ANL-ART-264
ANL-METL-46

Deploying Extended Reality (XR) for Digital Operations and Maintenance (O&M) at the Mechanisms Engineering Test Loop (METL)

Nuclear Science and Engineering Division

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1 EXECUTIVE SUMMARY

This report documents the preliminary efforts to digitize operation and maintenance (O&M) activities for the Mechanisms Engineering Test Loop (METL). METL became operational in September 2018 with the mission to provide an ecosystem for Advanced Reactor Development (ARD). METLs flagship facility's primary purpose is conducting small to intermediate scale tests for Sodium Fast Reactors (SFR) [1]. Its' resemblance to commercial SFR's intermediate heat transport system, prototypic operating conditions, and industrial construction practices/materials provides the overarching benefit of establishing a proving ground for emerging operations and maintenance (O&M) activities such as incorporating Extended Reality (XR) applications throughout the program lifecycle.

1.1 Purpose & Background

Construction, maintenance, and operations of Nuclear Power Plants (NPPs) are expected to be constrained by skilled labor [2]. Commercializing the fourth generation (GEN-IV) of NPPs may amplify the challenge of acquiring and retaining qualified employees as it will be a new frontier for design/build firms and operators. In a sensitive industry such as Nuclear Energy, exceptional training and performance is imperative, thus a nuclear workforce could be the linchpin for the continued success of the current NPP fleet and realization of GEN-IV NPP deployment goals. This challenge motivated the METL team to acquire commercially available XR hardware and software, create XR content, integrate XR with its' existing arsenal of digital capabilities and demonstrate and deploy the applications for testing at METL with the expectations of ultimately deploying the technology at a commercial reactor.

1.2 Acknowledgement

This research was sponsored by the U.S. Department of Energy, Office of Nuclear Energy, for the Advanced Reactor Technologies (ART) Research and Development Program under Contract DE-AC02-06CH11357. We gratefully acknowledge the support provided by Alice Caponiti of DOE-NE, Deputy Assistant Secretary. Office of Reactor Fleet and Advanced Reactor Deployment; Janelle Eddins, Advanced Reactor Development Team Lead; Kaatrin Abbott of DOE-NE, Advanced Reactor Technologies, Fast Reactor Manager; Ashley Finan, National Reactor Innovation Center Former National Technical Director, Brad Tomer, Acting National Reactor Innovation Center National Technical Director, and Bo Feng of Argonne National Laboratory, ART R&D Fast Reactor National Technical Director.

The authors are grateful for the support from Christian Kourkoumelis, Jay Johnson and Argonne Business and Information Systems (ANL-BIS) as they were vital in establishing and maintaining a strong and secure network infrastructure to enable the integration of these advanced technologies. The authors would also like to acknowledge TrueScan3D for their on-site work of reality capture and imaging as well as architectural model creation.

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2 Extended Reality (XR) Background

In this report, Extended Reality (XR) is considered as a spectrum of environments that includes (in increasingly virtual order): assisted Reality (aR), Augmented Reality (AR), Mixed Reality (MR), Augmented Virtuality (AV) and Virtual Reality (VR). Hardware to host these technologies consists of common consumer mobile products (smart phones and tablets), smart glasses/head mounted tablets, and various headsets. The hardware dictates the XR environment implemented which is summarized in the table below. Laptops and desktops can host any of the environments and some VR headsets require being tethered to a host desktop, so the table omits these 'console devices'. Furthermore, all the devices listed in Table 1 could run an aR program but by the definition of aR, it must be hands-free thus consumer mobile is unmarked.

Table 1. XR Hardware/Software Compatibility

Device / Environment	Consumer Mobile	Head Mounted Tablet	Headset
assisted Reality (aR)		X	X
Augmented Reality (AR)	X		X
Mixed Reality (MR)			X
Augmented Virtuality (AV)			X
Virtual Reality (VR)			X

Optimal XR subset/hardware selection criteria should be heavily weighted by the application, work environment, and end-user. Evident from Figure 1 and Figure 2, some devices are more suited than others for "hands-on" work. Program administrators may need to forego rich experiences in exchange for robust hardware that can withstand the workers' dirty, cold, hot, humid, remote, or hazardous environment. The objective of this research was to investigate potential XR use cases at METL which could not only translate to NPP cost reduction but also be cross-cutting to other industries.

Figure 1. Headset for AR/MR (left) and AV/VR (right).

For this report we are defining the following terms consistently throughout the document. Assisted reality allows simultaneous use of both hands, screen viewing and application navigation. Assisted reality generally uses smart glasses or an arm mounted screen to place under the users' eye. Augmented reality 'projects' an object into a real environment and viewing perspectives or animations can be changed via screen buttons or by physically moving to a different location. Mobile devices are commonly used for augmented reality, but a headset may also be used. Mixed reality builds upon augmented reality but allows the projected/digital object to be manipulated by physically interacting with digital buttons. Presently, specialized headsets are needed to track hand/eye motion while providing a clear view of reality to support mixed reality. Augmented virtuality involves donning a headset which covers the users' eyes to immerse them in a virtual environment. A camera on the headset in conjunction with hand tracking and connected/compatible hardware then enables the user to manipulate the real component which can be used as an input to the virtual environment. Note, this report does not consider the hand-held joysticks packaged with headsets as 'real components' as these are integral with the headset. Virtual reality is essentially identical to augmented virtuality minus interacting with real components.

3 assisted Reality (aR)

Deploying aR requires the use of specialized hardware that enables hands-free operation. The device used for METL demonstrations does not alter the view or perception of the physical environment but rather provides a screen visible in the user's field of vision. This is achieved by having a miniaturized tablet screen mounted to a boom and the computer hardware organized in a wearable band/arm form factor. The device is secured to the user via band, baseball cap/bump cap or hard hat (shown in Figure 2). The cursor or mouse is controlled by the operator tilting their head and information is input by audibly using the phonetic alphabet/numbers, stating "mouse click" to select characters (useful for password entry) or using voice dictation.

Figure 2. aR Device Mounted to Hardhat

3.1 Procedure aR Use Case

The predominant method to distribute procedures is to provide a document developed with word processor software so that it may be printed or viewed on a computer/tablet. Various industries require the flexibility of word-processed procedures as they can be followed via computer/tablet or printed on paper. Many front-line workers opt for the latter as it is easy to carry along while working 'on the floor' or 'in the field' and do not have to worry about the electronic devices being lost, stolen or broken.

The hardhat mounted aR hardware form factor may be able to shift the frontline worker culture towards digital procedures, unlocking many benefits discovered by the METL team. A METL aR use case involved digitizing the word processor based METL "Fill Procedure". METL test vessels are filled by applying a slightly higher positive pressure to the METL Dump Tank and opening a valve connected to a dip tube. The differential pressure transfers sodium from the Dump Tank, through the dip tube to the primary piping loop and ultimately to test vessels. Performing this maneuver using contemporary practices required two-three operators. One operator would manage the supervisory control and data acquisition (SCADA) program in the control room while the other moved around the plant to manipulate manual valves. Utilizing the aR device, the procedure was implemented electronically in the field which provided numerous benefits as identified below:

- Computerized Maintenance Management System (CMMS) connectivity and increased documentation.
- A single operator would be able to perform the procedure efficiently.
- Live data streams accelerate and reduce errors in verification steps.
- Media content could be leveraged to increase procedure clarity.

3.1.1 *CMMS Integration*

A digital procedure enables connectivity with a CMMS, streamlining work order creation/close out and seamlessly adding data/charges to work orders. In the METL "Fill Procedure" example, a work order is automatically generated once an operator fills out basic information such as their name and a brief description of the work (Figure 3, top) and submits the information. This

process could also be conducted in reverse (i.e., a work order is generated by the CMMS admin/Operations Manager and the operator enters a valid work order to continue with the procedure). Upon completing the procedure, an operator can audibly add any other relevant information and close out the work order (Figure 3, bottom).

