SANDIA REPORT

Customer Interface Document for the Molten Salt Test Loop (MSTL) System

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Sandia National Laboratories

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Abstract

The National Solar Thermal Test Facility at Sandia National Laboratories has a unique test capability called the Molten Salt Test Loop (MSTL) system. MSTL is a test capability that allows customers and researchers to test components in flowing, molten nitrate salt. The components tested can range from materials samples, to individual components such as flex hoses, ball joints, and valves, up to full solar collecting systems such as central receiver panels, parabolic troughs, or linear Fresnel systems. MSTL provides realistic conditions similar to a portion of a concentrating solar power facility. The facility currently uses 60/40 nitrate "solar salt" and can circulate the salt at pressure up to 600psi, temperature to 585°C, and flow rate of 400-600GPM depending on temperature. The purpose of this document is to provide a basis for customers to evaluate the applicability to their testing needs, and to provide an outline of expectations for conducting testing on MSTL. The document can serve as the basis for testing agreements including Work for Others (WFO) and Cooperative Research and Development Agreements (CRADA). While this document provides the basis for these agreements and describes some of the requirements for testing using MSTL and on the site at Sandia, the document is not sufficient by itself as a test agreement. The document, however, does provide customers with a uniform set of information to begin the test planning process.

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PURPOSE

The purpose of this document is to define the interface requirements for customer test skids that will be connected to the Molten Salt Test Loop (MSTL) system at Sandia National Laboratories' National Solar Thermal Test Facility (NSTTF). The document defines connection requirements for mechanical, electrical, control interfaces and data acquisition. This document also outlines the safety requirements, site access, and working with Sandia National Labs.

ACRYNOMS

DAQ – Data Acquisition System
DOE – US Department of Energy
DUF – Designated User Facility
EMO – Emergency Off Button
ES&H – Environment Safety & Health
FMEA – Failure Mode & Effects Analysis
JSA – Job Safety Analysis
L,H – non critical alarm (low and high)
LL, HH – Critical alarm (low and high)
LOTO – Lock/Out Tag/Out
MAWP – Maximum Allowable Working Pressure
MSTL – Molten Salt Test Loop
NI – National Instruments Corporation
NSTTF – National Solar Thermal Test Facility
PAQS – Process Acquisition System
PECS – Process Equipment Control System
POC – Point of Contact
PSDP – Pressure Safety Data Package
Sandia / SNL – Sandia National Laboratories
TWD – Technical Work Document
WFO – Work for Others (agreement)
WP&C – Work Planning & Control

MSTL SYSTEM OVERVIEW

The Molten Salt Test Loop system consists of a furnace full of molten nitrate salt ($60\%\,NaNO_3$-$40\%\,KNO_3$), a pump, piping to three parallel test stands, and an air-salt cooler. A simplified flow schematic showing the control and salt monitoring instrumentation is shown in Figure 1. An isometric view of the facility is shown in Figure 2. The system provides salt to the experiments located at the three test stands with the pump. The available salt temperature is 300-585°C (572-1085°F). The salt temperature is controlled by electric immersion heaters in the furnace where the salt is stored and by the air-salt cooler which removes heat put into the system by either pump work or by solar input from the experiment. The maximum available salt pressure is 40 bar (580psi) and is set by the pump and the backpressure control valve. The maximum flow rate available in the system is 44-50 kg/s, depending on temperature and thus salt density (400gpm).

