ANL-ART-73
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Mechanisms Engineering Test Loop – Phase I Status Report – FY2016

Nuclear Engineering Division

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Mechanisms Engineering Test Loop– Phase I Status Report – FY2016

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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 FY2016. Currently, METL is 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 as it will provide invaluable performance data and reduce the risk of failures during plant operation.

METL also provides development opportunities for younger scientists, engineers, and designers who will ultimately lead the advancement of U.S. liquid metal technologies. The hands-on experience with METL, both successes and perceived failures, will ultimately lead to better liquid metal technology programs that can support the commercialization of advanced 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 but is not limited to, sensors for the rapid detection of hydrogen presence 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 sodium 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.

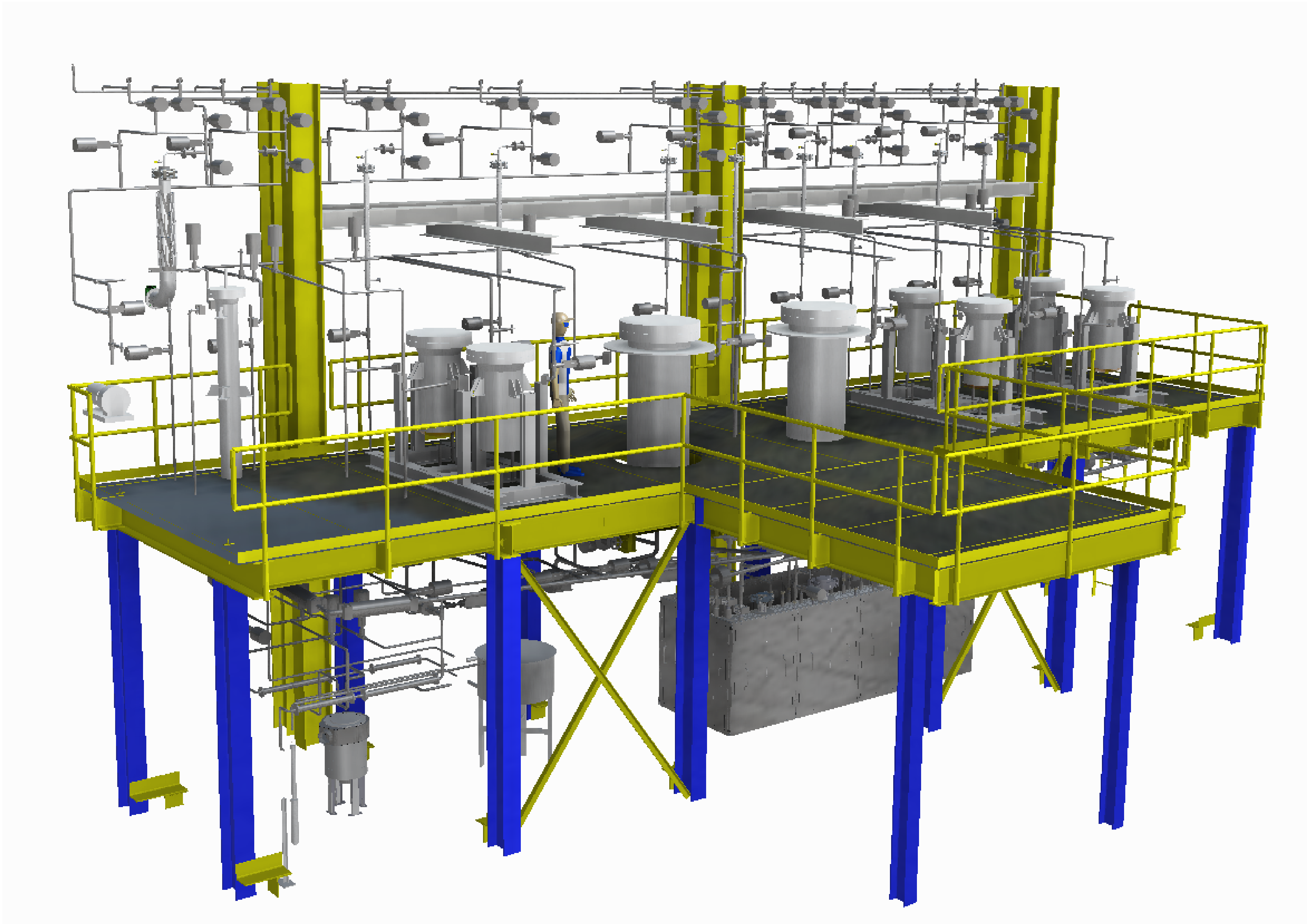

Figure 1 –A 3D model of the Mechanisms Engineering Test Loop showing Phase I and four additional test vessels.

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. Three-Dimensional (3D) models of Phase I can be found below in Figure 2 and Figure 3.

The following list provides a brief summary of the status for the Phase I systems and components as of September 2016:

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 detailed design and analysis for the METL piping system was completed in late 2015. The plumbing design meets the requirements of ASME B31.3-2012 for Category M fluid service.

Piping System Fabrication and Installation - Argonne Central Shops (ANL-CS) coordinated the fabrication, installation, and testing of the METL piping sub-assemblies, supports and system integration. Valves, piping, tubing, fittings, hangers, supports, and other required hardware for Phase I are installed. Additionally, ANL-CS machined all piping subassemblies and installed the finished sections into the Bldg. 308 hi-bay. Welding was performed both on site by ANL-CS and through a local welding and weld inspection company.

Heaters & Thermal Insulation – All of the 300 mineral insulated (MI) cable heaters have been secured to the METL piping system. Ceramic band heaters are to be mounted on the outer walls of the dump tank, test vessels, cold trap, and plugging meter. The contract to insulate the METL piping system and vessels has been awarded to an outside vender. The piping will be insulated using 1" of Cerablanket beneath 2" of Pyrogel XT-E. The Cerablanket is installed underneath the Pyrogel to protect the Pyrogel from excessive heat due to the temperature limitations of this insulation material.

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

Kammer Valves – Twelve 1.5" pipe Kammer/Flowserve valves have been welded into the METL loop.

Swagelok Valves – All Swagelok valves for Phase I have been installed. This includes 40 electro-pneumatic and 58 manual valves. Additional valves for future phases are either on-site or installed.

Pressure Relief Valves – Fourteen "Toter" pressure relief valves (PRVs) are installed into the vapor space of METL. These PRVs have a set-point of 20 [psig] and are capable of operating at 1200 [°F].

Dump Tank – The 800 [gal] dump tank was shipped to Northland Stainless in order to have the nozzles reinforced. The nozzle loads were calculated using CAESAR-II, an industry standard software package for piping analysis. Post-manufacturing, the calculated nozzle loads exceeded the load allowed for the existing dump tank. Therefore, the dump tank was shipped to the original manufacturer for nozzle reinforcement. The dump tank has reinforced nozzles to withstand the forces attributed to thermal expansion and is installed into the piping system. Lastly, the thermocouples have been tack-welded into position.

Expansion Tank – The expansion tank was also shipped to Northland Stainless to weld on stronger nozzles. The expansion tank had its' nozzles reinforced and is installed into METL as well. Expansion tank thermocouples have been tack-welded in place as well.

Cold Trap – The cold trap nozzles were reinforced by an outside vendor. The cold trap has been repaired, re-certified, returned to Argonne, and is installed into the METL piping system. The cold trap has its' thermocouples and MI cable heaters installed.

Economizer – The vendor completed and delivered the economizer. The economizer is designed to be installed between the cold trap and the main loop as a sodium-to-sodium heat exchanger. At 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]. The economizer has been installed into the METL piping system and is equipped with thermocouples and MI cable heaters.

Plugging Meter – The plugging meter and its' respective equipment (thermocouples, ceramic band heaters, MI cable heaters, ambient air blower, air duct, and variable frequency drive) has been installed.

Test Vessels – A bid package for new test vessels was sent to several manufacturers. In May 2015, Northland Stainless was awarded the contract to fabricate the two 18" vessels and two 28" vessels for the Phase I. Northland Stainless is the manufacturer of the dump tank and the expansion tank. The two 18" vessels required additional nozzle bracing as well. All of the test vessels were delivered to Argonne in May 2016. Three of the four vessels are installed.

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. The inert gas system has been connected to METL and all fifty-two electro-pneumatic valves.

Vapor Traps & Filters – The filters and vapor traps for METL have been fabricated by ANL-CS. The dump tank vapor trap was fabricated by an outside vendor. The filters are located downstream of the vapor traps and are the final sodium aerosol filters before the inert gas stream exits the building. All six vapor traps and filters are installed into the downstream system of METL.

Pumps & Flowmeters – All of the electromagnetic pumps and flowmeters have been fabricated, calibrated, and delivered to Argonne. 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. All of the electromagnetic pumps and flowmeters are installed.

Data Acquisition & Control System – Eurotherm control cabinets were designed to control the heaters and automatic valves within METL. Eurotherm control cabinets have been delivered to Argonne and are currently being installed. An operator can adjust the Eurotherm output by using either a touch-screen interface or a LabVIEW system that communicates to the Eurotherm via Ethernet. All of the National Instruments data acquisition enclosures have been fabricated by Argonne engineers. Additionally, all of the thermocouple umbilical enclosures have been installed and routed.

Carbonation Process – A sodium removal system has been designed and fabricated by Argonne. 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.

Sodium – 800 [gal] of sodium has been delivered from MSSA. Currently, the sodium is in the Bldg. 308 hi-bay and is contained within sixteen separate steel 55 [gal] drums. A procedure has been developed and equipment was purchased to transfer the sodium from the individual drums into the dump tank.

Flexi-Cask System – A "Flexi-Cask" system has been fabricated by a local vendor to allow for the insertion and removal of test assemblies from METL test vessels without allowing the atmosphere 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. Preliminary flexi-cask demonstrations have begun.

Bldg. 308 Maintenance – A new waterproof membrane was installed on top of the Bldg. 308 hi-bay. Additionally, the exterior of the Bldg. 308 hi-bay was given a new coat of weather-proof epoxy.

1.3 Acknowledgement

This research was sponsored by the U.S. Department of Energy, Office of Nuclear Energy, for the Advanced Reactor Technologies (ART) Research and Development Program under Contract DE-AC02-06CH11357. We gratefully acknowledge the support provided by Carl Sink of DOE-NE, Advanced Reactor Technologies, R&D Program Manager; Thomas Sowinski of DOE-NE, Advanced Reactor Technologies, Fast Reactor Manager; Steven Reeves, Advanced Reactor Technologies; and Robert Hill of Argonne National Laboratory, ART R&D Co-National Technical Director.

The METL team would like to extend their gratitude to Argonne's Central Shops. The Phase I installation of the METL piping system was greatly facilitated by the leadership and coordinated efforts of William Toter and Robert Sommers of Argonne's Central Shops. In addition, we gratefully acknowledge the outstanding welding capabilities of Damon Simpson, Robert Sommers, and Daniel Berkland; whose welds passed radiography and dye penetrant testing every time.

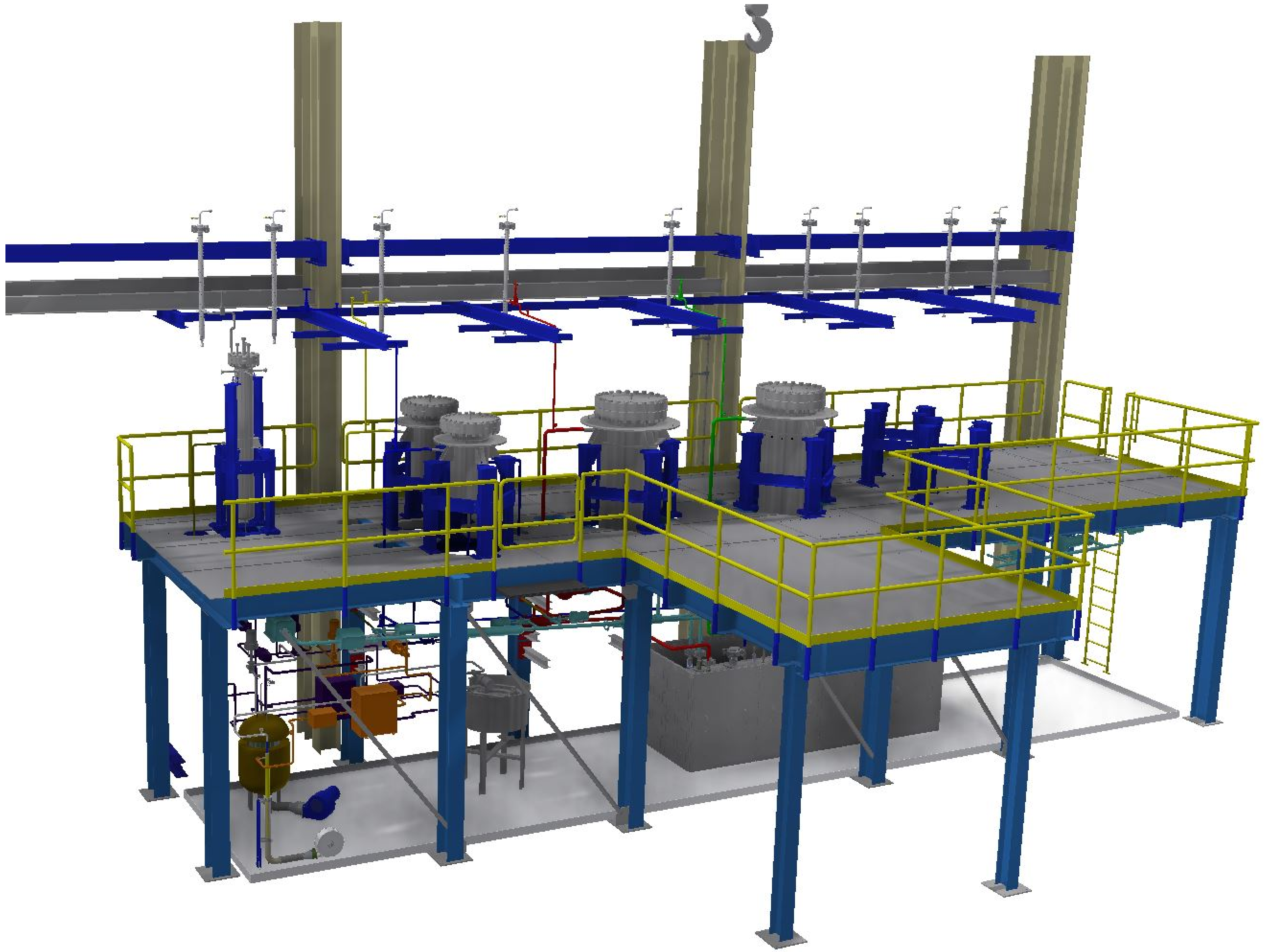

Figure 2 – A 3D model of METL after Phase I is complete.

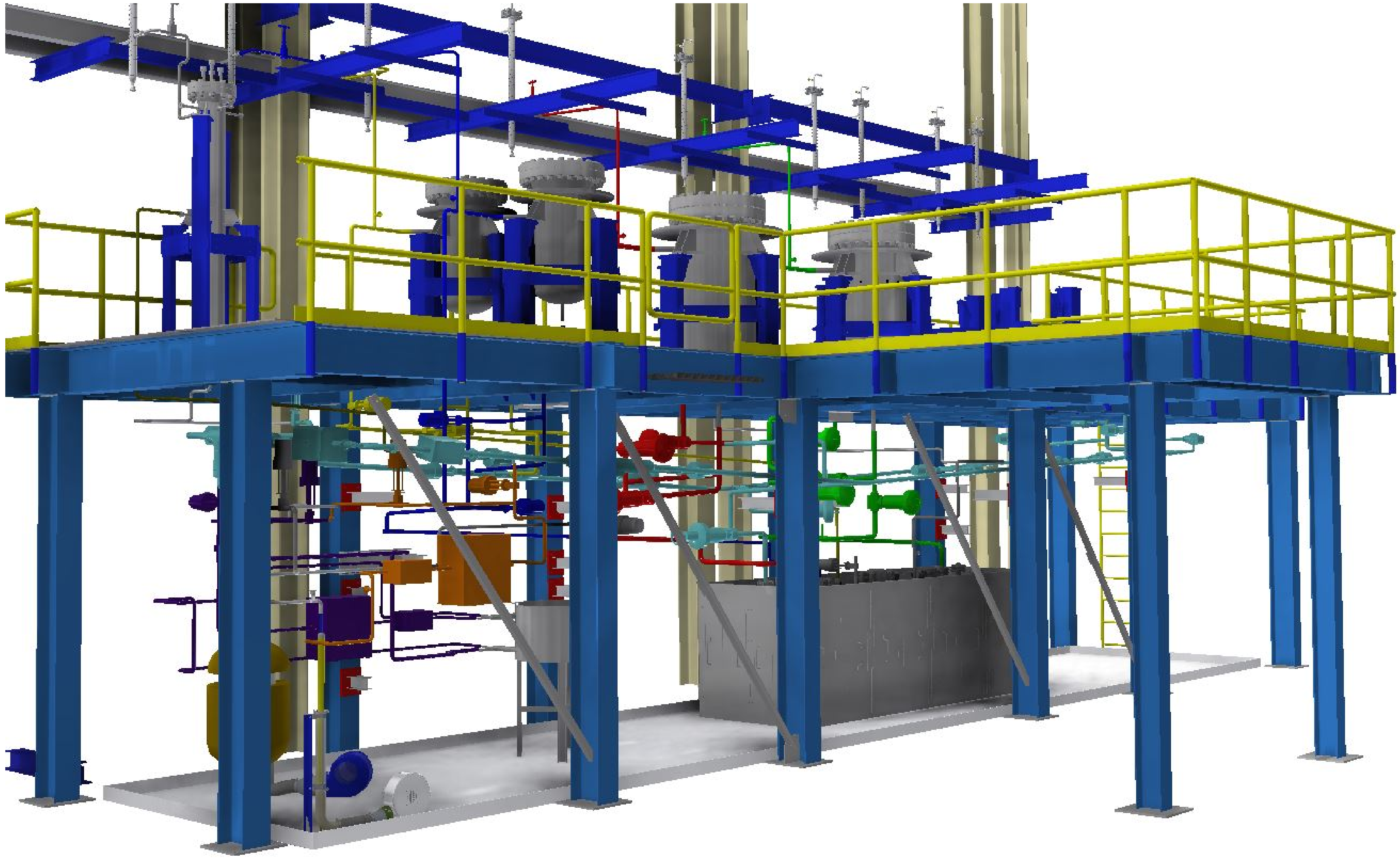

Figure 3 - A 3D model showing the Phase I piping and equipment arrangement underneath the mezzanine.

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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 many 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 striping 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 Phase I for the 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 (e.g., a heat exchanger), 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/m^3] to ~825 [kg/m^3] when heated from 208 [°F] to 1000 [°F]. The additional 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.

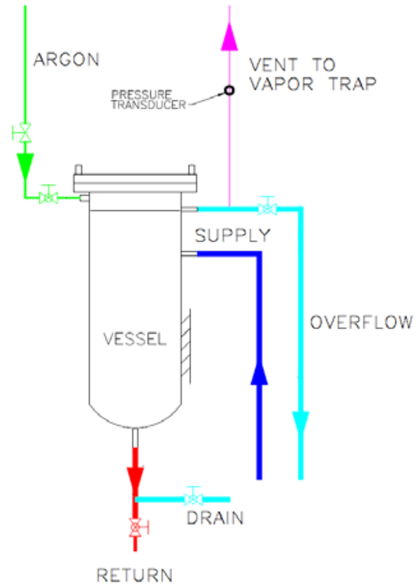

Figure 4 - A depiction of the various test vessel connections and their orientation.

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 Argonne 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 looking West to East. 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 in a flat position using a series of large tabs, as shown in Figure 7, mounted to the mezzanine columns. 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

A vendor was contracted to design the METL piping system in February 2014. Argonne received the final package of deliverables from the vendor in May and June 2015. Their scope of work was completed and the contract was closed out in February of 2016. According to their scope of work, the vendor was responsible for:

a) Designing the entire METL piping system (not just Phase I) to meet Argonne technical requirements and ASME B31.3-2012 for Category M fluid service.

b) Developing the piping and valve support systems.

c) Creation of all drawings required for a fabricator to build the piping system.

The current piping configuration is reflected in Figures 1, 2, and 3. 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.

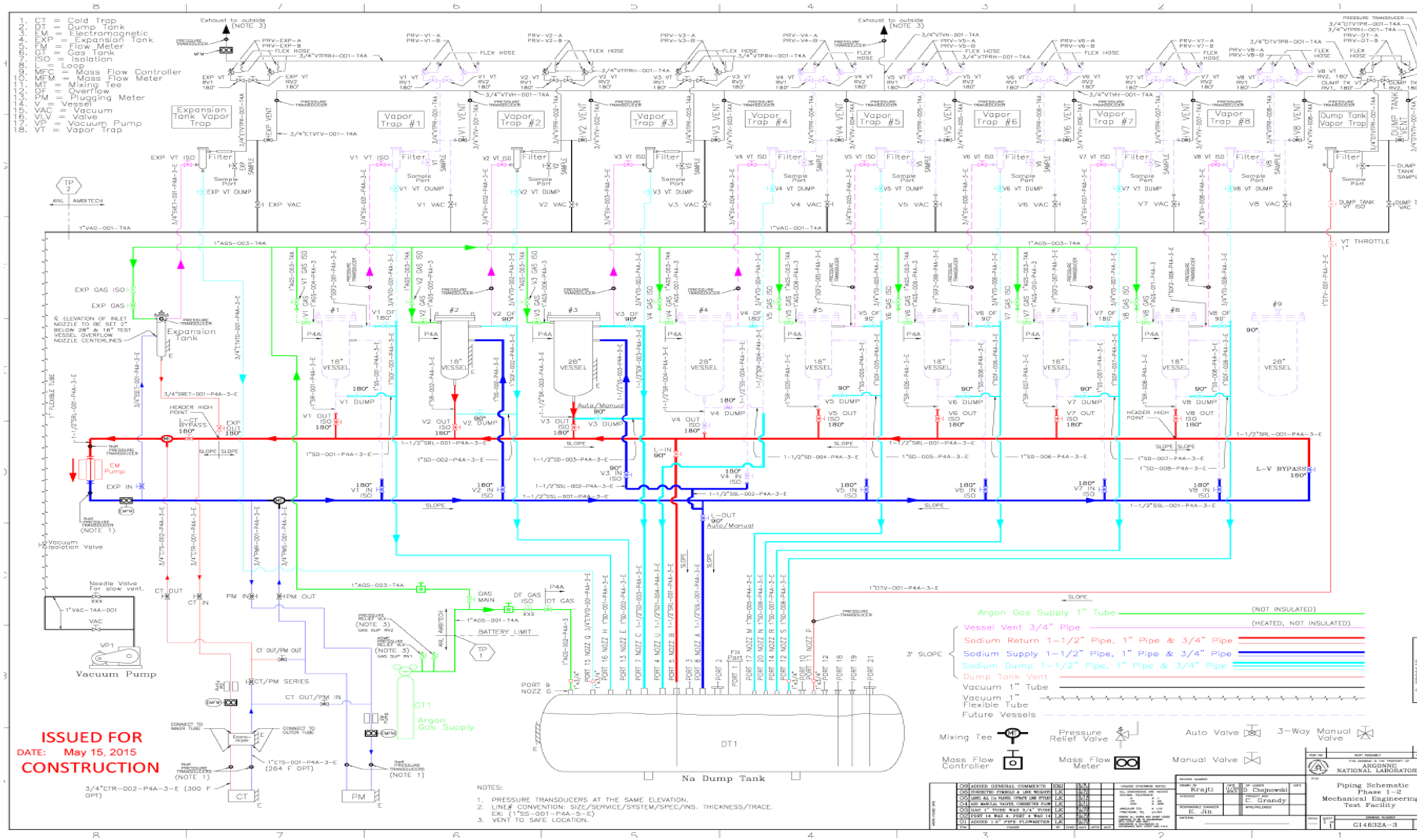

Figure 8 - The METL P&ID that was issued for construction by Ambitech.

