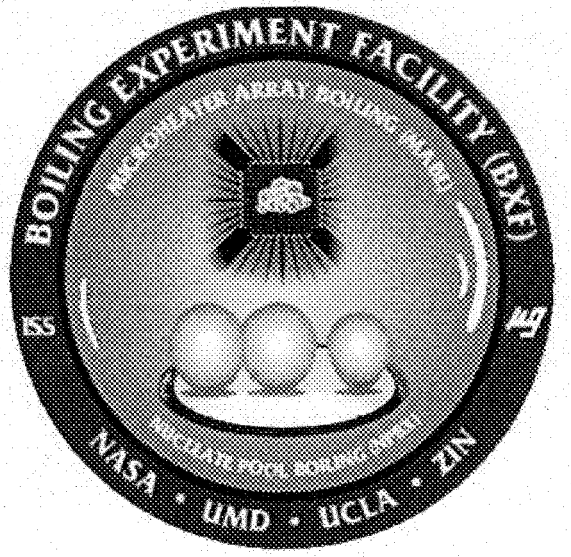
Boiling eXperiment Facility (BXF)

HLS88:
The Boiling eXperiment Facility (BXF) for the Microgravity Science Glovebox (MSG)



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Boiling eXperiment Facility (BXF)

Abstract

Boiling is an effective means of cooling by removing heat from surfaces through vaporization of a working fluid. It is also affected by both the magnitude and direction of gravity. By conducting pool boiling tests in microgravity, the effect of buoyancy on the overall boiling process and the relative magnitude of other phenomena can be assessed.

The Boiling eXperiment Facility (BXF) is being built for the Microgravity Science Glovebox. This facility will conduct two pool boiling studies. The first study the Microheater Array Boiling Experiment (MABE) uses two 96 element microheater arrays, 2.7 mm and 7.0 mm in size, to measure localized heat fluxes while operating at a constant temperature. The other experiment, the Nucleate Pool Boiling eXperiment (NPBX) uses a 85 mm diameter heater wafer that has been "seeded" with five individually-controlled nucleation sites to study bubble nucleation, growth, coalescence and departure.

The BXF uses normal-perfluorohexane as the test fluid and will operate between pressures of 60 to 244 kPa. and temperatures of 35 to 60 deg C. Both sets of experimental heaters are highly instrumented. Pressure and bulk fluid temperature measurements will be made with standard rate video. A high speed video system will be used to visualize the boiling process through the bottom of the MABE heater arrays.

The BXF is currently schedule to fly on Utilization Flight-13A.1 to the ISS with facility integration into the MSG and operation during Increment 15

Boiling eXperiment Facility (BXF)

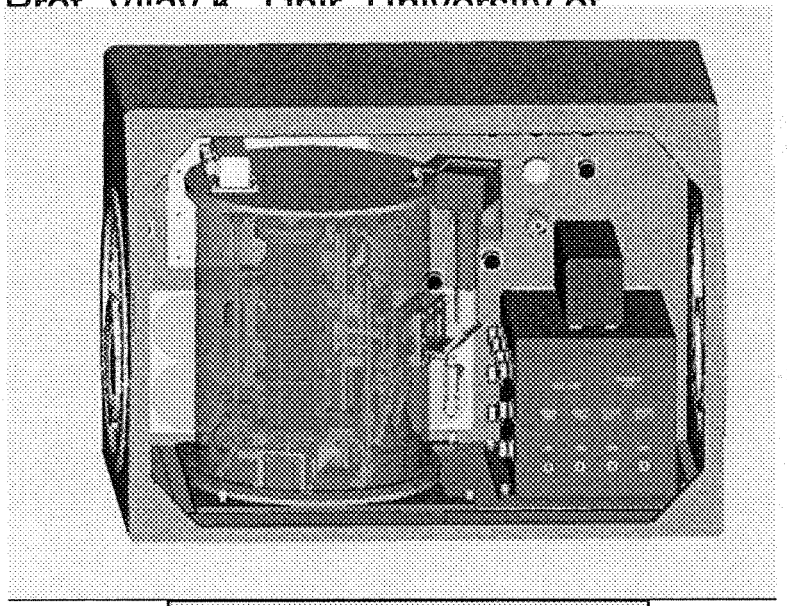
Overview

The Boiling eXperiment Facility is designed to fit inside the Microgravity Science Glovebox (MSG) and allow the operation of two distinct experiments:

