NRIC National Reactor Innovation Center

MSTEC

Molten Salt Thermophysical Examination Capability

Toni Karlsson (PI/TPOC) and Carson Stronks (PM)

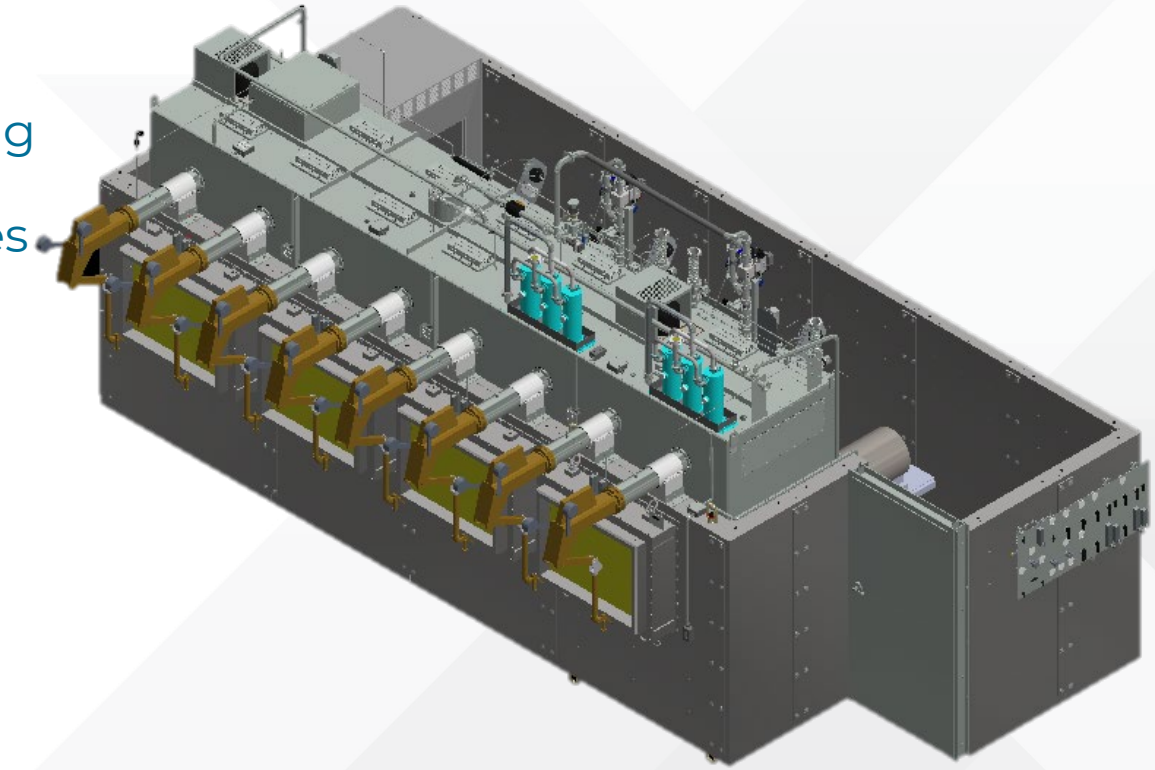
04/01/2025



MIS-25-83518

Overview

- Technical Description – a shielded modular hotcell with an inert argon atmosphere, housing characterization equipment for determining thermophysical and thermochemical properties of high temperature liquids not limited to but focusing on irradiated fuel salts.
- Location – Materials and Fuels Complex (MFC), Fuel Conditioning Facility (FCF), RM 35.
- Compatible Materials:
  - Chloride, fluoride salts.
  - Fresh fuel salts and irradiated fuel salts.
  - Pyrophoric material - U, Pu metal.
  - Gases – H_2, HCl, Cl_2, HF, F_2, NF_3.
  - Beryllium containing salts.
  - Many others.



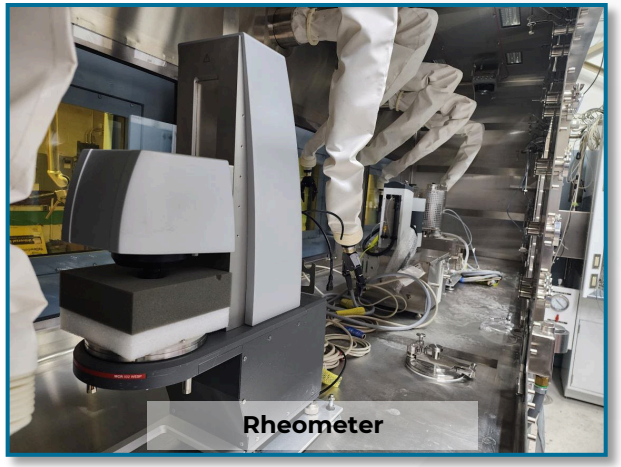
Overview

Modular Hot Cell:

- Shielded on one side.
- Glove ports on the other side.

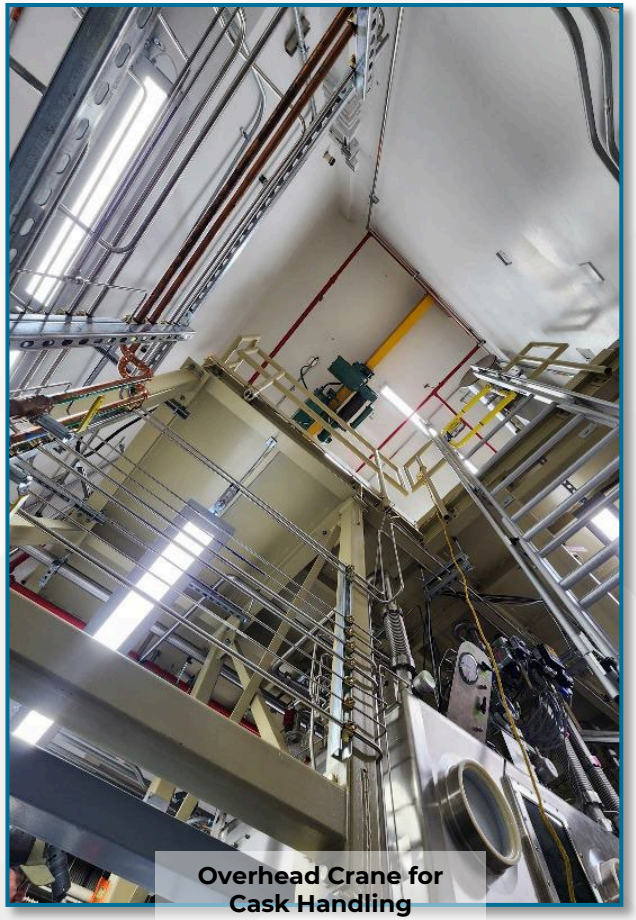
Instrumentation (≥ 1000°C)

- Rheometer – viscosity.
- Densitometer/pycnometer – solid and liquid density.
- Simultaneous Thermal Analyzer (STA) – invariant and transition temps, weight loss.
- Differential Scanning Calorimeter (DSC) – specific heat capacity.
- Well furnace – corrosion, salt synthesis, electrochemistry.
- Versatile experimental space.