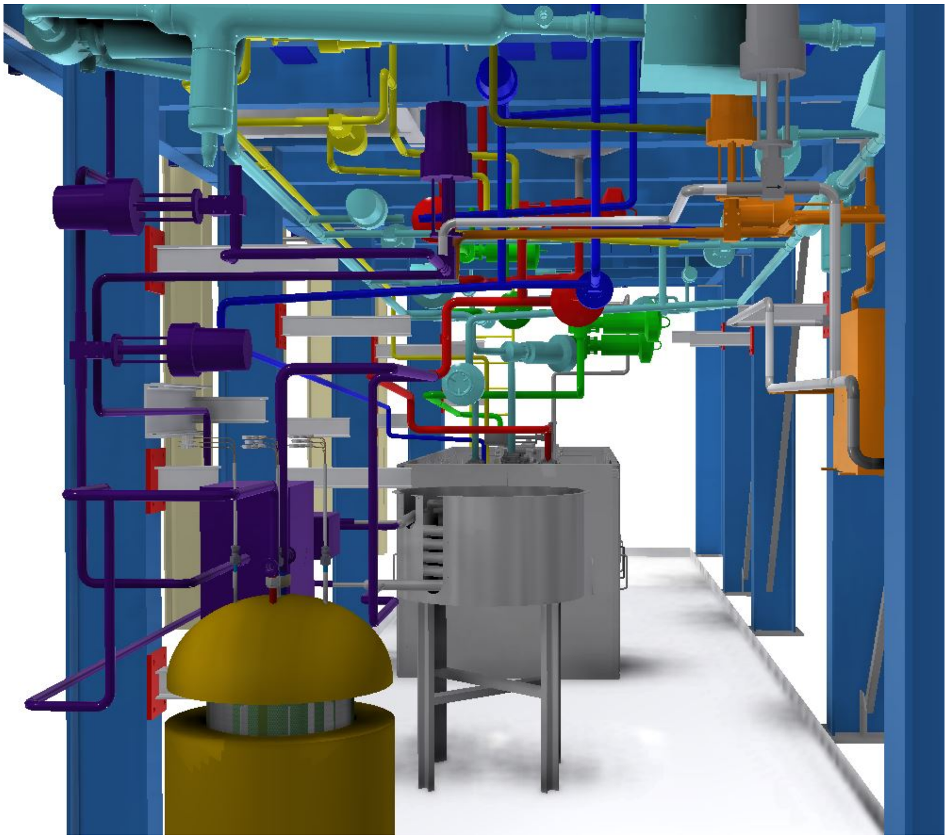

Figure 9 - A 3D model of the uninsulated Phase I piping system beneath the mezzanine. (View faces east.)

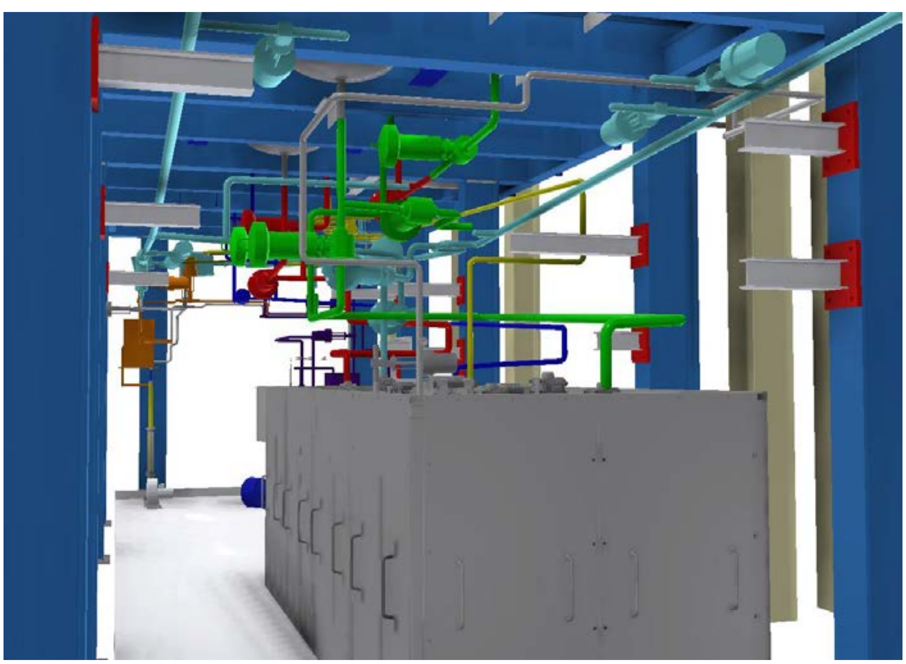

Figure 10 - A 3D model of the uninsulated Phase I piping system beneath the mezzanine. (View faces west).

3.2.2.2 Piping & Hardware

All of the piping, pipe fittings, and hangers/supports required for Phase I have been delivered to Argonne and installed. The METL piping system is constructed from seamless 316/316L piping and tubing.

The seamless 316/316L piping, shown in Figure 11, was delivered by a vendor 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 were machined with a custom ‘J’-groove in preparation for the automatic welding procedure. Prior to welding, all piping and fittings were cleaned using custom tanks filled with Citranox, as shown in Figure 13.

All 78 of the custom-engineered ‘spring can’ supports (Figure 14) for the final phase of METL were delivered. Figure 15 through 18 demonstrate different types of hangers and supports that were used to support the METL piping system. All support hardware was connected to the piping using lugs or shoes, which are depicted in Figure 16 and Figure 17

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

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

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

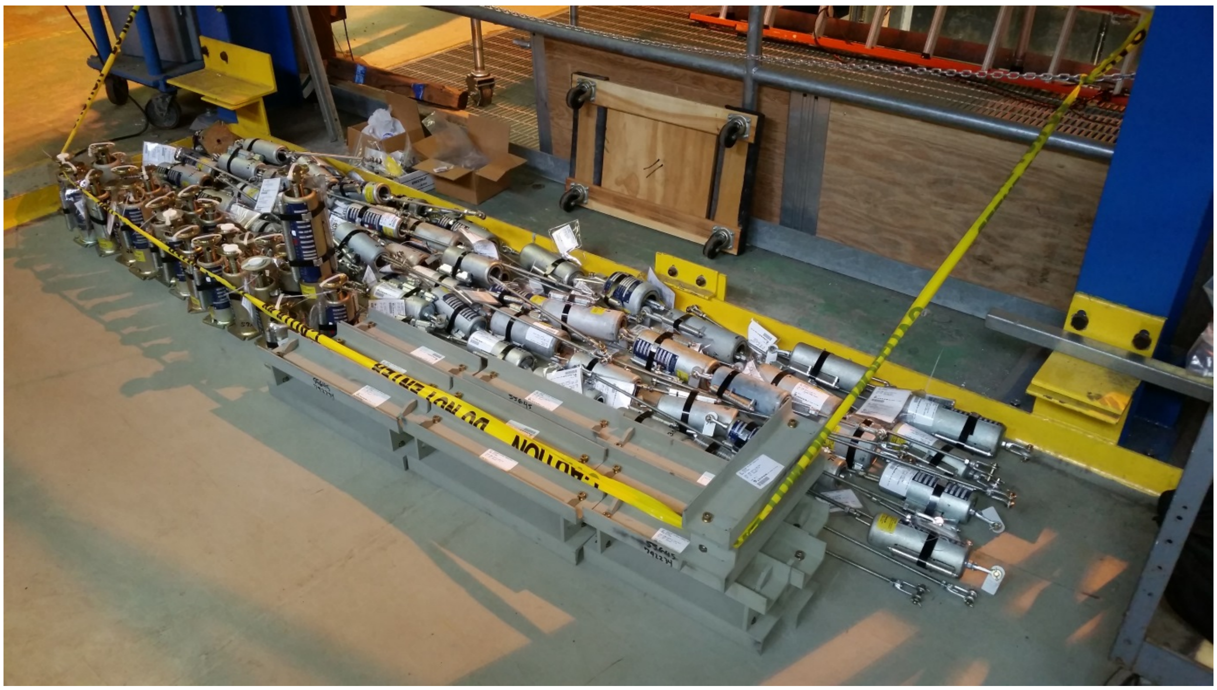

Figure 14 - A photo of the METL piping hangers and support.

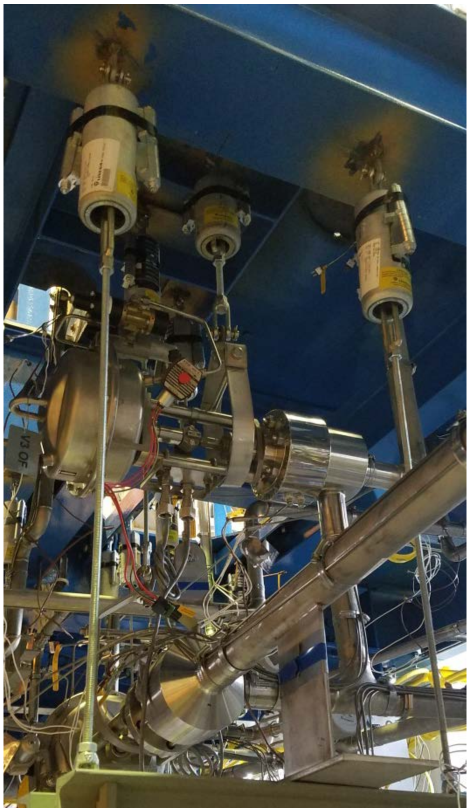

Figure 15 – Picture of the piping supports. The spring can hangers are welded to the support steel underneath the mezzanine.

Figure 16 - A photo of a pipe lug that is connected to the spring can.

Figure 17 - A picture of a pipe shoe that is supporting a section of the piping from underneath.

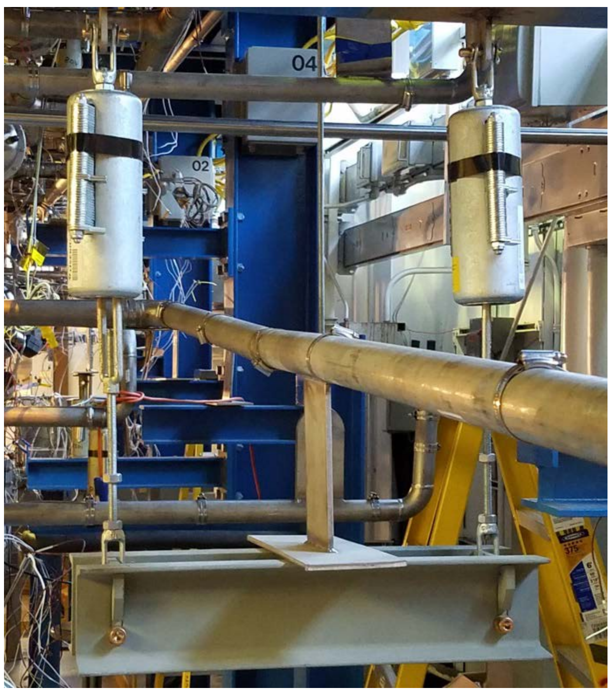

Figure 18 – A section of the METL piping being supported by a trapeze via spring cans.

3.2.2.3 Pipe Fabrication & Installation

ANL-CS has completed the installation of the pipe hanger support steel located below the mezzanine, as shown in Figure 19. Additionally, ANL-CS has finished the fabrication of the horizontal support steel and pedestal supports for the piping system and/or equipment, shown in Figure 20.

Pipe and pipe fittings were machined by ANL-CS according to the piping isometric drawings, depicted in Figure 21. Pipe subassemblies were welded by both ANL-CS and a local vendor. Any piping weld that is expected to be exposed to liquid sodium underwent radiographic non-destructive examination, which exceeds the 20% inspection requirement according to ASME B313.3 piping code requirements for Class M fluids. Examination of the welds was performed onsite by a vendor and off site at another vendor's quality control facilities. Additionally, Argonne Quality Assurance (QA) inspected all of the field welds utilizing dye penetrant. All of the welds have passed radiography and dye penetrant testing. The results of the qualified welding procedure are shown in Figure 22.

Figure 19 - 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 ½"-13 fasteners. (Note: all welds will be repainted before piping assemblies are installed.)

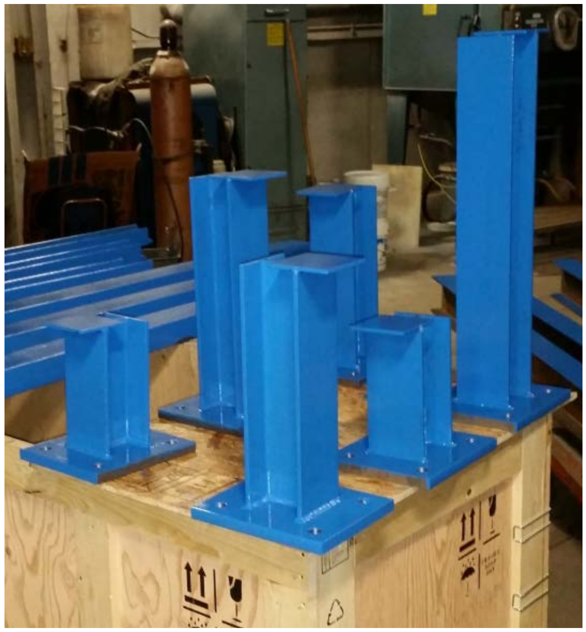

Figure 20 - A photo of the horizontal piping supports prior to installation. These supports will be bolted to the vertical columns beneath the mezzanine.

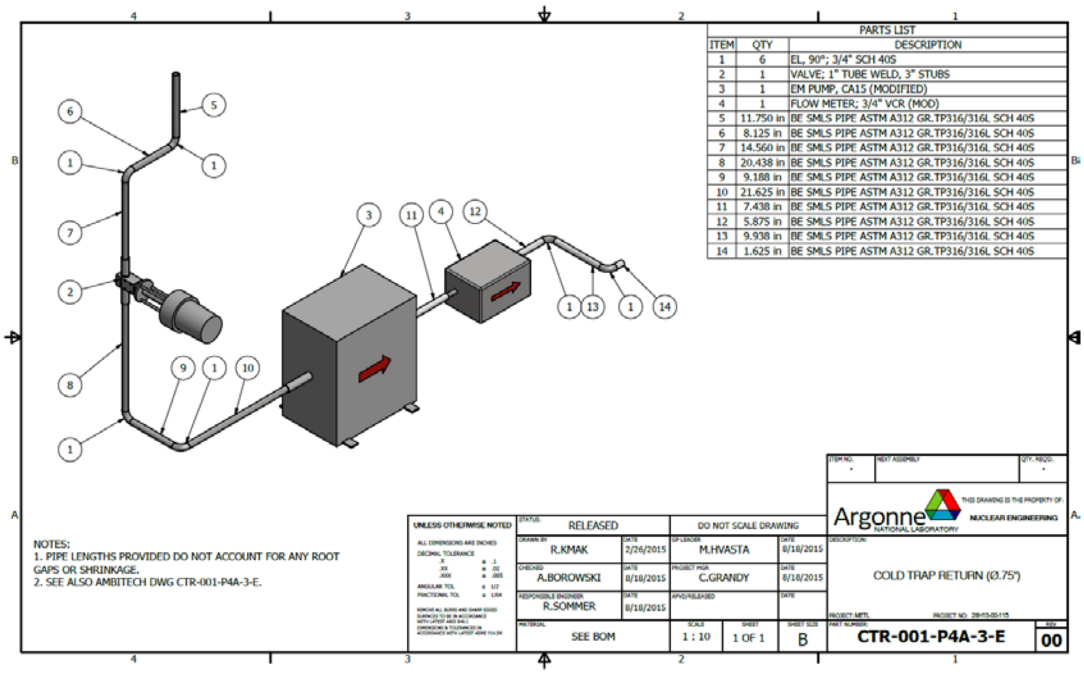

Figure 21 - A sample piping ISO produced by ANL. This updated ISO is based on Ambitech drawings but gives Central Shops the required dimensions of the piping and equipment prior to installation.

Figure 22 - 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 Pipe to Tube Transitions and Reinforcements

Tubes and pipes were used to construct the METL piping system as they are readily available in stainless steel and are both suitible for sodium service. However, the sizing designation between tube and pipe is quite different. Tubing size is specified by an outside diameter and wall thickness (e.g. 1” - 065 tube is a piece of tubing with a 1” outside diameter and a 0.065” wall thickness. Piping is specified by schedule and pipe size but is less intuitive than tubing (e.g. 1” schedule 40 pipe has an outside diameter of 1.315” and a wall thickness of 0.133”).

The fact that 1 inch tubing and 1 inch pipe have different dimensions led to the creation of pipe to tube transitions (Figure 23). Due to stress caused by different operating conditions of METL, a few sections of pipe to tube transitions needed extra material welded on as a reinforcment. These reinforcements ensured the transitions would be able to withstand the thermal expansion stresses. An example of a transition reinforcement is presented below in Figure 24.

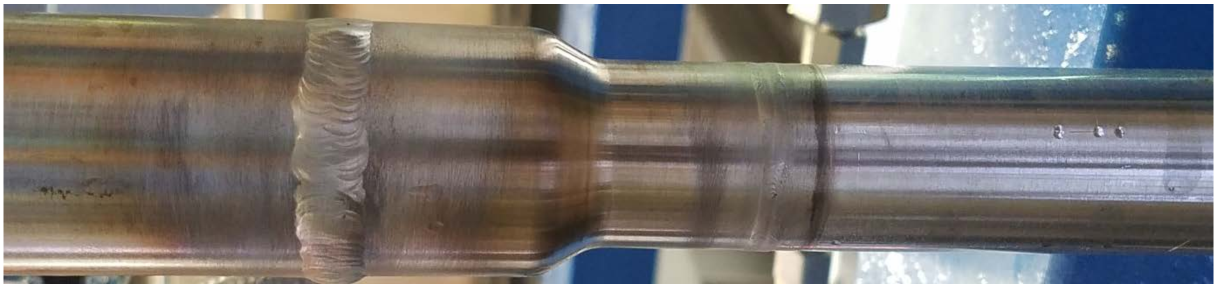

Figure 23 – A 1in pipe to 1in tube transition.

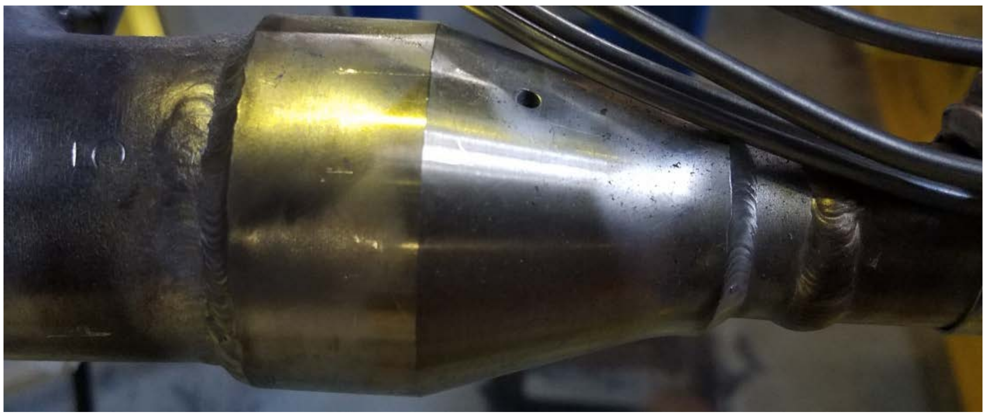

Figure 24 – Reinforced pipe to tube transition.

3.2.2.5 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 (Figure 27).

During FY2014, Argonne engineers talked to mineral insulated (MI) cable heater manufacturers to discuss the METL trace heating design. Conversations with 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 25, 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' length of empty 1.5" Schedule 40 pipe and then wrapped in ceramic-blanket insulation. These two 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 26.

In FY2015, the piping design was completed by the vendor and Argonne engineers were able to plan the MI cable heater zone layout using the finalized 3D models. Guidance for determining heater zone parameters was provided by the former Manager of the Energy Technology Engineering Center. Using the guidelines to size the heater zones on the sodium-filled pipe, it was determined that Phase I piping will require 136 heater zones. The heater zones and their respective process control thermocouples were determined by adhering to the following rules.

