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SPECIFICATIONS FOR AND PRELIMINARY DESIGN OF A PLANT GROWTH CHAMBER FOR ORBITAL EXPERIMENTS

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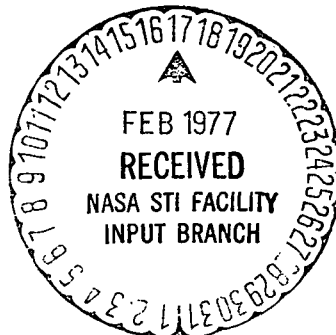
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16 Abstract It has been proposed by various members of the scientific community that plant experiments be performed on board the space shuttle. To permit the proper execution of most tests, the craft must contain a plant-growth chamber which is adequately designed to control those environmental factors which can induce changes in a plant's physiology and morphology. In this paper, the various needs of, and environmental factors affecting, plants have been identified. Further, the permissible design, construction and performance limits for a plant-growth chamber have been set, and tentative designs have been prepared for units which are compatible with both the botanical requirements and the constraints imposed by the space shuttle.			
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OBJECTIVES

The purpose of this research was to design a plant growth chamber which would be suitable for botanical experimentation in space.

LIMITATIONS

There are numerous constraints which have been imposed on the development of a plant growth chamber by the design of the Space Shuttle. In addition to these limits, several other constraints have been superimposed that will hopefully reduce the costs and increase the usability of the chambers, thereby improving the possibility that a plant growth chamber will be constructed and flown on the Space Shuttle. The requirements are:

a. The chambers must be capable of being used in both Spacelab and Biomedical Experiments Scientific Satellite (BESS) without modification.

b. The chamber should be a well-designed growth chamber in which equipment for single experiments can be placed as needed. A single-use chamber must be avoided.

c. The internal dimensions of the chamber must be as large as possible to permit maximum flexibility for the user.

d. The chamber should be designed so it can provide controlled environmental conditions for all of the following without modification:

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1. plant growth studies, with natural or artificial light
2. endogenous rhythm studies
3. geotropism studies and clinostat use
4. insect, invertebrate and lower vertebrate studies requiring a controlled environment
5. high-humidity conditions to permit seed germination and pathogen inoculation studies
6. tissue culture studies
7. bacteriological incubation
8. lower-mammal studies (if possible)

e. The precision of environmental control should not be sacrificed for those parameters which are proven to be critical for stable plant growth.

f. Space should be reserved for the possible addition of more precise control of some environmental parameters by later investigators.

g. Any design or technology which is new, experimental, untested, unproven, or not generally accepted by biologists must be avoided in the chamber at all costs.

In summary, the growth chamber should be relatively spartan, being nothing more than a large chamber with controlled light, carbon dioxide, temperature, and diurnal cycles; further, provisions for coarse humidity control, automatic watering, and environmental monitoring are essential.

RECOMMENDATIONS

The following pages present a listing of the specifications which should be met during the design of the plant growth chamber. The right-hand column presents some of the justification and rationale involved in the selection of these values.

Design Specifications

Justification

Temperature:

Temperature-operating-range:

The operating range should be 7° to 38° C.

Temperatures lower than 7° C will necessitate increased engineering to remove frost. The ability to maintain 38° C permits the chamber's use as a microbial incubator.

Temperature accuracy:

It must be possible to maintain $\pm 0.25^\circ \text{C}$ around set point as measured with the lights on and equipment and/or plants present in the chamber.

The presence of massive material in the chamber can greatly reduce the temperature accuracy if the air flow is not properly designed.

Spatial variation:

There must be no more than a 0.5°C difference between the high and low readings as measured at 10-cm intervals horizontally across the chamber at 1-m and 30-cm distances from the light barrier. Readings must be taken with lights on and plants in the chamber.

Fairly minor variations in temperature between points in the chamber can result in an enormous growth difference between specimens. If the temperature is not uniform across the chamber, the chamber will be of little value.

Regulator type:

Thermocouples would probably be best.

Resistive temperature transducers are not suitable for chamber use; they are too easily affected by humidity and airborne dirt. Mercury-filled hydraulic thermostats carry a toxicity risk in a closed system.

Regulator sensor location:

- a. The sensor should be located in the return air duct where it is shielded from the light source.
- b. The air flow over the unit must be at least 45-60 m/min.
- c. The duct around the sensor should be highly reflective.
- d. The system should be designed to prevent a temperature "overshoot" caused by the lag between a thermostat-ordered change in temperature and the sensor's perception of the change.

Since the sensor must be aspirated and shielded from light, this location eliminates the need for a separate housing and fan inside the growing area. The reflecting surface will reduce the heat absorption by the housing.

Compressors and heaters:

- a. These units must be adequate to provide the required heating and cooling capacities.
- b. The growing area should be completely isolated from the compressor's vibrations.
- c. Heaters must be designed so that the heating coils do not illuminate the interior of the chamber.

Vibration can cause biological effects and can damage equipment.

The visible light produced by heaters can cause significant biological effects.

Temperature monitoring:

- a. A thermistor, connected to a continuous recorder, should be located near the thermostat sensor in the duct. It must be aspirated with an air flow of 45-60 m/min and must be completely light shaded.
- b. Connections for at least four thermistors should be located in the growing chamber. The recorder should be wired to these connections and be capable of handling the data received from them.

This will provide a permanent and continuous record of the temperature in the chamber. Its location eliminates the need for a separate aspirated housing located in the growing area.

Experimenters will undoubtedly wish to determine the temperature of the chamber air, soil, and leaf, etc. To specify and fix both the type and location of the sensors now would be doing the experimenters a disservice.

Temperature controls:

- a. There must be two calibrated, variable-temperature controls which are activated by a 24-hr timer. The experimenter must be able to select a time interval on the clock during which the temperature control is switched from one thermostat to the other.
- b. There must be a calibrated, adjustable high-temperature cutoff which turns off both the lights and heaters each time the chamber temperature

This permits the setting of both a day and night temperature, as well as providing a variable thermal period. Alternating day/night temperatures are essential for normal development of many plant species. A continuously variable temperature program which simulates a gradual change in temperature does not seem justified at this time.

A thermal cutoff is essential to prevent a cooling malfunction from ruining the plant material in the chamber. Since it is possible that the temporary loss of illumination

exceeds a preset limit. In addition, an audible alarm must be sounded and a permanent mark recorded on the environmental recorder. It is essential that the cooling system, the electrical outlets, the timers, the recording equipment, and all other electrical materials continue to run when the thermal cutoff is activated.

- c. The unit must have a calibrated, adjustable, low-temperature cutoff which, when activated by a temperature below the preset minimum, will turn off the cooling. If cooling is provided by a compressor in the chamber, the power to the motor must be turned off (rather than closing the coolant valve). When the cutoff is activated, an alarm signal must sound and a mark must be placed on the experiment record.

Illumination:

Light loft:

- a. The lighting must be separate from the growing area.
- b. The top of the chamber should have 85-95 percent transmission of all wavelengths of visible light, be able to withstand the heat of the lights, and not be prone to static electricity. A 0.5-cm thickness of Plexiglas G may be suitable.
- c. The barrier must be clear rather than opaque. There

could have serious effects on the plants, the investigator must be aware of the malfunction. In many existing growth chambers, all electrical equipment is turned off when there is an overheat; thereby altering the photoperiod and needlessly destroying many experiments.

