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Mechanisms Engineering Test Loop (METL) Operations and Testing Report - FY2021

Nuclear Science and Engineering Division

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Mechanisms Engineering Test Loop (METL) Operations and Testing Report - FY2021

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Nuclear Engineering Division
Argonne National Laboratory

September 2021

1 EXECUTIVE SUMMARY

This report documents the operations and testing that was performed at the Mechanisms Engineering Test Loop (METL) during FY2021. The METL facility had a very successful third year of operations having logged about 944 days of operations with molten sodium either in a flowing or static condition. Operations were paused in April 20, 2021 to accommodate the refurbishing of building 308's alkali metal passivation booth and scrubber (AMPB&S). METL is being prepared to support a second larger experiment, the Thermal Hydraulic Experimental Test Article (THETA) and expects to resume the Gear Test Assembly (GTA) testing. The technology development team is also developing two additional experiments, a gripper test article and a flow sensor test article that are expected to go into METL in late FY22 or early FY23.

1.1 Purpose & Background

The METL facility has the capability to test small to intermediate-scale components and systems for advanced liquid metal technology development. Testing various 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.

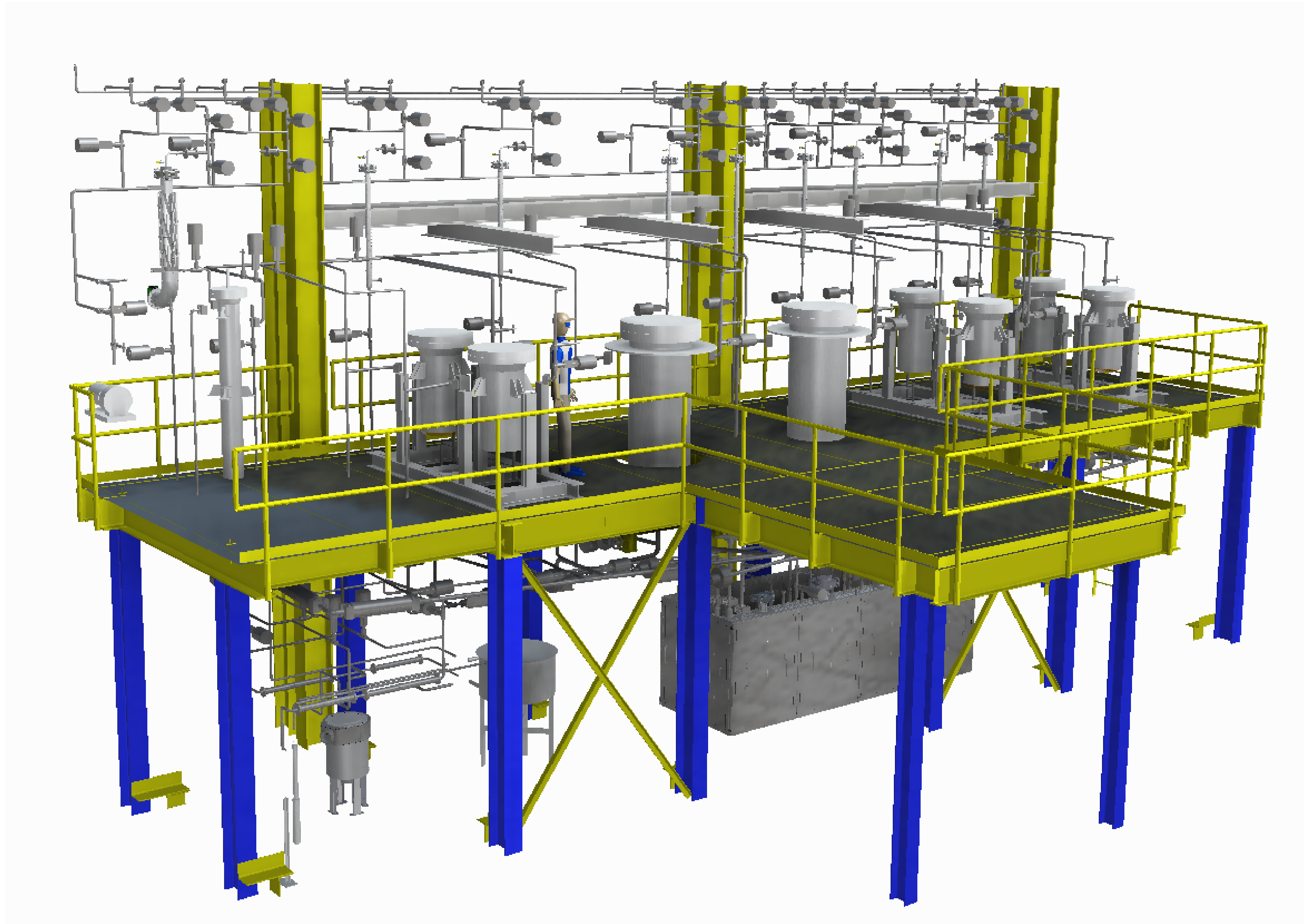
METL continues to provide development opportunities for younger scientists, engineers, and designers who will ultimately lead the advancement of U.S. liquid metal technologies. The hands-on experience with METL, both successes and perceived failures; will ultimately lead to better liquid metal technology 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 (1) 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.

5. *Health Monitoring of METL systems and components* – The development of sensors and prognostic techniques for deployment that can monitor and quantify materials degradation in liquid metal-cooled fast reactor primary systems. Technologies that detect degradation early, can survive in typical liquid metal-cooled fast reactor environments over extended periods of time, and can be embedded in/on structural materials to enable structural health monitoring (e.g., nondestructive examination techniques, remote or automated inspection techniques including visualization in optically opaque coolants) can be tested in METL.
6. *Thermal hydraulic testing in prototypic sodium environment* – A thermal hydraulic test loop could be used to acquire distributed temperature data in the cold and hot pools of a small-scale sodium fast reactor during simulated nominal and protected/unprotected loss of flow accidents. This testing could allow for the articulation of the heated region in the core to allow for a parametric study of IHX/core outlet height difference and its effect on thermal stratification of sodium in the hot pool. Ultimately this data will be used for validating CFD and systems level code.
7. *Human Machine Interface Technology* – Technologies for improving the ability of operators to understand what is happening inside the sodium environment. One example would be the ability to provide a refueling system operator to see in-vessel refueling in a virtual environment during in-vessel refueling.

As shown below in Figure 1, the design of the METL facility consists 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.



1.2 METL Operational Year II Accomplishments

The METL facility and team had a successful third year of operations that involved validating level sensing equipment and operating the GTA. The METL team remained productive during supporting facility renovations by progressing on experimental designs, upgrading/repairing METL components and supporting industry/academia needs. The following list is the significant accomplishments during the past reporting period:

- METL has maintained its sodium in a molten state (either flowing or static) for almost 3 years, since September 19, 2018 and drained the facility on April 20, 2021.
- Multiple sodium flowing and purification 'batch' campaigns were performed.
- The METL team has continued to confirm the functionality of the sodium purification cold trapping system and has purified the METL sodium down to 5 ppm oxygen.
- Refurbishing of building 308's alkali metal passivation booth (AMPB) was completed.
- The GTA was disassembled, and the parts were removed after cleaning. Modifications were made to the GTA gear housing to facilitate the draining of sodium.
- The GTA was rebuilt with new bearings, the same gear set, and improved gas seals.
- The GTA was inserted into Test Vessel #1 in preparation for the third round of testing.
- Assisted in the thirds Gear Test Assembly test campaign.
- The 28-inch flexicask arrived and assembly has commenced.
- Maintained alkali metal program support equipment (Building 308 Scrubber, Superheated Steam System, 18-inch Flexi-Cask, Carbonation System, Glovebox and Qualification Station)
- Began the construction of Test Vessel 6's argon gas and vent piping.
- A replacement and improved Cold Trap as well as RDT compliant Plugging Meter was fabricated and placed into storage.
- Performed the third test article extraction using the 18-inch flexicask from Test Vessel 1 (GTA extraction from Test Vessel 1) to the carbonation vessel
- Performed the third cleaning using moist carbon dioxide followed by disassembly of the GTA on the 18-inch test stand
- Continued demonstration of level sensor technologies (using an inductive level sensor, a differential pressure sensor, and a thermophysical property probe).
- Installed THETA experiment into Test Vessel 4 and mounted its supporting hardware.
- Prepared a procedure for the draining and freezing of the METL facility which occurred on April 20, 2021.
- Reconfigured the cold trap and plugging meter flow meters from hall-effect flow meters to permanent magnet flow meters
- Installed new ultrasonic flow meters on the main loop and the cold trap loop

1.3 Plans for FY2022 at METL Phase II

The METL facility will resume molten sodium operations in FY2022. During FY2022, we expect to be reconditioning the gear test assembly (4^{th} time) which was tested in FY2019-2020 and retesting the test assembly in Test Vessel 1, filling Test Vessel 4 for the first time to fill the THETA experiment with sodium for its initial testing and sodium qualifications, , running the primary section of the THETA experiment for thermal hydraulic code validation, conducting more inductive and thermal property level sensor development work, building upon the new control system for METL, commissioning the 28-inch flexicask system, and responding to industry and/or nuclear energy university program calls for experimentation in METL.

METL's Phase II construction continued to progress in FY2021 and beyond. Immediate efforts are focused on finishing Test Vessel 6. Test Vessel 6 piping is nearly 80% complete and will then be equipped with heaters, instrumentation, and insulation. The METL team will also provide support to the hydrogen sensor work as necessary – which is part of the ART programmatic work.

1.4 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 Alice Caponiti of DOE-NE, Deputy Assistant Secretary. Office of Reactor Fleet and Advanced Reactor Deployment; Janelle Eddins, Advanced Reactor Technologies, R&D Program Manager; Brian Robinson of DOE-NE, Advanced Reactor Technologies, Fast Reactor Manager; and Robert Hill of Argonne National Laboratory, ART R&D Fast Reactor National Technical Director.

The authors would like to extend their gratitude to core and extended METL team members Daniel Andujar, Dzmitry Harbaruk and Henry Belch for operating METL as well as supporting experimental work. The authors are extremely thankful for the support from Bill Toter, Bob Sommers and Daniel Berkland at Argonne National Laboratory Central Shops (ANL-CS) as they continue to provide assistance for METL maintenance and expansion as well as test apparatus fabrication. Lastly, efforts from Christian Kourkoumelis, Jay Johnson and Argonne Business and Information Systems (ANL-BIS) were vital in establishing a strong and secure network infrastructure to which the authors are grateful.

The authors are also very grateful to the former Argonne personnel who worked on EBR-II and sodium technology in the former Components Technology Division.

