

Mechanisms Engineering Test Loop – Phase I Status Report – FY2015

Nuclear Engineering Division

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1 EXECUTIVE SUMMARY

This report documents the current status of the Mechanisms Engineering Test Loop (METL) as of the end of FY2015. METL is currently in Phase I of its design and construction.

1.1 Purpose & Background

Once operational, the METL facility will test small to intermediate-scale components and systems in order to develop advanced liquid metal technologies. Testing different components in METL is essential for the future of advanced fast reactors because it will provide invaluable performance data and reduce the risk of failures during plant operation.

METL also enables the development of younger scientists, engineers, and designers who will ultimately lead the U.S. liquid metal technology development effort into future. The hands-on experience with METL, both successes and perceived failures, will ultimately lead to a better liquid metal technology program that can support the commercialization of advanced nuclear reactors.

Some examples of technologies that can be tested in METL include:

1. *Components of an advanced fuel handling system* – Fuel handling systems are used for the insertion and removal of core assemblies located within the reactor vessel. Undoubtedly, these components are essential to the successful operation of fast reactors. For liquid metal applications, fuel handling systems need to work inside the primary vessel and typically penetrate through the cover gas of the primary system. As a result, fuel handling systems must address issues associated with ‘sodium-frost’ buildup.
2. *Mechanisms for self-actuated control and shutdown systems* – These components have been conceived by various designers to provide added defense-in-depth for reducing the consequences of beyond-design-basis accidents. These self-actuated control and shutdown mechanisms include devices such as curie-point magnets and fusible linkages.
3. *Advanced sensors and instrumentation* – Advanced fast reactors contain sensors and instrumentation for monitoring the condition of the plant. Sometimes these components are required to work while immersed in the primary coolant. This category includes sensors for the rapid detection of the presence of hydrogen in sodium (which is indicative of a leak), the detection of impurities in the coolant (i.e., improvement of plugging meters or oxygen sensors), alternative methods of leak detection, improved sensors for level measurement, and other advanced sensors or instrumentation that improve the overall performance of the advanced reactor system.
4. *In-service inspection and repair technologies* – These systems include visualization sensors for immersed coolant applications and technologies for the welding and repair of structures in contact with the primary coolant.

As shown below in Figure 1, the design for the METL facility consists of a number of test vessels connected in parallel to a main loop. The different vessels share an expansion tank, purification system, and several electromagnetic (EM) pumps and flowmeters. This flexible, consolidated design minimizes infrastructure requirements and allows multiple experiments to be

performed simultaneously. In the future, additional vessels (not shown below) will allow for the study of thermal-hydraulic phenomenon, such as thermal striping.

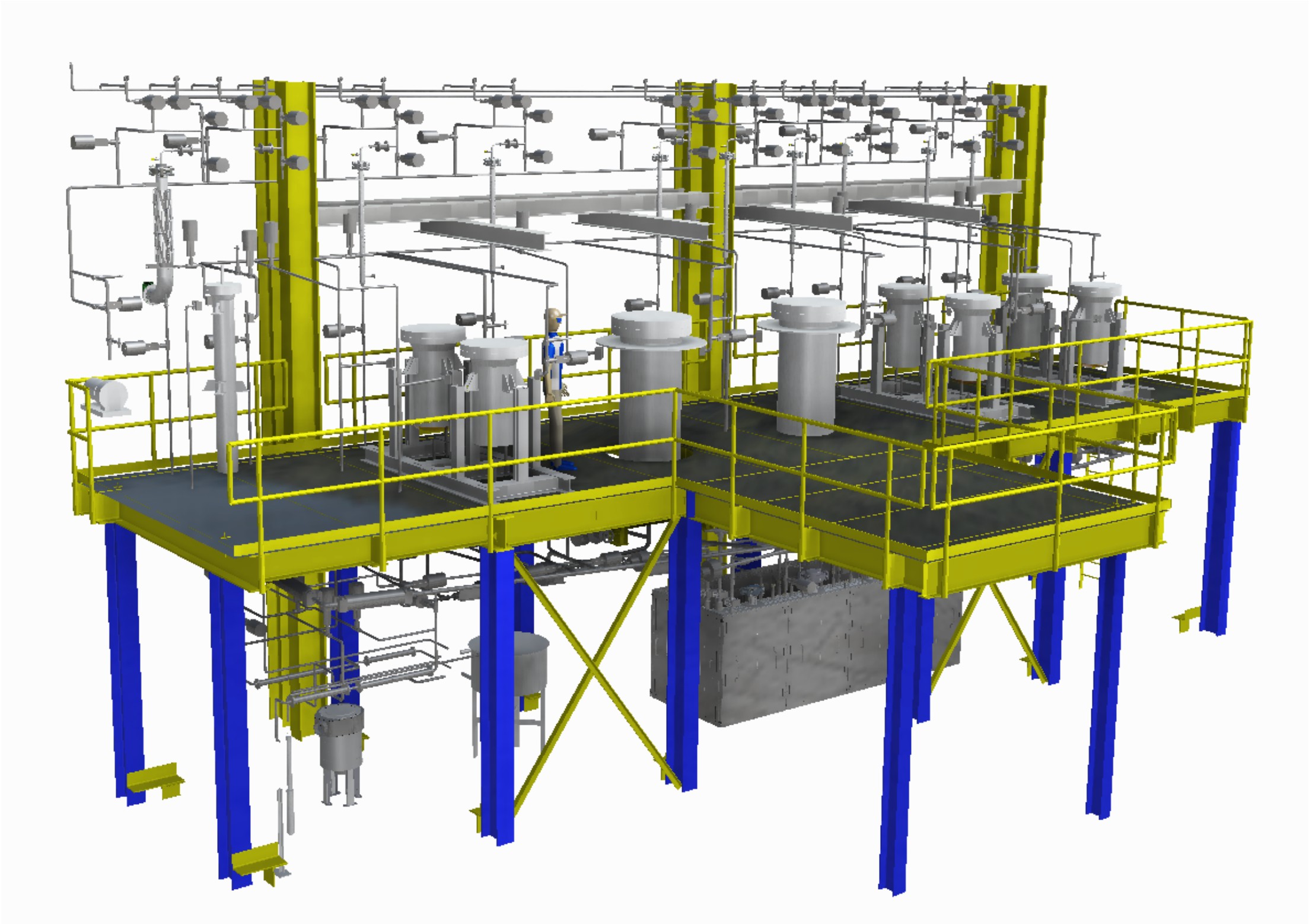


Figure 1 –A 3D model of the Mechanisms Engineering Test Loop showing Phase I and four additional test vessels.

1.2 Phase I Status Overview

Due to the anticipated cost of the entire facility and the expected flow of funding, it was decided to construct the METL facility in phases. 3D models of Phase I can be found below in Figure 2 and Figure 3.

The following list provides the status of the Phase I systems and components as of September 2015:

Mezzanine & Catch Pan – The mezzanine structure and catch pan are complete. The mezzanine will be used to support the vessels and piping system above the dump tank. The catch pan will ensure that potential sodium leaks do not interact with the concrete floor.

Piping System Design – The design and analysis for the METL piping system are complete. ANL received the final deliverable packages from the piping design vendor in May and June 2015. The piping design meets the requirements of ASME B31.3-2012 for Category M fluid service. The piping design placed excessive loads on some of the vessel nozzles. Those vessels have been shipped back to the original manufacturer for nozzle reinforcement.

Piping System Fabrication - ANL Central Shops is coordinating the fabrication, installation, and testing of the METL piping system and supports. Valves, piping, fittings, hangers, supports, and other required hardware have already been delivered to ANL. The installation of the support steel for the vessels, vapor traps, and piping is effectively complete and fabrication of the piping system is currently underway. Central Shops is responsible for machining all piping subassemblies and installing the finished sections into the Bldg. 308 hi-bay. Welding will be performed both onsite by Central Shops and through a local welding and weld inspection company.

Heaters & Thermal Insulation – The contract to insulate the METL piping system and vessels has been awarded to an outside vendor. The piping will be insulated using 1" of Cerablanket beneath 2" of Pyrogel XT-E. The Cerablanket ($T_{\text{Max}} = 2300$ [°F]), which will be installed directly onto the piping and heaters, will insulate the system and thermally protect the Pyrogel ($T_{\text{Max}} = 1200$ [°F]). ANL engineers have also been working closely with mineral insulated cable heater vendors to find and test suitable products that will meet the technical requirements of the piping system.

Thermal Mixing Tees – Both of the thermal mixing tees are complete. Thermal mixing tees will be installed downstream of the cold trap and plugging meter to minimize thermal cycling and fatigue in the piping system where different temperature fluid streams are mixed.

Kammer Valves – Eight 1.5" Kammer/Flowserve valves are currently onsite. An additional four 1.5" valves were ordered in June 2015 from Kammer/Flowserve for the second 28" test vessel.

Swagelok Valves – All Swagelok valves have been delivered to ANL. In total, 151 valves were ordered for the piping and tubing systems (88 manual / 63 electro-pneumatic valves).

Pressure Relief Valves – Ten pressure relief valves (PRVs) have been delivered to ANL. These PRVs have a set-point of 20 [psig] and are capable of operating at 1200 [°F].

Dump Tank – Based upon the piping design, the calculated nozzle loads exceeded the allowable limits for the existing dump tank. Therefore, the 800 [gal] dump tank was returned to the manufacturer to have the nozzles reinforced. The nozzle loads were calculated by the piping designer using CAESAR-II, an industry standard software package for piping analysis.

Expansion Tank – The expansion tank was also shipped to the vessel fabricator in order to have the nozzles reinforced in order to accommodate the piping loads.

Cold Trap – The cold trap nozzles were reinforced by the original manufacturer in order to accommodate the piping loads. The cold trap has been repaired, re-certified, and returned to ANL and will meet the piping system nozzle load requirements.

Economizer – The economizer was completed and delivered. The economizer is designed to be installed between the cold trap and the main loop as a sodium-to-sodium heat exchanger. With a nominal flow rate of ~ 1[gpm] through the cold trap, the economizer is expected to transfer about 25-30 [kW] when the loop is operating at 1000 [°F].

Plugging Meter – The plugging meter is fabricated and onsite. The blower fan and VFD for the plugging meter have also been delivered.

Test Vessels – A bid package for new test vessels was sent to several manufacturers. In May 2015, the contract to fabricate the two 18” vessels and two 28” vessels for the Phase I system was awarded.

Vessel Supports - Central Shops fabricated and installed all of the Phase I vessel supports. The supports for the test vessels and the expansion tank were designed by Argonne engineers to withstand a simultaneous fire and earthquake (850 [°F] / lateral 0.384 [g]).

Inert Gas System – A 1000 [L] Airgas micro-bulk system was installed outside the Bldg. 308 hi-bay. The argon gas supplied by this system will be used to inert the gas space above the sodium and actuate the electro-pneumatic valves.

Vapor Traps & Filters – The filters for METL have been fabricated by Central Shops. Three vessel vapor traps have already been produced by Central Shops and two more are currently being fabricated. The dump tank vapor trap was fabricated by an outside vendor and delivered to ANL. The filters are located downstream of the vapor traps and are the final sodium aerosol filters before the inert gas stream exists the building.

Pumps & Flowmeters – All of the electromagnetic pumps and flowmeters have been fabricated, calibrated, and delivered to ANL. An annular linear induction pump (ALIP) will be used to circulate the sodium through the main loop at approximately 10 [gpm]. Two AC conduction pumps will be used to push sodium through the cold trap and plugging meter

loops. The control panels for the pumps and flowmeters are installed on the METL mezzanine outside the control room.

Data Acquisition & Control System – The control cabinets are being designed to control the heaters and automatic valves within METL. An operator can adjust the output by using either a touch-screen interface or a LabVIEW system that communicates to the control cabinet via Ethernet. It is expected that the control cabinets will be ordered in September.

Carbonation Process – A sodium removal system has been designed and fabricated by ANL. The system will operate by flowing moist carbon dioxide into a spare test vessel that contains test articles removed from METL. The carbonation process will then gently react with the unwanted sodium residue to create sodium bicarbonate without the need for expensive and potentially hazardous steam or alcohol systems.

Sodium – 800 gallons of sodium have been delivered. Currently, the sodium is in the Bldg. 308 hi-bay and is contained within sixteen separate steel 55 gallon drums. A procedure was written and equipment was purchased to transfer the sodium from the individual drums into the dump tank.

Flexi-Cask System – A “Flexi-Cask” system is being fabricated by an outside vendor to allow for the insertion and removal of test assemblies from METL without allowing air to enter the vessels. This system is designed to use the crane in the Bldg. 308 hi-bay and will provide an inerted environment that operators can use to handle experiments.

1.3 Acknowledgement

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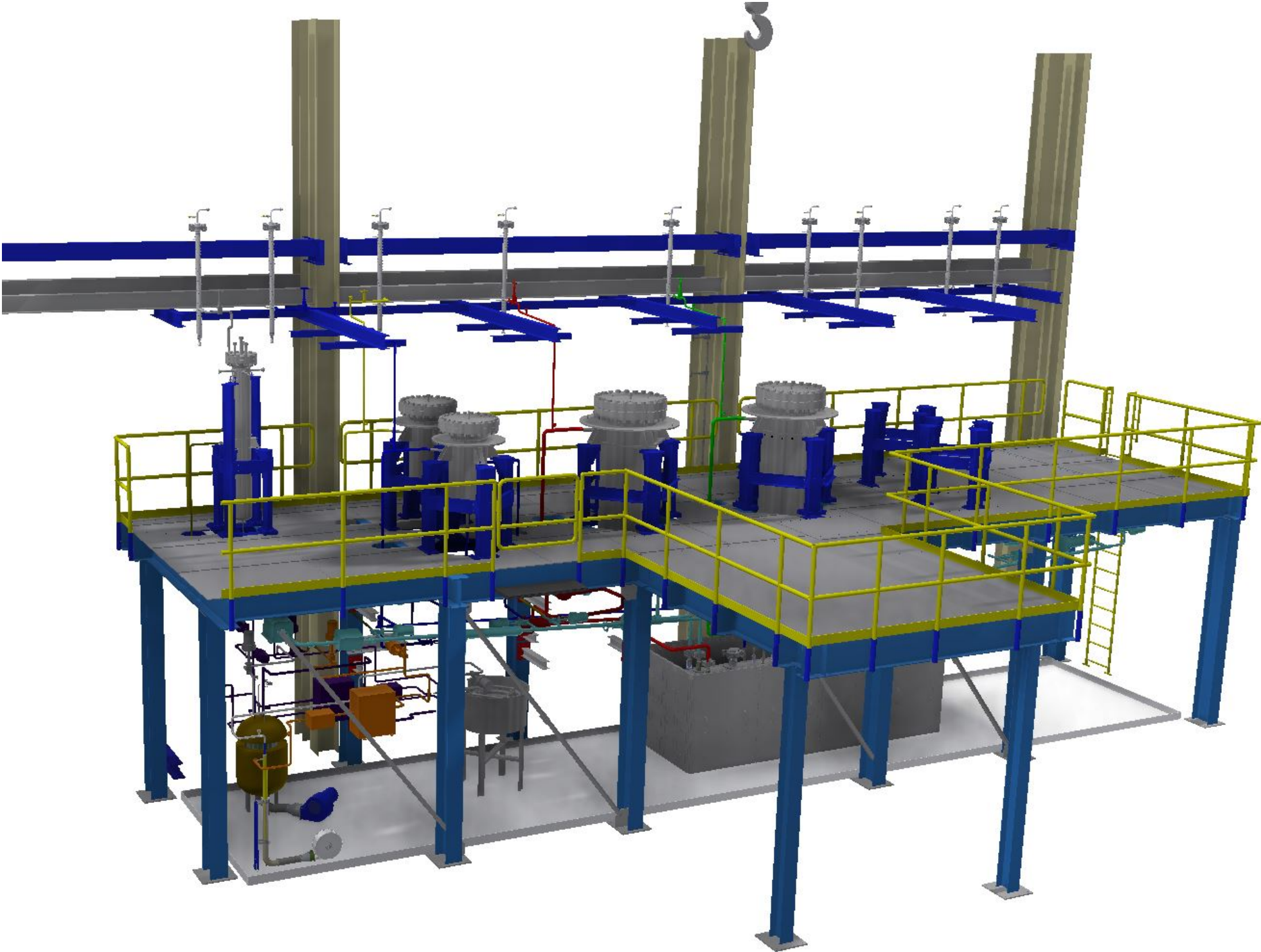


Figure 2 – A 3D model of METL after Phase I is complete.

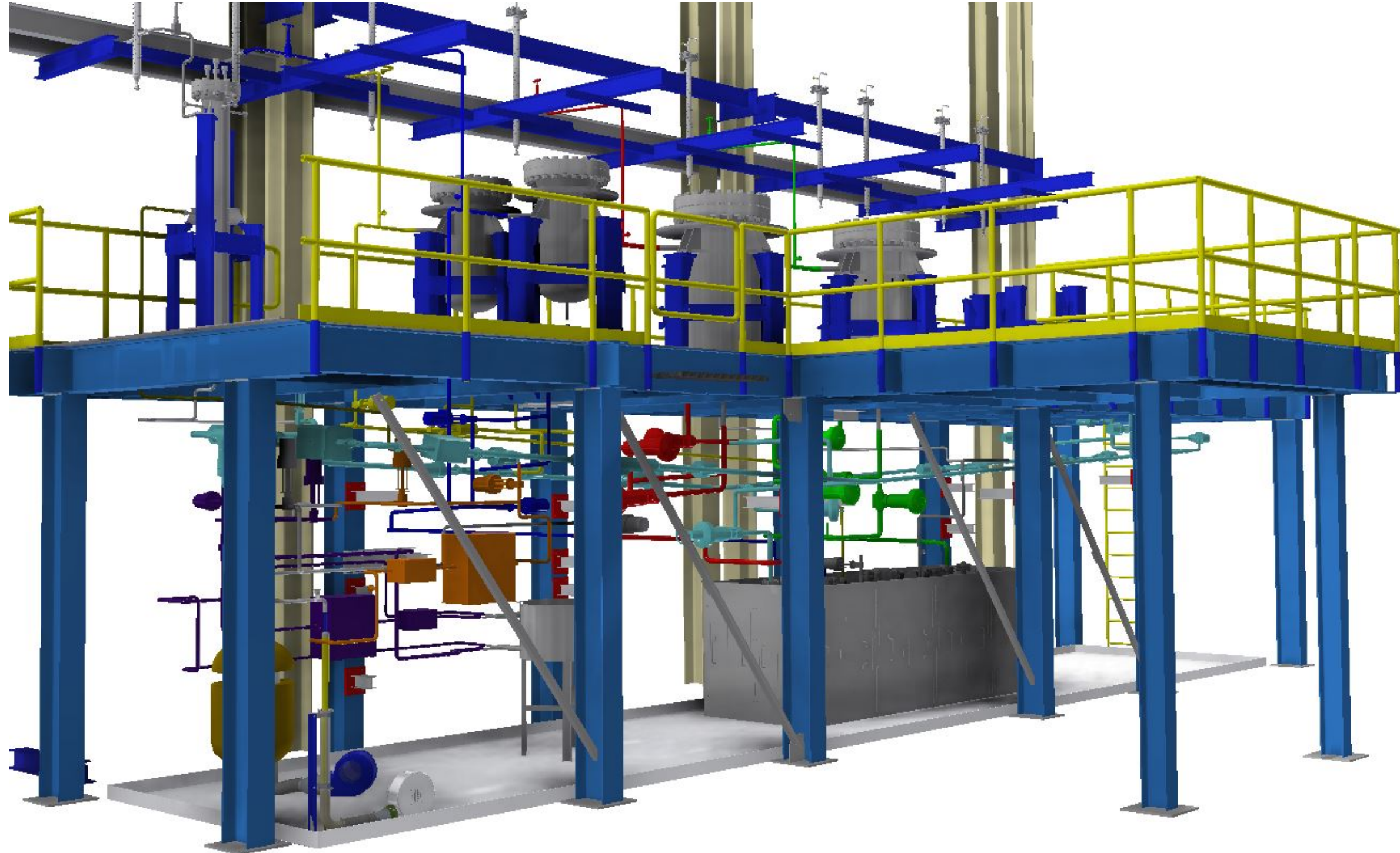


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2 Background & Objectives

The successful operation of sodium-cooled fast reactors will largely depend on how well all of the components work within a sodium environment. Therefore, the goal of the Mechanisms Engineering Test Loop (METL) is to provide the infrastructure and technical expertise required to test advanced technologies in a high-temperature sodium system. In turn, the results gleaned from experiments performed in METL will help to develop better advanced reactors.

2.1 Design Overview

The layout of METL follows the characteristic design of a sodium test facility. The facility consists of multiple test loops in which tanks/vessels, valves, and other components are interconnected via piping and tubing. The system is designed to handle both static and flowing sodium which permits each test vessel to be configured to suit the particular needs of an experiment. During operation, the sodium will be purified by passing it through the cold trap. Impurity levels can be continuously monitored using the plugging meter. The general design temperature of the facility is 1000 [°F] but the maximum design temperature of the 28” test vessels is 1,200 [°F].

2.2 Experiments & Future Work

The experiments to be carried out by the METL facility will cover nearly all aspects of testing for small or intermediate-scale sodium components. METL experiments can be characterized as: “proof-of-principle tests”, “proof-of-performance tests”, or “endurance tests” (1). Examples of such tests include:

- Gripper mechanisms to insert/remove simulated core assemblies
- Universal joints /cardan shaft testing
- Sodium radial bearing testing
- Sodium thrust bearing testing
- Electro-mechanical motors for in-sodium service
- Sodium hydrostatic/hydrodynamic bearing testing
- Advanced (integrated) cold trap system testing
- Small sodium valve testing
- Advanced instrumentation and measurement and test equipment
- Metal-on-metal friction testing for wear and self-welding behavior
- Sodium thermal stripping experimentation
- Bellows and seal systems
- Mechanisms for self-actuated shutdown systems (SASS)
- Other small and intermediate-scale components

3 System Description & Status

3.1 METL Phase I Design

Fabrication of the Phase I METL facility is focused on the main sodium loop, dump tank, two large (28") test vessels, two intermediate (18") test vessels, the purification system, the heating and control system, the expansion tank, and the mezzanine. Future phases will incorporate other components, test facilities, or install additional test vessels.

All piping, test vessels, and tanks will be equipped with heaters and insulation that can maintain sodium temperatures ranging from room temperature to a minimum of 1000 [°F]. The large 28" vessels are designed to contain static sodium up to 1200 [°F]. The temperature for each individual vessel, tank, or component can be adjusted by PID-controlled heaters to suit the particular needs of a test.

The density of sodium changes from ~920 [kg/m³] to ~825 [kg/m³] when heated from 208 [°F] to 1000 [°F]. This change in volume can be compensated for by using either the expansion tank or the cover gas space within each test vessel.

