

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
2101 NASA Road 1
Houston, Texas 77058-3696



Advanced Life Support Project Plan

Crew and Thermal Systems Division
Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas

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APPROVALS

Dane M. Russo
Manager, Advanced Human Support Technologies Program

Date

Donald L. Henninger, Ph.D., Manager, Advanced Life Support Project
Crew and Thermal Systems Division

Date

Table of Contents

- 1.0 INTRODUCTION
- 2.0 PROJECT OBJECTIVES
- 3.0 CUSTOMER DEFINITION AND ADVOCACY
- 4.0 PROJECT AUTHORITY
- 5.0 PROJECT ORGANIZATION AND RESPONSIBILITIES
 - 5.1 Project Organization
 - 5.2 Responsibilities
- 6.0 PROJECT TECHNICAL SUMMARY
- 7.0 SCHEDULE
- 8.0 PROJECT RESOURCES
- 9.0 CONTROLS
- 10.0 IMPLEMENTATION APPROACH
 - 10.1 Water Recovery Element
 - 10.2 Air Revitalization Element
 - 10.3 Solid Waste Management Element
 - 10.4 Food and Corp Systems Element
 - 10.5 Thermal Control Element
 - 10.6 Systems Integration, Modeling and Analysis Element
 - 10.7 System and Integrated Testing Element
 - 10.7.1 Bioregenerative Planetary Life Support Systems Test Complex
 - 10.7.2 Integrated Human Exploration Mission Simulation Facility (INTEGRITY)
 - 10.8 Flight Experiments Project Element
 - 10.9 Advanced Life Support External Investigations
 - 10.10 Advanced Life Support University Centers
 - 10.10.1 Commercial Centers
 - 10.10.2 Research Centers
 - 10.10.2.1 NASA Specialized Center of Research and Training
 - 10.10.2.2 Center for Food and Environmental Systems for Human Exploration of Space
 - 10.10.2.3 Center for Space Sciences
 - 10.11 International Collaboration
- 11.0 ACQUISITION SUMMARY
- 12.0 PROGRAM/PROJECT DEPENDENCIES
 - 12.1 Related Activities
 - 12.2 Education And Outreach
- 13.0 AGREEMENTS

13.1 Field Center Memoranda of Agreement

13.2 Other Agreements

14.0 PERFORMANCE ASSURANCE

15.0 RISK MANAGEMENT

16.0 SAFETY

17.0 TECHNOLOGY ASSESSMENT

18.0 COMMERCIALIZATION

19.0 REVIEWS

20.0 REFERENCE DOCUMENTS

21.0 CHANGE LOG

APPENDIX A. Bioregenerative Planetary Life Support Systems Test Complex (BIO-Plex) Top-Level Requirements

APPENDIX B. Advanced Life Support Roadmap

APPENDIX C. Approved FY 2002 Advanced Life Support Project Element Coordination Agreements and Technical Task Agreements

ACRONYMS

AEMC	Advanced Environmental Monitoring and Control [Project]
AHST	Advanced Human Support Technology [Program]
ALS	Advanced Life Support
ARC	Ames Research Center
ARS	Air Revitalization System
ASGSB	American Society for Gravitational and Space Biology
ATCS	Active Thermal Control System
BIO-Plex	Bioregenerative Planetary Life Support Systems Test Complex
BPC	Biomass Production Chamber
CCB	Configuration Control Board
CFESH	Center for Food and Environmental Systems for Human Exploration of Space [at Tuskegee University]
COTR	Contracting Officer's Technical Representative
CSS	Center for Space Sciences [at Texas Tech University]
CSTC	Commercial Space Technology Center
CTSD	Crew and Thermal Systems Division
EC	Organizational code for Crew and Thermal Systems Division
ECA	Element Coordination Agreement
ECLSS	Environmental Control and Life Support System
EDU	Engineering Development Unit
ER	Organizational code for Automation, Robotics, and Simulation Division
ES CTSC	Environmental Systems Commercial Space Technology Center
ESM	Equivalent System Mass
EVA	Extravehicular Activity
FPS	Food Processing Subsystem
FTCSC	Food Technology Commercial Space Center
FY	fiscal year
GSRP	Graduate Student Researcher Program
HRWRS	Hybrid Regenerative Water Recovery Subsystem
IALSWG	International Advanced Life Support Working Group
ICES	International Conference on Environmental Sciences
ICLSS	International Conference on Life Support Science
IMMWPS	Immobilized Microbe Microgravity Water Processing Systems
INTEGRITY	Integrated Human Exploration Mission Simulation Facility
IRB	Institutional Review Board
ISS	International Space Station
ITA	Internal Task Agreement
ITCS	Internal Thermal Control System
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LSBS	International Conference on Life Support and Biosphere Science
LSD	Life Sciences Division
m	meter
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NJ-NSCORT	New Jersey NASA Specialized Center of Research and Training
NRA	NASA Research Announcement
NRC	National Research Council

NSCORT	NASA Specialized Center of Research and Training
OBPR	Office of Biological and Physical Research
ORZS	Optimization of Root Zone Substrates [Flight Experiment]
POP	Program Operating Plan
R&TD	Research and Technology Development
SBIR	Small Business Innovation Research
SHFE	Space Human Factors Engineering [Project]
SIMA	Systems Integration, Modeling and Analysis
SIT	System and Integrated Testing
SLI	Space Launch Initiative
SPS	Solids Processing System
STS	Space Transportation System [Shuttle]
STTR	Small Business Technology Transfer Research
STWG	Science and Technology Working Group
SWM	Solid Waste Management
SWRS	Solid Waste Recovery System
TCCS	Trace Contaminant Control Subsystem
TCS	Thermal Control Systems
TEEM	Two-Phase Extended Evaluation in Microgravity
TIM	Technical Interchange Meeting
TOC	total organic carbon
TRL	Technology Readiness Level
TTA	Technical Task Agreement
TTU	Texas Tech University
VPGC	Variable Pressure Growth Chamber
VPU	Vegetable Production Unit
WBS	Work Breakdown Structure
WONDER	Water Offset Nutrient Delivery Experimental Research
WQM	Water Quality Monitor
WRS	Water Recovery System

1.0 INTRODUCTION

Life support systems are an enabling technology and have become integral to the success of living and working in space. As NASA embarks on human exploration and development of space to open the space frontier by exploring, using and enabling the development of space and to expand the human experience into the far reaches of space, it becomes imperative, for considerations of safety, cost, and crew health, to minimize consumables and increase the autonomy of the life support system. Utilizing advanced life support technologies increases this autonomy by reducing mass, power, and volume necessary for human support, thus permitting larger payload allocations for science and exploration. Two basic classes of life support systems must be developed, those directed toward applications on transportation/habitation vehicles (e.g., Space Shuttle, International Space Station (ISS), next generation launch vehicles, crew-tended stations/observatories, planetary transit spacecraft, etc.) and those directed toward applications on the planetary surfaces (e.g., lunar or Martian landing spacecraft, planetary habitats and facilities, etc.). In general, it can be viewed as those systems compatible with microgravity and those compatible with hypogravity environments. Appendix B defines the technology development “Roadmap” to be followed in providing the necessary systems for these missions.

The purpose of this Project Plan is to define the Project objectives, Project-level requirements, the management organizations responsible for the Project throughout its life cycle, and Project-level resources, schedules, and controls. This Plan is the top-level document for the Project and provides guidance and direction for its implementation by the participating NASA field centers, namely Ames Research Center (ARC), Kennedy Space Center (KSC), Marshall Space Flight Center (MSFC) and the Johnson Space Center (JSC) serving as the lead center. The Project Plan will be reviewed and updated annually to ensure that the Project remains properly focused and responsive to the goals of the Agency and Biological and Physical Research Enterprise.

2.0 PROJECT OBJECTIVES

In the NASA Strategic Plan, dated 2000, the goals of the Biological and Physical Research Enterprise include 1) conducting research to enable safe and productive human habitation of space, 2) enabling and promoting commercial research in space, and 3) using space research opportunities to improve academic achievement and the quality of life. Toward these goals an objective has been established to conduct research to ensure health, safety and performance of humans living and working in space. In support of this objective, the goal of the Advanced Life Support Project is to **provide life support self-sufficiency for human beings to carry out research and exploration safely and productively in space for benefits on Earth and to open the door for extended on-orbit stays and planetary exploration.** To accomplish this goal, the five major technical objectives of the Advanced Life Support Project are as follows:

1. Provide Advanced Life Support technologies that significantly reduce life cycle costs, improve operational performance, promote self-sufficiency, and minimize expenditure of resources for long-duration missions.

Supporting Objectives:

- Fully close air and water loops in a manner that eliminates expendables.

- Develop and integrate resource recycling/processing and contaminant control systems that increase the level of self-sufficiency.
 - Optimize food loop closure, with concomitant air and water revitalization, based on the growth of crop plants or other photosynthetic organisms.
 - Provide efficient, reliable active thermal control (heat acquisition, transport, and rejection).
 - Develop fully regenerative integrated systems technologies that provide air, water, food, and resource recovery from wastes.
2. Develop and apply methods of systems analysis and engineering to guide investments in technology, resolve and integrate competing needs, and guide evolution of technologies.

Supporting Objectives:

- Refine existing systems assessment tools to allow consideration of other life support related mission parameters.
 - Conduct on-going cost/benefit trades to guide technology investments.
 - Conduct advanced mission studies to guide definition of technology requirements, long-term investments, and evolution.
 - Develop methods for concurrent engineering of technologies from subsystems to integrated systems.
 - Develop system models and maintain an archival database of lessons learned, operational results and key design information.
3. Resolve issues of microgravity performance through space flight research and evaluation.

Supporting Objectives:

- Develop predictive models of liquid and liquid/gas behavior and interactions in microgravity that can be used as a basis for design of new life support hardware for microgravity applications.
 - Achieve equivalent productivity, control and predictability of bioregenerative life support components in microgravity as on Earth and characterize performance of bioregenerative systems at Lunar and Martian gravity (i.e., 1/6g and 1/3g, respectively).
 - Demonstrate microgravity performance of gravity-sensitive life support hardware components and subsystems (e.g., membrane behavior, microbe performance, crop nutrient delivery systems).
4. Ensure timely transfer of new life support technologies to missions.

Supporting Objectives:

- Develop and maintain effective relationships between the technology provider and mission user to establish needs for mission-specific technologies.
- Conduct definitive (ground and in-space) testing and verification.

- Conduct regular discussions between mission users and technology providers on technology development status and transfer processes.
- Disseminate scientific and technological information through journals, the Internet, electronic and video media, workshops, and special programs.

5. Transfer technologies to industrial and residential sectors for national benefit.

Supporting Objectives:

- Identify and initiate dual-use development early in the technology development cycle.
- Establish rapid response solicitation and funding mechanisms to maintain the national 'market edge.'
- Identify and provide incentives to NASA personnel that promote technology.
- Work in partnerships with intermediaries such as the entertainment industry, media, museums, etc. to bring the space experience to our Nation's citizens.
- Participate in preparation of instructional materials reflecting the discoveries and adventure inherent in space exploration through partnerships with educators, providing access to facilities, and supporting classroom instruction.
- Publish and distribute engineering and scientific findings in the open literature.
- Cooperate with other nations to design an international strategy for human space exploration.

To accomplish these objectives, the Advanced Life Support Project will conduct a focused Research and Technology Development (R&TD) effort to advance technology readiness of regenerative life support and thermal control components, validate regenerative life support technologies integration through long-term testing with humans, and identify terrestrial applications for life support technologies.