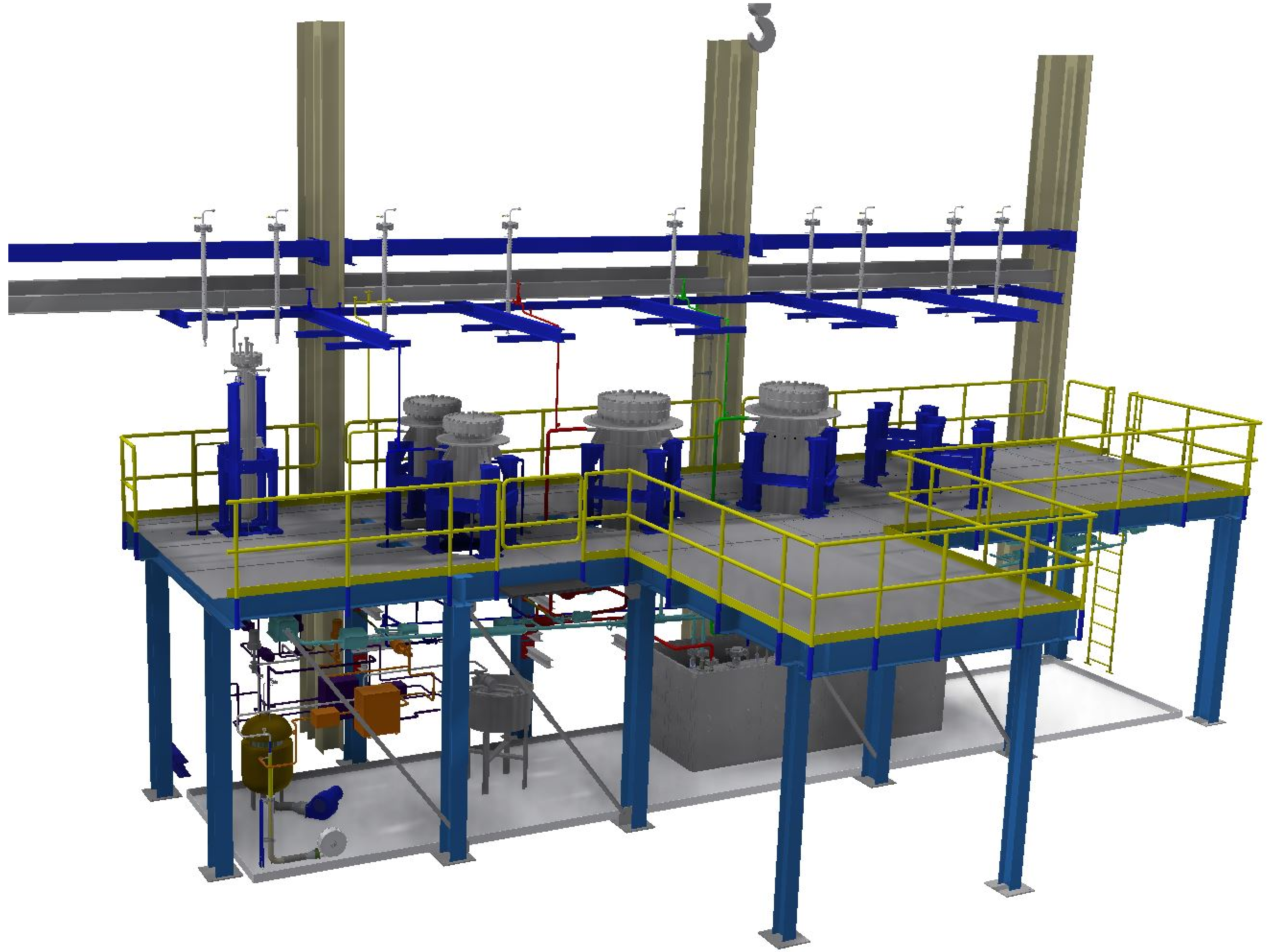


Figure 2 – A 3D model of METL after Phase I is complete.

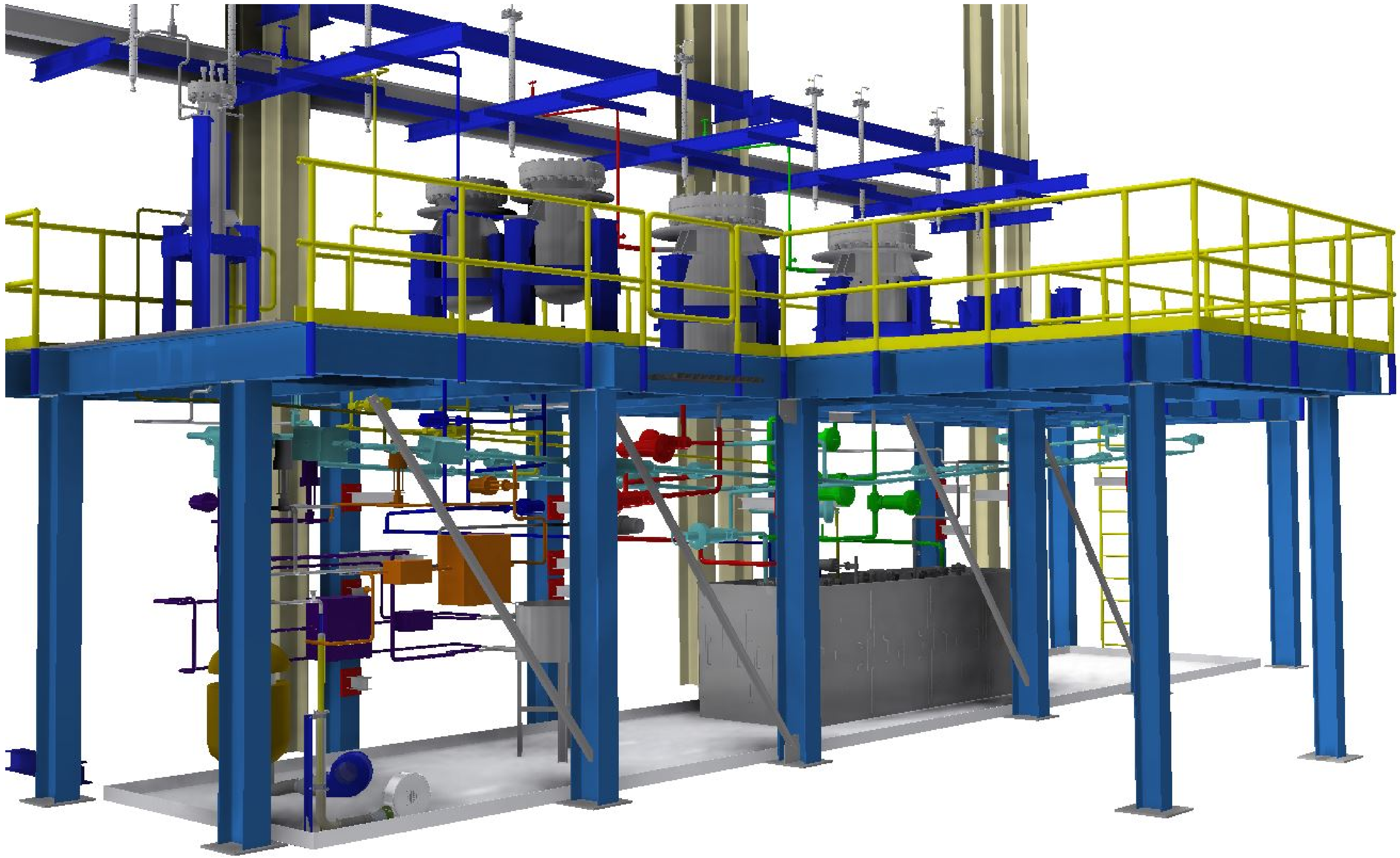


Figure 3 - A 3D model showing the Phase I piping and equipment arrangement underneath the mezzanine.

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2 Background and Objectives

The successful operation of sodium-cooled fast reactors will largely depend on how well their components work within a sodium environment. Therefore, the mission 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 environment. In turn, the results gleaned from experiments performed in METL will help to develop state-of-the-art 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 provide the environment suitable for the particular needs of an experiment. During operation, the sodium is purified by passing it through the METL 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 a 28” test vessel is 1,200 [°F] (Figure 2).

3 METL Operations

METL is a unique U.S. facility within the Department of Energy complex as it provides opportunity for researchers to test small to intermediate scale sodium components but also acts as an experiment itself. METL's infrastructure promotes flexible operations to accommodate virtually any device that fits within the volume of the Test Vessels but also has open mezzanine area and (3) inlet/outlet ports available to demonstrate larger or loop-type tests. In addition, METL's 20+ year operational life will garner information and experience essential for SFR commercialization that small/benchtop test apparatus which are periodically operated cannot supply.

METL's resemblance of a liquid metal reactors (LMRs) intermediate heat transport system yields data directly applicable to operations and maintenance of LMR systems and components. METL's configuration, scale, and years of continuous operation establishes a proving ground not only for SFR equipment but also supporting equipment and operational methods.

3.1 Continuation of GTA Campaign

The Gear Test Assembly (GTA) is an experiment for investigating wear profiles on gears which will be used in SFR fuel handling equipment. Details on this apparatus can be found in its annual report (2). The METL team supported the insertion of the GTA into Test Vessel 1, filled this vessel with sodium from the Dump Tank and then proceeded to circulate the sodium through the cold trap to purify the sodium. Post GTA test, the METL team drained sodium from Vessel 1 back into the Dump Tank, cooled down the vessel, removed the GTA from the Test Vessel 1 (using the 18-inch Flexi-Cask) and replaced the GTA with a blind flange on Vessel 1. The METL team proceeded to clean GTA parts with alcohol and disassembled the GTA (Figure 4).

Figure 4. Failed thrust bearing assembly in GTA.

3.2 Freeze and Cold Standby

METL is located in Building 308. Building 308 includes an alkali metal scrubber unit that is used for the removal of sodium oxide from the atmosphere in case of a leak of molten sodium. In FY21, the piping providing water to the scrubber was found to be severely corroded and in need of replacement. Internal funding was found to perform these repairs.

To accommodate the alkali metal scrubber system being offline (subsequently discussed) for repairs, METL was frozen and placed into cold standby. This cold standby state put METL into a condition that would eliminate any chance for a liquid sodium leak to occur during the B308 scrubber repair work. A cold standby state was achieved by draining the sodium in the METL loop into the dump tank and then freezing the sodium by de-energizing the system trace heating. METL system components were placed into a safe state, whereby accidental operation would not be possible; valves were locked in either an open or closed position and heater breakers were locked out.

An 18-page procedure was written, and a lead engineer was assigned to ensure the procedure was followed throughout the course of implementing the METL cold standby state, ensuring a safe process that would leave METL in a state accommodating the thawing of the sodium to bring the system back to hot standby following the scrubber repairs. The following paragraphs briefly describes the general steps taken to bring the METL facility to a cold standby state, where the vessels, expansion tank and primary loop were effectively drained, all heaters were turned off in the system, and the system was left in a configuration that allows for safe thawing and re-activation.

3.2.1 *Purify*

Before draining the system, the METL cold trap was operated for around 10 turnover cycles (~8 hours) to bring the sodium oxide content to a concentration of approximately 2 wppm. Sodium was pushed through all sodium wetted METL components including the cold trap loop, plugging meter loop, primary loop, expansion tank and test vessel 2 (test vessel 1 had been previously drained). This was an important step to reduce entrainment of oxide in uninsulated dead ends 'cold fingers' throughout the facility that could cause plugging of smaller orifices while bringing the system back to hot standby after cold standby. During this operation all of the sodium in the METL loop, besides the cold trap (which was at 168 °C), was at a temperature of 300 °C and the dump tank sodium temperature was set to 275 °C.

