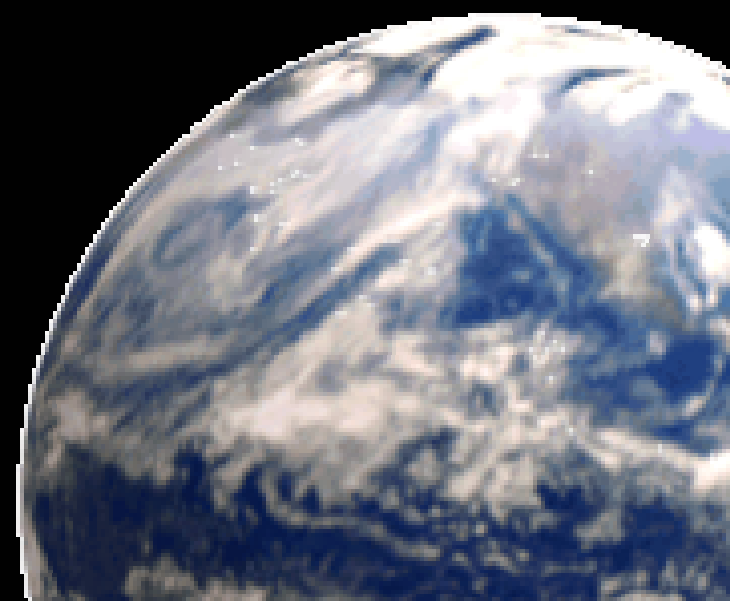
Organizing Questions for Reduced-Gravity Flammability

Fletcher Miller &
NASA and NCMR Project Scientists
for Combustion Flight Projects
Involving the Flammability of Solids



Strategic Research to Enable NASA's Exploration Missions
Cleveland, OH June22-23, 2004

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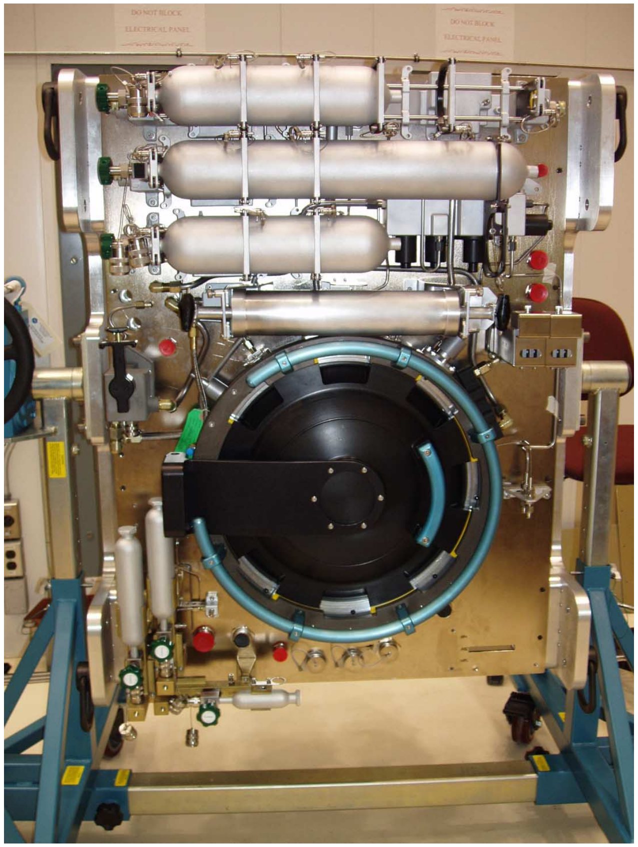
Background

- Currently there are six* combustion flight projects involving flammability of solids at various stages of development
  - Combustion Integrated Rack
  - FEANICS insert
- The objectives of many of these experiments is to perform **fundamental** research in combustion aboard the International Space Station
- Relevance to spacecraft fire safety was not the only factor in selecting flight projects.
  - Recommendations by outside peer review panels focused on science.

* Plus one international project



Combustion Integrated Rack (CIR)

Background

- A team consisting of of the Microgravity Flight Project Scientists for solid flammability experiments has been reviewing and prioritizing a set of organizing questions for fire prevention (material flammability).

The ability to answer these questions will be the major determinant in the selection of future flight experiments

In particular the team has been charged with determining:

1. What experiments must be conducted to best answer these questions?

2. Can some of the questions be answered using existing/planned hardware or experimental concepts?

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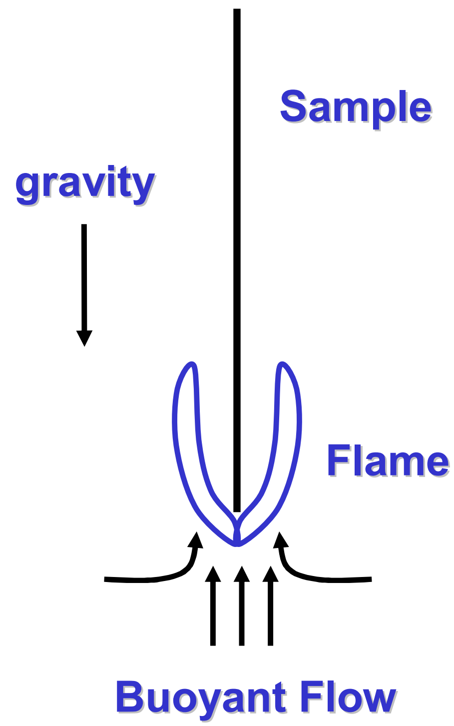
Microgravity Material Flammability Acceptance Criteria

1. Is the NASA STD 6001, Test 1 configuration conservative or non-conservative in assessing material flammability in reduced gravity*?

- NASA STD 6001, Test 1 is an upward flammability test, considered the most stringent test in normal gravity.
- A material that passes this test would most likely not burn in a *quiescent* microgravity environment
  - More research is needed on practical but "exotic" materials to verify this.
- The degree of conservatism varies with material and cannot be determined from the test data



* **Reduced gravity is taken here to mean either micro or partial gravity, though for today's session we will focus primarily on microgravity.**

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Quiescent Microgravity?

