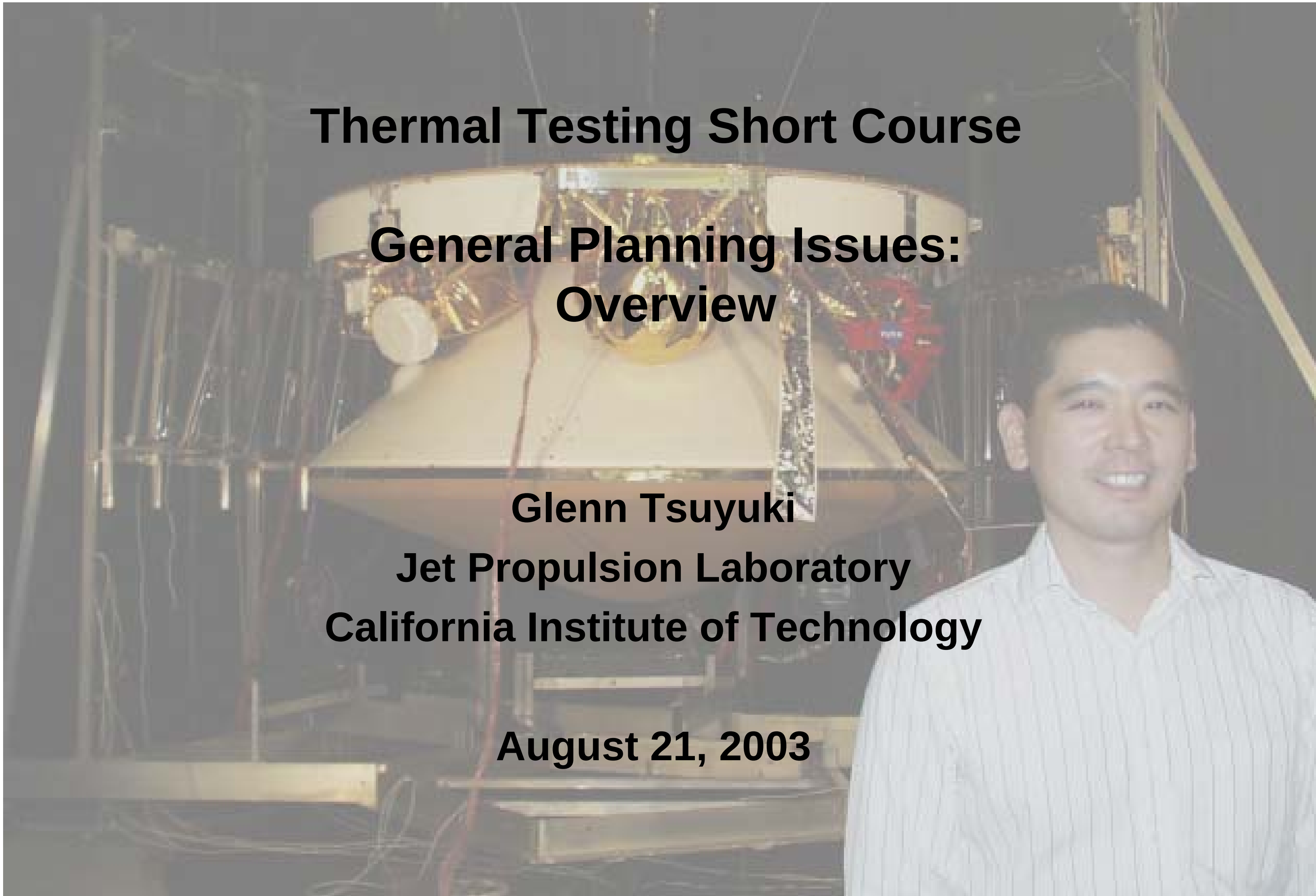

Thermal Testing Short Course

General Planning Issues: Overview

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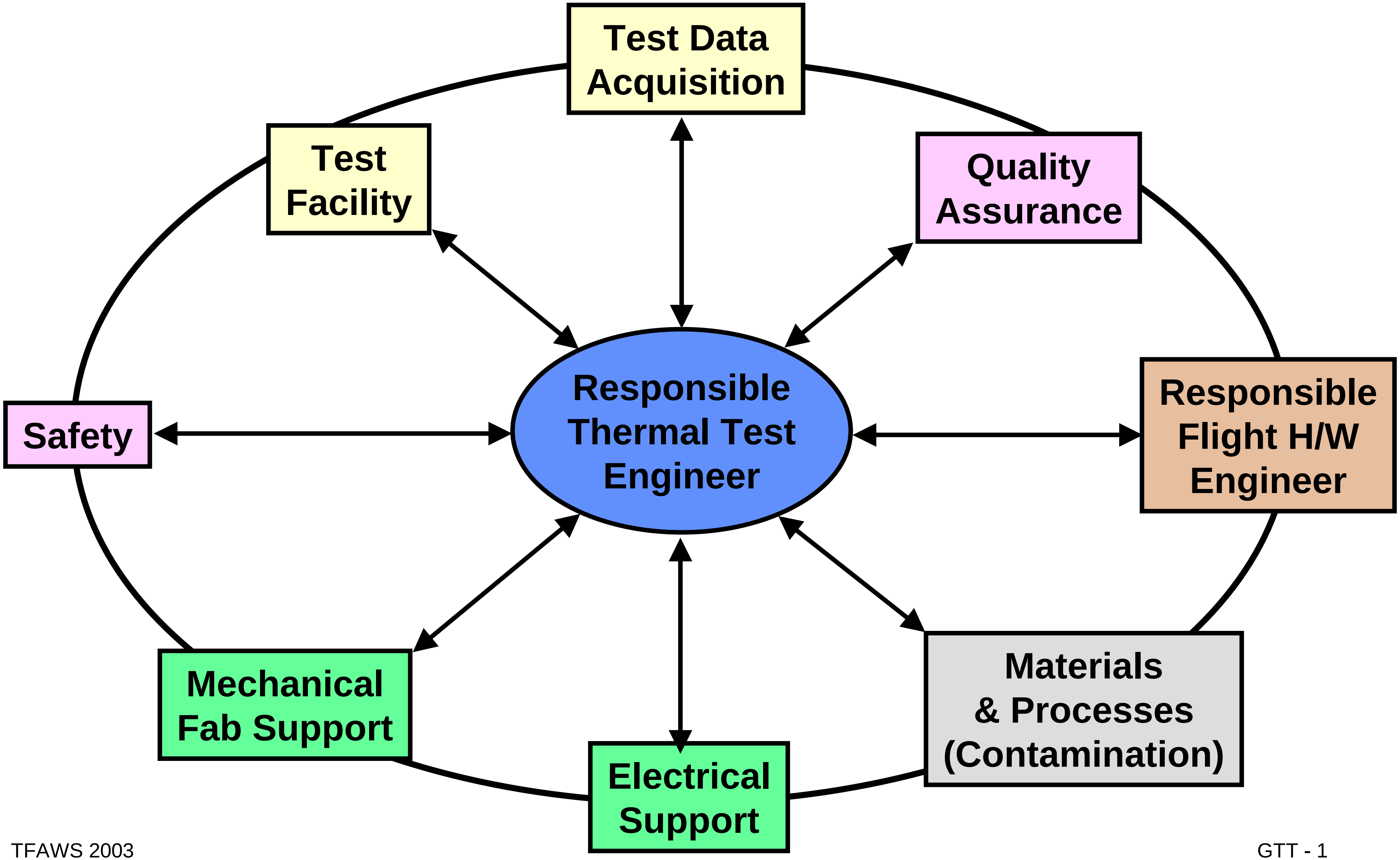
August 21, 2003

The World According to the Thermal Test Engineer



Your Role as Thermal Test Engineer

- **Understanding your role as responsible thermal test engineer**
  - **Clear and decisive communication with your interfaces is critical**
    - **Be proactive; attend to issues quickly & prevent new ones from arising**
  - **Develop well-defined and verifiable test objectives**
    - **This will define how the test will be simulated and instrumented**
    - **Identify special tests**
  - **Know your responsibilities for ensuring hardware & personnel safety**

- **Planning becomes more intertwined with other parties as you move from a thermal development test to an assembly-level qualification/acceptance test to a system-level thermal test**

- **Test planning involves a significant amount of your time & effort so allocate ample time in your schedule**

Elements of the Test Plan

- Objectives
- Test Article
- Test Setup
- Chamber Facility
- Data Acquisition
- Mechanical & Electrical Support Equip
- Test Matrix
- Cost & Schedule

Planning: "Rome Wasn't Built in a Day" (1/3)

