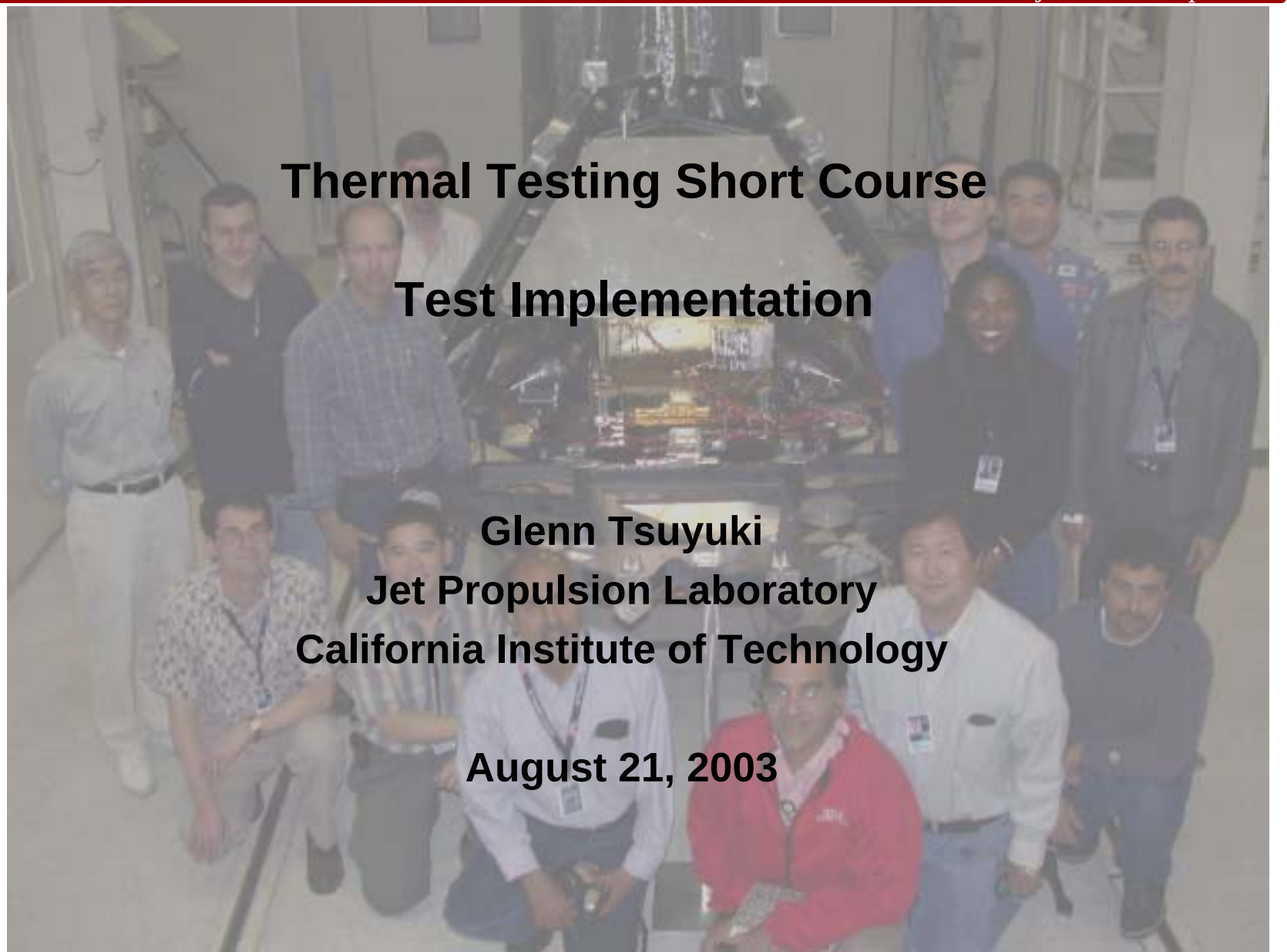

Thermal Testing Short Course

Test Implementation

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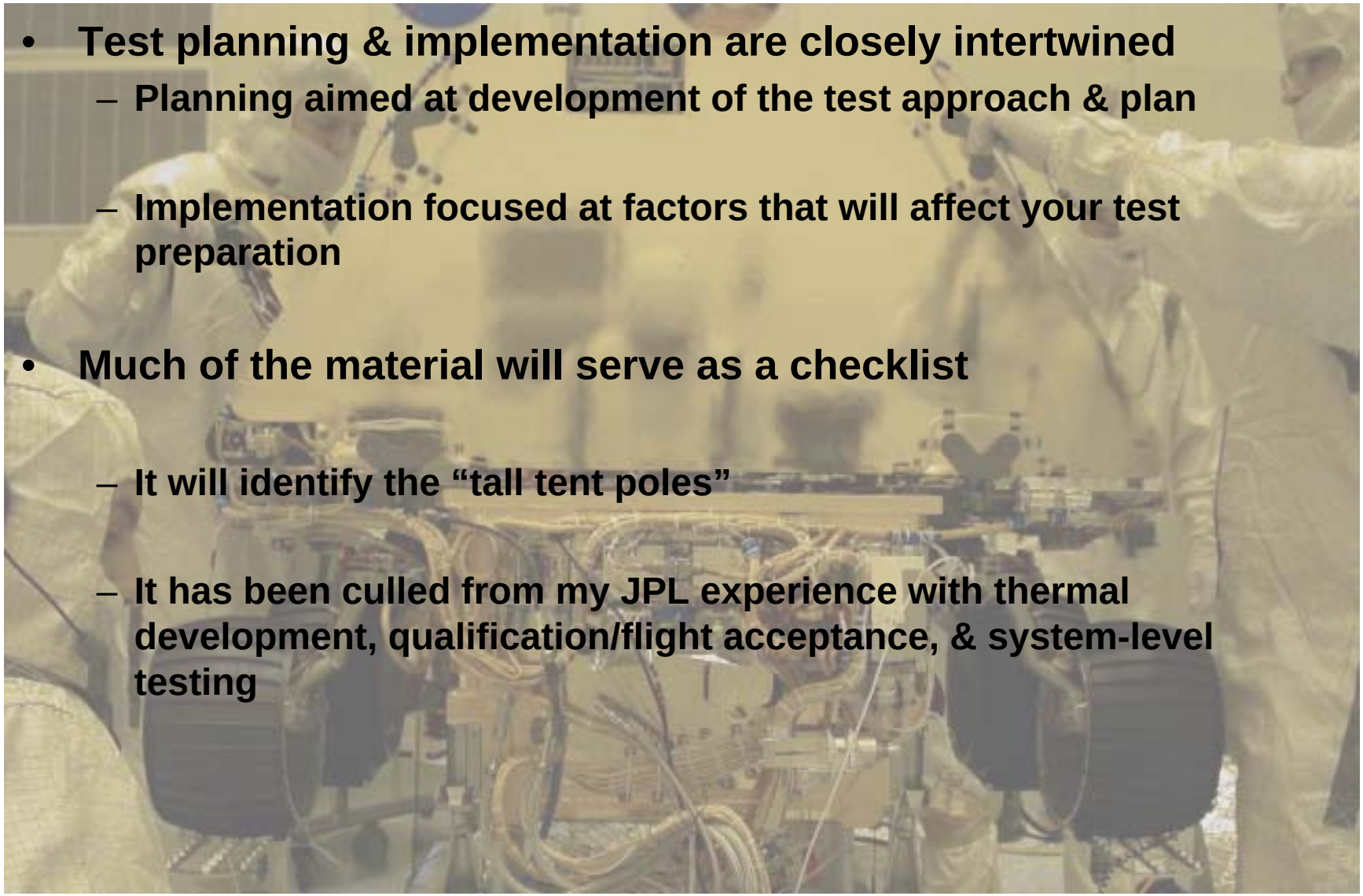
August 21, 2003

