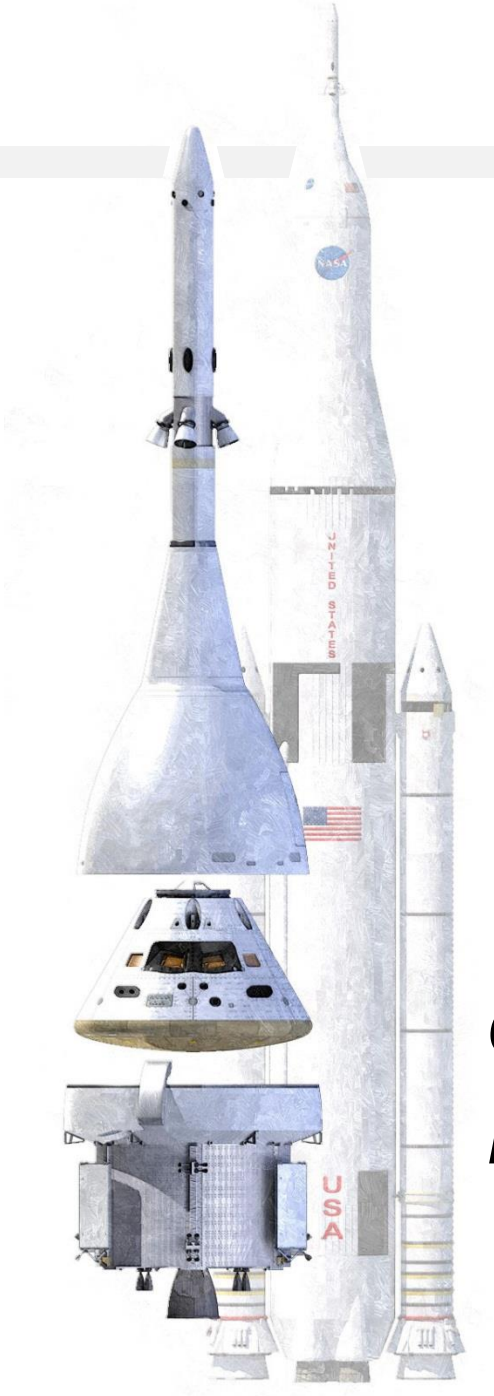


NASA Ames LEAF-Lite:

Using 50-kW Lasers to Test the Radiative Heating Component of the Orion Heat Shield

Geoff Cushman *NASA ARC – Jacobs Technologies*

November 29, 2016

Overview

- Part 1: Intro
  - What is LEAF-Lite
  - Purpose in IHF
  - My Role as an ALU
  - Walkthrough of optical setup
- Part 2: Developing a safe system
  - Laser Control and Safety System (LCSS)
  - Laser Safety Committee at NASA Ames
  - Training, Testing, and Experience
  - Conclusions, wrap up, and test videos.

Part 1: What is LEAF-Lite?

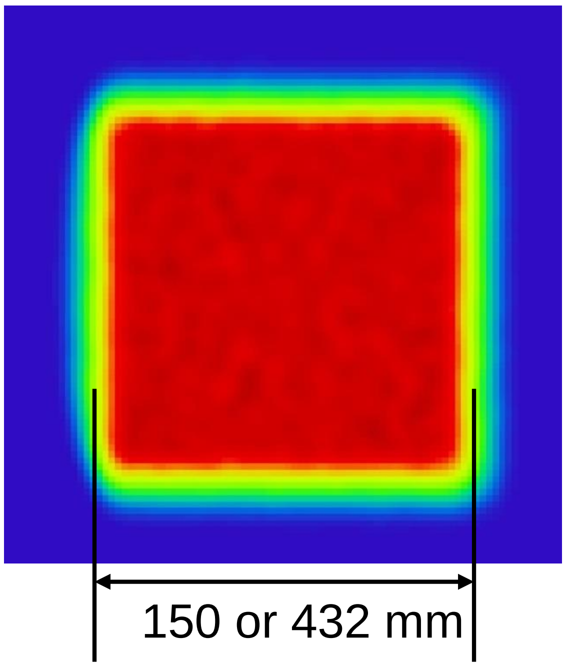
- Lunar Environment Arc-jet Facility (operational Jan 2017)
- Ames Interaction Heating Facility (IHF)
  - Studies and tests thermal protection systems (TPS materials) for atmospheric re-entry
  - Simulates convective heating but does not simulate radiative heating
- LEAF-Lite will allow the IHF to have a radiative heating component
- I will act as the Authorized Laser User (ALU) and setup and operate laser activity

LEAF-Lite Capabilities

- Radiant heating on wedge test articles or spot heating on panel test articles (0-300 W/cm^2)
  - 150 mm x 150mm (5.9 in.) square spot
- Radiant heating on panel test articles (0-100 W/cm^2)
  - 432 mm x 432mm (17 in.) dia. spot size
- < ± 5% variation in irradiance across spot; < ± 5% in stability and responsiveness
- Programmable intensity variation with < 1 sec time constant (profile simulation)
- 20 minutes continuous operation

LEAF-Lite Capabilities

Calculated Irradiance Pattern at Test Article Surface at 0-degree Incidence Angle



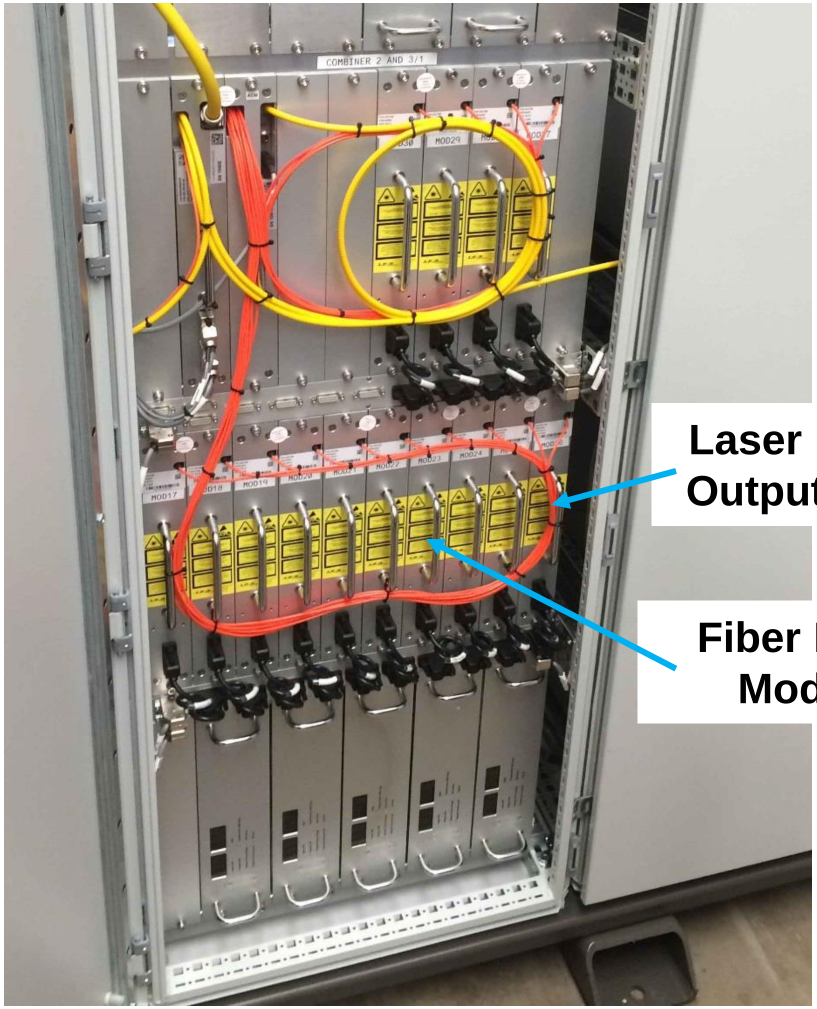
	6-inch	17-inch
Laser Count	**150 mm "square spot"**	**432 mm "square spot"**
50 kW 1 laser bank	222 W/cm^2	27 W/cm^2
100 kW 2 laser banks	444 W/cm^2	54 W/cm^2
150 kW 3 laser banks		80 W/cm^2
200 kW 4 laser banks		107 W/cm^2