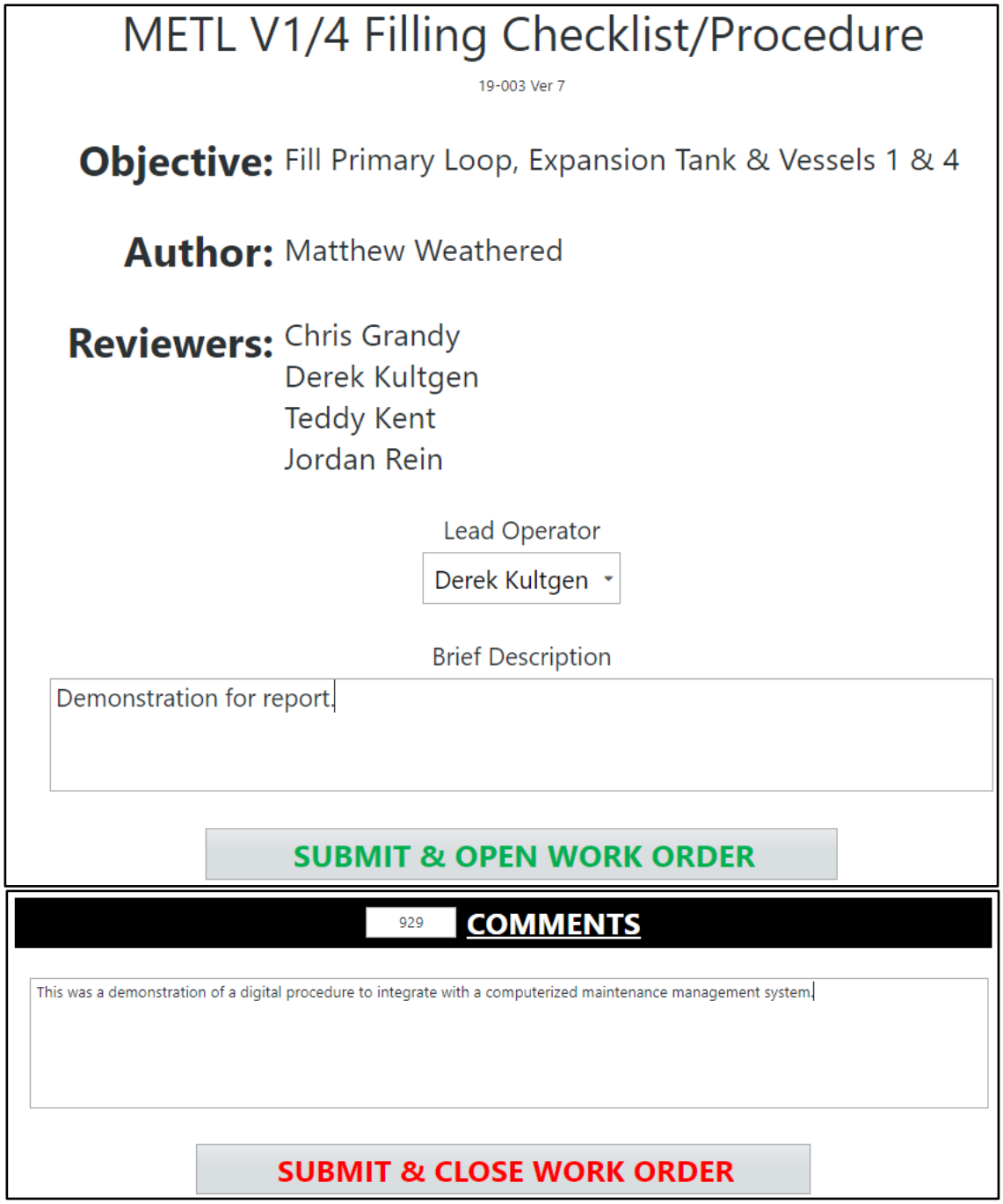
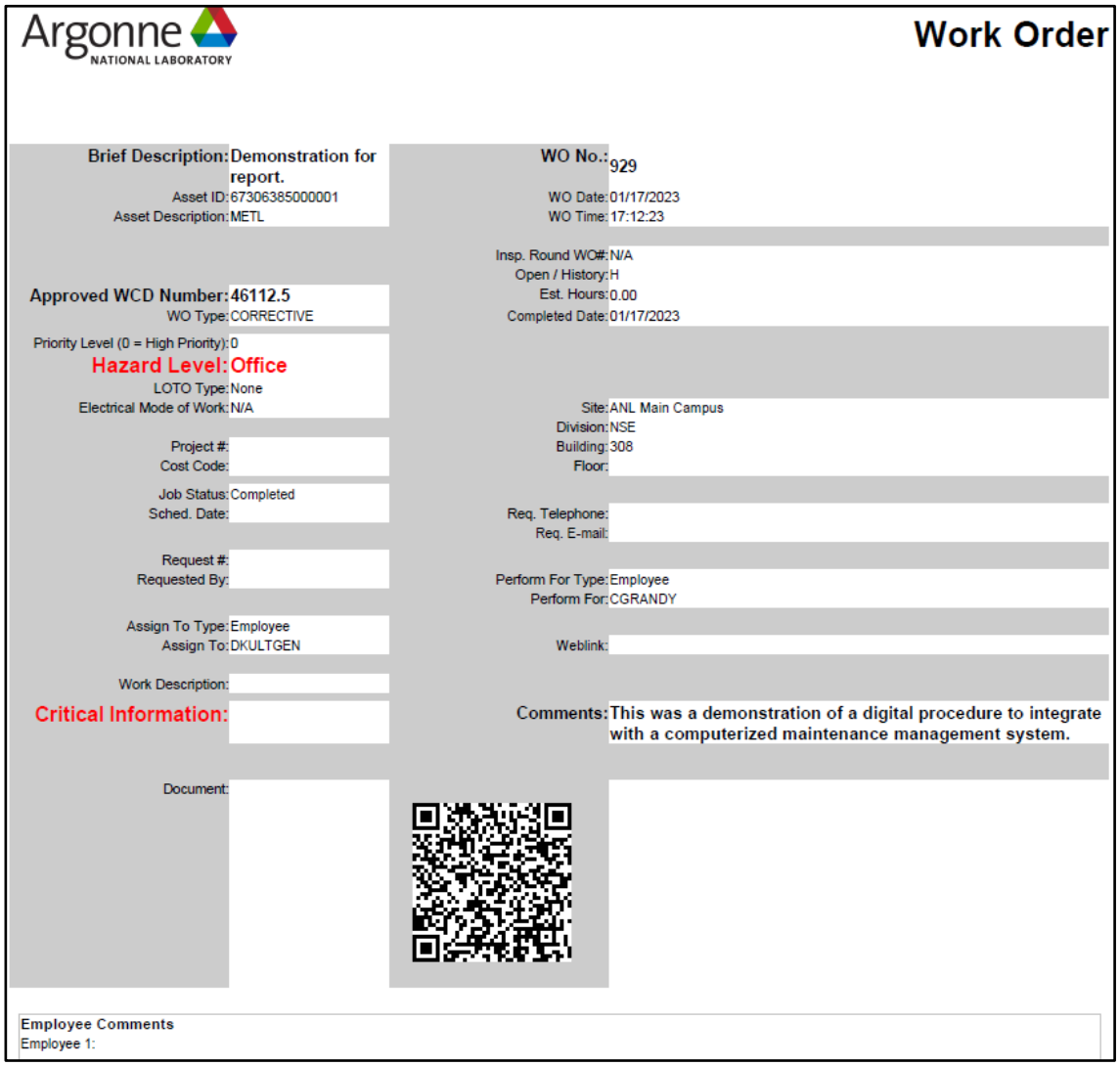


Figure 3. Digital Procedure Example - Front Page (top) and Close Out page (bottom).

Connectivity between the operator, procedure, and a CMMS have greater implications than simple work order opening and closing. Illustrated in Figure 4, data entered via head mounted tablet microphone in the digital procedure is automatically captured by the work order in the

CMMS. Enabling workers with 'on-the-fly' data entry (i.e., populate CMMS data while they are performing tasks as opposed to entering it from memory post-task completion at a console or importing from hand-written notes on a paper copy of the work order) is expected to increase data entry frequency and accuracy. The expected outcome is operational knowledge retention, refined instructions, increased efficiency, and pitfall avoidance. In addition, bridging the gap between CMMS software and frontline worker hardware is essential to creating a functional and well-received digital thread and workflow for technician-based roles.



Argonne NATIONAL LABORATORY

Work Order

Brief Description:	**Demonstration for report.**	**WO No.:**	929
Asset ID:	67306385000001	WO Date:	01/17/2023
Asset Description:	METL	WO Time:	17:12:23
		Insp. Round WO#:	N/A
		Open / History:	H
Approved WCD Number:	**46112.5**	Est. Hours:	0.00
WO Type:	CORRECTIVE	Completed Date:	01/17/2023
Priority Level (0 = High Priority):	0		
Hazard Level:	**Office**		
LOTO Type:	None		
Electrical Mode of Work:	N/A	Site:	ANL Main Campus
		Division:	NSE
Project #:		Building:	308
Cost Code:		Floor:	
Job Status:	Completed		
Sched. Date:		Req. Telephone:	
		Req. E-mail:	
Request #:			
Requested By:		Perform For Type:	Employee
		Perform For:	CGRANDY
Assign To Type:	Employee		
Assign To:	DKULTGEN	Weblink:	
Work Description:			
Critical Information:		**Comments:**	**This was a demonstration of a digital procedure to integrate with a computerized maintenance management system.**
Document:			

Employee Comments
Employee 1:

