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*NASA Reduced Gravity Student Flight Opportunities Program
2001 Flight Dates: August 23-31*

A STUDY OF OPTICAL PROPERTIES OF ZBLAN MICROSPHERES PRODUCED IN MICROGRAVITY

Principal Investigators:

Serena Eley, Dirk Englund, John Ferguson, Joseph Jewell, Philip Venturelli

Contact:

Serena Eley, seley@caltech.edu, (626) 395-1530

Advisers:

Dr. Lute Maleki, JPL Senior Research Scientist.

lmaleki@horology.jpl.nasa.gov, (818) 354-3688

Dr. Hideo Mabuchi, Assistant Professor of Physics at Caltech.

hmabuchi@caltech.edu, (626)793-9506

California Institute of Technology
1200 East California Boulevard
Pasadena, California 91125
(626) 395-6811



2 KC-135 Quick Reference Data Sheet

- *Principal Investigator:* Eley, Serena
- *Contact Information:* Caltech, MSC 406; Pasadena, CA 91126; seley@caltech.edu; (626) 395-1530 or (626) 395-3975
- *Experiment Title:* A Study of Optical Properties of ZBLAN Microspheres Produced in Microgravity
- *Flight Dates:* August 23-31
- *Overall Assembly Weight:* 58 lbs.
- *Assembly Dimensions (L x W x H):* 43.3" x 23.6" x 10.8"
- *Equipment Orientation Requests:* None.
- *Proposed Floor Mounting Strategy:* Bolts/Studs.
- *Gas Cylinder Requests:* None.
- *Overboard Vent Requests:* None.
- *Power Requirement (Type and Amps Required):* 115 V AC, 60 Hz, Single Phase; 110 Amps
- *Flyer Names for Each Proposed Flight Date (preferred):* Aug. 28: Serena Eley and Dirk Englund; Aug. 29: Joe Jewell and John Ferguson

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4 Flight Manifest

1. *Flyer Names for Each Proposed Flight Date (preferred)*: Aug. 28: Serena Eley and Dirk Englund; Aug. 29: Joe Jewell and John Ferguson; Alternate Flyer: Philip Venturelli
2. None of the participants has prior experience on the KC-135.

5 Experiment Background

The goal of this experiment is to fabricate undoped and doped ZBLAN microspheres in microgravity to investigate their quality factors (Q 's) and lasing properties. To accomplish this, we propose to conduct an experiment aboard the KC-135 that assesses the viability of the substance known as ZBLAN as a new alternative fiber optic medium. The world's communications network was revolutionized by the deployment of fiber optics systems. However, conventional silica-based fiber optics suffer from serious limitations. They are only capable of carrying information within a small range of the electromagnetic spectrum, and even within that range they exhibit a relatively high signal attenuation. Seeking to improve upon silica-based materials, researchers have fabricated glasses in the heavy metal fluoride family. The most promising of these glasses is ZBLAN, named for its zirconium, barium, lanthanum, aluminum and sodium components. ZBLAN can transmit light with losses close to the absolute theoretical minimum if properly produced. Unfortunately, when fabricated in a gravity well, tiny crystals form which destroy ZBLAN's potential transmittance properties. In a microgravity environment, there is experimental evidence that this crystallization does not occur.

Light resonances in these spheres could be extremely long-lived since the material attenuation coefficient will be much lower than for any microsphere ever fabricated. This could result in the realization of unprecedented quality factors. Furthermore, microsphere-based optical resonators serve as an effective medium for determining the effects of crystallization on transmittance. We believe that our erbium-doped ZBLAN microspheres can be used to create improved low-

threshold green lasers, which have a variety of applications in cavity quantum electrodynamics, communications, data storage, and medicine.

This experiment seeks to quantitatively compare the quality factor of ZBLAN microspheres fabricated in normal earth gravity versus microgravity aboard the KC-135. Our experiment highlights a novel approach to characterizing ZBLAN based on techniques refined from previous research. The fabrication procedure is derived from a technique developed by Dr. Lute Maleki and Dr. Vladimir Ilchenko of NASA's Jet Propulsion Laboratory, who are advising our group in its efforts. In 1998 Dr. Dennis Tucker of NASA's Marshall Space Flight Center showed that only very little crystallization occurs in ZBLAN fibers fabricated in a microgravity environment in a previous experiment aboard the KC-135. We have been in contact with him. Dr. Edwin C. Ethridge of Marshall Space Flight Center, who is PI of NASA'S NRA "Mechanism for the Crystallization of ZBLAN", has agreed to mentor our team. An experiment involving the production of ZBLAN fibers is also being considered for the International Space Station. In 1999 Serge Haroche of the Laboratoire Kastler Brossel demonstrated low-threshold green lasing with erbium-doped ZBLAN microspheres. We build upon these efforts to create an original experiment designed to measure the effects of gravity on the fabrication of ZBLAN microspheres for laser applications.