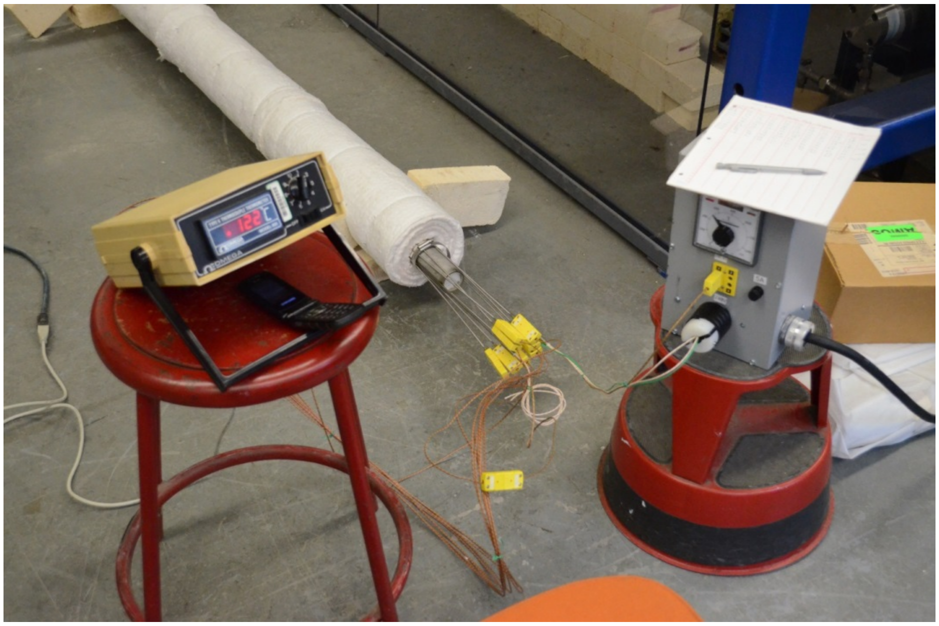

Figure 25 - A photo of the insulated MI cable heater test setup. Thermally insulating fire-bricks were used to keep the piping off the ground. This picture shows the pipe wrapped in ~ 2.5" of Morgan Thermal Ceramic insulation

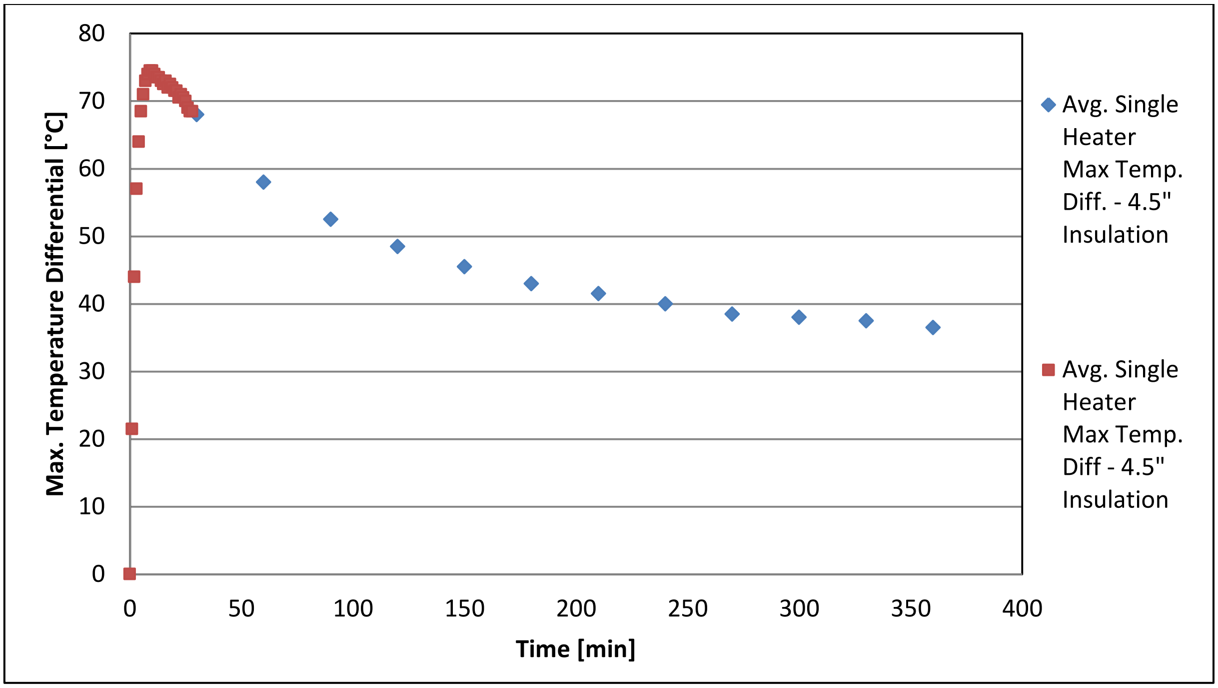

Figure 26 – The maximum measured temperature difference the heated 1.5" Schedule 40 pipe using a single heater. This temperature differential was achieved by leaving a single heater in the 'on' position.

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]

In FY2016, Phase I of the METL plumbing system was broken into 136 individual heater zones of various lengths. Heater zones less than 18 [in] could not be supplied with 240VAC so two 120VAC cable heaters were installed in their place. Also, each zone has a second MI cable heater for redundancy. Therefore, the METL piping system has 352 MI cable heaters, 352 internal type K monitoring thermocouples, and 229 process control thermocouples. An example of the MI cable heater and process control thermocouple installation is illustrated below in Figure 27.

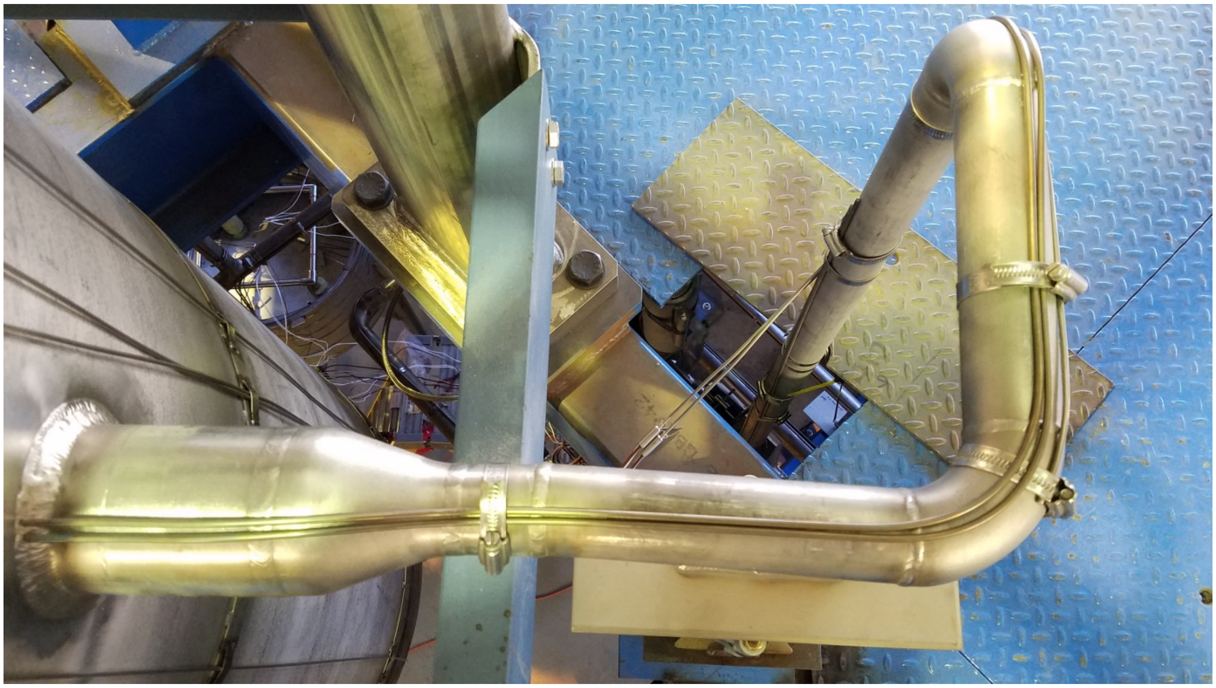

Figure 27 – MI Cable heater and type-K process thermocouple banded onto the outer wall of a segment of the METL plumbing system.

The piping system heater zones first had their process control thermocouples strapped to the piping zone via 316 stainless steel hose clamps. Then the MI cable heaters were strapped to the piping zone utilizing 316 stainless steel hose clamps, following a similar path as the aforementioned thermocouple. This allows for a close contact between the control thermocouple and the pipe as well as increased longevity of the MI cable heater during thermal expansion and contraction. As illustrated in Figure 28, the piping has thermocouples and MI cable heaters strapped to the outer diameter which will then be surrounded by 1 [in] of cerablanket and 2 [in] of pyrogel insulation.

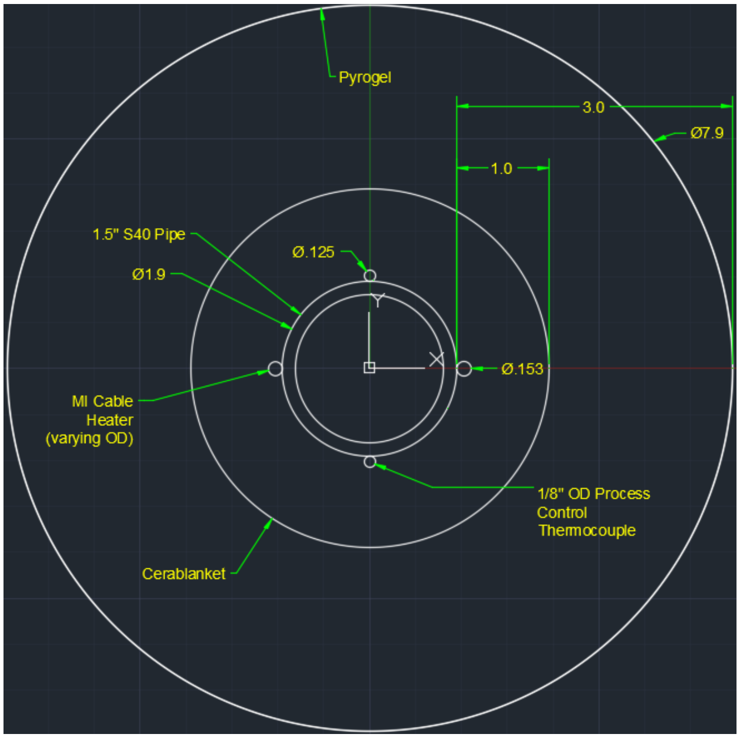

Figure 28 – Pipe Installation with process control thermocouples, MI cable heaters, cerablanket insulation, and pyrogel insulation.

3.2.2.6 Piping Insulation

Argonne 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 29 and Figure 30, using advanced insulating materials such as Pyrogel XT-E instead of traditional insulation like mineral wool or calcium silicate (CalSil) 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. Given the high demand for Pyrogel XT-E and the expected lead time for the insulation (about six months), the insulation was ordered in advance and is now on-site at Argonne.

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 31, 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 Argonne. This investigation confirmed the high-temperature stability of 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. (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

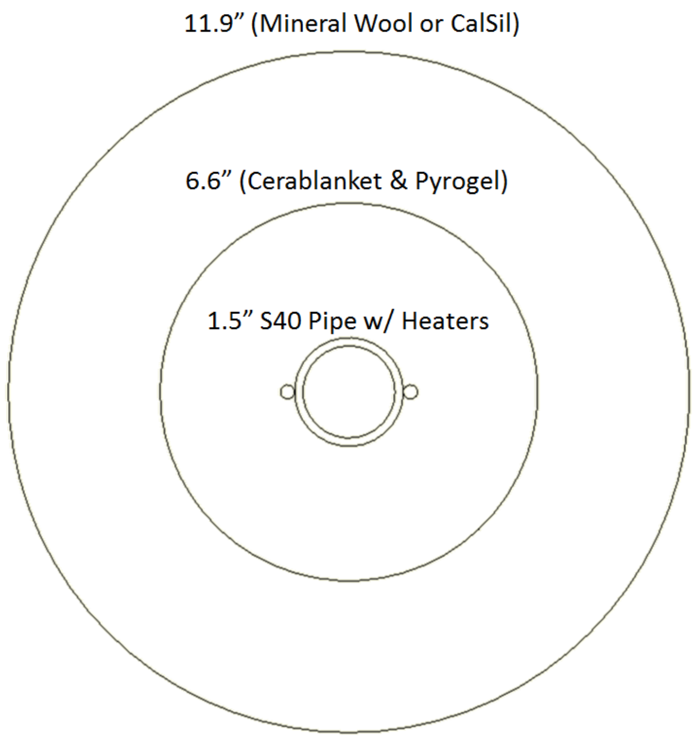

Figure 29 – A comparison of the required insulation thicknesses using different types of insulation. Thicknesses were calculated assuming an operating temperature of 1000 [°F] and a heater power input of 60 [W/ft]. Pyrogel XT-E has a maximum operating temperature of 1200 [°F] so a 1" layer of Cerablanket must be placed between the Pyrogel XT-E and the MI cable heaters.

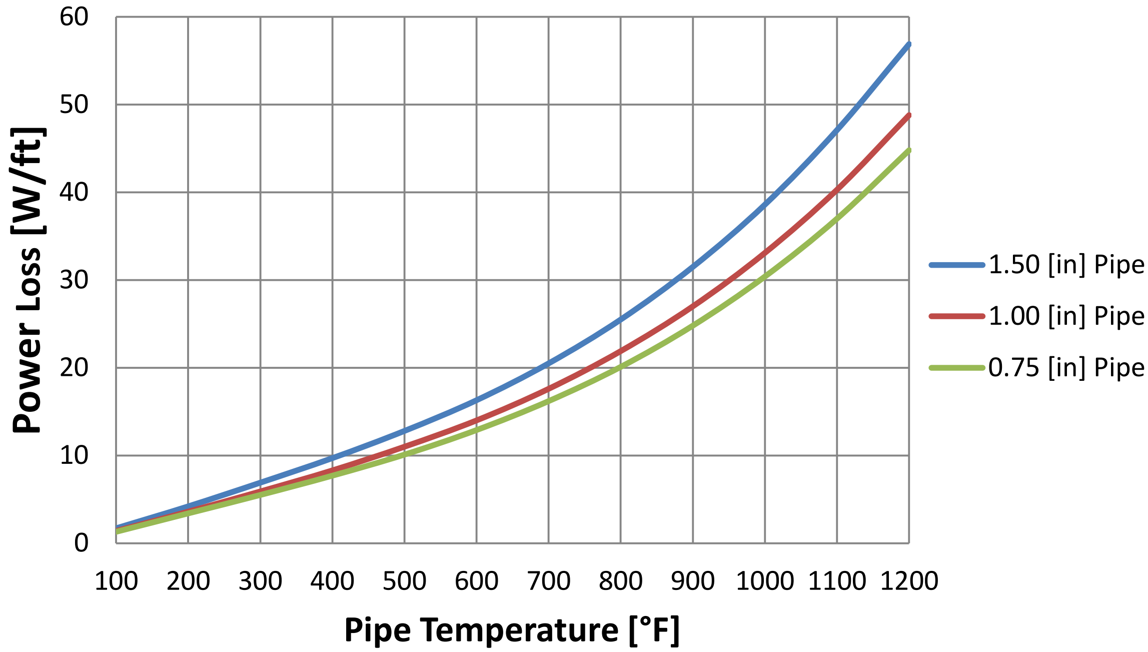

Figure 30 – The predicted METL piping thermal losses using 1" Cerablanket + 2" Pyrogel. The ambient temperature was assumed to be 32 [°F].

Figure 31 – 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, Argonne 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 (see Figure 34)

Figure 32 shows a drawing of the straight (180°) valve with actuator and Figure 33 shows the angle (90°) valve with actuator. Kammer valves are used on equipment which has 1-1/2” piping. Currently, this includes the two 28” test vessels. There are a total of twelve Kammer valves; seven 180° straight valves and seven 90° valves. Since, each valve is a unique heater zone; the Kammer valves have two ceramic band heaters strapped to them (Figure 36).

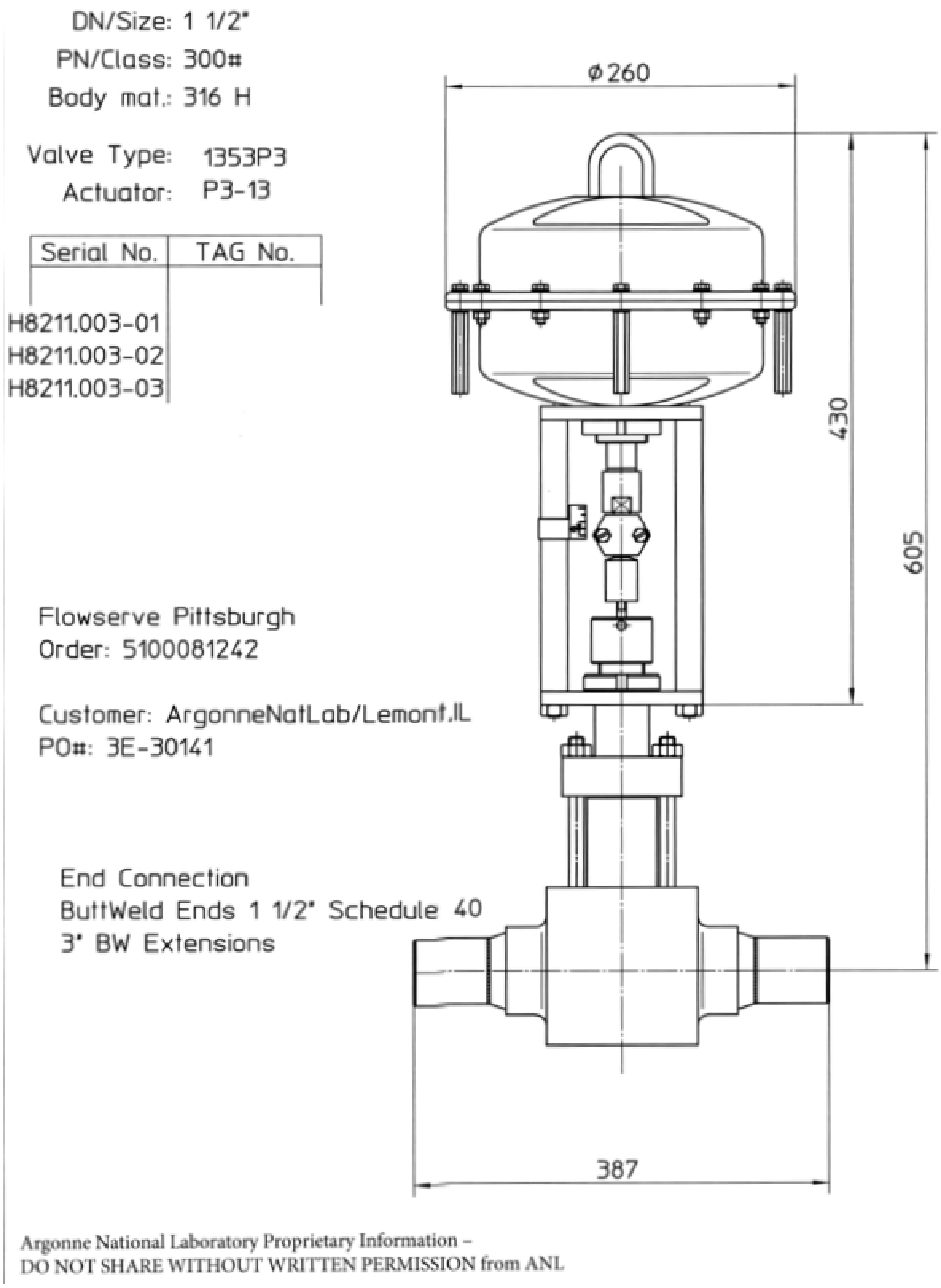

Figure 32 – The cut sheet for the straight Kammer valve.

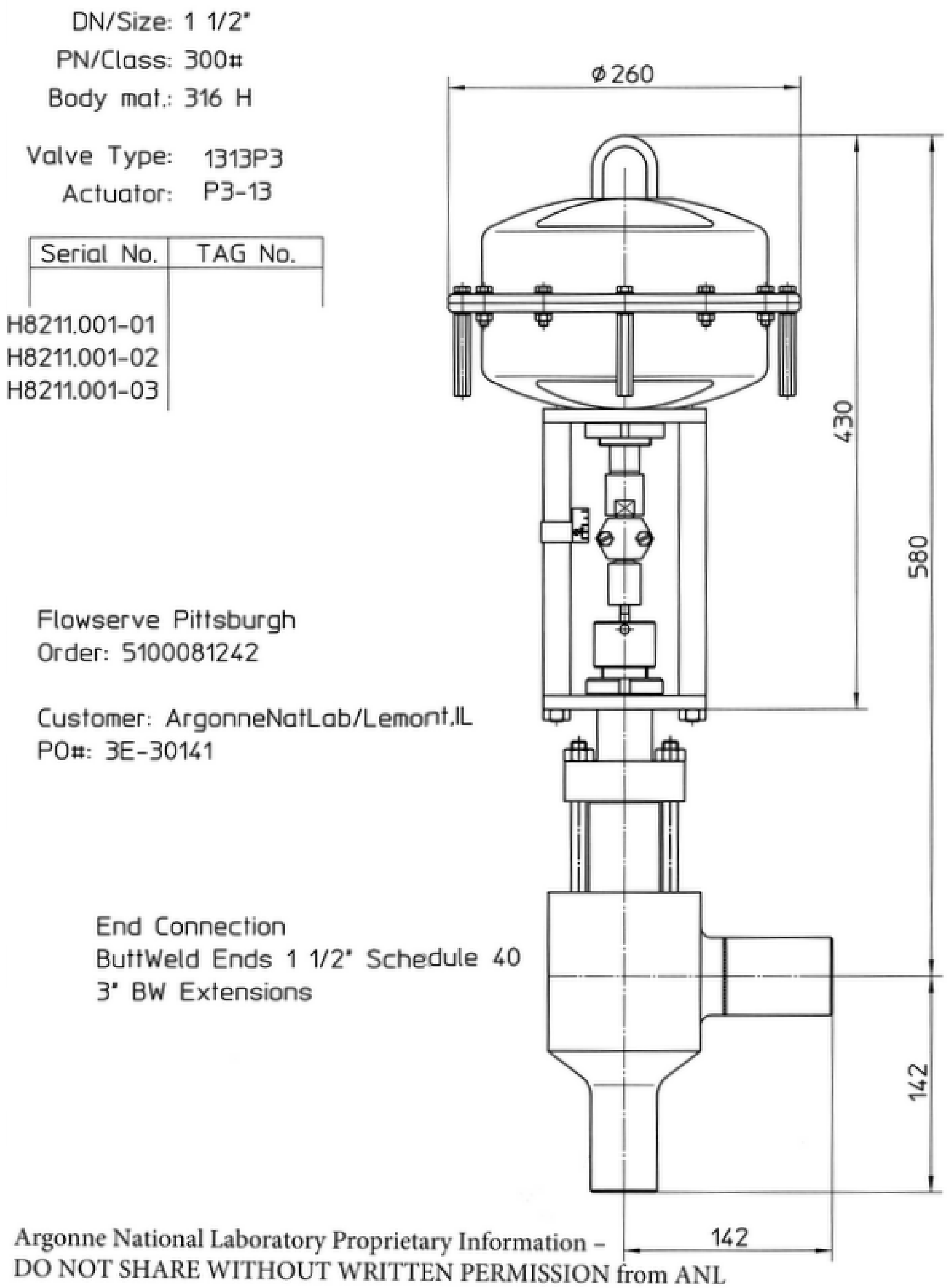

Figure 33 – The cut sheet for the 90° Kammer valve.

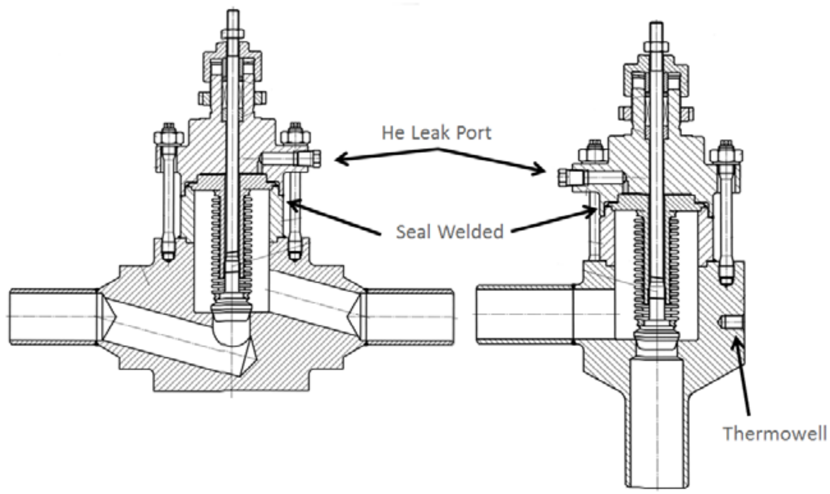

Figure 34 - A depiction of the submerged welded bellows within the Kammer valves. Sodium flowing past the submerged bellows will reduce the chances of impurity buildup.

