SEP/HET/LET Thermal Vacuum Test Plan

PREPARED BY: ______________________ ________________

R. Harrison Date

APPROVED BY:

______________________ ________________

J. Hawk Date
Thermal Engineer

______________________ ________________

TBD Date
IMPACT Instrument Manager

______________________ ________________

TBD Date
Project Manager

______________________ ________________

TBD Date
Mechanical Engineer

______________________ ________________

TBD Date
Electrical Engineer

TABLE OF CONTENTS

ACRONYM LIST

GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HET	High Energy Telescope
ICD	Interface Control Document
I/F	Interface
IMPACT	In-situ Measurements of Particles and CME Transients
LET	Low Energy Telescope
MLI	Multi-Layer Insulation
MGSE	Mechanical Ground Support Equipment
MHz	Megahertz
PRT	Platinum Resistance Thermometer
QCM	Quartz Crystal Microbalance
RGA	Residual Gas Analyzer
S/C	Spacecraft
SEP	Suprathermal Ion Telecope
STEREO	Solar Terrestrial Relations Observatory
TB	Thermal Balance
TCU	Thermal Control Unit
TD	Test Director
TE	Test Engineer
T/C	Thermocouple
T/M	Thermistor
TTC	Thermal Test Conductor
TV	Thermal Vacuum (cycling)
TVTE	Thermal Vacuum Test Engineer

APPLICABLE DOCUMENTS

- STEREO Environment Definition, Observatory, Component and Instrument Test Requirements Document.
- STEREO Contamination Control Plan.
- IMPACT Environmental Test Plan
- IMPACT Contamination Control Plan
- Functional Test Plan(s) TBD

1.0 INTRODUCTION

This document establishes the test conditions, requirements, and procedures for the IMPACT Instrument SEP Main Assembly (SEP Central/HET/LET) Thermal Vacuum test and Thermal Balance. The test will qualify the two SEP Main Assemblies (Ahead and Behind) for flight.

2.0 TEST OBJECTIVES

The primary objectives of this test are to:

1) Validate the thermal design by subjecting a SEP Main Assembly to thermal test environments that conservatively simulate the flight hot and cold environments. (TB)

2) Gather steady state data in order to correlate the thermal models. (TB)

3) Confirm the thermal interface between the SEP Main Assembly and spacecraft via mounting standoffs and cabling. (TB)

4) Verify that survival heaters perform as specified. That they maintain the hardware within survival limits in the simulated worst case flight conditions. (TB and TV)

5) Verify that the operational heaters perform as specified. That they maintain the hardware within operational limits in the simulated worst case flight conditions. (TB and TV)

6) Verify the functionality of the SEP Main Assemblies at hot and cold environments in accordance with the STEREO Environment Definition, Observatory, Component and Instrument Test Requirements Document. (TV)

7) Verify hot and cold turn on of all components. (TV)

8) Insure proper workmanship through six thermal vacuum cycles per the STEREO Environment Definition, Observatory, Component and Instrument Test Requirements Document. (TV)

9) Bakeout the components according to contamination requirements. (TV)

3.0 SUCCESS CRITERIA

The following compliance matrix illustrates how the Test Objectives will be achieved during the test:

Objective	Compliance Criteria
Validate the thermal design	Subject a SEP Main Assembly to test environments outlined in Table 1 that conservatively simulate the flight hot and cold environments and verify that all temperatures are within limits with margin.
Gather steady state data in order to correlate the thermal models.	Thermal Balance to the stability criteria stated in Section 6.9.6 must be achieved at hot and cold environment conditions and data is gathered.
Confirm the thermal interface between the SEP Main Assembly and spacecraft via mounting standoffs and cabling	Temperature gradients across the interfaces should be within 3°C agreement between the test results and correlated thermal model.
Verify that survival heaters perform as specified (100% duty cycle at 25V). That they maintain the hardware within survival limits in the simulated worst case flight conditions.	The survival heaters keep the SEP Central/HET/LET instruments above Cold Survival temperature limits at the Cold Survival test environment settings outlined in Table 1. All thermostatically controlled heater circuits should be tested for proper function.
Verify that the operational heaters perform as specified (75% duty cycle at 30.5V). That they maintain the hardware within operational limits in the simulated worst case flight conditions.	The operational heaters keep the SEP Central/HET/LET instruments above Cold Operational temperature limits at the Cold Operational test environment settings outlined in Table 1. All thermostatically controlled heater circuits should be tested for proper function.
Verify the functionality of the SEP Main Assemblies at hot and cold environments in accordance with the STEREO Environment Definition, Observatory, Component and Instrument Test Requirements Document	With the instrument components at or beyond the operational soak goal temperatures outlined in Table 6, all hardware passes functional testing.
Verify hot and cold turn on of all components.	After a powered-off soak with the instrument components at or beyond the survival soak goal temperatures outlined in Table 6, all electronics properly turn on and operate.
Insure proper workmanship through six thermal cycles.	After six thermal cycles the SEP Central/HET/LET Instrument passes a functional test.
Bakeout the components to contamination requirements.	Before the end of the bakeout, TQCM readings meet the bakeout criteria of the Contamination Requirements.

4.0 DESCRIPTION OF TEST HARDWARE

The test hardware consists of the test article and ground support equipment (GSE). The test article is the collection of flight hardware being tested including instrument components and flight blankets, isolators and cabling. GSE is any hardware in support of the test but exclusive of the test article. GSE includes the chamber and its control system, solar simulator, cryopanel, mounting interface plate, test heaters, thermocouples, interface cabling, TQCMs, any stimulii required for functional testing and the thermal data acquisition system.

4.1 TEST ARTICLE

The test article for the TB test is the Ahead SEP Main Assembly consisting of three parts (1) HET, (2) LET, and (3) SEP Central. The assembly is mounted to the interface plate using the 6 flight isolator feet. Flight-like MLI will be installed in the flight configuration. Radiator surfaces will have high emissivity silver Teflon to dissipate heat. Ground straps between the test article and the interface plate will be configured as flight-like as possible. Flight cables will be routed and secured to the interface plate as flight-like as possible. The cables that, in flight, run along the spacecraft deck to other electronics boxes will be coiled up and attached to the interface plate under an MLI blanket. GSE cables will run from the flight cables to the chamber feed-thru connecter and to external GSE. A picture of the Instrument in TB test configuration is shown in Figure 1.

The test articles for the TV test are both flight SEP Main Assemblies. The assemblies are mounted to the interface plate without thermal isolation. There will be no MLI on the test articles. Radiator surfaces will be the unchanged from TB. Ground straps between the test article and the interface plate will be configured as flight-like as possible for electrical considerations. Flight cables will be coiled up and attached to the interface plate (under an MLI blanket?). GSE cables will run from the flight cables to the chamber feed-thru connecter and to external GSE. A picture of the Instrument in TV test configuration is shown in Figure 7.

4.2 GSE

The JPL supplied GSE will include two cryo/heater plates with attached interface plates and a solar simulator. Project supplied GSE will include Test article mounted test heaters. The functions of these thermal GSE components are described below:

4.2.1 Cryo/Heater Plates and Solar Simulator

Two instrumented cryo/heater plates are needed for testing. One 12x15” cryo/heater plate used with a single SEP Central/HET/LET assembly (Ahead) simulates the Spacecraft mounting interface during Thermal Balance, and will be temperature controlled to values shown in Table 1. The second TBDxTBD” cryo/heater plate is used in TV to drive both the Ahead and Behind SEP Central/HET/LET Instruments to the goal temperatures shown in Table 6. The cryo/heater plates must be controllable and stable to within 2°C of their setpoint. The S/C interface needs to be controlled between -18^{o}C and $+45^{o}$C for Thermal Balance. The cryo/heater plate used during Thermal Vacuum must be capable of driving the Instruments to -35^{o}C and $+40^{o}$C. Each cryo/heater plate will carry an interface plate which will be drilled to mount the test article(s). The S/C interface plate will need an MLI blanket on top, facing the Instrument. The backside of the cryo/heater plate should have an MLI blanket to isolate it from the chamber shroud. The solar simulator will simulate solar heating from the Sun and will be flux controlled to values shown in Table 1 during Thermal Balance. The solar simulator should be calibrated prior to the test so the operator can set to a voltage to obtain the desired flux.

4.2.2 Test Heaters

Test heaters (approx. 5 watts max., supplied by the Project) shall be placed on the side of each SEP Central Ebox. The heaters will enhance temperature cycling capabilities when needed and protect the flight hardware during Thermal Balance in the case of a solar simulator failure. Test heaters (approx. 5 watts, supplied by the Project) shall be placed on the top of the LET Instruments. This will enhance LET hot survival temperatures without surpassing survival temperatures in the Ebox. All four test heaters shall be independently controlled with separate JPL supplied GSE variable power supplies. Heaters shall be supplied (and installed on the Instrument) by the Project, but wiring to GSE harnesses shall be done at JPL.

5.0 TEST TEAM

The following personnel or their designated representatives will be associated with these tests:

Test Directors	- TBD
Thermal Test Conductor	- TBD
Thermal Vacuum Test Engineer	- TBD
Contamination Engineer	- TBD
Product Assurance Engineer	- TBD

Note: Additional personnel will provide support as required.

The Test Director (TD) has the overall responsibility for managing the test. The TD approves all test plans and procedures and has the responsibility of determining the Instrument is in flight configuration. The Test Director or a representative is responsible for approving all major deviations to the test procedure. The TD is also responsible for assuring all objectives of the thermal test will be satisfied. The TD will assure that fixtures and all components of the Test Article(s) are supplied and properly integrated for the test.

The Thermal Test Conductor (TTC) is responsible for coordinating TV Test Environmental activities. The TTC monitors the thermal test during actual operation and verifies that all systems are acting correctly and all test activities are executed. The TTC is responsible for detecting any out-of-limit temperature conditions of the test components and taking the necessary steps to correct that condition. The TTC is also responsible to determine when steady state conditions are achieved to continue to the next set point or to conclude the test. The TTC shall have the responsibility to adjust the test condition temperatures based on test data.