As shown in Figure 4, each test vessel will have dedicated lines for sodium supply, return, overflow, and drain. Additionally, all test vessels will be connected to an argon supply line and a vent line that is connected to a vapor trap. With only one vessel on-line, the maximum flowrate through a vessel will be 10 [gpm]. The sodium overflow line will be used to control the sodium levels in the test vessels. A sodium dump can be carried out independently for each test vessel by opening the associated dump valve in case of an emergency.

The large catch pan (~1000 [gal]) located under the mezzanine is designed to collect METL sodium spillage in the event of a sodium leak. The catch pan will maintain a barrier between the spilled sodium and the underlying concrete.

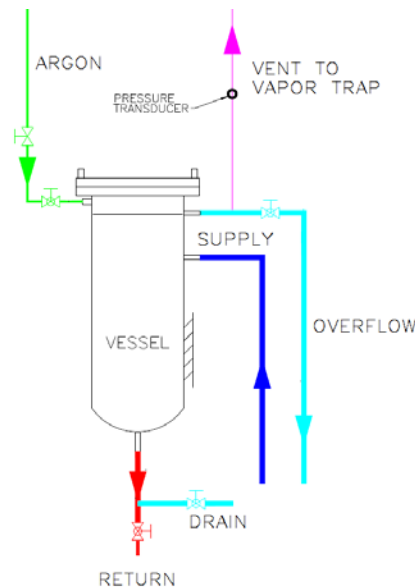


Figure 4 - A depiction of the various test vessel connections and their orientation.

3.2 Status of Phase-I Subsystems & Components

3.2.1 Mezzanine & Catch Pan

The test vessels will be installed on top of a mezzanine structure so they can be located above the main piping system, dump tank, and catch pan. METL was designed this way so that the elevation difference between the test vessels and dump tank would assist with draining in the event of an emergency, such as a leak.

The mezzanine structure was designed by ANL engineers before it was sent to an architecture/structural engineering firm for final analysis. The structure is meant to support six separate 12,500 [lbs] vessels that are evenly-spaced and centered on the mezzanine. The design loads were conservatively estimated to allow for future expansion of the facility by adding additional tanks or experiment. Figure 5 shows an overhead photo of the completed mezzanine before the vessel supports or deck plate penetrations were added.



Figure 5 – A photo taken from above the mezzanine (top = east, bottom = west). This photo was taken before vessel supports or deck plate penetrations were added.

The completed catch pan is installed beneath the mezzanine structure, as shown in Figure 6. The catch pan is made from 3/8" thick ASTM 516 Grade 70 plate and was designed to hold the entire sodium inventory of METL in the event of a leak. The catch pan features all-welded construction to ensure that sodium does not interact with the concrete floor. The catch pan is not directly anchored to the ground, but is instead held flat and in position using a series of large tabs mounted to the mezzanine columns, as shown in Figure 7. These tabs will allow the catch pan to thermally expand and accommodate a sudden high-temperature sodium leak.



Figure 6 – A photo of the catch pan under the METL mezzanine. The catch pan can hold ~1000 [gal] of sodium and is made from 3/8" plate. (Areas where paint has been removed were subjected to weld analysis.)



Figure 7 – Photos of the tabs used to position and flatten the catch pan. Left - a tab connected to the mezzanine structure. Right - a tab anchored to the floor that is used to hold flat the catch pan.

3.2.2 *Piping System*

3.2.2.1 *Piping Design*

An outside vendor was contracted to design the METL piping system in February 2014. ANL received the final package of deliverables from the vendor in May and June 2015. According to their scope of work, the piping design vendor was responsible for:

- a) Designing the entire METL piping system (not just Phase I) to meet ANL technical requirements and ASME B31.3-2012 for Category M fluid service.
- b) Developing the piping and valve support systems.
- c) Creating all drawings required for a fabricator to build the piping system.

The current piping configuration is reflected in Figures 1 & 2. The latest piping and instrumentation diagram (P&ID) for METL can be seen in Figure 8. 3D models of the Phase I piping system below the mezzanine can be seen in Figure 9 and Figure 10. The piping design documentation was accepted in September 2015.

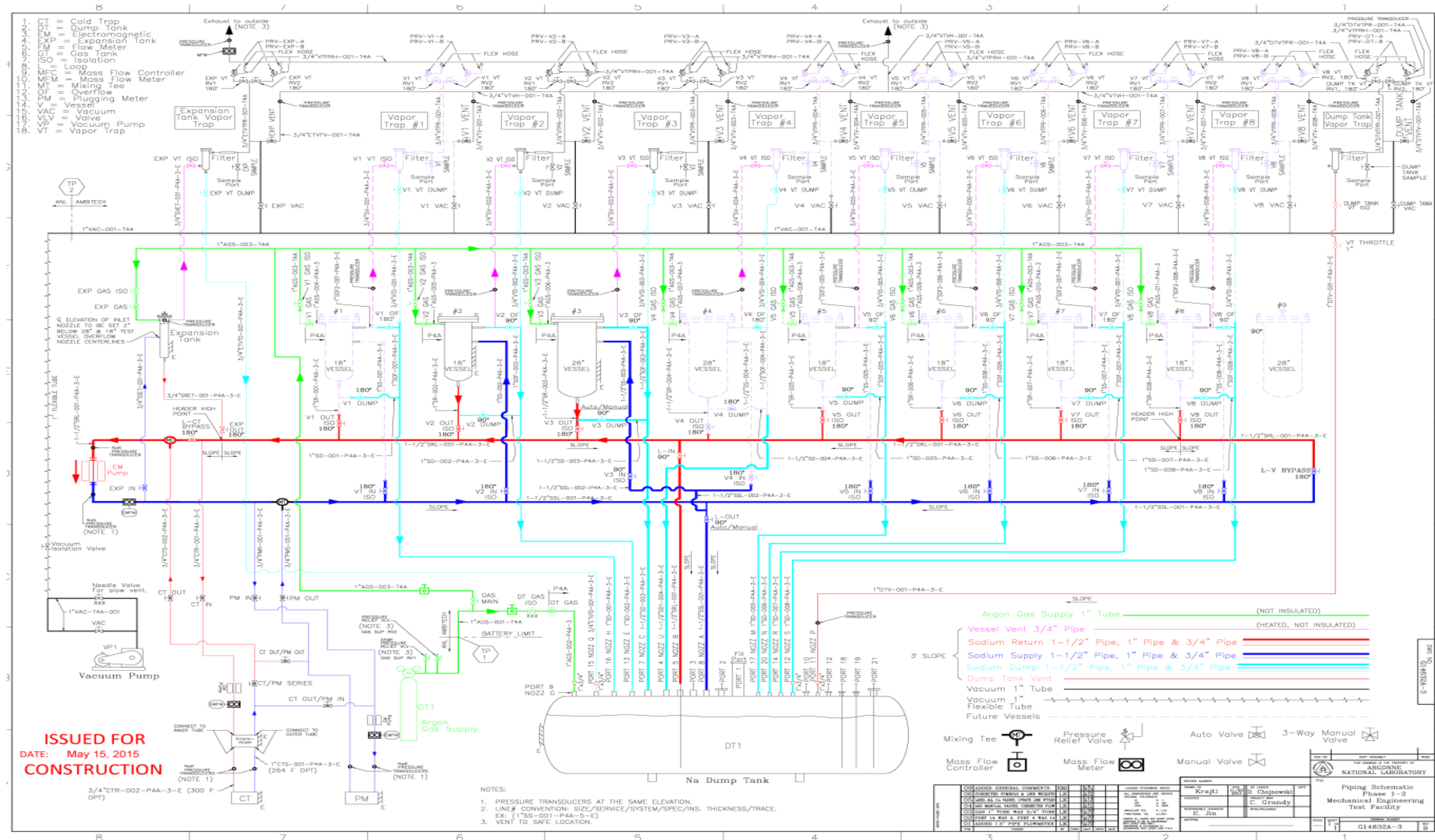
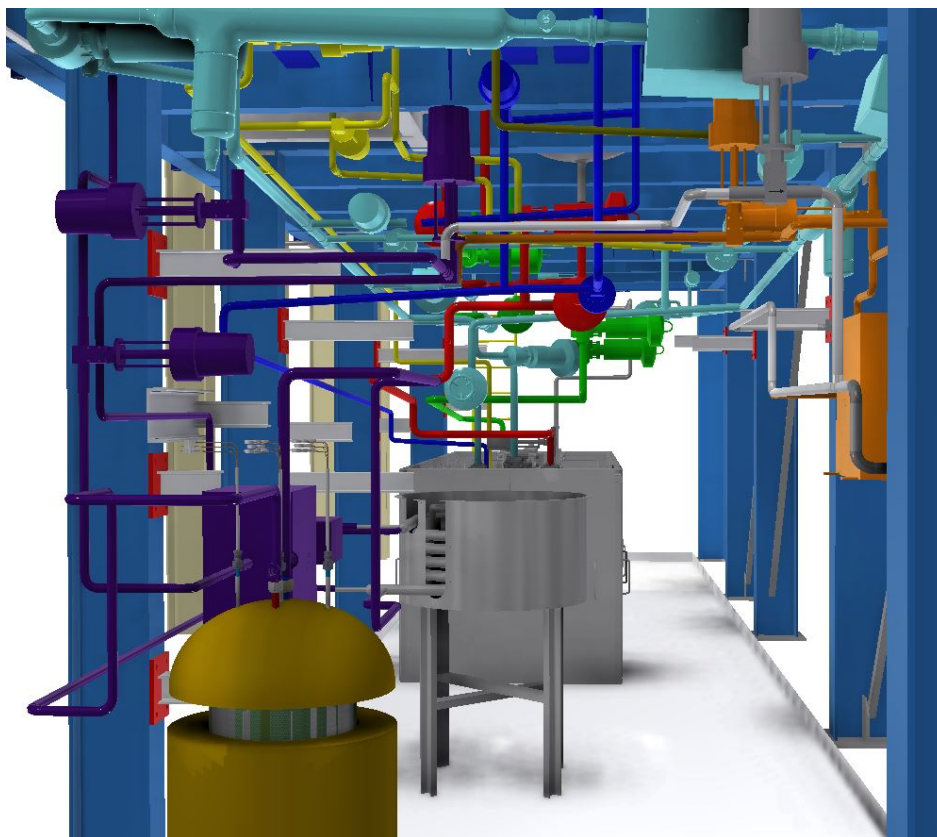


Figure 8 - The METL P&ID that was issued for construction by Ambitech.



*Figure 9 - A 3D model of the uninsulated Phase I piping system beneath the mezzanine.
(View faces east.)*



*Figure 10 - A 3D model of the uninsulated Phase I piping system beneath the mezzanine.
(View faces west).*

3.2.2.2 Piping & Hardware

All of the piping, pipe fittings, and hangers/supports required for Phase I have been delivered to ANL.

The seamless 316/316L piping, shown in Figure 11, was delivered in 10 [ft] lengths. All piping was produced in the US and meets the requirements of ASTM A312. Extra piping and fittings were purchased to have spare material on-hand during fabrication and to allow for weld qualification on the actual materials that will be installed.

Table 1 – Delivered piping for Phase I METL

Pipe Size (Sch. 40)	Qty. [ft]
0.75"	520
1"	520
1.5"	270
Total	1310

Over six hundred (634 total) pipe fittings were ordered. All seamless 316/316L fittings were produced in the US and meet the requirements of ASME B16.9 and ASTM A403 WP-S. As shown in Figure 12, the piping and fittings are being machined with a custom ‘J’-groove in preparation for the automatic welding procedure. Prior to welding, all piping and fittings will be cleaned using custom tanks filled with Citranox, as shown in Figure 13.

As shown in Figure 14, all 78 of the custom-engineered ‘spring can’ supports for the final phase of METL were delivered. Figure 15 shows drawings of the different types of hangers and supports that will be used. All spring can hardware will connect to the piping using lugs or shoes, which are depicted in Figure 16 and Figure 17, respectively.



Figure 11 - A photo of the seamless 316/316L piping delivered to ANL Central Shops. Piping was ordered in 10 [ft] lengths. All piping is 1.5", 1", or 0.75" Sch. 40.



Figure 12 - A photo of the pipe fittings that are being prepped for weld.
(Left = as received, Right = with 'J' prep.)



Figure 13 - A photo of METL piping components being washed in a Citranox bath.

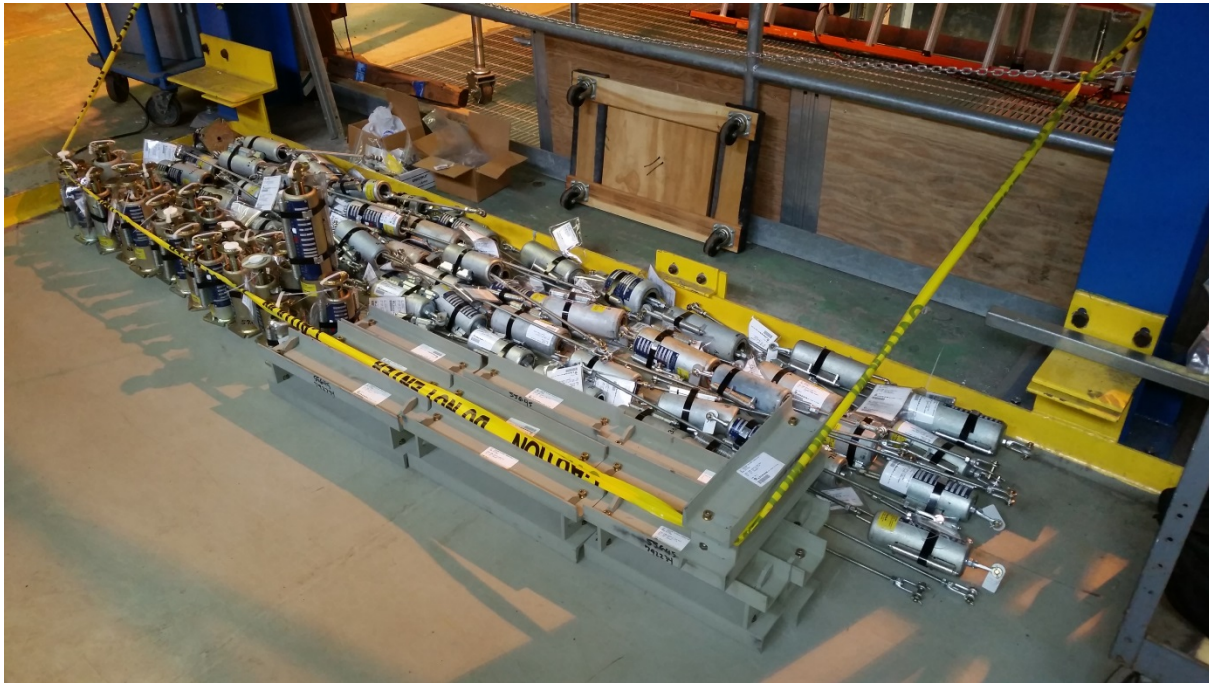


Figure 14 - A photo of the METL piping hangers and supports.

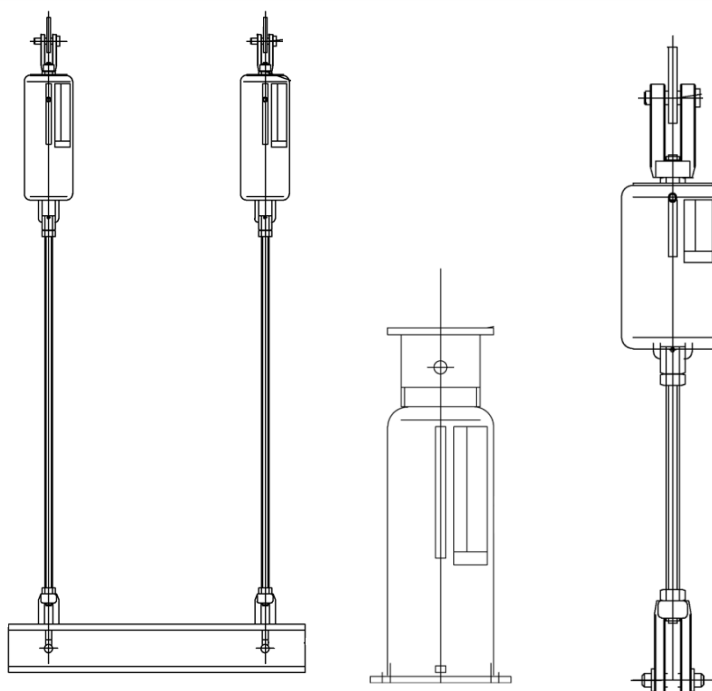


Figure 15 - Drawings of the piping support. The spring can hangers will be welded to the support steel underneath the mezzanine.

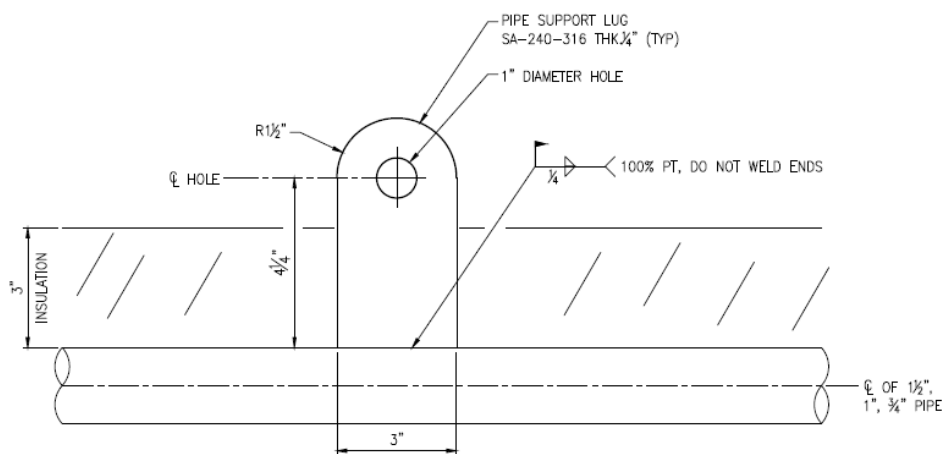


Figure 16 - A depiction of the pipe lugs that will connect to the pipe hangers.

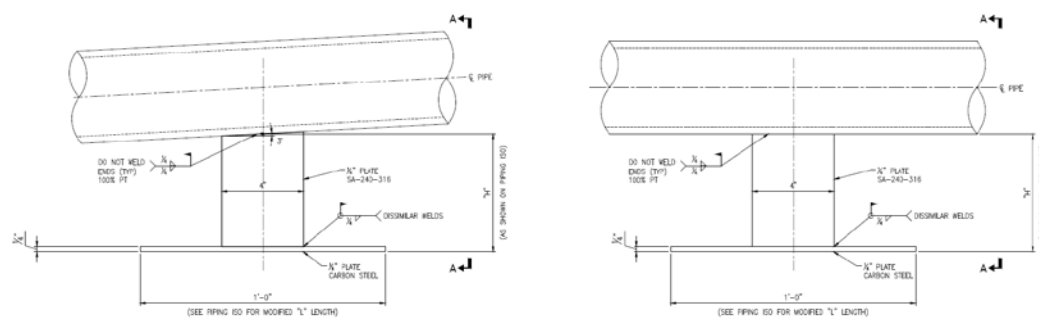


Figure 17 - A depiction of the pipe shoes that will support the piping from underneath.

3.2.2.3 Pipe Fabrication & Installation

Central Shops has effectively completed the installation of the pipe hanger support steel located below the mezzanine, as shown in Figure 18. Additionally, Shops has completed the fabrication of the horizontal support steel and pedestal supports for the piping system and/or equipment, shown in Figure 19.

Pipe and pipe fittings are being machined by Central Shops according to the piping design and ANL piping isometrics as depicted in Figure 20. Pipe subassemblies will be welded by both Central Shops and a local vendor. Currently, it is expected that 100% of the welds exposed to liquid sodium will undergo non-destructive, radiographic examination, which exceeds ASME B31.3-2102 requirements for Category M fluids. Examination of the welds will be performed onsite and at off-site quality control facilities. The results of the qualified welding procedures are shown in Figure 21.



Figure 18 - A photo of the pipe hanger support steel located beneath the mezzanine. All supports are A36 L4"x4"x3/8" angles connected to the mezzanine using welded tabs and 1/2"-13 fasteners.
(Note: all welds will be repainted before piping assemblies are installed.)

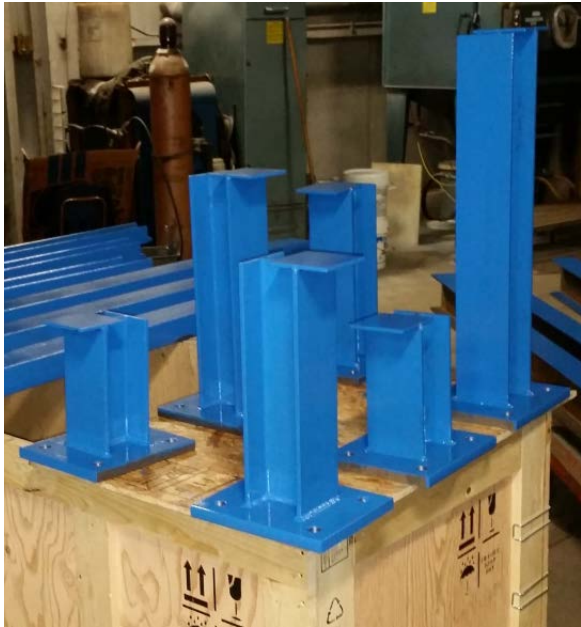


Figure 19 - A photo of the horizontal piping supports prior to installation. These supports will be bolted to the vertical columns beneath the mezzanine.

