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FLOW ENHANCED ELECTROCHEMICAL SENSORS FOR MOLTEN SALT REACTORS

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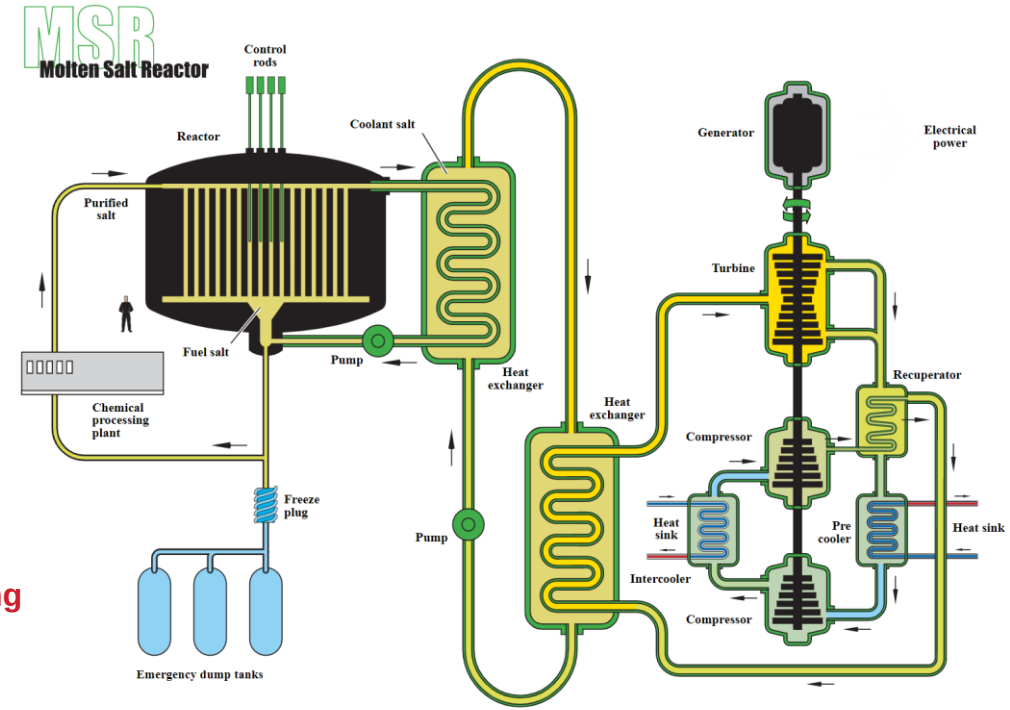
Advanced Reactor Safeguards and Security Stakeholder Meeting

SAFEGUARDS AND PROCESS MONITORING FOR MOLTEN SALT REACTORS

The dissolved actinides within fuel salts make MSRs a challenge for safeguards

- High temperatures and corrosive salts make it difficult to design sensors with sufficient longevity, stability, and accuracy
- Simple flush-out accountancy is impossible to implement
- Actinides may be present in a variety of chemical/oxidation states (e.g. UF_3, UF_4)
- Fission products and corrosion products may plate out in various regions of the loop

The ultimate goal of this project is to provide MSR vendors electrochemical sensors capable of making salt composition and flow rate measurements to satisfy broad NRC licensing requirements for materials accountancy, criticality safety, and corrosion monitoring.



DOE Gen4 Road Map (downloaded from: http://www.ne.doe.gov/genIV/documents/gen_iv_roadmap.pdf)

