# JPL's Thermal Testing Philosophy

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# JPL's Mission



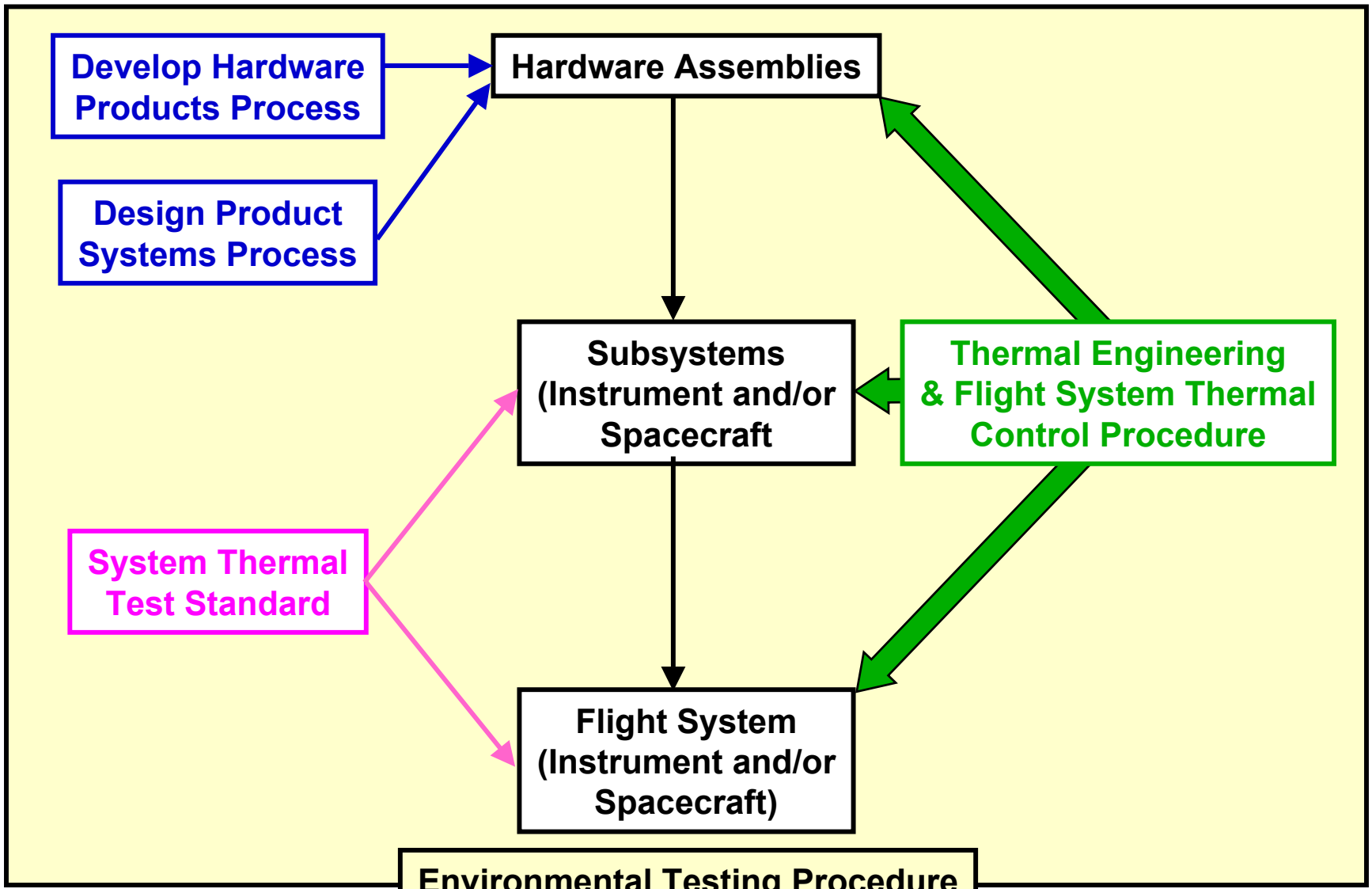
- **JPL is an operating division of the California Institute of Technology & is a Federally Funded Research & Development Center (FFRDC)**

- **JPL's primary mission, performed under contact to NASA, is the robotic exploration of the solar system; for example**
  - **Mars Scouts 2007, Mars Reconnaissance Orbiter, Mars Exploration Rover, Mars Odyssey, Mars Global Surveyor**
  - **Deep Impact, Dawn, Stardust, Genesis**
  - **Galileo, Cassini, Ulysses, Voyager**

- **JPL also has significant involvement with NASA programs in Earth Sciences & Astrophysics**
  - **TOPEX/Poseidon, Jason, Jason 2, GRACE, CloudSAT**
  - **NSCAT, QuikSCAT, SeaWinds, MLS, MISR, AIRS, TES**
  - **SIR-C, SRTM**
  - **SIM, SIRTF, GALEX, WF/PC on HST, IRAS**

