U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Molten Salt Reactor PROGRAM

# Salt Loop and Capability for Testing Sensors and Off Gas Components – FY24

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**+Many collaborators**

OAK RIDGE National Laboratory

**Annual MSR Campaign Review Meeting 16-18 April 2024**

# DOE-NE MSR Program Milestone FY24

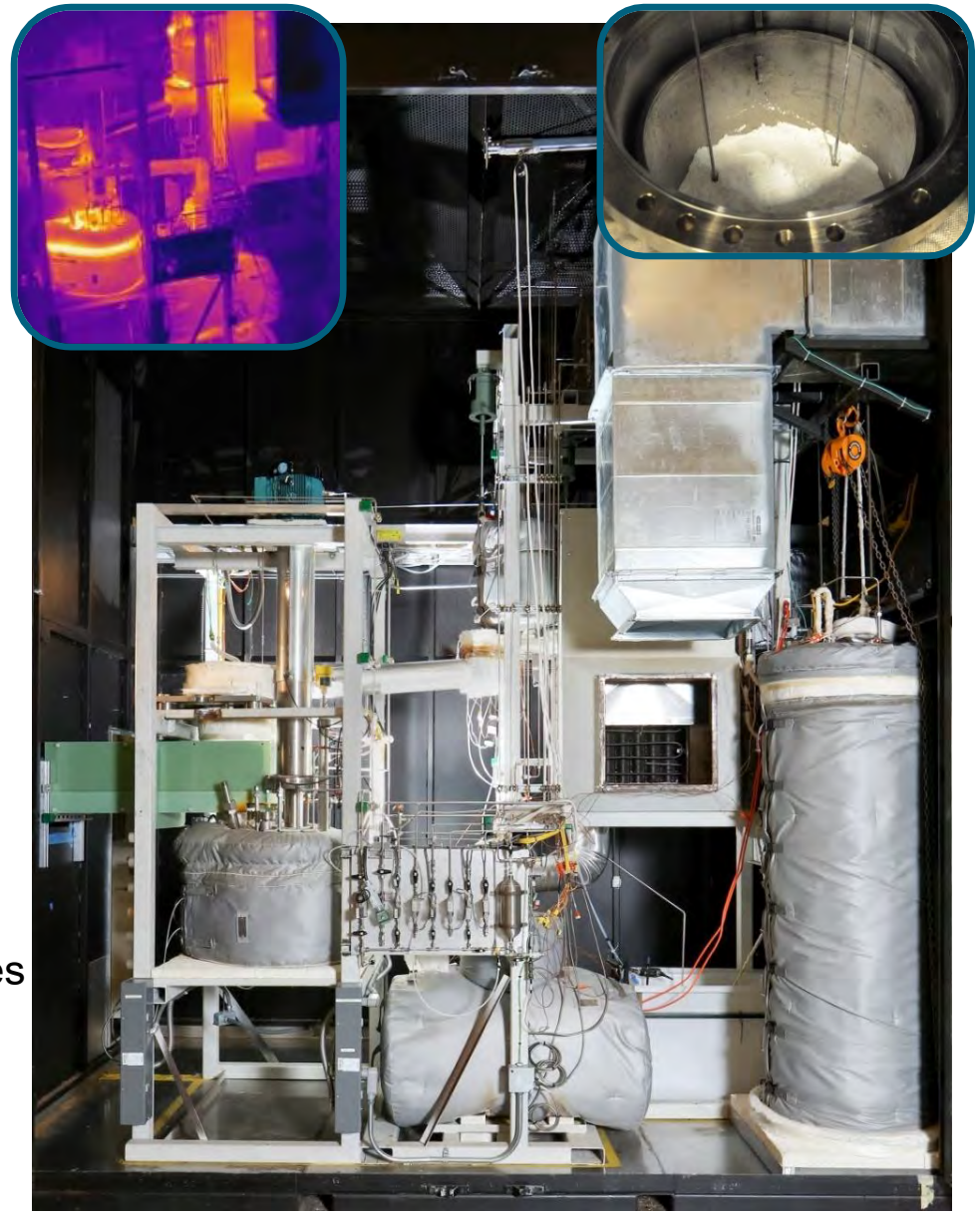
| WP | Milestone | Date |
|---|---|---|
| AT-24OR070202<br>Salt Loop and Capability for Testing Sensors and Off Gas Components | Complete two test campaigns in support of collaborative sensor testing and creation of datasets for use in model verification. | 9/30/2024 |

