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Mechanisms Engineering Test Loop (METL) Operations and Testing Report – FY2019

Nuclear Science and Engineering Division

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Mechanisms Engineering Test Loop (METL) Operations and Testing Report – FY2019

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1 EXECUTIVE SUMMARY

This report documents the operations and testing that was performed at the Mechanisms Engineering Test Loop (METL) during FY2019. The METL facility had a very successful initial year of operations having logged over 365 days of operations with molten sodium either flowing or static. FY2019 saw the commissioning, insertion, and extraction of the first test assembly in METL. In addition, METL is being prepared to support a second 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 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 with four additional test vessels.

1.2 METL Operational Year I Accomplishments

The METL facility and team had a very successful first 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 365 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) since September 19, 2018.
- Multiple sodium flowing and purification campaigns have been performed during 24/7 operations.
- The METL team has confirmed the functionality of the sodium purification cold trapping system and has purified the METL sodium down to 5 ppm oxygen.
- The METL team filled Test Vessel #2 with sodium for the first time after the METL main loop and expansion tank fill.
- Level sensor technology has been developed to support the filling of the expansion tank and test vessels. The inductive level sensor was reported in a separate milestone report in March 2019 (1).
- The METL team qualified for insertion into METL the first test article – a gear test assembly for insertion into METL.
- The first test article – Gear Test Assembly – was inserted into Test Vessel #1 on 12/11/2018.
- The 18-inch flexicask underwent testing and refinement to include a clear inert enclosure with gloveports for easier accessibility to removed test articles.
- The 18-inch flexicask was commissioned for service in METL.
- The 18-inch flexicask testing and commissioning activities provided information to support the design development of the 28-inch flexicask.
- The 28-inch flexicask design was finalized and request for quotation was prepared to procure the flexicask.
- Performed a design extension of METL to support the thermal hydraulic experimental test article (THETA) which included the procurement of Test Vessel 6, installation of vessel supports.
- Installed the Mk-III Inductive Level Sensor into METL
- Commissioned the moist carbon dioxide reaction system for reaction of residual sodium from METL test articles.
- Performed the first extraction using the 18-inch flexicask from Test Vessel 1 (GTA extraction from Test Vessel 1)
- Performed the transfer of the GTA from Test Vessel 1 to the Carbonation Reaction Tank.
- The METL team is in the process of reacting the residual sodium from the Gear Test Assembly.

During FY2019, the Argonne METL team gave many tours to professionals visiting Argonne.

1.3 Plans for FY2020 at METL Phase II

The METL facility will continue to operate with molten sodium during FY2020.

METLs Phase II construction is currently underway and will continue to progress in FY2020+. Immediate efforts are focused on installing another 18” Test Vessel (V6) and an Air-to-Sodium Heat Exchanger (ASH-X). Test Vessel 6 (V6) piping subassemblies have been fabricated, radiographed and are ready for installation. V6 along with its support columns are on-site and waiting to be installed. An order for the ASH-X has been placed and is expected to arrive early FY2020.

1.4 Acknowledgement

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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

Four METL operational campaigns were pursued during FY2019. The purpose and duration varied but all campaigns involved METL being monitored twenty-four hours a day, seven days a week. These operational campaigns were achieved by rotating operators every twelve hours. Throughout METLs operation, different configurations were successfully tested which further highlights METLs ability as a facility to provide a versatile and accommodating environment for experimentation.

3.1 Initial Demonstration Campaigns

There were two initial demonstration campaigns with similar objectives. The first initial demonstration began on September 19, 2018 and lasted for approximately three weeks. This demonstration filled METL’s Expansion Tank, Primary Loop, Cold Trap and Plugging Meter with sodium at 250°C. The methodology was nearly identical to the sodium transfer from drums to the Dump Tank as argon gas was used to push sodium through a dip tube and into a different vessel. The dip tube is “Nozzle B/Port 5” on the Dump Tank and the positive argon gas pressure in the Dump Tank was regulated using a tank-blanketing regulator. However, in this instance, the dry equipment (Expansion Tank, Cold Trap, Plugging Meter, Primary Loop, etc.) was evacuated prior to the sodium fill. Filling these components in the absence of argon gas reduced the potential of cover gas entrainment that can decrease instrumentation accuracy and electromagnetic pump performance. Selectively closing/opening valves ensured the sodium’s flow path was bottom-up to minimize further entrainment.