- **Why is a plan needed?**

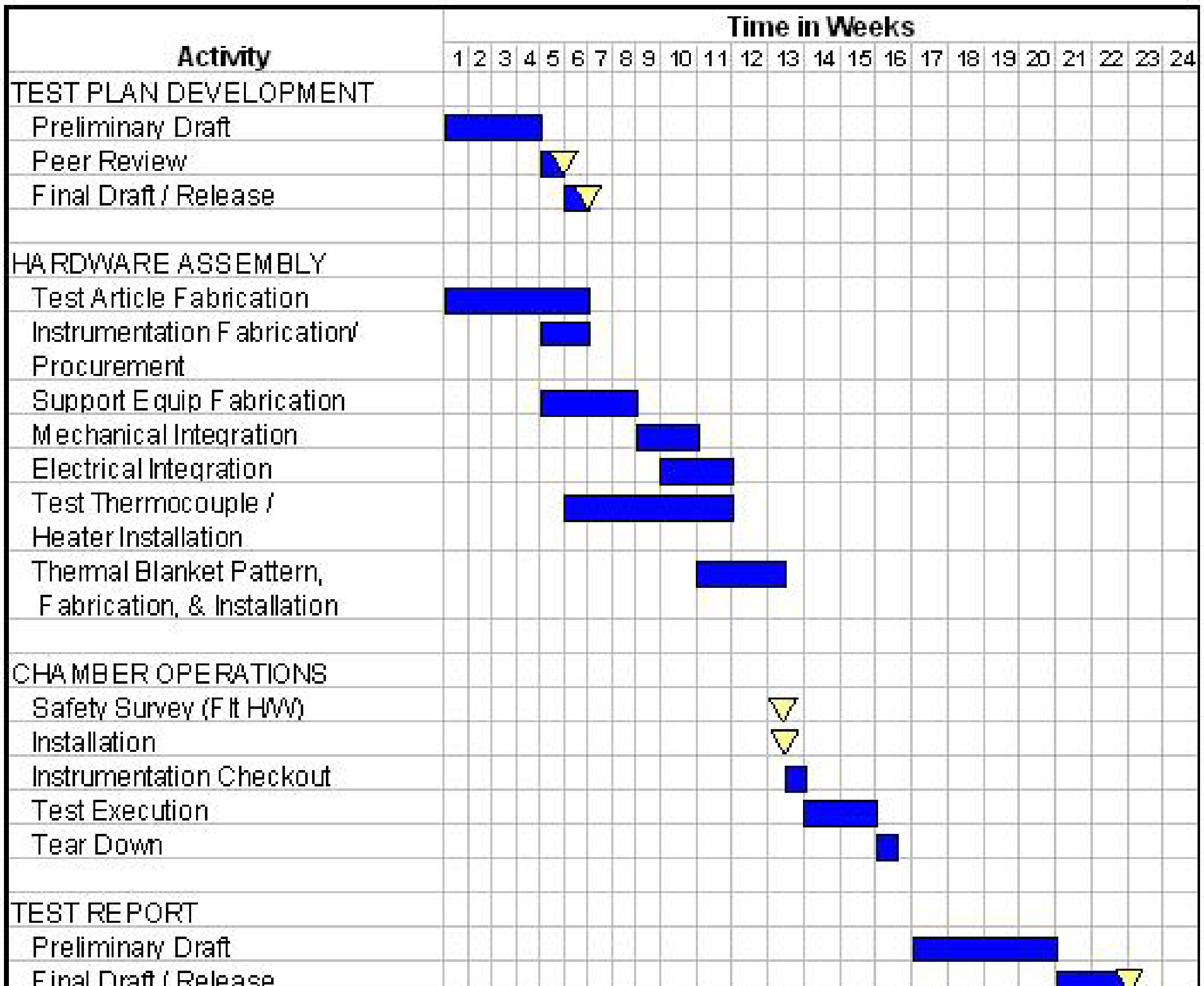
  - **Tool that initiates & guides the test planning & preparation process**

  - **Acts as the driver to totally engage the responsible thermal test engineer**
    - **Allows you to stay on top of all test aspects, even as the test evolves**

  - **Stimulates feedback from the key interfaces**
    - **Leads to a more efficient use of resources**

Planning: “Rome Wasn’t Built in a Day” (2/3)

- **How long does the planning & preparation process take?**
  - **Schedule shown is typical of development testing**



Planning: "Rome Wasn't Built in a Day" (3/3)

- **High-level schedule for system thermal testing (STT)**

Event	Timing
Preliminary STT Concept	Thermal PDR
STT Preliminary Plan Peer Review	4 Weeks Prior to Thermal CDR
Preliminary STT Plans	Thermal CDR
Preliminary STT Plan Release	2 Weeks Prior to ETRR
Preliminary STT Plan Summary	ETRR
STT Final Plan Peer Review	6 Weeks Prior to STT Start
STT Final Plan Project Review	4 Weeks Prior to STT Start
STT Final Plan Sign-off	2 Weeks Prior to STT Start
STT Preliminary Results Presentation	1 Week After STT End
STT Final Test Report Peer Review	10 Weeks after STT End
STT Final Test Report Release	3 Months After STT End

Objectives: "The Chicken is Involved for Eggs; The Pig is Committed for Pork"

- **Test objectives are the very core of the test**
  - **Specific**
  - **Verifiable from the test results**

- **Objectives fall into two categories**
  - **Primary**
  - **Secondary or Special**

- **Primary objectives**
  - **Very often, linked to Project Level 3 & 4 requirements**
  - **"To determine the survival heater power for the worst-case cold Martian surface thermal environment"**
  - **"To demonstrate in-specification telescope optical performance at the hot and cold flight acceptance temperature levels"**
  - **"To verify that the temperature control design will maintain the spacecraft and all its elements within allowable flight temperature ranges while operating over the environmental extremes expected for the mission"**