The Thermal Vacuum Test Engineer (TVTE) is responsible for the verification of the cleanliness of the chamber, fixtures and cables prior to the initiation of the test. The Thermal Vacuum Test Engineer also serves as the interface between the Thermal Test Conductor and the facility operators. The Thermal Vacuum Test Engineer is responsible for the operation, monitoring and maintenance of the test facility and auxiliary systems such as fixtures, cold plates, conditioners, etc.

The Contamination Control Engineer is responsible for assuring that the test is performed in accordance with proper contamination requirements. This person is also responsible for monitoring the contamination data to assure that the chamber, fixtures, meet the established contamination criteria.

The Product Assurance Engineer (PAE) responsibilities are contained in Section 8.0.

6.0 TEST PROGRAM

6.1 FACILITY DESCRIPTION

The tests will be conducted in a Thermal Vacuum Facility at JPL. The thermal shroud within the chamber can be controlled to temperatures between –180°C and +TBD°C. The facility must be capable of maintaining the pressure below $5x10^{-6}$ Torr for this test. The facility must meet the following contamination criteria prior to the start of the test: (300Hz/hr @100°C on a –20°C Quartz Crystal Microbalance (QCM)). The facility has the capability to read out (TBD) test thermocouple sensors.

6.2 TEST CONFIGURATION

The TB test chamber internal configuration is shown in Figure 1. The TV test chamber internal configuration is shown in Figure 7. For both tests the test article(s) mount to a cryo/heater plate through an interface plate and use the chamber as the radiating environment. A solar simulator is used to simulate the solar flux upon the Instrument during TB. Test heaters mounted to the test article(s) will be used to help reach soak goals in TV and for protection of the instrument in the event of solar simulator failure in TB.

6.3 TEST SET-UP

The Project will provide all materials and equipment pertaining to SEP Central/HET/LET operation including wiring harnesses and ground support equipment. JPL will provide all feed through connector plates for temperature sensors, and electrical harnessing.

JPL will provide T/Cs with associated signal conditioning and recording equipment including computer monitors to display T/C data in tabular and “real time” plotted format. The IMPACT project will provide the EGSE and personnel required to operate and monitor the SEP Central/HET/LET Instrument during the functional tests.

6.4 INSTRUMENTATION

There are numerous thermocouple temperature sensors on the test article and GSE that need to be read out continuously during this test. There are thirty-two T/Cs on the SEP Central/HET/LET Instrument during TB as listed in Table 2 and shown in Figures 2-6. There are twenty-eight T/Cs on the SEP Central/HET/LET Instruments during TV as listed in Table 3 and shown in Figure 8.

The test article is equipped with flight thermistor temperature sensors which are read out by the EGSE, some of which will not be available when the test article is powered off. A list of all T/M temperature sensors is included in Table 4.

Unfortunately, no test thermocouples can be mounted internally. Test T/Cs can only be mounted on the external surfaces of the Instrument. Internal component temperatures (with their own test limits) can be monitored by the flight telemetry electronics. Test T/C temperatures will be monitored during the test, but the red and yellow temperature limits should only be used as a rough estimate as to internal component temperatures. There could be up to a 15^{O}C difference between internal component temperatures and external thermocouple readings, due to poor heat transfer paths.

6.4.1 Test T/Cs on GSE

There should be two T/Cs placed on each cryo/heater interface plate. The facility shroud should already be equipped with temperature sensors.

6.5 TEMPERATURE LIMITS

The temperature limits on the hardware are contained in Tables 2-4. Thermocouple limits are shown in Tables 2-3. Internal component (thermistor) temperature limits are shown in Table 4, but must be monitored by flight telemetry electronics and not by test thermocouple instrumentation.

6.6 TEMPERATURE CONTROL

The T/Cs will be used to determine SEP Central/HET/LET Instrument temperature stability. The chamber shroud, cold/heater plates, and solar simulator will be used to adjust environmental conditions. Internal component temperatures shall be monitored as well, but will use the flight telemetry electronics circuitry.

6.7 TEMPERATURE CYCLING FOR TV TEST

The predicted temperatures of SEP Central/HET/LET in flight (on the Ahead and Behind STEREO Spacecrafts) are shown in Table 5. Test Red limits are also shown for reference. **Components should be cycled at least 10^{O}C above the hot flight predicts and 5^{O}C below the cold flight predicts shown in Table 5, but care must be observed to not exceed the test Red limits**. The TV test soak goals which include the above margins are shown in Table 6.

The survival thermostats on LET and SEP CENTRAL have turn-on temperatures of approximately minus 26^{O}C. Therefore, predicted component flight survival temperatures are in this range for the cold condition. When transitioning to the Cold Survival soak, the environmental settings for Cold Survival balance from Table 1 should be used for the shroud and cryo, but may be adjusted to achieve desired temperatures.

The Hot Survival soak is somewhat of a non-realistic case, since in flight the Instrument gets the hottest during hot operational conditions. However, a hotter than nominal TV condition is useful for stressing the Instrument's components in a non-operational scenario. The bakeout certification is performed at this temperature.

6.8 CONTAMINATION/ELECTROSTATIC REQUIREMENTS

The SEP Central/HET/LET Instrument is contamination and Electro-Static Discharge (ESD) sensitive in the test configuration and the following shall be adhered to at all times:

6.8.1 Contamination

The SEP Central/HET/LET Instrument will be double bagged for transportation to the TV facility. All test fixtures and instrumentation/harnessing will be cleaned by Contamination Control (CC) prior to use in the TV facility. Cleanroom uniforms are required during use and handling of hardware inside the TV facility. A log will be kept to record personnel entering and exiting the chamber.

The facility must meet the following contamination criteria prior to the start of the test: (300Hz/hr @100°C on a –20°C Quartz Crystal Microbalance (QCM)).

One 15 Mhz TQCM shall be placed viewing the Central/HET/LET Instrument and within 3 feet of the Instrument. The Contamination Engineer shall verify that both(?) are properly placed prior to closing the chamber door. This TQCMs shall be held at -20 C throughout the test, with the exception of the TQCM bake out portion. The data will be used for evaluation of the cleanliness of the SEP Central/HET/LET Instrument.

The instrument bakeout will be performed at the beginning of the TV test, and will last the duration specified by the contamination engineer (eight hours). The bakeout criteria is TBD.

6.8.2 Electrostatic

The SEP Central/HET/LET Instrument is ESD sensitive in the test configuration and proper grounding of the hardware and personnel is required.

6.9 TEST DESCRIPTION

6.9.1 Pre-Test Activities

Pre-operation activities include positioning the solar simulator at the chambers quartz window and mounting the SEP Central/HET/LET Instrument and heater plates in the chamber.

6.9.2 Test Readiness Review

A test readiness review (TRR) will be conducted prior to the test and attended by personnel involved in the test. The test procedure and any other pertinent documentation will be reviewed and discussed to resolve any problems or discrepancies with regards to safety, test configuration, facility requirements, and test operations. The test procedure must be approved prior to the test. An "as run" test procedure will be generated during the test by the TD or designated representative. Deviations to the test procedure during the test shall be recorded as red lines to the original procedures and will be approved by either the TD or designated representative and quality assurance engineer prior to performing the deviation.

6.9.3 Pre-Test Check List

The following is a list of steps required before TB testing occurs.

1. Drill holes in the S/C simulator interface plates to the appropriate drawings. Test fit Ahead SEP Central/HET/LET assembly to the TB interface plate using the flight isolators (6) to be supplied by the Project. Test fit both SEP Central/HET/LET assemblies to the TV interface plate.
2. Clean interface plates.
3. Certify cleanliness of chamber with all possible GSE installed.
4. Calibrate the solar simulator before installing it to the chamber.
5. Install all test T/Cs on the Ahead SEP Central/HET/LET assembly per Table 2 and Figures 2-6.
6. Install two T/Cs onto the top of the two cryo/heater plates.
7. Install and wire the test heaters to the Ebox and LET top.
8. Attach ground strap to interface plate.
9. Coil flight cable and attach to interface plate.
10. Install MLI blanket to the top of the interface plate and feed ground strap and flight cable connecter through access holes in MLI.
11. Mount Ahead SEP Central/HET/LET assembly to the TB interface plate using the flight isolators (6).
12. Attach ground strap to Ahead SEP Central/HET/LET assembly.
13. Attach proper flight cable connecter to instrument.
14. Install the interface plate with SEP Central/HET/LET Instrument and its harnesses into the chamber and make all electrical and plumbing connections.
15. Perform functional tests on the heaters and T/Cs to verify nominal installation.
16. Perform functional tests on the SEP Central/HET/LET Instrument to verify nominal installation.
17. Close the Chamber

6.9.4 Instrumentation Check

Prior to testing, the test facility will be checked out and verified to be ready for testing. Installation and checkout of the required instrumentation will be conducted on the test article prior to closing the TV chamber door.

6.9.5 Temperature Rate of Change

The chamber shroud shall not exceed a rate of change of (5°C/min). The bulk Instrument temperature shall not exceed a rate of change of more than (3°C/min). Care must be exercised not to overshoot Red limits.

6.9.6 Thermal Stabilization Criteria

Environmental stability will be reached when the Chamber and heater plates are within 2°C of its setpoint. Hardware temperature stability during TV is achieved when the temperature is within 3 °C of the plateau and the rate of change is less than 1 °C/hour.

Test Article stability for Thermal Balance will be reached when the T/Cs come to equilibrium at < (0.1°C/hr) change for at least (1) hours.

6.9.7 Test Description

NOTE: Any functional testing with HVs being turned on requires a chamber pressure at or below 5.0E-6 torr, for 10 hours prior to the HV being turned on. Perform only limited HV tests if the pressure is any greater than 5.0E-6 torr.