Introduction



- **Test planning & implementation are closely intertwined**
  - **Planning aimed at development of the test approach & plan**
  - **Implementation focused at factors that will affect your test preparation**
- **Much of the material will serve as a checklist**
  - **It will identify the "tall tent poles"**
  - **It has been culled from my JPL experience with thermal development, qualification/flight acceptance, & system-level testing**

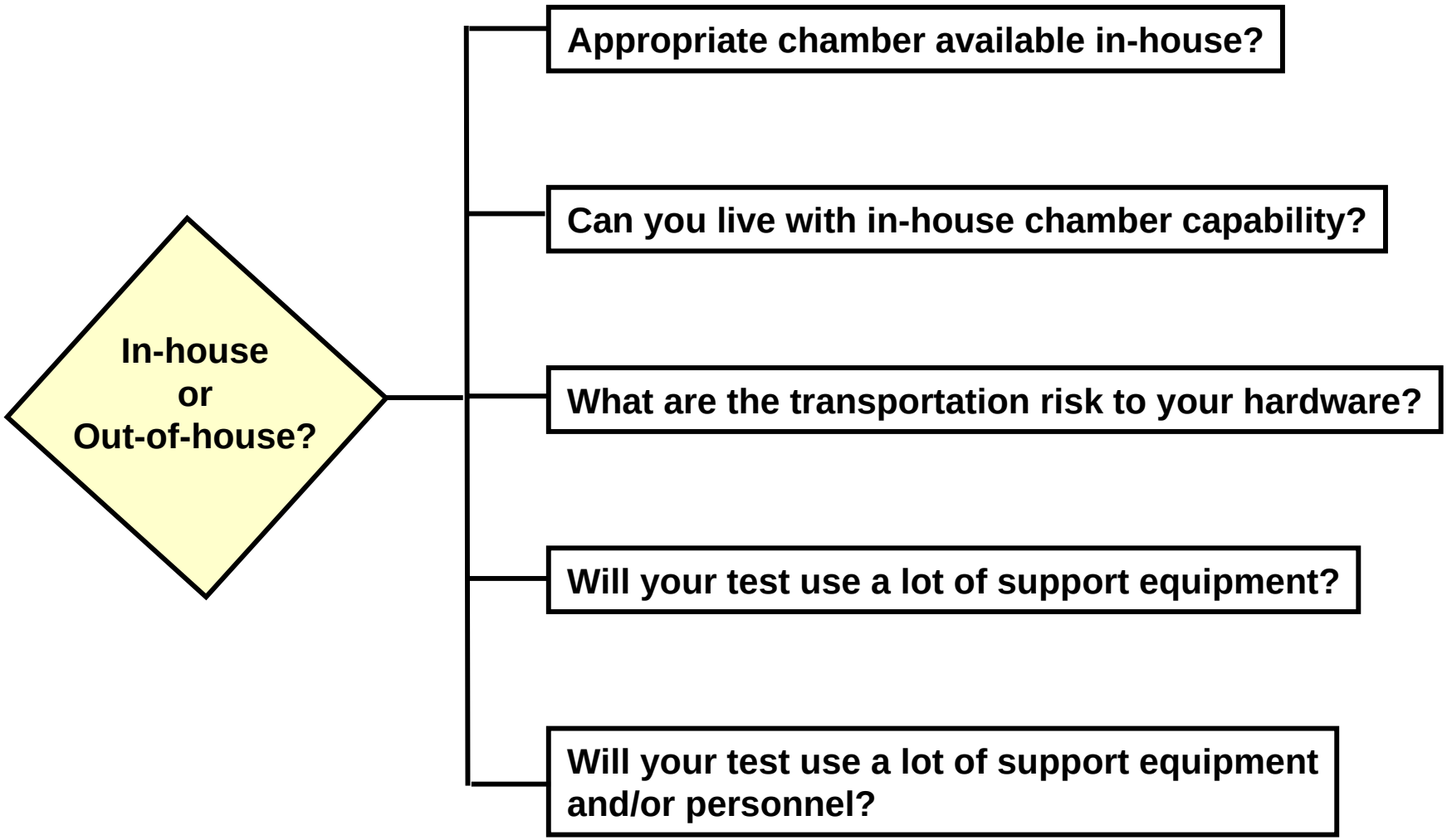
"Sharpen Your Saw"

- **You are responsible for overseeing a multitude of tasks & issues covering a wide spectrum of interfaces**
  - **A process for proactively addressing & attending to each task is essential**
    - **Prioritized task list that is reviewed daily**
    - **War charts**
    - **Daily logbook**
- **You should know the working style of your team & interfaces**
  - **Leverage on strengths**
  - **What is their preferred method of communication?**
  - **Avoid springing "surprises"**
  - **Who requires more of your attention & who can be given a "long leash?"**
- **You should be familiar your institutional and/or project procedures for conducting tests**