Rheometer

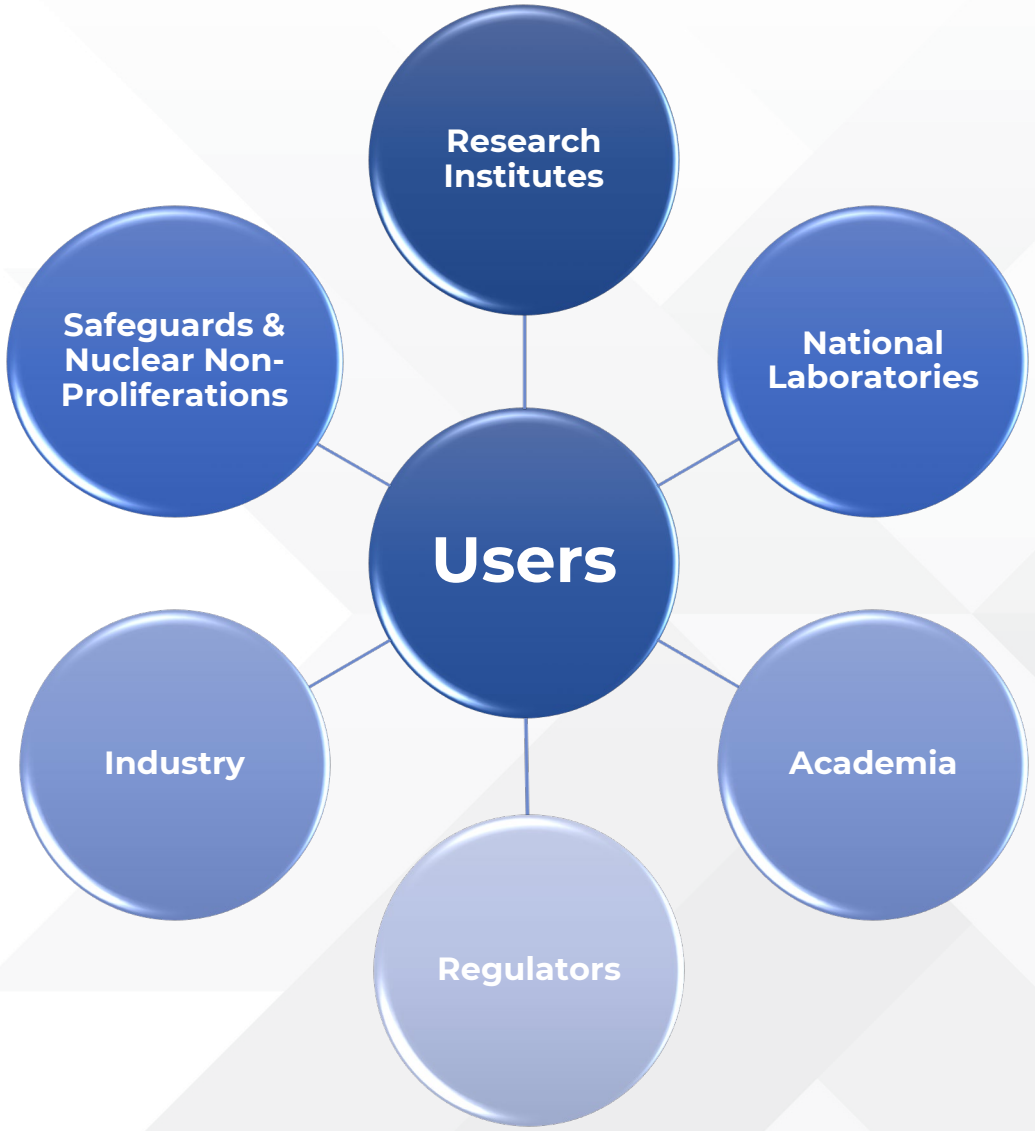
Open Research Space



Overhead Crane for Cask Handling

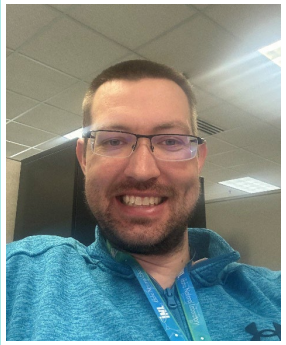
Overview

- **Purpose/Objective:** Provide users with characterization equipment, infrastructure, and technical staff necessary to produce critical data needed to design, demonstrate, license, and operate an Molten Salt Reactor (MSR).
  - Provide reliable data sets on properties including viscosity, density, heat capacity, thermal conductivity, melt temperature, vapor pressure, redox chemistry, and salt purification methods.
  - Offers versatile space for users to setup one-of-a-kind experiments and to perform small-scale exotic salt fabrication.



MSTEC Project Overview

Core INL Team Members

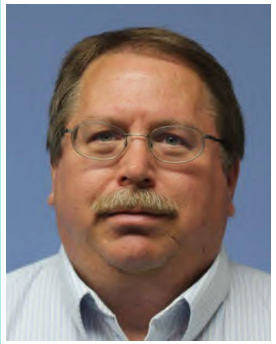

Carson Stronks
Lead PM


Stephen Warmann
PM


Toni Karlsson
Lead Scientist


Adam Butikofer
Lead Design Eng.


Dale Wahlquist
Design Eng.


Mark Borland
Glovebox SME


Evan Lovel
Lead Electrical Eng.


Barbara Houck
Lead Nuc. Safety


Numerous other individuals contribute to the success of MSTEC

Subcontracts

- Applied Engineering Services – Engineering support design, construction, ventilation (ongoing)
- DR & Sons Construction – Phase II MSTEC Installation (nearly complete)
- Extract Technologies (Walker Barrier) – Glovebox and shielding (complete)
- Wälischmiller Engineering GMBH – Manipulators (complete)
- Amentum – Nuclear safety (complete)
- C&H Construction – Phase I Construction - D&D and Facility Modifications (complete)

Milestones for FY25

- M2: Complete Installation of Eight Manipulators complete. (Complete)
- M3: Complete the Concept of Operations document. (Complete)
- M2: Initiate MSTEC Readiness Review Process .(Due 08/30/2025)
- M2: Complete Management Self Assessment. (Due 09/29/2025)

Accomplishments

FY20

- **Kickoff, May 1st 2020**
- Assembled a team of diverse and uniquely skilled people.
- Procured characterization equipment.
- Completed the design requirements for MSTEC.
- Finished numerous Idaho National Laboratory (INL) engineering documents (source term and shielding calcs, floor loading analyses, south wall removal analysis, ventilation evaluation, installation logistics evaluation, etc).

FY21

- Instrumentation:
  - Integrated feedthroughs (cooling, electrical, gas) in interim glovebox.
  - Setup rheometer, DSC, pycnometer, densitometer.
  - **Initiated testing equipment in non-rad lab.**
- Engineering:
  - **Held several design reviews for MSTEC (>40 people), finalized conceptual design.**
  - Issued manipulator and hot cell purchase orders (PO's).
  - Put out to bid the Request for Proposal (RFP) for construction work for FCF facility mods.
- Nuclear Safety:
  - Finalized major mod determination
  - Finalized Hazards Evaluation and accident scenarios.
  - Reviewed safety design strategy (SDS).

FY22

- Instrumentation:
  - **Procedure development and demonstration of equipment on non-rad salts.**
  - Finalized electrical and feed through drawings.
  - Finalized modifications needed for hot cell use.
  - **Developed a Concept of Operations.**
- Engineering:
  - **100% design review with Walker Barrier**
  - Engineering design review at INL.
  - **FAT test for manipulators.**
  - Decontamination & Initiate D&D of the sodium washroom.
- Nuclear Safety:
  - **Finalize draft revision of SAR-403.**
  - Submitted and addressed comments from ISRC.
  - Drafted DOE-ID submittal letter.

Accomplishments

FY23

- Instrumentation:
  - Setup and demonstrating well furnace and STA-skimmer.
  - **Developed MSTEC training and operator qualification plan.**
  - Writing glovebox and instrumentation operating procedures.
- Engineering:
  - Structural inspections complete: no major structural upgrades.
  - Removal of south wall.
  - Roll-up door installed, outer wall extended, painted, crane removed, Ar lines routed, lighting upgraded
  - Steel shield wall section. fabrication, manipulator, and shielded glass fitting complete.
- Nuclear Safety:
  - **Safety Analysis Report (SAR) submitted to DOE-ID**
  - INL Nuclear Safety address comments.

FY24

- Instrumentation:
  - Ensured operations of instruments on non-rad standard materials.
  - Prepared equipment for transfer to MSTEC.
  - Developed training plans and user qualifications.
  - Developed operating procedures for glovebox and equipment.
- Engineering:
  - **Received glovebox and all auxiliary equipment at INL, 82 tons.**
  - **Repaired Crane.**
  - **Installed MSTEC shielding.**
  - **Installed mezzanine.**
- Nuclear Safety:
  - Continue to work with DOE on SAR/ Technical Safety Report (TSR) revision.