Thermal Balance

Cold Survival in Sun and survival heater turn on

1. Once the chamber pressure is lower than $5x10^{-6}$ torr, verify the test article is powered off and enable all survival heaters at 25 volts. Bring the shroud to LN2 temperature and the cryoplate to -18°C at a rate not to exceed 5°C/min. The shroud is to stay flooded for the duration of the Thermal Balance portion of the test. The solar simulator should stay powered off to speed the transition but can be used if transition rate becomes excessive.
2. Transition test article to the survival heater turn on temperature (-26.1°C specified) at the fastest rate not to exceed 3°C/min.
3. When leading temperature on test article reaches -16°C (10° from goal), temporarily turn on solar simulator at 1308W (minimum solar flux) to verify the ability to stop the transition.
4. Turn off or reduce solar simulator power to reestablish transition to survival heater turn-on.
5. Verify that all survival heaters activate. Take data snaps at each activation. Record heater activation data in Table 7.
6. Reduce survival heater voltage to 23V to saturate the survival heaters and set solar simulator voltage to achieve 1308W flux (Cold_Survival_in_Sun_Balance setting). Do not further adjust survival heater voltage unless temperatures approach lower survival limit or heater turn off temperature. Requirement is that survival heaters can maintain the instrument within survival limits at 25V.
7. Let the balance control T/Cs on the test article come to equilibrium at (< 0.1°C/hr change for 1 hour). Soak for four hours after this criterion is met. Keep the cryos (shroud and coldplate) within 2 degrees of their setpoints and the solar simulator voltage at the proper setting.
8. Take appropriate data snaps. Record survival heater voltage and current.

Cold Operation in Sun

9. Set survival heater voltage to (35V max).
10. Bring the cryoplate to -13°C at a rate not to exceed (5°C/min).
11. Set the solar simulator voltage to achieve 1308W flux (Cold Operational setting).
12. Verify that all survival heaters deactivate. Test heaters on the top of LET and on SEP Central Ebox may be used to reach survival thermostat turn-off (-9.4C). Take data snaps at each deactivation. Record heater deactivation data in Table 7.

13. When all test article temperatures are within operational limits, simultaneously turn-on the instrument, enable the operational heaters at 30.5V and disable the survival heaters. Set LET software controlled operational heater setpoints to activate operational heaters.
14. Let the balance control T/Cs on the test article come to equilibrium at < 0.1°C/hr change for 1 hour. Soak for four hours after this criterion is met. Keep the cryos within 2 degrees of their setpoints and the solar simulator voltage at the proper setting.
15. Take appropriate data snaps. Record operational bus voltage and current. **Need to be able to determine time averaged heater power on LET software controlled operational heaters.**

Hot Operation in Sun

16. Bring the cryoplate to +45°C at a rate not to exceed 5°C/min. Set the solar simulator voltage to achieve 1654W/m^2 flux (Hot Operational setting).
17. Transition test article to the Hot Operational Balance at the fastest rate not to exceed 3°C/min. Adjust the solar simulator setting as necessary to maintain transition rate within limits.
18. Set LET software controlled operational heater setpoints to deactivate operational heaters.
19. Adjust solar simulator setting from Hot Operational setting only if necessary to avoid exceeding any operational limits on the test article.
20. Let the balance control T/Cs on the test article come to equilibrium at < 0.1°C/hr change for 1 hour. Soak for four hours after this criterion is met. Keep the cryos within 2 degrees of their setpoints and the solar simulator voltage at the proper setting.
21. Take appropriate data snaps. Record operational bus voltage and current.

Return to Ambient

22. Keep the test article powered on at 35V(max), set all software controlled operational heaters to 27°C (ambient+5) and enable all operational heaters.
23. Bring cryos (shroud and cryoplate) to +22°C and solar simulator to zero power at rates not to exceed 5°C/min on GSE or 3°C/min on the test article.
24. Shut down test article when solar simulator is off, cryos are at ambient (+22°C) and instrument starts to drift up.
25. Shut off all electronics inside chamber and secure all cryos.
26. Start coldfinger 8 hours before beginning backfill.
27. Once the temperatures are below 27^{O}C begin to backfill the chamber with dry nitrogen
28. Turn off Cold Finger at 100 Torr
29. Backfill the chamber to 600 torr. **Nitrogen backfilling must occur at a reduced rate so not to cause air turbulence near the Instrument. Backfill very slowly for the first 20 minutes. Backfilling must take at least 90 minutes. Nitrogen must be filtered through a 0.5-micron filter before it enters the chamber.**

Chamber Break

30. Instrument Behind SEP Main Assembly assembly per Table 3 and Figure 8 (this step can be performed prior to chamber break).
31. Install and wire the test heaters to the Behind Assembly Ebox and LET top if not already done. (this step can be performed prior to chamber break)
32. Remove test article (Ahead SEP Main Assembly) from chamber
33. Remove MLI from test article (Ahead SEP Main Assembly)
34. Reinstrument Ahead SEP Main Assembly assembly per Table 3 and Figure 8
35. Mount test articles (Ahead and Behind SEP Main Assemblies) to standard cold plate without isolation Attach ground straps.
36. Attach proper flight cable connecters to instruments.
37. Install the interface plate with SEP Central/HET/LET Instruments and its harnesses into the chamber and make all electrical and plumbing connections.
38. Perform functional tests on the heaters and T/Cs to verify nominal installation.
39. Perform functional tests on the SEP Central/HET/LET Instruments to verify nominal installation.
40. Close the Chamber

Thermal Vacuum (Cycling)

Transition rates and stability criteria

The maximum rate of temperature change on the test article is 3 °C/min. Care must be exercised not to overshoot Red limits. Temperature stability is achieved when the temperature is within 3 °C of the soak goals as stated in Table 6 and the rate of change is less than 1 °C/hour.

Cycle 1

Bakeout and Hot Survival Soak

41. Once the chamber pressure is lower than $5x10^{-6}$ torr, verify the test article is powered off, bring the cryoplate to 40°C at a rate not to exceed 5°C/min.
42. Turn on the test heaters on the LET and SEP Central and adjust their power levels to help raise the the test article to the Hot Survival soak goal (40^{o}C) at a rate not to exceed 3°C/min without surpassing any Survival red temperature limits.
43. The shroud is to be transitioned to approximately 35°C but must always be 5°C colder than the coldest temperature on the test article.
44. When the soak critera has been met (temperature within 3°C of soak goal and rate of change less than 1 °C/hour) declare start of Hot Survival Soak and take appropriate data snaps.
45. The Bakeout begins once soak criteria has been met and will not conclude until the Contamination Engineer is satisfied that the bakeout criteria has been met.
46. The Instrument must soak at this hot condition (Hot Survival Soak)for a minimum of one hour or until the Contamination Engineer declares the end of Bakeout whichever takes longer.
47. When the Thermal Test Director is satisfied the soak requirements have met, declare end of Hot Survival Soak and take appropriate data snaps.

Hot Turn-on and Hot Operation Soak #1

48. Bring the shroud to approximately 30°C
49. Bring the cryoplate to 35°C at a rate not to exceed 5°C/min
50. Adjust the test heaters on the LET and SEP Central to bring the test article to the Hot Operational Soak goal (35^{o}C) at a rate not to exceed 3°C/min
51. When the soak critera has been met (temperature within 3°C of soak goal and rate of change less than 1 °C/hour) declare start of Hot Operational Soak #1 and take appropriate data snaps.
52. Turn on the SEP CENTRAL HET/LET Instrument and perform functional tests.
53. Ensure power supply to the instrument is set to 30.5 volts.
54. Adjust shroud, cryo and test heaters as necessary to maintain soak conditions without violating any Operational Red Limits.
55. Soak for a minimum of one hour after turn-on or to completion of functional testing, whichever takes longer.
56. When the Thermal Test Director is satisfied the soak requirements have met, declare end of Hot Operational Soak #1 and take appropriate data snaps.

Cold Survival Soak

57. Enable the survival heaters at 35V (max).
58. Turn off the SEP CENTRAL HET/LET Instrument.
59. Bring the shroud to approximately -40°C
60. Bring the cryoplate to -35°C at a rate not to exceed 5°C/min
61. Adjust the test heaters on the LET and SEP Central to bring the test article to the Cold Survival Soak goal (-35^{o}C) at a rate not to exceed 3°C/min. The survival heaters should actually prevent the instrument from reaching the soak goal.
62. Let the SEP CENTRAL HET/LET Instrument survival heaters come to a repeated duty cycle (or as determined by the thermal test director to be steady). Take data snaps at each heater activation and deactivation. Record heater activation data in Table 7.
63. Reduce voltage to survival heaters and test heaters as necessary to achieve the Cold Survival Soak goal (-35^{o}C) at a rate not to exceed 3°C/min and without surpassing any Survival red temperature limits.
64. When the soak critera has been met (temperature within 3°C of soak goal and rate of change less than 1 °C/hour) declare start of Cold Survival Soak and take appropriate data snaps.
65. The Instrument must soak at this hot condition (Cold Survival Soak) for a minimum of one hour.
66. When the Thermal Test Director is satisfied the soak requirements have met, declare end of Cold Survival Soak and take appropriate data snaps.

Cold Turn-on and Cold Operation Soak #1

67. Ensure SEP CENTRAL HET/LET Instrument is turned off except for survival heaters.
68. Increase survival heater voltage to 35V (max)
69. Bring the cryoplate to -25°C at a rate not to exceed 5°C/min.

70. Adjust the test heaters on the LET and SEP Central to help raise the the test article to the Cold Operational soak goal (-25^{o}C) at a rate not to exceed 3°C/min.
71. The shroud is to be transitioned up to approximately -30°C but must always be 5°C colder than the coldest temperature on the test article.
72. When the soak critera has been met (temperature within 3°C of soak goal and rate of change less than 1 °C/hour) declare start of Cold Operational Soak #1 and take appropriate data snaps.
73. Disable the survival heaters.
74. Turn on the SEP CENTRAL HET/LET Instrument and perform functional tests.
75. Ensure power supply to the instrument is set to 30.5 volts.
76. Adjust shroud, cryo and test heaters as necessary to maintain soak conditions without violating any Operational Red Limits.
77. Soak for a minimum of one hour after turn-on or to completion of functional testing, whichever takes longer.
78. When the Thermal Test Director is satisfied the soak requirements have met, declare end of Cold Operational Soak #1 and take appropriate data snaps.