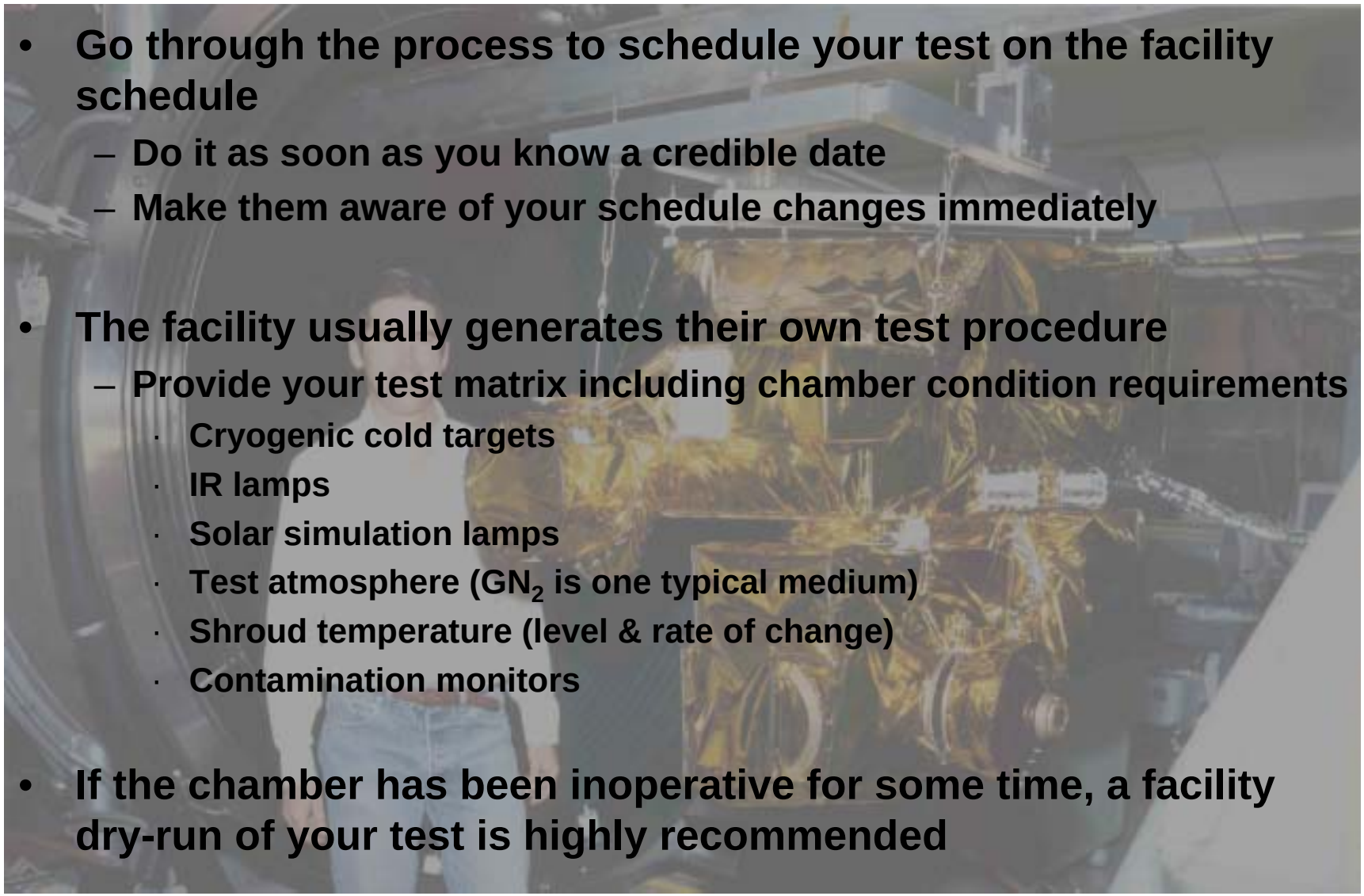
Prioritized Focus Areas

- **Test Facility**
- **Data Acquisition & Instrumentation**
- **Mechanical & Electrical Support Equipment**
- **Interfacing with Integration & Test**
- **Testing with Flight Hardware**
- **Safety**
- **Test Execution**

Where Should You Test?