- In an emergency, totally quiescent conditions in microgravity cannot be assured.
- Possible sources of air movement:
  - Ventilation system if it cannot be turned off or decay time if it can.
  - Crew movements
  - Use of fire extinguishers
  - Small leaks from the module, or venting
  - Residual g (0.1 mg ~ 1 cm/s)
- The most flammable condition for some materials is at very low velocities, below those for upward spread in normal gravity
- Experiments and models show that in very low speed flows the flame prefers to spread upstream (opposed flow) compared to downstream.
- The question of conservatism of Test 1 therefore may rest on the determination of velocity and flow direction at which to compare.
- **In partial gravity, such as lunar or Martian conditions, there will always be buoyant flow.**

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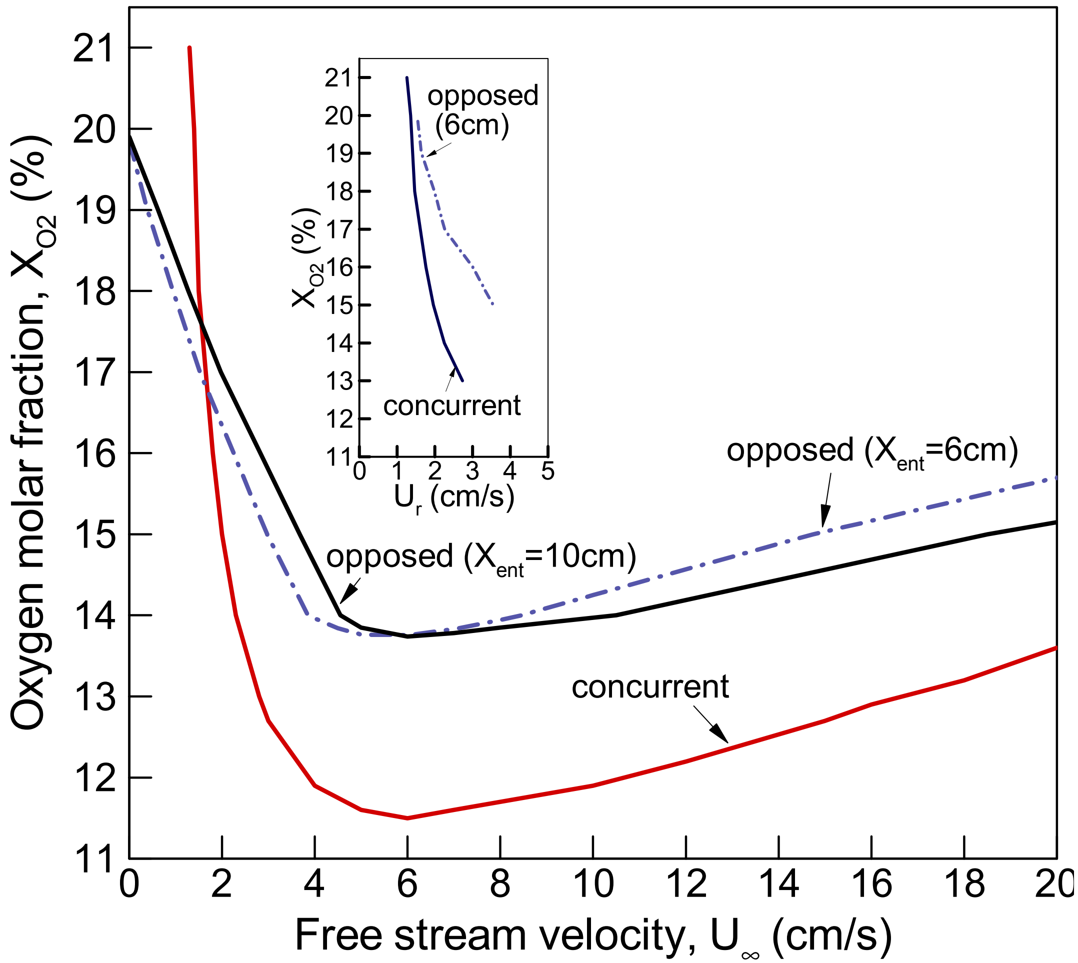
Calculated Concurrent vs. Opposed Extinction Limits

(Kumar, Shih, & T'ien, *Combustion and Flame*, 2003)



Thermally thin solid (paper)

Two-dimensional model with radiation

Two entrance lengths considered for opposed flow

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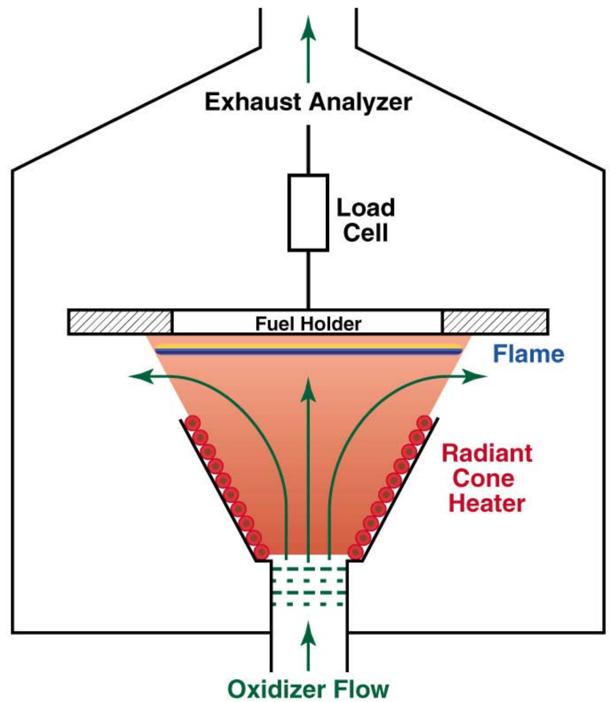
Microgravity Material Flammability Acceptance Criteria

2. Is there a normal gravity test that can quantify material flammability in reduced gravity either by itself or in conjunction with NASA-STD-6001,Test 1?