Cycles 2-6

Hot Operation Soak #N

79. Verify the test article is powered on at 30.5V and that survival heaters are disabled.
80. Bring the cryoplate to 35°C at a rate not to exceed 5°C/min.
81. Turn on the test heaters on the LET and SEP Central and adjust their power levels to help raise the the test article to the Hot Operational soak goal (35^{o}C) at a rate not to exceed 3°C/min without surpassing any Operational red temperature limits.
82. The shroud is to be transitioned to approximately 30°C but must always be 5°C colder than the coldest temperature on the test article.
83. When the soak critera has been met (temperature within 3°C of soak goal and rate of change less than 1 °C/hour) declare start of Hot Operational Soak #N and take appropriate data snaps.
84. Perform functional tests.
85. Ensure power supply to the instrument is set to 30.5 volts.
86. Adjust shroud, cryo and test heaters as necessary to maintain soak conditions without violating any Operational Red Limits.
87. Soak for a minimum of one hour or to completion of functional testing, whichever takes longer.
88. When the Thermal Test Director is satisfied the soak requirements have met, declare end of Hot Operational Soak #N and take appropriate data snaps.

Cold Operation Soak #N

89. Verify the test article is powered on at 30.5V and that survival heaters are disabled.
90. Bring the shroud to approximately -30°C.
91. Bring the cryoplate to -25°C at a rate not to exceed 5°C/min.

92. Adjust the test heaters on the LET and SEP Central to help bring the the test article to the Cold Operational soak goal (-25^{o}C) at a rate not to exceed 3°C/min.
93. When the soak critera has been met (temperature within 3°C of soak goal and rate of change less than 1 °C/hour) declare start of Cold Operational Soak #N and take appropriate data snaps.
94. Perform functional tests.
95. Ensure power supply to the instrument is set to 30.5 volts.
96. Adjust shroud, cryo and test heaters as necessary to maintain soak conditions without violating any Operational Red Limits.
97. Soak for a minimum of one hour or to completion of functional testing, whichever takes longer.
98. When the Thermal Test Director is satisfied the soak requirements have met, declare end of Cold Operational Soak #N and take appropriate data snaps.

Return to Ambient

99. Keep the test article powered on and increase voltage to 35V(max)
100. Enable all operational heaters and set all software controlled operational heaters to 27°C (ambient+5) in stages to avoid to exceeding 3°C/min.
101. Bring the cryoplate to 27°C at a rate not to exceed 5°C/min.
102. Turn on the test heaters on the LET and SEP Central and adjust their power levels to help raise the the test article to 27°C at a rate not to exceed 3°C/min.
103. The shroud is to be transitioned to 22°C but must always be 5°C colder than the coldest temperature on the test article.
104. Shut down the test article when the shroud and cryo are at their goals and the instrument temperature starts to drift up with zero test heater power.
105. Shut off all electronics inside chamber and secure all cryos.
106. Start coldfinger 8 hours before beginning backfill.
107. Once the temperatures are below 27^{O}C begin to backfill with dry nitrogen.
108. Turn off Cold Finger at 100 Torr
109. Backfill the chamber to 600 torr. **Nitrogen backfilling must occur at a reduced rate so not to cause air turbulence near the Instrument. Backfill very slowly for the first 20 minutes. Backfilling must take at least 90 minutes. Nitrogen must be filtered through a 0.5-micron filter before it enters the chamber.**

7.0 DOCUMENTATION

7.1 CHANGES TO TEST PROCEDURE

7.1.1 During Test

Deviations to the test procedure during the test shall be recorded in the chronological test log and approved by both the TD and the PAE prior to performing the deviation. The deviation number shall be recorded at the affected line of the “as run” procedure. Procedure errors recorded during the test shall be incorporated in the test plan prior to testing subsequent items.

7.1.2 Post-Test

Changes that result from either design changes or discrepancies shall be incorporated as a subsequent revision to the test plan. Other changes shall be processed as deviations or waivers.

7.2 TEST DATA

The test data will be recorded as required in order to document SEP Central/HET/LET Instrument performance during testing. Test data and "as run" procedures will be kept in the test logbook and submitted to the TD by the test engineers upon completion of the test.

7.3 TEST LOG BOOK

A chronological log will be keep by the Test Engineer throughout the testing program. The logbook will contain a copy of the test plans. The Test Engineer will make daily entries in a brief manner describing the days testing activities. In addition, the log will record the operating times of the test as well as significant events such as failures, damage, or photo records.

The thermal test conductor shall also maintain a log.

7.4 TEST REPORT

Following completion of the test, a report shall be written in order to document the results of the tests, including a discussion of data with conclusions and/or recommendation. The original shall be submitted to the SEP Central/HET/LET Project within thirty working days after test completion. The Test Engineer will submit the test report.

7.5 TEST FAILURE AND ANOMALY REPORTS

7.5.1 Test Failure Criteria

Either of the following constitutes a failure of the test:

1. Unacceptable operation of the test article during the time that the test is being conducted

2. No data is recorded due to failure of the instrumentation or recording equipment

7.5.2 Failure Reports

Malfunction or failure that requires corrective action or re-testing will result in a Failure Report.

8.0 QUALITY ASSURANCE

The performance of this plan will be under the cognizance of the assigned Product Assurance Engineer (PAE) or a designated representative. The PAE will verify that the test article is ready for the test by:

1. Verifying the presence of an approved test procedure

2. Verifying completion and documentation of all SEP Central/HET/LET Instrument assembly and inspection operations.
3. Verifying that all support fixtures are within current proof load limits.
4. Visual inspection of the test article and the test set-up for correct configuration and handling/safety constraints.
5. Verify that the assembly of the test article is per the design.

9.0 SAFETY

This test shall be conducted in accordance with the GSFC standards of Safety and Engineering Services Division Safety Manual Rev A, with no unacceptable risks or hazards to the test article and personnel.

Test directors must assure that the test complies with all Occupational Safety and Health Act (OSHA) regulations and that protective equipment is used where necessary.

10.0 TECHNICAL PHOTOGRAPHY

Photographic services will be provided by JPL. The TD shall arrange appropriate times to take photographs before closing the TV chamber. The purpose for using technical photographs is to document the test set-up and to record any relevant data taken during the test. The test set-up photographs should capture the test article, instrumentation, and test equipment. Discrepancies and unusual data should also be photographed.

ZONE	Hot Operation	Cold Operation	Cold Survival
Chamber Shroud	-180°C	-180°C	-180°C
S/C Cryo Panel	+45°C	-13°C	-18°C
Solar Simulator	1654W/m^2	1308W/m^2	1308W/m^2
LET Heater	If needed	If needed	If needed
Ebox Heater	If needed	If needed	If needed

Table 1: TB Test Environment Settings

T/C Sensor Number	Location	Figure #	Yellow Limits (°C)	Red Limits (°C)	Yellow Limits (°C)	Red Limits (°C)
			Operational		Survival	
1	+X SEP CENTRAL	2	-30/+45	-35/+50	-35/+45	-40/+50
2	+X SEP CENTRAL	2	-30/+45	-35/+50	-35/+45	-40/+50
3	+Z SEP CENTRAL	2	-30/+45	-35/+50	-35/+45	-40/+50
4	+Z SEP CENTRAL	2	-30/+45	-35/+50	-35/+45	-40/+50
5	+X/-Y HET	2	-30/+35	-35/+40	-35/+35	-40/+40
6	+Y SEP CENTRAL	2	-30/+45	-35/+50	-35/+45	-40/+50
7	+Y SEP CENTRAL	2	-30/+45	-35/+50	-35/+45	-40/+50
8	+Z SEP CENTRAL	2	-30/+45	-35/+50	-35/+45	-40/+50
9	+X/+Y LET CYLINDER	2	-60/+60	-65/+65	-70/+70	-75/+75
10	+X /+Y LET	2	-30/+35	-35/+40	-35/+35	-40/+40
11	+X/+Y LET	2	-30/+35	-35/+40	-35/+35	-40/+40
12	+Z LET	2	-30/+35	-35/+40	-35/+35	-40/+40
13	+Y/-X LET	2	-30/+35	-35/+40	-35/+35	-40/+40
14	-Y/+X LET	2	-30/+35	-35/+40	-35/+35	-40/+40
15	+Z LET	2	-60/+60	-65/+65	-70/+70	-75/+75
16	-X/-Y LET CYLINDER	3	-30/+35	-35/+40	-35/+35	-40/+40
17	-X/-Y LET	3	-30/+35	-35/+40	-35/+35	-40/+40
18	-X/-Y LET	3	-30/+35	-35/+40	-35/+35	-40/+40
19	-X/+Y LET	3	-30/+35	-35/+40	-35/+35	-40/+40
20	-X/+Y HET	3	-30/+35	-35/+40	-35/+35	-40/+40
21	+Z SEP CENTRAL	3	-30/+45	-35/+50	-35/+45	-40/+50
22	+Z SEP CENTRAL	3	-30/+45	-35/+50	-35/+45	-40/+50
23	+X SEP CENTRAL	3	-30/+45	-35/+50	-35/+45	-40/+50
24	+X SEP CENTRAL	3	-30/+45	-35/+50	-35/+45	-40/+50
25	+X SEP CENTRAL	3	-30/+45	-35/+50	-35/+45	-40/+50
26	+X SEP CENTRAL	3	-30/+45	-35/+50	-35/+45	-40/+50
27	+X SEP CENTRAL	3	-30/+45	-35/+50	-35/+45	-40/+50
28	-Y SEP CENTRAL	4	-30/+45	-35/+50	-35/+45	-40/+50
29	-Y SEP CENTRAL	4	-30/+45	-35/+50	-35/+45	-40/+50
30	-Z SEP CENTRAL	5	-30/+45	-35/+50	-35/+45	-40/+50
31	-Z SEP CENTRAL	5	-30/+45	-35/+50	-35/+45	-40/+50

32	-Z SEP CENTRAL	5	-30/+45	-35/+50	-35/+45	-40/+50
33	S/C Simulator Heater Plate	1	N/A	N/A	N/A	N/A
34	S/C Simulator Heater Plate	1	N/A	N/A	N/A	N/A

