Plant Growth Facility - Split Plenum (PGF-SP) Critical Design Review (CDR) (TAGES/RASTA)

Prepared by: Bionetics

Date:09/09/2002

Agenda

Part One

- Introduction 8:30 - 8:50
  - Introductions
  - Project Overview
- Requirements and Architecture 8:50 - 11:30
  - Driving Requirements
  - Hardware Overview
  - Key Goals
  - Operating Modes
  - Interfaces/Standards/Specifications
  - System Overview/Performance
- Lunch 11:30 - 12:30

Agenda

Part Two

- **Subsystem Design and Analysis 12:30 - 4:30**
  - **Single Locker Design**
  - **Double Locker Design**
  - **Tray Insert Assembly**
  - **Plant Growth Chambers**
  - **LED Light Module**

Day Two 8:15 - 9:15

- **Air Filtration System**
- **Electronic Control System**
- **Front Interface Panel**
- **Green Fluorescent Protein Imager**

Agenda

Part Three

- **Electrical and Software 9:15 - 11:15**
  - **Electrical design**
  - **Software**

Agenda

Part Three

- **System Summary and Project Status** **11:15 - 11:30**
  - **Weight and Center of Gravity**
  - **Power Usage**
  - **Lunch** **11:30 - 12:00**

    12:30 - 2:30
  - **Risk Overview**
  - **Reliability and Maintainability**
  - **Hazards and Material Usage**
  - **Flight Testing**

Agenda

Part Three

- **System Summary and Project Status** **2:30 - 3:00**
  - **Project Status and Schedule**
- **Reviewers comments** **3:00 - 4:30**

Introduction

- **Purpose: This is the critical design review for the PGF-SP hardware which will be used on the RASTA and TAGES-2SD experiments. This review will provide NASA and LSSC Management with the data required to authorize the fabrication of flight hardware.**

- **Scope: This review covers specifically the PGF-SP hardware flight design and its intended use in generic plant experiments as well as specific requirements from RASTA and TAGES-2SD.**

LSSC Team

- Flight Project Manager: Bill Wells
- Lead hardware engineer: Mark Kelsch
- Electrical and Optical engineer: Trevor Murdoch
- Software and systems: Don Platt
- Biomedical Engineer: Roberteen McCray
- Hardware Technicians: Bill Mandeville and Allen Williamson
- NASA Project Manager: Guy Etheridge
- RASTA PI: Dr. Gary Stutte
- RASTA Project Engineer: Bill McLamb
- TAGES-2SD PI: Dr. Robert Ferl
- TAGES-2SD Project Engineer: Kelly Norwood
- Payload Science Coordinators: Howard Levine, Liz Stryjewski

Project Overview

- **Mission Statement: Design an automated plant growth facility to support the TAGES-2SD and RASTA experiments. Provide a payload which safely operates on orbit as well as at ground facilities. Provide an easy to use payload with potential for upgrade and improvement. Provide a payload which is versatile enough to be used for other higher order plant experiments. Maximize utility for cost of development.**

Project Overview

- Experiments supported
- RASTA
  - Principle investigator: Dr. Gary Stutte
  - Plant: *Raphanus sativus* L. (radish)
  - Purpose: Study effect of cabin atmosphere and microgravity on plant development.
- TAGES-2SD
  - Principle investigator: Dr. Robert Ferl
  - Plant: *Arabidopsis thaliana*
  - Purpose: Establish the utility of GFP stress indicator as a real time plant health check on orbit.

Project Overview

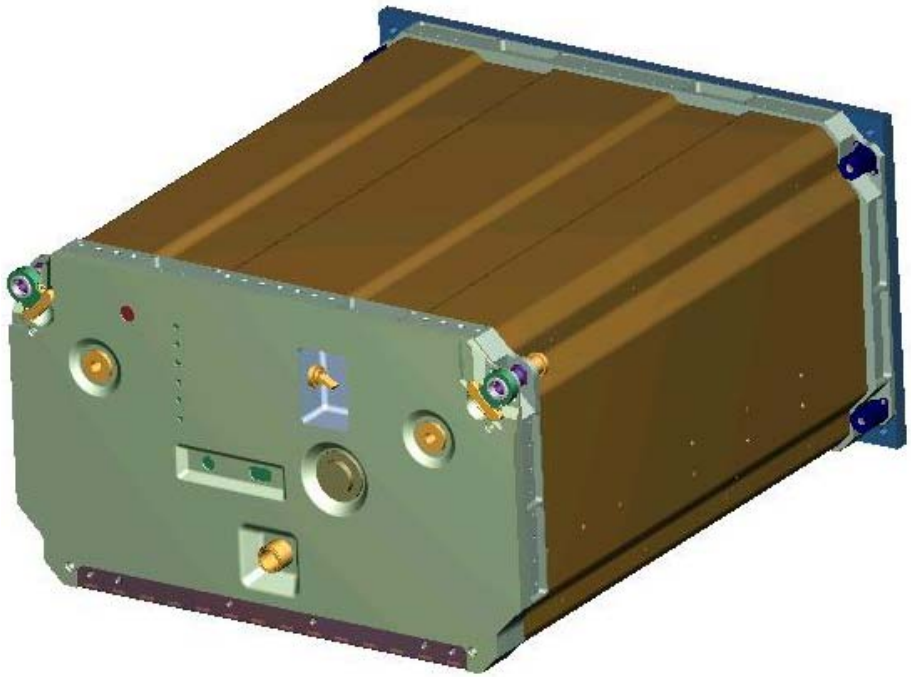
- PGF-SP development started in 2000
  - Started as modification to PGF
- Addition of TAGES-2SD and ISS compatibility to project scope
- PDR held in 1/00
- Prototype completed in 08/01
- Testing and modification of prototype up to TAGES-2SD SVT
- TAGES-2SD SVT completed on 5/24/02

Project Overview

- Prototype PGF-SP performance summary
  - Temperature control to ambient temperature
    - Failed to achieve 4°C below ambient target
  - Humidity control when prime intact
  - Ample lighting
    - More than 500 μmoles/m^2/sec when at full power
  - Carbon Dioxide control within 100ppm of set point
    - When Plant Growth Chamber leak rate was low
- Redesigned Thermal Control System breadboard performance summary
  - Temperature control to 6°C below ambient

