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Molten Salt Test Loop (MSTL) System Customer Interface Document - Rev. 2

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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 40 bar (600psi), temperature to 585°C, and flow rate of 44-50kg/s(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 articles 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 containing approximately 40,000 kg 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 and a photo of the system in Figure 3. 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 (240kW) where the salt is stored and by the air-salt cooler which removes heat (1.4MW) 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 (400-600gpm). The flow rate is set primarily by the pump and the flow control valves on the outlet of 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 customer's 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 approximately 800 gallons.

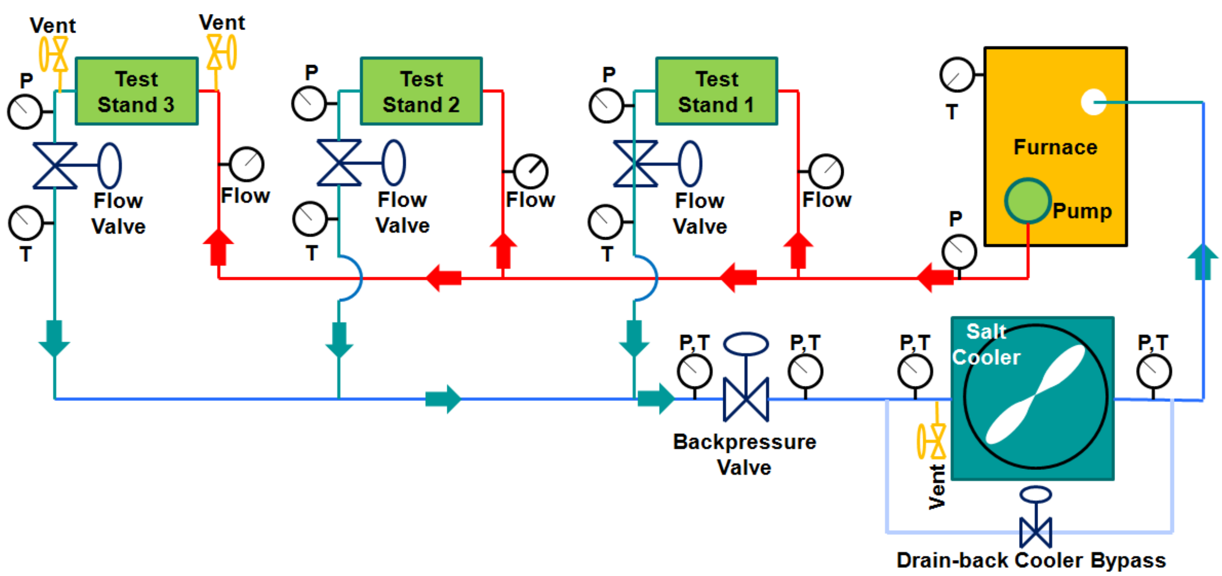

Figure 1. Simplified system schematic shows 3 test stands for parallel testing of solar components.