- Attempts to relate Test 1 results to data from other standard tests have met with limited success
- Various methods have been (are being) evaluated
  - limiting oxygen index (maximum oxygen concentration to extinguish a flame)
  - Forced Ignition and Spread Test (FIST)
  - Equivalent Low Stretch Apparatus (ELSA)
- Desirable: Preserve Test 1 data base, though it may need to be expanded to cover other oxygen concentrations.



Conceptual drawing of the apparatus to be tested in the WSTF Controlled Atmosphere Cone Calorimeter.

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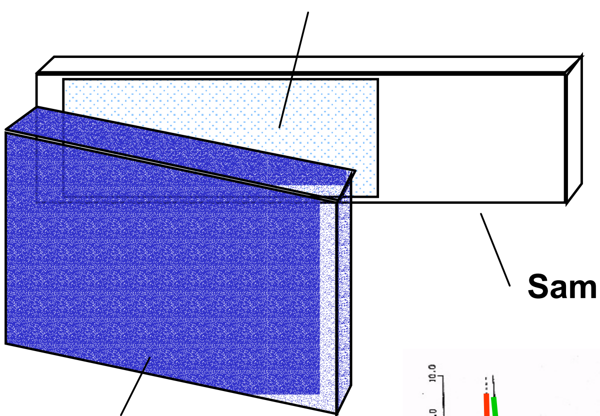
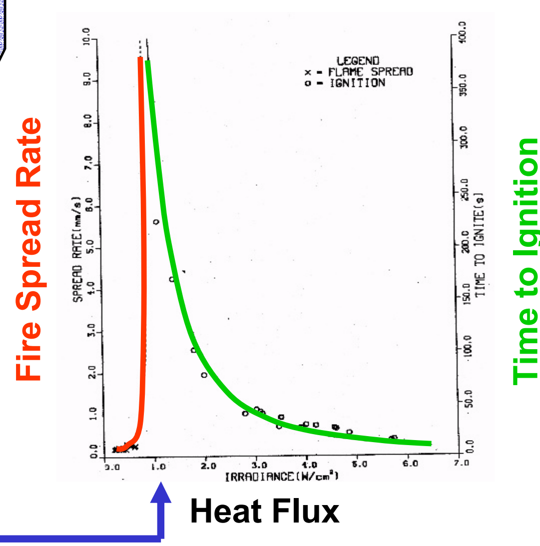
Forced Ignition and Spread Test (FIST)

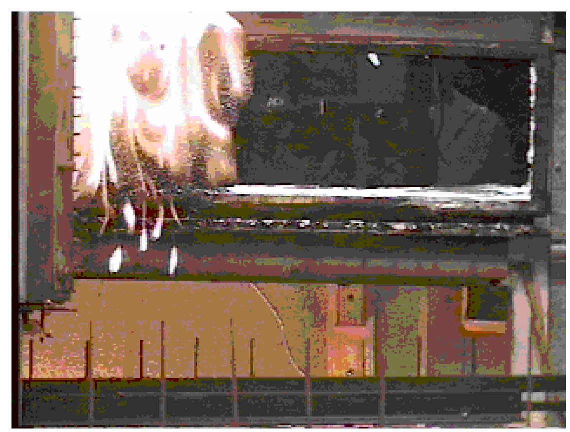
Principal Investigator: Prof. Carlos Fernandez-Pello, Univ. of Cal. at Berkeley





Objectives:

- Develop and verify a simplified theory for LIFT-styled ignition and flame spread in 1-g and 0-g
- Determine if 1-g and 0-g behaviors are correlated
- Develop a flammability test method to rank the hazards of materials used on spacecraft using time to ignition, fire spread rate, material properties, critical heat flux



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Microgravity Material Flammability Acceptance Criteria

3. How can NASA Standard 6001, Test 1 results be quantified to indicate flammability in reduced gravity? (Can additional, useful data be gathered without changing the test procedure?)

- Test 1 is normally a pass/no-pass test; no determination of passing margins.
- On-going research by Buckley and Torero is quantifying flame stand-off distances from Test 1 to determine an experimental mass-transfer number
- Comparison of experimental and analytical results allows ranking of flammability
- Modeling of Test 1 has compared well with experiment for PMMA

Microgravity flame with low flow velocity

Upward Flame Spread Test

The laminar nature of both flames makes it possible to use a simple formulation to correlate normal and microgravity results.

$$B = \frac{\text{net heat liberated by combustion}}{\text{heat input to fuel + heat loss}}$$

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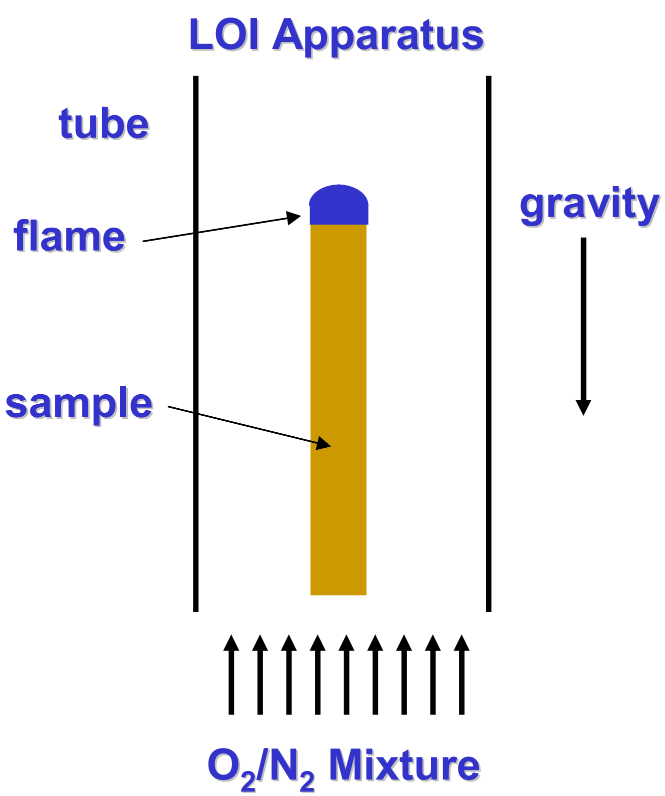
Material Flammability and Ignitability in Reduced gravity

4. How does the flammability, ignitability and Limiting Oxygen Index (LOI) of a material change with gravitational level?