Table 2: TB Thermocouple Locations

Sensor Number	Location	Figure #	Yellow Limits (°C)	Red Limits (°C)	Yellow Limits (°C)	Red Limits (°C)
			Operational		Survival	
1	Ahead SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
2	Ahead SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
3	Ahead SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
4	Ahead SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
5	Ahead HET	8	-30/+35	-35/+40	-35/+35	-40/+40
6	Ahead HET	8	-30/+35	-35/+40	-35/+35	-40/+40
7	Ahead Bottom of LET	8	-30/+35	-35/+40	-35/+35	-40/+40
8	Ahead Top of LET	8	-30/+35	-35/+40	-35/+35	-40/+40
9	Ahead SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
10	Ahead SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
11	Ahead SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
12	Ahead SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
13	Ahead Side of LET	8	-30/+35	-35/+40	-35/+35	-40/+40
14	Ahead Side of LET	8	-30/+35	-35/+40	-35/+35	-40/+40
15	Behind SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
16	Behind SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
17	Behind SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
18	Behind SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
19	Behind SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
20	Behind SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
21	Behind SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
22	Behind SEP CENTRAL	8	-30/+45	-35/+50	-35/+45	-40/+50
23	Behind HET	8	-30/+35	-35/+40	-35/+35	-40/+40
24	Behind HET	8	-30/+35	-35/+40	-35/+35	-40/+40
25	Behind Side of LET	8	-30/+35	-35/+40	-35/+35	-40/+40
26	Behind Side of LET	8	-30/+35	-35/+40	-35/+35	-40/+40
27	Behind Bottom of LET	8	-30/+35	-35/+40	-35/+35	-40/+40
28	Behind Top of LET	8	-30/+35	-35/+40	-35/+35	-40/+40
29	S/C Simulator Heater Plate	8	N/A	N/A	N/A	N/A
30	S/C Simulator Heater Plate	8	N/A	N/A	N/A	N/A

Table 3: TV Thermocouple Locations

T/M Sensor No.	Location	Flight Allowable (°C)	Operational Yellow Limit (°C)	Operational Red Limit (°C)	Survival Yellow Limit (°C)	Survival Red Limit (°C)	Monitor
L6	A_LET TOP PCB	-25/+40	-30/+45	-35/+50	-35/+45	-40/+50	S/C
H3	A_HET PCB	-25/+40	-30/+45	-35/+50	-35/+45	-40/+50	S/C

S5	A_POST REG Board	-25/+40	-30/+45	-35/+50	-35/+45	-40/+50	S/C
L1	A_LET TOP PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
L2	A_LET TOP PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
L3	A_LET TOP PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
L4	A_LET TOP PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
H1	A_HET PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
H2	A_HET PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
S1	A_Logic Board	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
S2	A_POST REG Board	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
S3	A_BIAS Supply	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
S4	A_LVPS	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
L16	B_LET TOP PCB	-25/+40	-30/+45	-35/+50	-35/+45	-40/+50	S/C
H13	B_HET PCB	-25/+40	-30/+45	-35/+50	-35/+45	-40/+50	S/C
S15	B_POST REG Board	-25/+40	-30/+45	-35/+50	-35/+45	-40/+50	S/C
L11	B_LET TOP PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
L12	B_LET TOP PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
L13	B_LET TOP PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
L14	B_LET TOP PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
H11	B_HET PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
H12	B_HET PCB	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
S11	B_Logic Board	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
S12	B_POST REG Board	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
S13	B_BIAS Supply	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument
S14	B_LVPS	-25/+30	-30/+45	-35/+50	-35/+45	-40/+50	Instrument

Table 4: Internal Component Telemetry (Flight Thermistors)

Component	Cold Biased AHEAD S/C (^{O}C)	Cold Biased Behind S/C (^{O}C)	Hot Biased Ahead S/C (^{O}C)	Hot Biased Behind S/C (^{O}C)	Oper. Red Limits Cold/Hot (^{O}C)
LET					
TOP PCB	-13.0	-15.0	24.5	25.0	-35/+50
BOTTOM PCB	-13.8	-16.1	24.5	25.0	-35/+50
DETECTORS	-18.6	-21.0	24.3	26.4	-35/+40
HET					
DETECTORS	-18.5	-18.6	20.0	20.0	-35/+40
SEP CENTRAL					
Logic Board	-18.6	-15.3	17.7	21.7	-35/+50
POST REG Board	-17.3	-14.5	19.5	22.4	-35/+50
BIAS Supply	-14.5	-13.1	23.5	24.4	-35/+50
LVPS	-15.0	-13.6	28.8	26.2	-35/+50
HET Electronics	-13.5	-12.6	23.6	23.3	-35/+50

S/C Monitored Thermistors

Table 5: Predicted Operational Flight Temperatures

AHEAD Control T/C, T/M	BEHIND Control T/C, T/M	Hot Srv (^{O}C)	Hot Op (^{O}C)	Cold Srv (^{O}C)	Cold Op (^{O}C)
LET T/C #8	LET T/C #28	40	35	-35	-25

SEP CENTRAL T/M's H3, S5	SEP CENTRAL T/M's H13, S15	40	35	-35	-25

Table 6: Thermal Vacuum Soak Goal Temperatures

SEP CNTRL/HET/LET Instrument Heater Circuits

Survival Circuits

Component		T'stat temp range				Power	Current	Circuit	Measured Temperatures		Measured Current
	Circuit	Close	Open	Service	Verify	@ 25 V	@ 25 V	Res.	Close	Open	@ TBD V
	Desig.	(C)	(C)	Desig.	Sensor [1]	(W)	(amp)	(ohms)	(C)	(C)	(amp)
AHEAD LET	Surv	-26.1+-4.4	-9.4 +/- 4.4		TML6 (T)	1.3	0.05	481.00			
BEHIND LET	Surv	-26.1+-4.4	-9.4 +/- 4.4		TML6 (T)	1.8	0.07	357.00			
AHEAD SEP CNTRL	Surv	-26.1+-4.4	-9.4 +/- 4.4		TMS5(T)	3.0	0.12	208.00			
BEHIND SEP CNTRL	Surv	-26.1+-4.4	-9.4 +/- 4.4		TMS15(T)	2.8	0.11	227.00			

Notes:

