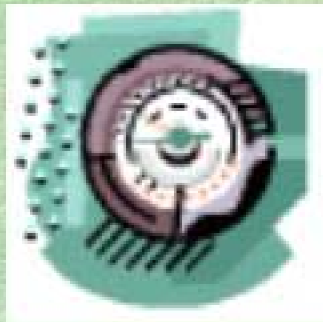

Control Methods for Thermal Testing

TFAWS Conference 2003
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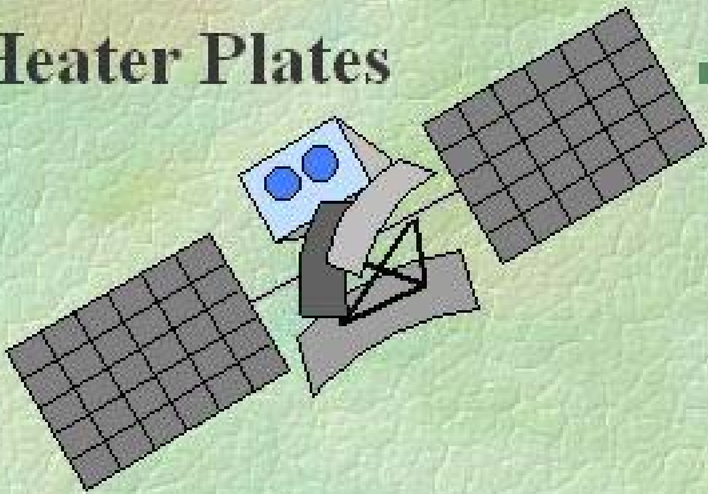
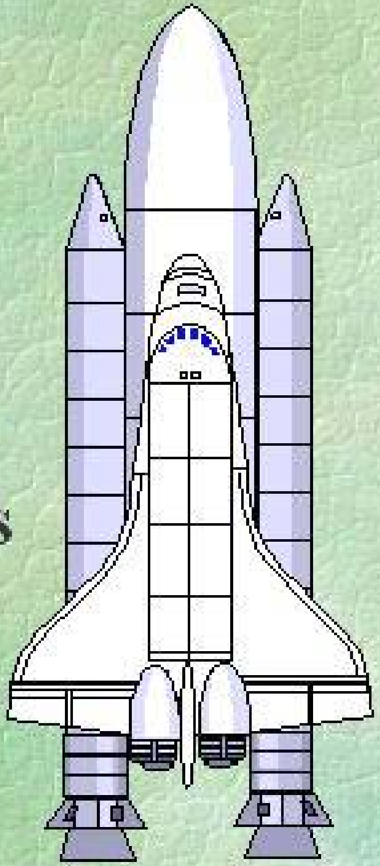
Thermal Control Methods

- Chambers
- Dewars
- Cryopanels
- Cold Plates
- Heater Plates

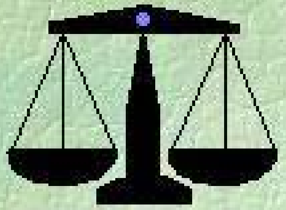
- Cal-rods
- Lamps
- Coolers
- Test Heaters
- Test Blankets





How to Use Control Methods

- For **Thermal Balance** the heat flows and heat transfer mechanisms should be the same for test and flight. Test heaters may be used to simulate fluxes that can not be imposed using cryopanels or the chamber.

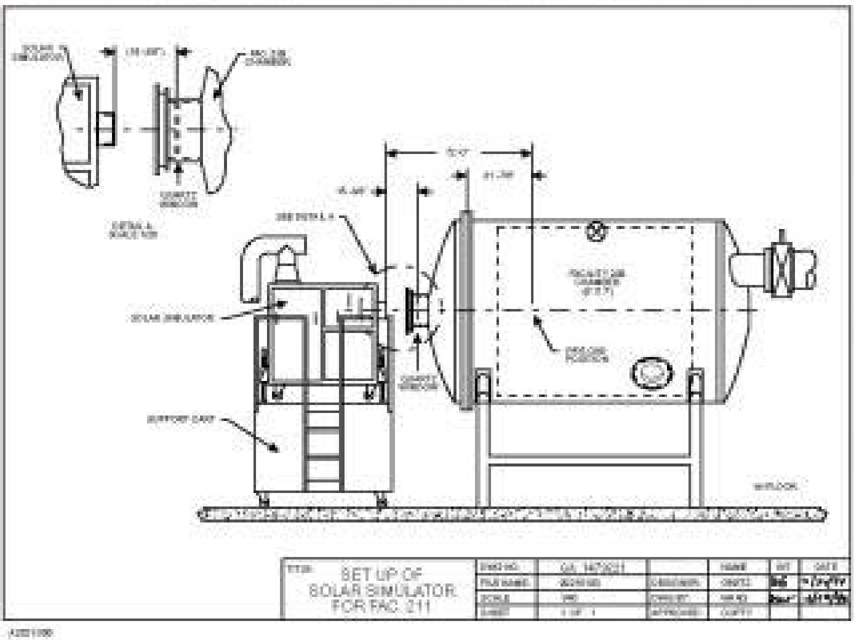


- For **Thermal Vacuum** the environment doesn't need to be flight like. Any use of cryopanels, heater plates, test heaters, etc. that produce the desired temperatures can be used. Use of test heaters to protect the hardware and elevated payload temperatures make for a safer, easier and faster test.