A faulty compressor can result in below-freezing temperatures in the chamber. Further, the common cause of such failures is the sticking of the coolant valve, thereby necessitating more reliable means of turning off the cooling during a low-temperature event.

Lights placed in the chamber generate too much heat and create an excessive thermal gradient. Further, electrical malfunctions can cause the production of ozone and ethylene.

With a transparent top, the chamber can be illuminated by sunlight if the artificial lights are replaced with a mirror system. To prevent a shift in the spectral quality, the barrier must not selectively absorb certain wavelengths.

Opaque barriers would probably result in some reduction of light intensity

must be no struts or supports for the barrier over the growing area.

at the chamber floor. Struts and supports would definitely affect the evenness of light distribution across the chamber floor.

- d. The lights should be mounted on a sliding rack so that they can be easily pulled out for service and cleaning of the barrier window.

The lights and the window will require frequent service. Further, different investigators will probably wish to replace the type of light bulbs to achieve different spectral qualities. When the chamber is used as a microbial incubator, the entire loft can be removed to conserve weight.

Light bulbs:

- a. Cool-white fluorescent bulbs (1500 mA, T-12 type) should cover the chamber ceiling.

Other lighting systems produce too much heat (e.g., xenon), are not well accepted by most botanists (e.g., xenon, HID), or have not been proven to be superior to cool-white bulbs (e.g., grolux, other fluorescent bulbs).

- b. Enough 60- to 100-W incandescent bulbs should be distributed across the ceiling to equal 30 percent of the fluorescent bulb wattage. The use of long-life bulbs may be preferable due to the excessive vibration imposed on the filaments during launch.

The incandescent light is essential to provide the far-red light necessary for normal plant development.

Bulb arrangement:

- a. The bulbs should be as close together as possible (5-20 mm of space between) to provide maximum light, yet permit air flow for cooling.

If the bulbs are positioned too closely, their cooling will be reduced due to restricted air flow; the elevated bulb temperature will significantly reduce the light output.

- ~~b. The ends of the fluorescent tubes (30-60 mm back from the pins) should not be over the growing area.~~

~~The light output from the ends of the bulbs is very poor. Either the bulbs can be longer than the growing area or a bulb arranged at right angles to the primary light bank can be positioned to cover each end of the bulbs.~~

- c. The fluorescent bulbs should be paired so that when a pair

This provides a simple means of controlling the light intensity.

is turned off, a dark area is not created. The best arrangement would be to pair bulbs 1-10, 2-9, 3-8, 4-7, and 5-6 if 10 bulbs are used.

- d. The incandescent bulbs can hang below the fluorescent tubes; if a sturdy filament is available in a thin bulb, the lamp can be used to replace the fluorescent bulb.
- e. The incandescent bulbs should be spaced so their illumination is evenly spread over the chamber floor.

To provide even illumination, it may be necessary to install high-watt bulbs in the corners, intermediate-watt bulbs along the sides, and low-watt bulbs in the center.

Light intensity:

- a. The unit should be able to produce 3000-5000 fc as measured after 100 hr of bulb operation, at a distance of 1 m from the light barrier.
- b. When measured at 10-cm intervals across the chamber floor, the variation in intensity must not exceed 5 percent.

Measurement of intensity must be delayed since fluorescent bulbs dim most rapidly the first 100 hr of use, then decline at a much slower rate thereafter.

Although "dark" spots may not be noticed by the human eye, they can have serious effects on the uniformity of growing conditions.

Lamp loft:

- a. The inner roof of the loft should be highly reflective.
- b. The lamp loft must have a cooling system which is separate from the growing area.
- c. The temperature around the lamps must be controlled within a 23° to 25° C range.
- d. The air flow over the lights should be 65 ±15 m/min on a continual basis.

This will increase the downward light reflection and reduce the transfer of heat to the spacecraft.

The loft may contain ethylene and ozone; thus, the air must not reach the chamber.

The light output of fluorescent bulbs drops substantially as their temperature increases above this optimum range.

This air flow is adequate to maintain a stable temperature. Use of a cycling fan to cool can result in an oscillation of light intensity; a

25 percent drop in illumination has been observed when a cooling fan turns off.

e. The cooling air should enter at the ends of, and just below, the tube. The air is exhausted via a chimney located above the lamps so that the air flows between the tubes.

This arrangement provides the best cooling and ensures that the ends of the bulbs are kept cooler than the center. If other bulb types are used, the cooling flow may need to be changed.

f. The ballasts probably should not be located in the lamp loft since they must not share air with the growth chamber. They must be cooled so that they don't exceed their rated temperature. A 5-cm separation between ballasts and an air flow of 60 to 90 m/min may be sufficient to keep the surface temperatures below 90° C.

The heat of the ballasts, if in the loft, could alter the light intensity. In addition to their shortened lifespan, overheated ballasts will release pyranol and ethylene. Since the latter has significant growth effects on plants, cooling is essential.

g. Each ballast should be individually controlled by a circuit breaker mounted on the front of the instrument panel.

In addition to providing for illumination control, this will prevent one failure from making all the lights inoperative.

h. Only the lights and their supporting equipment (e.g., timers, ballasts, lamp circuit breakers, etc.) should be located on top of the chamber.

The provision for a window in Spacelab and the possibility of converting the entry port of BESS into a window mean that some experimenters will be able to replace the entire lamp loft with a system to permit entry of sunlight into the chamber. Proper design of the chamber now will permit easy conversion of the unit later.

Illumination control:

a. Individual circuit breakers should be used to turn off pairs of bulbs. With the exception of the central pair, the bulbs turned off by a single breaker should not be adjacent to each other.

A d.c. system for varying the intensity of the fluorescent lights, although possibly useful, does not appear justified at this time. In all probability, most experimenters will desire a single intensity level which is preset on the ground. It

appears that enough flexibility in intensity is possible using such a system. For example, assume there are 14 bulbs which are paired as follows:

1 2 3 4 5 6 7 7 6 5 4 3 2 1.

If all bulbs are on, 100 percent intensity results. If bulb pair 4 is off, 85 percent intensity results. If pairs 2 and 6 are off, 71 percent intensity results. If pairs 3, 5, and 7 are off, 58 percent intensity results. If pairs 2, 3, 5 and 7 are off, 43 percent intensity results. If pairs 1 and 5 remain on, 29 percent intensity results. If pair 5 remains on, 14 percent intensity results.

- c. The incandescent bulbs would best be controlled by individual switches and/or by replacing the bulbs with different wattages.

The use of a rheostat to reduce the bulb intensity would alter the red/far-red ratio and possibly have serious biological consequences.

Photoperiod control:

- a. The fluorescent lights and incandescent lights should be controlled by separate timers.
- b. The timers must also be easily converted so that one timer operates both incandescent and fluorescent lights, thereby ensuring their synchronous performance.
- c. The timer should be capable of turning the lights on and off repeatedly at 15-min intervals (or less) throughout the day.