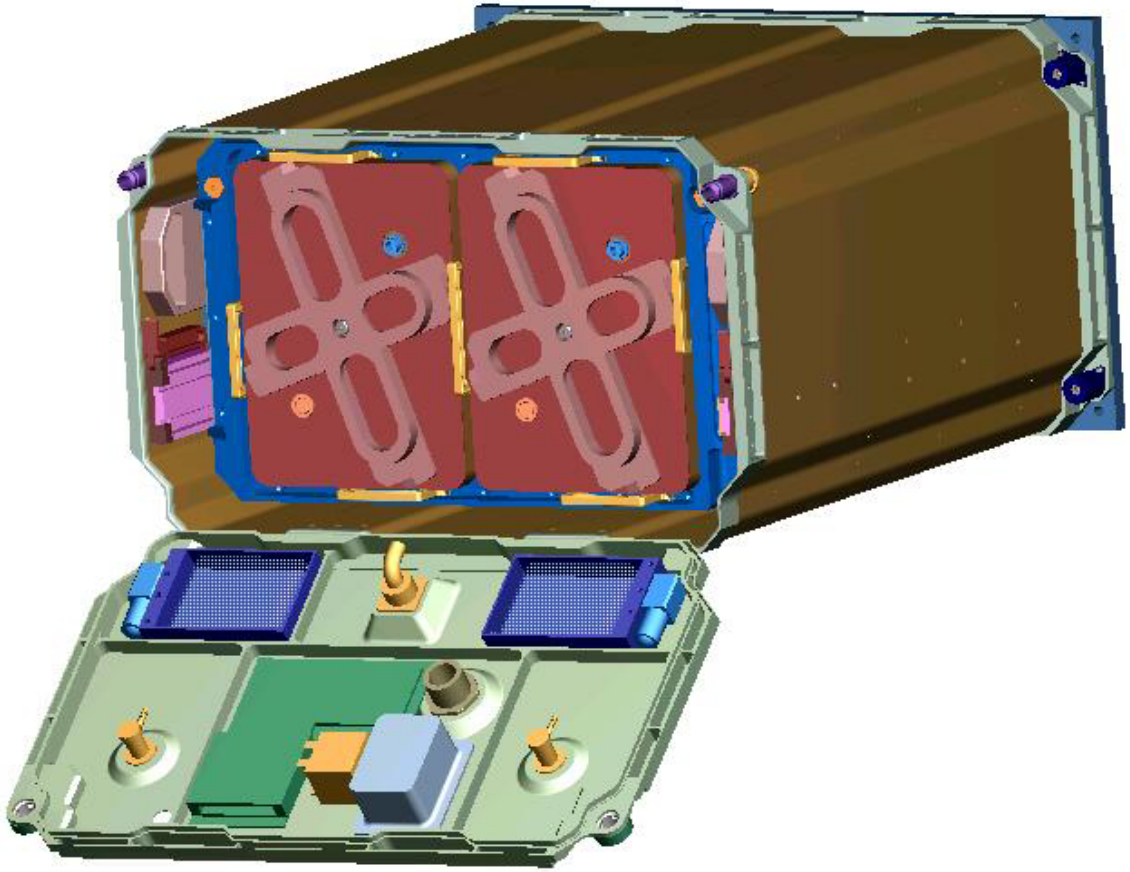
PGF-SP Hardware

- **Highly Flexible, Capable and Upgradeable Plant Growth Facility**
- **Front air cooled, rear air cooled or ISS water and air cooled configurations**



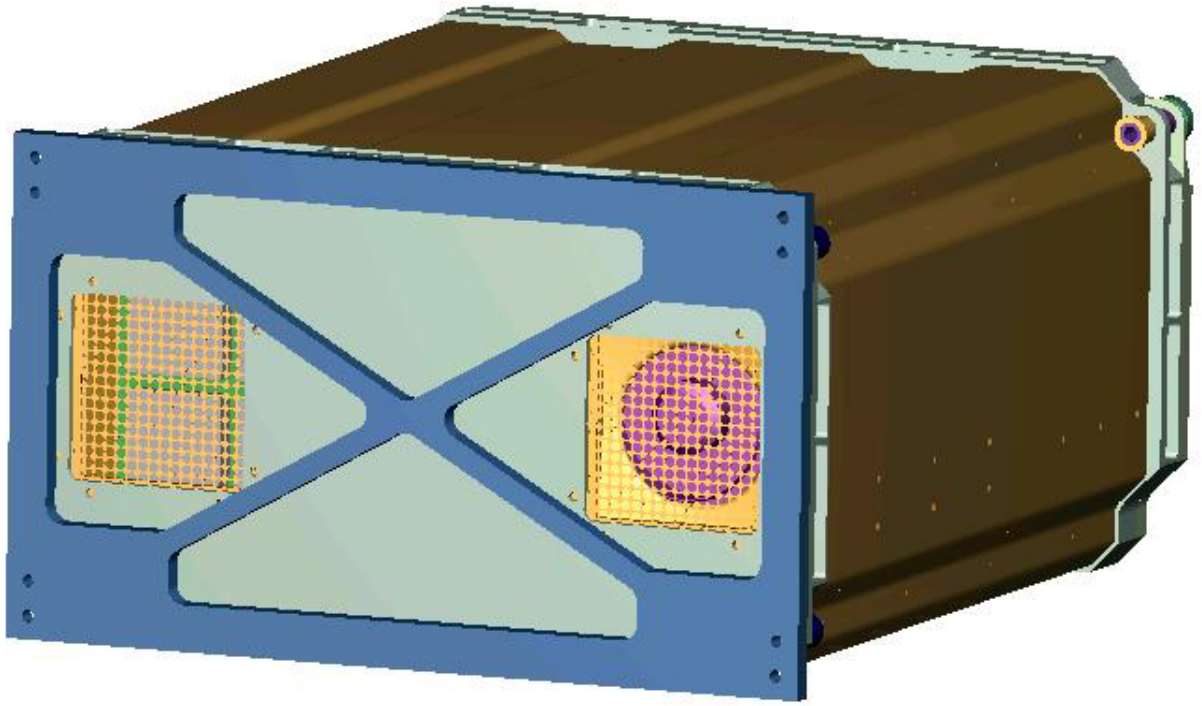
PGF-SP Hardware

- **Two large independent plant growth chambers (PGCs)**
- **Large range of environmental control**



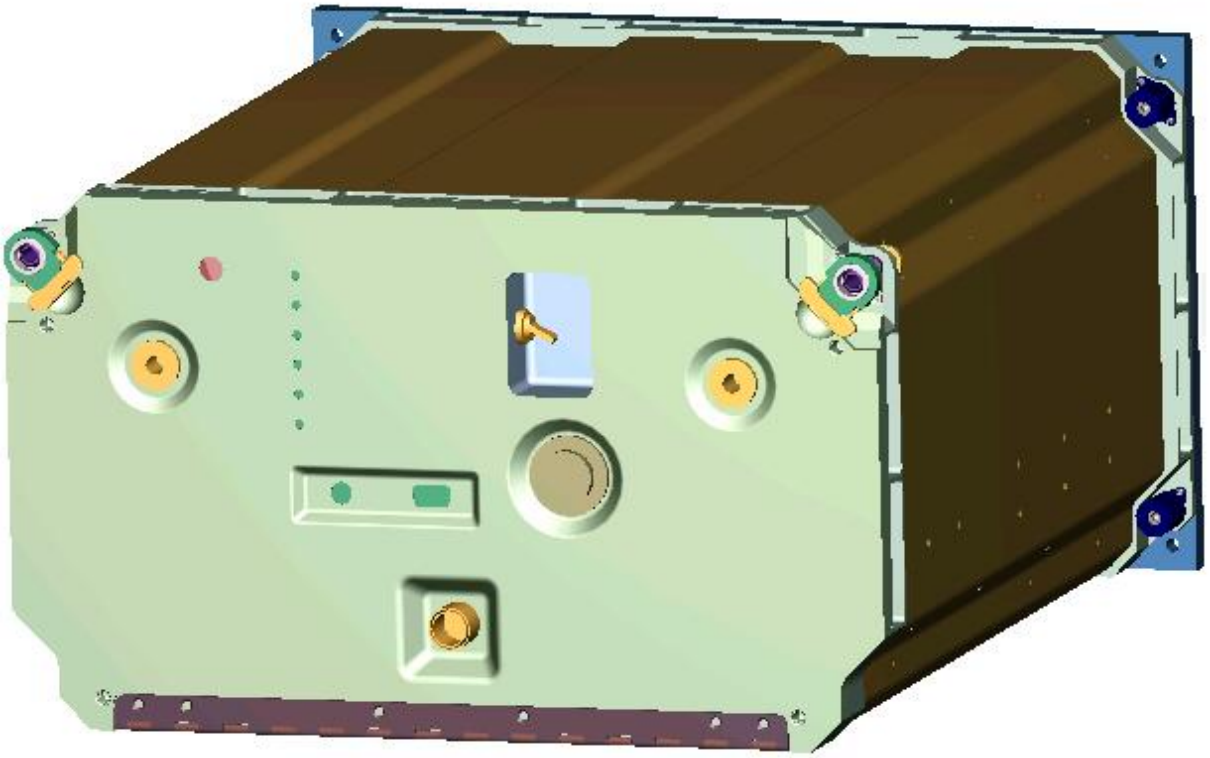
Single Locker Configuration

- **Middeck Launch and Extended Missions on ISS**
- **Rear air cooled for Middeck (36 cubic feet per minute)**