Please see the References at the end for technical references.

6 Experiment Description

The purpose of our experiment in flight is to produce microspheres of ZBLAN glass (both undoped and doped). To make a sphere, a 15cm long ZBLAN fiber is inserted into one end of a fiber splicer. The splicer creates a high voltage between two electrodes that are separated by a small distance of 1cm. The air between the electrodes breaks down, and the resulting plasma carries the current. This small voltage arc is hot enough to melt the extremely thin fiber at a fairly rapid rate, so that a small sphere beads up at the end of the fiber. Producing a sphere that's $100\mu\text{m}$ in diameter takes about 5 seconds. After a sphere is produced at the end of the fiber, the fiber is secured in a petri dish.

6.1 Test Objectives

In our experiment, we are most interested in the lasing and transmittance properties of the ZBLAN microspheres. To determine the transmittance properties, we will rely mainly on measuring the quality factor Q of the undoped ZBLAN microspheres and comparing the measurements to values obtained for silica-based microspheres produced under the same conditions. We expect to find much higher values for Q for spheres produced in $0 \cdot g$ than in $1 \cdot g$. To investigate the lasing properties, we observe the absorbed pumped power and the output intensity of green radiation. As mentioned above, the lasing threshold is predicted to be lower for ZBLAN spheres produced in $0 \cdot g$.

6.1.1 Post-Flight: Data Analysis

1. take microspheres to Pasadena, CA, for testing at JPL and Caltech
2. Testing Undoped ZBLAN Microspheres and Undoped Silica-Based Microspheres:
 - *Measurements:*
 - excite resonant modes in spheres using single-mode tapering technique
 - observe output intensity using photo-detector coupled to resonator using tapering technique
 - observe transient response: excite resonator with short pulse, then observe how the oscillating signal decays in time; determine quality factor Q
 - observe steady-state response: determine Q
 - compare Q values obtained for ZBLAN microspheres produced in $1 \cdot g$ and $0 \cdot g$ to those obtained for silica-based microspheres under corresponding conditions
 - *Expected Results:*
 - higher Q for microspheres produced in $0 \cdot g$ than for those produced in $1 \cdot g$
 - higher Q for ZBLAN microspheres than for silica-based microspheres
 - higher conduction frequency range for ZBLAN microspheres
3. Testing Doped ZBLAN Microspheres:
 - couple microsphere to silicon diode and take three measurements:
 - pump-power from near-infrared laser absorbed in microsphere
 - Q of pump mode
 - intensity of green up-conversion radiation using a spectrum analyzer
 - *Expected Results:*
 - higher Q for microspheres produced in $0 \cdot g$ than for those produced in $1 \cdot g$
 - silica-based microspheres show less efficient up-conversion than ZBLAN microspheres
 - expect higher Q for ZBLAN microspheres than for silica-based microspheres
 - expect lower lasing threshold for ZBLAN microspheres produced in $0 \cdot g$ than for ZBLAN microspheres produced in $1 \cdot g$ and for silica-based microspheres



Figure 1: Image of Splicer ORIONICS FW-310

7 Equipment Description

- *Fiber Splicer FW-310*. See Fig. 1. Strapped to bolts on mounting board, which in turn are bolted to the aircraft floor. Straps used are those provided by the program.

Specifications

- ARC: High frequency AC, tungsten electrodes.
 - POWER: AC input: 105-130V, 220-240V, 60VA at 50/60 Hz.
DC input: 12-15V, 30W. Wire Gauge = 12.
 - BATTERY: Internal 4.0 A-hr NiCad battery.
 - CASE: Molded fiberglass, “O”-ring sealed. Dust and watertight when cover is closed and latched.
 - SIZE: 13.7” x 12” x 9.75” (35 cm x 30 cm x 25 cm)
 - WEIGHT: 28 lbs (12.7 kg)
 - SHIPPING WEIGHT: 36 lbs (16.3 kg)
 - SHOCK: Can withstand a drop of one foot onto a concrete floor without internal damage when cover is closed and latched.
- 3 “Out-Box” containers. Made from Tupperware boxes: square base with 4” sides, 2” height. About 0.1 lbs (50 gm). With lids. Styrofoam glued to bottom on one half of box for holding fibers. Screwed to mounting board. See Fig. 2.

