



ANL-ART-210  
ANL-METL-24

## **Mechanisms Engineering Test Loop (METL) Operations and Testing Report – FY2020**

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**Nuclear Science and Engineering Division**

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## **Mechanisms Engineering Test Loop (METL) Operations and Testing Report – FY2020**

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Nuclear Engineering Division  
Argonne National Laboratory

September 2020



## 1 EXECUTIVE SUMMARY

This report documents the operations and testing that was performed at the Mechanisms Engineering Test Loop (METL) during FY2020. The METL facility had a very successful second year of operations having logged over 730 days (as of September 19, 2020) of operations with molten sodium either flowing or static. The METL piping and vessel system was filled with sodium on September 19, 2018 after a successful transfer of sodium from fifteen 55-gallon drums. FY2020 saw the successful reconditioning and insertion of the Gear Test Assembly (GTA) for its second round of testing, the full use of the 18-inch Flexi-Cask system, the second extraction of the GTA from METL, and the removal of sodium from the GTA test article by the carbonation process followed by an alcohol wash. In addition, METL is being prepared to support a second larger experiment, a thermal hydraulic experiment, called Thermal Hydraulic Experimental Test Article (THETA).

### 1.1 Purpose & Background

The METL facility has the capability to 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 should provide invaluable performance data and reduce the risk of failures during plant operation.

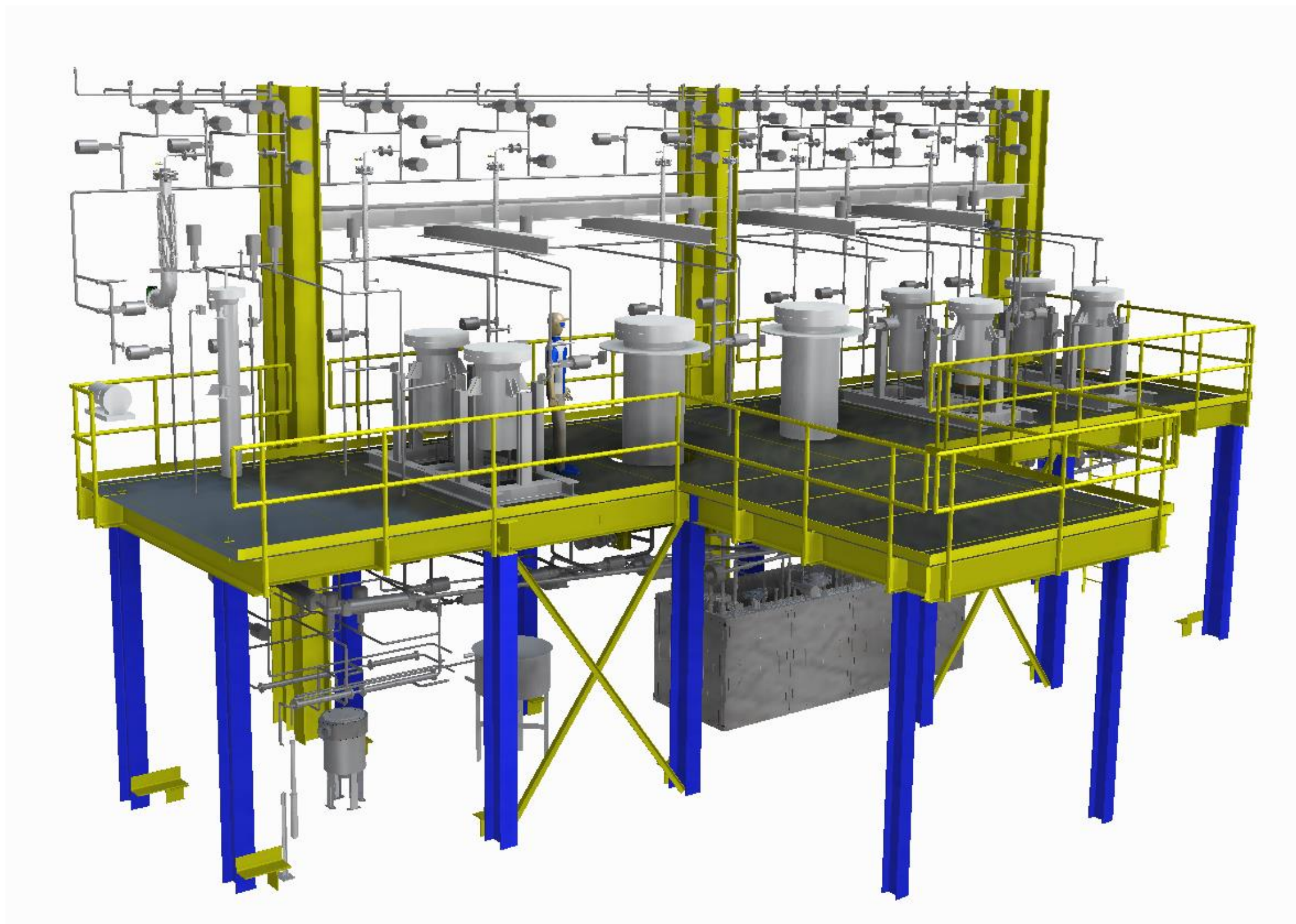
METL continues to provide development opportunities for younger scientists, engineers, and designers who will ultimately lead the advancement of U.S. liquid metal technologies. The hands-on experience with METL, both successes and perceived failures; will ultimately lead to better liquid metal technology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

As shown below in Figure 1, the design of 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.



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





## 1.2 METL Operational Year II Accomplishments

The METL facility and team had a very successful second year of operations. After initial commissioning of the facility in late FY2018, the METL facility was filled with sodium in September 19, 2018 and the sodium coolant was maintained in a molten state for over 742 days. 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 2 years, since September 19, 2018.
- Multiple sodium flowing and purification campaigns have been performed during 24/7 operations.
- 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.
- The GTA was removed from the carbonation process (that was started in FY19).
- An alcohol wash system was developed for the GTA that supports the accelerated removal of sodium from the test article.
- 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.
- Performed the first insertion of a test article into a drained sodium vessel (GTA) which required the use of the 18-inch flexicask to maintain an argon inert atmosphere.
- The GTA was inserted into Test Vessel #1 in preparation for the second round of testing.
- Assisted in the second Gear Test Assembly test campaign.
- The 18-inch flexicask testing and commissioning activities (in FY19) provided information to support the design development of the 28-inch flexicask.
- The 28-inch flexicask design was fabricated by an outside vendor and was delivered to Argonne in FY20.
- Maintained alkali metal program support equipment (Building 308 Scrubber, Superheated Steam System, 18-inch Flexi-Cask, Carbonation System, Glovebox and Qualification Station)
- Installed Test Vessel 6 onto its “dixie cup” support columns.
- Received vapor trap, filter and piping subassemblies for Test Vessel 6 from ANL-Central Shops.
- A replacement and improved Cold Trap was designed, procured and received.
- An RDT compliant Plugging Meter was designed and ordered – it is currently in fabrication.
- Performed the second test article extraction using the 18-inch flexicask from Test Vessel 1 (GTA extraction from Test Vessel 1)
- Re-commissioned the moist carbon dioxide reaction system for reaction of residual sodium from METL test articles with improved capabilities.
- Performed the second cleaning and disassembly of the GTA on the 18-inch test stand
- Transferred sodium into USV test facility.

- Continued demonstration of level sensor technologies (Inductive, Differential Pressure, and Thermophysical Property).
- Cloud-based asset management software was obtained, populated and utilized for work activities and parts inventory.
- A contractor performed 3D laser scanning and photography of Building 308/309.
- Released first version of METL Software Developer Kit for accelerated test program creation.
- METL’s Supervisory Control and Data Acquisition System (SCADA) was overhauled to “future proof” itself, distribute data more efficiently and broadly, ensure robust control and provide scalability so it can grow with the METL complex.
- Created an IT node room within METL’s control room to upgrade the SCADA network.