The flow rate is set by the pump and the flow control valves on the input to each test stand. The system is designed to provide uninterrupted flow for tests up to 3000 hours with full capabilities for data collection and process monitoring. The test system can accept and remove up to 1.4MW solar thermal input and is sized to include a full size, large aperture trough module. Other anticipated experiments include flowing salt corrosion tests and accelerated life testing of components for troughs, towers, linear Fresnel, or thermal storage systems. The system is designed to gravity-drain back to the furnace upon loss of pump pressure and the piping and valves are fully heat traced to prevent salt freeze-up on system fill. There is an adjacent, temperature controlled building which contains the system control computer and the data acquisition system which has the capability to collect data from both the MSTL system as well as from experiments. The maximum amount of molten salt that may be dedicated to any one test article without affecting the performance of other test articles inserted in the other two loops is 836 gallons.
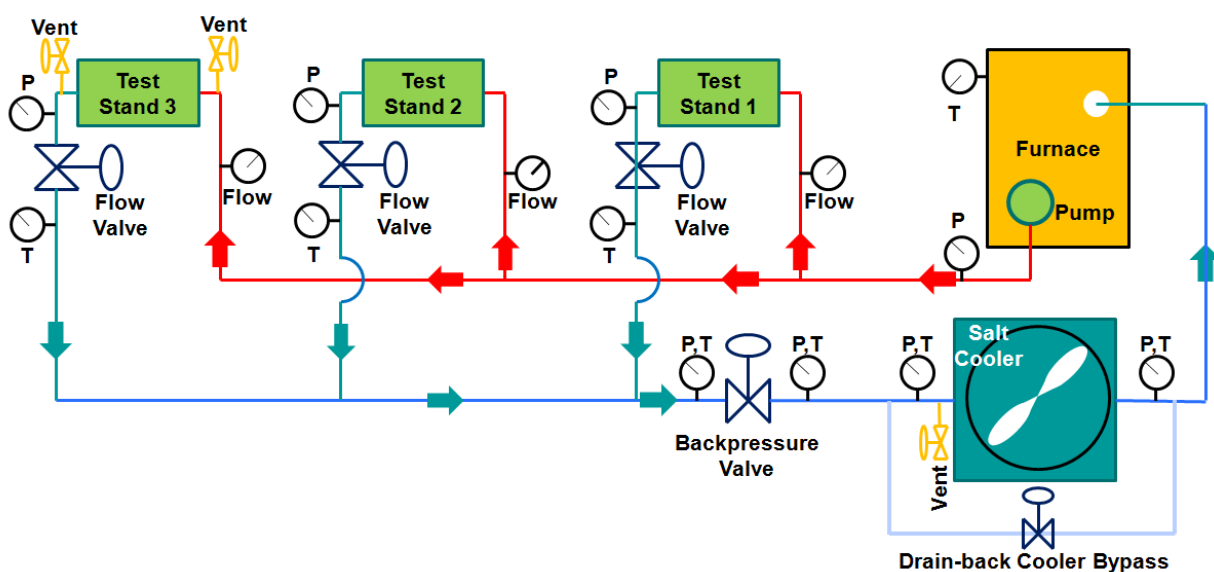
Figure 1. Simplified system schematic shows 3 test stands for parallel testing of solar components.
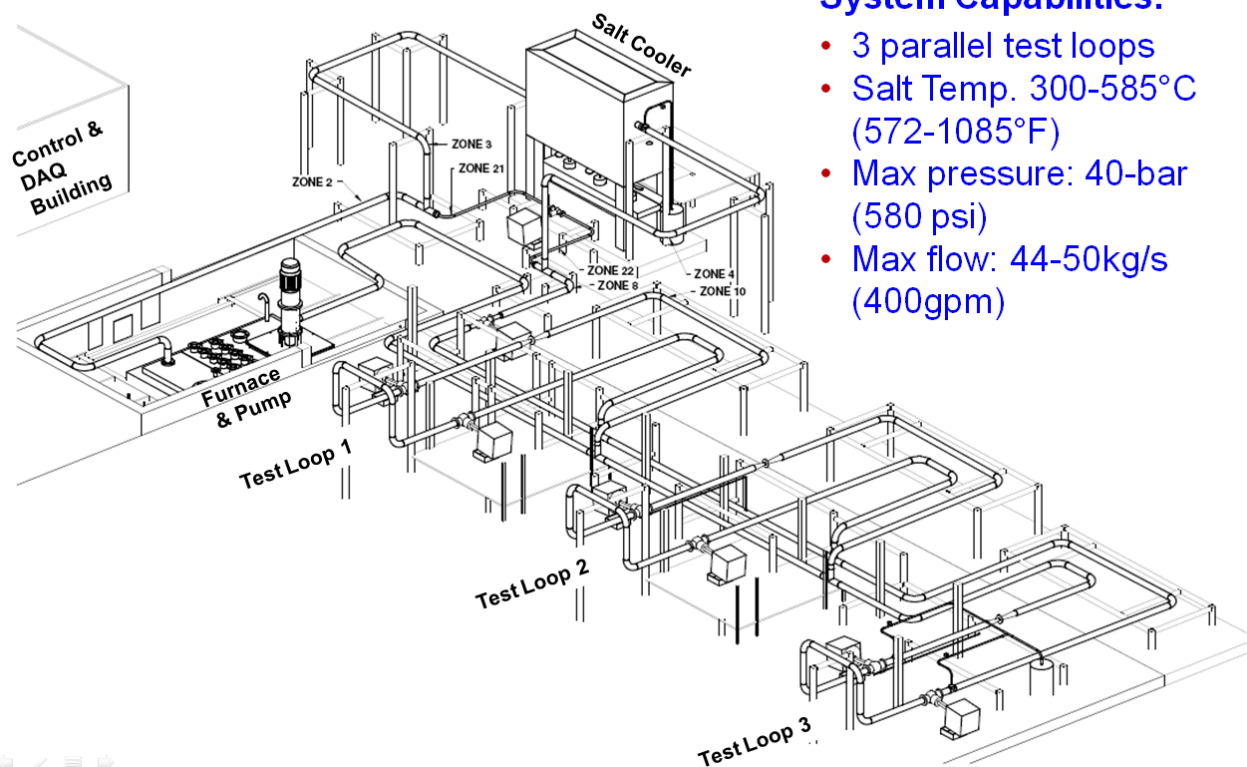
System Capabilities:
- 3 parallel test loops
- Salt Temp. 300-585°C (572-1085°F)
- Max pressure: 40-bar (580 psi)
- Max flow: 44-50kg/s (400gpm)

Figure 2. Isometric view showing system hardware and test stands.

SAFETY CONTROLS INTERFACE

1.1 Controls/Communications Interface

This section describes the hardware control signals that interface between an Experimenter's control system and the Molten Salt Test System (MSTL) PECS system. This will allow the Experimenter to independently develop their controls by interfacing a set of electrically isolated predetermined signals. The signals are described below.

If the experiment has no controls and will always be available for testing, the signal is not necessary.
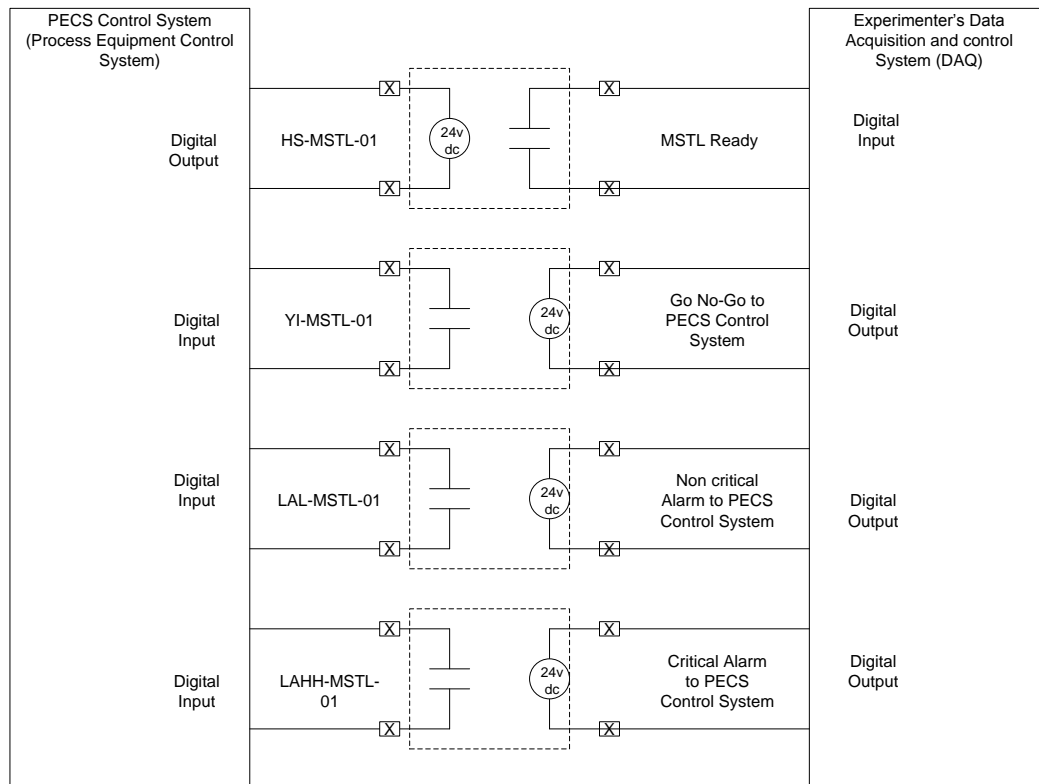
Figure 3. MSTL control interface to customer test skid.

