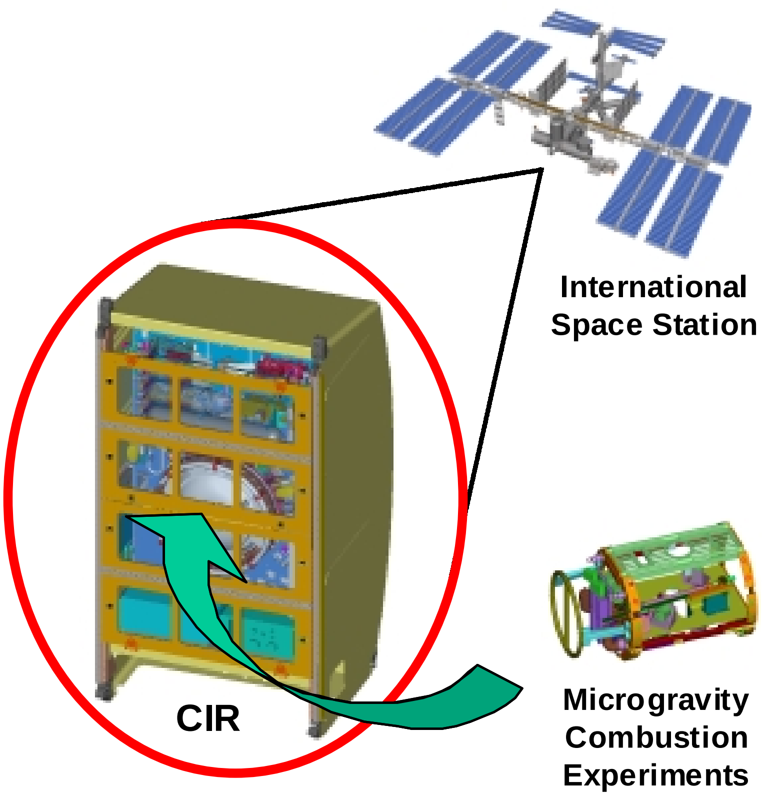
National Aeronautics and Space Administration
John H. Glenn Research Center

Revision: Basic

Principal Investigator's Guide to Microgravity Combustion Science in the ISS Fluids and Combustion Facility



Combustion Integrated Rack Payload Accommodations

May 18, 1999

PREFACE

The International Space Station will provide scientists from industry, academia and the government with unparalleled opportunities for research in space. The ISS will enclose more than 1,716 cubic yards of pressurized space and house six dedicated laboratory modules. The primary facility for microgravity combustion research on-board ISS will be the Fluids and Combustion Facility (FCF) Combustion Integrated Rack (CIR). This facility is being developed to support sustained, systematic research on-board ISS and will be capable of accommodating five to fifteen microgravity combustion experiments per year during the more than ten years that ISS will be operational after assembly complete. The accommodations provided to Principal Investigators by the FCF Combustion Integrated Rack are summarized in this document.

This document is intended to be used by Principal Investigators entering NASA's Microgravity Combustion Science Program and/or those investigators currently in the Program who are seeking combustion experiment flight opportunities using the International Space Station (ISS). In addition to broadly describing the Microgravity Combustion Science Program and future flight opportunities on-board ISS in the FCF Combustion Integrated Rack, this guide outlines the role of the Principal Investigator during the conceptual stage of the experiment development process, including a description of the Science Concept Review held early in the experiment formulation process and the content of the Science Requirements Document (SRD) in which the overall objectives and specific scientific requirements for an experiment are documented by the Principal Investigator.

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MICROGRAVITY COMBUSTION SCIENCE PROGRAM

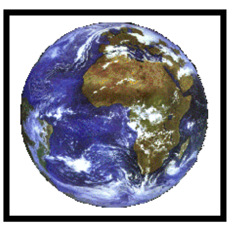
Combustion is a key element of many critical technologies used in society today such as electric power production, home heating, surface and air transportation, space propulsion and materials synthesis. Effects of gravitational forces impede combustion studies, since combustion involves production of high temperature gases whose low density results in buoyant motion. Gravity, therefore, vastly complicates the execution and interpretation of combustion experiments. Gravity also causes particles and droplets to settle, inhibiting studies of heterogeneous flames. Combustion scientists use microgravity to simplify the study of many combustion processes leading to an enhanced fundamental understanding of combustion processes.

Relevance of Combustion:

- Combustion processes provide 85% of the world's energy needs
- Combustion is a primary source for ground transportation, electrical power production, residential and commercial heating, manufacturing and industries
- Combustion enables contemporary aircraft and spacecraft propulsion

Unwanted fires and explosions can be harmful to humans and the environment

Pollution control is necessary to maintain a healthy environment
Combustion is central to industrial and manufacturing processes



Atmospheric change and global warming need to be controlled. Combustion efficiency is important to conserve our natural resources.

Spacecraft propulsion and fire safety are key concerns for the human exploration and development of space.

Areas of Emphasis in the Study of Combustion:

- Combustion Efficiency (Power/Propulsion)
- Pollution and Particulate Formation
- Fire Prevention, Suppression and Safety
- Incineration of Flammable Wastes
- Applied Combustion Science & Technology

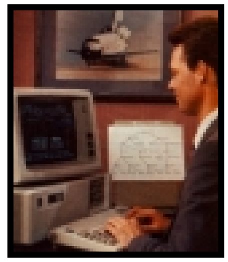
The following areas of research are emphasized in the Microgravity Combustion Science Program:

- Premixed gas flames
- Gaseous diffusion flames
- Combustion of Liquid Fuel Droplets and Sprays
- Combustion of Solid Particles and Dust Clouds
- Flame Spread Across Liquid and Solid Fuel Surfaces
- Smoldering Combustion
- Combustion Synthesis of Materials

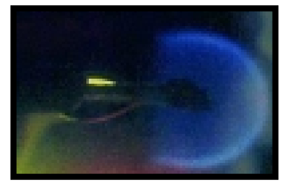
The Microgravity Combustion Science Program seeks a coordinated research effort involving both space-based and ground-based research. Ground-based research forms the foundation of the Program, providing the necessary experimental and theoretical framework for development of rigorous understanding of basic combustion phenomena. This research can eventually mature to the point where it becomes the focus of a well-defined flight experiment.

Microgravity Combustion Science:

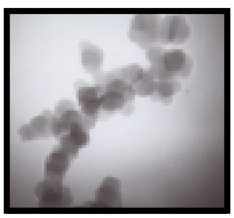
- Microgravity permits more fundamental studies of combustion processes and phenomena.
- Buoyancy-induced flows and sedimentation can be virtually eliminated in microgravity.
- Forces and phenomena that are difficult or impossible to study on Earth are revealed more readily, leading to greater basic understanding of combustion.