System designed for rapid changeover

Fiber Laser Technology

- <u>**Fiber Laser**</u>
  - Arrays of individual diode lasers provide “pump” light for fiber having an active laser core
  - Active core is ytterbium-doped silica that emits 1.07-µm wavelength light
  - 1-kW fiber laser modules combined into single fiber (200 µm core)
  - Use of fiber lasers is widespread in industry at the 10 to 20-kW level

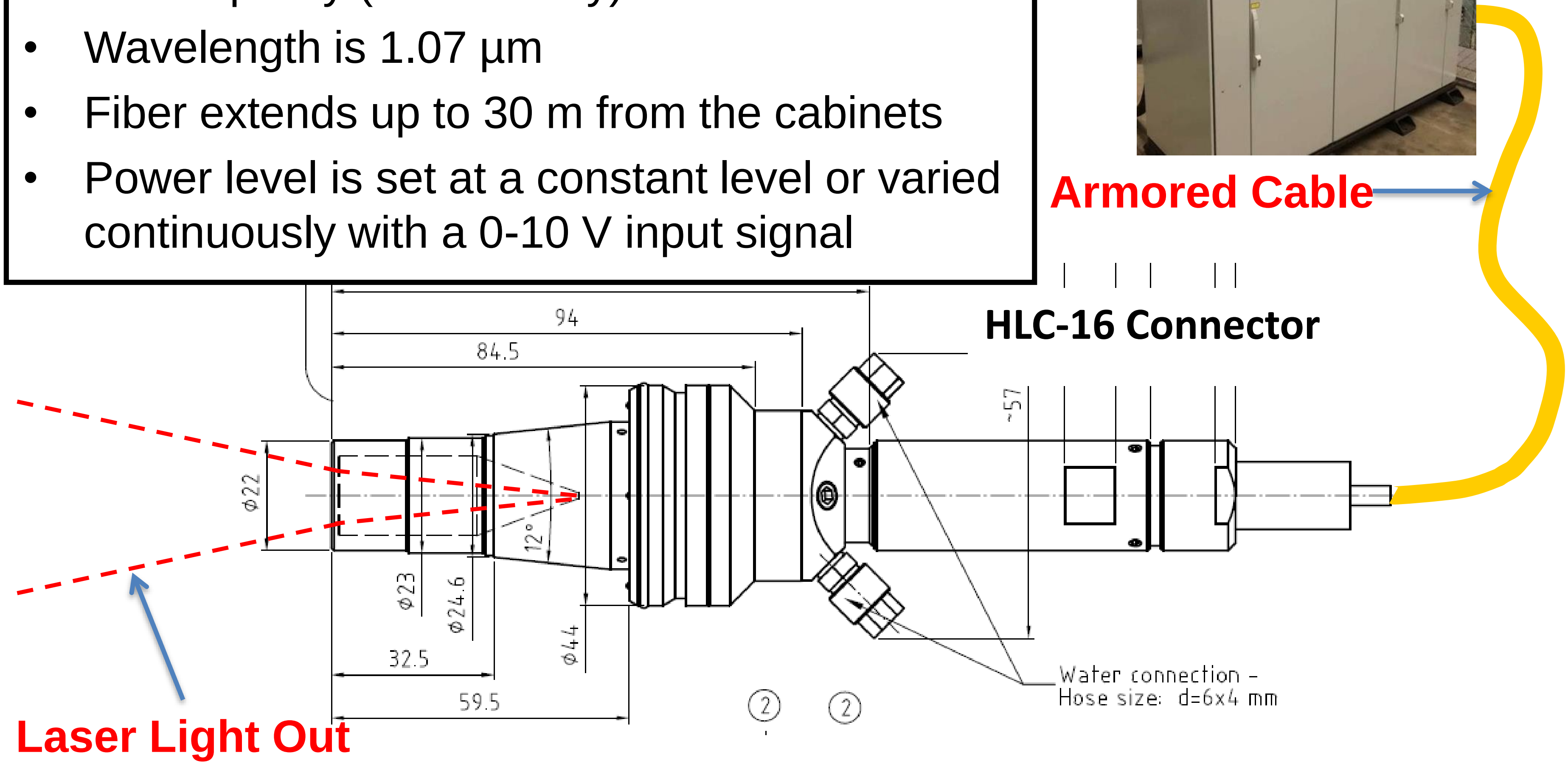
IPG Photonics 1-kW Fiber Laser Modules



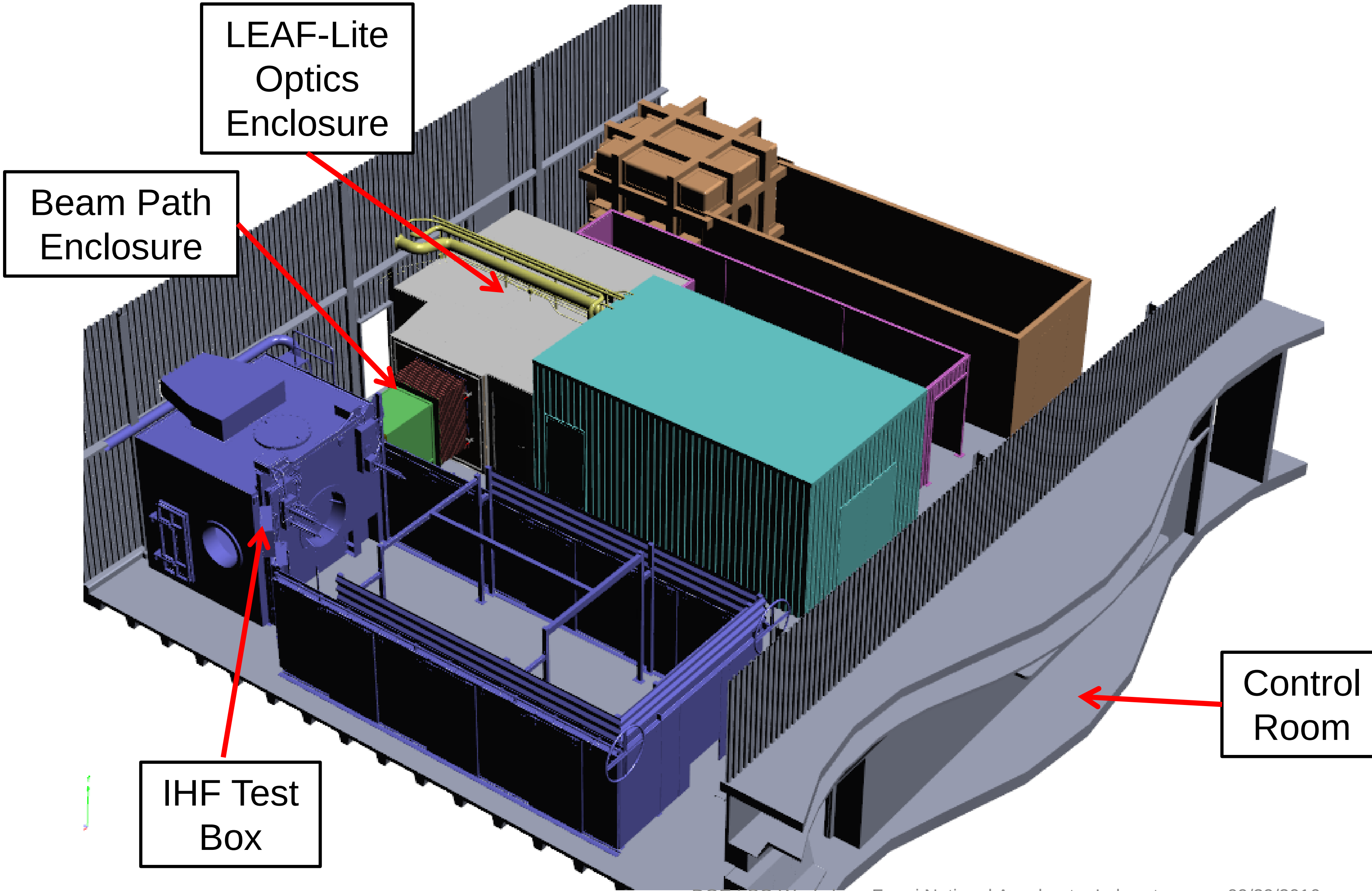
50-kW Fiber Laser Properties

- Laser beam emitted from 200 µm (0.008-inch) diameter fiber core
- Beam quality (focus ability) is about $M^2 \approx 30$
- Wavelength is 1.07 µm
- Fiber extends up to 30 m from the cabinets
- Power level is set at a constant level or varied continuously with a 0-10 V input signal