1.2 MSTL Ready: (HS-MSTL-01)

The PECS control system will send a *MSTL Ready* to the Experimenter's control system when the PECS system is ready to test. The Experimenter's control system can use this signal as needed. The signal will drive an interposing relay for electrical isolation.

1.3 Go No-Go from Experimenter: (YI-MSTL-01)

This signal will be sent from the Experimenter's control system to the PECS control system. If a test is in progress and the *MSTL Ready* signal is removed (Open circuit), the MSTL test will go into a normal test shutdown. The signal will drive an interposing relay for electrical isolation. If the experiment has no controls and will always be available for testing, the signal is not necessary. If there is any need for the experimenter's system to need to signal readiness before testing begins, this signal is a mandatory signal.

1.4 Alarm Signals

Each of the 3 test stations will have 2 alarm signals sent from the Experimenter's control system to the PECS control system. These signals are not mandatory if the Experimenter's control system does not need them.

1. LAL-MSTL-01

   This signal is a non-critical alarm digital input at the PECS control system. The experimenter's control system will send the PECS control system an OPEN contact closure when the experimenter's data acquisition system requires a Normal Test Shutdown. A contact closure will indicate normal operations. If the experimenter does

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not want to use the signal, it will be electrically shorted at the PECS control system. This is not a mandatory signal. The Normal Test Shutdown is defined in the appendix.

2. LAHH-MSTL-01

This signal is a critical alarm digital input at the PECS system. The Experimenter's control system will send the PECS system an OPEN contact closure when the experimenter's control system requires an Emergency Test Shutdown. A contact closure will indicate normal operation. If the experimenter does not want to use the signal, it will be electrically shorted at the PECS control system. This is not a mandatory signal.

1.5 Emergency Stop Buttons

The Experimenter's control system must have an emergency stop tied in series with our emergency stop buttons. We will supply a hook up location for these signals. When an emergency stop button is pushed, the system will go into an emergency shut-down procedure. The Emergency Stop circuit is shown below:
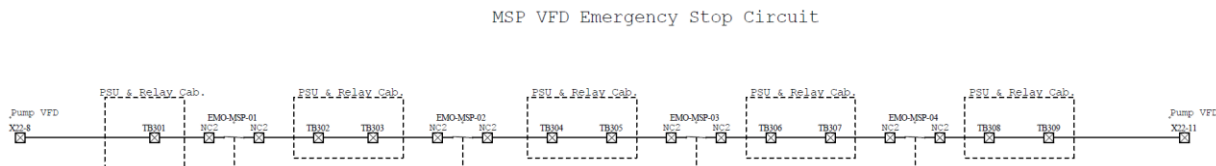
Figure 4. A schematic of the MSTL emergency stop circuit.

1.6 Wiring Details

The conductor size and wiring/conduit requirements are to be determined during initial design reviews between the experimenter and the Sandia PI.

1.7 Logging Data Signals

The experimenter will interface necessary signals for data logging using a National Instruments Compact DAQ cDAQ-9188 Ethernet based data acquisition chassis. The following types of signals have been tested:

1. Analog Input Voltage
2. Analog Input Current
3. Resistance
4. Thermocouples
5. RTDs
6. Thermistors
7. Strain Gages

Below is a list of National Instruments modules tested:

1. NI-9213, 16 Channel TC module
2. NI-9237, 4 channel, simultaneously samples, 50KS/s, 1/4 to 1/2 bridge
3. NI-9426, 32 ch, 24v sourcing digital input module
4. NI-9476, 32 ch, 24v sourcing digital output module

5. NI-9219, 24bit Universal Analog input, current and voltage

Other National Instruments cRIO modules may work (especially if they are the same type as the signal types above). Please check with us to make sure.

Each of 3 test stands will have an Ethernet port, we will assign the customer the Ethernet address.

The Experimenter will be provided with raw data and calibrated data. The system can store calibration information.

1.8 Checkout of Experimenters DAQ System
- Experimenter's DAQ, safety, and alarm communications must undergo interface checkout prior to testing on MSTL
    - This will be a point to point test by signal injection.

1.9 Electrical Power Interface
There are two different voltage classes available to the experimenter.
1. 120/208, 3 phase, 4 pole, 5 wire system. A female Hubble 100 amp receptacle (Hubble HBL5100R9W) is located to the south of each test loop. Each receptacle is protected via a fused disconnect. The fuses will be required to be sized for the experimenter's load requirements. The maximum fuse and circuit rating is 100 amps. The experimenter will provide:
    - Hubble plug (HBL5100P9W rated at 120/208, 3 phase, 4 pole, 5 wires, 100 amps)
    - Flexible power cable rated for the environment in which it will be installed and the load of the test skid. (SEOOW type cord or equivalent)
2. 277/480, 3 phase, 4 pole, 5 wire system. A female Hubble 100 amp receptacle (Hubble HBL5100R7W) is located to the south of each test loop. Each receptacle is protected via a fused disconnect. The fuses will be required to be sized for the experimenter's load requirements. The maximum fuse and circuit rating is 100 amps. The experimenter will provide:
    - Hubble plug (HBL5100P9W rated at 120/208, 3 phase, 4 pole, 5 wires, 100 amps)
    - Flexible power cable rated for the environment in which it will be installed and the load of the test skid. (SEOOW type cord or equivalent)

The experimenter shall determine the size of the power cable and the fuses in the above fused disconnects. The test skid shall have a single main electrical disconnect rated for the environment (NEMA 3R or better) and electrical load of the entire experiment. This disconnect shall de-energize the entire experimenter's skid.
The experimenter shall take precautions to protect their electrical equipment, including power cable, from damage from molten salt, thermal damage, heat, weather, etc.

The experimenter shall ensure their electrical system is designed, constructed and tested to meet all code requirements. The electrical system shall be UL listed or tested by a recognized testing laboratory.

Note: The experimenter can request a waiver from the above requirement. In order to obtain a waiver all electrical components shall be UL-listed, and shall be used in the manner for which UL certified them. All UL listed items shall be installed per manufacturer recommendations and the entire system shall be tested and shall pass the tests for megger, ground integrity and bonding. The tests performed and their results shall be permanently attached to the equipment. Upon arrival at SNL the authority having jurisdiction will review the equipment, the test results, the wiring methods and workmanship to determine if a waiver will be provided.

An electrical equipment inspection will be performed by SNL and an acceptance memo will be provided to the experimenter before any power is applied to the test skid. OSHA does not allow any energized hands-on electrical work at or above 50 volts, SNL enforces this and the experimenter shall abide by this requirement. At any time the experimenter performs work on their electrical system they will be required to follow all approved procedures to ensure the system is de-energized and safe to work on.