The aforementioned equipment was successfully filled with sodium within five minutes and the level was indicated using an inductive level sensor installed in the Expansion Tank. Then the temperature was increased to 300°C to facilitate wetting the surfaces with sodium to optimize electromagnetic equipment performance. The remaining activities for this campaign required the circulation of sodium through the Cold Trap for three weeks to remove sodium-

oxides and other impurities. Cold Trap operating parameters for this period was a flow rate of 1 GPM and a saturation temperature of 173°C, which roughly equates to an oxygen concentration of 5 ppm.

The second initial demonstration began on November 26, 2018 and was similar to the first but provided further assurance that METL would successfully serve as a proving ground for experimental equipment and presented the opportunity to troubleshoot issues with the electromagnetic pumps and flow meters identified in the first demonstration. Efforts in this demonstration focused on filling Test Vessel #2 with sodium, purifying the sodium and then isolating the test vessel. Since, the electromagnetic equipment and liquid service pressure transducers were already submerged; a positive argon gas pressure on both the Dump Tank and Test Vessel was used. This operation was again achieved using a tank-blanketing regulator to supply the Dump Tank with positive argon gas pressure to push sodium through its dip tube. Similar to the sodium drum transfer; back pressure regulators were used to relieve argon gas pressure as the Expansion Tank and Test Vessel were filled and a manifold was constructed to tie the vapor spaces of the two vessels together as shown below (Figure 4).

Figure 4. Back Pressure Manifold

Vessel sodium level during filling was monitored using the previously discussed inductive level sensor in the Expansion Tank as well as an array of thermocouples inserted in Test Vessel 2. Lastly, sodium was purified for two weeks and then remained molten and static until the Gear Test Assembly (GTA) demonstration.

One issue that arose during the first demonstration was a sporadic flow meter signal, which did not appear to be due to electromagnetic interference but rather a limitation of the installed equipment. A section of data acquired below (Figure 5 - Left) provides an example of this

behavior for all three flow meters. The noisy signal made accurate flow control nearly impossible so the flowmeter control program was obtained from the OEM and the METL team applied a lead-lag filter (Figure 5 – Right). The lead-lag filter was able to successfully reduce the noise and provide a stable enough signal for PID control.

Figure 5. Flow Meter Noise (left) and Filtered Signal (right)

3.2 GTA Campaign

Following the successful Test Vessel 2 filling, the GTA was inserted into Test Vessel 1 (Figure 6). Test Vessel 1 was not “baked-out” with the GTA installed prior to filling, as was the procedure with other METL components due to the potential of compromising the GTA graphite gas seals. Once, the GTA flange bolts were torqued, equipped with instrumentation, heaters and motors; it was insulated.

Subsequent to GTA insertion, Test Vessel 1 was heated to 250°C and filled with sodium. Utilizing the primary loop pump, sodium was circulated through Test Vessel 1 and the Cold Trap to purify the entire METL sodium inventory minus the Dump Tank. METL was operated in this configuration for two weeks, then the pump was shut off and Test Vessel 1 was isolated from METL’s primary loop.

Now surrounded by clean and molten sodium, GTA began its testing sequence to simulate gear loads that would be present when pulling a fuel assembly out of the core of a sodium-cooled fast reactor. GTA performed 9,800 fuel rod lifting and lowering cycles and operated for 327 hours before shaft seizure. Following the GTAs first experimental operations, sodium in Test Vessel 1 was drained into the Dump Tank and Test Vessel 1 cool down was initiated. Once, Test Vessel 1 was near room temperature; insulation, instrumentation, heaters and other components were removed to prepare it for extraction from METL using the Flexi-Cask.