Some experimenters may wish to terminate each photoperiod with either all incandescent or all fluorescent light, thereby controlling the final form of phytochrome.

Most investigators will prefer that all of the lights go on and off at the same time. Since as little as a 1-min difference between the timers may convert enough phytochrome to cause biological effects, one timer must be able to operate both lighting systems.

In addition to producing a desired photoperiod, this type of timer will permit the construction of "skeleton" photoperiods for use in studying endogenous rhythms.

Radiation monitoring:

- a. Measure the photosynthetically active radiation (PAR) using a PAR meter. This will ensure that the lights operate as planned during the experiment. More precise measurements of the energies at various wavelengths are best made on the ground.
- b. Provisions for the easy addition of a sensor capable of monitoring in the 700- to 800-nm range is advisable. Some investigators may wish to monitor the far-red light levels during their experiments.
- c. Electrical outlets should be provided for experimenters who wish to use more sophisticated forms of light measurement. Additional environmental measurements are essential, but selection of the equipment should be left up to the experimenters.
- d. Mount the sensor about 30 cm from the back wall at a height of 1 m from the lights. The support for the sensor should be thin and flexible so that the experimenter can position the sensors where he desires. The location of the sensor is important since it should be out of the way of the operators, must not shade the plants, be positioned away from the chamber walls, yet provide light intensity readings in the direct vicinity of the test plants. Thus, the sensors would be most valuable if they were easily movable since different experimenters will have different needs.
- e. The sensors should be cosine corrected.
- f. The intensity of light as observed by the PAR meter should be continuously recorded.

Additional light requirements:

- a. The chamber interior, while operating normally must be completely light tight with no light leaks or glowing components. No light should be visible to a dark-adapted individual located inside the chamber while the chamber is operating in a well-lighted room. A very small amount of light accidentally provided to the plants during their dark phase is enough to ruin many experiments. A dark-adapted human eye is the best sensor of light leaks.

b. When the chamber is in the dark phase, it is necessary to provide either a locking device on the door (with appropriate manual overrides both inside and outside) and/or an illuminated sign outside the chamber warning the operators that the dark phase is in progress.

With no terrestrial guidelines as to the time of day, it would be easy for an experimenter to accidentally open the chamber door during the dark phase and ruin the experiment.

c. To ensure light tightness, the heater coils must be located so that they do not project any visible light into the chamber interior.

d. The door gasket should be magnetic to ensure a light-tight seal.

e. A black velveteen cloth "tunnel" should be designed and constructed to permit an experimenter to open the chamber without letting in room light during the plants' dark period.

It is unlikely that it will be possible to turn off the spacecraft's lights each time an experimenter needs access to the plants; thus, a large bag fitting around the door in which the experimenter can stand, open the door, and work with the plants, would be of great value.

Atmospheric Composition:

Carbon dioxide:

a. The chamber must have an injection system for adding carbon dioxide into the chamber's airstream.

Carbon dioxide is not likely to be intentionally added to the capsule air; thus, it must be provided with the chamber. In addition, even if there is ambient carbon dioxide available, rapidly growing plants will consume enough of the gas in a small closed system to stress the plants within 30 min.

b. The normal range of carbon dioxide in the chamber should be 300-350 ppm (0.23-0.27 mm Hg).

This level of the gas is similar to the normal terrestrial concentration.

c. Depending on the level of carbon dioxide which is maintained in the space capsule, it may be necessary to install "scrubbers" to reduce the carbon dioxide concentrations to the desired levels.

Since the crew members will be producing carbon dioxide, there may be diffusion of the gas into the chamber, resulting in levels which are considerably above the terrestrial levels.

d. The use of "make-up" air from the space capsule is not adequate to provide stable levels of carbon dioxide.

Most commercial growth chambers which depend on using room air to replace the photosynthetically depleted carbon dioxide do not work well. If enough air were admitted to maintain elevated levels during the day, the burden on the cooling system would be too great, the levels would be uncontrolled, and the chamber would be open to other gases and volatiles which were present in the spacecraft.

e. The carbon dioxide should be continually monitored, recorded, and if it drops below the minimum level, it should be added to the chamber; an infrared analyzer may be the preferable measuring system.

The level of carbon dioxide must be actively maintained since the rate of plant growth depends in part on the level of this gas. A system in which the gas is metered on a periodic basis by a clock is not acceptable since a drop or increase in the growth rate could cause too much or too little gas to be present in the chamber.

f. The sampling tube for the gas should be located in the return air duct.

The levels in the duct would be lowest.

g. The system should be capable of being easily modified so that higher levels of carbon dioxide could be added if an experimenter so desired (e.g., 1000-3000 ppm).

If there are plans to grow plants in space for their use as food, some experiments must be performed to attempt maximizing crop yield in space using, among other things, carbon dioxide enrichment.

Oxygen:

a. The amount of oxygen must be monitored and regulated within a range of 135-170 mm Hg.

In all probability, any system which is adequate for maintaining proper oxygen levels for the crew members will be suitable for the normal growth of plants.

- b. Some means of maintaining reduced oxygen levels in the chamber would be an option that some experimenters might request. However, this would not be required for normal use.

It is possible that there will be requests for lowered oxygen levels or for anaerobic conditions in the chambers. For example, lower oxygen levels might be used to improve plant yield, or the chamber might be needed to culture anaerobic bacteria.

Nitrogen:

The presence of nitrogen gas may be required in some experiments. However, it would not be required for normal use.

Any tests involving the fixation of nitrogen would require this gas. The capability of adding small amounts of nitrogen, perhaps at the expense of oxygen (thereby maintaining the same total partial pressure), may be very useful. However, since the spacecraft will be at 1/4 normal pressure, any requests to elevate the nitrogen to the levels found on Earth would be unreasonable since it would necessitate constructing a gas-tight chamber capable of withstanding a pressure difference of about 600 mm Hg.

Atmospheric impurities:

An activated charcoal filter must be fitted so that all air (including the recirculating air) will pass through it.

The presence of ethylene and other impurities can cause serious biological effects. Since plants produce considerable quantities of ethylene and other biologically active volatiles, the recirculating air must be filtered.

Plant Watering:

Nutrient solution storage:

- a. The container must be large enough to contain all of the nutrient solution required for the mission.
- b. The container must be non-reactive when exposed to the nutrient solution, and must not release ions or plastic components into the solution.

A plant's requirement for various minerals is most easily met by providing them in a dissolved form. This also permits the use of hydroponics with no major chamber revisions.

- c. The container must be capable of being pressurized to force the liquid to the plants.
- d. A pressurized air system must be provided to force the liquid from the tanks.
- e. The flow line entering the chamber should be valved off so that the investigator can select the delivery method compatible with his needs.
- f. Delivery of the liquid must be controlled by a 7-day time clock.

The specific means that will be employed to water and fertilize plants depend on the scientist's experimental design; e.g., some may wish to "trickle" solutions on the surface of the medium, some may mist roots in a test of hydroponic systems, while others may require manual watering. Thus, to design a specific watering system at this time would be doing the experimenters a great disservice. At this stage of development, the chamber must be as flexible as possible.

In most cases, a routine schedule of fertilizing will be followed.