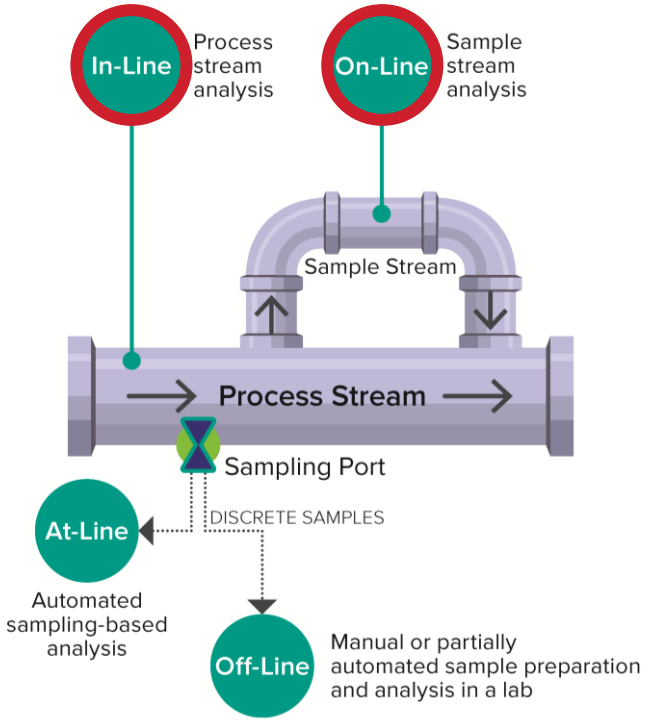
IN-LINE AND ON-LINE MOLTEN SALT MONITORING

Safeguards and process monitoring technology can be classified several broad groups

- In-Line
- On-Line
- At-Line
- Off-Line

Each group of measurements has a different range of developmental costs and expected performance profiles.

In-line and on-line sensors typically provide rapid, continuous monitoring but must be robust and long-lasting to permit installation in the main coolant or fuel salt lines.



IN-LINE AND ON-LINE MOLTEN SALT MONITORING

Argonne has a variety of salt composition/chemistry monitoring technologies under development for CSP, MSR, and fuel reprocessing applications