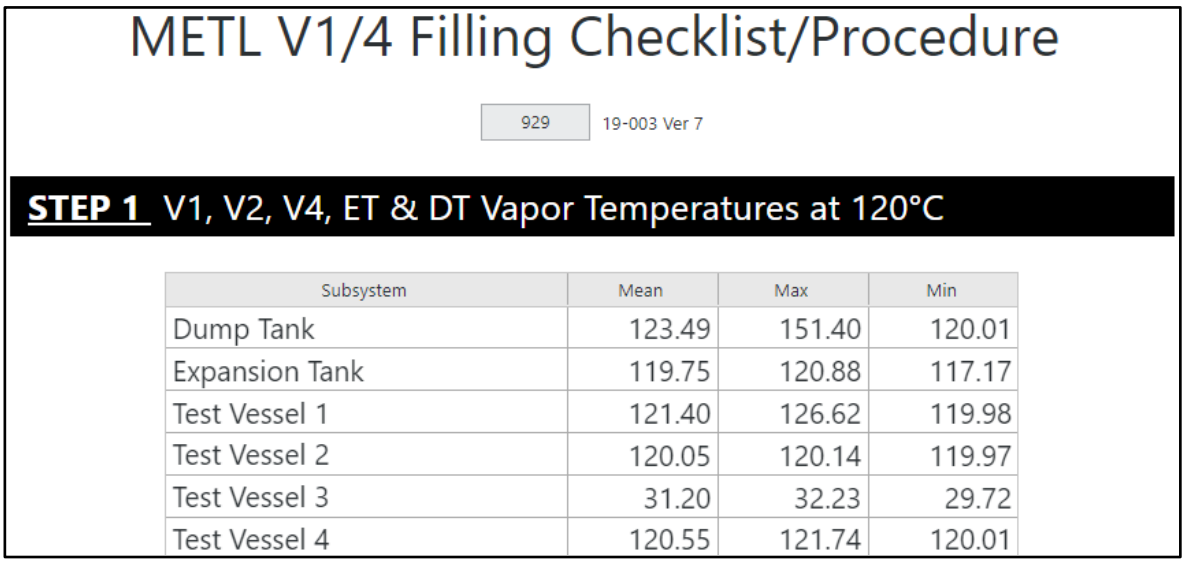
Figure 4. METL Work Order Example.

3.1.2 *Sole Operator Efficiency and Live Data*

Tasking a single operator with filling METL using contemporary practices would require a worker to walk around the facility while looking for a safe place to set their tablet/laptop or paper procedure to mark off checkboxes. They would also have to go in/out of the control room to navigate through the control program to view data to ensure the facility is in the appropriate state for conducting the procedure. An aR device mounted to a hardhat enables the operator to follow the electronic procedure hands-free. Integration with their personal protective equipment

alleviates concerns with losing or damaging the computing hardware and tethers the procedure to the worker so it is not left behind while traversing the facility.

Below in Figure 5, is a screenshot of a step within the METL "Fill Procedure" which highlights the capability of being able to stream live data to a worker as they go through the procedure. If viewing this step from an aR device, pertinent sensor data shown in the table of Figure 5 would update at roughly 1Hz. This provides the worker with sensor data that is relevant to the specific procedure sequence, so they do not have to navigate through a complex SCADA graphical user interface filled with extraneous information. Furthermore, if performing a step result in fluctuating or transient conditions (e.g., opening a valve which changes the pressure), they are able to monitor the instrumentation values real-time while making adjustments.



Subsystem	Mean	Max	Min
Dump Tank	123.49	151.40	120.01
Expansion Tank	119.75	120.88	117.17
Test Vessel 1	121.40	126.62	119.98
Test Vessel 2	120.05	120.14	119.97
Test Vessel 3	31.20	32.23	29.72
Test Vessel 4	120.55	121.74	120.01

Figure 5. Digital Procedure Example – Live Data.

3.1.3 *Accelerating Verification Steps*

Briefly described in the subsequent section, METLs I&C is extensive, and the SCADA program was developed to ensure an operator can access every piece of data and manipulate any automated component. This can be problematic when conducting a specific procedure as an operator has to sift through tree elements to find specific operating conditions and verify, they are within the procedure's specification. METLs digital procedure streams the data needed at each verification step but also allows the operator to enter manual information. Figure 5 is an example which displays the live position data of electro-pneumatically actuated valves but also enables the user to audibly select which manual valves are open or closed.

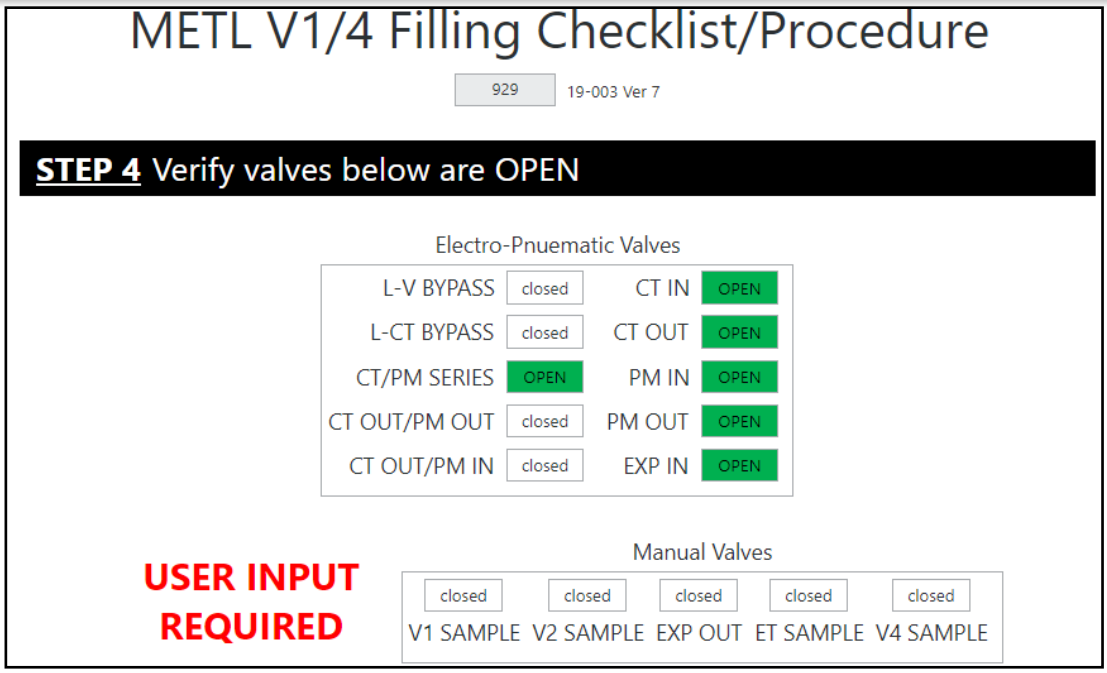


Figure 6. Digital Procedure Example – User Entry

Adopting aR and having a fully digital procedure facilitates programming logic into the procedure which can improve quality assurance. Although not implemented in this use case, a digital procedure could be scripted to provide some additional functionality:

- Prevent an operator from advancing to subsequent steps if the live stream data is outside the procedure's specifications.
- Require a time-stamped 'electronic signature/sign-off' for assigning accountability.
- Sign-on to work order/procedure thus notifying other workers the task is in progress, preventing duplication and/or conflicting operations.
- Tracking completion time to identify inefficiencies in the process or procedure.

3.2 Inspection aR Use Case

The Industrial Internet of Things (IIoT) continues to be adopted and proliferated through many complexes as historically 'dumb' devices are becoming increasingly more connected with the ability to transmit numerous data points. Often, this data is obtained through a device's own portal or through a SCADA. Many of METLs sensors and devices have their own portal which can be accessed through a web browser, but in an overwhelming majority of circumstances, METL team members observe live sensor readings via a LabVIEW executable program which serves as a Human Machine Interface (HMI). The HMI displays individual and compiled sensor data as well as read/write controls based on the user-selected tree item (Figure 7, left side). METL frontline workers have access to the HMI executable as it can operate on any Windows device which has a firewall conduit and METL can only be controlled if the user enters the proper credentials (reserved for trained operators).