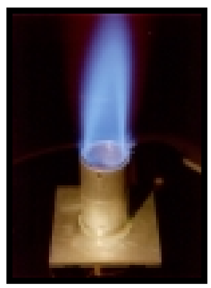
Microgravity combustion science data is used validate models and develop computational tools to predict combustion behavior.



Research in microgravity permits a new range of combustion experimentation by eliminating nearly all of the gravity-driven forces that lead to buoyancy-induced flows and sedimentation.



Soot Micrograph: Microgravity combustion research has practical significance to a variety of problems in everyday life, such as combustion-generated pollutants.



Technology Benefits: Patented ring stabilized burner could significantly lower NOX pollution and improve energy efficiency of gas appliances.

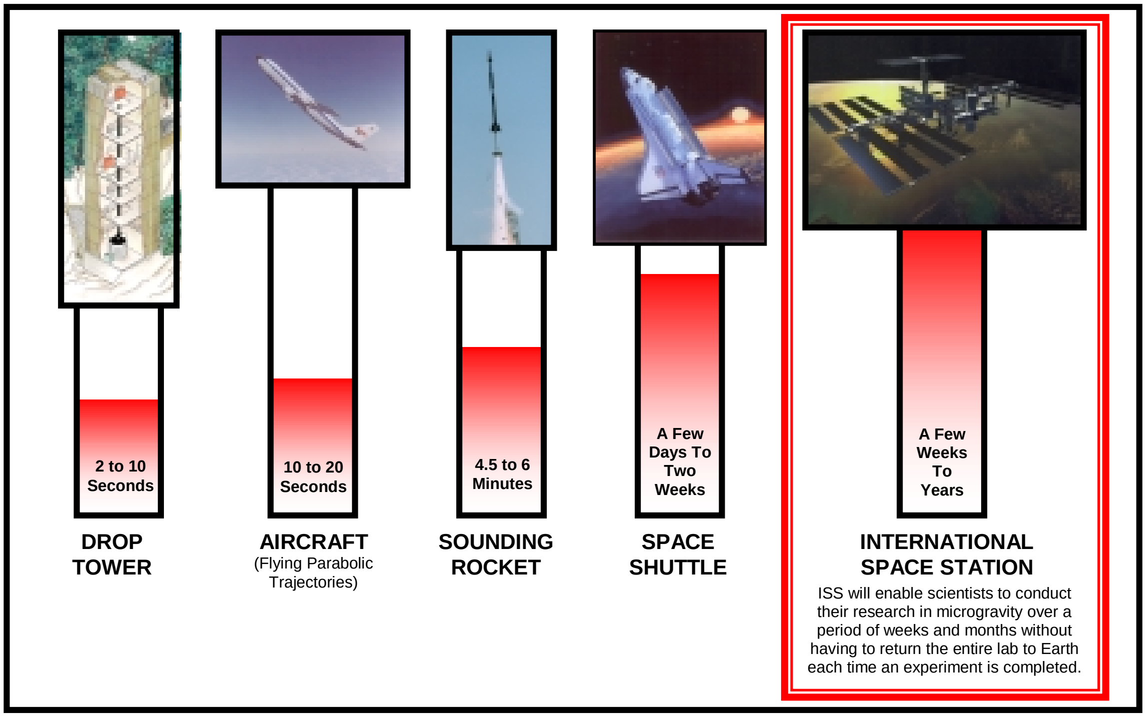
Areas of Study in Microgravity Combustion Science:

- Premixed and gaseous diffusion
- Combustion of fuel droplets and sprays
- Combustion of solid particles & dust clouds
- Flame spread on liquid and solid surfaces
- Smoldering combustion
- Combustion synthesis

The NASA research proposal solicitation process provides researchers from industry, academia and government with the opportunity to apply for funding for combustion flight experiments and for ground-based experimental and theoretical research in microgravity combustion science. NASA Research Announcements (NRA) for microgravity combustion research and flight experiment opportunities are typically issued every other year by the NASA Headquarters Office of Life and Microgravity Sciences and Applications (OLMSA). The next opportunity to submit a proposal for research in the Microgravity Combustion Science Program will be in the fall of 1999. Investigations selected for flight experiment definition must successfully complete a number of subsequent development steps, including internal NASA and external peer review of the flight experiment in order to be considered for a flight assignment. More information about the selection process and research opportunities can be found on the Internet at the following NASA OLMSA web site: http://www.hq.nasa.gov/office/olmsa/

MICROGRAVITY COMBUSTION RESEARCH PLATFORMS

Microgravity combustion science investigations are accomplished using a variety of research platforms, which support both ground-based investigations and flight experimentation. These research platforms have, in the past, included drop towers, aircraft flying parabolic trajectories, sounding rockets and the Space Shuttle. In the future, the primary platform for microgravity combustion flight experiments will be the International Space Station.



The **2.2 Second Drop Tower** allows investigators to test experimental packages (up to 125 kilograms) in a microgravity environment for a period of 2.2 seconds. Experiments assembled on a drop frame structure are enclosed in a drag shield that has a high weight-to-frontal area ratio and a low drag coefficient. A gravitational acceleration of less than 10^{-4} g is obtained during the fall since the experiment package falls freely within the drag shield. Battery packs provide onboard power to the experiment. Data is acquired by high speed motion picture cameras (frame rates up to 1,000 frames per second), video cameras, and on-board data acquisition systems used to record data supplied by thermocouples, pressure transducers and flow meters. Normal operations provide the opportunity for 8 to 12 drops per day to be performed. More information on the 2.2 second drop tower can be found on the Internet at the following site: http://zeta.lerc.nasa.gov/facility/dtower.htm.