# Overview of JPL's Products & Processes





# JPL's Thermal Testing Philosophy for Thermal Design Purposes



- **JPL uses early thermal development testing in the thermal design evolution cycle to proactively develop robust designs**
  - **Empirically determine key driving thermal parameters that are difficulty to quantify analytically**
  - **Understand temperature sensitivity to key boundary conditions**
  - **Demonstrate proof-of-concept**
- **System thermal testing serves multiple objectives**
  - **Empirically validate system-level thermal design for thermally extreme conditions**
  - **Validate flight system functionality under flight-like environmental conditions**
    - **Include verification of flight thermal hardware such as electrical heaters with mechanical thermostats, temperature sensors, heat pipes, etc.**
  - **Gather test data for analytical thermal model correlation**
    - **Calibrated tool for "Verification by Analysis"**

# JPL's Thermal Testing Philosophy for Hardware Products



- **JPL uses protoflight (PF)/qualification (QUAL) to uncover workmanship defects & vulnerable design features**
  - **Interplanetary flight systems require high reliability since their in-flight duration may be several years**
  - **These types of missions experience minimal thermal cycling**
    - **Thermal cycles are limited on flight hardware to 33% of expected ground + flight**
    - **Dwell times at hot or cold soak test cases protracted to ensure reliability**
  - **Earth-orbiting & Mars-surface missions experience more pronounced thermal cycling**
    - **Hardware packaging must demonstrate life cycling to 3 times expected flight (packaging verification qualification)**
    - **Non-compliance requires a Project waiver**
      - One-time or limited use items (e.g., deployment mechanisms)
  - **Typically, these tests are conducted in vacuum (< $10^{-5}$ torr)**
- **Flight acceptance (FA) testing used to certify hardware whose design has undergone QUAL testing**

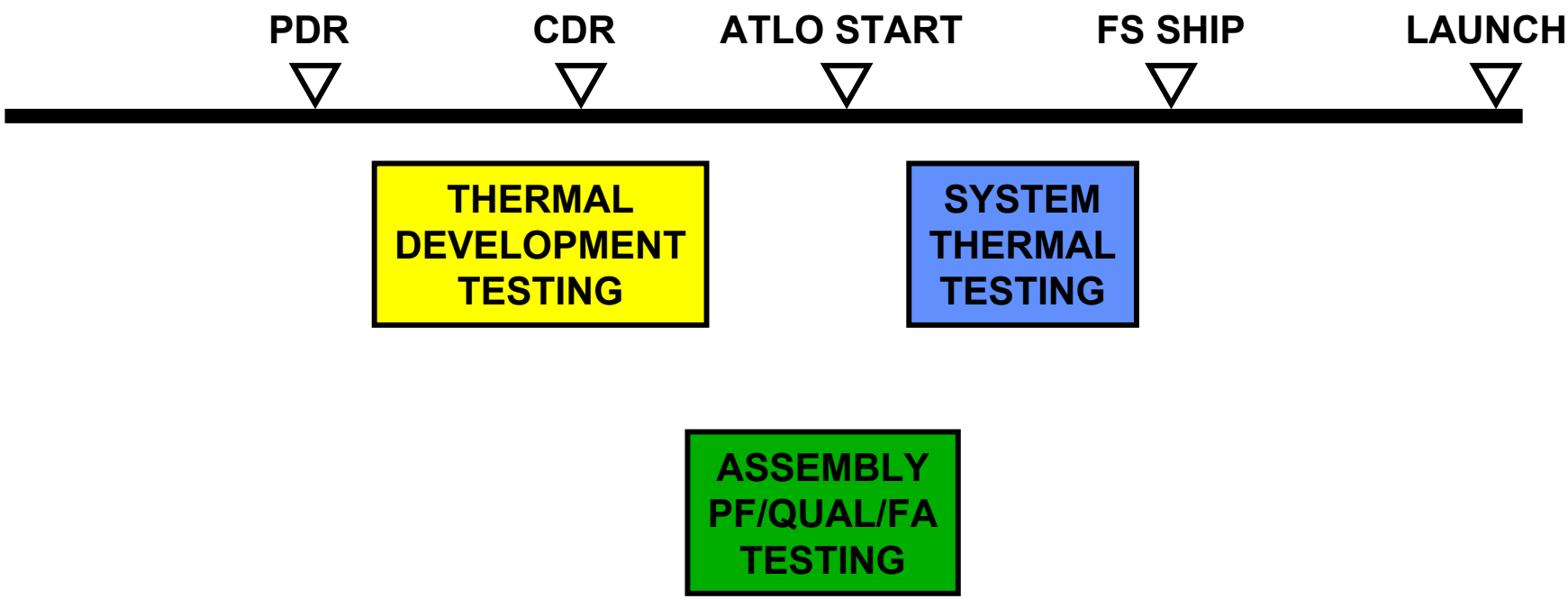
# JPL Governing Thermal Testing Documents



| TYPE OF THERMAL TEST | GOVERNING DOCUMENT | INTERNAL JPL DOCUMENT ID |
|---|---|---|
| System or Flight Assembly Level Thermal Balance | System Thermal Testing Standard | 58172 |
| | Design Product Systems Process | 57354 |
| | Environmental Testing Procedure, Revision 3 | 33832 |
| Flight Assembly PF/QUA/FA | Assembly and Subsystem Level Environmental Verification Standard | 60133 |
| | Develop Hardware Products Process | 57752 |
| | Environmental Testing Procedure, Revision 3 | 33832 |
| Thermal Development | Thermal Engineering and Flight System Thermal Control Procedure, Revision 1 | 33014 |
| | Environmental Testing Procedure, Revision 3 | 33832 |