3.2.2 *Drain*

After purifying the sodium, all pumps were shut off and the system valves were placed into an orientation to promote the draining of the primary loop, expansion tank and test vessel 2 (tst vessel 1 had been previously drained) of sodium via gravity through the L-OUT valve. Note that the L-OUT valve was used as it does not lead to a dip tube (as with L-IN valve) thus reducing the amount of mixing of impurities at the base of the dump tank and eliminating any possibility of pushing sodium from the dump tank back into the primary loop.

Argon cover gas was set to regulate a constant overhead pressure of 6-8 PSIG in the expansion tank and vessels to ensure vacuum was not pulled during the drain as sodium was evacuated from the system volume. Note, a significant volume of argon would be pulled into the loop and exposed to the internal surfaces of the facility during the draining operation. Therefore, a 230

L dewar of ultra-high purity argon was valved into the system, instead of using the less pure 1000 L micro-bulk of high purity argon that is typically used.

After evacuating the facility with an initial gravity drain, the system valves in the primary loop were arranged in such a manner so as to promote draining when argon pressure was increased in the expansion tank- effectively ensuring all areas of the primary loop were drained.

3.2.3 *Valve Lock-out/Tag-out*

It was important to eliminate the risk of accidental operation of the electro-pneumatic sodium wetted valves while METL was in cold standby. Any valves that were to remain open were mechanically locked out and tagged out (LOTO) in the open position to eliminate accidental operation of the normally closed valves that passively default to the closed position with spring tension. This was important as accidental operation of the valves due to loss of electrical power could tear the fragile bellows as frozen sodium residue residing in the bellows could create an obstruction.

3.2.4 *Diagnostic Loop Freeze*

After LOTO-ing all of the valves into a safe state for freezing, the purification and diagnostic loops (cold trap and plugging meter) were frozen. Note that the diagnostic loop resides at a lower elevation than the main primary loop, so draining the diagnostic loop of sodium was not possible. Therefore, an approach to safely freeze the sodium in this region was developed. The diagnostic loop process control heaters were switched off and locked out from the "inside-out"- where the cold trap (CT) and plugging meter (PM) heaters were locked out first and then heaters were consecutively locked out away from these components towards the primary loop, Figure 1. This inside-out approach was performed to avoid trapping a volume of sodium with active process heat control behind a region where the sodium had frozen, the result of this being that thermal expansion of the sodium would not be accommodated and undue thermal expansion stress could be imposed on the piping.

3.2.5 *Remaining System Freeze*

Following the diagnostic loop freeze, the primary loop was frozen by locking out the process control heaters sequentially starting with the diagnostic loop inlet/outlet and working outwards, Figure 5. The expansion tank and test vessel process heaters were all turned off and locked out. The dump tank heaters were then all turned off and locked out. Finally, the vapor trap heaters were all turned off and locked out. The temperatures in the systems were periodically monitored to ensure the sodium was freezing and the argon cover gas pressure was maintained by the regulator at ~6 PSIG. After the system reached a steady state, the 1000 L micro-bulk of high purity argon was valved back into the cover gas system and the system pressure was monitored daily to ensure a positive pressure of inert cover gas was maintained over the frozen sodium.

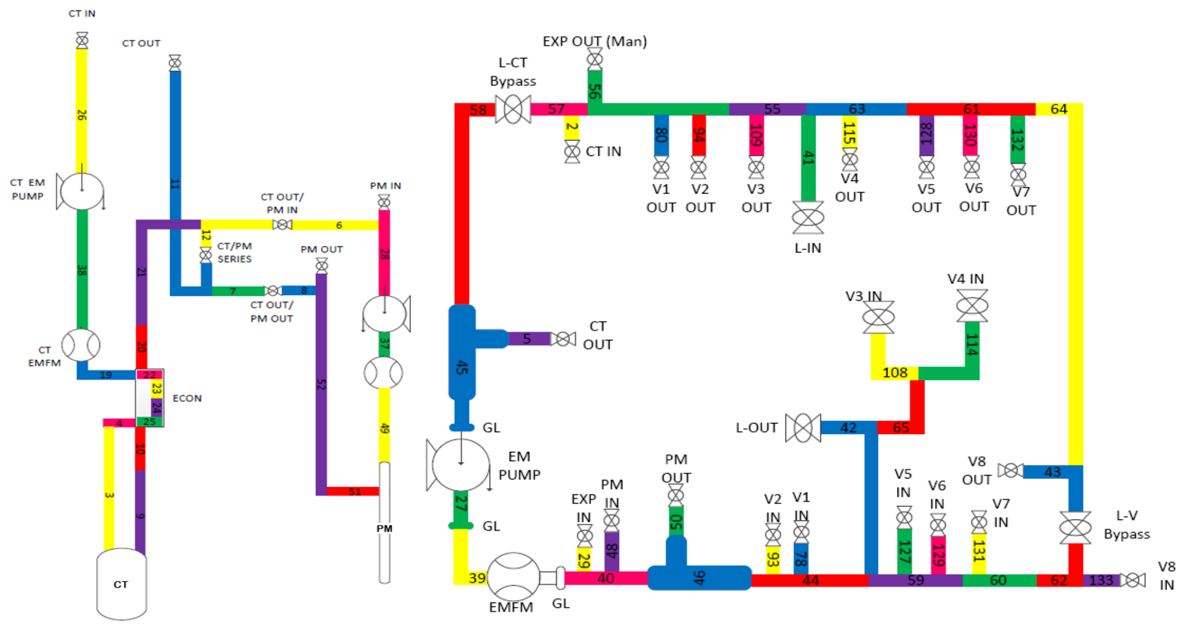


Figure 5. Diagnostic (left) and primary (right) loop heater zone schematics

3.3 Development of Infrastructure and Supporting Equipment

3.3.1 *28" Flexi-Cask*

A Flexi-Cask enables the insertion/extraction of test vessel experiments while maintaining an argon inert environment over the test vessel reducing impurity contamination of the test vessel. A Flexi-Cask is equipped with (2) pocket doors, a glove bag and a lifting disc. This configuration was used successfully to install and to remove the GTA for multiple test campaigns. The current Flexi-cask is suited for mating with an 18" Test Vessel. Due to its proven ability to maintain a quality atmosphere, a scaled-up version for use on the 28" Test Vessels was designed. The 28" Flexi-Cask will be assembled, tested and utilized for THETA in FY2022.

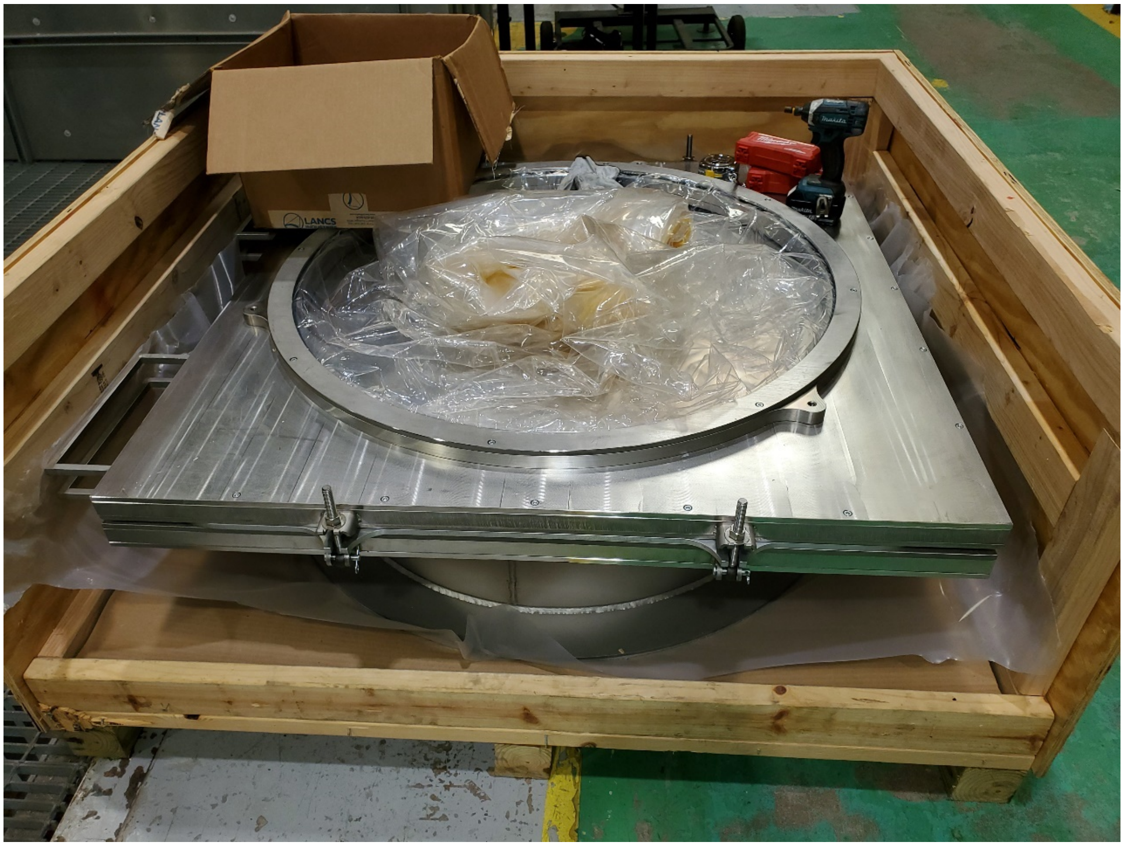


Figure 6. Flexi-Cask for 28" Test Vessels

3.3.2 *Test Apparatus Supporting Infrastructure*

3.3.2.1 *Uninterruptible DC Power*

There are many repetitive DC power installations and equipment found throughout METL and their function is the same, supply data acquisition equipment and instrumentation with a DC power supply capable of withstanding intermittent power outages. Components consist of two or more DC power supplies and a redundancy module fed from a UPS.

A consolidation plan in the form of an electrical single line diagram is illustrated below in Figure 7. A 20kVA UPS is a load on METLs diesel fed panelboard, this provides quadruple redundancy for the AC supply side of the UPS. The UPS feeds a fused disconnect to energize a new/separate panelboard. Loads on the UPS panelboard include the entire control room, multiple METL power distribution units (PDU) (SurfRIO PDU, SurfX0 PDU and PES PDU) and a PDU dedicated for experiments (XNET PDU). The XNET PDU will power ANL network switches and multiple triple redundancy DC power supplies. In total, experimenters will have access to 80A of DC power and ANLs network with layers of redundancy and the ability to withstand power blips.

