



ANL-ART-263  
ANL-METL-44

## **Mechanisms Engineering Test Loop (METL) Experimenter's Guide**

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**Nuclear Science and Engineering Division**

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## 1 Introduction

The Mechanisms Engineering Test Loop (METL) was built to streamline and accelerate the in-sodium testing of systems and components under conditions that simulate a sodium-cooled fast reactor pool environment. The METL team at Argonne National Laboratory (ANL) can assist experimenters in achieving their technical goals by providing liquid-metal expertise and access to infrastructure required for most alkali metal related research. This document offers a brief overview of METL and provides a basic design guide for researchers interested in conducting research at the facility. Additional information regarding the history and operations of METL can be found in §6.1. **Furthermore, high resolution images found in this document as well as CAD files of aforementioned vessels can be provided upon request.**

## 2 METL Overview and Experimental Capabilities

METL is located at ANL in the Bldg. 308 hi-bay, which was built to accommodate large alkali metal research projects. As shown in Figure 1, METL consists of support systems and experimental test vessels connected in parallel to a primary piping loop. The support systems listed in Table 1 are operated by METL staff and provide the infrastructure and functionality required for most experiments. Table 2 provides the range of operating conditions for different METL components.

Experiments in METL are installed in either an 18-inch or 28-inch test vessel. Figure 1 shows a simplified P&ID of a test vessel with sodium and gas connections labeled. Figure 3 and Figure 4 present elevation views of the 18-inch and 28-inch vessels respectively.

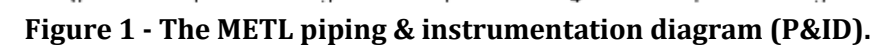
**Table 1 - METL Components and Support Systems.**

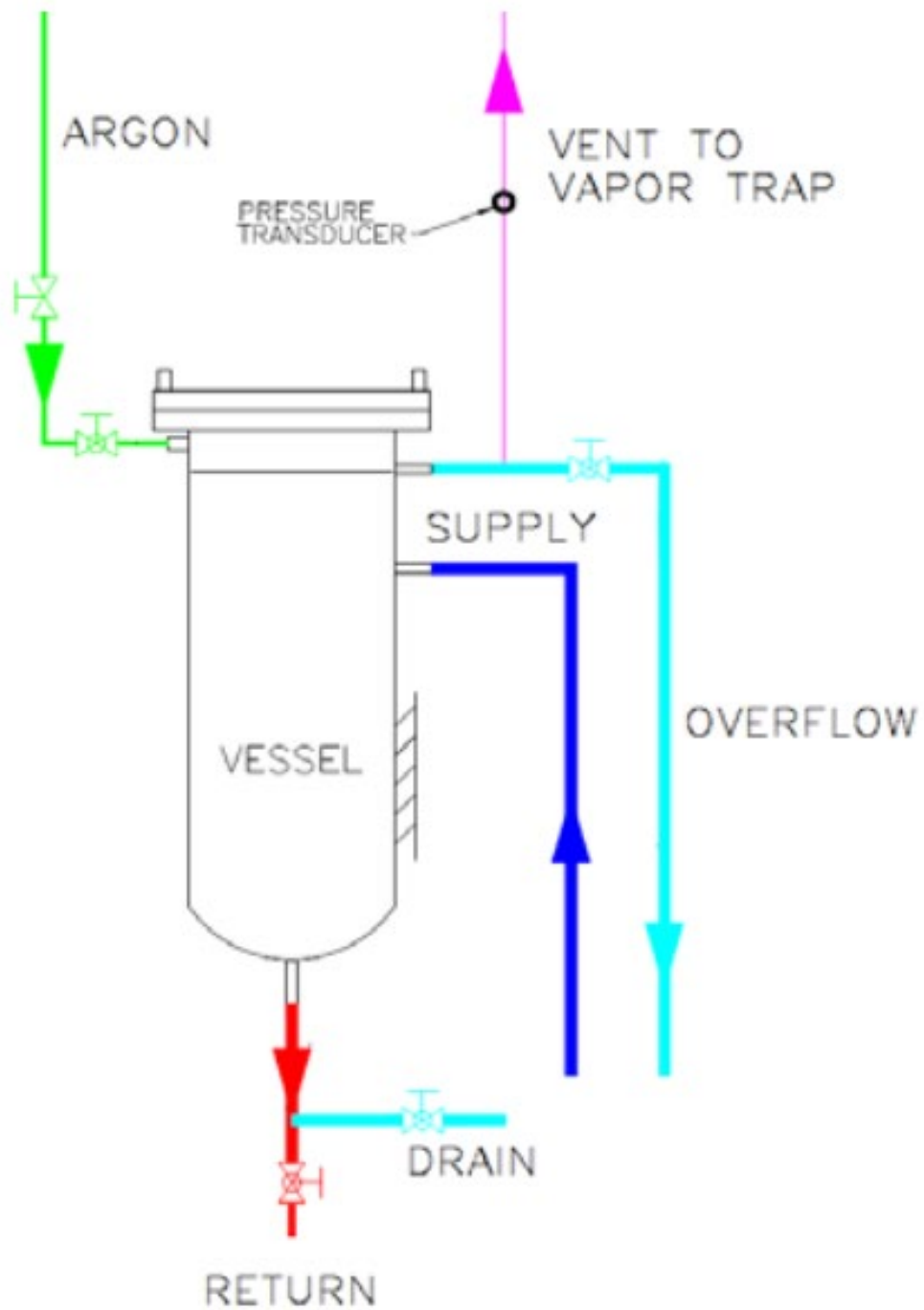
<b>Component / Support System</b>	<b>Function / Details</b>
Scrubber	Sodium disposal, clean-up, fire/smoke management
Catch pan	Sodium spill containment and fire prevention
Pumps & flowmeters	Sodium flow control (0-10 [gpm], 0-100 [psid])
Valves	Welded bellows, electro-pneumatic sodium flow control and system isolation
Cold trap & plugging meter	Impurity removal and quantification
Dump tank	Sodium storage, dump/drain, level sensing
Expansion tank	Accommodate changes in sodium volume, level sensing
Argon cover gas	High-purity, inert cover gas, fill/drain operation
Pressure transducers	NaK diaphragm type, pressure measurements in sodium and gas space
Vacuum systems	Fill/drain operation, air removal, entrained gas removal
Vapor Traps	Removal of sodium vapor from vented cover gas
Heaters & temperature control	Room temp – 1000 or 1200 [°F] (system specific)
Data acquisition / control system	Data logging and system control
Carbonation system	Sodium clean-up and removal from test articles
Flexicask	Insertion/removal of test articles while under cover gas
Crane	Moving hardware, installation of test equipment
Glovebox	Perform room-temp work in an inert environment