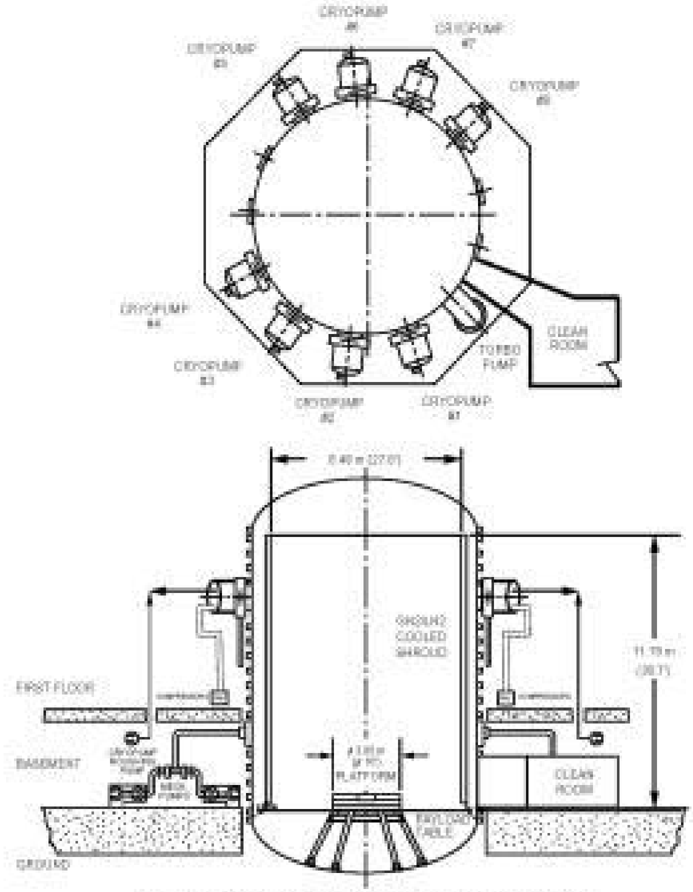
Chambers

- Every chamber is different; the thermal engineer should be aware of the capabilities of the test facilities. One of the first things the thermal engineer should do is to determine which chamber(s) the payload can fit into and if that chamber meets the general requirements. The chamber represents the overall sink for the payload. The thermal engineer may vary the temperature of the chamber shroud for various test cases.
- Cryo-pumped or Diffusion Pumped (Contamination Issue)
- Temperature Regimes:
  - Flooded with Liquid Nitrogen, (LN_2 approximately 80-90 K)
  - Controlled with Gaseous Nitrogen (GN_2 approx. 170-375 K)
  - Liquid Helium (20-30 K)
- Vibration Requirements
- Cleanliness Levels and Contamination Issues