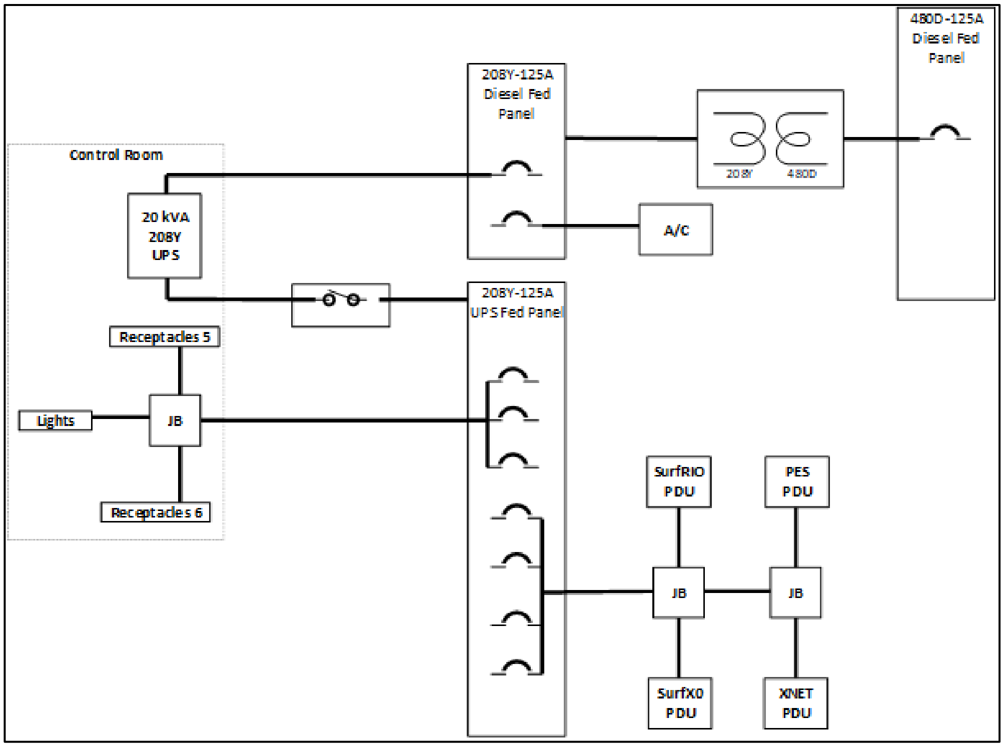


Figure 7. UPS Single Line Diagram.

3.3.2.2 *Networking*

Figure 8, left) in building 308, one in the high-bay and the other in the experimental assembly zone (room B162). The METL team installed ethernet keystone jacks with a home run connection to a satellite network enclosure. Each METL experimental 'bay' has a box of ethernet jacks (Figure 8, right), totaling 24. METL experimenters, internal or external, now have secure and head-less access to their experimental equipment for remote control and monitoring.

Figure 8. Satellite network enclosure (left) and ethernet jacks (right) for experimental support.

3.4 Continuous Improvement and Expanded Capability

The rapid development of technology, research demands for SFRs, and constraints on resources demands a constant evolution of METL. The needs identified in the first few years of METL's operation included additional instrumentation/controls and connectivity. Methods to address these concerns have been pursued in FY2021 and efforts to grow and expand METL will continue.

3.4.1 *Instrumentation*

Flow meter and level sensor improvements were made in FY2021. Existing electromagnetic flow meters were disassembled and reconfigured to utilize 'tack-welded' electrodes on the duct as opposed to using the OEM differential signal between two hall-effect sensors to acquire an electric signal indictive of the flow rate. In addition to repurposing the original electromagnetic flow meters, an ultrasonic flowmeter from an outside vendor was installed on the primary loop of METL.

3.4.1.1 *Electromagnetic Flow Meters*

METL used three commercially available electromagnetic flowmeters (EMFM) to monitor sodium flow. Figure 9 shows an overview of a typical EMFM installation. Overtime, both EMFMs failed (erroneous or no signal) and repairs attempted by the manufacturer were unsuccessful. The failure mode was hypothesized to be overheating of the Hall sensor elements. Therefore, to improve their robustness, METL's cold trap and plugging meter FMs were converted to more traditional permanent magnet based EMFMs.

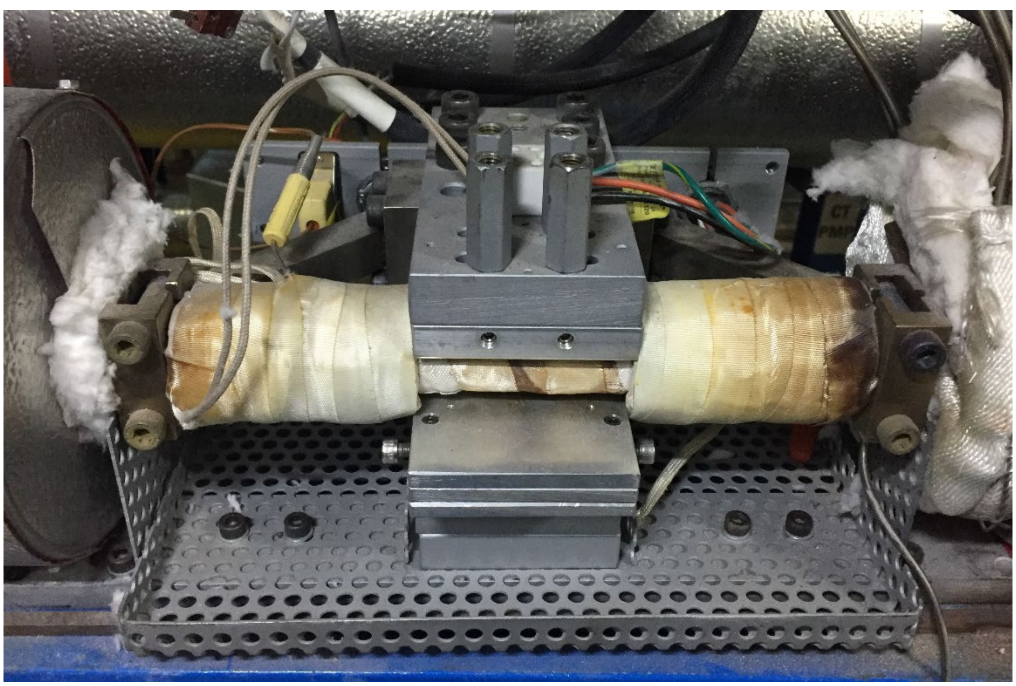


Figure 9. Commercially available EMFM installation.

Figure 10 shows a sketch of an example permanent EMFM. A permanent magnet based EMFM correlates liquid-metal flowrates to an induced voltage caused by the electrically conductive fluid passing through a stationary (DC) magnetic field. This voltage can be measured by a pair of electrodes mounted externally to the conduit.

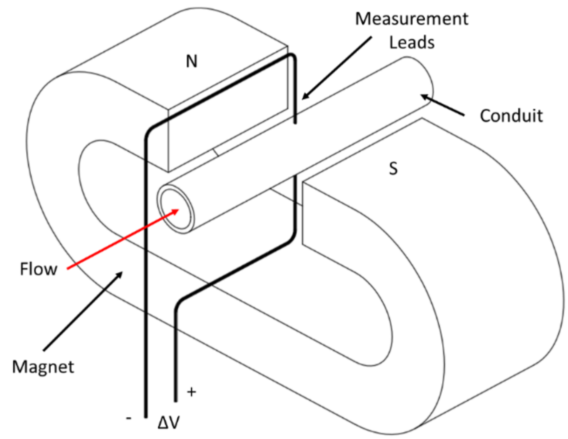


Figure 10. Permanent magnet flow meter conceptual design.

Prior to disassembling the commercially available EMFMs, the as-built dimensions were recorded, and a simple solid model was constructed for each. Given the installed magnet size, type, and spacing, the centerline magnet field strength was about 0.1 T, which was estimated to produce a small signal at the target flowrates. Solid models were modified by replacing the existing magnets with stronger and tightly spaced NdFeB magnets. Applying analytical and numerical models, the new design yielded a 200-300% increase in magnetic field strength.

This analysis provided a case to begin disassembly and thus both commercially available EMFMS were stripped down to the bare conduit in preparation for installing signal measurement leads (Figure 11, left). Electrodes constructed of 1/100-inch-thick feeler gauge were spot welded onto the conduit over the magnet centerline, orthogonal to the magnetic field (Figure 11, right).

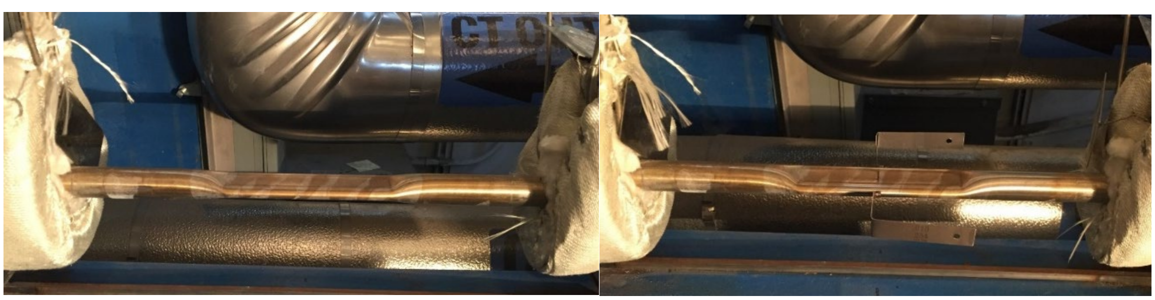


Figure 11. Flow meter conduit, bare (left) and spot welded electrodes (right).

A 1/2” stack comprised of 1/8” NdFeB magnets were mounted to modified upper and lower section yokes which were affixed to the main yoke. Magnetic field measurements were conducted using a F.W. Bell model 5180 Gauss meter with a transverse probe tip. Shown below in Figure 12, physical measurements agreed well with the FEA model.

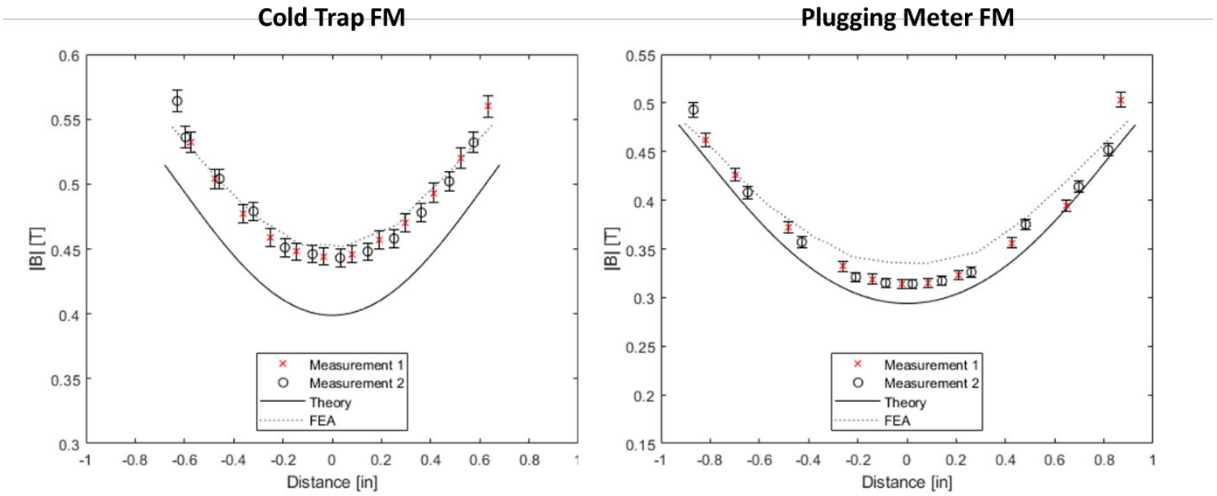


Figure 12. Magnetic field measurements versus theoretical and numerical predications.