3.0 CUSTOMER DEFINITION AND ADVOCACY

The main customer for the Advanced Life Support Project is the Advanced Human Support Technology (AHST) Program, which is sponsored by the NASA Headquarters Office of Biological and Physical Research (OBPR). The Advanced Life Support Project will provide technology developments that are targeted for NASA Programs involving human space exploration such as ISS and future exploration initiatives. To ensure customer advocacy, the Advanced Life Support Project will keep the AHST Program Manager and the Headquarters AHST lead apprised of Project accomplishments and significant findings that improve on Advanced Life Support Project metrics and may have notable impact on NASA Programs.

4.0 PROJECT AUTHORITY

The JSC serves as the lead center for the Advanced Life Support Project. NASA's ARC and KSC are supporting Field Centers for the Advanced Life Support Project. MSFC is also a contributing Field Center. The governing body responsible for the oversight of the Advanced Life Support Project is the Office of Bioastronautics in the JSC Space and Life Sciences Directorate. The Advanced Life Support Project is managed from the Crew and Thermal Systems Division of the JSC Engineering Directorate.

5.0 PROJECT ORGANIZATION AND RESPONSIBILITIES

In conjunction with JSC being designated as the Agency's Center of Excellence for Human Operations in Space, NASA Headquarters has assigned JSC the lead center management roles for the Space Medicine and Biomedical Research and Countermeasures programs, as well as the AHST Program that includes the Advanced Life Support Project. In assuming lead center responsibility for these programs, JSC has formed the Office of Bioastronautics. Figure 5.0-1 defines the structure and content of the JSC Office of Bioastronautics and how it relates to the Advanced Life Support Project.

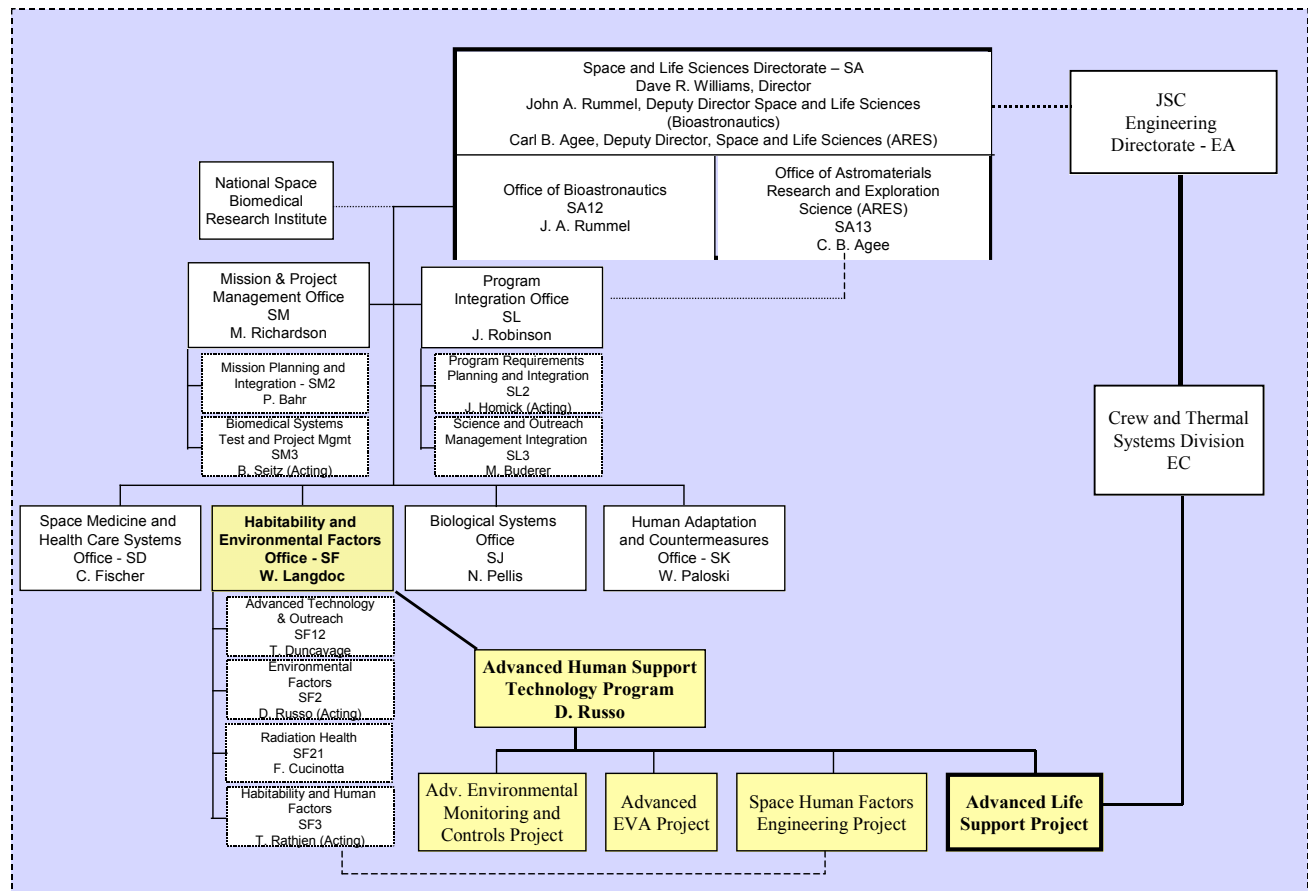


Figure 5.0-1. JSC Office of Bioastronautics

5.1 Project Organization

The Advanced Life Support Project of the Advanced Human Support Technology Program is organized as defined in Figure 5.1-1. The Advanced Life Support Project management responsibility resides with the Advanced Life Support Project Manager who is supported by a Deputy Project Manager, Chief Scientist, Chief Engineer and Element Leads. The Advanced Life Support Deputy Project Manager will assist the Project Manager in carrying out his responsibilities and will function as the Project Manager in his absence. The Advanced Life Support Chief Scientist is responsible for the overall scientific integrity of the Advanced Life Support Project. Additionally, the Chief Scientist will assist Headquarters in preparation of the NRA solicitations, peer review of proposals, feasibility of implementation reviews, and selection of research proposals for funding. The Advanced Life Support Chief Engineer is responsible for the overall engineering and integration integrity of the Advanced Life Support Project. Additionally, the Chief Engineer will help guide Element Leads in technology development planning and selection.

As depicted, the Advanced Life Support Project consists of eight major R&TD Elements. These are the Water Recovery Element, the Air Revitalization Element, the Solid Waste Management Element, the Food and Crop Systems Element, the Thermal Control Element, the Systems Integration, Modeling and Analysis (SIMA) Element, the System and Integrated Testing (SIT) Element and the Advanced Life Support Flight Experiments Element. These R&TD Elements and the roles of the Advanced Life Support Element Leads are described further in Section 10.0. Other components of the Advanced Life Support Project include the following Advanced Life Support University Centers:

- The New Jersey NASA Specialized Center of Research and Training (NJ-NSCORT) at Rutgers University and Stevens Institute
- The Center for Food and Environmental Systems for Human Exploration of Space (CFESH) at Tuskegee University
- The NASA Environmental Systems Commercial Space Technology Center (ES CSTC) at the University of Florida
- The NASA Food Technology Commercial Space Center (FTCSC) at Iowa State University
- The Center for Space Sciences (CSS) at Texas Tech University

The Advanced Life Support University Centers are described in more detail in Section 10.10. The Advanced Life Support Project is also supported by a large number of external Principal Investigators conducting R&TD activities via NASA Research Announcement (NRA) grants, Small Business Innovative Research (SBIR) grants, Small Business Technology Transfer (STTR) grants, Graduate Student Researcher Program (GSRP) grants, and National Research Council (NRC) fellowships.

Other Advanced Life Support Project functions contributing to meeting stated goals include Education and Outreach, Schedule and Budget analysis, administrative assistance, and SBIR/STTR subtopic management. The Advanced Life Support Project Education/Outreach Manager is responsible for formulating and implementing the strategy for the Advanced Life Support Project to fulfill its responsibilities for education and public outreach. The Advanced Life Support Education and Outreach objectives are described in Section 12.2. The Advanced Life Support Project Schedule and Budget Analyst is responsible for collecting and maintaining all schedules and budgets, insuring compliance with Project policy with respect to obligation and costing of resources. The Advanced Life Support Project Administrative Assistant is responsible for day-to-day administrative support for the Advanced Life Support Project Office

including arranging logistics support for meetings, coordinating workshops and planning meetings, taking meeting minutes, and distributing Advanced Life Support Project materials.

The Advanced Life Support Project Science and Technology Working Group (STWG) and Advisory Committee provide external oversight and advice to the Project. The STWG is chartered by NASA Headquarters to review and provide guidance and recommendations in all areas of concern to the Advanced Life Support Project. The STWG assesses and makes recommendations to Advanced Life Support Project with respect to distribution of tasks (e.g., across research and technology development, ground and flight tasks, Technology Readiness Levels (TRL) of candidate technologies, near and far-term activities, and research/development vs. integrated systems testing). In addition, the STWG: a) conducts reviews and scientific/technical evaluations of specific project elements or tasks within the Advanced Life Support Project, b) reviews and offers input to Advanced Life Support Project Documents, including Project Plans, Roadmaps, Advanced Life Support Requirements Document, c) assists the Project in development of options for implementation (e.g., future directions, projects, and alternative approaches), and d) provides insight into, and connection with, related outside activities (e.g., private industry, academia). The Advanced Life Support Project Advisory Committee is an internal body consisting of representatives from each of the participating NASA Field Centers and supporting university centers. This group will meet annually and serve to advise the Project Manager on matters of Project direction and strategy, budgets, schedules.