Some Typical values	LOI
Polyurethane foam	16.5
PMMA (Perspex)	17.3
Poly(ethylene)	17.4
Poly(propylene)	17.4
Poly(styrene)	17.8
Plywood	23.0
Nylon 6.6	24-29
Nomex	28.5
PVC (unplasticised)	45-49
PTFE (Teflon)	95

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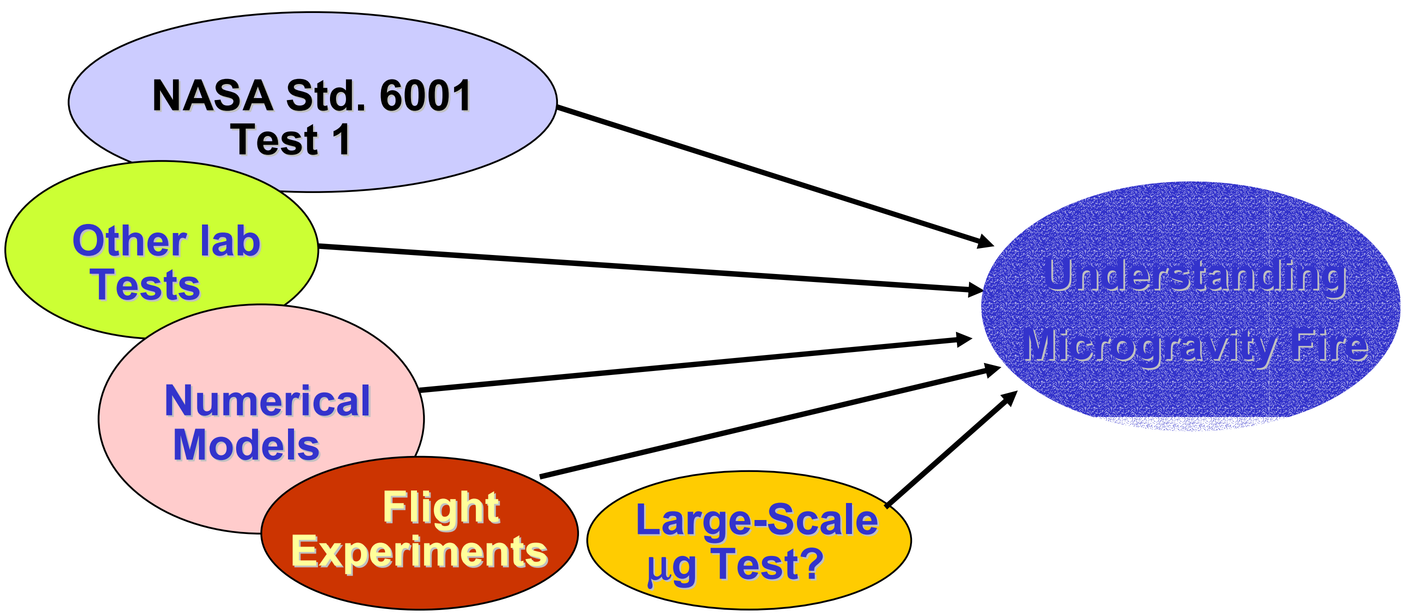
Fire in Microgravity

5. How can the results of small-scale experiments be used to determine the behavior of large-scale fires?
   a. Extend results to conditions and geometries that haven't been tested
   b. How will flames grow and spread in real situations?



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Exploration Environments

6. How do the flammability and ignitability of materials change in high-O_2 mole fraction, low-pressure, reduced gravity environments?

- Exploration environments may have an enriched oxygen, low pressure atmosphere.
  - Skylab 70% oxygen, 5 psia
  - Apollo 100 % oxygen, 5 psia
  - EVA Shuttle/ISS 30% oxygen
- Test 1 is run at atmosphere of use, though data base is smaller at higher oxygen concentrations.

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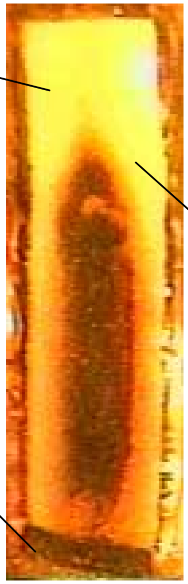
Smoldering

7. How does the propensity for non-flaming/smoldering combustion of materials change in high-O2 mole fraction, low-pressure, reduced gravity environments?

- Smoldering not covered under NASA Std. 6001, Test 1.
- One planned flight experiment:

  Smoldering, Transition and Flaming (STaF)

  PI: Prof. Carlos Fernandez-Pello
  Univ. of Cal. at Berkeley



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Ignition & Products

8. What are the other credible ignition sources, other than electrical overheating and electrical short circuits that will exist on exploration vehicles? Do these sources increase or decrease the propensity for ignition in reduced gravity?

- Waste Storage
- Solid Fuel Oxygen Generators
- High pressure oxygen system
- Laser use?

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Your Input

Questions:

- Are these the right questions?
- How would you change them?
- Are there other questions that should be considered?

Concepts:

Reiteration of what we need to determine:

1. What experiments must be conducted to best answer these questions?
2. Can some of the questions be answered using existing/planned hardware or experimental concepts?