Objectives: "The Chicken is Involved for Eggs; The Pig is Committed for Pork"

- **Secondary or special objectives**
  - **Tests present unique opportunities to obtain additional empirical information to more fully understand the thermal design**
  - **If properly planned, the gathering of this information will be of minimal impact to the primary test flow**
  - **Examples**
    - **Sensitivity of temperature to power**
      - Optimize size of flight heaters
      - Assess effect of poorly-known or degraded thermal properties
      - Assess heater element failure
    - **Sensitivity of temperature to boundary conditions**
    - **Determine temperature changes after switching from primary to redundant equipment**
    - **Obtain information for mission operations**
      - How long can heaters (or equipment) be turned off?
      - How long does it take a heater to do its warm-up job?

Objectives: "The Chicken is Involved for Eggs; The Pig is Committed for Pork"

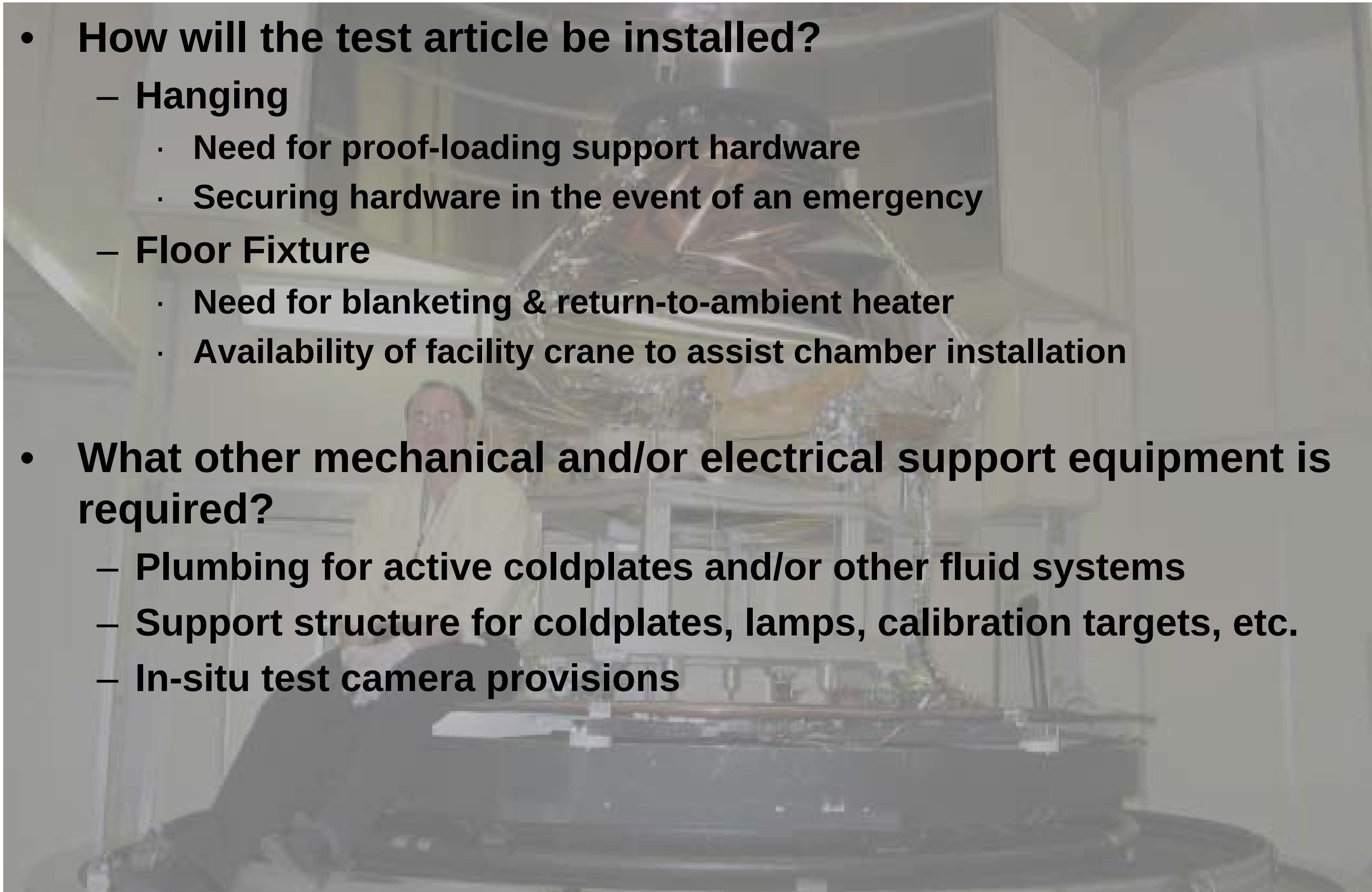
- **"Permissible" temperature limits when using flight hardware**
  - **Although there are established Level 3 allowable flight temperature limits, there is no universally accepted interpretation of permissible limits during test**
  - **Permissible test limits are the criteria for the generation of problem/failure documentation**
    - **A balance between hardware safety & test flexibility must be struck**
    - **Flight hardware should be only exposed to temperature levels within previous environmental test experience**
    - **At JPL, flight acceptable (FA) test limits have constituted permissible test limits**
      - Enabled testing to continue when marginal allowable flight temperature violations occurred

> – **You must unambiguously define these limits & reach agreement with the appropriate parties <u>before the test begins</u>**

Test Article: What Is It That We're Testing?