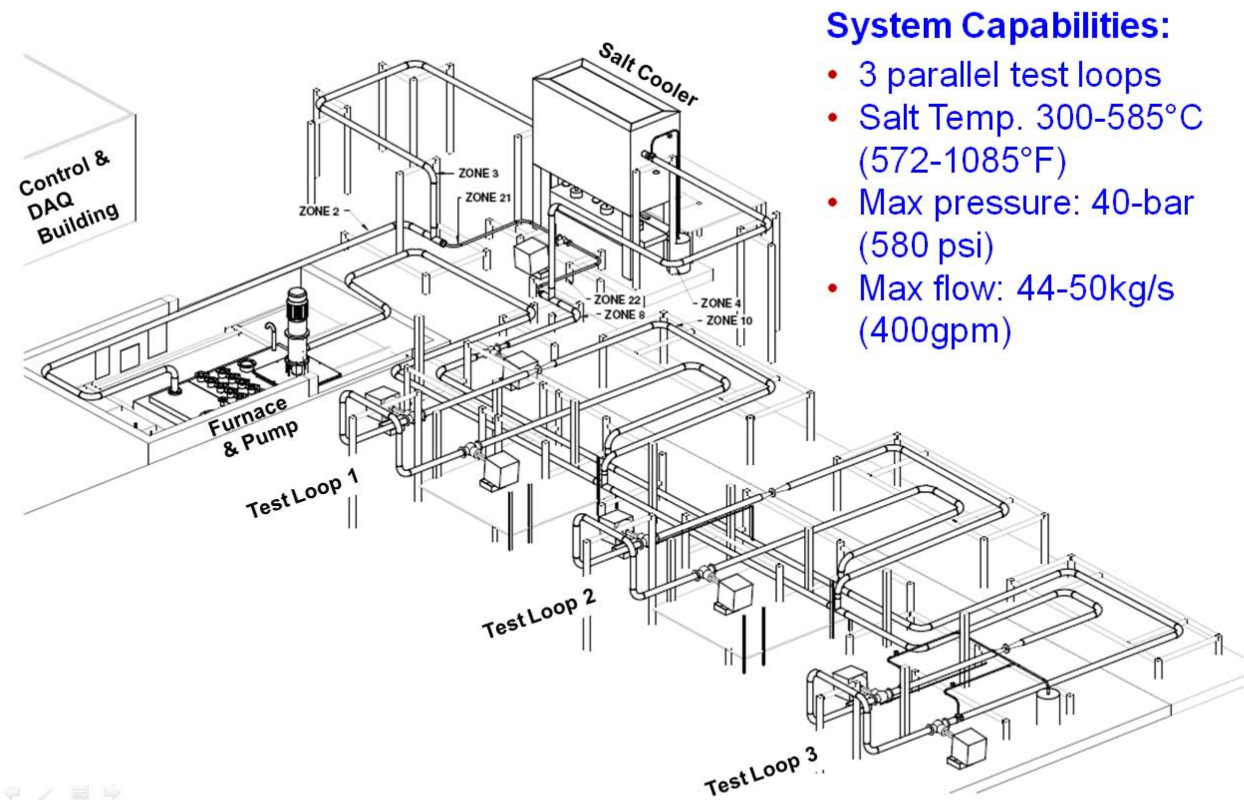

Figure 2. Isometric view showing system hardware and test stands.

Figure 3. The molten salt test loop system (foreground) shown with the central receiver test field to the north.

SAFETY CONTROLS INTERFACE

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 interface will allow the Experimenter to independently develop their controls by interfacing a set of electrically isolated predetermined signals. The signals are described below. The interface schematic is shown in Figure 4 where the boxed items on the right of the Figure are to be supplied by the experimenter. The box at the bottom of the Figure only applies to test loop 3. Each of the individual signals and the requirements for that signal are detailed below. For each signal in the Figure, "X" represents the loop number (1,2,3) in which the experiment is to be installed.