Figure 6. GTA Inserted into Test Vessel 1 (left) with Motors Installed (right)

3.3 Post GTA Campaign

The last METL operation campaign for FY2019 involved refilling Test Vessel 2 with sodium and then purifying. During purification, raw electric flow meter data was collected for subsequent analysis to see if its performance could be improved with alternative data acquisition hardware. In addition, a second plugging meter test was attempted. Currently, at the end of FY2019, sodium remains molten but not flowing (so static) in all of METL other than Test Vessels 1, 3, and 4.

3.4 Some Additional Operations

3.4.1 *PID Tuning*

Once flow meter signals were stabilized, the preliminary tuning of the PID controllers for the electromagnetic pumps and blowers was pursued. Both the pumps and blowers were tuned using the Minimum Integral of Absolute Error (IAE) method as from an operations standpoint; calculating the gains is minimally disruptive and yields the desired results. The primary

loop pumps performance is summarized in Figure 7. The vertical red line indicates when a user changed the set point and the corresponding set point value is listed. The blue line represents the flow rate so it is readily visible that the pump is able to reach its new set point with little to no over-shoot and stabilize the flow rate in under sixty seconds.

Figure 7. Primary Loop Pump PID Tuning Results

The preliminary PID tuning of the Cold Trap and Plugging Meter electromagnetic pumps and blowers was successfully demonstrated as well. The Cold Trap and Plugging Meter pumps had similar performance to the Primary Loop pump. Currently, the most critical PID controller for METL is the Plugging Meter blower as it will have a fluctuating set point during operation and this set point must be reached at a user-defined rate. PID tuning results for the Plugging Meter are summarized in Figure 8.

Each line represents the Plugging Meters internal temperature with respect to time. The difference between the two is the set point rate as the red line is with the tuned PID controller set to $2^{\circ}\text{C}/\text{min}$ and the blue line has a rate of $1^{\circ}\text{C}/\text{min}$. Therefore, if the blower was perfectly in control then the slope of the red and blue line would be 2 and 1 respectively. The slope values for each run are bold and have an enlarged font. These values are quite close to the actual user-defined rate, which indicates the Plugging Meter blower is well controlled.

Figure 8. Plugging Meter Blower PID Tuning Results

3.4.2 Plugging Temperature Indicator (PTI)

A summary of Plugging Meter theory and operation is provided in previous METL reports (1), as previously discussed; its ultimate purpose is to determine the plugging temperature to calculate the level of sodium oxide contamination within METL. The Plugging Meter continues to be the primary contamination-monitoring device for METL and was successfully demonstrated on 5/23/2019 as shown in Figure 9.

Figure 9. Successful Contamination Level Measurement

Utilizing RDT Standard F3-40T (2) as a reference, the Plugging Meters pump was held at a fixed speed to flow 0.75 gpm of sodium through the Plugging Meter. Concurrently, the Plugging Meter's blower was activated and began to cool the sodium flowing through the Plugging Meter, which corresponds to the red internal temperature data points. The cooling rate was 15.8 °C/min between 530 and 540 minutes but was reduced to 0.6°C/min between 540 and 590 minutes as the sodium became increasingly subcooled.

The Plugging Meter's temperature was held at the subcooled temperature of 110°C (well below the systems saturation temperature or Cold Trap temperature, blue line) which caused sodium oxides to precipitate out of the bulk solution and deposit on the Plugging Meter's orifice. Although the pump remained at its initial fixed speed, the flow rate decreased at a rate of 0.31 gpm/hr and the differential pressure increased due to the collection of solid sodium oxides on the orifice.

When a considerable drop in flow rate was realized (flow rate neared 0.2 gpm), the Plugging Meter's blower was relaxed to allow the Plugging Meter temperature to increase as seen around 670 minutes. The increase in temperature increased the bulk fluids sodium oxide solubility so solid oxides collected on the orifice plate began to dissolve back into solution, which in turn allowed the flow rate and differential pressure to return to their initial unrestricted values.