- *“In-Box” container.* Made from Tupperware box: 8.5” x 6.5” x 3.5” (21.6 x 16.5 x 8.0 cm); 0.3 lbs (120 gm) with lid. Styrofoam glued to bottom on opposing sides for holding fibers. Screwed to mounting board. See Fig. 2.
- *Mounting Board.* Made of wood. 43.3” x 23.6” x 1.0” (110 x 60 x 2.54 cm). 30 lbs. Bolted to aircraft floor. See Fig. 2.
- *Tool Bag.* Sturdy bag with zipper on side and two side pockets. 8” x 8” x 4”. Screwed to mounting board. See 2.
- *Wire Cutter* Used for cutting fibers. Placed in tool bag.
- *Camera.* Nikon Rebel G. To be placed in bag.

The experimenters are strapped down in front of the mounting board. One experimenter produces the spheres with the fiber splicer; the other one handles taking the fibers out of the “in-box” and securing them in the “out-box” after they have been used.

8 Structural Analysis

Our entire apparatus will weigh below 60 lbs (the splicer will be used without its top). It’s center of gravity will be 2.8” off the aircraft floor, and it will be mounted on a 1” wooden board.

The most weight that any bolt could hold, in the case of 9g acceleration and all the weight supported by a single bolt, is therefore 540 lbs—well below the 5000 lb limit of the mounting grid. The straps we will use to bolt down the fiber splicer will be 2” thick and will support up to 5000 lbs. The maximum tensile strength (in the case of 9g acceleration and the entire fiber splicer held by a single strap) is only 270 lbs—again, well below the critical limit.

To get an idea of the torques on the mounting bolts, consider the extreme case of a 60 lb mass 3” directly above a mounting point, accelerated at 9g. This acceleration will put a torque of 135 ft-lbs on the mounting point. This will cause an upward force of 18 lbs on a second mounting point 20” behind the first. This is very easily within the aircraft’s limitations.

9 Electrical Load Requirements

9.1 Schematic

The only that requires electricity is the fiber splicer. It draws no more than 30W at 110V AC when in operation, which is no more than 10 seconds per parabola. See Fig. 3.

9.2 Load Table

We use only one wire, which never draws more than 0.3 Amps. See 7.