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Flow Enclosure Accommodating Novel Investigations in Combustion of Solids (FEANICS)

June 23, 2004

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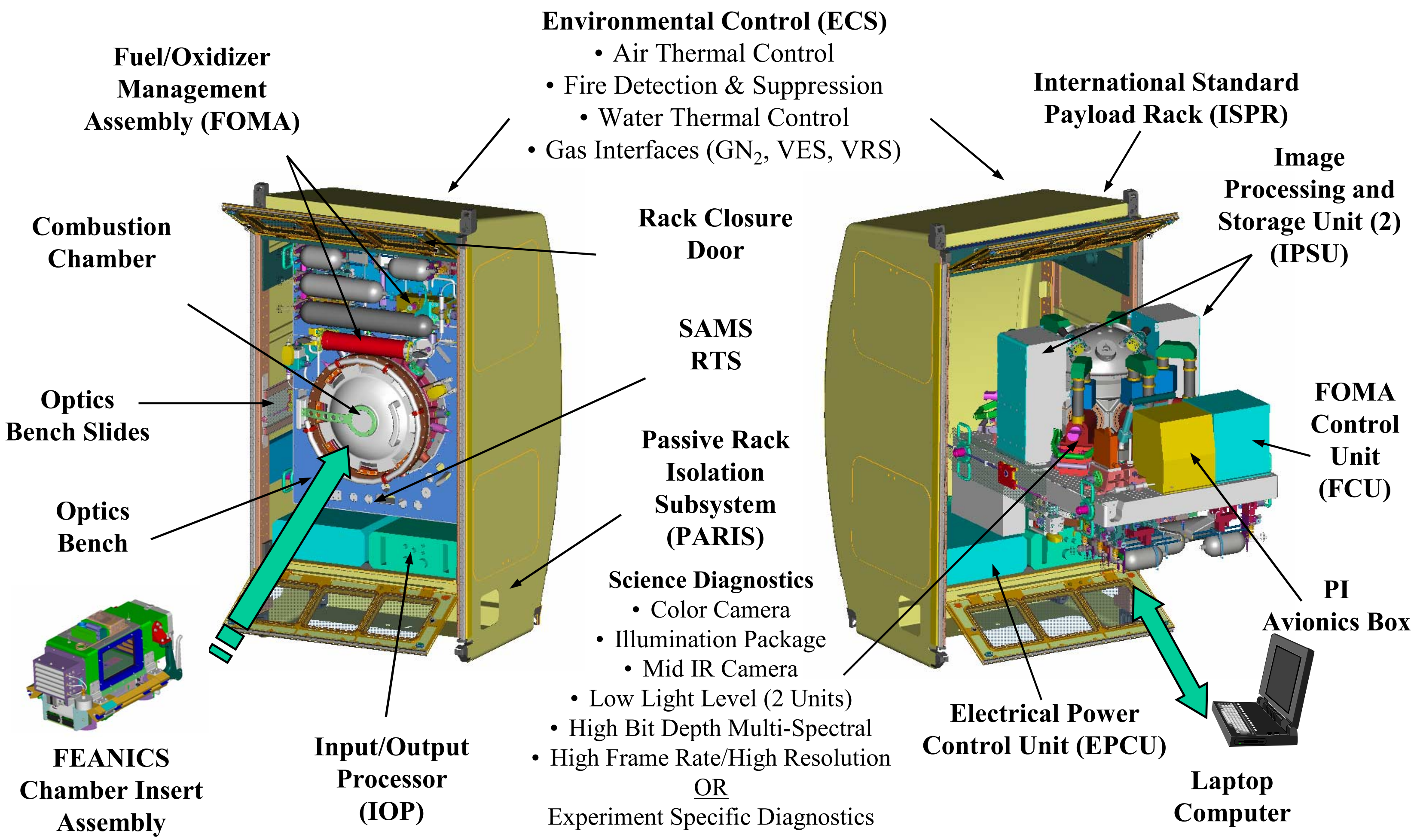
Combustion Integrated Rack Overview



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FEANICS-1 Capabilities

- **15 cm W x 12 cm H x 30 cm L flow tunnel test section**
  - Top surface of fuel flush with tunnel floor
  - 0-25% and 4-96% O_2 sensors at tunnel inlet and outlet
  - 4 LEDs for illumination
  - Gas phase thermocouple for gas inlet and outlet temperature
- **Quiescent or Flow tests with adjustable velocity up to 20 cm/s**
- **Concurrent or Opposed flow testing**
- **Pressures from ~0.5 to ~3.0 atm**
- **Testing:**
  - Flow tests below 27% O_2; We can control O_2 and pressure.
  - Flow tests above 27% O_2; We can control O_2; but no pressure control
  - Quiescent tests: No O_2 or pressure control
- **Ignition by hot wire (one per sample)**
- **Radiant Heater to heat/pyrolyze fuel (peak radiance ~20 kW/m^2)**
- **Carousel Fuel Sizes**
  - Max: 11.5 cm W x 18 cm L x 1.2 cm thick for a 3-sided carousel
  - Min: 3 cm W x 18 cm L x 1.2 cm thick for an 8-sided carousel