Flow meter yokes were mounted to the conduit and reassembled with a new flexible tape heater, thermocouple, and insulation. Securing the magnet yoke to the piping followed and the installation was complete (Figure 13) upon the routing of power and signal wiring. Commissioning and calibration of the modified EMFMs is expected to occur in early FY2022 after METL is thawed and brought to hot standby condition.

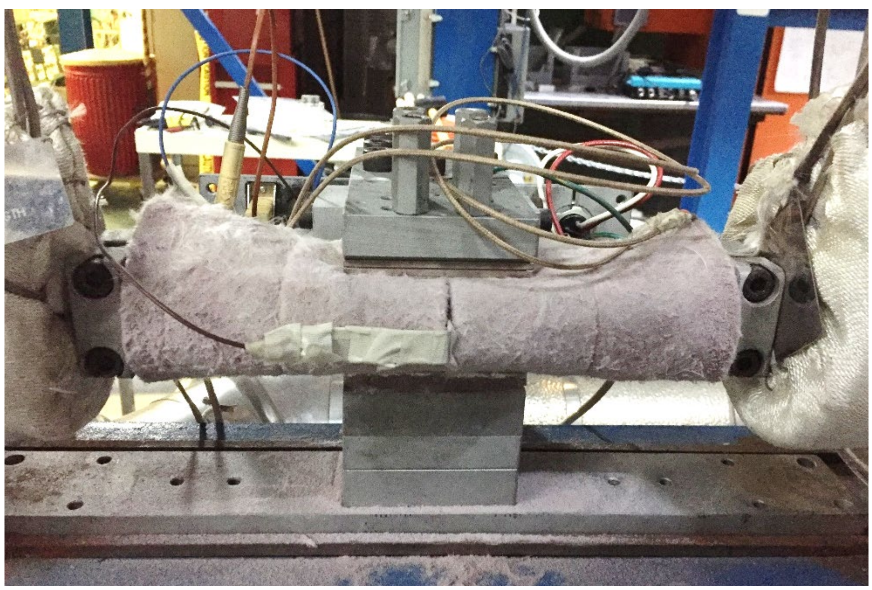


Figure 13. Final assembled of modified EMFM (protective should not shown).

Two FLEXIM ultrasonic flowmeters were installed on the METL piping to measure high-temperature liquid sodium flow rates. The high-temperature transducers include large waveguides and mounting fixtures to keep the sensitive electronics at a safe operating temperature (Figure 14).

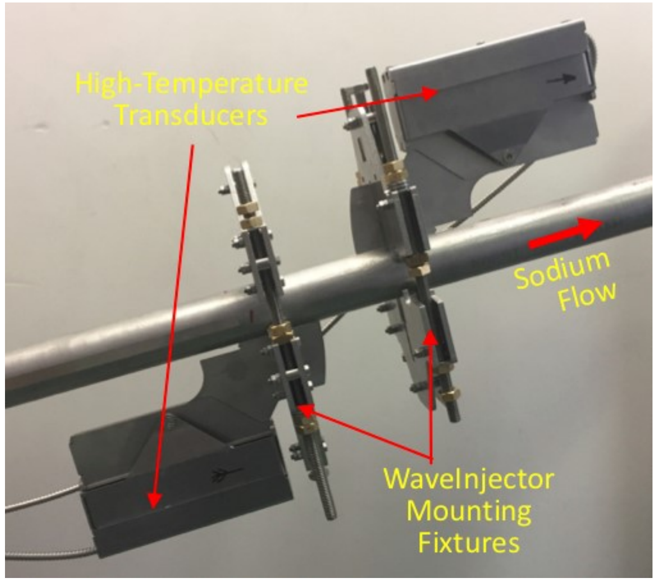


Figure 14. High-Temperature FLEXIM Configuration.

The flowmeters were installed on 1.5” (primary loop) and ¾” (cold trap loop) SC40 316ss piping. These diameters are small enough that the curvature of the pipe circumference can interfere with the transmission of pressure waves between the waveguide and the piping. To address this, small flats were cut along the length of the piping to provide better contact between the waveguide and pipe wall. This was accomplished using a special cutting tool provided by the manufacturer

The cutting tool was designed to use the mounting fixtures as a guide, so these were the first items to be installed. Insulation was removed from the piping section where the FLEXIMs were to be installed. Each flowmeter system included two ultrasonic transducers that each required a mounting fixture. The distance between each fixture was determined based on the piping geometry and the process fluid (liquid sodium at 300°C). The mounting fixtures fit the 1.5” piping without modifications, but they were too large for the ¾” piping. Stainless steel “shoes” were fabricated to be able to mount the standard fixtures to the smaller piping (Figure 15).

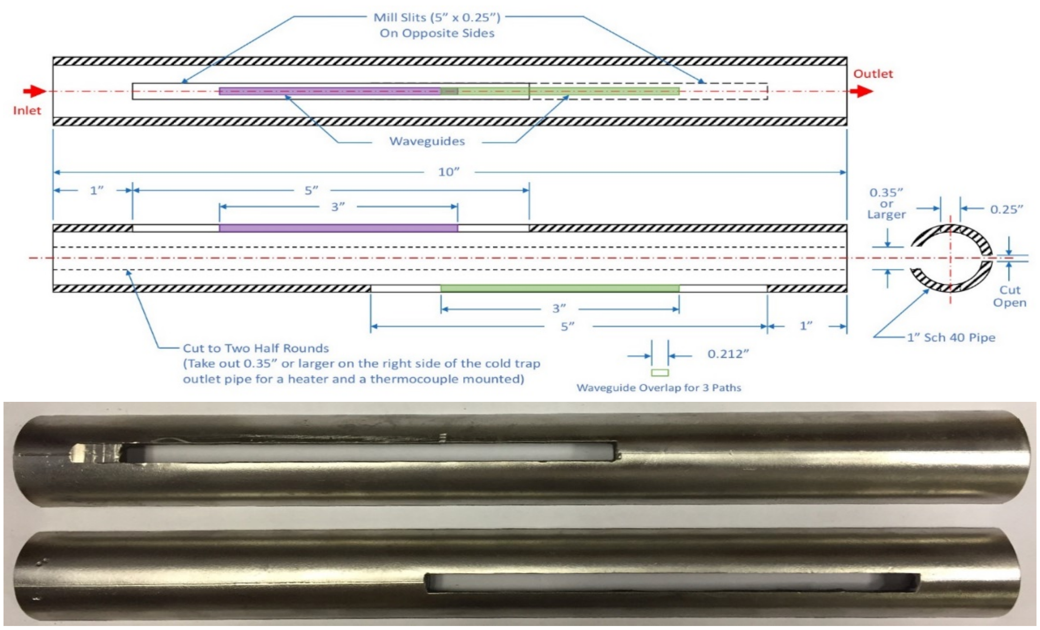


Figure 15. Mounting fixture shoe design (top) and shoes (bottom).

Cutting the flats for the 1.5" piping system followed the standard procedure set by FLEXIM. The cutting tool was inserted in the guide features on the mounting fixtures. Then the cutting tool was repeatedly pulled through the guide features so that some material was removed from the pipe wall. Once the flats cut on the pipe were slightly wider than the thickness of the waveguide, the cutting was complete. Following this, the transducers were installed in the mounting fixtures on alternate sides of the prepared piping section. Again, separation between each transducer needed to be set according to measurements determined using the pipe geometry and the process fluid. Once the separation distance was set, the transducers were fastened to the pipe using a bolt that compressed the waveguide to the flat section of piping. A thin sheet of silver was placed between the waveguide and the pipe flat to fill any gaps and give the transducer greater physical contact. The FLEXIM system installed on the 1.5" piping section is shown in Figure 16.

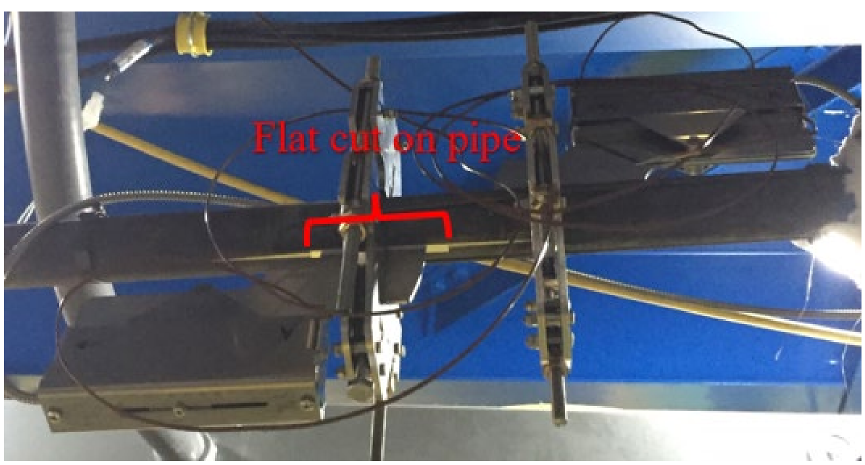


Figure 16. FLEXIM ultrasonic flow meter mounted to 1.5" piping with flat section indicated.

The inclusion of the "shoes" on the ¾" pipe system made the flat cutting operation difficult. The cutting tool could not be used, and instead fine sandpaper and polishing stones were used to form the flat on the pipe section. This was accomplished by cutting the sandpaper into small strips thin enough to fit in the slots cut in the shoes. Then a machinist's parallel was used to apply pressure to the sandpaper while it was placed in the slot. The parallel with sandpaper was slid in the slot until enough material was removed from the pipe to form a flat. Polishing stones were used to clean up the surface as needed. The waveguides were installed in the mounting fixtures and held against the pipe using the compression bolt. Silver sheet was used again to maximize the contact area between the waveguide and pipe flat.

The cabling was then routed from the transducers to the control unit, completing the install of the FLEXIM systems. The control unit is equipped with MODBUS TCP communications and will be integrated with METLs SCADA program early FY 2022. Insulation was reinstalled around the installed units to ensure the piping section could be brought back to operating temperature (Figure 17).