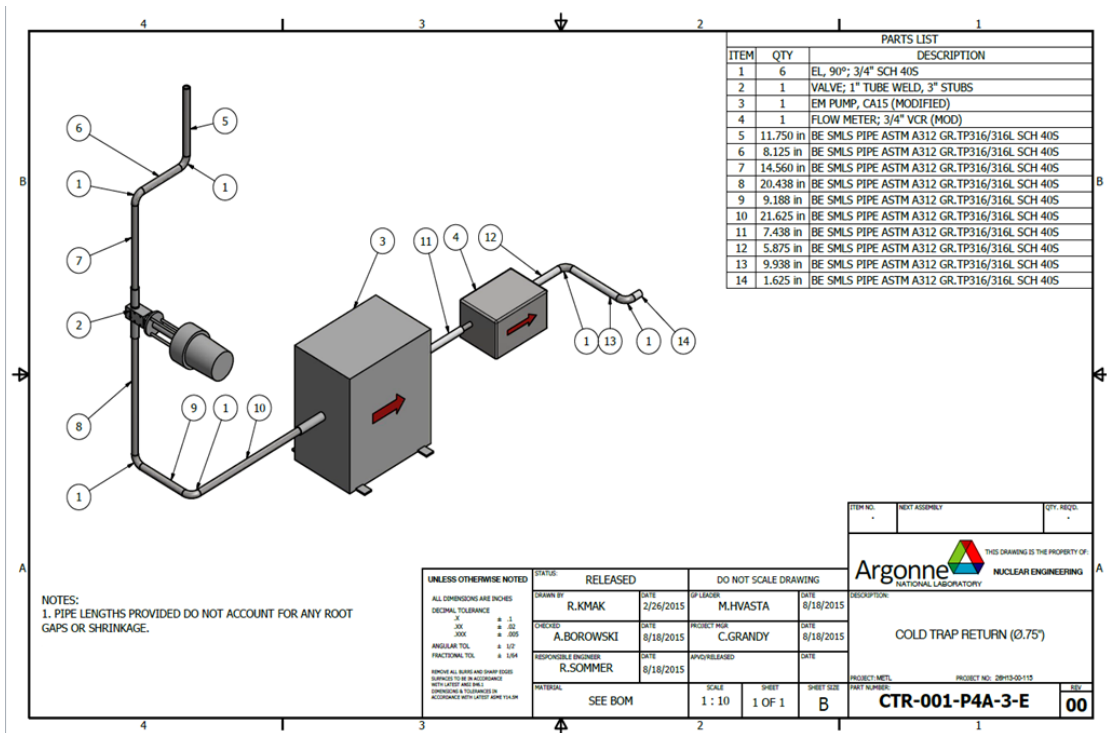


Figure 20 - A sample piping ISO produced by ANL. This updated ISO gives Central Shops the required dimensions of the piping and equipment prior to installation.



Figure 21 - A photo of sample welds on 0.75" and 1" piping. The initial automatic weld and the subsequent manual TIG weld can be seen for both pipe sizes.

3.2.2.4 Heaters & Heater Zones

The METL piping system will be heated using mineral insulated (MI) cable heaters. These long, flexible heaters can be formed and banded onto the piping system to create “heater zones” of different lengths and geometries.

During FY2014, ANL engineers talked to mineral insulated (MI) cable heater manufacturers to discuss the METL trace heating design. Conversations with different vendors indicated that a linear power density of 60 [W/ft] was appropriate for MI cable heaters banded to the outside of 1000 [°F] piping.

As shown in Figure 22, a series of tests were conducted with 1/8” and 1/4” diameter MI cable heaters to determine their suitability for METL. During these tests, the MI cable heaters were attached to a 6 [ft] length of empty 1.5” Schedule 40 pipe and then wrapped in ceramic-blanket insulation. The major results from these tests were:

- a) Both 1/8” and 1/4” diameter MI cables were able to heat the entire surface of the pipe to at least 1000[°F] within several hours using 60 [W/ft]. (The maximum expected heat/cool rate for METL is ~300 [°F] per hour, as recommended by the manufacturer of Grayloc fittings.)
- b) MI cable heaters should have an outer diameter of 0.25” or greater to provide adequate electrical insulation (Table 2).
- c) The maximum temperature difference around the pipe was measured to be ~75 [°C], as shown in Figure 23.

In FY2015, the piping design was completed by the piping design vendor and ANL engineers were able to plan the MI cable heater zone layout using the finalized 3D models. By using the following guidelines¹ to size the heater zones on the sodium-filled pipe, it was determined that Phase I piping will require 132 heater zones.

- a) Heater zones cannot be longer than 10 [ft].
- b) Changes in elevation must be limited to 3 [ft].
- c) A pipe heater zone starts/ends whenever there is a valve or Grayloc fitting.

The Specification for the MI cable heaters was also updated to more closely reflect the corresponding former RDT standards. ANL engineers are currently working with three vendors to procure sample heaters for another round of testing.

¹ The heater zone lengths were discussed and agreed to with the former Manager of the Energy Technology Engineering Center.

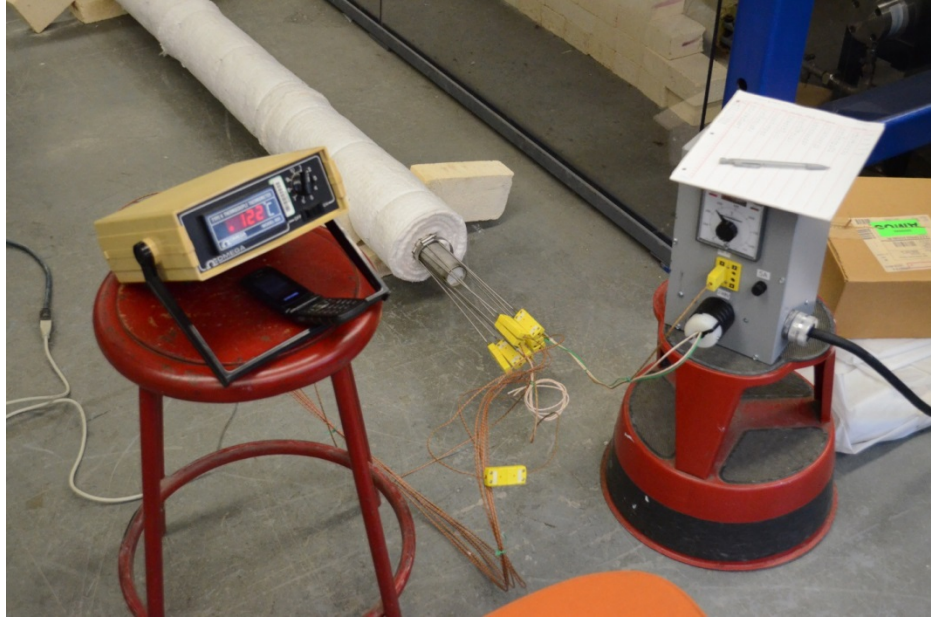


Figure 22 - A photo of the insulated MI cable heater test setup. Thermally insulating fire-bricks were used to keep the piping off the ground. This picture shows the pipe wrapped in ~ 2.5" of ceramic insulation

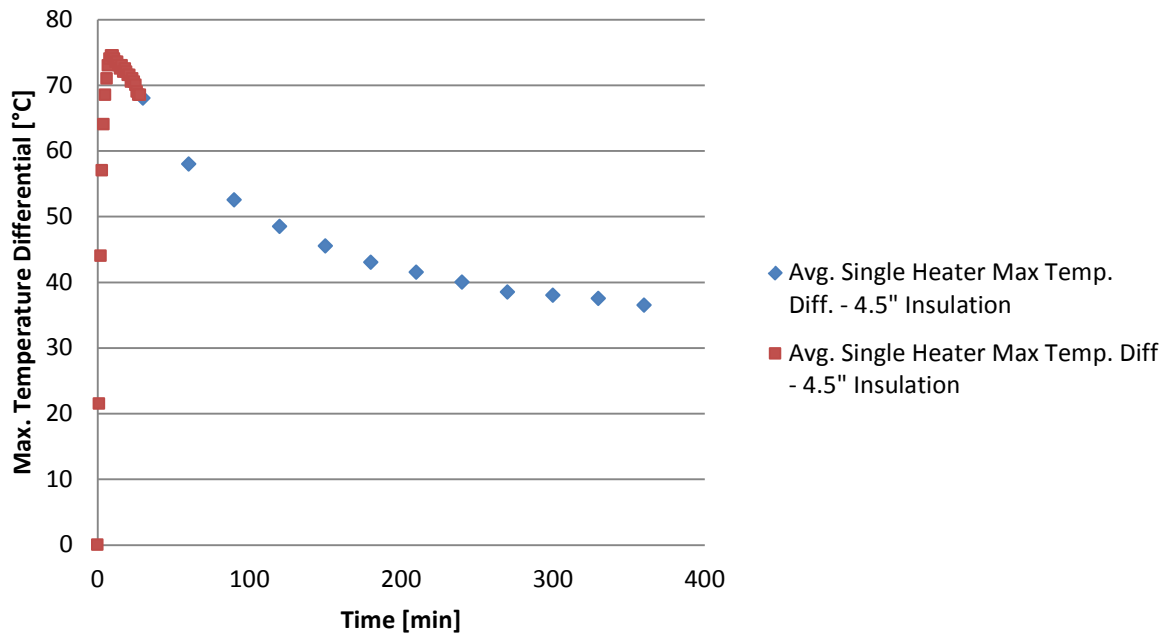


Figure 23 – The maximum measured temperature difference the heated 1.5" Schedule 40 pipe using a single heater. This temperature differential was achieved by leaving a single heater in the 'on' position.

Table 2 – The results of the heater electrical insulation tests.

	1/8" Diameter	1/4" Diameter
Before Testing	> 0.1 [GΩ] @ 500 [VDC]	> 10 [GΩ] @ 1000 [VDC]
After Testing	21.5 – 24.4 [MΩ] @ 500 [VDC]	1.60 – 1.71 [GΩ] @ 1000 [VDC]

3.2.2.5 Piping Insulation

ANL engineers have decided to insulate the METL piping system using 1" of Cerablanket beneath 2" of Pyrogel XT-E. (The inner layer of Cerablanket will protect the Pyrogel XT-E from the high-temperature MI cable heaters.) As shown in Figure 24 and Figure 25, using advanced insulating materials such as Pyrogel XT-E instead of traditional insulation like mineral wool or CalSil (calcium silicate) will allow the METL piping system to achieve identical levels of thermal performance at a fraction of the overall size (diameter) and weight.

The contract to insulate the METL piping system was awarded to an outside vendor in May 2015. The vendor has done insulation work at ANL before and is familiar with Lab safety policies. Given the high demand for Pyrogel XT-E and the expected lead time for the insulation (about six months), the vendor was given permission to start purchasing and delivering all required materials to ANL.

The sodium-compatibility of Pyrogel XT-E was investigated during FY2014 when a series of burn tests were performed to evaluate potential hazardous interactions with high-temperature sodium. As shown in Figure 26, bricks of sodium were placed on top of the Pyrogel XT-E within the Bldg. 308 burn stall. For each test, 1 [lb] of sodium was ignited using an oxy-acetylene torch. Each fire was permitted to burn to completion (10-15 [min]) and the burns were recorded on video tape. These tests indicated that Pyrogel XT-E behaved comparably to Cerablanket, which has been used successfully on other sodium systems.

In addition to the sodium burn tests, the Pyrogel XT-E was also studied by the Analytical Chemistry Laboratory (ACL) at ANL. This investigation determined the high-temperature stability of the Pyrogel XT-E as well as its chemical and physical composition.

Table 3 shows that the Pyrogel XT-E lost about 7-8% of its mass in going from room temperature to 800 [°C] / 1472 [°F]. (Manufacturer data states that the insulation is only rated to 650 [°C].)

Table 3 – Weight loss data for Pyrogel XT-E at several temperatures as measured by Argonne ACL (2).
(Samples were held at temperature for at least 4 [hrs].)

	Fraction of Initial Mass After Heating to Temperature, wt%			
Sample	200°C / 392°F	400°C / 752°F	600°C / 1112°F	800°C / 1472°F
Pyrogel XTE #1	97.8	95.6	93.2	92.7
Pyrogel XTE #2	98.0	95.5	92.9	92.4
Average:	97.9	95.5	93.0	92.5

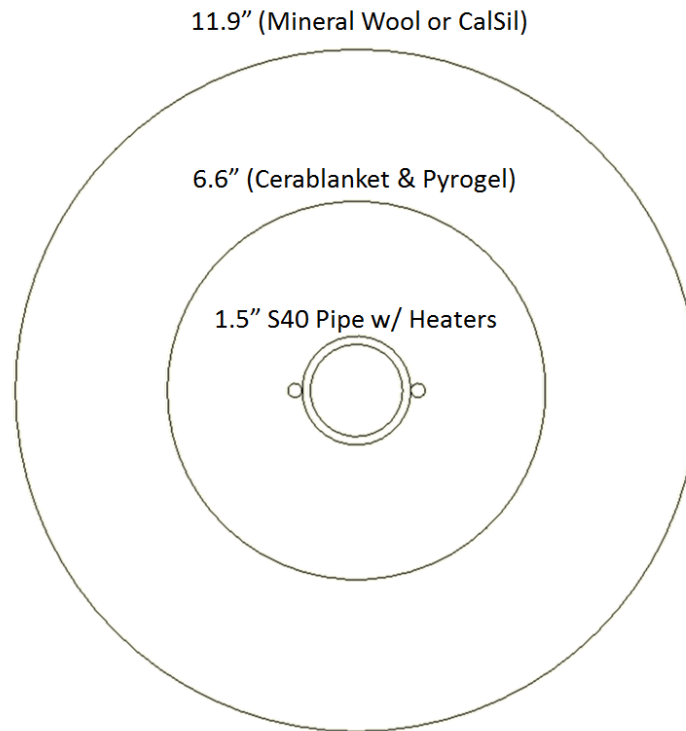


Figure 24 – A comparison of the required insulation thicknesses using different types of insulation. Thicknesses were calculated assuming an operating temperature of 1000 [°F] and a heater power input of 60 [W/ft]. Pyrogel XT-E has a maximum operating temperature of 1200 [°F] so a 1" layer of Cerablanket must be placed between the Pyrogel XT-E and the MI cable heaters.

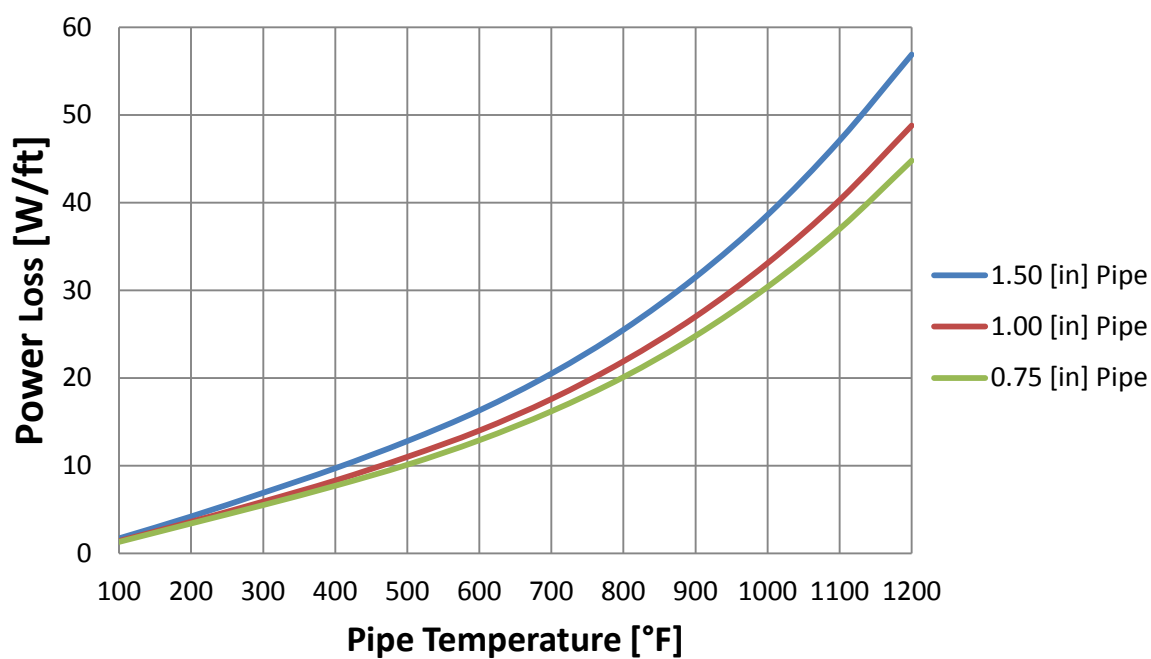


Figure 25 – The predicted METL piping thermal losses using 1" Cerablanket + 2" Pyrogel. The ambient temperature was assumed to be 32 [°F].



Figure 26 – Left: A photo of 1 [lb] of sodium resting on top of Pyrogel XT-E insulation. The insulation was inserted into a steel burn pan and the fires were carried out in the Bldg. 308 burn stall. Right: A still-frame from the video footage of the sodium burns. The flames above the Pyrogel XT-E reached a maximum height of 12-18", which was comparable to the Cerablanket tests.

3.2.3 Valves

3.2.3.1 Kammer / Flowserve Valves

The main loop of the METL facility will use 1.5" Sch. 40 piping. Valves connected to the main loop must be made from sodium-compatible materials, have a weld-bellows seal to ensure leak-tightness, and be capable of operating at 1200 [°F]. Given these size and technical requirements, ANL engineers decided to use valves made by Kammer / Flowserve that have the following features:

- Integral Seat
- Seal welded design for reliability
- Thermowell connection
- Angle body bellows cycle life ~ 25,000 full cycles
- Maximum operating conditions: 365 [psig] @ 1000 [°F] / 185 [psig] @ 1200 [°F]
- Electro-pneumatic operation (24 [VDC] control voltage, ~50 [psig] supply pressure)
- Submerged welded bellows design

Figure 27 and Figure 28 show the valves in as-delivered condition. Currently, eight Kammer / Flowserve valves have been delivered to ANL. The order for the remaining four valves has been placed and delivery is expected between Nov. 2015 and Feb. 2016.

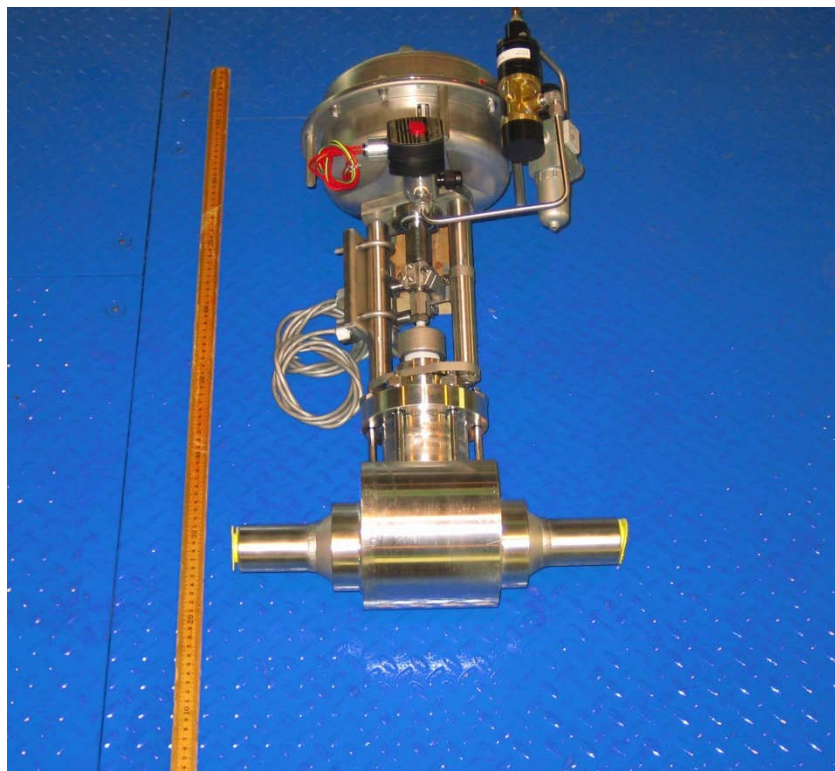


Figure 27 – A photo of a delivered Kammer 1.5" straight valve.



Figure 28 – A photo of a delivered Kammer 1.5" angle valve.

3.2.3.2 Swagelok Valves

Due to the cost and six-month lead time associated with Kammer valves, Swagelok valves will be used on all parts of the system that do not require 1.5" Schedule 40 piping. Swagelok valves are readily available in sizes up to 1" tube or 0.75" Sch. 40 pipe. These valves come with a welded-bellows seal, are rated for sodium service up to 1200 [°F], and have prepped ends for butt-weld connections. Custom 1" Schedule 40 pipe valves are available from Swagelok through special order.

Swagelok valves for liquid sodium service will use pipe on the inlet and outlet instead of tube to provide an additional corrosion allowance. All Swagelok valves with piping connections have undergone radiographic analysis to ensure leak-tightness. Valves downstream of the vapor traps and filters will utilize the standard tube connections with a wall thickness of 0.065" since sodium corrosion will not be an issue.

All 151 Swagelok valves required for the final phase of METL have been delivered to ANL (Table 4). Photos of electro-pneumatically and manually actuated Swagelok valves can be seen in Figure 29 and Figure 30 respectively.

Table 4 – Swagelok valves for METL

Part #	Size	Actuation
SS-8UW-TQ3-HT	0.75" Tube	Manual
SS-12UW-TR3-HT	1" Tube	
SS-12UW-PE3-HT-CZ	0.75" S40 Pipe	
SS-12UW-PG3-HT-CZ	1" S40 Pipe	
IS-SS-12UW-PG3-HT-8C1M-CZ	1" S40 Pipe	Electro-pneumatic
SS-8UW-TQ3-HT-6CM	0.75" Tube	
IS-SS-12UAW-PG3-HT-8C1MCZ	1" S40 Pipe Angled	
IS-SS-12UW-PE3-HT-8C1M-CZ	0.75" S40 Pipe	

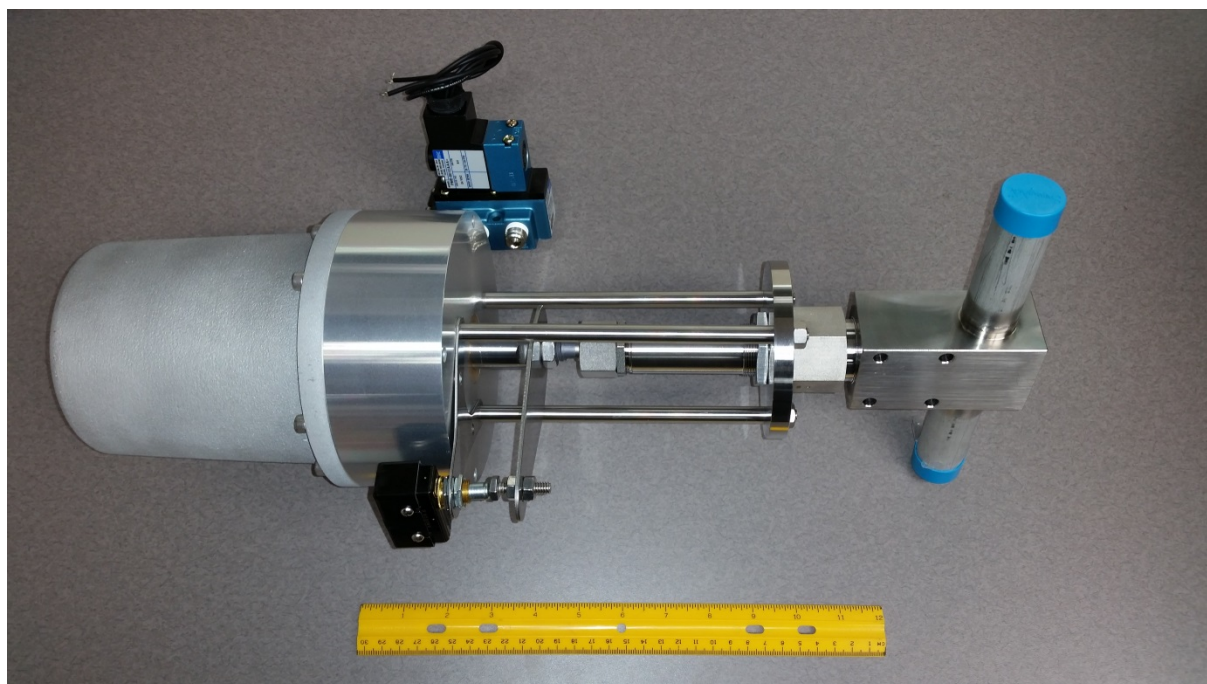


Figure 29 - A photo of an electro-pneumatic Swagelok valve with factory-welded 1" Sch. 40 pipe ends. The valve will be actuated using ~50 [psig] argon. A position indicator on all electro-pneumatically actuated valves will help METL operators verify the state of the valve.