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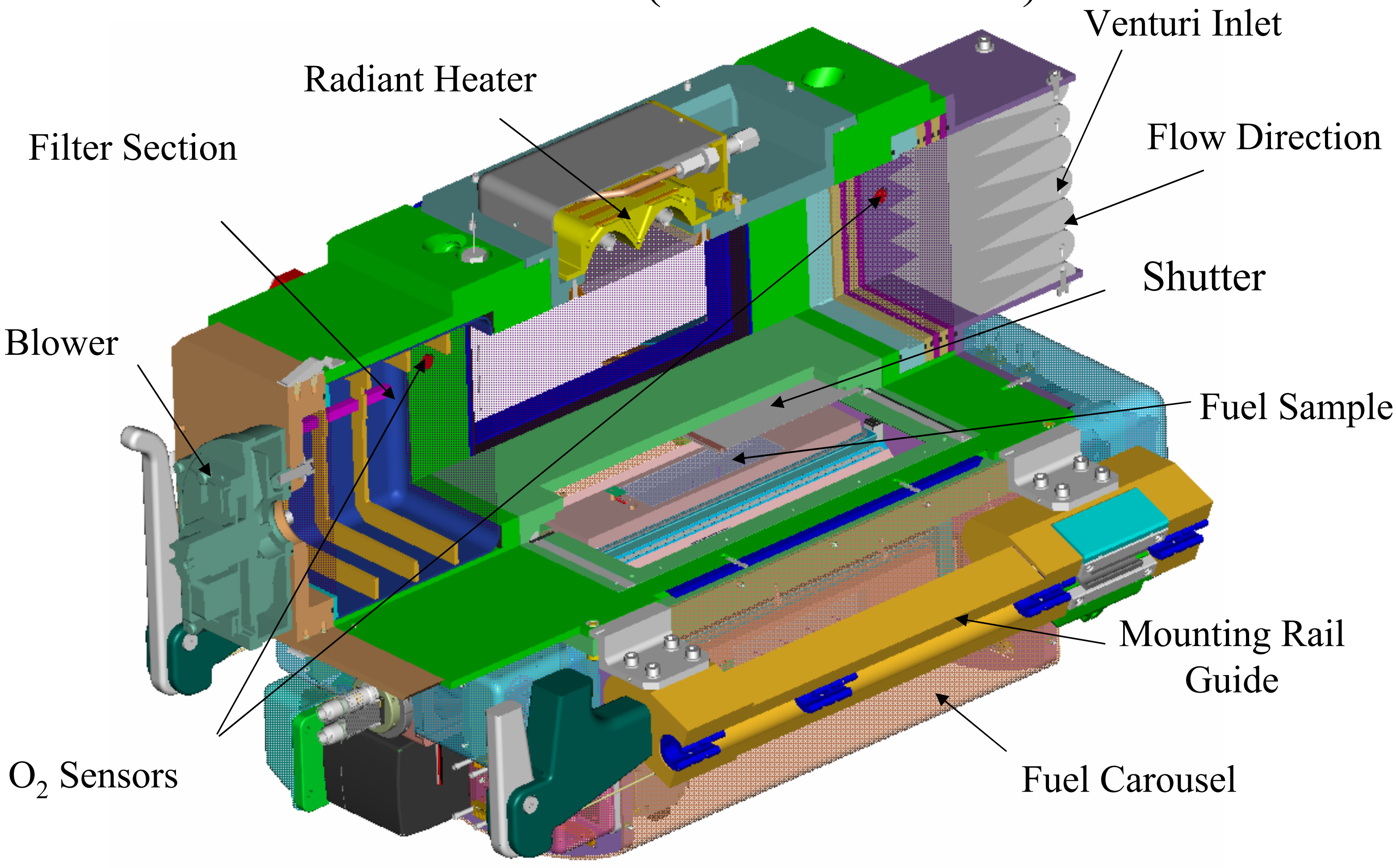
FEANICS-1 Insert (w/Radiant Heater)



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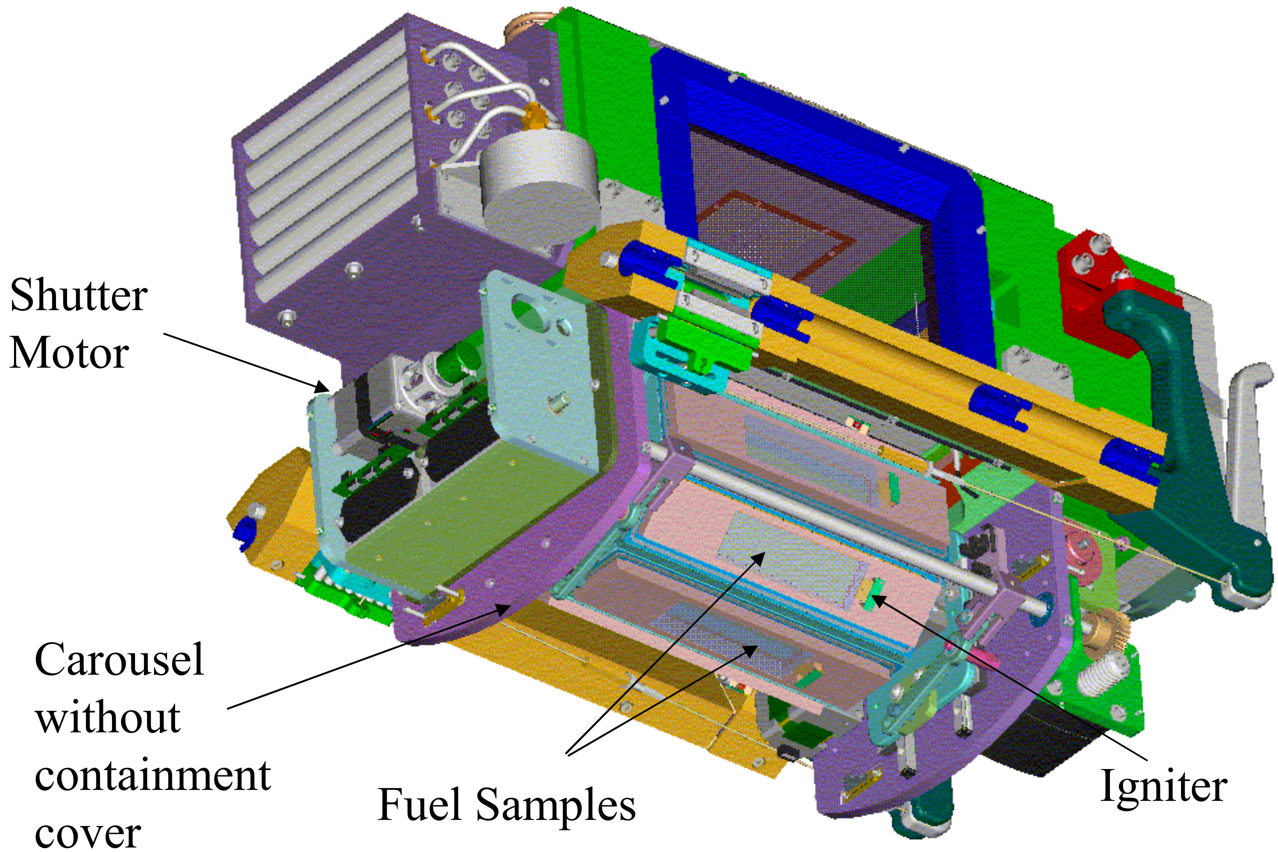
FEANICS-1 Insert with 8-Sided Carousel