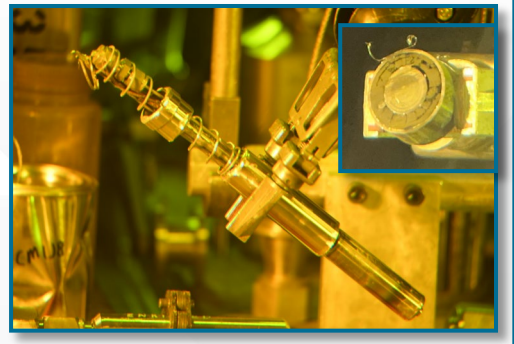
Accomplishments

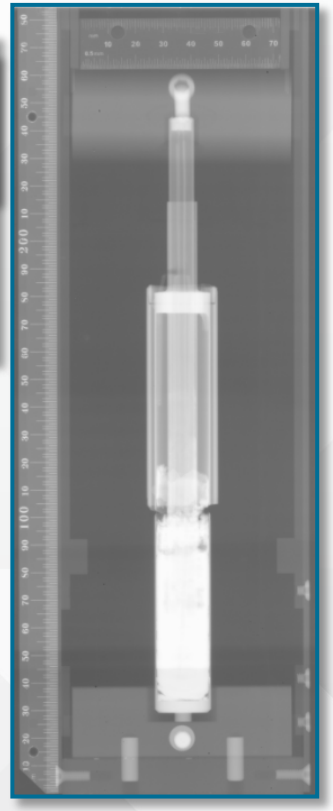
FY25

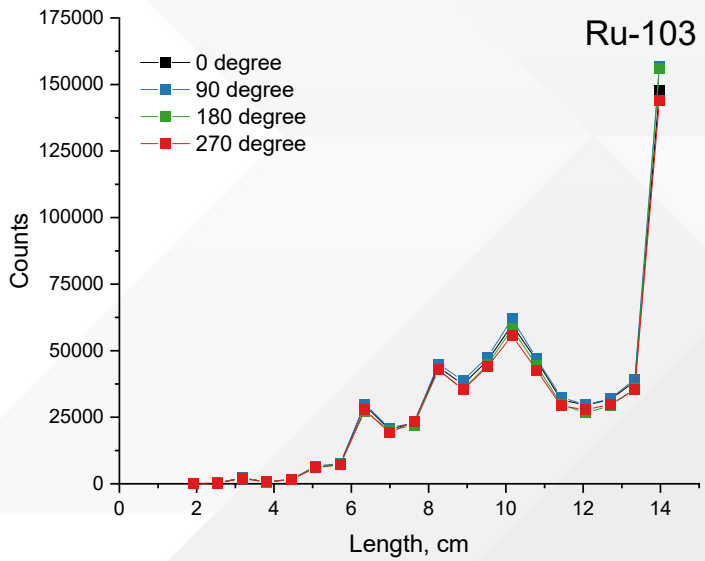
- Instrumentation:
  - Issued operating procedures for glovebox and equipment.
  - Completed training plans and user qualifications.
  - Transferred equipment into the MSTEC glovebox.
  - Plumbing gas lines and connecting power supplies.
- Engineering:
  - Installed glovebox and all auxiliary equipment at INL, 82 tons.
  - Installed manipulators.
  - Installed mezzanine.
  - Installed purification bed.
  - Working to finish up electrical.
- Nuclear Safety:
  - MSTEC is now incorporated into facility SAR/TSR.

Remaining Activities

- Major activities remaining:
  - FY25:
    - Complete instrument integration.
    - MSTEC management self assessment.
    - MSTEC contractor readiness assessment.
    - MSTEC DOE readiness assessment and final commissioning.
  - FY26:
    - Graded experimental approach (non-rad, dU, irradiated).
    - Initiate thermal property testing of irradiated fuel salt.







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Interest in MSTEC infrastructure

Agreement	Description
SPP with Seaborg Technologies of Denmark	5-year agreement to study thermophysical properties of unirradiated molten salt, irradiate molten salt in Advanced Test Reactor (ATR) core, and measure thermophysical properties of irradiated salt in MSTEC.
CRADA with Korean Atomic Energy Research Institute	5-year agreement to study thermophysical properties of unirradiated molten salt, irradiate molten salt in ATR core, and measure thermophysical properties of irradiated salt in MSTEC.
NAAREA	4-year agreement to perform salt synthesis, fresh fuel salt properties, fuel salt irradiation in ATR, and Post Irradiation Examination (PIE).
MCRE ARDP	2-year effort to measure thermophysical properties of unirradiated fuel salt.
MRTI Molten Salt Irradiation	3-year Laboratory Directed Research and Development (LDRD) to irradiate molten salt fuel in the Neutron Radiography Reactor (NRAD) core and subsequent thermophysical property measurements on the irradiated salt. Serves as basis for Korean Atomic Energy Research Institute (KAERI) and Seaborg irradiations.
DOE MSR Campaign	Recurring annual scope to study thermophysical properties of plutonium-bearing MSR fuel salts.
Safeguard & Nonproliferation	MSTEC work scope is included on two NA-22 proposals, MSR safeguard technologies.
Fuel Cycle	Develop and demonstrate fuel cycle technologies.

Questions ?

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www.nric.inl.gov

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METL

Mechanisms Engineering Test Loop Operations, Maintenance, and Improvements (O&M)

Christopher Grandy
Deputy Director, Nuclear Science and Engineering Division Argonne National Laboratory

04/01/2025

MIS-25-84059

METL O&M Project Overview (1/2)

- This work provides the necessary funding to operate maintain the Mechanism Engineering Test Loop facility and supporting infrastructure located at Argonne National Laboratory.
  - NRIC provides funding for METL O&M (+Improvements) - starting around April 2022.
  - Prior to April 2022 – this work was funded by DOE's Advanced Reactor Technologies (ART) program.
- Personnel working on METL O&M:
  - Derek Kultgen – Manager of the METL Facility
  - Teddy Kent – METL Operations Engineer
  - Jordan Rein – METL Operations Engineer
  - Matt Weathered – METL Operations Engineer
  - Alex Grannan – METL Operations Engineer
  - Evan Ogren – METL Operations Engineer
  - One plus technician
  - Other support personnel from various organizations on site

METL O&M Project Overview (2/2)

- *Advanced Reactor Technology (ART)-FRP Program Objective - Develop advanced fast reactor technology solutions to allow commercial deployment.*
  1. Train next generation engineers and scientists by engaging them in advanced reactor concept design and analysis and fundamental studies that support fast reactor Research and Development (R&D).
  2. Design and develop scalable advanced technologies for reducing the cost and/or increasing the performance of fast reactor technology.
     - Cost reduction
     - Improve safety performance
     - Increase system reliability
  3. Preserve and manage data, knowledge, and experience related to past United States (U.S.) Department of Energy (DOE) fast reactor design, operations, tests, and component technology.
  4. Re-establish the U.S. infrastructure to support the testing of advanced technologies for fast reactor applications.
  5. Collaborate internationally on advanced reactor R&D through bilateral or multilateral agreements.
     - Utilize international collaborations to leverage and expand R&D investments.

- **METL supports all these Program Objectives.**

- **METL also supports the National Reactor Innovation Center (NRIC) Mission to support the deployment of advanced reactors.**

METL Facility Purpose - Re-establish U.S. Infrastructure

- To test small or intermediate scale advanced liquid metal components and instrumentation in sodium for the future of advanced fast reactor system development.
- To develop and provide performance data on systems and components used in sodium and reduce the risk of failures during reactor plant operations.
- Will provide needed U.S. infrastructure (both personnel and hardware) to test liquid metal systems and components.
- This work supports our international collaborations

  The U.S. lacks this testing infrastructure.