Advanced Life Support Project Organization

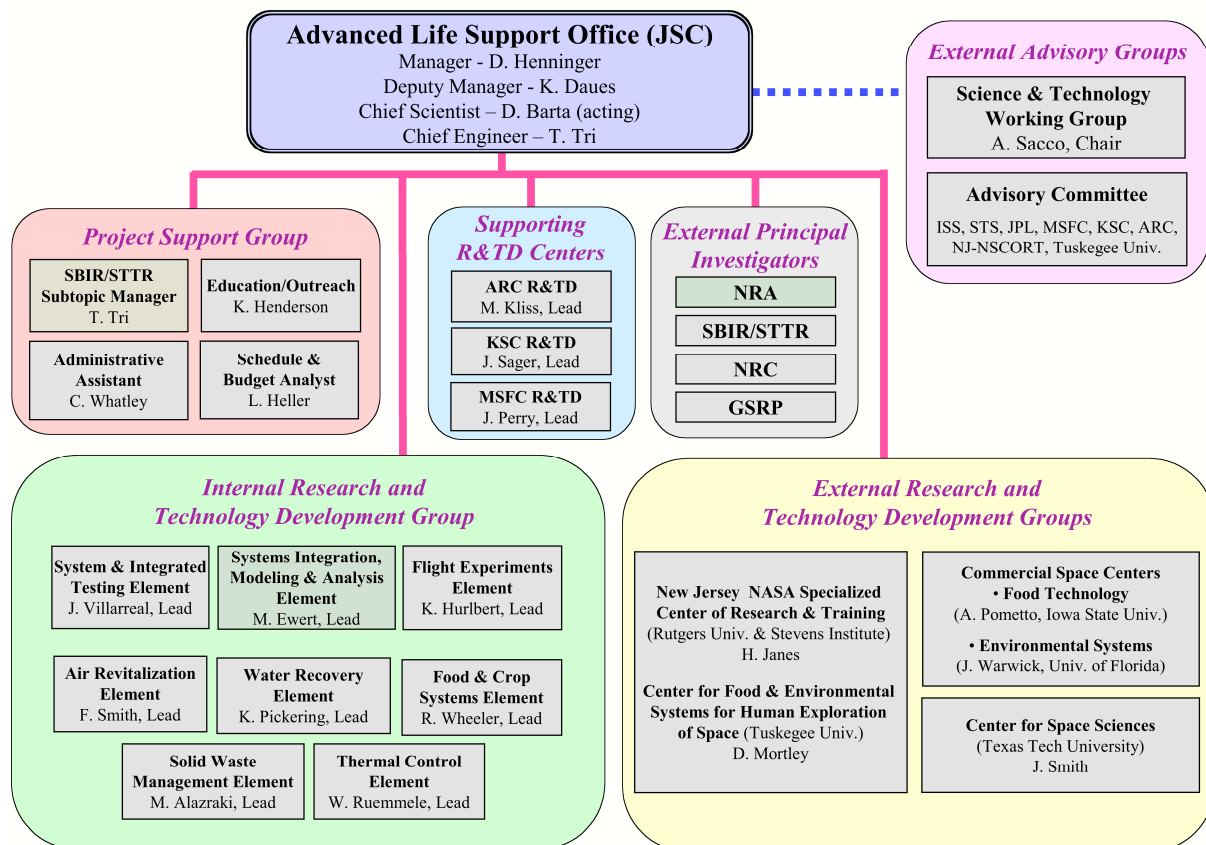


Figure 5.1-1 Advanced Life Support Project Organization

5.2 Responsibilities

There are four major participating NASA Field Centers in the Advanced Life Support Project: ARC, JSC, KSC, and MSFC. The responsibilities, as defined below, have been agreed to in Memoranda of Agreement, which will be reviewed annually and revised as necessary to provide clear understanding of roles and responsibilities.

JSC, as designated lead center, has delegated the authority and overall Advanced Life Support Project management responsibility to the Engineering Directorate, Crew and Thermal Systems Division (CTSD). CTSD also is responsible for the development of biological and physicochemical subsystem/component (TRL 3-6) technologies and flight experiments; the integration of physicochemical/biological systems technologies, including systems-level testing with humans; and the lead for systems modeling and analysis activities.

ARC, through its Space Science Division, is responsible primarily for conducting focused research and technology development (i.e., basic principles through component/breadboard validation) directed at physicochemical processes, emphasizing system closure and self-sufficiency, for the following life support functions:

1. Solid waste management
2. Water recovery
3. Atmosphere revitalization

Additionally, ARC: a) supports development of dynamic analytical models associated with JSC life support systems analyses, b) supports application of information systems technologies to life support systems control, c) provides technical review and monitoring of research and technologies proposed for the Project in the area of physicochemical regenerative systems, and d) supports development of flight experiments for regenerative systems as appropriate. Finally, ARC participates in Project planning and associated technical, budget, and schedule reviews.

KSC, through its Biological Science Branch, is responsible primarily for focused research and technology development (i.e., basic principles through component breadboard validation) directed at biological systems technologies for use in regenerative life support systems, emphasizing system closure and self-sufficiency as follows:

1. Characterize plant biomass production at a scale sufficient for multi-crop studies.
2. Evaluate nutrient solution recycling and nutrient recovery methods and systems.
3. Integrate and evaluate gray water and human waste processing methods and systems.
4. Support baselining of system engineering requirements for closed systems.
5. Support microbial ecological testing of preliminary advanced life support system components (e.g., air, water, and food and crop systems)

Additionally KSC: a) compiles and analyzes data developed by the Project on horticultural requirements and physiological responses for candidate crops and bioreactors, b) provides technical review and monitoring of research and technologies proposed for the Project in the area of biological systems, and c) supports development of flight experiments for biological

systems. Finally, KSC participates in Project planning and associated technical, budget, and schedule reviews.

MSFC supports development of Advanced Life Support Project technology and provides a link to ISS Environmental Control and Life Support Systems (ECLSS) status, operational issues, lessons learned, and upgrade requirements. MSFC also supports air revitalization technology development activities as well as Advanced Life Support Project strategic planning and SBIR recommendations.

6.0 PROJECT TECHNICAL SUMMARY

For long-duration space missions beyond Earth orbit, regenerative life support systems will be required not only to achieve a high degree of closure of the air and water loops, but also to begin to close the food loop. For long duration space mission in Earth orbit (e.g., ISS), advanced life support system upgrades to current systems can increase degrees of closure of the air and water loops, reduce resupply requirements, reduce stowage volume requirements and thereby increase resources available for research. Accordingly, the Advanced Life Support Project has established general requirements and design considerations as defined in JSC 38571A, dated January 1998, for the conduct of research and technology development activities. This document defines general requirements for an advanced environmental control and life support system that are independent, or nearly independent, of mission length and destination. In general, advanced life support technologies must:

- Regenerate air, water, and food in a manner that minimizes overall logistical burdens, minimize demands on space habitat resources, ensure habitability, and promote self-sufficiency.
- Manage wastes to maintain a safe environment within the habitat and minimize waste storage and buildup, and process wastes to achieve optimum resource recovery, when required.
- Minimize involvement of the crew in life support system operation while assuring proper monitoring and control of essential systems.
- Provide effective environmental monitoring to preclude hazardous conditions (e.g., fire, buildup of toxic contaminants).
- Provide thermal control without the use of expendable heat sinks and without imposing a hazard to the crew.
- Assure prolonged reliability of components and systems.
- Provide for *in situ* maintenance.
- Minimize the impact of life support on planetary environments.

7.0 SCHEDULE

Major schedule milestones for the Advanced Life Support Project, pending adequate annual budgets, are as follows:

FY 2002

- Ground test a biological water system that can dramatically reduce resupply mass
- Assist NASA headquarters in selecting a new NSCORT for Advanced Life Support
- Complete development of a carbon dioxide reduction engineering development unit based on the Sabatier process and associated new compressor technology
- Complete annual update to Advanced Life Support Metric calculation
- Complete an update of the Advanced Life Support Requirements Document
- Complete an update of the Advanced Life Support Baseline Values and Assumptions Document

FY 2003

- Reinitiate planning for Bioregenerative Planetary Life Support Systems Test Complex (BIO-Plex) development
- Complete development of a water processing test article based on vapor phase catalytic ammonia removal
- Conduct a nitrifying biological waste water processor in-flight demonstration
- Conduct integrated air revitalization technology tests at JSC
- Complete annual update to Advanced Life Support Metric calculation

FY 2004

- Resume build-up of the BIO-Plex Facility
- Demonstrate long-duration microgravity operation of plant nutrient delivery system
- Complete annual update to Advanced Life Support Metric calculation

FY 2005

- Complete human-rating of BIO-Plex and demonstrate operational readiness
- Select candidate technologies for the first BIO-Plex integrated test
- Complete annual update to Advanced Life Support Metric calculation
- Demonstrate the optimization of root zone substrates flight experiment in microgravity

FY 2006

- Complete annual update to Advanced Life Support Metric calculation
- Demonstrate on-orbit two-phase waste water oxygenation separation technology and an associated sensor package

Future Planning

- Initiate a 120-day test with 4 humans in BIO-Plex before the end of FY 2008
- Demonstrate a nitrification kinetics of waste water flight experiment in microgravity
- Demonstrate on-orbit inoculation of a bioprocessor on ISS
- Demonstrate an air evaporation brine recovery system in microgravity
- Select Advanced Life Support technologies for and conduct a 240-day test with 4 humans in BIO-Plex
- Develop a vegetable production unit (VPU) to that could provide dietary supplements and psychological enhancements to the environment of the ISS

- Demonstrate technologies that would reduce the overall mass per person per year to support humans on extended-duration space flight by a factor of 2 (reduction is relative to the projected baseline mass as calculated in 1999 for ISS technologies) by FY 2008
- Additional long-duration human tests are planned in BIO-Plex between FY 2008 and FY 2016 (e.g., a 95% Food Production/50% Waste Recovery test and a 95% Food Production/95% Waste Recovery test)
- As a goal, technologies that would reduce the overall mass per person per year to support humans on extended-duration space flight by a factor of 3 are to be demonstrated by FY 2014 (reduction is relative to the projected baseline mass as calculated in 1999 for ISS technologies)

Achievement of these milestones is expected to provide much of the critical information required to support a decision to initiate upgrades to ISS or the Space Shuttle and to embark on long-duration human missions in support of NASA long-range goals. The Advanced Life Support Project advances individual technologies to a TRL of 6 so that if any NASA space flight program wishes to utilize this technology to improve program goals, that program can embark on the appropriate flight hardware development efforts.

8.0 PROJECT RESOURCES

Resource requirements for the Advanced Life Support Project are developed, reviewed, and updated annually according to the Agency and Office of Bioastronautics Program Operating Plan (POP) guidance and direction. The resource appropriations to this program and projects are identified within the details of the annual Operating Plans.

9.0 CONTROLS

The fundamental structure of the Advanced Life Support Project, as defined in Figure 5.1-1, is based on a strong Project Manager/Element Lead team relationship and open communications. The decision-making body will be the Project Manager, Deputy Project Manager, Chief Scientist, Chief Engineer, the eight Element Leads, and the Advanced Life Support supporting Center Leads. This group will meet monthly to chart top-level Project strategy and implementation guidelines and to discuss issues.

The Project Manager and staff are accountable for the overall programmatic aspects of the Project as defined below with inputs from the Element Leads. Specific control measures include:

- Review and approval of all Advanced Life Support Element plans for compliance with the NASA Strategic Plan and the Advanced Life Support Project Plan.
- Review of Element strategic plans and implementation plans (e.g., Element Coordination Agreements and Technical Task Agreements) on an annual basis to assess progress and justification for continued work.
- Conduct of formal technical, cost, and schedule reviews for each Element on a quarterly basis. As a goal, all funded budgets will be obligated and 85% of resources will be costed within the fiscal year in which they are allocated.

- Providing project-level technical status to NASA Headquarters and the AHST Program on a biweekly basis.
- Chairing the Advanced Life Support Advisory Committee.
- Chairing the Advanced Life Support Configuration Control Board (CCB). The Advanced Life Support CCB will address ground test bed and flight experiment design/build-up inconsistencies with Advanced Life Support Project requirements, ground test bed and flight experiment changes that result in the need for additional funding, changes which impact controlled milestones, and any issues requiring CCB input or decision as determined by the Element Lead and the Advanced Life Support Project Manager.
- Chairing Test Readiness Review Boards and Utilization Readiness Review Boards for Advanced Life Support tests and facilities.
- Assembling an independent Advanced Life Support STWG, comprised of 8 to 12 members representing a balance of experience, including government, industry, and academia and having recognized expertise in appropriate scientific and technical areas. The Advanced Life Support STWG should include Advanced Life Support Project customers, individuals having some crosscutting interaction with the Advanced Environmental Monitoring and Control (AEMC) and Space Human Factors Engineering (SHFE) Projects, as well as members outside the Advanced Life Support Project. The Advanced Life Support STWG will generally meet once a year. Meetings may be held in conjunction with appropriate conferences or at government, industry, or university facilities in order to provide the membership exposure to current Advanced Life Support activities.