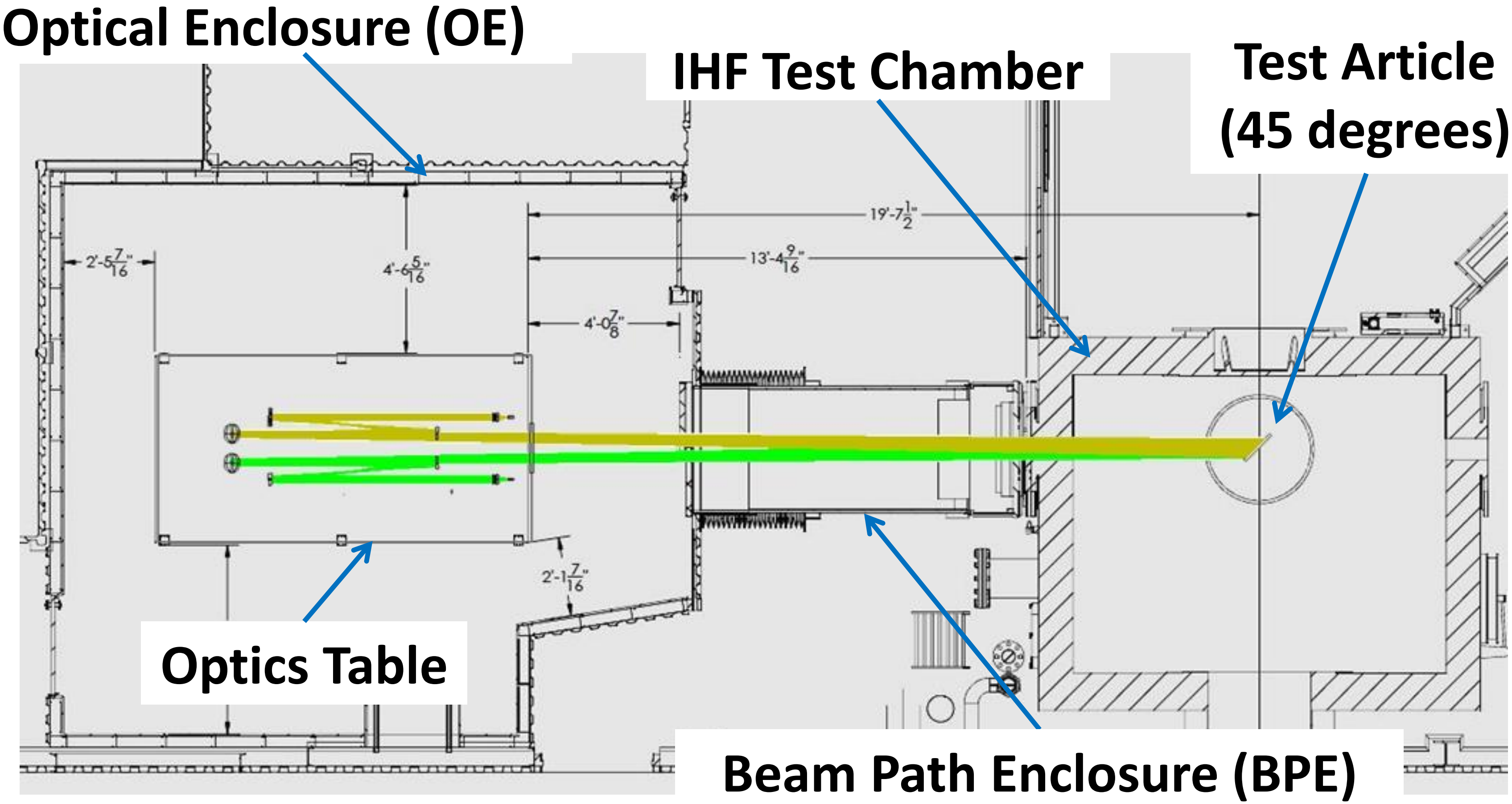
Armored Cable



LEAF-Lite Setup in IHF

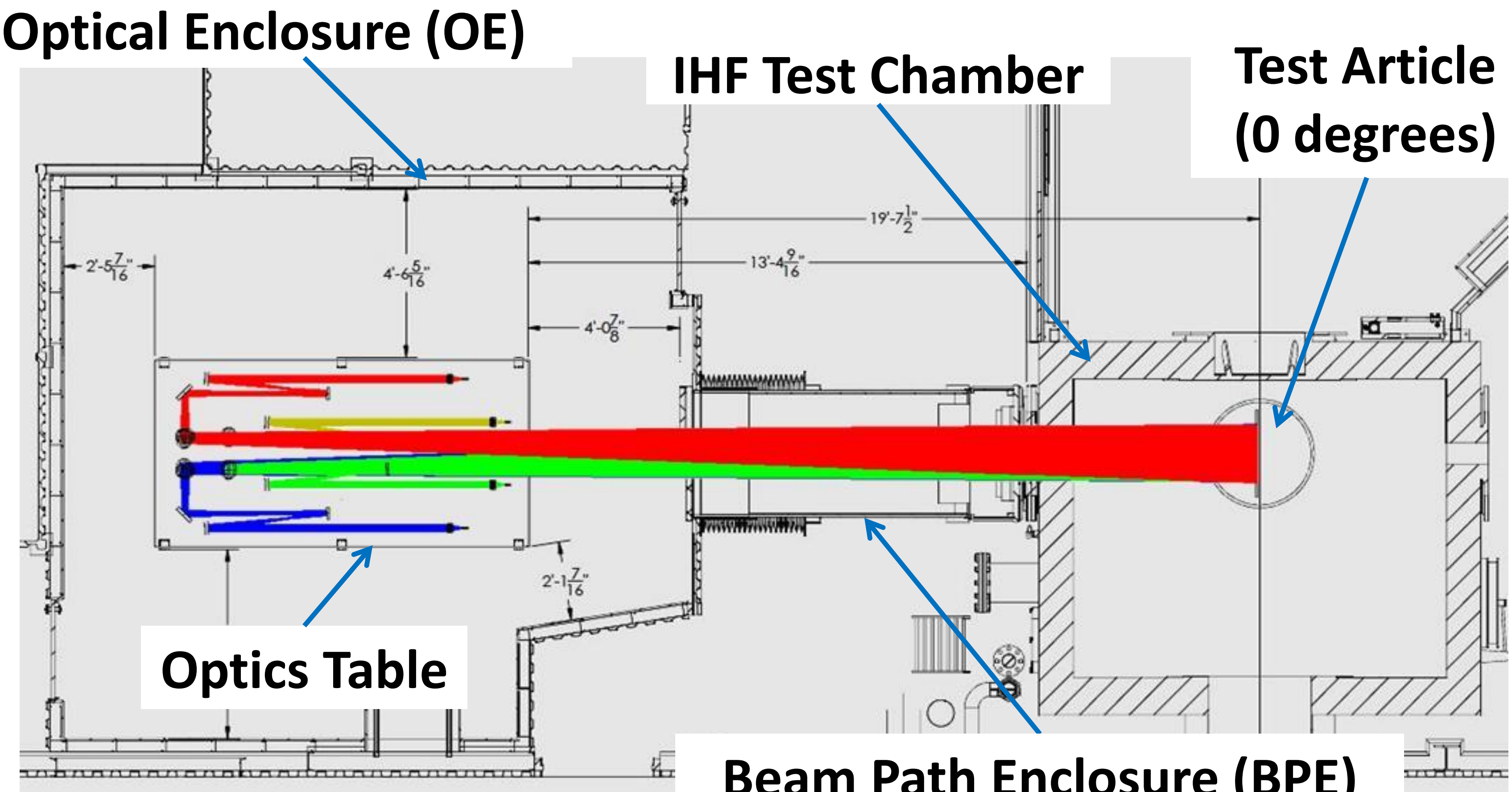


Final Layout for Two-Beam Setup (Plan View)



Full beam path confinement of 100-kW beam power

Final Layout for Four-Beam Setup (Plan View)