- Miro-heater Array Boiling Experiment (MABE) PI: Prof. Jungho Kim, University of Maryland
- Nucleate Pool Boiling Experiment (NPBX) PI: Prof. Vijay K. Dhir, University of California at Los Angeles

OVERALL OBJECTIVES

- The BXF experiments will provide data on nucleation, bubble dynamics, vapor removal and associated heat transfer under reduced gravity conditions.
- Validate numerical simulation models that will serve as design tools.
- Pool boiling data will have significant impact on the design of thermal control, food processing and water reclamation.



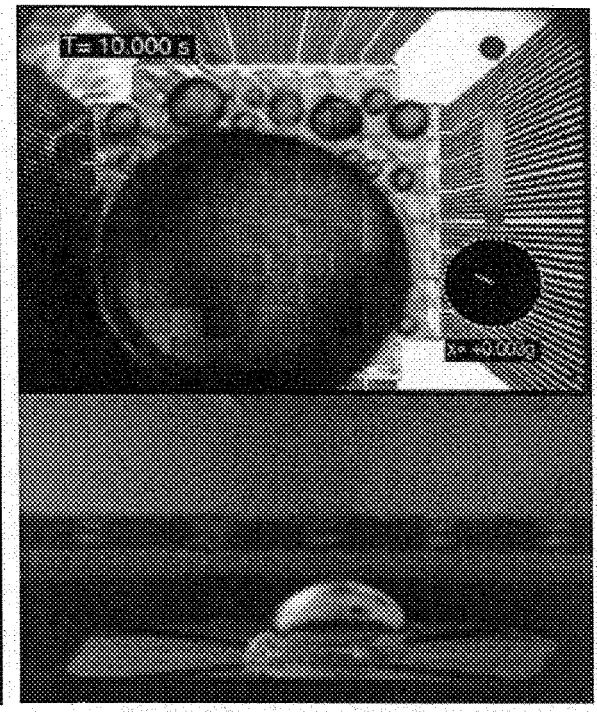
BXF payload in MSG

Boiling eXperiment Facility (BXF)

Microheater Array Boiling eXperiment (MABE)

- Microheater Array Boiling Experiment (MABE) is an experiment planned to obtain spatially and temporally resolved boiling heat transfer measurements in microgravity using an array of microheaters.

- Prof. Jungho Kim of the University of Maryland is the principal investigator for MABE and is seeking to determine the differences in local boiling heat transfer mechanisms in microgravity and normal gravity from nucleate boiling, through critical heat flux and into the transition boiling regime.



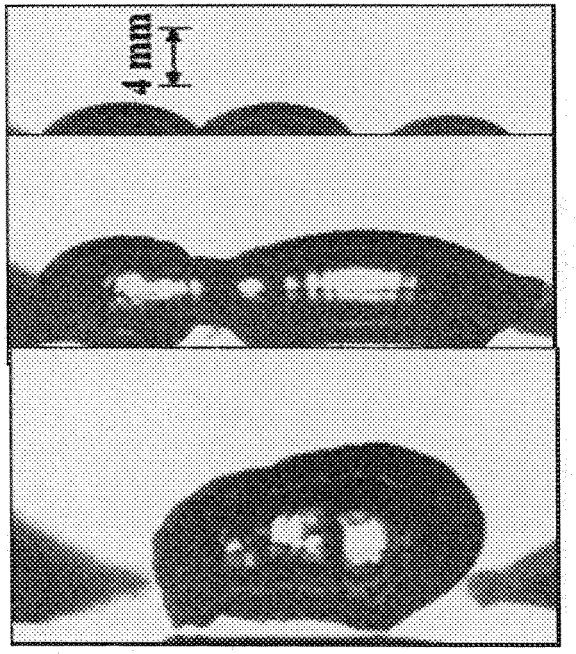
Subcooled nucleate boiling in microgravity: one view (top) through the microheater array colorized with actual heat flux distribution, and a second view (bottom) from the side

Boiling eXperiment Facility (BXF)

Nucleate Pool Boiling eXperiment (NPBX)

- Nucleate Pool Boiling eXperiment (NPBX) is an experiment planned to develop a basic understanding of heat transfer and vapor removal processes taking place during nucleate boiling from a well characterized surface.