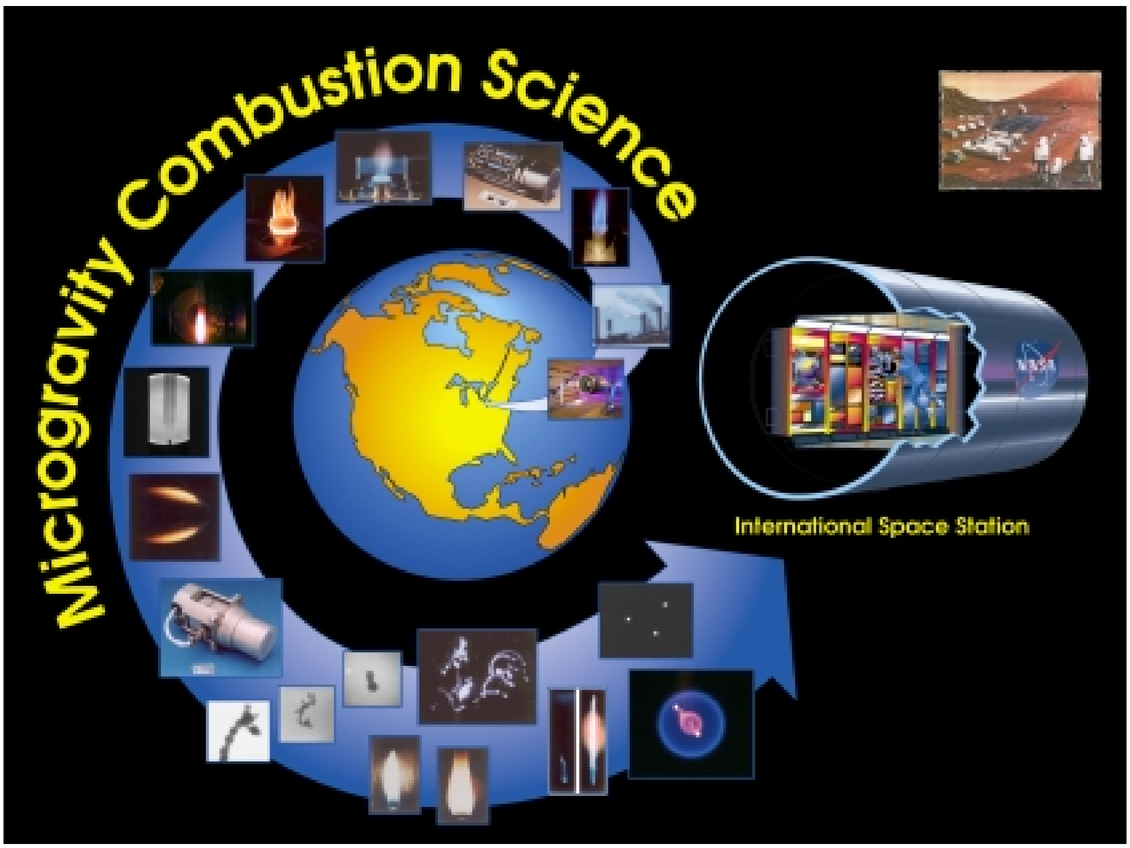
The **5.18 Second Zero-Gravity Facility** has a 132-meter free fall distance in a drop chamber which is evacuated by a series of pumpdown procedures to a final pressure of 1 Pa. Experiments utilizing hardware up to 450 kilograms are mounted in a one-meter diameter by 3.4 meter high drop bus. Gravitational acceleration less than 10^{-5} g is obtained. Visual data is acquired through the use of high speed motion picture cameras. Also, other data such as pressures, temperatures, and accelerations are either recorded on board with various data acquisition systems or are transmitted to a control room by a telemetry system capable of transmitting 18 channels of continuous data. Due to the complexity of drop chamber operations and time required for pump-down of the drop chamber, typically only one test is performed per day. More information on the 5.18 second drop tower can be found on the Internet at the following site: http://zeta.lerc.nasa.gov/facility/zero.htm.

Reduced-Gravity Aircraft are flown in parabolic arcs to achieve 20-25 seconds of microgravity. The aircraft obtains a low-gravity environment by flying a parabolic trajectory. As many as 40 parabolic trajectories may be performed on a typical flight. Gravity levels twice those of normal gravity occur during the initial and final portions of the trajectory, while the brief pushover at the top of the parabola produces less than one percent of Earth gravity (10^{-2} g). Several experiments, including a combination of attached and free-floated hardware (which can provide effective gravity levels of 10^{-3} g for periods up to 10 seconds) can be integrated in a single flight. Both 28 volt DC and 100 volt AC power are available to accommodate a variety of experiments. Instrumentation and data collection capabilities must be contained in the experiment packages. More information on reduced gravity aircraft can be found at the following Internet site: http://zeta.lerc.nasa.gov/kjenks/kc-135.htm.

Sounding Rockets produce higher quality microgravity conditions for longer periods of time than airplanes. Microgravity conditions vary with the rocket type and payload mass. Sounding rockets are basically divided into two parts, solid-fuel rocket motor and payload. The payload is the section that carries the instruments to conduct the experiment and sends the data back to Earth. NASA currently uses 15 different sounding rockets. These rockets can carry payloads of various weights to altitudes from 30 miles (48 km) to more than 800 miles (1,287 km). Scientific data are collected and returned to Earth by telemetry links, which transfer the data from the sounding rocket payload to the researchers on the ground. In most cases, the payload parachutes back to Earth, where it is recovered and reused. Normal operations provide the opportunity for an average of 30 NASA sounding rockets launches each year. Sounding rocket information can be obtained at the following Internet site:
http://www.wff.nasa.gov/pages/soundingrockets.html

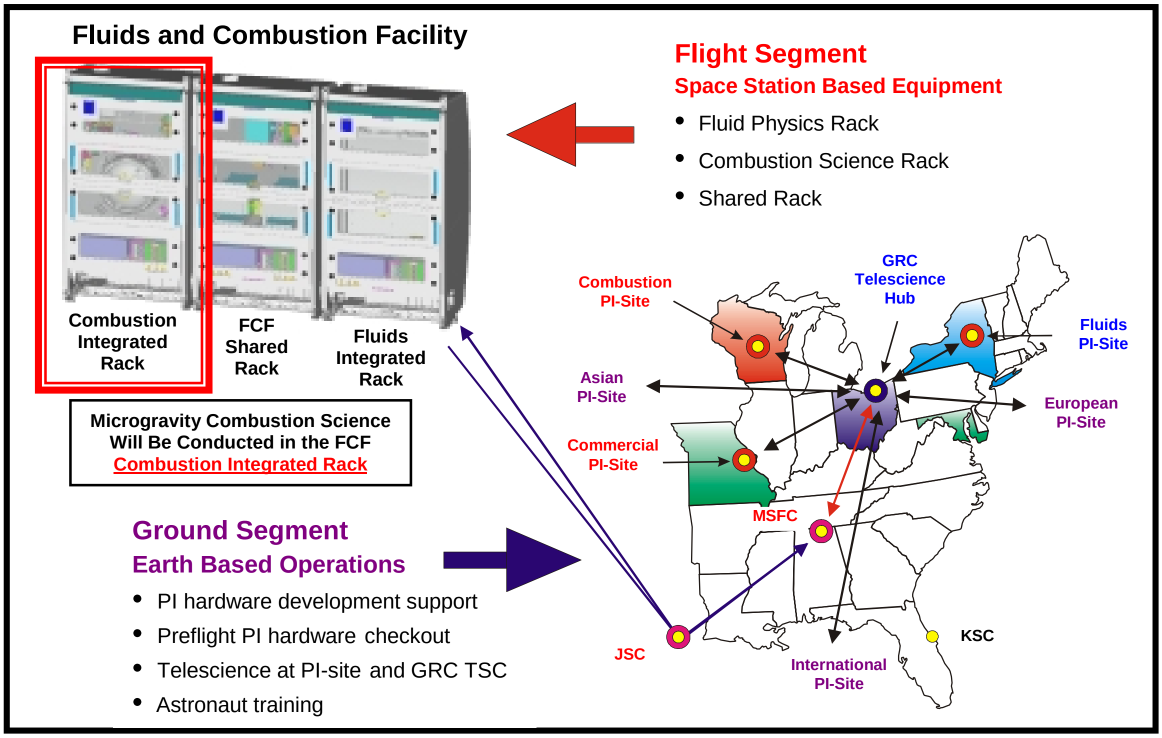
Space Shuttle is a reusable launch vehicle that can maintain a consistent orbit and provide up to 17 days of high quality microgravity conditions. The Shuttle, which can accommodate a wide range of experiment apparatus, provides a laboratory environment in which scientists can conduct longer-term microgravity investigations. A number of primary microgravity combustion flight experiments performed in the past decade used the Space Shuttle as a platform (i.e., in middeck lockers (lockers located in the middeck area of the Orbiter cabin), get-away specials (i.e., small self-contained payloads in cylindrical containers located externally), or in spacelab/spacehab laboratories located in the cargo bay of the Space Shuttle. As NASA proceeds from the Shuttle era to the Space Station era, less microgravity combustion experiments will be conducted on-board the Shuttle and microgravity research activities will transition to ISS. Information on the Space Shuttle can be found at: http://www.shuttle.nasa.gov