# Liquid Salt Test Loop (LSTL)

## Largest F salt loop in DOE

| | |
|---|---|
| Salt | NaF-KF-LiF (FLiNaK) |
| Operating Temp. | 700°C |
| Flow rate | ≤4.5 kg/s (136 lpm) |
| Operating pressure | Near atmospheric |
| Primary Materials | Inconel 600 |
| Loop volume | 80 liters |
| Power | 200 kW induction<br>~20 kW trace |
| Primary piping ID | 2.67 cm (1.05 in.) |
| Initial operation | Summer 2016 |

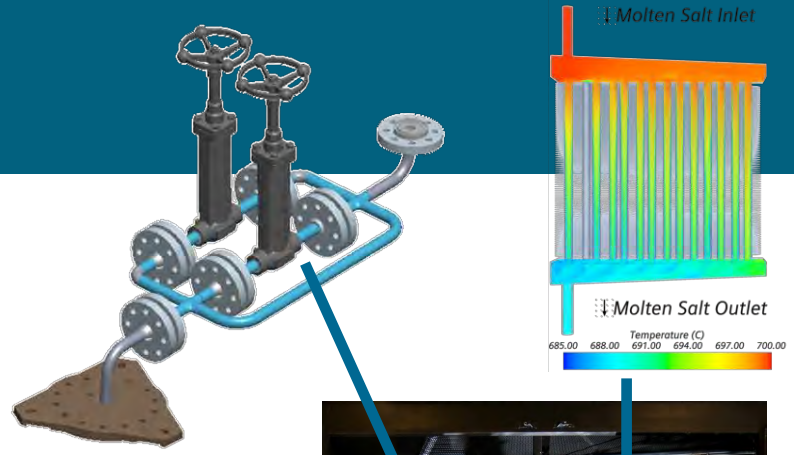
- Integral environment for testing and demonstration of technologies
- Large batch (165 kg) purification system to prepare/refresh salt
- Appreciable power and I&C
- Was and still is state-of-the-art

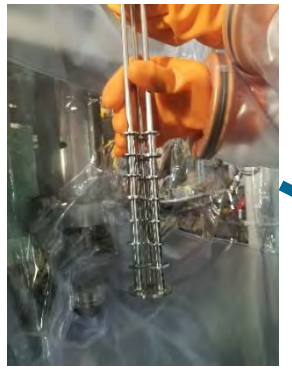


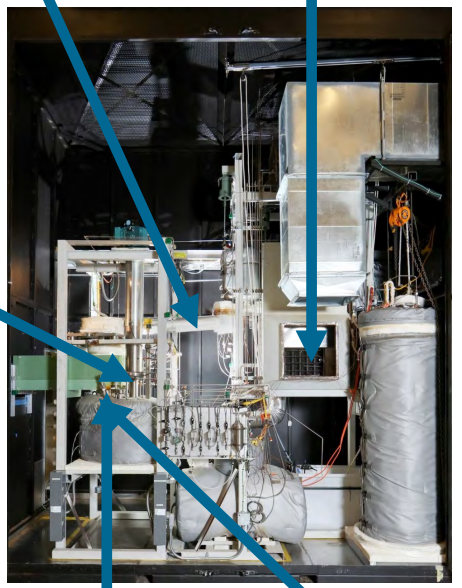
# Liquid Salt Test Loop (LSTL) Historic Efforts