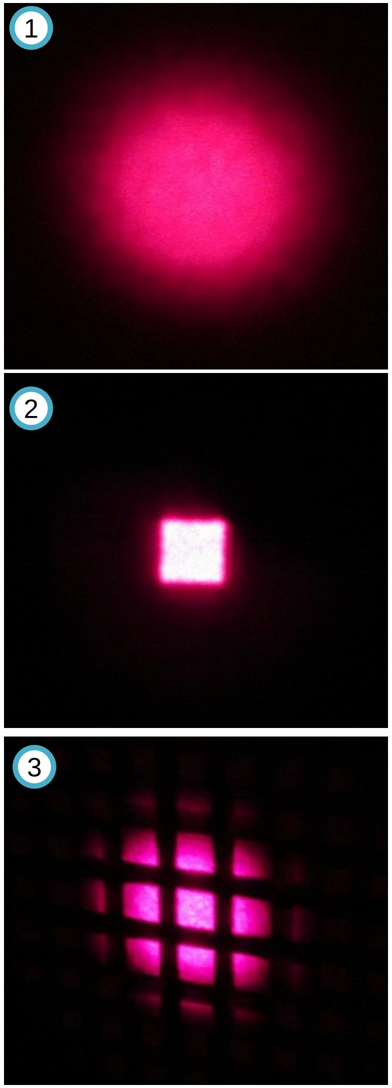
Full beam path confinement of 200-kW beam power

Optical Setup

1) Gaussian beam emerges from collimator

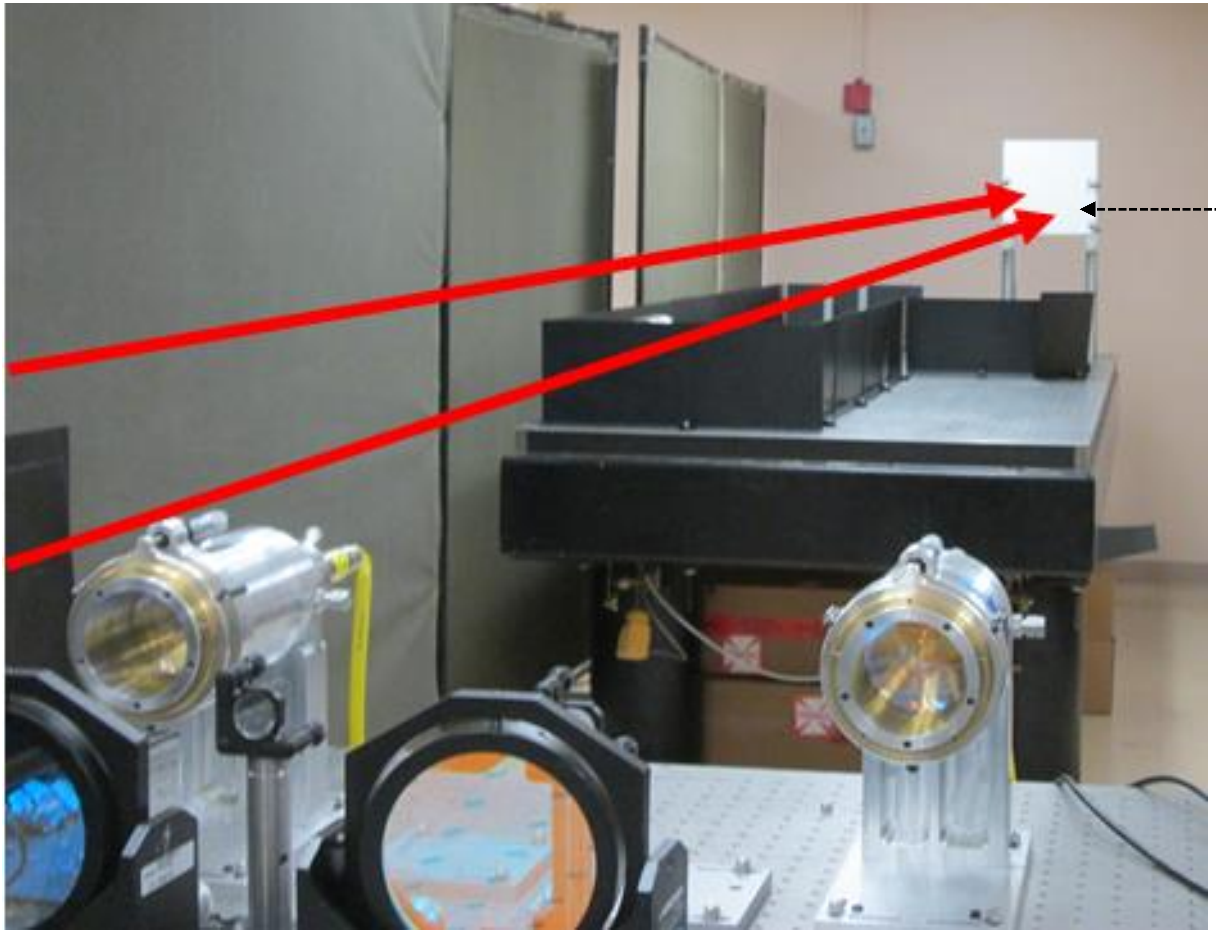
2) Beam at the focus of the integrator (1cm x 1cm square spot)