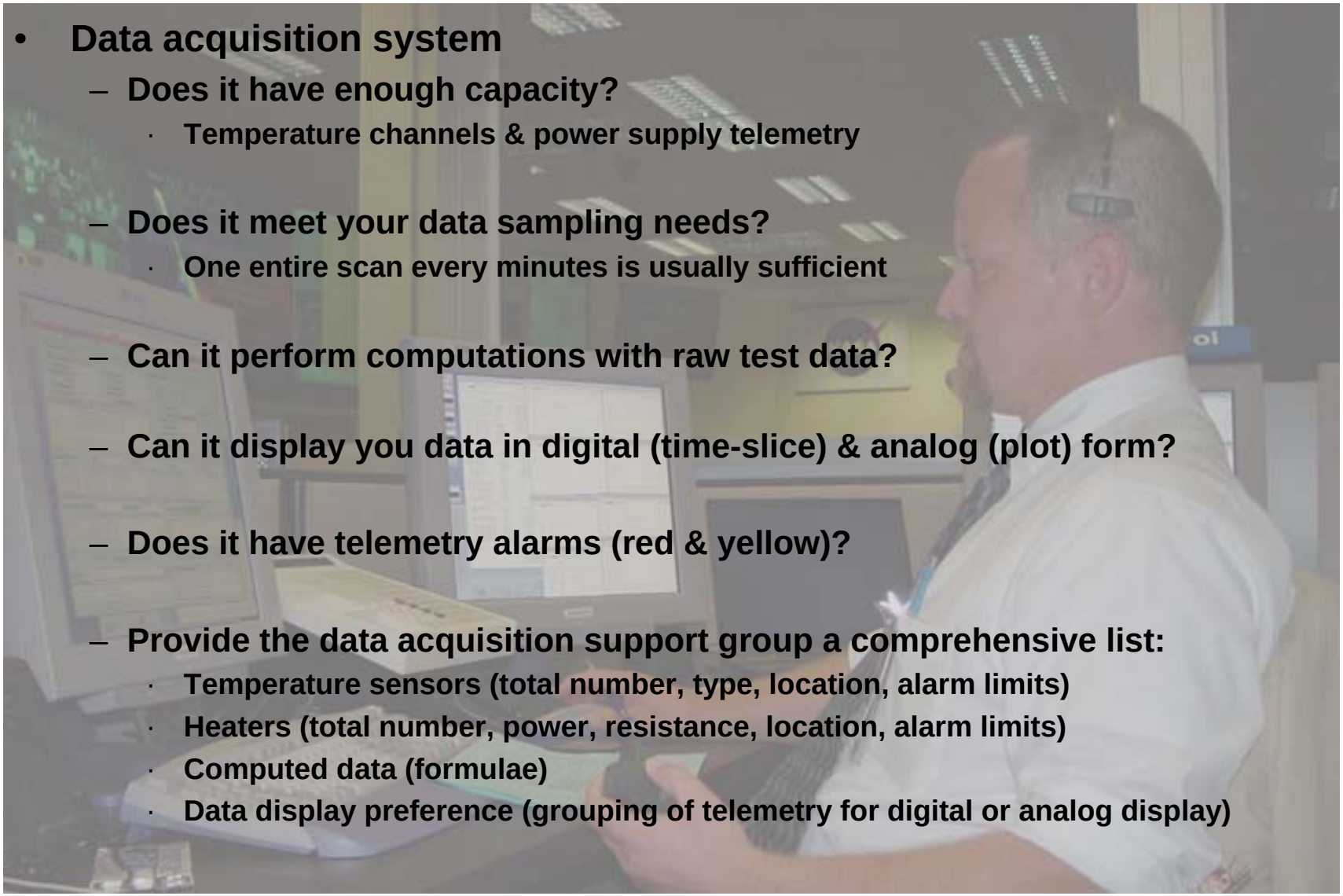


Chamber Facility's Role



- **Go through the process to schedule your test on the facility schedule**
  - **Do it as soon as you know a credible date**
  - **Make them aware of your schedule changes immediately**
- **The facility usually generates their own test procedure**
  - **Provide your test matrix including chamber condition requirements**
    - **Cryogenic cold targets**
    - **IR lamps**
    - **Solar simulation lamps**
    - **Test atmosphere (GN_2 is one typical medium)**
    - **Shroud temperature (level & rate of change)**
    - **Contamination monitors**
- **If the chamber has been inoperative for some time, a facility dry-run of your test is highly recommended**

Data Acquisition & Instrumentation (1/5)

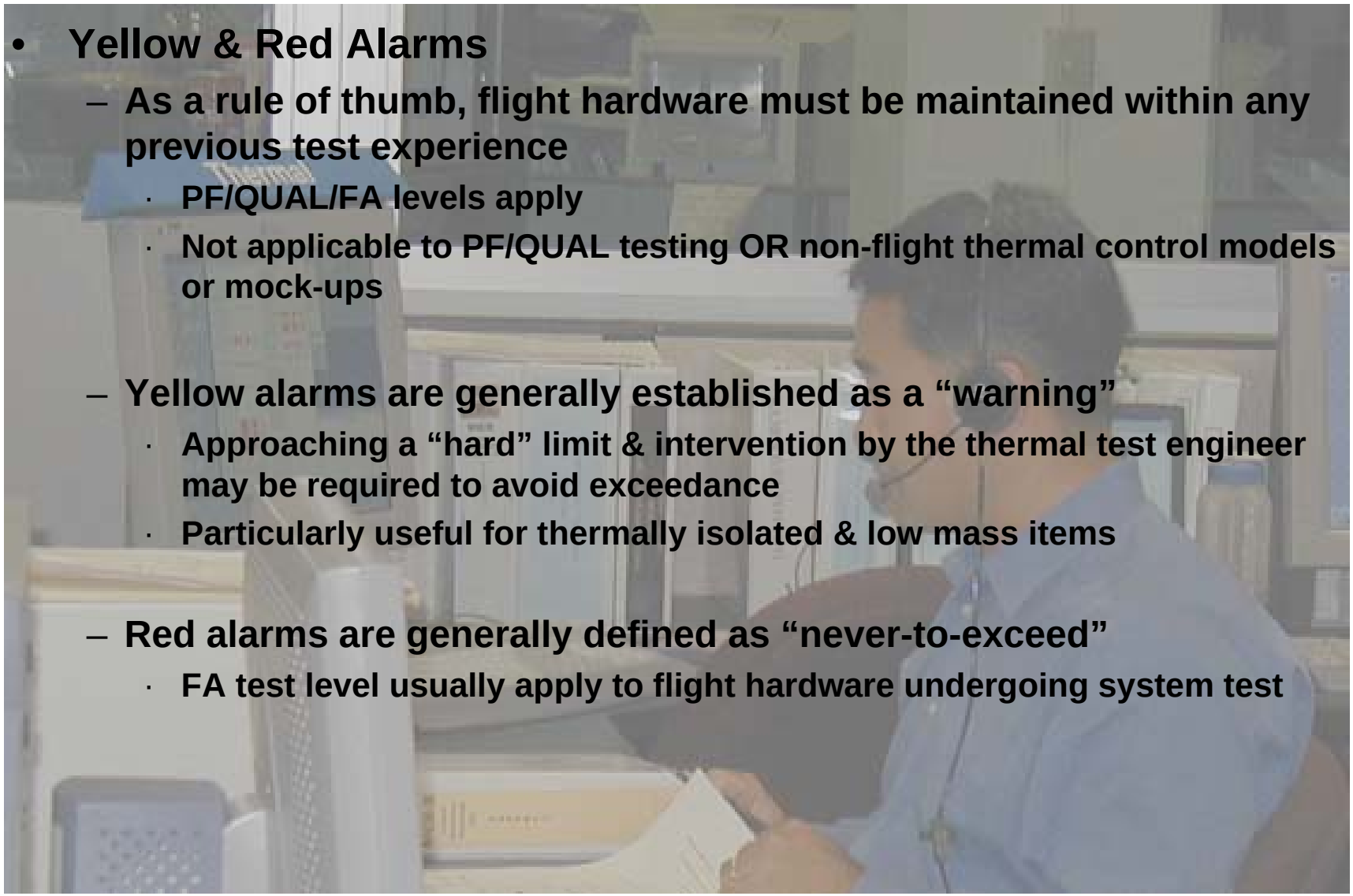


- **Data acquisition system**
  - **Does it have enough capacity?**
    - **Temperature channels & power supply telemetry**
  - **Does it meet your data sampling needs?**
    - **One entire scan every minutes is usually sufficient**
  - **Can it perform computations with raw test data?**
  - **Can it display you data in digital (time-slice) & analog (plot) form?**
  - **Does it have telemetry alarms (red & yellow)?**
  - **Provide the data acquisition support group a comprehensive list:**
    - **Temperature sensors (total number, type, location, alarm limits)**
    - **Heaters (total number, power, resistance, location, alarm limits)**
    - **Computed data (formulae)**
    - **Data display preference (grouping of telemetry for digital or analog display)**

Data Acquisition & Instrumentation (2/5)

- **Temperature instrumentation**
  - **Thermocouple type: Type E, 26 AWG**
    - **Chromel/Constantan recommended to maximize temperature/voltage sensitivity & to minimize parasitic heat leak**
    - **Smaller gauge wire may be needed for very low thermal balance cases**
      - These thermocouples are more susceptible to breakage
  - **Consider redundant thermocouples in critical situations**
    - **Avoid the need for a chamber break in an event of a failure**
  - **Provide sufficient lead time for the installation of thermocouples that are buried inside hardware assemblies**
    - **May result in "clip & fly" approach; may need to consider shielding or grounding open thermocouple**
  - **Place a test thermocouple on every test heater & have its telemetry visible**
  - **For external surface thermocouples, use tape to match actual surface emittance**