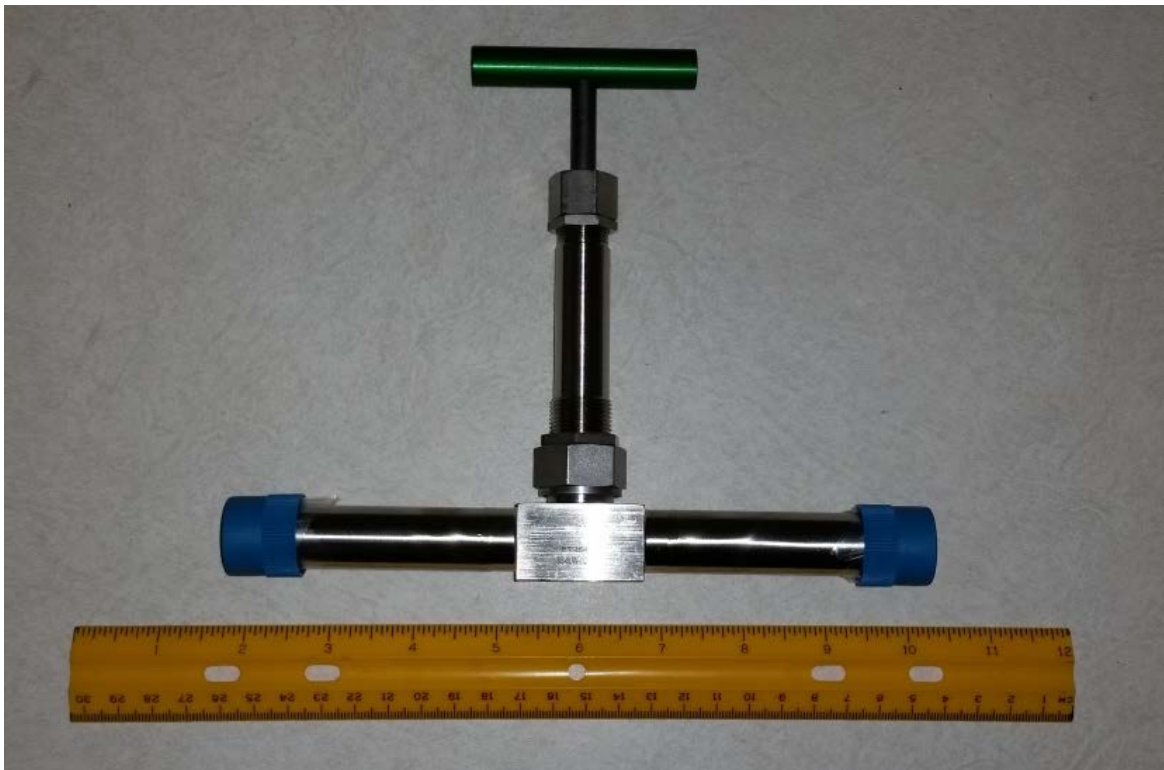


Figure 30 - A photo of a manual Swagelok valve with 0.75" tube ends.

3.2.4 Dump Tank

The sodium dump tank, shown in Figure 31, will be installed directly on top of the catch pan. The dump tank is 151" long, has an inner diameter of 41", an outer diameter of 42", and a designed capacity of ~840 [gal]. The dump tank is rated for 200 [psig] at 1000 [°F].

There are twenty-one ports located at the top of the dump tank. Each test vessel has an independent drain line that is connected directly to one of these connections. A sodium dump can be carried out for all test vessels simultaneously or for specific vessels in the case of an emergency. To minimize the impact of thermal shock during an emergency drain, the dump tank will be connected to the main loop and vessels using all-welded construction.

Currently, eighteen of the dump tank nozzles are being reinforced by the vessel manufacturer in order to withstand the anticipated loads generated by the piping system during changes in thermal temperature. (Three of the nozzles are reserved for instrumentation and do not need to be changed.) The nozzle loads were calculated by the piping designer, using CAESAR-II piping stress analysis software. The dump tank is expected to be returned to ANL late November 2015.



Figure 31 – A photo of the dump tank after being uncrated and positioned on top of the catch pan.

3.2.4.1 Dump Tank Enclosure & Thermal Insulation

The dump tank will be capable of operating continuously at 1000 [°F]. To maintain this operating temperature the dump tank will have ~13 [kW] of installed heating power distributed over six different heater zones. Additionally, the dump tank will be installed within the thermal enclosure that is depicted in Figure 32.

The space between the dump tank and the enclosure panels will be filled with vermiculite, a pourable thermal insulation. The panels of the enclosure can be easily removed to provide access to heaters, thermocouples or instrumentation located on the outside of the tank. It is calculated that the dump tank filled with 800 [gal] of sodium can be heated from room temperature to 1000 [°F] in about four days using this heater/insulation configuration.

The dump tank enclosure has been designed fabricated by ANL Central shops, as shown in Figure 33.

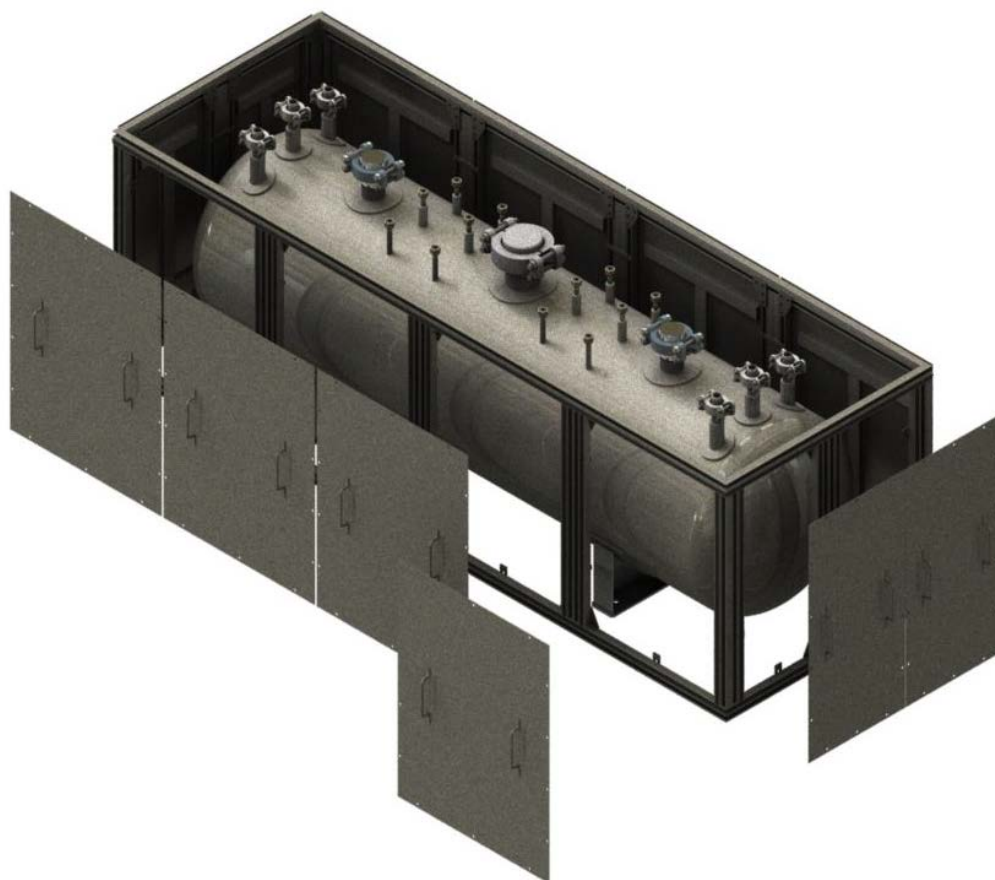


Figure 32 – A 3D model of the dump tank enclosure. Easily removable panels will provide access to the heaters and thermocouples on the dump tank. The enclosure will contain vermiculite thermal insulation.



Figure 33 – A photo of the dump tank thermal enclosure. The removable panels are fabricated from stainless steel sheet metal and bolted to a galvanized Unistrut frame.

3.2.5 Level Sensors

It will be important to monitor the sodium level in both the dump tank and the expansion tank. Different types of level sensing technologies were explored for use in METL but it was found that commercially available level sensors (ultrasonic, guided-wave radar, magnetostrictive, capacitive, float, etc.) were unable to operate in a sodium environment at the design temperature of 1000 [°F]. As a result, ANL has been designing and testing level sensors for use in METL.

3.2.5.1 Inductive Level Sensors

Inductive level sensors have been successfully used in high-temperature sodium systems in the past. As seen Figure 34, the sensor consists of two bifilar coils contained within a stainless steel thimble that can be submerged in sodium. One of the coils is connected to a signal generator while the other coil is connected to a sensitive voltmeter or oscilloscope. Figure 35 shows how the magnetic field produced by the sensor is altered by the presence of an electrically-conductive, non-magnetic liquid metal. The linear, repeatable changes to the circuit can be measured and calibrated to indicate sodium level within METL.

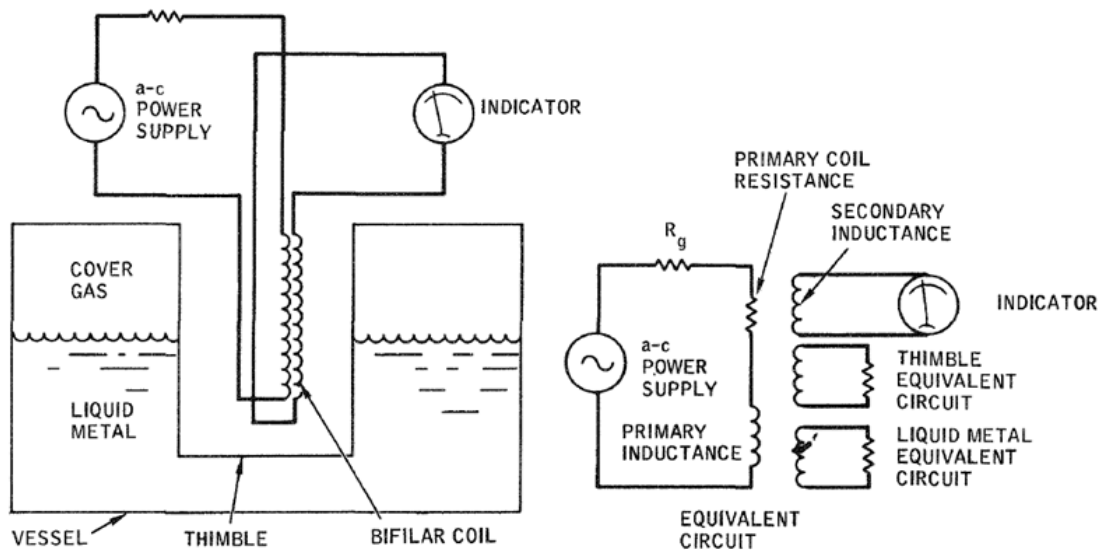


Figure 34 – A diagram showing the operation of an inductive level sensor (3).

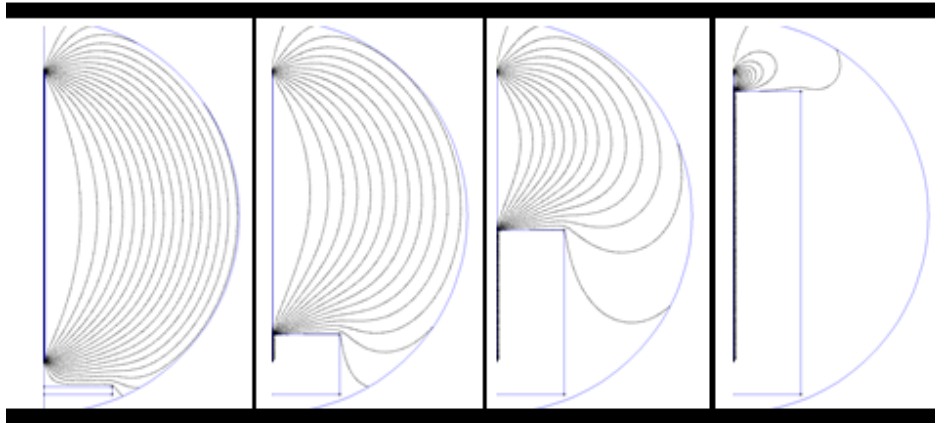


Figure 35 – A picture depicting how sodium level affects the magnetic field produced an inductive level sensor. The changes to the magnetic circuit can be calibrated to determine sodium level. These pictures were produced using FEMM.

Previous ANL level sensor designs have been shown to lack the robustness required for long-term use in METL. New inductive level sensors are being designed for use in the METL dump tank using stronger wire with thicker electrical and thermal insulation. (All materials used in the sensor must be rated for continuous operation at 1000 [°F].)

Previous level sensor tests used an aluminum tube as a proxy for liquid sodium. As the aluminum tube was moved up or down with respect to the coils there was a noticeable change in the output of the sensor. As shown in Figure 37, the output signal was sensitive to the operating frequency of the AC power supply and it was found that an operating frequency of ~3.8 [kHz] provided the maximum change in signal. As shown in Figure 38, the output of the sensor is very linear.

To help ensure the safety and performance of the inductive level sensors, the 316SS thimbles are being designed in accordance with thermowell code ASME PTC 19.3 TW-2010.



Figure 36 – A photo of the experimental setup being used to benchmark an inductive level sensor.

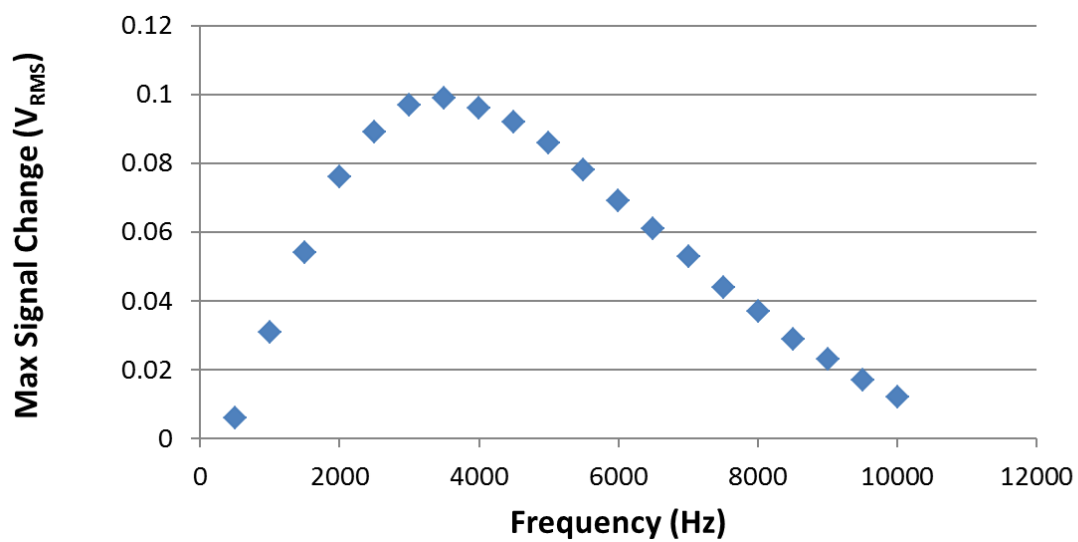


Figure 37 – The maximum change in the output signal as a function of operating frequency.

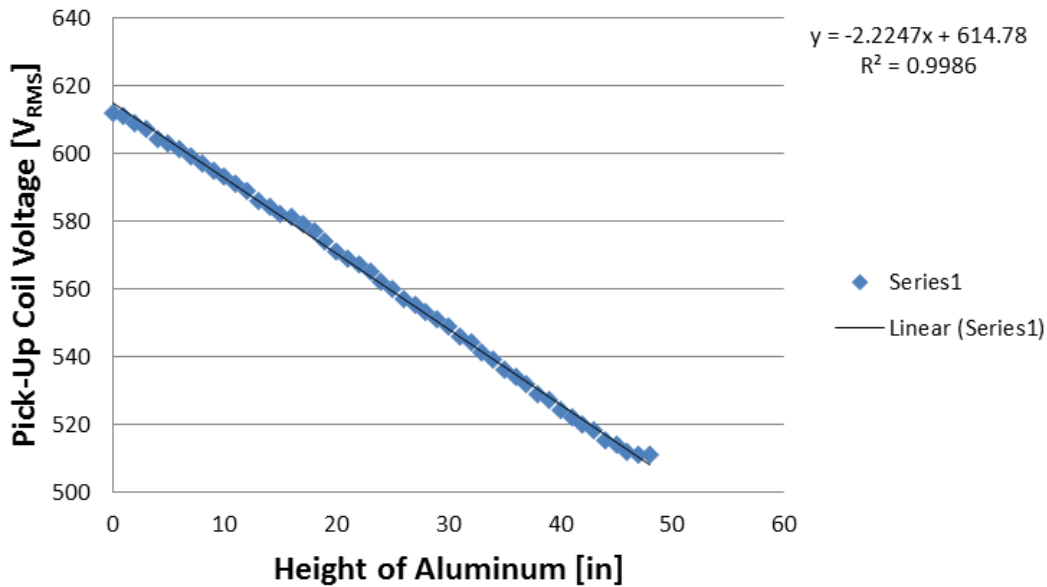


Figure 38 – Initial data from the inductive level sensor tests.

3.2.5.2 Differential Pressure Level Sensor

Differential pressure level sensors will also be used within the METL dump tank and expansion tank. As seen in Figure 39, this type of sensor operates by measuring the pressure difference between the gas space and the bottom of an argon-filled dip tube ($\Delta P = \rho g h$). Since the density of sodium as a function of temperature is very well known, this type of sensor will be an accurate method of level detection that can be used to calibrate other level sensors.

ANL engineers initially worked with a vendor to produce a prototype NaK-filled transducer that could be used in METL, as shown in Figure 40. This sensor model is typically used in the high-pressure plastic extrusion industry but the sensor body, diaphragm, and Grayloc fittings shown in Figure 41 are all made from Inconel-718 so it could also be used in high-temperature sodium systems.

Concerns over the accuracy and sensitivity of the vendor hardware prompted ANL engineers to talk to another vendor regarding custom NaK-filled pressure transducers for the DP gauge. Thus far, ANL has ordered fourteen single-point pressure sensors from the second vendor for use within METL. These fourteen sensors will connect to the system using Grayloc fittings. ANL engineers are continuing to work with the new vendor to develop a differential pressure sensor that has sufficient resolution ($\sim 1/4$ [in-H₂O]) to be used as a level sensor. The proposed ΔP gauge would have a much large diaphragm than the original sensor, and could be connected to the gas space of the dump tank or expansion tank using VCR fittings.

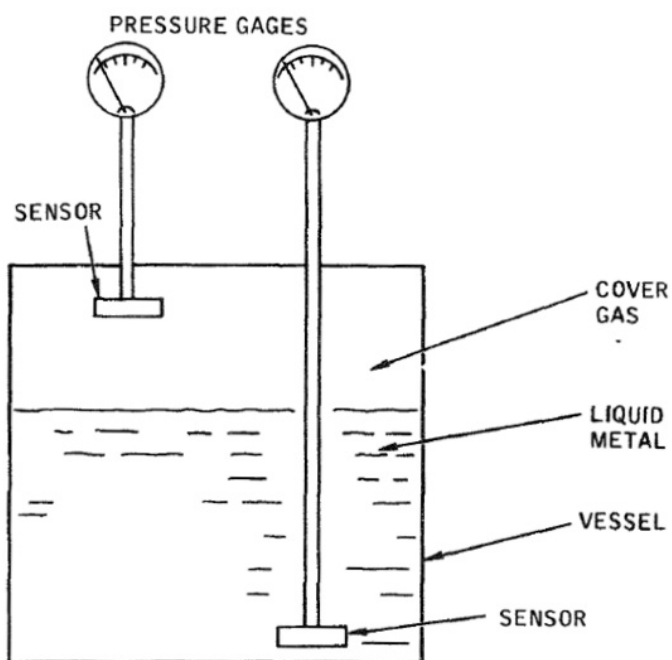


Figure 39 – A schematic showing the operating principle of a differential pressure level sensor (3).



Figure 40 – A photo of the NaK-filled pressure transducer that has been delivered to ANL. The transducer can connect to the METL piping system using a Grayloc hub.



Figure 41 – A close-up photo of the diaphragm of the first transducer. The diaphragm is ~ 1/2" in diameter. This small diameter is not expected to provide the adequate sensitivity that is required for the METL level control system.

3.2.6 Purification & Impurity Monitoring System

High concentrations of oxygen or other impurities within the sodium can accelerate corrosion or cause unwanted plugging. Impurities can be introduced into the system whenever new components are installed, if leaks occur, or when more sodium is added to the dump tank.

In order to control and measure the amount of impurity in the flowing sodium, METL will have a purification system that consists of a cold trap, a plugging meter, an economizer, two EM pumps, two flowmeters, and four pressure transducers, as depicted in Figure 42. All components within the purification system are rated for temperatures ranging from 0 - 1000 [°F] and pressures ranging from 1E-4 [Torr] to a minimum of 100 [psig] in accordance with the ASME codes.