The **International Space Station** is a semi-permanent facility that will maintain a low Earth orbit for up to several decades. The International Space Station will afford scientists and engineers a unique on-orbit research facility, in which complex, long-duration experiments can be performed. The ISS will enable scientists to conduct their research in microgravity over a period of several months without having to return the entire laboratory to Earth each time an experiment is completed. The primary carrier of microgravity combustion experiments in ISS will be the Fluids and Combustion Facility (FCF) Combustion Integrated Rack (CIR). General information about the International Space Station can be found at the following Internet site: http://station.nasa.gov.



ISS FLUIDS AND COMBUSTION FACILITY

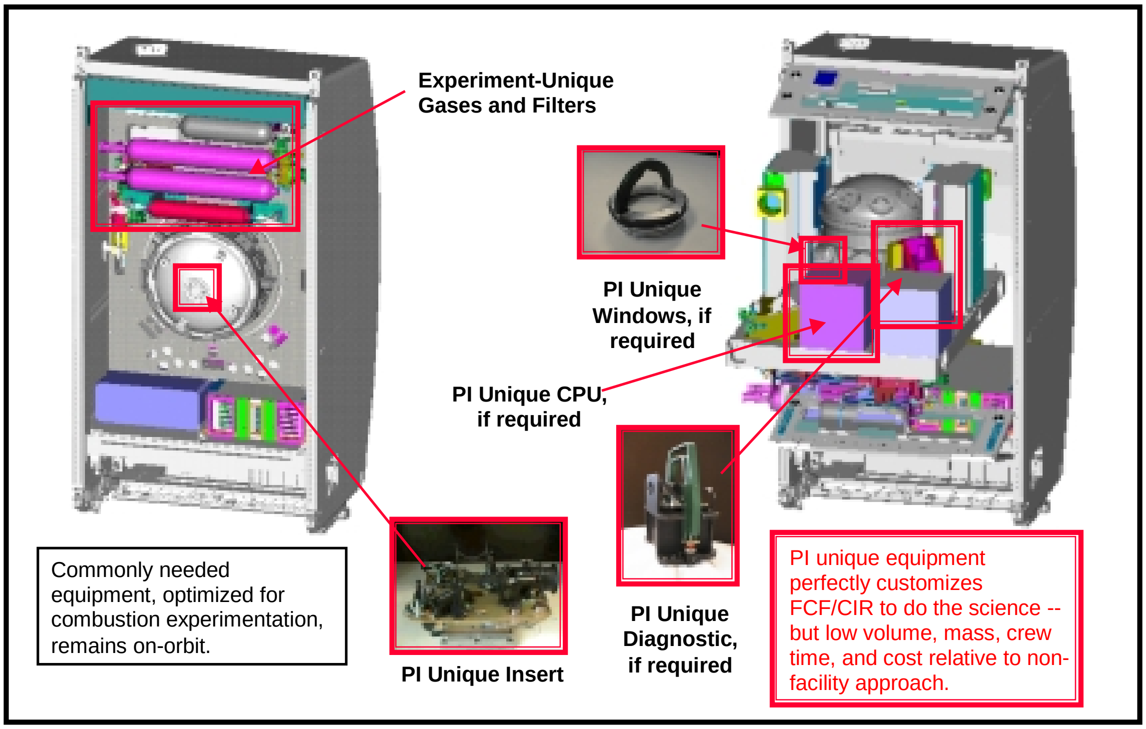
The ISS Fluids and Combustion Facility (FCF) is a modular, multi-user facility that will support Microgravity Fluid Physics and Microgravity Combustion research on board the International Space Station. The FCF will be a permanent on-orbit research facility that will enable NASA's Human Exploration and Development of Space (HEDS) Microgravity Program objectives to be met. The FCF is being designed to support sustained, systematic research in the ISS over the ten to fifteen year lifetime of ISS, after its assembly has been completed on-orbit. The facility is being designed to accommodate 5 to 15 Fluid Physics experiments per year and 5 to 15 Combustion Science experiments per year, depending upon ISS resources and Microgravity Research Program resources that are made available to support investigations in these research disciplines.



The FCF Flight Segment will consist of three on-orbit racks that will be located inside the US Laboratory Module of the ISS. These racks are the Combustion Integrated Rack (CIR), the Fluids Integrated Rack (FIR) and the Shared Accommodations Rack (SAR). The Combustion Integrated Rack will be optimized to support a diverse range of microgravity combustion science investigations on-board ISS. It will be the first FCF rack deployed to ISS and is currently planned for launch to ISS on UF-3 in 2003. The CIR will initially operate independently from other FCF racks, supporting the first set of microgravity combustion science investigations on board ISS. After other FCF racks are deployed to ISS, the CIR will operate in conjunction with those racks to leverage their capabilities, thereby maximizing combustion experiment through-put and science return from ISS.