1.10 Mechanical Interface

The experimenter will mechanically connect to the MSTL system through 6" nominal diameter pipe (schedule 80XS). The experimenter's apparatus will typically be welded into to the pipe, though high-temperature flanged connections may be considered for shorter term experiments or experiments that need to be disconnected from the system on occasion (as determined by the MSTL engineer). The material of the experiment must typically be 300 series stainless steel, Inconel 625, or Haynes 230. Other materials will be considered on a case-by-case basis by the MSTL engineer depending on system configuration and other experiments currently in the system. The pipe location for each experiment is listed in Table 1. The surface of the test area is gravel, so the exact height to the pipes can be adjusted somewhat, though the preferred method would be to have the experiment able to be raised to the specified height. The experimenter's system must gravity drain back to the furnace on power loss, requiring a vacuum relief valve at the highest point. If drain-back from an experiment is not possible or not feasible, then the experimenter must either be willing to have their experiment freeze-up or must have some other means of dealing with salt in a power-off condition.

Table 1. Experiment connection and test area dimensions.

Test Stand	Pipe Height	Pipe Size	Pipe Connection	Available Test Area*
1	6'	6" sch80XP	Butt Weld	35'x67'
2	6'	6" sch80XP	Butt Weld	30'x67'
3	3'	6" sch80XP	Butt Weld	25'x67' **

The MSTL system is designed to have stationary inputs to the experiment that do not transmit force, torque, or expansion to the experiment. Therefore, the experimenter must accommodate all thermal expansion of the experimental system within the experiment through the use of

sliding mounts, flexible couplings, or other means, and the experimenter must minimize the stress and motion that is put on the MSTL system due to thermal expansion to prevent stress failure from pipe bending. Determination of "minimized stress and motion" must be approved by the MSTL engineer.

The experimenter will be responsible for supplying a Pressure Safety Data Package (PSDP) on Sandia's template that shows calculations of the Maximum Allowable Working Pressure (MAWP) of the experiment and data sheets, weld inspection reports, and any other supporting evidence to ensure that the experiment meets the MAWP with component ratings acceptable margin of safety. As part of the work agreement, this data package can be designated as part of Sandia's scope of work, but the experimenter will be required to provide any design calculations and information that will expedite the completion of the PSDP. In many cases, the experimenter and Sandia personnel will conduct a Failure Mode and Effects Analysis (FMEA) on the experiment to anticipate and mitigate potential failure modes of the experiment. Based on the results of the PSDP and FMEA, an operating procedure will be created for the experiment that includes information on any exclusion areas needed (limiting personnel presence near the experiment when running under pressure), and any special catch trays or spray blocking needed to protect adjacent equipment and the environment.

1.11 Structural/Civil Interface

The MSTL system is designed to have multiple experiments installed at the same time on the 3 parallel test loops. Because of the flow restrictions on the pump, there will be instances in which salt will need to be flowed through one experiment as a bypass to allow the desired flow conditions to be achieved in another experiment's test loop. When creating the Work for Others (WFO) agreement, it will be necessary for any restrictions on bypass flow conditions to be designated including allowable flowrate, pressure, and temperature.

The ground surface under the experiment is gravel. The experimenter and Sandia personnel will together determine any foundations or excavations that are necessary for the experiment. However, whenever possible it will be advantageous for the experimenter's apparatus to be self-contained on a skid that can sit on top of the gravel surface. It is understood that this will not be sufficient for all experiments and that some apparatus will require footings and mounting hardware which will be accommodated when possible, usually at the experimenter's expense. Sandia National Laboratories has rigorous safety requirements for construction-like activities. Because of the challenge and expense of meeting these requirements initially, it will typically be advantageous for experimenters needing construction-like activities, to utilize one of Sandia's approved contractors for construction activities. These contractors can subcontract with an experimenter's preferred contractor if desired at some expense for the monitoring and administering of Sandia processes.

1.12 Other Utilities

The system has a rotary screw air compressor that has maximum capability of 132psi and 38.6cfm. Because of other air demands and piping losses, the experimenter can expect 50psi air with a maximum usage rate of 20cfm. This air is provided to the experimental test stand in 0.5" diameter tubing and has a ½" quick-disconnect fitting for connection. Each test stand has a 0-50psi gauge for monitoring of air pressure.

ADMINISTRATIVE INTERFACE AND REQUIREMENTS

1.13 Site Access

Experimenter personnel will need to meet Sandia National Laboratories' (SNL) and National Solar Thermal Test Facility (NSTTF) site access requirements. SNL requirements will include completing a DOE/SNL badge request which once granted, will allow for entrance through the Kirtland Air Force Base gates. Foreign Nationals can also be accommodated within this process. However, there are additional requirements and training that must be completed for this to take place. Make the MSTL Facility Manager aware of all Foreign Nationals requiring access and allow additional time for processing of access requests.

NSTTF requirements for unescorted access and work privileges include viewing of the site safety video, reading and signing the site operating procedure, and completion of additional training depending on anticipated activities and proposed work scope. The training requirements will be included prior to any agreement with SNL.

Experimenter owned cell phones, PC or laptop computers, and cameras are allowed to be onsite and used at the NSTTF. Wireless internet access is available through the Sandia Hotel Network (SHN).

Standard business hours for the NSTTF are from 07:00 a.m. through 16:00 p.m. Monday through Friday.

SITE LOCATION AND GEOGRAPHY

The NSTTF site is a large and remote facility located approximately ten miles south and east of Albuquerque New Mexico. The site geography can be described as high mountain desert and is subject to weather extremes and inhabited by potentially dangerous wildlife. In the summer months the site can become very hot. It is not uncommon for daytime temperatures to reach 90º to 100ºF from early June through September. Sunburn, heat exhaustion, and sun stroke must be guarded against. High winds and thunder storms with lightning are common throughout the spring, summer, and fall. These adverse weather conditions are monitored for and when they present a danger to site personnel, site radio announcements requiring all personnel to seek cover inside the nearest structure are made. In the winter months, snow and very cold temperatures can occur. Winter temperatures adjusted for wind can exceed minus 20ºF. Frostbite of exposed skin and hypothermia can readily occur in these conditions. Due to the remote location and potential hazards, all personnel working outside of Building 9981 (Main office/control building) are required to have a radio on their person or within their group to monitor site communications, to report emergencies, or to call for assistance.

Dangerous wildlife (rattle snakes and coyotes) can be on the site; they are indigenous to the area and can be encountered. If wildlife is perceived to be or becomes a danger, do not approach it and contact the site Environmental Safety & Health Point of Contact (POC).