10.0 IMPLEMENTATION APPROACH

The Advanced Life Support Project is comprised of eight interrelated technical Elements and five supporting university centers as shown in Figure 5.1-1. The degree of technology development performed by the Advanced Life Support Project can best be explained by using Figure 10.1-1 which describes nine levels of technology readiness which range from a “1” for “basic principles observed and reported” to “9” which is “actual system ‘flight proven’ through successful mission operations.” The technology readiness levels (TRL) of 1 through 5 are generally thought of as research and technology development. Similarly, Figure 10.1-2 depicts the R&TD phases for the Project, emphasizing that as the TRL of candidate technologies increases, the number of options decrease. Thus, the Project will continue to develop only those technologies that show the most promise in terms of meeting mission requirements

Advanced Life Support Elements Leads are responsible for coordination of all activities associated with the Element including Element activities:

- at Supporting Field Centers (JSC, ARC, KSC, and MSFC)
- at NSCORTs and Commercial Space Technology Centers
- with NRA and other external Principal Investigators
- at Advanced Life Support University Centers
- with SBIR/STTR grants and other studies.

Elements Leads develop Element Coordination Agreements (ECAs) and Technical Task Agreements (TTAs), Memoranda of Understanding, Element Roadmaps, and Element Plans. Appendix C contains the approved fiscal year 2002 Element Coordination Agreements and TTAs. Element Leads conduct Element Technical Interchange meetings and workshops, as needed. In addition, they develop supporting Element facilities for integration and testing. This includes developing facilities requirements documents and facilities layouts, equipment acquisition lists, including related cost and schedule, facilities testing schedules and facilities operations guidelines.

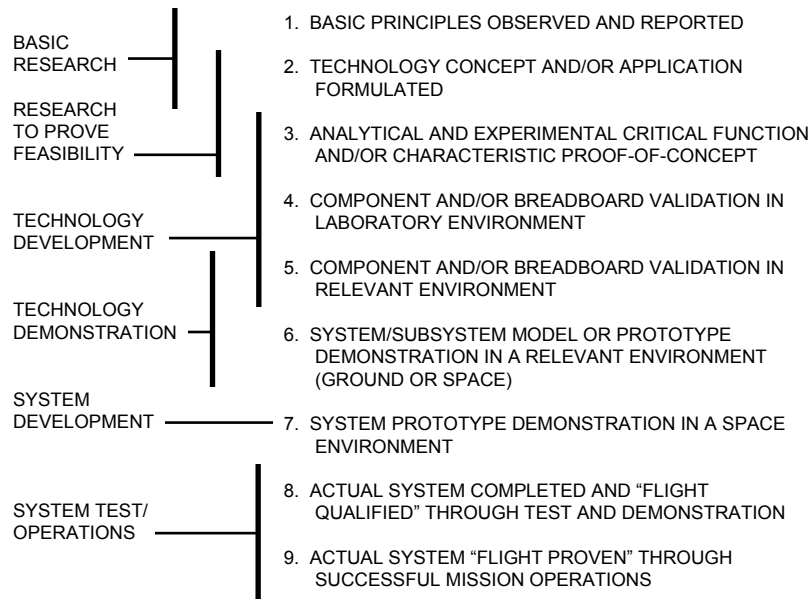
Element Leads are responsible for the management of the associated Element budget including budget planning and tracking of obligations and costing. The Element Leads provide input to support the development of annual POP submissions, year-end costing forecasts and updates to the Advanced Life Support Activities Database.

Element Leads may also serve as the Contracting Officer's Technical Representative (COTR) for Advanced Life Support technology development efforts (contracts, grants, and cooperative agreements). As COTRs, the Element Leads are required to support the development of statements of work, technical proposal evaluations, renewal reviews and to provide recommendations.

Participation in relevant Advanced Life Support meetings, including biweekly Advanced Life Support Technical Interchange Meetings, monthly program/project/element management meetings, annual strategic planning meetings, Division quarterly reviews, Principal Investigator meetings, etc. is also required of Element Leads. Element Leads will provide biweekly reports of Element highlights, quarterly Technical, Cost, and Schedule Review updates to the Project Manager, and submissions for Advanced Life Support website regarding significant achievements, documentation and education/outreach items for a wide audience. Technical/scientific coordination with the Advanced Life Support Chief Engineer, Chief Scientist and other Advanced Life Support Elements is expected of each Element.

Upon restart of the BIO-Plex effort, as described in Section 10.7.1, Element Leads will actively participate as Advanced Life Support Leads on the BIO-Plex Team.

TECHNOLOGY READINESS LEVELS *



* From SSP 50198 (11/22/95)

Figure 10.1-1 Technology Readiness Levels

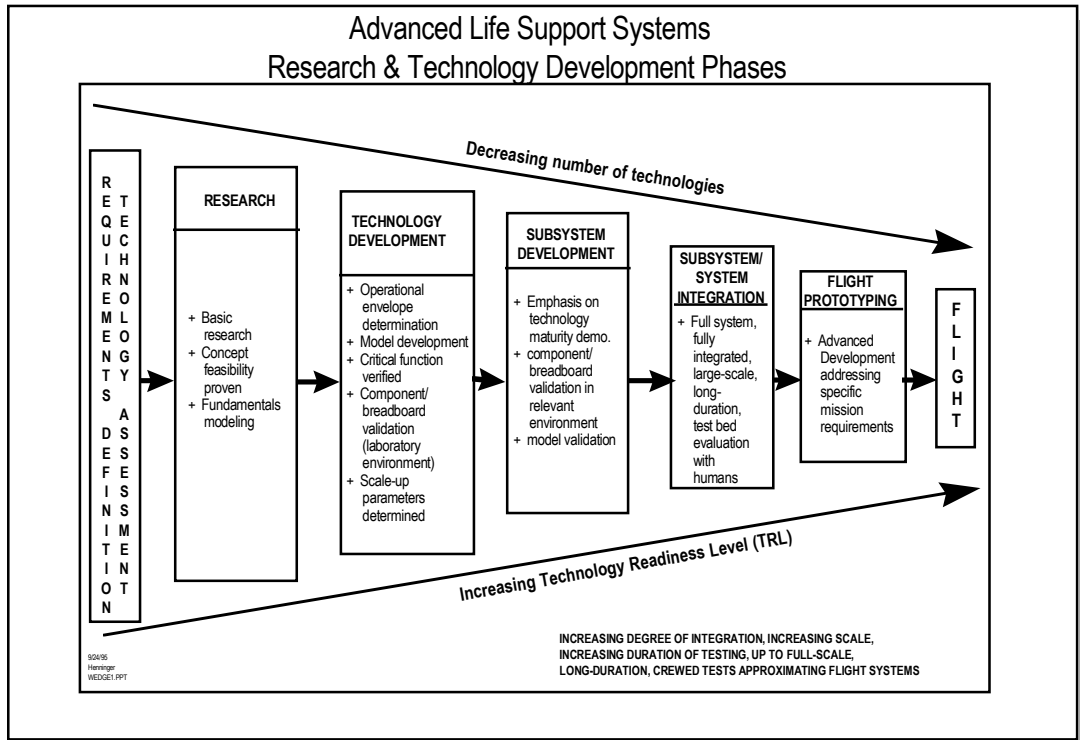


Figure 10.1-2 Advanced Life Support Research and Technology Development Phases

10.1 Water Recovery Element

The Water Recovery Element is responsible for developing both biological and physicochemical systems to increase efficiency and decrease cost of water recovery and reuse with applications to both vehicular and planetary platforms. The goals of the Water Recovery Element are to 1) reduce the equivalent system mass (ESM)¹ of water recovery subsystems and integrated systems, 2) establish biological systems as a reliable option for water recovery by answering questions regarding sizing, stability and lifetime, 3) reduce potable water certification time, and 4) prepare for and support long duration integrated life support systems human testing, 5) coordinate efforts with the SIMA Element, the SIT Element and BIO-Plex system integration teams related to water recovery and to work cooperatively with other Advanced Life Support Elements, and 6) utilize flight experiments, when appropriate, to verify advanced water recovery technologies.

10.2 Air Revitalization Element

The Air Revitalization Element is responsible for developing advanced air revitalization technologies for space vehicle (Space Shuttle, ISS, transit vehicle) applications and long duration planetary mission applications. Air revitalization technologies will serve several

¹ Equivalent system mass (ESM) is a technique by which several physical quantities which describe a system or subsystem may be reduced to a single physical parameter, mass. The primary advantage is to allow comparison of two life support systems with different parameters using a single scale. This is accomplished by determining appropriate mass penalties or conversion factors to convert the non-mass physical inputs (e.g., power or crew time or volume, etc.) to an equivalent mass.

functions within an integrated bioregenerative life support system, contributing to carbon dioxide removal, oxygen generation and distribution, and trace contaminant control while minimizing mass, volume, power, waste, consumables, and crew time requirements. Air revitalization technology development will include designing, building and maintaining prototype and Engineering Development Units, laboratory facilities for integrated testing and integrated test bed. The goals of the Air Revitalization Element are to 1) support potential advancement of the ISS baseline air revitalization system by focusing near-term Advanced Life Support air revitalization technology development toward an advanced Sabatier carbon dioxide (CO₂) reduction subsystem, including CO₂ compressor and microgravity liquid/gas rotary separator and test the Sabatier in an integrated fashion in cooperation with MSFC, 2) develop an integrated air revitalization test facility capability at JSC to support all potential Advanced Life Support customers, including Space Shuttle, ISS, BIO-Plex, SIT, SIMA, Advanced Life Support Flight Experiments and other applicable programs and projects, 3) support SIMA analysis and modeling activities with data related to air revitalization technologies., 4) coordinate efforts with the SIT Element and BIO-Plex system integration teams related to air revitalization and to work cooperatively with other Advanced Life Support Elements, and 5) utilize flight experiments, when appropriate, to verify advanced air revitalization technologies.

10.3 Solid Waste Management Element

The Solid Waste Management Element is responsible for developing advanced technologies for safe and effective methods of solid waste management with applications to space vehicles and long duration planetary missions. Solid waste management technologies ranges from solid waste collection hardware (e.g., trash receptacles) through processing hardware for resource recovery (e.g., incineration systems). Solid waste management technology development includes designing, fabricating, integrating and testing of prototype and higher fidelity hardware in both laboratory and ground-based integrated human test facilities. The goals of the Solid Waste Element are to 1) determine solid waste processing functionality needed for space-generated waste streams (e.g., stabilization, sterilization, etc.), 2) reduce overall solid waste management system ESM for all potential space missions, 3) provide technologies that can recover resources from solid waste when appropriate with overall integrated mission objectives, 4) coordinate efforts with the SIMA Element, the SIT and BIO-Plex system integration teams related to solid waste management and to work cooperatively with other Advanced Life Support Elements, and 5) utilize flight experiments, when appropriate, to verify advanced solid wastes management technologies.

10.4 Food and Crop Systems Element

The Food and Crop Systems Element is responsible for developing advanced food systems for space vehicles and long duration missions that use a combination of extended shelf life stored foods and raw food products produced from higher plants. Plants (crops) serve several functions within an integrated bio-regenerative life support system, including food production, air revitalization, water recovery, and waste recycling. Food and crop systems research should address nutritional, psychological, safety, and acceptability requirements, while minimizing mass, volume, power, waste and trace gas emissions. Food and crop systems technology development should include designing, building and maintaining crop production hardware and food processing equipment for converting raw crops into edible ingredients and products. The goals of the Food and Crop Systems Element are to 1) use flight experiments to verify crop cultivation technologies for space vehicle applications, 2) develop and evaluate a vegetable production unit (salad machine) for fresh vegetable production on ISS and space vehicles, 3)

develop bioregenerative life support system based on higher plants, 4) develop advanced technologies for controlled environment crop production for space missions, 5) develop an advanced stored food system for ISS and space vehicles applications augmented by fresh minimally processed vegetables, 6) develop an advanced food system based on crops grown as part of a bioregenerative life support system, 7) develop a mature bioregenerative life support system based on higher plants, and 8) coordinate efforts with the SIMA Element, the SIT and BIO-Plex system integration teams related to food and crop systems and to work cooperatively with other Advanced Life Support Elements.