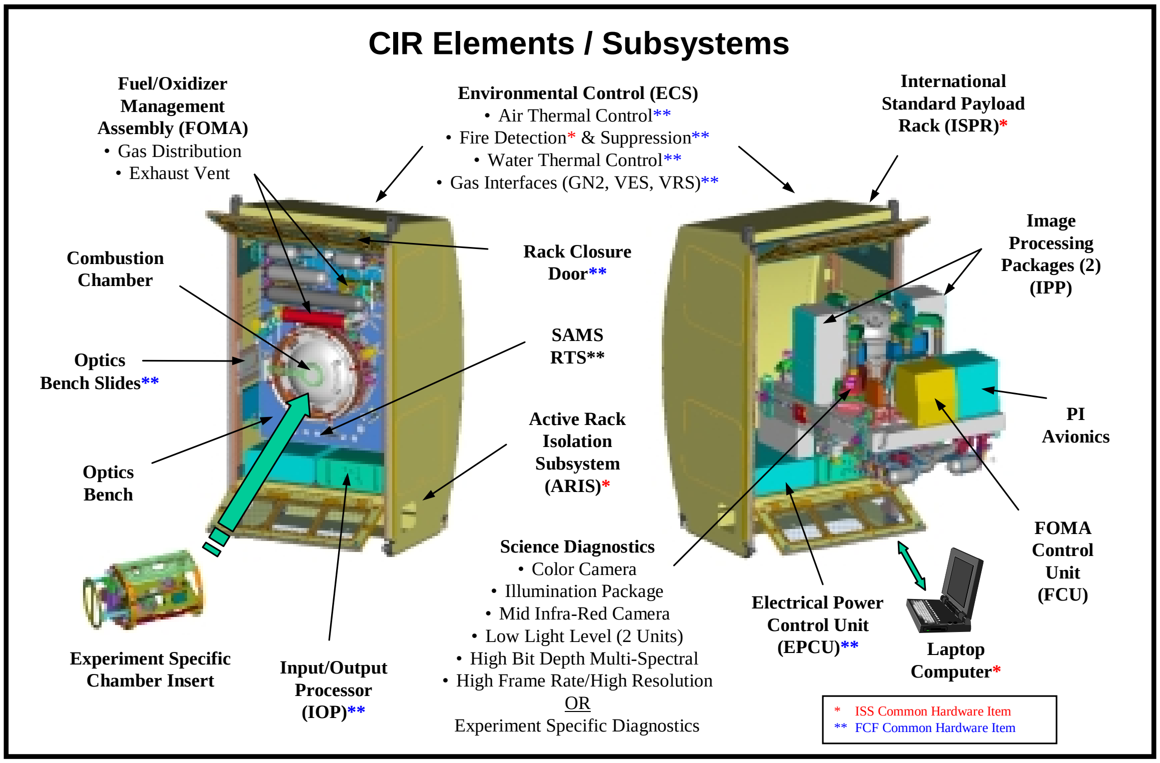
FCF COMBUSTION INTEGRATED RACK

The FCF Combustion Integrated Rack (CIR) will provide a platform for sustained, systematic microgravity combustion research on-board ISS. Principal Investigators will be able to use this microgravity environment to isolate and control gravity-related phenomena, and to investigate processes that are normally masked by gravitational effects and thus are difficult to study on Earth. A diverse range of combustion research can be accommodated in the CIR, including (but not limited to) studies of laminar flames, reaction kinetics, droplet and spray combustion, flame spread, fire suppressants, condensed phase organic fuel consumption, turbulent combustion, soot and polycyclic aromatic hydrocarbons and material synthesis.



The CIR will provide the majority of required hardware and infrastructure to perform combustion science investigations in ISS. In this way the cost and development requirements for individual experimenter's hardware is minimized. However, key components of the CIR will be on-orbit replaceable to enable it to be customized for each new combustion experiment that will be performed in it. The CIR's modular, flexible design will also permit upgrades, incorporation of new technology and provide for on-orbit maintenance during the >10 year life span of the facility.

A Principal Investigator that plans to use the CIR as a research platform for combustion experimentation will typically develop science-specific equipment that will be installed in the CIR to perform the experiment. The following types of hardware and software items may be needed to tailor the CIR to accomplish the specific research objectives of a microgravity combustion experiment: Intrusive diagnostics (i.e. thermocouples); igniters; sample cells; combustion chamber insert; experiment gases (contained in FCF-provided bottles); exhaust vent filter(s); science-specific diagnostics; Specialized electronics; control software (scripts).



The CIR will provide an optics bench for combustion experimentation in ISS. The layout of the bench can be optimized for each new combustion experiment. A 100-liter combustion chamber is located in the center of the optics bench. It incorporates eight windows, which can be replaced on-orbit. Windows will be selected for the wavelength of lights most important to the PI and/or changed out if contaminated. The CIR's Fuel Oxidizer Management Assembly (FOMA) will deliver gaseous fuels, diluants and oxidizers to the combustion chamber. The FOMA can support static and dynamic mixing of gases with very high precision and accuracy. This assembly also provides for access to vacuum and cleaning of combustion by products to make them safe to vent overboard after the experiment is conducted. The composition of gases in the combustion chamber will be measured using the CIR gas chromatograph. Illumination sources and cameras covering a wide spectral range for various scientific measurements can be mounted outside each combustion chamber window. These cameras and light sources can be removed and replaced quickly, with all electrical and data connections made automatically upon crew installation. The final alignment of the cameras and their operation will be by remote control from Earth.

CIR PAYLOAD ACCOMMODATIONS

The following payload accommodations are available to an experiment performed in the CIR. More detailed information about the CIR can be found at the following web site: http://einstein.lerc.nasa.gov/fcfsite/cirpdr/index.html.

Optics Bench:
- **Front/Rear Access:** Bench folds down
- **UML's:** 9 universal mounting locations for diagnostics and avionics.
- **Bench Dimensions:** 90.2 width x 124.5 length x 10 cm depth

Gas Delivery System:
- **Gas Bottle Sizes and Pressure**: 3.8, 2.25 and/or 1.0 liter gas bottles. Up to 14 MPa (2000 psig) bottle pressure
- **Diluents**: Nitrogen ISS-supplied. Others PI-provided in 1.0, 2.25 or 3.8 L bottles.
- **Oxidizers**: Up to 85 O2% in 1.0 L bottle; 50% O2 in 2.25 L; 30% O2 in 3.8 L bottle.
- **Fuels**: 1.0 L or 2.25 L bottles
- **Flow Rates:** Oxidizer/Diluent - 30 SLM each manifold (90 SLM max). Fuel- 2 SLM
- **Pre-Mixed Gases:** Can be used (bottles).
- **On-Orbit Gas Blending**: Can blend up to 3 gases on-orbit (Factor 4 weight savings)
- **Static Gas Blending**
  - Partial pressure method using chamber
  - < ±0.2 % absolute gas blend accuracy
- **Dynamic Gas Blending:**
  - Mass flow controllers used
  - Accuracy for Oxygen Blends
    - < 25% O_2: ± 1.0% absolute
    - > 25% O_2: ± 2% of reading
  - Flow Rate Accuracy: ± 1.0 % of MFC F.S.