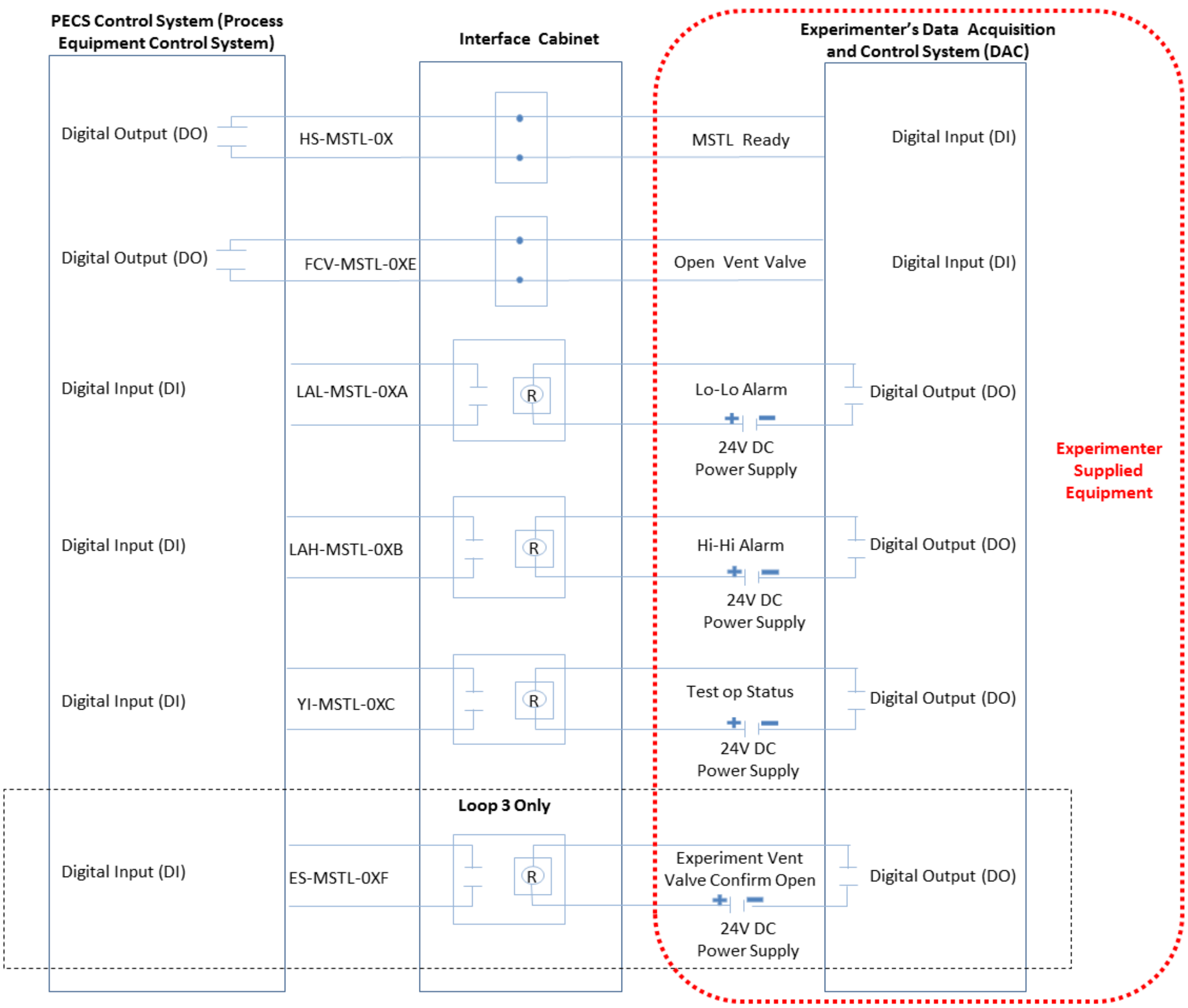

Figure 4. MSTL control interface experimenter's test skid. In the signal labels "X" would be replaced with 1,2,or 3 depending on loop in which the experiment is installed.

MSTL Ready: (HS-MSTL-0X)

The PECS control system will send a *MSTL Ready* (signal held high) to the Experimenter's control system when the PECS system is ready to test. The Experimenter's control system may use this signal as needed. The signal will drive an interposing relay for electrical isolation. This signal can be used as a signal of MSTL health and will go low when MSTL is shutting down. If the experimenter's system needs to perform certain actions to drain back, the MSTL Ready signal is the best indication of a test shutdown occurring.

Test Operation Status from Experimenter: (YI-MSTL-0XC)

This signal, also referred to as experiment go/no-go, will be sent from the Experimenter's control system to the PECS control system indicating that the experimenter's system is ready for MSTL to supply flowing salt. The signal is checked by MSTL and must show high to permit the start of the MSTL system. After this point, MSTL does not monitor this signal. For each test loop, a jumper may be installed in MSTL to signify whether MSTL will require a Go/No-Go signal for that particular loop. If the experiment has no controls and will always be available for salt flow testing, this 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. The signal may be supplied automatically or can be the result of an operator changing the signal to high, but should automatically reset to low if experiment damage could occur from an unexpected start of salt flow.