### 1.3 Plans for FY2021 at METL Phase II

The METL facility will continue to operate with molten sodium during FY2021. During FY2021, we expect to be reconditioning the gear test assembly (2<sup>nd</sup> time) which was tested in FY2019 and retesting the test assembly in Test Vessel 1, installing the thermal hydraulic experimental test article (THETA) into METL test vessel 4, running the primary section of the THETA experiment for thermal hydraulic code validation, conducting more inductive level sensor development work, completing the commissioning of a new robust 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 is currently underway and will continue to progress in FY2020 and beyond. Immediate efforts are focused on installing another 18” Test Vessel (V6) which is currently installed in its designated location, but the fabricated piping subassemblies have not yet been installed. To fully install Test Vessel 6 (V6) piping segment that connects to the dump tank will require that the sodium in the dump tank be made frozen. 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

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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 unrivaled support from Bill

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<sup>1</sup> In September 2020, Thomas Sowinski recently replaced Tim Beville as the Program Manager for the Advanced Reactor Technologies program.

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 Kourkouvelis, 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 Components Technology Division.

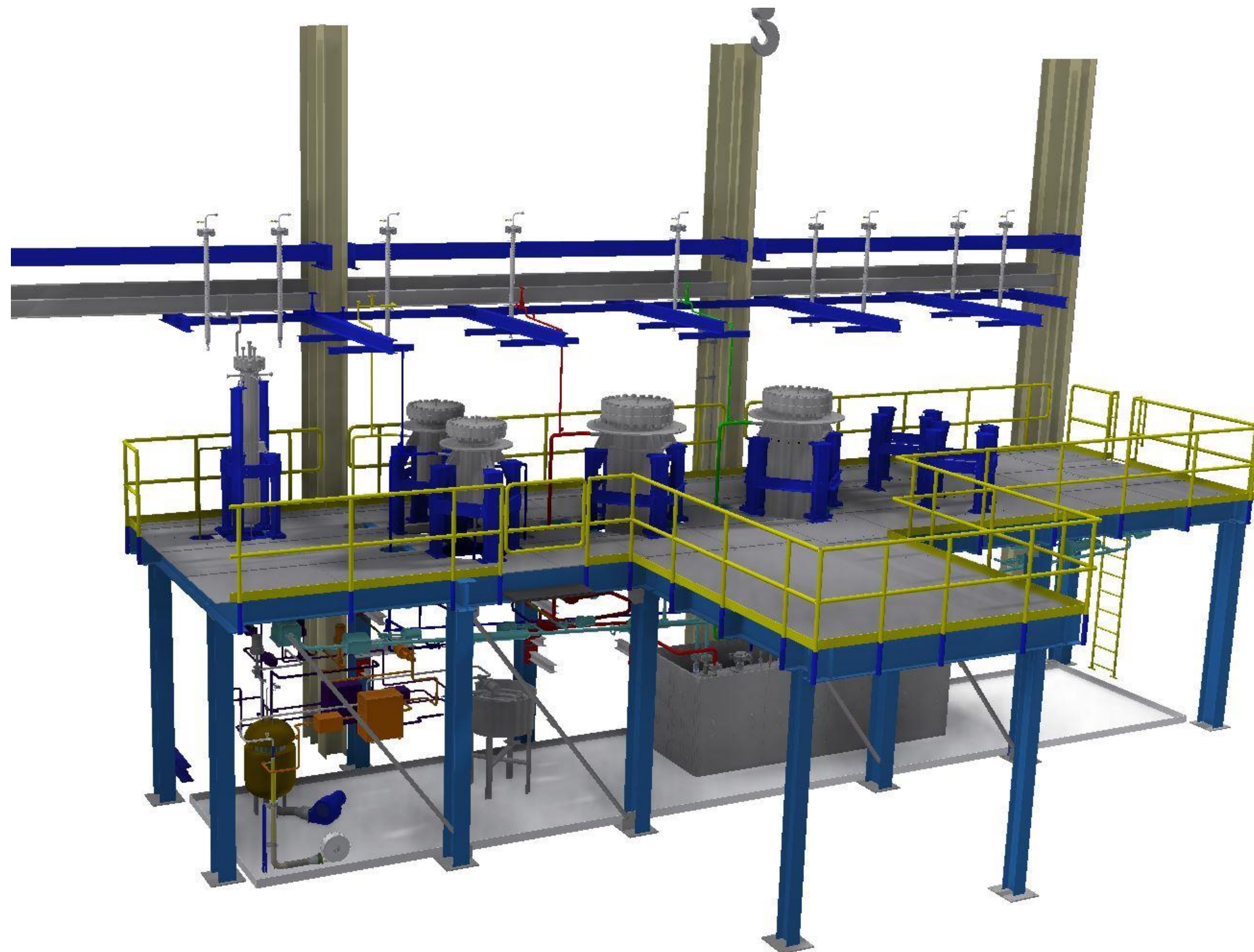
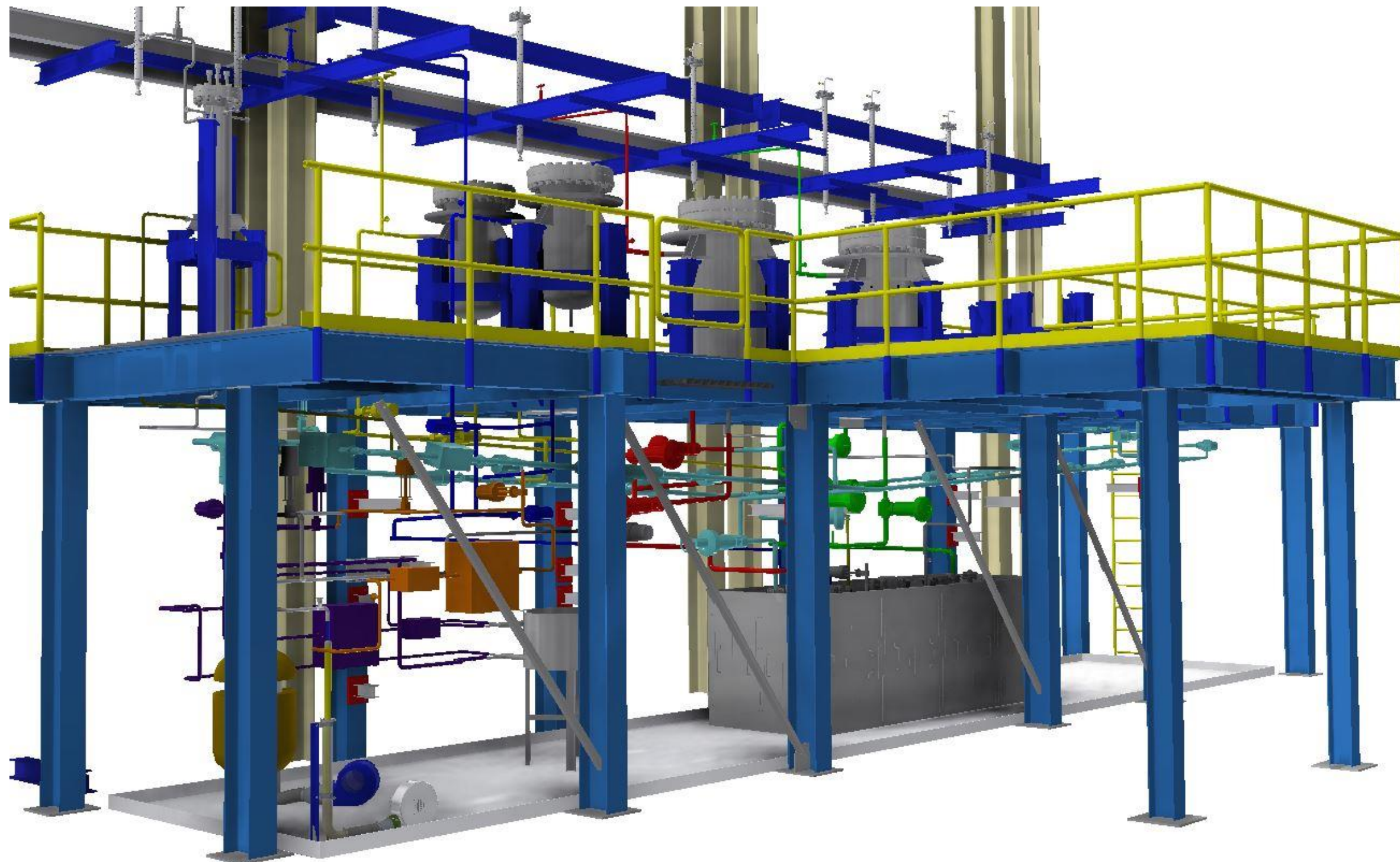


Figure 2 – A 3D model of METL after Phase I is complete.