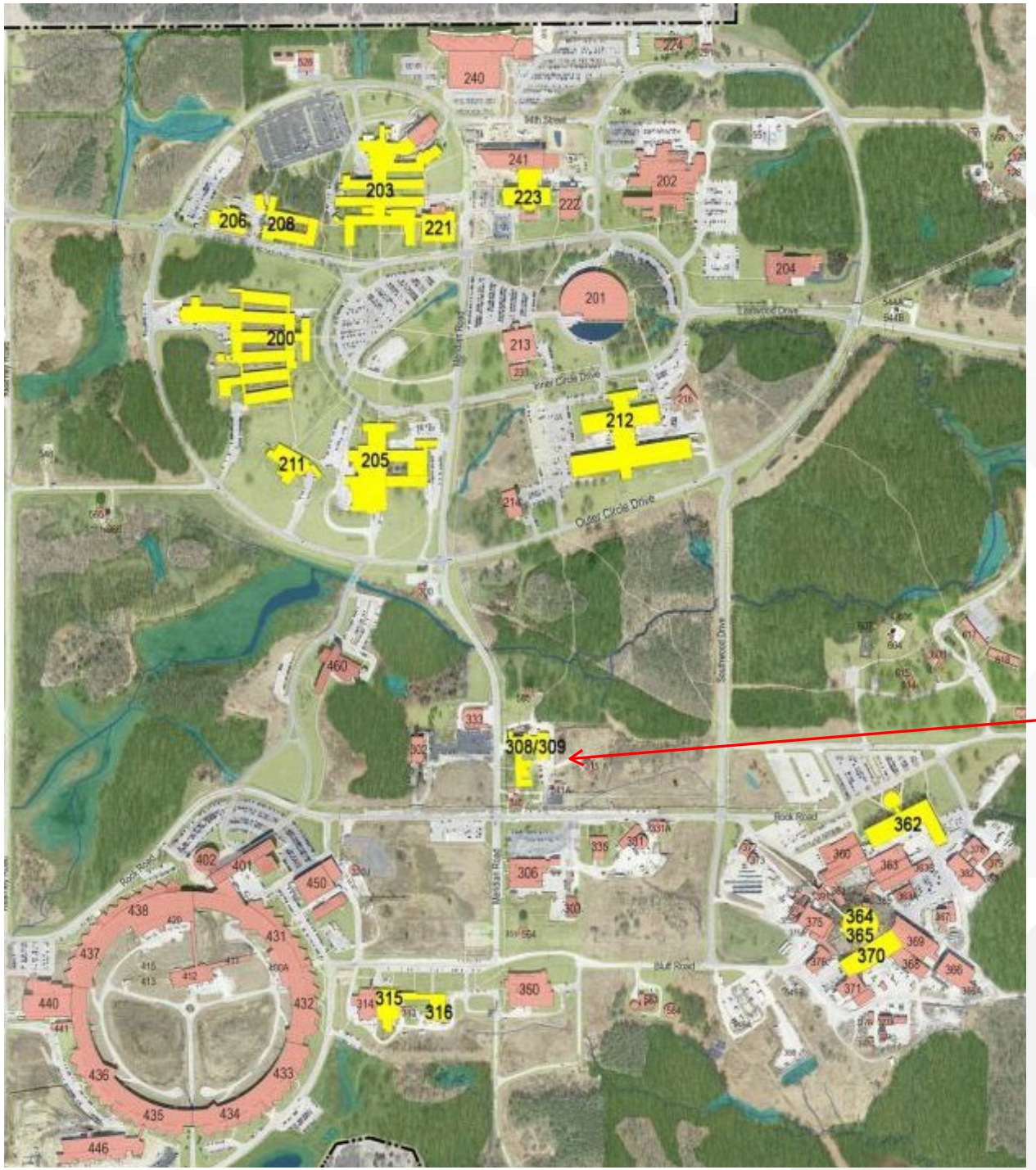
https://www.etec.energy.gov/

METL

- Located in B308
- Large highbay structure
- Historically used for liquid metal technology development
- Currently houses
  - METL
  - NSTF
  - USV/TAS/H_2

B308

APS



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METL is located in B308 Highbay

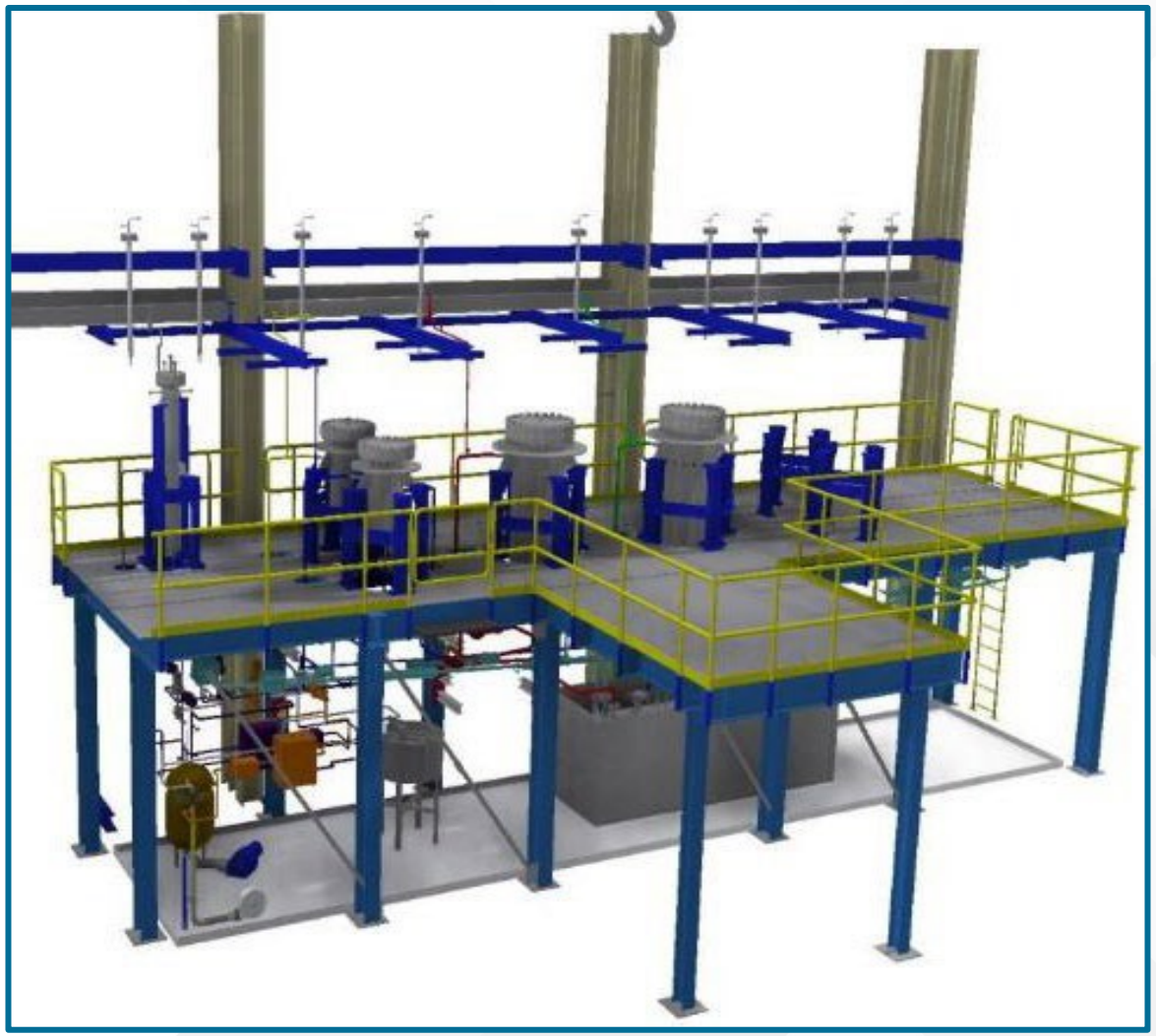
- B308 is protected by an alkali metal passivation booth.
  - Permitted for alkali metal treatment
  - 300 lbs/hr – normal
- 600 lbs/hr in emergency
- 30,000 scfm scrubber blower
- Can treat all alkali metals via burning and reaction
- Facility is unique in the DOE and U.S. complex
- B206 is also protected by an alkali metal passivation booth.

Mechanisms Engineering Test Loop (METL)

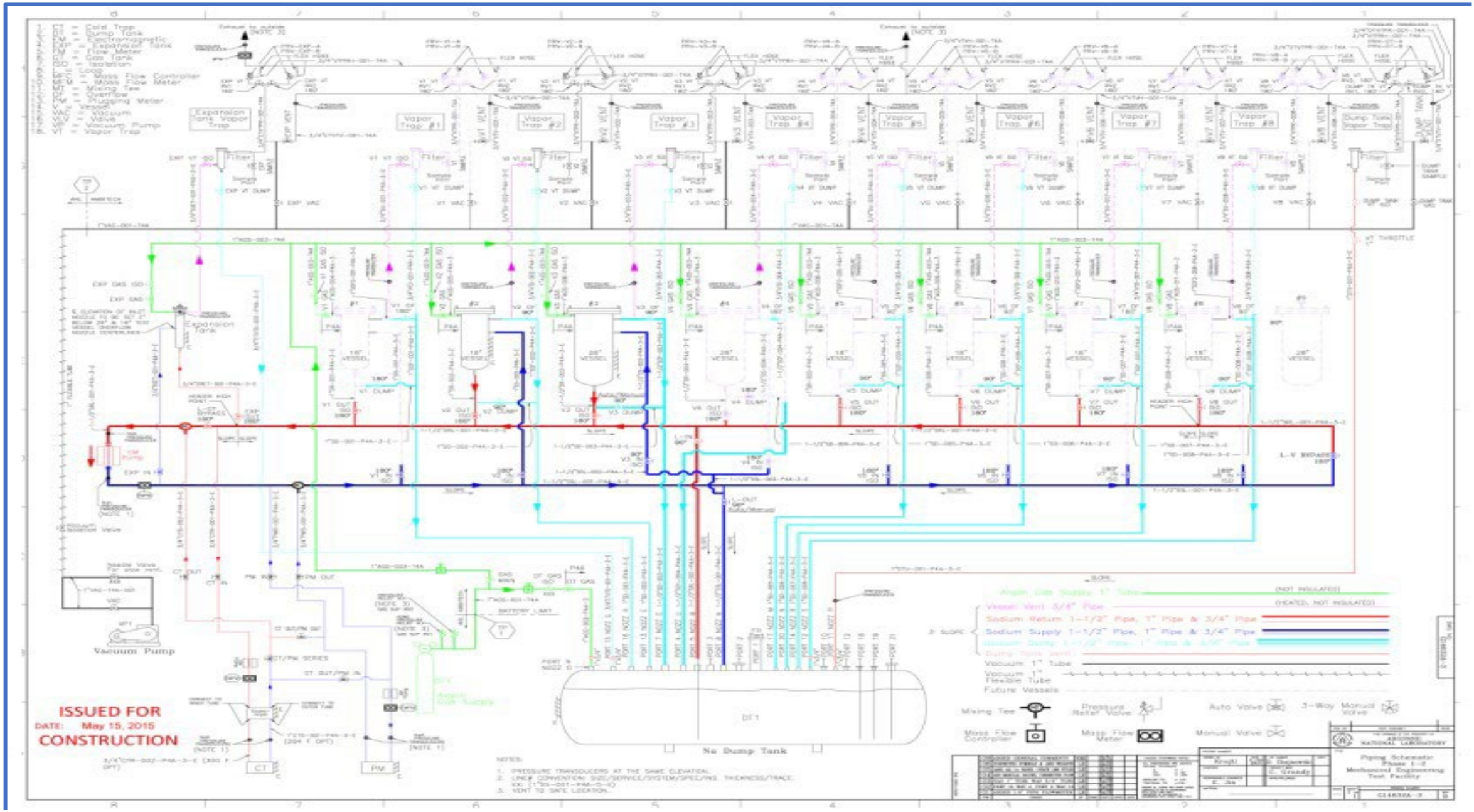
- **To test small or intermediate scale advanced liquid metal components and instrumentation in sodium (e.g.):**
  - Gear Test Assembly for Compact Refueling Machine
  - Sodium Level sensor technology
  - Thermal-Hydraulic Experimental Test Article (THETA)
  - Gripper Device for Compact refueling machine
- **METL consists of:**
  - ~3,000 kg of reactor-grade sodium – purified via cold trap
  - Two 18-inch test vessels and two 28-inch test vessels (Phase I)
  - Max system temperature = 1000°F (except for 28-inch test vessels – 1200°F)
  - Test vessels can be isolated from main loop
- **Provides much needed U.S. infrastructure (both personnel and hardware) to test liquid metal systems and components.**