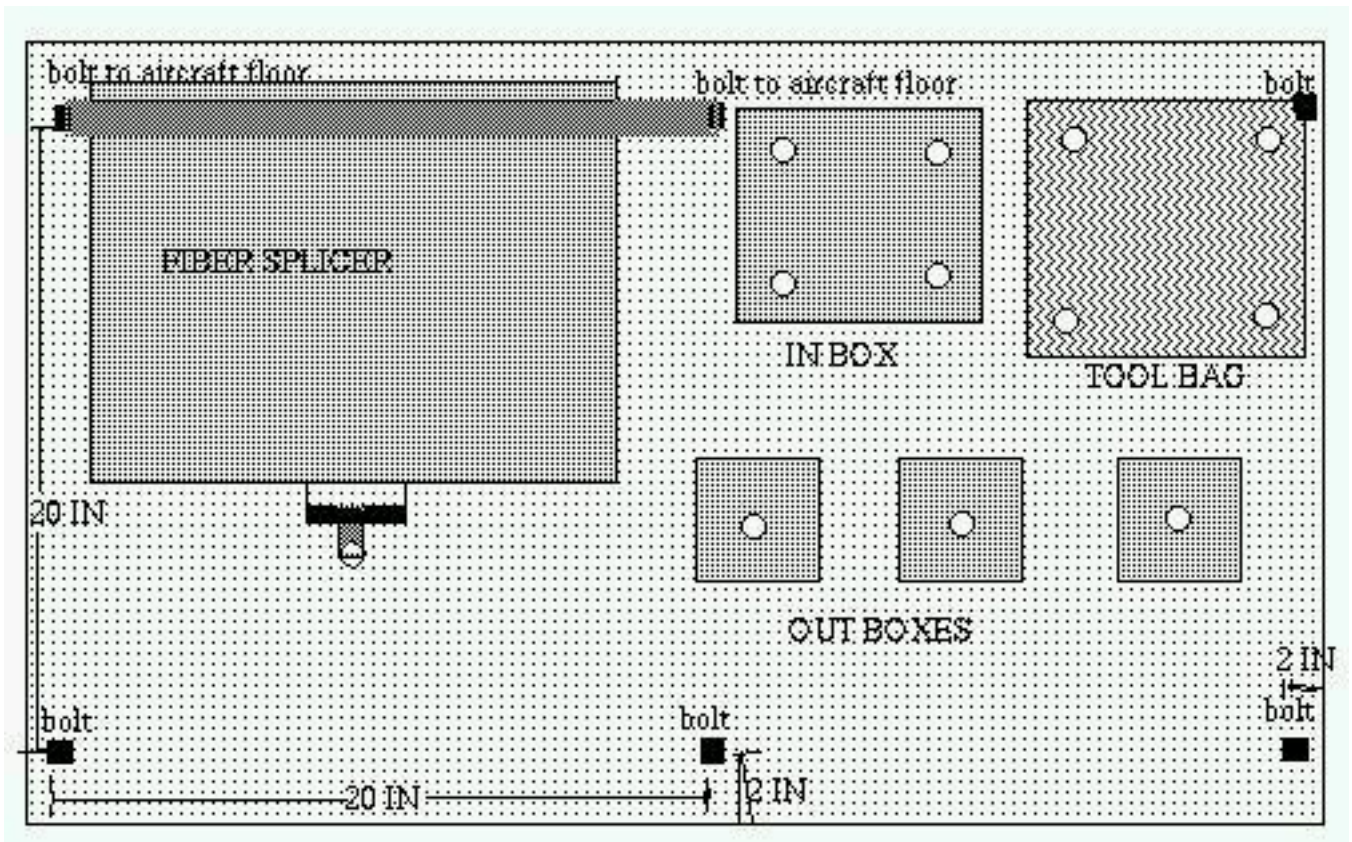


Figure 2: Experiment Setup. The small dark squares represent bolts to the aircraft floor; the small light circles represent bolts/screws to the mounting board.

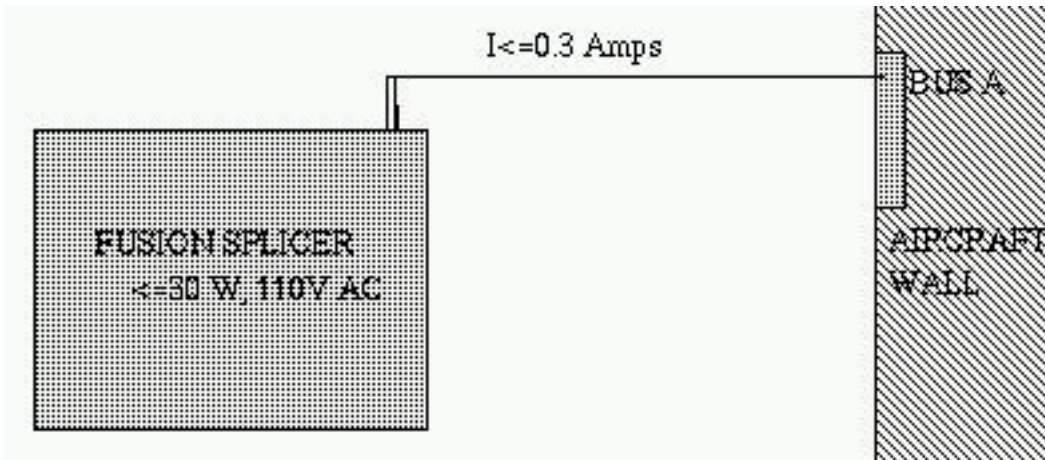


Figure 3: Schematic of Electrical Wiring

9.3 Emergency Shutdown Procedures

The fiber splicer only operates if one of the experimenters is holding down a button. It has a manual shut-off switch, which interrupts the power circuit.

10 Pressure Vessel Certification

Not applicable.

11 Laser Certification

Not applicable.

12 Parabola Details and Crew Assistance

No crew assistance will be required. See the Procedure section (Sec. 22) for parabola details.