1. (T) denotes sensor at thermostat, (H) denotes sensor at heater

Table 7: Flight Heater Checkout Fill-in Table

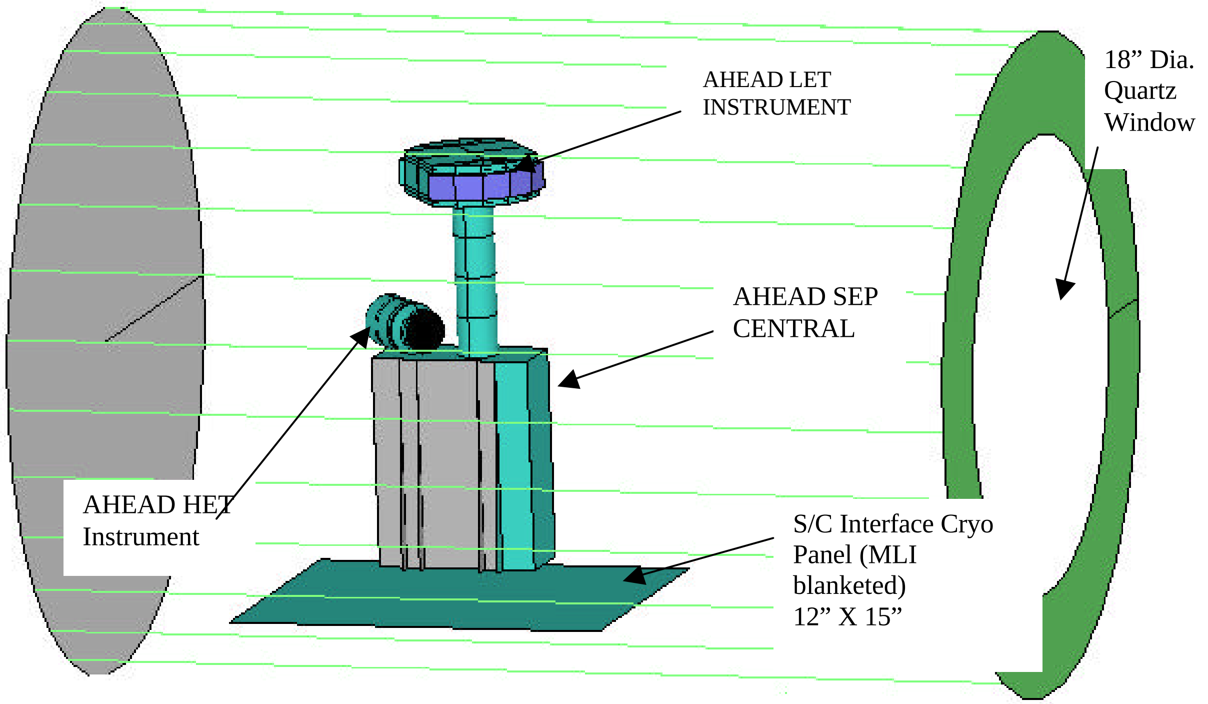


Figure 1: TB Chamber Layout

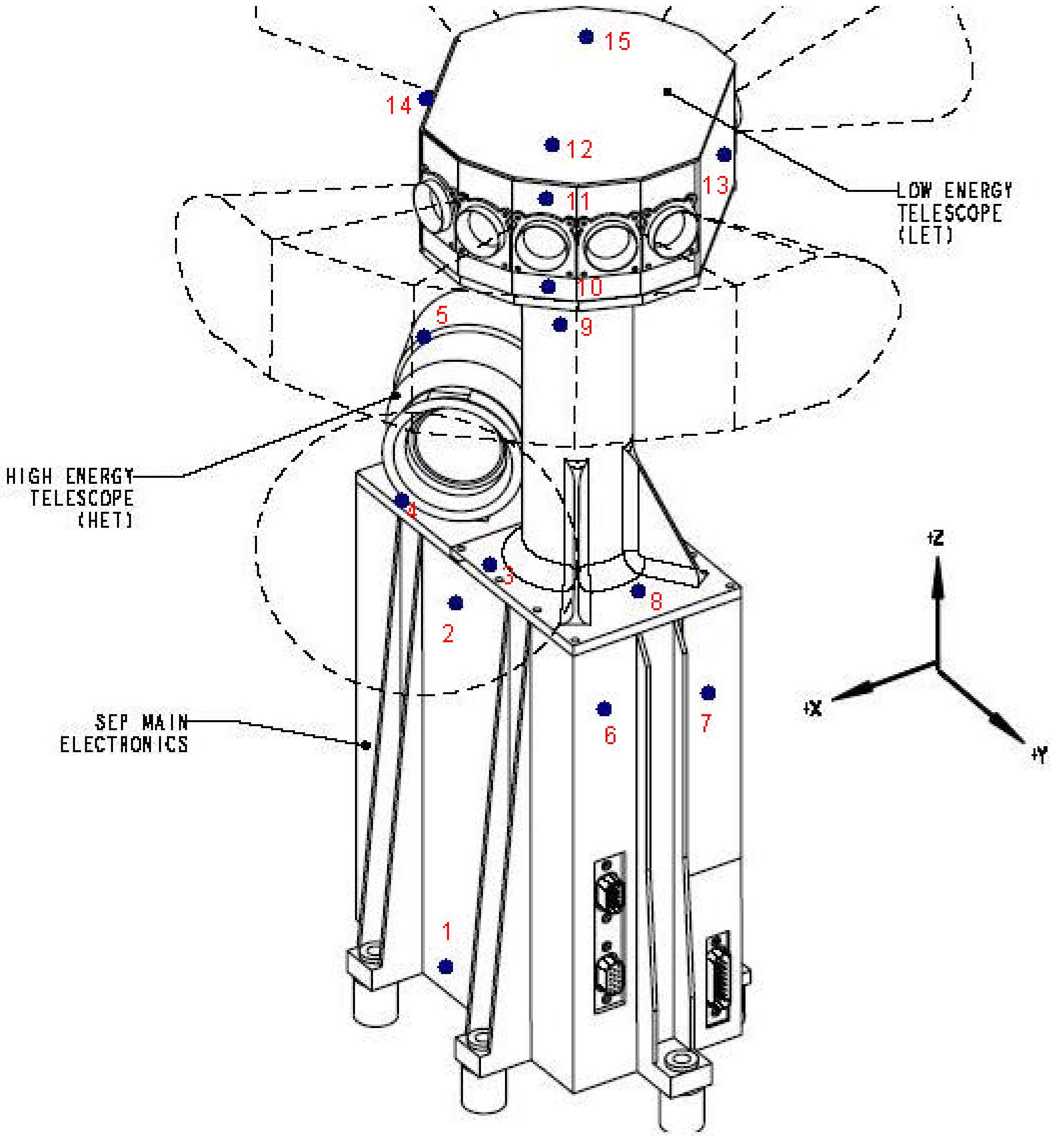


Figure 2: Thermal Balance T/C Locations

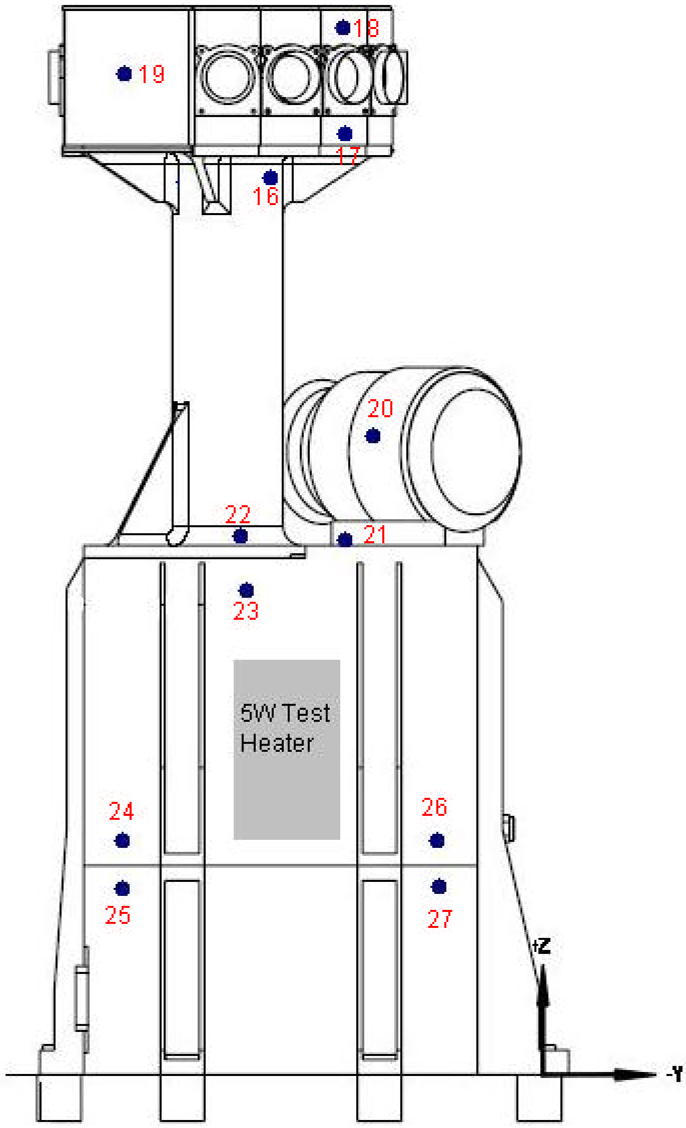


Figure 3: Thermal Balance T/C Locations

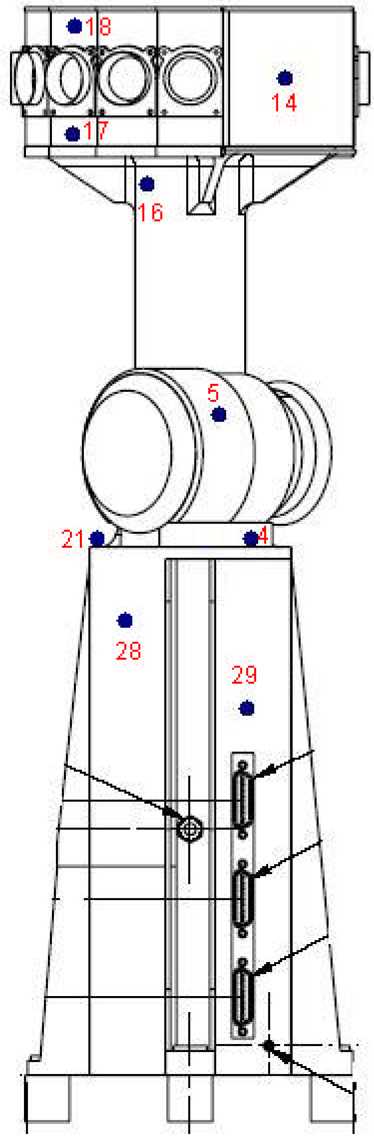