# Typical Thermal Testing Flow





# Environmental Requirements Are Mission-Unique



- **JPL Design Principles recommend specific temperature margins & thermal cycling**

- **Each project develops an "Environmental Requirements Document (ERD)"**
  - **Captures Design Principles as the baseline**
  - **Provides for tailoring based on such criteria as critical functionality & lifetime**
  - **Prescribes mission-unique specifications for temperature margin between allowable flight temperature (AFT) & test levels (PF/QUAL/FA), PF/QUAL/FA dwell times, & number of thermal cycles**

# Thermal Design Validation Considerations (1/3)



- **System-level thermal testing enables validation of flight thermal hardware**
  - **Primary & secondary heater strings including thermostats, if any**
  - **Heater power margin**
    - **General guideline is a maximum 75% duty cycle in the worst-cold case**
  - **Temperature sensor measurements comparison to test thermocouple readings**
  - **Heat pipe/CPL start-up**

- **Steady-state criteria**
  - **Each flight system responds differently**
  - **Prescribing a temperature rate of change or heat flow criteria is arbitrary without incorporating specific thermal characteristics**
  - **While JPL specifies a temperature rate of change, steady-state determination is left to the discretion of the test conductor**
    - **If the steady-state temperatures can be credibly extrapolated from test data, then a test case can be considered "steady"**

# Thermal Design Validation Considerations (2/3)



| Test Characteristic | Thermal Development | System or Flight Assembly Thermal Balance |
|---|---|---|
| Number of Thermal Cycles | Not applicable if no flight hardware used | Minimized since thermal cycling is considered a limited & consumable resource |
| Dwell Time | Sufficient for steady-state determination | Sufficient for steady-state determination |
| Temperature Range | Allowable flight temperature (AFT) | Allowable flight temperature (AFT) |

# Thermal Design Validation Considerations (3/3)



| Test Characteristic | Thermal Development | System or Flight Assembly Thermal Balance |
|---|---|---|
| Temperature Extremes | Not to exceed a known material limit and/or safe condition if no flight hardware used | Not to exceed FA |
| Transition Rate | Not to exceed a known material limit and/or safe condition if no flight hardware used | Not to exceed a safe hardware condition; Limiting items include optics (<8°C/hr) |
| Thermal Stability | <0.3°C for 3 consecutive hours or at discretion of cognizant test conductor | <0.3°C for 3 consecutive hours or at discretion of cognizant test conductor |