ENVIRONMENTAL SAFETY & HEALTH (ES&H) REQUIREMENTS

Sandia has implemented a comprehensive ES&H program that meets all local, state, and national standards and requirements. It is the policy of Sandia to protect Members of the Workforce and the public, prevent incidents, protect the environment through integration of environmental stewardship and sustainability throughout the life-cycle of its activities, and ensure regulatory compliance. Sandia Corporation conserves natural resources and protects the environment. All MSTL test activities will be expected to meet all applicable Sandia ES&H requirements. The SNL MSTL test engineer will ensure that all ES&H concerns are addressed and resolved.

WORK PLANNING & CONTROL (WP&C)

In an effort to ensure that all work is conducted in a safe and efficient manner, Sandia WP&C requirements will be adhered to. This process verifies that all proposed work activities are well defined and within the NSTTF operating envelope, the associated hazards are identified and controls put in place to mitigate them, receive management authorization to commence, and provides feedback for improvement in safety and efficiency. Work packages containing a scope of work, Technical Work Documents (TWDs), Job Safety Analyses (JSAs), management authorization, and avenues for feedback and improvement are generated depending on the rigor level of the proposed work activities. Contact the department Work Planner for assistance with all WP&C questions.

TRAINING REQUIREMENTS

All MSTL experimenters will be required to obtain some level of facility and/or Sandia training. For those users agreeing or desiring to have little or no hands on involvement with test installation, operation, and removal, training requirements will simple and minimal. For those users that request to be involved in test installation, operations, and removal, training requirements will be applied on a graded approach depending on the level of involvement and safety considerations. Both can be readily accomplished.

MSTL FACILITY/TEST ARTICLE COMPATIBILITY REQUIREMENTS

To ensure compatibility between the MSTL systems and test article requirements, a documented compatibility analysis will be required for all potential test articles. A graded approach will be applied when completing compatibility analyses depending on test size, materials used, complexity, duration, and other operational considerations. Information derived from

compatibility analyses will be used to identify and mitigate testing hazards, develop operational procedure steps and requirements, and set test system limits and exclusion area boundaries.

TEST/SAFETY PLAN

To ensure test safety, prevent scope creep, and define desired testing requirements, a documented Test/Safety plan will be required for all MSTL test articles or systems. Test/Safety plans will include but are not limited to system requirements (pressures and temperatures), test durations and cycles, required instrumentation, required data collection and disposition, special installation techniques and/or considerations, start up and shut down requirements, user presence during checkout (required), and user presence during testing (optional but strongly suggested). The Test/Safety plan must be reviewed and approved by the MSTL Engineer.

TEST ARTICLE DISPOSAL

Experimenter will be responsible for the removal, disposition, and/or disposal of all test articles unless specific and documented arrangements have been made in advance with Sandia to perform these actions.

SEQUENCE OF OPERATIONS

The following section describes the MSTL design sequence of operations. The information is a general description and is not intended to describe all possible sequences or parameters. While the description (taken from the design specification) has some information that the experimenter will not need (e.g. indicator changes on the PECS control screen), the information is included here both to enhance the experimenter's understanding of the system and to ensure that this description matches design documents with nothing left out.

1.14 General System Overview
1. The MSTL system shall provide functionality outlined in the following sequences of operations.
2. System Graphic Indications
   a) The graphics showing the system and equipment shall change color based on the operating condition of the system and equipment. The following system color indication shall apply to system graphics:
      (1) "Green Solid Color" system conditions shall indicate a condition where the associated equipment is operating under normal conditions (running with no alarms).
      (2) "Yellow Solid Color" system conditions shall indicate that the associated equipment is energized however system status has not be achieved or the equipment has not reached its normal operating condition (i.e. temperature is not at setpoint).
      (3) "Red Solid Color" system conditions shall indicate that the associated equipment is "de-energized".

b) The graphics showing the system and equipment shall change color and blink if an alarm condition for the system exists. Alarm conditions are defined in the Alarm Spreadsheet.
    (1) "Yellow Blinking Color" system condition shall indicate that a low level alarm condition is present with the system or equipment.
    (2) "Red Blinking Color" system condition shall indicate that a high level alarm condition is present with the system or equipment.

3. Test Parameters
a) The operator shall enter the following parameters prior to the initiation of any test:
    (1) The Test Loop Leg to be in operation.
    (2) The required test flow rate (gpm) and deadband.
    (3) The required test pressure (psig) and deadband.
    (4) The required test temperature (°C) and deadband.
    (5) The required system ramp rate for heating of the furnace during a test.
b) All operator setting shall be saved to a test configuration file.

1.15 Furnace Pre-Heat Initial Start-Up (If experiment requires new salt)

1.15.1 General Overview
The following sequence outlines the control functions required to pre-heat the furnace prior to the installation of the salt. Once construction of the MSTL system has been completed, the system must be preheated before salt may be introduced into the system.

1.15.2 System Sequence
a) Prior to start-up, the "Furnace System Graphic " shall indicate on computer screen all furnace components (pump, heaters, and sensors) as de-energized (highlighted "Red").
b) Prior to salt fill, the furnace inner pot shall be pre-heated to 300°C by energizing and modulating the immersion heater SCR's using a PID control loop. The status of each heater shall be monitored by through the current transmitters. Once current is detected, the heater highlighted color shall change from "Yellow" to "Green". The "Furnace System Graphic" shall indicate the electrical energy percentage each SCR is operating at and current SCR setpoint.
c) Safety interlocks in the system shall limit the immersion heater SCR's to 30% heating capacity when inner furnace is empty. These safety interlocks shall apply to each individual immersion heater.
d) The furnace temperature tree shall indicate the air temperature within the furnace every 6-inches from the bottom to the top. The furnace immersion heaters shall modulate at a maximum 30% heating capacity until the temperature tree sensors stabilize at all elevation levels at 300°C, +/- 20°C over a 1 hour period (adjustable). Once the air temperature reaches 300°C, the furnace temperatures shall change to highlighted "Green".
e) Each immersion heater high limit thermocouple sensor shall be used to de-energize the individual immersion heater if the high limit setpoint of 590°C is exceeded. If an immersion heater is disabled on a high limit condition, an alarm shall be initiated that

identifies which heater has malfunctioned and been disabled. The heater unit shall be highlighted "Red" and shall blink until operator has recognized the failure.

f) In the event an immersion heater is disabled on a high limit condition, the remaining heaters shall be limited to a maximum heating capacity of 30% when operating in the Pre-Heat Mode when the furnace inner pot is empty.

g) The furnace is highlighted "Yellow" indicating that the furnace inner pot has not pre-heated to 300°C. The furnace is highlighted "Green" indicating that the furnace inner pot has pre-heated to 300°C for over 1-hour period.

h) Once the unit has maintained pre-heat condition, the system shall notify the operator the furnace has reach pre-heat condition and is ready to accept salt. The immersion heater shall continue to modulate to maintain temperature at 300°C, +/- 20°C.