*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 all of the 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 be configured to suit the particular needs of an experiment. During operation, the sodium is 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 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 service devices 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 real estate 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 ran cannot supply.

METL's resemblance of an SFRs intermediate heat transport system yields data directly applicable to operations and maintenance of SFR 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. Experimental deep learning programs for control or diagnostics can be tested and deployed on METL to demonstrate their viability before deploying them on larger scale plants for concern of extended down times or system failures. METL's newly established SCADA network could also be used for reverse-engineered hacking attempts to prove its security or identify weaknesses; both of which would assist in ensuring GEN-IV reactors have a robust enough cyber security and IT system to even deploy Machine Learning (ML) or Artificial Intelligence (AI) that promise O&M cost reduction.

#### 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), replaced the GTA with a blind flange on Vessel 1 and placed the GTA into the carbonation systems reaction tank for decontamination (Figure 4). Following the carbonation process (3), the METL team removed the GTA, cleaned parts with alcohol and disassembled the GTA.



*Figure 4. GTA Installed in Vessel 1 (left) and in the Process of Extraction (right).*





*Figure 5. GTA Cleaning (left) and Disassembly (right).*

### 3.2 28" Vessel Heat-Up

During previous METL operations, all of its components reached their maximum operating temperature with the exception of the 28" Test Vessels. In FY2021, new vessel support columns were installed to offer increased heat transfer resistance, to reduce the test vessels heat loss, and to ensure a "touch-safe" support column. An attempt was made to heat Vessel 4 (28" Test Vessel) to its maximum operating temperature of 650°C using its external heaters. Vessel 4 reached 525°C before this test was paused due to temperature differential constraints. The METL team reached out to heater manufacturer(s) for a configuration that will be capable of "isothermally" raising the 28" Test Vessels temperature to 650°C. Their proposal is currently under review.

After the Test Vessel 4 was cooled down, efforts were made to remove the bolts of the test vessel lid. A few flange bolts could not be removed using conventional tools such as an impact gun. A hydraulic torque wrench (Figure 6) was procured to provide the necessary force to remove the flange bolts. The hydraulic pump is driven by a small electric motor, the hydraulic pressure is used to spin a ratcheting hex collar to achieve torques up to 3,000 ft-lbs.



*Figure 6. Hydraulic Torque Wrench.*

The hydraulic torque wrench successfully removed the remaining bolts except for one. High-temperature galling resulted in the nut “welding” to the bolt thread. Ultimately, this nut was cut off so the bolt could be removed. Galling will be combated in the future by installing Inconel 718 plated nuts.

### **3.3 Development of Infrastructure and Supporting Equipment**

The resources required for a well-rounded alkali metal research program are extensive. The METL facility complex extends throughout four buildings on Argonne’s site for liquid metal experimental support. Testing is conducted in METL which is housed in building 308’s high-bay but experimental assembly zones for instruments and smaller test articles were established in spaces throughout Building 308. Building 309 houses inventory, a 4-port glovebox, Flexi-Cask(s) and spare/experimental test vessel flanges. Building 208’s F-wing



and building 206's high-bay house experimental assembly zones as well as qualification stations that allow scientists and engineers to ensure their devices are compatible with METL and demonstrate them using a simulant fluid such as water prior to METL insertion.

### 3.3.1 28" Flexi-Cask

A Flexi-Cask enables the insertion/extraction of test vessel experiments while maintaining an inert environment. The Flexi-Cask is equipped with (2) pocket doors, glove bag and a lifting disc. This configuration was used successfully to install/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 a 28" Test Vessel was designed and received in FY2020 (Figure 7). The 28" Flexi-Cask will be assembled, tested and potentially utilized for THETA in FY2021.



Figure 7. 28" Flexi-Cask received at Building 308.

### 3.3.2 28" Triad Flange

METL has the ability to support a myriad of experiments, including those occupying less than the vessels volume. A "Triad" flange (Figure 8) was conceived for installation onto a 28" test vessel for the insertion of specialized instrumentation and components. A Triad consists of numerous ports that vary in size and mechanical connection. This allows for rapid installation/removal of compact or smaller experiments such as heat pipes, oxide detectors,

level sensors, etc. A version of the Triad for installation on an 18” test vessel is currently in development.



Figure 8. 28” Triad Flange

### 3.3.3 *Glovebox*

A 4-port Argon glovebox (Figure 9) was received and assembled during the previous fiscal year to configure hardware requiring sodium-potassium alloy (NaK) or other highly reactive materials. In FY2020, the glovebox was commissioned by purging (6) 330 cu-ft Argon bottles through the glovebox. The glovebox is filled with Argon and maintains a pressure between +0.2 - +0.5 mBar. Argon oxygen and moisture levels are maintained below 0.1 and 0.5 ppm, respectively. The glovebox is equipped with PROFINET communications and the aforementioned internal conditions will be incorporated into METL’s data acquisition system in FY2021.



Figure 9. Building 308 Glovebox

#### 3.3.4 Carbonation System

METL's carbonation system involves bubbling dry CO<sub>2</sub> through a water column and then delivering this humid CO<sub>2</sub> to a reaction chamber containing sodium contaminated equipment. The moist CO<sub>2</sub> reacts with the sodium to create sodium bicarbonate (baking soda) which can then be brushed off thus decontaminating the test apparatus. In FY2020, a 208Y/120 sub panel (FIGURE) was installed near the carbonation system to centralize its power feeds. The new sub panel also has the capacity to add heaters onto the carbonation systems reaction chamber to reduce condensation. In addition, the carbonation systems control system and gas analyzer calibration manifold was upgraded. The carbonation system successfully operated for two GTAs cleaning operations to react its residual sodium.