Alarm Signals

Each of the 3 test stations has connections for 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. However, these signals are very useful for troubleshooting and are the only means of a customer's experiment to request that MSTL be shut down and salt flow stopped.

1. **Non-Critical Alarm (LAL-MSTL-0XA)**

   This signal is a non-critical alarm digital input to the PECS control system and signifies an alarm condition that DOES NOT require a shutdown. A contact closure will indicate normal operations. An open contact signifies that an alarm condition has occurred. This alarm will be logged in the MSTL Alarms and Events log which is very useful for troubleshooting the order of events leading up to an unintended shutdown. If the experimenter does not want to use the signal, it will be electrically shorted at the PECS control system. If the experimenter chooses to use this signal, the experimenter's control system will need to provide 24V DC to energize the relay.

2. **Critical Alarm (LAH-MSTL-0XB)**

   This signal is a critical alarm digital input to the PECS system and is used by the customer to request a shutdown of the MSTL system. The Experimenter's control system will send the PECS system an OPEN contact closure when the experimenter's control system requires a Normal 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 but is generally useful for the protection of both MSTL and the customer's experiment. If the experimenter chooses to use this signal, the experimenter's control system will need to provide 24V DC to energize the relay.

Vent Valve Open Request (FCV-MSTL-0XE)

The MSTL system provides a capability to request that a customer's system open its vent valves to permit drain back to the furnace. If a customer's system has a pipe altitude over 8ft or if the experiment contains a significant amount of salt, it may be determined that vent valves will be needed to permit drain back when the MSTL system stops pumping. These valves will be automatic valves and the timing of actuation will be requested by this signal.

Experiment Vent Valve Confirm Open (ES-MSTL-0XF)

If a vent valve is required to be included in the experiment (due to salt volume or altitude) for the purpose of enabling drain back on pump shutdown, the experimenter will be required to supply the Vent Valve Confirm Open signal. The purpose of this signal is to confirm that the vent valve has successfully opened and the receipt of this signal will permit PECS to begin a timer countdown until MSTL's vent valves are allowed to open. This signal is important to prevent accidental release of salt by opening the MSTL vent valves if there were a significant amount of salt at a higher altitude. It is important to note that this signal shall be an indication of actual valve position and shall not be only a signal of intended position. The experimenter's control system shall provide 24V DC to energize the signal for this relay if it is to be utilized.

Emergency Stop Buttons

The Experimenter's control system must have an emergency stop tied in series with MSTLS's emergency stop buttons. The experimenter shall provide a NEMA 4 push/pull type, two position mushroom switch with two sets of DPDT contact blocks and a push button guard. A schematic of the Emergency Stop button wiring is shown below in Figure 5. The E-Stop button controls two circuits. One circuit is directly connected to the pump VFD and causes immediate shutdown of the pump. The other circuit is a controls circuit that initiates proper shutdown of the PECS system for drainback to the furnace.