10.5 Thermal Control Element

The Thermal Control Element is responsible for developing and testing improvements to the Thermal Control Systems (TCS) used in integrated life support systems by NASA, in order to improve performance and reduce mass, power, and volume. Temperature and humidity control of the spacecraft atmosphere is essential to life. Just like providing air, water and food to sustain life in space exploration, maintaining a thermally comfortable environment is also part of life support. Thermal control of the air is high integrated with the air and water systems since air is processed by the condensing heat exchanger and condensate is sent to the water recovery system. The Advanced Life Support Project is making use of the synergism between the Thermal Control Element and the other Advanced Life Support Elements to explore system-level efficiencies such as waste heat utilization, reduction of thermal loads and the most appropriate use of refrigeration systems. The goals of the Thermal Control Element are to 1) develop an improved TCS to produce benefits at the system/vehicle level by allowing more infrastructure to be devoted to other areas such as; payload, crew volume, mission duration, avionics environment, food and science sample preservation, or reducing vehicle launch mass and volume, 2) provide improvements that can be applied to ISS, Space Shuttle, other NASA spacecraft, planetary missions, and other commercial and military users, 3) provide commercial uses or spin-offs that can include civilian aircraft, satellites, and a broad range of terrestrial applications, 4) coordinate effort with the SIMA Element, the SIT and BIO-Plex system integration teams related to TCS and to work cooperatively with other Advanced Life Support Elements, 5) utilize flight experiments, when appropriate, to verify advanced TCS technologies.

10.6 Systems Integration, Modeling and Analysis Element

The Systems, Integration Modeling and Analysis (SIMA) Element will develop, apply and maintain methods of systems analysis and engineering for space vehicle and surface habitat life support systems to guide investments in research and technology development, resolve and integrate competing requirements, and guide evolution of advanced life support system architecture. To support the Advanced Life Support Project and this overall objective the SIMA Element will:

- Coordinate systems integration, modeling, controls and analysis for advanced life support technologies among the Advanced Life Support Field Centers and advise associated academic and commercial organizations.
- Develop mathematical models of advanced technologies to assess their benefits to ISS, Shuttle and future missions. This includes the Advanced Life Support Sizing Analysis Tool, the Advanced Life Support Metric Spreadsheet, ARC's Matlab/Simulink Dynamic System Model, and detailed subsystem or component models (e.g., biological water processor, air system model, etc.)

- Perform analysis to support design and testing of selected advanced life support technologies.
- Perform transient systems integration and controls analyses to identify technical issues for integration of the advanced technologies into an advanced life support system
- Develop, coordinate, and maintain the procedure for the Advanced Life Support Research and Technology Development Metric and compute, on an annual basis, metrics to assess progress over current state-of-the-art advanced life support technologies.
- Maintain the Advanced Life Support Requirements Document, the Advanced Life Support Systems Integration Modeling and Analysis Reference Mission Document and the Advanced Life Support Baseline Values and Assumptions Document.
- Refine existing procedures for systems assessment to consider the entire mission including transit spacecraft and surface habitats. Consider medical and scientific needs, obtain synergism with life support systems, resolve incompatibilities, and evaluate options.
- Conduct advanced mission studies to guide definition of technology requirements, long-term investments, and the evolution of technologies through ground and space-based test beds.
- Develop system design tools and models and maintain an archival database of lessons learned, operational results, and key design information.

10.7 System and Integrated Testing Element

The System and Integrated Testing (SIT) Element is responsible for leading, planning, coordinating and advising the integrated testing efforts for other Advanced Life Support Elements. SIT is responsible for providing support to the other Advanced Life Support Elements beginning with a planning and definition phase, then with the design of test facilities, and later with assistance during testing. SIT is responsible for defining a consistent test process for hardware developers in order to facilitate the transition into an integrated test facility. Included in SIT responsibilities is the planning for and development of the BIO-Plex integrated test facility.

10.7.1 BIO-Plex

Comprehensive testing of a human-rated regenerative life support system on Earth is critical for the development of an Advanced Life Support system for use on planetary surfaces. The overarching objective of the BIO-Plex is to acquire the information and operational experience necessary to define performance and design requirements for advanced, regenerative life support systems (up to TRL 6) that will be utilized by future flight systems in a planetary surface habitat. To support this objective, extended-duration tests of full-scale, integrated, regenerative

life support systems will be performed under closed, controlled conditions with human test subjects.

The primary objective of the BIO-Plex is to support the physical integration of regenerative physicochemical and biological life support subsystems to create fully functional air revitalization, water recovery, biomass production, food processing, solids processing, and thermal control systems. The ability to accommodate long-duration, closed-loop testing of these integrated systems within a large-scale control volume is another key objective. Also important is supporting the evaluation of integrated control strategies and data acquisition and recording approaches for the various subsystems comprising the complex system. The BIO-Plex must be flexible in its design to support testing of a wide variety of candidate technologies and approaches with varying degrees of crew autonomy. At the same time, the facility must be designed to a sufficiently high level of fidelity to be reasonably representative of a future planetary habitat.

The ability to accommodate testing pertinent to disciplines other than Advanced Life Support is an additional objective of the BIO-Plex. Human factors play a significant role in the test bed's design with respect to maintaining test crew productivity and ensuring their overall comfort, which are factors vital to the success of long-duration tests. Disciplines such as human physiology, psychology, sociology, nutrition, microbiology, etc., will also benefit from cooperative efforts in support of human testing within the test bed.

Per JSC Center management direction, the BIO-Plex was placed in temporary "stand-by" mode in April 2001. At that time system infrastructure Preliminary Design Reviews had been completed for the Air Revitalization System, the Water Recovery System, Biomass Production System, the Food Processing System, the Solids Processing System, the Thermal Control System, the Human Accommodations System, and the Integrated Life Support and Habitability System. The basic chamber complex, the Utilities Distribution Module and the Control and Communications Center infrastructure were in place. Additionally, the emergency management system, fire detection system, fire suppression system, electrical power distribution, utility lighting system, and modular flooring system had been installed. The current Advanced Life Support Project schedule anticipates resuming the BIO-Plex Project in FY 2003 with a planning activity leading to the restart of the facility buildup in FY 2004. This schedule places the BIO-Plex Operational Readiness Review in FY 2005 and the first human test in FY 2008, assuming that current funding profiles and civil servant support requests are provided.

The top-level requirements and current proposed human testing sequence for the BIO-Plex is contained in Appendix A.

10.7.2 Integrated Human Exploration Mission Simulation Facility (INTEGRITY)

A more progressive concept proposed by the Advanced Life Support Project would expand the BIO-Plex Project to become NASA's 'next step' after ISS build-up and before the initiation of any exploration flight program. This initiative, Integrated Human Exploration Mission Simulation Facility (INTEGRITY) initiative, is currently in the conceptual development stage. The Advanced Life Support Project plans to discuss this initiative with other NASA organizations during FY 2002 in order to develop this idea further and gauge interest across the agency.

Objective of the INTEGRITY initiative would be to design and build a ground test bed capable of accurately simulating all elements of a series of long- duration human planetary exploration missions. It would operate as an actual set of long- duration human planetary missions, involve

all elements of a mission, integrate and evaluate enabling technologies (providing a focus to R&TD), develop and validate new management techniques including new risk and cost estimation techniques for large complex programs with international and commercial and academic partners develop and validate new techniques for education/ outreach and public affairs (marketing). The purpose of this initiative would be to properly and intelligently prepare for eventual human planetary exploration missions (e.g., Earth neighborhood, Mars, etc.). This is a way to be able to demonstrate that NASA can manage the technical, schedule and cost risks associated with a planetary mission such that in the future when NASA seeks approval for the mission, NASA can show quantitatively that it can manage the risks.

Potential attributes the INTEGRITY initiative could include:

- 1) Making it a mission in every respect – it just doesn't leave the Earth
 - Establish a set of missions (~ 5 – 6) lasting from ~100 days up to~1000 days to be conducted over a 10 - 15 year period
 - Establish “baseline technologies” for the missions (tests) and conduct on- board “flight” experiments during the missions (tests) - if Shuttle and ISS flight experiments are cycled through this facility, success rates for flight experiments should improve
 - Missions are selected; real requirements are generated; real milestones are established (focus for R&TD)
 - Active Shuttle and ISS flight experiments program still needed for microgravity research and technology validation
 - Conduct appropriate work at other analog sites to address specific concerns best evaluated at these sites – (e.g., Antarctica, Haughton Mars Project)
- 2) The test bed could be high fidelity, operated for long duration, utilize human test crews, and include all elements associated with any long-duration planetary human exploration mission.
 - Participating NASA technical components would include mission operations, medical/psychological operations and research, crew accommodations, crew selection activities, vehicle and habitat designers, life support, communications, planetary exploration, planetary protection, Extravehicular Activity (EVA), robotics, and rovers.
 - Elements, such as rendezvous and docking; propulsion; guidance, navigation and control, etc., could be simulated.
- 3) This initiative could allow NASA to address new management techniques needed for large complex missions of the future.
 - Opportunity to develop and learn how to use new and more effective management techniques (e.g., bring in the best business school experts to advise; embed metrics to evaluate effectiveness of new techniques)
 - Develop and evaluate new cost and risk estimation techniques
 - Upon completion of these missions, NASA could have validated management techniques and a cadre of managers trained in their use
- 4) This initiative could allow NASA to incorporate international partners.
 - If one assumes that actual human exploration missions will be international, now is the time to learn how to effectively work together; develop common exploration policies (e.g., planetary protection, power sources, etc.).
- 5) This initiative could allow NASA to incorporate commercial partners.
 - This initiative could provide opportunities to develop new paradigms for working with commercial entities

6) This initiative could allow for excellent NASA Education and Outreach and NASA Public Affairs opportunities.

7) This initiative would allow NASA to re-invigorate NASA employees and contractors because it would real (i.e., not just a paper study).

A conceptual illustration of the current location of the BIO-Plex facility in JSC's building 29 rotunda and how it might be expanded to encompass the INTEGRITY initiative is depicted in Figure 10.7.2-1.