**Table 2 - An Overview of METL.**

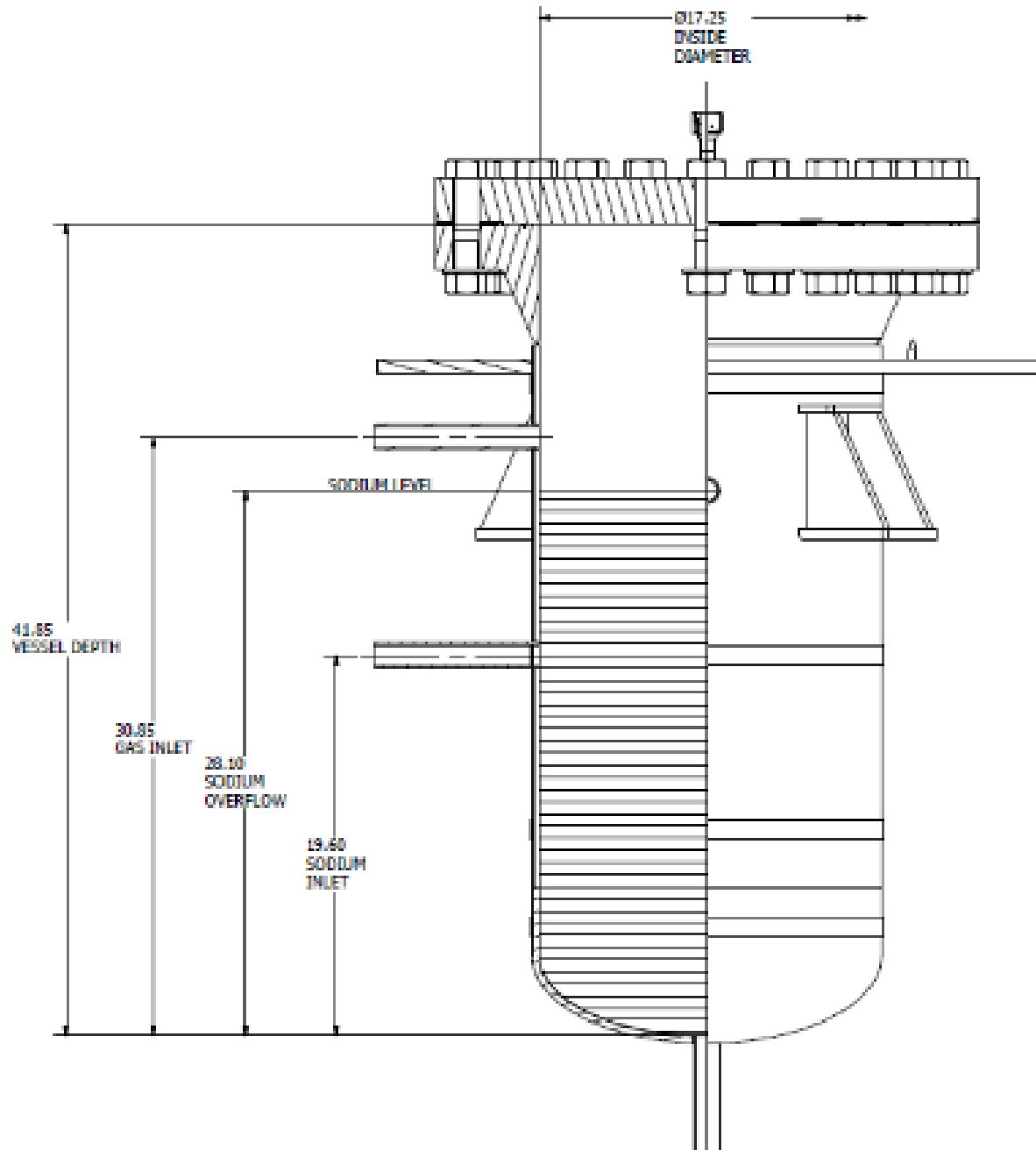
<b>System / Topic / Parameter</b>	<b>Value</b>
R-Grade Sodium Inventory	Current inventory = 750 [gal] (as of Aug. 2021) Dump tank capacity = 840 [gal] Catch pan capacity = approx. 1000 [gal]
Electric Power	~ 1 [MW]
Sodium Purity	~ <=5 [wppm] oxygen
Main Loop Flow Rate	0-10 [gpm]
18" Vessel	18" nominal vessel with a minimum wall thickness of 0.328" Height = approx. 34.25" Internal Capacity = approx. 40 [gal] Static operation = Room Temp – 1000 [°F] Dynamic operation = 250 - 1000 [°F] Rated pressure = 100 [psig] @ 1000 [°F]
28" Vessel	28" nominal vessel with a minimum wall thickness of 0.615" Height = approx. 62 5/16" Internal Capacity = approx. 170 [gal] Static operation = Room Temp – 1200 [°F] Dynamic operation = 250 - 1000 [°F] Rated pressure = 100 [psig] @ 1200 [°F]
Expansion Tank	Inner diam. = approx. 8.5" Height = approx. 80" Internal Capacity = approx. 20 [gal] Static operation = Room Temp – 1000 [°F] Dynamic operation = 250 - 1000 [°F] Rated pressure = 100 [psig] @ 1200 [°F]
Dump Tank	Inner diam. = approx. 41" Length = approx. 151" Internal Capacity = approx. 840 [gal] Static operation = Room Temp – 1000 [°F] Dynamic operation = 250 - 1000 [°F] Rated pressure = 200 [psig] @ 1000 [°F]
Crane Access (Bldg. 308 hi-bay)	20 [ton] w/ 5 [ton] auxiliary. The height of the inside of the 5-ton crane hook to the top of each vessel (vessel with no flange) is 189-190 inches. This crane hook height value is the same for both the 18 and 28 inch vessels.
Notes & Conversions	1000 [°F] ≈ 538 [°C] 1200 [°F] ≈ 650 [°C] 100 [psi] ≈ 6.89 [bar] 1 [gal] ≈ 3.78 [liter]







**Figure 2 - A depiction of the flow within a test vessel. Valves can also be used to isolate a test vessel from the rest of the system.**