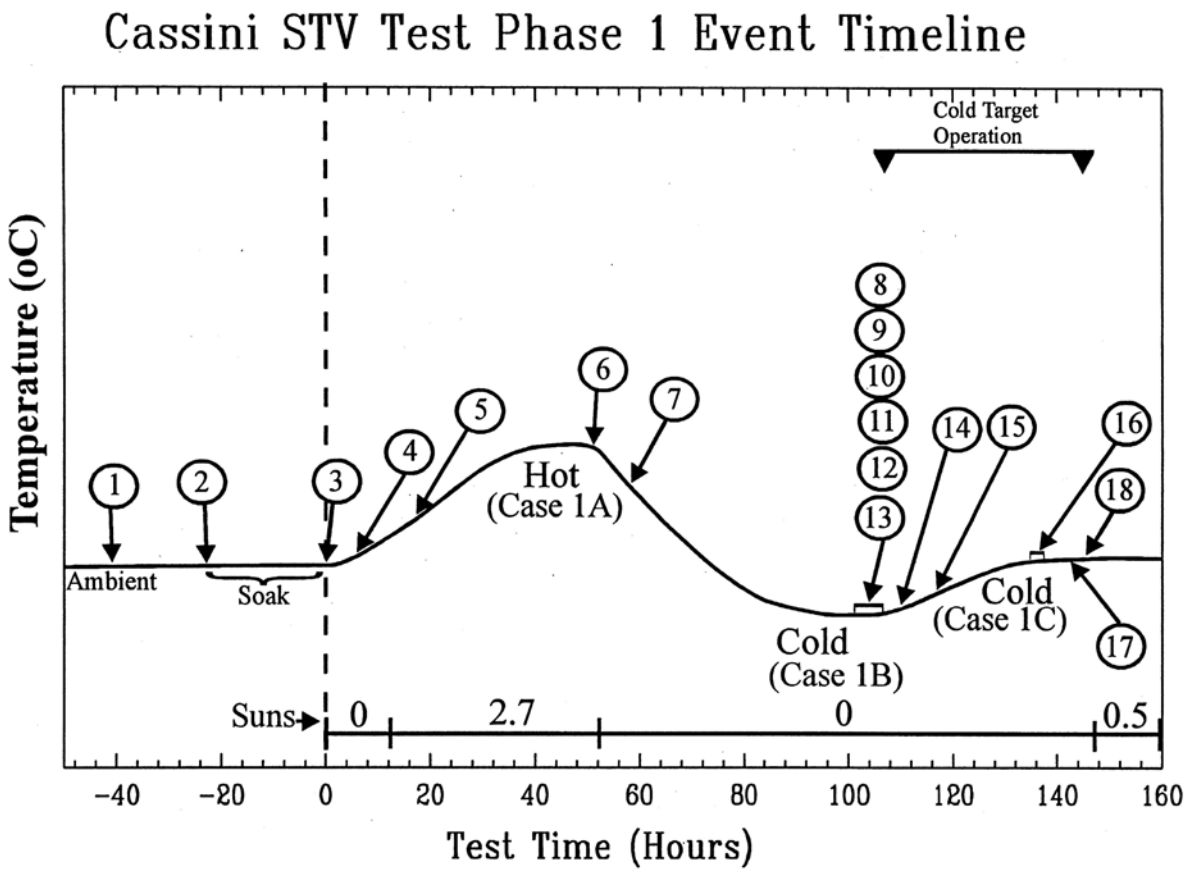
# Hardware Certification Considerations

*Thermal Test Discussion Panel*

| Test Characteristic | Flight Assembly PF/QUAL/FA |
|---|---|
| Number of Thermal Cycles | Fight assemblies: Typically 3 to 10 cycles<br>Packaging: 3 times worst-case flight |
| Dwell Time | Tailored on a unique Project basis, Typically 144 hours HOT & 24 hours COLD |
| Temperature Range | PF/QUAL: AFT - 15°C to AFT + 20°C (Electronics shall minimally be -35 to +75°C)<br>FA: AFT ± 5°C |
| Temperature Extremes | PF/QUAL: AFT - 15°C to AFT + 20°C (Electronics shall minimally be -35 to +75°C)<br>FA: AFT ± 5°C |
| Transition Rate | Not to exceed a safe hardware condition; Limiting items include optics (<8°C/hr) |
| Thermal Stability | <0.3°C for 3 consecutive hours or at discretion of cognizant test conductor |