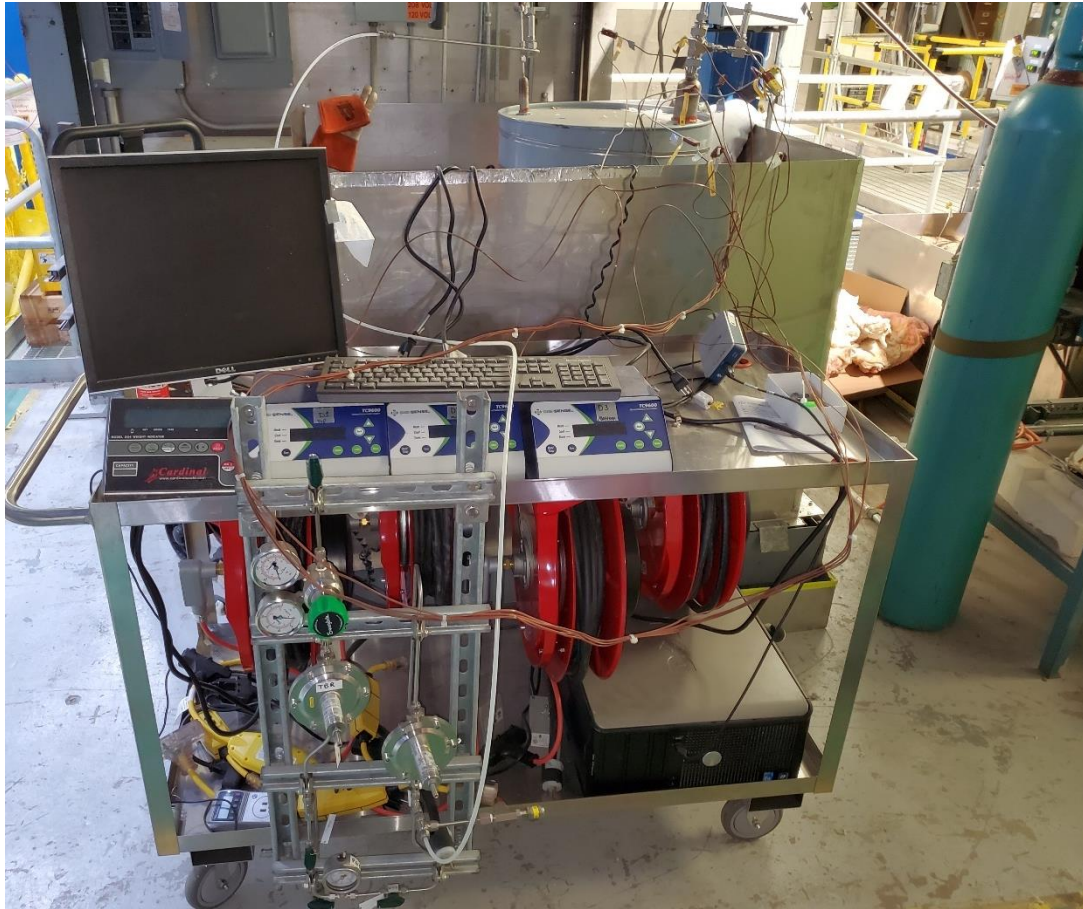


Figure 10. CO<sub>2</sub> Sub Panel Energizing Gas Analyzers and Heaters.

### 3.3.5 Sodium Containers and Under-Sodium Viewing System (USV) Sodium Transfer

Due to their historical success from transferring (15) 55-gallon drums of sodium into METL's Dump Tank, the METL team was requested to assist in the transfer of 30-gallons of sodium from a drum into the dump tank of the Under Sodium Viewing (USV) apparatus. Details regarding USV can be found in the references section (4). The sodium transfer was accommodated by modifying and upgrading equipment used to transfer sodium into METL and connecting it to USV dump tank (Figure 11).





*Figure 11. Sodium Transfer Cart.*

Historically, Argonne has had a container that was used for the transferring of sodium from test article to test article. Argonne created a specification and acquired (4) 30-gallon ASME containers suitable for sodium storage (Figure 12). These containers are rated for 74psig at 302°F. Once filled, they provide a means of quickly transferring sodium into smaller sodium test apparatus by pressurizing the head of the container through specified VCR connections and push sodium through its integrated dip tube. The containers also have (2) 2" ports for ASME inspection, these could also be repurposed for inserting instrumentation such as level sensors for a quick benchtop test/calibration.



*Figure 12. 30-Gallon Sodium Storage and Transfer Container.*

### **3.4 Asset Management**

A cloud-based computerized maintenance management system (CCMS) was acquired, populated with over 1,600 assets, and utilized throughout FY2020. The assets are numbered by division (accounts for the event the system expands outside Nuclear Science and Engineering) and project. Further organization is provided by asset type and sub-type (e.g. valve as the asset type and liquid sodium service as the asset sub-type). Documents, web links and its location on a floor plan can also be associated with an asset to provide further clarification for the specific installation.

The CMMS contains additional METL asset information such as serial/model numbers, parent/child asset(s), location and manufacturer. Other features to be used in the future include inventory control, project management and generating periodic reports to track key performance indicators (KPIs). Preventative maintenance (PM) or “scheduled activities” were applied to assets to ensure instruments remain calibrated, consumables replaced, bearings greased, etc. There are eighty-six PM work orders with generation frequencies ranging from weekly to quinquennially. KPIs currently being tracked/reported include the completion of PM specific work orders.

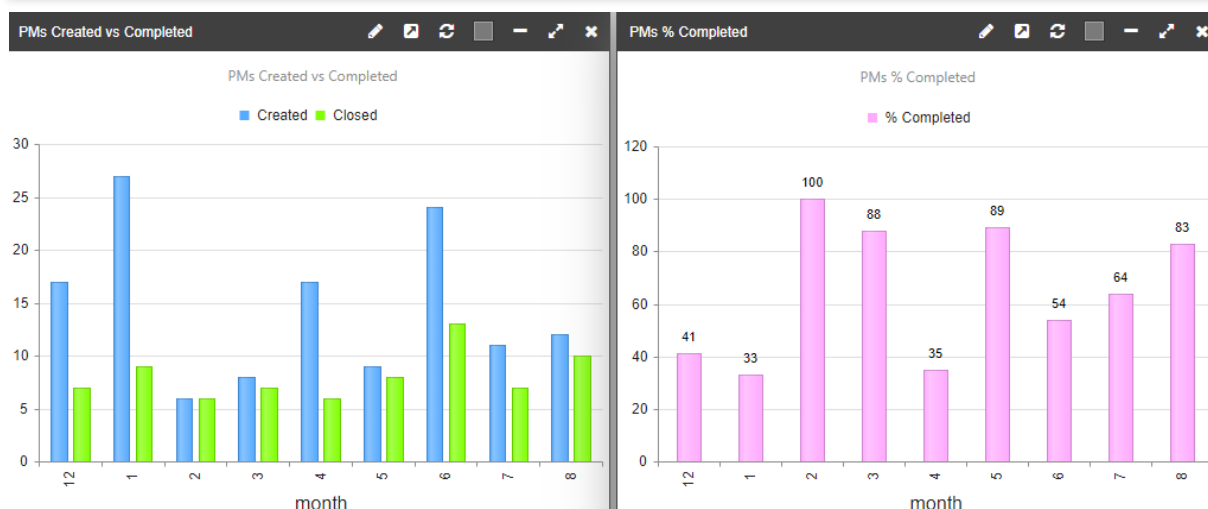


Figure 13. CMMS KPI Report.

These work orders along with corrective actions provide a history for individual components (called assets) for improving METL operational efficiency but may also find further use for advanced fault detection. Upon further ML/AI maturity, METL’s CMMS data is expected to build a bridge from ML to AI as it supplies “human” information such as previous diagnostic methods, repairs performed, parts utilized, serial/model number (allows for periodic internet polling to find recall/known issue information) and scheduled activities performed. The CMMS has the ability to upload SCADA data into the CMMS. This SCADA data may provide further value to ML/AI as the number of cycles a valve undergoes, the energy a heater consumes, number of thermal cycles a vessel experiences, or hours a pump/blower operates could be input into algorithms in conjunction with work orders for predictive maintenance ML and automatically assign corrective actions with a list of required parts/procedures using AI.

### 3.5 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, access to Argonne’s network, additional space for experimental support (electrical enclosures, fabrication/assembly areas, etc.), work/part inventory and tools to assist in the conceptualization and execution of experiments. Methods to address these concerns have been identified or pursued in FY2020 and efforts to grow/advance METL will continue.

#### 3.5.1 Electromagnetic Equipment

The electromagnetic pumps and flow meters are located below METL’s mezzanine and all of the electrical enclosures to operate them are located on the second level just outside of the METL control room as shown in Figure 14. Each pump and flow meter has its dedicated enclosure and therefore many redundant components. In FY2020, plans to consolidate this equipment into a single enclosure (to conserve space), under the mezzanine and near the electromagnetic hardware were designed. Relocating/consolidating these enclosures opens valuable floor space on the mezzanine for experimenters, removes numerous conduit routes in

a congested area and allows the repurposing of bus plugs currently feeding these enclosures. Furthermore, the new enclosures will support the new circuit boards installed on the electromagnetic flow meters.



*Figure 14. Control Infrastructure for Electromagnetic Pumps and Flowmeters.*

### **3.5.2 Control Room**

Due to the network upgrade required for enabling a high-performance and scalable SCADA system, METL's control room was equipped with the infrastructure required to also serve as a DOE compliant network node room. Work involved routing power from an automatic transfer switch (ATS) for redundant power supplies and replacement of the HVAC system.

Power was taken from the ATS to energize the equipment shown in Figure 15 which, consists of a 480v panel board, 480/240v transformer, disconnect and 120/240v panel board. Control room HVAC, lights and receptacles are all fed from the 120/240v panel board. In the event of a power outage from the primary feed, the UPS keeps critical equipment powered until the ATS supplies the equipment with the redundant utility power feed.