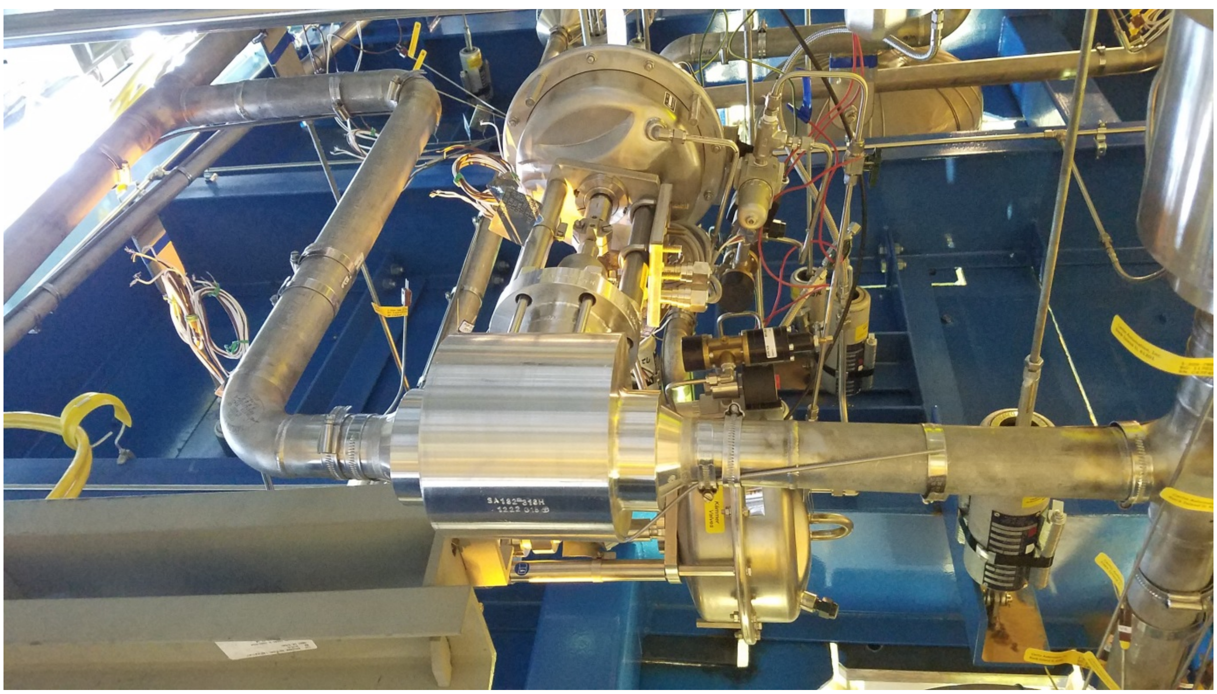

Figure 35 – A photo of a Kammer 1.5” straight valve installed.

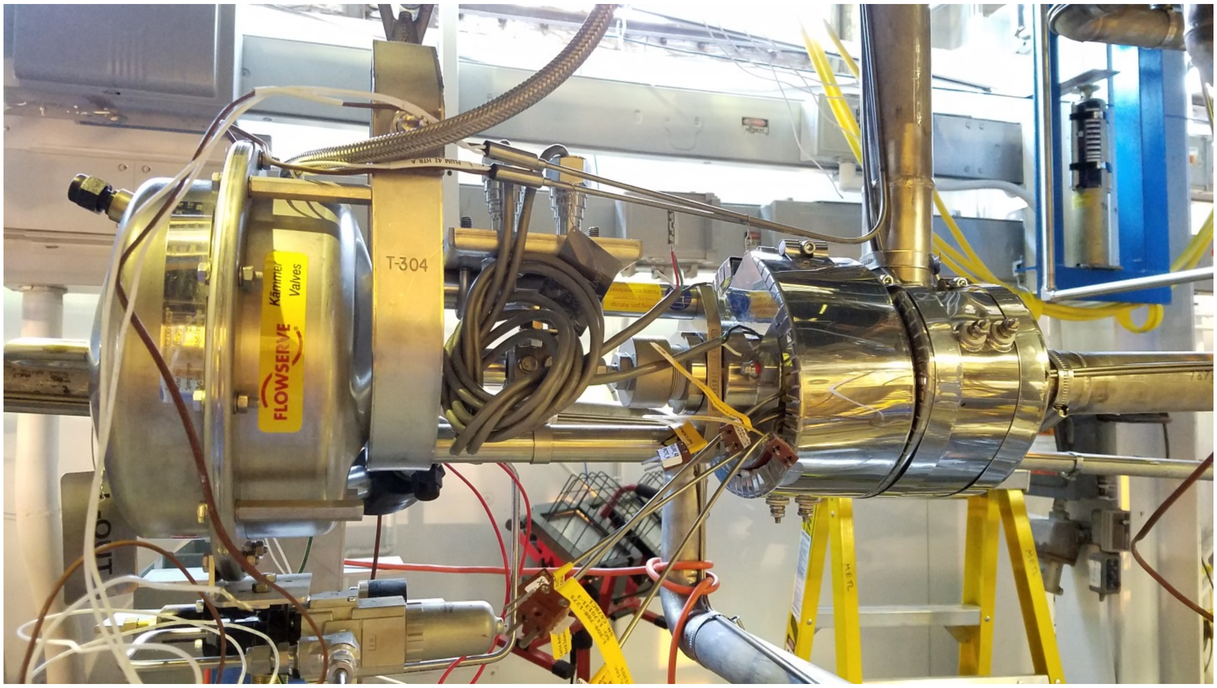

Figure 36 – A photo of a Kammer 1.5” angle valve installed with ceramic band heaters.

3.2.3.2 Swagelok Valves

Swagelok valves are 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-welded connections. Custom 1” Schedule 40 pipe valves were made available from Swagelok through a special order.

Swagelok valves for liquid sodium service 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 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 Argonne (Table 4). Photos of electro-pneumatically and manually actuated Swagelok valves installed can be seen in Figure 37 and Figure 38, 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	

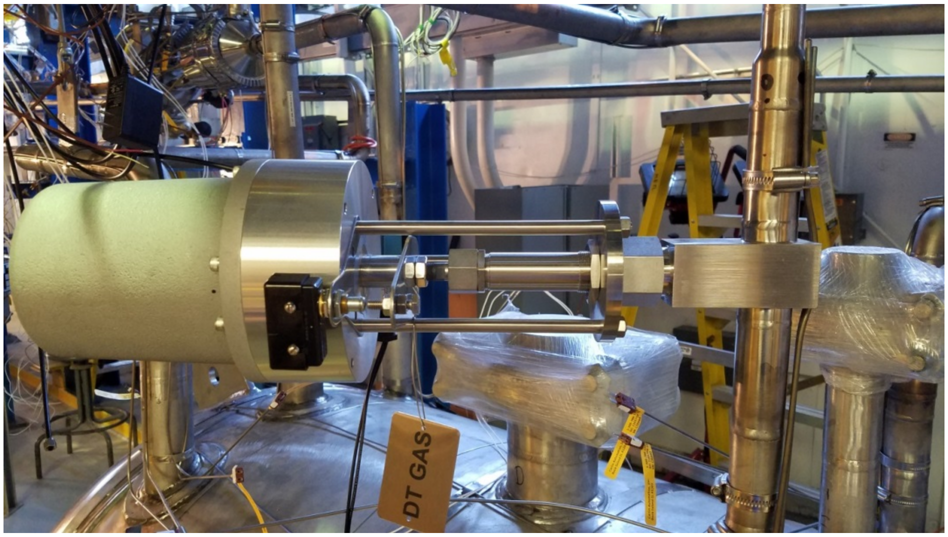

Figure 37 - A photo of an electro-pneumatic Swagelok valve with factory-welded 1" Sch. 40 pipe ends. The valve will be actuated using ~50 [psig] argon. A position indicator on all electro-pneumatically actuated valves will help METL operators verify the state of the valve.

Figure 38 - A photo of a manual Swagelok valve with 1" tube ends.

3.2.4 *Dump Tank*

The sodium dump tank, shown in Figure 39, is 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 has thermal baffles (Figure 40), installed in each of the nozzles, to minimize heat transfer from incoming hot sodium with the relatively cooler nozzles. These baffles allow for a 230°C sodium temperature differential to exist between the dump tank and a test vessel during an emergency drain without thermally shocking the dump tank.

Eighteen of the dump tank nozzles were reinforced by the vessel manufacturer (Northland Stainless), 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 Ambitech, using CAESAR-II piping stress analysis software. The dump tank is installed on the catch pan and all of the connections for Phase I have been completed.

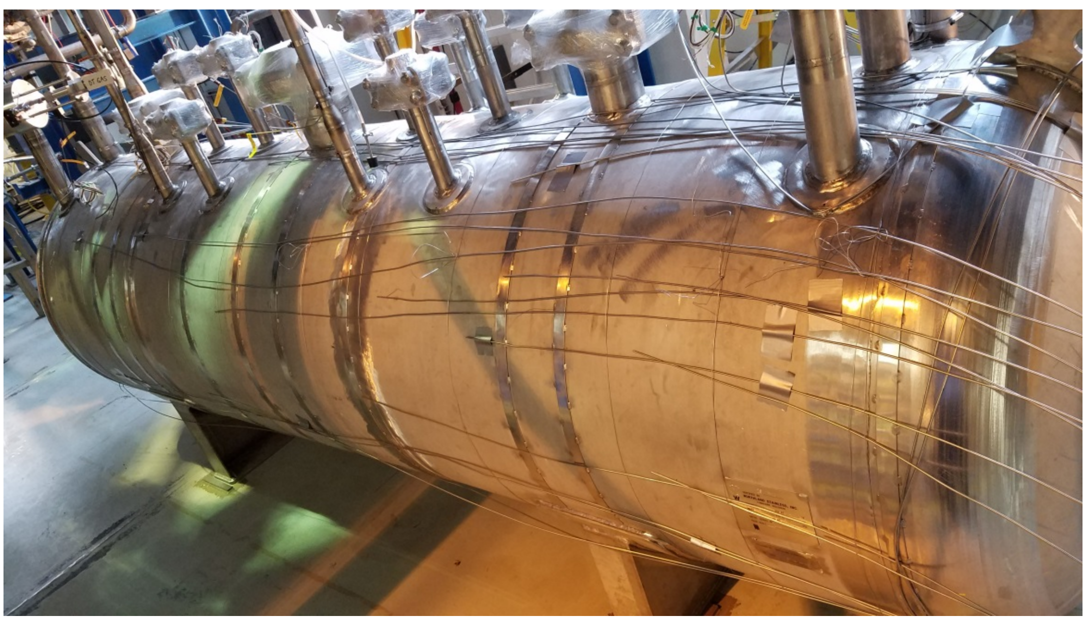

Figure 39 – A photo of the dump tank on the catch pan with thermocouples tack-welded on its’ instrumentation bands.

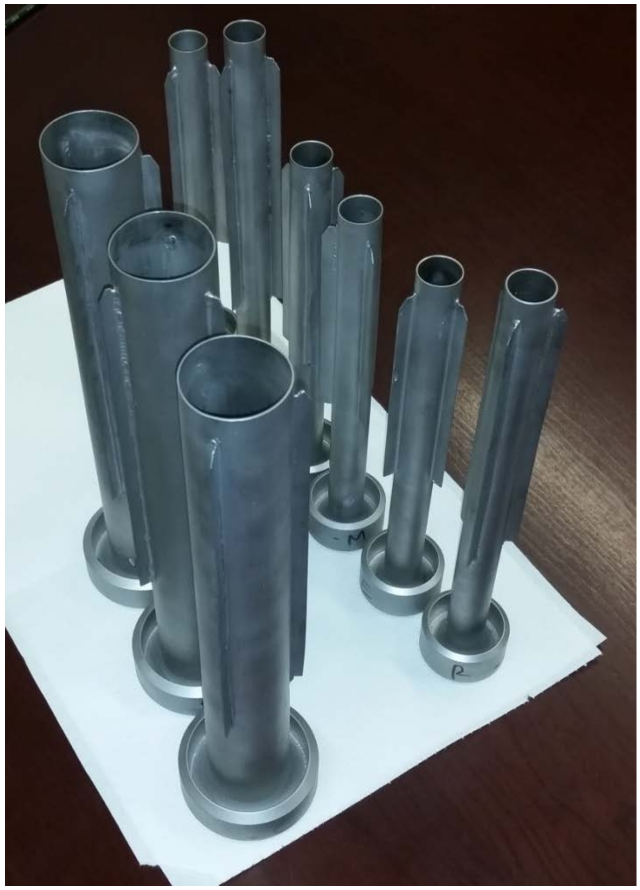

Figure 40 – Dump Tank Thermal Baffles.

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 ceramic band heaters installed to provide electric resistance heating distributed over six different zones. Additionally, the dump tank will be installed within the thermal enclosure that is depicted in Figure 41. The dump tank enclosure has been designed and fabricated by ANL-CS and is shown in Figure 42.

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.

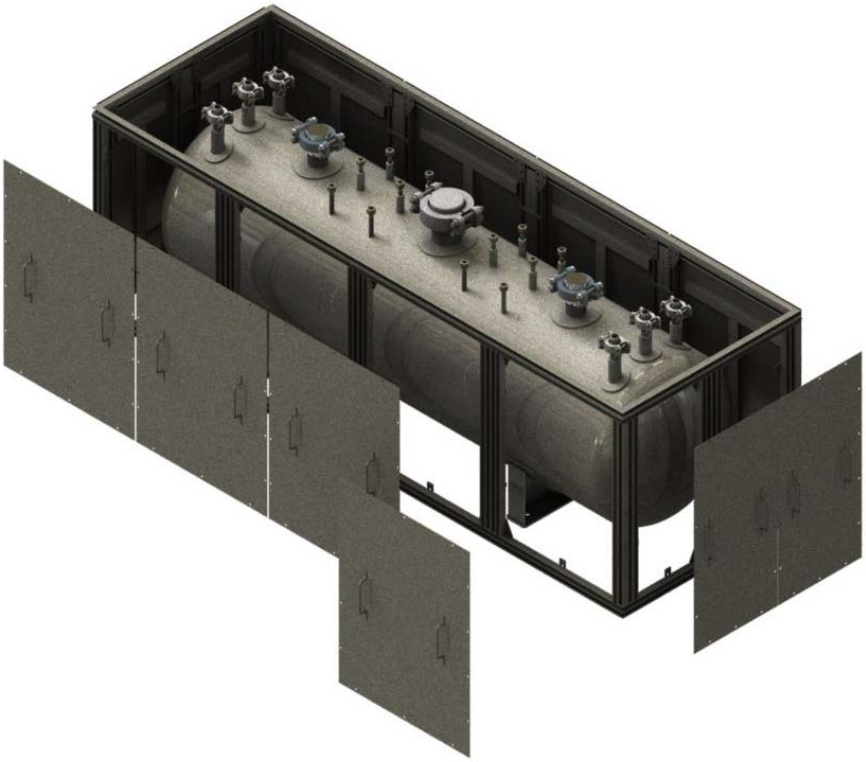

Figure 41 – A 3D model of the dump tank enclosure. Easily removable panels will provide access to the heaters and thermocouples on the dump tank. The enclosure will contain vermiculite thermal insulation.

Figure 42 – 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.

Piping systems and equipment that experience a large range of temperatures need to be allowed to expand and contract to ensure the stress doesn't exceed the materials' limit. Therefore, anchor points are minimized so the system is allowed to feely move. METL's vessels are the only anchor points. However, the dump tank is a large enough vessel that is expected to experience significant growth and contraction (upwards of an inch). Therefore, the dump tank cannot act as a true anchor point and requires free movement.

To accommodate this, restraints were welded to the catch pan around the feet of the dump tank. As illustrated below in Figure 43, the feet on the right are restrained on three sides and the left feet are restrained on one side. This allows the dump tank to expand right to left (east to west in reality) without becoming unaligned.

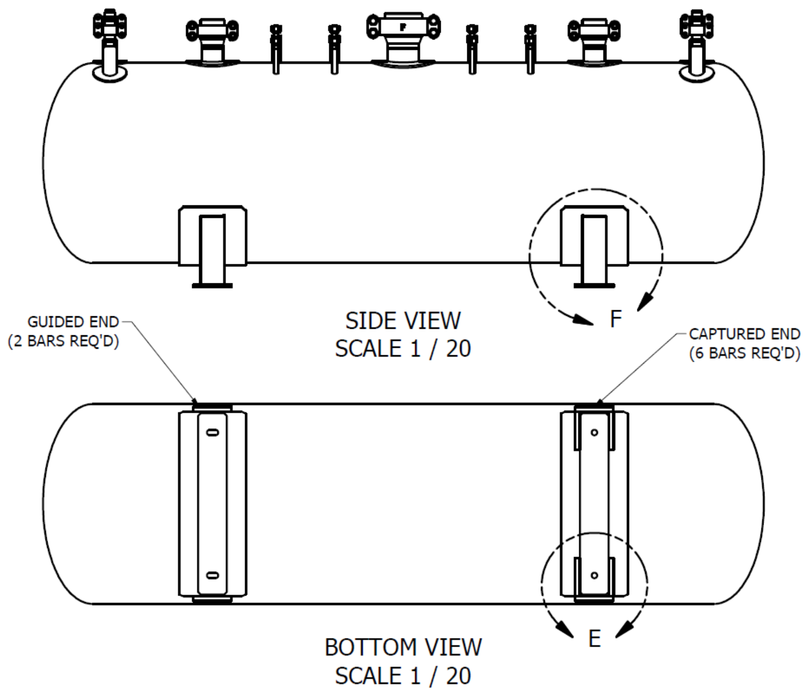

Figure 43 – A photo of the dump tanks' restraints.

3.2.5 **Level Sensors**

It is 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, Argonne 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 in Figure 44, 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 45 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.

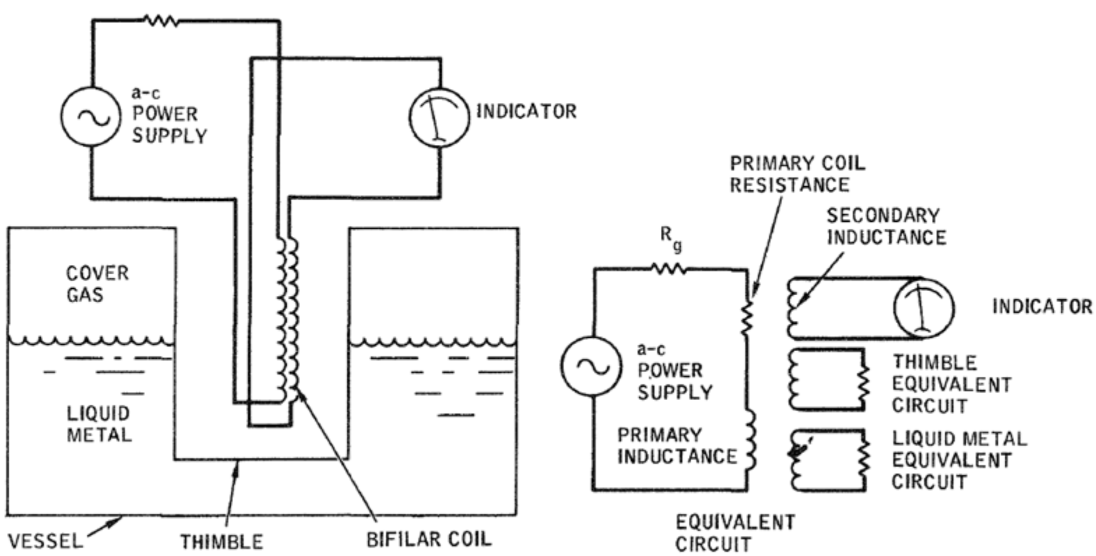

Figure 44 – A diagram showing the operation of an inductive level sensor (2).

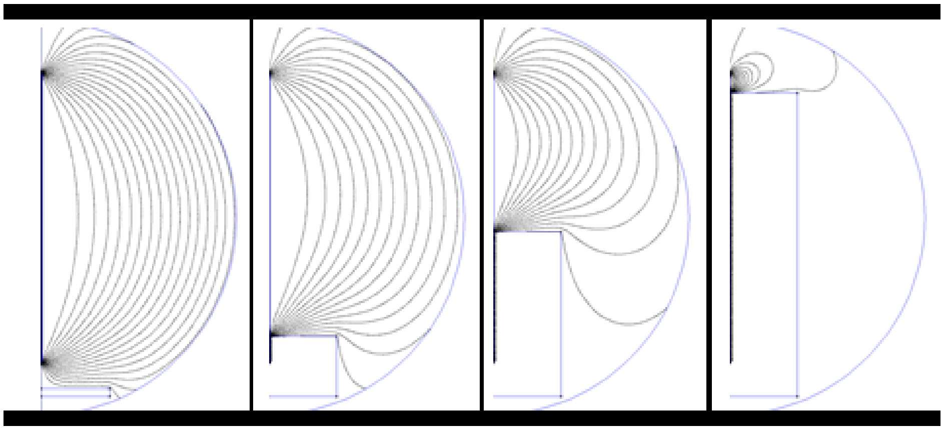

Figure 45 – A picture depicting how sodium level affects the magnetic field produced an inductive level sensor. The changes to the magnetic circuit can be calibrated to determine sodium level. These pictures were produced using FEMM.

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 47, 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. Figure 48 plots the change in signal versus the height of the aluminum tube and the results yield a strong linear relationship. 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.

Previous Argonne level sensor designs 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].)

Figure 46 – A photo of the experimental setup being used to benchmark an inductive level sensor.

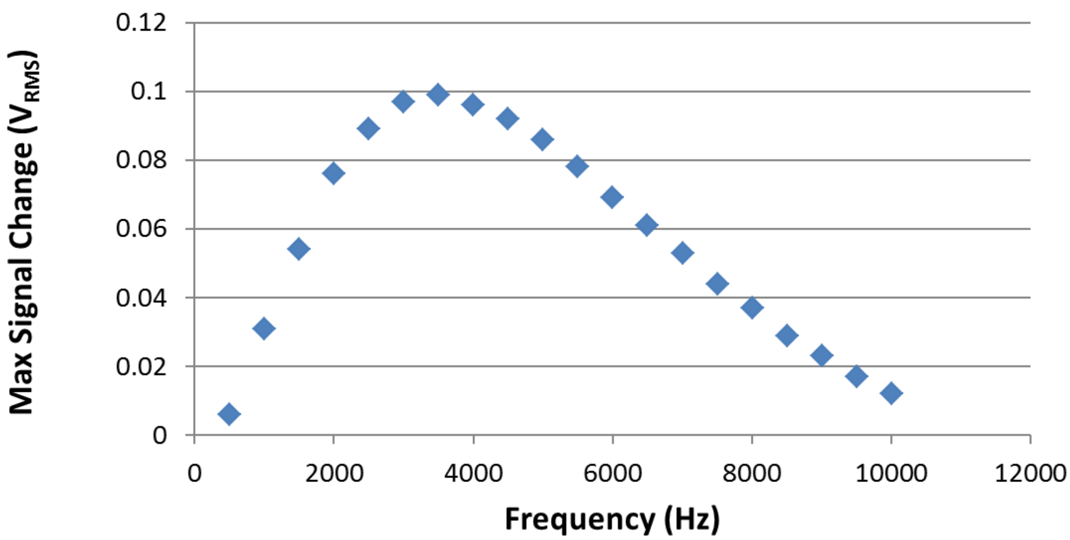

Figure 47 – The maximum change in the output signal as a function of operating frequency.