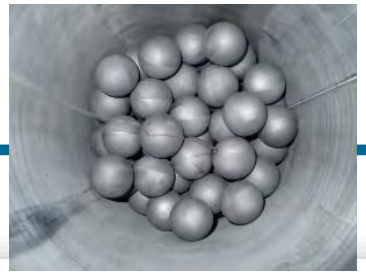
- High-level series of efforts over the last several years:
  - Repurified salt through hydrofluorination
  - Restarted loop, SiC section cracked on cool down
  - Disassembly and cleanout of SiC pieces, designed new heated section
  - Fabricate and install new section
  - Restarted loop and ran tests

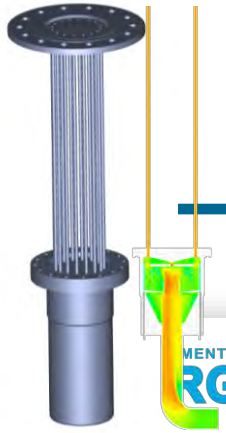
- Example topical studies
  - Evaluated 2x NaK filled pressure transducers, failed
  - Flange design, success
  - Radar level gauge, success
  - Pump characterization, partial
  - Valve test plan, halted
  - TRACE code modeling
  - HX freezing numerical eval.
  - GT corrosion coupon addition