- **Developmental testing usually uses non-flight hardware**
  - **You must define the key thermal requirements for the fabrication of the test article**
    - **How important is fit & form?**
    - **How important is the article mass?**
    - **How will internal power be simulated?**
    - **Replication of heat transfer paths including radiation (i.e., surface finish)**
    - **Egress of test heater & temperature sensor cabling**
    - **Avoid cadmium-plated fasteners (not vacuum qualified)**
  - **Use of flight hardware will complicate the test planning**
- **Protoflight/Qualification & Flight Acceptance testing involves flight hardware**
- **System-level testing involves primarily flight hardware**
  - **However, EM or QUAL units may be used as substitutes when flight hardware is late**
  - **You will need to assess the impact to your objectives if such substitutions occur**

Test Set-up Considerations



- **How will the test article be installed?**
  - **Hanging**
    - **Need for proof-loading support hardware**
    - **Securing hardware in the event of an emergency**
  - **Floor Fixture**
    - **Need for blanketing & return-to-ambient heater**
    - **Availability of facility crane to assist chamber installation**
- **What other mechanical and/or electrical support equipment is required?**
  - **Plumbing for active coldplates and/or other fluid systems**
  - **Support structure for coldplates, lamps, calibration targets, etc.**
  - **In-situ test camera provisions**

Test Facilities Considerations

- **Ensure that the facility has been certified for the environmental testing that you will conduct**
  - **Facility safety survey**
  - **Cleanliness**
- **Select minimally-sized chamber subject to:**
  - **Test objectives**
  - **Critical mechanical clearances to chamber wall**
  - **Accommodation of other support hardware**
- **Most thermal tests require a cold shroud**
  - **Understand temperature ranges & stability**
  - **Understand impact of close proximity of the test article to shroud**
  - **Do you also require a door shroud?**
- **Optical test articles may require a chamber window**
  - **Special thermal considerations to reduce impact of window**
    - **Reduce aperture area with thermal blanketing or highly reflective shield**
    - **Use a long-length chamber & place test article as far from the window as possible**
- **Ensure that the surrounding external chamber area is sufficient for staging and accommodation any GSE**

Test Data Acquisition Planning (1/2)

- **How do you determine where the thermocouples & test heaters are located?**
  - **Temperature data that will directly lead to verifying your objectives**
  - **Temperature data that will provide a better understanding of your design**
  - **Temperature data that will not be measured in-flight**
  - **What hardware requires safeguarding in event of a facility failure or test problem?**
  - **Consider supplementing flight heaters where practical**
    - **Accelerate achievement of steady-state**
    - **Accelerate transition to return-to-ambient**
  - **Consider *in-situ* massive support equipment which need warm-up acceleration upon return-to-ambient**

- **Defining computed data from raw test data**
  - **Maximum, minimum, & average temperatures**
  - **Spatial temperature difference**
  - **Temperature rate of change**
  - **Internal power dissipation**

Test Data Acquisition Planning (2/2)

- **Defining how you want the data sampled and displayed**
  - **What data should be grouped together for display?**
  - **Define display lists & plots for implementation**
  - **Formulate yellow & red alarm temperature limits**

- **Power supply capabilities**
  - **Define quantity & capability**
    - **Voltage or current range**
    - **Define maximum voltage and/or current limits**
  - **Availability of proportional heater controllers**
  - **Replication of thermostatic heater control**