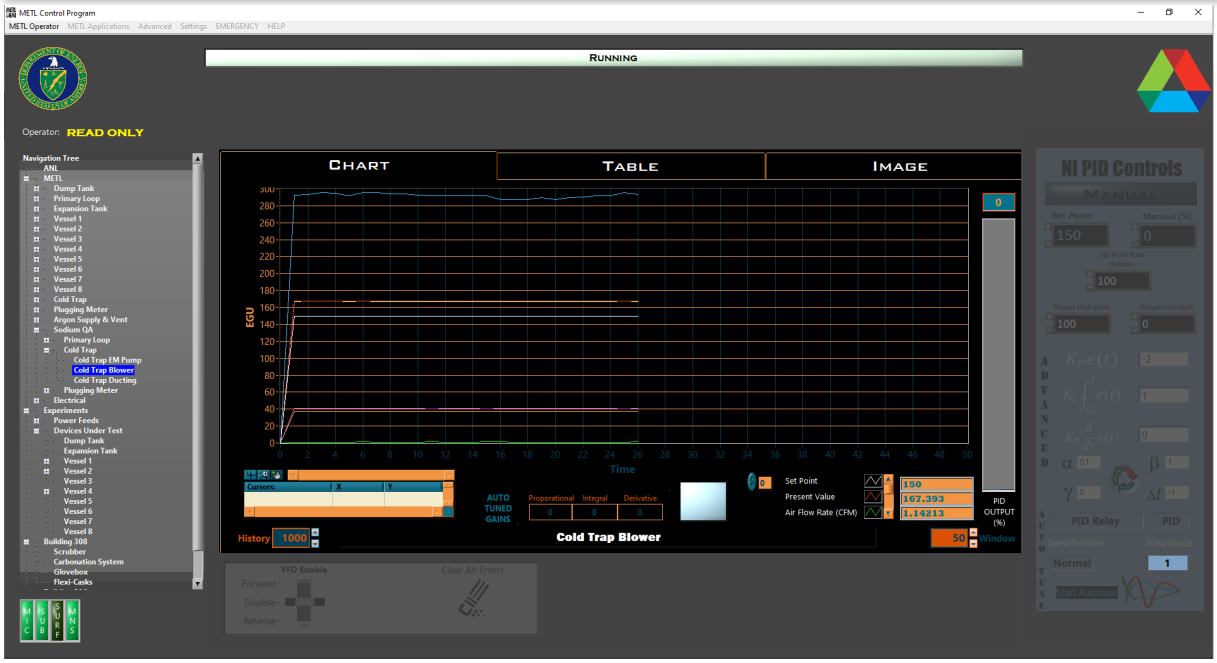


Figure 7. METL HMI Executable.

The HMI is invaluable to an operator, but the larger views are difficult to read on smaller screens/devices and laptops/tablets become cumbersome when a frontline worker needs to use their hands. Furthermore, the expansive list of tree elements can be confusing or difficult for a frontline worker to find the asset of interest and in many cases rely on an operator to relay information to them in the field via phone. Using the camera on a head mounted tablet, a technician can now scan a QR code attached to an asset (Figure 8).

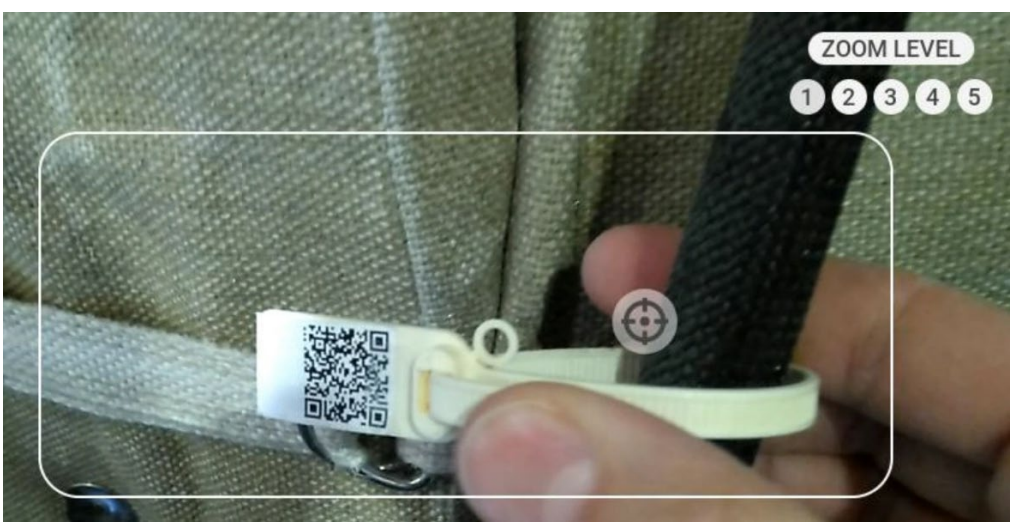


Figure 8. aR Screenshot of Asset QR Code.

Upon successfully reading a QR code the size of a thumbnail, the device automatically goes to a live data page (Figure 9, left). A technician now has access to asset specific data which they can view in their peripherals and use to troubleshoot. This specific example illustrates a heater zone asset page which displays the heater's asset number, current draw in amperes, PID

output/call for heat in percent and a trend of its temperature (red line) compared to its setpoint (black line). The worker can quickly troubleshoot as they can verify the sensor is reading appropriately or the operator has the heater to an acceptable set point, that the controller is calling for the heater to be energized and that the heater is drawing current (no amp clamp required).

Audibly selecting the 'META Data' link provides the technician with asset meta data as shown in Figure 9, right. The worker can view the manufacturer and serial number of the heater or effectively any field that is populated in the CMMS or Enterprise Asset Management/Resource Planning system. Work order history, spare parts inventory, location of spare parts, manufacturer, etc. data can all be provided directly to the person physically performing the work.

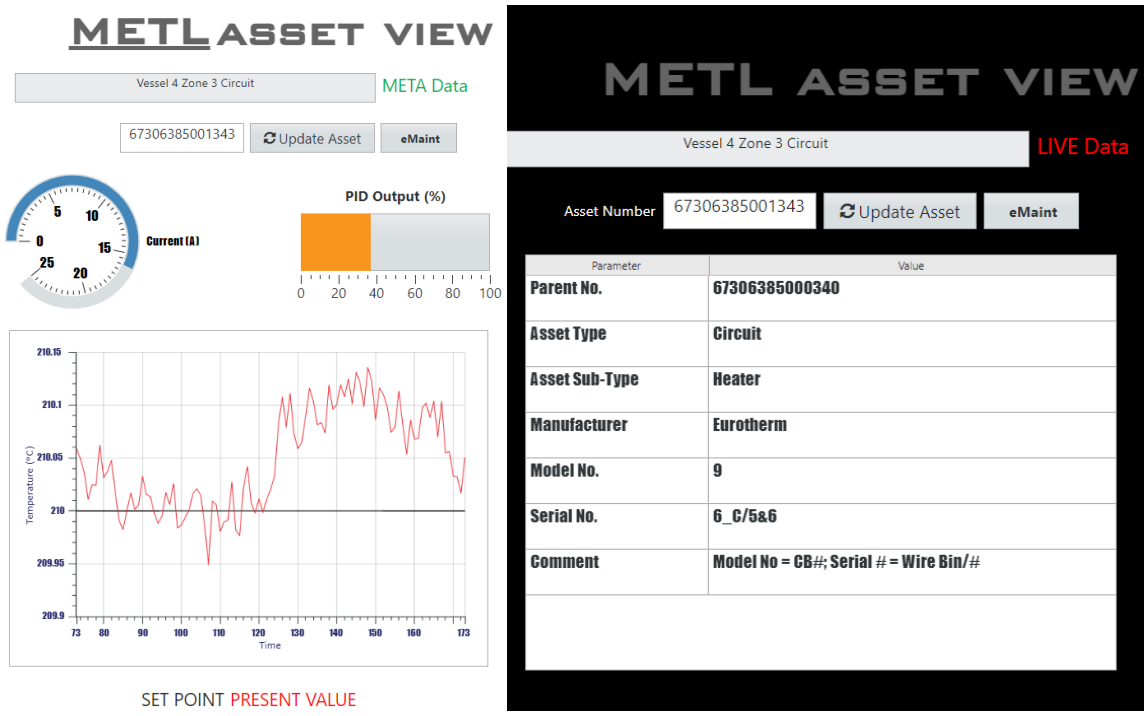


Figure 9. Asset View – Live Data (left) and Meta Data (right).

4 Augmented Reality (AR)

A common industrial Augmented Reality (AR) use case is to overlay an asset's 3D CAD model in a real environment. Extracting CAD models from a console for real-world display can enhance communication, collaboration, and understanding as intensions are much clearer when components or systems are visualized at their installation location or viewed assembled at full-scale with the capability to 'walk-around' the component.

4.1 Design Stage Example

Successfully executing complex engineering projects require the acquistion and adoption of custom system and components that demand involvement from cross-departmental stakeholders. Synchronization among these parties is critical during the design phase to ensure manufacturability, funtionality and longevity are maintained. AR is able to establish a line of communication between designers, fabricators and end-users by using a consumer mobile device's camera to hover over an engineering drawing which acts as an image-target to activate an augmented 3D representation of the design as shown below in Figure 10.