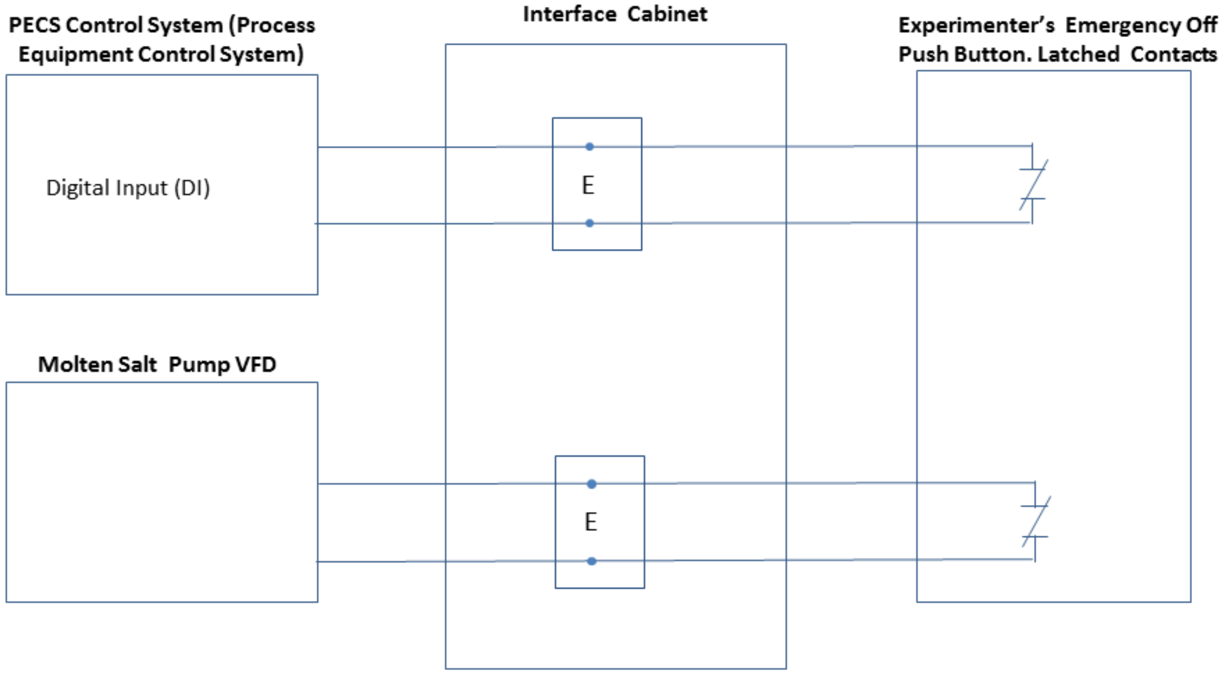

Figure 5. A schematic of the experimenter's interface to the MSTL emergency stop circuit.

Wiring Details

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

Logging Data Signals

MSTL has the ability to record signals from both the full MSTL system as well as from customer systems. To utilize this capability, the customer collects their data to a National Instruments Compact DAQ system that has Ethernet communication capability. Each MSTL test stand has an Ethernet port allowing the customer's data to easily be collected by the MSTL DAQS computer. 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 rolled-up data from the customer's experiment and the DAQS system will be provided to the customer in files containing either specific tests or 24 hour data sets that contain both calibrated and raw data.
Though MSTL is not designed to provide measurement signals to customer control systems in a real-time manner, it may be possible to install signal splitters. The need for this capability will be evaluated on a case-by-case basis.

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.

Electrical Power Interface

There are two different voltage classes available to the experimenter.

1. 120/208, 3 phase, 4 pole, 5 wire system (see Figure 6, Blue Receptacle). 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)
    - A power analysis detailing the load requirements of the test so that the fuses can be correctly sized.
2. 277/480, 3 phase, 4 pole, 5 wire system (see Figure 6 Red Receptacle). 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)

Figure 6. A MSTL Experimenter Connection Test Stand Showing the Electrical Power Receptacles (left) and the Controls Interface Box (right)

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 may 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. 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.

Mechanical Interface

MSTL provides 3 connection points for the parallel testing of 3 customer's experiments as shown in Figure 7. The inverted U-bend shown in the Figure is removed and the customer's experiment is attached at that point. The experimenter shall mechanically connect to the MSTL system through 6” nominal diameter pipe of appropriate schedule to withstand the test rig pressure capability with temperature derating and test lifetime considerations. . The experimenter’s apparatus will typically be welded 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). Flanges that have been used thus far are Grayloc brand 6” hubs with silver coated seal rings. The material of the experiment must typically be 300 series stainless steel, Inconel 625, or Haynes 230. The MSTL piping is currently SS347, so welding to the system is most easily done with 300 series stainless. 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.

Figure 7. The customer connection point for loop 1.