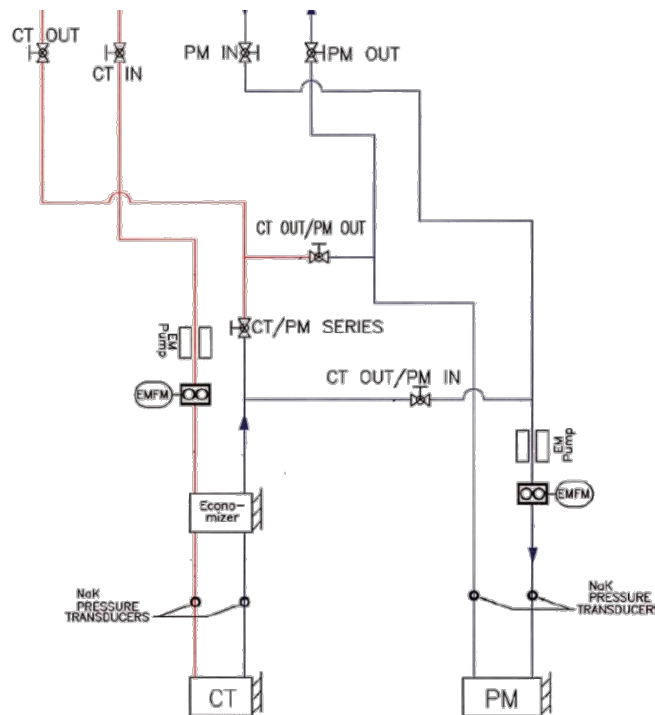


Figure 42 – A detail of the METL P&ID showing the functional layout of the purification system. The cold trap is abbreviated as “CT” and the plugging meter is abbreviated as “PM”.

The purification system is designed to work in four different operational modes:

- 1) *Purification mode* - Only the cold trap is in use. This mode can be used after a test article has been inserted or removed since there could be a higher impurity concentration and a greater likelihood of clogging the plugging meter.
- 2) *Measuring mode* - Only the plugging meter is in use. Without the cold trap, this mode can only be used to monitor the impurity levels within the flowing sodium.

3) *Purification/Measuring mode* - Both the cold trap and the plugging meter are in use while connected to the main loop in parallel. This mode may be used to simultaneously clean and monitor the bulk sodium.

4) *Test mode* - Both the cold trap and the plugging meter are connected in series. This mode can be used to determine the effectiveness of the cold trap at different temperatures and flow rates.

3.2.6.1 Cold Trap

The cold trap operates by cooling a small fraction of the flow in the main piping system to temperatures just above the freezing point of sodium. At these colder temperatures the solubility of oxides, hydroxides, or other impurities is drastically reduced. If dirty sodium enters the cold trap it will become super saturated with the impurity as it is cooled. The impurities will then precipitate out of solution and adhere to the stainless steel mesh packing within the volume of the cold trap. The clean, cool sodium can then reenter the main loop as the cleaning process continues. It is expected that sodium leaving the cold trap will contain oxygen concentrations < 5 [ppm]. (See Figure 43 for the saturated oxygen concentration of sodium.)

In order to cool the sodium, the cold trap loop relies on both an economizer and a 2000 [ft³/min] blower fan. Together, these two components can reduce sodium temperatures from a maximum of 538 [°C] / 1000° [F] to the plugging temperature (110-150 [°C]) at a nominal flow rate of 1 [gpm].

Cold Trap Design Parameters:

Temperature:

Minimum operating temperature: 110 [°C] / 230 [°F]
Maximum operating temperature: 538[°C] / 1000 [°F]

Flow:

Minimum: 0.2 [gpm]
Maximum: 2 [gpm]
Nominal: 1 [gpm]

Impurity concentration after purification:

Oxygen < 5 [ppm]
Hydrogen < 5 [ppm]

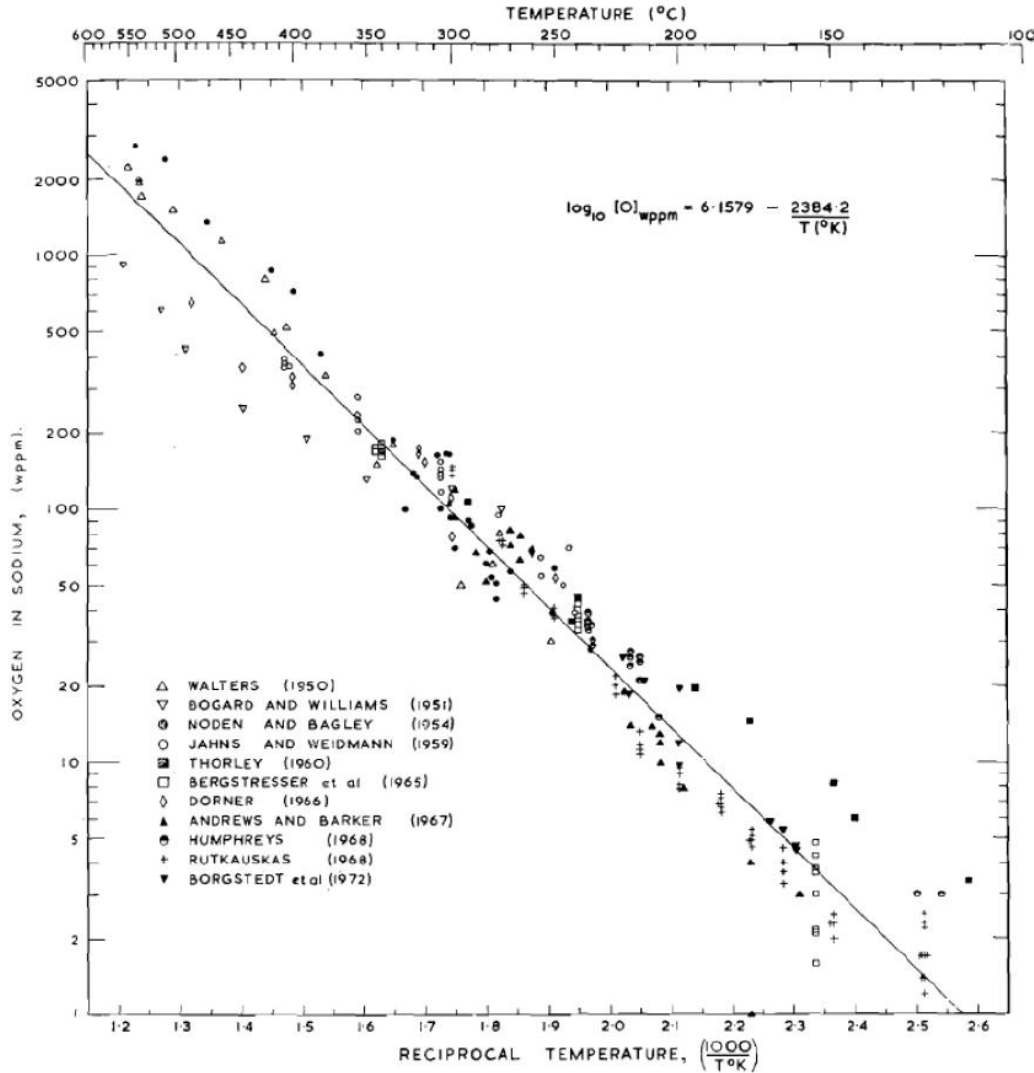


Figure 43 – Solubility of oxygen in sodium as a function of temperature (4). The equation in the corner of this graph is commonly referred to as the Noden correlation.

During FY2014, the cold trap was fabricated and delivered. The size of the air inlet at the bottom of the cold trap was increased to accommodate an anticipated 1500-2000 [CFM] air flow rate. Finally, a sheet metal manifold was fabricated by Central Shops to duct the cooling air out of the Bldg. 308 hi-bay, as shown in Figure 44.

During FY2015 the cold trap was returned to the manufacturer to have the inlet and outlet nozzles reinforced to withstand the anticipated piping loads due to thermal expansion and contraction. Figure 45 shows a picture of the cold trap nozzles before and after reinforcement. The cold trap is currently at ANL awaiting installation in METL.



Figure 44 – A photo of the cold trap with the air duct installed and before nozzle reinforcement.



Figure 45 - Photos of the cold trap nozzles before (TOP) and after (BOTTOM) reinforcement.

3.2.6.2 Economizer

As shown in Figure 46, the economizer is a ~ 40 [ft] tube-in-tube helical coil counter-flow heat exchanger that was designed to recuperate some of the heat losses incurred from the cold trapping process. Hot, unpurified sodium from main loop flows towards the cold trap in the inner tube of the economizer. Cold, purified sodium leaving the cold trap and returns to the main loop by flowing along the opposite direction within the annular region on the outside of the helical shell.

As shown in Figure 47 and Figure 48, the economizer is meant to be installed within a custom enclosure designed to keep the coils at the appropriate elevation and spacing. A centering frame within the enclosure prevents the economizer from shifting due to thermal expansion/contraction during operation.

During FY2015, the economizer coil was completed and delivered. The coil is currently onsite awaiting installation.

Economizer Design Parameters:

Hot side inlet temperature: 1000 [°F] / 538 [°C]

Hot side outlet temperature: 273 [°F] / 134 [°C]

Cold side inlet temperature: 240 [°F] / 116 [°C]

Cold side outlet temperature: 967 [°F] / 519 [°C]

Flow rate: 0.2 - 2 [gpm]



Figure 46 - A photo of the completed economizer coil at ANL Central Shops.



Figure 47 - A photo of the economizer within the tank. The economizer coils are centered using the internal frame. To prevent metal-on-metal rubbing, the internal frame is padded with high-temperature fiberglass insulation.



Figure 48 – 3D model of the economizer within the containment.

3.2.6.3 Plugging Meter

The completed plugging meter was delivered to ANL in FY2014 along with the associated blower fan and VFD. The plugging meter will measure sodium impurity levels within the flowing sodium. (A conceptual depiction of a plugging meter can be seen in Figure 49.)

During operation, sodium will enter the plugging meter from the main loop. This hot sodium will be cooled to below the saturation temperature of any impurities that it may contain. These impurities will precipitate out of solution and gradually plug an orifice plate. While the flow rate is dropping, the cooling air flow is gradually reduced so that the temperature of the sodium at the orifice can slowly increase. Impurities will continue to precipitate out of solution and contribute to plugging so long as the sodium is below its saturation temperature. When the sodium at the orifice reheats to a certain temperature the plug will begin to dissolve and the flow rate will return to normal (5).

The saturation temperature of the impurity corresponds to the minimum in flow rate just as the plug begins to re-dissolve into solution. It is at this point that, “since the rate of change of flow is zero, the precipitation and dissolution rates are equal, and, by definition, the temperature at this condition is the equilibrium saturation temperature of the impurity in solution (6).”

Unfortunately, a plugging meter is non-discriminant so any impurity in the system could plug the flow restriction, not just oxygen. Nonetheless, it is typically assumed that the predominant impurity is oxygen. Therefore, once the saturation temperature has been measured, the Noden correlation (Figure 43) can be used to determine the oxygen concentration of the sodium.

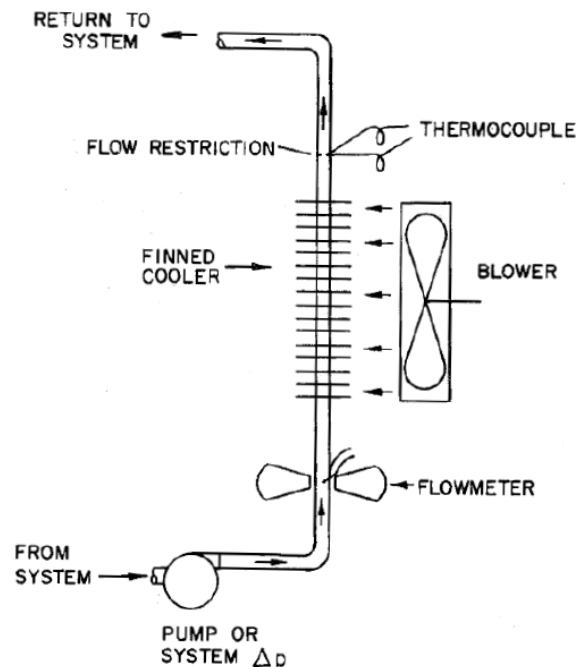


Figure 49 – A conceptual depiction of a plugging meter (7).

The METL plugging meter has a long tube-in-pipe design, as depicted in Figure 50. The upper section of the plugging meter is an economizer that recuperates heat when incoming and outgoing sodium pass through it. The incoming sodium is cooled down to the plugging temperature by the air from the blower as it flows down along the annular region of the plugging meter. Different sodium plugging temperatures can be reached by adjusting either the flow rate of the air or the sodium.

Plugging Meter Design Parameters:

Inlet temperature:	1000 [°F] / 538 [°C]
Outlet temperature:	859 [°F] / 459 [°C]
Coldest temperature:	228 [°F] / 109 [°C] (near the orifice plate)
Cold side outlet temperature:	967 [°F] / 519 [°C]
Nominal flow rate:	0.15 [gpm]

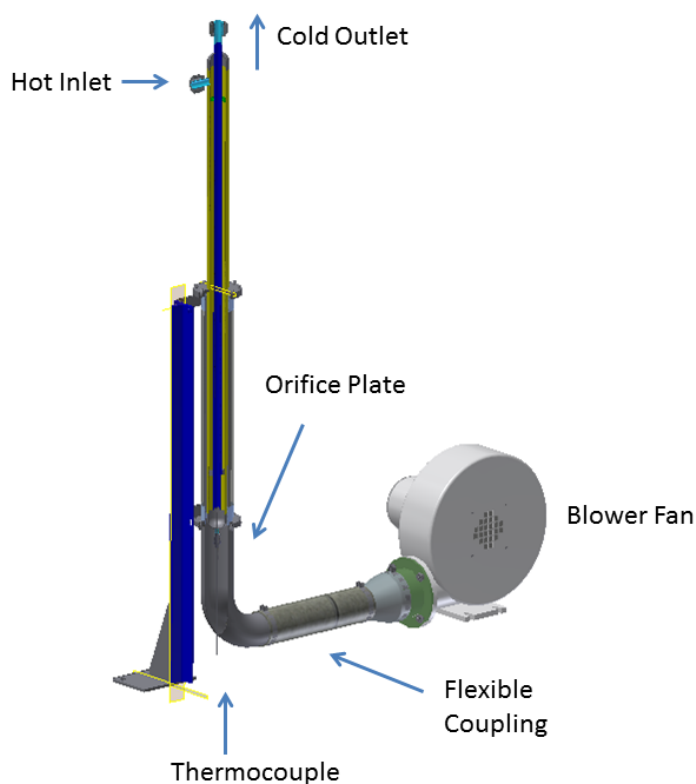


Figure 50 – A 3D model of the plugging meter.

3.2.6.4 Thermal Mixing Tees

Two thermal mixing tees were designed, fabricated, and delivered to FY2014. A photo of a completed mixing tee can be seen in Figure 51.

Two tees will be installed in the main piping system. One of the mixing tees will be located where the sodium leaving the economizer reenters the main loop. Another identical mixing tee will be similarly positioned downstream of the plugging meter. Since the sodium leaving the purification systems will be colder than the main loop, the thermal mixing tees will mitigate the harmful effects associated with thermal shock and thermal cycling within the piping system.

Figure 52 shows how the cold sodium from the purification system will be injected into the hot sodium flowing in the main loop. As shown in Figure 53, an orifice consisting of seven small holes promotes mixing between the two streams while four identical baffles act to still the flowing sodium so that the welds on the cold inlet are not exposed to large or rapid temperature gradients.

Cold sodium mixes and thermally equilibrates with the hot sodium inside the mixing sleeve. A thin liner within the sleeve prevents cold sodium from touching the outer containment of the mixing tee, as shown in Figure 54.



Figure 51 – A photo of one of the completed thermal mixing tees.

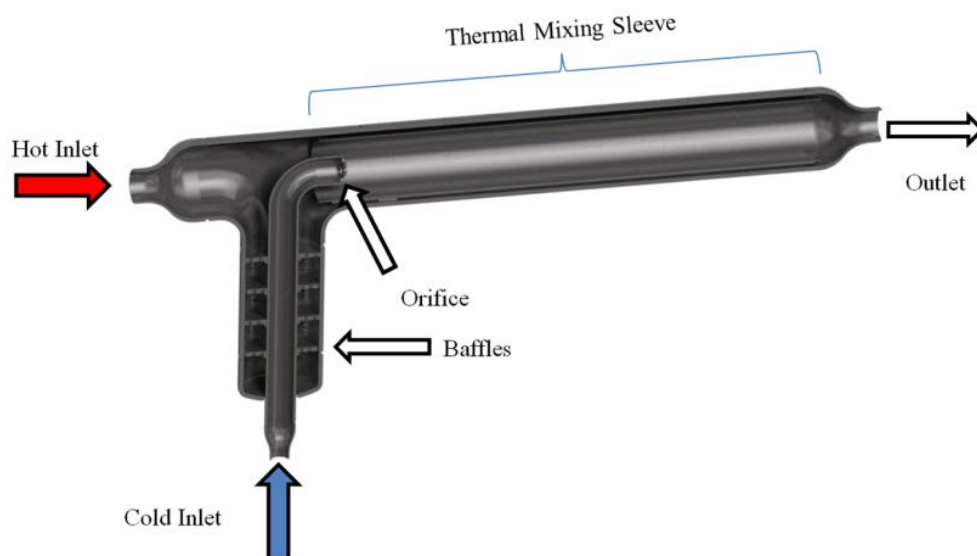


Figure 52 – A cut-away model of the thermal mixing tees used in the main loop.

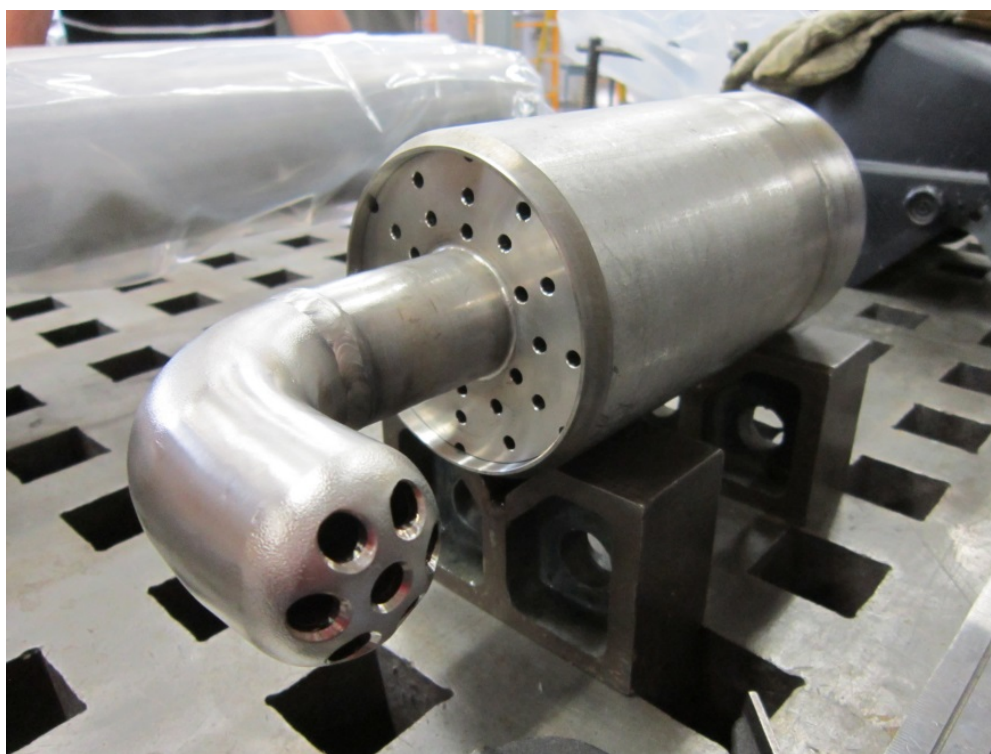


Figure 53 – A photo detailing the orifice and baffles of the thermal mixing tee.



*Figure 54 – A photo looking down the thermal mixing sleeve. Hot and cold sodium mix within the thermal liner.
Hot, unmixed sodium is able to flow between the liner and the outer containment.*

While designing the thermal mixing tees it became apparent that calculating the required mixing length was a complicated problem that depended strongly on flow rate, geometry, and the thermophysical properties of sodium. Analysis of thermal mixing tees is continuing at ANL with the use of FLUENT / ANSYS, as indicated by Figure 55. This research will hopefully yield a series of correlations that will allow future mixing tee designers to analyze these components more easily, and without the need for finite element analysis.

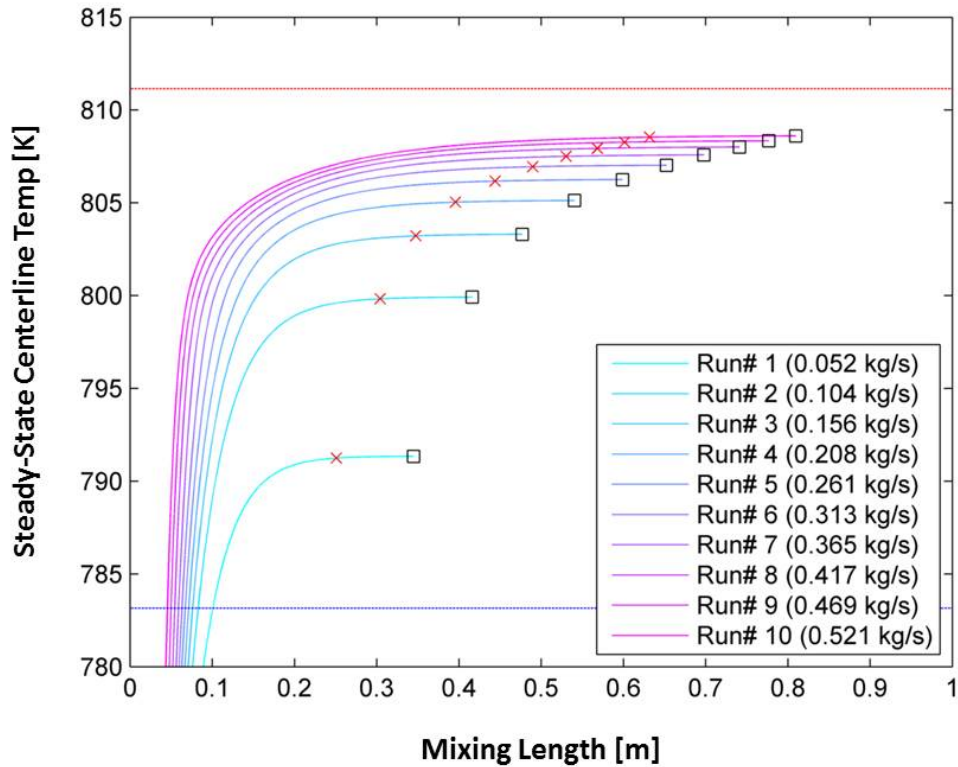


Figure 55 – Results from FLUENT / ANSYS analysis investigating the required mixing length for the METL cold trap. The different runs correspond to different flow rates of the hot sodium in the main loop. The squares indicate the equilibrated centerline temperature. The X's indicate where the centerline temperature is within 0.1 [K] of the equilibrium temperature.