Figure 4: Thermal Balance T/C Locations

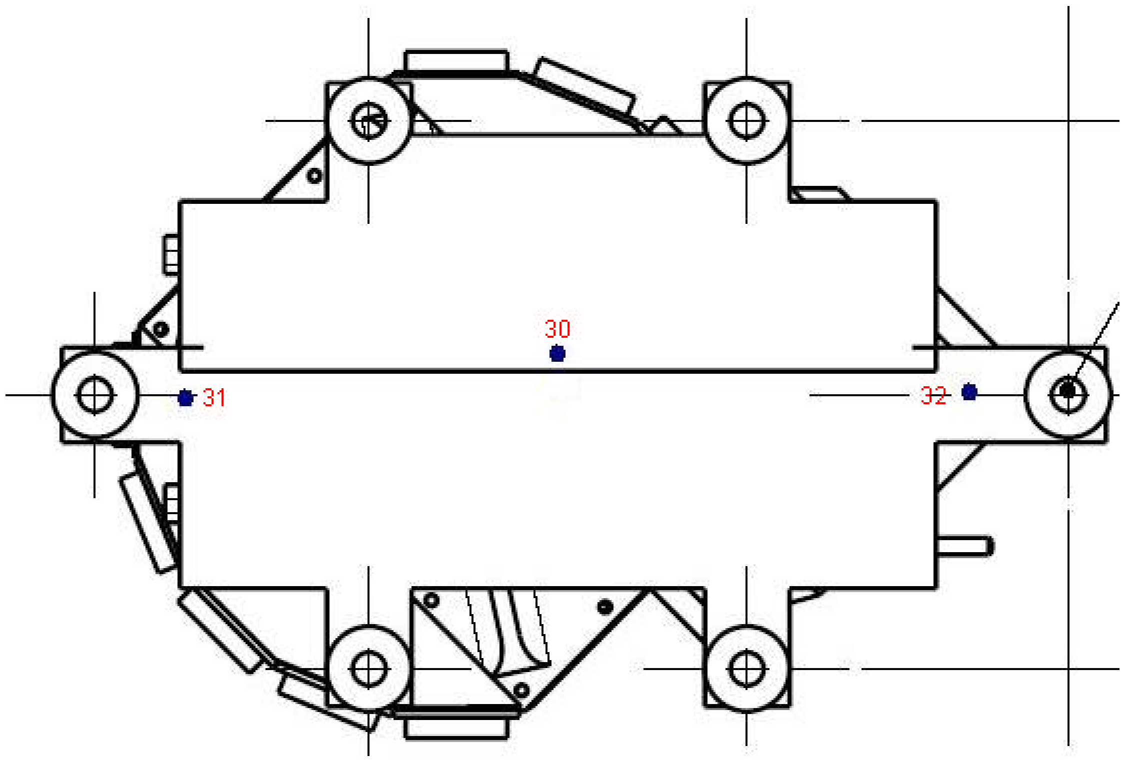


Figure 5: Thermal Balance T/C Locations

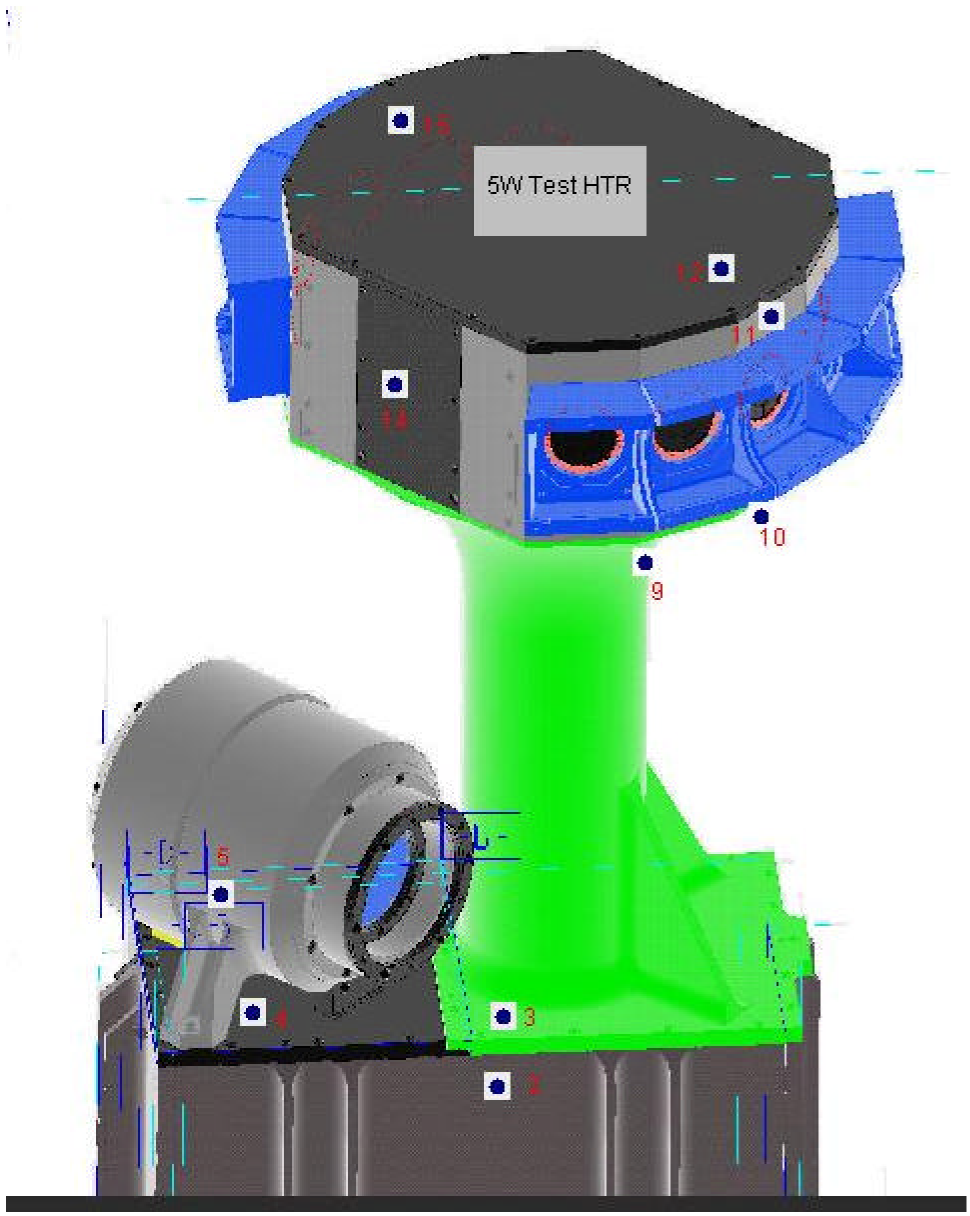


Figure 6: Thermal Balance T/C Locations

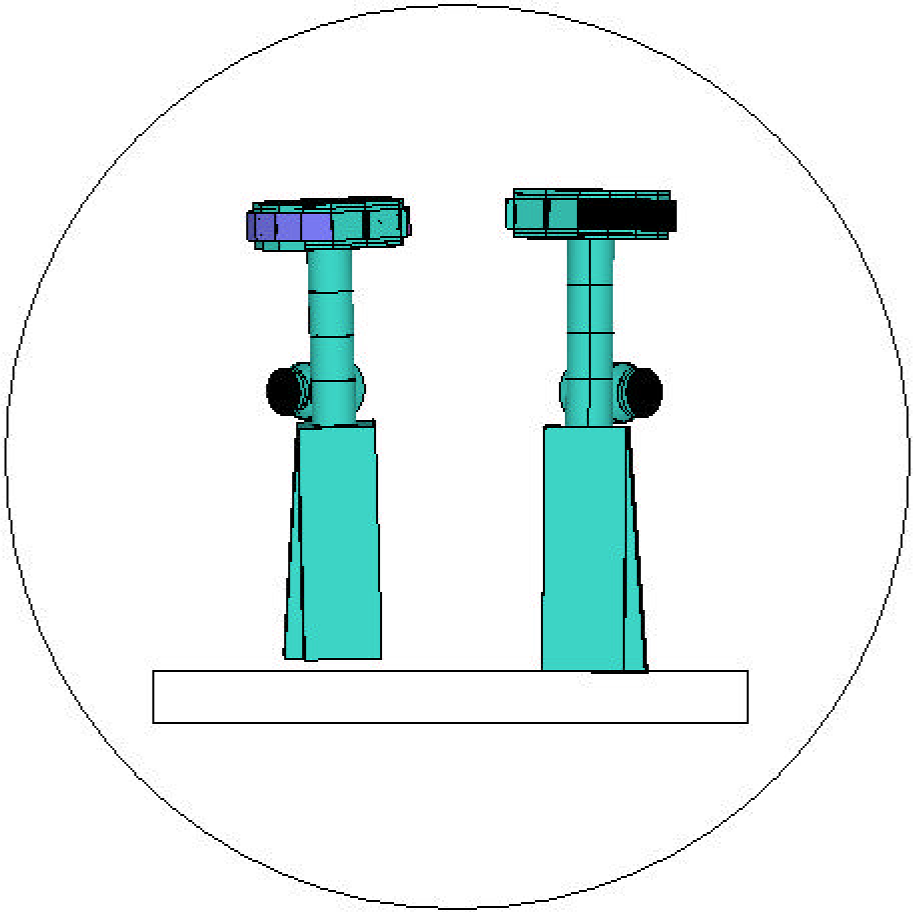


Figure 7: TV Chamber Layout

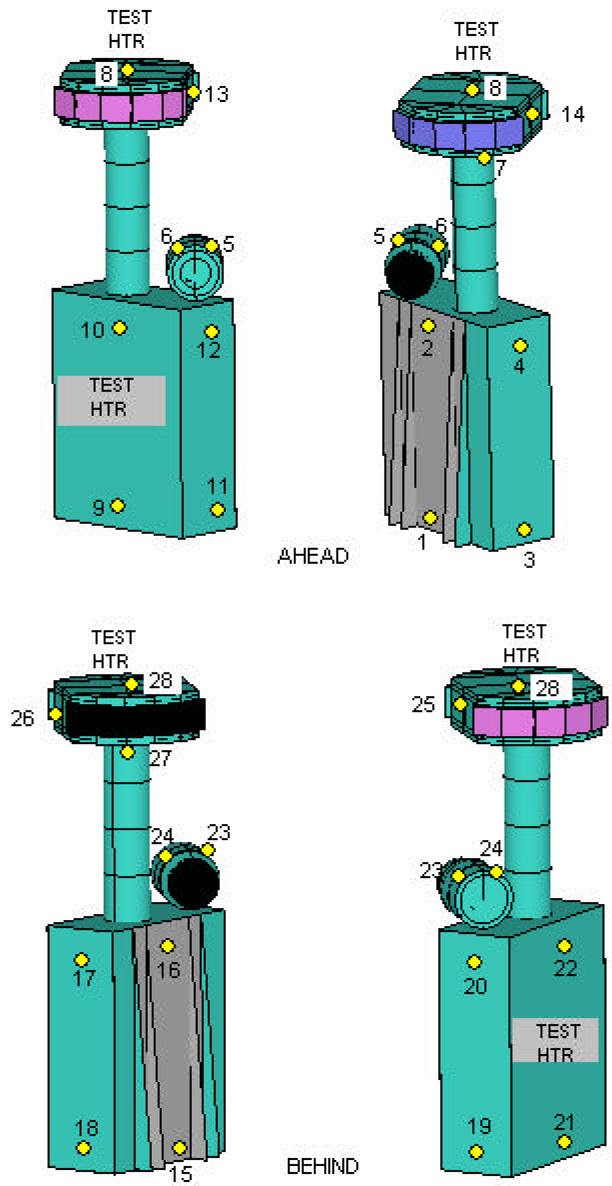
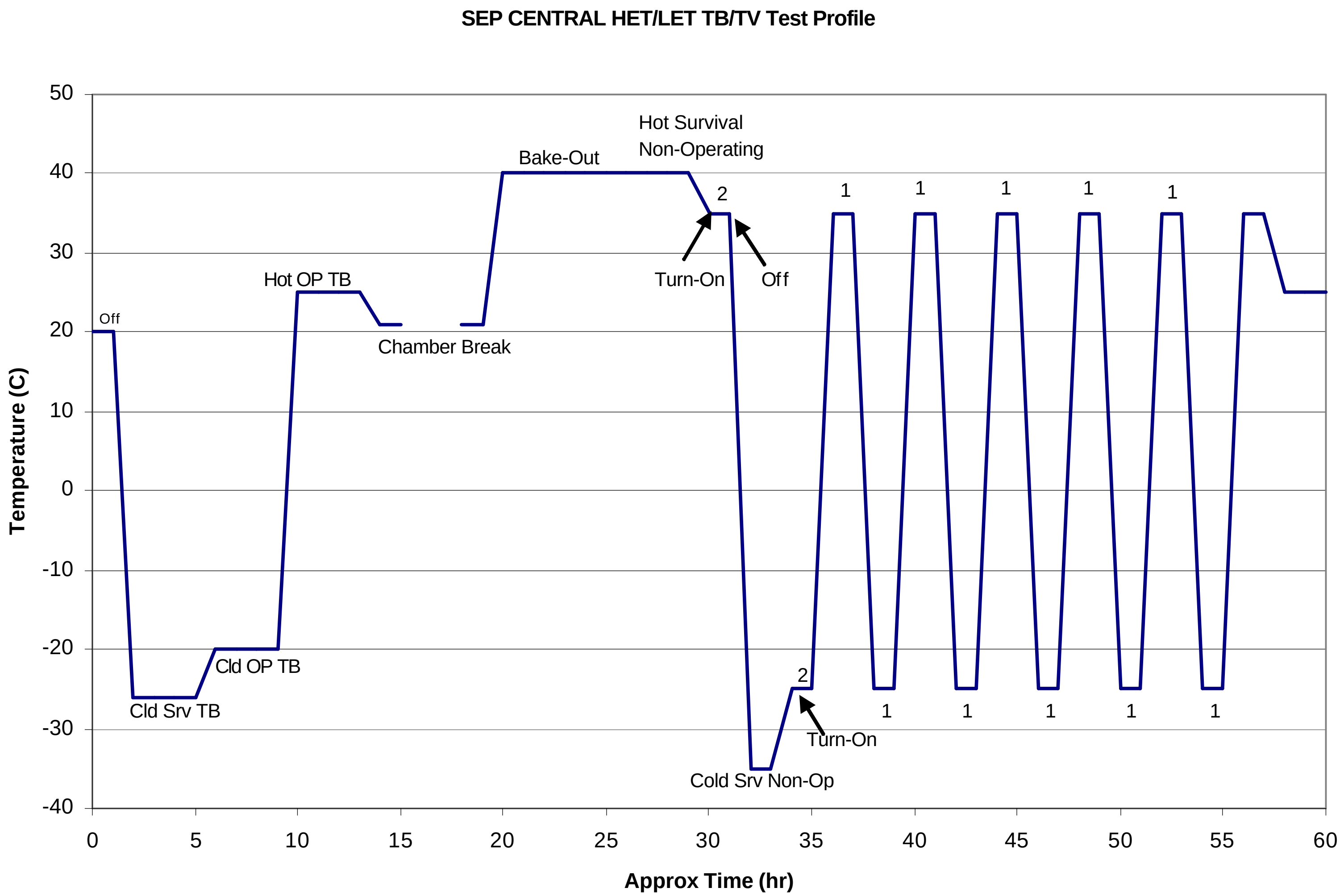