At-Line, Off-Line

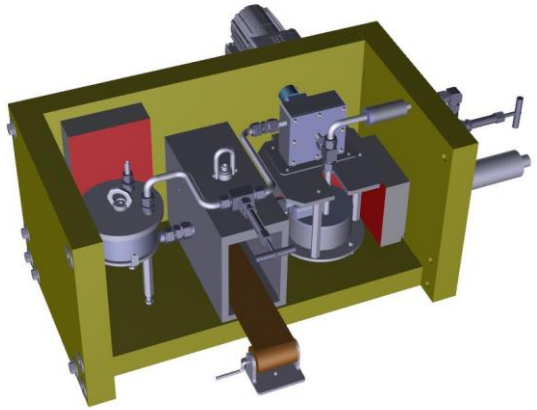
- Salt Sample Extractor / Microsampler

On-Line

- Windowless Optical Cell Sampling Loop

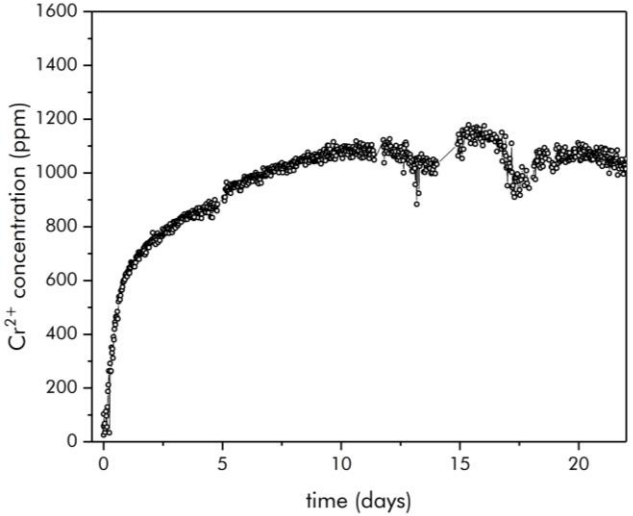
In-Line, On-Line

- Electrochemical Sensors

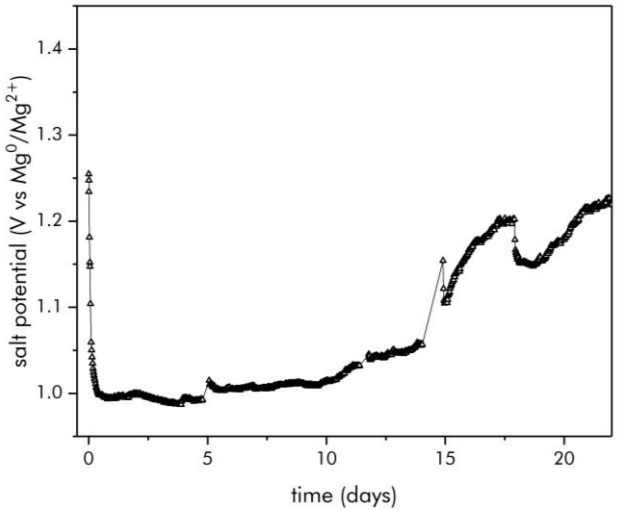


FLOW LOOP MONITORING

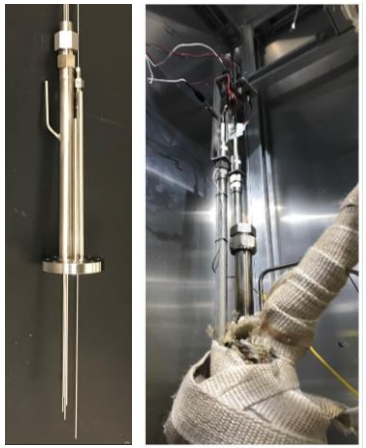
Argonne has operated electrochemical sensors for years-long durations in fuel reprocessing equipment and for months-long durations in molten salt flow loops. These sensors provide salt composition, redox state, and salt depth information. However, none of the probes used to date were specifically designed to deal with flowing conditions – shrouding or installation of the sensors in quiescent regions was needed to achieve proper operation.



Cr^{2+} concentration vs. time during typical TCL experiment



Salt potential vs. time during typical TCL experiment



Typical multielectrode array sensor

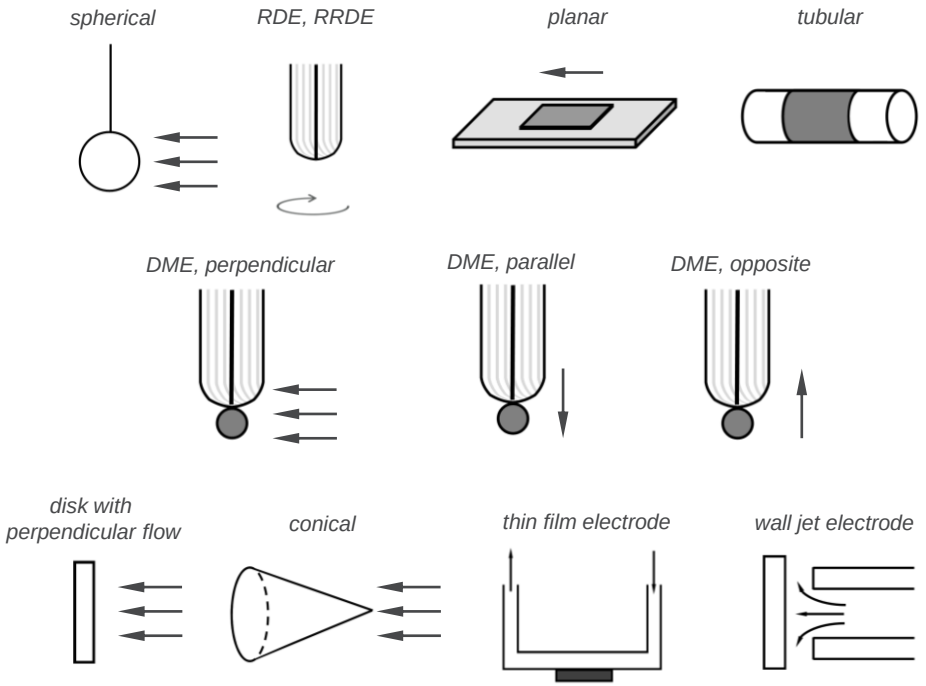
ELECTROANALYTICAL SENSORS FOR FLOWING LIQUIDS

For a properly-designed electrochemical sensor, conditions with fluid flow provide opportunities for improved sensor performance (e.g., by enabling potentiostatic and galvanostatic measurements). In addition to composition measurements, the local flow velocity may also be measured.