Watering:

- a. The watering system has all of the same requirements of the nutrient solution system.
- b. The water should also be delivered via pressure and controlled by a 7-day timer.
- c. The water tanks should be designed to receive the excess condensate water that will not fit in the steamer storage tank.

Due to transpirational losses through leaves, water will have to be added on a frequent basis. Most investigators will not want to add nutrient solution to replace these water losses.

This will permit watering on a periodic basis.

Humidity Control:

Range needed:

A relative humidity (RH) of 50-90 percent at 25° C is acceptable. If the chamber is to be used as a microbial incubator or a pathogen inoculation chamber, 100 percent RH would need to be maintained.

~~There is no evidence that fluctuations of humidity within the range of 50-90 percent affect plant growth.~~ Further, since RH varies with temperature, a more meaningful measure would be the vapor pressure deficit since it indicates the rate at which evaporation will occur.

Method of addition:

- a. The best method would be by steam injection.
- b. An alternate method is to force water through small nozzles with compressed air (3-5 kg/cm²).

Steam would have the least effect on the temperature in the chamber.

Water cooler than the dew point would dehumidify the air; the mist would also cause a decrease in temperature.

Regulation:

- a. To maintain 100 percent RH, a timer which causes the steamer to run periodically is acceptable (e.g., 5 min of steam every 25 min).
- b. For most situations, it will only be necessary to raise the RH to 80-90 percent when it drops below 50 percent.

More precise control of humidity would be a waste of space and money.

- c. Locate the humidity sensor in the return air duct.

The sensor must be aspirated and located close to the temperature sensor.

- d. The humidity sensor should be connected to the environmental parameter recorder as well as to the limit switch which operates the humidification system.

It will be essential to know what ranges of humidity were experienced during the experiment.

- e. The best type of sensor would probably be a dew point hygrometer.

- f. Water condensed from the evaporator coils should be collected by a vacuum system and pumped back into the storage tank for the steamer. Excess water should be returned to the watering tanks.

The steamer storage tank should be large enough to accommodate the volumes of the nutrient and water tanks, or else has to be provided with a system to pump the surplus condensate back to the water tank.

Dehumidification:

Dehumidification is not required for plant growth and is not likely to be requested.

Air Flow:

Direction:

Air should move from the top to the bottom of the chamber.

An upward flow is unacceptable for bacteriological incubators and is less desirable for plant growth since the roots are cooler than the air temperature. Air which is injected in the horizontal, laminar flow will tend to flow over the top of the plants if the chamber is very crowded; thus, the temperature directly around the leaves would be different from the air temperature.

Rate:

The flow rate should be 24 \pm 5 m/min.

Studies indicate this rate is optimal for growth.

Monitoring:

A multiple-wire, hot-wire anemometer is probably best. The sensor should be flexibly mounted so that the experimenter can position it at plant height and the data can be recorded on the environmental recorder.

An experimenter should be aware of the average air speed and must keep a record in case any circulation failures occur during the experiment.

Filtration:

a. Incoming air ducts must have activated charcoal filters.

This will remove various contaminating gases.

b. The air leaving the chamber must pass through a large filter or series of filters to remove dust and debris.

There may be considerable amounts of dust given off by the potting mixtures.

c. The filters must be designed so that they have a minimal pressure drop across them and so that they do not easily clog.

With a large pressure drop, the partial vacuum resulting on the downwind side of the filter could pull impurities into the chamber.

Chamber Construction:

Front:

- | | |
|--|--|
| a. The entire front of the chamber should be easily removable so that the contents can be easily changed between experiments. | Use of large equipment in the unit will necessitate removal of the front. |
| b. Several different front panels should be available to permit the experimenters the option of placing doors where they will need them. | The value of the chamber will be its flexibility resulting from its ease of modifications; e.g., some researchers may need glove ports, others camera mounts, etc. |
| c. It may be worthwhile to design the chamber so that an expansion unit to permit growth of tall plants in BESS can be bolted onto the bottom. | The BESS can support a taller chamber than can Spacelab, and its mission duration will be longer. A few experimenters may require additional height. |

Door:

- | | |
|---|--|
| a. The doors should be sealed by a magnetic gasket and should be capable of being opened from the inside. | This ensures an air- and light-tight seal on the doors, while providing for operator safety. |
| b. The door should be as large as possible to permit easy access to the chamber. If possible, a second, smaller door should be mounted in the large door. | A large door will be essential at some times; however, its continual use during an experiment will affect the air flow, the temperature, the gas concentrations, etc. Thus, a smaller door is essential. |
| c. The door should have a warning sign which is illuminated when the dark phase is in progress. | This will reduce the chance of an accidental opening of the chamber door during the plants' night. |
| d. A small viewing window with a light-tight cover should be placed on the door. | |

Chamber interior:

- | | |
|---|---|
| a. The interior of the chamber must be specular aluminum. | This is essential to provide the necessary reflectance and durability of the chamber walls. |
|---|---|

b. All interior portions of the unit must be free of ferrous materials.

Continuous high humidity is very hard on iron.

c. The insulation should be about 5 cm thick in the walls.

Shelving:

a. The shelving should be open mesh, preferably aluminum.

The shelving must permit the passage of air and yet be strong enough to support the various equipment and plant supporters needed for experiments.

b. The maximum loading capacity of the shelving (at 1 g) should be 200 kg/m².

This would be an adequate loading capacity to support a 20-cm depth of water.

c. The shelves should be easily adjustable by the use of wall clips.

There is no need for a mechanical lifting shelf since the level will be set while the unit is on the ground. Since some experimenters will want the plants closer to the lights, the shelf must be adjustable.

Air ducts:

Any air ducts which are needed to conduct air along the sides of the chamber should be located inside of the growing area and be constructed of transparent materials.

If the ducts are located on the outside of the chamber, the growing area of the unit is reduced. If the ducts are inside, they would shade all plants below them. However, by using internal transparent ducts, only the tops of tall plants have their available space reduced.

Environmental monitor:

There must be a suitable system for recording all of the data generated by the environmental sensors.

The data must be in a form which is readily usable by the investigator.

General construction:

All of the operating gear should be positioned so that it is easily accessible for service.

The necessity for periodic maintenance and the possibility of a failure during the mission make this requirement essential.

Project Review:

After a preliminary design of the chamber is completed, an expert in design and use of plant growth chambers must review the plans and be permitted to modify them to improve the usability of the chamber.

The person who is probably most qualified to perform this review is:

Dr. Robert J. Downs
N. C. Agricultural Experiment
Station
North Carolina State University
Raleigh, VA.

The chamber designs presented in figures 1-8 attempt to encompass all of the previous specifications. The actual sizes of the various components depicted in the figures are meant to be approximations of the probable sizes of known components; thus, they are undoubtedly depicted as being considerably larger than necessary to meet the engineering specifications.