**Figure 3- METL 18" vessel showing dimensions and sodium elevation.**

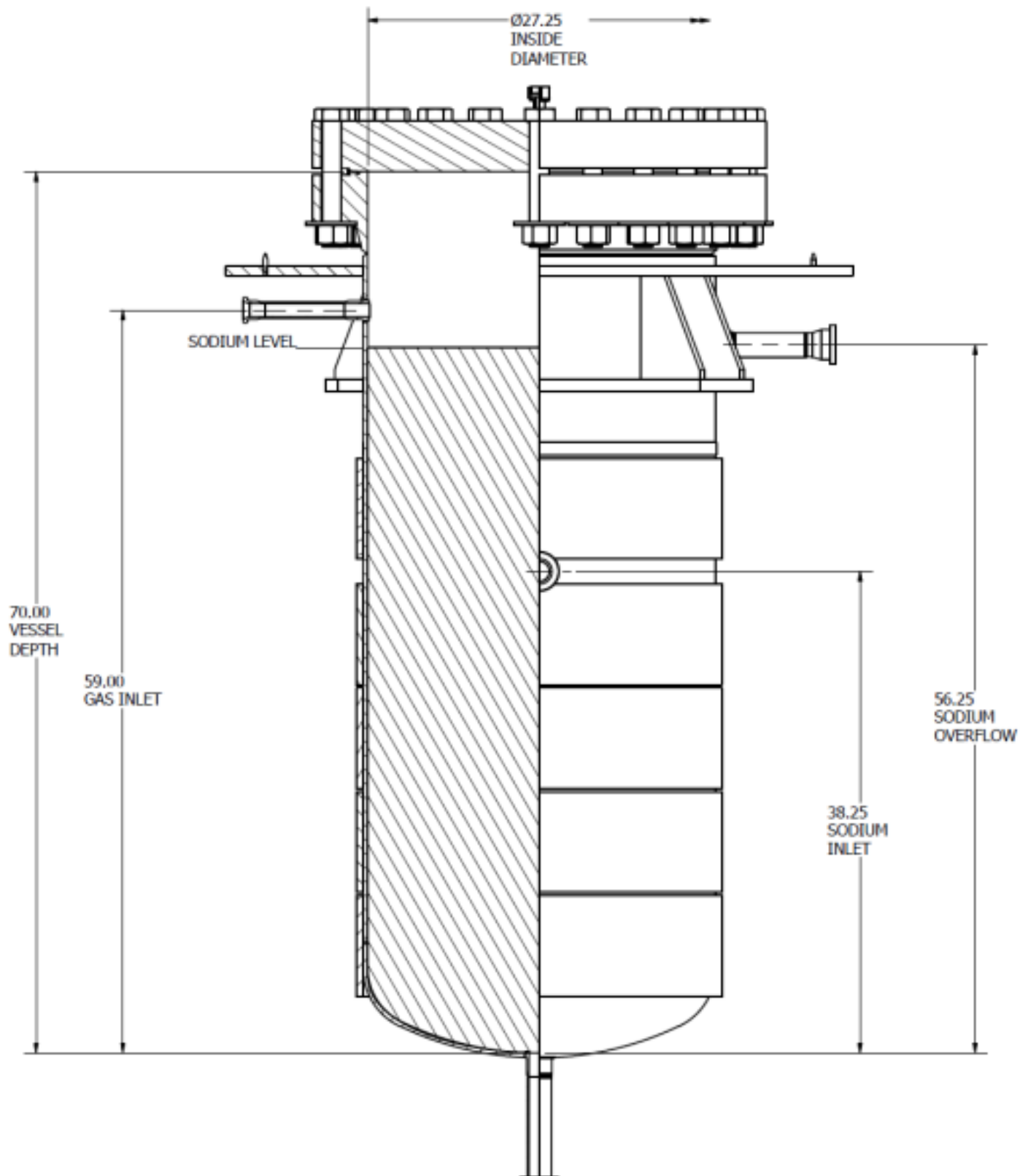
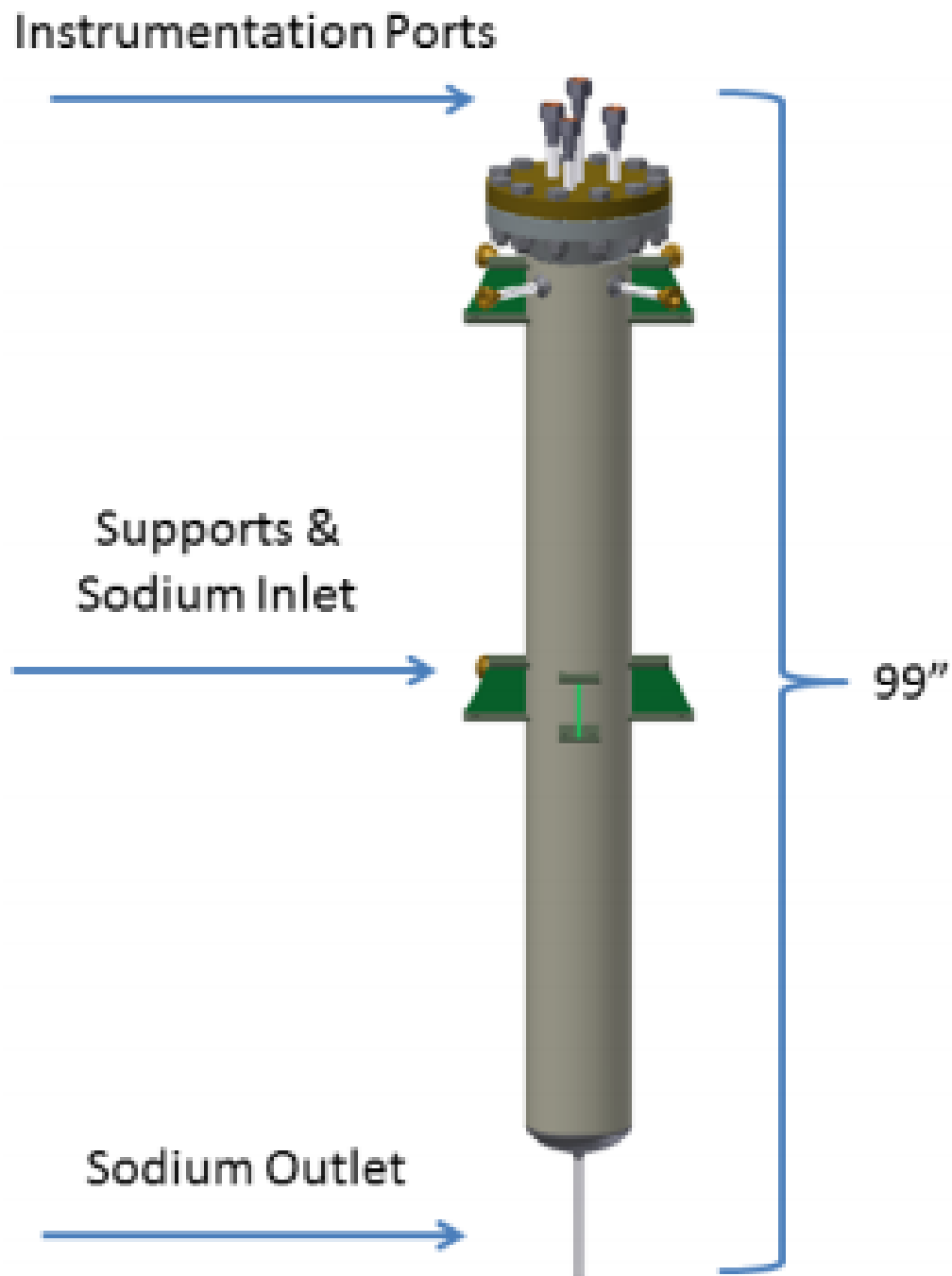


Figure 4- METL 28" vessel.