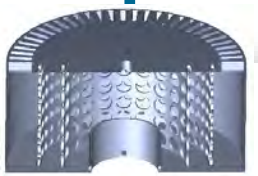






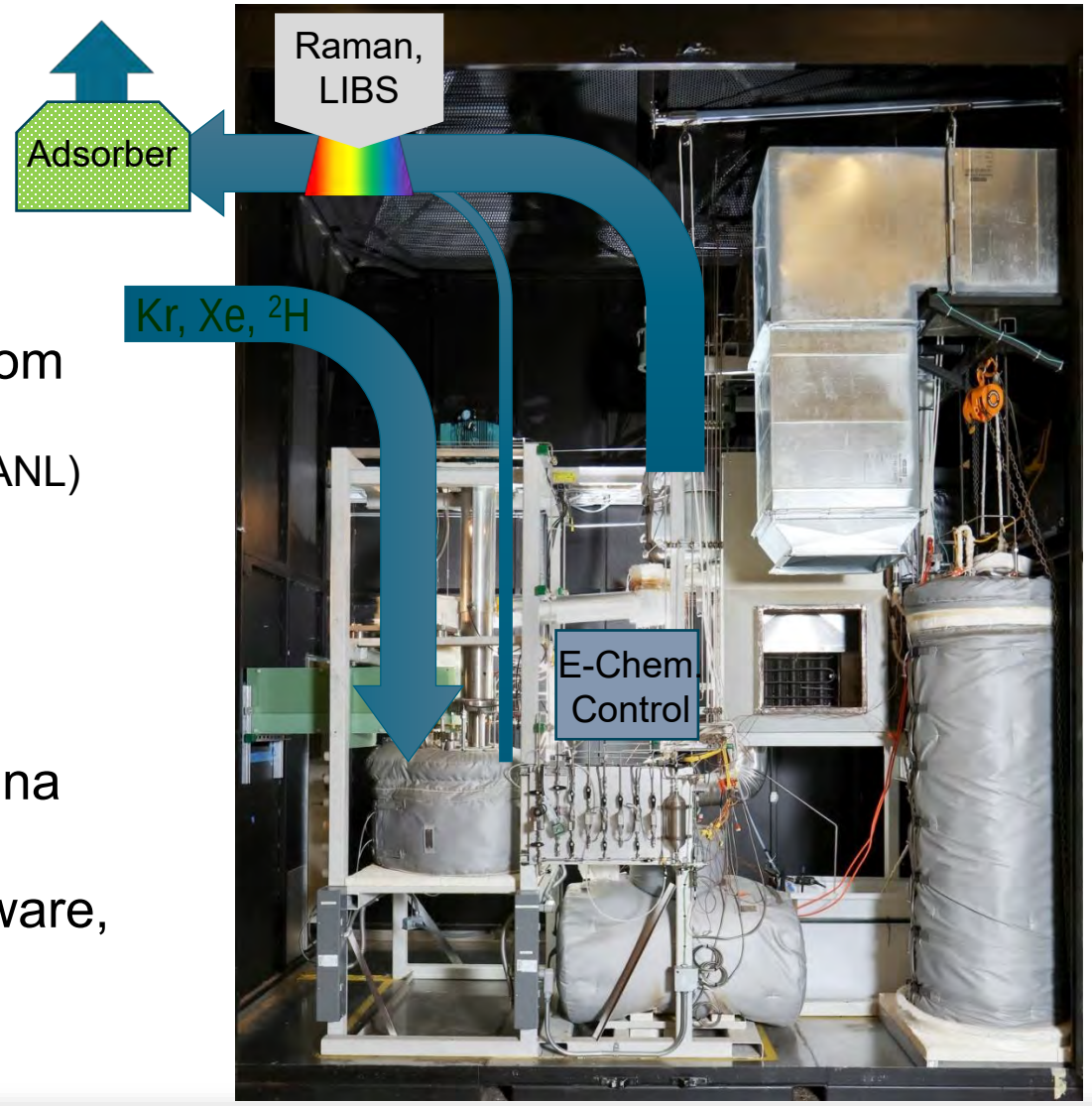




# Liquid Salt Test Loop (LSTL)
# Recent: Study species transport and sensors

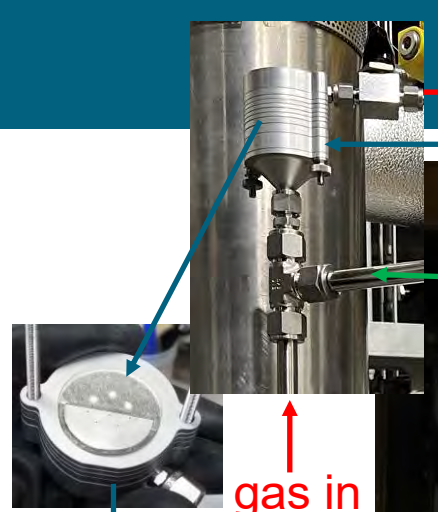
## Multi-year and Progressive Goals:

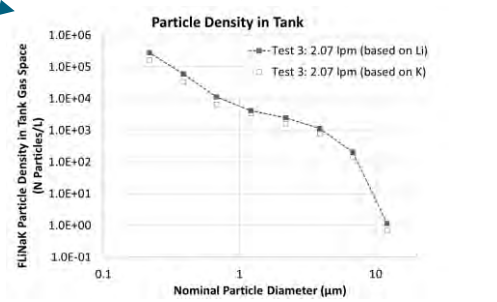
- Injection and tracking of species
  - Gases: Kr, Xe, $^{2}H$
  - Iodine, Cerium, etc.
- Parallel development and demonstration of sensors from collaborators
  - Raman (PNNL), LIBS (ORNL), E-Chem monitoring and control (ANL)
  - Novel sensors from industry and universities
  - *In situ corrosion sensors (ORNL)*
- Collaborative design and testing of off-gas treatment
  - Noble gas (i.e. Xe) adsorbers, aerosol capture
- Provide validation data for species transport phenomena models and integral predictions
- Other piggyback tests – adv. materials/coatings, hardware, O&M methods