- The Nucleate Pool Boiling Experiment, NPBX, led by Prof. Vijay K. Dhir of the University of California, Los Angeles, will study bubble nucleation, growth and departure and the cooling that is achieved under microgravity conditions



High-speed time-lapse imagery documenting nucleation of 3 separate vapor bubbles (top image), coalescence of the middle and right bubble (middle image) and finally after all the vapor bubbles have merged.

Boiling eXperiment Facility (BXF)

Key Role of Innovation and Technology

- BXF experiments will provide data on nucleation, bubble dynamics, vapor removal and associated heat transfer under microgravity conditions.
- Validated numerical simulation models could serve as design tools.
- Pool boiling data will have significant impact on the design of thermal control, food processing and water reclamation technologies.
  - Two-phase thermal control offers isothermal temperature control, reduced pumping power and smaller system mass.
  - Pool boiling is a limiting case of flow boiling → No Flow
  - Some models for flow boiling utilize a pool boiling term that is opposed by a single phase convection term

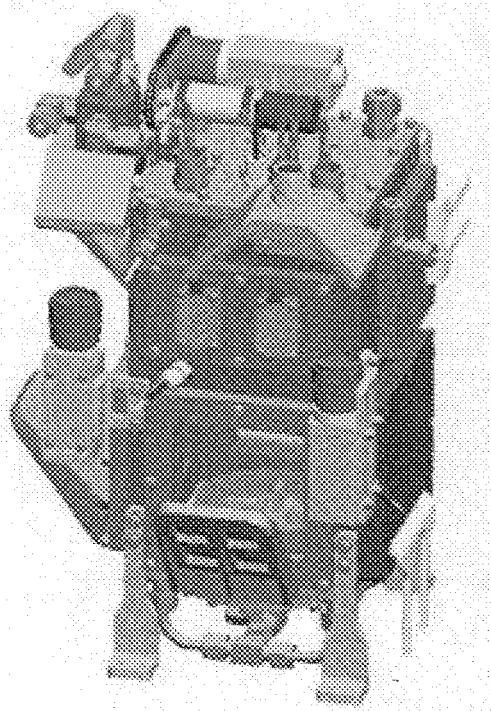
$$h_{2\Phi Flow} = h_{Pool\ Boiling} - h_{Liquid\ Flow}$$

  - Temperatures associated with boiling are sufficient for killing bacteria in food.

Boiling eXperiment Facility (BXF)

Experiment Specific Hardware

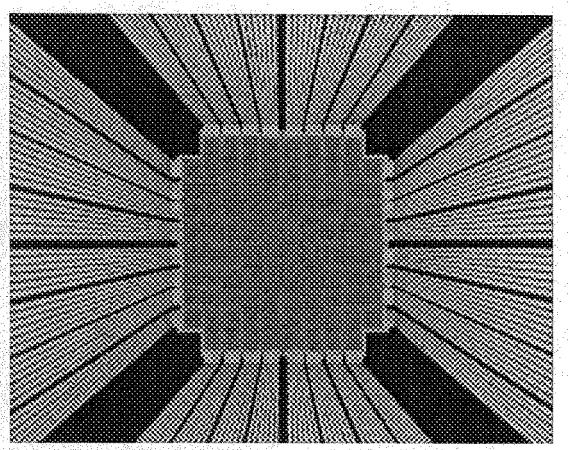
- One experiment, Microheater Array Boiling Experiment (MABE) utilizes two heater arrays (7 mm^2 and 2.7 mm^2). Each heater array consists of 96 individually controlled heaters that operate at a constant temperature and record the power required to maintain that temperature.
- The other experiment, Nucleate Pool Boiling Experiment (NPBX), utilizes a single heater array, consisting of 5 independently controlled nucleation sites or cavities. Each cavity has its own set of 7 heaters, one that directly heats the cavity and the remaining six heaters that surround the cavity.
- All three heater arrays are located in a single test chamber. Temperature, pressure, and video will be acquired throughout the testing process.

