The purpose of this subtopic is to develop advanced control system technologies that can support an integrated approach to the command and control of Advanced Life Support (ALS) for future long-duration human space missions, including a permanent human presence on the Moon and Mars. The control strategies for ALS systems must deal with continuous and discrete processes and with dynamic interactions between subsystems such as air revitalization, water recovery, food production, solids processing, and the crew. The goal of autonomously controlling an ALS system challenges many areas of technology, including distributed data management and control, sensor interpretation, planning and scheduling, modeling and simulation, and validation and verification of autonomous control systems. These various technology areas must eventually be integrated into a coherent system that runs day after day for years and that can effectively interact with crewmembers who place their lives in its hands. The control strategy must be able to reach across; the system and into its parts to gather all data necessary to achieve its control objectives. Interfaces to crew, ground control, and other spacecraft systems must allow for insight into control strategies, choices, and pending actions and allow for manual control at any level.

The challenges of controlling regenerative life support for an enclosed crew environment involve the ALS goals to minimize expendables, to minimize crew and ground involvement, and to incorporate biological systems for recycling air, water and solids. The interdependence of environmental processing systems, and the need for reducing operations support costs are included. There is a need for the development and evaluation of control architectures and strategies which meet these challenges, both by building on current advances in distributed, modular, object-based protocols, and by new advances in integration of agent technology, planning, and resource management across heterogeneous systems. This includes:

**New Control Strategies for Closed-Loop Systems**

Advanced Life Support consists of a combination of physico-chemical systems with biological systems to recycle air, water, solid waste, plants, and food. The system is closed with respect to hydrogen, oxygen, and carbon in order to reduce the amount of consumable air water and food necessary for extended human presence on other planets. Closed systems and biological systems have different constraints and control paradigms than conventional processes. There is a need for new control algorithms, analyses, strategies, and techniques that can accommodate this architecture.
Distributed Network Protocols, Including Support for Fieldbus and Intelligent Controllers

The robustness of the control and data paths for equipment and subsystems is determined by the fieldbus protocols that connect them. Fieldbus protocols have been developed for the special needs of the aerospace and process control industries. There is a need for investigation and adaptation of these protocols, and the development of new protocols to support the type of distributed intelligent systems and networks envisioned for human exploration missions. These protocols need to be robust and fault-tolerant, and to support a large number of heterogeneous systems. Ideally, these protocols should support both local and interplanetary connectivity.

Development of Ontologies for Communication Among Autonomous Systems or Control Agents

Human exploration missions involve hundreds of systems developed by dozens of organizations. To develop software that can integrate across these systems and integrate with operations requires the use of common terminology across multiple disciplines. A common taxonomy or common ontology needs to be developed for the types of control problems associated with integrated control of advanced life support systems.

Software Development Methodologies for Autonomous Systems

This includes requirements management, testing, performance metrics, and long-term maintenance support, including development for growth and support for model-based simulations. There is a need for new tools to support the development of distributed autonomous control systems throughout the program life cycle. This includes tools for managing prototyping, requirements, design, design knowledge capture, testing, and growth and maintenance across multiple development teams.

Approaches for Integration of New Controls Technology (both hardware and software) with Existing Legacy Systems

Some space technologies are relatively mature. New controls technology must be compatible with legacy fieldbuses and operations concepts in addition to providing new functionality. There is a need for tools and development methodologies that can accommodate growth in system functionality.

Fault Detection, Isolation and Recovery (FDIR) Across Multiple Systems; Sharing of Parameters and Data Between Heterogeneous Systems

The majority of FDIR approaches focuses on single subsystems and depend on a homogeneous platform and software architecture, often using a blackboard or shared memory model to share data between modules. There is a need to perform FDIR across multiple heterogeneous systems across networks. Ideally, FDIR should support cooperative efforts between group operations and planetary systems.

Control System Failure Tolerance

Critical systems provide functional redundancy in the case of failure or performance degradation. There is a need for new approaches to providing failure tolerance for both hardware and software components of the control systems. Of particular importance is the reduction of crew time for maintenance, and reduction of dependence on re-supplying hardware, as these are the most expensive constraints on these systems.
Planning and Scheduling

This includes reactions to system faults, supporting adjustments to operations, inventory, and logistics because of planned and unplanned maintenance. There is a need for tools to support development and deployment of applications that support planning and scheduling. Developed applications should support the integration of both planet-side and Earth-side activities.

Development and Integration of Autonomous System and Intersystem Control with Crew and Ground Operations

There is a need for tools, architectures, and technology that can support integration of operations between crew, ground operators, ground applications, and onboard applications.

Development of Architectures that Support a Range of Autonomy, from Fully Autonomous to Fully Manual, with the Corresponding Range of Support for Human Interaction

Autonomous systems for human exploration missions must provide visibility, situational awareness, and an ability to change the level of autonomy based on both situation and human input. As unexpected situations arise that are outside the scope of design, autonomous control systems must interact with crew and ground operators at varying levels of transparency. Unlike Earth-based systems, the planet-side crew will not be subsystem experts and may be isolated from ground support. Local systems must safely and robustly aid the crew in both troubleshooting and nominal operations. There is a need for software architectures and development methodologies, including system and crew modeling, to provide such capabilities.