*Figure 15. METL Control/Node Room Redundant Power*

METL is housed in the building 308 high-bay, to date, this facility does not have active air cooling. In FY2020, the METL control room 1-ton air window conditioner was replaced with a 3-ton mini-split heat pump (Figure 16) and all of the fluorescent lights were substituted with L.E.D. equivalents.



*Figure 16. Minisplit Outdoor (left) and Indoor (right) Heat Exchangers*

### **3.5.3 3D Scan and Imagery**

A contractor was hired to perform 3D scanning and photography in late FY2020. The 3D photography was used to document METL's progress as it transitions through its phases,

obtain rough dimensions and provide virtual tours to researchers, sponsors, and clients. The interface and use is extremely similar to Google Maps ©. Navigation can be performed quickly using the “doll house” feature, viewing a floor plan or you can “walk” through the facility and rotate 360° by selecting different viewpoints (boxed in red below in Figure 17). This feature is expected to assist clients in developing their experiments and has already been effective with communicating METL’s capabilities to funding opportunity announcement applicants. In addition, the 3D photography is directly compatible with virtual/augmented reality (VR/AR) headsets which could also provide an entirely new vantage point for operators/sponsors/clients. The data acquired on METL could be fed into this experience real-time as well.



Figure 17. “Street View” of METL Dump Tank.

The 3D laser scanning gathered millions of data points at each of its scan locations. The contractor then compiled these scans together to generate a point cloud which encompasses all of the scans. Two versions of the point cloud were delivered to Argonne, one that condenses all of the points into one for every 10mm and the raw point cloud. The condensed version is much lighter and therefore easier to work with/import into software packages such as Revit © and Navisworks ©.



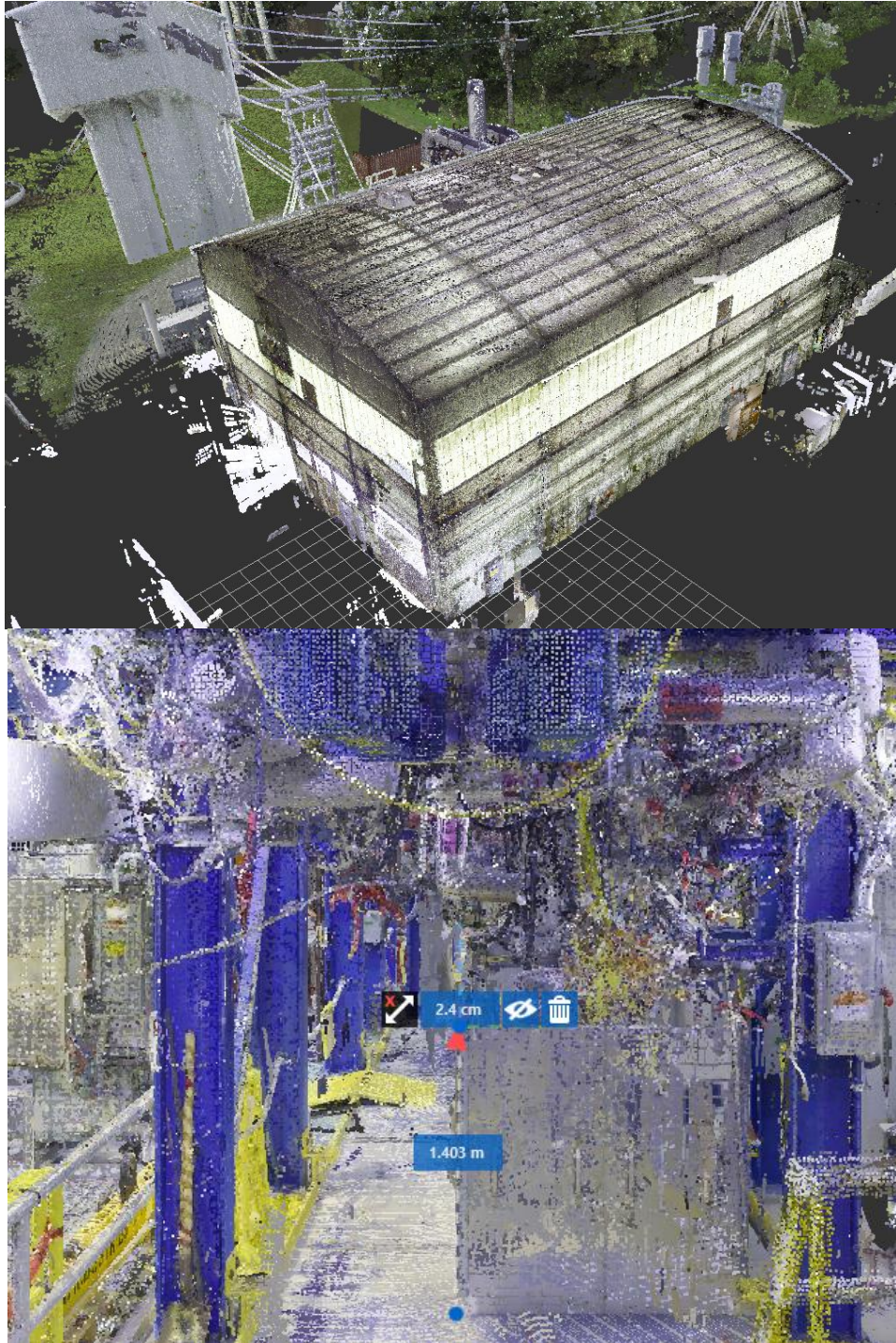


Figure 18. Condensed (10mm) Point Cloud of Building 308 (top) and METL (bottom).

The point cloud is shown above in Figure 18 using Recap ©. Point clouds are not as aesthetically pleasing as the 3D photography, but its measurement accuracy is far superior (3D Photography measurement accuracy is  $\pm 1\%$  and 3D laser scanning promises within an inch or better). The measurement in Figure 18, shows the Dump Tanks retaining wall height as 1.403m. It was measured with a tape measure to have a height of 55.25 inches or 1.40335m. The same measurement using 3D photography resulted in 4'7" which equates to

55 inches or 1.397m. The point cloud will allow the recreation of METL in CAD to provide a better digital as-built model that includes external features. The point cloud recreation of an as-built METL integrated with CMMS information and sensor data is expected to enable the generation of a true digital twin (DT) and thus further advance predictive operations and maintenance.

#### **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 FY2021. Specifically, a new experiment, the Thermal Hydraulic Experimental Test Article (THETA) is expected to be inserted into METL in FY21. THETA mimics a pool-type sodium fast reactor, its unique capabilities and state-of-the-art instrumentation can deliver essential thermal hydraulic data for safety analysis and other code development but, could easily be configured to provide whole system simulations. A detailed report regarding THETA progress as well as Air-to-Sodium Heat Exchanger specifications can be found in ANL Report "Thermal Hydraulic Experimental Test Article - Status Report for FY2020" (5). In anticipation of additional experiments and an 18" "Triad" flange, an 18" Test Vessel was obtained in FY2019. This additional 18-inch test vessel will be installed at Test Vessel 6.

##### **4.1 Test Vessel 6**

An additional 18" Test Vessel (V6) identical to the installed 18" Test Vessels was secured to its support legs in FY2020. The vapor trap, filter and piping subassemblies were fabricated by ANL-Central Shops in FY2020 and are ready for installation.