# Thermal Balance Test Profile



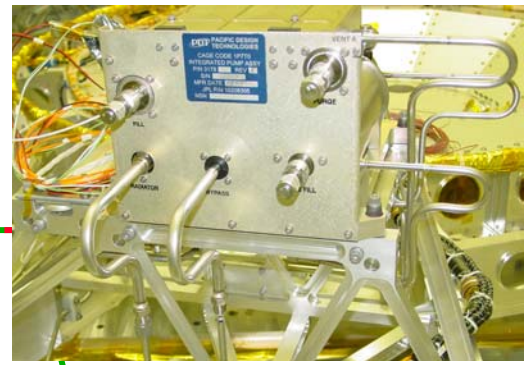


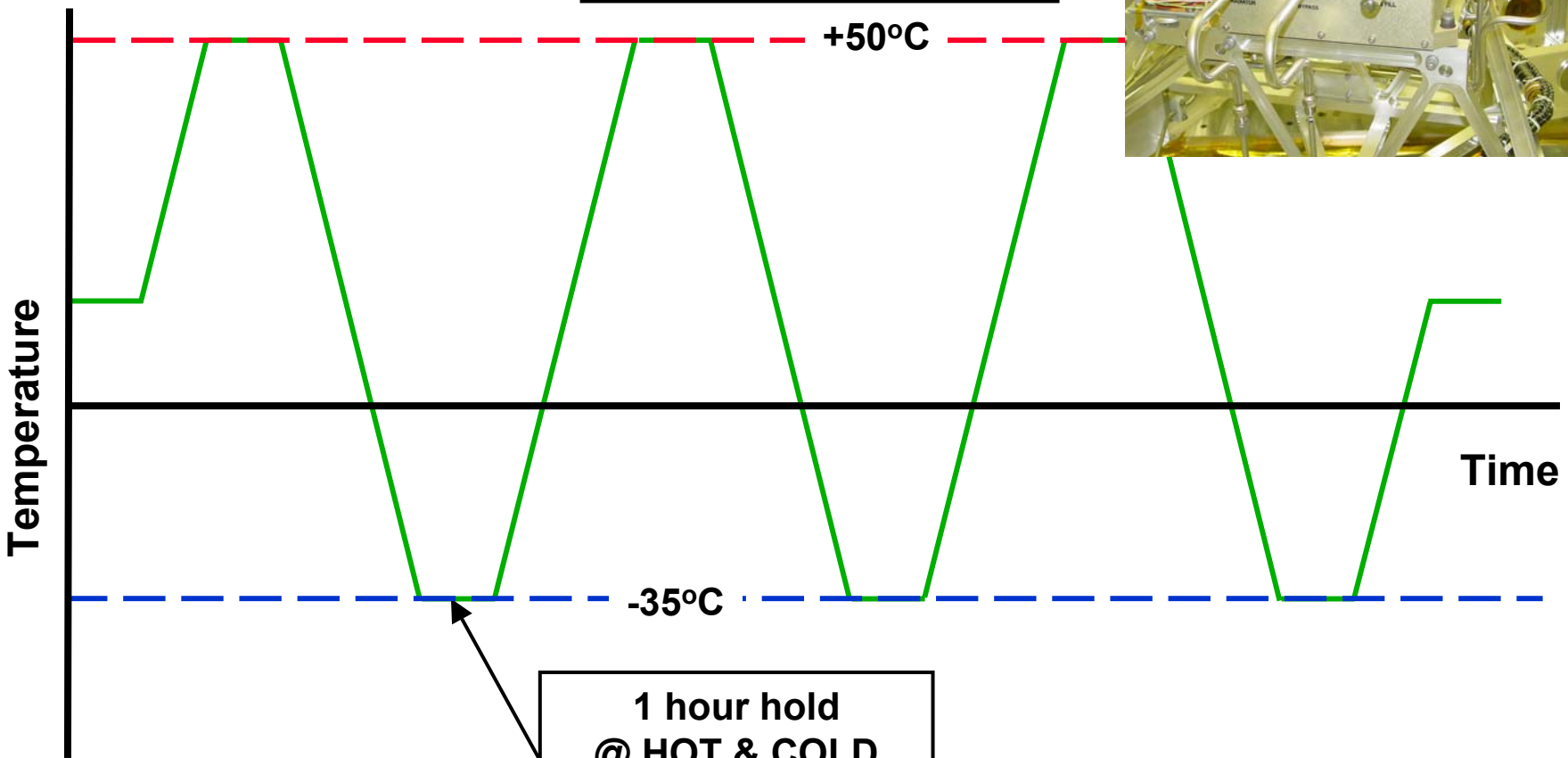

| Event No. | Description |
|---|---|
| 1 | S/C Baseline Test |
| 2 | Close Chamber |
| 3 | Nitrogen Flush<br>Start Cooling Shrouds |
| 4 | Turn OFF Purge |
| 5 | Configure Power for Case 1A |
| 6 | Turn off Heaters TBD for Cooldown Acceleration |
| 7 | Configure Power for Case 1B |
| 8 | CIRS Interference Test |
| 9 | CAPS HV Test |
| 10 | CDA Interference Test |
| 11 | ISS Interference Test |
| 12 | Radar 30 minute Turn-ON |
| 13 | RWA 30 minute Turn-ON |
| 14 | Turn on Heaters for warm-up acceleration |
| 15 | Configure Power for Case 1C |
| 16 | CIRS, VIMS & ISS Functional Tests and CIRS Microphonics Test |
| 17 | Configure Power for Backfill |