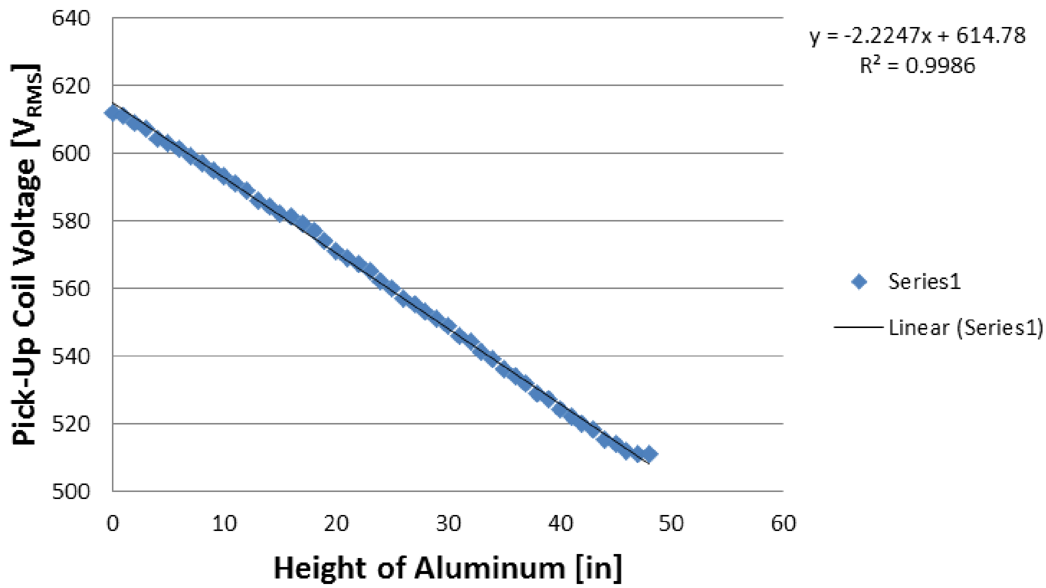

Figure 48 – Initial data from the inductive level sensor tests.

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 49, this type of sensor operates by measuring the pressure difference between the gas space and the bottom of an argon-filled dip tube. Additionally, the density of sodium as a function of temperature is very well known and acceleration due to gravity is assumed constant; the simple hydraulic equation (EQ:1) below can be utilized to compute the height of the sodium

$$h = \frac{\Delta P}{g\rho} \qquad \text{EQ:1}$$

Where:

- ΔP = differential pressure
- g = gravitational constant
- h = height of the fluid
- ρ = density of the fluid

The differential pressure sensor is not only an accurate method of level detection but can be used to calibrate other level sensors as well. In FY2016, Argonne engineers approved drawings developed by a vendor for the creation of a differential pressure sensor (ΔP gauge) that has sufficient resolution (~1/4 [in-H_2O]) to be used as a level sensor. Each differential pressure transmitter has two NaK (sodium potassium alloy) filled capillary lines which will be connected to their respective process port via 1” VCR.

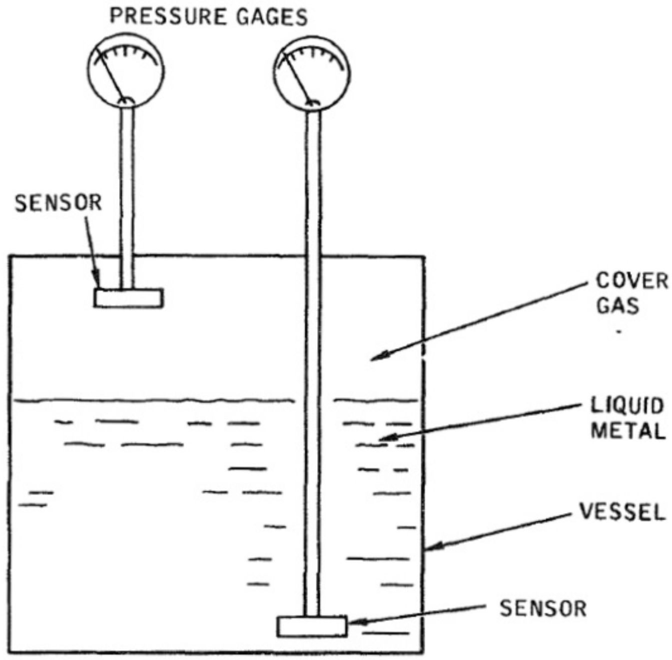

Figure 49 – A schematic showing the operating principle of a differential pressure level sensor.

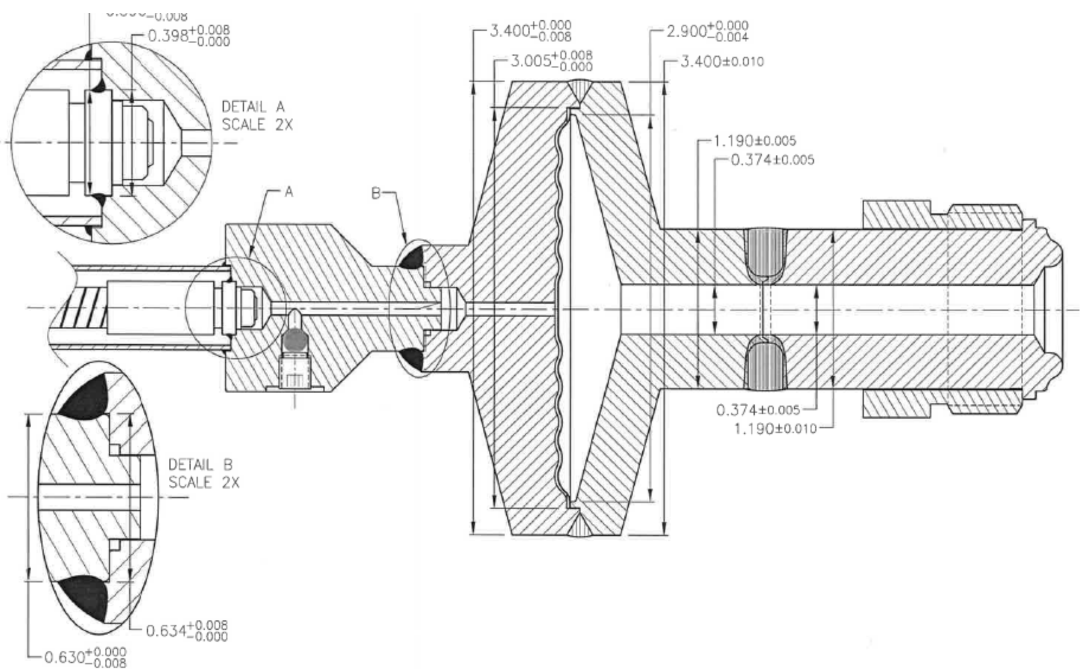

Figure 50 - A drawing of the NaK-filled differential pressure transducer that will connect to the dump tank and expansion tank gas space using VCR fittings. The large diaphragm on this sensor should offer ΔP resolution ≈ 0.25 [in-H_2O] for more accurate sodium level determination.

The ΔP gauge can be connected to the gas space of the dump tank and expansion tank using VCR fittings, as shown above in Figure 50. The VCR connections are rated to 537°C and are more compact than Grayloc connections. Other than the two VCR connections, the ΔP gauge has 100% welded construction. A drawing of the ΔP gauge assembly (transmitter, capillary lines, diaphragm seals, and 1" VCR connections) is shown below in Figure 51.

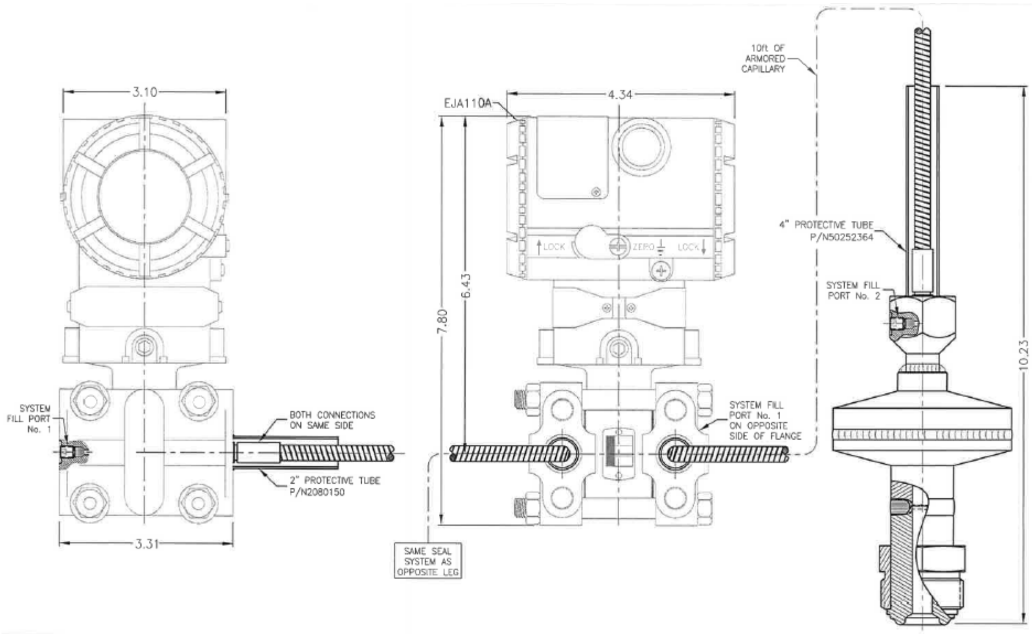

Figure 51 – ΔP gauge Assembly for Level Measurement in the Dump Tank and Expansion Tank.

3.2.6 Purification & Diagnostic 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 has a purification system that consists of a cold trap, a plugging meter, an economizer, two EM pumps, two flowmeters, and four pressure transducers, and is depicted in Figure 52. 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.

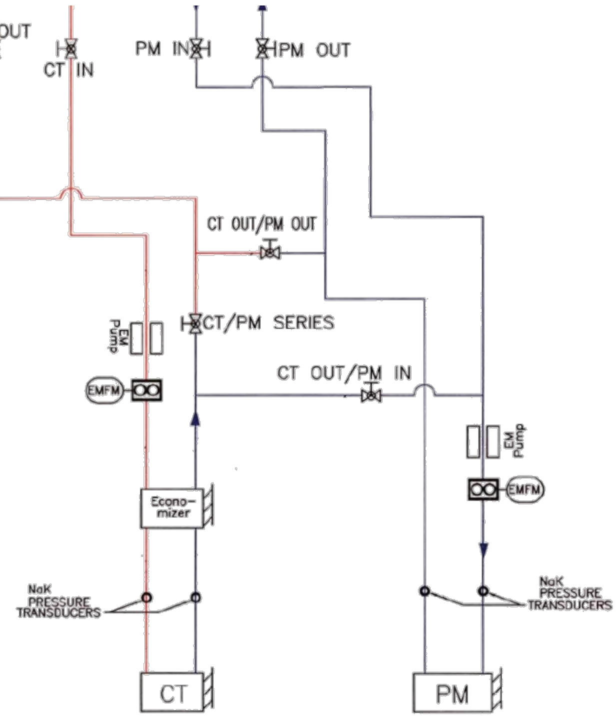

Figure 52 – A detail of the METL P&ID showing the functional layout of the purification system. The cold trap is abbreviated as "CT" and the plugging meter is abbreviated as "PM".

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 becomes 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 under five parts per million. (See Figure 53 for the saturated oxygen concentration of sodium.)

In order to cool the sodium, the cold trap loop relies on both an economizer and a blower to push ambient air over the cold traps heat transfer fins. 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]

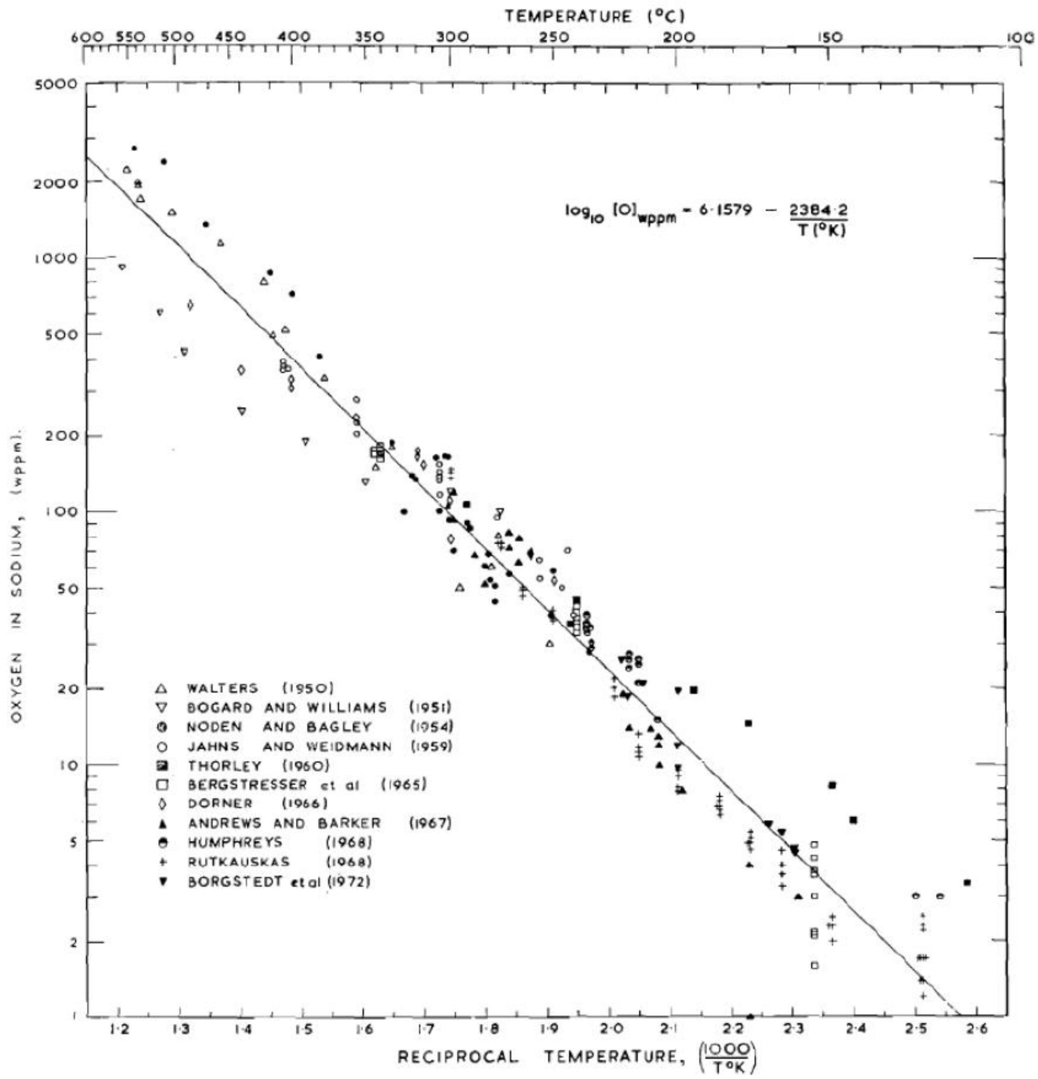

Figure 53 – Solubility of oxygen in sodium as a function of temperature (3). The equation in the corner of this graph is commonly referred to as the Noden correlation.

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 ANL-CS to duct the cooling air out of the Bldg. 308 hi-bay.

During FY2015 the cold trap was sent to Ability Engineering to have the inlet and outlet nozzles reinforced to withstand the anticipated piping loads due to thermal expansion and contraction. Figure 54 shows a picture of the cold trap nozzles before and after reinforcement. The cold trap is currently installed in METL as shown in Figure 55.

Figure 54 - Photos of the cold trap nozzles before (TOP) and after (BOTTOM) reinforcement.

The cold trap has many type-K thermocouples welded inside the cold trap so that they are exposed to sodium flow for precise measurement and control. Additionally, the blower utilized to deliver cooling air to the cold trap is equipped with a variable frequency drive. To monitor the amount of contamination retained in the cold trap, inlet and outlet pressures of the cold trap are measured.

Figure 55 – Cold Trap Welded into the METL

3.2.6.2 Economizer

As shown in Figure 56, 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 the main loop flows towards the cold trap in the inner tube of the economizer. Cold, purified sodium leaving the cold trap 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 57, the economizer is 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 vendor completed and delivered the economizer and was installed in FY2016 (Figure 58). The economizer has its' MI cable heaters and thermocouples installed. The economizer will be considered 100% complete once the retainer is filled with vermiculite insulation. All vermiculite insulation for the economizer and dump tank is staged at Argonne and ready for insertion.

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

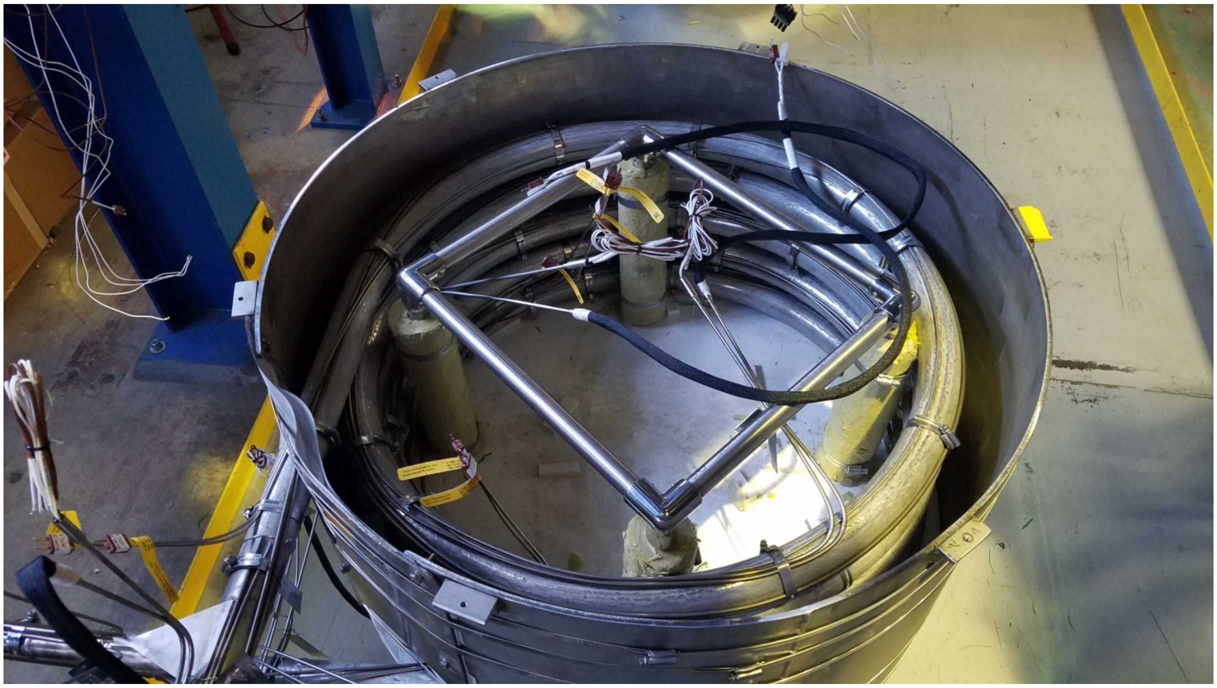

Figure 57 - A photo of the economizer within the tank. The economizer coils are centered using the internal frame. To prevent metal-on-metal rubbing, the internal frame is padded with high-temperature fiberglass insulation.

Figure 58 – The economizer installed into the purification (cold trap) loop.

3.2.6.3 Plugging Meter

The completed plugging meter was delivered to Argonne in FY2014 along with the associated blower fan and variable frequency drive (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 59.)

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 for a given impurity level. 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 (4).

The saturation temperature of the impurity corresponds to the minimum 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 (5)."

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 53) can be used to determine the oxygen concentration of the sodium.

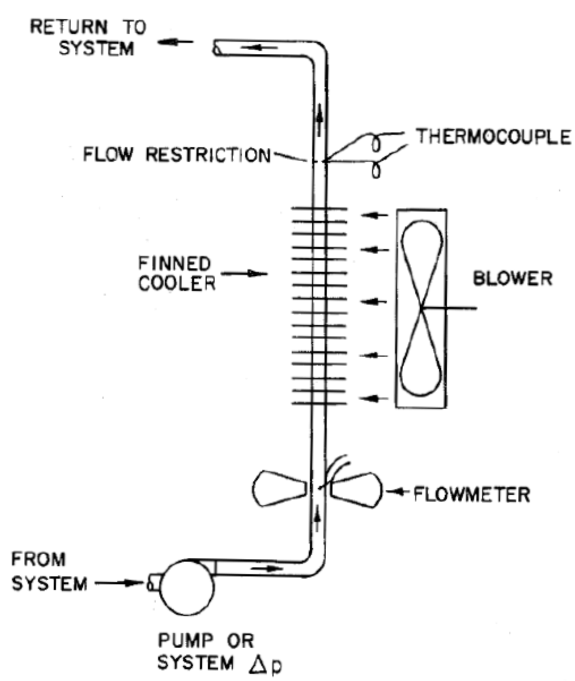

Figure 59 – A conceptual depiction of a plugging meter (6).

The METL plugging meter has a long tube-in-pipe design and is shown below in Figure 60. 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 60 – Plugging Meter Installed into the METL with its' blower and VFD.

3.2.6.4 Thermal Mixing Tees

Since the sodium leaving the purification systems will be relatively colder than the main loop, thermal mixing tees are needed to mitigate the harmful effects associated with thermal shock and thermal cycling within the piping system. Two thermal mixing tees were designed, fabricated, and delivered in FY2014. A photo of a completed mixing tee installed in the METL piping system can be seen in Figure 61.

Two tees are installed in the main piping system. One of the mixing tees is located where the sodium leaving the economizer reenters the main loop. Another identical mixing tee is similarly positioned downstream of the plugging meter. In Figure 61, the branch of the thermal mixing tee is connected to the outlet of the plugging meter loop with the run of the tee connected to the primary loop.

Figure 61 – A photo of one of the thermal mixing tees installed into the METL piping.

3.2.7 Test Vessels

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

Major changes to the new 18” vessels that are installed in METL compared to previous designs are:

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

d) Supported via side lugs instead of legs.

