fully-automated data monitoring and recording.

## ARTIST'S CONCEPT DRAWINGS

Most of the design details for the Ames PGM have not been finalized, but several different designs have been envisioned for the plant enclosure itself. These alternatives are illustrated in Figs. 1 to 3. Common to each of these designs is the concept of modular support systems; as illustrated in the figures, each of the plant enclosures are connected to the same array of supporting equipment. These support systems are the subsystems of the PGM that will take the majority of the engineering effort involved in the construction of the PGM.

Figure 1

Ames Plant Growth Module A

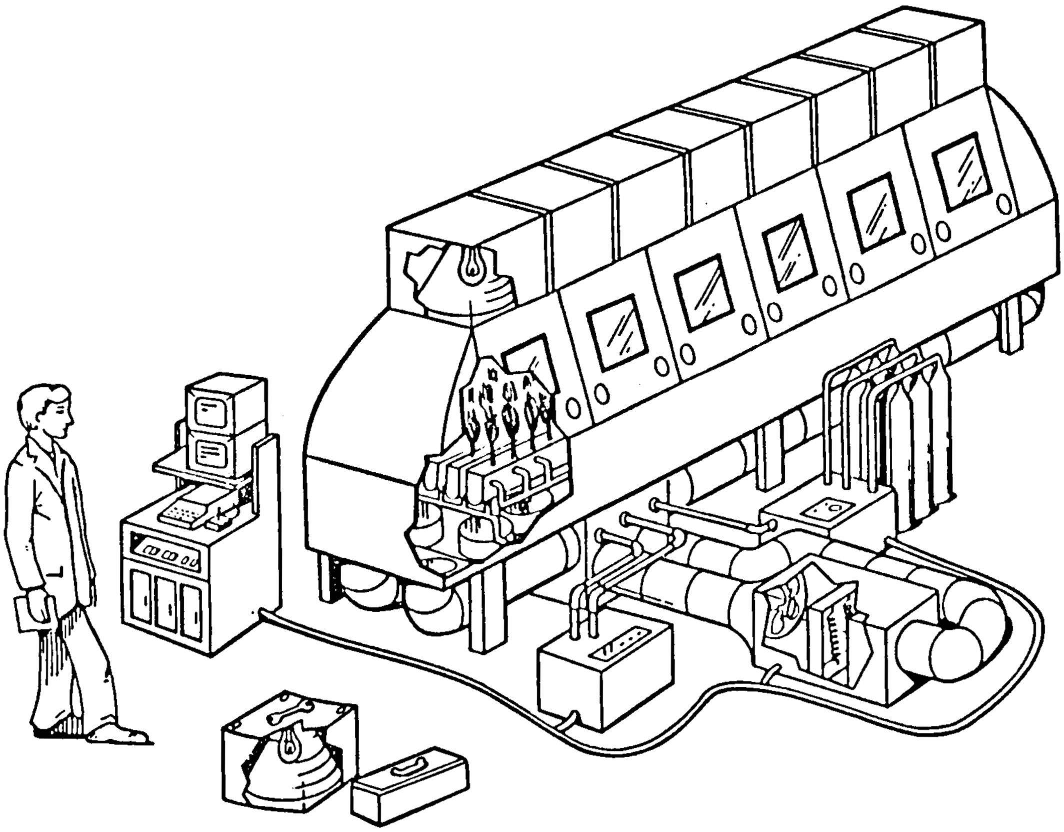


Figure 2

Ames Plant Growth Module B

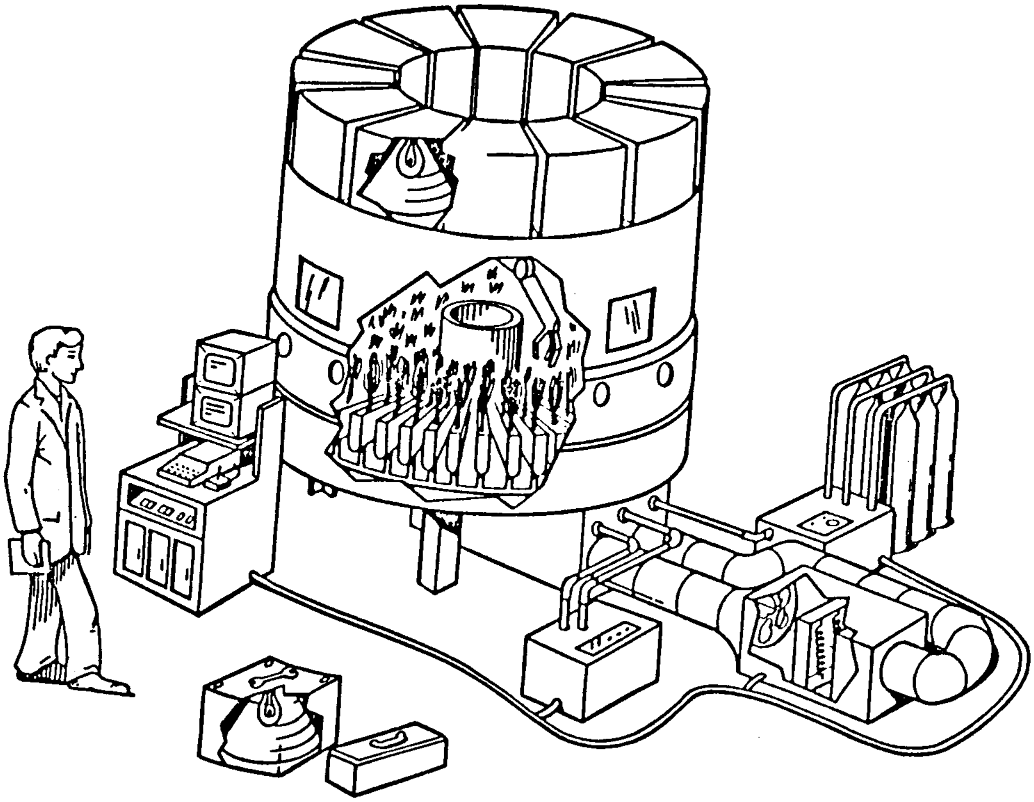
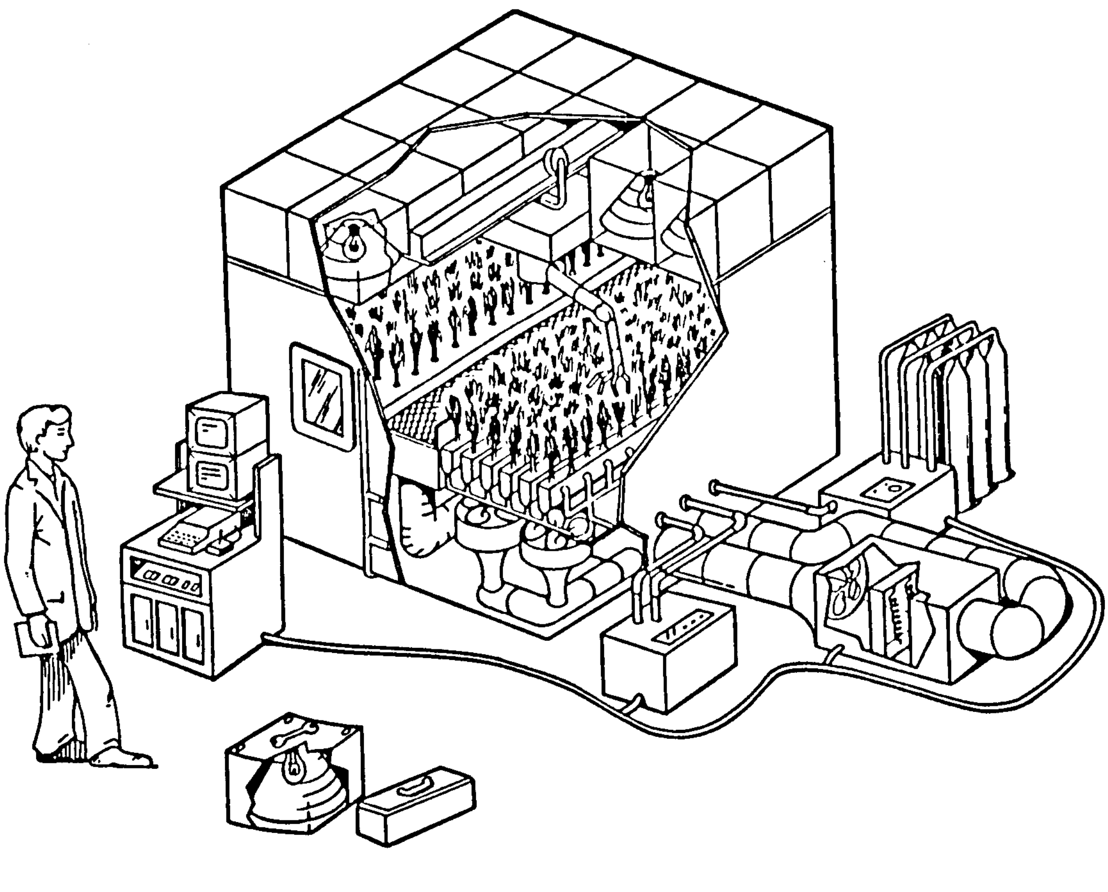