Single Locker Configuration

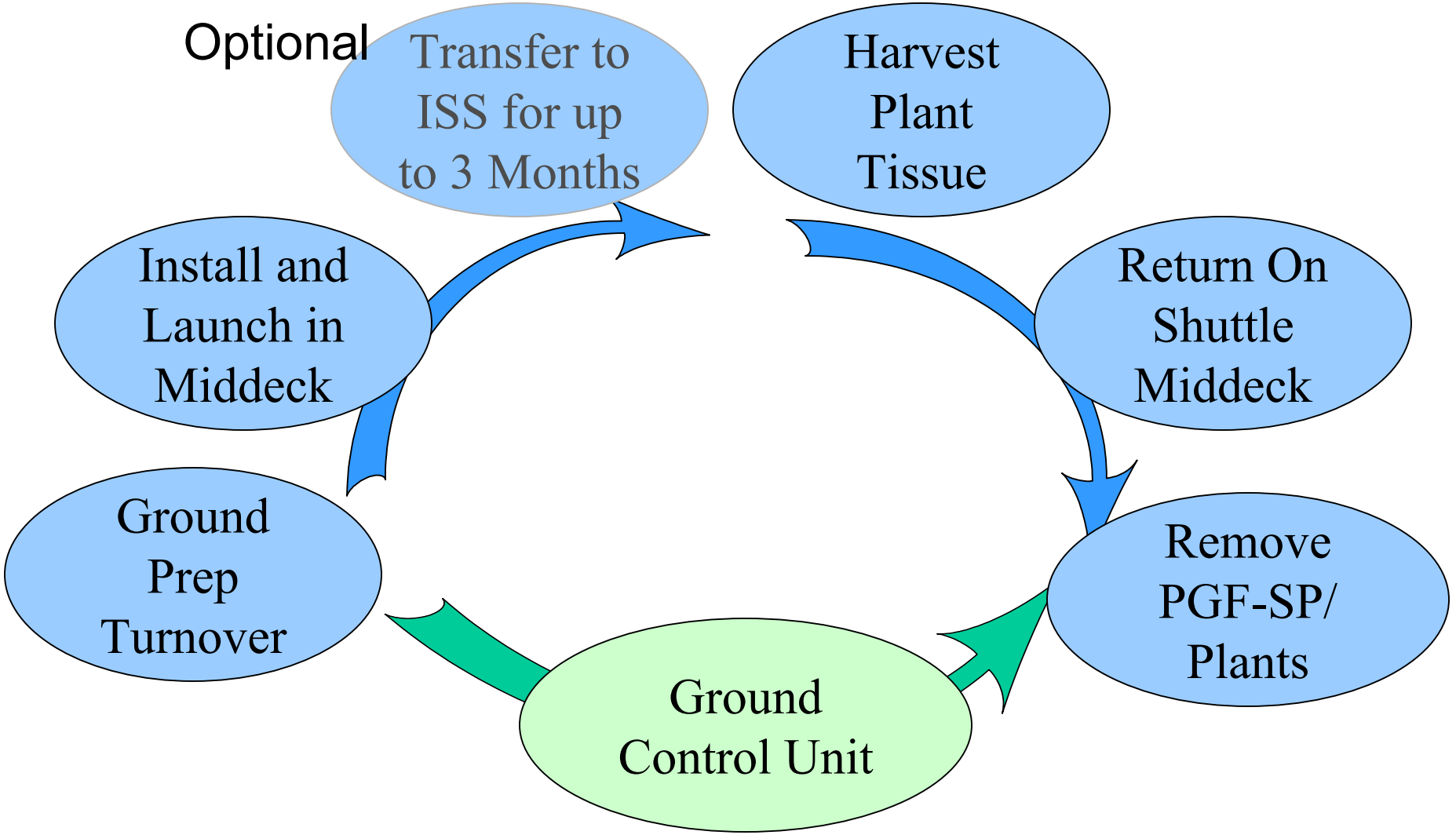
- **Additional hookup for Moderate Temperature Water Loop (MTL) for International Space Station operation (ISS)**



Double Locker Design

- Double locker converts PGF-SP to front breather
- Additional volume used for stowage and mini-freezer

PGF-SP Mission Overview



System Key Requirements

- Safety
  - Structural integrity, Liquid containment, EMI/EMC
  - Flammability, Odor and Off Gassing
  - Operator Safety (sharp edges, touch temperatures)
- Environmental Control
  - Temperature, Humidity, CO2, Lighting, VOCs
- Data Acquisition
  - Environmental monitoring, plant imaging
- Weight
- Power Consumption/Heat Rejection
- Reliability

Environmental Control Requirement Comparison

Requirement	TAGES-SD Requirement	RASTA Requirements	PGF-SP End Item Specification
Temperature(°C)	21±3	23±0.5	23-26, ±0.5
Relative Humidity (%)	80 (60-90)	70 ±5	60-85 ±5
CO_2 Control (ppm)	1500 (700-2000)	1500 ±75	700-3000, ±75
PAR/PPF (umole/m^2/s)	80 (80-150)	>300, mission duration dependent	50-300
Ethylene Filtration (ppb)	As low as possible	<50	<50
VOC Filtration	NR	75% below ambient	75% below ambient
Gas Sampling	NR	Yes, without chamber removal	Yes, provisions for port/septum
Nutrient Delivery	NR	Yes, without chamber removal; manual delivery/dispersion; depends on root media	Automated condensate recovery/reservoir of water only

Functional Requirement Comparison

Requirement	TAGES-SD Requirement	RASTA Requirement	PGF-SP End Item Specification
EUE Imaging	Excitation and image capture of GFP plants	NR	Excitation and image capture of GFP plants
General Imaging	Desired	Desired	Yes, top down view of chamber
Downlink images	yes	yes	RS 422 serial port
Crew access to plants	yes	Yes	Yes, removable root tray
Growth volume	No specific requirement	TBD radish plants, based on mission duration	44 in2 per chamber; 8.0” height, 2” base depth
Root tray growth media	Foam; holding device for imaged plants	Foam or Arcillite; Arcillite root/shoot barrier	Experiment specific

Goals

- Accuracy of control and data acquisition
  - High accuracy for better experiment repeatability
- Flexibility and upgradeability
  - Use of PGF-SP as generic hardware
- Plant Volume
  - Maximize volume of plant tissue possible
- Light Level
  - High output for light hungry plants
- User interface
  - Easy to use effectively with minimal training and effort

Interfaces

- Plants
  - Biocompatibility, size, and environmental control
- Middeck Mechanical, Thermal and Electrical Interfaces
- Orbiter Environment
- Express Rack Mechanical, Thermal and Electrical Interfaces
- ISS environment
- Express Rack Control Software
- Crew Laptop Software
- Ground Support Equipment

Operating Environment

	Middeck	Express Rack	PGF-SP Requirement
Nominal Cabin Temperature	18.3- 26.7°C 65 - 80°F	17 - 28°C 62.6 - 82.4°F	17 - 28°C for normal operation
Maximum Cabin Temperature	35°C 95°F	46°C (MPLM) 114.8°F	Limited Operation to 35°C Shutdown over 35°C
Nominal Cooling Air Temperature	26.7°C 80°F	18.3 - 29.4°C 65 - 85°F	18 - 29.5°C for normal operation
Maximum Cooling Air Temperature	35°C 95°F	46°C (MPLM) 114.8°F	Limited Operation to 35°C Shutdown over 35°C
Humidity (RH)	20 - 80%	25 - 75%	20 - 80% , no exposed surfaces colder than 16

Operating Environment

	Middeck	Express Rack	PGF-SP Requirement
Nominal Air Pressure	9.7 - 18.1 psia	13.9 - 15.2 psia	9.7 - 18.1 normal operation
Max/Min Air Pressure	7.8 - 18.1 psia	0 - 15.2 psia	0 psia non-operating

Thermal Interfaces

	Middeck	Express Rack	PGF-SP Requirement
Cabin Cooling	Allowed	Restricted on future missions	Multiple configurations
Avionics Air Flow	18 or 36 CFM	15+/-3 CFM	36 CFM on Middeck 15+/-3 with MTL
Moderate Temperature Water Loop Flow	N/A	50 lbm/hr nominal	50 lbm/hr
MTL Temperature	N/A	16.1 - 23°C 61 - 73.4°F	16.1 - 23°C for normal operation
Maximum Exhaust Temperature Air/Water	48.9°C 120°F	48.9°C 120°F	48.9°C 120°F
Avionics Air Sealing	2 scim	Eliminated	2 scim in Middeck

