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CELSS PROGRAM MEETING

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INTRODUCTION

During the spring of 1986, the CELSS program observed several important milestones. The first was the agreement by Ames Research Center to accept responsibility for overseeing and conducting CELSS program science. A second was the recognition by the National Commission on Space that bioregenerative life support should be promoted within NASA. The third was the decision by the NASA Headquarters Life Sciences Division to seek additional support (via a funds augmentation) specifically for the continued development of the CELSS Breadboard project at Kennedy Space Center.

Meanwhile, the CELSS program had undergone formal critique by a subcommittee of the Life Sciences Advisory Committee (LSAC). That committee underlined the importance of continued emphasis within the program on the scientific aspects of CELSS. The program also had been reviewed by a subcommittee of the National Academy of Sciences Space Sciences Board (SSB), and there are strong indications that the SSB report, when released, will support the goals of the CELSS program.

The renewed attention to CELSS science prompted consideration of ways in which Ames Research Center could promote the goals of the CELSS program within its institutional constraints. The decision was made to bring together, in a relatively small, interacting group, the scientists within the CELSS program whose expertise is in the growth of higher plants. These scientists were then asked whether it would be useful for Ames to play a role in promoting their work and that of the program as a whole. The ground rules for the discussion were that any work undertaken by ARC would:

1) Not compete with work presently anticipated at universities, in industry, or in connection with the KSC Breadboard project,

2) Complement and extend research efforts at universities and industry, and

3) Support and complement work planned for the Breadboard project.

The decision to consult first with plant scientists was made because the concept of a CELSS usable in space depends heavily on attaining high production rates by vascular plants. It is anticipated that interactions with scientists in other parts of the program will be useful in the future. Although Ames itself lacks expertise in plant physiology and crop production, its potential contributions in such areas as chemical analysis, automation, computational equipment, data collection and analysis, shop construction facilities, and physical laboratory space can complement the plant science expertise that could be contributed by university scientists.

The goal of the meeting was to draw upon the accumulated experience and knowledge of those Principal Investigators who have been working on CELSS-related problems for a number of years. Many basic questions already have been experimentally addressed by these scientists, allowing them and other attendees to formulate specific sets of inquiries. The PIs were asked to identify the critical science problems inherent in maintaining high plant productivity and crop yield in closed life support systems, and to identify the priority with which those problems should be attacked. They were then asked to project the analytical techniques and technology required in approaching those critical questions. It was anticipated that discussions would bring out problems of mutual interest which could be most effectively addressed by an experimentally active team that would combine Ames' capabilities with a committed group of Principal Investigators. In achieving these intentions, this meeting was gratifyingly successful.

PROCEEDINGS

An informal yet intensive meeting was convened over 2 1/2 days (April 23-25, 1986) at the Carmel Valley Inn, Carmel Valley, California. The following scientists were in attendence:

Ray Huffaker - University of California at Davis
Robert MacElroy - Ames Research Center
Cary Mitchell - Purdue University
David Raper - North Carolina State University
John Rummel - Ames Research Center
Frank Salisbury - Utah State University
Stephen Schwartzkopf - University of California at Davis
David Smernoff - University of New Hampshire
Theodore Tibbitts - University of Wisconsin, Madison
John Tremor - University of New Hampshire

Dr. MacElroy, manager and monitor of the Ames CELSS-related work, served as host and moderator of the meeting. He opened with a discussion of the current state of the program and an evaluation of its future. He also described Ames' capabilities related to supporting a CELSS science effort, including development of flight experiments. While pointing out that any such work at Ames necessarily would be complementary to university or industry studies and to KSC's CELSS Breadboard Facility (CBF), he posed the questions:

Can Ames and a consortium of investigators who are experts on higher-plant growth be useful in promoting the goals of the CELSS program by extending the capabilities of the individual investigators?

Can such a combination be assembled to produce important and necessary scientific research results for the CELSS program?