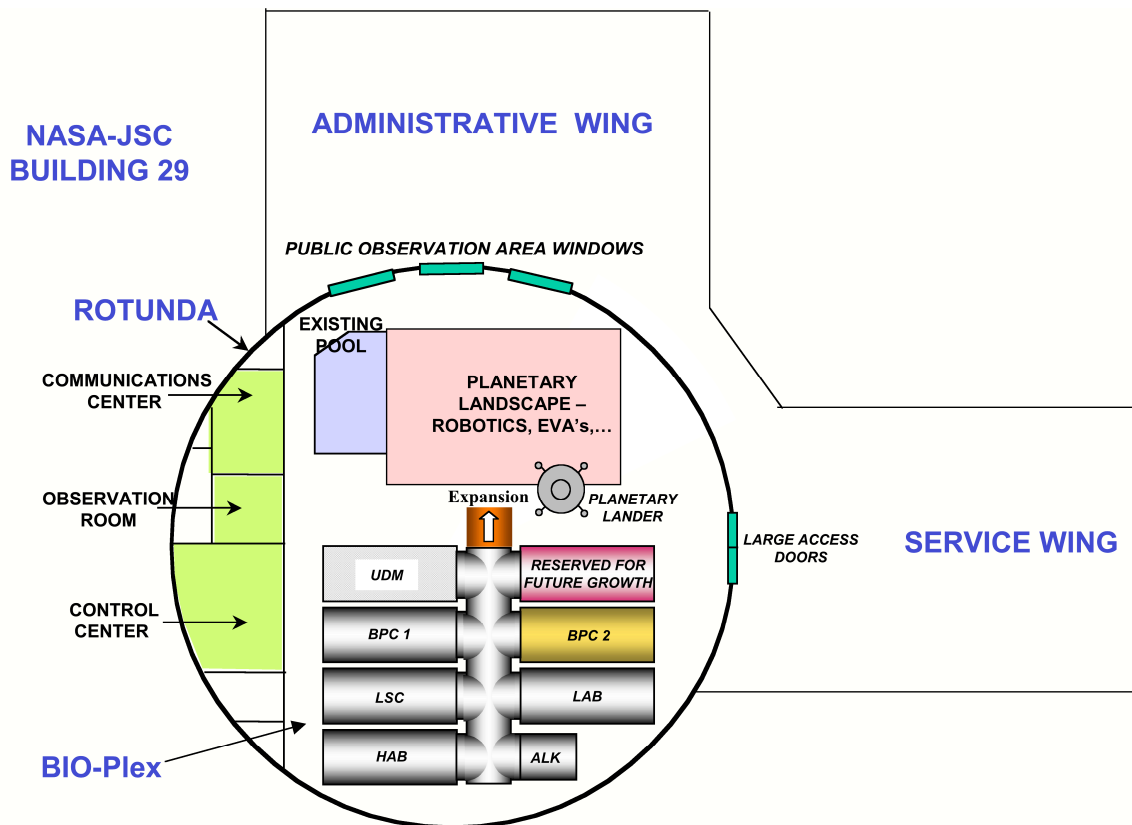


Figure 10.7.2.-1 Integrated Human Exploration Mission Simulation Facility (INTEGRITY)

10.8 Flight Experiments Element

The Flight Experiments Element is charged with the responsibility of conducting flight experiments, which will complement the activities conducted in ground laboratories and ground test bed facilities. These corollary flight experiments will be used to evaluate life support components and subsystems to serve as upgrades to existing flight subsystems (such as to reduce expendables) and to validate performance of advanced technologies for future flight systems onboard human space vehicles. Flight experiments might also be utilized to assess technologies in the 1/3rd- and 1/6th-g gravity fields of Mars and the moon, respectively, by utilizing a centrifuge onboard a vehicle. These flight experiments will cover a range of technology readiness levels ranging from research (TRL 1-3) to testing subsystems or processes in a relevant environment (TRL 6-7). Currently, Advanced Life Support flight

experiments will focus on near-term Space Shuttle Orbiter flight opportunities with increased emphasis on use of ISS facilities after 2005. The goals of the Flight Experiments Element are to 1) provide support to all elements of the Advanced Life Support program for conceptual development and demonstrations/evaluations of Advanced Life Support technologies in micro- and partial-g, 2) develop and implement an Advanced Life Support KC-135 Flight Experiments Initiative to allow early and inexpensive demonstrations/evaluations of Advanced Life Support concepts/technologies and 3) provide and implement a well-defined program for on-orbit Advanced Life Support experiments, in coordination with Shuttle and ISS, to allow long-duration demonstrations/evaluations of Advanced Life Support technologies.

Currently the Advanced Life Support Project has four flight experiments activities in varying stages of development. These are listed in Table 10.8-1.

Table 10.8-1 Status of Advanced Life Support Flight Experiments

Flight Experiment	Objective	Platform	Status
Immobilized Microbe Microgravity Water Processing Systems (IMMWPS)	Technology demonstration of a microbial water processor system in microgravity	Shuttle Middeck	Certification for Flight initiated in fiscal year 2002; ready for flight in 2003
Water Offset Nutrient Delivery Experimental Research (WONDER)	Addresses the question of comparability of environmental conditions between the flight and ground experiments by employing three different porous tube and substrate compartment wetness level treatments.	Shuttle Middeck	Critical Design review 90% complete; Could be ready for flight in 2004; May need to consider ISS as the primary platform if Shuttle manifest is not available in a timely manner
Optimization of Root Zone Substrates (ORZS) Flight Experiment	Provides measurements and models required for selection and management of plant rooting media for life support plant growth systems	Shuttle Middeck	Pre-Phase A Definition Phase to be reviewed in 2002; Could be ready to fly in 2004
Two-Phase Extended Evaluation in Microgravity (TEEM)	Provides fully developed 2-phase flow data and demonstrates closed-loop 2-phased system operation in microgravity	Shuttle Payload Bay	Deferred pending flight opportunity; Hardware in storage

The Advanced Life Support KC-135 Flight Experiments Initiative provides on-going support to planned Advanced Life Support flight experiments and Advanced Life Support research and technology development projects, and supports upgrade capabilities and technology demonstrations for ISS and future human missions. These tasks/tests provide direct support/technology demonstrations for all other Advanced Life Support Elements and other Advanced Life Support research programs (e.g., NRAs, SBIRs).

10.9 Advanced Life Support External Investigations

Fostering creativity and the emergence of new ideas is essential for the success of the Advanced Life Support Project. Consequently, the Advanced Life Support Project utilizes the

NRA process to augment internal R&TD. This announcement, which is updated and released annually, solicits highly innovative proposals based on cutting-edge technologies and bold, novel approaches, even though they may contain some risk of failure. Proposals are evaluated by an independent peer-review panel for overall scientific and technical merit; after which they are evaluated by the Advanced Life Support Project for program relevance and feasibility of implementation.

10.10 Advanced Life Support University Centers

10.10.1 Commercial Space Technology Centers

The Advanced Life Support Project will utilize innovations developed by two Commercial Space Technology Centers (i.e., the Food technology Commercial Space Center (FTCSC) managed by Iowa State University and the Environmental Systems Commercial Space Technology Center (ES CTSC) managed by the University of Florida) to augment Advanced Life Support R&TD. Pending successful demonstration of the feasibility of innovations produced by these commercial centers, Advanced Life Support Elements will consider the innovations for further development. There will be an annual comprehensive review of operations and management of these Centers using the Annual Reports and any other documentation requested on the operation of the Centers. A review by NASA officials can be conducted to evaluate the effectiveness of these Centers after three years of operation to determine changes needed for improvement. In year four of operation a review of the effectiveness of these Centers will be conducted by NASA officials to determine whether a Center will be terminated at the end of year five or continued for another five years after year five.

The mission of the ES CSTC is to lead a national effort in developing environmental systems technologies that meet NASA's needs for human space flight, while also serving as a catalyst for commercial, terrestrial application of the technologies developed. The ES CSTC will work with NASA, academia, and industry partners who are currently advancing environmental systems technologies. The principal thrust of the ES CSTC shall be "Resource Recovery" technology development for water recovery, solid waste recovery, and air revitalization (including monitoring and controls technologies specific to these areas). The ES CSTC was established on December 1, 2000 via a 5-year Cooperative Agreement.

The mission of the FTCSC is to lead a national effort in developing foods and food processing technologies that enhance space missions and advance commercial food products through cooperative efforts with NASA's scientists and technologists, commercial companies, and academic researchers. The FTCSC was established on October 5, 1999 via a 5-year Cooperative agreement.

10.10.2 Research Centers

10.10.2.1 The New Jersey NASA Specialized Center of Research and Training (NSCORT)

The NSCORT program was established to advance fundamental knowledge in biological and biomedical sciences and technology with the ultimate application of this knowledge to enable human space flight and long-term planetary missions. The NSCORT program is expected to enhance NASA's base of scholarship, skills and performance in the space biological and biomedical sciences and related technological areas and also expand the pool of research

scientists and engineers trained to meet the challenges ahead as we prepare for future human space exploration missions. Specific goals of the NSCORT program are:

- to expand our understanding of specific scientific and technical challenges associated with biological and biomedical sciences and related technological areas;
- to provide substantial long-term funding to the research community in a manner that encourages the development of a stable base upon which problem-solving strategies of benefit to NASA and the public can be built;
- to involve a broad spectrum of high caliber students, research scientists and engineers in the activities of the NSCORT; and
- to facilitate the rapid transfer to NASA of knowledge gained and technology developed consistent with of its missions.

The New Jersey NASA Specialized Center of Research and Training (NJ-NSCORT) is a multidisciplinary, multi-institutional organization tasked to generate new knowledge to help address problems of human life support associated with long duration space missions and lunar or Mars outposts. NJ-NSCORT was established at Rutgers University in May 1996 via a five-year contract to bring together engineers and scientists from Cook College of Rutgers University and Stevens Institute of Technology to conduct research and develop technologies that will be used in the analysis, design and operation of bioregenerative life support systems. Research performed by NJ-NSCORT is focused on the needs of bioregenerative life support by involving interacting teams of researchers in the areas of biomass production, food processing and nutrition, waste processing and systems studies, and modeling. Collaboration between the NJ-NSCORT, commercial and agricultural industry, and the public marketplace provides a forum for technology transfer and instantaneous feedback to associated engineers, technicians, and scientists. This contract is scheduled to end on December 31, 2001. In FY 2002, the NJ-NSCORT received a congressional set-aside to continue work on life support issues in closed environments for an additional year.

Results of an on-going solicitation for a new Advanced Life Support NSCORT are anticipated in 2002. The new Advanced Life Support NSCORT will provide for basic and applied research in the areas of 1) Solid Waste Processing and Resource Recovery, Water Recovery and Air Revitalization, 2) Biomass Production, Food Processing and Food Safety for Long Duration Missions, and 3) Systems Analysis and Integration with the Advanced Life Support Project. Additionally the new NSCORT will establish programs, classes and research opportunities that promote understanding of NASA and Advanced Life Support-related science and technology for undergraduate, graduate, and postdoctoral education at all member institutions within the NSCORT. Education and outreach programs will be created for or expanded by the activities of the NSCORT that target minority or underrepresented groups within the NASA community. In particular, programs that promote public understanding of food safety issues, especially among consumers from underrepresented groups will be emphasized.

10.10.2.2 The Center for Food and Environmental Systems for Human Exploration of Space (CFESH) at Tuskegee University

The unique contribution of CFESH is the development and refinement of information, technology and systems for growth, processing, utilization and recycling (waste) of sweet potatoes and peanuts that meet the design plans the Advanced Life Support Project. The two crops can be processed into a variety of foods using both foliage and roots and nuts as part of an integrated food and environmental system for human life support in space. The work of

CFESH is organized under four interdisciplinary research teams of life sciences and engineering faculty and students charged with developing the horticultural protocols and systems and control technologies needed for Advanced Life Support. Integral to the goals of NASA is the training of minority and other students some of whom will pursue Ph.D. degrees and later choose scientific, engineering or technical careers with NASA and the space program.

The CFESH Germplasm Development and Improvement Team has the responsibility to evaluate sweet potato and peanut cultivars with superior performance in controlled environments and having desirable traits for an advanced life support system-compactness of growth will be important, but also high yield and dry matter content, early maturity, and good nutritive qualities and taste. Both conventional breeding and molecular genetics techniques are being used to achieve these goals.