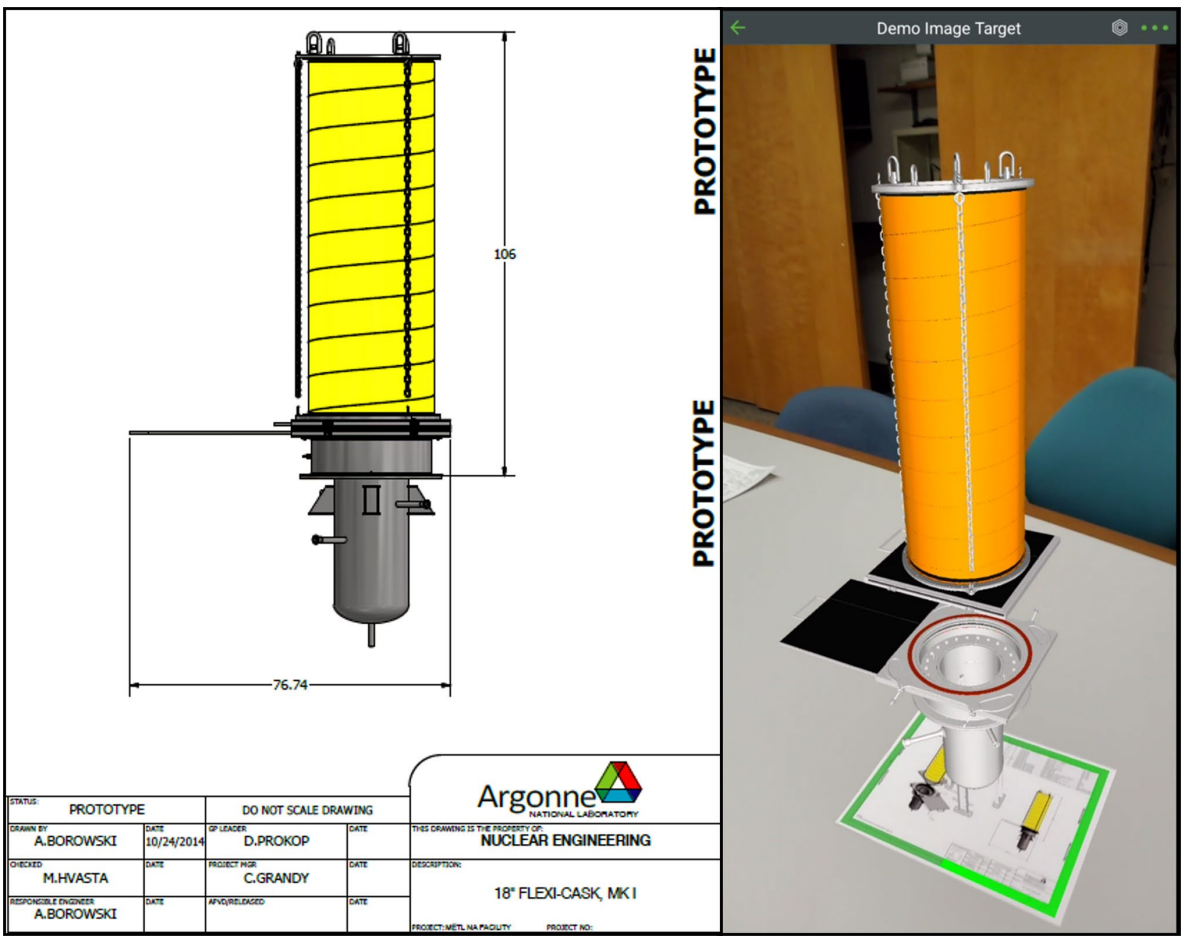


Figure 10. METL Flexi-Cask Prototype Drawing (left) and Image Target-Based AR (right).

The example above shows a flexible cask that provides an inert argon gas blanket by collapsing/expanding to insert/extract experimental articles from METLs test vessels. Two 'trapdoors' (black squares in image above) must be manually and quickly inserted/removed to

allow the cask to enclose the experiment as well as seal off the test vessel. The flexi-cask is manipulated via an overhead crane and various parts must be attached or removed to secure the cask to different rigging equipment and flanges. AR is a valuable tool to communicate all of this in a design review meeting as it can animate the sequence of operations as well as augment a full or reduced-scale CAD model.

4.2 New Fabrication Demonstration

The ability of METL's flagship facility to house hundreds of gallons of molten sodium and distribute this inventory to multiple test vessels for 30 years of operation at prototypic SFR temperatures is derived from its high pedigree design and robust construction. METL vessels and piping were designed to ASME BP&V and B31.3 (category M fluid), respectively. Meeting these criteria involved welding hundreds of piping subassemblies and then field-welding them together to interconnect all of METLs test vessels. Fabricators are instructed to perform these tasks via piping subassembly isometrics (Figure 11, left) and vessel engineering drawings (Figure 11, right). Deciphering hundreds of these quickly leads to confusion, requiring welders and fabricators to seek consultation from engineers who must supplement their knowledge by reviewing and interpreting the CAD models and drawings on a laptop or desktop.

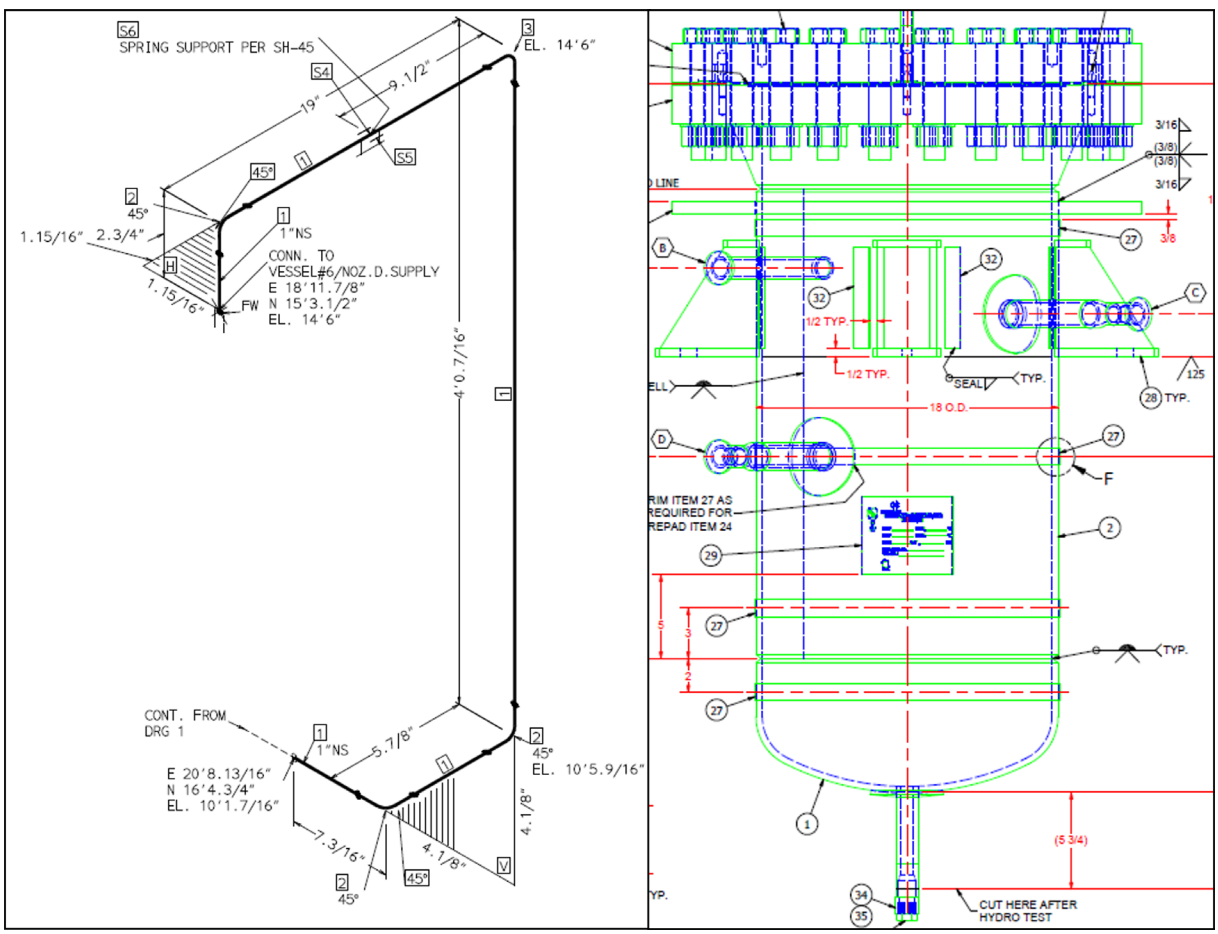


Figure 11. METL Piping (left) and Test Vessel (right) Drawing.

Experiencing these real-world inefficiencies inspired the following METL AR use case for new fabrication and assembly activities. Using a consumer mobile product, a welder can scan a QR

code on their work order which provides a model target of the vessel (Figure 12, left, white outline). The commercially available software recognizes the outline and augments the vessel with all of its piping connections (Figure 12, right); including labels that reference the standard piping ISO drawings. Overlaying the CAD assembly over the physical test vessel alleviates concerns a fabricator may have such as orientation, connection points, subassemblies, etc. It can also improve installation and fabrication quality as everything is defined and the worker does not feel obligated to use their judgement and engineering is able to focus on their present tasks.