METL Systems and Components

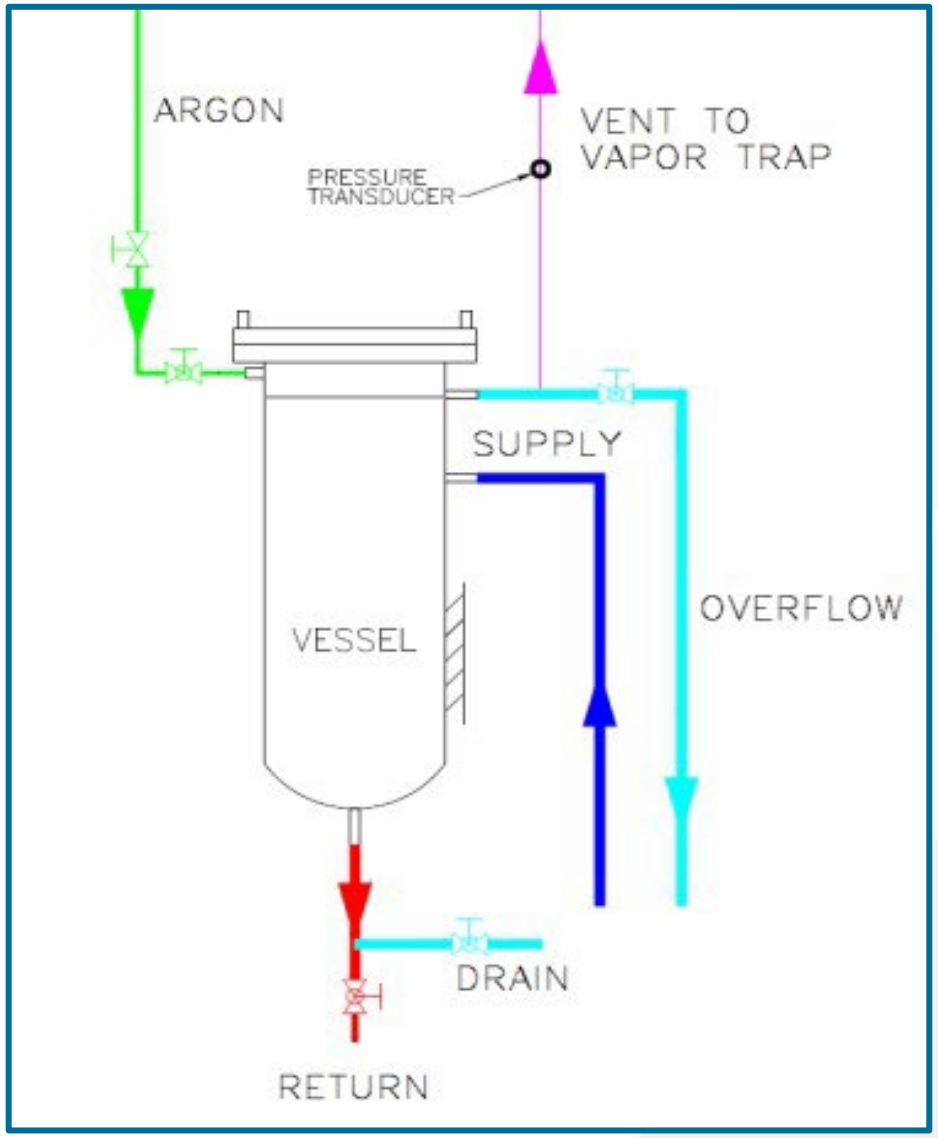
- METL consists of:
  - Four Test Vessels (18 and 28 inch)
  - Dump Tank
  - Expansion Tank
  - Purification System (cold trap)
  - Plugging meter
  - Vapor trap
  - Inert gas system
  - Valves
  - Connected piping system
  - Mezzanine
  - Catchpan
  - R-grade sodium
  - Heat Tracing
  - Heater and Valve control cabinets
  - Instrumentation and Control
- METL Auxiliary and supporting Infrastructure and systems