Figure 3

Ames Plant Growth Module C



## PGM SUBSYSTEMS

As a result of joint scientific/engineering group meetings, the PGM design has been divided into ten subsystems (Fig. 4). This section provides a functional description of each of the PGM subsystems, along with a preliminary equipment list and a descriptive schematic.

### 1. Enclosure and Access

The functions of this subsystem are 1) to maintain an atmosphere that is isolated from the external atmosphere, 2) to maintain an atmosphere that is closed with respect to the exchange of materials, and 3) to provide a container within which the control system can maintain specific environmental conditions that are independent of outside environmental variables. Fig. 5 is a schematic diagram of this subsystem.

Typical Enclosure and Access Equipment

- Shell
- Illumination port
- Observation port
- Glove ports
- Electrical and plumbing interface ports
- Robotics mounting pad
- Airlock
- Airlock door

Figure 4

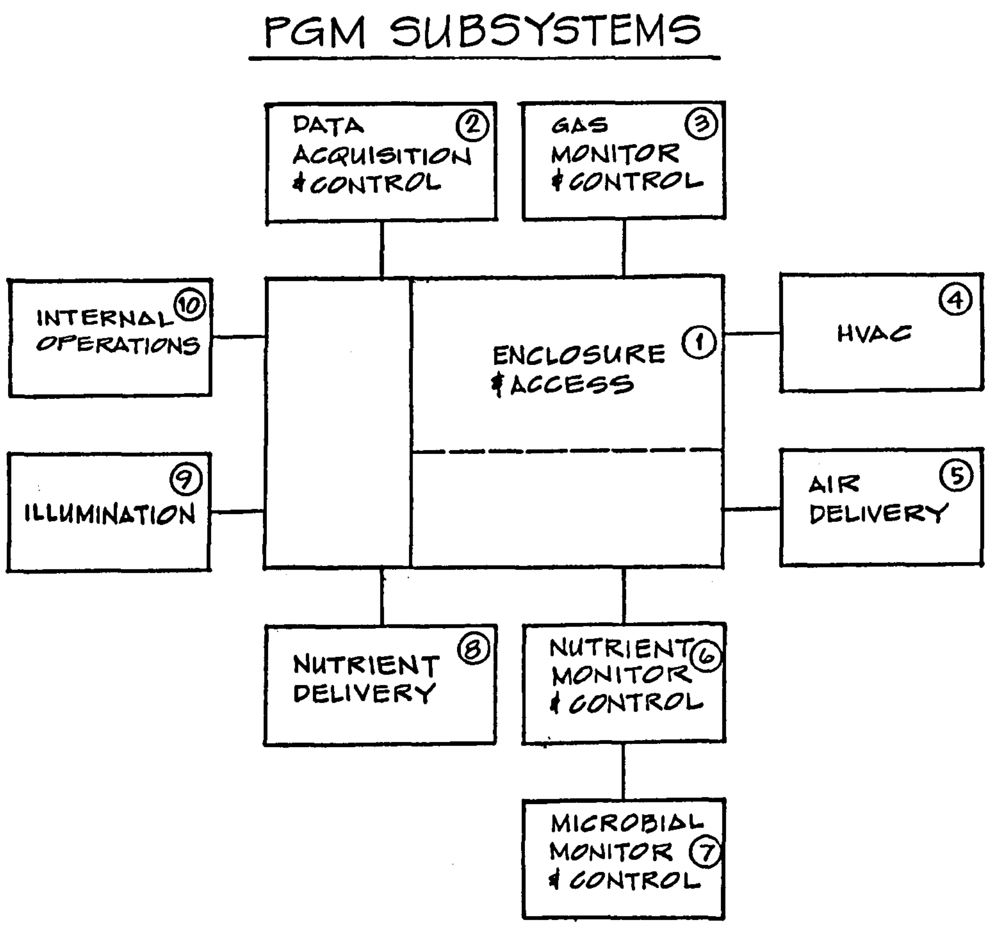
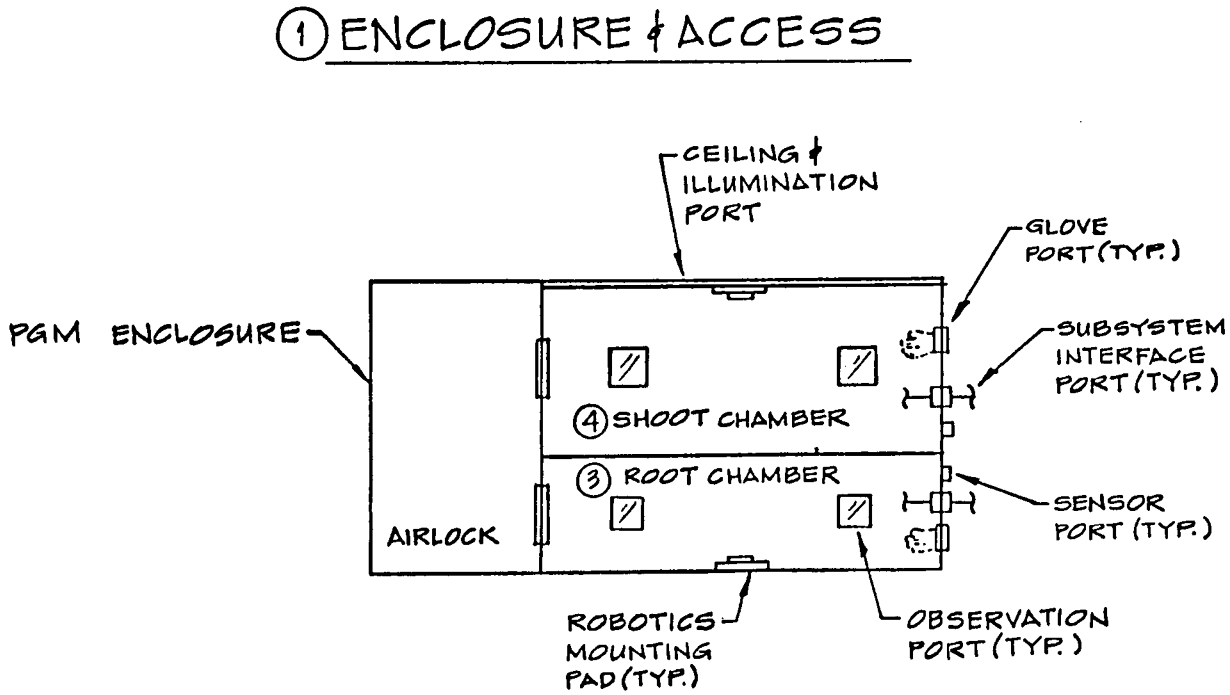

PGM SUBSYSTEMS
DATA ACQUISITION & CONTROL ②
GAS MONITOR & CONTROL ③
INTERNAL OPERATIONS ⑩
ENCLOSURE & ACCESS ①
HVAC ④
ILLUMINATION ⑨
AIR DELIVERY ⑤
NUTRIENT DELIVERY ⑧
NUTRIENT MONITOR & CONTROL ⑥
MICROBIAL MONITOR & CONTROL ⑦

Figure 5



① ENCLOSURE & ACCESS
CEILING & ILLUMINATION PORT
GLOVE PORT (TYP.)
PGM ENCLOSURE
SUBSYSTEM INTERFACE PORT (TYP.)
④ SHOOT CHAMBER
③ ROOT CHAMBER
SENSOR PORT (TYP.)
AIRLOCK
ROBOTICS MOUNTING PAD (TYP.)
OBSERVATION PORT (TYP.)

## 2. Data Acquisition and Control

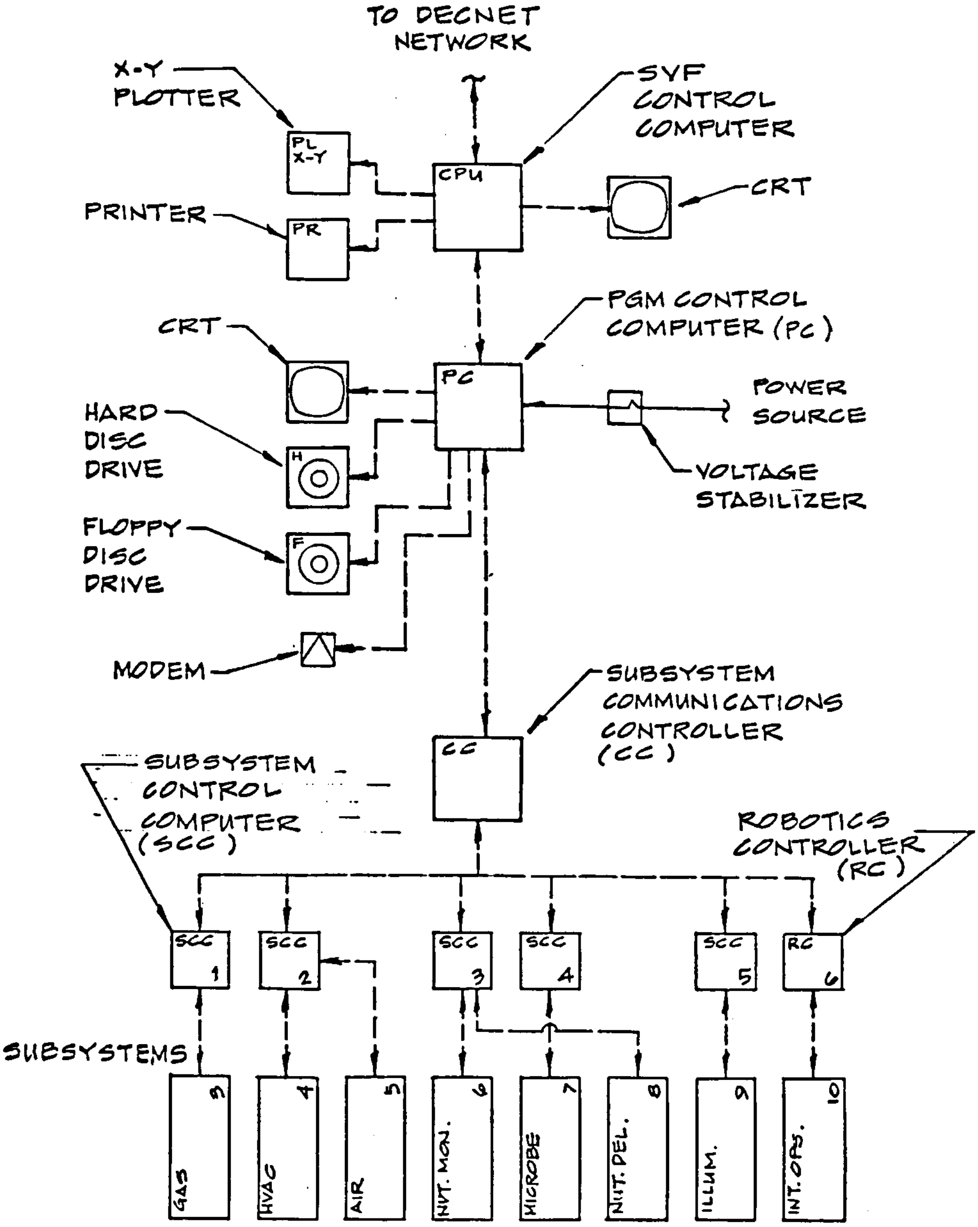
The functions of this subsystem are 1) to monitor the PGM environment and maintain that environment according to a specified set of control instructions, and 2) to record, analyze and report data for use in experimental analysis. Fig. 6 gives a schematic for this subsystem.