**Figure 5 - The METL expansion tank.**

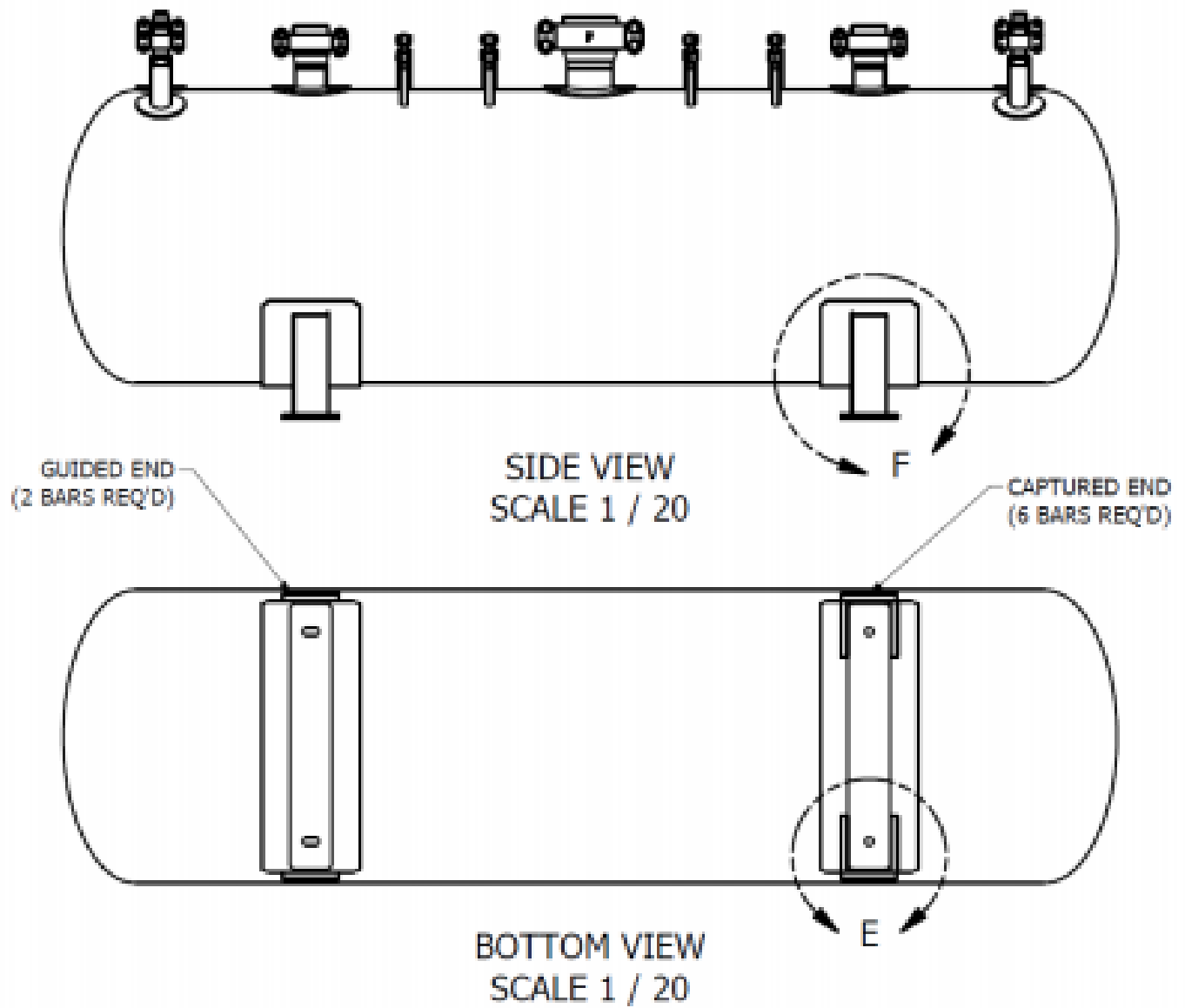


Figure 6 - The METL dump tank.

### 3 Designing an Experiment for METL

This section will describe design considerations for METL experiments. A METL team member will be assigned to support the design of an experiment destined for METL testing.

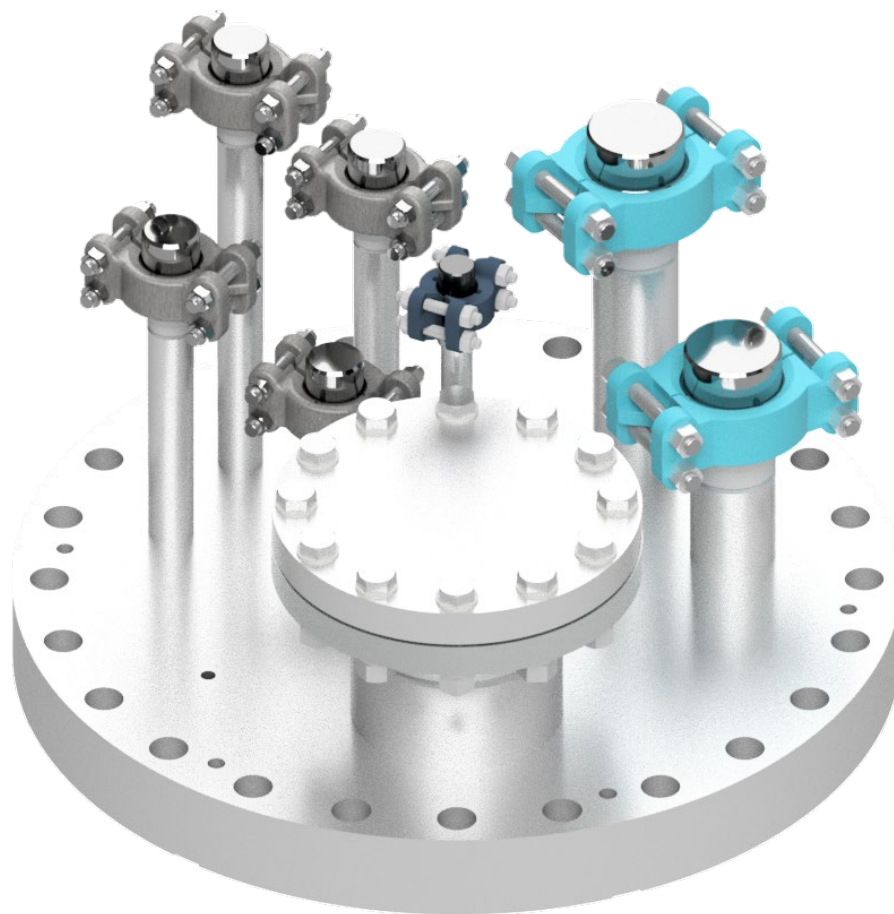
#### 3.1 Required Laboratory Policies

All tests conducted at ANL must adhere to the Work Planning and Control (WPC) and Integrated Safety Management (ISM) practices as required by the Department of Energy (DOE). The METL team will ensure that experiments originating outside of ANL conform to ANL's work planning and control processes.

#### 3.2 Test Vessel Design Constraints

Vessel experiments will be installed in either an 18-inch or 28-inch METL test vessel. These vessels have several constraints and experimenters must design their test articles within these parameters. Table 3 lists the 18-inch and 28-inch vessel constraints required to ensure safe and successful operation.

An adapter flange is also available for smaller component or instrumentation testing. This flange has one 8" 300# ANSI flange, two 3.5" Grayloc ports, four 1.5" Grayloc ports, and one 1" Grayloc Port. (Figure 7).