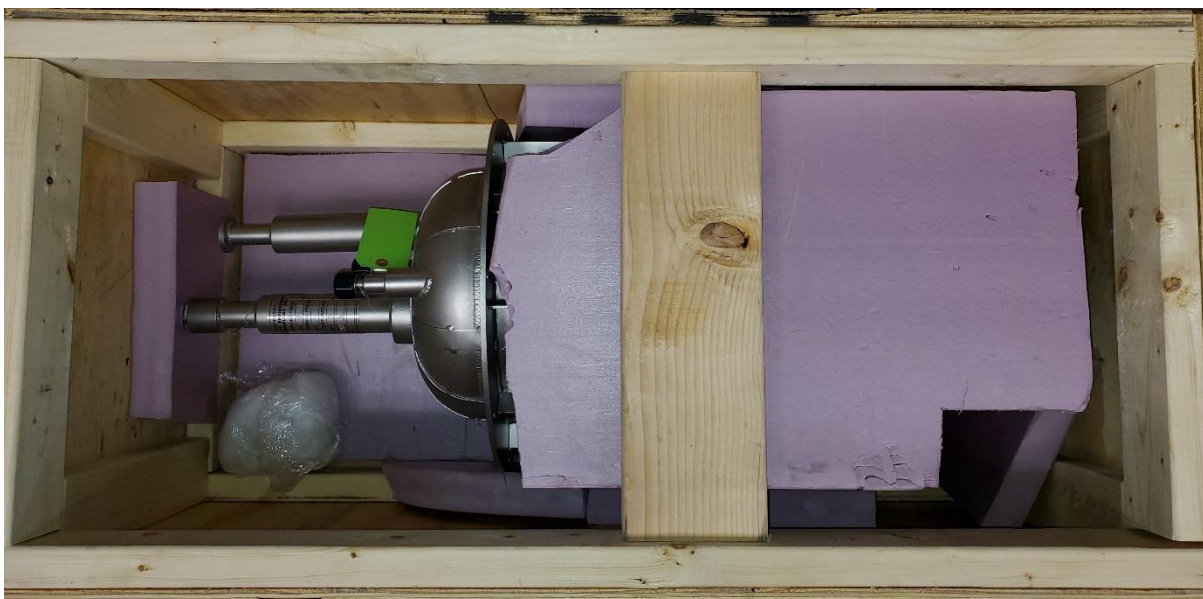




*Figure 19. Vessel 6 (18" Test Vessel)*

#### **4.2 Procurement of Spare Cold Trap and Plugging Meter**

METL utilizes a Plugging Meter and Cold Trap to monitor sodium impurities and then filter them out of the bulk sodium, respectively. In anticipation of the Cold Trap becoming full of sodium oxides at some point in the future, a replacement Cold Trap was specified, ordered and received. A freeze plug was also designed to assist in maintaining Cold Trap purity during installation.



*Figure 20. Cold Trap Mark II Received.*

The original Plugging Meter design was designed from a similar device used on EBR-II. In the 1970s the DOE created Reactor Development Technology (RDT) standards for equipment used by SFRs such as a Plugging Meter. A notable feature of the RDT Plugging Meter is the inclusion of a clearing pin which can be removed via magnetism in the event the smaller orifices become completely plugged. Standard RDT F3-40T (6) in conjunction with installation, maintenance and operation experience with the original Plugging Meter was used to design the new plugging meter (Figure 21). The new Plugging Meter has been ordered and it is expected to be received prior to the end of the calendar year.



Figure 21. RDT Plugging Meter (oriented horizontally for white space reduction)

## 5 METL Supervisory Control and Data Acquisition (SCADA) System Overhaul

Summarizing the FY 2019 version of this report, new hardware was installed to de-centralize METL controls (7). The data acquisition/control was separated into (3) tasks that include main operations, surface and subsurface. There are (3) real-time controllers in charge of these processes, which log data to an external hard drive locally but also forward the data to METL's Network Server (MNS).

The main and surface operations are shared by the main industrial controller (MIC) and cDAQ link controller (LincDAQ). MIC provides communication to the Eurotherm equipment (( 22) Mini8s and (6) PAC T2750s) which control the heater zones for the entire facility and MICs FPGA inputs the beam "smoke" detector signals and outputs an alkali metal scrubber start signal. In addition, the MIC is the master for the energy/power quality meters, UPSs and circuit breaker shunts on the power feeds for experiments. In FY2021, MIC is expected to also host I<sup>2</sup>C communication for DC power supplies, SCPI for benchtop instruments and PROFIBUS/PROFINET for European PLCs/instruments.

There are (9) data acquisition chassis strategically located throughout METL which are used to measure temperatures, pressures and output control signals. These chassis are not compatible with MIC due to its Linux OS. The LincDAQ is a Windows embedded 7 controller that provides a "link" to these historical chassis. Eventually, the LincDAQ and its historical cDAQ-9188XT data acquisition chassis will be phased out and replaced with a surface cRIO (SurfRIO) and Linux compatible cDAQ chassis. This will allow control functions to be further segregated by controller and no longer need any to have shared responsibilities.

Subsurface operations are handled by the Subsurface cRIO (SubRIO). The SubRIO controls/monitors equipment associated liquid sodium functions such as electromagnetic pump VFDs/variacs, electromagnetic flow meters, pressure transducers, air blower variable frequency drives (VFDs), dampers and internal thermocouples. Therefore, the SubRIO is responsible for the Primary Loop, Cold Trap and Plugging Meter. Until all equipment is time sensitive network compatible, the SubRIOs Field Programmable Gate Array (FPGA) gathers GPS data from one of its modules.

Pending successful testing, the SubRIO will also be the master to a MODBUS/TCP to Highway Addressable Remote Transducer (HART) gateway. The HART gateway under test has (4) HART channels and each channel can support (7) HART instruments when wired in parallel. All sodium service (liquid or vapor) pressure transducers are 4-20mA output instruments with HART capabilities. HART uses the existing current signal but applies frequency shift keying so that the analog signal can send a digital message. This enables the transducer to send more than just its primary value (gauge pressure) on the existing conductor pair. HART instruments such as Coriolis mass flow controllers (METL does not have Coriolis mass flow controllers) are able to send density, flow rate and temperature measurements via HART. In addition to process variables, manufacturer, model/serial number and calibration data can also be transmitted via HART. Implementing HART is expected to provide further value to METL from an industrial internet of things (IIoT) and Digital Twin (DT) perspective.

### **5.1 Data Acquired/Controls**

METL's previous SCADA system acquired (6) vessel/tank Argon gas pressures, (6) liquid sodium pressures, (10) argon gas vent pressures, (4) sodium level measurements, (52) valve positions, (3) sodium flow rates, Argon relief flow rate, (220) process temperatures and (462) monitoring thermocouples, (6) UPS data [battery charge level, temperature, current draw, etc.], (4) ground fault relay data [breaker trip, continuity, ground-fault] and (220) heater zone fault data [broken input, over-temperature, acknowledgement, etc.].

The new SCADA system's data points include the aforementioned readings with the addition of (220) heater currents, (220) heater PID outputs, (2) blower air velocities/temperatures, (2) beam "smoke" detectors, (4) energy meter data [energy, L-L voltage, power factor, frequency, etc.], (2) power quality meter data [voltage/current harmonics, reactive power/energy, etc.] and (3) variable frequency drive data [current, power factor, frequency, motor torque, DC bus voltage, etc.]. METL's SCADA system continues to control the heaters as well as the (3) electromagnetic pumps, (2) blowers, (4) mass flow controllers, (236) electric shunts, (52) electro-pneumatic valves, (2) air dampers and alkali metal scrubber starter.

### **5.2 METL Software Development Kit (SDK)**

METL's new SCADA system utilizes (3) real-time controllers, a Windows server and a windows control room P.C. Future plans include, at a minimum, an additional (2) real-time controllers. The first version of a METL Software Development Kit (SDK) was released in FY20 to minimize the effort in maintaining all the controllers that operate METL as well as improve efficiency of the on-boarding process for new devices/programs. METL's SDK meta data is stored in two large spreadsheets (one for read-only data and the other for read/write) allowing for swift patches.

#### ***5.2.1 Data Standardization***

Determining a proper method of standardizing data required an analysis on inter-LabVIEW application communication methods as well as an understanding of protocols used by other industrial controllers and edge computing. Using National Instruments (NI) Current Value Table (CVT) library provides inter-application communication which can be extended to inter-target communication by installing the CVT Client Communication (CCC) library. Since, the CVT library uses global variables as its foundation, an alternate but similar library,

named TAGBUS, was used to standardize inter-application communication. TAGBUS consists of (3) components: tag, table and dictionary.