Applications:

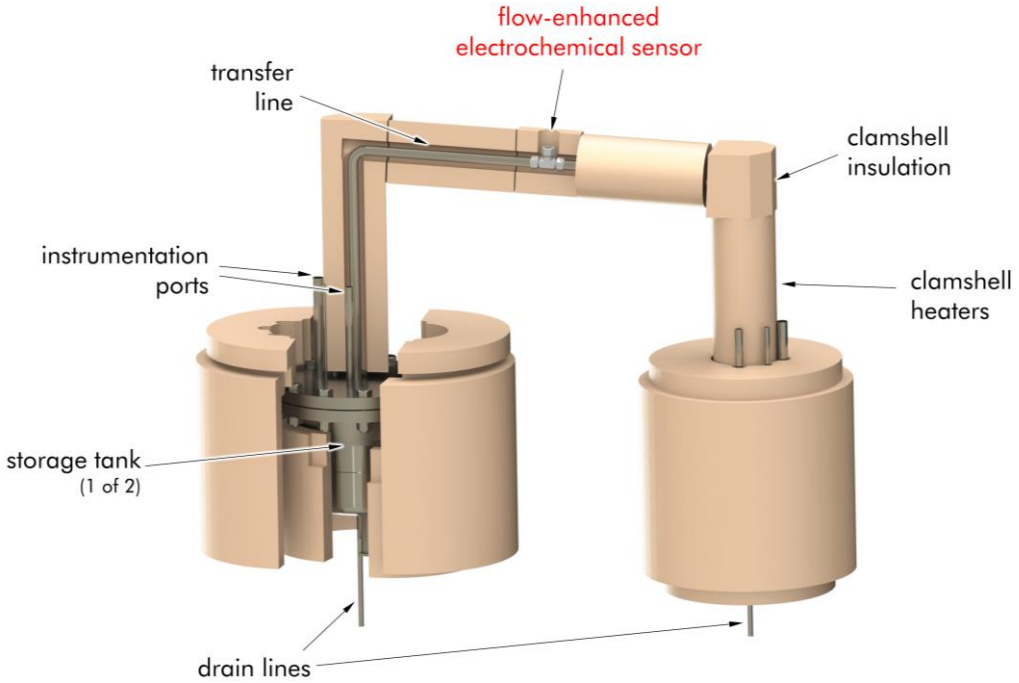
- Medical
  - Ion-selective electrodes (ISEs)
- Pharmaceutical
- Laboratory
  - High performance liquid chromatography (HPLC)
- Industrial
  - Gas detectors

Typical Hydrodynamic Electrode Systems



MODULAR FLOW INSTRUMENTATION TESTBED (MFIT)

- A modular flow system is being designed and constructed to allow for the testing of a variety of safeguards-relevant sensors
- The system consists of two tanks that may be individually pressurized to provide flow through a transfer line.
- The transfer line may be readily replaced to examine flow conditions consistent with either on-line or in-line measurements (tube diameter from ~1/8″ up to 1″)
- Many ports are included to permit the testing of a variety of sensors installed in the transfer line or in the tanks.



SYSTEM SPECIFICATIONS

A final flow system design has been created based on the testbed requirements and associated flow calculations. A P&ID including the combined glovebox systems has also been completed.

Safety calculations and documentation are being finalized to permit operations of the flow system inside of the glovebox environment.

Modular Flow Instrumentation Testbed Requirements

Property	Detail	Estimated Values	Units
Salt Compatibility	Primary and Secondary Salts	Chloride and fluoride, uranium bearing with actinide surrogates	-
Temperature range		500-700	°C
Maximum flow rate		1	std L/s
Minimum continuous flow duration	Approx. (flow rate dependent)	~1	min
Loop Material	Vessel, piping, etc.	316L, Inconel 600	
Tubing Diameter Range	Main flow conduit tubing	0.32-2.54 cm [0.125-1.0"]	cm [inch]
Maximum Salt volume		~10	L