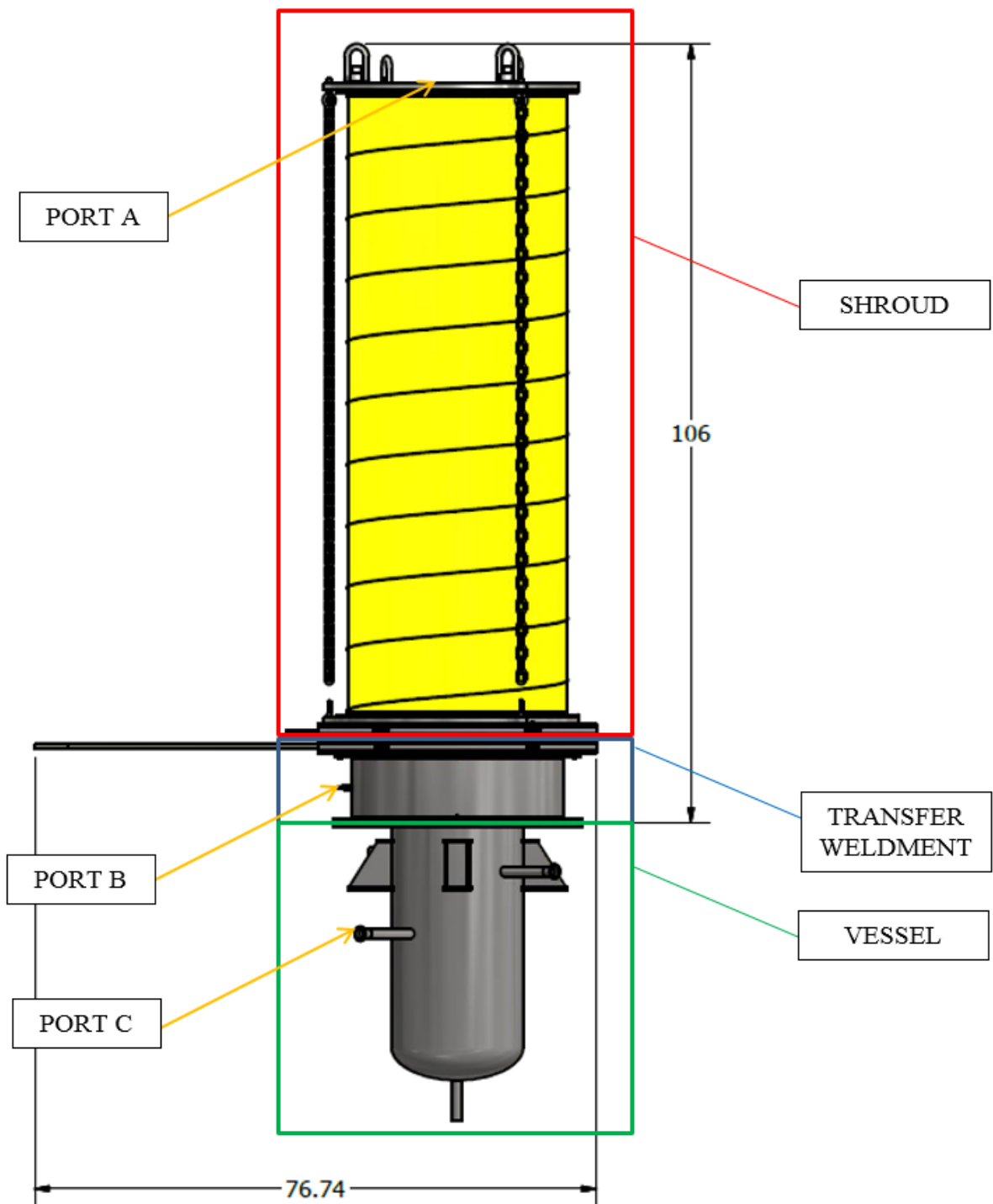
**Figure 7 - Adaptor Flange for Instrumentation Testing**

In addition to vessel constraints, there are also space constraints on the METL mezzanine deck due to vessel supporting equipment. Generally, test articles designed within the flange footprint will have fewer deck-space considerations. However, if the test article requires additional space, experimenters must consult with METL team members to create the best solution within the given deck-space constraints.

**Table 3 - Design restrictions for the 18" and 28" test vessels.**

	18" Test Vessel	28" Test Vessel
Required flange type and flexicask connection(s)	ANSI B16.5 Class 300 18" RF Blind Flange in 304/304L dual rated SS (See Figure 3)	ANSI B16.47 Series B Class 400 28" RF Blind Flange in 304H Stainless steel (See Figure 4)
Vessel dimensions	18" nominal vessel with thickness of 0.328" min. Height = approx. 34.25" (See Figure 2)	28" nominal vessel with thickness of 0.615" min. Height = approx. 62.31" (See Figure 3)
Max test article weight	2,847 lbm (includes the vessel cover at 397 lbm)	5,784 lbm (includes the vessel cover at 1,111 lbm)
Max test article size	Maximum diameter of test article below flange face: 15.75" to allow ~0.75" clearance of inside vessel  Maximum length of test article below flange face: 34.25"	Maximum diameter of test article below flange face: 25.25" to allow ~0.75" clearance of inside vessel  Maximum length of test article below flange face: 62.3"
Max test temp/pressure	Static operation – Room temp – 1200 [°F] Dynamic operation = 250 - 1000 [°F] Rated pressure = 100 [psig] @ 1000 [°F]	Static operation = Room Temp – 1200 [°F] Dynamic operation = 250 - 1000 [°F] Rated pressure = 100 [psig] @ 1200 [°F]
Availability of Test Assembly Test Stand?	Yes – a test stand is available for the 18-inch test articles	Yes – a test stand is available for the 28-inch test articles