Chambers



SOLAR SIMULATOR SET UP AT CHAMBER



CHAMBER AND VACUUM SYSTEM SCHEMATIC
FACILITY 290

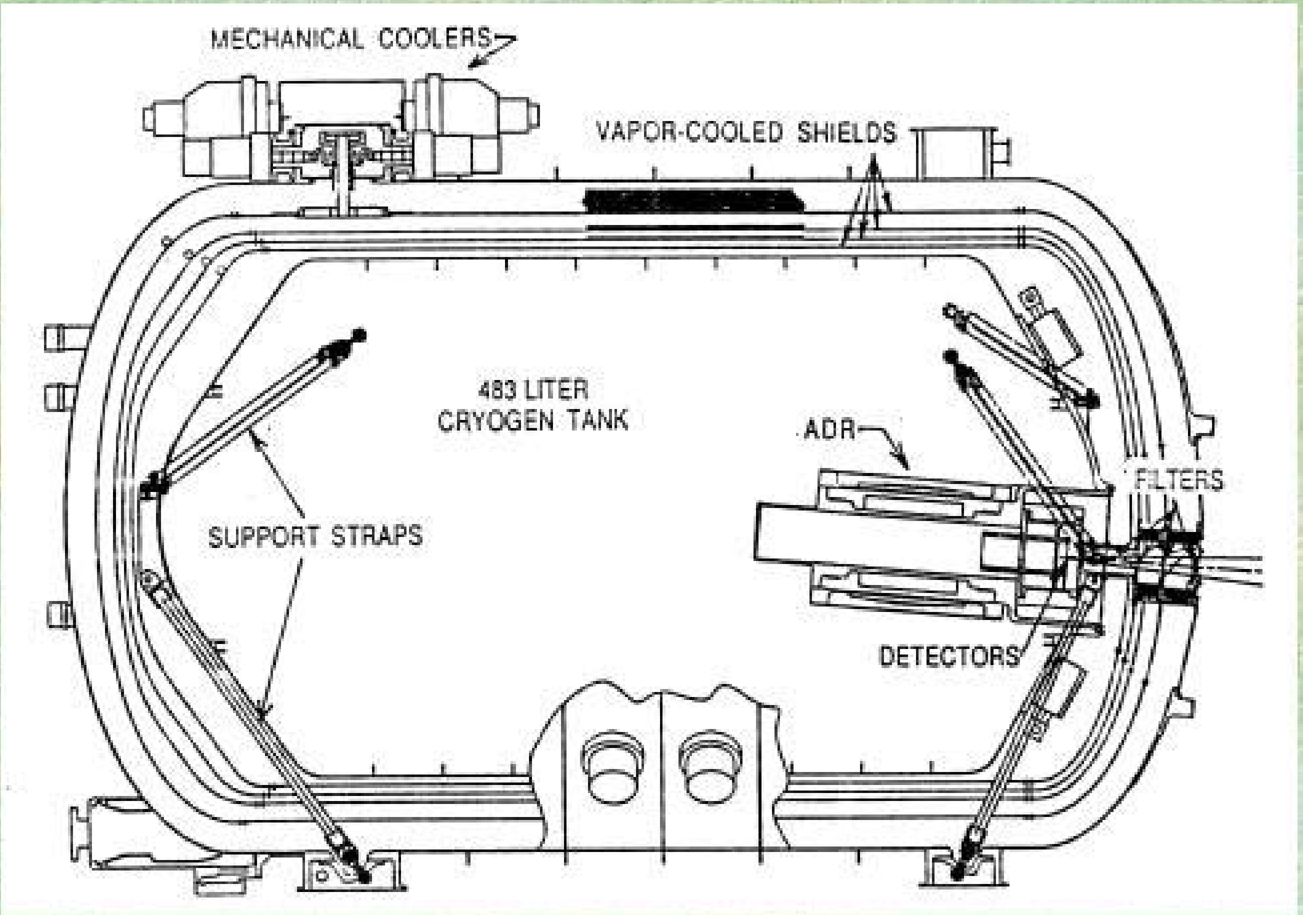
Some GSFC Facilities

Dewars

- Cooling available over temperature range 0.3 - 80 Kelvin (with gaps)
  - Solid Cryogens
    - Argon (Triple Point Temperature = 83.8 K)
    - Nitrogen (Triple Point Temperature = 63.2 K)
    - Neon (Triple Point Temperature = 24.4 K)
    - Hydrogen (Triple Point Temperature = 14.0 K)
  - Liquid Cryogens
    - ^{4}He (Lambda Point Temperature = 2.17 K)
    - ^{3}He (0.34 K--record for lowest on-orbit temperature)

- ***Gravity Effects on Cryogen***

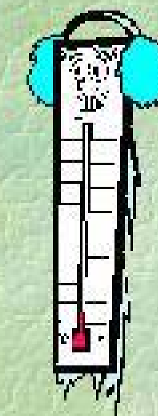
Dewars



MECHANICAL COOLERS
VAPOR-COOLED SHIELDS
483 LITER
CRYOGEN TANK
ADR
FILTERS
SUPPORT STRAPS
DETECTORS

Cryopanels

- Cryopanels are plates that are radiative sinks for critical areas (i.e. radiators, apertures, etc.).
- Temperature Regimes:
  - GN_2 approximately 130-375 K
  - LN_2 approximately 80-90 K
  - Helium approximately 20-30 K



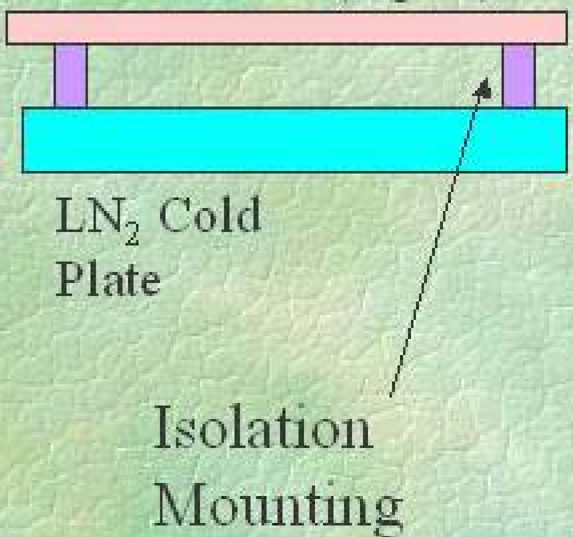
- For Thermal Vacuum the temperatures of the cryopanels may be colder than the flight environment to aid in reaching qualification temperatures.
- For Thermal Balance the temperature of the cryopanel is set to approximate the net energy flow from/to the critical area.