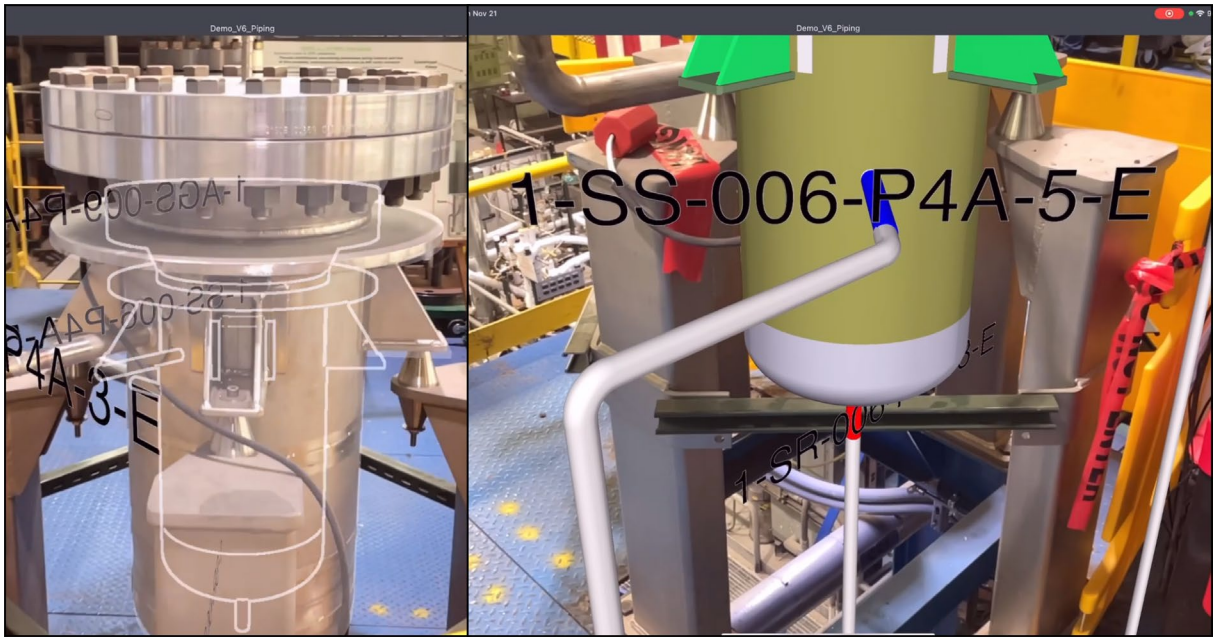


Figure 12. AR Vessel Outline (left) and Assembly (right).

4.3 Retrofit Construction

Advances in reality capture have led to additional and more detailed CAD content. However, there can be a lack of continuity between an enterprise's divisions and groups which can lead to some groups having very detailed CAD models with product lifecycle management while others have just crude sketches. The demand for in-situ sodium testing has required METL to expand from its' original footprint and capacity. A mezzanine extension will be installed over an existing sodium experiment, the Under Sodium Viewing (USV) experiment to increase METL's square footage to support the assembly and cleaning of test articles. While METL's CAD is extensive, it does not include USV as USV CAD is minimal.

Light Detection and Ranging (LiDAR) in conjunction with 3D cameras were used to perform reality capture of building 308's high-bay (includes METL flagship facility) for creating as-built documentation and providing 3D tours. LiDAR scans are 'registered' together to create a point cloud. The point cloud provides a 3D representation of the scanned volume and can be used to obtain accurate dimensions for recreating as-built models using off-the-shelf CAD software.

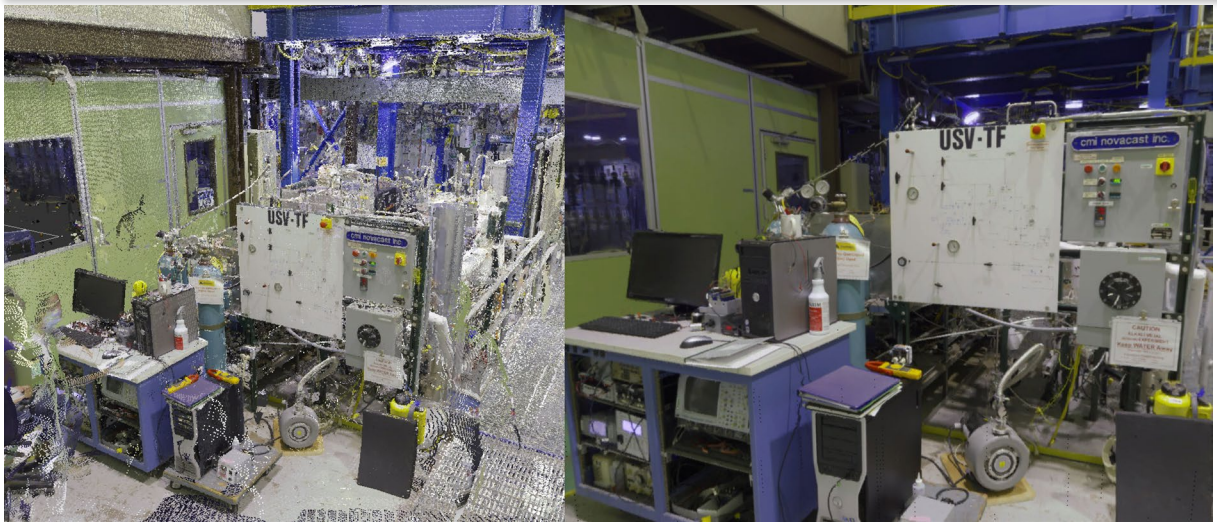


Figure 13. Point Cloud, Point View (left) and Scan View (right)

The aforementioned process requires specialized hardware and programs to acquire LiDAR scans and generate a point cloud but there is also utility with less sophisticated LiDAR. A tablet equipped with LiDAR in conjunction with commercially available software was used to scan the area occupied by USV. This 'area scan' (Figure 14) is less granular than a point cloud scan but can be conducted in a matter of minutes and is used for devices to automatically recognize a location populated with extended reality content.

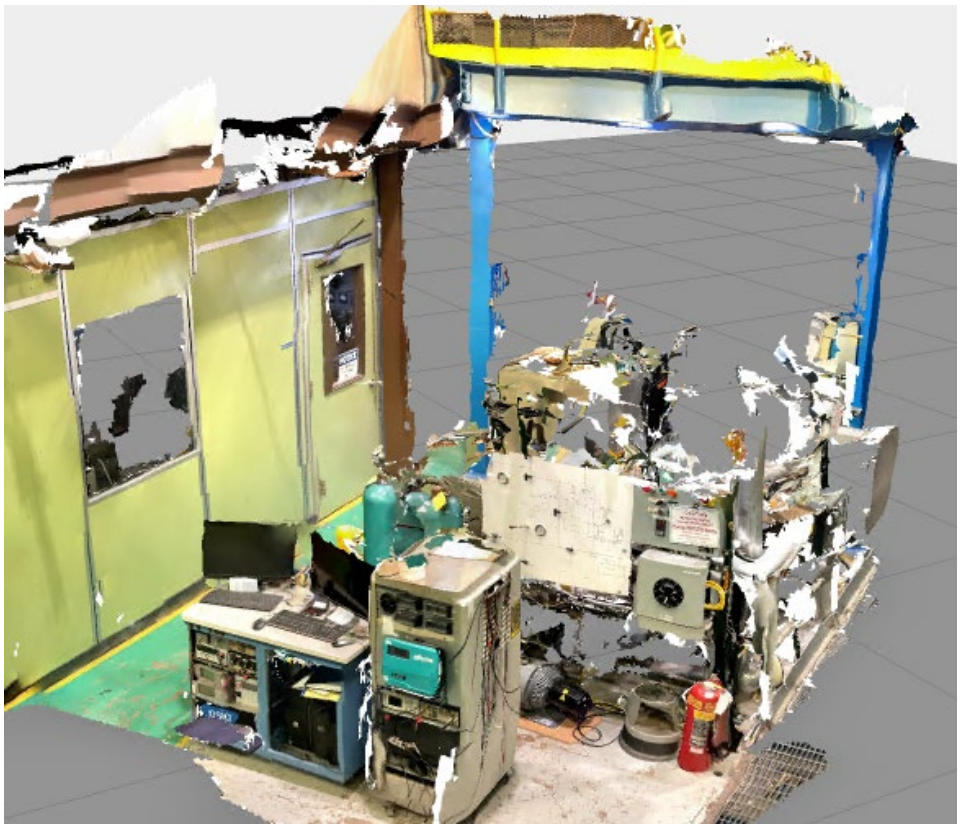


Figure 14. Tablet LiDAR Scan

This scan along with a CAD model of the mezzanine extension were imported into an AR/MR software development environment and published to a server. Using a mobile device or AR/MR headset, the software is able to automatically recognize the scanned area via onboard camera and augment the CAD model of the mezzanine extension as shown below in Figure 15. Construction managers or designers can now walk around and see the extension installed to determine if there are any interferences or conflicts with existing equipment that has yet to be captured via point cloud or 3D model. Depending on the severity of the interference, the design could be reworked, or existing facility modified prior to mezzanine installation saving time and effort compared to making corrections during construction.