A tag is an object in the TAGBUS library with (4) attributes: name, default value, data type and meta data. The conglomeration of tags is a dictionary and the grouping of tag values by their data types is a table. Tags are identified within a dictionary by their name and then a dictionary provides the location within the table and dictionary of its present value, default value, data type and meta data. Tags allow for human-readable identification of data points so specific sensor data can be quickly obtained or grouped with other sensors. The naming convention for METL’s SDK is provided in the example below using a semicolon as the delimiter.

*Table 1. METL Tag Examples*

Type	Tag	Data	
Read Only	MIC:MINI8:Array of Single:HTRO:Dump Tank Vessel Zone 1	PID Present Value	PID Output
Read/ Write	MIC:T2750:VLVRW:Boolean:Expansion Tank Valve EXP GAS:3:101	Valve Command	

Placing the master controller’s name (MIC) prior to the slave controller’s name (MINI8 or T2750) allows for quickly filtering out all tags associated with the master or the slave. Furthermore, tags could be segregated based on the actual component (e.g. all tags associated with the Expansion Tank or Dump Tank). The ability to categorize data legibly and redistribute accelerates future program development and allows for less-experienced developers to contribute. Discussed in the next section, TAGBUS complements NIs data logging format.

### **5.2.2 Data Logging**

Historically, data was saved to an ASCII text file that could be copy/pasted into a spreadsheet for further analysis. Although fast and effective, this method was not scalable. NI developed an add-on called Technical Data Management Streaming (TDMS). TDMS files are organized by group(s) containing channel(s). Therefore, to create a TDMS file from TAGBUS data, tags can be filtered by a group (e.g. Electrical Power Enclosure 4) and data type (e.g. Array of Single) to save all the channels (Power, Energy, etc.) associated with this filter or group.



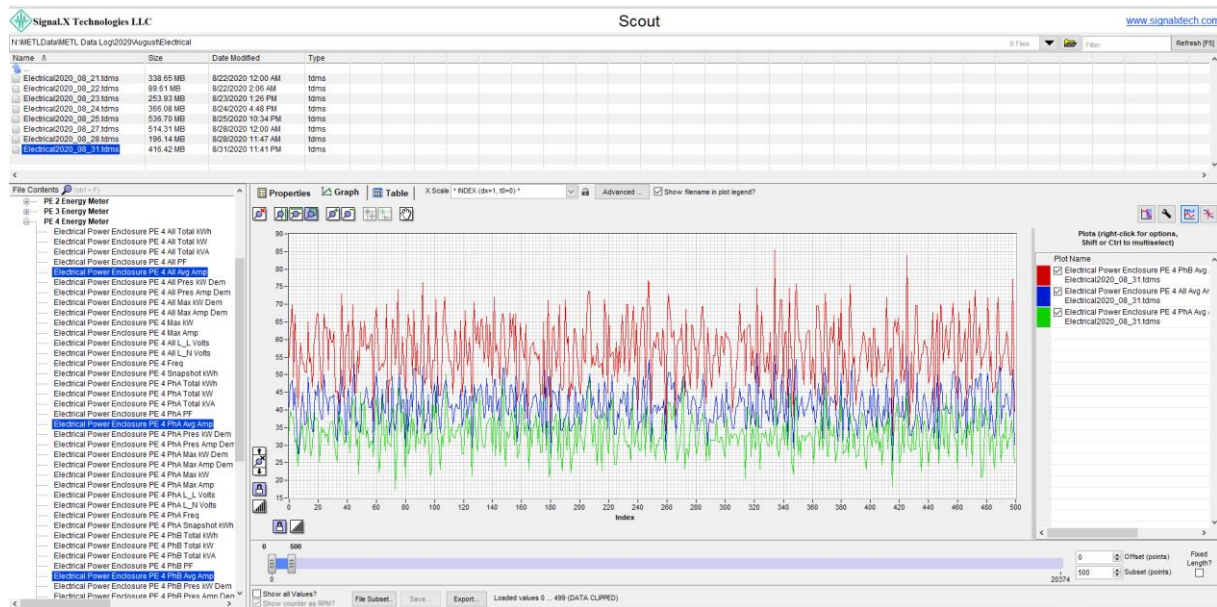


Figure 22. TDMS Data from Power Enclosure 4's Electric Meter

TDMS files are compatible with NI's Diadem ©, Microsoft Excel ©, Mathworks Matlab © and other vendors have created their own programs specifically for TDMS files such as Signal X's Scout © (Figure 22). A drawback to continuously logging to TDMS files is the amount of RAM required to write to a large file. Many techniques were tested to try and minimize this "memory leak" but due to the large amount of data and high frequency, a new file must be created/closed every hour. Therefore, the folder/file hierarchy is "Year\Month\Day\Subsystem\_YYYY-MM-DD\_HR.tdms" where, subsystem could be Dump Tank, Cold Trap, Vessel 1, etc. Logging METL (no major operations or experiments) read only data consumes  $\approx 42$  GB/day.

Read-only data is logged as it is acquired but Read/Write data is only logged upon a change of value. In FY2020, an electronic logbook was incorporated where Read/Write data is saved along with any errors or operator notes. The logbook (Figure 23) also uses TDMS files but since the file sizes are much smaller, this file is only updated monthly. Its groups include controls, notes and errors where its channels are time, operator name, tag name, control name, new value and previous value.

	File "Entries_2020 Group "Controls" Time	File "En Group "Year	File "En Group "Month	File "E Group "Day	File "Entri Group "Co Operator	File "Entries_2020_09.tdms" Group "Controls" Tag	File "Entries_2020_ Group "Controls" Control	File "Entr Group "C Value	File "Entri Group "C Previous
index 0	15:05:07	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS:3:104	Valve HCA	On	Auto
1	15:05:07	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS	Valve Command	TRUE	FALSE
2	15:05:22	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS:3:104	Valve HCA	Off	On
3	15:05:22	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS	Valve Command	FALSE	TRUE
4	15:06:09	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS:3:104	Valve HCA	On	Off
5	15:06:09	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS	Valve Command	TRUE	FALSE
6	15:06:19	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS:3:104	Valve HCA	Off	On
7	15:06:19	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS	Valve Command	FALSE	TRUE
8	15:06:53	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS:3:104	Valve HCA	On	Off
9	15:06:53	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS	Valve Command	TRUE	FALSE
10	15:06:59	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS:3:104	Valve HCA	Off	On
11	15:06:59	2020	09	10	dkultgen	MIC:T2750:VLVRW:U16:Vessel 1 Valve V1 GAS	Valve Command	FALSE	TRUE
12	16:20:35	2020	09	10	dkultgen	SubRIO:PhySig:PIDRW:Array of Double:Sodium QA Primary Loop PID EM Pump:0:0	Manual Output	50.00	0.00
13	16:20:53	2020	09	10	dkultgen	SubRIO:PhySig:PIDRW:Array of Double:Sodium QA Primary Loop PID EM Pump:0:0	Manual Output	0.00	50.00
14	16:21:50	2020	09	10	dkultgen	SubRIO:PhySig:PIDRW:Array of Double:Sodium QA Primary Loop PID EM Pump:0:0	Manual Output	50.00	0.00
15	16:22:00	2020	09	10	dkultgen	SubRIO:PhySig:PIDRW:Array of Double:Sodium QA Primary Loop PID EM Pump:0:0	Manual Output	25.00	50.00
16	16:22:14	2020	09	10	dkultgen	SubRIO:PhySig:PIDRW:Array of Double:Sodium QA Primary Loop PID EM Pump:0:0	Manual Output	50.00	25.00
17	16:25:30	2020	09	10	dkultgen	SubRIO:PhySig:PIDRW:Array of Double:Sodium QA Primary Loop PID EM Pump:0:0	Manual Output	100.00	50.00
18	16:27:18	2020	09	10	dkultgen	SubRIO:PhySig:PIDRW:Array of Double:Sodium QA Primary Loop PID EM Pump:0:0	Manual Output	0.00	100.00

Figure 23. METL Digital Logbook.