3) Diverging beamlets to be reimaged at scatter-plate

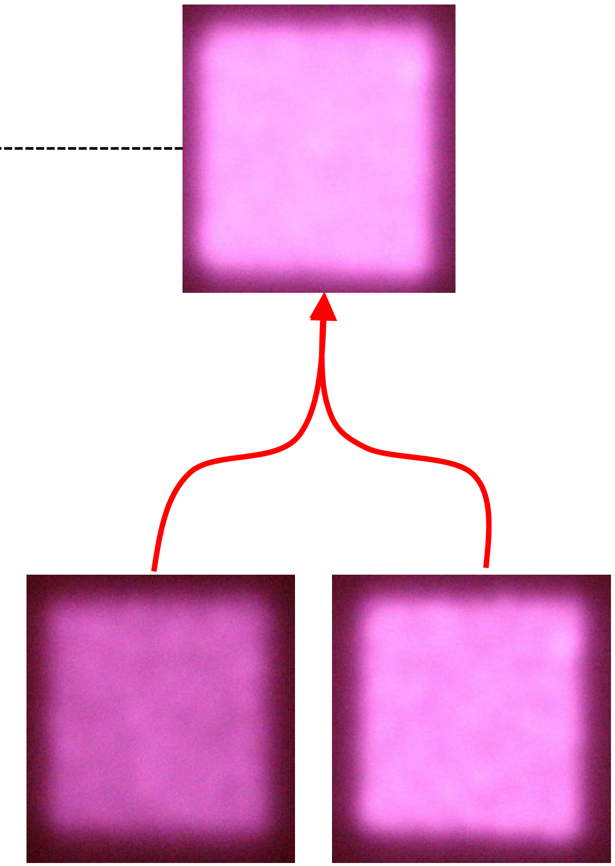


*Images of red guide beam in practice lab

Optical Setup



Two beams incoherently combined onto a single square (image of IR beam)



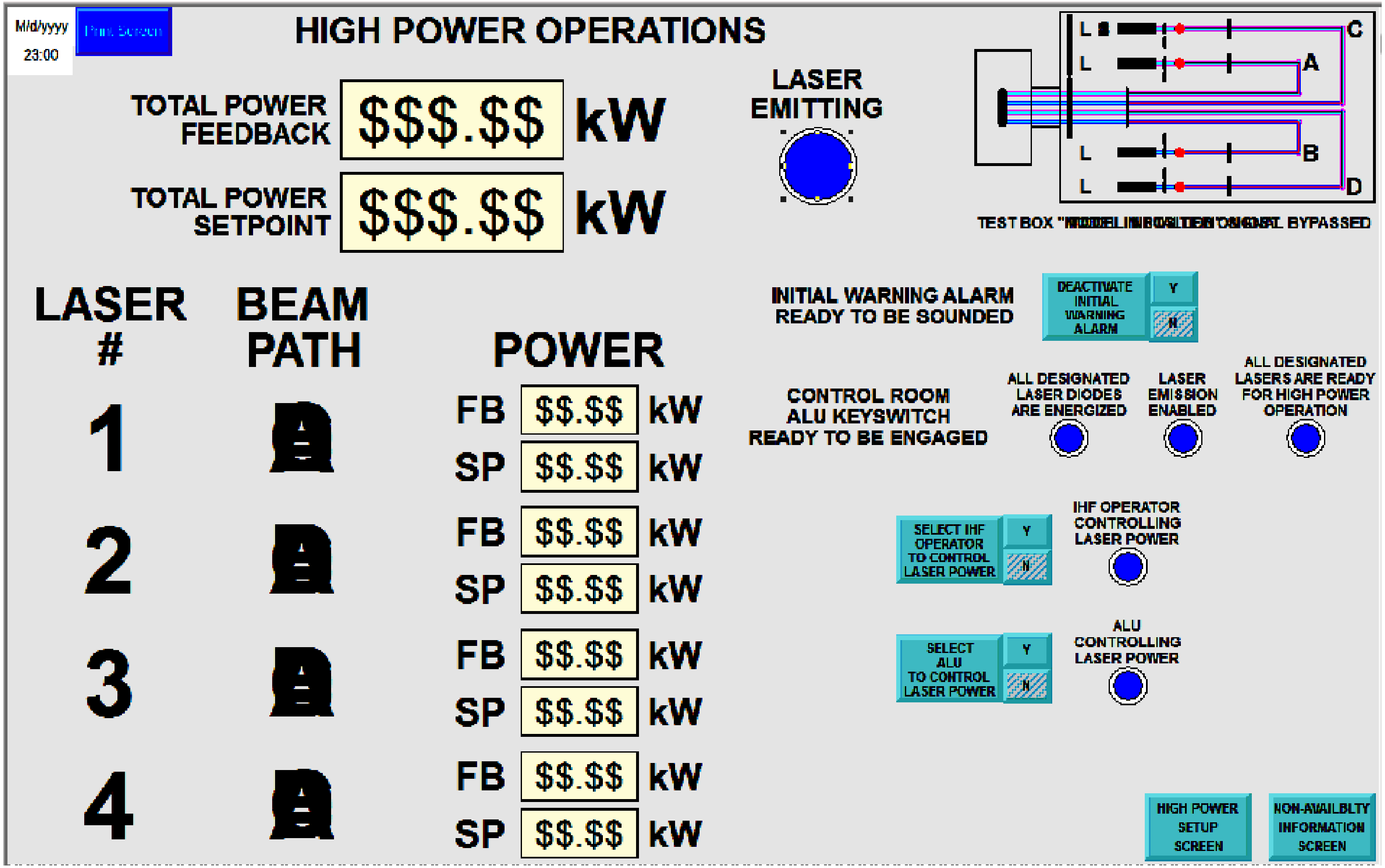
Part 2 Overview: Lessons Learned

- Laser Control and Safety System (LCSS)
  - Design of LCSS with operators/engineers/safety in mind throughout entire process
- Integration of Code Q (Safety at NASA Ames) throughout entire process
- Training, Testing, and Experience
  - Development of test lab
    - Simulation tests
  - Risk Reduction Tests