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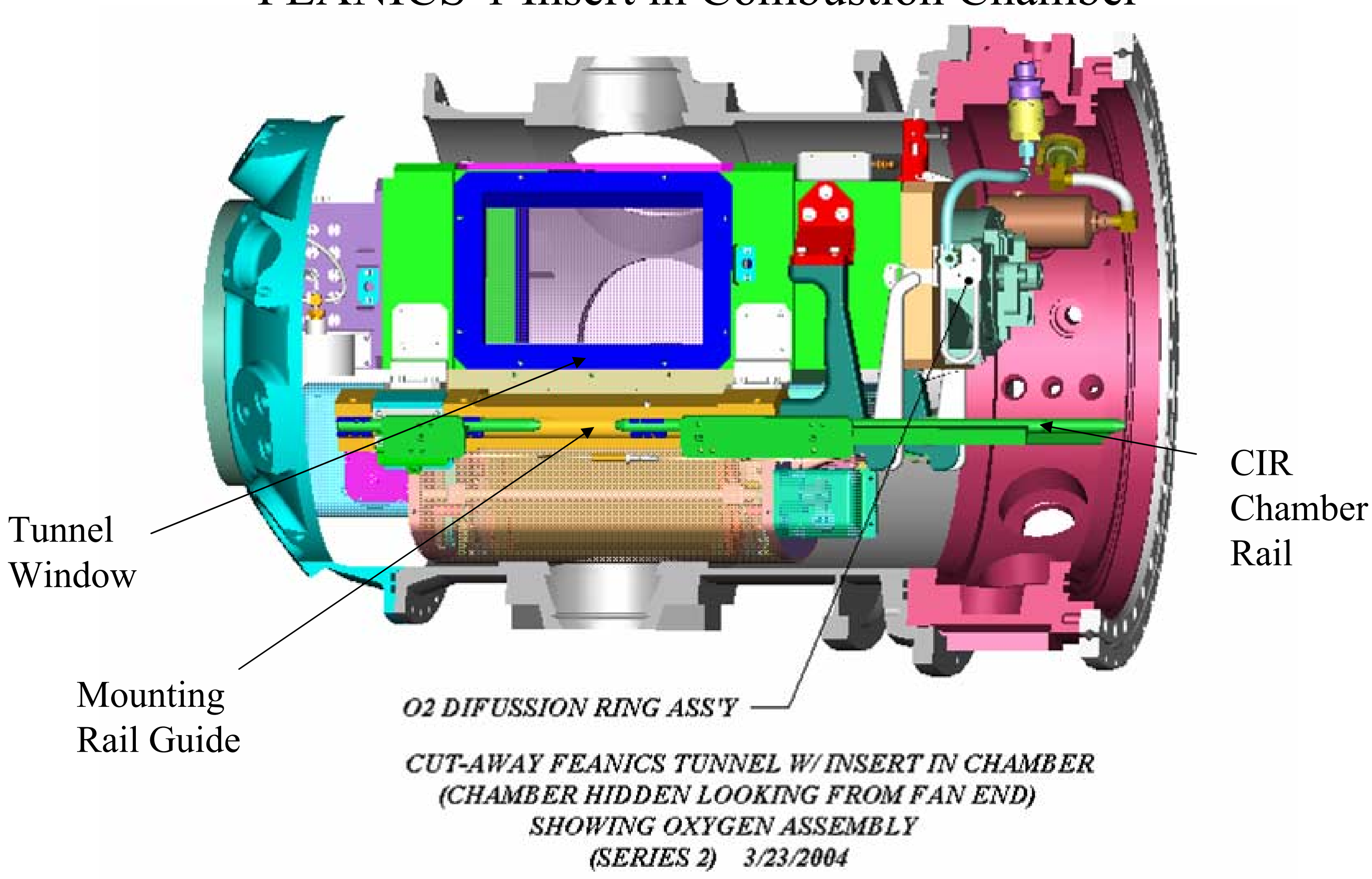
FEANICS-1 Insert in Combustion Chamber



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FEANICS-2 Capabilities

- **Similar to FEANICS-1 with the following exceptions**
  - Fuel located in center of tunnel section
  - Split Flow inlet and exit
  - 15 cm W x 12 cm H x 26 cm L flow tunnel test section
  - Ignition by 30 W CO_2 laser
- **Fuel Sizes (Max)**
  - 13 cm W x ~ 800 cm L x ~ 0.4 mm thick on a continuous fuel roll.
  - 10 cm W x 16.9 cm L x 1 cm thick in an end loader (7 max).
- **Plan for Fuel Roll was to use a camera to track flame position and feed fuel into the flame to keep flame position fixed. CIR lost capability to process video real time.**