Cryopanels

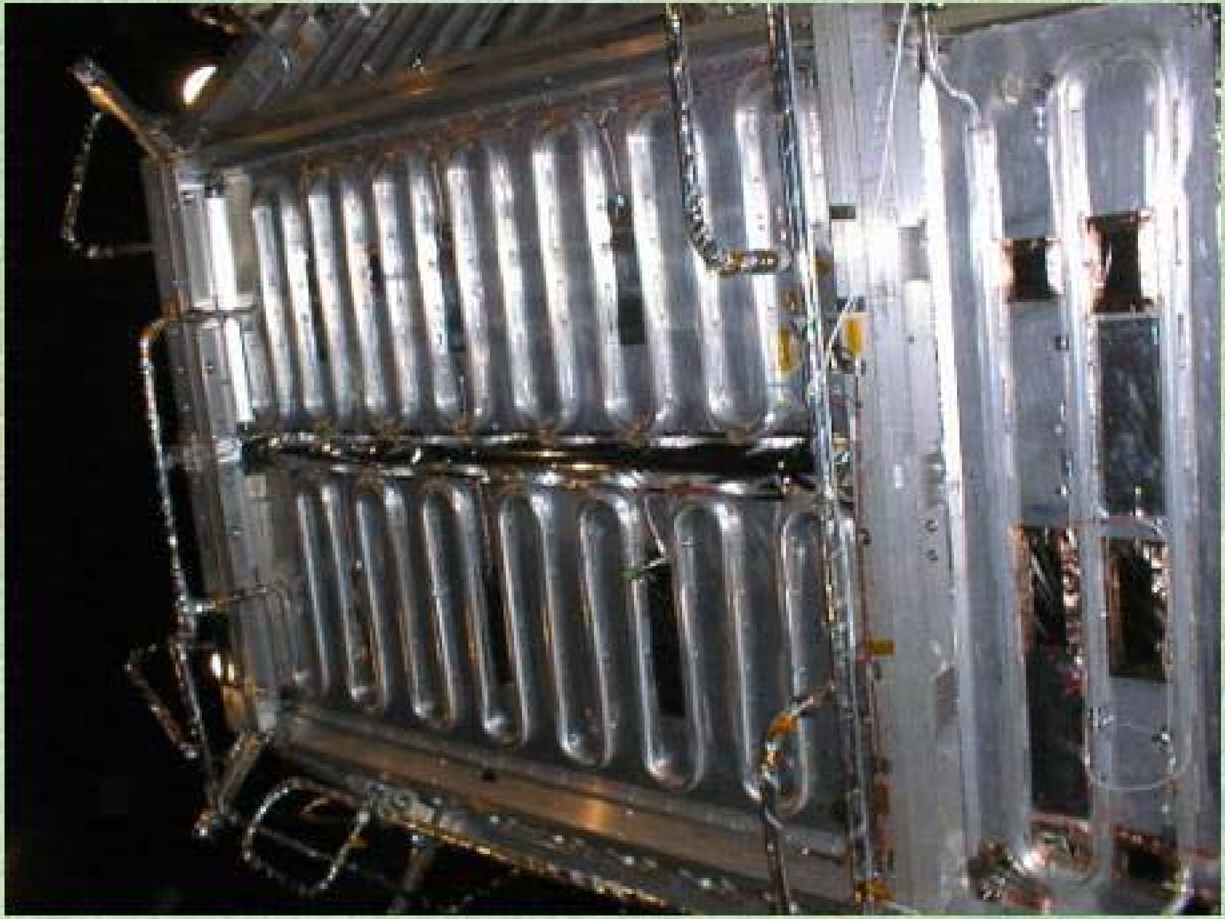
- Cryopanels are long lead-time items.
- GN_2 Cryopanels require a Thermal Conditioning Unit (TCU) to control temperatures.
  - Have a back-up TCU
  - Beware of ice plugs
  - Gradients within cryopanel can be large and depend on size, flow rates, and heat load. Temperature sensors on tube inlets and outlets & multiple panel locations.
  - Multiple cryopanels may be "chained" on the same TCU. Temperature control may be difficult.
- If you need LN_2 control for one part of the test, and GN_2 for another part design to accommodate a "switchable" supply.
- Many Helium Cryopanels have a black painted open-face honeycomb surface in order to enhance emissivity at low temperatures.

The "Tweens"

- What do you do when you need temperatures between LN2 and GN2?
  - Utilize heaters on LN_2 Cryopanels. Typically requires a flux-controlled heater and a device to regulate the LN_2 flow. It can be difficult to control to exact temperatures with this method.
  - Mount a heater plate on a cold plate. The coupling between the heater plate/cold plate and the heater power available must be sufficient to achieve temperature goals. (higher stability)



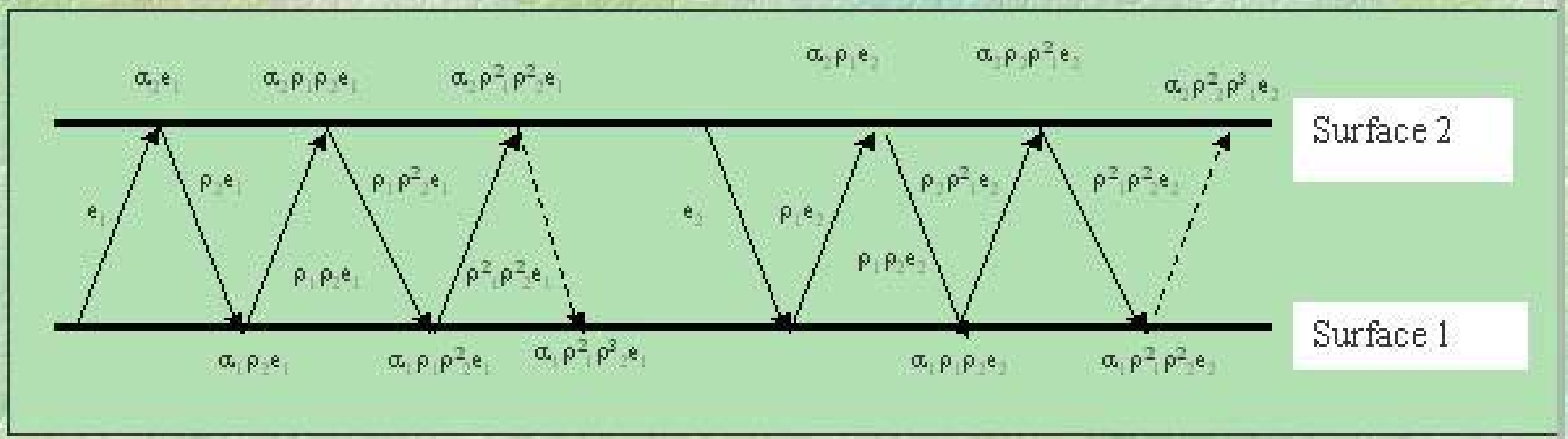
Cryopanel



Cryopanel with Heaters

The Bounce Back Effect

- *No surface is a perfect absorber (like space).*
- *The amount of energy transferred to a cryopanel, heater plate, or the chamber is a function of the separation distance, temperatures, and surface properties.*