1.16 Piping System Heating Control

1.16.1 General Overview

The following sequence outlines the control functions required to preheat the piping system prior to flowing salt through the system during for a test. This sequence occurs when the piping system has been shutdown prior to a testing.

1.16.2 System Sequence

a) At start-up, "Pipe Heat Trace System Graphic" shall indicate at the operator workstation (highlight) all pipe heat trace zones and valve body zones as "Red" indicating that heat trace zone is not pre-heated to setpoint. Valve bonnet heat zone as "Red" indicating that heat trace zone is not pre-heated to setpoint

b) Each heat trace zone shall have its own adjustable setpoint and dead band. These setpoints as well as the maximum rate of rise required by the valve manufacturer shall be stored in the configuration file which shall have the ability to be modified by the operator. Default temperature setpoints shall be 300°C with a dead band of +/- 20°C for piping and valve bodies. Default temperature setpoints shall be 275°C with a dead band of +/- 15°C for valve bonnets. Under most test scenarios, the piping and valve bonnet heat trace zones shall operate at the default values. The valve bodies and bonnets shall not be heated faster than the rate of rise value.

c) The PECS shall energize and operate the pipe heat trace zones to increase pipe temperature to setpoint. The PECS shall energize and operate the valve body heat trace zone to increase the valve body temperatures the operating test setpoint. The PECS shall energize and operate the valve bonnet heat trace zones to increase valve bonnet temperatures to 280°C. Each heat trace zone shall be highlighted "Yellow" when it is energized.

   (1) The piping heat trace zones will cycle "on-off" through the PECS until pipe temperature sensors stabilize at setpoint for a 30 minute period.

   (2) Once a specific pipe heat trace zone has stabilized, "Pipe Heat Trace System Graphic" shall highlight "Green" the specific zone that the temperature has been satisfied.

   (3) The valve body heat trace zones will cycle "on-off" through the PECS until valve body temperature sensor stabilize at setpoint for a 30 minute period.

   (4) Once a specific valve body heat trace zone has stabilized, "Pipe Heat Trace System Graphic" shall highlight "Green" indicating the specific valve body

zone that the temperature has been satisfied. Under normal control the valves shall not be operated unless the valve bodies are above 300°C.

     (5) Each valve bonnet has two temperature sensors. Valve bonnet heat trace zones shall modulate through the SCR by the PECS using a PID control loop until the average of the two bonnet sensors has stabilize at setpoint for a 30 minute period. Minimum heat trace modulation control shall be no less that 30%.

     (6) Once the average of the two sensors has stabilized, "Pipe Heat Trace System Graphic" shall highlight "Green" the specific valve bonnet zone that the temperature has been satisfied.

d) The status of each heat trace circuit shall be monitored through current switches. If current is not detected for a zone when commanded on, the heat trace circuit shall be turned off and the zone shall blink "Red" indicating a zone failure

e) Once all piping system heat trace zones (pipe and valves) have been satisfied, the PECS shall notify operator that the piping system pre-heat start-up has been completed. All zones shall continue to maintain minimum temperature setpoint as long as system is energized.

1.17 Air-Salt Cooler Pre-Heat Start-up

1.17.1 General Overview
The following sequence outlines the control functions required to preheat the salt cooler prior to flowing salt through the system.

1.17.2 System Sequence
a) Prior to start-up, the "Air-Salt Cooler System Graphic" shall indicate on the operator workstation (highlight) all cooler components (cal-rod heaters, fan(s), damper actuators, discharge louver actuators and sensors) as de-energized "Red". Cooler temperature setpoints shall be stored in the configuration file which shall have the ability to be modified by the operator. The initial temperature setpoint shall be 300°C.

b) In de-energized mode, the dampers are fully closed, and the discharge louvers shall be fully closed.

c) Prior to initiating salt flow, the cooler heat exchanger shall be pre-heated to setpoint by energizing the internal cal-rod heaters and modulating the SCR's through the PECS using a PID control loop. The cal-rod heaters shall be energized to maximum heating capacity (highlighted "Yellow"). The dampers and discharge louvers shall remain fully closed during pre-heat mode.

d) The Cooler cal-rod heaters shall modulate until the internal heat exchanger surface temperature sensors stabilize at setpoint +/- 20°C for a 60 minute period (adjustable).

e) Once the cooler heat exchanger surface temperature has stabilized, the "Air Salt Cooler System Graphic" shall highlight "Green" indicating that the temperature has been satisfied.

f) Once the heat exchanger pre-heat temperature has been satisfied, the PECS shall notify the operator that the cooler system pre-heat start-up has been completed. All cal-rod heaters shall continue to modulate to maintain minimum temperature setpoint as long as system is energized. The dampers and discharge louvers shall remain fully closed until salt flow is initiated.

1.18 Normal Furnace Operation

1.18.1 General Overview

The following sequence outlines the control functions for the furnace during normal test operations.

1.18.2 System Sequence

a) Once the furnace has been loaded with Salt, the immersion heaters shall maintain a minimum temperature of 300°C at all times. The level sensor shall automatically display the current salt fluid level in feet from bottom of furnace and useable salt fluid level in feet (bottom 3 feet of salt are not useable, therefore subtract 3 feet from total salt height to obtain useable salt level).

b) Safety interlocks in the PECS shall limit the immersion heater SCR's to 30% heating capacity when furnace level is below 3 feet of salt from the bottom of the furnace. These safety interlocks shall apply to each individual immersion heater. If the level falls below 2'-6", the PECS shall disable the pump and open all automated valves to allow the salt to drain back to the furnace. Alarms shall be generated on de-energizing pump and low level conditions. Alarms shall be generated on opening vacuum relief control valves.

c) The PECS shall modulate the SCR heaters together with a common output to maintain the furnace temperature at the new setpoint as measured by the temperature tree. The status of each heater shall be monitored through the current transmitters. Once current is detected, the heater highlighted color shall change from "Yellow" to "Green". The "Furnace System Graphic" shall indicate the electrical current each heater is operating at and the SCR setpoint. If current is not detected when a heater is energized or the current exceeds the manufacturer's maximum current setpoint, the heater shall be disabled and an alarm shall be initiated that identifies which heater has malfunctioned and been disabled. The heater unit shall be highlighted "Red" and shall blink until operator has recognized the failure.

d) The operator shall be capable of re-setting operation temperature between a minimum 300°C to a maximum 580°C through the operator workstation. The operator shall be locked out from setting temperatures below 300°C and above 580°C. If the average salt temperature at all 6-inch elevations as measured by the temperature tree drops below 275°C or exceeds 590°C the PECS shall alarm.

e) The furnace is highlighted "Yellow" indicating that the furnace has not heated to the new test setpoint. The furnace is highlighted "Green" indicating that the furnace inner pot has heated to the new test setpoint.

f) Each immersion heater high limit thermocouple sensor shall be used by the PECS to de-energize the individual immersion heater if the high limit setpoint of 590°C is exceeded. If an immersion heater is disabled on a high limit condition, an alarm shall be initiated that identifies which heater has malfunctioned and been disabled. The heater unit shall be highlighted "Red" and shall blink until operator has recognized the failure.