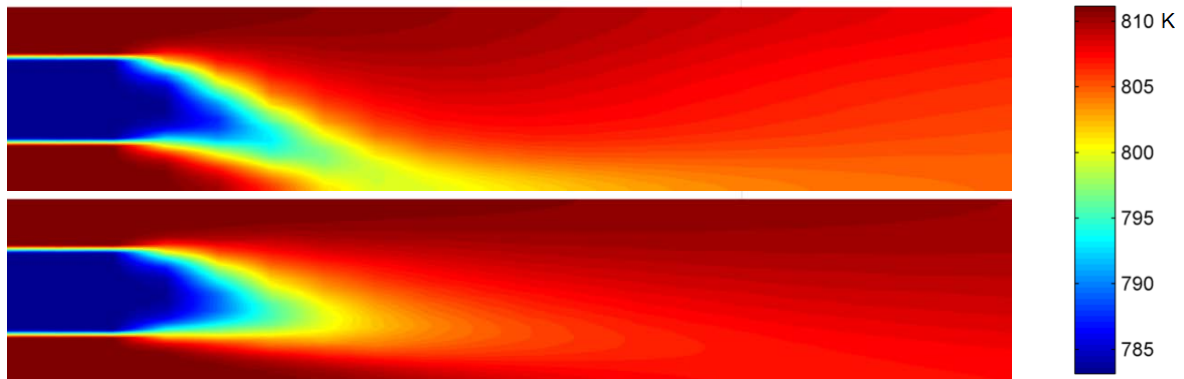


Figure 56 – Calculated steady state thermal contours produced by the sodium thermal mixing tees accounting for different flow rates and buoyancy. These figures were generated by D. Lisowski using ANSYS/FLUENT. (Top & Bottom: $g = 9.81 \text{ [m/s}^2\text{]}$, $V_{\text{cold}} = 0.065 \text{ [m/s]}$. Top: $V_{\text{hot}} = 0.058 \text{ [m/s]}$, Bottom: $V_{\text{hot}} = 0.144 \text{ [m/s]}$.)

3.2.7 *Test Vessels*

In May 2015, a vessel manufacturer was awarded the contract to build two 18” vessels and two 28” vessels for Phase I of METL. Since then, ANL engineers have been working with the vessel fabricator and offering feedback on drawings, calculations, and welding procedures.

The two new 18” vessels will have nearly the same design as the preexisting vessel shown in Figure 57 and Figure 58. The major changes to the new 18” vessels will be:

- a) Reinforced nozzles to withstand piping loads from thermal expansion and contraction
- b) Modified nozzle orientation to conserve space on top of the mezzanine
- c) Updated flange design that will facilitate installation, and removal of test articles

In addition to these changes, the two new 28” vessels will also be modified to use support lugs instead of legs, as depicted in Figure 59 and Figure 60. The new 28” vessel supports will provide more room for maintenance underneath the mezzanine and will not require side bracing.

All new test vessels will perform the same functions as previously anticipated. The 18” test vessels are intended for the study of smaller components that do not require a large test vessel. The 18” vessels can simulate the thermal-hydraulic environment of a typical fast reactor with a maximum sodium flow rate of 10 [gpm] and maximum temperature of 1000 [°F]. The total volume in the vessel is about 40 [gal].

Similarly, the 28” test vessels, will be used to conduct performance testing of actual and/or prototypical components associated with in-vessel retrieval and insertion. These larger vessels will have a maximum sodium flow rate of 10 [gpm] and maximum operating temperature of 1,200 [°F] while filled with static sodium and isolated from the main piping system. The total volume in the vessel is about 170 [gal].

All test vessels are designed so that different types of assemblies can be easily tested by connecting to the system using standard flange sizes. The top rim of the vessel is designed to accommodate the flexi-cask system that will be used for test article removal.

The preexisting 18” vessel will be used to pressure test and helium-leak check experiments that will go into the METL facility. The preexisting 28” vessel may be repurposed to become the cleaning vessel that connects to the carbonation system.



Figure 57 – A photo of the preexisting 18" vessel during a fabrication inspection. (This photo was taken during FY2014).

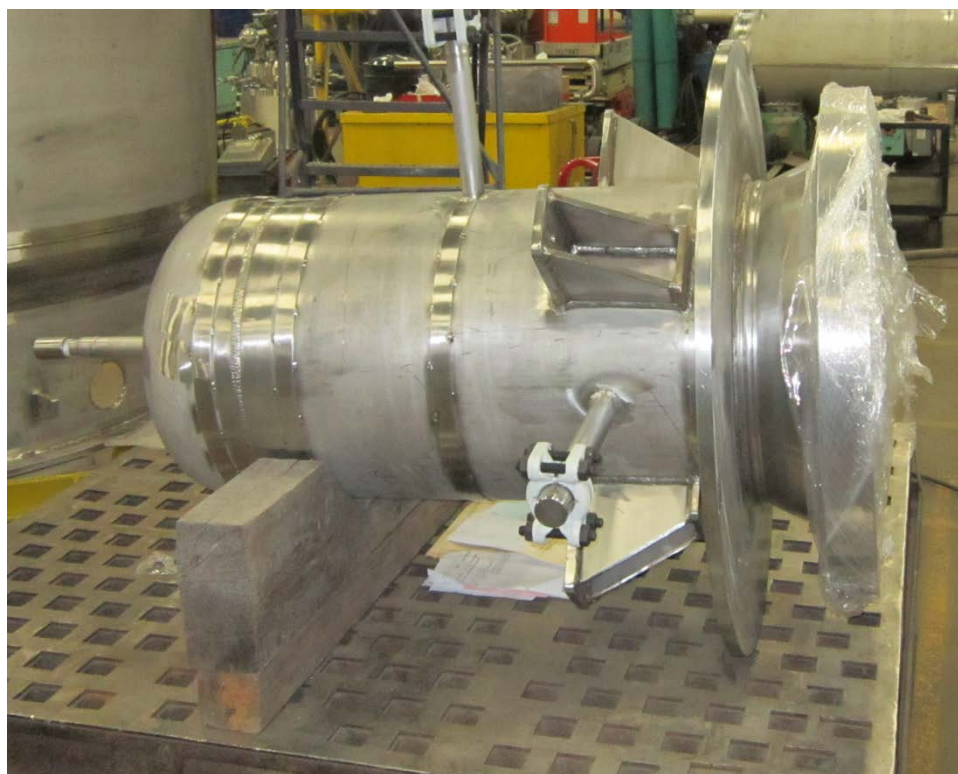


Figure 58 – A photo of the preexisting 18" vessel during a fabrication inspection. The vessel had already been cleaned, so the top flange (right side) was sealed with plastic wrap. (This phot was taken during FY2014).



Figure 59 - A 3D model of a 28" vessel. The legs have been removed and replaced with support lugs that are located closer to the top of the vessel.

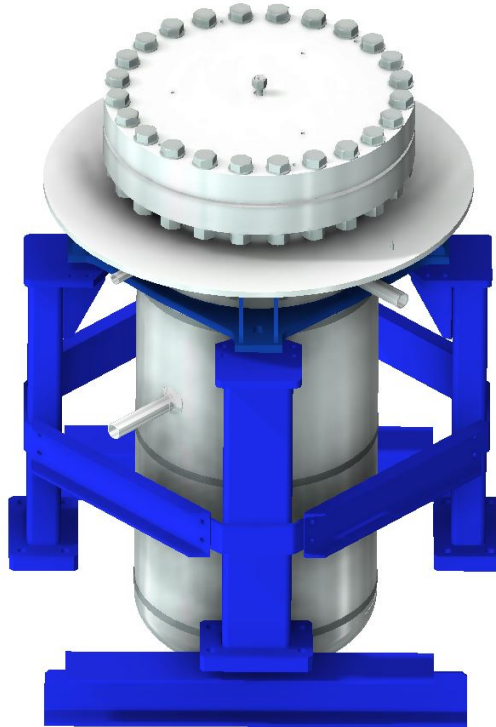


Figure 60 - A 3D model showing a 28" vessel installed within the support structure.

3.2.8 *Expansion Tank*

The function of the expansion tank is to accommodate changes in liquid level that result from changes in temperature or flow. The expansion tank was fabricated and delivered to ANL during FY2014, as shown in Figure 61 and Figure 62. During the spring of FY2015, the expansion tank was returned to the original manufacturer so that the nozzles could be reinforced to withstand the anticipated piping loads. Nozzle reinforcement is expected to be completed by mid-October.

As illustrated in Figure 63, the body of the tank is approximately 80” long and 8.7” in diameter. It will be about half full during the normal operation which will leave enough gas space to accommodate changes in volume.

The sodium level of the loop will be measured from within the expansion tank. A differential-pressure level sensor and an inductive level sensor will be used to monitor METL liquid level (see Figure 34 and Figure 39).



Figure 61 – A photo of the expansion tank during a fabrication inspection. (This photo was taken during FY2014).



Figure 62 – A photo of the top of the expansion tank. The top flange has four 1" VCR fittings. (This photo was taken during FY2014).

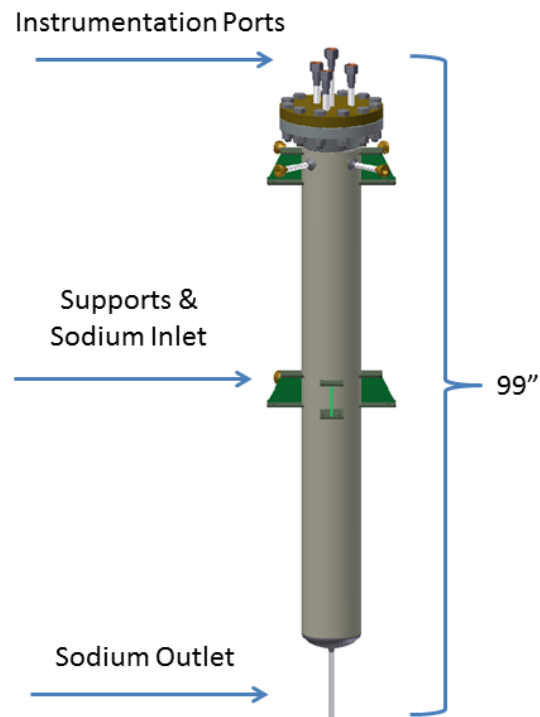


Figure 63 – A 3D model of the expansion tank.

3.2.9 Vessel Supports and Imitators

During FY2015, the design, fabrication, and installation of the supports for the expansion tank, two 18" vessels, and two 28" vessels was completed. The vessel support structures were designed by ANL engineers to withstand a simultaneous fire and earthquake (850 [°F] / lateral 0.384 [g]).

As depicted in Figure 64, the different support structures connect directly to the mezzanine structure. Beneath the mezzanine deck plates, the support structures consist of horizontal beams welded into position, as shown in Figure 65. The vessels will be attached to vertical stainless steel columns that are bolted to the horizontal supports, as shown in Figure 66.

To expedite the installation of the piping system, 'vessel imitators' were designed by ANL engineers and fabricated by an outside vendor. As shown in Figure 67 and Figure 68, the vessel imitators provide geometrically accurate mounting locations to support the piping that will connect to the expansion tank and four test vessels while the expansion tank is being reinforced and the test vessels are being fabricated. The use of these imitators will allow progress to be made in parallel with both the piping fabrication and installation and the various vessels that can accommodate the piping loads.

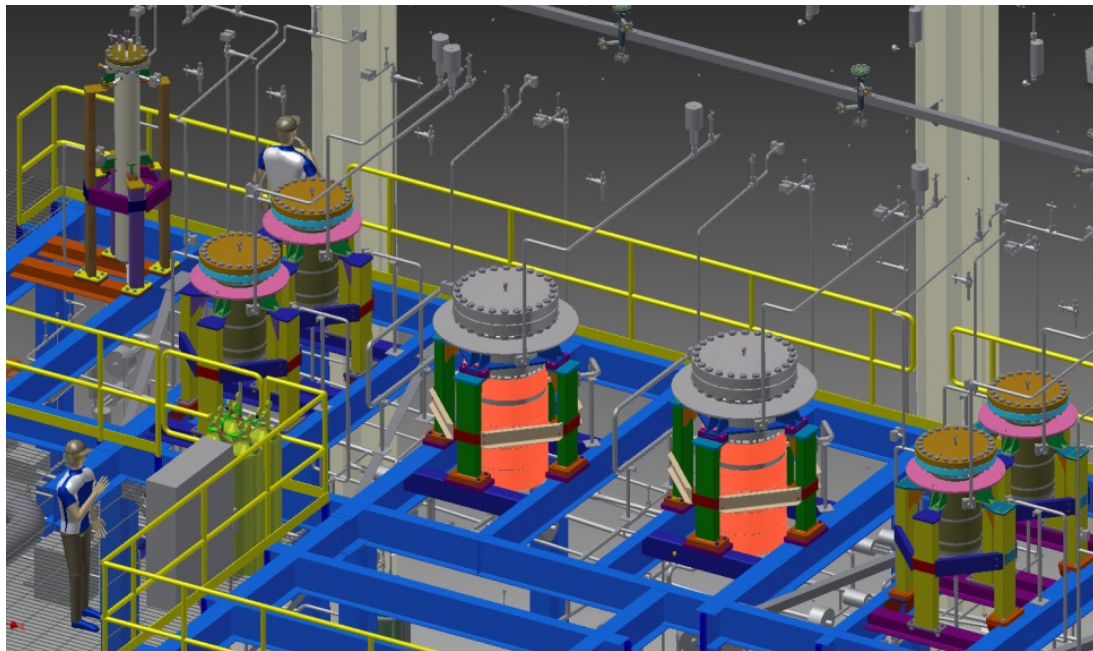


Figure 64 - A 3D model of the vessels and vessel supports.

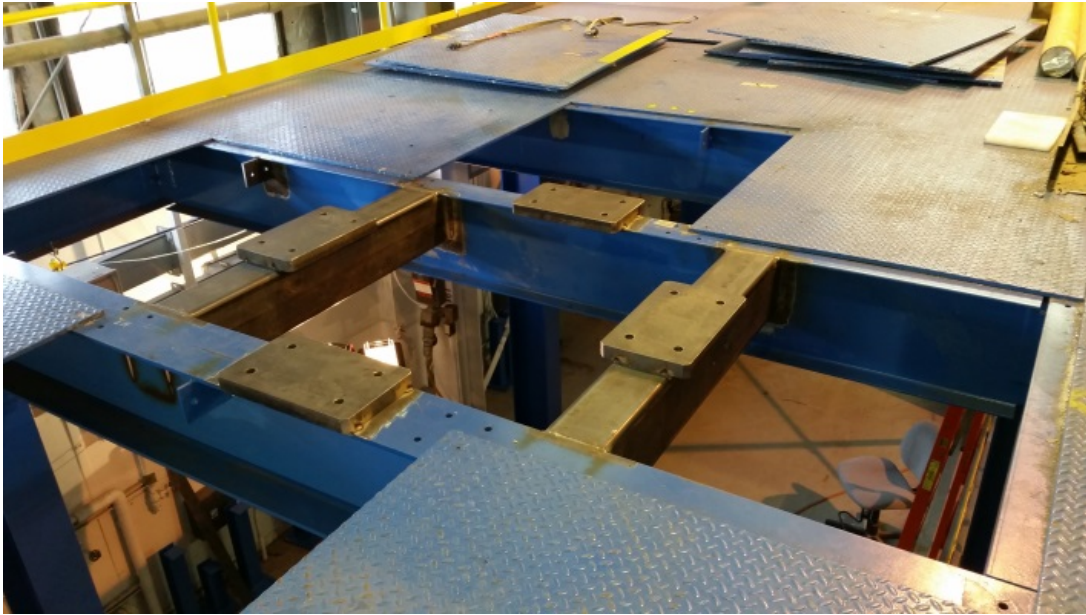


Figure 65 - A photo of the 28" vessel support steel attached to the mezzanine structure.



Figure 66 - A photo of the installed 18" vessel stainless vertical supports. (Holes to accommodate the vessel and piping have been cut in the mezzanine deck plates since this photo was taken.)

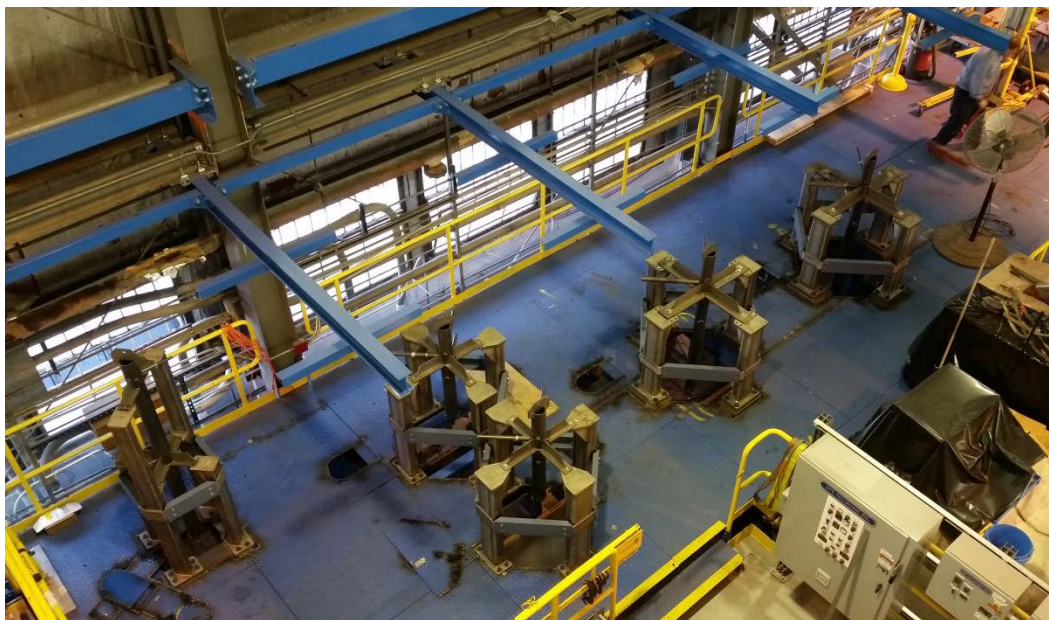


Figure 67 - An overhead photo of the METL mezzanine showing the installed vessel supports and vessel imitators required for Phase I.



Figure 68 - A photo of an 18" vessel imitator. The pipes extending radially from the imitator indicate where the nozzles on the actual vessel will terminate.

3.2.10 Inert Gas System

The METL facility will use argon cover-gas to maintain an inert environment above the liquid sodium. Cover-gas lines will connect to the dump tank, expansion tank, and each test vessel. The argon supply and distribution system is designed to:

- Purge and blanket the piping system, vessels, and tanks
- Maintain the required net positive suction head (NPSH) for the EM pumps
- Displace sodium from the system in order to achieve rapid draining
- Regulate and control the test loop pressure
- Inert equipment during removal and cleaning operations

The argon will be supplied to METL from a 1000 [liter] Airgas ‘micro-bulk’ system located outside the Bldg. 308 hi-bay. This micro-bulk system contains high-purity liquid argon (< 1 [ppm] oxygen). On-line diagnostics within the tank will provide METL operators with the real-time level within the tank and will automatically send a refill request to Airgas whenever the liquid argon drops below 3/8th full. The argon supply will also be able to provide 50 [psig] argon required to operate electro-pneumatically actuated valves.

As shown in Figure 69, the microbulk system is installed and ready to be connected to the METL piping/tubing system.



Figure 69 - A photo of the installed 1000 [liter] microbulk system outside the Bldg. 308 hi-bay. The microbulk system was installed during FY2015.

3.2.11 Vent System

The vent system will allow METL operators to purge the system and prevent over-pressurization. Vapor traps will be installed between the vessels and the vent tubing so that sodium vapor and/or aerosols are prevented from entering the unheated lines. A representation of the vent system that will be attached to the expansion tank, dump tank, and each test vessel can be found in Figure 70.

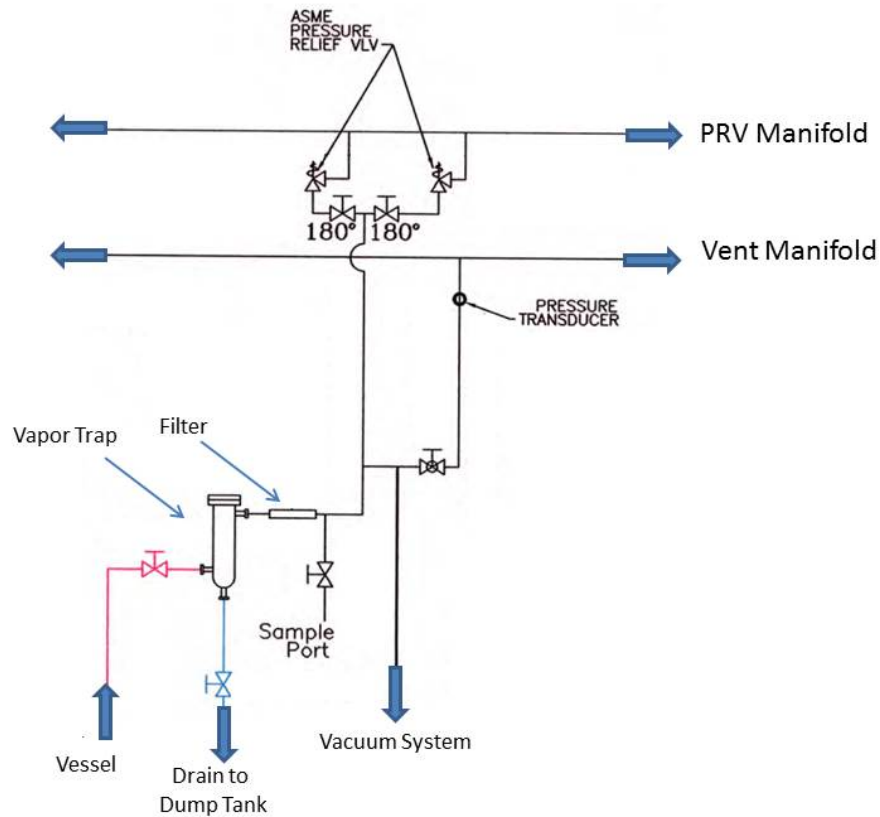


Figure 70 – A detail of the METL P&ID showing the vent system that will be connected to the expansion tank, dump tank, and each test vessel. All components downstream of the vapor trap and filter will be made of 0.065" wall thick seamless tubing since sodium corrosion is not a major concern.

3.2.11.1 Pressure Relief Valves

Ten of the pressure relief valves (PRVs) for Phase I METL have been delivered, as shown in Figure 71. The valves will have a set-point of 20 [psig] and will be capable of operation at 1200 [°F]. As shown in Figure 70, two PRVs will be connected to the expansion tank, dump tank, and each test vessel. This configuration will allow METL operators to perform maintenance on one PRV after transitioning the system to utilize the other. This process will ensure that over-pressurization protection is never removed from a tank or vessel.



Figure 71 - A photo of the delivered pressure relief valves.

3.2.11.2 Vapor Traps & Filters

The filters, dump tank vapor trap, and three of the five vessel vapor traps required for Phase I have been fabricated and delivered to ANL. Central Shops is currently fabricating the remaining two vessel vapor traps. As shown in Figure 72, the support steel for the vapor traps located above the mezzanine has been installed during FY2015.