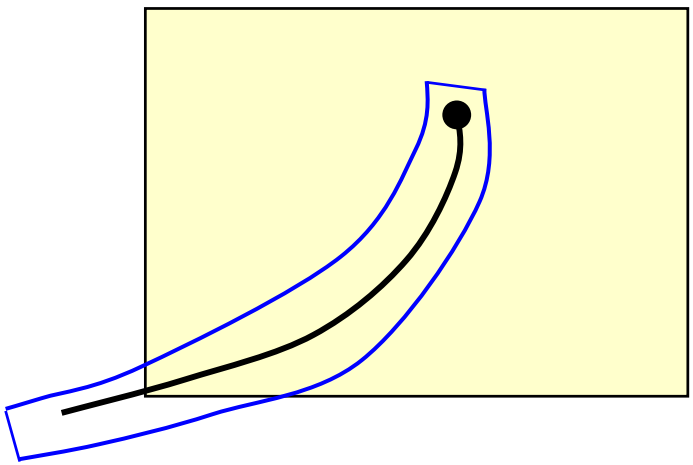
Data Acquisition & Instrumentation (2/5)



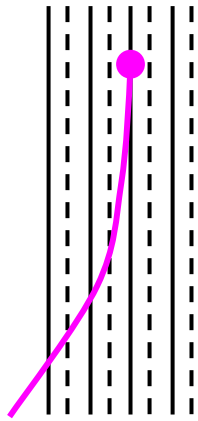
- **Yellow & Red Alarms**
  - **As a rule of thumb, flight hardware must be maintained within any previous test experience**
    - **PF/QUAL/FA levels apply**
    - **Not applicable to PF/QUAL testing OR non-flight thermal control models or mock-ups**
  - **Yellow alarms are generally established as a "warning"**
    - **Approaching a "hard" limit & intervention by the thermal test engineer may be required to avoid exceedance**
    - **Particularly useful for thermally isolated & low mass items**
  - **Red alarms are generally defined as "never-to-exceed"**
    - **FA test level usually apply to flight hardware undergoing system test**

Data Acquisition & Instrumentation (3/5)

- **Thermocouples locally disturb flight-like thermal balance**
  - **Complicates accurate measurement for low heat flow situation (e.g., thermal blankets)**
  - **Minimize non-flight features to the maximum extent practical**

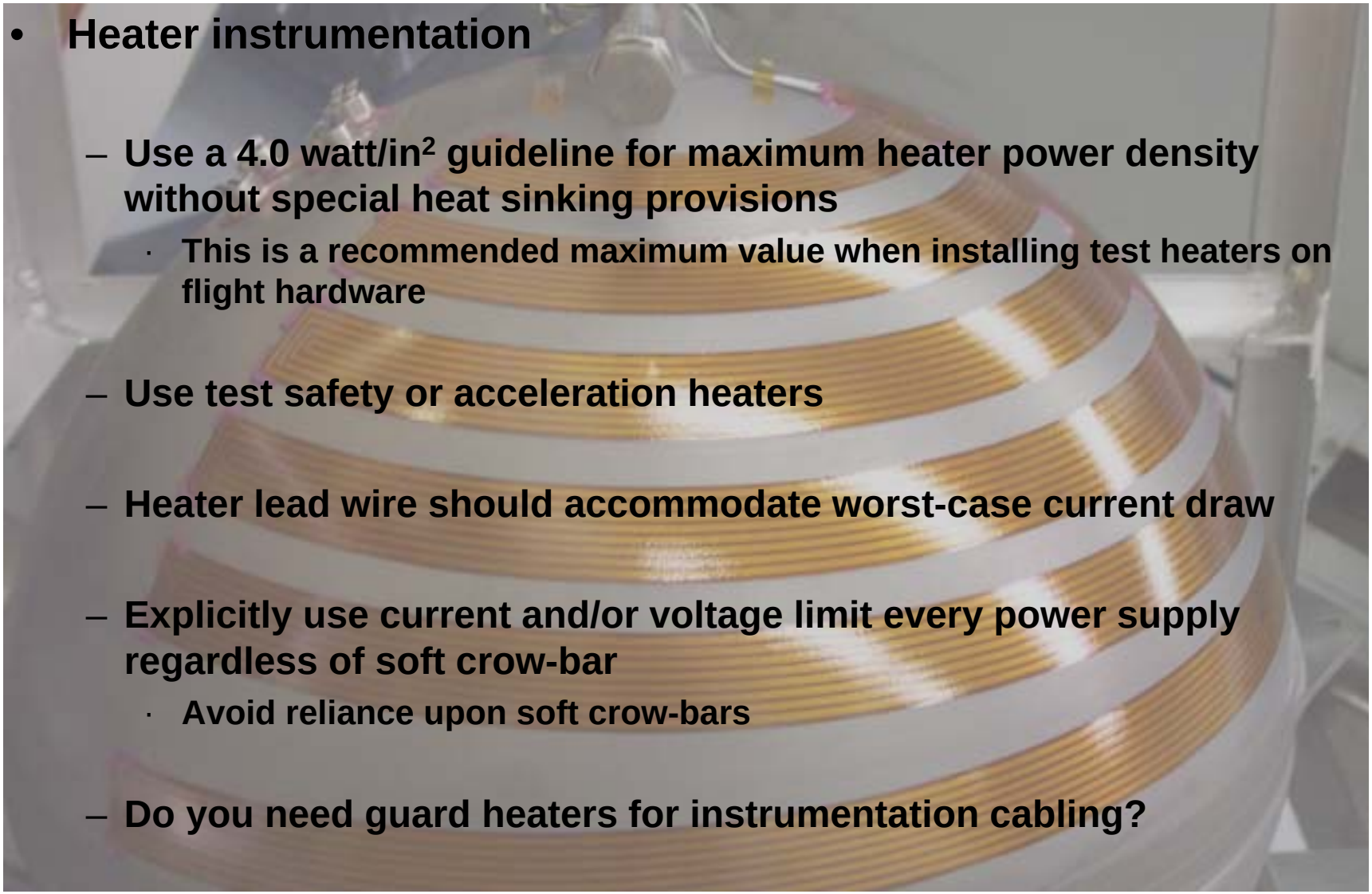


If mounted on an exterior surface, thermally sink thermocouple wire to exterior surface & match exterior surface emittance



If the blanket is non-flight, attach thermocouple to 2nd or 3rd inner layer & route maximum length of wire inside blanket