Exhaust Vent System:
- Adsorber cartridge/re-circulation loop cleans post-combustion gases to ISS limit
- **Adsorber Cartridge Sizes:**
  - Large: 76 mm ID x 355mm L
  - Medium: 51 mm ID x 279 mm L
  - Small: 25 mm ID x 203 mm L
- **Adsorber Cartridge Contents**
  - Silica Gel: H20, alcohol, aromatics, olefin
  - Molecular Sieve: Removes water
  - Activated Carbon: Hydrocarbons
  - Lithium Hydroxide: CO2, Acid gases
- **Recirculation Flow Rate:** 20 SLM max.
- **Flow Through w/ Real Time Vent:** TBD

Gas Chromatograph:
- Samples chamber gases prior to venting
- **Lower Detection Limit:** 100 ppm (depending upon compound)
- **Detection Accuracy:** ± 2.0 %

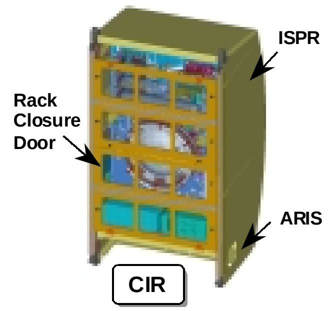
Thermal Control:
- **Air cooled diagnostics at UML's** - 450 or 225 watts, depending on UML.
- **Water Cooled PI insert in chamber**: Up to 3 kW heat rejection to water. 17.2 C inlet temperature. Min. flow rate 25 lb/hr.

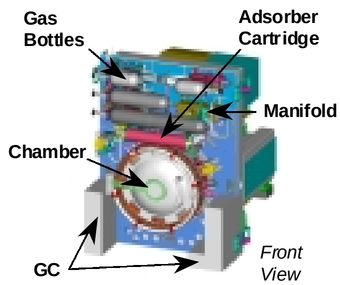
ISS-Supplied Gases/Vacuum:
- **Gaseous Nitrogen**: 4.4 kg/s max. flow
- **VES**: Used for bulk gas removal. Throughput of 0.13 Pa*liter*sec @ 0.1 Pa
- **VRS**: Used to maintain long duration vacuum (<0.1 Torr) with minimal flow rates

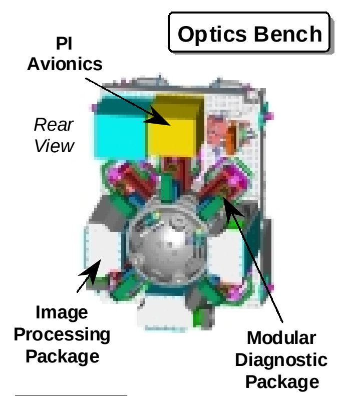
Electrical Power:
- 28 Vdc, 8 amp circuit(s) at each UML
- Three 120 Vdc x 4 amp circuits for PI TBD

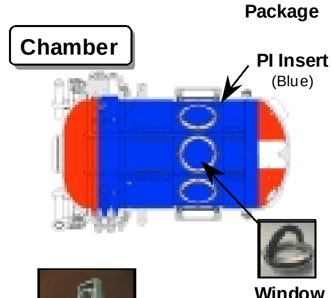
Operations:
- Telescience from GRC TSC and PI Site

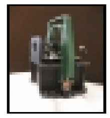
CIR Payload Accommodations











Diagnostics

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CIR Web Site: http://einstein.lerc.nasa.gov/fcfsite/cirpdr/index.html

Combustion Chamber:
- **Internal Volume**: 101 free liters
- **Internal Dimensions**: 40 cm dia/90 cm long
- **Pressure Rating**: Vacuum to 135 psia (8.2 atm) maximum design pressure.
- **PI Access**: Breech lock front lid for quick crew access to PI insert in chamber
- **Mechanical interface**: PI insert interfaces to chamber via rails at 22.5°+/- horizontal
- **PI Viewing Ports**: Eight window locations, enabling 3 simultaneous orthogonal views.
- **PI Access ports:** Ports at rear of chamber

Window Specifications:
- **Field of View**: 115 mm diameter
- **Window Materials**: Fused silica: 0.2-1.0 µm, Sapphire 0.17-5.5 µm (TBD), ZnSe: 2.5-10 µm (TBD). Other materials PI-qualified to fly
- **Window Position**: 20.0 cm centerline from optics bench. 4 Pairs, 180 degrees Apart

Chamber PI Interfaces/Resources:
- **Electrical**: Four electrical feed-throughs deliver up to 440 Watts (28 V, 4 amp circuits)
- **Cooling Water**: Secondary cooling water loop provides 25 to 300 lb/hr water flow, with 6.35 psid available delta P. 17.2 C inlet temp
- **Pressure transducers**: Two at rear end cap with ranges up to 50 and 100 psia +/- 0.04% accuracy. Two at IRR with range up to 50 psia +/- 0.05% accuracy.
- **Thermistors**: Two at IRR with range of -75 C to 300 C and accuracy of +/-0.05% C over range of 15 C to 35 C.
- **High Pressure oxidizer/diluent supply**: Gaseous oxidizer/diluents up to 2000 psig.
- **Static Mixer Port**: Provides oxidizer/ diluents to the chamber blended dynamically & allows partial pressure mixing in chamber
- **Fuel Port**: Delivers gaseous fuel to chamber. Liquid fuels supplied w/ PI insert.
- **Automatic Vent:** Allows chamber gas recirculation with return at rear of chamber.
- **Manual Vent:** Enables evacuation of chamber when CIR is unpowered.
- **GC Sampling of Chamber Gases**: Global sampling of chamber contents.

Diagnostics:
- **Baseline CIR Digital Cameras**:
  - HiBMs, Laser Illumination, HR/HFR w/ APT, Low Light Level UV (2), Mid IR
  - 6 Locations, replaceable on-orbit with PI-provided cameras
- **Image Processing Packages**:
  - 36.4 Gbytes of image data storage direct to disk at 30 MB/s.
  - Sustained image recording > 20 minutes