Typical Data Acquisition, Analysis and Control Equipment

- PGM Control computer
- CRT
- Operator's console
- Printer
- X-Y Plotter
- Hard Disc system
- Floppy Disc system
- Auto-dial modem
- Uninterruptible power supply
- Chart recorders
- Optically-isolated relays

Figure 6

② DATA ACQUISITION, ANALYSIS & CONTROL



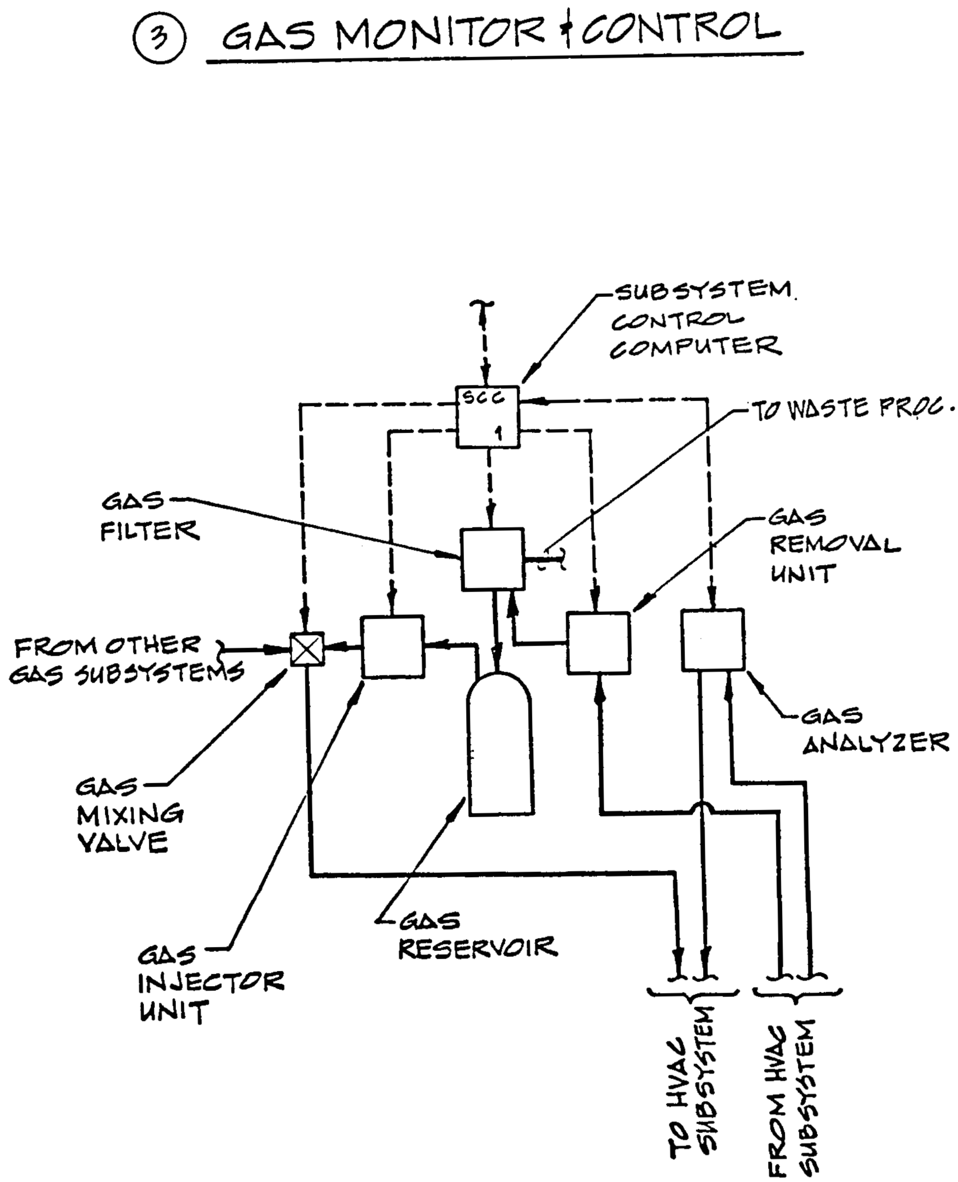
## 3. Gas Monitor and Control

The functions of this subsystem are 1) to monitor atmospheric gas concentrations and maintain a specified gas balance, 2) to monitor and calculate carbon uptake and oxygen production due to photosynthesis, and carbon dioxide production and oxygen uptake due to respiration, 3) to monitor and replenish atmospheric gas buffers and 4) to remove any volatile components from the atmosphere. Fig. 7 presents a schematic for this subsystem.