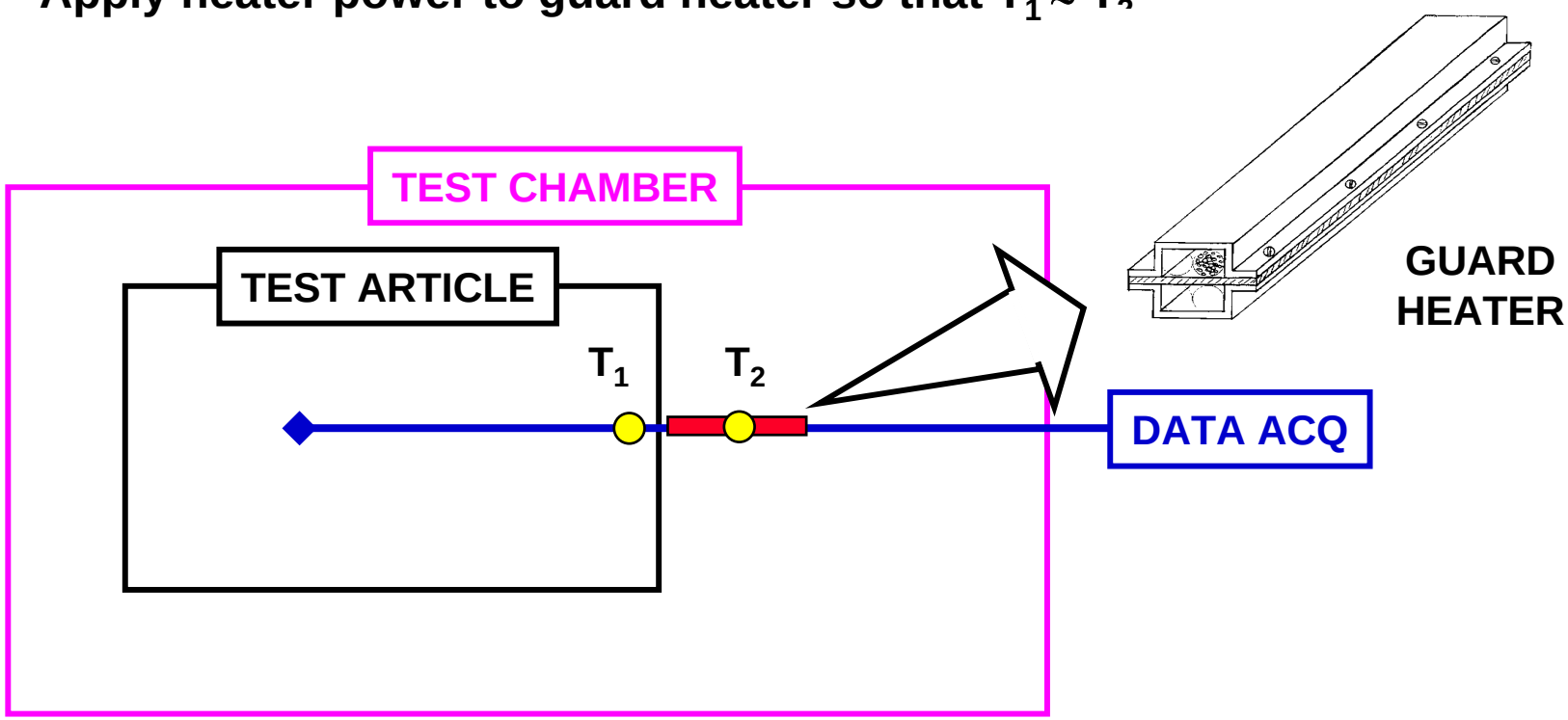
Data Acquisition & Instrumentation (4/5)



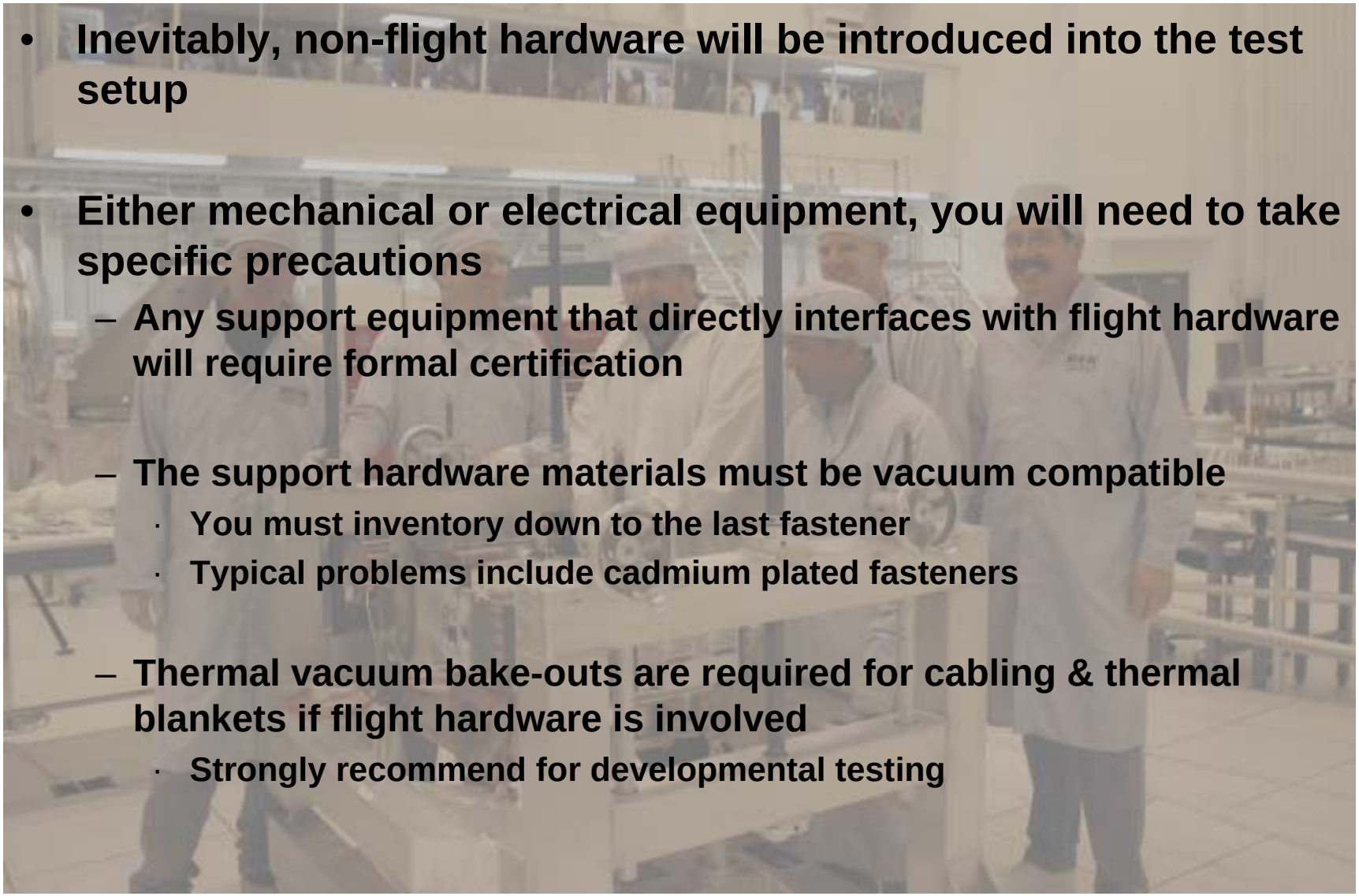
- **Heater instrumentation**
  - **Use a 4.0 watt/in^2 guideline for maximum heater power density without special heat sinking provisions**
    - **This is a recommended maximum value when installing test heaters on flight hardware**
  - **Use test safety or acceleration heaters**
  - **Heater lead wire should accommodate worst-case current draw**
  - **Explicitly use current and/or voltage limit every power supply regardless of soft crow-bar**
    - **Avoid reliance upon soft crow-bars**
  - **Do you need guard heaters for instrumentation cabling?**