Energy Transferred to a Cryopanel

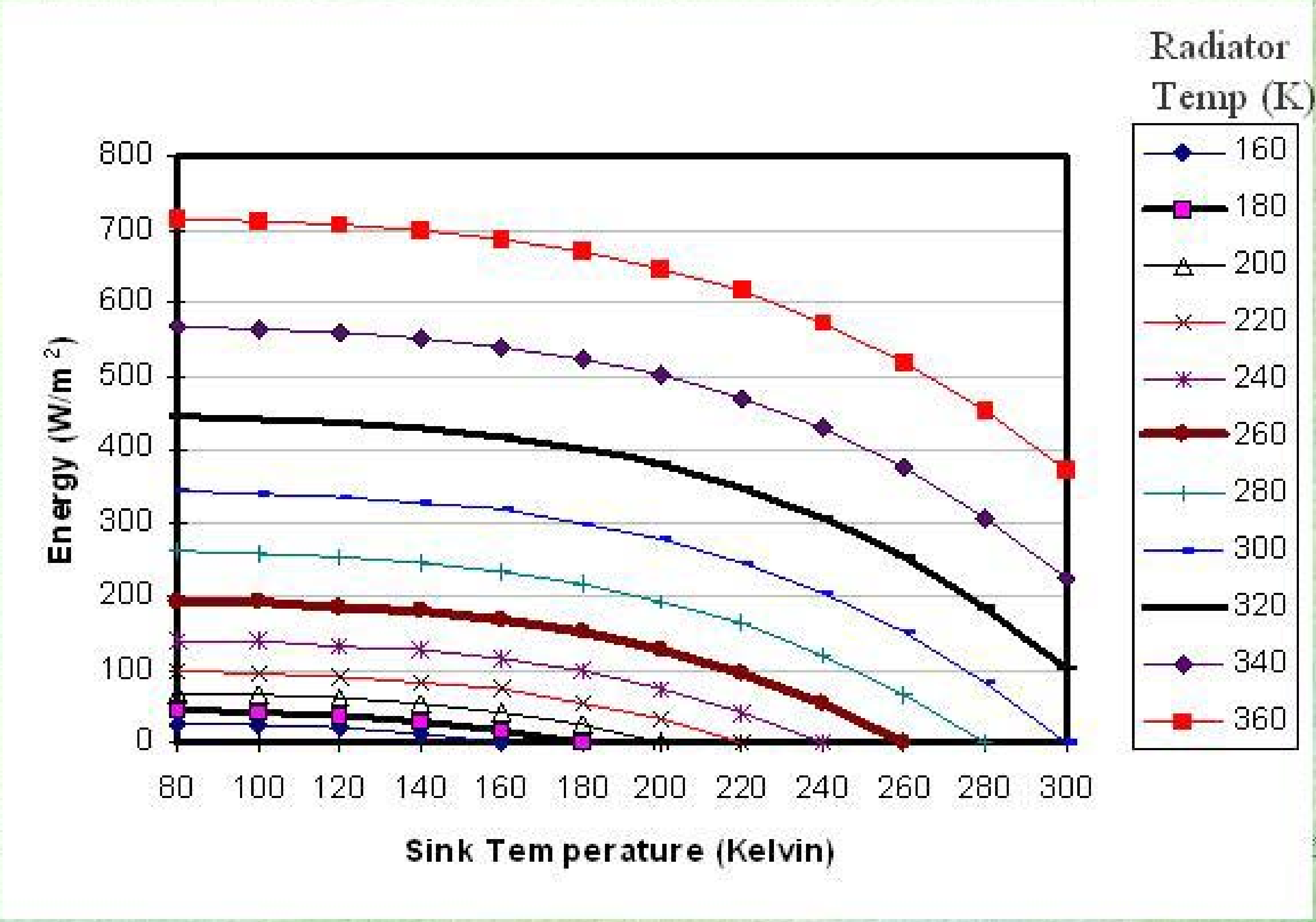
$$q = \sigma F_{1\text{-}2} (T_1^4 - T_2^4)$$