Previous literature and testing discovered that if the orifice temperature is recorded at the time of the flow rates inflection point; this temperature corresponds to the saturation point as the oxide transfer is in equilibrium. Therefore, this temperature can be used to calculate the sodium oxide concentration level. This test further reinforced Plugging Meter theory as the Plugging Meters internal or orifice temperature at the point of flow rate inflection was 178°C, which closely agrees to that of the Cold Trapping or saturation temperature of the bulk sodium, which is 175°C. In conclusion, the Plugging Meter successfully measured the oxygen content to be 5.7 wppm.

3.4.1 Flexi-Cask

The most significant challenge with test article insertion/removal from a Test Vessel is ensuring the atmosphere is not introduced into the Test Vessel to contaminate frozen sodium found on vessel walls. This obstacle was overcome for the GTA by utilizing the Flexi-Cask. A series of photos highlighting Flexi-Cask usage for the GTA are shown below in Figure 10.

The top left image shows that the Flexi-Cask has its trap doors removed from its gates and is lowered over the GTA using the overhead crane. The Flexi-Cask's top plate has penetrations to allow lifting shackles to be attached to the GTA itself, which allows the crane hook to be transferred to the GTA while ensuring the Flexi-Cask remains attached to the GTA during lifting/transport.

An argon gas purge was used to lower the oxygen concentration level inside of the Flexi-Cask. Once, the oxygen concentration was low enough, the Flexi-Cask top assembly/GTA was raised until there was enough clearance for the insertion of the lower trap door into the Flexi-Cask bottom assembly's gate. The lifting continued until the upper trap door could be placed inside of the top assembly gate. The clamps holding the top and bottom Assembly of the Flexi-Cask together were removed and the GTA/Flexi-Cask top assembly were transported to the carbonation system where it mated with an identical bottom assembly.

When the GTA/Flexi-Cask top assembly arrived to the Carbonation Systems Reaction Chamber, the upper door in the top assembly's gate was removed and the GTA was lowered into the reaction chamber until the flanges mated. The lifting shackles on the GTA were removed and the overhead crane hook was transferred back to the Flexi-Cask's top assembly lifting lugs. The Flexi-Cask's top assembly was then attached to the GTA mockup (see Figure 25) which was previously secured to a blind flange.

The blind flange/Flexi-Cask top assembly was then moved to Test Vessel 1 where the top assembly was able to connect with the bottom assembly. The blind flange was lowered until it reached the bottom assembly's gate. The gate was removed and the blind flange was lowered to be reunited with Test Vessel 1. The blind flange now sealed Test Vessel 1 from the air atmosphere so the Flexi-Cask could be removed and put away in storage. Lastly, the flange bolts were torqued and the vessel was pressurized with Argon to 10 psig for a preliminary leak test.

Figure 10. Flexi-Cask Collage. Top Left – Flexi-Cask has been placed over GTA on top of vessel. Top Right – GTA extracted from Test Vessel 1 while inside cask. Bottom – Top of Cask and GTA detached from lower gate and base of cask and in route to Carbonation system.

3.4.2 Carbonation System

Alkali metals can be removed from surfaces in numerous ways such as burning, reacting with water/steam or alcohols. The GTA contained gears, bearings and other mechanical components that were operated under load in a molten sodium environment. These gears and components will be inspected for wear and damage after processing in the carbonation system. In addition, the goal is to reuse the as many parts of the GTA equipment as possible. This fact requires that the sodium removal method be gentle as to not damage the surface and lead to defects, which were not attributed to sodium operation.

Therefore, as described in the previous section, the GTA was secured inside the reaction chamber of the Carbonation System (Carbonation system details can be found in previous METL reports (2)). A seven-gallon column of water was heated to 40°C. Dry CO₂ was delivered at the bottom of this column through a sparger. The hot water bath increased the temperature of the CO₂, which increased the solubility of water in the CO₂. In turn, CO₂ at the top of the column was now humid and could be delivered to the reaction chamber where it interacted with sodium adhered to the GTAs surfaces. The primary product of the humid CO₂/sodium reaction was sodium bicarbonate as shown in the image below (Figure 11).