All of the vessels have been fabricated and are shown being staged at Northland Stainless in Figure 62. The vessels were to be fabricated using only 304 stainless steel material. After arrival of the test vessels, the manufacturer stated that there was a documentation issue and one of the 18” vessels’ neck body was constructed of 304 stainless while, its’ flange is composed of 316 stainless. The fabricator was unaware of the documentation error and believed both the body and flange were composed of 304 stainless steel so; they proceed to weld the pieces together. Although, 316 stainless steel is generally considered a higher quality material due to the presence of molybdenum to prevent corrosion; the ASME pressure vessel code views both materials to have the same coefficient of thermal expansion. However, a more detailed analysis of the difference in the 304/316 stainless steel behavior was pursued by Argonne engineers. Therefore, a stress analysis of the vessels with all 304 stainless steel construction and 304/316 construction was pursued under steady state and transient conditions.

Figure 62 – A photo of the vessels during inspection at Northland Stainless.

All of the new test vessels perform the same function 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 have a 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. These larger vessels will have a maximum operating temperature of 1,200 [°F]. 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 and insertion. A preexisting 18” vessel will be used to pressure test and helium-leak check experiments that will go into the METL facility. A preexisting 28” vessel may be repurposed to become the cleaning vessel that connects to the carbonation system.

Currently, three of the four vessels have been installed into the METL piping system on the mezzanine as shown in Figure 63. The ANSYS transient and steady state analysis revealed the stress induced by the different stainless steel (304/316 SS) thermal expansion coefficients would not yield any detrimental outcomes so, the second 18” vessel is currently in the process of being re-certified and installed into METL.

Figure 63 – Three of the four vessels installed on the mezzanine.

The 18” vessels’ body does not break the plane of the mezzanine however, the larger 28” vessel bodies actually protrudes through the METL mezzanine deck as shown in Figure 64. Like the dump tank, all of the vessels have thermocouples tack welded onto their “instrumentation bands” for monitoring and controlling the heaters. One of the 18” and 28” vessels with thermocouples installed can be seen in Figure 65. Each vessel is equipped with 36 thermocouples placed strategically on the vessel to monitor stress concentrations and heater output. Each vessel will have four individually controlled heater zones.

Figure 64 – 28” Vessels protruding the mezzanine of the METL.

Figure 65 – 18” Vessel (left) and 28” Vessel (right) installed with thermocouples.

3.2.8 Expansion Tank

The function of the expansion tank is to accommodate changes in liquid level that result from changes in temperature in the METL system. The expansion tank was fabricated and delivered to Argonne during FY2014. During the spring of FY2015, the expansion tank was returned to Northland Stainless so that the nozzles could be reinforced to withstand the anticipated piping loads. Nozzle reinforcement has been completed and the expansion tank is now installed into METL (shown in Figure 66).

The body of the tank is approximately 80” long, 8.7” in diameter, and is constructed of 304 stainless steel. It will be about half full during the normal operation which will leave enough gas space to accommodate changes in volume due to density changes caused by altering the sodium temperature. 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 the METL liquid level on the mezzanine (see Figure 44 and Figure 49). Additional instrumentation can also be envisioned and inserted into the expansion tank via one of its’ connections (Figure 67).

Like the test vessels and dump tank; the expansion tank is to have ceramic band heaters (Figure 68) bolted together to surround its’ circumference. Additionally, like the aforementioned equipment, the expansion tank has numerous thermocouples for monitoring and heater control (30 thermocouples and 3 individual heater zones).

Figure 66 – A photo of the expansion tank installed into the METL with thermocouples

Figure 67 – A photo of the top of the expansion tank. The top flange has four 1" VCR fittings for instrumentation insertion. (This photo was taken during FY2014).

Figure 68 – Ceramic Band Heaters to be mounted on all of the Pressure Vessels

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 Argonne engineers to withstand a simultaneous fire and earthquake (850 [°F] / lateral 0.384 [g]).

As depicted in Figure 69, 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 70. The vessels are attached to vertical stainless steel columns that are bolted to the horizontal supports (Figure 71).

Prior to the arrival of the vessels and to expedite the installation of the piping system, ‘vessel imitators’ were designed by Argonne engineers and fabricated by HR Slater. Figure 72 and Figure 73, shows that the vessel imitators provided geometrically accurate mounting locations to support the piping that connect to the expansion tank and four test vessels while the expansion tank was being reinforced and the test vessels were being fabricated. The use of these imitators allowed progress to be made in parallel with both the piping fabrication and installation and the various vessels that can accommodate the piping loads.

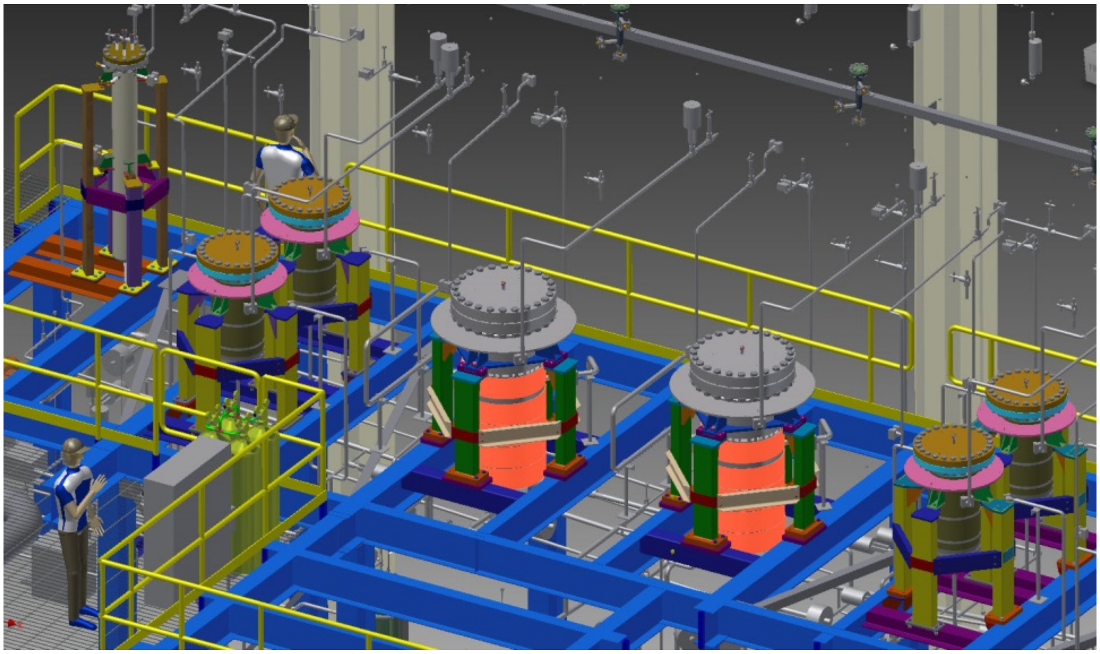

Figure 69 - A 3D model of the vessels and vessel supports.

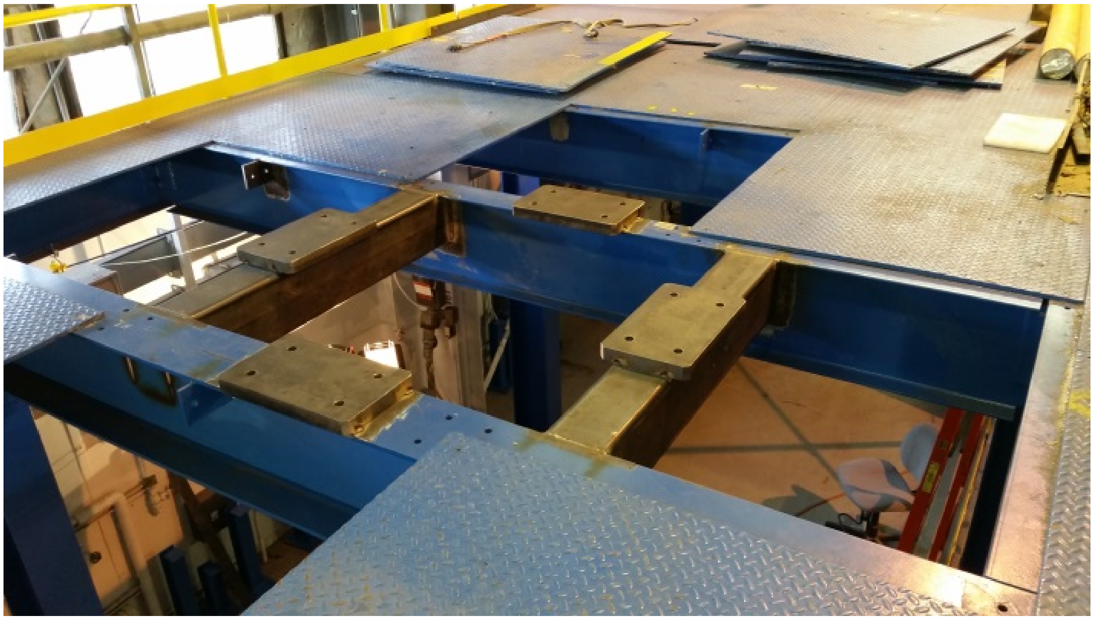

Figure 70 - A photo of the 28" vessel support steel attached to the mezzanine structure.

Figure 71 - 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.)

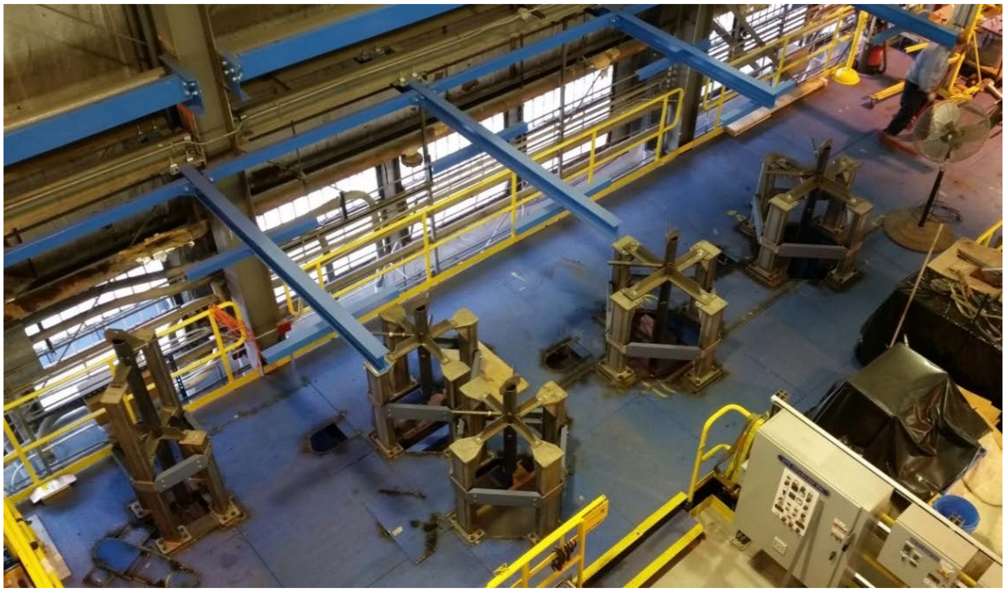

Figure 72 - An overhead photo of the METL mezzanine showing the installed vessel supports and vessel imitators required for Phase I.

Figure 73 - 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, each test vessel, and electro-pneumatic valves. 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
- Actuate electro-pneumatic valves
- Bubble argon through a ΔP gauge dip tube.

The argon is supplied to METL from a 1000 [liter] Airgas 'micro-bulk' system located outside the Bldg. 308 hi-bay (Figure 74). This micro-bulk system contains high-purity liquid argon (< 1 [ppm] oxygen). On-line diagnostics within the tank provides the METL operators with real-time level measurement within the tank and will automatically send a refill request to Airgas whenever the liquid argon drops below 3/8^{ths} full. The argon supply will also be able to provide 50 [psig] argon required to operate electro-pneumatically actuated valves.

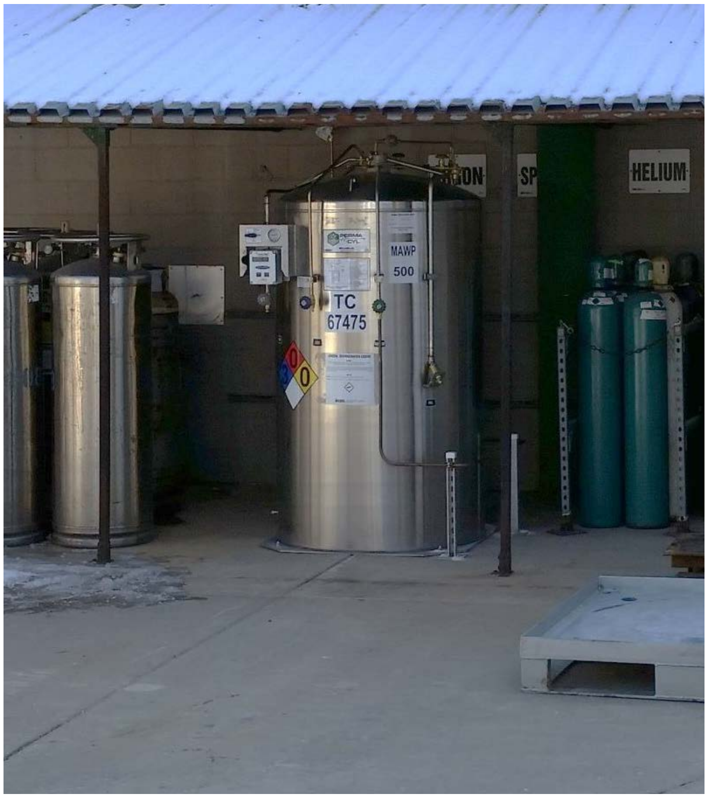

Figure 74 - A photo of the installed 1000 [liter] microbulk system outside the Bldg. 308 hi-bay. The microbulk system was installed during FY2015.

METL has pressure relief valves designed to open in the event the METL system pressure exceeds 20 [psig] and the microbulk tank can reach pressures up to 500 [psig]. To further prevent the system pressure from reaching 20 [psig] an upstream regulator was installed. Additionally, the valve actuators cannot experience pressures higher than 100 [psig]. Therefore, two parallel lines were installed from the argon ‘microbulk’ system, each with their own regulator (Figure 75). One regulator controls the system argon pressure (less than 20 [psig]) and another controls the valve actuator pressure (less than 60 [psig]).

Figure 75 – Inter Gas System Regulators. Left regulator is for system pressure control and the right is for valve actuator pressure control.

3.2.11 Vent System

The vent system will allow the 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 is attached to the expansion tank, dump tank, and each test vessel can be found in Figure 76.

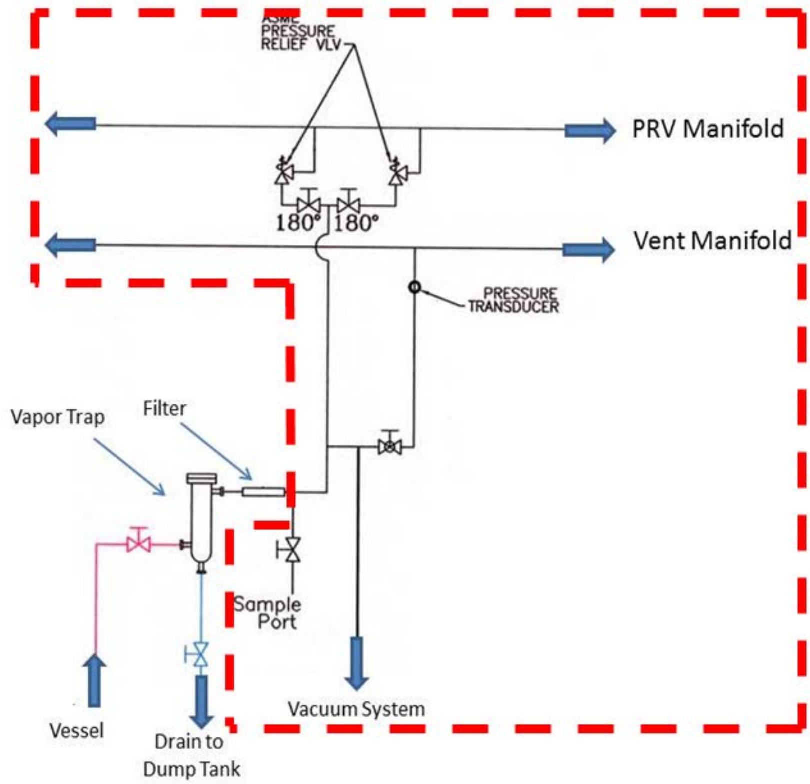

Figure 76 – A detail of the METL P&ID showing the vent system that will be connected to the expansion tank, dump tank, and each test vessel. All components downstream of the vapor trap and filter will be made of 0.065" wall thick seamless tubing since sodium corrosion is not a major concern.

Components inside of the dashed red line in Figure 76 are actually found on a separate sub-component of METL named, the downstream manifold. The downstream manifold is shown below in Figure 77; it houses sample port valves, pressure transducers, pressure relief valves, vacuum valves, and relief selector valves. The expansion tank, dump tank, test vessels, and four future loops all have a set of the aforementioned equipment. The downstream manifold compactly and efficiently houses all of this equipment in one convenient location, on the western end of the mezzanine.

Figure 77 – Downstream Manifold. (Notice four future loops are not connected but rather welded shut until future expansion)

3.2.11.1 Pressure Relief Valves

Fourteen of the pressure relief valves (PRV) for Phase I of the METL have been installed, as shown in Figure 78. The valves have a set-point of 20 [psig] and are capable of operation at 1200 [°F]. As illustrated in Figure 76, a pair of PRVs are connected to the expansion tank, dump tank, and each test vessel. This configuration will allow the METL operators to perform maintenance on one "Toter" 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 during maintenance.

Figure 78 - A photo of the pressure relief valves installed.

3.2.11.2 Vapor Traps & Filters

The filters, dump tank vapor trap, and test vessel vapor traps required for Phase I have been fabricated and installed. Figure 79 shows that the support steel for the vapor traps are located above the mezzanine. This equipment was installed during FY2016.

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 are installed in the inert gas vent lines of the expansion tank, dump tank, and each test vessel. The vapor traps have been designed to maintain a downstream concentration of sodium hydroxide at less than 1.15 [mg/m³] during steady-state operations. (See Figure 80 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. Raschig rings, that serve as the random packing within the vapor trap, are shown in Figure 81. The Raschig rings have been inserted into the vapor traps along with stainless steel mesh for additional surface area.

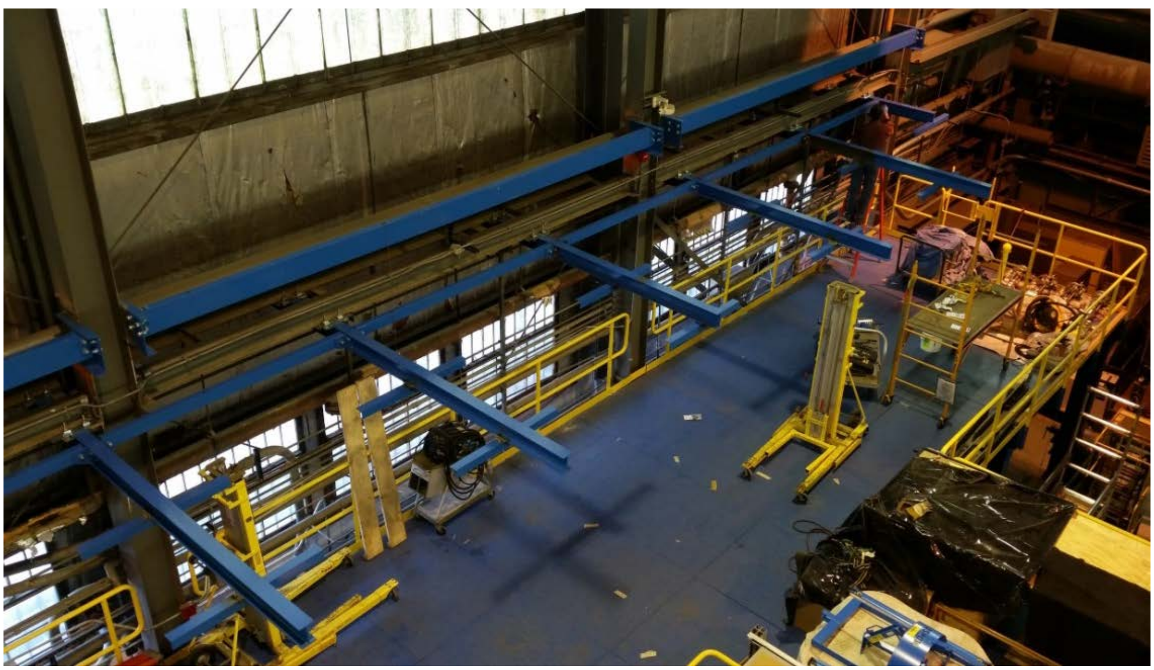

Figure 79 - A photo of the completed vapor trap supports and cantilever beams. The cantilever beams will support the pipes connecting the vessels and vapor traps.

			Argon Pressure [psig]					
Temp [C]	Temp [K]		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 80 - 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 (7).

Figure 81 – A photo of ¼” x ¼” Raschig rings that will increase the surface area within the vapor traps.

Dump Tank Vapor Trap (DTVT)

During an emergency drain, up to 800 [gal] of sodium could be driven back into the dump tank within 15 [min] utilizing argon gas pressure. Accordingly, the DTVT must be able to remove the sodium vapor and/or aerosols from the argon that is displaced out of the dump tank by the draining sodium. As shown in Figure 82, 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 the outside of the vapor trap and the radiant band-heaters). Ducted air and radiant band-heaters are used to maintain the operating temperature of the device. The DTVT was designed by Argonne and then fabricated and tested by a local vendor during FY2015. The DTVT is currently installed as shown in Figure 83.

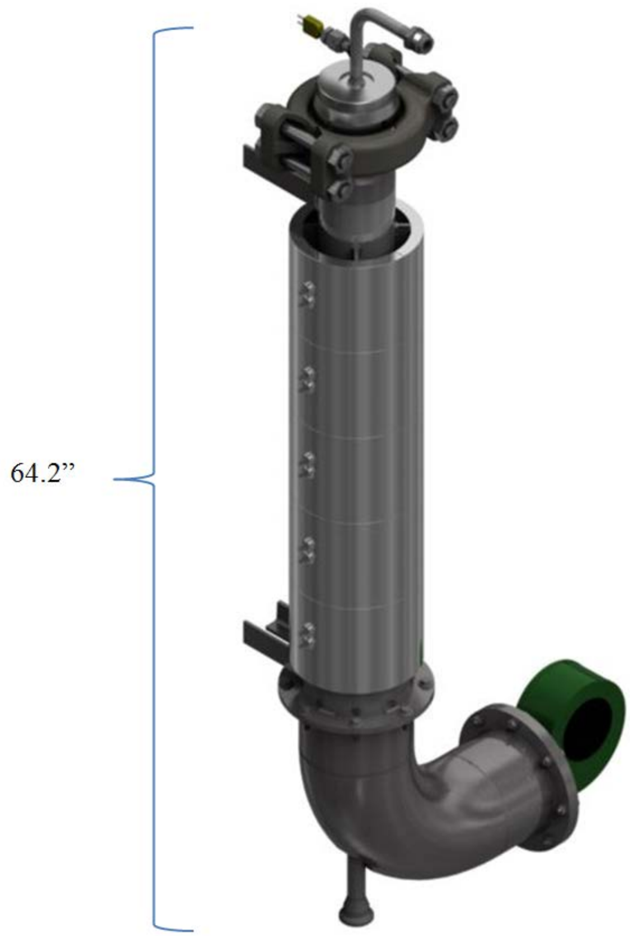

Figure 82 – A 3D model of the dump tank vapor trap.