Laser Control and Safety System

- System that runs and monitors LEAF-Lite's lasers and safety parameters
  - Laser set point and feedback
  - Interlocks, E-Stops, photodiodes, thermocouples, ambient light sensors
- End user involved throughout entire design
  - Developing Logic Diagrams
  - Developing Human Machine Interface (HMI) Screens
  - Shared information about each sensor

Human Machine Interface (HMI) Screens



High Power Operations Screen Display

- Various sensors that are actively monitored by the LCSS

Sensor	Two-Beam	Four-Beam
Thermocouple	20	44
Photodiode	12	20
Camera	10+	10+

- Not mentioned here:
  - Interlocks, E-Stops, KIRK Key mechanical interlocks, Lock out tag out

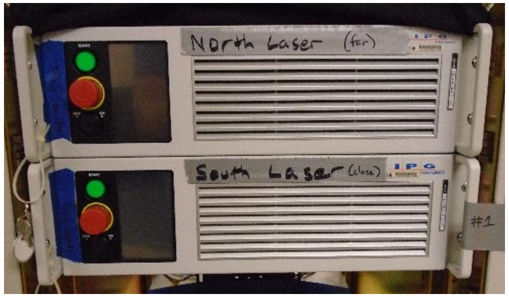
Non-ionizing Radiation Safety Committee (NRSC)

- All laser systems that contain either class 3b or 4 must be approved by the NRSC.
- Usually straight forward process and must get the following approved:
  - Standard Operating Procedures
  - Laser Experience Form
  - Specifics about system: Laser, interlocks, goggles
  - Walkthrough of system

NRSC continued

- LEAF-Lite had to take a more in-depth approach
  - Early integration and communication
  - Gradual build up of laser power in practice lab
    - 20mW -> max 10W -> 30kW tests on site enclosed

20mW laser



Two 10-W lasers

On site 30-kW tests

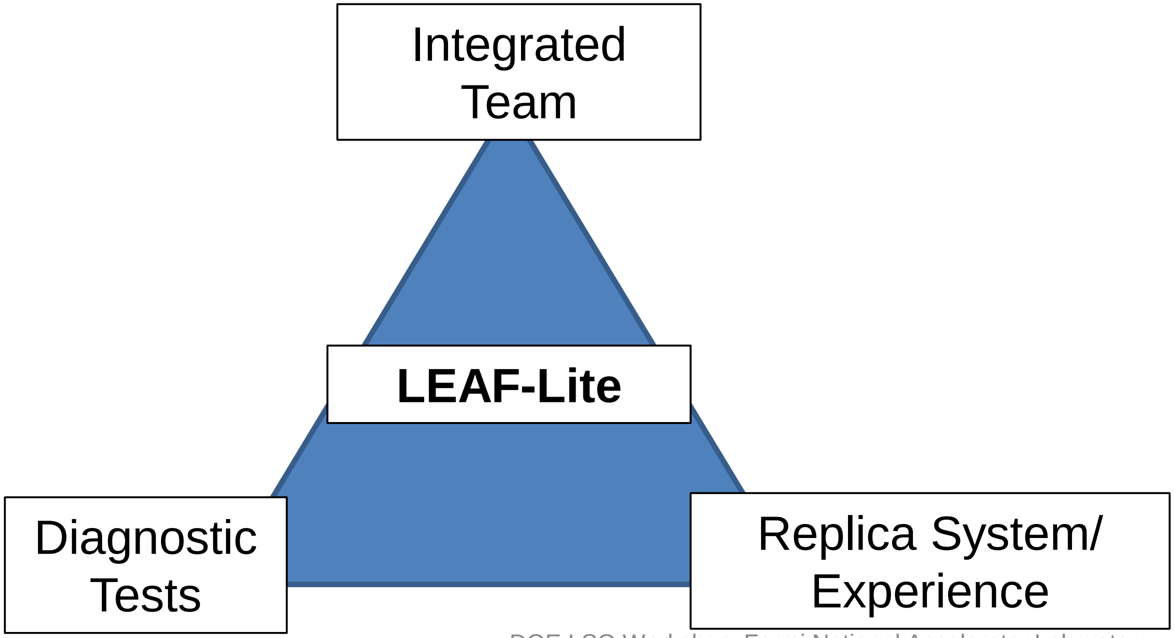
Building trust through safe practices and tests

Major LEAF-Lite Tests

- **Diagnostics Tests in RHT Lab (Ongoing)**
- **High Power Tests at NASA Ames N229 High Bay**
  - Commissioning Test I & II (April 2015): Test first and second lasers
  - Components Test (August 2015): Testing N_2 Cooled Collimator
  - Commissioning Test III (February 2016): Test third laser and various laser capabilities
- **Risk Reduction Tests at Air Force Research Lab, Kirtland AFB in New Mexico**
  - RRT1 (January 2015): Test optical materials with a 50-kW laser
  - RRT2 (October 2015): Test various optical enclosure wall materials to laser radiation
  - RRT2-2 (January 2016): continuation of test with additional samples and combination: See Videos (B1-4 & T1)

Conclusions

- When building a high power laser system:
  - Early integration of end users, engineers, and safety
  - Work to test as many diagnostics as possible with varying power
  - Setup a replica system with a manageable power level



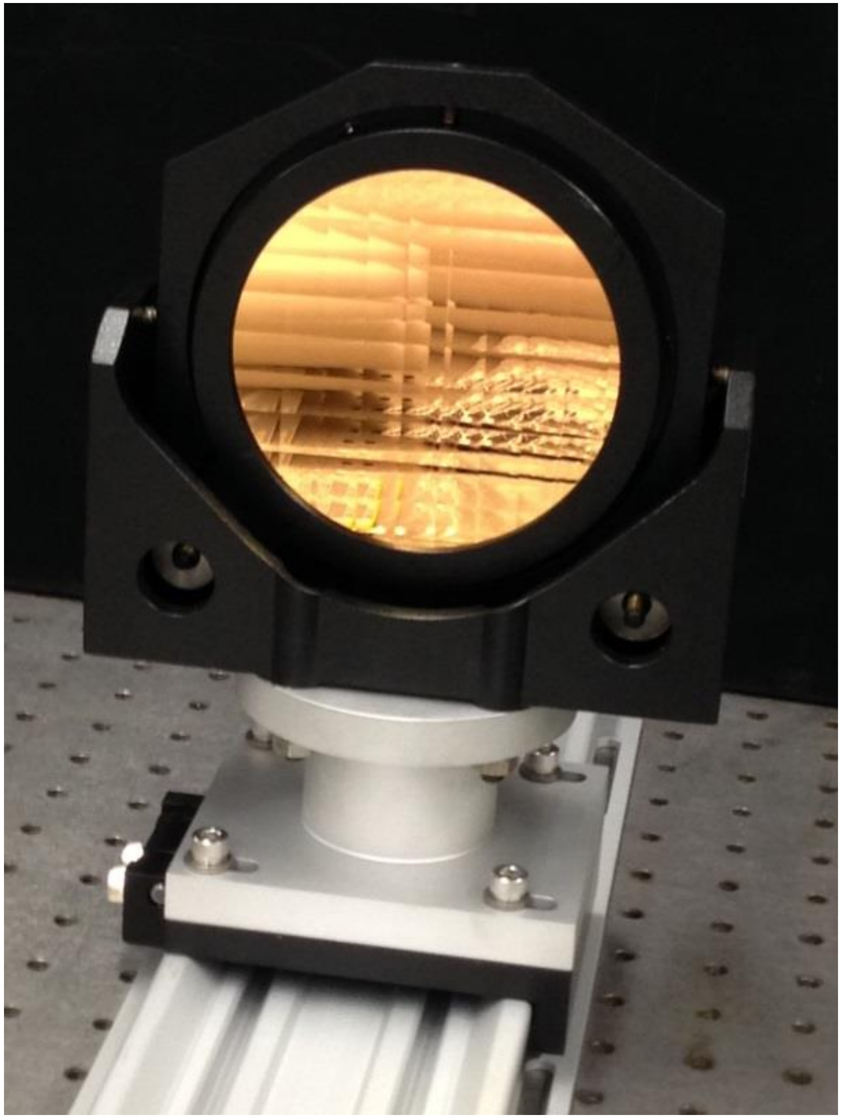
Questions?