### Typical Gas Monitor and Control Equipment

- $CO_2$ Analyzer
- $O_2$ Analyzer
- Gas Chromatograph
- Solenoid valves
- Mixing valves
- Injecting valves
- Gas line filters (0.2 micron sintered metal)
- Gas line cold traps
- Pressure gauges
- Multichannel IR Analyzer
- Gas cylinders
- Pumps
- Compressors
- Flow monitor/control valves

Figure 7



3 GAS MONITOR + CONTROL
SUBSYSTEM CONTROL COMPUTER
SCC
1
TO WASTE PROC.
GAS FILTER
GAS REMOVAL UNIT
FROM OTHER GAS SUBSYSTEMS
GAS ANALYZER
GAS MIXING VALVE
GAS RESERVOIR
GAS INJECTOR UNIT
TO HVAC SUBSYSTEM
FROM HVAC SUBSYSTEM

## 4. Heating, Ventilation, Air Conditioning (HVAC)

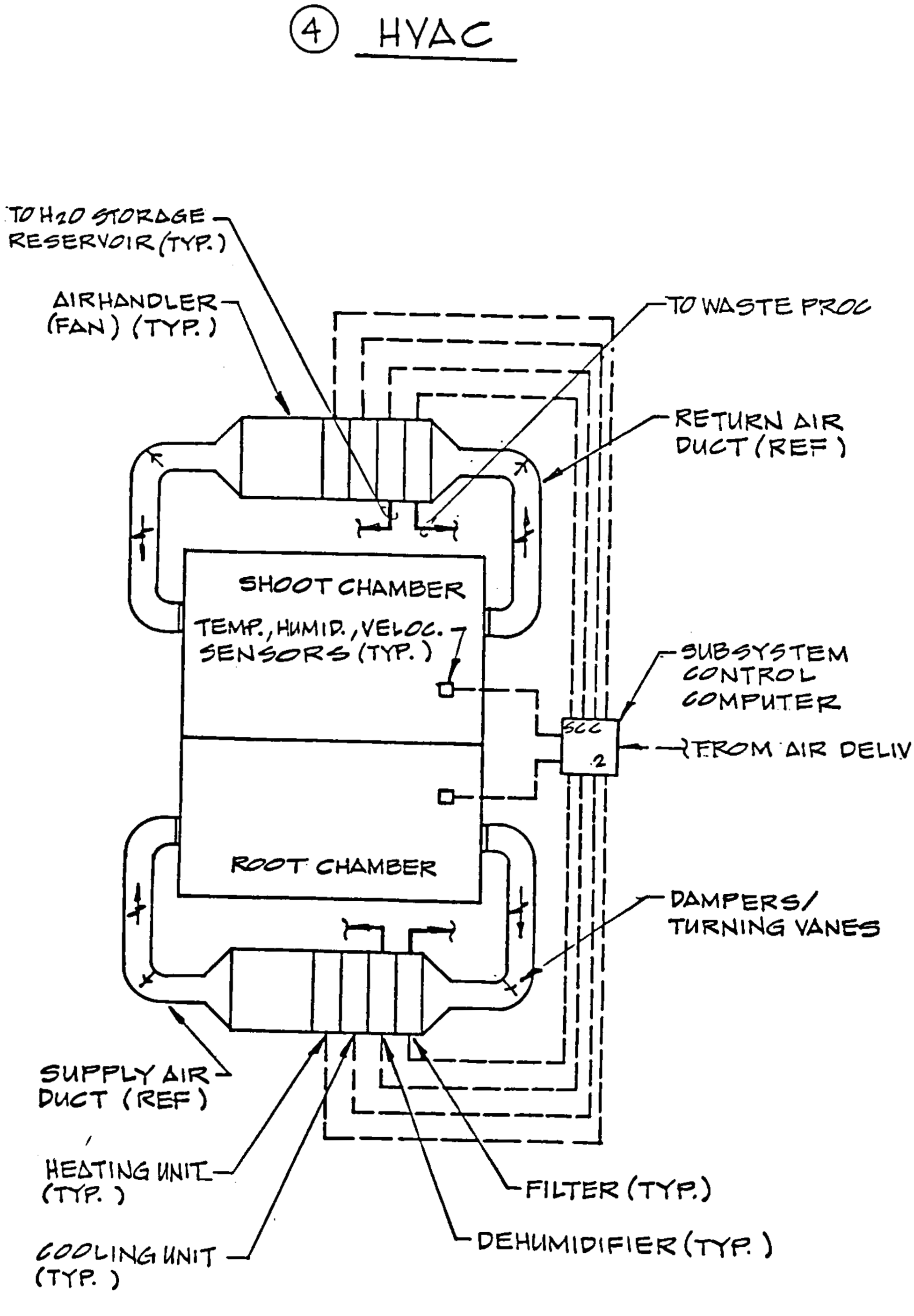
The functions of this system are 1) to monitor and control atmospheric temperature and humidity, and 2) to monitor and calculate transpirational water loss from the plant canopy. Fig. 8 gives the schematic for this subsystem.

Typical HVAC Equipment

- Air conditioner
- Heater
- Filters
- Humidifiers
- Dehumidifiers
- Pressure sensors
- Flow sensors
- Temperature sensors
- Relative humidity sensors
- Fans
- Dampers
- Turning vanes

DESIGN (cont.)