In asking these questions, Dr. MacElroy emphasized the essential nature of the support and direct involvement of the investigators. He explained that the role of Ames would be to respond to the scientific requirements of those investigators for the development of the necessary equipment for experimentation and for supporting the conduct of those experiments.

The meeting was opened to discussion. The subject and direction of the interchange varied considerably, but was first directed toward identifying research areas that were not being, or could not be, effectively addressed by the present principal investigators. Second, an attempt was made to select from the research areas identified those that could be undertaken by Ames and to outline the scope of that research. And third, mechanisms of research proposal development and personnel involvement were considered. The following is a summary of these discussions.

<u>Volatiles and Soluble Organics, Microbial Activity, Disease, and Productivity</u>

The participants emphasized the need to know more about the consequences of <u>closure</u> on the growth of plants. Specifically, plants in an atmosphere-closed system are expected to produce volatile organics, and these organics will likely accumulate. Some of these volatile compounds may have specific or general effects on plant productivity or on human occupants of a CELSS. While it may be possible to remove such materials by filtration through activated charcoal or by incineration, the effect of the volatiles on plants is unknown and should be determined. A similar situation exists for the nutrient delivery system, but in that case it also is true that many species of bacteria also will accumulate along with water-soluble organics. The identities and effects of soluble organics are not known. The concern for closure at this stage in the development of CELSS was felt to center more on the need for "non-leaking" chambers than on the problems associated with the total recycling of elements.

Another major environmental factor that may impact productivity, and that is not being adequately addressed by the PIs and probably will not be experimentally treated by the CBF, is microbial activity, particularly in the recycling nutrient solution. Since microbial control is a major problem in open hydroponic systems, it is assumed that in a closed system it will also be significant. Very little presently is known about microbial population-dynamics, community stability, nutrient competition, the dynamics of the nitrogen cycle, potential microbial pathogenicity, or how populations might be optimized to the benefit of higher plants. Russian experiments have demonstrated that the microbial interaction with a closed environment is dynamic. A large number of species are involved, the species mix is changing with time and their numbers are related to the life cycle of the plant and to the health of the crop. Further, some of the genera can be circumstantially pathogenic in man; the health implications of a closed environment, with its concommitant volatile organic and microbe constituents, is largely unknown.

It was mentioned that higher plant productivities are reaching a maximum in open systems. This brought up a list of related questions: Will productivity be comparable in closed systems? Will closure alter the reliability of production? What are the consequences of growth in a closed chamber to polyculture? Will the microbial load and species distribution change in significant ways as the system is removed from contact with the external environment, thus affecting productivity? What sizes of reservoirs are required, and to what extent will the accumulation of materials in the closed system affect the buffers? Are questions that have been raised about the stability of such a system well founded?

During this phase of the discussion it became obvious that well-controlled experiments to answer questions like these will require access to closed plant growth system. Moreover, it is likely that more than one chamber will be required. It was suggested that a minimum of three chambers will be needed, with each chamber capable of maintaining several plants of any one of the candidate species for a full crop production cycle. Ideally, such chambers should be available at the same time, but institutional support and budgetary considerations may dictate the fabrication and trouble-shooting of one unit first, with others closely following. The Principal Investigators expressed the concern that they have more than enough to do in their home laboratories without involving themselves directly in the development of closed chambers at ARC. These comments suggested the possibility that the necessary equipment might be constructed at Ames but used by all, as a complement to the efforts of the program and to the tasks of the individual investigators. In any case, the group felt strongly that closed chamber construction at Ames would be much more cost- effective and should ensure superior construction over having individual investigators design and construct closed chambers at each location.

Another clear advantage of constructing closed chambers at Ames would be the ability to provide research support to the CBF at Kennedy. If and when problems arise during CBF operations, closed, well-monitored units of known and controlled parameter response and with a materials-accounting system, could be instrumental in sorting out the unknowns. Closed chambers at Ames would provide a valuable capability for problem solving that would be distinct from capabilities of the CBF.