13 Free Float Requirements

Our experiment does not incorporate any free-floating components.

14 Institutional Review Board

Our experiment does not incorporate any human, animal, or biological tests of any kind.

15 Hazard analysis

Hazard Analysis Report = Hazard Source checklist + Detailed hazard description

15.1 Hazard Source Checklist

- Flammable/combustible material, fluid (liquid, vapor, or gas): N/A
- Toxic/noxious/corrosive/hot/cold material, fluid (liquid, vapor, or gas): N/A
- High pressure system (static or dynamic): N/A
- Evacuated container (implosion): N/A
- Frangible material: N/A
- Material susceptible to stress corrosion: N/A
- Inadequate structural design (e.g. low safety factor): N/A
- High intensity light source (including laser): N/A
- Ionizing/electromagnetic radiation: N/A
- Rotating device: N/A
- Extendible/deployable/articulating experiment element (collision): N/A
- Stowage restraint failure: N/A
- Stored energy device (e.g. mechanical spring under compression): N/A
- Vacuum vent failure (i.e. loss of pressure/gas): N/A
- Heat transfer (habitable area over-temperature): N/A
- Over-temperature explosive rupture (including electrical battery): N/A
- High/Low touch temperature: N/A
- Hardware cooling/heating loss (i.e. loss of thermal control): N/A
- Pyrotechnic/explosive device: N/A
- Propulsion system (pressurized gas or liquid/solid propellant): N/A

- High acoustic noise level: N/A
- Toxic off-gassing material: N/A
- Mercury/mercury compound: N/A
- Organic/microbiological (pathogenic) contamination source: N/A
- Sharp corner/edge/protrusion/protuberance: N/A
- Flammable/combustible material, fluid ignition source (i.e. short circuit, under-sized wiring/fuse/circuit breaker): N/A
- High voltage (electrical shock): 1
- High static electrical discharge producer: N/A
- Software error: N/A
- Carcinogenic material: N/A

15.2 Detailed Hazard Description

- Hazard Number: 1.
- Hazard Title: High voltage (electrical shock).
- Hazard description: The fiber splicer uses a high voltage arc which is required for the experiment. With improper care, the arc could shock one of the experimenters.
- Hazard Causes: the shock could be caused by one of the following events:
 1. Contact with the fusion area.
 2. Contact with the fiber.
- Hazard control(s): A protective block helps isolate the fusion area and minimize any contact with external conductors. During operation of the fusion splicer, the experimenter will not make direct contact with the fiber. Rather, the splicer has an insulated mechanism used to advance and retract the fiber in the fusion area. In the case of a shock, fuses in the power supply and fiber splicer would cut power to the system.

16 Tool Requirements

- Tools necessary during flight (kept in tool bag):
 - Two pairs of stainless-steel tweezers
 - KimWipes
 - A Wire Cutter

- Tools necessary on the ground:
 - Four (4) pairs of stainless-steel tweezers
 - KimWipes
 - Rubbing alcohol dispenser
 - Adaptor as battery charger
 - Soldering iron
 - Solder
 - Wrench
 - Needle-nose pliers
 - Wire cutter/stripper
 - Fiber strippers
 - Fiber cleaver
 - Large and small screw drivers
 - Hex wrench (for fiber splicer case)

The team will provide all of these tools. We will have a toolbox in which everything but the adaptor/battery charger will be kept (due to size restrictions) and all of our tools will be labeled "Caltech" or "CIT" in black marker on masking tape.

We have reduced the number of tools actually necessary in flight to the bare minimum, requiring only lab tweezers, wire cutters, and KimWipes for cleaning the fibers (should they accidentally become contaminated during flight).

17 Photo Requirements

1. We would like a still photographer to take general photos of our team in action, and a few photographs during each flight of us performing our experimental procedure (during one or two parabolas), and at least one close-up of a microsphere forming in the fiber-splicer. There is a viewing window at the front of the device to facilitate this.
2. A videographer will be required only for a short period of time on each flight (no more than 10 or 15 minutes). We wish to have an example of our experimental procedure (during one or two parabolas) recorded on videotape, and during a separate parabola would like close-up video of a microsphere forming in the fiber-splicer. There is a viewing window at the front of the device to facilitate this.
3. No S-band downlink is required.
4. No camera poles are required.