Figure 8



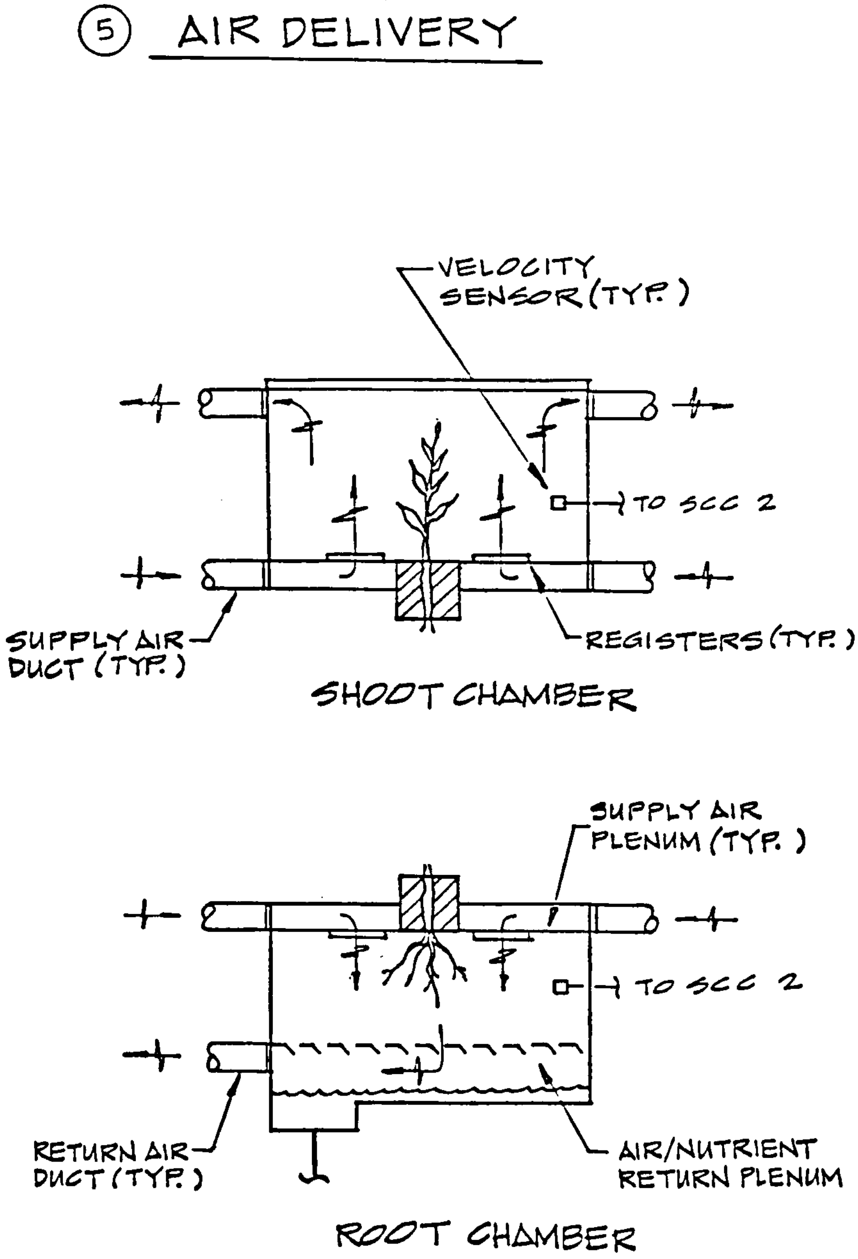
## 5. Air Delivery

The function of this system is to provide uniform, homogeneous atmospheres for both the aerial and root zones of the PGM. Fig. 9 illustrates the design schematic for this subsystem.

### Typical Air Delivery Equipment

Return air plenum (top and root zones)
Supply air plenum (top and root zones)
Flow sensors
Registers
Dampers
Turning vanes

Figure 9



5 AIR DELIVERY
VELOCITY SENSOR (TYP.)
TO SCC 2
SUPPLY AIR DUCT (TYP.)
REGISTERS (TYP.)
SHOOT CHAMBER
SUPPLY AIR PLENUM (TYP.)
TO SCC 2
RETURN AIR DUCT (TYP.)
AIR/NUTRIENT RETURN PLENUM
ROOT CHAMBER

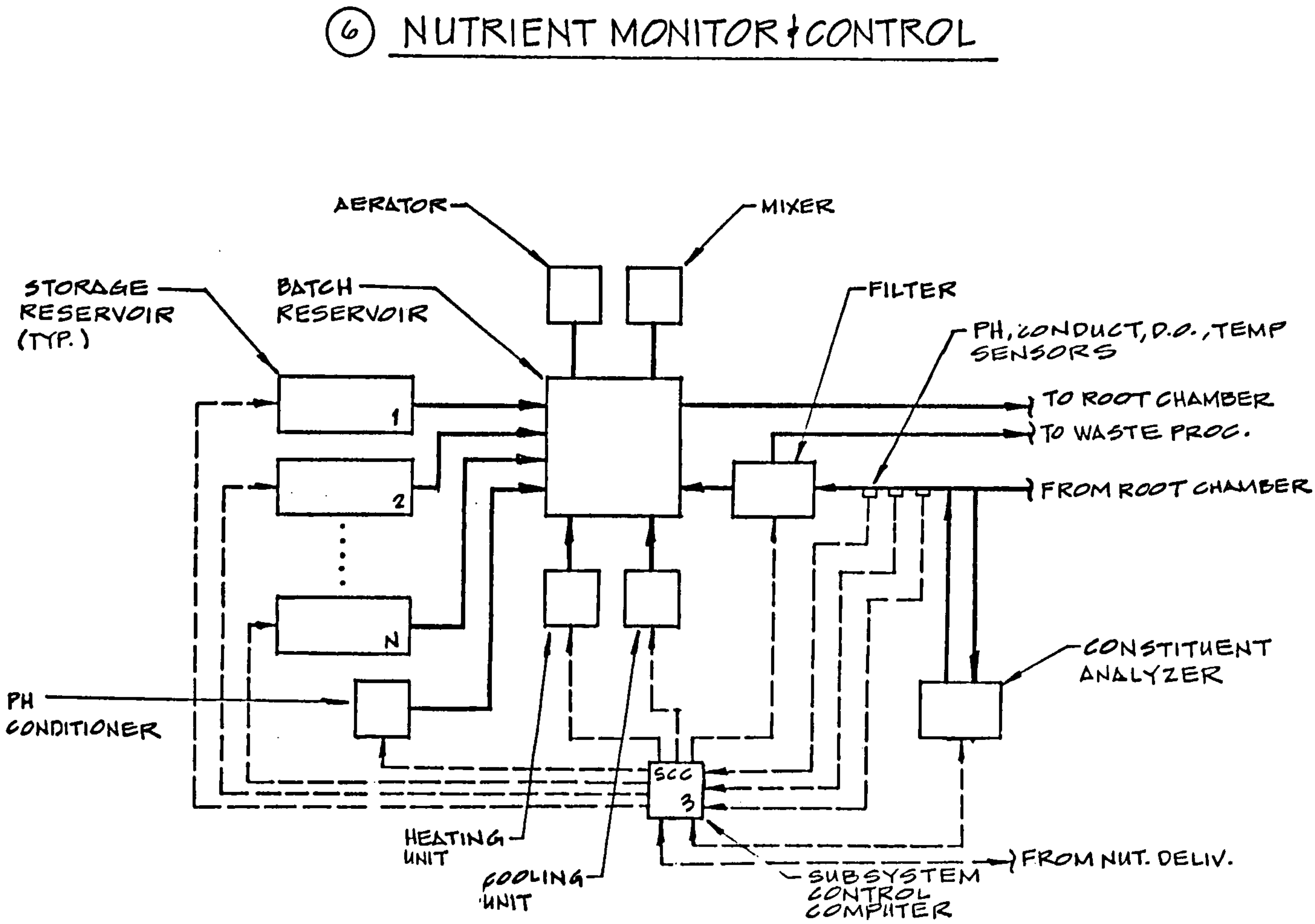
## 6. Nutrient Monitor and Control

The functions of this subsystem are 1) to monitor and control the concentrations of individual nutrient elements in solution, 2) to monitor and control bulk nutrient solution parameters such as pH, conductivity and dissolved oxygen, and 3) to monitor and control nutrient solution temperature, and 4) to calculate and report nutrient uptake reports. Fig. 10 gives a schematic for this subsystem.