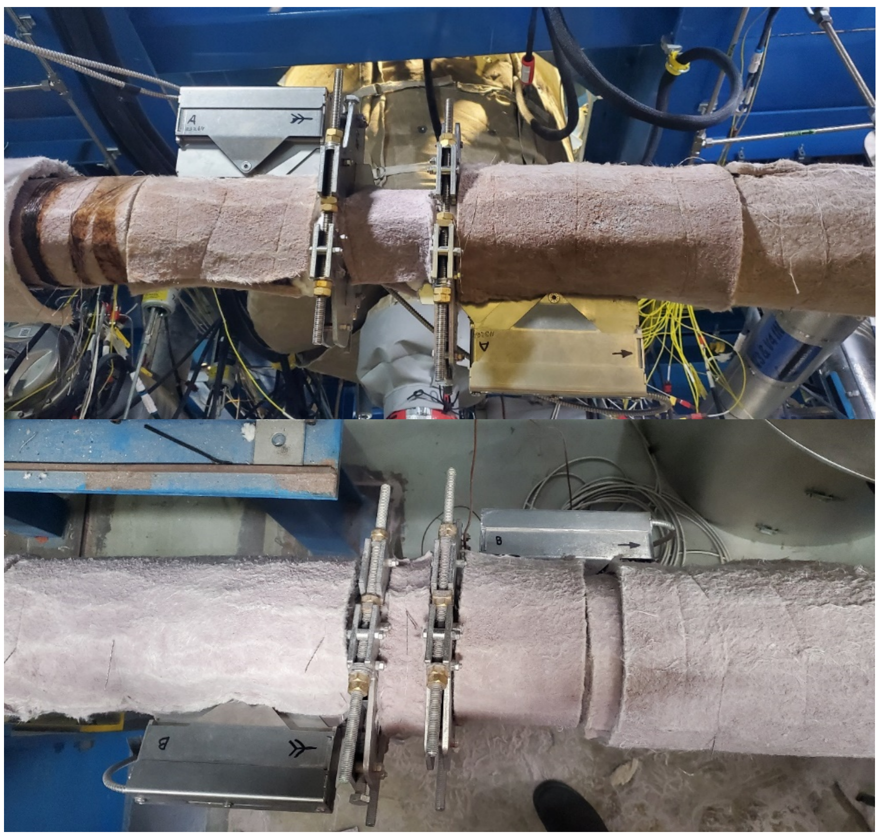


Figure 17. 1.5" (top) and ¾" (bottom) FLEXIM systems installed and wrapped with insulation.

Originally, METLs expansion and dump tank were equipped with an inductive and differential pressure level sensor. Due to the experimental nature of the inductive level sensor and the plugging of the dip tube on the differential pressure level sensor in the expansion tank, this prompted the installation of a thermal property level probe in test vessel 2 as it is vacant. The thermal property level probe has an internal heater to raise the probes surrounding fluids film temperature, due to the significant difference in thermal conductivity between sodium and the argon cover gas, the temperature decay rate is also vastly different. Wrapped around the heater is an array of axially distributed thermocouples to measure the temperature and thus sodium height is indicative of the transition of different temperature decay rates. The success of the thermal property probe in test vessel 2 motivated the METL team to design, build and install a version to replace the differential pressure level sensor in the expansion tank as shown in Figure 18.

3.4.2 *Supervisory Control and Data Acquisition (SCADA)*

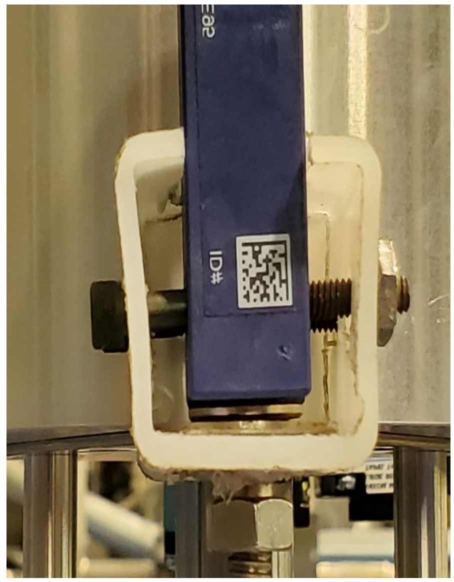
Improvements to METL's SCADA system in FY2021 included adding a web server, wireless capabilities, developing a toolkit for processing data files, verifying use of computerized maintenance management system (CMMS, eMaint) API and developing plans to upgrade valve actuators and replace obsolete data acquisition hardware.

3.4.2.1 *Web Server*

A web server was deployed to METL's network server (metlserv) which allows a developer to obtain METL information via URL API. The API allows external/internal web servers to poll data from metlserv to host a website displaying METL operational data as well as providing a universal means of acquiring METL data. One example case includes the demonstration of cyber security using Quantum Key Distribution (3).

3.4.2.2 *Wireless Capabilities*

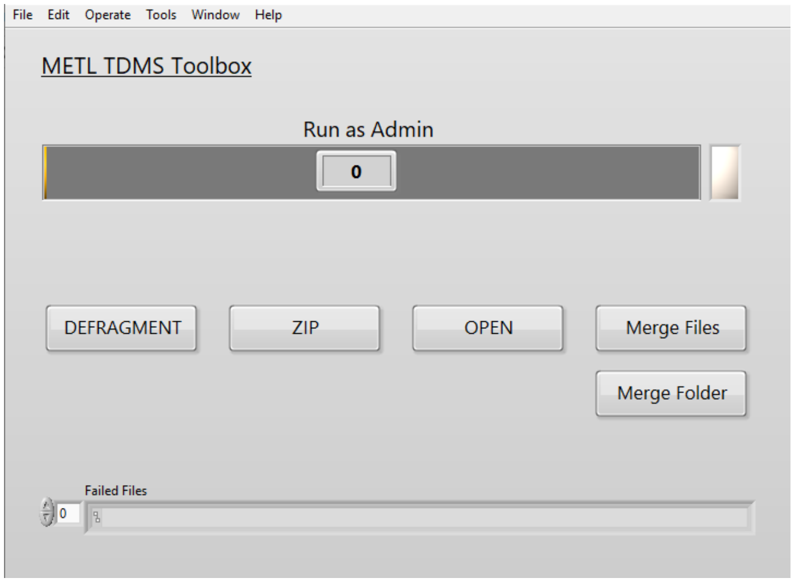
Two wireless instrumentation and control product lines were integrated with METL's SCADA. Schneider Electric's Harmony Hub line offers wireless and battery-less products, two of which were demonstrated on METL. A push button to activate safety systems and retrofitting hardwired valve position indicators with battery/wireless versions were successfully and reliably proven to function 50+ feet outside of METL's footprint.



Harmony Hub instruments are limited to boolean (on/off) instruments with the exception of a couple temperature/humidity and current sensors. Wireless products by National Control Devices (NCD) were procured and tested to provide a universal and wireless I/O solution. Unlike the Harmony Hub product line, NCD requires a power supply but for a completely wireless solution their products were configured to operate from a standard cordless tool battery.

3.4.2.3 *METL TDMS Toolbox*

METL's SCADA program saves files in a Technical Data Management Streaming (TDMS) file format. Data is logged as soon as it is acquired and since there are various data acquisition products with different rates for data collection, the index files required for prompt TDMS file viewing become quite large. A TDMS toolbox program (Figure 20) for METL was developed to defragment the index files, zip folders and merge files/folders for ease/rapid transportation/sharing of METL TDMS data files.



3.4.2.4 *CMMS (eMaint) API*

The CMMS (eMaint) API allows for other programs to read/write data from/to its' cloud-based platform. METL's SCADA system was able to make API calls to the CMMS. Establishing communication between the two builds a road for advanced analytics and autonomous O&M. A use case demonstrated in FY2021 involved using METL's SCADA program to make an API call to the CMMS to inform an operator whether a valve was LOTO-ed (out-of-service) and being repaired. Other potential uses could involve:

- Transient triggered work orders - if a component experiences a transient, a work order for inspection is automatically triggered and assigned to a technician thus reducing maintenance costs compared to historical maintenance which is usually a function of an arbitrary period of time.

- Automatic calibration and scaling updates – when a manual calibration is performed, the SCADA program is informed and polls the scaling data from the calibration certificate found in the CMMS and updates its software to ensure accurate instrumentation. Alternatively, if an automatic calibration is performed by the SCADA program it can upload the information to a work order in the CMMS for documentation purposes and to notify the maintenance team.
- Operator verification for remote security – SCADA integration with a CMMS could also provide another layer of operational/cyber security, the CMMS would assign tasks to an operator via work orders and the SCADA would only allow operators under this work order to perform operations related to the aforementioned work order.

3.4.2.5 *Future Developments*

Presently, all of METL's valves are either open or closed. This limited valve actuation introduces operational challenges with maintaining consistent Argon gas cover pressures.

Proportional controllers for Swagelok valves were acquired from a third-party vendor and are currently being tested.

METL's pressures and internal heater thermocouples (monitoring thermocouples) are collected via NI cDAQ 9188-XT chassis. This product is slated for obsolescence, to account for this, ten cDAQ-9189s were ordered. The new cDAQs will ensure the team continues to receive support from the manufacture but also allows the removal of a Windows real-time controller from the SCADA as these versions can support a Linux master.

4 METL Phase II Configuration

METL's Phase 1 configuration included two 18-inch test vessel and two 28-inch test vessels. The overall original design allowed for the expansion of METL to include an additional four (4) 18-inch test vessel.

METL will continue to support GTA test runs and is expected to house additional experiments in FY2022. The Thermal Hydraulic Experimental Test Article (THETA, Figure 21) was inserted into METL in FY2021 and will begin testing in FY2022. A detailed report regarding THETA progress can be found in ANL Report "Thermal Hydraulic Experimental Test Article - Status Report for FY2021" (4).

Figure 21. Test vessel 4 with THETA installed.

METL is expected to house a new experiment in FY23 for prototyping sodium flow meters (FSTAr). FSTAr (Figure 22) is currently under development and will be fitted to a 28" test vessel. Many critical components are on schedule to arrive mid FY22 so construction may commence next fiscal year.

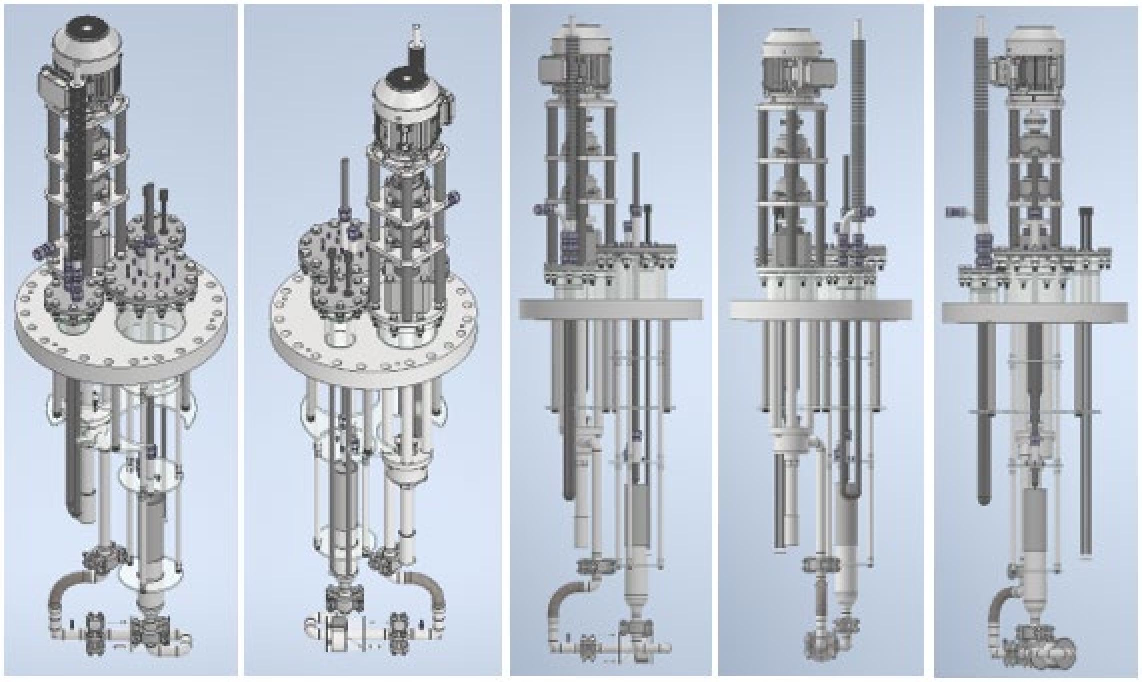


Figure 22. Preliminary overview and elevation of FSTAr

4.1 Test Vessel 6

An additional 18” Test Vessel (V6) identical to the installed 18” Test Vessels was secured to its support legs. The V6 vapor trap, filter and piping subassemblies were fabricated by ANL-Central Shops in FY2020 as well. In FY2021, ANL-Central Shops installed the vapor trap, filter, argon vent and gas piping subassemblies (Figure 23).