$$F_{1\text{-}2} = (1/\varepsilon_2 + 1/\varepsilon_1 - 1)^{-1}$$

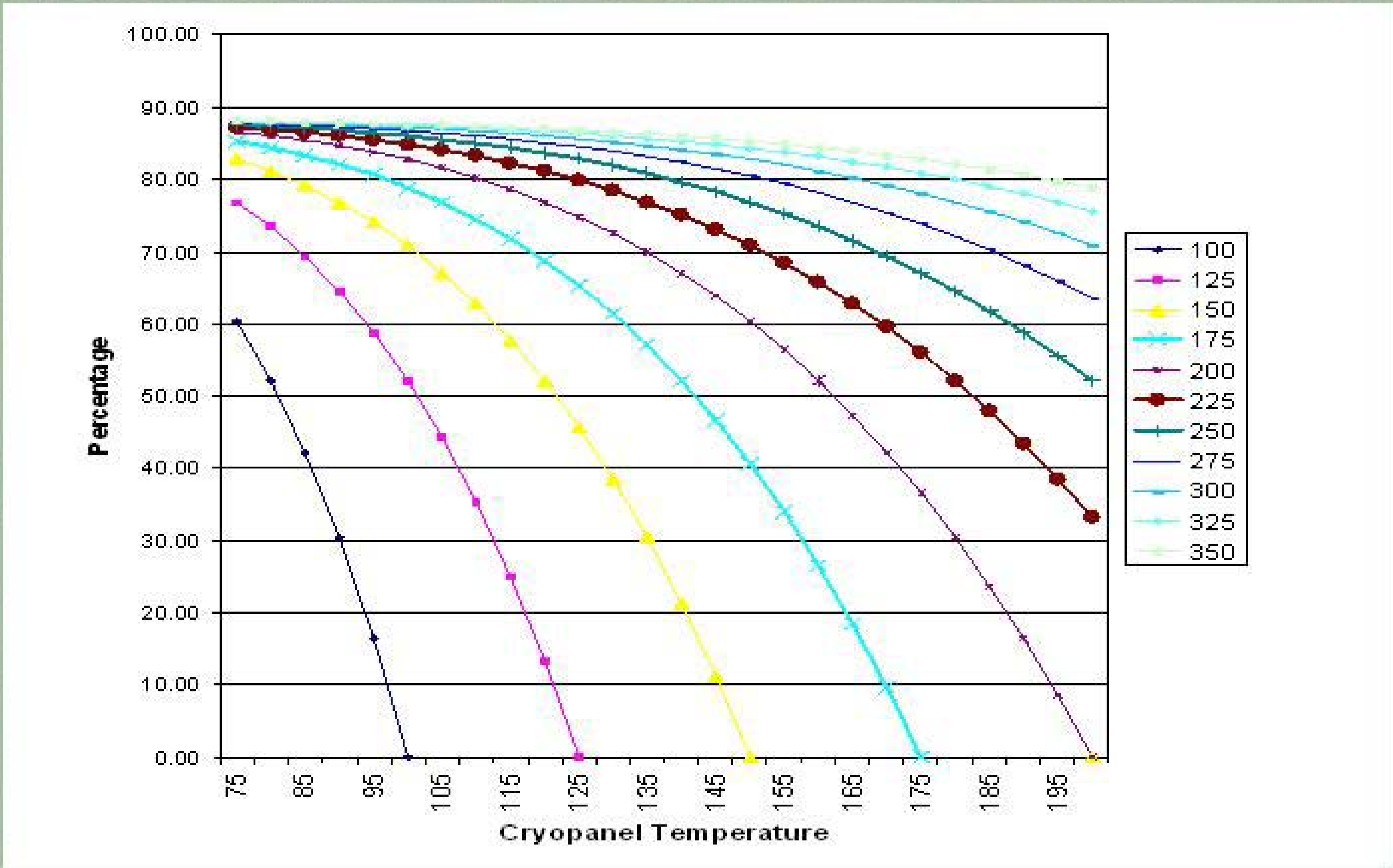
Where:

- q - energy flow from radiator surface to cryopanel
- $F_{1\text{-}2}$ - view factor from radiator surface to cryopanel
- ε - emissivity
- σ - Stephan Boltzman Constant
- T - temperature (in absolute temperature)

Energy Transferred Per Unit Area to a Cryopanel (ε=0.85) From a Flat Radiator Plate (ε=0.85)



Fraction of Energy Transferred by a Radiator Plate (ε=0.85) to a Cryopanel (ε=0.85)



The Net Effect

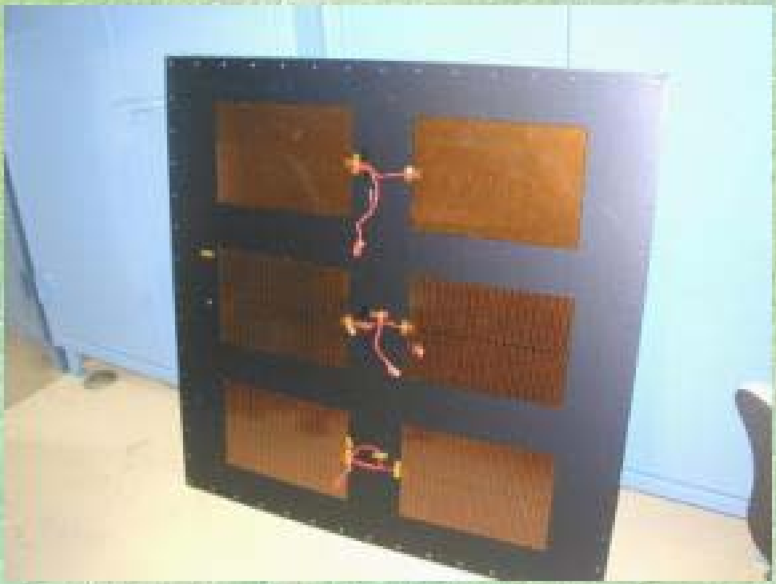
The net effect is the the cryopanel's temperature has to be colder than the flight sink temperature to accurately simulate the flight condition.