| 18 | turn ON Purge |

# MER IPA SN001
# PF Thermal Vacuum Test Profile

*Thermal Test Discussion Panel*

3 thermal cycles with 50 & 24 cumulative hours hot & cold, respectively

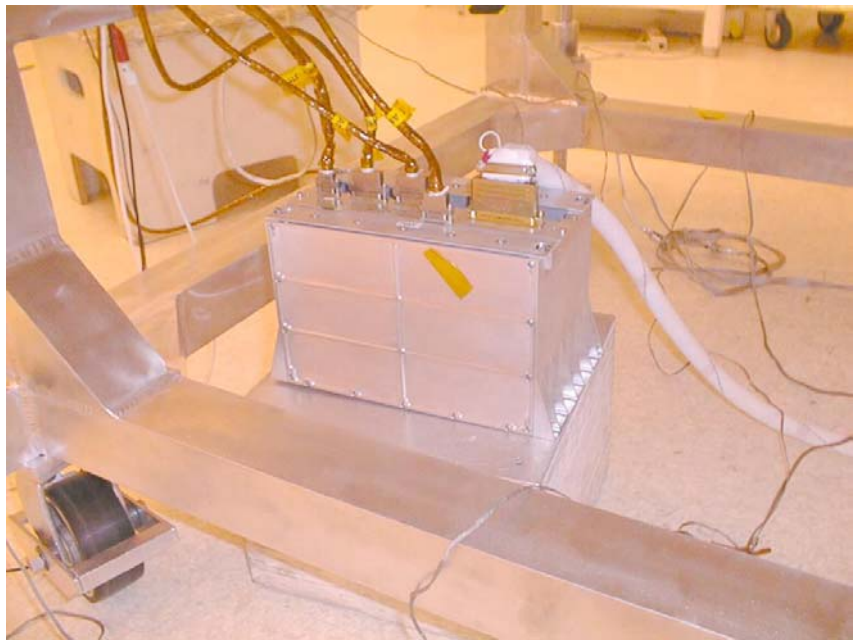




# Case Study – Electronics Box



- **An externally mounted power distribution box (PDB)**
  - **Nominal power dissipation: 36 watts**
  - **Safe mode power: 8 watts**
  - **AFT limits:**
    - **Op: -20 to 45°C**
    - **Survival: -20 to 50°C**
  - **Predicted temperature range:**
    - **-5 to 34°C for a 5-year low-earth orbit mission (EOL optical properties & dissipation)**
  - **Requires thermostatic heaters to maintain PDB at or above –15°C**
    - **Thermostat setpoints: -15 & -5C**
    - **Powered on survival bus operating between 24 & 32V**