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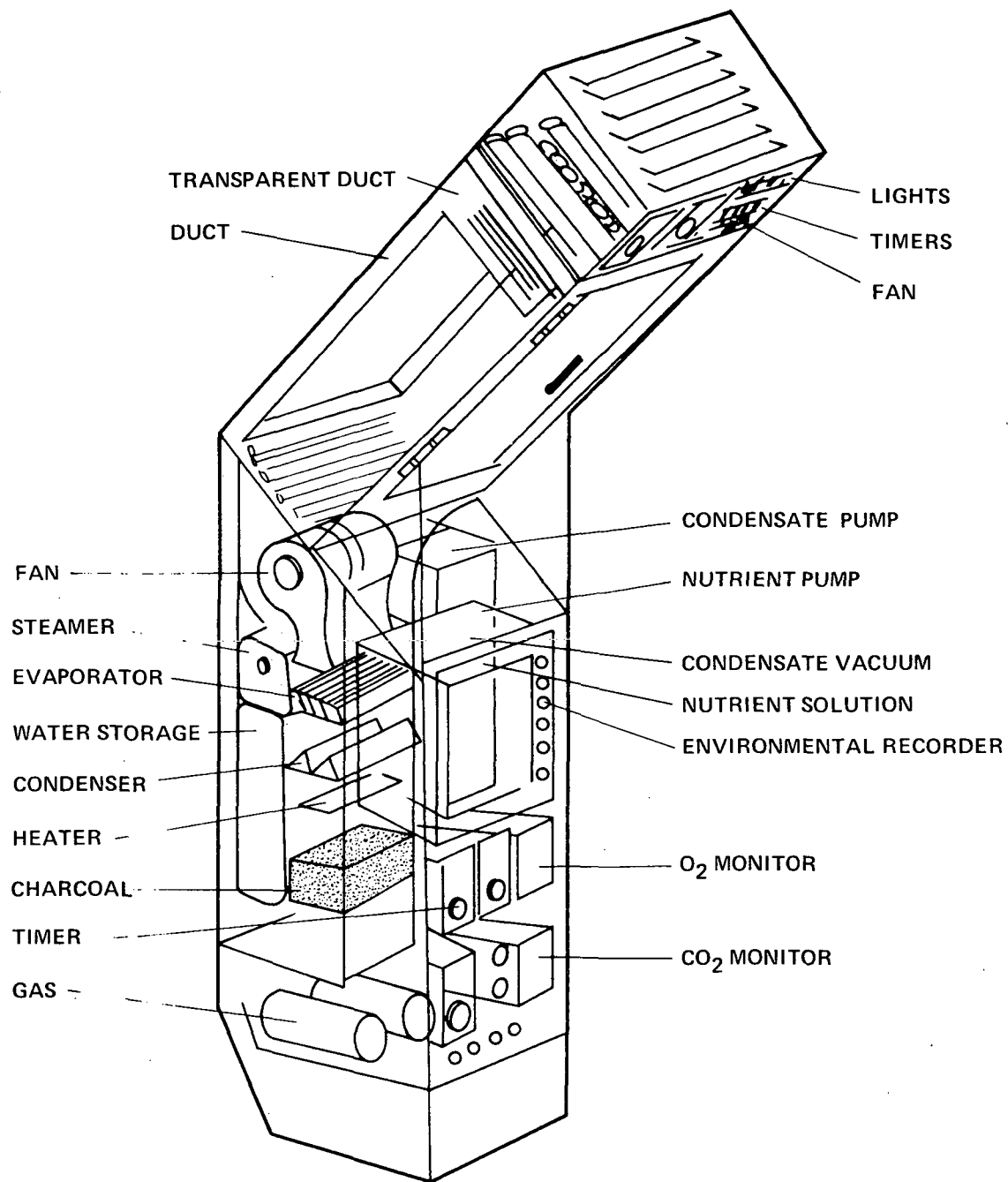


Figure 1.- A transparent view of a chamber designed to fit in a single Spacelab rack. Note that only materials associated with lighting are located above the growing area.

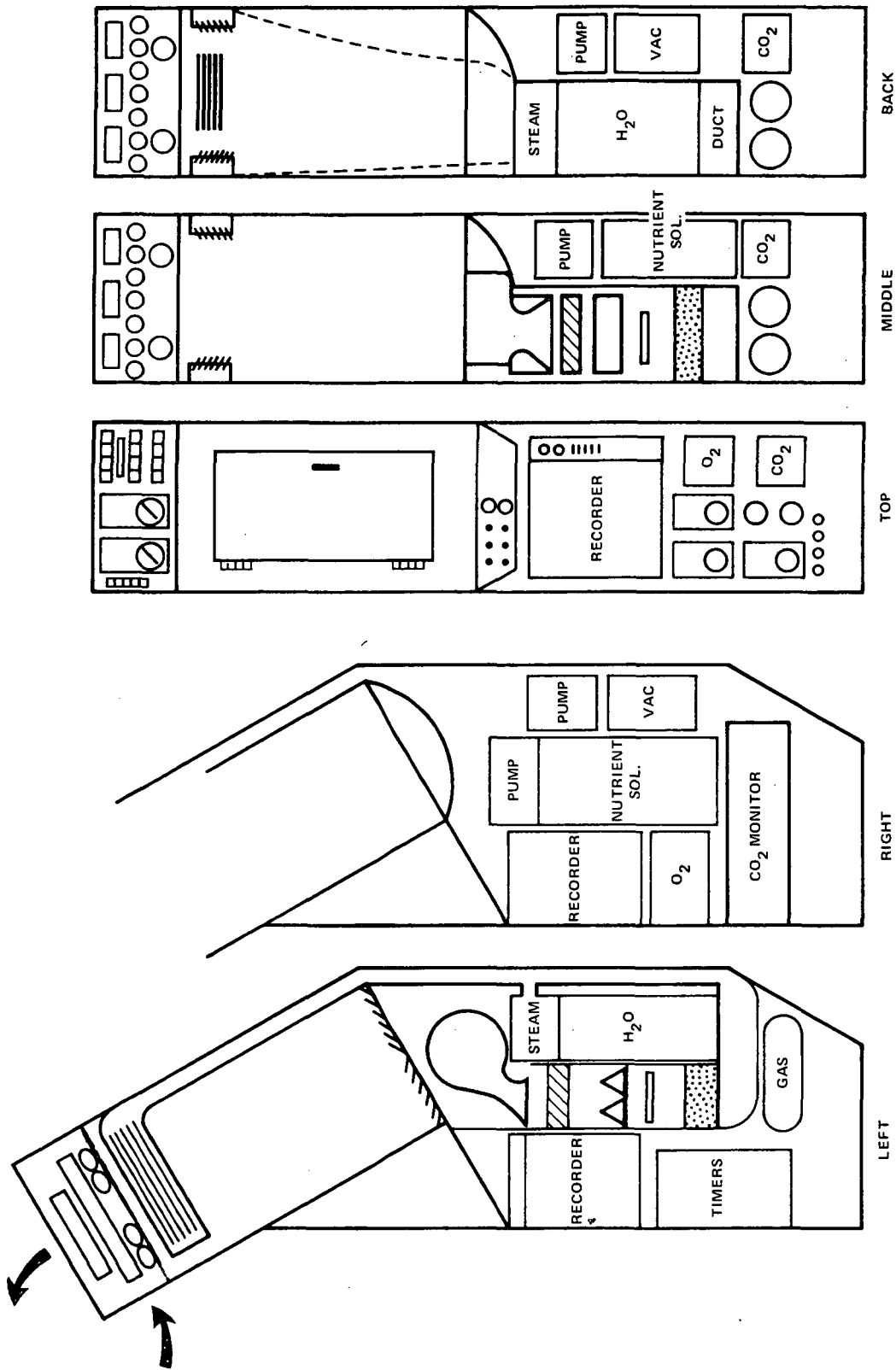


Figure 2.- Front and side views of a chamber designed for a single rack. Located in the exhaust duct below the growth cabinet are the dust filter, fan, evaporator, condensate collector, heater, and charcoal filter.