The experimenter shall be responsible for supplying a Pressure Safety Data Package (PSDP) utilizing 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 signifying an acceptable margin of safety. As part of the work agreement, this data package may be designated as part of Sandia's scope of work, but the experimenter shall be required to provide any design calculations and information that will expedite the completion of the PSDP. For the safety analysis of each experiment that is connected to MSTL, 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.

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 shall 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 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.

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

Site Access

Experimenter personnel shall meet Sandia National Laboratories' (SNL) and National Solar Thermal Test Facility (NSTTF) site access requirements. SNL requirements include completing a DOE/SNL badge request and DBIDS application which, once granted, allows 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 including country of citizenship and allow additional time (currently 45 days minimum) for processing of access requests. There may be extra expenses and/or schedule limitations caused by having foreign nationals on site due to escorting requirements.

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 (but at no other Sandia locations). Wireless internet access is available through the Sandia Hotel Network (SHN) though a request to the MSTL engineer must be made in sufficient time to allow the initiation of an account for each person requiring access. This system automatically logs out users after 24 hours, so it typically is not easily usable for remote monitoring of test equipment.

Standard business hours for the NSTTF are from 07:00 a.m. through 16:00 p.m. Monday through Friday. Access outside of these hours, though discouraged, is potentially available at an increased cost due to increased personnel requirements for safety out of normal work hours.

There is a published weekly fee for site access for customers. This fee is used to recover costs of badging, site access, receiving of shipments, workspace for the customer, and access to phone, fax, and copier. The current weekly site access rate can be found on the website for the National Solar Thermal Test Facility.

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. As part of these requirements, there may be requirements for the customer to be present at certain ES&H planning events and certain expenses to the customer may come about due to the need to prepare and review safety documentation. The customer should also make the MSTL engineer aware of any environmental effects (loud noises, emissions, or ground penetrations of any depth) that might require additional paperwork.

All tests must plan for the completion of a Failure Mode and Effects Analysis (FMEA) as a means of confirming that important safety considerations have been effectively evaluated and addressed. The FMEA will be conducted by Sandia personnel and the customer shall plan on providing attending the event to properly address items considered.

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. Customers requiring the additional training should consider budgeting extra time and money for the required training.

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 (flowrate, 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.

LIFTING JIGS AND FIXTURES

Sandia has strict requirements on the use of lifting jigs and fixtures. Typically, any lifting devices that will be used in a test are required to have drawings signed by a structural Professional Engineer, a load test in all configurations of lifting, and will likely be required to pass a safety inspection performed by Sandia’s structural and safety engineers. In addition to these requirements, a plan for how any items are to be lifted and moved will be required. All of these documents and activities must be completed before any lifting is allowed to occur so proper schedule accommodation for these processes should be included in planning.

It should be noted that any lifting requiring a crane must be done through one of Sandia's preferred construction contractors who have completed Sandia Safety plans. Crane lifts should be noted in the early planning stages so that appropriate quotes can be requested for lifting services.

The NSTTF has a Lull extended reach telehandler with 10,000 lb lifting capacity, and expert operators to use the vehicle. Whenever possible, test rigs should be designed in sections that are easily handleable with this vehicle in order to reduce cost.

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. Test article removal, dismantlement, and preparation for shipping must be pre-funded before the work can be completed, and in most cases must be pre-funded before construction begins.

MSTL OPERATIONS GUIDELINES

The MSTL system has a sophisticated and adaptable control system for the inclusion of experiments. There are limitations to what is already available, though modifications may be possible at the Experimenter's expense.

There are important aspects of utilizing the MSTL system that affect every Experimenter so these items are outlined below.