### Typical Nutrient Monitor and Control Equipment

- pH sensors
- Conductivity sensors
- Dissolved Oxygen sensors
- Temperature sensors
- Liquid level sensors
- Filters
- HPLC
  - High pressure pump
  - Automatic injector valve
  - Ion-specific columns
  - Detectors (UV and conductivity)
- Heater
- Cooler
- Mixing pump
- Aerator
- Nutrient solution component reservoirs
- Metering pumps
- Nutrient solution reservoir

Figure 10



⑥ NUTRIENT MONITOR & CONTROL
AERATOR
MIXER
STORAGE RESERVOIR (TYP.)
BATCH RESERVOIR
FILTER
PH, CONDUCT, D.O., TEMP SENSORS
TO ROOT CHAMBER
TO WASTE PROC.
FROM ROOT CHAMBER
1
2
N
PH CONDITIONER
CONSTITUENT ANALYZER
SCC
3
HEATING UNIT
COOLING UNIT
SUBSYSTEM CONTROL COMPUTER
FROM NUT. DELIV.

## 7. Microbial Monitoring and Control

The functions of this system are 1) to monitor and control microbial concentrations in both the nutrient solution and atmospheric phase, and 2) to report monitored microbial densities. Fig. 11 illustrates the schematic for this subsystem.

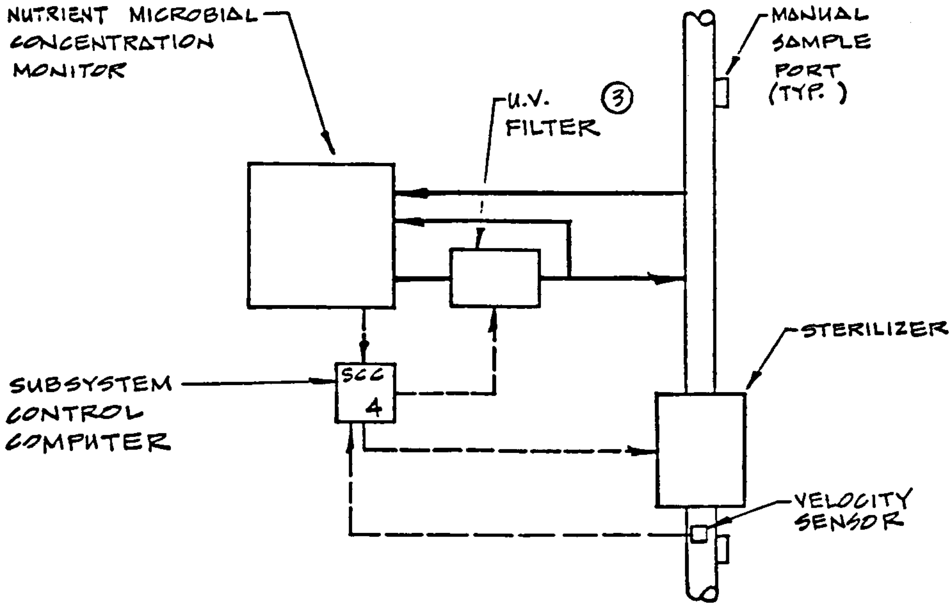
Typical Microbial Monitoring and Control Equipment

FTIR Spectrophotometer
UV Sterilizers
Flow monitor/control valves
Pumps
Externally-accessible sample port

DESIGN (cont.)

Figure 11

7 MICROBIAL MONITOR & CONTROL



## 8. Plant Support and Nutrient Delivery

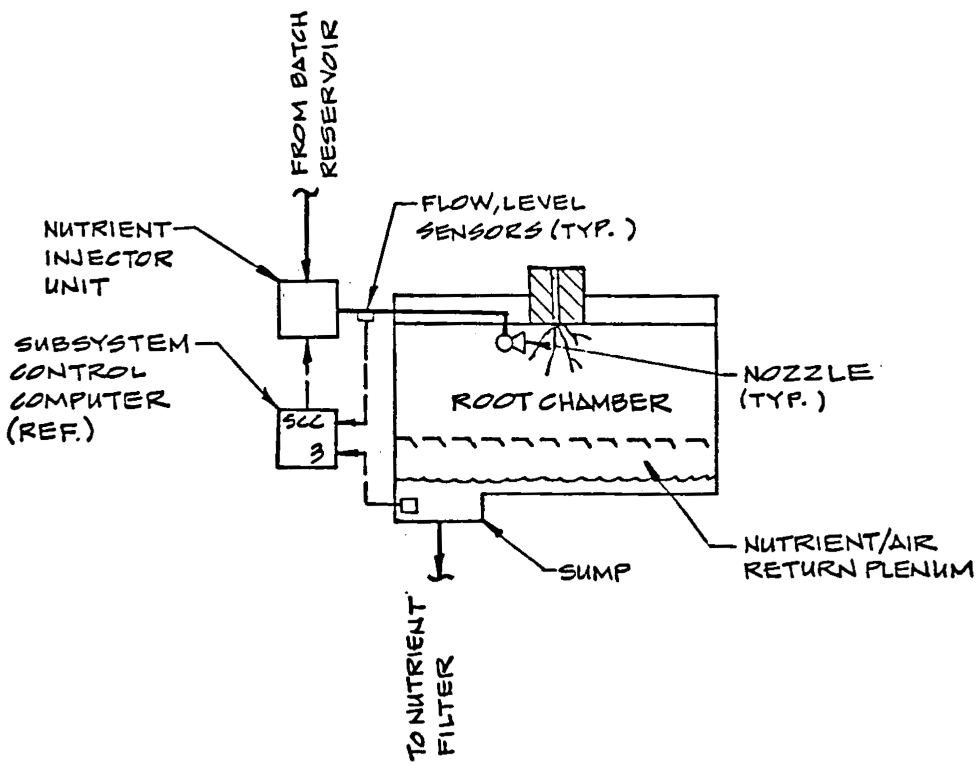
The functions of this subsystem are 1) to provide structural support for the plants' roots and stems, 2) to distribute a homogeneous nutrient solution to the plants in a uniform fashion, and 3) to remove contaminants from the nutrient solution. Fig. 12 presents a schematic of this subsystem.