Whenever cover-gas is vented from METL, sodium vapor and/or aerosols can be carried out of the system. To prevent sodium vapor from leaving the main system, vapor traps will be installed in the vent lines of the expansion tank, dump tank, and each test vessel. The vapor traps have been designed to maintain downstream concentration of sodium hydroxide at less than 1.15 [mg/m³] during steady-state operations. (See Figure 73 for the calculated sodium concentration at different cover-gas temperatures and pressures.)

The vapor traps are designed to continuously operate at ~120 [°C] so that the collected sodium vapor can be drained back into the system. The Raschig rings that will serve as the random packing within the vapor trap have already been delivered to ANL, as shown in Figure 74.

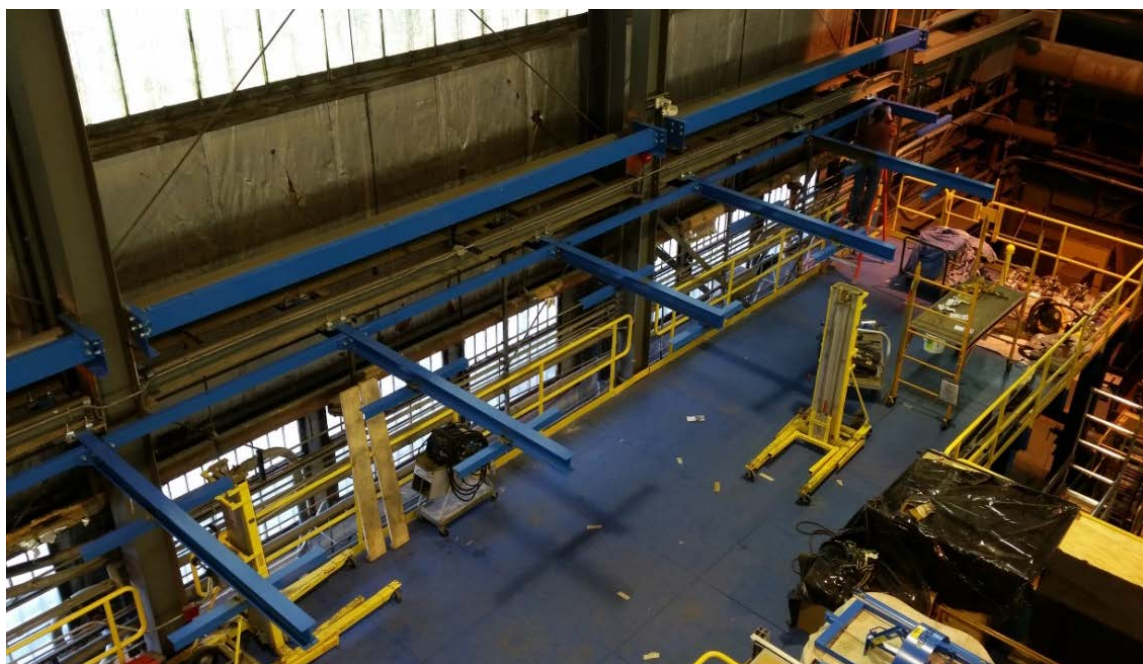


Figure 72 - A photo of the completed vapor trap supports and cantilever beams. The cantilever beams will support the pipes connecting the vessels and vapor traps.

Temp [C]	Temp [K]		Argon Pressure [psig]					
			2	4	6	8	10	
100	373.15		1.42E-07	1.42E-07	1.42E-07	1.42E-07	1.42E-07	[g Na / m ³] (Green = Acceptable / Red = Unacceptable)
125	398.15		1.08E-06	1.08E-06	1.08E-06	1.08E-06	1.08E-06	
150	423.15	Ideal vapor trap outlet ->	6.45E-06	6.45E-06	6.45E-06	6.45E-06	6.45E-06	
175	448.15		3.14E-05	3.14E-05	3.14E-05	3.14E-05	3.14E-05	
200	473.15		1.29E-04	1.29E-04	1.29E-04	1.29E-04	1.29E-04	
225	498.15	Acceptable vapor trap outlet ->	4.55E-04	4.55E-04	4.55E-04	4.55E-04	4.55E-04	
250	523.15		1.42E-03	1.42E-03	1.42E-03	1.42E-03	1.42E-03	
275	548.15		4.00E-03	4.00E-03	4.00E-03	4.00E-03	4.00E-03	
300	573.15		1.02E-02	1.02E-02	1.02E-02	1.02E-02	1.02E-02	
325	598.15		2.42E-02	2.41E-02	2.41E-02	2.41E-02	2.41E-02	
350	623.15		5.31E-02	5.31E-02	5.31E-02	5.31E-02	5.31E-02	
375	648.15		1.10E-01	1.10E-01	1.10E-01	1.10E-01	1.10E-01	
400	673.15		2.14E-01	2.14E-01	2.14E-01	2.14E-01	2.14E-01	
425	698.15		3.97E-01	3.97E-01	3.97E-01	3.97E-01	3.97E-01	
450	723.15		7.05E-01	7.05E-01	7.05E-01	7.05E-01	7.05E-01	
475	748.15		1.20E+00	1.20E+00	1.20E+00	1.20E+00	1.20E+00	
500	773.15		1.98E+00	1.98E+00	1.98E+00	1.98E+00	1.98E+00	
525	798.15		3.17E+00	3.17E+00	3.17E+00	3.16E+00	3.16E+00	
550	823.15		4.92E+00	4.92E+00	4.91E+00	4.91E+00	4.90E+00	
575	848.15		7.46E+00	7.44E+00	7.43E+00	7.42E+00	7.41E+00	
600	873.15		1.11E+01	1.10E+01	1.10E+01	1.10E+01	1.10E+01	

Figure 73 - This table shows the calculated concentration [g/m³] of sodium in argon as a function of temperature and pressure. 1.15 [mg] of sodium per every 1 [m³] of argon is considered to be acceptable. These numbers were calculated using (8).



Figure 74 – A photo of 1/4" x 1/4" Raschig rings that will increase the surface area within the vapor traps. (This photo was provided by the manufacturer of the Raschig rings.)

Dump Tank Vapor Trap (DTVT)

During an emergency drain, up to 800 [gal] of sodium could be pushed back into the dump tank within 15 [min]. Accordingly, the DTVT must be able to remove the sodium vapor and/or aerosols from the argon that is pushed out of the dump tank by the draining sodium. As shown in Figure 75, the DTVT has a blower fan that provides the active heat removal to handle emergency drain conditions. The air is ducted along the length of the vapor trap between and radiant band-heaters used to maintain the operating temperature of the device.

The DTVT was designed by ANL and then fabricated and tested during FY2015, as shown in Figure 76. The DTVT is currently onsite awaiting installation.

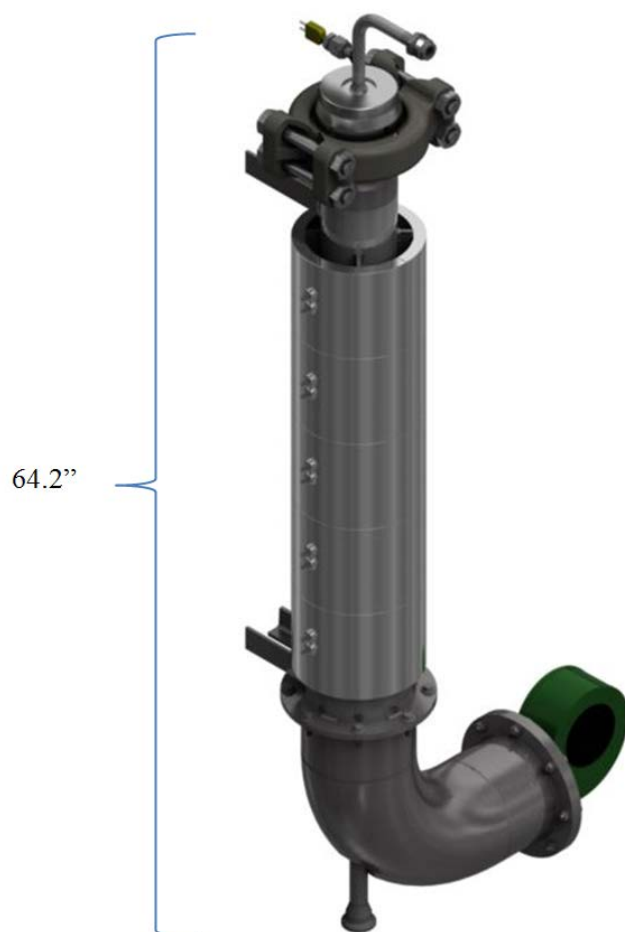


Figure 75 – A 3D model of the dump tank vapor trap.



Figure 76 - A photo of the completed dump tank vapor trap during an inspection at the manufacturer.

Vessel Vapor Traps (VVT's)

Unlike the DTVT, the VVT's do not have an active cooling system since they will not be used during emergency drains. The VVT's have been designed to have the same overall dimensions as the DTVT to enable interchangeability during operation and so that a common support design can be used for all vapor traps.

As shown in Figure 77, spiral-wound MI cable heaters will be used to maintain the vessel vapor traps at ~ 120 [°C]. Testing and analysis performed with a thermal imaging camera indicated that the required pitch for the MI cable is roughly the diameter of the vapor trap (see Figure 78).

Thus far, three of the five VVT's required for Phase I have already been fabricated and tested by Central Shops. The remaining VVT's are expected to be delivered by October 2015.

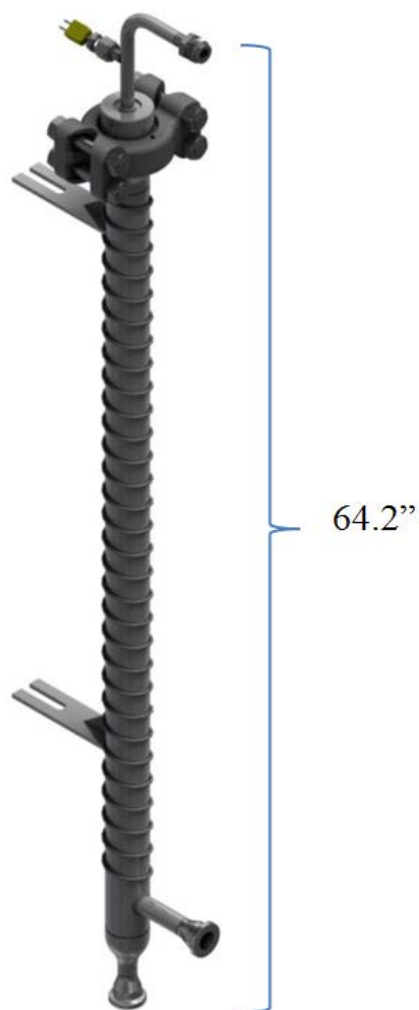


Figure 77 – A 3D model of the vessel vapor trap.

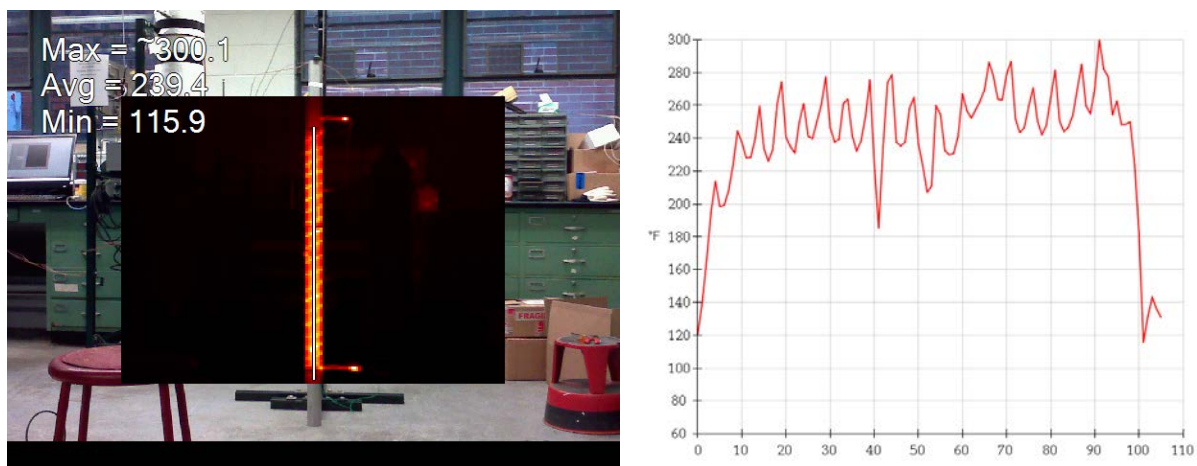


Figure 78 – Left: An infrared image of the small vapor trap heater test using a coiled MI heater cable. Right: The temperature profile along the outside of the smaller vapor trap as measured with the infrared camera.

3.2.11.2.1 Filters

Filters will be installed downstream of each vapor trap. The filters, depicted in Figure 79, are designed to capture sodium aerosols that were not eliminated by the vapor traps. Each filter contains a finned tubing element to provide additional surface area for aerosols to adhere to, as shown in Figure 80. The additional holes in the finned tube element help to ensure that the unheated filters will not clog during operation, even if the finned section becomes completely filled with solid sodium.

All six filters required for Phase I have been fabricated, radiographed, and pressure tested by Central Shops, as seen in Figure 81.

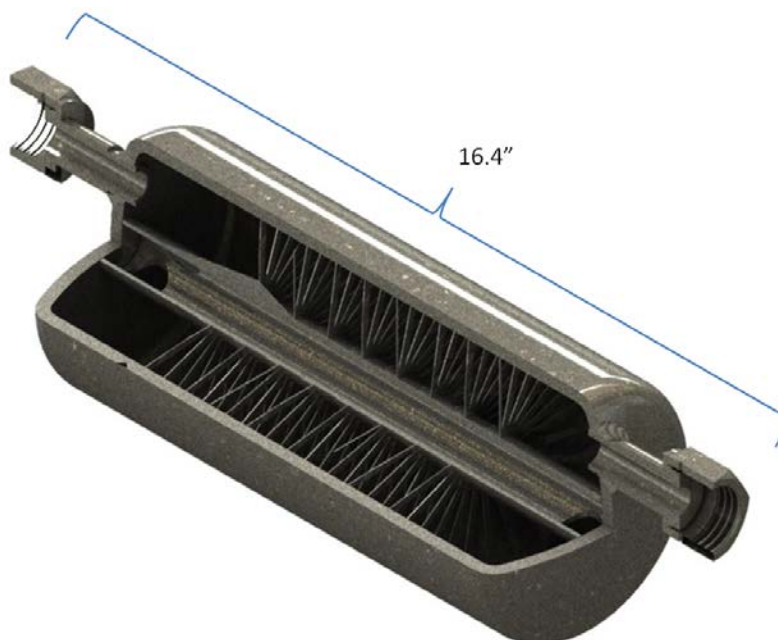


Figure 79 – A 3D model of the filter assembly. The finned tubing element provides surface area for the accumulation of sodium aerosols.

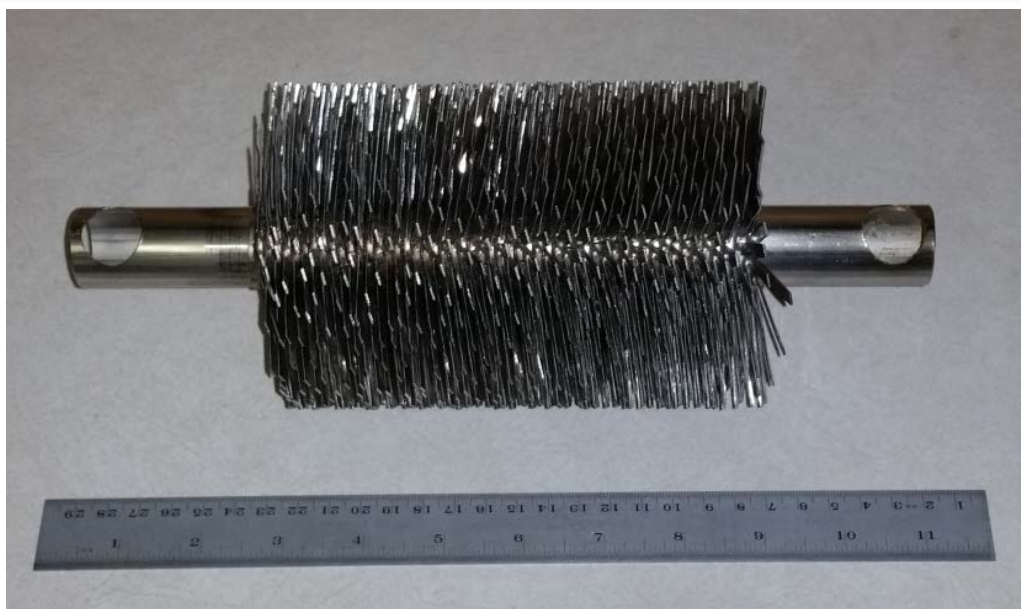


Figure 80 – A photo of the finned tubing element. The additional holes on the ends of the tube ensure that the filter cannot become clogged during operation.



Figure 81 - A photo of the six completed filters required for Phase I.

3.2.11.3 Vacuum Pumps

For the initial cleaning and “bake-out” of vessels as they come online, a dedicated vacuum pump will be temporarily installed next to the vessel. This method will reduce the amount of time required to clean a vessel since conductance losses would be minimized. However, for the typical operation of METL, since the facility will have many components with long distances between them, the overall plan for evacuating components is to use a distributed type vacuum system. The vacuum pumps have not yet been ordered.

3.2.12 *Electromagnetic Pumps & Flowmeters*

All of the electromagnetic (EM) pumps, flowmeters, and control systems that will be used in METL have been delivered to ANL².

3.2.12.1 *Electromagnetic Pumps*

An annular linear induction pump (ALIP) (Model: LA-125, see Figure 82) will be used to push sodium through the main loop and test vessels. Two AC conduction pumps (Model: CA-15, see Figure 83) will control the flow of sodium through plugging meter loop and the cold trap loop. The ALIP will connect to the main loop using 1-1/2" Grayloc fittings while the two conduction pumps will be butt-welded to the 3/4" piping in the purification system.

Frozen sodium within the main EM pump can be melted using the built-in preheating mode, which is equivalent to 20% pump power. This custom preheat mode quickly cycles the VFD between forward and reverse in order to generate heat within the pump without exerting a net force on the sodium. Once the sodium within the pump is liquid, the pump will be operated by changing the settings on a variable frequency drive. For long term experiments, a constant operating condition can be maintained by using CMI Novacast's flow meter and associated control system.

Coil temperature of the ALIP is an important parameter that must be routinely monitored in order to preserve the coil integrity and ensure pump longevity. The pump power supply has an automatic feature that will turn the pump off if thermocouples embedded within the pump body exceed a certain temperature. Additionally, forced air cooling is also provided to the ALIP to help maintain low coil temperatures. Due to the reliability concern when using cooling fans, a safety feature was added to the control system to monitor cooling fan operation. A current transducer monitors the amperage draw for the cooling fans, and if a change is detected (as when a fan stops operating), a warning light is illuminated.

² There was no new work in FY2015 on the pumps and flow meters.

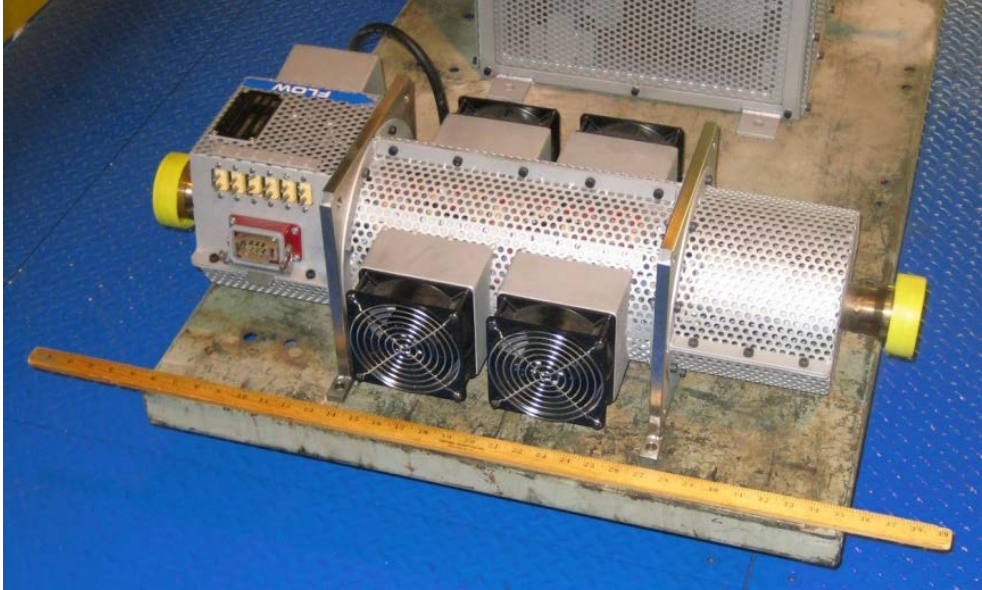


Figure 82 – A photo of the annular linear induction pump (ALIP) that has arrived at ANL. This pump will be installed in the main loop.



Figure 83 – A photo of the two conduction pumps (CA-15) that have arrived at ANL. These two pumps will be used to move sodium through the plugging meter and cold trap.

Specifications of the LA-125:

Mechanical:

- Dimensions: $L = 637$ [mm], $D \leq 425$ [mm]
- Weight: $M \leq 80$ [kg]
- Installation: Orientation only affects drainage, not performance.
- Connections: 1.5" Schedule 40 pipe Grayloc hub
- P_{Max} : 6 [bar] / 90 [psi Δ]

Thermal:

- Cooling: Max ambient temperature = 55 [°C]

Coil temperature should be kept at ≤ 220 [°C].

External fans are built into the design.
- Heating: Resistive heaters can preheat pump to 300 [°F] / 149 [°C]

Power supply provides 3-phase power to drive the induction pump and single-phase to power the trace heater.

Electrical:

- Power Supply: 480 [VAC] / 60 [Hz] / 3-phase

Control methods:

- A variable frequency drive (VFD) will be used to power the pump. The control resolution of the VFD is expected to be $< 1\%$. During normal operation, the flow rate will be measured using the flowmeters provided by CMI Novacast.

Flow:

- The pump can have reverse flow operation. The max flow rate is 10 [gpm]. The pump NPSH is 0.7 [bar-abs] / 10.2 [psia].