Structural Interfaces

	Middeck	Express Rack	PGF-SP Requirement
Mounting Features	VPMP	Express Rack	Both, bolt pattern identical
Single Locker Maximum Dimensions	10.757x18.125x21.062	10.757x18.125x21.062	
Double Locker Maximum Dimensions	21.822x18.125x21.062	21.822x18.125x20.562	
Load Environment	Middeck	Middeck, MPLM envelope	Middeck only, waiver required for ISS missions
Human Interfaces	N/A	EXPRESS Rack Par 12.0	EXPRESS Rack Par. 12.0

Power and Data Interfaces

	Middeck	Express Rack	PGF-SP Requirement
Input Voltage Range	28 ± 4 Vdc	28 + 1.5/-2.5 Vdc	28 ± 4 Vdc
Maximum Current	20.0 A	20.0 A	20.0 A
Maximum Power	By manifest	By manifest	By manifest
Grounding and Isolation	1 megohm	1 megohm w/pararelle capacitance ≤ 10 μF	1 megohm w/pararelle capacitance ≤ 10 μF
External Computer Interface	RS 232, Crew Laptop	Ethernet, Serial, analog	Crew laptop and Ethernet

Controlling Specifications and Standards

- End Item Specification -
  - PLANT GROWTH FACILITY – SPLIT PLENUM, END ITEM SPECIFICATION, L-9005.1
- Experiment Requirements Documents
  - LSSC-TAGES-2SD-ERD
  - RADISH ASSIMILATION IN SPACEFLIGHT TESTBED ATMOSPHERES - ERD
- IDDs
  - NSTS-21000-IDD-MDK
  - NSTS-21000-IDD-ISS
  - SSP 52000-IDD-ERP
  - SSP 52005
- Materials
  - MSFC-HDBK-527/JSC 09604
- Safety
  - NSTS 1700.7B
  - NSTS 1700.7B, ISS ADDENDUM