An early goal of the program, then, would be to develop and standardize a unit and duplicates that could be constructed for use at Ames. Eventually, additional replicas of these chambers could be built for distribution to PI laboratories. In that way, experimental results gained at university laboratories could be directly compared within the context of the overall program.

Nutrient Delivery Systems

It was agreed that the problems associated with nutrient delivery were common to all CELSS higher plant work. It is an issue that the CBF project will likely never address in detail and something that Ames technology and analytic capability might be logically adapted to developing. Additionally, it is an issue whose study would benefit greatly from the combined experience of the PI's.

At the heart of the problem lies the lack of knowledge about how to maintain a stable, optimum nutrient system, how to precisely monitor and regulate the separate nutrients being supplied to the plants, and particularly, how to determine changes requiring regulation that may be needed as plants mature. Also, there is almost no information on how to monitor and control organic compounds that accumulate in the recirculating solutions. Different nutrient sources act in unpredicted ways (the responses of plants to different forms of nitrogen were discussed in some detail). Good control of nutrient application might significantly conserve the nutrients, prevent "luxury consumption", and even lead to an increased productivity and yield. Relationships between uncontrolled nutrient concentrations, the possible toxic consequences of luxury consumption (for human consumers), and attendant deleterious effects on yield also entered into this discussion. Root zone aeration, as a function of nutrient delivery rate, is another factor requiring attention in the development of a nutrient system.

The consensus was that nutrient control is as important as control of the enclosed atmosphere, and that both should be major research priorities. It was noted that work on the development of nutrient delivery systems, having continuous analysis and precise constituent control capability, could and should proceed independently of the development of a closed system. When completed, the nutrient systems would be integrated into the closed chambers and be made available to individual investigators (and possibly KSC) for integration into their growing units.

Lighting System

Although a unique role of Ames was not recognized for this area of research, it was agreed that increased knowledge and intelligent use of spectral effects might significantly enhance productivity. The group emphasized the need for expanded research into both unique means of directing light to plants (e.g., in-canopy lighting, light pipes, etc.) and developing improved irradiation sources (e.g., more efficient energy conversion and better spectral balance). The individual PIs would have neither the time nor the facilities for such studies, and a lighting system for a closed unit at Ames would be necessary as one of the controllable variables. It was also agreed that the CBF project would be unlikely to find a place in its schedule for this basic research. This research is not crucial to the development of a functional CELSS, but it is emphasized and felt to deserve attention because plant lighting currently demands the greatest power consumption of all CELSS components.

These three categories of experimental interest are not unique to any one plant species, although any specific application may be. In addition to these, other areas that might be a natural outcome of a combined effort at Ames were touched upon. They included work on definition of the reliability and stability of a closed CELSS, the development of models to enable increased control, the effects of a common environment on polyculture in closed chambers (and how polyculture might be accommodated), non-destructive growth monitoring, calibration and standardization, and automation and robotics.

Study of many of these issues could come much later in the gradual development of an experimental system. To paraphrase the words of one participant, an Ames/university coordinated effort will, by focusing on controlled systems and closed chamber units, provide an opportunity to extend findings from species to species in a standard system, provide a facility to coalesce different findings and interests, and provide a common ground for the principal investigators to interact with each other in a quantitative way.

Another advantage that was seen for this strategy was that Ames' involvement in the activity would result in a "research presence" that would attract and provide means for supporting guest investigators. In this connection, it was agreed that, at the appropriate times, the principal investigators or their laboratory representatives would work directly with equipment at Ames.

Flight Experiments

Dr. MacElroy outlined the potential flight opportunities, domestic and foreign, for CELSS-type experiments. In so doing, he distinguished between the requirements and involvement of the Space Biology program and the CELSS program. These two programs of course have many common interests, and it was suggested that the May 17 meeting with space biology and CELSS would provide a good forum to discuss these issues.