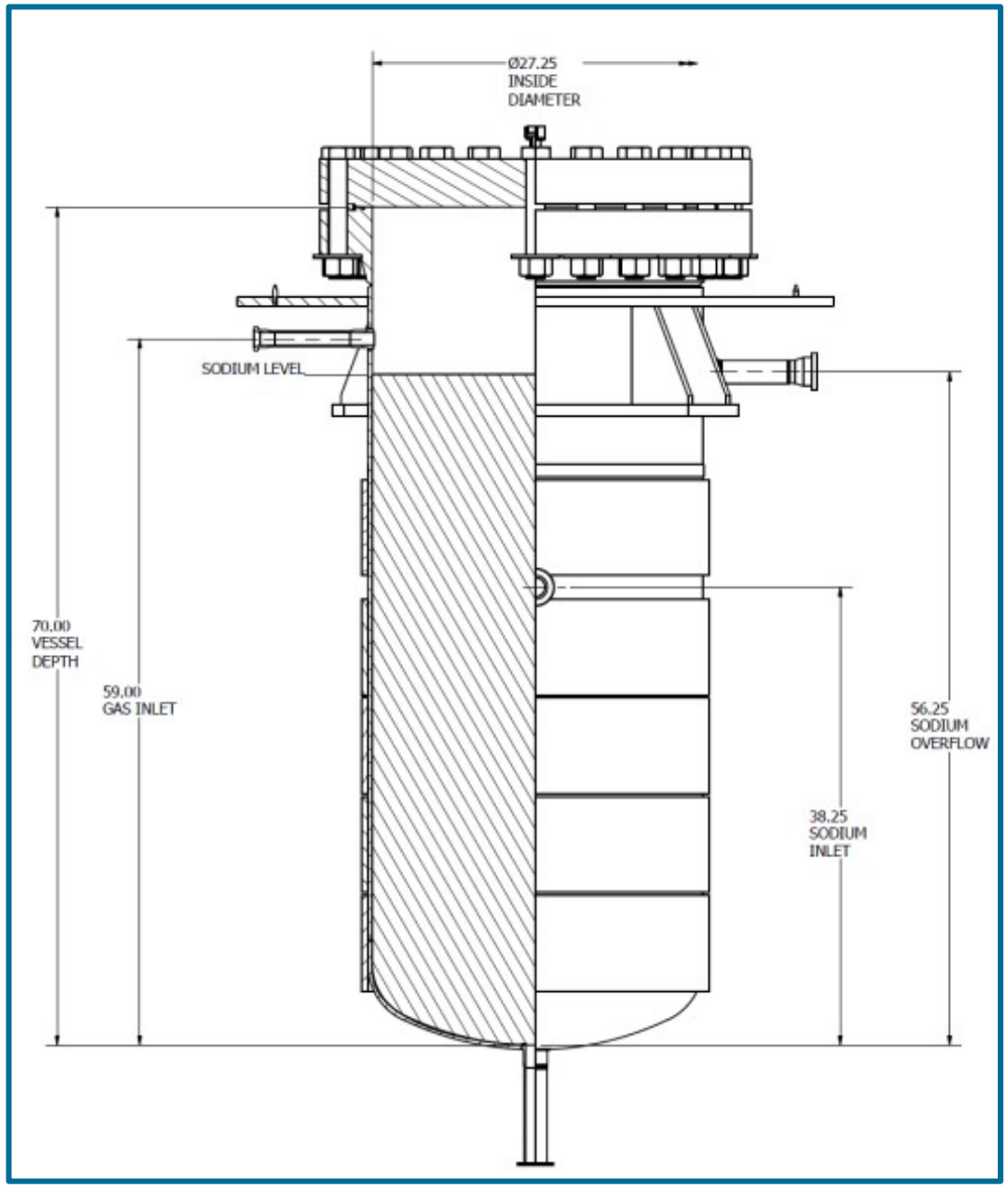
METL P&ID

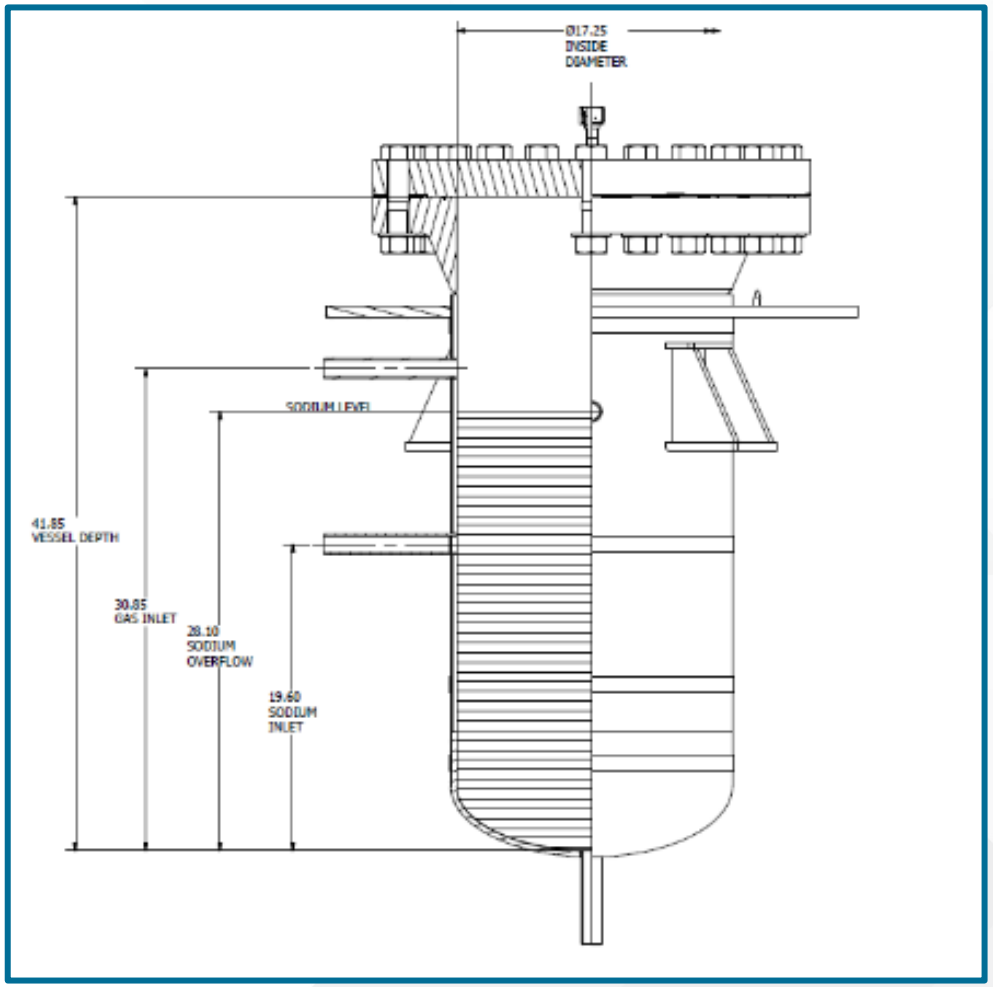

ISSUED FOR
DATE: May 15, 2015
CONSTRUCTION
Vacuum Pump
Na Dump Tank
Expansion Tank
Vapor Trap #1
Vapor Trap #2
Vapor Trap #3
Vapor Trap #4
Vapor Trap #5
Vapor Trap #6
Vapor Trap #7
Vapor Trap #8
Sump Tank Vapor Trap
Piping Schematic
Phase 1-2
Mechanical Engineering
Test Facility

METL Test Vessel – Generic Flow



18-inch vessel + 28-inch vessel





18-inch vessel - ~50 gallons

28-inch vessel - ~150 gallons

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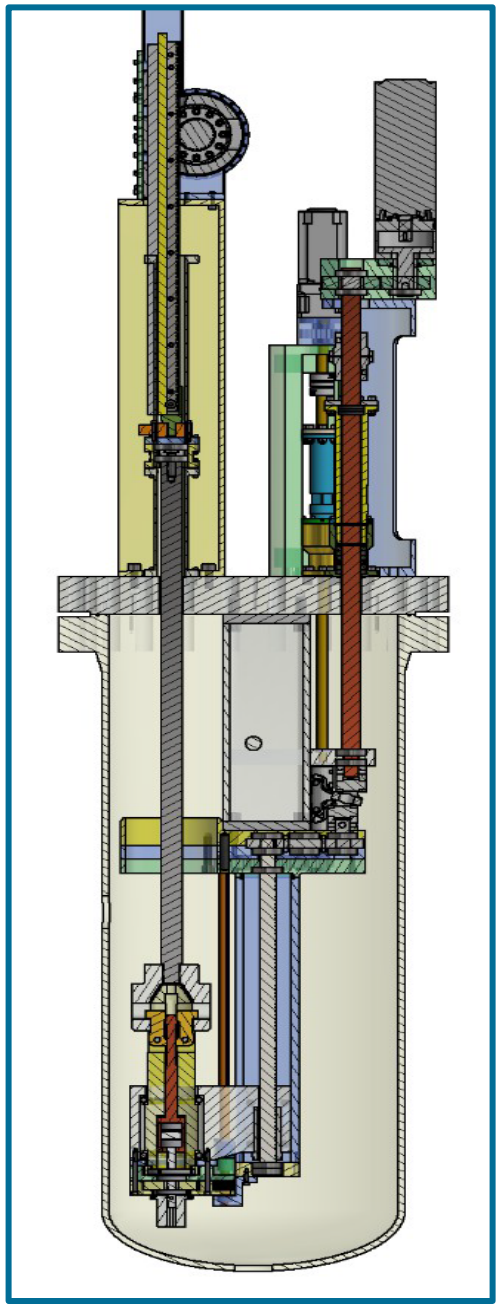
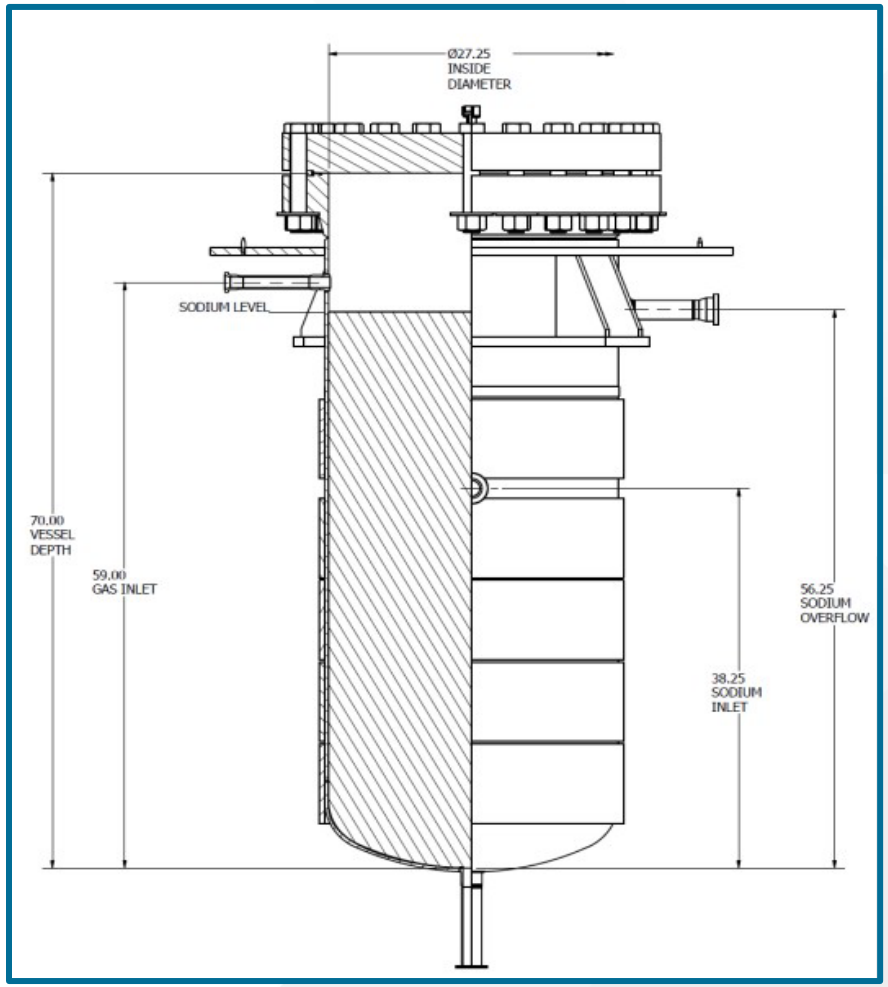
28-inch test vessel experiment – example