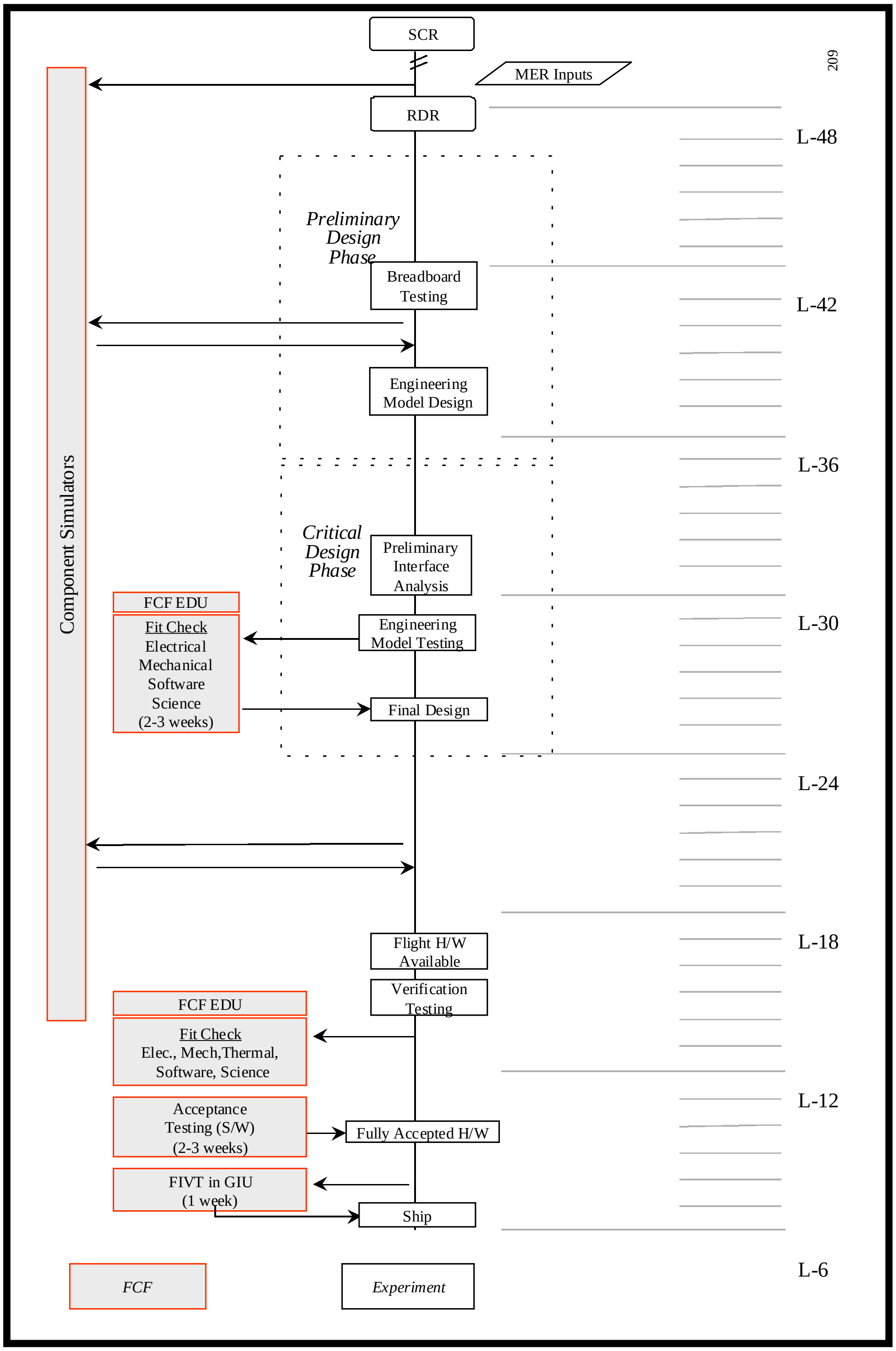
PI Hardware Specifications:
- **Chamber Insert**: Maximum dimensions of 600 mm long x 396 mm dia.
- **Test Section:** maximum dimensions: 450 mm (axis); 300 mm (width); 180 mm (height)
- **PI Avionics**: 30.9 x 27.0 x 26.4 cm. 440 Watts; Air cooled.

Vibration Isolation:
- Active Rack Isolation Subsystem (ARIS)
- 10-5 to 10-6 g acceleration environment over frequency range from 0.01 to 10 Hz

5/99

PI EXPERIMENT DEFINITION

The following flow chart illustrates the process for selected experiments to be accommodated in the FCF Combustion Integrated Rack aboard ISS. This process contains several reviews and milestones starting with the Science Concept Review (SCR) and the Requirements Definition Review (RDR).



After selection for the flight program, an experiment will enter the experiment definition phase. The purpose of this phase is to establish the science concept. The primary review in this phase is the Science Concept Review (SCR). The purpose of the SCR is to establish that the scope and feasibility of the experiment have been adequately addressed and to propose a definitive flight experiment. A well defined and clearly written Science Requirements Document (SRD) is crucial for a successful SCR. The SRD, written for both peer scientists and engineers, describes the scientific justification, the need to conduct the experiment in microgravity, and the necessary requirements for the experiment. The SRD does not, however, contain detailed concepts or engineering drawings of the proposed experiment. General content of an SCR and a table of contents for an SRD included in the next sections of this document for reference.

Assuming that it is determined that the investigation should be carried out in hardware built specifically for that experiment, the activity then enters the hardware definition phase. The focus of this phase is to define the baseline hardware concept necessary to conduct the experiment and to establish the project baseline - including the project planning documentation. The primary review in this phase is the RDR. The purpose of the RDR is to baseline the science requirements, assess the conceptual design and engineering feasibility, and assess the project planning. The SRD is finalized after the RDR. Upon successful completion of this phase, the authority to proceed is given for flight development. At this point a significant emphasis is placed on the engineering activities associated with design, fabrication, assembly and testing of the flight instrument.

Management of the hardware development phase (Preliminary Design Phase and Critical Design Phase) is the responsibility of the Program Manager. During this phase, the hardware is designed, fabricated, assembled and tested. Included in the testing are the science verification tests to insure that the hardware can perform the functions required to meet the science requirements of the various experiments. Standard flight hardware development design reviews, such as the Preliminary Design Review (PDR), the Critical Design Review (CDR), and the Preship Review (PSR), occur during this phase. Procedures for flight experiment, mission timeline, and crew training are developed. Development concludes with the delivery of the flight hardware for mission integration.

SCIENCE CONCEPT REVIEW OUTLINE

i. Welcome (NASA GRC Division Chief or Program Manager)

ii. Instructions to Science Panel (NASA Enterprise Discipline Scientist)

0. Executive Summary (PI)
1. Goals/Objectives
2. Proposed Space Experiment (concept diagram)
3. Benefits (potential application)

1. Introduction and Background (PI)
1. Description of Science
2. Brief Historical Overview of Science
3. Currently Active Research
4. Current Status of Understanding
5. Gaps in Understanding this Experiment Plans to Fill

2. PI Research Related to Proposed Space Experiment (PI)
1. Experiments - 1g Laboratories, Drop Towers, and Aircraft
2. Models - Numerical and Analytical

3. Proposed Space Experiment (PI)
1. Objective and Hypothesis of Proposed Investigation
2. Benefit to Science and Technology
3. Flight Experiment Description
4. Science Requirements
5. Test Matrix
6. Success Criteria (minimum and complete)
7. Anticipated Results

4. Justification for Extended Duration Microgravity Environment (PI)
1. Limitations of Terrestrial (1-g laboratory) Testing
2. Limitations of Drop Towers and Aircraft
3. Need for Accommodations in the ISS, Space Shuttle or Sounding Rocket
4. Limitations of Modeling Approaches

5. Use of Data Obtained from Proposed Space Experiment (PI)
1. Data Reduction and Analysis
2. Model or Hypothesis Verification

6. Proposed Space Experiment Concept (PS or PI)
1. Description of Experiment Concept (cartoon and block diagrams)
2. Measurements and Diagnostics Required
3. Experiment Procedure