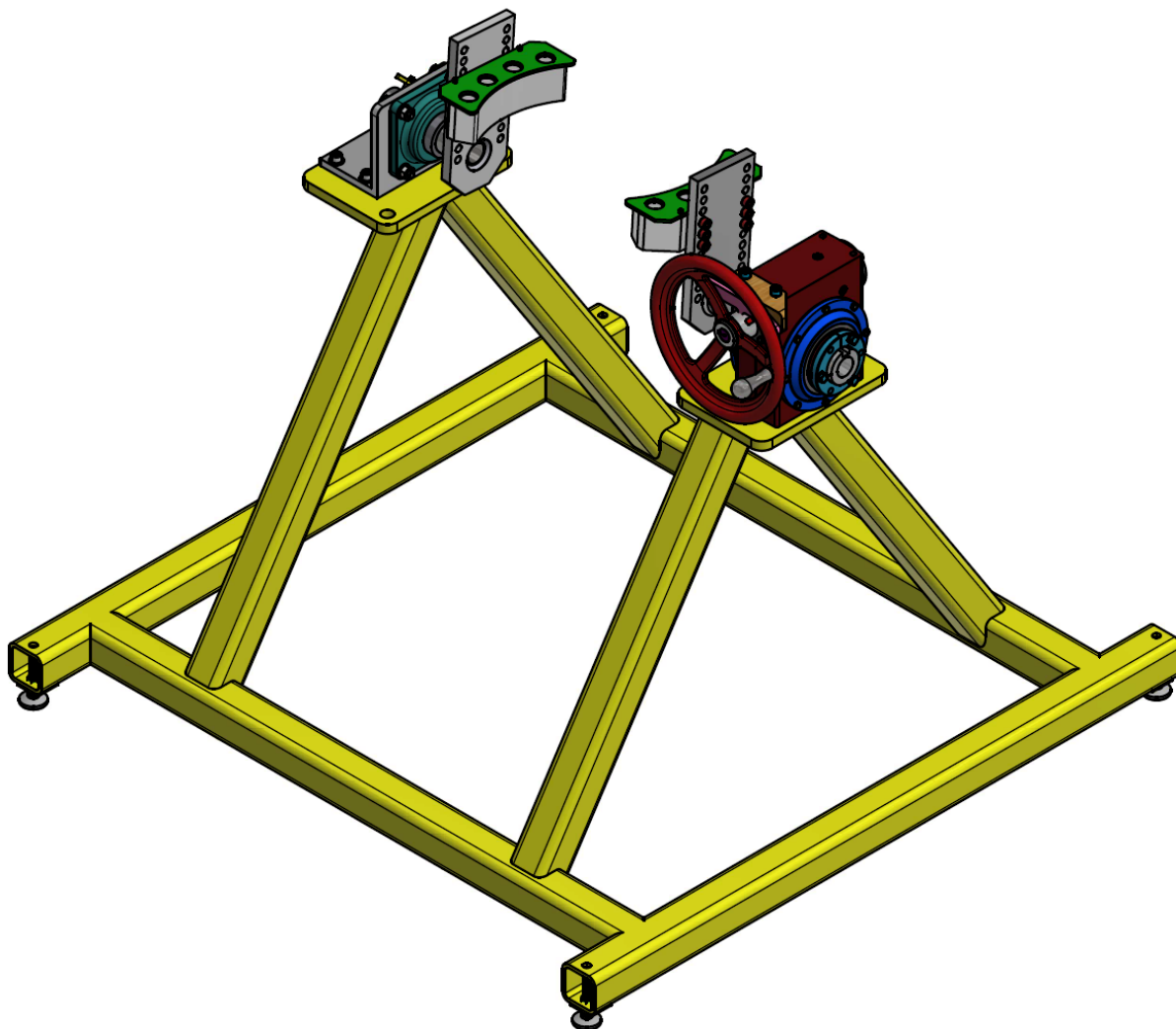




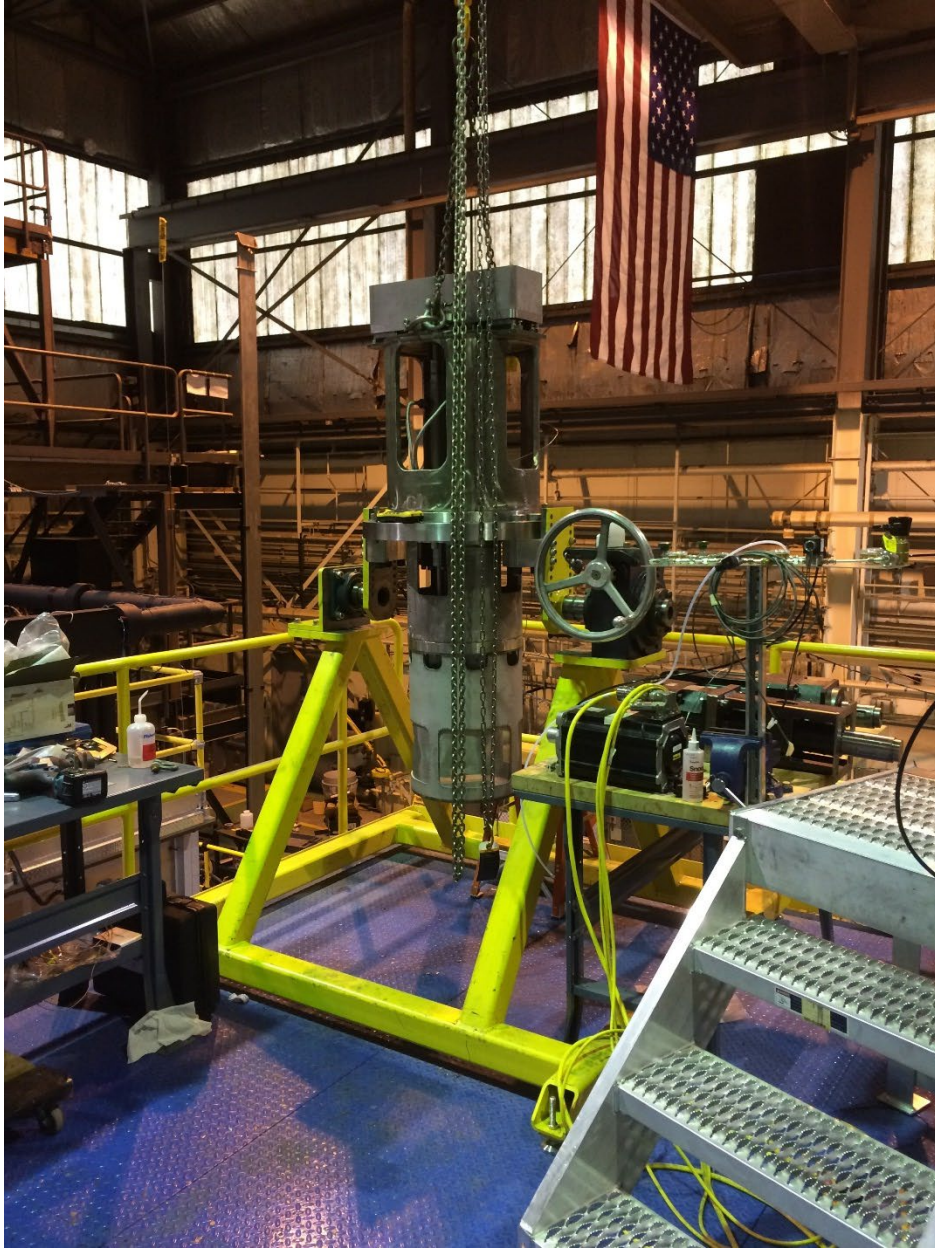
**Figure 8 - Flexicask shown on the 18-inch test vessel. The yellow shroud is now made from clear plastic.**

In addition to the mezzanine deck space constraints, the vessel assembly test stand will have additional space constraints. These test stands are available to aid in assembly and disassembly

of both 18-inch and 28-inch flange test articles. Figure 9 shows an isometric view of the 18-inch test stand. The test article flange is bolted to the test stand which can be used to rotate a test article upside-down if required if an experimenter wishes to use the “flipping” feature. The geometric constraints of the test article are included in Table 3. Figure 10 show the a test assembly installed on the test stand awaiting installation into a METL test vessel.



**Figure 9 - Isometric View of 18-inch Test Stand**



**Figure 10 - Picture of the Gear Test Assembly on the 18-inch test stand on the METL Mezzanine being prepared for insertion.**

### **3.3 General Design Considerations**

In addition to vessel-specific constraints there are also some general constraints for all METL test articles.

- Relevant industry codes shall be considered during test article design. METL representatives shall be notified of any code deviation and design may be subject to ANL subject matter expert or authority having jurisdiction approval.
- Experiment cover gas pressures should avoid exceeding 15 psig.