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METL Virtual Tour and Web Site

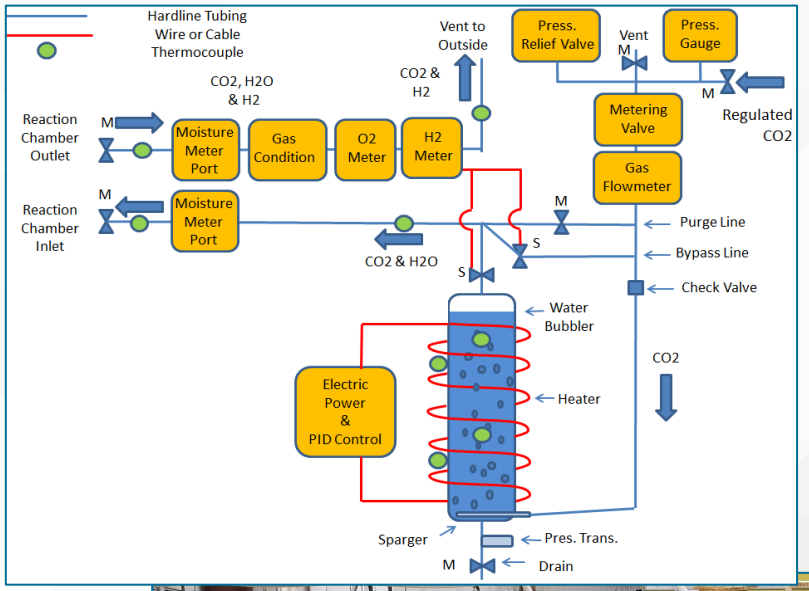
Virtual tour of METL: https://youtu.be/W4tfBd8rZ68

METL web site: https://www.anl.gov/nse/METL

METL O&M Project Progress (1/6)

METL O&M project work scope includes (e.g.):

- Operating, maintaining, and improving METL
- Operating, maintaining, and improving the supporting infrastructure for METL
- Periodic circulation and purification of sodium in METL
- Coordination of experiment installation, removal, and cleaning in METL infrastructure
- Maintaining the 18-inch and 28-inch flexicask systems
- International collaborations under Gen-IV – CDBOP under the technical area of testing facilities
- Adding additional test vessels and support systems



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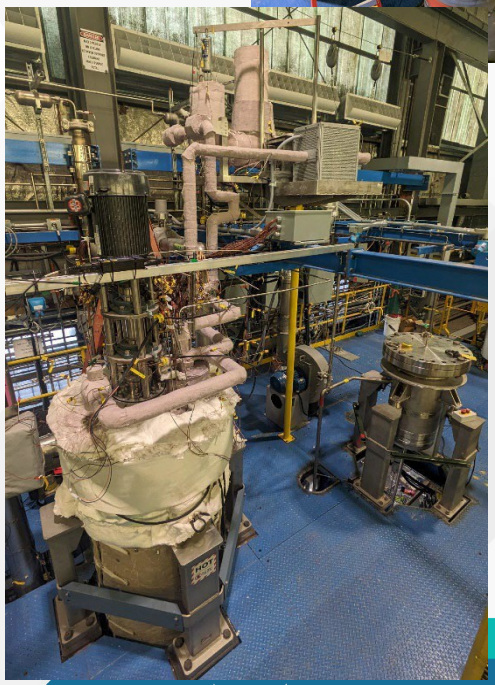
METL O&M Project Progress (2/6)

Accomplishments for FY24/25:

- METL was successfully operated continuously from September 19, 2018.
  - About 6.5 years
  - METL was drained on April 20, 2021 and then frozen to effect modifications to the B308 scrubber unit – first time for drain and freeze
  - METL was drained on July 15, 2024 and the dump tank frozen to support the installation of Test Vessel 6
- METL is maintained in a hot molten state 24 hours a day, seven days a week.
- The METL team maintained purification of the sodium via cold trapping down to 5ppm oxygen and recently replaced the cold trap
- METL supported the installation and testing of two test articles – GTA (test #8 and #9) and THETA
- METL supported the cleaning of the GTA using the carbonation system
- An off-the-shelf structural health monitoring system was installed on Test Vessel 6 piping

Installating THETA



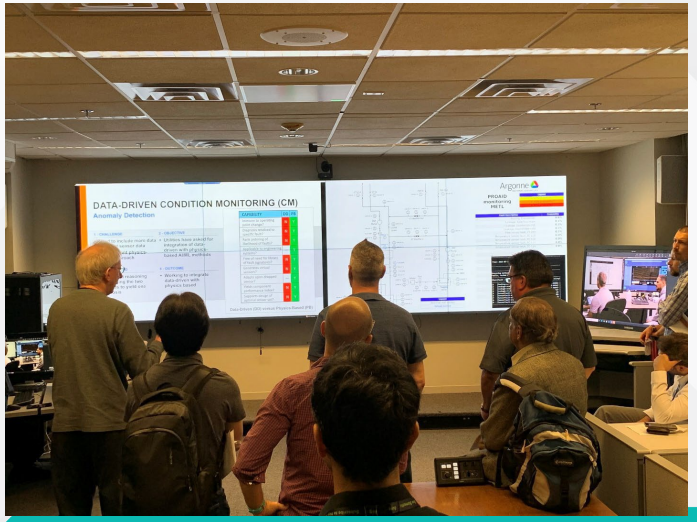
THETA installed in METL

METL O&M Project Progress (3/6)

Accomplishments for FY24/25:

- We completed the installation of another 18-inch vessel (Test Vessel 6).
  - Piping was welded into the METL supply, return, drain, and gas supply and exhaust lines.
  - Piping and vessel were instrumented and heat traced.
  - Piping and vessel were insulated.
  - FY24 M2 milestone was missed due to the need for welders to complete SMT-3.
  - FY25 M2 milestone was completed in January 2025.
- METL Experimenters Guide was updated and published.
- Operate and Maintain METL to support testing
  - GTA testing – related to milestone – M3AT-23AN0502011 / M3AT-24AN0502012
  - THETA testing – related to milestone – M2AT-23AN0502012 / M2AT-24AN0502011
  - Installation of piping health monitoring system – M4AT-23AN0502015
- Making preparations for GrTA and F-STAr testing.
- We are also making preparations for our first Industry test article. – April 2025
- Provided support to ASI program for a diagnostic Software demonstration program.
  - METL provides a unique facility for demonstrating diagnostic and prognostic software.

Test Vessel 6



METL Prognostic Demonstration

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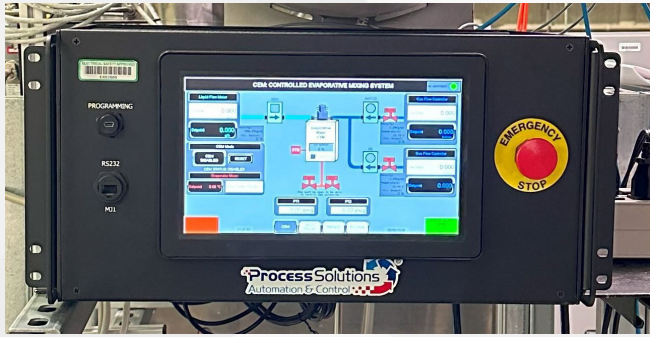
METL O&M Project Progress (4/6)

- **Wet-Vapor Nitrogen Cleaning System**
  - A new system in the METL facility that uses wet-vapor in a Nitrogen carrier gas to passivate residual sodium and aid in the cleaning and disassembly of METL test articles and components.
  - Provides direct control of the mixing of wet-vapor/steam with Nitrogen carrier gas. Additional Carbon-Dioxide flow control allows system to mimic and enhance moist carbon dioxide bubbler processes traditionally used for sodium passivation.
- **Features:**
  - **Wet-Vapor/Steam**: < 1100 grams/hr (0.3 gals/hr) fed from 30 gallon DI water tank.
  - **Gases:** Nitrogen, Carbon Dioxide, Argon, 5-100 liters/min
  - **Mixture Temperatures:** < 200°C
  - **Heat Trace:** Heated plumbing lines < 200°C, prevents thermal losses from mixing unit to reaction vessel
  - **Reaction Vessel:** 28” METL vessel suitable for all METL test articles
  - **Diagnostics:** thermocouples, pressure transducers, humidity sensors, hydrogen and oxygen gas monitors