Data Acquisition & Instrumentation (5/5)

- **Cabling guard heater implementation**
  - **The objective is to reduce loss from cabling to chamber**
  - **This is accomplished by controlling the local heat flow where cabling egresses from test article**
  - **Apply heater power to guard heater so that $T_1 \approx T_2$**



Mechanical & Electrical Support Equipment

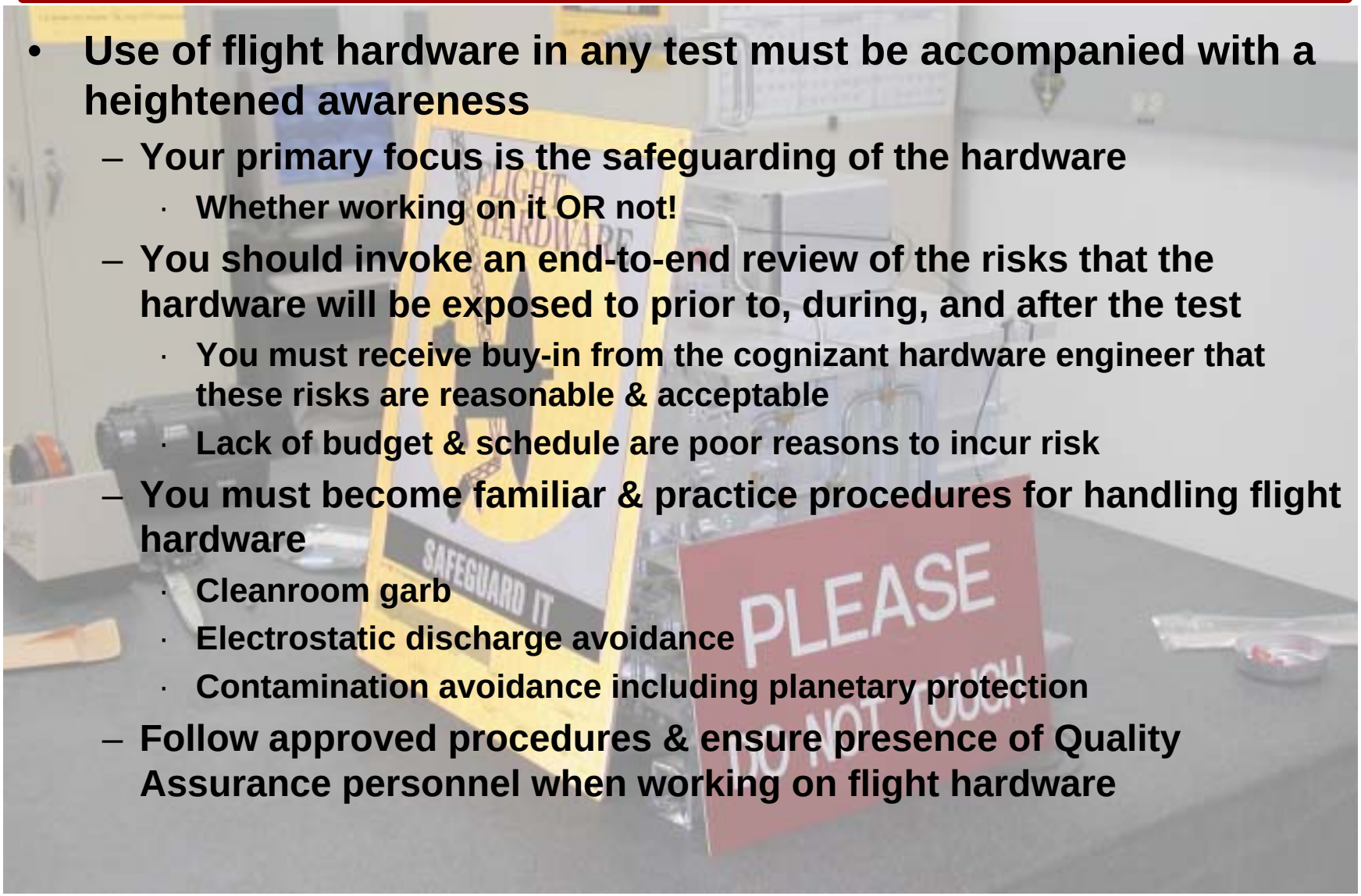


- **Inevitably, non-flight hardware will be introduced into the test setup**
- **Either mechanical or electrical equipment, you will need to take specific precautions**
  - **Any support equipment that directly interfaces with flight hardware will require formal certification**
  - **The support hardware materials must be vacuum compatible**
    - **You must inventory down to the last fastener**
    - **Typical problems include cadmium plated fasteners**
  - **Thermal vacuum bake-outs are required for cabling & thermal blankets if flight hardware is involved**
    - **Strongly recommend for developmental testing**

Interfacing with Integration & Test

- **The I&T team plays are critical role for thermal testing involving flight hardware**
  - **They drive when the hardware is available for testing**
  - **They can also help by providing better skilled resources to bear**
  - **Regular coordination with I&T must take place well before the start of testing**
- **Important issues prior to the test:**
  - **Installation of test thermocouples & heaters**
  - **Definition of special functional test cases**
  - **Identify need for mechanical and/or electrical support equipment**
  - **Coordinate the move & integration of the test hardware into the chamber**