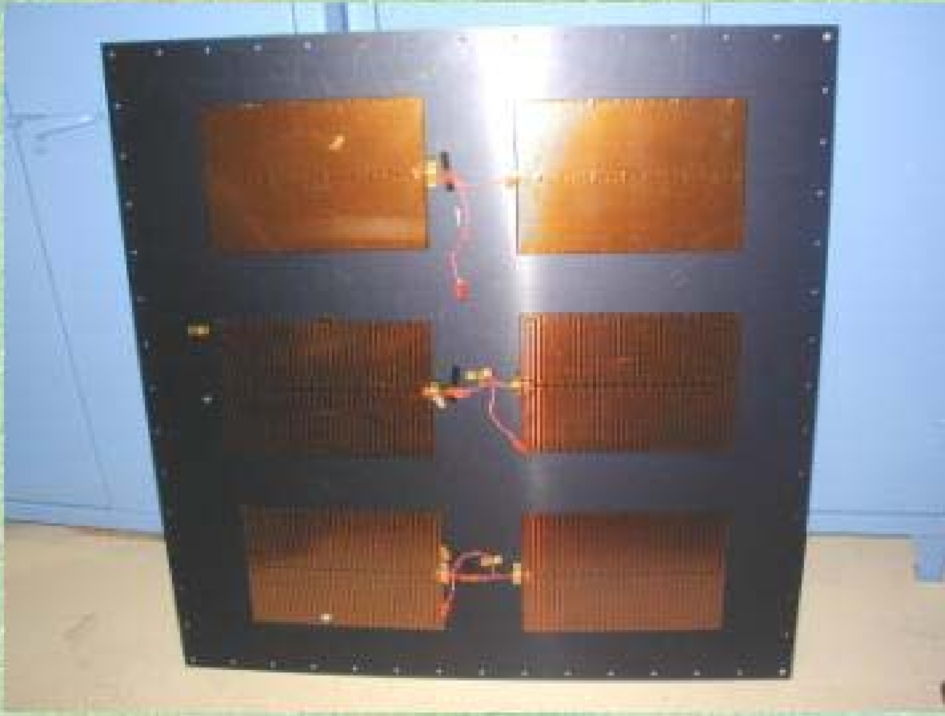
Cold Plates/Heater Plates

- **<u>Cold Plates</u>** – Cold plates are similar to Cryopanels except that they provide conductive (not radiative) sinks for components. These can be flooded or controlled with a TCU. A cold plate is thicker than a cryopanel, has bolting patterns on it, and may have a low emissivity finish.
- **<u>Heater Plates</u>** - Heater plates provide a radiative sink for components. They are different from cryopanels since they contain no working fluid.

Cold Plate

Heater Plate





Test Heaters

- Heater Element
- Control Sensor or Thermostat
- Monitor Sensor(s)
- Power Supply & Controller
- Stability Requirements
- Redundancy Requirements

Why Do We Need Test Heaters?

- Flux Controlled
  - To Simulate Environmental Fluxes
  - To Facilitate Parametric Studies
  - To Replace Power of Components not Present in the Test
  - To Protect Hardware and Aid with Transitions (to a lesser extent)
- Temperature Controlled
  - To Protect Flight and Test Hardware
  - To Keep Hardware at Qualification Temperatures
  - To Control Temperature of GSE (Heater plates)
  - To Speed-Up Transitions From Cold to Hot Plateaus
- Guard or "Zero Q"
  - To Minimize Non-Flight Conductive Heat Transfer From the Spacecraft (I.e. Test Cables, Mounting interfaces)

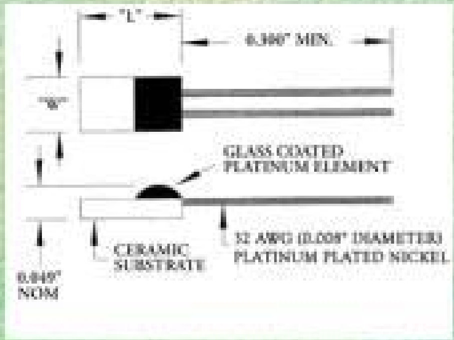
Goddard's Zero Q Method

- For cabling, the heater is attached to the cable approximately two feet from the spacecraft. Two temperature sensors spanning the connector interface (one on the spacecraft at the connector, the other on the cable at the connector) controls the heater to minimize the temperature difference between the sensors.
- For mounting interfaces the thermal engineer should use as much isolation as possible between the test component and the mount. The heater is placed on the mount and two temperature sensors spanning the interface are used.

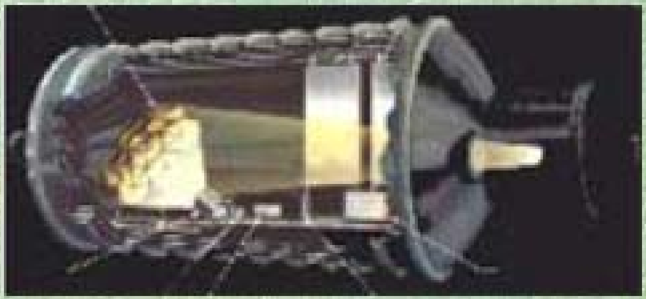
Control Sensors

- Must Be Compatible With Controller System
- Must Operate in Desired Temperature Regime
- Must Produce Response Needed (i.e. Temperature Sensitivity)
  - Diodes
  - Thermocouples
  - Thermistors
  - Platinum Resistance Thermometer
  - Germanium Resistance Thermometer (0.05-10K)
  - Ruthenium Oxide Thermometer (0.05-30 K)
  - Resistance Temperature Detectors (RTD)