### Typical Nutrient Delivery Equipment

Pumps
Mist nozzles or injectors
Nutrient recovery sump
Flow monitor/control valve
Liquid level sensors
Air/liquid separator plenum

Figure 12

## ⑧ NUTRIENT DELIVERY



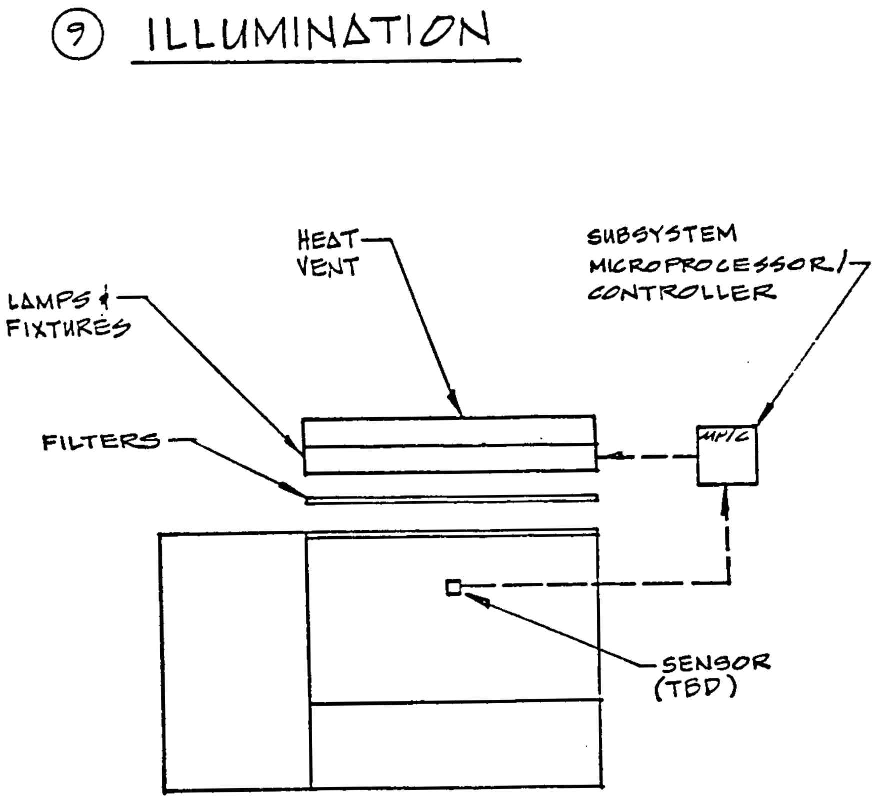
## 9. Illumination

The function of this subsystem is to provide radiant energy of specific, controllable intensity and spectral quality to support photosynthesis. Fig. 13 illustrates a schematic for this subsystem.

### Typical Illumination Equipment

Lamps (HID, Metal Halide, Fluorescent)
Light (PAR) sensors
Spectral radiometer
Controllable lamp ballasts
Optical and IR filters
Housing / Barrier

Figure 13


9 ILLUMINATION
HEAT VENT
SUBSYSTEM MICROPROCESSOR/CONTROLLER
LAMPS & FIXTURES
FILTERS
SENSOR (TBD)

## 10. Internal Operations

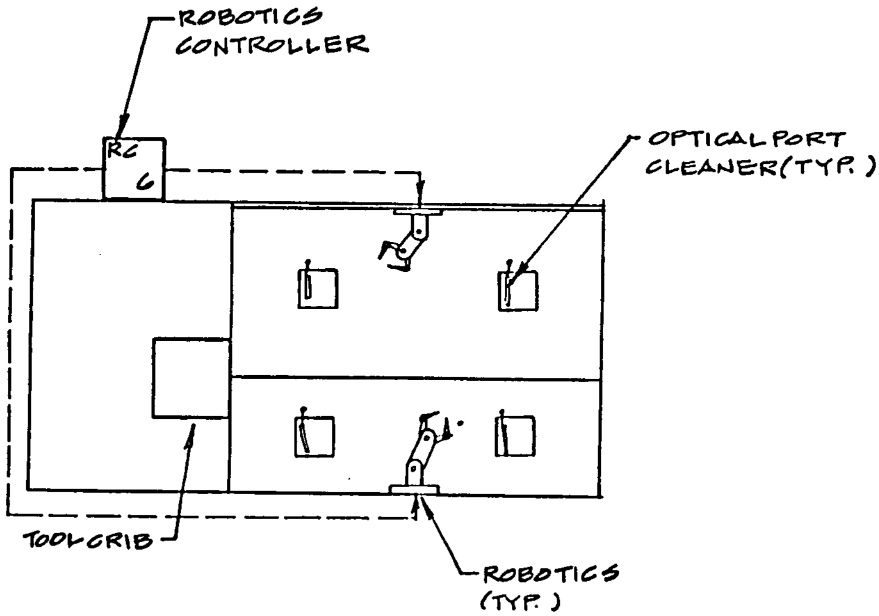
The functions of this subsystem are 1) to perform internal maintenance when the PGM is functioning, 2) to provide a means for planting, moving, and harvesting plants within the PGM, and 3) to provide a mobile sampling/sensing capability within the PGM that could be used to obtain additional environmental and biological data. Fig. 14 gives a schematic for this subsystem.

Typical Internal Operations Equipment

- Robotics
- Tool crib/tool set
- Optical port cleaners
- Seeder
- Harvester
- Mobile sensor platform

Figure 14

(10) INTERNAL OPERATIONS



# HARDWARE DEVELOPMENT PLAN

## DEVELOPMENT AND REVIEW PROCESS

In order to provide for an orderly translation of the scientific requirements for the PGM into a well-engineered reality, some canonical procedure is needed that will allow for an interchange between the eventual users of the PGM and the design team involved in its construction. As such, this is not a new problem, and the development plan outlined in Fig. 15 illustrates one such procedure that has been used at NASA to develop flight projects. Because the construction of the Ames PGM is not tied to the schedule of any launch vehicle, the development plan need not be quite so formal, so the dates shown in Fig. 15 may change as the design effort progresses. What should be emphasized is that the design reviews give project management an opportunity to evaluate the different design options in the early stages of the process, and with enough feedback to ensure that those options are implemented when PGM construction is begun.

Figure 15