Figure 8: Thermal Vacuum T/C Locations



1 = Stabilize, Soak 1Hour and Test Concurrently.
2 = Stabilize, Turn On, Soak 1Hour and Test Concurrently.

Figure 9: SEP Central HET/LET TB/TV Test Temperature Profile

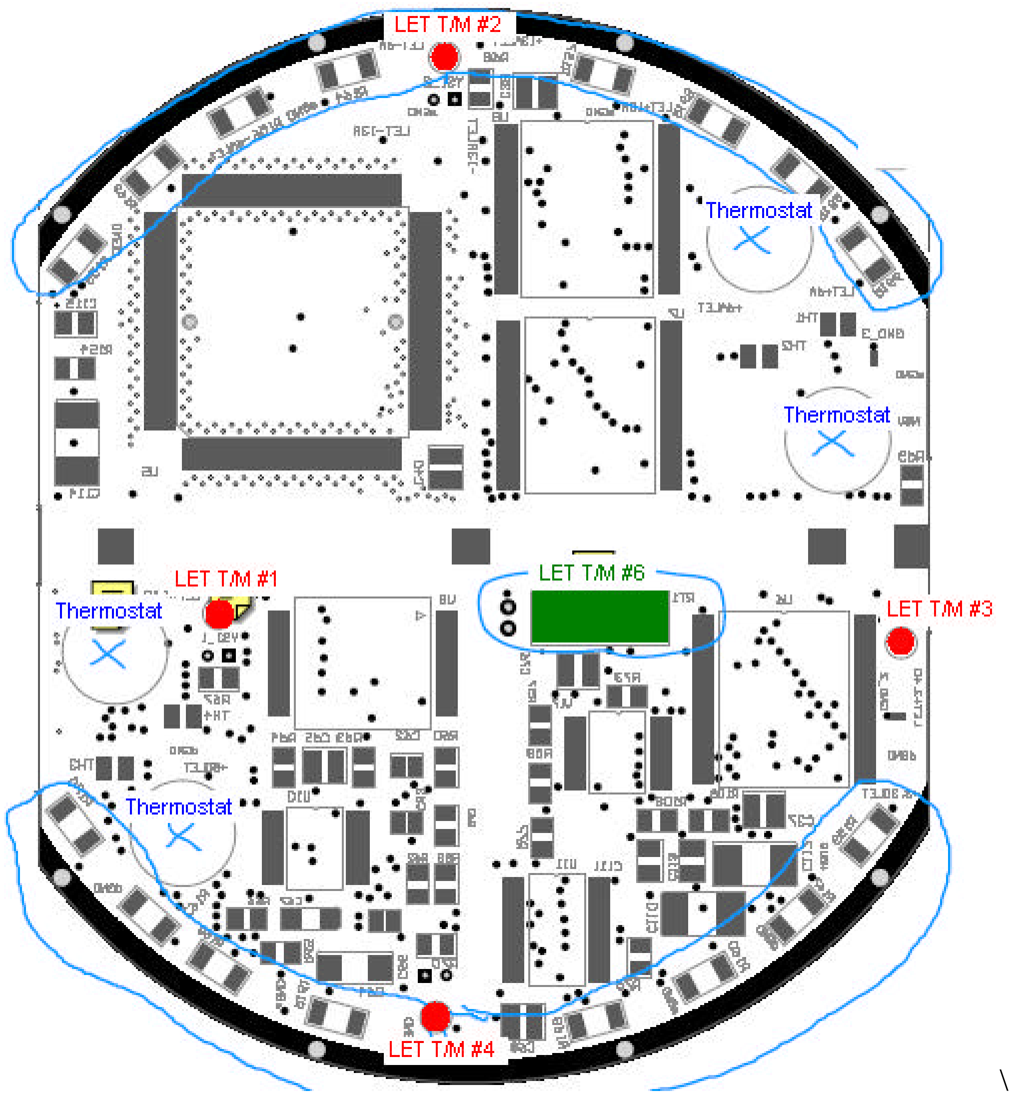


Figure 10: AHEAD LET Thermistor Locations (Through view of top PCB)

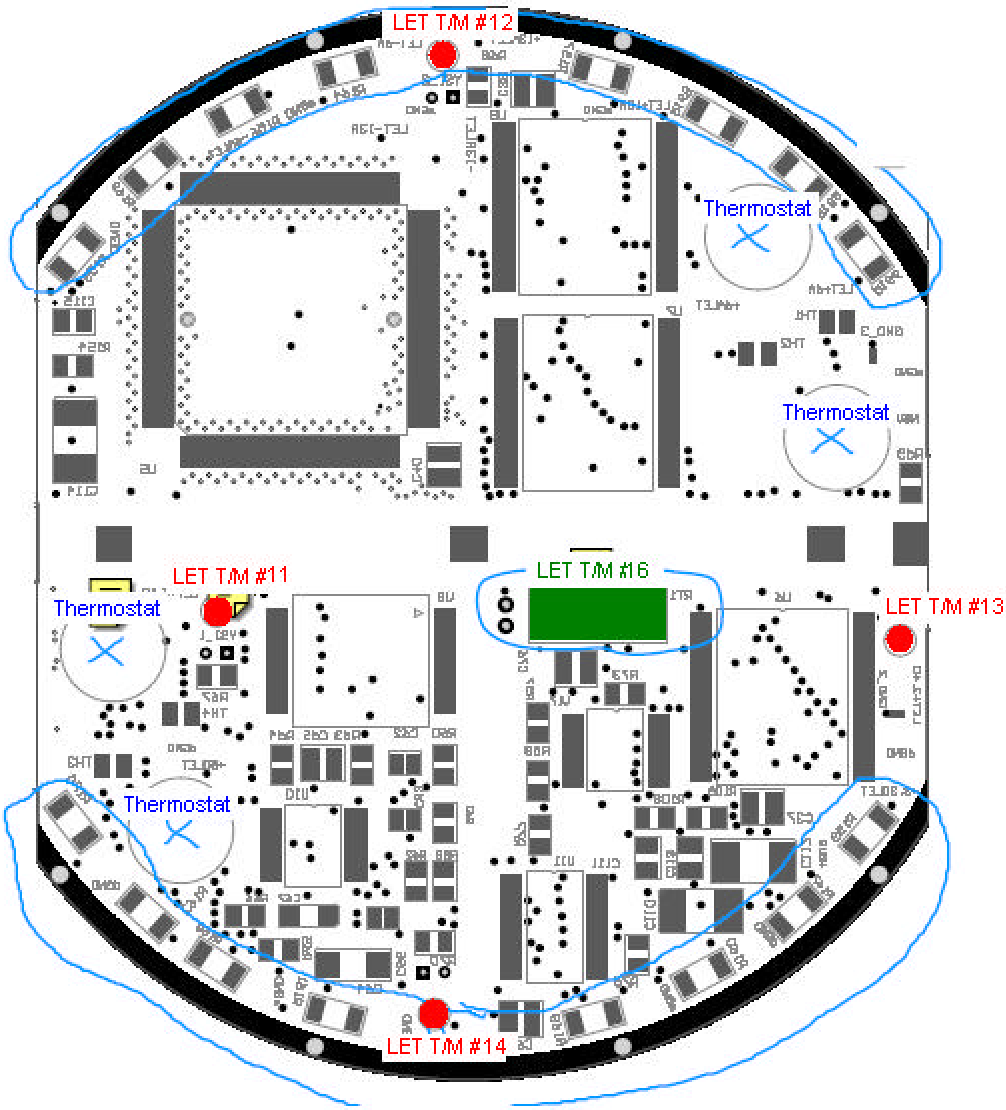


Figure 11: BEHIND LET Thermistor Locations (Through view of top PCB)