Plant Growth Module Documentation

In September, 1984, a workshop was convened at Ames to consider and prescribe scientific requirements for a closed Plant Growth Module similar to the closed chamber discussed here. One attendee at both meetings drew a distinction between the formerly-considered module and the closed chambers under current consideration. In keeping with the experimental mission envisioned for the chambers being considered at Carmel, it was thought reasonable to re-evaluate the original requirements. Therefore, attendees at the Carmel Valley meeting were asked to revisit the requirements for a generalized chamber in light of current discussion.

There was agreement that only cosmetic changes to the format of the report need be made - that the scientific requirements remained intact. It was agreed that a 2 to 3 m^3 controlled and monitored chamber was of an effective size to provide adequate space for the crop species being studied and yet was small enough to allow manipulation and monitoring through arm ports in the side. It was suggested that an updated science requirements description could be made part of the present report, and that the final report should also include the conceptual chamber design developed at Ames in late 1984.

Approaches and Mechanisms

Discussion on the last day focussed on mechanisms of involvement between the Principal Investigators and Ames Research Center. There was agreement that a Consortium of Principal Investigators should be organized to direct and to participate in the development and experimental use of specific research apparatus at Ames: a 2 to 3 m^3 sealed chamber and ancillary equipment.

In particular, this proposed chamber/system would, over the course of development, be comprised of a complex of parameter control, monitoring, and data collection devices, nutrient delivery and lighting systems. The design would allow for monitoring microbial population densities and changes , soluble or volatile organic material concentrations - in the atmosphere and nutrient systems.

Over the course of this discussion, methods of forming the group and making it effective were addressed:

1) Recognition of the activities and goals of a Consortium could be formalized by the development of a Memorandum of Understanding between Ames and each of the involved universities.

2) Support for the research and required equipment was discussed. The approach that seemed most feasible and practical involves the joint preparation of a research proposal that describes the experimental use and appropriate design of such equipment within the context of an Ames/PI Consortium effort. The proposal would be submitted to NASA for peer review. Funding of the work could be through either existing research cooperative agreements or through other instruments to be decided later.

Some time was spent discussing the possible content of a proposal, how it might be coordinated, and ultimately managed upon implementation. It was suggested that the proposal should spell out the primary goals, the equipment needed, and the experiments that should be conducted. For example, a primary goal might be to compare biomass and food productivity of a crop in three chambers, one a closed system with no air or nutrients purification, one a closed system with controlled air and nutritional purification, and one an open system with frequent exchange of air and fresh nutrient solution. Frequent interaction would be anticipated from particular PIs with expertise in the specific crop under study at any particular time. Such an experiment with a single crop might constitute a milestone for each PI, and secondary goals could be prioritized.

The participants also believed that a coordinating PI should be identified in the proposal, and should be resident at Ames. Dr. Schwartzkopf was thought to be a strong candidate for that responsibility. A number of other candidates, of various degrees of availability or suitability, also were proposed and considered. At that point, one of those present observed, "you can't recruit without a proposal, and a contact at Ames is needed now to generate the proposal." Further discussion of a permanent coordinator was curtailed, and it was agreed that John Tremor would serve as the proposal coordinator.

In further consideration of what might go into the proposal, it was suggested that a first year effort might involve initial test work, of the kind projected above, with the existing small (single plant) chambers of Dr. Schwartzkopf. The second year of the proposed work could be used to complete and test the larger closed chambers, and the closed experiments could begin the third year. To complement this schedule it was suggested that the nutrient system be developed in parallel with the closed system.

In consideration of plans for future meetings, the observation was made more than once that an assemblage of no more than ten people was a very efficient size for a planning group. As such, it would be desirable to keep future meetings of the group at a similar scale. While the mix of disciplines would change as other researchers were called upon, the total number of people involved should remain about the same. It was also agreed that Dr. William Knott be included in future briefings and meetings to help secure the relationship between the CELSS efforts at Ames and at Kennedy.

The meeting ended with the promise that Ames would draft a report of the meeting for distribution and begin the process of building an acceptable Memorandum of Understanding. Ames personnel will submit the proposal for peer review. Plans were made to keep all concerned informed throughout the proposal development period, and perhaps to meet again before the proposal is submitted.