Testing with Flight Hardware



- **Use of flight hardware in any test must be accompanied with a heightened awareness**
  - **Your primary focus is the safeguarding of the hardware**
    - **Whether working on it OR not!**
  - **You should invoke an end-to-end review of the risks that the hardware will be exposed to prior to, during, and after the test**
    - **You must receive buy-in from the cognizant hardware engineer that these risks are reasonable & acceptable**
    - **Lack of budget & schedule are poor reasons to incur risk**
  - **You must become familiar & practice procedures for handling flight hardware**
    - **Cleanroom garb**
    - **Electrostatic discharge avoidance**
    - **Contamination avoidance including planetary protection**
  - **Follow approved procedures & ensure presence of Quality Assurance personnel when working on flight hardware**

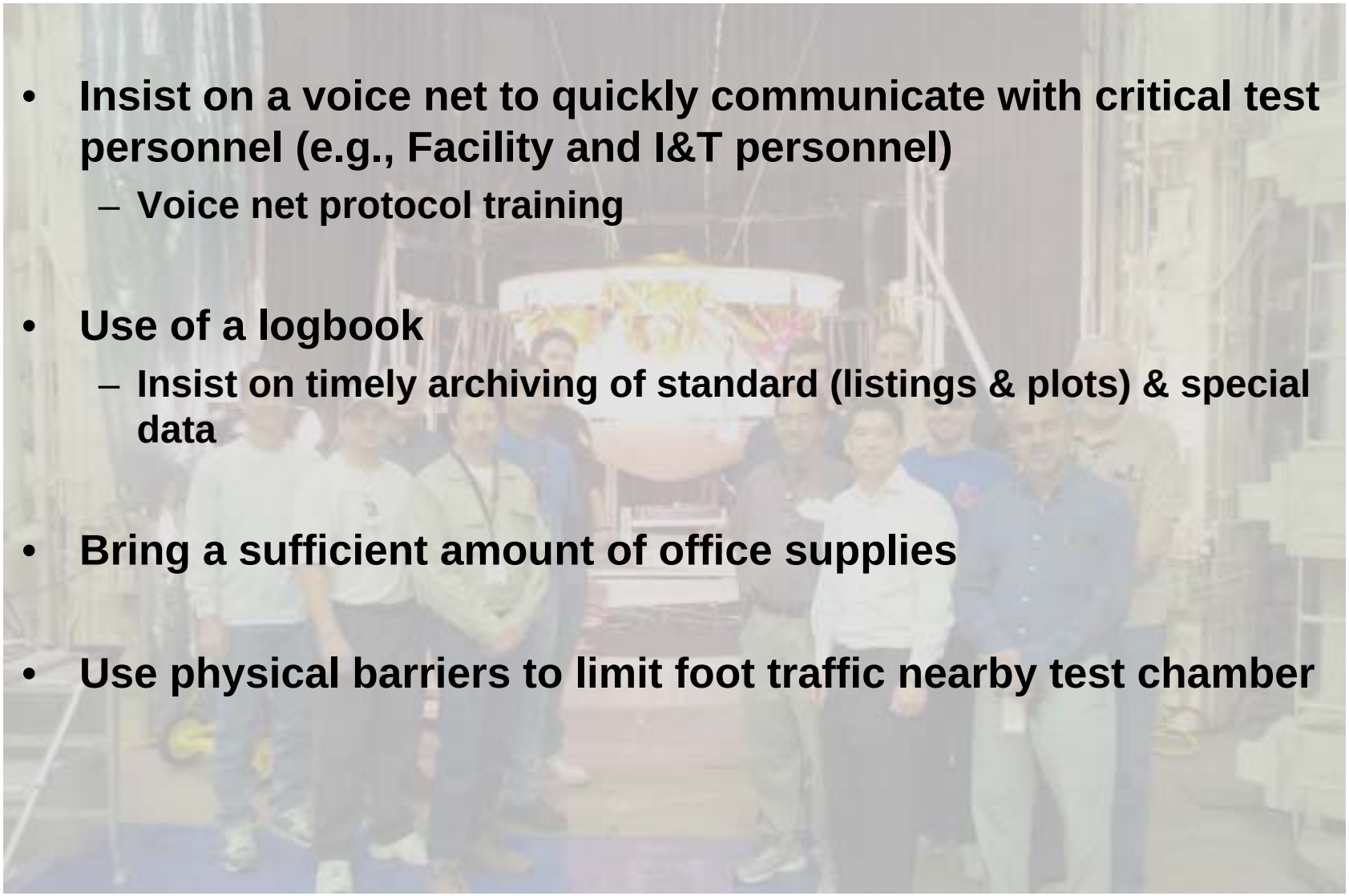
Safety First!

- **Your other primary focus must be the safety of everyone involved with your test**
  - **Is the test facility certified?**
    - **Consider support equipment such as cranes or other hoisting devices**
  - **Is your test staffing adequately trained to perform their functions?**
    - **"Buddy" system usage**
    - **Entry into confined spaces**
    - **Entry into spaces where GN_2 or LN_2 was used**
  - **Has test plan/procedure been survey & approved by Safety?**
    - **Emergency evacuation procedures**
    - **Emergency contact information**
    - **Loss of facility power procedures**
    - **Loss of data acquisition procedure**
    - **Loss of facility vacuum procedure**

Considerations For Executing the Test (1/2)

- **Use an optimal test matrix strategy**
  - **Rule of Thumb: First test case should be coldest environment & then subsequent case are incrementally warmer**
  - **Rule of Thumb for critical events: Avoid scheduling critical events during the graveyard shift**
  - **Use a system engineering approach to all functional verification or validation aspects of the thermal design**
  - **Seek out input from hardware cognizant engineer or I&T engineers for recommendations for special tests**
- **Balanced monitoring workforce to prevent mistakes**
  - **Rule of Thumb for around-the-clock testing: 3 shifts with 2 test monitors for a 9-hour duration with an overlap of 1 hour between shifts for a hand-over briefing**
  - **Provide monitoring relief after 5 consecutive days**
- **Ensure your monitoring staff has adequate data acquisition training**
- **Insist on a voice net to quickly communicate with critical test personnel (e.g., Facility and I&T personnel)**

Considerations For Executing the Test (2/2)



- **Insist on a voice net to quickly communicate with critical test personnel (e.g., Facility and I&T personnel)**
  - **Voice net protocol training**
- **Use of a logbook**
  - **Insist on timely archiving of standard (listings & plots) & special data**
- **Bring a sufficient amount of office supplies**
- **Use physical barriers to limit foot traffic nearby test chamber**

References

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

- Yarnell, N. "Design, Verification/Validation and Operations Principles for Flight Systems," Section 4.8.2.1, Thermal Control Design Margin, Internal JPL Document D-17868, March 3, 2003.

- 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.