Figure 11. Sodium Bicarbonate (white flaky material) found on GTA

Periodically, when hydrogen production ceased, the GTA would be lifted out of the reaction chamber to inspect the progress of the carbonation process. The bicarbonate layer was brushed off to expose virgin sodium and then the GTA was secured back in the reaction chamber so that the carbonation process could resume. Currently, the GTA is undergoing a batching process of disassembly and reacting away residual sodium. Essentially, the GTA is inserted in the carbonation system for sodium removal for a few weeks, removed from the carbonation system, disassembled to reveal additional sodium and then placed back into the carbonation system.

4 Continuous Improvement

Initial METL commissioning began in FY2017 by bringing the entire loop up to its maximum operating temperature of 538°C. Lessons learned during commissioning and the aforementioned operational campaigns have motivated the METL team pursue some enhancements to METL to support experimental operations. In FY2019, the METL enhancements focused on some additional instrumentation and communications/control.

4.1 Instrumentation

METL was equipped with additional sensors in FY2019 to improve safety, reliability and accuracy. Thermocouples and hot wire anemometers were installed on the Cold Trap and Plugging Meter to measure airside temperatures and velocities respectively. An array of thermocouples were installed into Test Vessel 2 to improve the precision and accuracy of level measurements.

METLs Argon Microbulk system was upgraded with a new control board, which allows the collection of Argon liquid level data so that it may be refilled prior to the vendors' current notification as well as provide a rough value of Argon usage. AC motors found in METL (pumps and blowers) now have current switches to provide "proof" logic to ensure a motor does not remain in a locked rotor state.

The building 308 scrubber can be activated by three methods, which include locally by a switch, remotely using the control program or automatically using beam detectors. Building 308 has a beam smoke detector for the entire high bay that notifies the ANL Fire Department. However, in FY2019 two METL dedicated beam smoke detectors were installed to proactively detect any alkali metal fires, notify METL first responders and automatically operate the scrubber prior to tripping the high bay smoke detector.

4.2 Communications/Controls

Currently, METL's supervisory control and data acquisition (SCADA) system is a monolithic application deployed to a Windows 10 PC. Although functional, there are significant limitations to this installation and the ability to add additional devices is cumbersome. Furthermore, the PC is a linchpin to the entire operation as in the event of a failure or restart; control nor data acquisition of any METL component is possible, this is illustrated with Figure 12.

Figure 12. Current METL Network and SCADA Architecture

In accordance with Figure 12, the METL control room computer (PC) acts as a MODBUS master to (22) Mini 8s, (6) PAC T2750s and a host of (8) cDAQ 9188XTs. In the event of PC failure all cDAQ 9188XTs will cease to operate. The Mini 8s and T2750s will continue to operate and keep METL at its last commanded set point but no data is saved as the METL PC is the link from these components to the Network Storage Device.

Additional limitations include off-site and wireless monitoring. If a technician or engineer is performing work in the field that requires monitoring of the system; they must connect to an Argonne WAP and VPN into Argonne's network and then run a METL Viewer application to see any data. The same applies for the individual if they are not located on Argonne's site. METL remote control is only possible if the METL PC is operating and an operator must use third party software such as Team Viewer. Lastly, if the METL PC fails there is no way to notify team members as the METL PC is the only device capable of sending an email/text or dialing a team member to inform them of a failure.

The METL team has worked closely with the EGS-IT department as well as Argonne's BIS-Networking and BIS-cyber security department to develop a solution, which is illustrated below in Figure 13.

Figure 13. New METL Network

METLs network is to be transferred from being an isolated private network to becoming a private subnet on Argonne’s primary network. This allows authorized users with MFA workstations to be automatically connected to the METL subnet whenever they are connected to Argonne’s network. Authorized non-MFA users can still be on the METL subnet but will have to login to the MFA Bastion Server which EGS-IT will manage. Lastly, read-only devices such as the tablets used for monitoring METL while working in the field will have direct access to the METL subnet through ANLs authenticated WAP and information regarding METLs status can be displayed throughout ANLs campus via Kiosks.