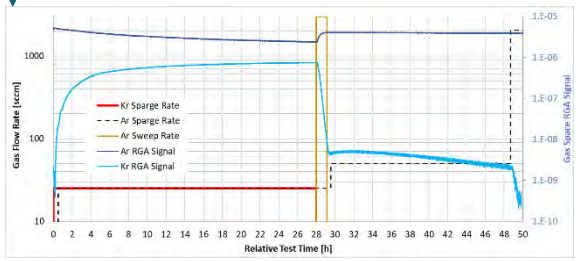


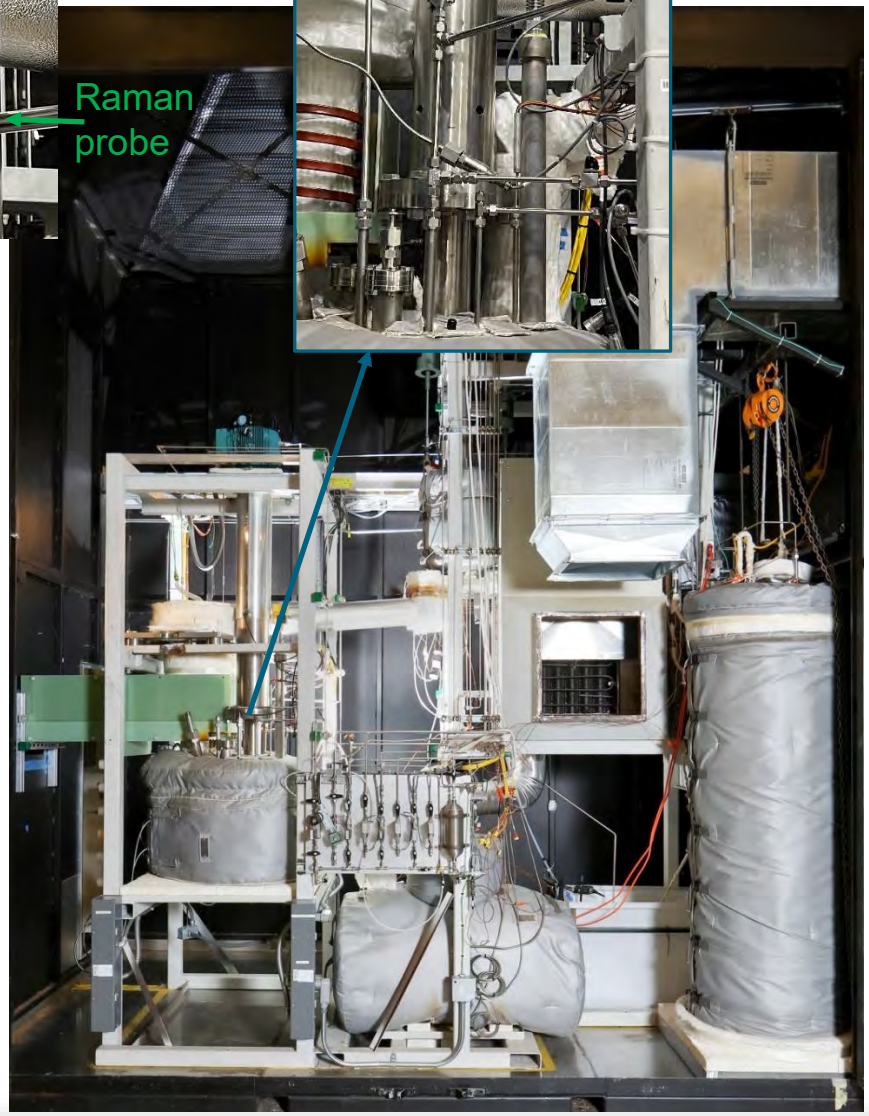
# Liquid Salt Test Loop (LSTL) FY23 Efforts

- Focus on species transport and sensor exposure
- Test flowmeter for VT (NEUP)
  - 4 pump speeds, 4 hours, 600°C
- Aerosol characterization, 4 tests
- Species injection: Kr
- Expose sensor
  - E-Chem monitoring and control (ANL)
  - Raman (PNNL)
- Provide info for modeling
  - SAM (ORNL)
  - MELCOR (SNL)
- New heated section performance
- Pump tank gaseous leak suspected at end FY23, confirmed early FY24



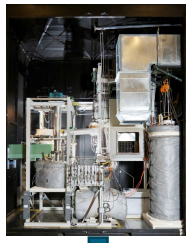



Yoder, G., Robb, K., Dominguez-Ontiveros, E., Felde, D., Fugate, D., & Holcomb, D. (2023). *Start-up operation experience with a liquid fluoride salt forced convection loop*, ORNL/TM-2023/2978, Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (United States). https://doi.org/10.2172/1995677