7. Science Plan to RDR (PI)
1. Identify Critical Tasks and Plans for Resolution
2. Other Science Activities

8. Summary (PI)

9. Engineering Plan to RDR (PM)
1. Identify Critical Engineering Feasibility Issues
2. Develop Plan for Resolution of Engineering Feasibility Issues
3. Develop Schedule and Costs

10. Rough Order of Magnitude Schedule and Costs to Flight (PM)

11. Science Panel Caucus (PS to attend as an observer and answer questions)

12. Science Panel Feedback to PI

13. Concluding Remarks (NASA Enterprise Discipline Scientist)

SCIENCE REQUIREMENTS DOCUMENT OUTLINE

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- 5.12 Postflight Data Deliverables
- 5.13 Success Criteria
  - 5.13.1 complete Success
  - 5.13.2 Minimal Success

6.0 **REFERENCES**
7.0 **APPENDIX – EXPERIMENT DATA MANAGEMENT PLAN**

PAYLOAD PROCESSING AND INTEGRATION SUPPORT

An extensive amount of ground support equipment will be made available to support processing, integration and check-out the Principal Investigator's experiment hardware and software prior to flight. In addition to the on-orbit CIR flight rack, there will be three additional supporting racks on earth. They are a Ground Integration Unit (GIU), an Experiment Development Unit (EDU), and a Payload Training Center (PTC) Trainer.

Engineering Development Unit (EDU)
The CIR EDU will be a high fidelity model, very similar to the CIR flight model. It will be located at GRC and made available to experiment developers during their hardware and software development and pre-flight testing. This unit will be used for interface verification and configuration selection testing.

Payload Training Center (PTC) Trainer.
The Payload Training Center (PTC) Trainer, which will be deployed in the PTC at Johnson Space Center (JSC), supports crew training. It will contain flight-like crew interfaces, and be comprised of mock-ups, brassboard level components and other non-flight components. The PTC Trainer will include a standard experiment equipment trainer, that can be used to train on the installation of a generic experiment chamber insert or modular experiment computer. This fully integrated PTC Trainer will be supplemented with experiment specific part task trainers, as necessary, that may be required to train the crew on the operation and maintenance of the experiment hardware.

Ground Integration Unit (GIU)
The CIR GIU will be located at GRC and will be used for final interface verification testing of experiment hardware, as well as for on-orbit troubleshooting. The GIU will be virtually identical to the CIR flight unit.

<u>Experiment Integration and Operation</u>
Because the FCF and CIR hardware are designed to reduce the overall cost of individual experiments by providing substantial common capabilities, the experiment equipment alone cannot perform the scientific objectives of the experiment. Therefore, a multi-tiered integration support scheme, consisting of CIR simulator, experiment engineering, and experiment flight hardware integration testing, is envisioned.

FCF Simulator Testing
Simulators of FCF/CIR flight hardware will be available to experiment developers during the development of their hardware. Simulator equipment will be designed to emulate those interfaces between the facility and the experiment that must be tested early and often throughout the experiment development, so as to assist in the design of the experiment hardware and software. Simulators for the CIR will be produced to simulate, at a minimum, electrical and C&DH interfaces, and be

used extensively for interface verification testing between the facility and the experiment.

Simulators of available FCF/CIR configurable equipment, such as cameras, light sources, filter cartridges, etc will also be provided for PI use. Early in the experiment development cycle, the FCF/CIR configurable equipment will require evaluation for suitability for use on a particular experiment. In addition to this engineering evaluation, diagnostic simulators may be required to support science testing prior to the experiment Requirements Definition Review.

Once a particular piece of FCF/CIR configurable equipment has been selected for use by an investigator, the experiment developer must conduct testing to optimize the configuration of the equipment. This testing will be used to select the settings, parameters, test sequence, and overall configuration of the FCF/CIR configurable equipment.

Experiment Engineering Hardware Testing
The next level of integration support conceptualized is testing between experiment engineering hardware and the CIR EDU. This testing will satisfy the following objectives:

- Interface verification (mechanical, electrical, thermal, software and fluid)
- Preliminary science acquisition
- Preliminary FCF configuration and parameter selection
- Test sequence identification
- Crew procedure validation

This testing will nominally occur 24 months prior to launch, and is expected to last 2-3 weeks for each experiment.

Experiment Flight Hardware Testing
Eventually, the experiment flight equipment will be integrated into the EDU to satisfy the following objectives:

- Interface verification (mechanical, electrical, thermal, software and fluid)
- Ground science acquisition
- Final CIR configuration and parameter selection
- Final test sequence identification
- PI familiarization training
- Experiment acceptance testing

A flight-like user interface will be provided at this stage of the integration testing. This testing will nominally occur 15 to 9 months prior to launch, and is expected to last 2-3 weeks for each experiment.

GIU Testing

The last level of integration support, which provides the highest fidelity integration testing platform, is referred to as the Final Interface Verification Testing (FIVT). Completely tested and accepted experiment equipment will be integrated into the GIU. This test will consist of high-fidelity interface verification, and will include an abbreviated mission simulation in order to fully exercise the software interface. This test will last approximately 1-3 days and occur approximately 1 to 2 months prior to shipping the hardware to KSC. The hardware and software configuration will be frozen at the successful conclusion of this test. If any changes in hardware or software are required after the FIVT, the FIVT will normally be repeated.

Operations
As mentioned above, command and control of microgravity combustion experiments conducted on-board ISS in the FCF/CIR will be orchestrated from the TSC located at the Glenn Research Center. The TSC is responsible for distributing the necessary voice, video and/or data to the remote PI site.

Post-Landing Payload Activities
Some PI's may require additional ground data to supplement the actual microgravity data obtained aboard the ISS. If necessary, the EDU will support additional science acquisition, on a non-interference basis. This testing, when necessary, is expected to last approximately 1-2 weeks.

TERMINOLOGY AND ACRONYMS

CIR Combustion Integrated Rack

FCF Fluids and Combustion Facility

FIR Fluids Integrated Rack

GRC Glenn Research Center

ISS International Space Station

L-24 Launch minus twenty four months

NRA NASA Research Announcement

OLMSA Office of Life and Microgravity Sciences and Applications

PI Principal Investigator

PM Project Manager

PS Project Scientist

RDR Requirements Definition Review

SAR Shared Accommodations Rack

SCR Science Concept Review

SRD Science Requirements Document

Science Panel Consist of qualified scientists in the field, including members from previous review panels with prior knowledge of the experiments as appropriate. The Program Scientist will act as an ex-officio member of the Science Review Panel. This panel will review the science requirements to determine their scope and maturity, and verify the need for the microgravity environment. They will also review the results of the science feasibility demonstrations and the explicit experiment, which is being proposed. They will review the emerging conceptual hardware design to identify engineering feasibility issues to be addressed during the hardware Definition Phase.

UF-3 ISS Utilization Flight #3

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