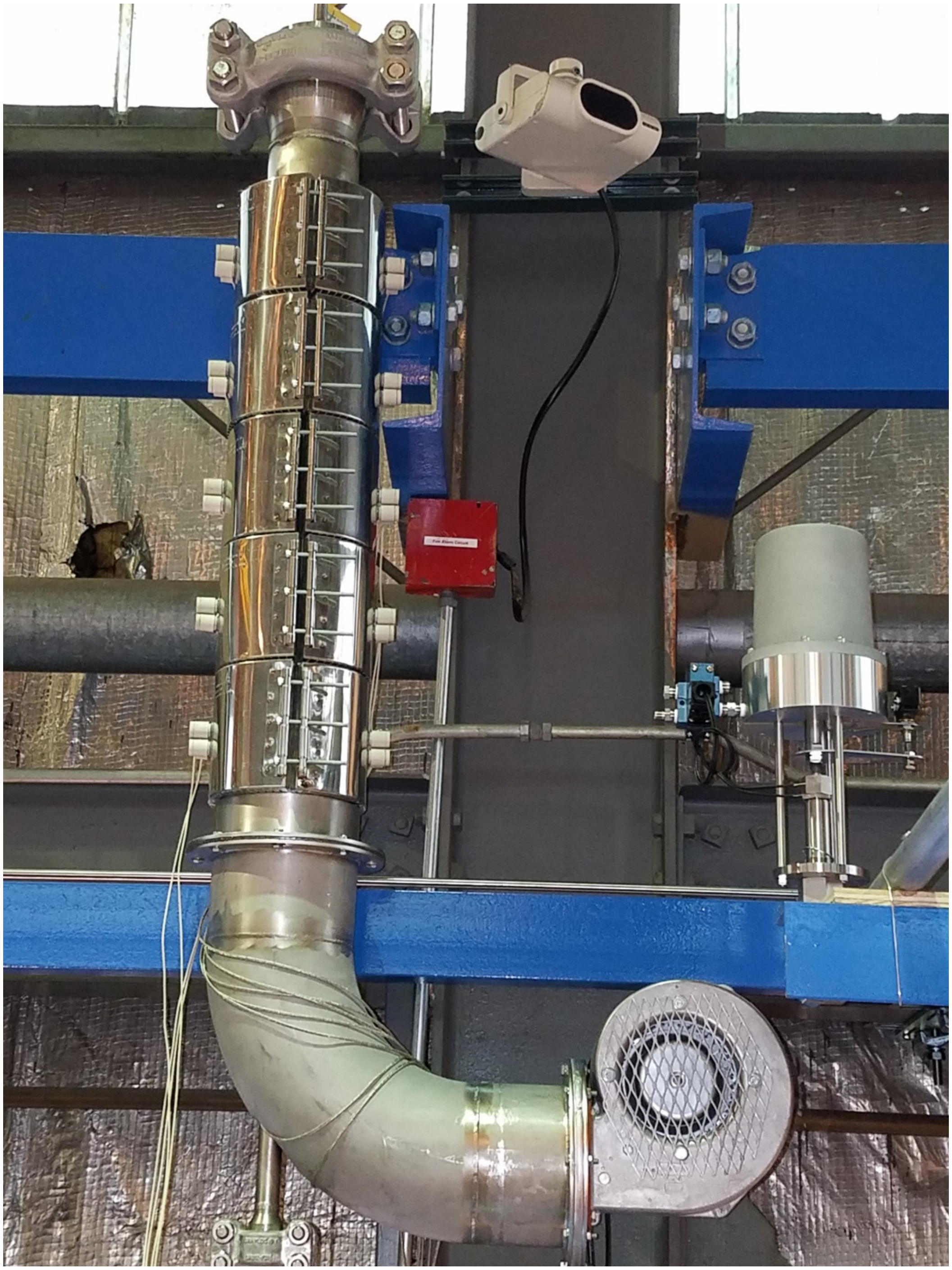

Figure 83 - A photo of the completed dump tank vapor trap during an inspection at Meyer Tool & Mfg.

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 84, spiral-wound 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 85). All five of the VVT's required for Phase I have already been fabricated, tested, and installed by ANL-CS.

Figure 84 – A single VVT (left) and the remaining VVTs (right).

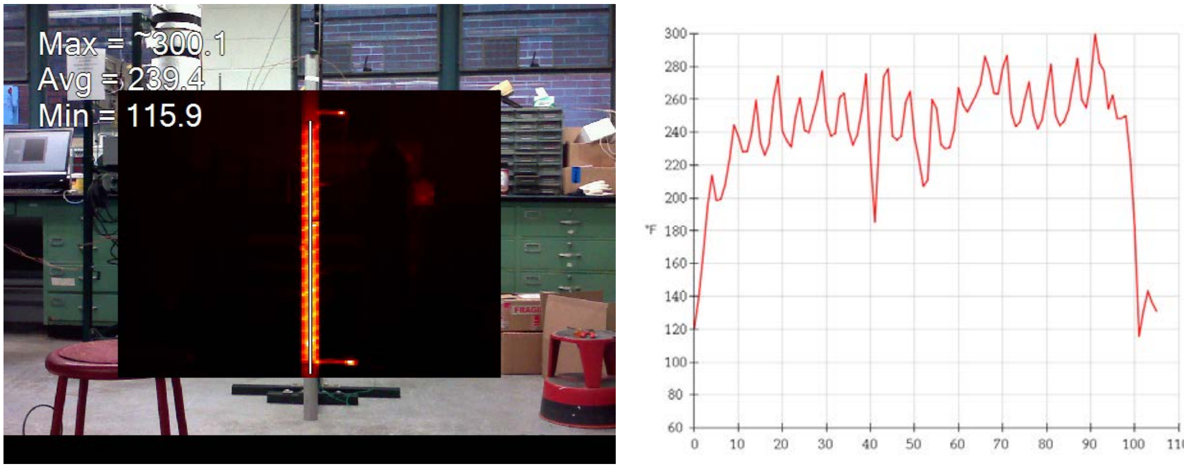

Figure 85 – Left: An infrared image of the small vapor trap heater test using a coiled MI heater cable. Right: The temperature profile along the outside of the smaller vapor trap as measured with the infrared camera.

3.2.11.2.1 Filters

Filters are installed downstream of each vapor trap. The filters, depicted in Figure 86, 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 87. 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, pressure tested, and installed by ANL-CS. Figure 88 provides a photo of the filters installed at the outlet of the vapor trap.

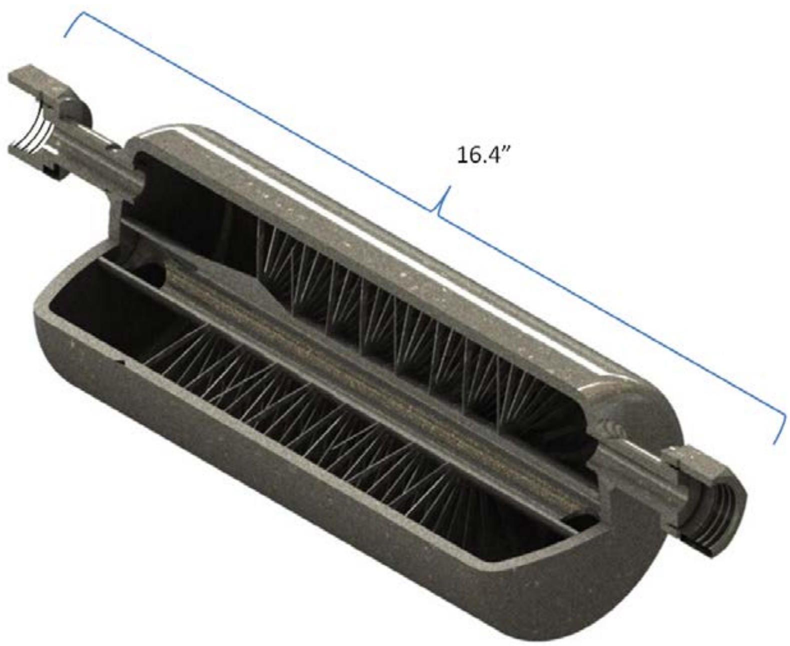

Figure 86 – A 3D model of the filter assembly. The finned tubing element provides surface area for the accumulation of sodium aerosols.

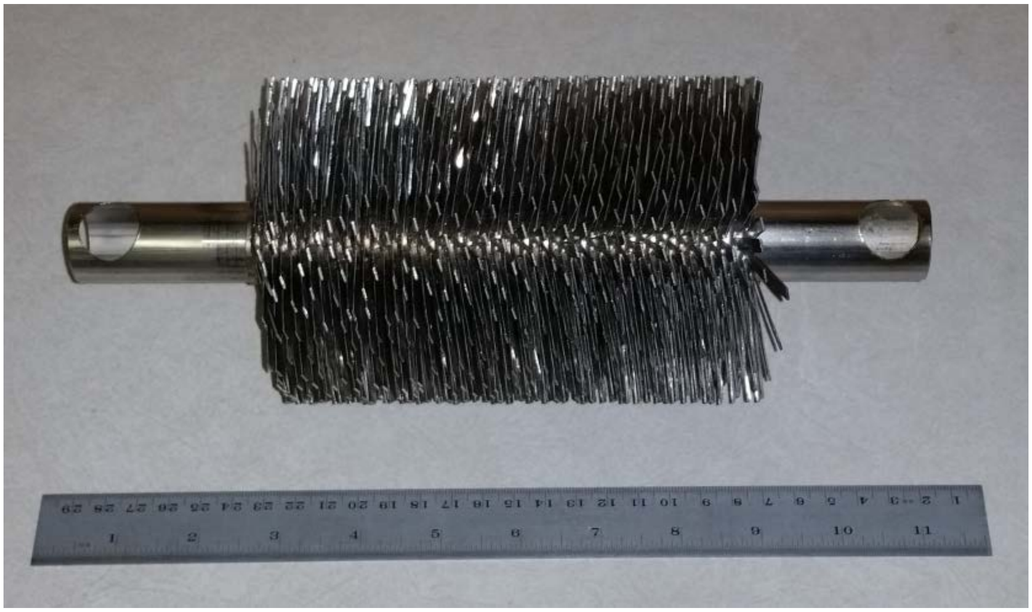

Figure 87 – A photo of the finned tubing element. The additional holes on the ends of the tube ensure that the filter cannot become clogged during operation.

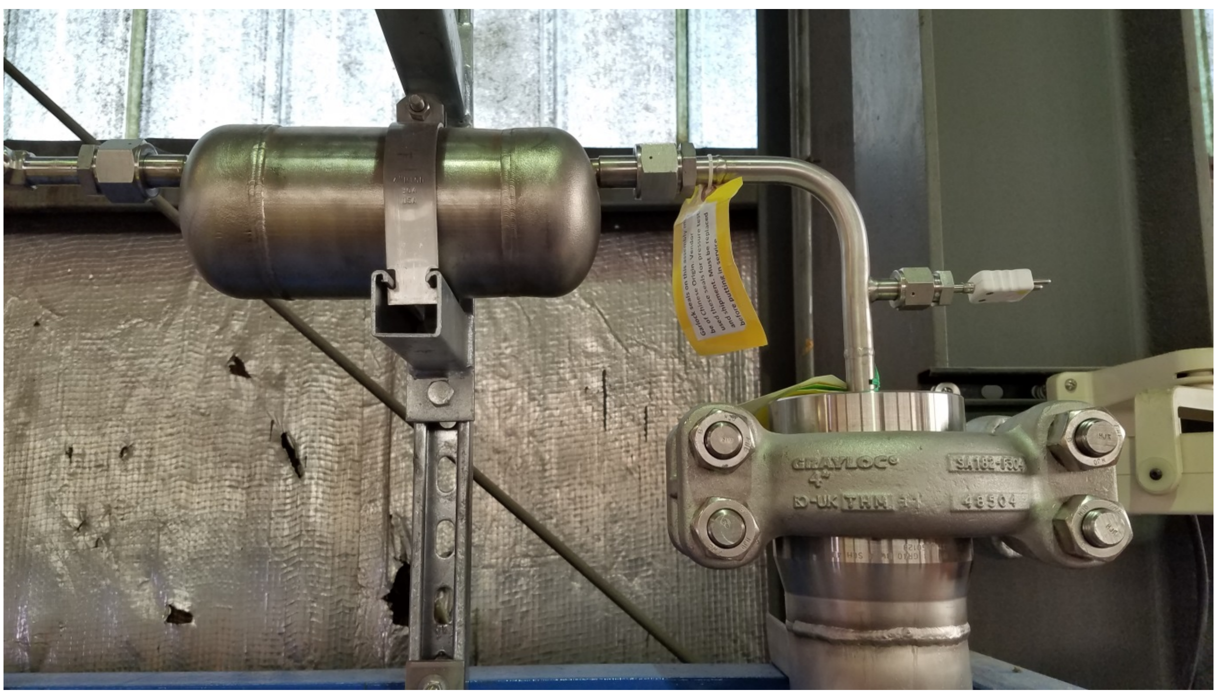

Figure 88 - A photo of the six completed filters required for Phase I.

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; the overall plan for evacuating components is to use a distributed type vacuum system. This is because the facility has many different components which are located throughout the METL footprint. Agilent will be installing a vacuum pump for the METL team to test its' ability to pull a vacuum on METL in October 2016.

*3.2.12 **Electromagnetic Pumps & Flowmeters***

All of the electromagnetic (EM) pumps, flowmeters, and control systems have been installed and will be considered complete once they are electrified. The primary, purification, and diagnostic loops all have their own individual EM pump and flow meter. All of the EM pumps and flowmeters were provided by an outside vendor.

3.2.12.1 Electromagnetic Pumps

An annular linear induction pump (ALIP) (Model: LA-125, see Figure 89) will be used to push sodium through the main loop and test vessels. Two AC conduction pumps (Model: CA-15, see Figure 90) 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 ¾" 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 the vendor'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.

Figure 89 – A photo of the annular linear induction pump (ALIP) that is installed in the main loop.

Figure 90 – A photo of a conduction pump (CA-15, right) and EM flow meter (left) that are installed in the diagnostic (plugging meter) loop. The diagnostic and purification loop utilize identical EM pumps and flowmeters.

Specifications of the LA-125:

Mechanical:

- Dimensions: L = 637 [mm], D ≤ 425 [mm]
- Weight: M ≤ 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 the vendor.

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 are used in METL. One of the flow meters (shown in Figure 91), will monitor the flow through the main loop while the other two (shown in Figure 92) monitor flow through the 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 has a 1-1/2" Grayloc hub on each end. And flowmeters in the purification/diagnostic system are 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 $1x10^{-4}$ Torr (vacuum) to 218 [psig].

Flowmeter in the main loop:

- Flow rate of 10 [gpm] +10% / -0% at pressure of 5 [psi Δ]
- ±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]
- ±3.5% of the full scale value at 300 [°C]

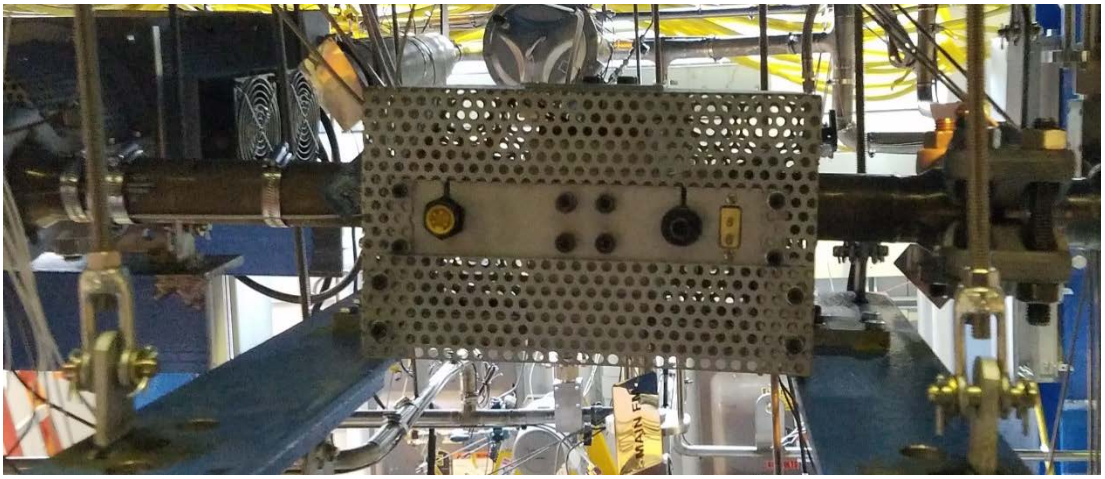

Figure 91 – Installation of the flow meter for the primary loop.

Figure 92 - Picture of the purification (cold trap) loops' pump (left) and flow meter (right).

3.2.12.3 *Pump & Flowmeter Control Panels*

Each pump and flowmeter has a dedicated control and output panel. As shown in Figure 93, the controls for all the pumps and flowmeters were installed during FY2014. Bucking transformers and variable speed drives for the AC conduction pumps are to be installed in the fall of 2016.

Figure 93 – 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, Argonne engineers were able to determine the exact quantity and power requirements of all the Phase I heater zones. A scalable, industrial hardware system was designed and fabricated by Eurotherm. This hardware will 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
Eurotherm 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 (NI) 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 Eurotherm 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 94. 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 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 94.

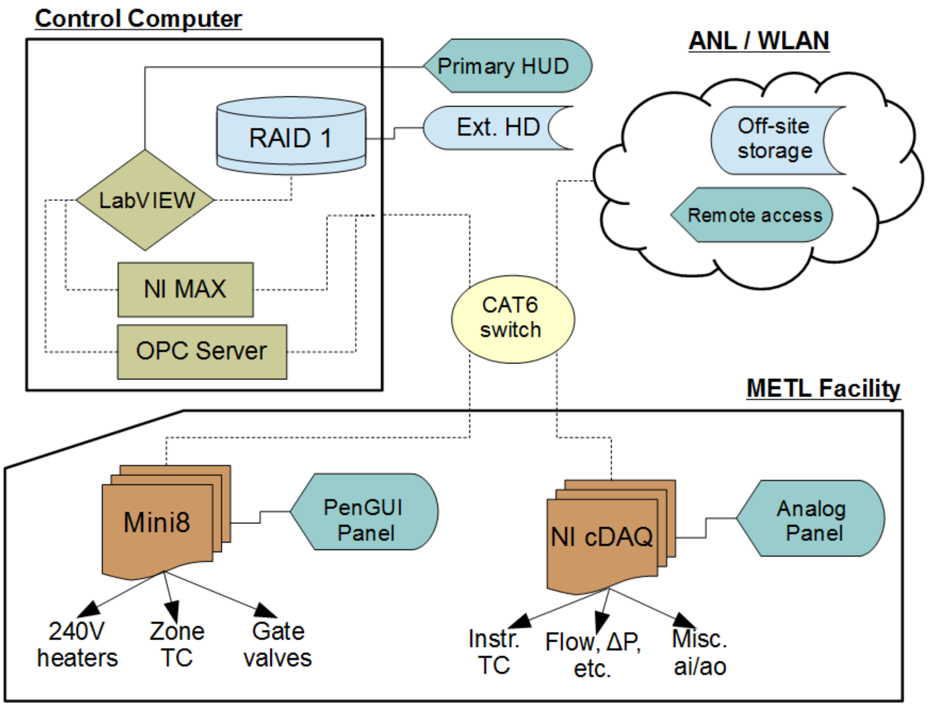

Figure 94 – Proposed communications network to be used for METL.

3.2.13.2 Eurotherm Enclosures

After several internal safety review meetings, Argonne engineers have opted to use hardware to provide ground-fault protection of equipment (GFPE). Illustrated in Figure 95, a 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. Argonne engineers have decided to use ‘intelligent’ or shunt-enabled breakers in each heater zone to provide added protection against runaway heaters should an SSR fail in the ‘closed’ position. Argonne engineers worked closely with Eurotherm to determine the appropriate power and control layout for Phase I of METL. All of the power and control enclosures were created, delivered, and installed in building 308. Currently, they are awaiting electrification.

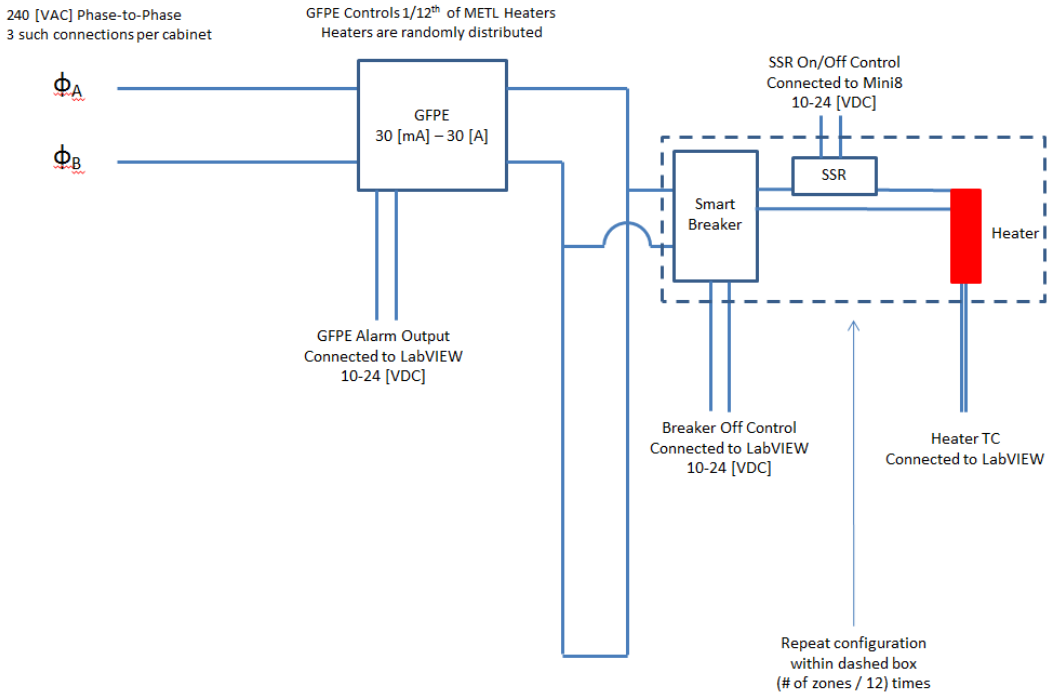

Figure 95 - An illustration showing the METL heater control circuit design.