1. Flow - MSTL uses the pump, in conjunction with the Flow Control Valves on each test stand (FCV-1,2,3) to control the flow rate. MSTL must maintain an overall system flow rate of 400gpm to ensure that the air-salt cooler will not freeze up. If an experiment needs lower flow than 400gpm, one of the other test stands will be put into "Bypass" mode and will flow the excess quantity of salt through the bypass test stand. Because the flow meter is on the inlet side of the test stand, there is no means for MSTL to measure the outlet flow from the test stand.
2. Pressure – MSTL uses a combination of the pump and back-pressure control valve (FCV-4) to set the system pressure based on a pressure measurement taken at the pump outlet (PT-MSP-01). MSTL also sometimes uses the test stand loop flow control valves (FCV-1,2,3) in conjunction with FCV-4 if high pressures are utilized. This allows the system to keep all valves operating in their linear control range where changes are most accurate.
    a. Important note: - Test Loop Pressure – Each test stand in MSTL only has the flow control valves on the outlet side; there are no valves on the inlet side. Therefore, MSTL does not have the ability to isolate a test stand from the pressure generated in the MSTL system. If an Experimenter needs a test stand to be isolated, the customer's test rig must include control valves on the test stand inlet and outlet. Experimenters may also be required to install a bypass before these valves that allows flow through the test stand loop even if the test stand has been isolated.

   b. Pressure is measured individually for each test stand at the outlet of the test stand (PT-MSTL-01,02,03), and collectively for the system at the pump outlet (PT-MSP-01) and just before the backpressure control valve (PT-MSTL-04),
3. Temperature – MSTL sets the temperature of the salt provided to the test stands by heating the furnace (tank) in which the salt is stored. This is done with electrical heating. If the salt is returned to the furnace colder than desired, the electrical salt heaters will work to raise the temperature. If the salt is returned hotter than desired (due to solar flux, for instance), the Molten Salt Cooler will remove heat.
   a. Heating Rate – MSTL can heat the salt inventory at a rate of [10°C /hr].
   b. Cooling Rate – MSTL can cool the salt inventory at a rate of [60°C/hr].
   c. MSTL does not have the ability to cycle salt temperature at a faster rate than shown in a and b. If higher cycling rate is required, the Experimenter must include heaters/coolers in the Experiment.
   d. Heat Trace, Piping, and Valves – The heat trace on the piping and valves is set to keep the entire MSTL system at a nominal 300°C setpoint. Some local temperatures may be higher (especially on valves) to keep salt from freezing, but it can be assumed that everything in the system stays at 300°C whether a test is running or not. This setpoint is independent of the desired salt temperature for an experiment.

Startup Sequence – MSTL and Experiment

The following sequence is a general view of the MSTL startup process. It includes some references to communications with the Experimenter's test stand.

<u>System Startup</u>

1. MSTL operator strokes all MSTL valves
2. MSTL put in PreHeat mode, achieves temperatures for test
3. Experimenter confirms readiness of Experimenter test rig (temperature, valve positions, controls readiness, etc.)
4. Experimenter sets Experiment Go/NoGo to high
5. Experiment operator confirms ready to start to MSTL operator
6. MSTL operator sets desired initial flow and pressure in Test Operations Screen
7. MSTL operator starts Test Operations (all steps a-k are automated MSTL start sequence)
   a. MSTL moves Flow Control Valves FCV-1,2,3 to 25%
   b. MSTL moves Backpressure Control Valve FCV-4 to 75%
   c. MSTL confirms Vent Valves FCV-5,6,7, and Cooler Bypass Valve FCV-8 are closed (0%)
   d. MSTL starts pump in speed control mode to 600 rpm (2min ramp)
   e. At 600rpm, MSTL waits 600s to allow all air to be ejected from MSTL
   f. MSTL moves Experimenter's test stand valve (FCV-1,2,3) to desired open % based on CV curve. Other test stand valves are either closed or set to open % if in bypass mode.
   g. MSTL ramps pump speed to 400gpm, and is now in Flow Control mode
   h. MSTL operator may now open MSTL "Silo" doors on air-salt cooler if cooling will be needed.

i. Experimenter's test stand valve (FCV-1,2,or 3) and pump speed are modulated to maintain flow
j. MSTL ramps FCV-4 in Pressure control mode to achieve desired test pressure (pump may change speed to maintain flow)
k. [MSTL sets MSTL-Ready to high]?????
l. MSTL is now ready for operation