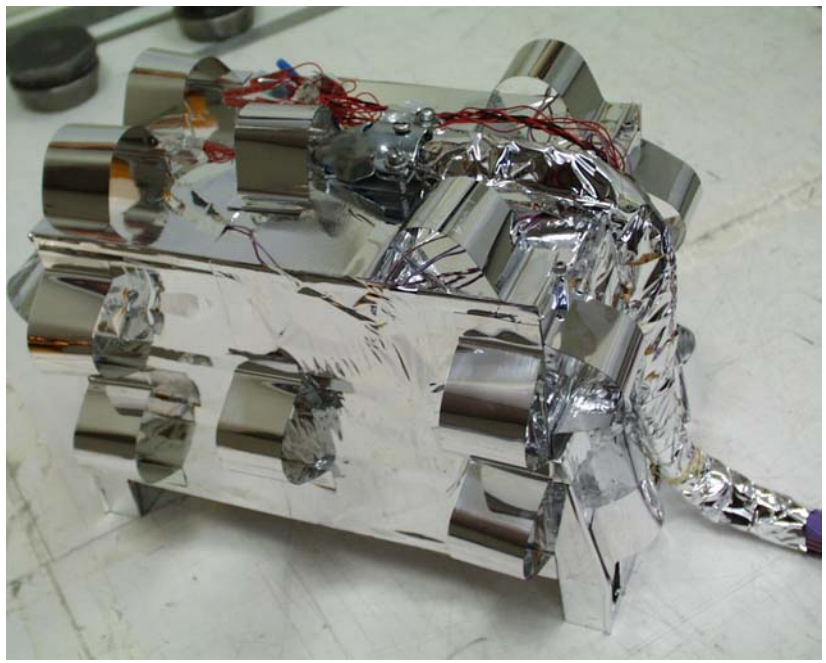
# Thermal Design Assumptions



**Primary & backup survival heater strings that have both power switches enabled**

**Primary & backup thermostats setpoints staggered**

**Radiator area probably needed, provisions in place to permit easy area modification**



**No heat flow allowed through mounting I/F**

**Insulation covers entire unit except for radiator area**

**AFT limits apply to the bulk average temperature**

**Heater power < 24W (current draw < 1 amp, only series thermostats required)**

# Hardware Design Assumptions (1/2)

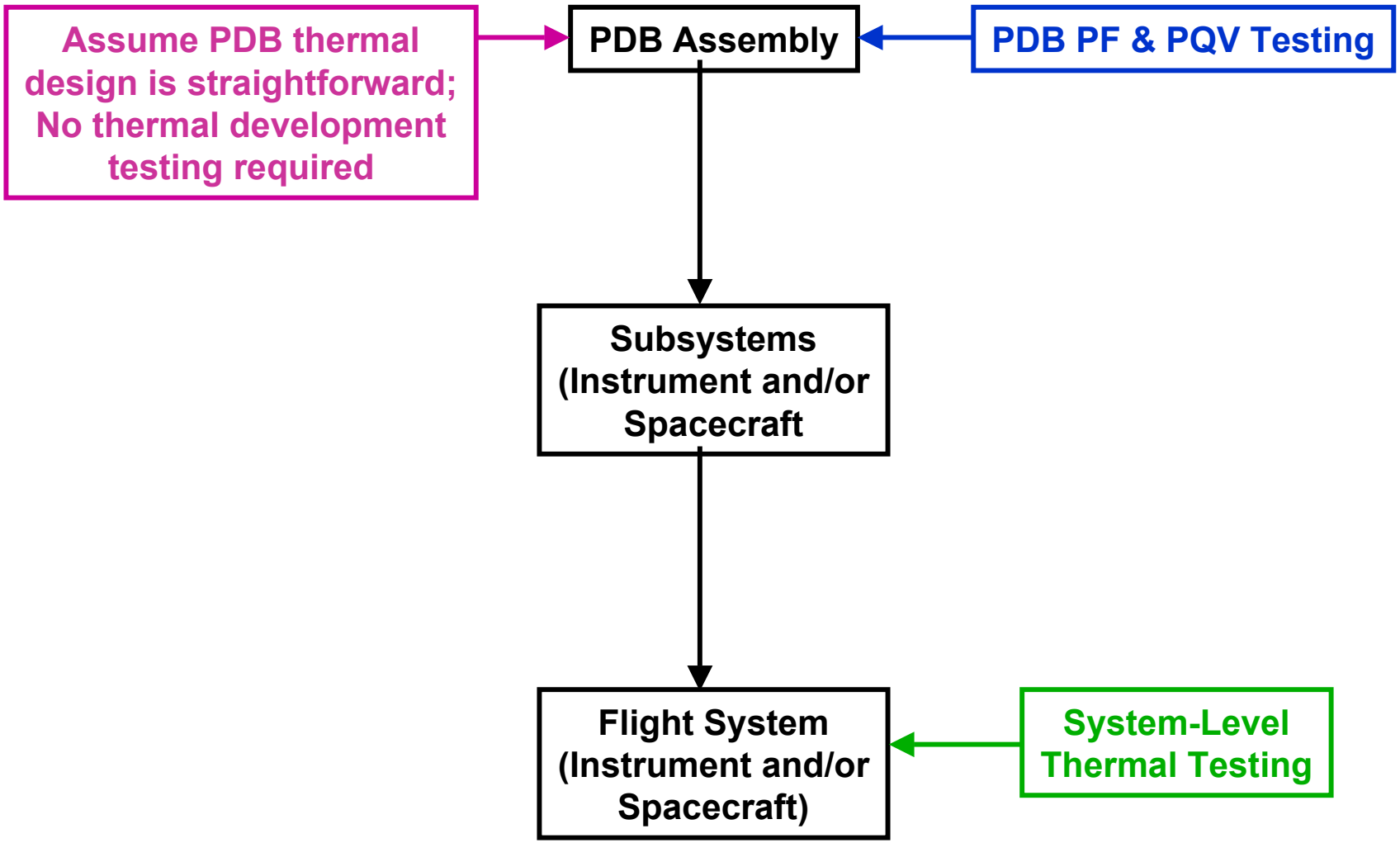


- **Assume PF test program**
  - **PF operating test levels: -35 (cold) & 70°C (hot)**
    - **Driven outside –15/+20°C margin to meet minimum of –35 to 70°C**
    - **3 to 10 thermal cycles**
    - **Dwell cumulative 24 hrs cold & 144 hrs hot**
    - **Assume a temperature ramp rate of 120°C/hr is acceptable**
  - **PF survival test levels: no cold test required, covered by operational test**
    - **Unit "turn-on" at non-operating levels captured by PF operating test**
  - **Assume hardware can fit into 3-foot diameter thermal vacuum chamber**

- **Assume electronics packaging qualification successful**
  - **Assume 2 cycles a day for 5 years = 3650 flight cycles**
  - **Assume ground testing adds additional 6 thermal cycles**
  - **3 times life = 10,968 thermal cycles**