There are a total of five Eurotherm enclosures. One of the enclosures is a control enclosure (CE1) and is shown below in Figure 96. CE1 has twenty-two Mini-8 Eurotherm controllers which communicate over Ethernet via OPC server or MODBUS. Each controller is capable of processing sixteen heater PID loops with thirty-two type K thermocouple inputs. The Mini-8 calculates PID percentage based on the set point, present value, and user-defined proportional gain, integral and derivative times.

Then, the Mini-8s communicate its' percentage to T2750 controllers located in the power enclosures (discussed subsequently) to physically close or open a circuit to its' respective heater. The duration each circuit is closed is proportional to the percentage value received from a Mini-8. As previously discussed, in the event a host computer or display panel fails; the Mini-8's have their own real-time microprocessor so they will continue to operate at their last specified condition.

Figure 96 – Control Enclosure (CE1).

Type K thermocouples are accurate, repeatable, inexpensive, and readily available. However, their relationship to temperature is a function of millivolts (mV) of electrical potential. To ensure the integrity of the signal and protect it from electromagnetic interference; twenty-one thermocouple umbilical enclosures (Figure 97) were installed throughout the METL footprint. These enclosures have forty-eight screw terminals to connect twenty-four individual type K thermocouples. An umbilical is connected to all of these terminals with type K thermocouple twisted pair wire which is surrounded by a shield, grounding "drain" wire, and insulation. These umbilical cords are routed and connected to a mini-8 controller inside CE1 on the mezzanine. The distance from an enclosure to a mini-8 varies but can be upwards of 80 feet.

Figure 97 – Thermocouple Umbilical Enclosure.

There are a total of four power enclosures (PE1 through PE4). PE1 and PE2 house the hardware responsible for controlling higher currents such as ceramic band heaters for the test vessels, dump tank, and expansion tank. PE3 and PE4 contain hardware that controls the heater zones for the valves and piping system which draw far less current. The power enclosures are located northwest of the mezzanine in Building 308 as shown in Figure 98.

Figure 98 – (Front to Back) Power Enclosures 4, 3, and1-2. PE1 and PE2 are located in the same rear column with PE 2 on the left. (Roof penetrations are for air conditioning units)

All power enclosures are analogous with respect to the equipment they contain such as; circuit breakers, distribution blocks, solid state relays (SSRs), miniature circuit breakers, Foxboro T2750 programmable automation controller(s), 24VDC power supplies, and shunt trips. All of this equipment is wired together and neatly routed through wire ducts. This equipment can be seen below in Figure 99. Power will be supplied from Building 308's electrical yard to the PEs and then will be distributed throughout METL via 14" X 14" wireway. In summary, the functions of the power enclosures are:

- Utilize 24VDC power supplies to provide excitation for the T2750s.
- T2750 receives a signal from a Mini-8 to close or open the contact on an SSR by delivering or withholding a 24VDC signal
- A circuit breaker will close its' contacts automatically in the event the equipment draws excessive amounts of current.
- If the SSR fails closed (run away SSR), a T2750 outputs a 24VDC signal to activate the shunt which then forces the aforementioned breaker closed.
- There are ground fault circuit interrupters (GFCI) which will open the circuit if current leakage is present.
- PE3 contains a T2750 that directly actuates all of the valves found in METL.

Figure 99 – Hardware found in PE1, 2, 3, and 4. DC power supplies and T2750s are located on the left and circuit breakers, shunts, and SSRs are shown to the right

3.2.13.3 PenGUIN Display Panel

Installed on the exterior of CE1 is a standalone display panel that provides communication with the 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 100.

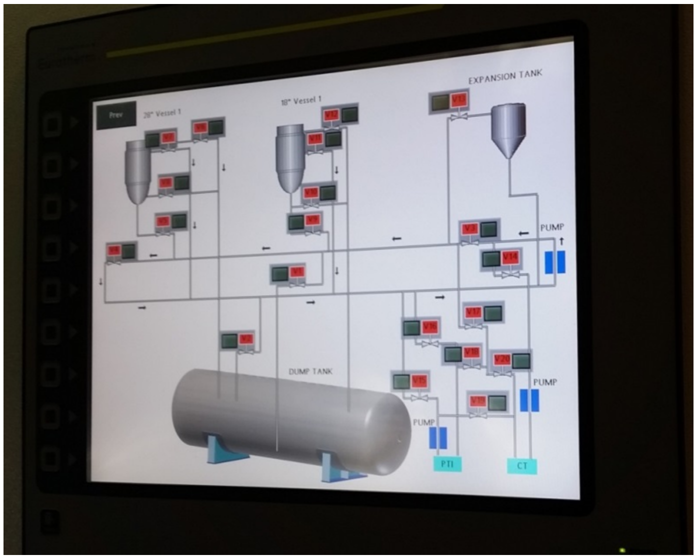

Figure 100 - A photo of the PenGUIN display panel, valve states shown

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 101. The controllers discussed in section 3.2.13.2 are suitable for operating heaters and valves as their data sampling and response time does not have to be rapid. However, METL has components and operations that will require faster performance; possibly to the level of kHz. These will be managed with National Instruments (NI) hardware.

Figure 101 - 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.

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 102. Twelve of these devices will be installed along the METL mezzanine to provide control, data acquisition, and flexibility for future experiments. An NI power supply and distribution block (Figure 102, right) will provide the NI chassis with excitation. Eurotherm controllers have their own software to program their logic as does NI hardware. NI hardware uses LabVIEW software to program their logic. LabVIEW will also be used to write programs to interface with Eurotherm controller logic.

Figure 102 - A photo of an NI c-DAQ 9188, 8 module chassis (left) and NI power supply (right).

LabVIEW is capable of communicating directly with the Mini8 via an OPC server or MODBUS, 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 103.

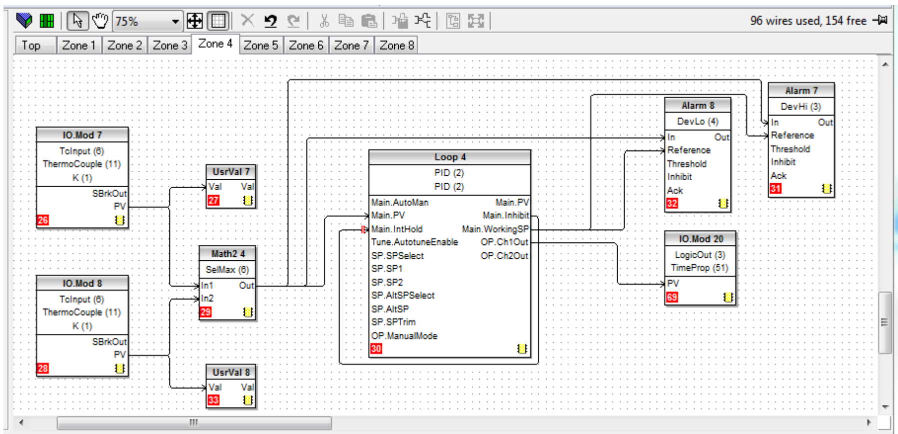

Figure 103 - An example of an iTools recipe, Mini8-1 PID loop

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 104.

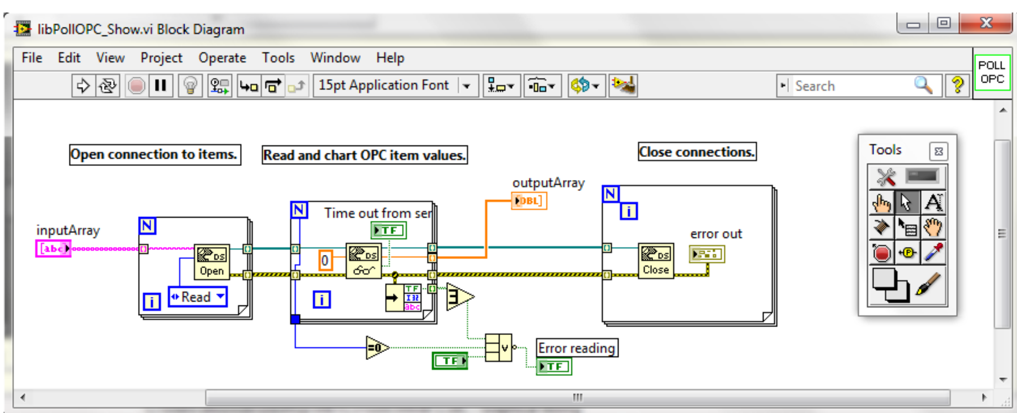

Figure 104 - A LabVIEW block diagram for opening OPC connection and polling Mini8 values

3.2.14 ***Instrumentation***

METL cannot only be envisioned as a facility for multiple experiments, but also as an experimental apparatus itself. Therefore, instrumentation is required not only for proper and safe operation but for measuring the performance of its components. Instrumentation for Phase I includes pressure transducers, thermocouples, inductive level sensors, differential pressure sensors, and volumetric flow meters/controllers.

3.2.14.1 Pressure Transducers

Argonne engineers initially worked with an outside vendor to produce a prototype NaK-filled transducer that could be used in METL (Figure 105). This sensor model is typically used in the high-pressure plastic extrusion industry but the sensor body, diaphragm, and Grayloc fittings shown in Figure 106 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 Gefran hardware prompted Argonne engineers to initiate discussions with another vendor regarding custom NaK-filled pressure transducers for the differential pressure (DP) gauge. Thus far, Argonne has ordered fourteen single-point pressure sensors from the second vendor for use within the METL. These fourteen sensors will connect to the system using Grayloc fittings, as shown in Figure 107. All fourteen pressure sensors have arrived at Argonne and are awaiting installation. An example of the pressure transducer is shown in Figure 108.

Figure 105 – 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 106 – A close-up photo of the diaphragm of the transducer. The diaphragm is ~ ½" in diameter. This small diameter is not expected to provide the adequate sensitivity that is required for the METL level control system.

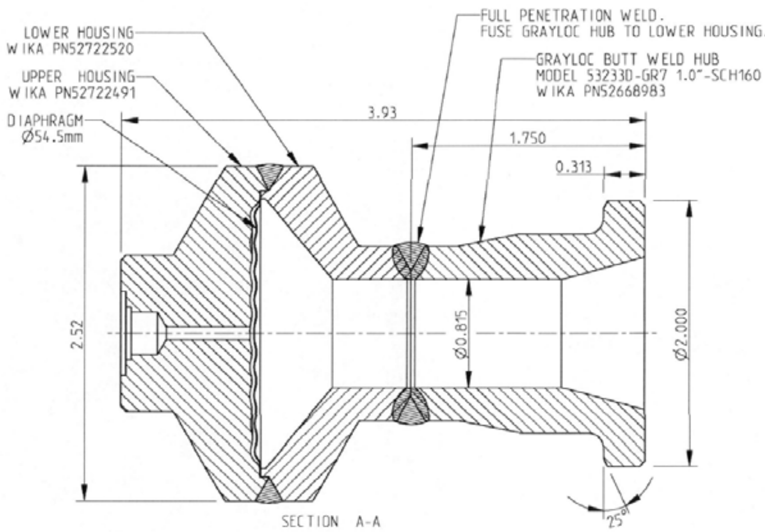

Figure 107 - A drawing of the single-point NaK-filled pressure transducers that will connect to the METL system using Grayloc fittings. This sensor is rated for 200 [psig] at 1200 [°F].

Figure 108 – Yokogawa pressure transmitter with a NaK filled capillary connected to a WIKA pressure diaphragm seal with a welded Grayloc connection.

3.2.14.2 Thermocouples

Currently, all of the temperature measurements are made with type K thermocouples which have a standard limit of error of ±0.75% (Figure 109). The majority of the thermocouples are ungrounded, stainless steel sheathed, and have a high temperature mini male connector. These thermocouples are strapped to the METL piping system and vessels. However, there are instances where the thermocouples' sheath is in direct contact with the sodium. Currently, these occurances include the following:

- Cold Trap
- Plugging Meter
- Vapor traps for test vessels, expansion tank, and dump tank

Figure 109 – Over 500 Type K thermocouples and 10,000 feet of type K thermocouple wire were ordered for Phase I of the METL.

Thermocouples with their sheath in contact with sodium on the cold trap and plugging meter are welded directly into their respective component as these will experience a liquid sodium environment. The vapor trap thermocouples should only be exposed to sodium aerosols/vapors. Therefore, these are welded into a VCR fitting (Figure 110) which can actually be removed/replaced on the vapor trap.

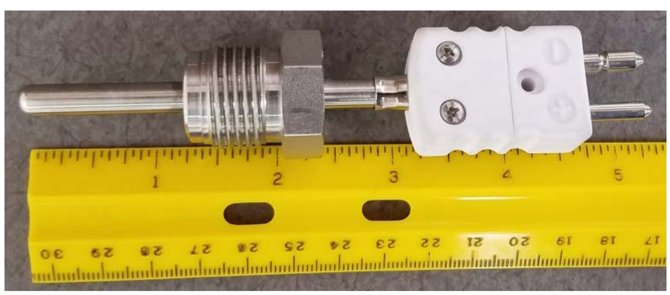

Figure 110 – In-flow vapor space thermocouple probe.

3.2.14.3 Argon Volumetric Flow Controllers

The argon cover gas flow into the vapor space of the vessels, expansion tank, and dump tank needs to be controlled, so two independent mass flow controllers (Figure 111) were installed downstream of the argon regulator (Figure 75). These controllers may also be used to control the bubbling of argon gas into the dip tube of the differential pressure transmitter. The controllers are able to handle 1000psi and have a control range 1 – 2500 lpm.

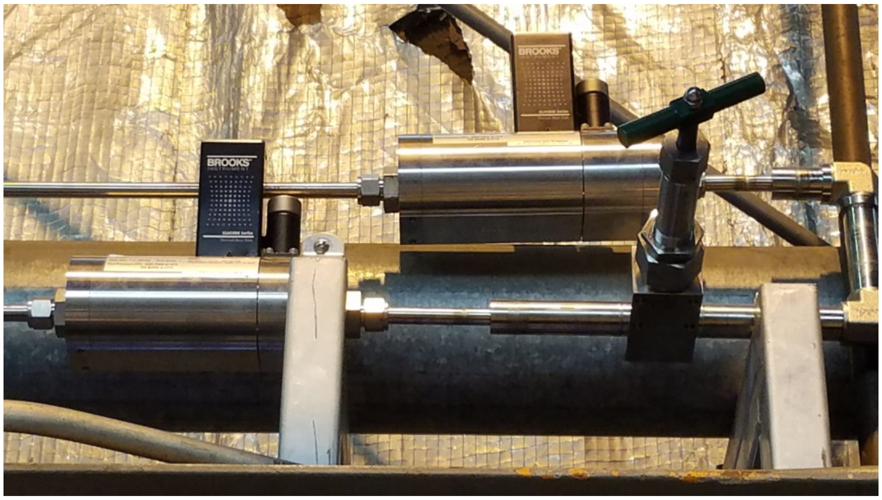

Figure 111 – Argon Mass Flow Controllers.

*3.2.15 **Flexi-Cask System***

When test articles are installed, repaired, or removed there is a possibility that air could contaminate the sodium that is frozen to the experiment or vessels. To limit the risk of air contamination, a flexi-cask system will be used to provide an inerted atmosphere for the vessels and test articles.

As shown below in Figure 112, the flexi-cask system will be lowered onto the vessels. The volume within the flexi-cask will be kept inerted using a constant argon purge. The flexi-cask system will operate using the pre-existing crane in the Bldg. 308 hi-bay, as shown in Figure 113.

During FY2015, the design of the flexi-cask was completed and the contract to fabricate the flexicask was awarded to an outside vendor. The completed flexicask is currently on-site awaiting assembly and preliminary testing.

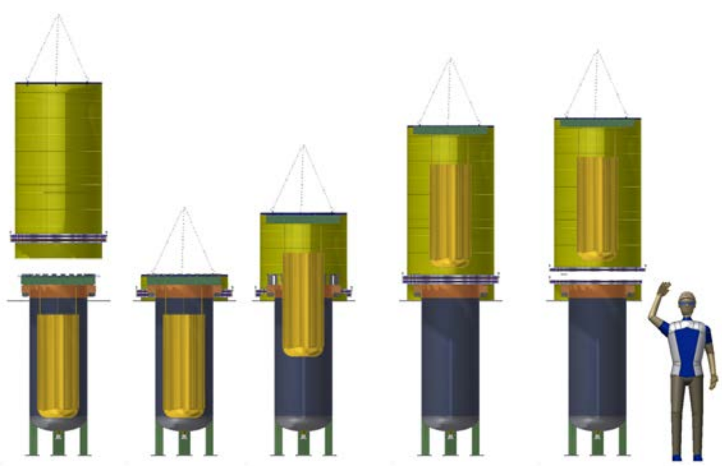

Figure 112 – A 3D model depicting of flexi-cask operation.

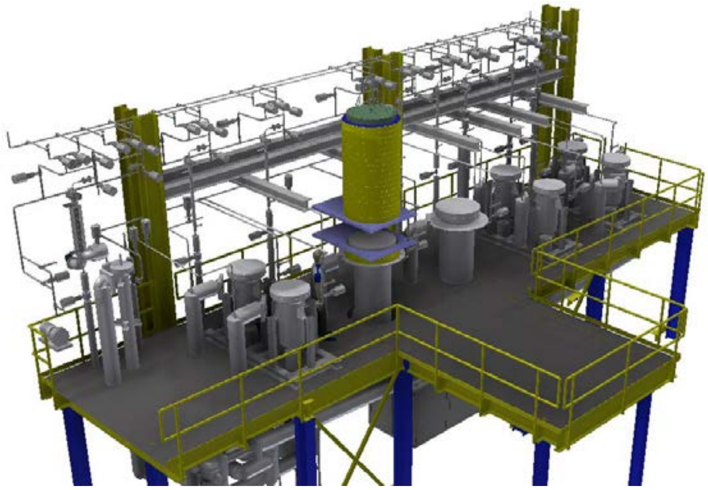

Figure 113 – A 3D model showing how the flexi-cask system will operate above the METL facility.

*3.2.16 **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 Argonne several years ago for the EBR-II deactivation program.

The carbonation process works by bubbling CO_2 through a water column in order to carry trace amounts of moisture into a vessel containing the used test articles. The moisture and CO_2 react with the sodium residue in one of the two following processes:

$$Na(s) + CO_2(g) + H_2O(g) \rightarrow NaHCO_3(s) + \ 0.5\, H_2(g) \qquad \Delta H^\circ_r \approx -313 \text{ [kJ/mol]}$$

$$2\, Na(g) + CO_2(g) + H_2O(g) \rightarrow Na_2CO_3(s) + H_2(g) \qquad \Delta H^\circ_r \approx -496 \text{ [kJ/mol]}$$

The P&ID of the carbonation system that has been built at Argonne can be found in Figure 114. The completed CO_2 bubbler system, shown in Figure 115, is able to hold 7 [gal] of deionized water. Depending on the operating temperature and CO_2 flow rate, the water inventory can be transferred from the carbonation system in 3-4 days.

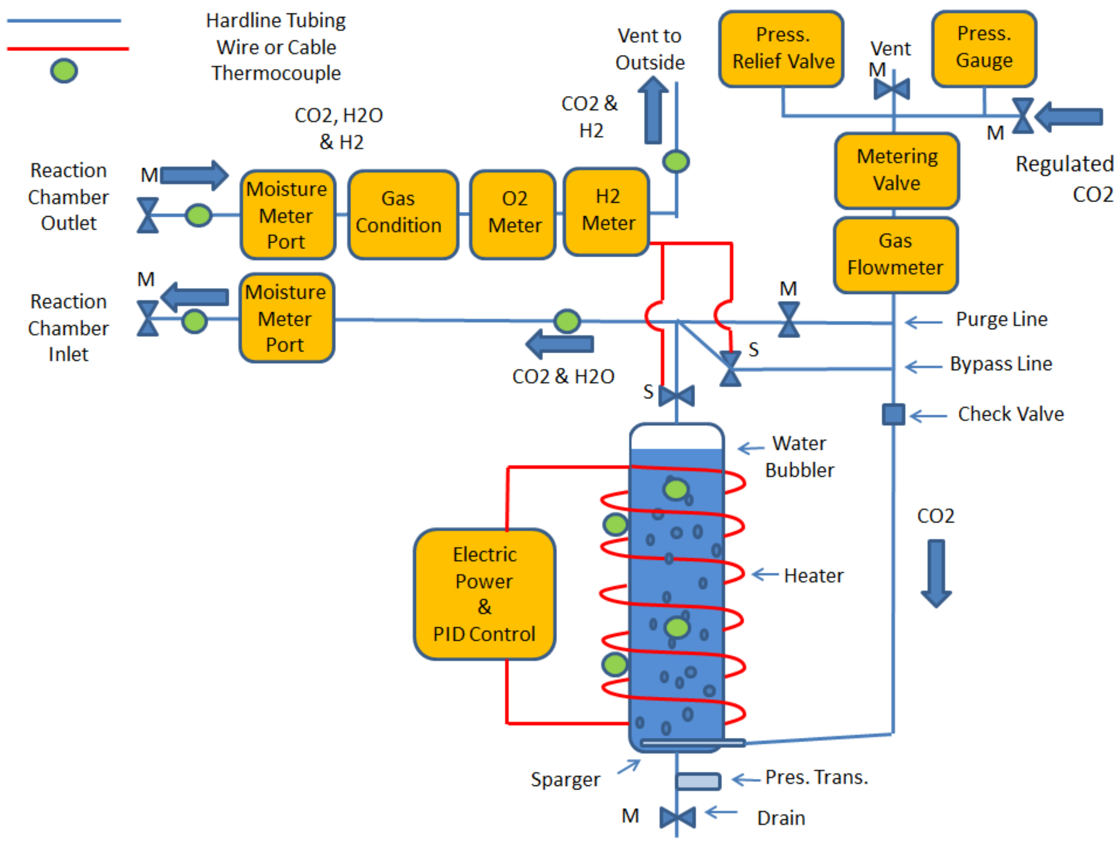

Figure 114 – A P&ID for the carbonation system. (M = manual valve, S = solenoid valve).

Figure 115 – 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.

3.2.17 ***Sodium***

Fifteen 180 [kg] drums of R-Grade (99.9%) sodium were delivered to Argonne. 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 116.

Figure 116 – 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.

*3.2.18 **Bldg. 308 Roof & Exterior***

During FY2015 a new waterproof membrane was installed on top of the Bldg. 308 hi-bay by Roofs Inc. Additionally, the exterior of the hi-bay was repainted with a weather-proof epoxy.

The total cost of the work was over ~ $1M. Senior lab management fully supports the experimental work being conducted in Building 308.

Figure 117 - A photo of the Bldg. 308 hi-bay. During FY2015 a new waterproof membrane was installed over the preexisting roof and the exterior of the building was repainted with a weather-proof epoxy.

4 Summary

The preceding report provided a summary of the status of the METL facility as of September 2016. A tremendous amount of effort has gone into advancing the design and fabrication of Phase I for the facility. A special focus of FY2016 was on the fabrication and installation of the vessel and piping system for METL and procurement of the instrumentation and controls system. The majority of the equipment has arrived and is currently being installed. Procurement and installation of the remaining Phase-I components and systems will continue into FY2017. The facility is expected to go through shakedown testing, commissioning, and initial sodium fill operations in early FY2017.

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