Platinum RTD



Lamps and Cal Rods



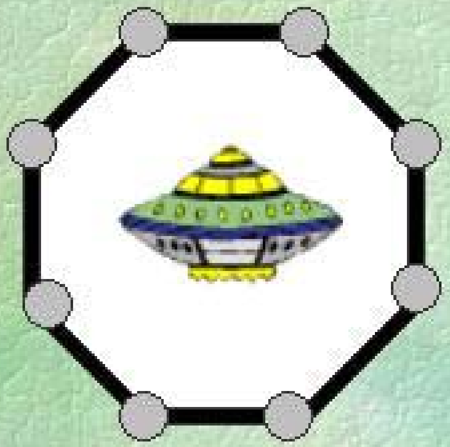
- Lamps- Used to simulate solar flux or to warm surfaces. The spectral intensity and wavelength distribution of lamps should match solar inputs on the spacecraft.
- Cal Rods- Thin cylindrical rods with heating elements within them that are used to simulate flux input. May have a reflector to focus energy.

Solar Simulation

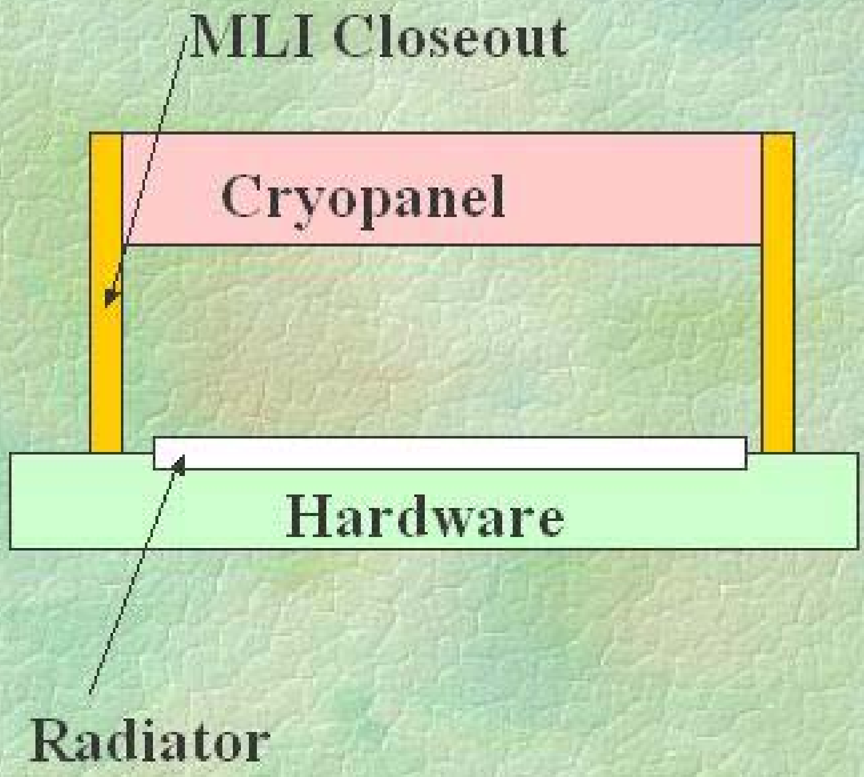
- Measure/Map beam intensity and uniformity
- Measure beam spectral content- Adjust absorptance in analysis.
- Beware of chamber reflections
- Measure divergence angle
- Solar Beam ≠ Real Sun

Test Blankets

- **Wrap Test Cables and Fiber Optics**
- **Protect Test Hardware (i.e. stimuli, hat couplers)**
- **Minimize Gradients or Power in Test GSE (I.e. heater plates)**
- **Reflect Energy to Other Locations**
- **Achieve Close-out**



MLI Close-Outs



- Ensure That Radiator Only Sees Cryopanel Environment
- Attachment to Hardware
- Inner Layer Low or High Emissivity?
- Grounding
- Venting

Mechanical Coolers

- **Thermoelectric Coolers**- semiconductor-based electronic component that functions as a small heat pump. Heat moves through the module in proportion to the applied voltage. Devices offer active cooling and precise controllability. Used primarily for "spot cooling" (cooling of a single component).
- **Coolers** are also used to "Recycle" cryogen in a closed loop system. On the MAP project we had large Helium panels that would have utilized a lot of cryogen if there hadn't been a closed loop helium refrigeration system.

Heat Pipes

- Design with testing in mind
- Ground tests are sensitive to orientation
- Level devices may be needed to keep assembly level to 0.1"

Contamination Monitoring

- **Quartz Crystal Microbalance**
  - Thermoelectric QCM and cryogenic QCM
- **Residual Gas Analyzer**
- **Cold Finger or Scavenger Plate** - Cold apparatus that gathers outgassed materials
- **Witness Mirrors** - Aluminum coated mirrors for reflective ultraviolet measurements
- **Fourier Transform Infrared Spectrometer (FTIR)**
- **Gas Chromatography/Mass Spectrometry (GC/MS)**

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- Satellite Thermal Control Handbook, David G. Gilmore, editor The Aerospace Corporation El Segundo, California
- Goddard Environmental Test and Integration Facilities Handbook, October 2000.
- Thermal Design Course, C. Mosier, NASA/GSFC, 2003