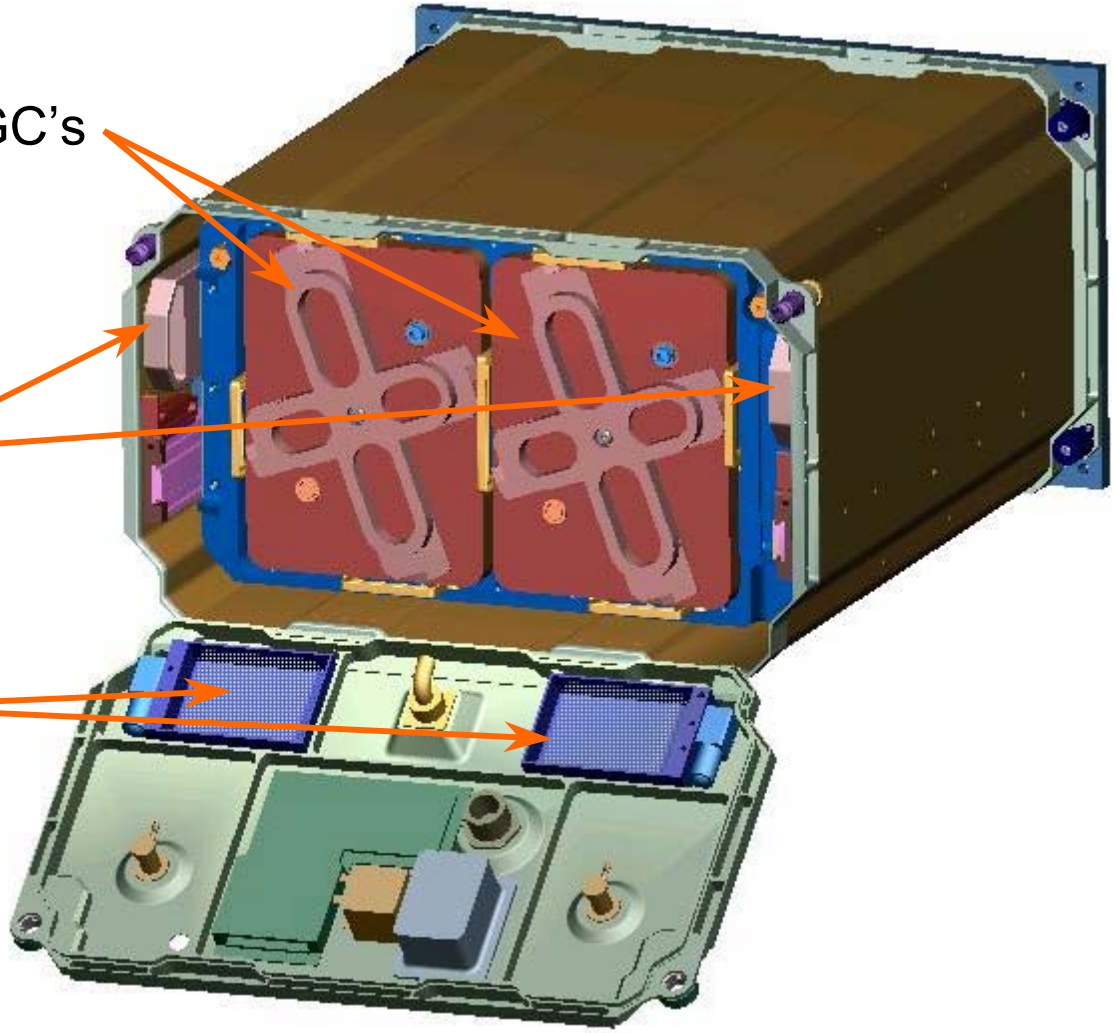
System Overview

Root Trays Installed in PGC's

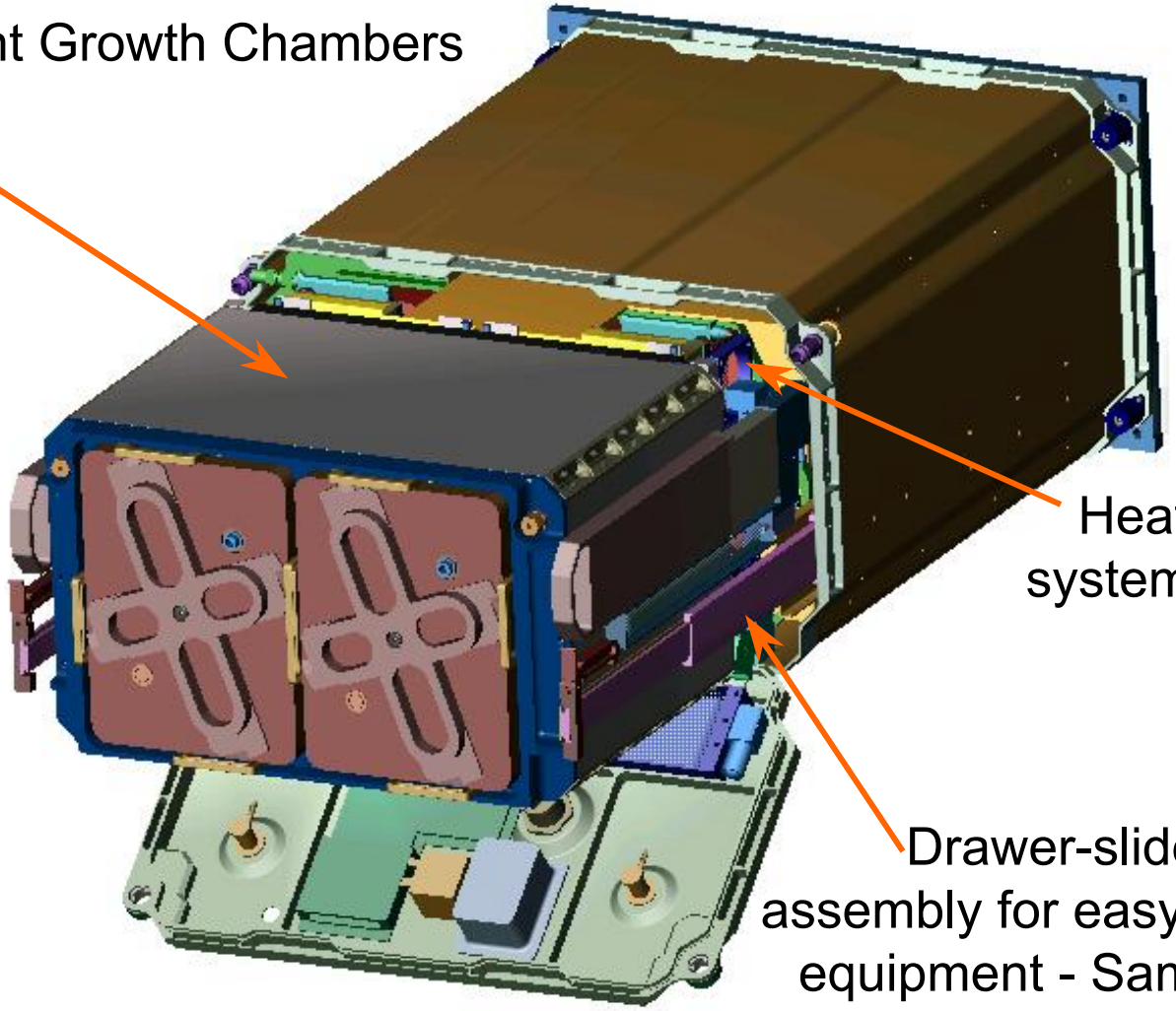
Air Scrubber Modules

Nutrient Reservoirs

Easy Crew Access for on orbit operations



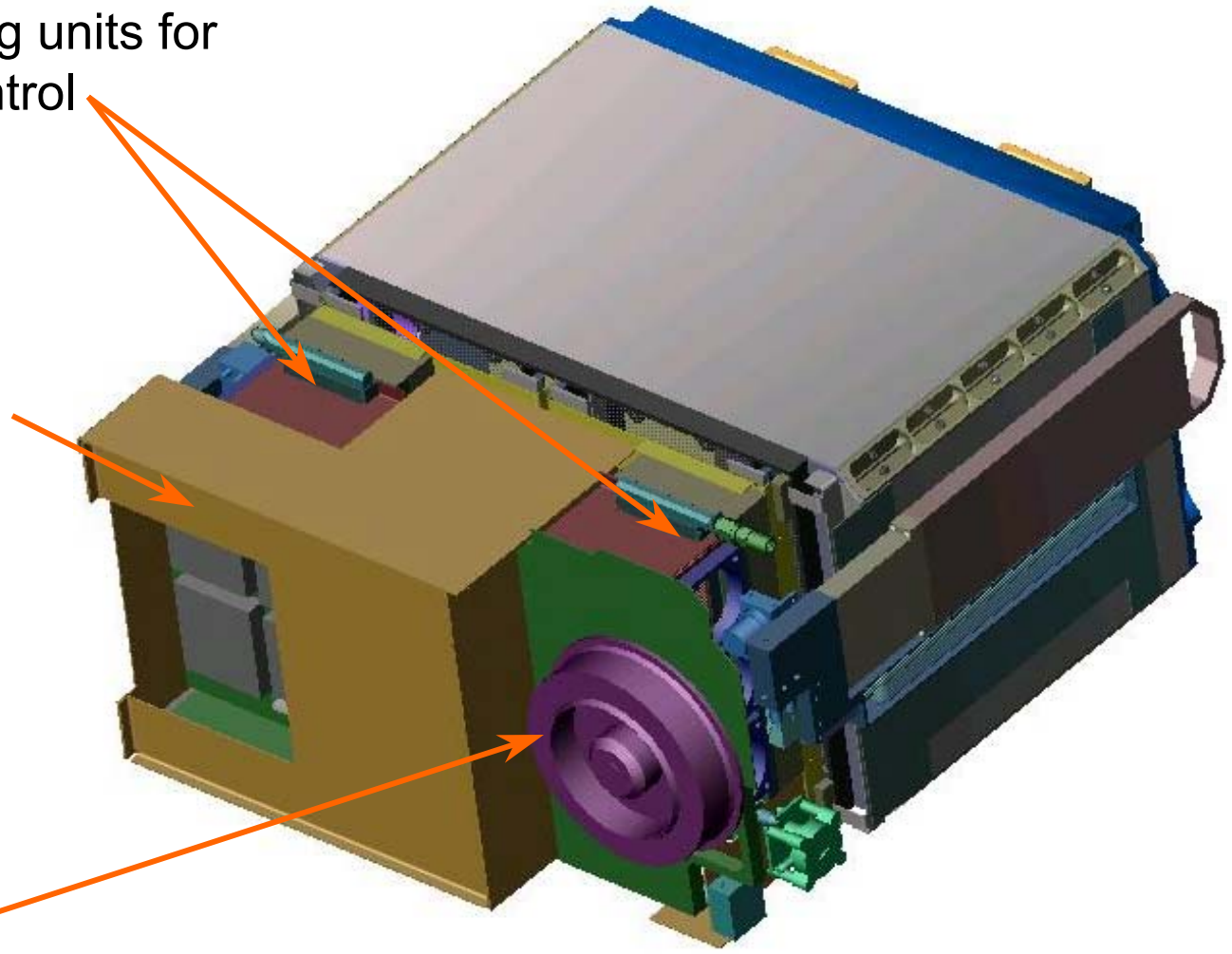
System Overview



System Overview

Thermoelectric cooling units for PGC temperature control

Electronic Control Unit (ECU)



Inlet impeller

System Features

- Middeck and EXPRESS Rack Compatible
- Moderate Temperature Water Loop (MTL) cooled for EXPRESS Rack missions
- Highly automated system reduces crew time
  - Crew time may be limited to once a week maintenance in some cases
- Generic Plant Imaging
- Condensate recovery and automated watering
- Two independently controlled growth chambers to create redundancy or comparisons within an experiment
- Easy to access systems reduce maintenance time

Maximum System Capabilities

- Temperature control up to 8°C below ambient
- Humidity control between 60% and 80% RH
- Lighting up to 350 μmoles/m^2/sec at surface of root zone
- Total growth area of 88 in^2
- Growth height of 8 in.
- Root Tray depth of 2 in.

Normal System Operational Modes

- **Powered Off**
  - **Backup battery maintains internal clock**
- **Standby Mode**
  - **ECU up and running**
  - **Locker cooling fans on**
  - **Internal cooling water loop running**
  - **Sensors active**
  - **Ready for commands**
- **Experiment Mode**
  - **All systems controlling to pre-programmed set points**
  - **Recording and storing data to hard disk drive**
- **Park Mode**
  - **Same as experiment mode but hard disk drive disabled for launch and landing**
  - **Data stored in volatile memory**

Off Nominal System Operational Modes

- **Watchdog Control Mode**
  - **ECU main computer (CDMS) fails to respond or reboot**
  - **Watchdog processor performs system checks and reports state of health**
  - **Individual control processors continue to control environment to last set point**
  - **Processors store data to local EPROM memory**
  - **Imaging accomplished remotely through RS232 or Ethernet port**
- **Heat Reduction Mode**
  - **High inlet or outlet temperatures are sensed**
  - **LED lighting disabled**
  - **PGC Heaters disabled**
  - **Cooling power limited to ten (10) watts per PGC**
  - **Entered automatically**
  - **Return to experiment mode after 30 minutes**