1.19 Control Valve Bonnet Cooling System

1.19.1 General Overview

1. The PECS shall operate the valve bonnet cooling system for each control valve to insure the average of the two valve bonnet temperature sensors does not exceed 290°C. If the temperature reaches this setpoint, the PECS shall operate the cooling system according to the following

1.19.2 System Sequence

a) The valve bonnet heat trace SCR should be modulate to 0%.
b) The supply and exhaust butterfly valves shall open.
c) The supply air fan shall start and modulate using a PID control loop to maintain the valve bonnet temperature at a setpoint of 290°C.
d) If the temperature of the valve bonnet reaches 285°C, the fan should shut off and the butterfly valves shall close.
e) The heat trace SCR shall resume modulation to maintain the valve bonnet temperature at 280°C.

1.20 Test Operation

1.20.1 General Overview

The following sequence outlines the control functions for the system during test operations.

1.20.2 System Sequence

a) Prior to initiating salt flow (energize pump), the operator shall receive notification that the furnace, air salt cooler, and piping system including valve bodies and valve bonnets pre-heat temperatures have been satisfied through the operator workstation. The operator shall then initiate the test through a screen button on the operator workstation.
b) Once the furnace has reached the temperature setpoint and stabilized for a period of 10 minutes, the PECS shall open the Backpressure Control Valve FCV-4 to full % open position and close all vacuum breaker valves.
c) The operator shall set the number of Active Flow Loops by selecting whether the test will allow actuation of 1, 2, or 3 loop flow control valves. The operator will assign the Test Loop, the Bypass Loop, and the Spare Loop as appropriate. The operator shall assign the Maximum Allowable Test Position (MATP) % open for the loop flow control valves FCV-1, FCV-2, FCV-3. If Active Loops is less than 3, it is acceptable for Max Allowable % Open to be 0% for the inactive loops.
d) If Active Loops >1, Open Bypass Loop FCV to MATP, else open Test Loop FCV to MATP.
e) Using VFD speed feedback, ramp pump VFD to 50% (adjustable) over 2 minutes (adjustable) and operate in this condition for 10 minutes (adjustable). Over final minute, determine if flow in bypass loop has stabilized. If stable, continue to 4c, if not stable query operator to add run time or to adjust Bypass FCV MATP, or to continue to next step, or to abort the test in normal test shutdown.
f) If Active Loops = 1, skip step f. If Active Loops > 1, Open test loop FCV to MATP. Run in this condition for 10 minutes (adjustable) or until flow measurement in both Test loop and Bypass loop are stable. If time has elapsed and flow is not stable, query

operator to add run time or to adjust Active Loop MATP, or to continue to next step, or to abort the test in normal test shutdown.

g) If Active Loop <3, skip step g. If Active Loops = 3, close Test Loop FCV and open Spare Loop FCV to MATP. Operate in this condition for 10 minutes (adjustable) or until flow in Bypass Loop and in Spare Loop are stable. If time has elapsed and flow is not stable, query operator to add run time or to adjust Spare Loop MATP, or to continue to next step, or to abort the test in Normal Test Shutdown.

h) Ramp pump speed down to 30% (adjustable) under speed control.

i) Open Test Loop FCV to MATP.

j) PECS shall query Operator for Bypass FCV % open setpoint. This value shall be changed by the operator and not by the PECS PID loop. The value shall be available for the operator to adjust during testing, but PECS shall limit the rate of valve position change so that changes cannot occur faster than 10% per minute (adjustable). The PECS shall position the valve to the % open setpoint .

k) Begin PID control of the Pump VFD using the Flow Setpoint of the Test Loop as the control value. Adhere to pump rate change limitations as set by manufacturer. If flow rate will not stabilize, query user to adjust Bypass loop position setpoint, or to continue to start backpressure Control Valve FCV-4 control loop, or to abort test in Normal Test Shutdown mode.

l) When flow rate in Test Loop is stable, start PID control of the Backpressure Control Valve FCV-4. FCV-4 control shall be limited to 10% position change per minute (adjustable). As the Backpressure Control Valve FCV-4 modulates and increases/decreases the flowrate, the speed of the pump shall modulate to compensate and maintain the flowrate setpoint.

m) The PECS shall Energize Pump VFD and ramp up pump speed to reach the flow setpoint using a PID control loop. Pump VFD ramp-up speed shall be set to take 2 minutes (adjustable). Control of the pump PID loop shall be set-up so that the pump can only operate within the temperature and pressure limits established by the manufacture for the pump.

n) After 10 minutes of pump flowrate being stabilized at setpoint, the backpressure valve shall begin to modulate using a PID control loop to increase pressure to the operator setpoint in the test leg per the pressure sensor. The backpressure valve modulation speed shall be limited to 10% modulation per minute to allow the pump VFD to increase in speed back to flow setpoint.

o) Once the pressure and flow rates have reached setpoint for 2 minutes (adjustable), the backpressure valve and flow meter shall be highlighted "Green".

p) The salt cooler shall be energized in the following sequence through the PECS when the cooler outlet temperature is 5°C (adjustable) above the test temperature setpoint.

    (1) Dampers and discharge louvers shall be energized to open fully. Fans shall remain de-energized until the salt temperature exceeds test temperature setpoint by 5°C (adjustable).

    (2) Once the temperature exceeds setpoint by 5°C (adjustable) with the discharge louvers and dampers fully open and the fan VFD's shall be energized. The PECS shall modulate the fans between minimum speed and full speed using a PID control loop to maintain the salt discharge temperature at the test temperature setpoint.