The hardware solution for increased reliability and connectivity involved replacing a central PC with numerous embedded controllers. Three processor based and user-programmable FPGA embedded controllers were procured and are named MIC, SubRIO and SurfRIO. Another Windows embedded controller named LincDAQ was also obtained which provides a link between MIC and the historical cDAQ 9188XTs. A condensed overview of the architecture that will be deployed in FY2020 is illustrated below in Figure 14.

Figure 14 New METL SCADA Architecture (Note: SurfRIO is not shown as it is not expected to be implemented until the end of FY2020.)

MIC, LincDAQ and SubRIO can operate independently of one another and transmit data to each other. They also support local storage devices so as long as the device is operating, data will be saved. Furthermore, for example, if the SubRIO fails, the operator can still control devices connected to MIC and LincDAQ and vice versa. All devices will directly communicate with the METL Network Storage (MNS) Server called MARS and Argonne's email server, which allows the controllers to send emails directly to METL team members, or to Argonne's emergency notification system MIR3. MARS will serve as a bulk storage device but also be a web server, able to transmit data to other servers located throughout campus such as NYX. The addition of a dedicated METL server (MARS) will also allow the development of mobile applications to reduce further the dependence on humans to be on site for METL control/monitoring.

MIC is short for Main Industrial Controller and LincDAQ provides a link to the historical cDAQs and is the host for all (8) 9188XT cDAQs. MIC and LincDAQ are housed in the enclosure below. MIC will be the new Modbus master to the (22) Mini8s, (6) PAC T2750s, (2) PM800 Power Quality Meters, (10) EM4900 electric meters, (1) TCP/RTU gateway, (1) TCP/Serial gateway, (1) TCP/Profibus Gateway, (1) TCP/Profinet Gateway and TCP/I²C gateway. Furthermore it will have direct communication with (2) cDAQ-9185s and (1)

Ethernet/IP PLC. MIC will also run the algorithms for shunt, valve and heat up sequence logic.

Figure 15. MIC Enclosure. MIC (Top Left) and LincDAQ (Top Right). Rack mount equipment (Bottom to Top), UPS, Ethernet Switches, Triple Redundant DC Power Supply and Fiber Optic Uplink.

The SubRIO will operate equipment associated with liquid sodium service or “submersed” operations such as all the electromagnetic pumps and flow meters and blowers as well. The SubRIO will be a Modbus master for the VFDs used on the Cold Trap and Plugging Meter blowers as well as a HART host for smart transducers. The SubRIO is located below METLs mezzanine in the photo below. The SurfRIO will operate equipment that have sodium vapor service or “surface” functions such as argon gas mass flow controllers and the Dump Tank Vapor Traps blower. In addition, the SurfRIO will eventually take the role of a Modbus TCP master/Profibus Slave gateway from MIC and also be a HART host.

Figure 16. SubRIO (Top) Enclosure.

4.3 Additional Operational Support Items

METLs control room revitalization continued in FY2019 with the removal of a window air conditioner and installation of a mini-split ductless heat pump. Storage areas were identified for the removal of tools/hardware from the control room and all control room electrical circuits are now tied to Building 308's backup diesel generator.

Argonne National Laboratory has continued to show its support for alkali metal research by investing in the necessary infrastructure to protect people, equipment and the environment during unexpected alkali metal breaches as well as hardware to pacify safely materials contaminated with alkali metals.

Specifically, in FY2019, Argonne management provided the METL team with funds to procure parts for use on the Building 308 Alkali Metal Scrubber and Superheated Steam System. These funds allowed for the acquisition of a PLC and associated hardware/software to replace the Scrubbers current electro-mechanical relay control system with a new direct digital control system. Other funds were used to procure piping and instrumentation to build a

new superheated steam system for treating residual alkali metals. Lastly, reinforcing their support for alkali metal programs, Argonne management awarded funds to purchase a new glovebox (Figure 17) which will allow the METL team to experiment with other alkali metals such as sodium-potassium alloys (NaK).