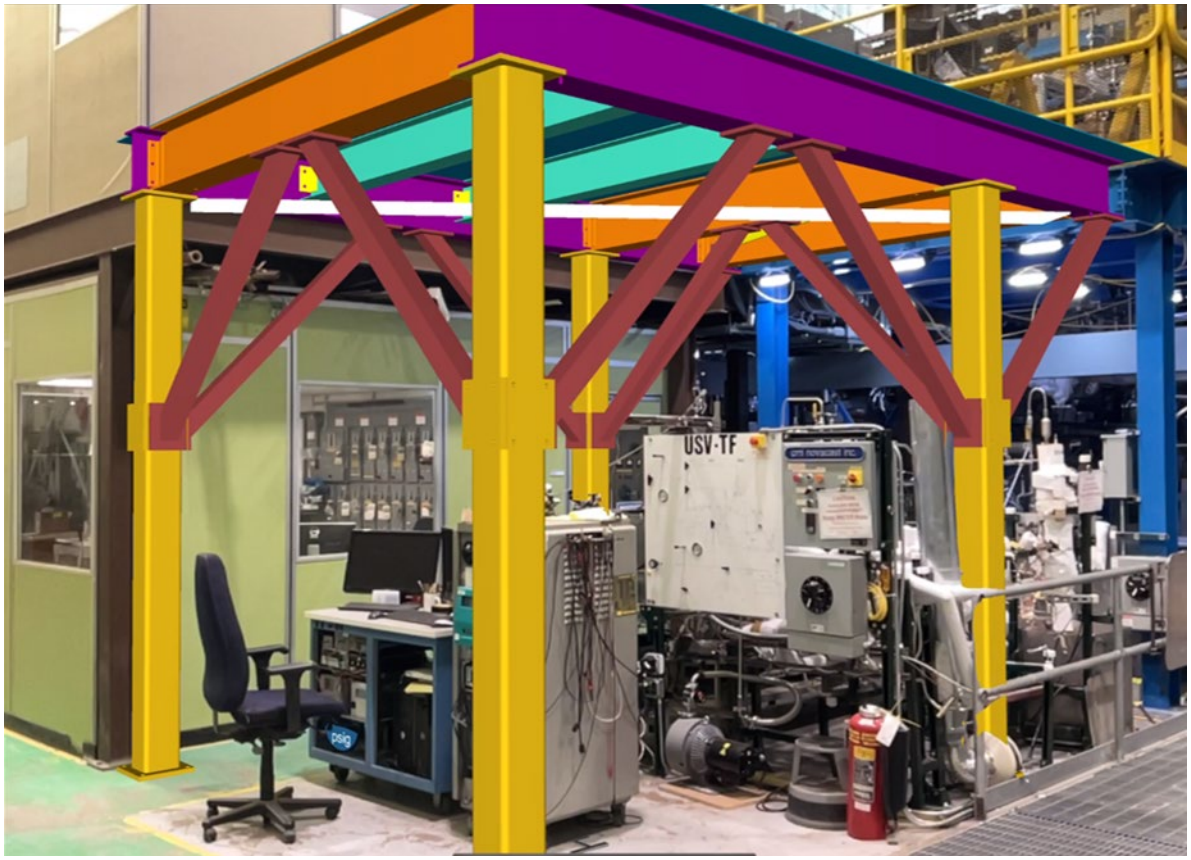


Figure 15. Augmented Mezzanine Retrofit.

5 Mixed Reality (MR)

Mixed Reality (MR) applications enable a user to interact with augmented content and thus MR can arguably be considered AR with additional functionality. A prominent MR use case is for instructions as workers are equipped with a headset that allows them to view their workpiece with additional information overlayed. Interacting with the instructions via MR allows the user to press buttons and interact with CAD models without picking up and placing a consumer mobile device every time they need to execute an event.

5.1 Visualization

The entire CAD model of METLs flagship facility was imported and integrated with buttons for use in MR. Analogous to many industrial plants, many assets cannot be seen as they are housed within a containment, covered with insulation, or located out of plain sight. Transitioning operational and maintenance knowledge of the NPP fleet from the current light-water reactors (LWR) to Gen-IV reactors will be a challenge from an operational aspect (such as in-service inspection) as many Gen-IV reactors such as SFRs use an opaque coolant. Crews performing maintenance activities will no longer be able to 'see' what they're working on or mechanical equipment they're controlling. In addition, high radiation areas may not permit human entry and require robotic manipulation, further complicating work completion.

METLs MR demonstration established the ability for METL crew members to 'see through' insulation by augmenting a CAD model of METL (with insulation hidden) over the physical facility. Specifically, METL has an economizer (a tube-in-pipe heat exchanger) located inside a stainless-steel container filled with vermiculite insulation (Figure 16).

Figure 16. Physical Economizer.

Donning an AR/MR headset, the METL team was able to walk-through the facility and visualize its' components prior to insulation (Figure 17, left). An MR button which can be switched via hand gesture recognition by the headset turned the economizer's container

visibility on and off (Figure 17, right). A simple but effective use case how MR can provide METL personnel additional clarity and help with on-boarding and training new members.

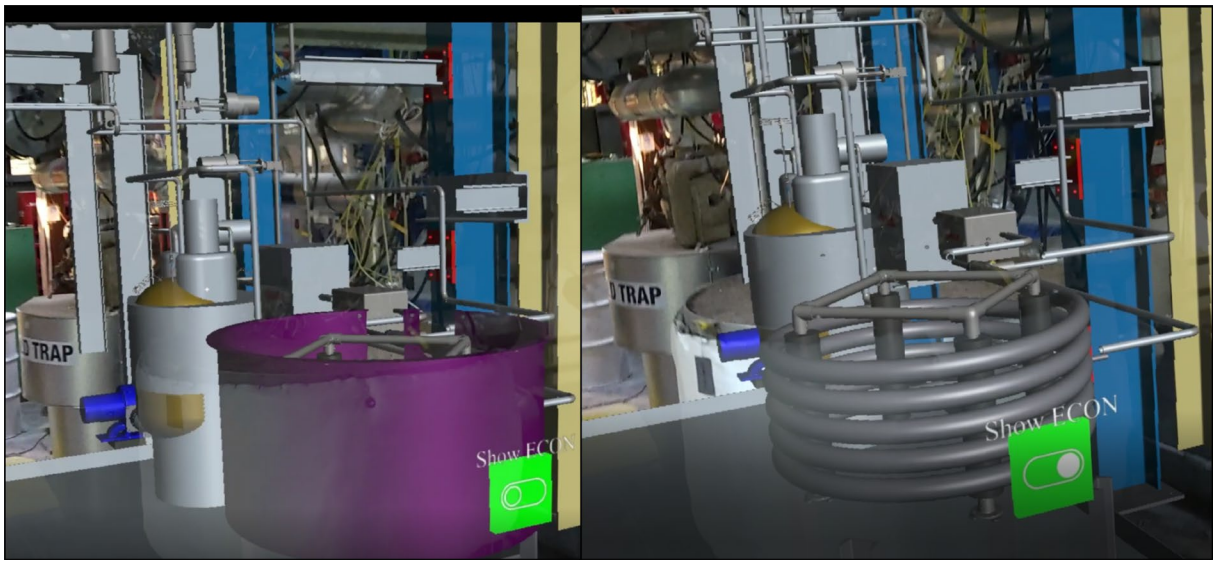


Figure 17. View Prior to (left) and After (right) Switching the MR Button.

5.2 METL Experiment Application

The Gear Test Assembly (GTA), METLs inaugural experiment, drives gears submersed in sodium via stepper motors external to the test vessel with the purpose of evaluating the longevity of gears using sodium as a lubricant. Once inserted into a test vessel, the device(s) under test (gears) are no longer visible and upon submerging in sodium no camera would be able to provide images of the gears. An MR experience of GTA was created with the intent to provide operators/experimentalists visual feedback. A user equipped with an MR headset is able to walk-around the test vessel to see an augmented CAD model of GTA and gauge/numerical indicator displaying vibration data (Figure 18). The user can press a 3D (virtual) button which makes housings, support structures and hardware transparent to reveal gears. The gears also animate (spin) to indicate which direction the gears are spinning as the experiment alternates rotational direction.

Figure 18. GTA MR, Augmented Animation of Gears Under Test (center), Vibration Data Gauge (left) and 3D Button (right).