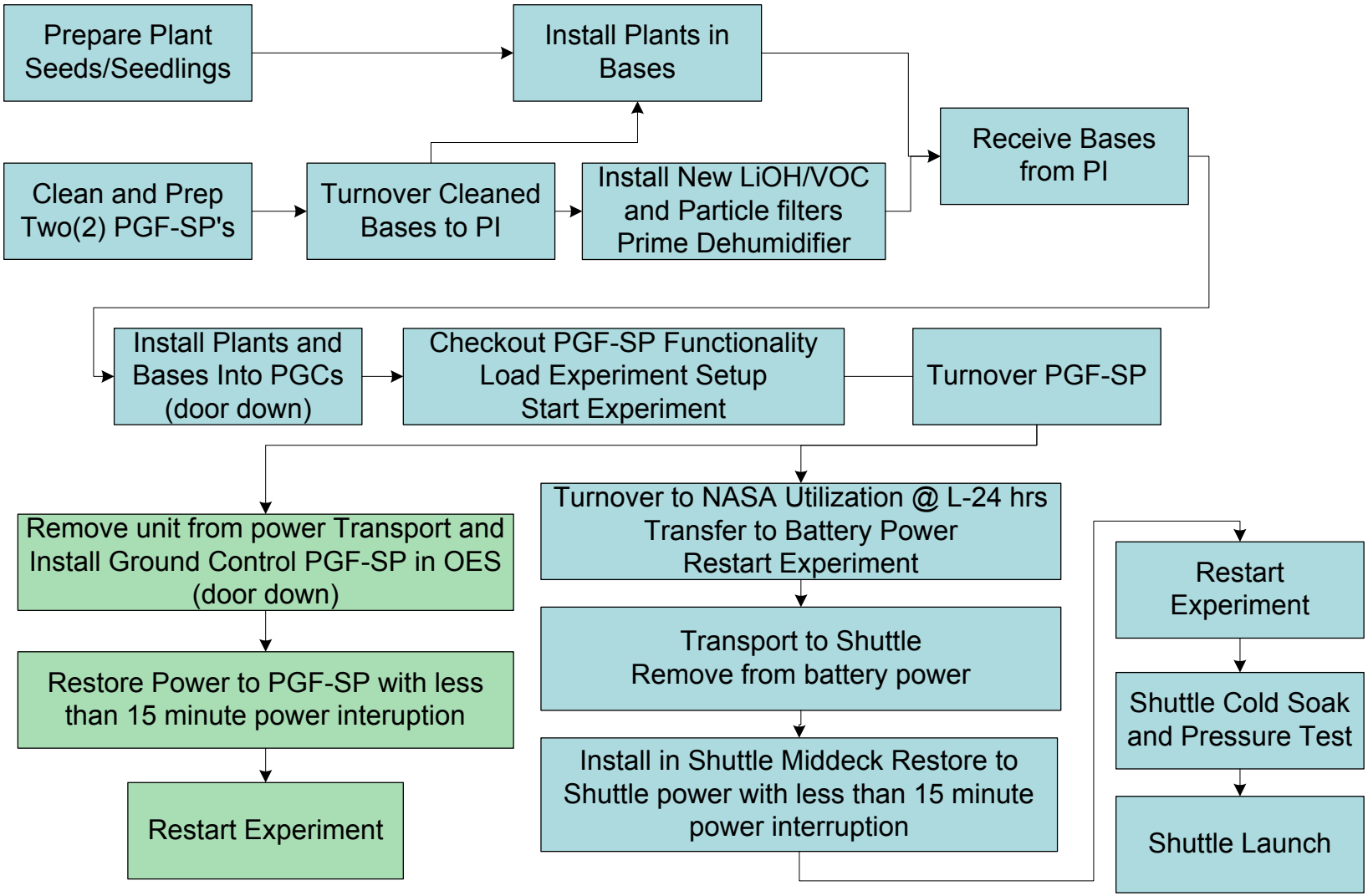
System Limitations

- **Overall lighting and cooling limited by power consumption and heat rejection**
  - **Air exhaust temperature will become the limiting factor**
  - **Highly dependent on avionics and cabin temperatures**
  - **Inlet air temperatures exceeding 30°C may effect temperature control performance**
  - **Inlet air temperatures exceeding 32°C or the outlet temperatures exceeding 45°C will result in shutdown of lights and reduction in cooling**
  - **Outlet air temperature exceeding 46°C will result in shutdown**

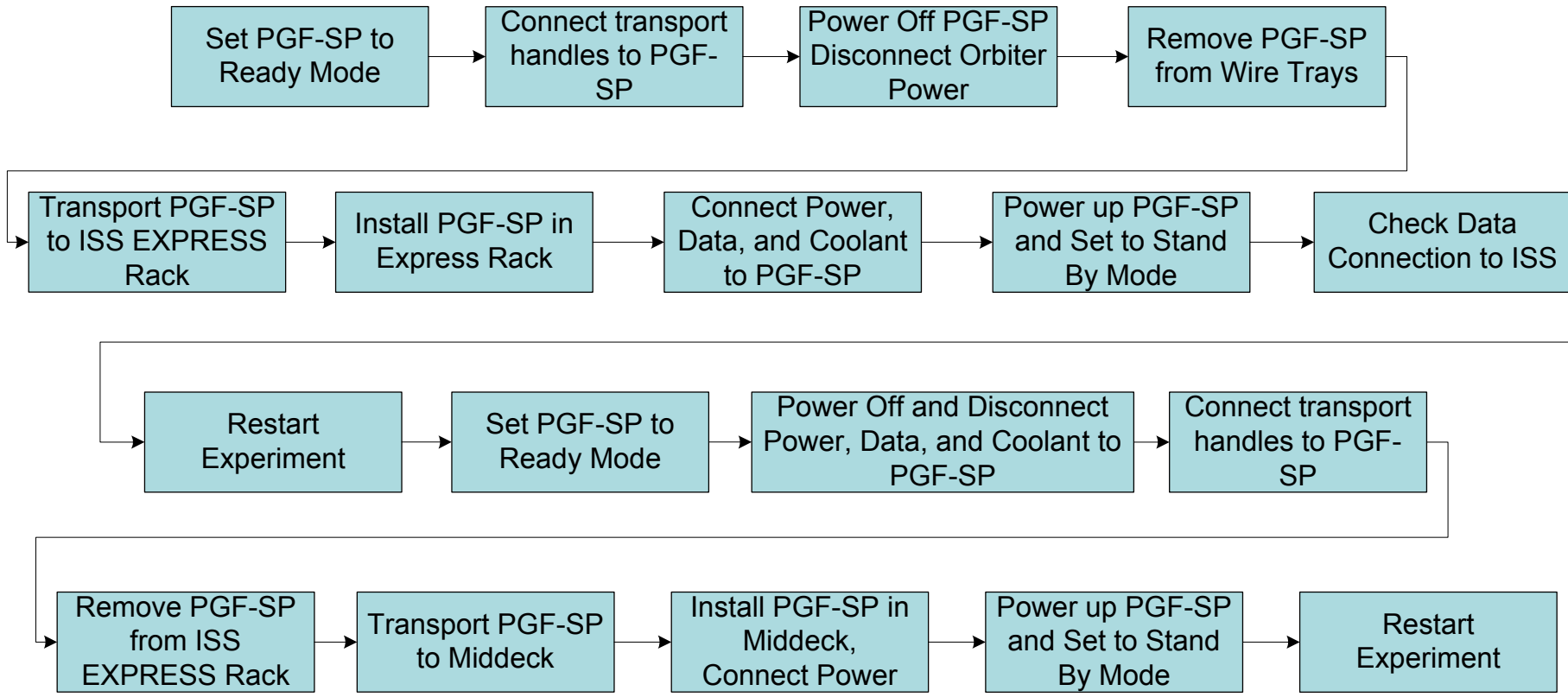
System Limitations

- Increasing growth chamber Carbon Dioxide accomplished by injecting avionics air
  - Low avionics Carbon Dioxide may result in out of limit condition
- Carbon Dioxide, Ethylene and VOC scrubbing agents are sacrificial and will require on orbit replacement
- Water reservoirs hold 100 ml of nutrient solution each and may require refilling on orbit