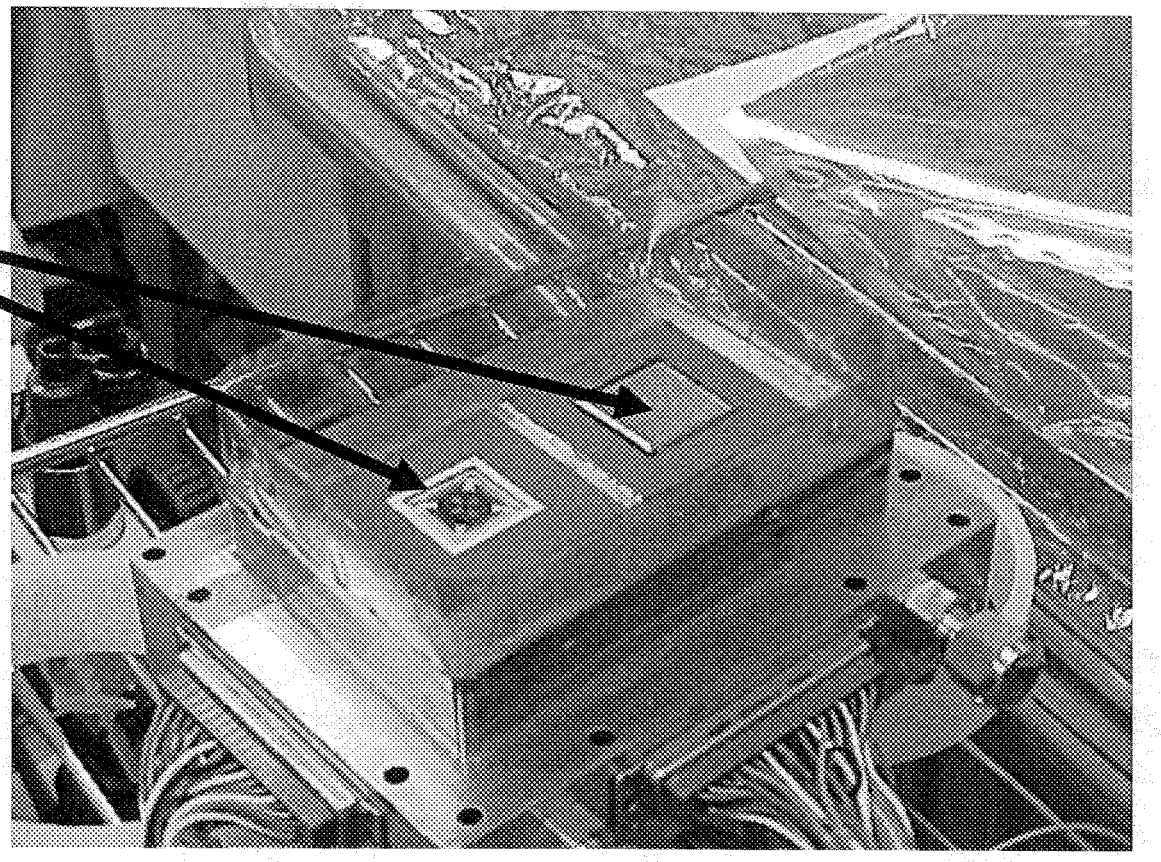


Boiling eXperiment Facility (BXF)

MABE Heater Arrays & Cooling Chamber

96 individually controlled microheaters

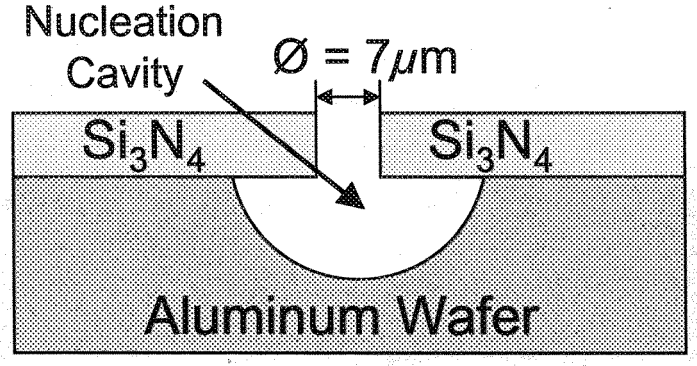




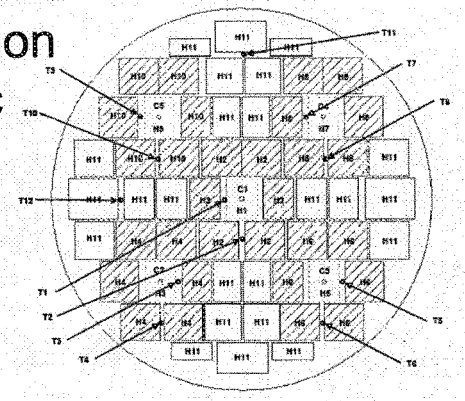
(Currently in MABE Heater testing configuration.)