- Thank you:
  - LEAF-Lite Team Members
  - NASA Ames Code Q and the NRSC
  - Jamie King, Matt Quinn, and the DOE LSO Workshop

End of presentation

- Extra slides below

View of Beam Integrator



- Used to transform a super-Gaussian beam into a flat-top beam
- Spherical-concave mirror (-1300mm ROC)
- Flat square facets (1cm x 1cm shown)
- Gold-coated with a Copper substrate

Beam Profiling Tests

- Ongoing tests with 10W lasers to characterize beam profiles
- Simulate window reflection
- System and position tolerance

One setup showing a simulation of window reflection

Laser Test Box

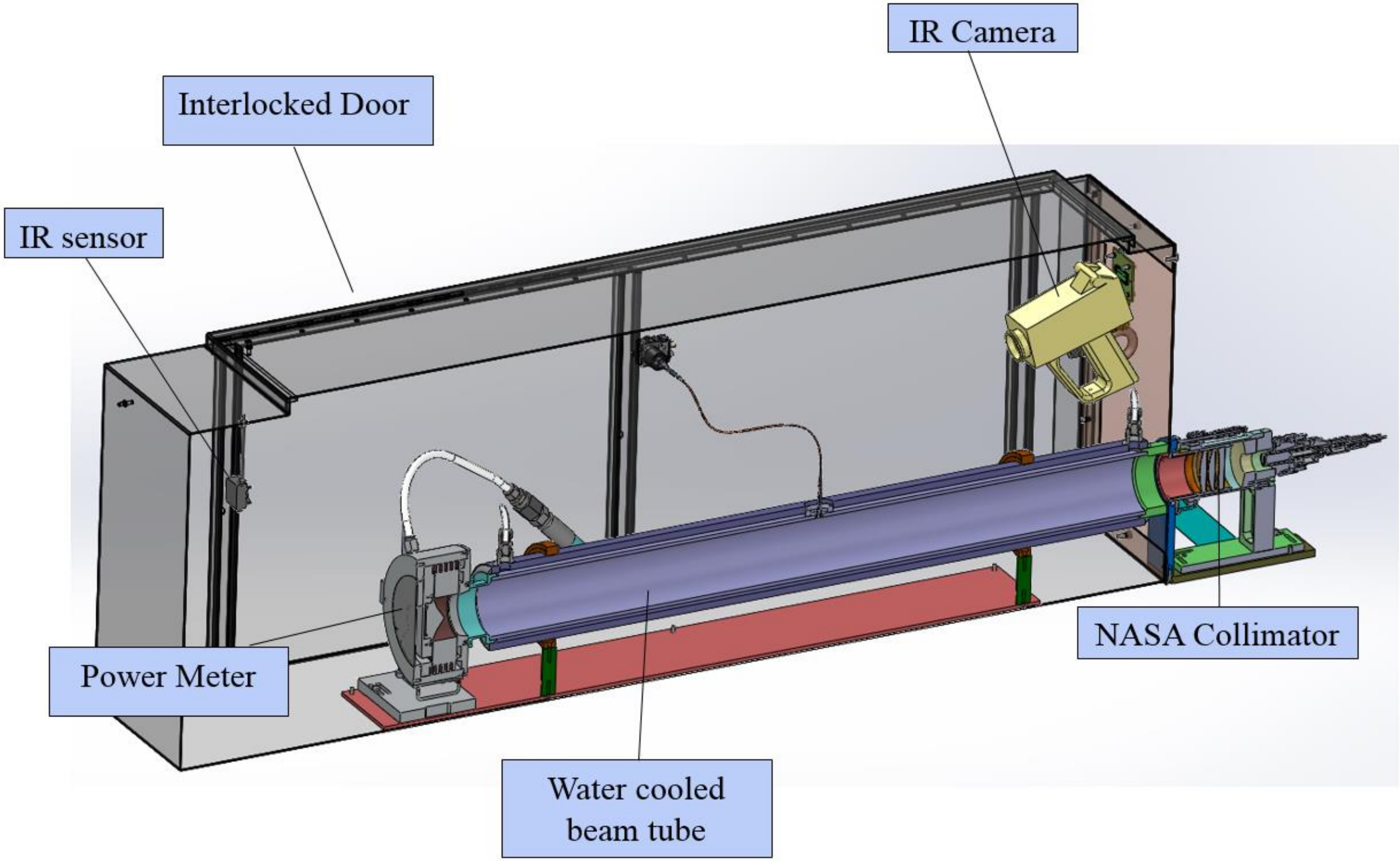
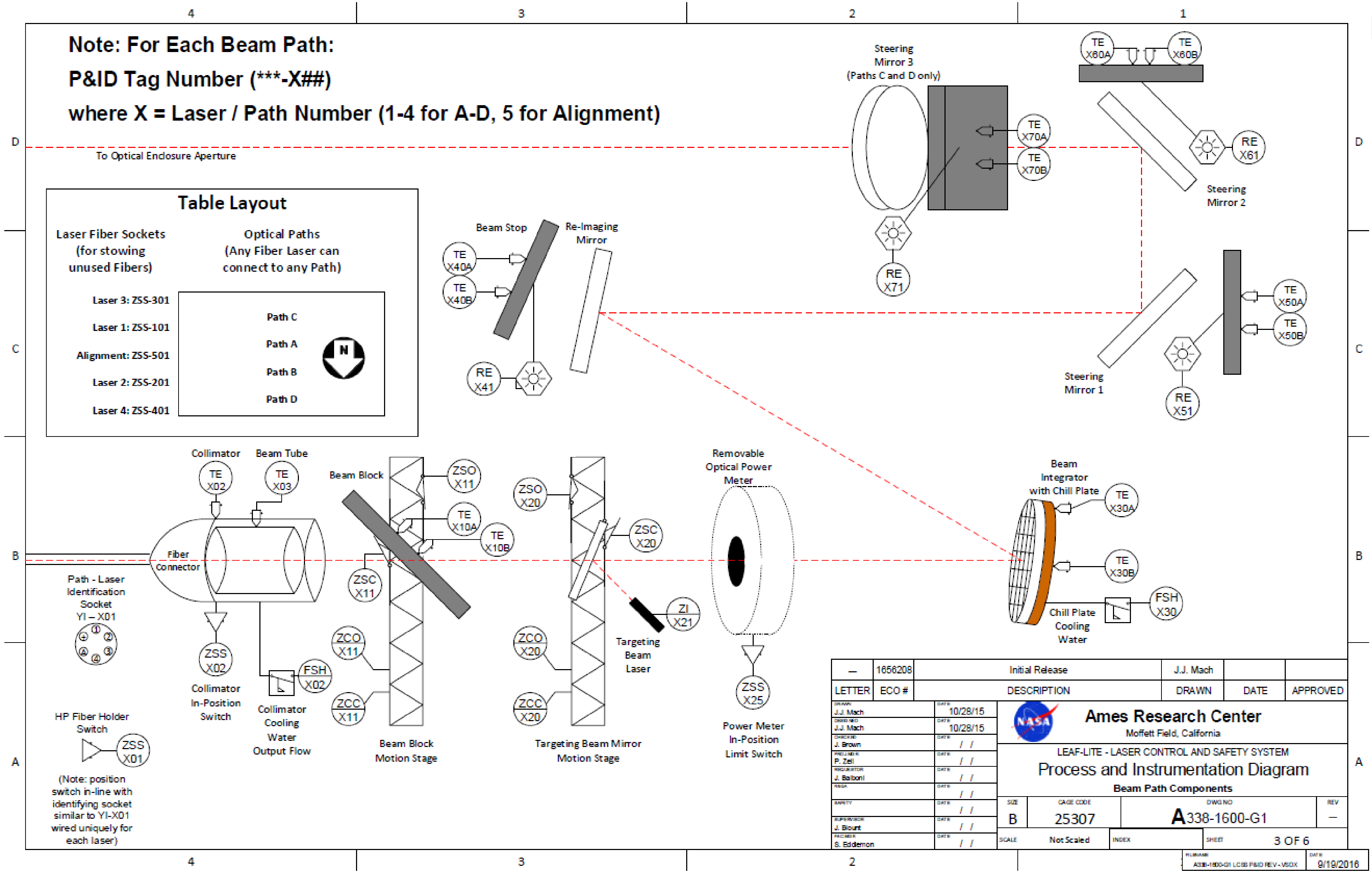
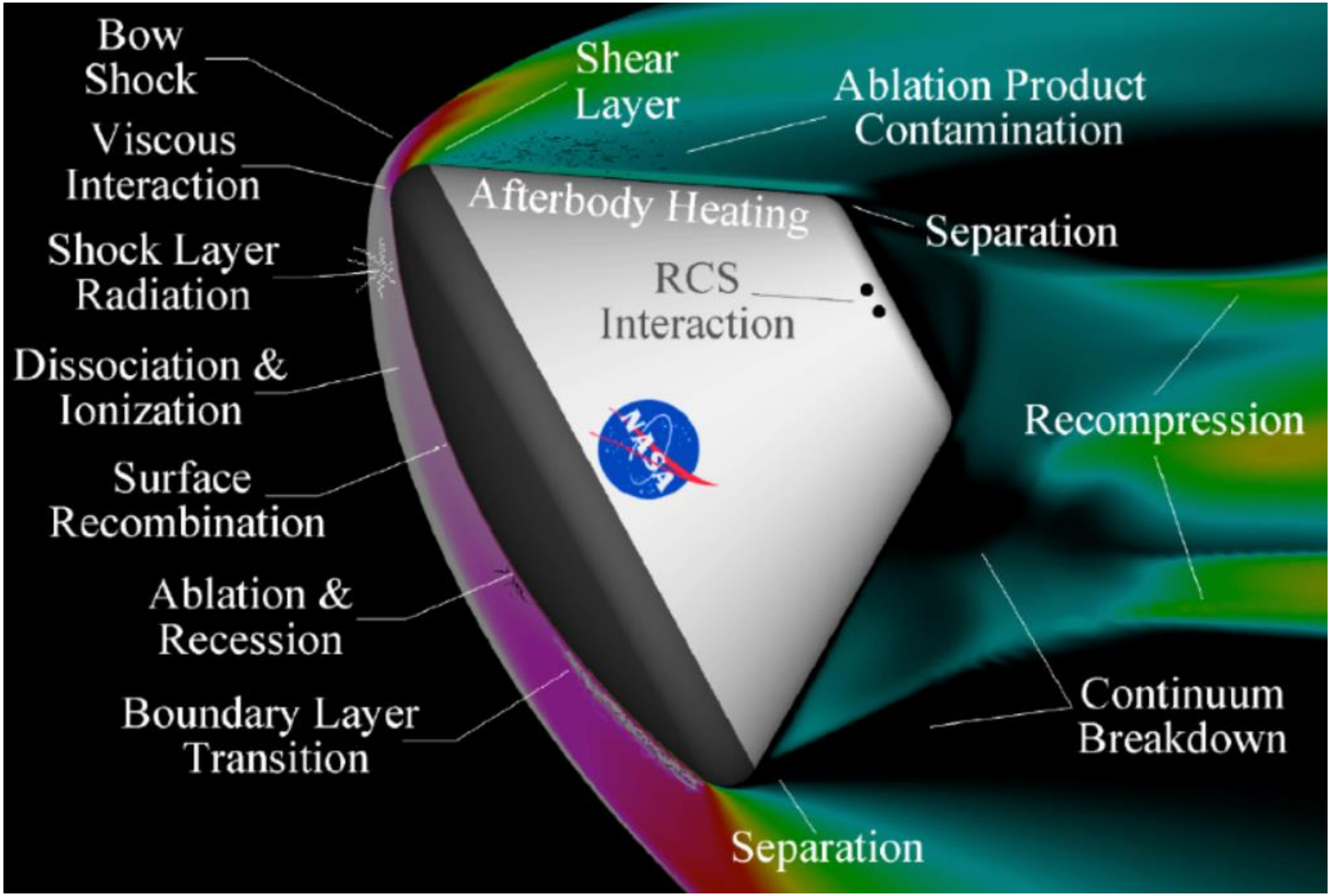


Table Sensors



Detailed Explanation of Conv vs Radiative Heating

- LEAF-Lite will be used to simulate the shock-layer radiation on the fore-body heatshield and the less-intense shear-layer radiation (coming in part from superheated fore-body heat shield ablation products being carried in the flow) to the flank, or afterbody, of the capsule. The plasma flow in the IHF is supersonic, not hypersonic (like in actual entry), and the bow shock it generates isn’t strong enough to create the level of species dissociation and ionization that, in actual flight, leads to significant shock-layer radiation. It can simulate the overall level of heat transfer to the surface, but only through convection. And, there’s no guarantee that a TPS material will respond the same to a purely convective heat load as it will to a combined (convective/radiant) load of the same magnitude. Hence the need for LEAF-Lite. See slide below


Bow Shock
Viscous Interaction
Shock Layer Radiation
Dissociation & Ionization
Surface Recombination
Ablation & Recession
Boundary Layer Transition
Shear Layer
Afterbody Heating
RCS Interaction
Ablation Product Contamination
Separation
Recompression
Continuum Breakdown
Separation