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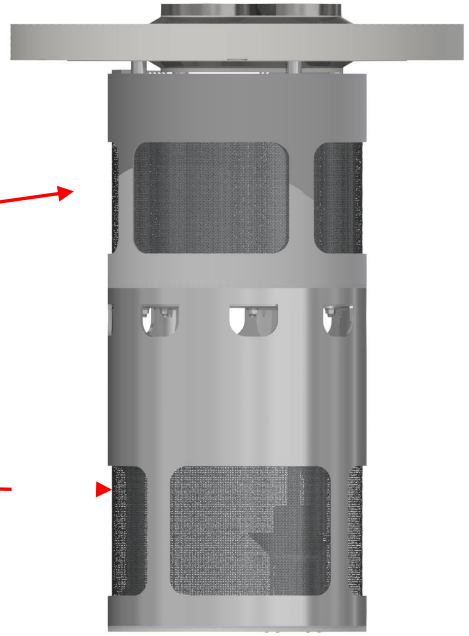
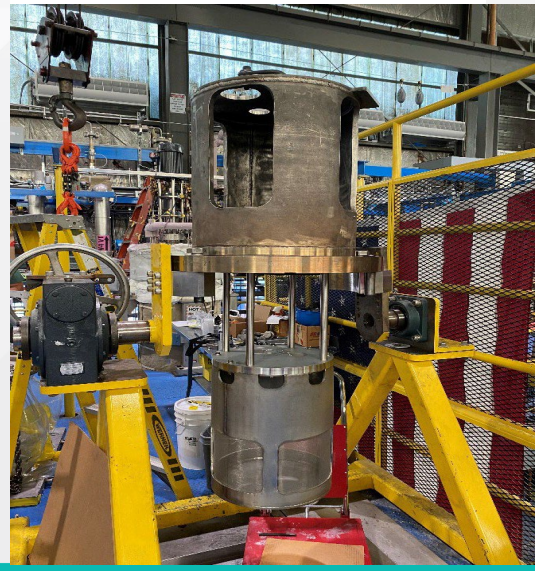
METL O&M Project Progress (5/6)

- METL Sample basket is composed of two parts
  - Upper vapor basket
  - Lower sample basket
- The METL sample basket is designed to be installed in one of the METL 18-inch test vessels.
- 18-inch test vessel max temperature: 1000F = 538C





METL O&M Project Progress (6/6)

METL Cold Trap Replacement:

- Cold trapping is the primary way of purifying sodium in loops and sodium reactors.
- As temperature is dropped, sodium oxide and hydride crystalize out into an area.
- METL has an air-cooled cold trap.
- We were purifying to 170C (about 5ppm)
  - Customer wants us to purify to 150C (about 2ppm oxide)
  - When we tried to purify below 170C we were losing flow – so we replaced the cold trap

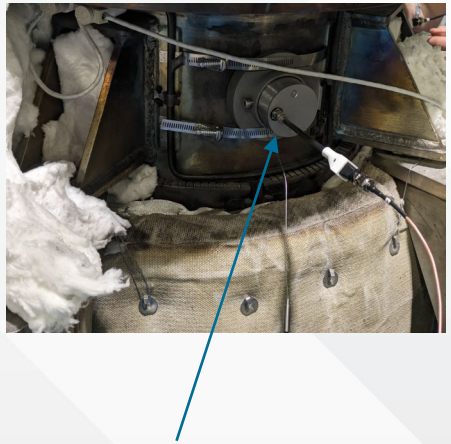
Old Cold Trap

New Cold Trap

New Cold Trap

METL Collaborations with NEUP

Fiscal Year Funding	Project FY-ID	Title	Organization	PI First Name	PI Last Name
2018	18-14908	Experimental measurements of fission product retention in liquid sodium	University of Wisconsin-Madison	Mark	Anderson
2018	18-15471	Integral Experimental Investigation of Radioisotope Retention in Flowing Lead for the Mechanistic Source Term Evaluation of LFR	University of New Mexico	Osman	Anderoglu
2019	19-16754	Simultaneous Corrosion/Irradiation Testing in Lead and Lead-Bismuth Eutectic: The Radiation Decelerated Corrosion Hypothesis	Massachusetts Institute of Technology	Michael	Short
2019	19-16811	Liquid metal-cooled fast reactor instrumentation technology development	University of Wisconsin-Madison	Mark	Anderson
2019	19-17355	Development of Versatile Liquid Metal Testing Facility for Lead-cooled Fast Reactor Technology	University of Pittsburgh	Jung-Kun	Lee
2020	20-19524	Non-Intrusive Flow Monitoring for Liquid Metal and Molten Salt-Cooled Reactors	Virginia Polytechnic Institue and State University	Gary	Pickrell
2021	21-24162	Self-powered wireless sensor system for health monitoring of liquid-sodium cooled fast reactors	University of Notre Dame	Yanliang	Zhang
2021	21-24389	High Temperature Electromagnetic Acoustic (EMAT) Transducers for Structural Health Monitoring	University of Cincinnati	Joseph	Corcoran
2022	22-27082	Dual Mode High Temperature MEMS Ultrasonic Sensor for Structural Health Monitoring of Liquid Metal Reactor	University of Illinois at Chicago	Didem	Ozevin
2022	22-26857	Characterizing Fast Reactor Failure Mode through Separate Effect and Prototypic Tests	Oregon State University	Guillaume	Mignot
2023	23-2903	Optical Sensors for Impurity Measurement in LMFRs (IC-1 Program)	University of Michigan	Milos	Burger



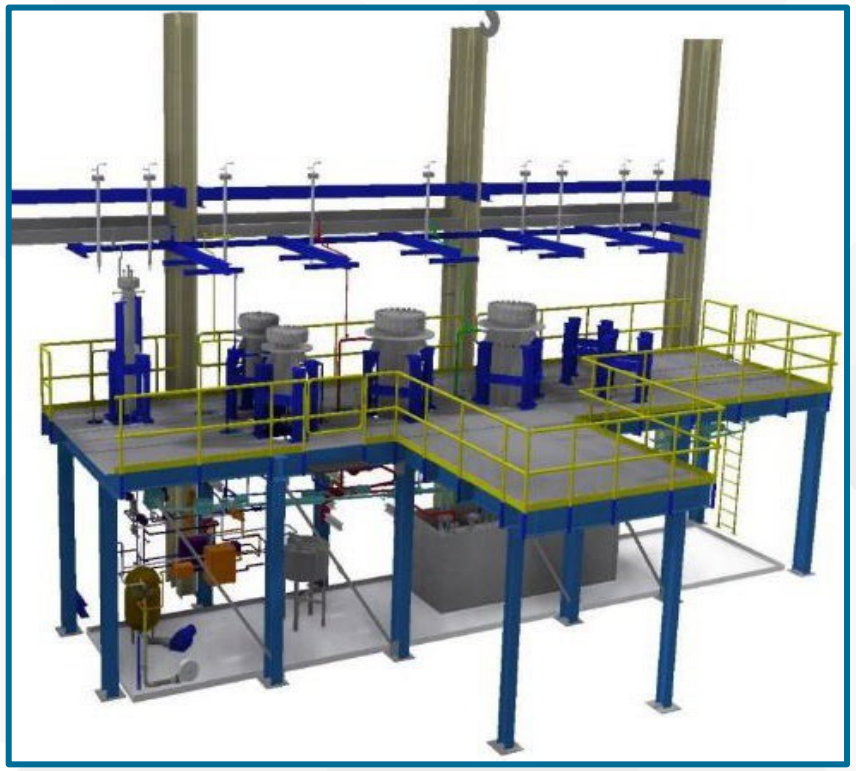
EMAT Sensor installed on Test Vessel 1

Collaborations with Industry

- We have a Small Business Innovation Research (SBIR) call for mechanical bearings for sodium applications.
  - We are working with a couple vendors who have received SBIR funding or who are in process of applying for SBIR funding.
- We completed a GAIN award with OKLO for the testing at the THETA test article which is located in METL Test Vessel 4.
  - THETA supports the validation of Oklo and Argonne THETA codes.
  - THETA work is also part of GIF CDBOP and THETA collaborations.
- We signed a Cooperative Research and Development Agreement (CRADA) with another company to test multiple test articles in METL.

METL O&M Summary

- METL has been in an operational status since September 2018.
  - Operations were paused during scrubber repairs, test vessel 6 installation, and cold trap replacement.
  - Operational about 6.5 years
- It provides the infrastructure and capability of testing multiple test articles in a prototypic sodium environment.
- It is the largest facility of its kind in the DOE complex.
- It is supporting DOE R&D, Nuclear Energy University Program (NEUP) and SBIR awardees, and industrial vendors.



Questions?

NRIC National Reactor Innovation Center

Contact: Cgrandy@anl.gov

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

www.nric.inl.gov