The CFESH Production and Environmental Systems Team focuses on gathering baseline data on growth and yield under varying controlled conditions of sweet potato and peanut. This team experiments with solid substrates such as lunar simulants and zeolites. Translation of the data into models to be used for predictive purposes is another task of this team.

The CFESH Waste Management and Recycling Team focuses on research on an integrated partially closed loop for biological waste resource recycling/crop production along with the protocols for attaining such.

The CFESH Food Technology and Utilization Team determines and evaluates the nutritive value of high performance cultivars of the two crops as well as deal with issues of food processing, safety and storage, and menu development in collaboration with centers working on other crops so that nutritionally-balanced and palatable meals can be available to future space explorers.

The CFESH was funded with a five-year, \$5 million contract renewal as a Center of Research Excellence. The center funding period is from January 1, 1997 to December 31, 2001. NASA's Equal Opportunities Programs Office (Code E) has extended this activity through June 2002 with an additional \$500K of fiscal year 2002. The new NSCORT, discussed in section 10.10.2.1, is strongly encouraged to include as a partner a Historically Black College or University, a Hispanic Serving Institution and/or an Other Minority University.

10.10.2.3 Center for Space Science (CSS) at Texas Tech University

A cooperative agreement was awarded to Texas Tech University (TTU) in FY 2000 to establish the Advanced Life Support Center for Space Science (CSS) funded via a Congressional earmark. Additional Congressional set-asides in FY 2001 and FY 2002 continue this activity. Texas Tech University will management and research and technology development focused in four areas: 1) maintenance and improvement of the Engineering Development Unit (EDU), a tightly sealed crop growth chamber originally developed by NASA ARC; 2) evaluation of an Integrated Water Recovery System for non-optimal conditions and terrestrial applications; 3) plant carbon allocation and partitioning of metabolites; 4) exploiting inherent features of problem solutions leading to improvements in human-centered computing. The EDU equipment will be available to any NASA-funded Advanced Life Support researcher; and EDU hardware/software and associated equipment, including all upgrades purchased with NASA funds, shall be returned to JSC within 90 days of the completion of the Cooperative Agreement.

The Advanced Life Support Project will incorporate CSS objectives into the biological water processor testing activities on a negotiated bases, review CSS requirements and designs for the water demonstration unit, provide EDU hardware to TTU, review CSS requirements and design modifications for the EDU, consult on EDU plant experiments, and accommodate TTU students at JSC.

10.11 International Collaboration

In order to take advantage of limited global resources available for research and technology development in the area of Advanced Life Support, the International Advanced Life Support Working Group (IALSWG) was established as an informal information exchange and strategic planning group composed of appropriate representatives from interested space agencies. It is not the intent of this group to be comprehensive or to necessarily have representation from all space agencies but to include those agencies interested in participating on an ad hoc basis.

Working relationships that evolve as a result of the efforts of this group are envisioned as specific and bilateral in nature rather than among multiple or all agencies involved in the group. The purpose for this is to maintain a simplicity and informality in the working relationships that develop, which might be lost if the group sought to establish a broad mandate (or binding charter) requiring the agreement of all agencies involved.

The purpose of the IALSWG is to create a forum for information exchange and strategic planning for the international Advanced Life Support community. In this context, the exchange of information is to be conducted for the purpose of gaining a better understanding of the work being done by each agency in the area of Advanced Life Support and to foster the development of targeted opportunities for cooperation or collaboration in specific areas of Advanced Life Support research and technology development. The identification of these targeted interactions would result in the development of recommendations for ways to proceed in order to achieve the targeted goals.

The format for the IALSWG meetings consists of presentations by each of the agencies represented, followed by group discussion and identification of possible collaborations and finally development of recommendations. The IALSWG meets at least once a year and exchange of information is encouraged on a continual basis in order to streamline the development of targeted interactions between meetings.

11.0 ACQUISITION SUMMARY

The Advanced Life Support Project funds and provides COTR support for NRA grants. The Project also provides COTR support for Advanced Life Support-related SBIR and STTR contracts. Additionally, the Advanced Life Support Project, pending adequate budget allocation, funds competitive procurements for the development of selected mid-range TRL Advanced Life Support technologies.

12.0 PROGRAM/PROJECT DEPENDENCIES

12.1 Related Activities

The Advanced Life Support Project develops technologies that may eventually support 1000-day exploration class missions. In that regard, it is dependent to some extent on the exploration scenarios developed by NASA's Exploration Office at JSC. There is also a close relationship between NASA's Fundamental Biology Program and the Food and Crops Systems Element related to technologies for biomass production. Additionally, Advanced Life Support requirements and technology developments are communicated to JSC's Bioastronautics Technology Working Group and are presented to the advanced life support community through papers and presentations at professional forums such as the annual meeting of the International Conference on Environmental Sciences (ICES), the biennial meeting of the International Conference on Life Support and Biosphere Science (LSBS) and the annual meeting of the American Society for Gravitational and Space Biology (ASGSB).

12.2 Education and Outreach

As the programmatic and management structure of the Advanced Life Support Project has come into focus, the need for a more consolidated and coordinated education/outreach activity has become apparent. At least two important goals for education and outreach in the NASA Advanced Life Support Project will be addressed. One will be to support a single education and outreach agenda that is representative of the major research and technology development activities of all NASA Field Centers participating in Advanced Life Support, namely, ARC, JSC, MSFC, and KSC. The second goal will be to emphasize the technological importance of the Advanced Life Support Project by increasing the content and visibility of Advanced Life Support. These goals are consistent with the current Education Outreach Program being followed by the NASA Headquarters OBPR.

The Advanced Life Support Project has developed four objectives to meet these goals: (1) Increase public awareness and understanding of Advanced Life Support, (2) Increase the Advanced Life Support contribution to NASA Educational Programs, (3) Improve communication between Advanced Life Support and OBPR Outreach Program Office, and (4) Increase visibility of Advanced Life Support to NASA and contractor colleagues. The strategies to achieve these objectives are to create partnerships with visitor centers, participate in professional and public events, and use Internet web sites and brochures that highlight Advanced Life Support technological advancements. The Advanced Life Support Project also plans to increase support of local and national educational programs, teacher workshops, science fair judging, and mentoring at each of the Field Centers. In addition, the Advanced Life Support Project will coordinate with the public affairs office at each Field Center to support tours, public attractions, and utilize media coverage to promote awareness of Advanced Life Support events and achievements.

13.0 AGREEMENTS

13.1 Field Center Memoranda of Agreement

The four major participating NASA field centers in the Advanced Life Support Project are ARC, JSC (which serves as lead), KSC and MSFC. The responsibilities of each center have been agreed to in Memoranda of Agreement, which will be reviewed annually and revised as necessary to provide clear understanding of roles and responsibilities.

13.2 Other Agreements

A Memorandum of Agreement has been signed between JSC's Space and Life Sciences Directorate and JSC's Engineering Directorate's Crew and Thermal Systems Division that defines the roles and responsibilities of each organization with respect to the development and operation of the BIO-Plex. A JSC Internal Task Agreement (ITA) is also developed annually and is signed by the JSC Engineering Directorate and the JSC Space and Life Sciences Directorate. The ITA identifies the planned activities and budget for the Advanced Life Support Project each fiscal year. Additionally, the Advanced Life Support Project enters into Technical Task Agreements (TTAs) with supporting organizations from participating NASA centers as the controlling mechanism for various Advanced Life Support Project tasks. Appendix C contains the most recent versions of the ITA and TTAs.

14.0 PERFORMANCE ASSURANCE

The AHST Program and NASA Headquarters OBPR assure the performance of the Advanced Life Support Project through regular reviews of performance progress. Additionally, the Advanced Life Support Project requires its Elements, as applicable (e.g., projects developing human-rated hardware), to identify relevant requirements documents and summarize the way in which they will be followed with respect to reliability, quality assurance, parts, materials and processes control, performance verification, contamination allowance and control, software assurance, and maintainability.

15.0 RISK MANAGEMENT

The Advanced Life Support Project manages technical, cost and schedule risk through regular reviews of project activities. Risk assessments and mitigation recommendations are provided to the AHST Program and NASA Headquarters OBPR, as needed. Each Advanced Life Support Element identifies technical, cost and schedule risk and, as needed, provides risk assessments and mitigation recommendations to the Advanced Life Support Project Manager. Project adjustments are made as necessary to meet Project objectives within cost and schedule guidelines.

16.0 SAFETY

The Advanced Life Support Project requires all Elements activities, as identified in Section 10.0, as well as all project management activities meet NASA safety requirements. Safety is a top priority with the Advanced Life Support Project. Quality assurance, safety, and readiness review processes (for tests, facility utilization and flight equipment and operations readiness) are strictly enforced at all participating NASA Centers. For any Advanced Life Support human testing, the JSC Institutional Review Board (IRB) will assure the health, safety, well being, and ethical treatment of human subjects participating in JSC ground-based studies or research protocols being conducted with crewmembers. JSC IRB also reviews research proposals that utilize US crewmembers. Additional information concerning the JSC IRB may be found in JSC 20483.

17.0 TECHNOLOGY ASSESSMENT

The Advanced Life Support Project is a research and technology development project. Technology thrusts are in the areas of advanced life support systems for water and solid waste management, food and crop systems, air revitalization, thermal control, and integrated life support systems optimization. The Advanced Life Support Project continuously assesses the merit of candidate technologies and develops only those technologies that show the most promise in terms of meeting mission requirements.

18.0 COMMERCIALIZATION

Advanced Life Support commercial space technology centers are described in Section 10.10.1. The Advanced Life Support Project Manager serves as the alternate COTR for the FTCSC. The Advanced Life Support Project Deputy manager serves as the COTR for the ES CSTC. The goal of each center is to advance the state of food or environmental systems technology, respectively; in order to develop or adapt technologies that will meet NASA's need for long-duration spaceflight, while serving as a catalyst for commercial, terrestrial application of the technologies developed. Additionally, the Advanced Life Support Project supports NASA SBIR and STTR small business programs by providing sub-topic definition, reviewing grant proposals and providing COTRs for relevant to Advanced Life Support objectives.

The Advanced Life Support Project also works with JSC's Office of Technology Transfer and Commercialization to transfer and enable commercialization of Advanced Life Support technologies to the private sector to create jobs, improve productivity, and increase competitiveness of United States companies. This technology transfer process involves moving ideas, concepts and products from the Government arena into the private sector, both directly by means of licenses and indirectly through cooperative partnerships between U.S. companies and NASA.

19.0 PROJECT REVIEWS

All aspects of the Advanced Life Support Project are routinely reviewed internally to ensure that the project and its contents meet scientific, engineering and quality objectives. The Advanced Life Support Project Manager conducts reviews of Advanced Life Support Elements to confirm compliance with safety, cost, schedule, and performance. The AHST Program Manager conducts reviews of the Advanced Life Support Project to confirm compliance with safety, cost, schedule and performance targets. Independent annual reviews are conducted by the STWG to provide guidance. Additional independent reviews are scheduled if new project elements are added or major changes to the Advanced Life Support Project are proposed.