Boiling eXperiment Facility (BXF)

NBPX Heater



Heater Backside Instrumentation Schematic



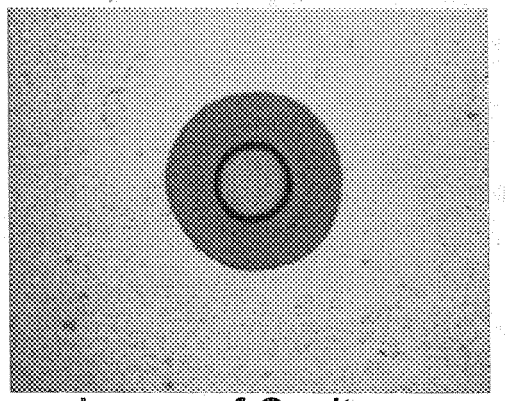
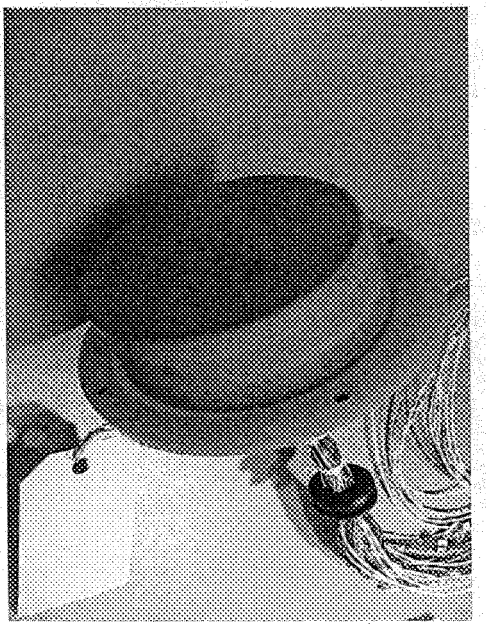
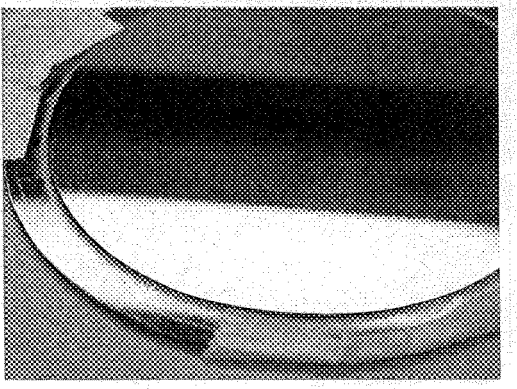