Figure 17. New 4-port Argon Glovebox with NI-Train and Chiller.

5 METL Experimental Support Infrastructure

5.1 Experimental Support Infrastructure

In anticipation of operating test apparatus in METL, some infrastructure required to operate experiments has been installed such as a dedicated argon gas and electrical supplies designated solely for the METL test articles.

5.1.1 *Electrical*

Due to METL providing the resource intensive liquid sodium environment, the majority of experiments are not expected to have large power requirements. The fused disconnects in Figure 18, supply 100A of 2 Φ 240VAC power. This is expected to be the most frequently used resource (other than liquid sodium) by experimenters, as this is sufficient power to energize a data acquisition system, valves, small motors and other instruments. Also, the disconnects can have lower current rated fuses installed, decreasing the capital cost and engineering design required for smaller experiments.

Figure 18 - Fused Disconnects for 2 Φ 240VAC Power Supply to Experiments

The first experiment for METL was the Gear Test Assembly (GTA) which aims to evaluate the performance of Inconel spur gears immersed in an 18-inch test vessel full of sodium (full details regarding GTA can be found in an ANL report “Gear Test Assembly – Status Report for FY2019” (3). This device requires these gears to be driven by two 480VAC 3 Φ motors. Accommodations for the GTA have been completed and are shown below in Figure 19.

Figure 19 - 3 Φ 480VAC Power Supply for Experiments.

The equipment above consists of a 200A disconnect that feeds a 3 Φ 480VAC circuit breaker panel which energizes two delta-wye transformers and a 100A fused disconnect. The delta-wye transformers supply energy to the GTA motors and act as an isolation device. The fused disconnect is available for future experiments and like the 240VAC power, the 480VAC fuses can be replaced with lower current rated ones for smaller experiments.

5.1.2 Flexi-Cask System

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

As shown below in Figure 20, the flexi-cask system is lowered onto the vessels. The volume within the flexi-cask is kept inerted using a constant argon purge. The flexi-cask system will operate using the pre-existing crane in the Bldg. 308 high bay, as shown in Figure 21.

Figure 20 – A 3D model depicting of flexi-cask operation.

Figure 21 – A 3D model showing how the flexi-cask system will operate above the METL facility.

The flexi-cask required some minor modifications once received from the outside vendor. These alterations were performed by ANL-CS and the flexi-cask assembly has been completed. Initial tests to measure the flexi-casks ability to retain argon gas during different scenarios were conducted prior to use on experiments.

Figure 22 - Flexi-Cask Demonstration in Qualifying Station

The flexi-cask rest plate diameter of the test vessels was reduced to alleviate excessive stress that would occur when heated. However, the smaller diameter rest plate could no longer support the flexi-cask. Therefore, extensions to the rest plate were designed and fabricated to be installed while the vessel is cold so the flexi-cask could be used and then removed once the vessel is ready to be heated. A rest plate extension installed versus the permanent rest plate is illustrated below in Figure 23.

Figure 23 - Vessel Rest Plate Extension

Equipping the flexi-cask with the yellow collapsible duct in Figure 22 introduced challenges when attempting to utilize the flexi-cask so in FY2019 this duct was replaced with an oversized glove bag (Figure 24). The glove bag was custom built by Lancs Industries and was specified with four ports (yellow flaps in Figure 24). These ports allowed the installation of gloves to allow operators to manipulate devices inside of the glove bag. The transition to the glove bag immediately proved successful as the bag was able to hold pressure and operators were able to detach the upper assembly from the lower (Figure 25).

Figure 24. Flexi Cask with Glove Bag Compressed (left) and Extended (right)

Figure 25. Pressurized Flexi-Cask (left), GTA Mock inside entire Flexi-Cask Assembly (Center), GTA Mock inside upper assembly detached from the lower and ready for transport.