Mechanical & Electrical Support Equipment

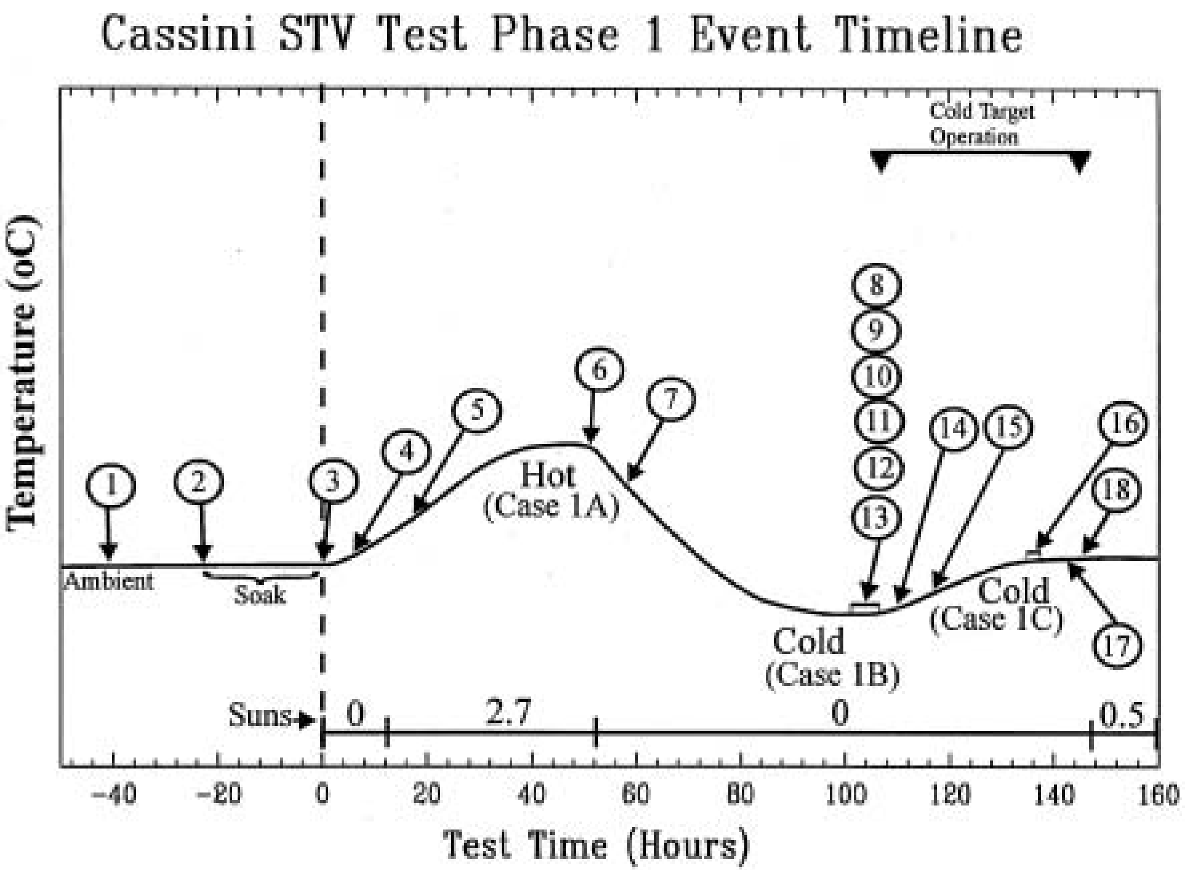
- **Development testing will require a significant amount of mechanical fabrication support**
  - **Get them involved with the planning process as early as possible**
    - **Seek feedback about feasibility of thermal mock-up design & fabrication**
      - Includes support hardware & thermal blanketing

- **PF/QUAL/FA & system-level testing will require flight technicians to assemble and integrate flight hardware for the test**
  - **Get involved to understand the mechanical & electrical integration flow**
  - **Identify the need for the fabrication of support hardware**
    - **Develop a mutually acceptable schedule**
  - **Identify key times where test instrumentation & blanketing can be installed**

Test Matrix Development Process (1/2)

- **The challenge: Determine how best to incorporate all of the test objectives within an allocated test time period**
  - **The resolution process involves the stakeholders of each test objective**
  - **This process becomes more complex when a system-level thermal test is involved**
- **The process**
  - **Identify major test divisions on a timeline**
  - **Identify when specific events occur**
  - **Focus on first accommodating primary objectives & then finding non-intrusive time periods (from a thermal perspective) for special tests & objectives**

Test Matrix Development Process (2/2)



Event No.	Description
1	S/C Baseline Test
2	Close Chamber
3	Nitrogen Flush 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