Image of Cavity viewed through Microscope



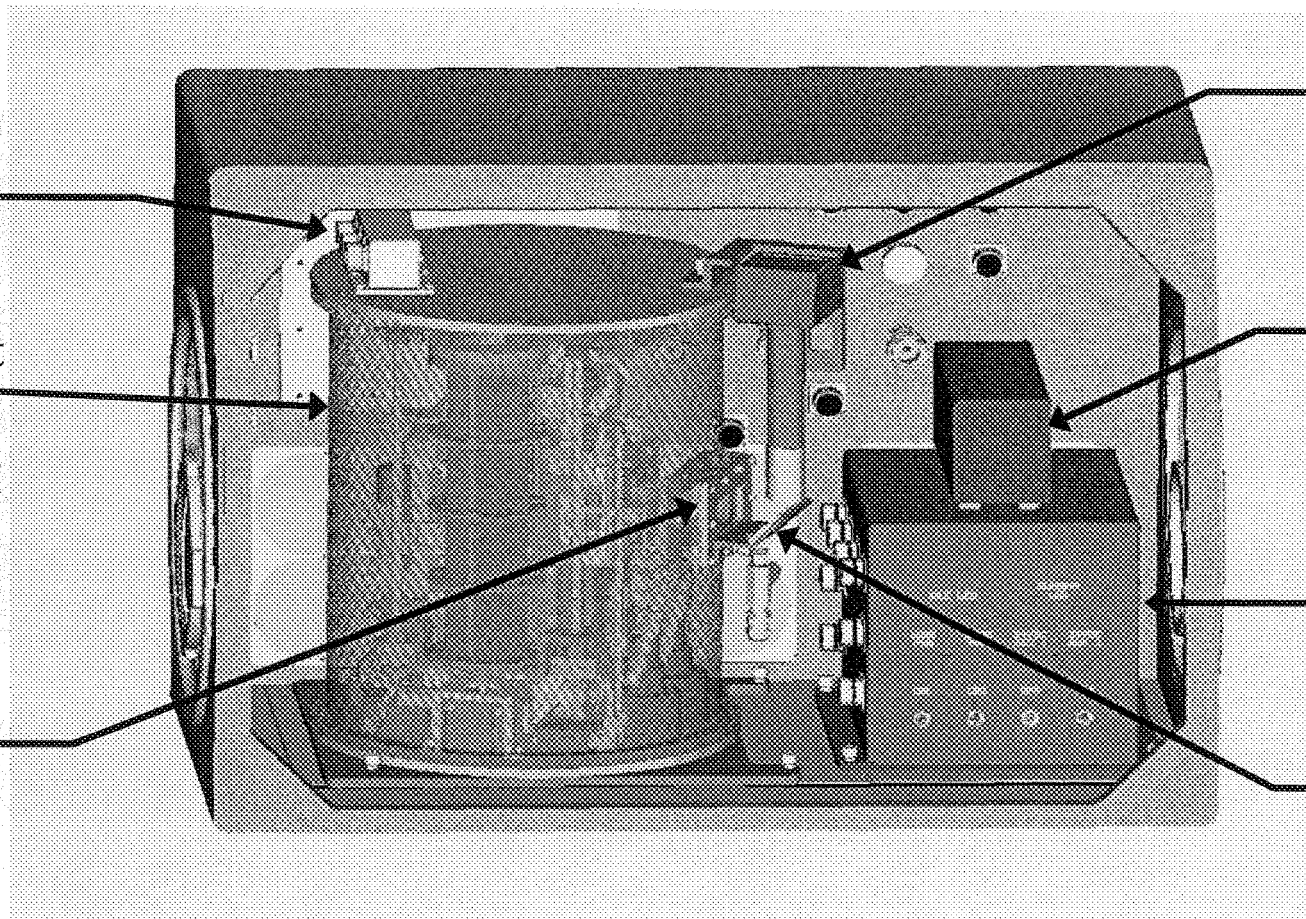
Heater Assembly



Polished Surface

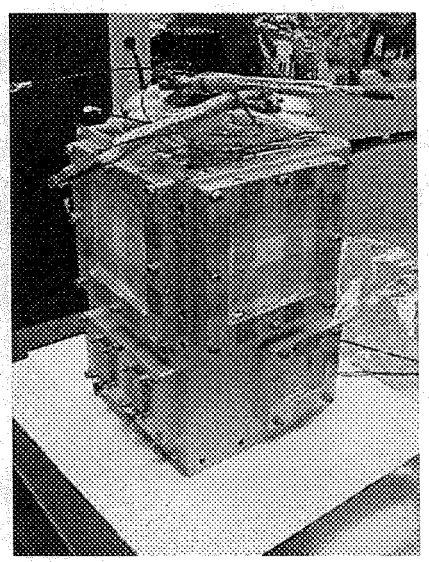
Boiling eXperiment Facility (BXF)

Flight Hardware in MSG

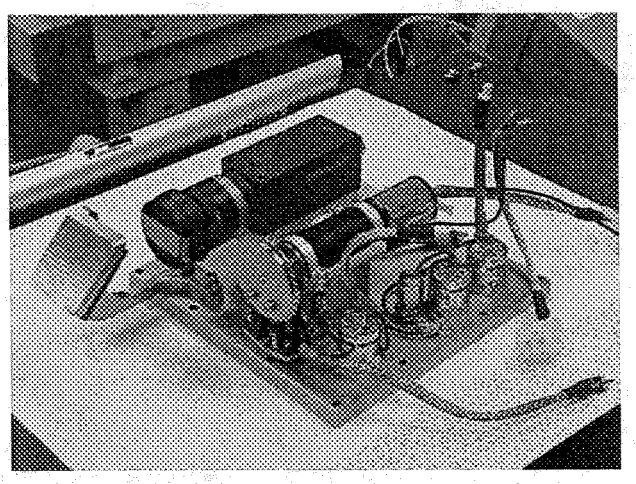


Boiling eXperiment Facility (BXF)