Mission Ground Operations

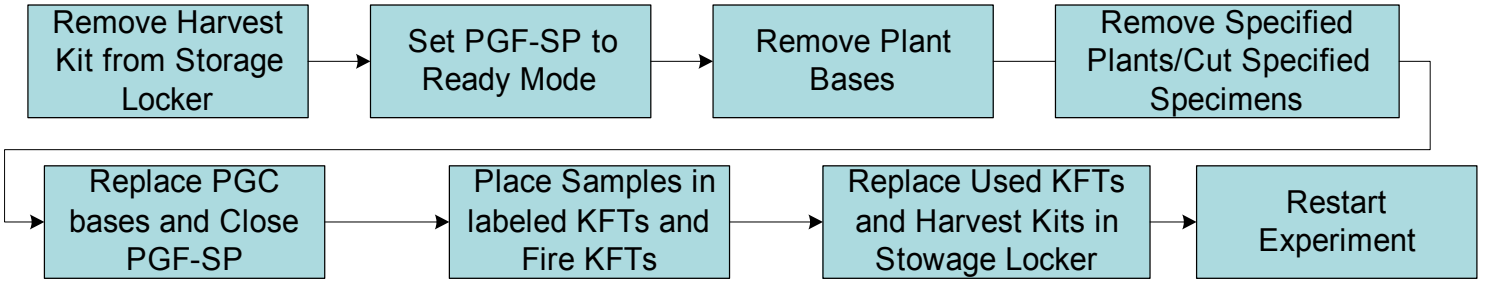


On-Orbit Middeck to Express Rack Transfer Operations

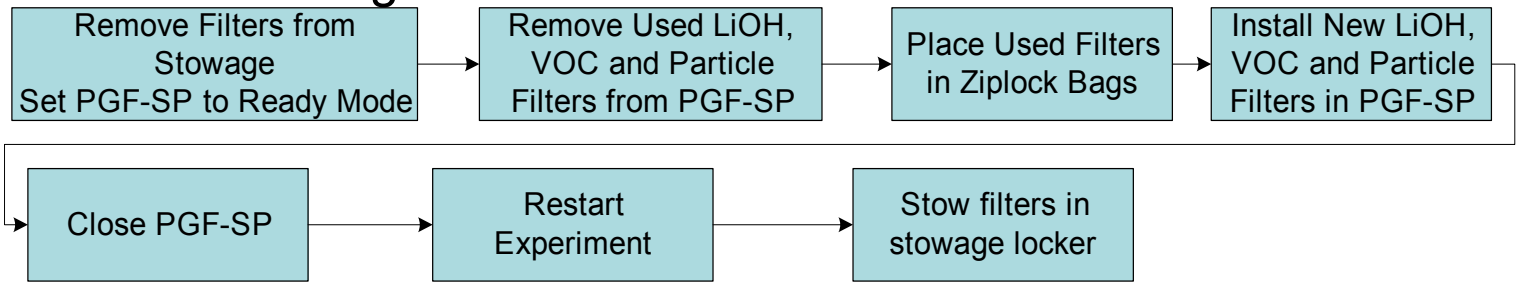


On-Orbit Operations

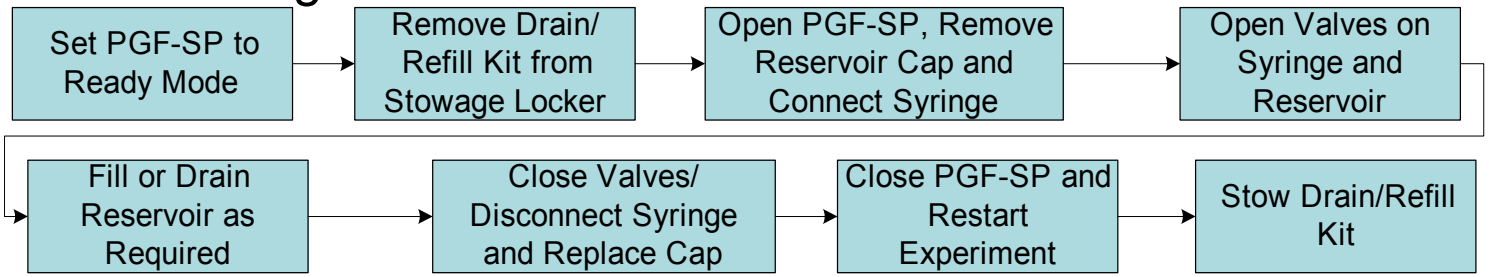
On-Orbit Harvest



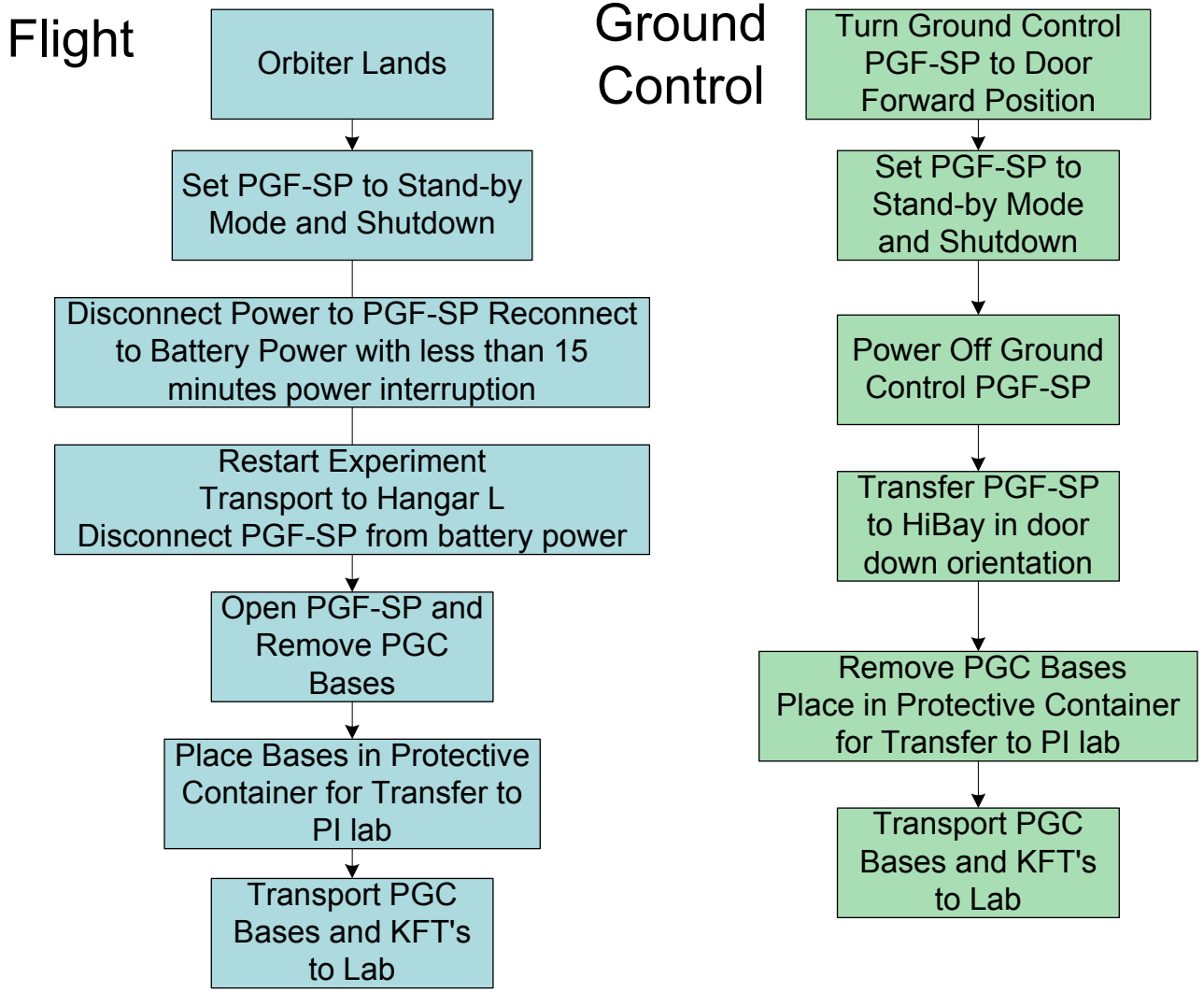
On-Orbit Filter Changeout



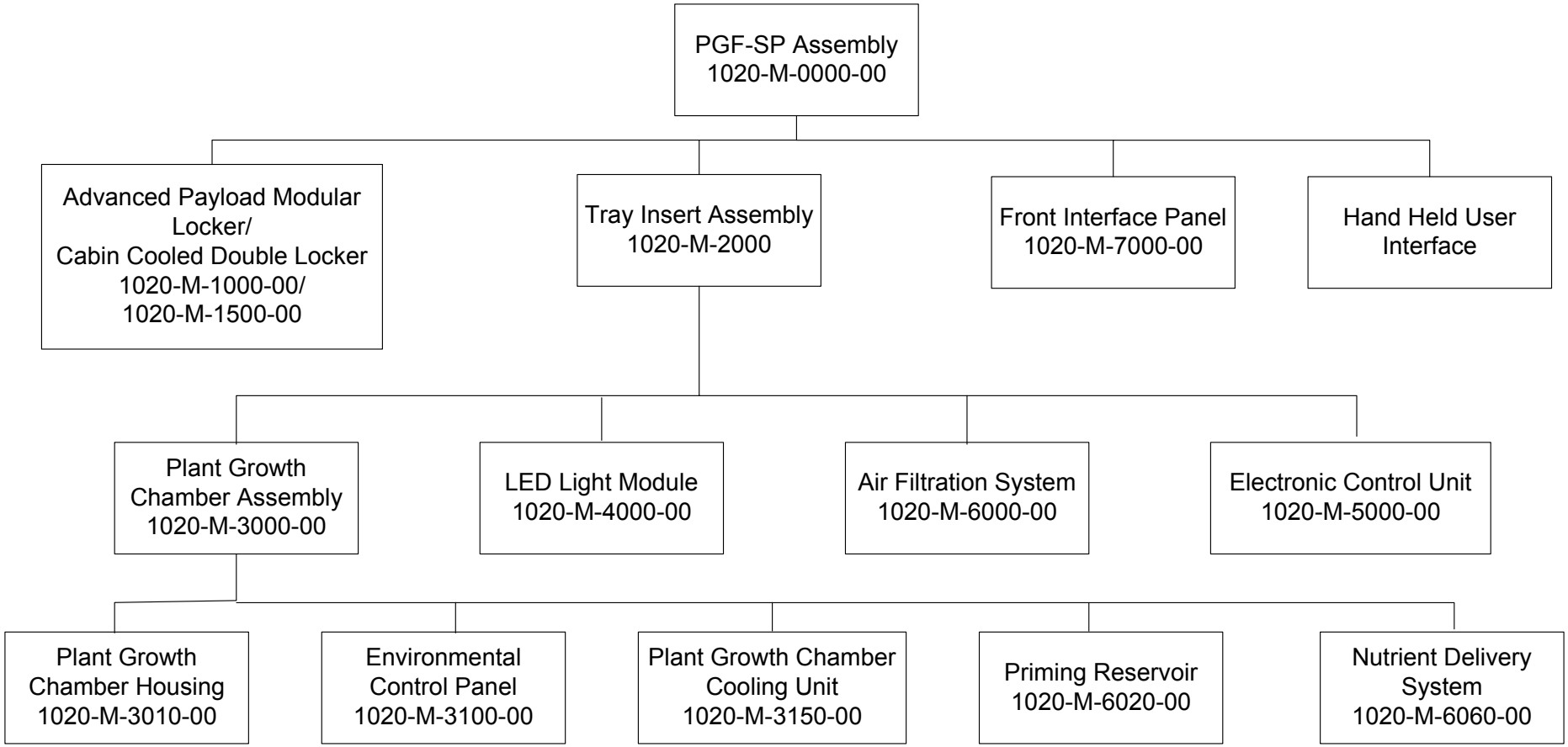
On-Orbit Watering



Landing Operations

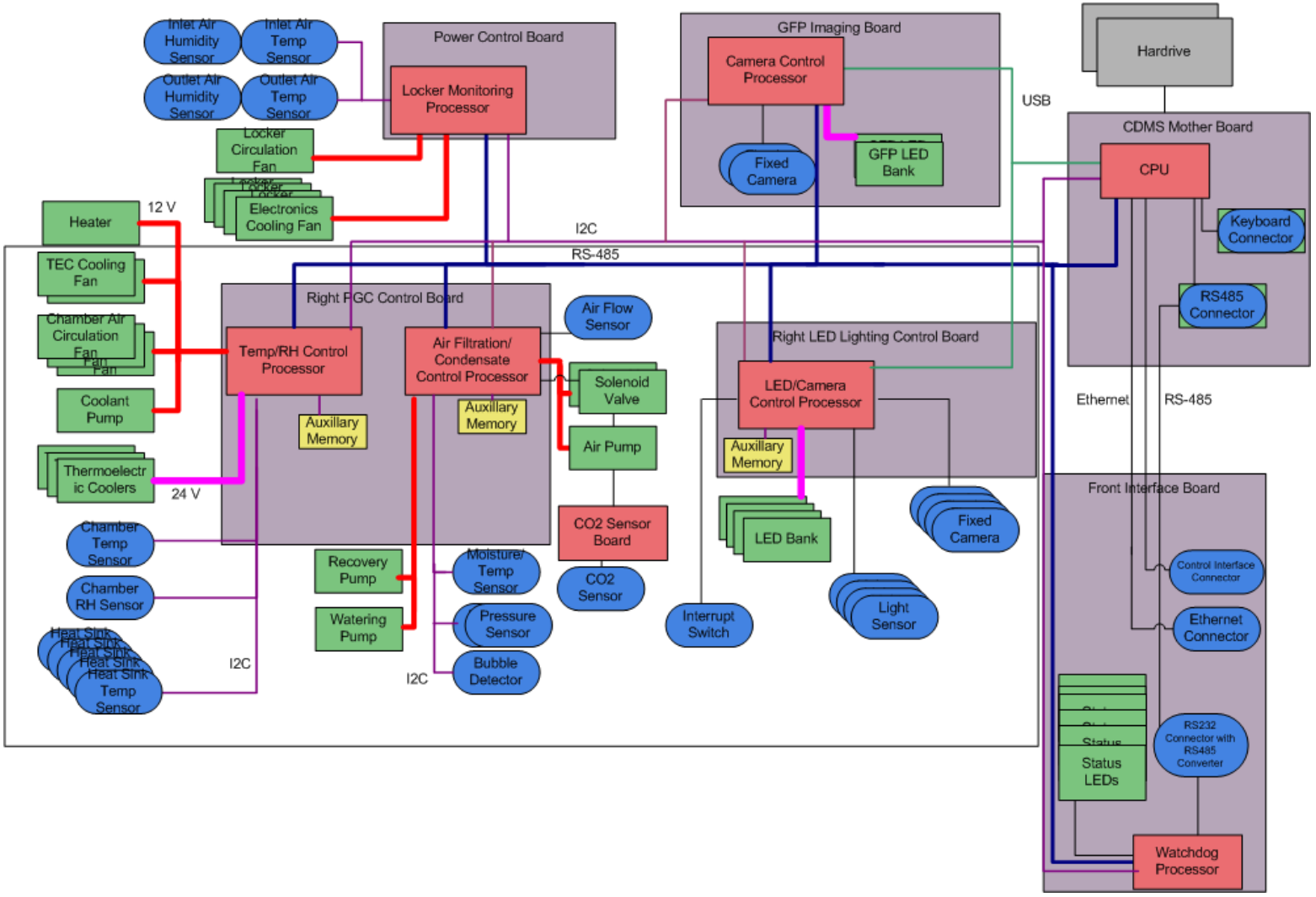


Hardware Tree



Upper Level Assemblies

Controller Functional Block Diagram



PGF-SP Subsystems

- Locker
  - Advanced Payload Modular Locker (APML)
    - Single Rear Breather
  - Cabin Cooled Double Locker (CCDL)
- Tray Insert Assembly (TIA)
  - Modular Assembly of all internal subsystems
- Plant Growth Chambers (PGC)
  - Growth volume and environmental control
- LED Light Module (LLM)
  - Light Emitting Diode (LED) growth lighting

PGF-SP Subsystems (continued)

- Air Filtration System (AFS)
  - Carbon Dioxide, ethylene and volatile organic compound (VOC) control
- Electronic Control Unit (ECU)
  - Automated control
  - Data acquisition and processing
  - Power distribution and management
- Front Interface Panel
  - Crew interface devices
- Experiment Unique Equipment
  - Green Fluorescent Protein Imager
    - Used on TAGES-2SD experiment