# Facility to Alleviate Salt Technology Risks (FASTR)

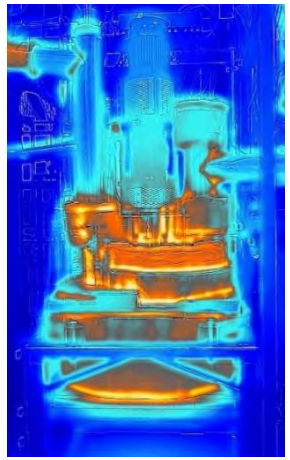
## Largest Cl salt loop in DOE

| | |
|---|---|
| Salt | NaCl-KCl-$MgCl_2$ |
| Operating Temp. | 725°C |
| Flow rate | ≤7.0 kg/s (228 lpm) |
| Operating pressure | Near atmospheric |
| Primary Materials | C-276 & Inconel 600 |
| Loop volume | 154 liters |
| Power | 400 kW Main Heater<br>~71 kW trace |
| Primary piping ID | 5.20 cm (2.05 in.) |
| Initial operation | December 2022 |



Compared to LSTL, FASTR is:

- 2x higher capacity pump
- 2x larger salt volume
- 2x larger pipe
- 2x thermocouples
- 2x main heating capacity
- 3x trace heating capacity
- 4x number of salt flanges



*Original development support by DOE-EERE SETO CPS 33875*

Robb, Kevin, and Kappes, Ethan. *Facility to Alleviate Salt Technology Risks (FASTR): Commissioning Update*. United States: **ORNL/TM-2023/2846**, 2023. Web. doi:10.2172/1960689.
Robb, Kevin, Kappes, Ethan, and Mulligan, Padhraic L. *Facility to Alleviate Salt Technology Risks (FASTR): Design Report*. United States: **ORNL/TM-2022/2803**, 2022. Web. doi:10.2172/1906574.

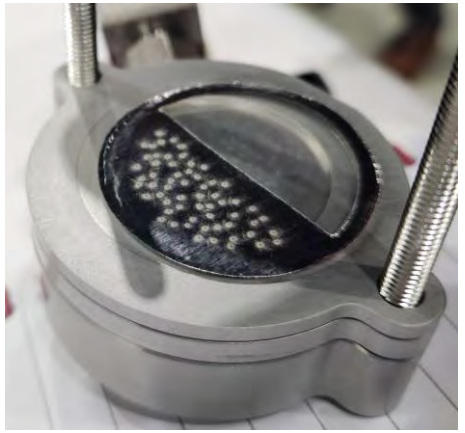
# FASTR
# Plans FY24

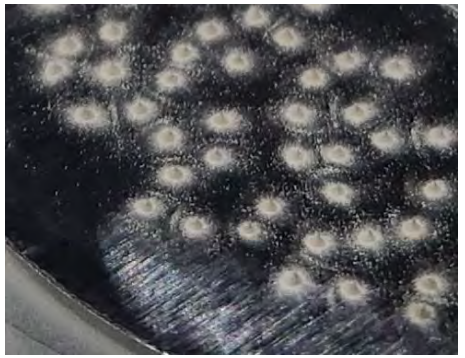
- With gas leak in LSTL, decided to focus MSR resources on FASTR for FY24, Goals:
  1. Repeat FY23 LSTL tests but with Cl salt
     - Expose PNNL Raman probe
     - Operate ANL multifunctional voltammetry sensors
     - Aerosol characterization tests
     - *End-FY: Operate PNNL Raman probe, Kr injection if resources allows*
  2. Gain operation experience and time
  3. Expose sensors for small business (separate under an EERE SBIR)

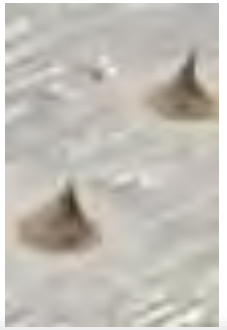
- Synergies
  - Digital Twin efforts
  - Mod-Sim efforts
  - Augmented reality test bed demonstration