20.0 REFERENCE DOCUMENTS

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- “ALS Research and Technology Development Project Plan,” JSC-38787, CTSD-ADV-302, Thompson, C. D., and Sager, J. C., (1998), Lyndon B. Johnson Space Center, Houston, Texas.
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- “BIO-Plex Life Support Systems Requirements Document”, JSC-39175, CTSD-ADV-350, (2000), Lyndon B. Johnson Space Center, Houston, Texas.
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- “Advanced Human Support Technology Flight Experiment Management Policy”, LSPD 99-1, (1999), Office of Life and Microgravity Sciences and Applications, Life Sciences Division, NASA Headquarters, Washington, DC
- “Advanced Life Support Systems Modeling and Analysis Project Baseline Values and Assumptions Document”, JSC-39317, CTSD-ADV-371, Drysdale, A. and Hanford, A., (1999), Lyndon B. Johnson Space Center, Houston, Texas
- “Advanced Life Support Systems Modeling and Analysis Reference Missions Document”, JSC-39502, CTSD-ADV-383, Rev. A, Hanford, A., Ewert, M. (November 2001), Lyndon B. Johnson Space Center, Houston, Texas
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21.0 CHANGE LOG

DOCUMENT CHANGE LOG FOR CTSD-ADV-348

REVISION LETTER/DATE	AUTHORITY FOR CHANGE	PAGES AFFECTED	BRIEF DESCRIPTION OF CHANGE	AFFECTIVITY END ITEMS/ SERIAL NO.
Rev B/Sept. 30, 1999	AHST Program	All	FY 2000 Update	All
Rev C/February 2002	AHST Program	All	FY 2002 Update	All

APPENDIX A. BIO-Plex Top-Level Requirements

The requirements for the Bioregenerative Planetary Life Support Systems Test Complex (BIO-Plex) cover four distinct areas: the facility itself, the life support system test articles to be tested, the human accommodations required for crew habitation, and the accommodations required to support additional science and technology objectives in the test bed.

A. Facility Requirements

The BIO-Plex facility, located in the Johnson Space Center Building 29 rotunda, shall be an atmospherically closed multi-chamber test bed large enough to house a crew of four for test durations in excess of 400 days. The current proposed human test sequence is shown in Figure A-1. The multi-chamber facility shall provide sufficient volume within which all life support system test articles for air revitalization, water recovery, biomass production, food processing, solids processing, and thermal control can be located, with the exception of external thermal control system hardware. The multi-chamber facility shall also provide sufficient internal volume to accommodate power, lighting, communications, data network, thermal system, air distribution, water distribution (potable and fire protection), and drainage utility runs throughout the complex. These energy, information, and safety utilities shall be interfaced to the external facility systems via a localized penetration interface for the purposes of simplifying leak detection, increasing aesthetics and maintaining high facility fidelity. External to the multi-chamber facility but also located in the Building 29 rotunda shall be a control and conferencing center outfitted to support human testing, with and without the presence of a test support staff. In addition to facility and test article control functions, the control and conferencing center shall also provide for personal and group teleconferencing with isolated test crews in the multi-chamber facility. Buildup and operation of the facility may be staged to accommodate budgetary restrictions and to systematically gain working knowledge of the facility and its systems.

B. Life Support System Test Article Functional Requirements

The BIO-Plex life support systems test article shall provide for a crew of four all requirements relating to air revitalization, water recovery, biomass production, food processing, solids processing, and thermal control. The life support systems shall also provide life support functions required by a crew of eight during a test change out period of up to seventy-two hours. The systems shall also be configured to support a crew of only two for up to ten days. The test article infrastructure located within the multi-chamber facility shall provide for modular change out of test article subsystems to support efficient reconfiguration of the overall life support system from test to test.

C. Human Accommodations Requirements

The BIO-Plex human accommodations shall support habitation of a crew of four for test durations in excess of 400 days. The human accommodations shall support habitation of eight crewmembers during a crew change-out period of up to seventy-two hours.

D. Science and Technology Support Accommodations

The BIO-Plex shall provide accommodations to support science and technology objectives related to advanced human missions to planetary bodies. The accommodations within the multichamber facility shall provide sufficient internal laboratory space to support experiments and evaluations similar to those performed during the Lunar-Mars Life Support Test Project tests in the Johnson Space Center Building 7 20-Foot Chamber Facility. Additionally, the accommodations shall provide sufficient internal laboratory space to house analytical equipment that will enable the crews to verify autonomously that all life support system functions are performing to within specifications (e.g., verify water potability, air quality, and food quality).

Approach: Proposed Human Testing Sequence

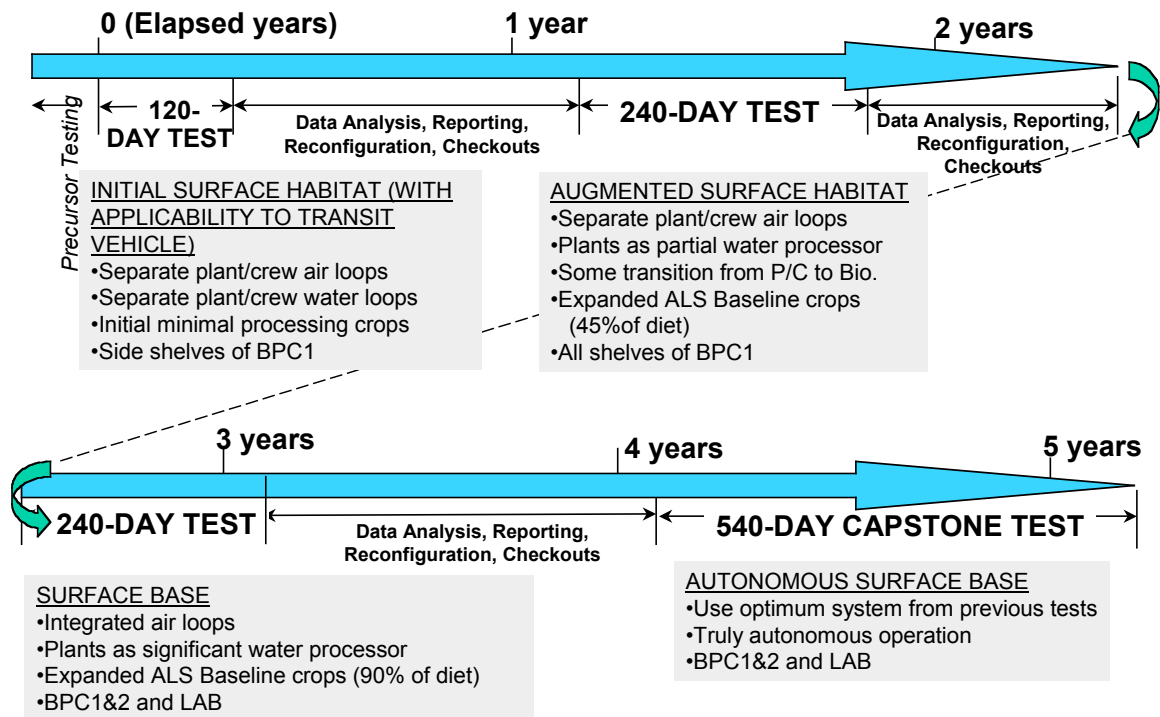


Figure A-1 BIO-Plex Human Testing Sequence

APPENDIX B. ADVANCED LIFE SUPPORT ROADMAP

Figure B-1 is the Advanced Life Support Project's "Roadmap." Figure B-1 consists of three pages (Figures B-1-1, B-1-2 and B-1-3) which fit together end-to-end, left-to-right from page 1 to page 3.

The first page depicts the Research and Technology Development portion of the Project Roadmap (Figure B-1-1). This describes the basic and applied research in the primary technical areas of air revitalization, water recovery, food production, food processing, solid waste management, and thermal control. The work depicted in this figure includes concept development based on scientific methods (basic research) and demonstration of concept feasibility based on scientific fact and test data. Successful research then progresses to where proof-of-concept and critical functions are demonstrated with experiments and parametric data obtained for model development and breadboard system design. Breadboards are then built and tested in laboratory environments to demonstrate performance and feasibility. Model development continues and the spectrum of process operating parameters and performance is established with the laboratory breadboard. Scale-up parameters are determined in preparation for further development.

The second page of the Advanced Life Support Project roadmap (Figure B-1-2) depicts how the development of the regenerative life support systems continues. Technologies are validated as components and breadboards in their relevant environments in order to validate their performance models. It is at this level that extensive trade analyses are carried out to assess competitive functional approaches. Technologies are then subject to process engineering and integration principles wherein they are designed and sized to the feed and production rate requirements and interfaces for integration with regenerative life support system component processes. Finally, long-duration testing in relevant environments is performed, integrated models are developed, and system trade studies are performed. These steps are depicted in the figure by the various test beds shown. The test beds range in degree of fidelity and degree of integration with the most advanced and long-duration test beds depicted on the right side of the figure. It is important to note the horizontal dashed line running the full length of Figures B-1-2 and B-1-3 that denotes the "microgravity transportation systems" (flight vehicles) as differentiated from the "hypogravity surface systems" (those systems which will be on the surface of the moon and/or Mars). This is an important distinction because, in order to fully evaluate technologies, it is important to impose the "relevant environment" so that evaluations are most meaningful. In the case of the microgravity environment, this of course means carrying out experiments and evaluations in space; namely, aboard the Shuttle, Russian Mir, and the International Space Station (ISS). These platforms are shown along the top of Figure B-1-2 and are shown having interactions with all test beds. Ground facilities identified in the far left-hand and lower half of the chart include Lunar-Mars Life Support Test Facility, the BIO-Plex, and any Advanced Life Support ground-based laboratories. Shuttle/Mir operations and flight experiments, ISS operations, and ISS flight experiments, respectively, are represented in the center portion of the upper half of Figure B-1-2. The far right side of Figure B-1-2 depicts "high fidelity" ground test facilities, which will be used in conjunction with focused flight experiments to fully validate the integrated life support systems. The results from these test beds will provide the basis from which specifications for the life support flight hardware will be developed, and will aid in identifying areas requiring advancements and thus, focus research and technology development efforts.

The third page (Figure B-1-3) represents the flight system requirements, i.e., the long-range focus or direction of the Advanced Life Support Project. The figure depicts the two primary sets

of human planetary missions consisting of returns to the moon and missions to Mars as depicted on the lower portion of the roadmap – the hypogravity environments. The upper portion of this page of the roadmap portrays the space transportation/habitation systems required to get to the moon and Mars – the microgravity environments. In addition to the two major gravity gradients, other differences or constraints are apparent. Namely, the mass, power, volume and thermal constraints on board a vehicle are much more severe than they are likely to be on the surface of the moon or Mars. The opportunity exists to accumulate mass (infrastructure) on either the moon or Mars over extended periods (over multiple missions both manned and unmanned); thus over time, there will be less severe restrictions on mass, power, volume and thermal requirements. It is with this in mind that intuitively it is expected that plants, as the primary component of a life support system, will have their best application on the surface of either the moon or Mars. To grow plants as the primary source of food for the crew and as the primary air and water regeneration processors requires considerable mass, power, volume and thermal capabilities. However, it is reasonable to expect that plants will be grown on board space transportation vehicles to provide some fresh food and psychological benefit to the crew, but it will be on a comparatively small scale. Thus, the life support systems for use on planetary surfaces are thought of as having a significant self-sufficiency element to them. More specifically, between growing plants for food, recycling all wastes, and utilizing planetary resources a crew on either the moon or Mars could be nearly capable of sustaining themselves without any resupply from Earth.

[Figure B-1 is contained in a separate electronic file]

APPENDIX C. ADVANCED LIFE SUPPORT APPROVED AHST INTERNAL TASK AGREEMENT, ELEMENT COORDINATION AGREEMENTS AND TECHNICAL TASK AGREEMENTS FOR FISCAL YEAR 2002

FOR INTERNAL USE ONLY

[Agreements are contained in separate electronic files]