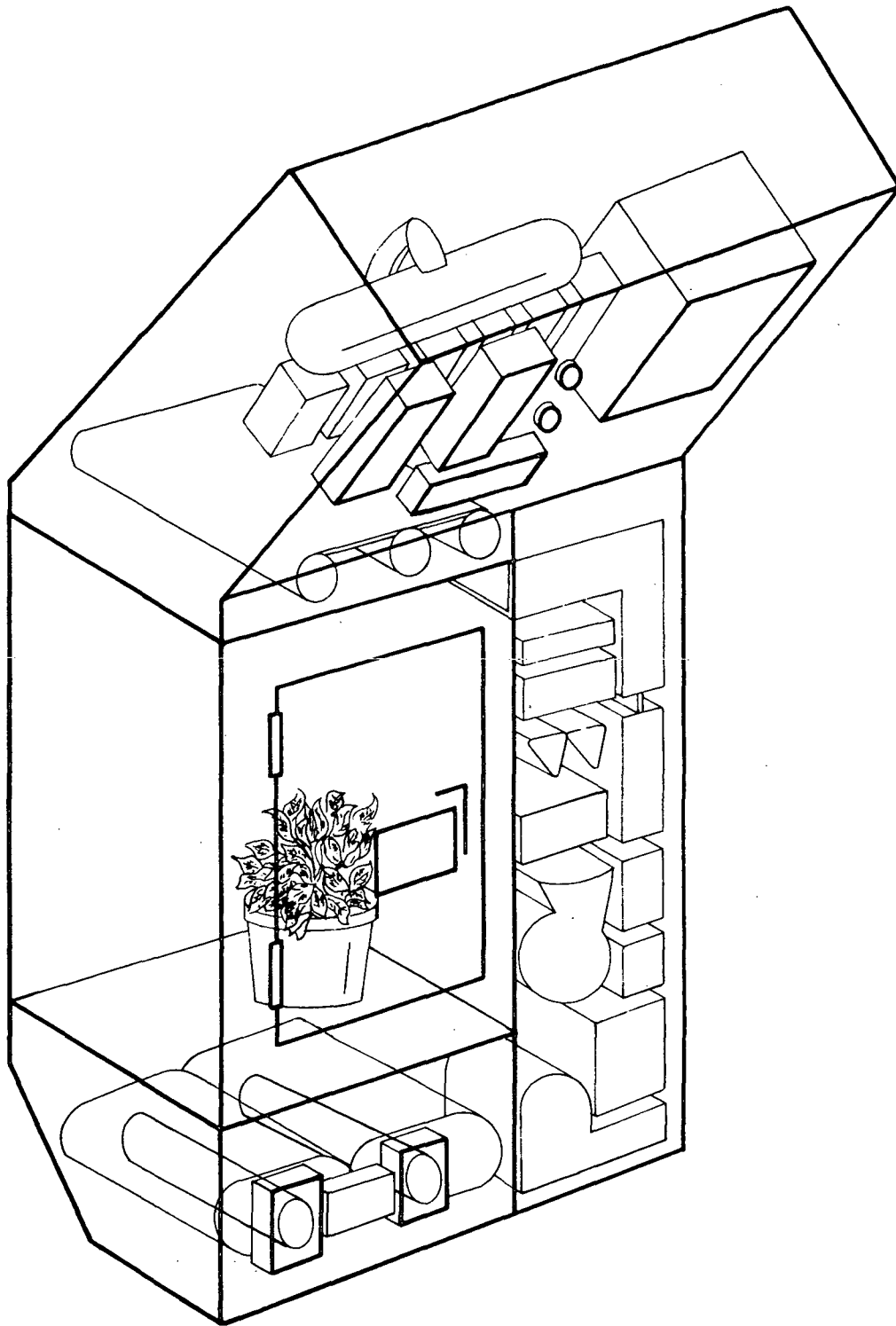


Figure 3.- A transparent view of a chamber designed to fit in a Spacelab double rack and be serviced by a single rack. The actual shapes of many internal components are not accurately portrayed; this figure is meant to convey the general configuration of the unit.