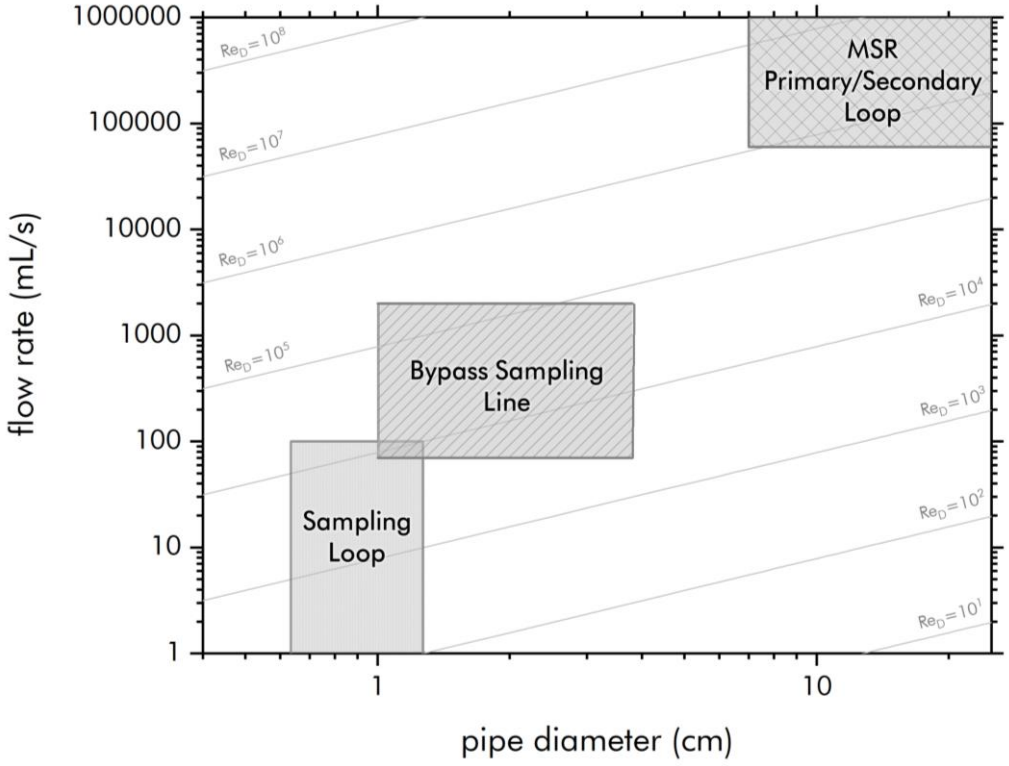
Instrumentation Suite

Thermocouples	Main heater, trace heating, etc.	~10	qty
Salt Chemistry Monitoring	Flow enhanced electrochemical sensors (flow conduit)	1	qty
	Multielectrode voltammetry sensors (in tank)	2	qty
Salt depth sensor	Multielectrode voltammetry sensors (in tank)	2	qty
Pressure Transducers	Gas space only	4	qty

PERFORMANCE ENVELOPE

Deployed sensors for an MSR may be installed within a sampling loop, a bypass sampling line, or within the primary/secondary piping.

The MFIT is designed to achieve conditions representative of all of these locations through direct coverage or through dynamic similarity (i.e. matched Reynolds number for the primary/ secondary loop)