Figure 23. Vessel 6 with argon supply and vent piping installed.

4.2 Plugging Meter

A new plugging meter (Figure 24) designed to RDT standard F3-40T was built in FY2021 and is on-site. A new cold trap was received the previous fiscal year so when presented the opportunity, METLs diagnostic and purification loops have the necessary equipment for improving their operations.

Figure 24. New Plugging Meter

5 Building 308 Investments

Constructed in the late 1950s, Building 308 was built to conduct alkali metal research and it continues to support this mission today. Previous fiscal years efforts were focused on the building envelope such as replacing the roof and painting the siding as well as increasing the electrical capacity of the power coming into the building from 1,000KVA to 2,000KVA. During FY2021, Building 308 again saw major investments by ANL. Expenditures included installing a roof top unit (RTU) for cooling the high-bay, reconfiguring its redundant power supply and repairing the B308 sodium scrubber unit.

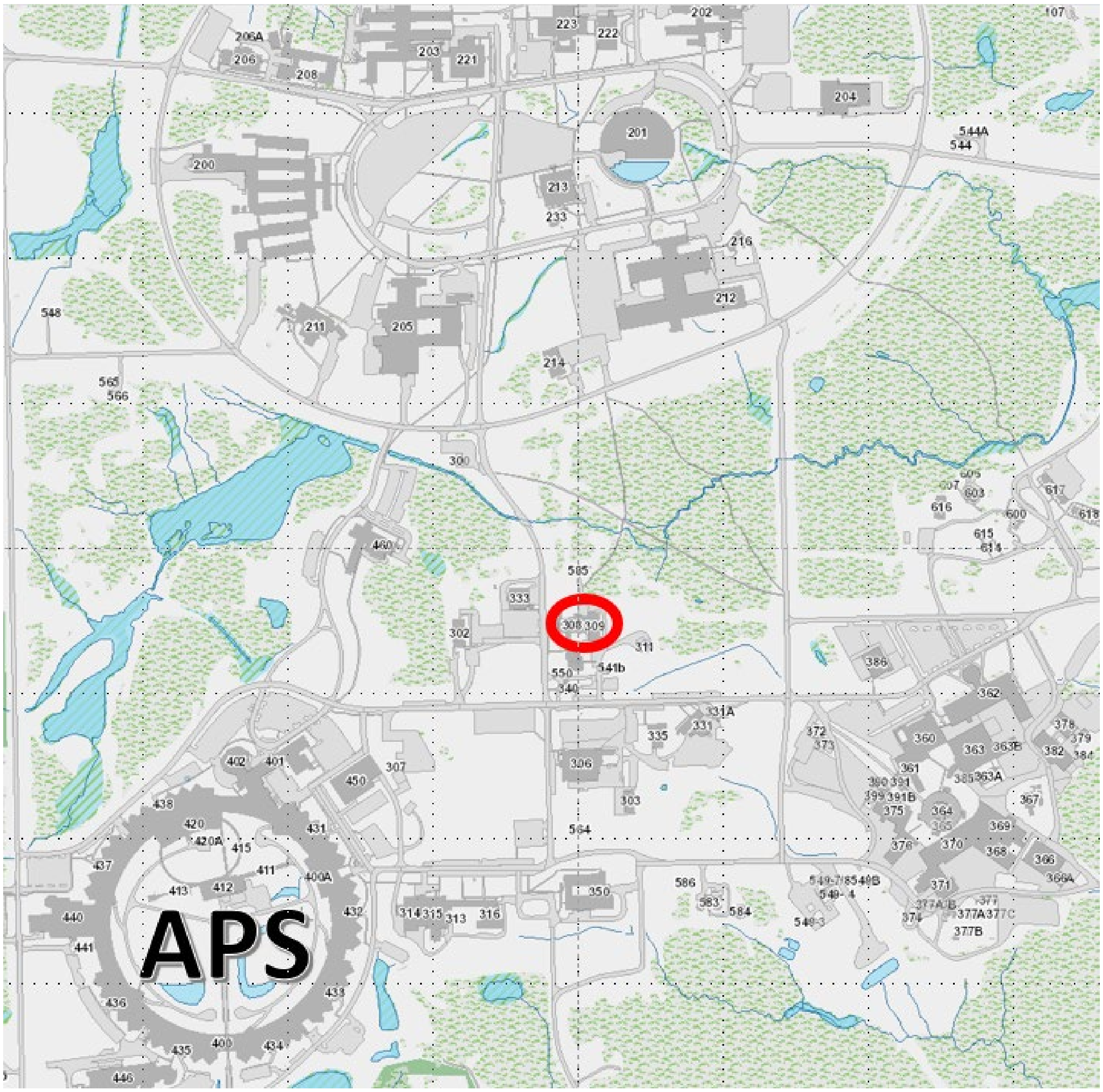


Figure 25. Buildings 308 and 309 (red circle) on ANL site.

5.1 Alkali Metal Passivation Booth & Scrubber Unit

Building 308 houses an AMPB&S to support alkali metal research. The AMPB&S consists of a superheated steam system, burn stall and scrubber (Figure 26). Hardware contaminated with alkali metals can be placed in the burn stall for passivation. The primary passivation/decontamination methods involve igniting (burning) the alkali metals with an oxy-acetylene torch or spraying equipment with superheated steam. The burning of alkali metals releases caustic smoke (alkali metal oxides) which must be extracted from the area and treated. Extraction and treatment is performed via the alkali metal fume scrubber which is also utilized in the event of a molten sodium leak from METL to pull smoke from the entire high-bay. Many of these systems underwent an upgrade in FY2021.

Figure 26. Scrubber prior to rehabilitation.

5.1.1 *B308 Alkali Metal Scrubber*

During preventative maintenance operations of the scrubber, a leak was identified in its' make-up water and steam supply line. The condition was beyond patching or repair (Figure 27) and initiated an 'emergency-only' mode of operation for the scrubber (i.e., the scrubber was only to be activated in the event of an alkali metal leak and fire within B308). Conducting scrubber repairs meant no corrective actions could be made during an alkali metal fire and therefore required METL to pause operations, drain its sodium inventory into the dump tank and freeze the entire facility.

Figure 27. Corroded water make-up line and missing steam piping after initial demolition.

The scrubber repair scope includes replacing the steam, make-up water and venturi water supply/circulation lines with new stainless-steel piping (Figure 28), patching the underground fiberglass water 'buffer' tank, installing new conduit and transitioning from electro-mechanical relay controls to processor-based controls. Steam and make-up water lines are housed in a 'ric-wil' system and are routed underground to feed the 'buffer' tank with make-up water to cool and dilute its contents, ensuring a pH between 6-8 as well as steam to prevent freezing. During 'ric-wil' installation, a leak in the underground fiberglass 'buffer' tank was identified and patched.

Figure 28. New 'ric wil' and stainless-steel piping

The scrubber contains a venturi housing which injects water into the smoke stream from the building and burn stall. The water supplied to the venturi housing can be circulated via pedestal pump inserted into the 'buffer' tank or directly from the make-up water line. All above ground piping and associated components (check valves, throttling valves, etc) to construct this circuit were replaced with stainless steel equivalents.

Figure 29. New Scrubber Water Stainless Steel Piping (shown insulated) to Venturi

The new scrubber control system consists of a CompactLogix L30ER programmable automation controller (PAC), Panelview HMI, pH probe, level sensor, thermocouples, current switches and flow meters. Currently, the PAC controls (Figure 30) the building inlet damper, blower isolation vane (hydraulic pump and two directional control valves), RTU shunt, make-up water and steam valves. Future integration will increase instrumentation and the PACs scope by controlling the overhead door, exhaust fan shunt, circulation pump and blower.

Figure 30. PAC Enclosure (left) and HMI (right).

5.1.2 *Superheated Steam*

The original superheated steam system was also reaching the end of its useful life. As mentioned above, the superheated system is used to pacify alkali metals in the burn stall. The superheated steam system consists of two 9-kWsuperheaters fed from utility saturated steam and plumbed in parallel to supply a steam wand. The lack of vacuum breakers caused water hammers, injecting domestic water into the steam line presented an error trap, valves leaked, and many components had severe corrosion. This prompted the entire demolition of the superheated steam system for the installation of a new stainless-steel variation.

Figure 31. Existing superheated steam system.

The purpose of the new superheated steam system remains but will have one 20-kW superheater as opposed to two 9-kW superheaters in parallel. The new design mimics the old with improvements to alleviate water hammer, facilitate heater element replacement negating the need for an entirely redundant superheater and separating the water stream from the steam. Furthermore, the previous superheaters were controlled via mechanical contacts whereas the new 20-kW heater is modulated using a SCR with MODBUS RTU communication, so superheat control is not compromised with one large heater. Superheated steam system overhaul also includes instrumentation such as pressure transducers, thermocouples, and a MODBUS RTU vortex flow meter. The new superheated steam system is currently under construction and is slated for completion early FY2022.