Reviewing Your Test Plan

Prior to Test → Test Execution ← After the Test

Test Plan Peer Review

Environmental Test Readiness Review

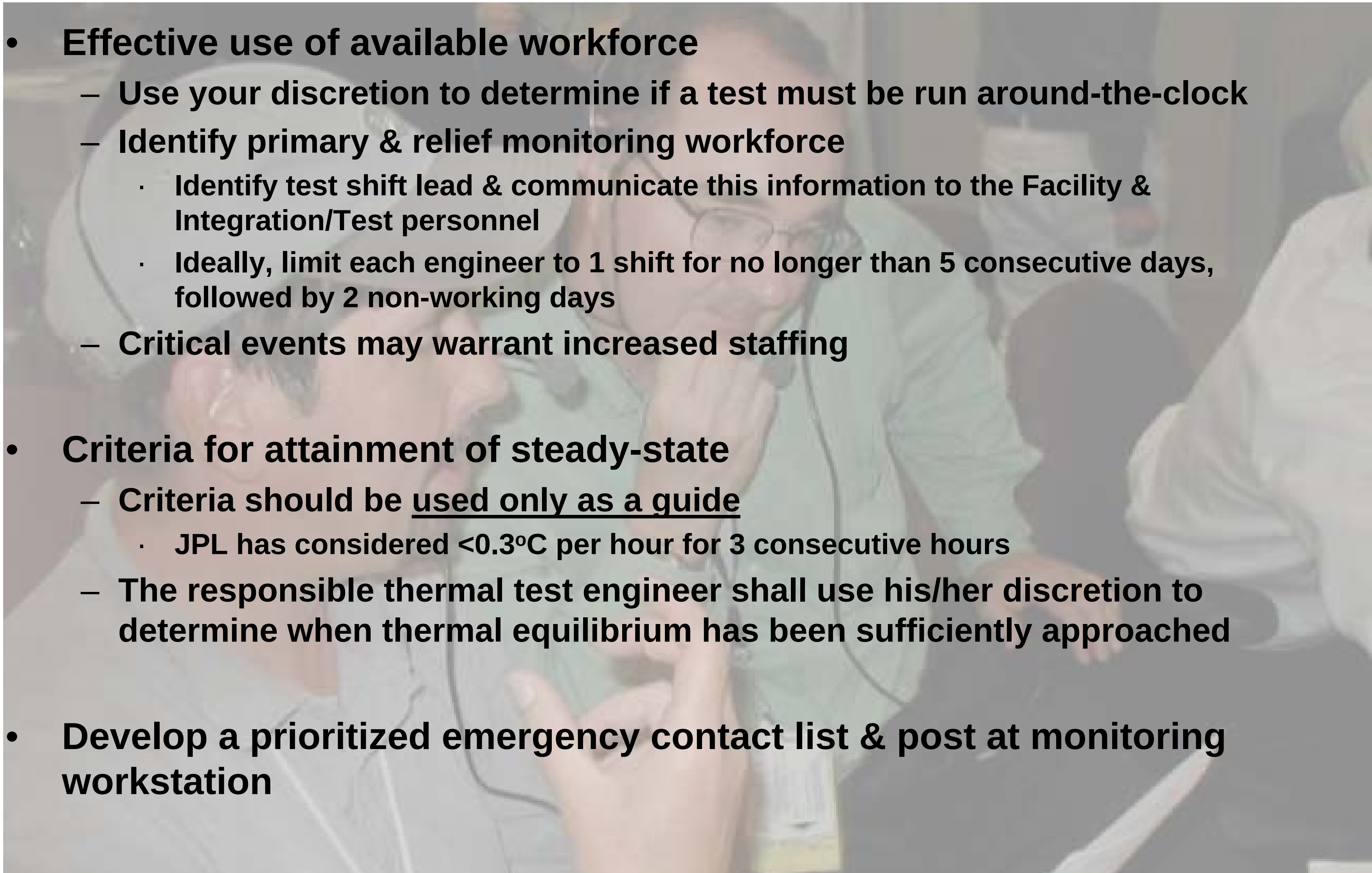
Operational Safety Survey

Test Results Review

Post-Test Review

Blue font indicates required when flight hardware present

Test Execution Considerations

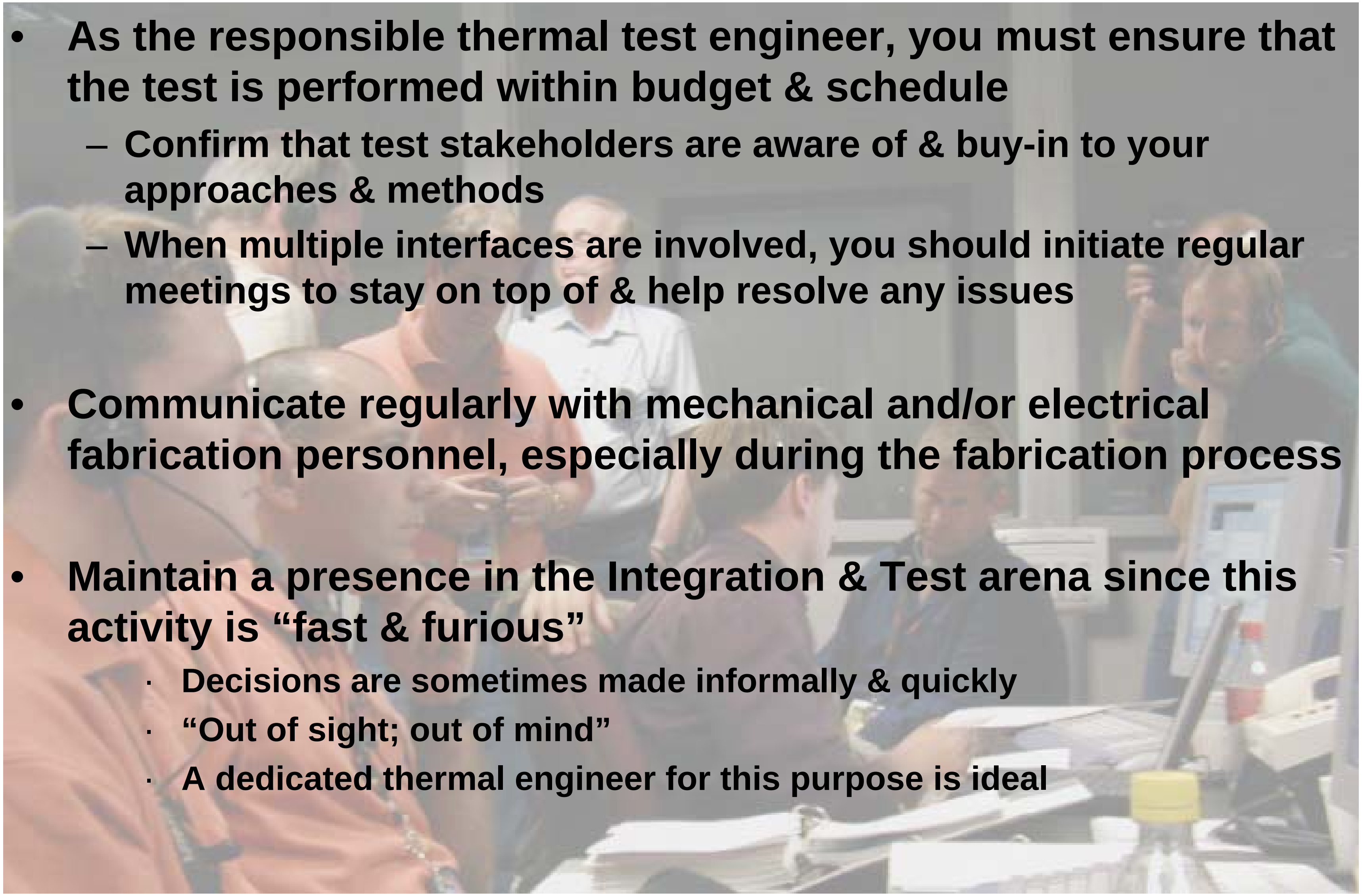


- **Effective use of available workforce**
  - **Use your discretion to determine if a test must be run around-the-clock**
  - **Identify primary & relief monitoring workforce**
    - **Identify test shift lead & communicate this information to the Facility & Integration/Test personnel**
    - **Ideally, limit each engineer to 1 shift for no longer than 5 consecutive days, followed by 2 non-working days**
  - **Critical events may warrant increased staffing**

- **Criteria for attainment of steady-state**
  - **Criteria should be <u>used only as a guide</u>**
    - **JPL has considered <0.3^{o}C per hour for 3 consecutive hours**
  - **The responsible thermal test engineer shall use his/her discretion to determine when thermal equilibrium has been sufficiently approached**

- **Develop a prioritized emergency contact list & post at monitoring workstation**

Communication Ensures Good Test Coordination



- **As the responsible thermal test engineer, you must ensure that the test is performed within budget & schedule**
  - **Confirm that test stakeholders are aware of & buy-in to your approaches & methods**
  - **When multiple interfaces are involved, you should initiate regular meetings to stay on top of & help resolve any issues**