- Wetted surfaces must be constructed of materials compatible with high-temperature sodium. Material compatibility charts are available in the §6.3 references. **Note: organic and halogenated materials are prohibited.**
- Experiments should consider compatibility with the Building 308 crane and the Flexi-cask system.
- Test articles should be designed to drain the maximum amount of sodium as possible. Include gravity drain ports wherever possible.
- Test articles shall constrain or secure any parts which have a tendency to break loose and are smaller than a vessel drain inner diameter.
- The following table (Table 4) provides the power circuits that are available near the indicated vessels. The building has 2,000KVA (total) provided to the building. A portion of that power can be used to support experiments.

**Table 4 - Power Available Near METL Vessels**

Vessel	120V 1 phase	240V 1 phase	480 V 3 phase
Dump Tank	20 amp circuits	100 amp	
Expansion Tank	20 amp circuits	100 amp	
Test Vessel 1	20 amp circuits	100 amp	(2) 80 amp
Test Vessel 2	20 amp circuits	100 amp	
Test Vessel 3	20 amp circuits	100 amp	(2) 60 amp*
Test Vessel 4	20 amp circuits	100 amp	(1) 60 amp

\*In progress

In addition to vessel-specific and general constraints, the following items should be considered for all METL experiments in no particular order:

- Maximum sodium temperature and flowrates.
- Power requirements for heating and other test equipment.
- Expected test duration.
- How much floorspace and/or wall-space will be required for controls, auxiliary equipment, etc.? Is remote operation feasible to conserve space in the Bldg. 308 hi-bay?
- How many people will be required to operate an experiment? How often will staff be required to monitor/operate the experiment?
- How many test iterations?
- Can the experiment withstand (multiple) freeze/thaw cycles, or does it need to be drained? During a prolonged power outage or other emergency, should the test article drain or allow sodium to freeze in place? (See Fink & Leibowitz referenced in §6.3 regarding sodium density changes from room temperature to max operating temperature.)
- Could pools or pockets of argon prevent flowing, liquid-sodium from contacting any part of the experiment? (Example – an inverted bowl held underwater or a diving bell.)
- How would a fire or other emergency affect the experiment? Could the experiment contribute to or exacerbate a fire or other emergency? Is the experiment ‘walk-away safe’?
- How will the components and feedthroughs be sealed? Seals must be sodium, gas, and vacuum (as necessary) compatible. Will moving components require a bellows system?

Currently for some of our test articles, we are using graphite seals and metallic bellows seals.

- How will test article cleanliness be assured prior to installation into METL?
- Is the experiment compatible with 'sodium frost'? Sodium frost is the vapor that deposits on the surfaces of components in the gas space of the sodium system.
- Does a level sensor need to be incorporated in the design of the test article to ensure there is sufficient sodium volume?
- Is there a particularly fragile portion of the system that could be installed by hand on the above flange cover region of the experiment after installing the cover with overhead crane.
- Will the experiment create impurities or oxides, and if so, can we identify/quantify to determine if allowable, and if so, if we need to have the cold trap online actively filtering impurity?
- The crane is used to pick up and insert (or remove) test articles from the test vessels. The flexicask has an interfacing plate that the rigging points penetrate through in order to maintain the inert atmosphere of the flexicask, but also to ensure that the crane is rigged directly to the test article that is being handled. That interfacing plate will have appropriate holes for rigging equipment and for the items (maybe a shaft) that cannot be removed from the test article when it is being handled.
- Some design lessons learned
  - This section is RESERVED for now, but will be populated in the future.

#### **4 Roles & Responsibilities: Planning, Operation, and Close-Out**

The METL team is responsible for the safe and ongoing operation of the METL facility. Therefore, in addition to assisting all experimenters and facility users in achieving their technical goals, the METL team must ensure that the METL facility continues to adhere to all ANL guidelines regarding safety and conduct. As such, the following steps must be taken in order to conduct a successful experiment in METL. These steps will be described in detail in the following sections.

1. Project Kickoff and Test Article Design
2. Design Review
3. Assembly and Testing (outside of METL)
4. Qualification for Insertion into METL
5. Insertion into METL Test Vessel
6. Operations
7. Conclusion of Operations
8. Sodium Draining
9. Removal from METL
10. Cleaning via the carbonation process
11. Disassembly
12. Return to Step 3 for iterative projects.
13. Project close-out

To facilitate and streamline communications between the METL team and experimenters, it is recommended that both parties assign a single point of contact (POC) to document problems as



they arise and subsequently coordinate and communicate the resolution of all issues during the different phases of the project. The METL team will assign a project coordinator for this project to shepherd the experiment through the experiment phases. The METL team can help customers with the design development of their test articles. In addition, Argonne has on site a Central Shops that can fabricate some components.

#### **4.1 Project Kickoff and Test Article Design**

This section outlines the planning and technical/safety review process.

##### **Kick-off Meeting(s)**

- Introductions and tour of the METL facility
- Discussion of experimental goals and objectives
- Feasibility discussion

##### **Basic Planning**

- Budget and schedule
- Possible impact on other experiments connected in parallel to the METL piping system
- Talk about ISM, WPC and lab-wide policies

##### **Data Package Preparation / Documentation Requirements**

- Discussion of what calculations or documentation is required prior to fabrication. Documentation could include literature review, hand calculations, simulations, PE-signoffs, etc.

##### **Fabrication, Inspection, and Acceptance**

- Determination of what quality assurance (QA) deliverables would be required prior to acceptance by ANL and the METL team. QA deliverables could include material certifications, weld certifications, weld radiographs, helium leak checks, pressure decay tests, cleanliness verification, weight verification, ASME or pressure vessel documentation, etc.

#### **4.2 Design Review(s)**

Design reviews will be completed in regular intervals to ensure the test article meets the requirements for testing in the METL facility. Additionally, these design reviews will serve as checks to ensure the test article meets the desired functions and programmatic requirements. At a minimum, a design review will be conducted after the conceptual, preliminary, and final designs are complete.

#### **4.3 Assembly and Testing**

Once the test article components are fabricated, they will be assembled to verify and ensure that form and fit are adequate. Then, where feasible, the test article will be operated in a non-sodium environment to ensure that it functions correctly. After this verification, the test article can then be qualified for insertion in METL. For example, the Gear Test Assembly (GTA) and the Thermal Hydraulic Experimental Test Article (THETA) were fully assembled at in Building 206 and tested in water. After successful testing in water, they were partially disassembled and

shipped to Building 308 for qualification and insertion into METL. This testing allowed for the entire assembly, including the controls and data acquisition system, to be tested. Any issues that arise during this testing could then be resolved prior to insertion into the METL facility.

#### **4.4 Qualification for Insertion into METL**

Prior to insertion of the test article into the facility, METL team members will qualify the experiment for insertion. These qualifications are on a case-by-case basis but may include:

- Review of the design package to ensure that the test article meets the requirements for insertion into METL.
- Verify work planning and control paperwork is in place for test article insertion and testing.
- Confirm that the test article interfaces with the crane and flexi-cask system.
- Find a location for the control system on METL platform.
- Perform testing or limited testing of the assembled test article.