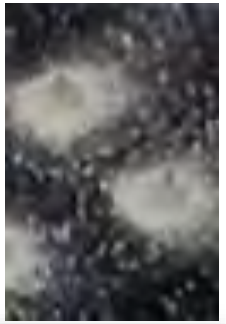
# FASTR
# Progress FY24

- Completed range of maintenance
  - Required pressure system and electrical DOE compliance activities
  - Repaired leaking fitting and failed trace heating
  - Replaced failed gas mass flow controller
  - Replaced line plugged with salt from unplanned transient experiment
- Restarted (**as of 4/3/24**)
  - Started heating salt 3/18, loop 3/25
  - Conducted three aerosol tests (more planned)
  - PNNL Raman probe exposed >200h (and counting) @ >500 C
  - ANL sensor run (4/2-3), salt appears similar to last time it was run
  - Pumping salt (4/3)!
  - Pump vibration testing
  - SBIR sensor test
  - *And more!*
- FY24 Milestone is on track







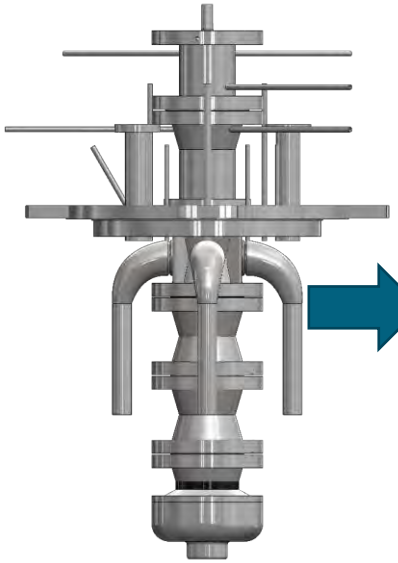


# FASTR
# Future

- Similar to LSTL vision: Focus on species transport and sensor exposure/testing
  - Species injection, start with noble gases (e.g. Kr)
  - Expose/test sensor
    - E-Chem monitoring and control (ANL)
    - Raman (PNNL)
- Continue aerosol characterization
  - Important impact on practical operations & mitigation measures
- Add/increase focus on verifying flow measurement
  - Broad stakeholder need defensible flow rates
  - Low-hanging fruit for heat transfer test
- Provide info for modeling
  - SAM (ORNL, ANL)
  - MELCOR (SNL)
- Increase run time and socialize operation experience

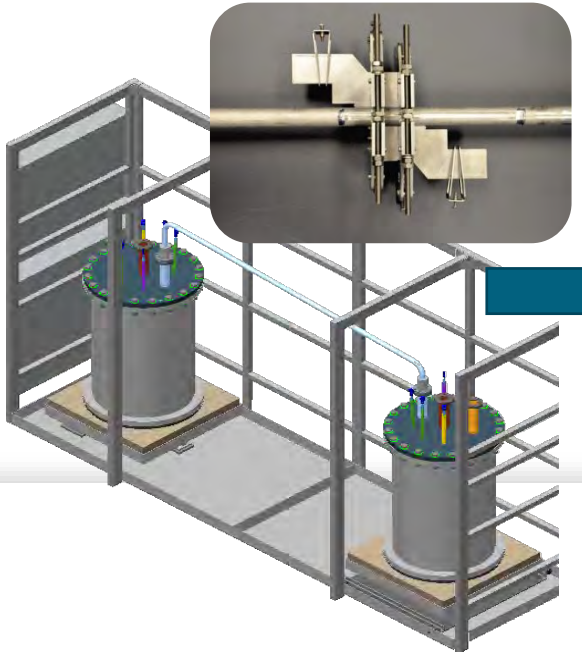
# Salt Pot Instrumentation and Components Evaluation Experiment (SPICEE)