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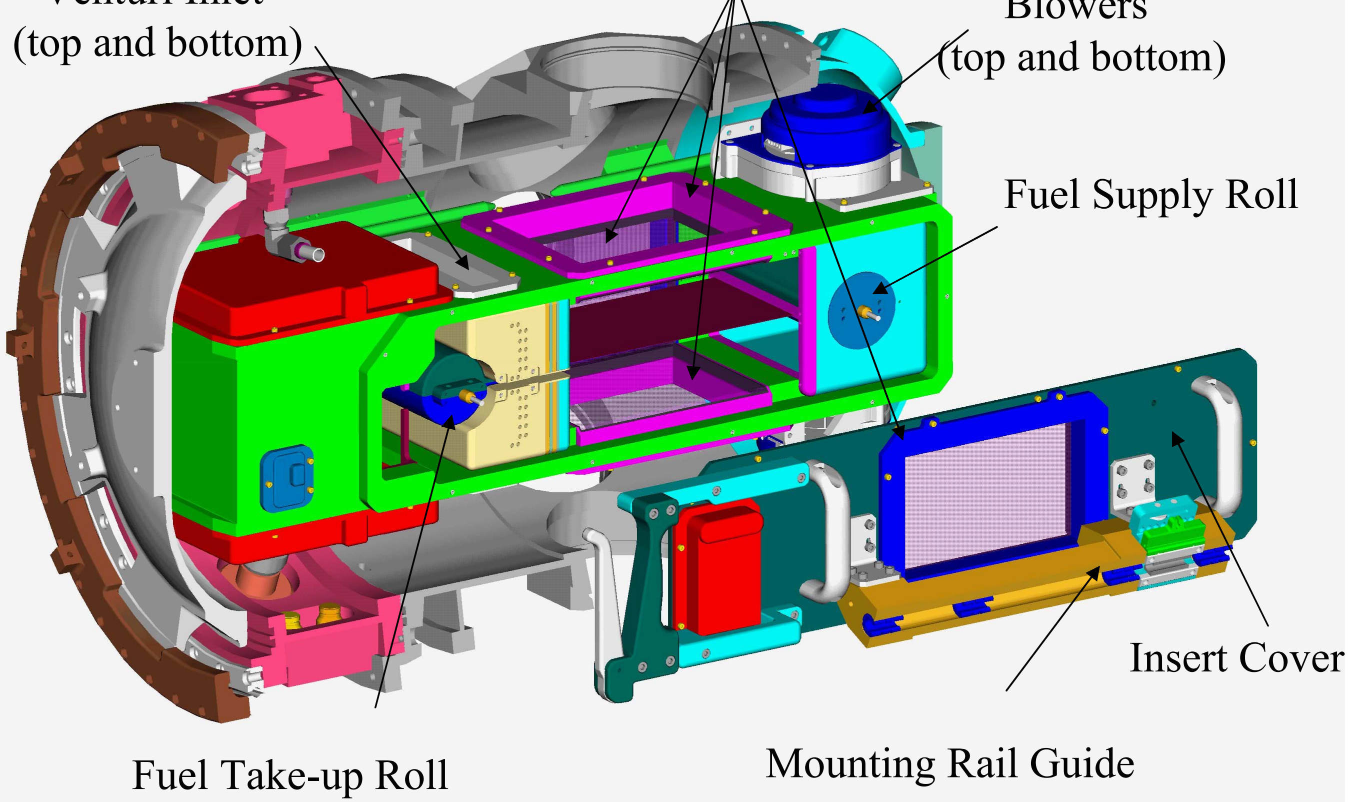
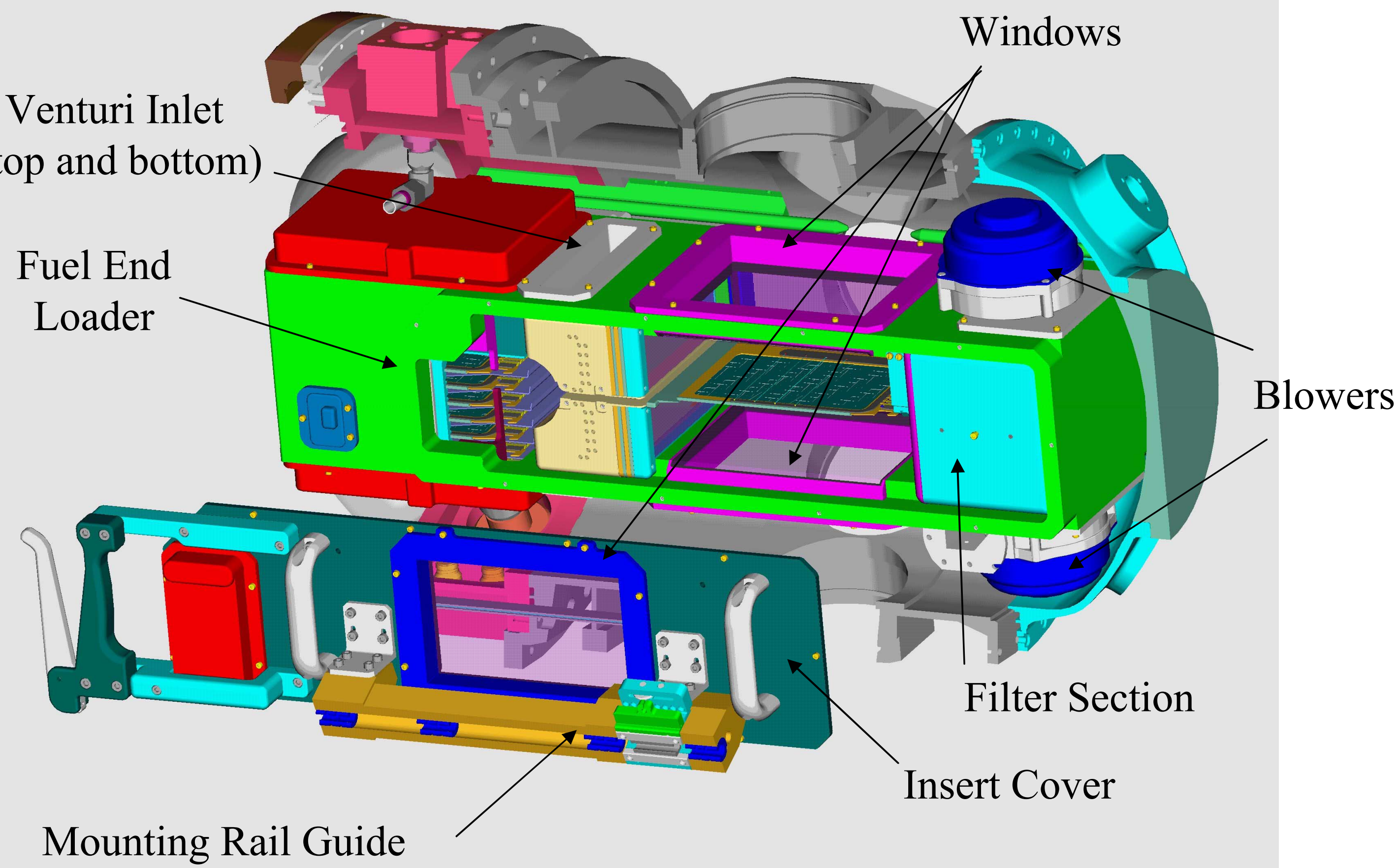
FEANICS-2 Insert with Fuel Rolls



FEANICS-2 Insert with End Loader



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Diagnostics Capabilities

Camera System	Pixels Array	Bit Depth (bits)	Frames Per Second	Spectrum (nm)
Low Light Level-IR	512x 512	12	30	400-900
Low Light Level-UV	512x 512	12	30	250-700
High Bit Multispectral	512x 512	12	15	650-950
Color	640x 480	8	30	400-700
Mid-IR	256x 256	12	120	3000-5000