#### **4.5 Insertion into METL Test Vessel**

After a test article is qualified for insertion into METL, a vessel and insertion time schedule will be selected. Prior to insertion, the vessel will be drained of sodium and allowed to cool. Then, the vessel flange will be removed using the flexi-cask system. Next, the flexi-cask is installed on the test article and used during the insertion process. Leak checking should be performed after installation to ensure that all seals are performing appropriately. A helium leak detector system is recommended for this task. After the test article is installed, other components may be installed along with instrumentation, power, and controls. Prior to filling the vessel, a dry run may be completed if necessary. Next, the vessel is preheated to at least 150 °C and filled with sodium from the main loop. Once filled, sodium will be circulated through the main loop, vessel, and into the cold trap purification system to clean the test article and setup the sodium operating conditions. Typically, a vessel is filled by sluicing sodium from the expansion tank or another vessel (that is not undergoing testing) to fill the vessel and then an argon push is performed to increase the sodium level in the vessels to the appropriate height.

#### **4.6 Operations**

Prior to formal operations, the test article operation will be checked after the sodium fill to ensure it functions properly. Once these checks are complete, the test article will either be operated by METL staff or by the PI in accordance with the approved test matrix. METL team members will aid with setting up the necessary environment for the experiment testing. This may include heating the vessel and sodium to the desired operating temperature and pressure. Or this may include setting up valve lineups and pump settings to achieve the desired experimental flowrates through the vessel.

The following should be discussed with the non-METL personnel regarding operations:

- Once the experiment is installed and operational, what are expectations and responsibilities.
- When will data be processed and shared?
- How much access will non-METL personnel have to the facility?

#### **4.7 Conclusion of Operations**

Once the test article operations have been completed, the METL operations team will drain the vessel while the test article is at temperature. This allows for maximum removal of sodium from the vessel.

Then, the test article will be disconnected from the control, instrumentation, and any power supplies in preparation for removal from the vessel. Additional equipment such as motors, cooling piping, etc. that may interfere with the flexi-cask interface and operations will be removed from the test article.

After sodium draining has been completed, the test vessel will be allowed to cool to ambient temperatures.

#### **4.8 Removal from METL**

Once the test article has cooled to ambient temperature, the METL operations team will verify that the test article is prepped for removal from the vessel. After these checks have been completed, the carbonation system will be prepared for receiving the test article. This may include mounting the 18-inch adaptor for those test articles. Then, the flange bolts will be removed and the appropriately sized flexi-cask will be interfaced with the test article. Once in place, the flexi-cask will be lifted with the crane to remove the test article while maintaining an inert environment. After lifting the test article above the flexi-cask doors, both will be closed, and the test article will be transferred to the carbonation system using the crane.

#### **4.9 Cleaning the Test Article**

There are several methods available to remove residual sodium from a test article and its subcomponents. The least energetic, yet longest duration, is the carbonation process. Any 18-inch or 28-inch test article can be installed in the carbonation system available at the METL facility. This system introduces moist carbon dioxide to a reaction vessel that houses the test article. The moist carbon dioxide reacts with the sodium to produce sodium bicarbonate (baking soda). This process is relatively slow and generates little to no heat and is therefore best for projects that wish to maintain the integrity of the test article. We typically process a test article for about 1 week in the carbonation process before it is inspected and removed.

The carbonation process is not capable of reacting 100% of the residual sodium away. Sodium will collect in small clearances and volumes where only a small surface area will be exposed. The carbonation reaction will occur at the exposed sodium layer, but the reaction does not penetrate infinitely into the sodium. If partial disassembly of the article is possible after a round of carbonation, this is advised to expose more unreacted sodium. If partial disassembly is not possible, the components are typically soaked in a static ethanol bath followed by a water bath. The ethanol is used to react away sodium at a slow enough rate to avoid auto ignition of the liberated hydrogen gas. The reaction process can be observed as small bubbles (hydrogen gas) generated at the sodium surface. Once the reaction is determined to be complete (i.e., no bubbles for a few hours) the ethanol can be replaced with water. The water is used to dissolve any remaining reaction products and rinse the components of ethanol. **WARNING** Both baths are high hazard operations and will be handled by METL staff. For example, the ethanol bath can ignite if sparks are generated during the reaction, so determining safe extinguishing methods is imperative. The water bath is capable of starting a water-sodium reaction if there is



too much residual sodium left. This is the process used for components that are being reused in future test articles.

Finally, any components that are not intended for use after testing and can be disposed of should use the alkali metal passivation booth. Bulk sodium can be melted from components and burned in the AMPB. Then the components can be treated with superheated steam to react the sodium away. This process is high energetic and will likely damage the components. This is only intended for components that are not needed further. This is also the fastest and cheapest method of sodium removal.

Work with a METL team member to plan the sodium removal and disassembly for best results.

#### **4.10 Disassembly**

During this phase of the project, the test article will be removed from the carbonation process and craned to an appropriately sized test stand for disassembly.

- Discussion of what calculations or documentation is required prior to fabrication. Documentation could include literature review, hand calculations, simulations, PE-signoffs, etc.

#### **4.11 Project close-out**

The cleaned test article (or cleaned test article parts) will be dispositioned appropriately.

Data from the test article experiment will be processed as necessary and shared. Data is typically captured by the test article's data acquisition system.

A final report will be prepared of the testing that was accomplished as required.

A review of the METL testing procedures and processes will be conducted so they can be improved in the future.

#### **4.12 Project Clean-Up and Close-Out**

This section addresses topics that must be discussed once a project is complete. Topics include:

- Cleanup using carbonation, steam, ethanol, etc.
- Removal of equip from METL
- Final write-up and deliverables
- Review of procedures and processes so they can be improved in the future.

### **5 Reference Materials**

The following resources provide additional information regarding METL construction/operation, safety & work-planning at ANL, and best-practices for sodium systems.

#### **5.1 METL Publications & Reports**

- <https://www.anl.gov/nse/mechanisms-engineering-test-loop-facility>

#### **5.2 Laboratory Safety & Work Planning**

- Integrated Safety Management (ISM)
  - <https://www.anl.gov/integrated-safety-management-program>

- Work Planning and Control
  - DOE-HDBK-1211-2014, Activity-Level Work Planning and Control (WPC) Implementation

### 5.3 General Information & Best Practices for Sodium Systems

- Liquid Metals Handbook (Sodium NaK Supplement), C. B. Jackson (editor), 1955.
- Alkali Metal Handling and System Operating Techniques, J. W. Mausteller et al, 1967.
- Sodium-NaK Engineering Handbook, O. J. Foust (editor), 1972.
- Thermodynamic and Transport Properties of Sodium Liquid and Vapor, J. K. Fink and L. Leibowitz, 1995.

## 6 Glossary

Abbreviation	Meaning
ANL	Argonne National Laboratory
DOE	Department of Energy
GTA	Gear Test Assembly
ISM	Integrated Safety Management
METL	Mechanisms Engineering Test Loop
POC	Point of Contact
QA	Quality Assurance
SFR	Sodium-cooled Fast Reactor
THETA	Thermal Hydraulic Experimental Test Article
WPC	Work Planning and Control



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