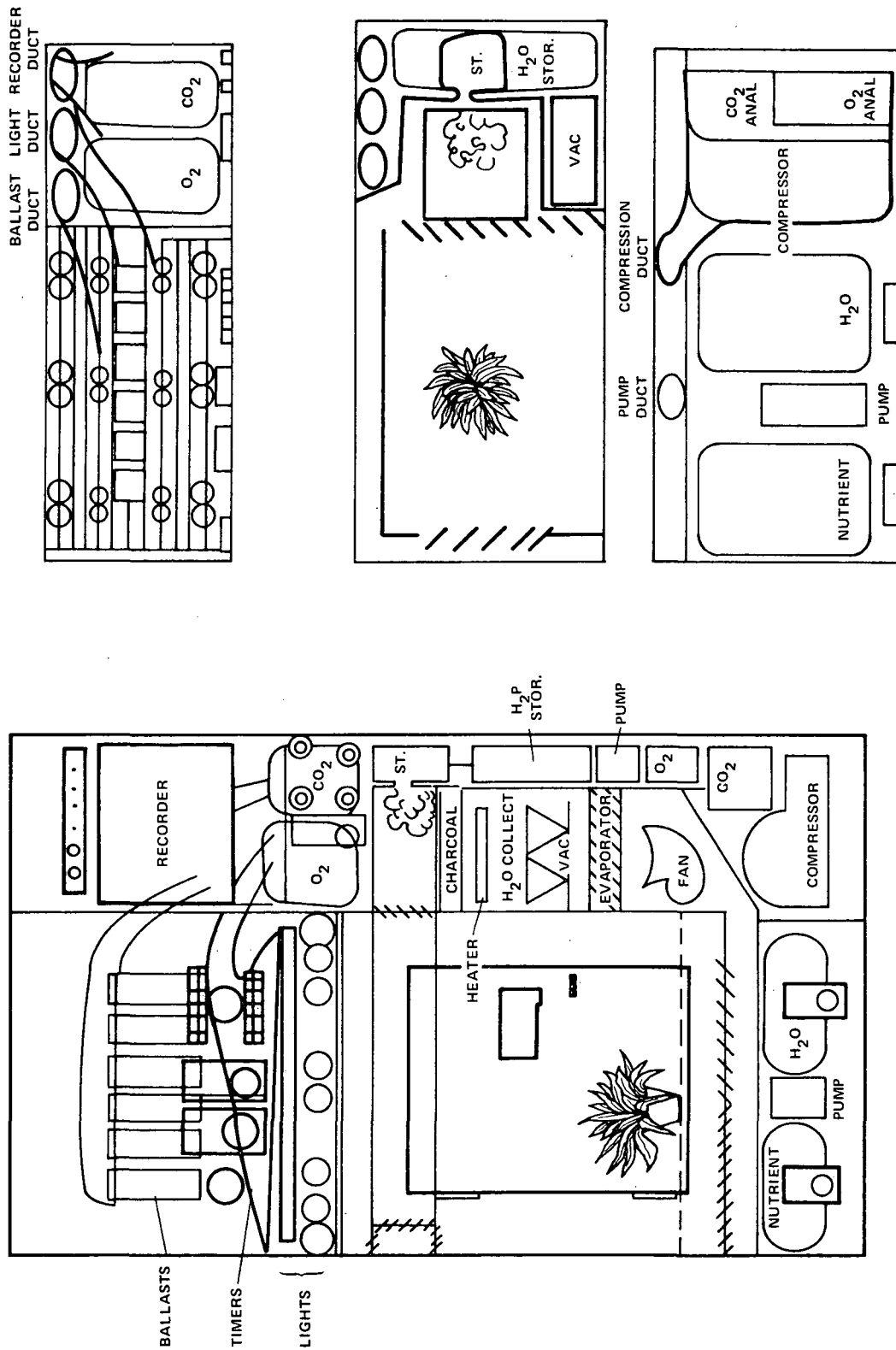


Figure 4.- A front view and three overhead views of the three-rack growth chamber. The sections are taken through the top, middle, and bottom of the unit. Note that the materials associated with the lights are all located above the unit.

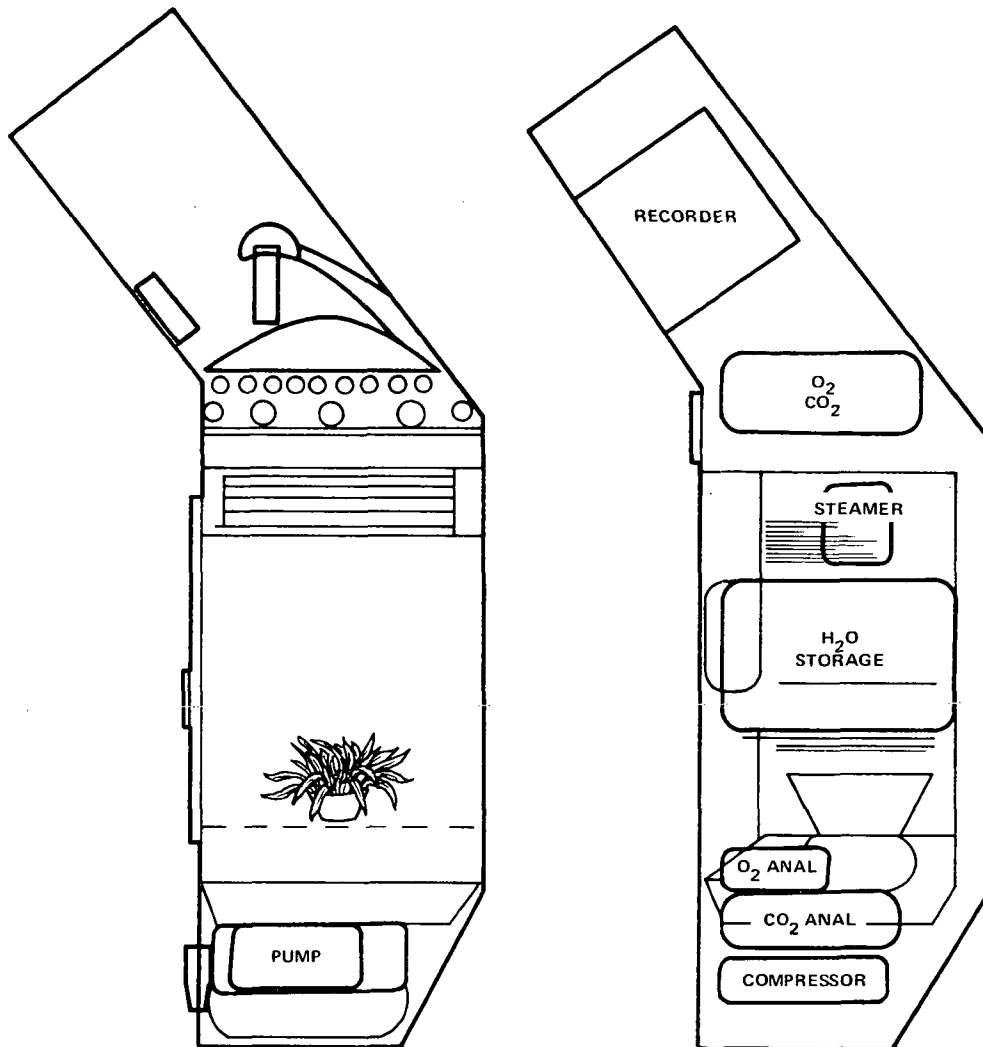


Figure 5.- Two side views of the three-rack chamber.