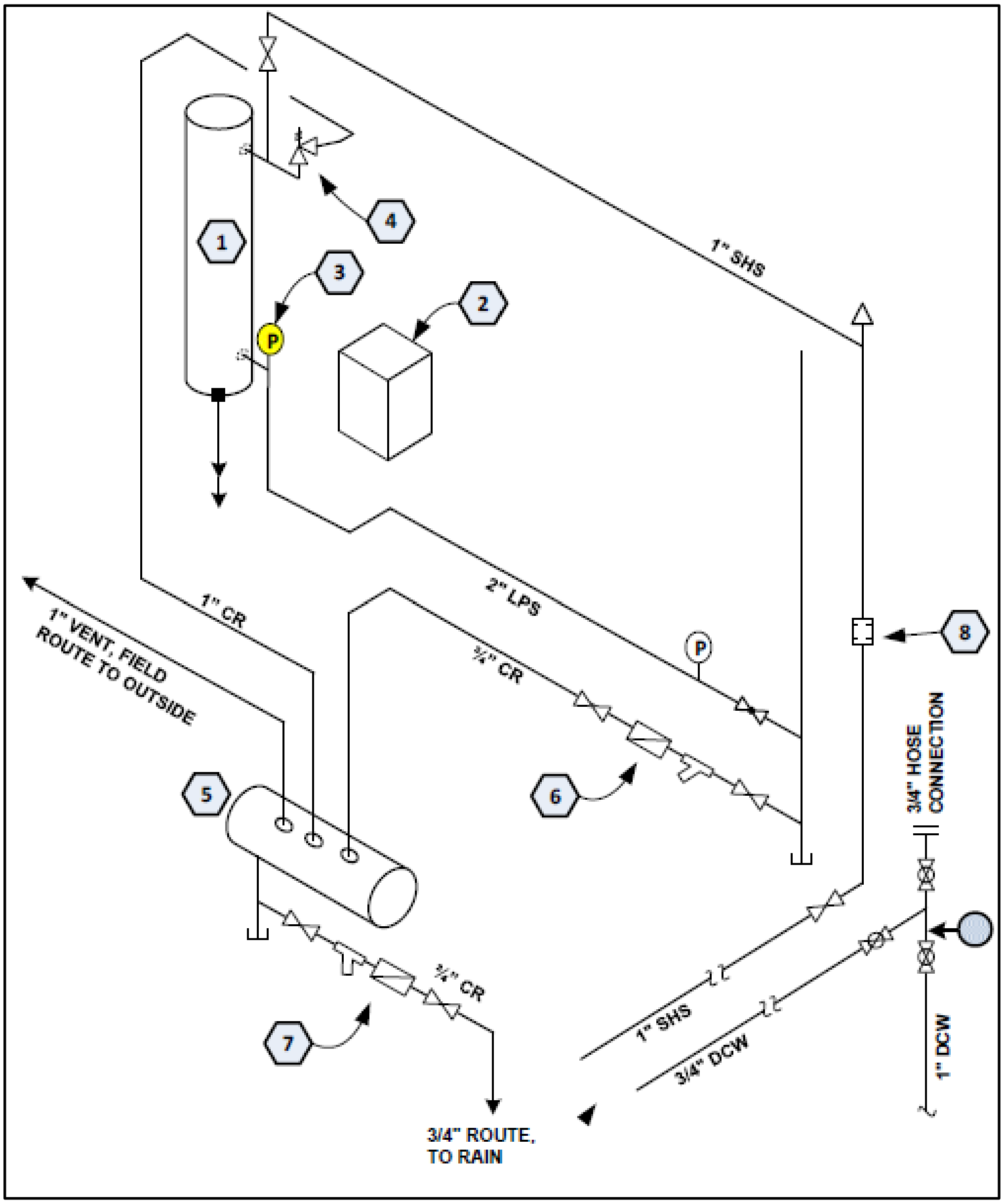


Figure 32. Superheated steam system upgrade P&ID.

5.2 High-Bay Cooling

The building 308 high-bay relied on exhaust and circulation fans to 'maintain' the temperature and provide occupants with comfort during summer. This equipment could not maintain consistent temperatures and humidity which made sensitive experimental work difficult as the ambient conditions were fluctuating. In FY2020 a 50-ton Trane Voyager RTU (Figure 33) was procured and installation was completed in FY2021. The RTU is dedicated to the high-bay with its supply and return ducting mounted to the north wall. The RTU is operational and integrated with the scrubber control system to shut-off during scrubber operation to prevent a short circuit of air flow.

Figure 33. Building 308 RTU and Ducting.

5.3 Redundant Power

Building 308 is equipped with an automatic transfer switch (ATS) fed from substation A and 100-kW 3Φ diesel generator to provide redundant electricity to energize critical loads during outages. This generator was commonly used to power the critical loads while work was being conducted on the grid feed. The generator suffered a catastrophic failure while electrifying equipment during substation work. A roll-up generator was used in the interim and ultimately the automatic transfer switch was fed from substation A and B to establish redundancy until a replacement could be realized.

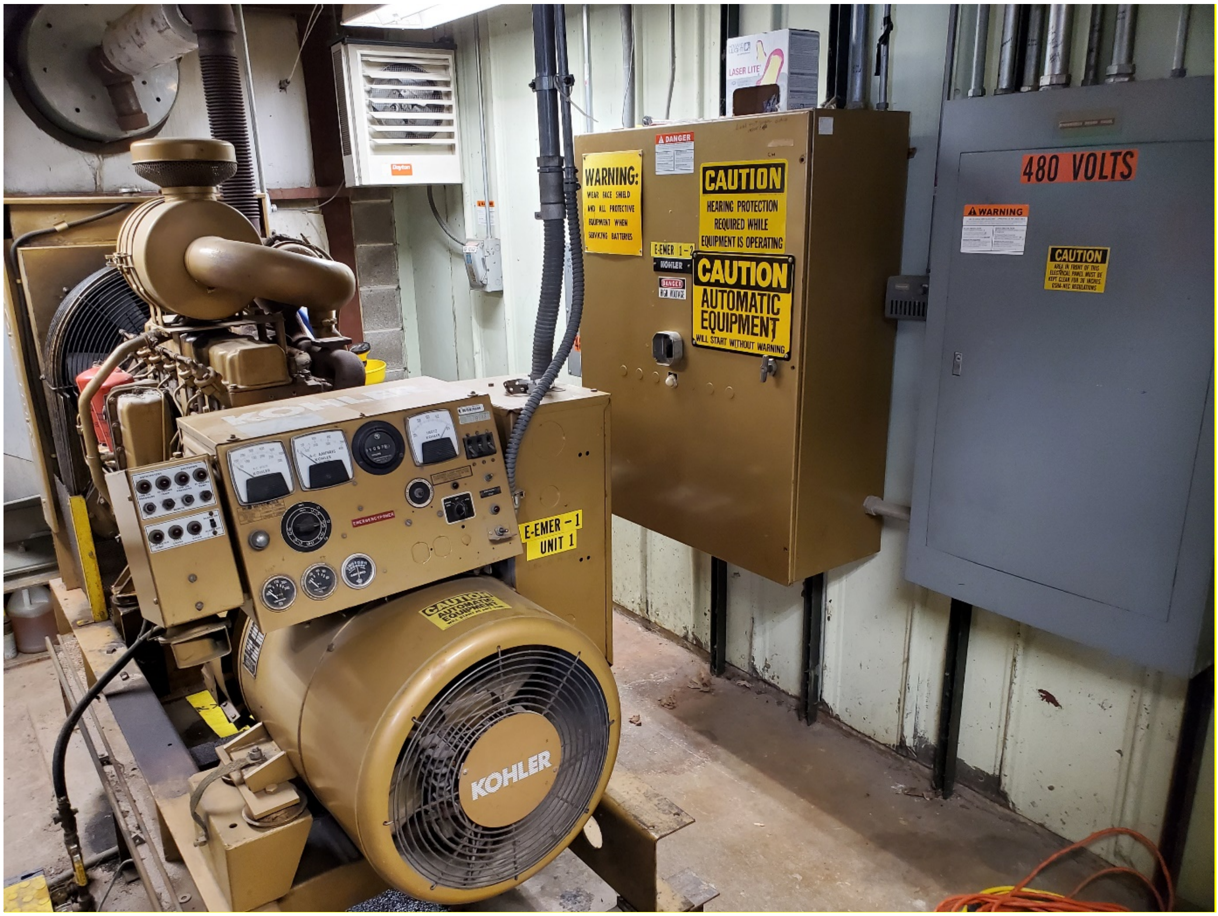


Figure 34. Old 100-kW generator, ATS and load center (left to right).

The new redundant power scheme includes two ATSes, one of which has a roll-up generator connection. This configuration will enable critical loads to be fed from either substation (A or B), a new 100-kW generator or a roll-up generator, providing quadruple power redundancy. The new generator has been procured and demolition of the old redundant power system is currently underway.

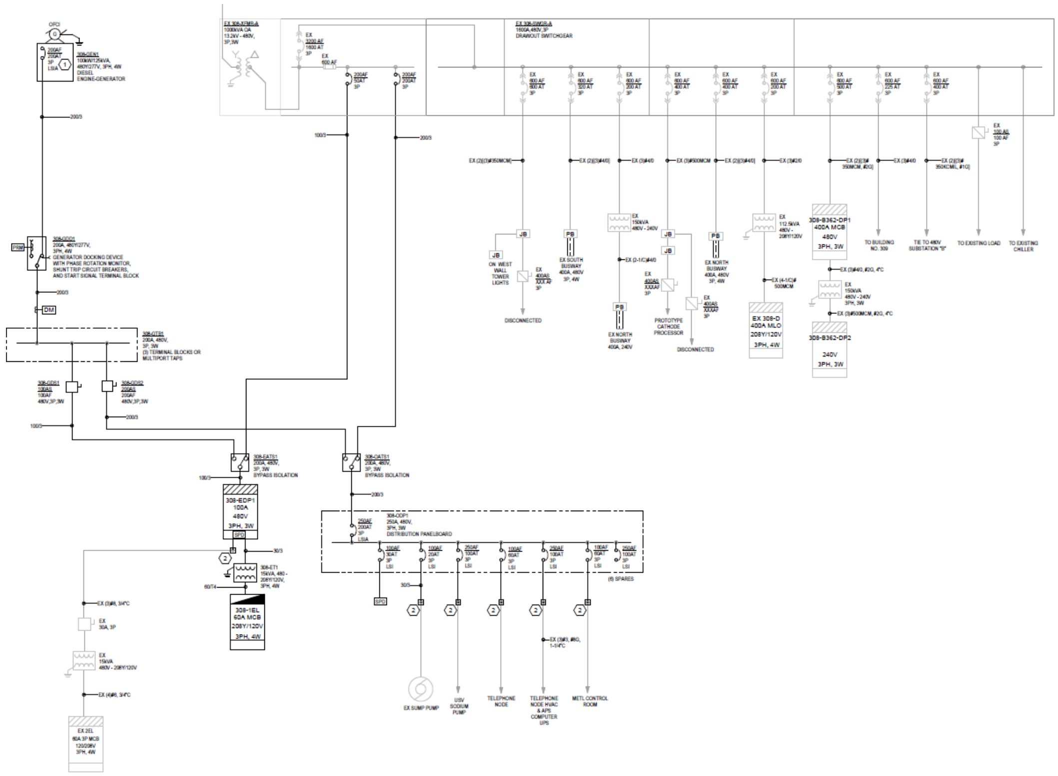


Figure 35. New redundant power single line diagram.

6 Summary

The preceding report provided a summary for the status of the METL facility as of September 2021. A tremendous amount of effort has gone into demonstrating METL's capabilities for another year, continuing with experimentation in METL, deploying a preventative maintenance/corrective action program, building upon current functions, and supporting future experimenters. The METL crew continues to work on expanding METL into Phase II, grow Argonne's alkali metal capabilities, developing and qualifying potential Sodium Fast Reactor technologies, and working to ensure METL remains a state-of-the-art testing facility by investing in new talent, components, and methods.

In conclusion, METL is a high-temperature sodium test facility, designed with an emphasis on testing flexibility to support near endless designs for experimental apparatus and has proven its ability to demonstrate Sodium Fast Reactor and other alkali metal technologies as well as further the understanding of associated phenomena.

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