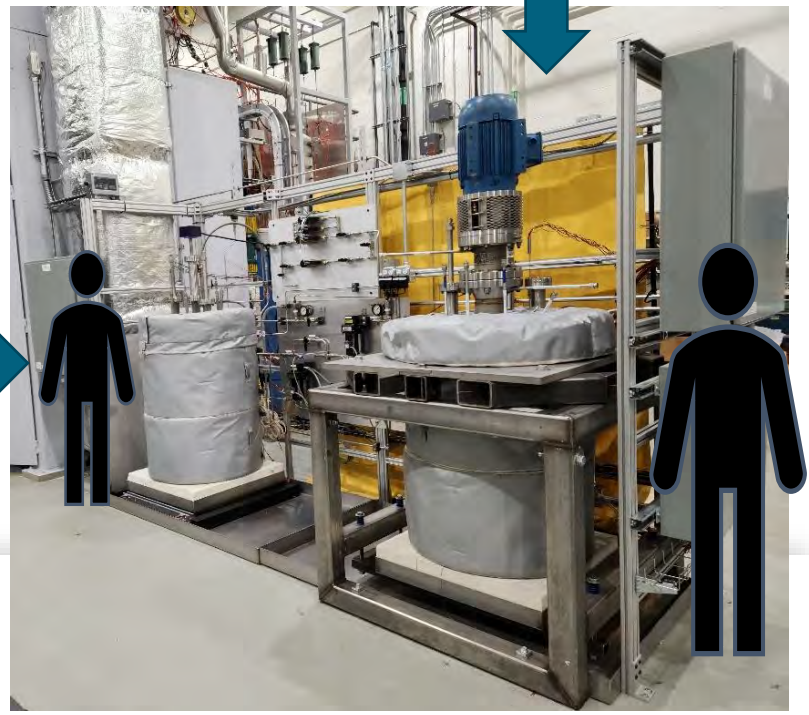
- Flow calibration stand for development of standards and to calibrate flowmeters for accurate and defensible data
- Demonstrate salt-wetted bearings to enable long-shaft pumps for pool-type reactors and larger sized pump



## Large two-tank system

| | |
|---|---|
| Salt | Cl or F-based |
| Operating temp. | 710°C @ 0.3 $MPa_{abs}$ |
| Flow rate | ≤5.8 kg/s |
| Operating pressure | Up to 0.3 $MPa_{abs}$ |
| Primary materials | SS & Ni |
| Salt volume | 120 liters |
| Power | ~27 kW trace |
| Primary piping ID | ~2.50 cm (1 in.) |
| Initial operation | TBD! |





# Roles of this type of effort

Forms a hub for technology:

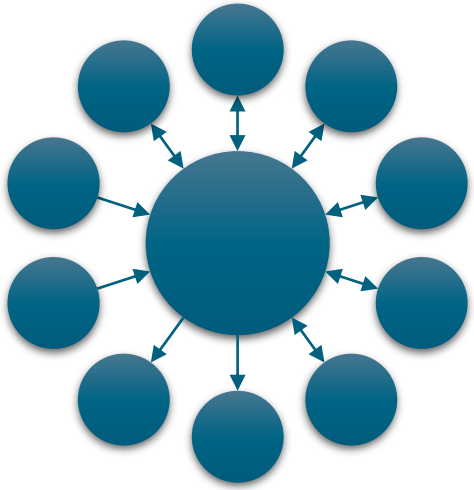
- Advancement & demonstration
- Collaboration & communication
- Independent verification
- 1st mover risk/cost absorption
  - Supply chain motivator

University
- Coupon exposure (GT NEUP)
- Flow meter test (VT NEUP)
- Education experience (interns)

Business
- Sensor demo. (SETO)
- System monitor demo. (LEEP)

Cross-Cutting
- Gas space particle transport
- Species transport plans
  - Off-gas monitoring
- Topical component studies
  - Pump
  - Valve
  - Flanges
  - I&C
  - Trace Heating
  - Heat exchanger
- MOSARD (reliability database)
- Lesson learned communication

Laboratory
- ANL e-chem sensor
- PNNL Raman sensor
- ANL/ORNL SAM V&V
- SNL MELCOR V&V
- INL/ORNL digital twin (IES)
- Property databases (usage)
- etc…



# Thank you!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