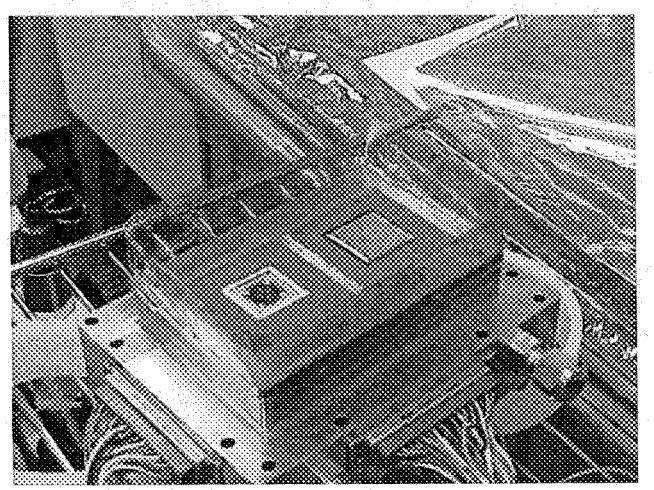
Flight Hardware in Assembly



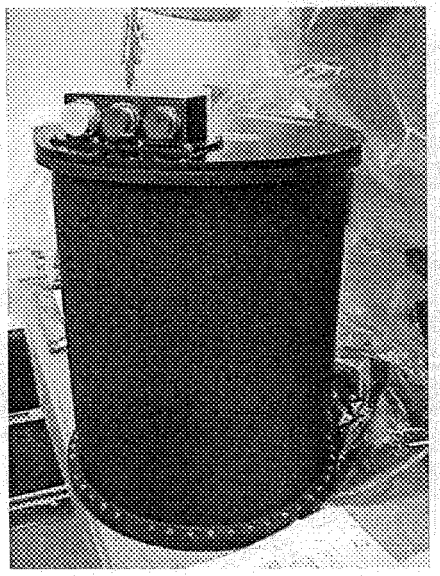
Test Chamber Housing (Sapphire windows are in place, but covered up for protection.)



Test Chamber Top Plate



MABE Heater Arrays & Cooling Chamber (Currently in MABE Heater testing configuration.)



Containment Vessel Housing

Boiling eXperiment Facility (BXF)

Test Fluid

- Commercial grade FC-72 from 3M was originally intended to be used.
  - Heat Transfer Fluid for Electronics
  - Holds large amounts of Dissolved Oxygen. Aspirated into Premature Infants lungs to help them breathe
  - MSDS indicated potential thermal decomposition above 200°C
- Concerns about Potential High Temperature Decomposition aboard ISS
  - Trace Contaminant Control Subassembly (TCCS) and Solid Fuel Oxygen Generator (SFOG) operate above 450°C
- FC-72 required additional approval to resolve toxicology issues.
- MABE PI requested change due to purity issues based on science.
  - FC-72 a blend of perfluorohexane isomers.
  - Most boil around 56°C, but there is a small percentage that boil more a couple of degrees below that.
  - Want to avoid "diffuso-thermocapillary" flows.
- Will use Aldrich Chemical Co.
  - Purity > 99+% perfluoro-n-hexane (PFNH).
  - Approved by JSC Toxicology
- Incorporate "verifiable" triple containment of test fluid.

Boiling eXperiment Facility (BXF)

Plans

- Complete Assembly
- PI Testing
- Launch
- ISS Testing

Boiling eXperiment Facility (BXF)

Acknowledgements

- Zin Engineering Team
  - Ed Selent, Bill Shiley, Bill Birchenough, Jim Charpie, Bill Arnold, Chris Lant, Natalie Goldin
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  - Prof. Jungho Kim, University of Maryland
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    - Dr. Gopinath Warrier, post-doc
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