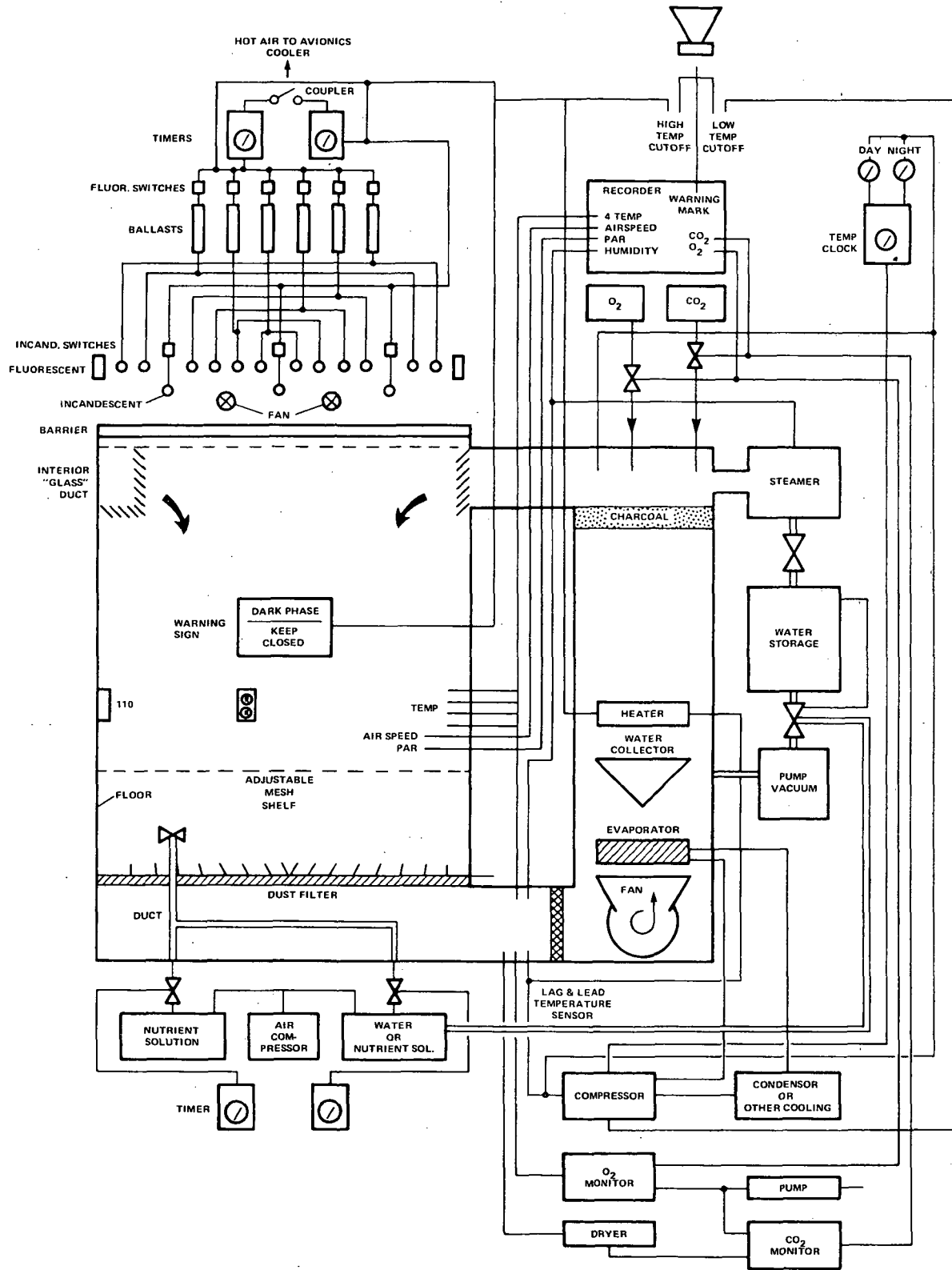


Figure 6.- A schematic drawing which indicates the various components of the chamber and shows how they interrelate.

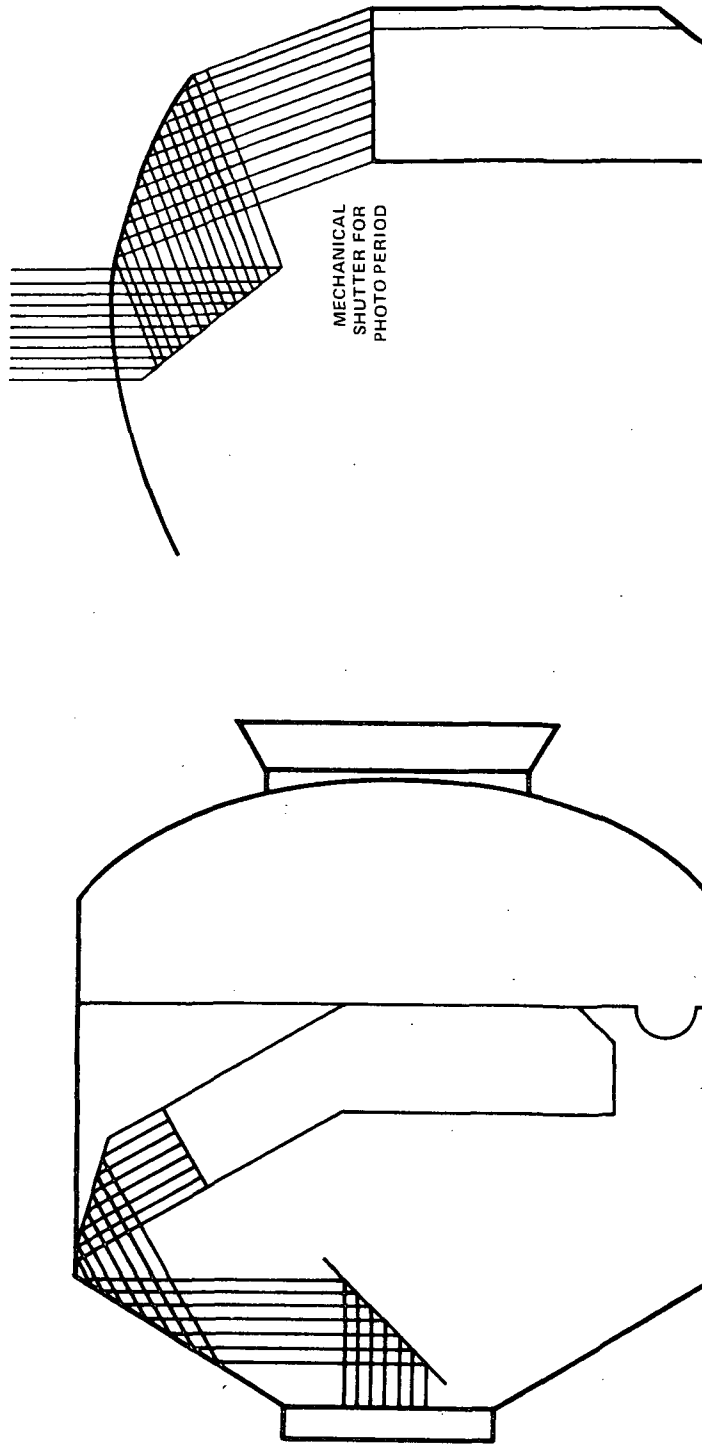


Figure 7.- The possible means by which sunlight can reach the plant chamber in the BESS (left) and in the Spacelab (right). Light enters the BESS via a window placed in the docking port, while in Spacelab, it passes through the observation window. Although the drawing on the right shows the three-rack unit with its light loft removed, the single-rack unit could also be used.

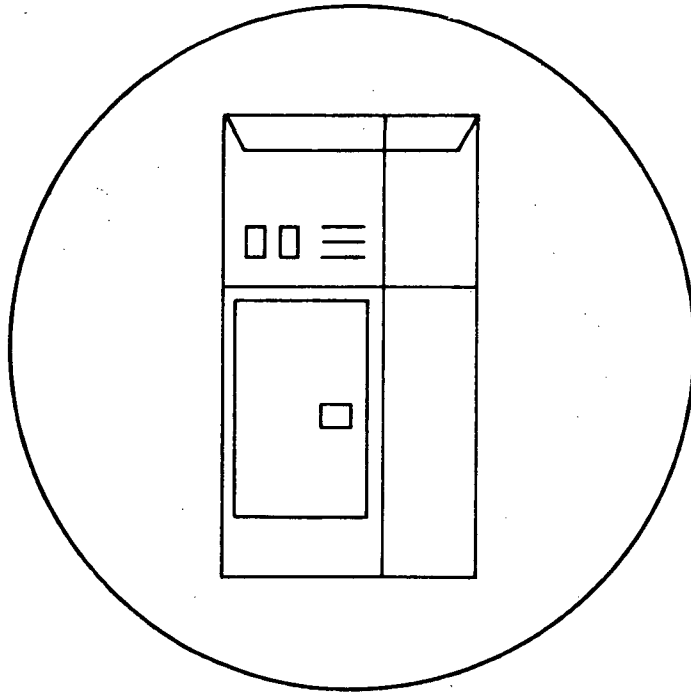


Figure 8.- A three-rack chamber located inside the BESS, indicating that the unit will fit inside the spacecraft.