18 Aircraft Loading

Our experiment will weigh less than 100 pounds, so two handles on either side of the board will allow two team members to manually lift it into place on the plane without undue strain. The board will be constructed to bolt directly into the grid on the floor of the KC-135 cabin.

19 Ground Support Requirements

We will require ground power (110V AC, 60W). Isopropyl alcohol is the only chemical that needs to be stored.

20 Hazardous material

The materials used aboard the KC-135 for this experiment are not toxic, corrosive, explosive, or flammable.

21 MSDS

No chemicals requiring a MSDS will be used.

22 Procedures

- Pre-flight operations: We will transfer the ZBLAN samples from our hermetically-sealed carrying case into the containers attached to the experiment board. The splicer electrodes will be cleaned. The accelerometer will be calibrated. A final check of the charge on our two batteries will be performed. We will require a standard 120-volt AC power outlet for our chargers. There are no special cabin-temperature or in-flight storage requirements.
- Take-off/Landing: There are no special procedures, equipment storage, or power requirements necessary during take-off or landing.
- Equipment shipping: The fiber splicer, AC/DC converter (on board), and battery will be shipped to NASA-JSC Ellington Field by UPS. Smaller or more sensitive components (such as the fiber samples themselves) will be hand-carried to Houston by one of the team members.
- Ground operations: The ZBLAN samples will be carried in a hermetically-sealed container to Ellington Field by one of the team members. Our experiment will arrive at Ellington largely intact (i.e. with everything attached to the board), except for the fiber splicer itself and two Lithium-Ion batteries, which will be shipped separately or carried to the site by team members. These will be attached to the board by means of straps

through the handle and across the back of the fiber splicer, and straps across the batteries (which will also be sunken into recesses in the board to provide lateral stability). The batteries will then be charged and the whole device tested. We will require a standard 120-V AC power outlet (for our battery charger) and the hand tools that are listed in section 16.

22.0.1 In-Flight: Equipment Operation During Various g-phases of the Parabolas

The procedure for production of each sphere (assuming two capable team members) shall be as follows:

- a. during level flight/2 g flight, member A removes the last completed microsphere from the splicer with tweezers
- b. member A packs the completed microsphere in the storage container ("out-box")
- c. while A is packing, member B loads a fresh ZBLAN sample into the fiber splicer with tweezers and lines it up
- d. during 0 g flight, member B activates the fiber splicer and pushes in the fiber to form the molten microsphere, then allows it to solidify (solidification will take less than 1 second).
- e. Note: in the event that one member becomes incapacitated during the course of the flight, it should still be possible to continue production at the planned rate of one microsphere per parabola, by combining the duties of members A and B in the order listed.

1. First Flight:

- (a) level flight: set up one fiber, then produce one microsphere, then set up another fiber
- (b) during first fifteen runs, produce undoped ZBLAN microspheres in microgravity: one each during $1 \cdot g$ conditions (level flight), and one during $0 \cdot g$ conditions.
- (c) during next five runs, produce undoped silica-based microspheres in microgravity: one each during $1 \cdot g$ conditions (level flight), and one during $0 \cdot g$ conditions.
- (d) during next two runs, produce undoped ZBLAN microspheres under $0 \rightarrow 1$ g conditions.
- (e) during next two runs, produce undoped ZBLAN microspheres under $1 \rightarrow 2$ g conditions.
- (f) during next two runs, produce undoped silica-based microspheres under $0 \rightarrow 1 \cdot g$ conditions

- (g) during next two runs, produce undoped silica-based microspheres under $1 \rightarrow 2 \cdot g$ conditions
 - (h) during remaining runs, produce undoped ZBLAN microspheres in microgravity: one each during $1 \cdot g$ conditions (level flight), and one during $0 \cdot g$ conditions.
 - (i) note that directly after each microsphere is produced, it is placed in a desiccator to limit water absorption.
2. Second Flight: repeat steps for First Flight, using doped ZBLAN/doped silica-based glass

22.0.2 Post-Flight

Post-Flight the batteries will be recharged, the completed microspheres of-flooded, and fresh (doped) ZBLAN samples placed in the onboard storage containers.

Off-Loading:

Using the same two handles that were used to load the equipment, our experiment board will be removed from the KC-135. UPS will ship the equipment back to team member Dirk Englund, who is going back to Caltech in Pasadena.

23 Bibliography

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