### 5.2.1 Inter-Network Communication

Reliable communication is the foundation for distributing control and data acquisition throughout the METL complex. Previously, machine-to-machine communication was handled by NI's Shared Global Variable server which acts as a "middle-man" to establish a connection, transmit data and correctly close the connection. Speed and ease of use are benefits to the Shared Global Variable server but at a cost of reliability. Industrial protocols were investigated as were other NI methods such as network streams. EPICS communication is generally used on large physics experiments and Ethernet/IP is widely known throughout industry. However, their functionality within the LabVIEW development environment could be more extensive so it was decided to use TCP/IP. NI developed a Simple TCP Messaging (STM) library, this library in addition to one developed in-house specifically for TAGBUS was used to facilitate rapid and reliable communication between all of the devices on the METL SCADA network.

### 5.3 Additional Libraries Created

Libraries and SDKs are essential for rapid development of future programs and to maintain revision control. In FY2020, numerous libraries were created to facilitate the SCADA lifecycle. A utilities library was developed for commonly used code in messaging, charts, tables, timing and configuration. The majority of METL's devices use MODBUS/TCP for communication and therefore an Argonne MODBUS library was created to handle common nuances with the MODBUS protocol such as reading/writing a coil as an integer or Boolean and reading/writing a holding register as an array of Booleans, an integer, or numerous holding registers as single precision floating point(s). Argonne specific libraries to animate and control sub panels (discussed subsequently), programmatically configure data acquisition chassis, log data and handle TCP/IP communication were also generated.

### 5.4 User Interface

The inherently different architecture between the previous and new SCADA system required a new user interface program/design. The previous SCADA system operated on a powerful central PC that performed controller communication, computed algorithms and displayed data. Data was then streamed to other screens via shared global variables (read-only). This

effectively reduces the number of programs required to two (a control program and a view only program). The view program was operable on numerous computers but the control program was restricted (for numerous reasons) to the central control room computer.

The new SCADA system employs numerous real-time controllers which are not configured for graphics (for optimal performance) and therefore “head-less”. A user interface is provided by two different programs, one for control and the other for viewing METL’s status. These programs are much different from their predecessors as now they are communicating directly via TCP/IP. The control program connects directly to the multi-client server for each controller whereas the view-only program connects directly to the multi-client server on MNS. This configuration yields the following benefits:

- Any computer with the control program installed and access to METL’s VLAN can control METL.
- METL can be controlled remotely.
- Multiple operators can control METL at the same time (also emphasizes the need for a digital logbook) – if needed.
- Countless kiosks running the view-only program could be deployed throughout the ANL campus or remotely without impacting controller performance (Obtains information from MNS).
- Since the View program connection to MNS is read-only it is not possible for someone to attempt to control METL from this program.

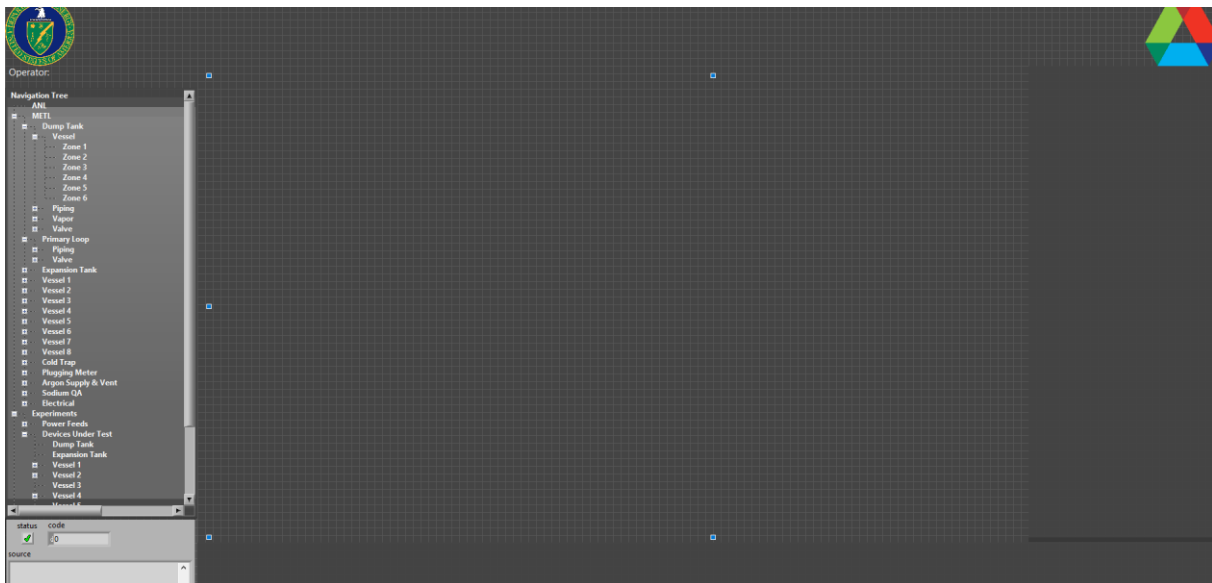


Figure 24. Main METL program (GUI is dynamically loaded when running so it appears empty)

Unlike their predecessors, each new user interface program also incorporates a sub panel. Sub panels are native to LabVIEW and allow the insertion of different program user interfaces. Incorporating a sub panel provides numerous benefits to graphical user interface (GUI) development. Since, the primary GUI does not contain all of the elements of the sub program GUI, developer computers do not begin to lag after placing advanced or a large quantity of

images, indicators, graphs, etc. Sub panels also support program distribution as, in the event a GUI needs to be added or updated, the smaller program GUIs can be sent as a patch or plug-in so that the main program does not need to be re-installed/updated.

## 5.5 Network and Security

The distributed control and ability for numerous operators on ANLs campus or from afar raises network and security issues. Furthermore, utilizing/implementing emerging technologies previously discussed such as VR/AR, DTs, and ML/AI, demand facilities to share their data securely to numerous applications, many of which reside on clouds. In FY2020, a strong effort was made to design and setup a fast, scalable, reliable and secure network capable of supporting METL’s SCADA while integrating the aforementioned technologies.

Network reliability will be improved in FY2021, as the network architecture will switch from a “daisy-chain” to a “star” pattern. This will ensure each device on the METL virtual local area network (VLAN) has a dedicated connection to the central managed switches in the METL control room. A benefit to the “star” pattern is the bandwidth is no longer restricted and therefore will be able to support the replacement of 100MBps devices to 1GBps. The most significant drawback to a “star” pattern is the distance between the switch and device but all of METL’s devices are well within the 100m limit of a Cat6a cable.

The METL team worked closely with the Energy and Global Security’s Information Technology (EGS-IT) group and Argonne’s Business Information Systems (BIS) division to ensure METL’s SCADA system has flexible operations without compromising security. This challenge was met by approaching from the SCADA program end as well as IT. Placing METL’s SCADA onto its dedicated VLAN within Argonne’s network allows access to Microsoft’s Active Directory which can verify usernames/passwords. Performing user control functions on METL requires an operator to be in the appropriate Active Directory group and enter their Argonne credentials correctly.

METL’s VLAN provides additional safeguards as an individual must meet the aforementioned requirements in addition to being on an Argonne computer that has a firewall conduit in place that allows it to communicate with devices on the METL VLAN. BIS and EGS-IT configured a bastion host which allows operators to control METL on a personal device or an Argonne one without a firewall conduit. However, the user must have a DoE smart card for multi-factor authentication and login with the correct credentials to access this bastion. There is also physical security to the network as the node room is also METL’s control room which is locked. Even upon a control room breach, the switches are managed so a device must be registered in Argonne’s Integrated Host Warehouse by METL’s administrator for it to communicate with hardware on METL’s VLAN. Unplugging controller ethernet cables simply results in the controller putting METL into a safe state. In summary, METL’s data and operations is extremely secure and the infrastructure could be used to test potential cyber-attack methods to ensure GEN-IV reactors are connected and secure.

## 6 Summary

The preceding report provided a summary for the status of the METL facility as of September 2020. 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, develop/qualify potential Sodium Fast Reactor technologies, and works 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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