Feedback from utilizing the flexi-cask for GTA extraction and blind flange installation has been input to the design of the 28" flexi-cask. The 28" flexi-cask will be used in an identical fashion but its size has been increased for the removal and installation of test articles designed for the 28" Test Vessels (Vessels 3 & 4). The design is finished, parts have been ordered and the flexi-cask for the 28" Test Vessels is expected to be ready for operation in FY2020.

5.1.3 Carbonation System

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

The P&ID of the carbonation system that has been built at Argonne can be found in Figure 26. The carbonation system consists of a CO₂ bubbler and reaction chamber. First, a column of water is heated just below its boiling point ($\approx 90^{\circ}\text{C}$). Then dry carbon dioxide is pushed through the bottom of the water column to create humid carbon dioxide at the top of the column. Humid carbon dioxide travels through a transfer line in order to carry trace amounts of moisture into the reaction chamber containing the used test articles. The moisture and CO₂ react with the sodium residue in one of the two following processes:

Figure 26 – A P&ID for the carbonation system. (*M* = manual valve, *S* = solenoid valve).

Figure 27 – A photo of the completed bubbler for the carbonation system. Carbon dioxide enters through the bottom of the system. Electric heaters are used to raise the temperature of the water to facilitate increasing the humidity of the water.

Reaction chamber supports along with the chamber itself were installed in FY2018. The carbon dioxide bubbler was installed on the NSTF mezzanine in B308 and a transfer line was installed connecting the bubbler to the reaction chamber. Lastly, the control system was revitalized to support autonomous operation.

Figure 28 - Reaction Chamber (left) Connected to Bubbler (right)

6 METL Phase II Configuration

METL is expected to house additional experiments in the near future. Specifically, a new experiment, the Thermal Hydraulic Experimental Test Article (THETA) is expected to be inserted into METL during FY2020. THETA mimics a pool-type sodium fast reactor. THETA's 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 FY2019" (4).

6.1 Test Vessels, Supports, Vapor Traps and Filters

An additional 18" Test Vessel (V6) identical to the installed 18" Test Vessels was procured in FY2019 and is on-site. Its initial purpose is to support THETA as a heat sink by providing a means to integrate an Air-to-Sodium Heat Exchanger for THETA or METL use. However, like its' brethren it can house nearly any experiment that fits inside of it. V6 will use "Dixie" cup supports all around. ANL-CS fabricated V6s Vapor Trap and Filter in FY2019 as well. All of the equipment discussed in this section are on-site and awaiting installation.

6.2 Piping Design, Fabrication and Installation

The initial piping design for METL encompassed eight test vessels so there was no additional piping design work required for installation of Test Vessel 6. The piping and fittings for the

aforementioned were also placed on order previously so ANL-CS was able to rapidly weld the piping subassemblies for Test Vessel 6 (V6) and send them out for NDE. All of the V6 piping subassemblies have been welded, inspected via x-ray, and are on-site ready for installation.

6.3 Air to Sodium Heat Exchanger

In lieu of Test Vessel 5, an Air-to-Sodium Heat Exchanger (ASH-X) was specified and is currently being fabricated by an outside vendor. The ASH-X will be used to expand THETA to include a secondary loop so that a pool type SFR/intermediate heat transfer loop simulations could be conducted. In addition to enhancing THETA's capabilities its piping configuration ties into METL as well so that METL's bulk sodium could be actively cooled; a capability it currently does not have as temperature decreases rely on natural heat transfer/losses. A drawing of the ASH-X is below in Figure 29.

Figure 29. Air-to-Sodium Heat Exchanger.

7 Summary

The preceding report provided a summary for the status of the METL facility as of August 2019. A tremendous amount of effort has gone into demonstrating METLs various modes of operation. In addition, METL was equipped with additional instrumentation and operational features in FY2019. The METL crew continues to work on expanding METL into Phase II, to grow Argonne’s alkali metal capabilities, to develop/qualify potential Sodium Fast Reactor technologies, and to work 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 is fully ready to demonstrate Sodium Fast Reactor and other alkali metal technologies as well as further the understanding of associated phenomena.

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