Specifications of the CA-15:

Mechanical:

- Dimensions: L = 650 [mm], D = 398 [mm], H = 506 [mm]
- Weight: M = 88 [kg]
- Installation: Orientation only affects drainage, not performance.
- Connections: Butt-welded connection
- P_{Max}: 6 [bar] / 90 [psi Δ]

Thermal:

- Cooling: Maximum ambient temperature 55 [°C]
No forced air cooling required / Current limited to ~ 25 [A]
- Heating: Resistive heaters can preheat pump to 300 [°F] / 149 [°C]

Electrical:

- Power Supply: 240 [VAC] / 60 [Hz] / single-phase.

Flow:

- The pump can have reverse flow operation. The max flow is 2 [gpm].

3.2.12.2 *Electromagnetic Flowmeters*

Two different types of electromagnetic (EM) flowmeters, shown in Figure 84, will monitor the flow through the main loop, cold trap, and plugging meter. Each of the three flowmeters can be coupled to the power supply of the corresponding EM pump to precisely control the sodium flow rate.

The flowmeter for the main EM pump will have a 1-1/2" Grayloc hub on each end. The flowmeters in the purification system will be butt-welded into the 0.75" Sch. 40 piping system.

Flowmeter Requirements:

All flowmeters are rated for minimum of 0 [°F] and maximum of 1112 [°F] / 600 [°C] at a pressure range of 1×10^{-4} Torr (vacuum) to 218 [psig].

Flowmeter in the main loop:

- Flow rate of 10 [gpm] +10% / -0% at pressure of 5 [psi Δ]
- $\pm 2\%$ of the full scale value at 300 [°C]

Flowmeters in the purification system:

- Flow rate of 2 [gpm] +10% / -0% at pressure of 3 [psi Δ]
- $\pm 3.5\%$ of the full scale value at 300 [°C]

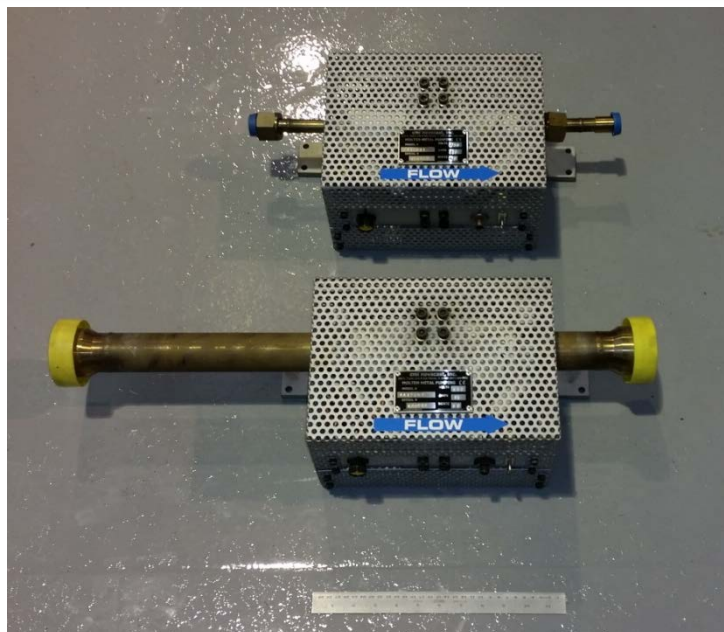


Figure 84 - Picture of the different EM flowmeter models. The top flowmeter will be installed in the purification loop. The bottom flowmeter will be installed in the main loop.

3.2.12.3 Pump & Flowmeter Control Panels

Each pump and flowmeter has a dedicated control and output panel. As shown in Figure 85, the controls for all the pumps and flowmeters were installed during FY2014.



Figure 85 – A photo of the installed control panels for the EM pumps and flowmeters.

3.2.13 Data Acquisition & Control System

During FY2015, the design of the METL piping system was completed. Using the finalized models and piping isometrics, ANL engineers were able to determine the exact quantity and power requirements of all the Phase I heater zones. A scalable, industrial hardware system is currently being designed by an outside vendor to control all of the heaters, valves, and other components that will be installed in METL.

As listed in Table 5, the primary components for Phase I are all CAT6 Ethernet enabled, so a local Ethernet network serves as the backbone for data transfer. CAT6 was selected for its high-speed data transfer capability, up to 1,000 [Mbit/s], which will provide a long term foundation for operator control and data acquisition.

Table 5 – An overview of the primary communications devices for Phase-I METL

Device	Description
Control Cabinet	Houses Mini8s and 240VAC heater zone disconnects
Mini8	PID temperature control for heater zones TC monitoring of heater zones Digital on/off logic for gate valves
PenGUIN display	Firmware based monitoring of Mini8
Analog display	Direct read-out of analogue flow, ΔP , etc., signals
Nat. Instr. cDAQ	Data acquisition of research-related analogue inputs (TC's, flow meters, ΔP , etc), analogue outputs (misc. control valves)
CAT6 hardware	DHCP server and link for CAT6
Central computer	Central access point for viewing, controlling, and logging of entire device suite via LabVIEW

3.2.13.1 Multi-Device Integration

Software communications and primary operator display will be built around LabVIEW, a development environment from National Instruments geared specifically towards data acquisition and experimentation. LabVIEW will be installed on the central control computer in order to provide access to the National Instruments and control systems. The combination of these platforms will create a framework for controlling METL components and logging data.

Due to mission critical demands for safety, functionality, and facility up-time, the data acquisition and control system features both redundant and firmware based systems, as depicted in Figure 86. For example, if a software glitch occurs, the METL operator will still be able to control critical systems via the PenGUIN display. Similarly, in the event of a total display failure, the autonomous Mini8's will continue to operate at their specified set points.

Logging of all these devices, including their user-defined set points, temperature read-outs, and valve position states, will be performed via the LabVIEW software and written to the disk in regular intervals. These log files will first be stored primarily on the local disk, which has been configured in a RAID1 for redundancy. Should any single hard drive fail, the system will continue to operate without interruption or loss of data. For archiving solutions, these files will backup nightly to both a local external hard drive and off-site (i.e. not inside the

Bldg. 308 hi-bay) onto an internal Argonne cluster. An example of the METL communications network is provided below in Figure 86.

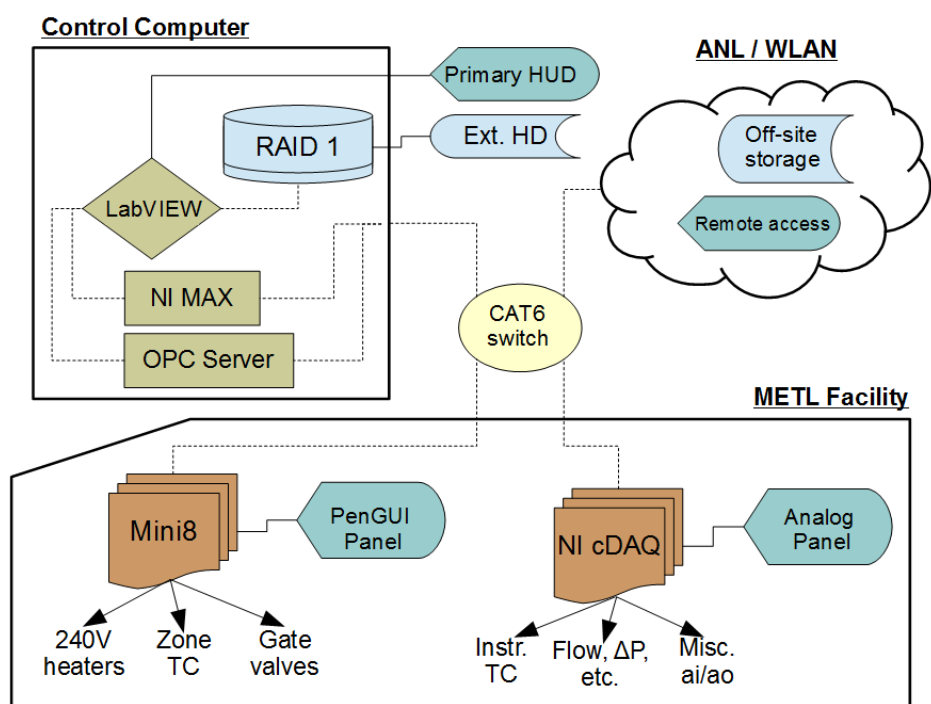


Figure 86 – An example of a communications network that could be used for METL.

3.2.13.2 Heater Control Cabinet

After several internal safety review meetings, ANL engineers have opted to use hardware to provide ground-fault protection of equipment (GFPE). As shown in the simplified wiring diagram below, every heater circuit in the system will be monitored by GFPE hardware with an adjustable set point. Implementing this hardware will ensure the METL power systems comply with NFPA 70-2014.

Additionally, solid state relay (SSR) failure was identified as the most likely type of fault in the power control system. ANL engineers have decided to use ‘intelligent’ or shunt-enabled breakers in each heater zone to provided added protection against runaway heaters should an SSR fail in the ‘closed’ position.

ANL engineers are working closely with the outside vendor to determine the appropriate power and control layout for Phase I METL. An updated quote from the vendor to reflect these changes should arrive early September 2015.

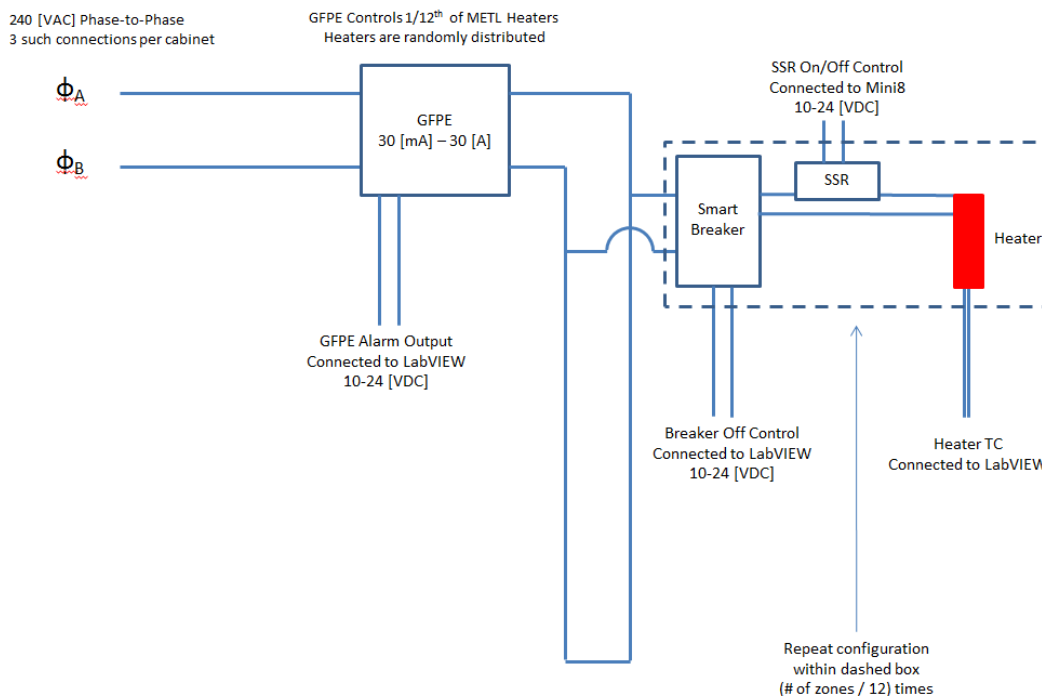


Figure 87 - An illustration showing the METL heater control circuit design.

3.2.13.3 PenGUIN Display Panel

Installed on the exterior of the control cabinet is a standalone display panel that allows communications with the four Mini8 controllers. This panel, while primarily an industrial device for routine monitoring, provides a redundant, robust and fully standalone means to view the condition of METL in the event of any computer crashes. An example of one page, showing valve positions above the dump tank, is shown below in Figure 88.

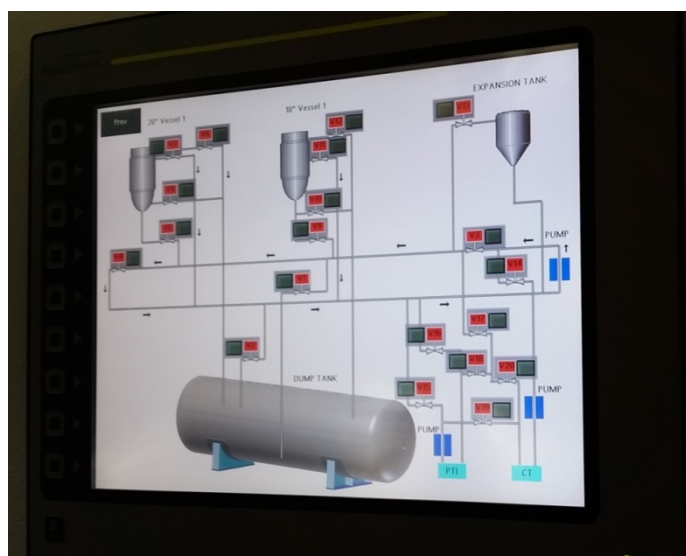


Figure 88 - A photo of the PenGUIN display panel.

3.2.13.4 METL Control Room & iTools / LabVIEW Programming

During FY2015 the control computer and flat-screen displays were installed into the refurbished METL control room, as shown in Figure 89. Additionally, a variety of NI hardware was purchased to accommodate the different types of digital, analog, and thermocouple signals that will be used in METL. A photo of a typical NI chassis can be seen in Figure 90. Twelve of these devices will be installed along the METL mezzanine to provide control, data acquisition, and flexibility for future experiments.



Figure 89 - A photo from within the METL control room. The control room was refurbished during FY2015. The cardboard boxes in the right of the photo are filled with NI hardware.



Figure 90 - A photo of a NI cDAQ-9188XT CompactDAQ Chassis (8-Slot Industrial Ethernet). Twelve of these devices will be installed around the METL mezzanine. A variety of modules with different capabilities can be installed into each slot.

LabVIEW is capable of communicating directly with the Mini8 via an OPC server, which ultimately provides a convenient point for running and logging experiments in METL. The Mini8s feature a hardware flash memory that stores a “recipe”, or programming logic that controls the operation of the device and its individual channels. Using a block-diagram system for programming, users are able to route wires to each of the Mini8’s parameters and create such schemes as PID heater controls, safety limit trip points, or valve logic. An example block diagram for Heater Zone #4, on the Mini8-1, is shown below in Figure 91.

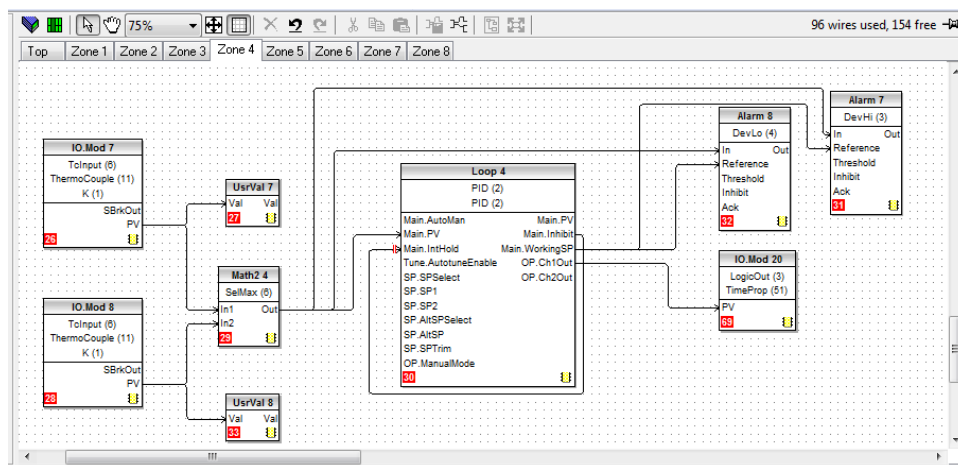


Figure 91 - An example of an iTools recipe, Mini8-1 PID loop.

The development of the LabVIEW system is still in-progress, and current efforts are focused on creating a scalable library system that can accommodate additional needs as the facility

grows. This style of programming, while similar to the iTools block scheme, is more complex but significantly more powerful. An example of polling the local OPC server for the Mini8 values is shown below in Figure 92.

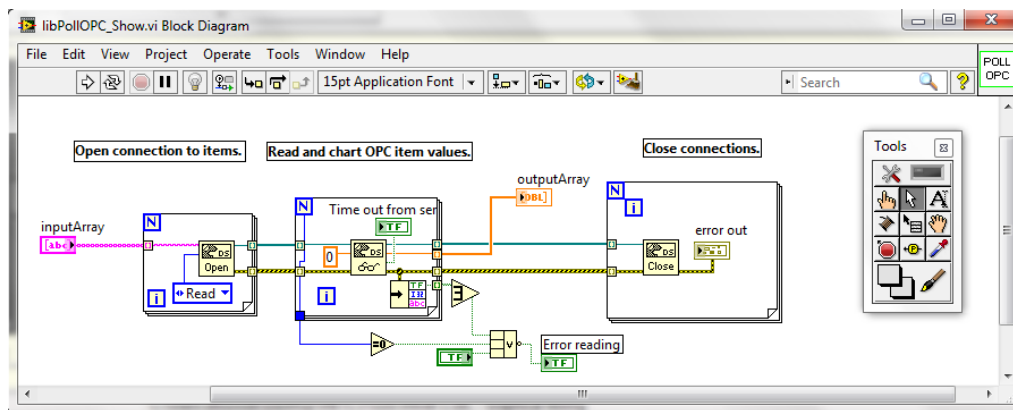
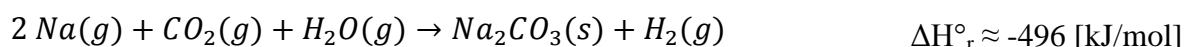
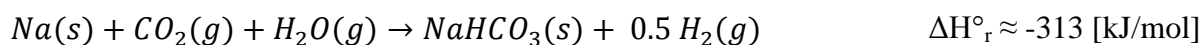


Figure 92 - A LabVIEW block diagram for opening OPC connection and polling Mini8 values

3.2.14 Carbonation System

When components are removed from METL they will be covered in frozen sodium residue. In order to safely and gently react away the unwanted sodium the components will be cleaned using a carbonation system. This process was originally developed by ANL several years ago for the EBR-II deactivation program.

The carbonation process works by bubbling CO₂ through a water column in order to carry trace amount of moisture into a vessel containing the used test articles. The moisture and CO₂ react with the sodium residue in one of the two following processes:



The P&ID of the carbonation system that has been built at ANL can be found in Figure 93. The completed CO₂ bubbler system, shown in Figure 94, is able to hold 7 [gal] of deionized water. Depending on the operating temperature and CO₂ flow rate, the water inventory can be transferred from the carbonation system in 3-4 days.

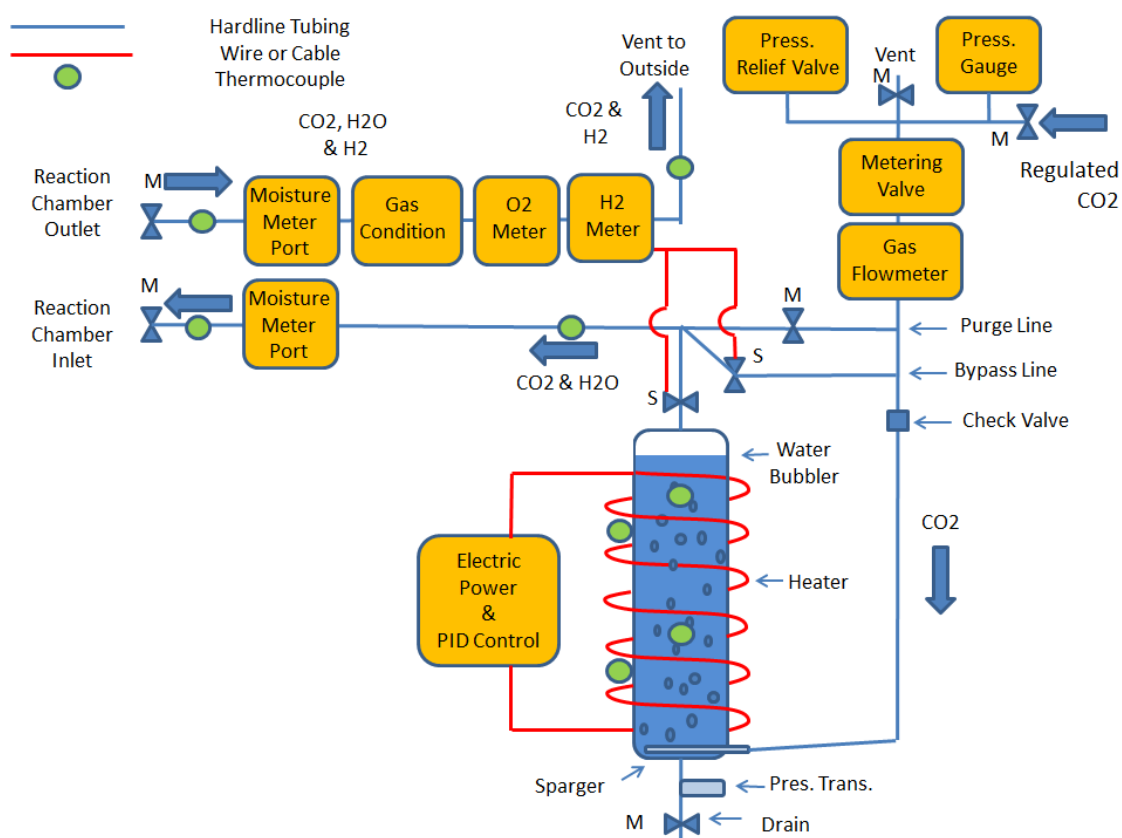


Figure 93 – A P&ID for the carbonation system. (M = manual valve, S = solenoid valve).



Figure 94 – A photo of the completed bubbler for the carbonation system. Carbon dioxide enters through the bottom of the system. Electric heaters will be used to raise the temperature of the water to facilitate increasing the humidity of the water.

3.2.15 Sodium

Fifteen 180 [kg] drums of R-Grade (99.9%) sodium were delivered to ANL. The total volume of this order is about 820 [gal] which is about 6,000 [lbs] of sodium. Currently, the sodium is contained within inerted 55 [gal] drums, as seen in Figure 95.



Figure 95 – A photo of the reactor-grade sodium within 55 [gal] drums. The sodium for METL is currently being stored in the Bldg. 308 hi-bay.

4 Summary

The preceding report provided a summary of the status of the METL facility as of September 2015. A tremendous amount of effort has gone into advancing the design and fabrication of the Phase I facility. A special focus of FY2015 was on the completion of the piping system design for METL. The piping system design forced changes to the nozzles for most of the various vessels as describe above. It was decided to change or reinforce the nozzles instead of increasing the piping length to reduce nozzle loads. This necessitated the repair of the dump tank, expansion tank, and cold trap nozzles. A number of the major parts have arrived and are waiting for installation in METL. Procurement and installation of the remaining Phase I components and systems will continue into FY2016 with the expectation that we will be commissioning METL in late FY2016.

5 Works Cited

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