(3) If the salt discharge temperature drops 5°C (adjustable) below the test temperature setpoint with the fans modulate back to minimum speed, the PECS shall begin to modulate closed the dampers using a PID control loop to maintain the discharge temperature at the test temperature setpoint. Once the dampers are closed, the discharge louvers shall be closed.

q) The salt pump shall have a set maximum number of times it can be started within a 24 hour period. This set point shall be programmed into the system at start-up according to the manufacturer's recommendation. The PECS shall initiate a low priority alarm when the pump has reached the maximum start number within a 24 hour period.

r) As a back-up flow indication to the system, the PECS shall calculate the flowrate using the differential pressure across FCV-4. The PEC shall utilize the Cv characteristics of the valve and using the valve position and differential pressure, shall calculate the flowrate through the valve. If the flow meter in the test stand that is being used to control the system fails, the PECS shall switch control of the system to the FCV-4 calculated flow control.

1.21 Normal Test Shutdown

1.21.1 General Overview
The following sequence outlines the control functions for the system during normal test termination.

1.21.2 System Sequence
a) At the end of the test, the operator shall activate an end test button on the operator workstation screen. The following sequence should also be initiated if any condition identified in the "Alarm Matrix" as a "High Priority Alarm" is reached.

b) The PECS shall modulate back the pump speed to 0% and stop the pump.

c) The PECS shall open the back pressure valve FCV-4.

d) The PECS shall reset the furnace operating temperature to the standby temperature setpoint entered by the operator. The furnace heaters shall modulate back to maintain the furnace temperature at setpoint.

e) The PECS shall modulate back the cooler fans to 0% and stop the fans.

f) The PECS shall close the cooler dampers and discharge louvers once the fans have stopped.

g) The PECS shall modulate open all flow control and bypass valves to allow salt to flow back to the furnace.

h) The PECS shall control the heat trace zones to maintain the temperatures at the default setpoints.

i) After a period of 10 seconds with the system pressure at zero, the PECS shall open all vacuum relief valves.

j) After a period of 60 minutes, the PECS shall close all valves except FCV-4 which shall remain open to allow for system expansion and contraction.

1.22 Emergency Test Shutdown

1.22.1 General Overview
The following sequence outlines the control functions for the system during an emergency test shutdown.

1.22.2 System Sequence
a) If during a test any of the following conditions occurs, the test system shall immediately be terminated.
>   (1) Any emergency shutdown switch is activated.
>   (2) The emergency shutdown button on the operator workstation is activated.
>   (3) Any condition identified in the "Alarm Matrix" as a "Critical Alarm" is reached.

b) The PECS shall stop the pump.

c) The PECS shall de-energize the furnace heaters.

d) The PECS shall stop the cooler fans.

e) The PECS shall close the cooler dampers and discharge louvers once the fans have stopped.

f) The PECS shall open all flow control and bypass valves to allow salt to flow back to the furnace using emergency override points.

g) The PECS shall control the heat trace zones to maintain the temperatures at the default setpoints.

h) After a period of 10 seconds with the system pressure at zero, the PECS shall open all vacuum relief valves using emergency override points

i) After a period of 60 minutes, the PECS shall close all control valves except FCV-4 which shall remain open to allow for system expansion and contraction.

1.23 Loss of Power Shutdown

1.23.1 General Overview
The following sequence outlines the control functions for the system during a loss of power to the system. The PECS and all associated actuators are on UPS power to allow the following sequence to occur.

1.23.2 System Sequence
a) The PECS shall lock out the pump to prevent automatic restart.

b) The PECS shall lock out the cooler fans to prevent automatic restart.

c) The PECS shall close the cooler dampers and discharge louvers.

d) The PECS shall modulate open all flow control valves to allow salt to flow back to the furnace.

e) After a period of 10 seconds with the system pressure at zero, the PECS shall open all vacuum relief valves.

f) If power is not restored within a period of 60 minutes, the PECS shall close all control valves except FCV-4 which shall remain open to allow for system expansion and contraction. If power is restored, the valves shall return to their prior test position for test restart.

g) Once power is restored, the PECS shall resume control of the furnace heaters and heat trace systems to maintain the temperatures at the default setpoints.

h) Once power is restored, the test sequence shall resume with a piping system pre-heat if the operator re-initiates the test through the operator workstation.

GLOSSARY

CompactDAQ – a modular data acquisition system with Ethernet connectivity.

Experimenter – The experimenter is a person who is using the MSTL system for an evaluation of molten salt for some purpose. They may bring their own experiment to attach to a test stand, or may use the MSTL system equipment. This person will be allowed to interface with the DAQ system to define the data that they want to collect. They may determine a test plan, but will rely on the operator to set up and operate MSTL.

MSTL Engineer – The MSTL engineer is a NSTTF staff member responsible for the safe day-to-day operation of the facility, coordinating all test activities and resolving scheduling conflicts, reviewing and approving experiment test plans, and ensuring that test components or systems are configured safely and compatible with the MSTL.

Operator – The operator is the qualified employee of Sandia or its contractors who operates the MSTL system using the PECS system. The operator has the ability to change parameters within the PECS environment, but these value changes will all be guided by max and min bounds that prevent unsafe operating conditions.

Programmer – The programmer has access and ability to change all parameters in the PECS, PAQS, and DAQ systems and therefore has the responsibility to confirm that values entered are not out of range. This person can make program changes to the software or download new control algorithms to the PAQS hardware.

Experimenter's Skid – For the purpose of this document the skid is the entire arrangement that will be under test. It will include but is not limited to the following: Controls, Mechanical systems, Electrical systems, Data acquisitions, etc. In some cases, the skid may be a portable item that is built off site and brought in for a test, a component mounted in existing MSTL piping, or it may be a fixed item that requires foundations and construction-like installation at MSTL.

Test Plan – A formal document that includes, but is not limited to the definition of test system requirements, (test parameters, testing duration and/or cycles, required instrumentation, data collection and disposition), experimenter presence for test check-out and testing, and special installation or other considerations. The test plan is developed through collaboration between the experimenter and the MSTL engineer and is approved by the MSTL engineer. A test plan is required for all test articles or systems.

Construction-like Activities – Small scale construction activities of short duration, such as those related to test and equipment setups. These include, but are not limited to scaffold erection, pouring of concrete pads or foundations, the use of mobile cranes in equipment erection, and excavations more than four feet deep.

Critical Alarm- A critical Alarm will initiate an Emergency Test Shutdown. An Emergency Test Shutdown is defined in section XV.

Non-Critical Alarm- A critical Alarm will initiate a Normal Test Shutdown. The Normal Test Shutdown is a graceful shutdown and is defined in section XV.

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