# Hardware Design Assumptions (2/2)

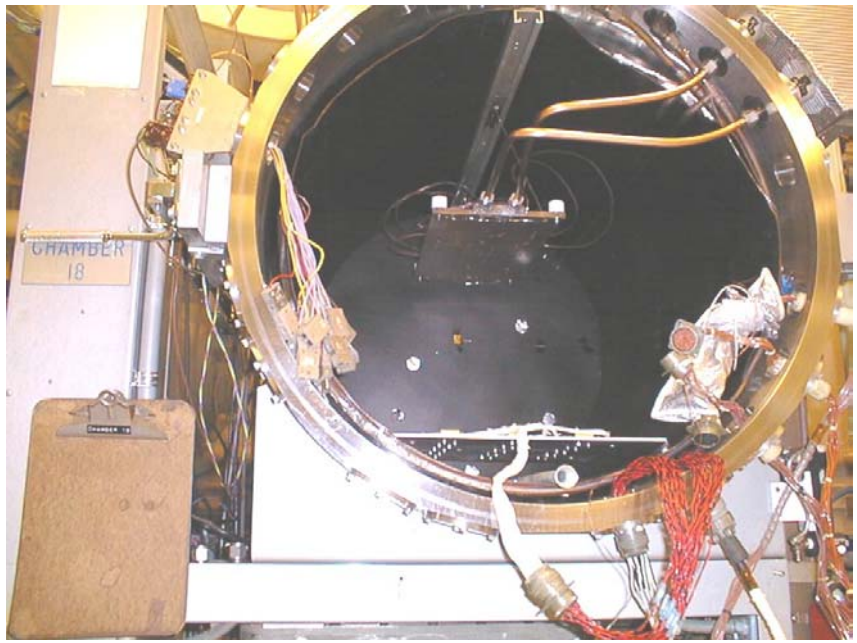




# PF Testing

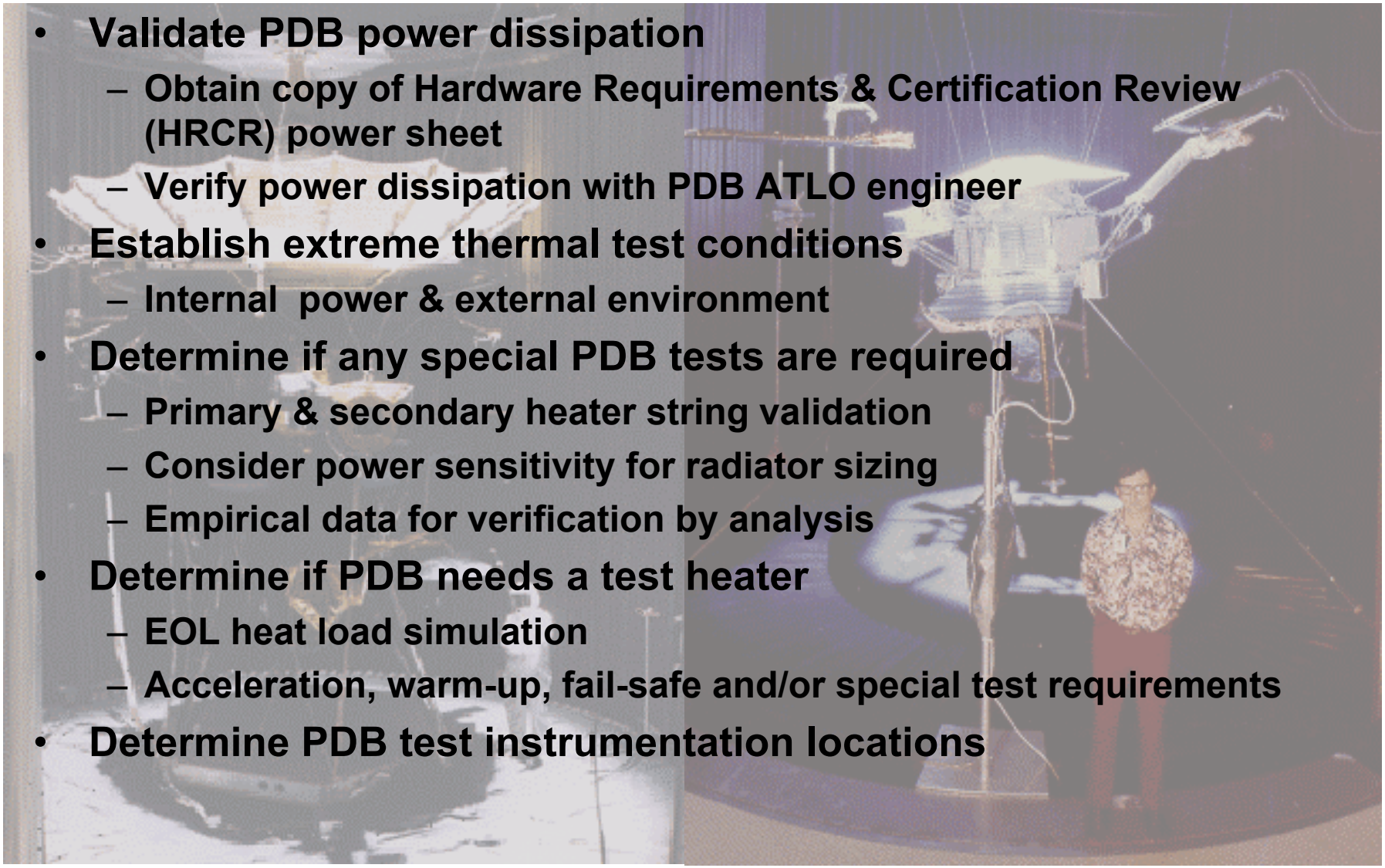


- **PF testing accomplished by mounting flight hardware to a heat exchanger & using chamber shroud**
  - **PDB will be covered with a test thermal blanket**
- **If multiple units were fabricated (i.e., flight spare), these units could be tested to FA levels upon concurrence from QA**
  - **FA operating levels: -25 to 50°C**
  - **FA dwell times: 24 hrs cold & 50 hrs hot**
  - **FA number of thermal cycles: probably 3**



# System Thermal Test (1/2)





- **Validate PDB power dissipation**
  - Obtain copy of Hardware Requirements & Certification Review (HRCR) power sheet
  - Verify power dissipation with PDB ATLO engineer
- **Establish extreme thermal test conditions**
  - Internal power & external environment
- **Determine if any special PDB tests are required**
  - Primary & secondary heater string validation
  - Consider power sensitivity for radiator sizing
  - Empirical data for verification by analysis
- **Determine if PDB needs a test heater**
  - EOL heat load simulation
  - Acceleration, warm-up, fail-safe and/or special test requirements
- **Determine PDB test instrumentation locations**

# System Thermal Test (2/2)



- **Establish test yellow & red alarms**
  - **Yellow: AFT limits**
  - **Red: FA levels**
- **Understand & accommodate ATLO's functional test needs for the PDB**
  - **Review end-to-end functionality V & V rather than focusing on temperature requirements**
  - **Determine need for any special test targets or support equipment**
- **Develop contingency plans in the event the design is deficient**

# References




- Siebes, G. "System Thermal Testing Standard," Internal JPL Document D-22011, March 15, 2002.

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- Greenfield, M. "A Guide for Temperature Control Engineers on Planning, Instrumentation, and Thermal Testing Activities for Spacecraft Level Solar Thermal Vacuum (STV) Tests," Section 3.0, Instrumentation Planning, Internal JPL Document D-7626, April 1990.

- Gilmore, D. (editor) *Spacecraft Thermal Control Handbook, Volume I: Fundamental Technologies,* American Institute of Aeronautics and Astronautics, Inc., Reston, VA, Chapter 19, Thermal Testing, 2002.