Successfully demonstrating GTA MR has broader implications to the nuclear energy industry. Many advanced reactor designs have coolants that are optically opaque. This restricts 'viewing' technologies that utilize ultrasonics for its' principle of operation (time-of-flight, intensity, etc.). Submerged Coolant Viewing (SCV) technologies can generate an image from ultrasonic scanning but presently, SCVs are custom design/build and have challenges navigating through the cooling system. Therefore, SCV applications in reactor plants are tailored to hardware identification. MR may prove to be a useful tool for operations as MR animations could be a function of sensor feedback on-board a device to augment its' operation real-time thus providing visual feedback to plant operators and technicians.

The nuclear industry may find MR particularly useful as many organizations have areas where the radiological levels are too high for human occupancy or require workers to adhere to an ALARA (as low as reasonably achievable) exposure policy. MR experiences could provide further clarity and data to remote processes that require robotics or articulators/actuators due to radiation levels. Furthermore, MR may be a useful training/practicing tool as radiological workers could practice their task via MR prior to performing the actual task in the radiological area. MR would be able to simulate the procedure to ensure all the appropriate steps are included, in the correct sequence and all the necessary tools to perform the task are accounted for without having a physical 'mock' version of the work thus providing a near in-situ experience.

6 Future Work

XR hardware and software is arguably in a state of discovery, but the high number of companies invested in its development is expected to translate to continued use and expansion into other industries. Pending continued funding and support, METL can continue XR use cases/demonstrations to study and investigate the potential for its adoption to reduce lifecycle costs for the existing NPP fleet as well as advanced reactors under development. As discussed above, METLs mission, infrastructure and workforce are well suited to experiment with technologies and practices which promise to improve the efficiency, affordability, and safety of NPPs of all designs.

6.1 Increase Hardware Variety and Count

Reiterating Section 2, the tasks associated with a work order will determine the appropriate XR hardware which will dictate the XR environment (aR, AR, MR, AV/VR). There are additional styles of XR hardware such as smart glasses and other wearables that the METL team has yet to investigate for METL O&M demonstration. Some devices support accessories such as a borescope or infrared camera which may also lead to additional utility, namely mechanical and electrical inspections. The work presented is a pilot program, increasing the number of XR hardware and making these devices available to the entire METL team as well as collaborators (ANL Central-Shops, ANL-Facilities, contractors, architectural and engineering firms) may yield further benefits.

6.2 Additional aR for the METL Frontlines

The METL team will continue to consider aR use for its' frontline workers and integrate equipment and processes which eliminate data silos to provide skilled workers with the tools and information they need to complete their tasks correctly and efficiently. Specific initiatives include:

- Polish digital procedures and boost frontline worker data entry with a finer merger between the hardware and CMMS.
- Connectivity with 'smart/IP' tools which can automatically populate a CMMS work order with their values (e.g., a smart/IP torque wrench which transmits its' Boolean and/or numeric value when its' setpoint has been reached)
- Provide option to view historical performance data on a scanned asset.

6.3 AR/MR for METL Experiments

METLs flagship facility hosts a variety of experiments such as complex machinery to demonstrate equipment for refueling reactors, apparatus for investigating thermal-hydraulic phenomena, and tailored instrumentation validation. Designing, fabricating, assembling, operating, and decommissioning these test articles require a multi-disciplinary effort led by its' Principal Investigator (PI). AR/MR tools are expected to be used throughout a test articles lifecycle but poised to provide the most value during assembly and decommissioning.

METLs inaugural experiment, the Gear Test Assembly (GTA) is a device that drives gears submersed in sodium via stepper motors external to the test vessel (Figure 19, left) [3]. The information on GTAs assembly and cleaning of this device is stored/disseminated predominately through the personal knowledge of its PI. AR/MR content may be generated to

provide step-by-step instructions for a novice technician to independently perform assembly/cleaning tasks.

Experiments that are more permanent such as the Thermal Hydraulic Experimental Test Article (THETA) can utilize AR/MR to more effectively communicate its' research mission to the public and sponsors. THETA (Figure 19, center) impressively mimics a pool-type SFR within one of METLs 28" test vessels but much of its' hardware is submerged in sodium and unable to be seen [4]. Using consumer mobile devices, the entire test article can be augmented over the test vessel, providing a visual aid to visitors on its capabilities. Using MR, parent assets could be turned visible/invisible to reveal nested assets as well.

The Flow Sensor Test Article (F-STAr) is an experiment which is currently in the assembly stage. F-STAr (Figure 19, right) was conceptualized to evaluate above core instrumentation [5]. AR/MR development environments have the capability to augment and visualize live data. Using AR/MR the velocity profiles of different test articles could be displayed adjacent to each other providing a real-time visual comparison of data acquired.

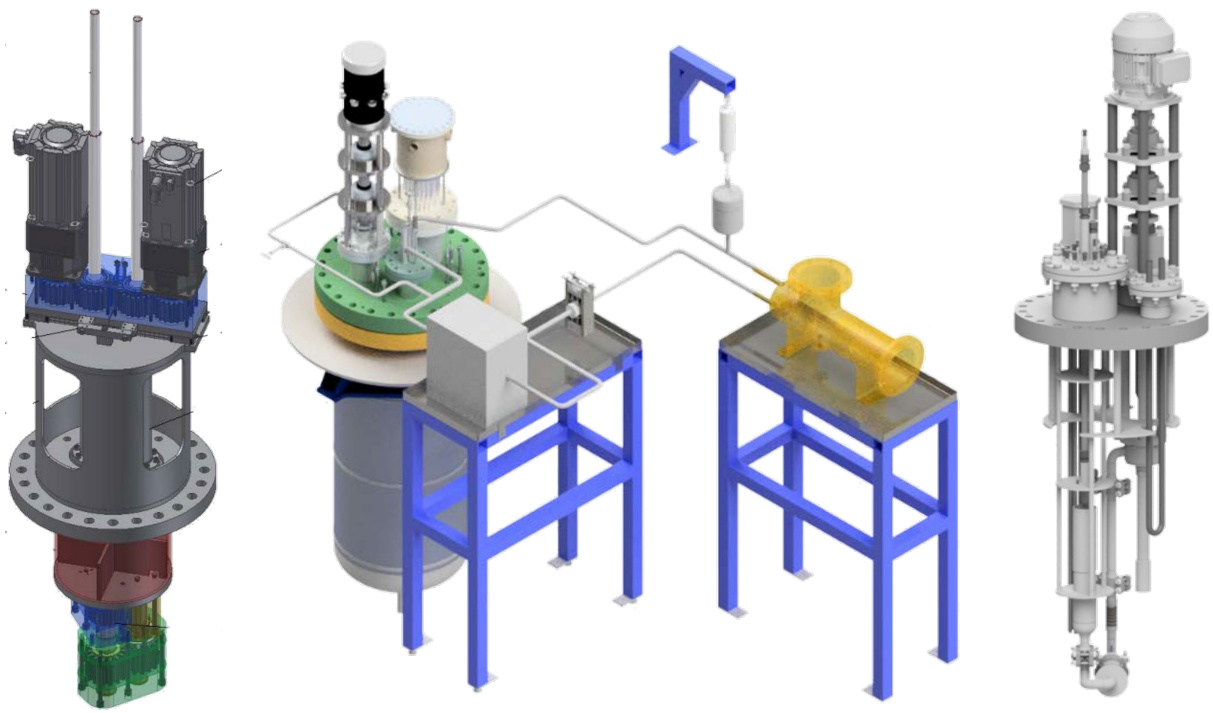


Figure 19. METL Example Experiments, GTA (left), THETA (center), F-STAr (right).

Another in-vessel test device is the Gripper Test Assembly (GrTA) which is a full-scale test article of an SFR advanced in-vessel fuel transfer machine gripper. The GrTA moves a pair of jaws (gripper) vertically to simulate the removal, insertion, or rotation of an SFR fuel assembly. This movement will cycle through automatically but could be fitted with a haptic joystick in conjunction with AR to see and feel the action of fuel assembly articulation.

7 Summary

METL is a unique U.S. facility within the Department of Energy complex as it provides an opportunity for internal and external researchers to test small to intermediate scale sodium components but also acts as a platform for experimentation. METL's infrastructure promotes flexible operations to accommodate a myriad of research initiatives. It is a state-of-the-art facility capable of hosting emerging technologies such as XR hardware/software. This report identified in-situ use cases for XR applications focused on METL operations and maintenance but is expected to be a beneficial tool throughout the nuclear lifecycle. METL's 30-year operational life will garner information and experience essential for SFR commercialization that small/benchtop test apparatus which are periodically operated cannot supply. METLs continued success throughout its 4+ years of operations and maintenance encouraged the investigation and pursuit of emerging and cutting-edge technologies such as XR while concurrently increasing system efficiencies, maintaining existing capabilities and improving ease of access for various experimenters.

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