- **Communicate regularly with mechanical and/or electrical fabrication personnel, especially during the fabrication process**
- **Maintain a presence in the Integration & Test arena since this activity is "fast & furious"**
  - **Decisions are sometimes made informally & quickly**
  - **"Out of sight; out of mind"**
  - **A dedicated thermal engineer for this purpose is ideal**

Be Proactive: Contingency Planning

- **Consider design weaknesses that may be uncovered as deficient**
  - **With & without breaking chamber, what additional testing could be performed?**
    - **Provide schedule margin to recover from a design deficiency**
  - **Could some design feature be included in the test setup to provide flexibility?**
    - **Provide more required radiator area or heater power**
  - **Identify “gotta have” test cases versus “wanna have” test cases**
    - **Recovery from a deficiency may result in deletion of test cases to meet Project schedule**
- **Consider the opposite where the test goes faster than expected**
  - **What additional testing would provide high value?**

References (1/2)

- **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 2.0, Test Planning, Internal JPL Document D-7626, April 1990.**

- **Farguson, C. "Mars Exploration Rover (MER) Project, Assembly Level Environmental Verification Specification (EVS) (Test and Analysis Requirements)," Internal JPL Document TS 518478, July 1, 2003.**

References (1/2)

- **Stultz, J. "Guidelines for the Preparation of Thermal Development Test Plans," JPL Internal Document IOM 3547-CAS-93-066, March 30, 1993.**

- **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.**