8. Experimenter performs necessary tasks to move experiment into operational mode.

Normal Test Shutdown and Emergency Test Shutdown (NTS and ETS)

Note – The only differences between NTS and ETS are 1) during NTS the pump is driven to a stop in a ramped deceleration whereas in NTS, the pump is allowed to freewheel to a stop on its own at whatever rate results from pump momentum, system backpressure, etc., and 2) NTS is program requested and ETS is the result of Emergency Stop buttons being pushed.

a. NTS is requested by MSTL or by customer's LAHH-MSTL-0X (where X is the Experimenter's test loop number) or ETS is initiated by drop of bit in the Emergency Stop circuit.
b. MSTL Ready Signal HS-MSTL-01 opens (goes low) indicating that a shutdown is occurring. This loss of signal can be used by a customer's experiment to initiate experiment shutdown procedures if needed.
c. Pump speed is ramped to 0 rpm or freewheels to 0 rpm (NTS and ETS respectively)
d. MSTL senses no pressure at the pump outlet (PT-MSP-01)
e. MSTL waits 60 seconds
f. MSTL fully opens test loop Flow Control Valves (FCV-1,2,3), Backpressure Control Valve (FCV-4), and Salt Cooler Bypass Valve (FCV-8)
g. If Experiment has vent valves:
    i. MSTL requests Experimenter's vent valves to open using FCV-MSTL-0XE
    ii. Experimenter test rig confirms vent valves open as reported by ES-MSTL-0XF
    iii. MSTL waits a set time (seconds) based on volume of Experimenter's rig
h. MSTL opens Salt Cooler Vent Valve FCV-7
i. MSTL waits 60 seconds
j. MSTL Opens Test Loop 3 Vent Valves (FCV-5,6)
k. MSTL waits 600 seconds
l. MSTL closes the vent valves (FCV-5,6,7), cooler bypass valve (FCV-8)
m. MSTL sets the Flow Control (FCV-1,2,3) and Backpressure Control Valve (FCV-4) to [50%]
n. MSTL control system waits for reset to Idle Mode

MSTL Normal Test Operation

Once start-up is completed, the MSTL system will automatically enter Normal Test Operation mode. During Normal Test Operations, the MSTL system will modulate the test loop flow control valve (FCV-1,2,3), the bypass valve if needed (FCV-1,2,3), the backpressure control valve (FCV-4), and the pump speed in order to maintain the desired flow rate (FT-MSTL-1,2,3) and system pressure (PT-MSP-01). It is also possible to run the system with one of the flow control valves (FCV-1,2,3) in fixed position mode where the valve position is locked and not eligible for modulation, though the bypass flow control valves and pump will be modulated to control system flow and pressure. If needed, the MSTL system will heat the salt using the furnace immersion heaters or cool the salt with the molten salt cooler. During a test, the MSTL operator can change the setpoint values for flow, pressure, or temperature and the system will modulate to achieve the new setpoint values. In some cases, a change in setpoints will be too drastic and drive the system into an unstable region during the transition, often resulting in an alarm and Normal Test Shutdown. To avoid this occurrence, it may be necessary to utilize intermediate setpoints to avoid the unstable region. The utilization of a test plan will help to identify any of these instances so that proper planning will avoid these regions during test.

During normal operation, the operation will continue until:

a.) The MSTL operator requests a Normal Test Shutdown (e.g. at the end of an experiment).
b.) The MSTL control system senses a high-high or low-low alarm condition and initiates a Normal Test Shutdown.
c.) The experiment triggers a critical alarm using LAH-MSTL-0XB and causing a Normal Test Shutdown.
d.) An Emergency Stop Button is pushed and an Emergency Test Shutdown is initiated.

It is important to note that because of system wait times for drain back (on shutdown) or for air purge (on startup), the cycle time from Normal Test Operation to shutdown to start-up and return to Normal Test Operations takes at least 25 minutes. Therefore, it is advantageous to put as many tests in succession as possible without stopping the system to save time.

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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