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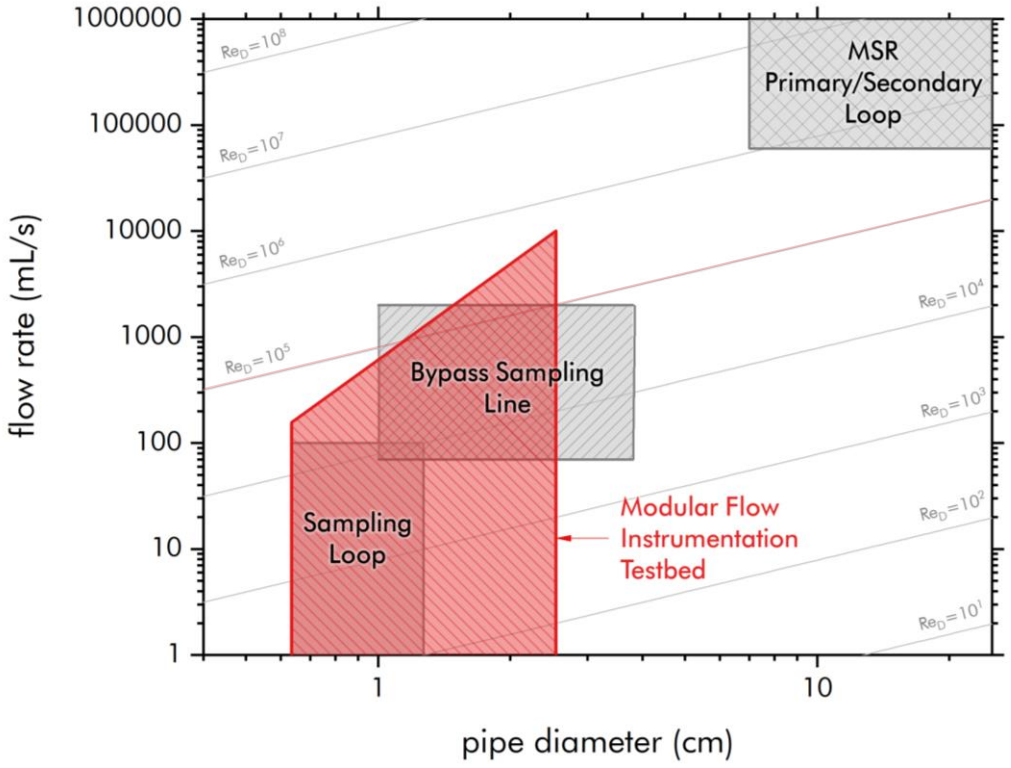


GLOVEBOX PREPARATION

A dedicated glovebox has been prepared for the installation of the MFIT. Upgrades to the gas supplies and associated systems have been made to support the flow system. Necessary safety documentation to permit usage of the pressurized flow system within the glovebox has been approved.

SALT PRODUCTION

Engineering-scale equipment is being developed to produce purified salt for the flow system.

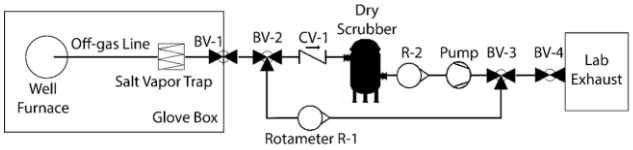
Earlier systems that were used to produce 1-3 kg of salt per batch are being expanded to produce 5-10 kg per batch with options for further scale-up.

Main Salts of Interest

- $MgCl_2$-KCl-NaCl (representative coolant salt)
- NaCl-UCl_3 (representative fuel salt)

Future Salts

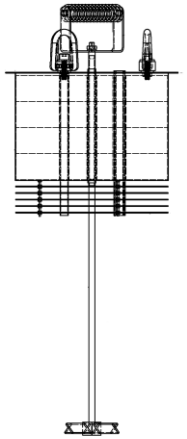
- Various Chlorides and Fluorides



Multi-kilogram salt purification system diagram

$MgCl_2$-KCl-NaCl

NaCl-UCl_3



Heat shield assembly for actively stirred purification process with reactive metal contacting

FLOW SYSTEM AND SENSOR OPERATIONS

Plan for Remainder of FY21:

- *March/April:* Shakedown operations with water
- *April:* Transfer flow system into glovebox
- *May-July:* Testing with coolant salt and added corrosion products
- *August-September:* Testing with U-bearing salts salt (NaCl-UCl_3)

Primary Near-term Goals:

Assess lifetime, accuracy, and stability of flow-enhanced electrochemical sensors across representative conditions.

Determine viability of use of flow-enhanced electrochemical sensor for MC&A and process monitoring purposes

FUTURE WORK

FLOW-ENHANCED ELECTROCHEMCIAL SENSORS

Testing with alternate fuel salt formulations (chlorides and fluorides)

Testing with fission product surrogates (rare earths, etc.)

Loop deployment at MSR vendor or national laboratory facility

- *Demonstrate flow rate and salt composition measurements under pulsatile flow conditions*
- *Demonstrate long-term performance*

MODULAR FLOW INSTRUMENTATION TESTBED

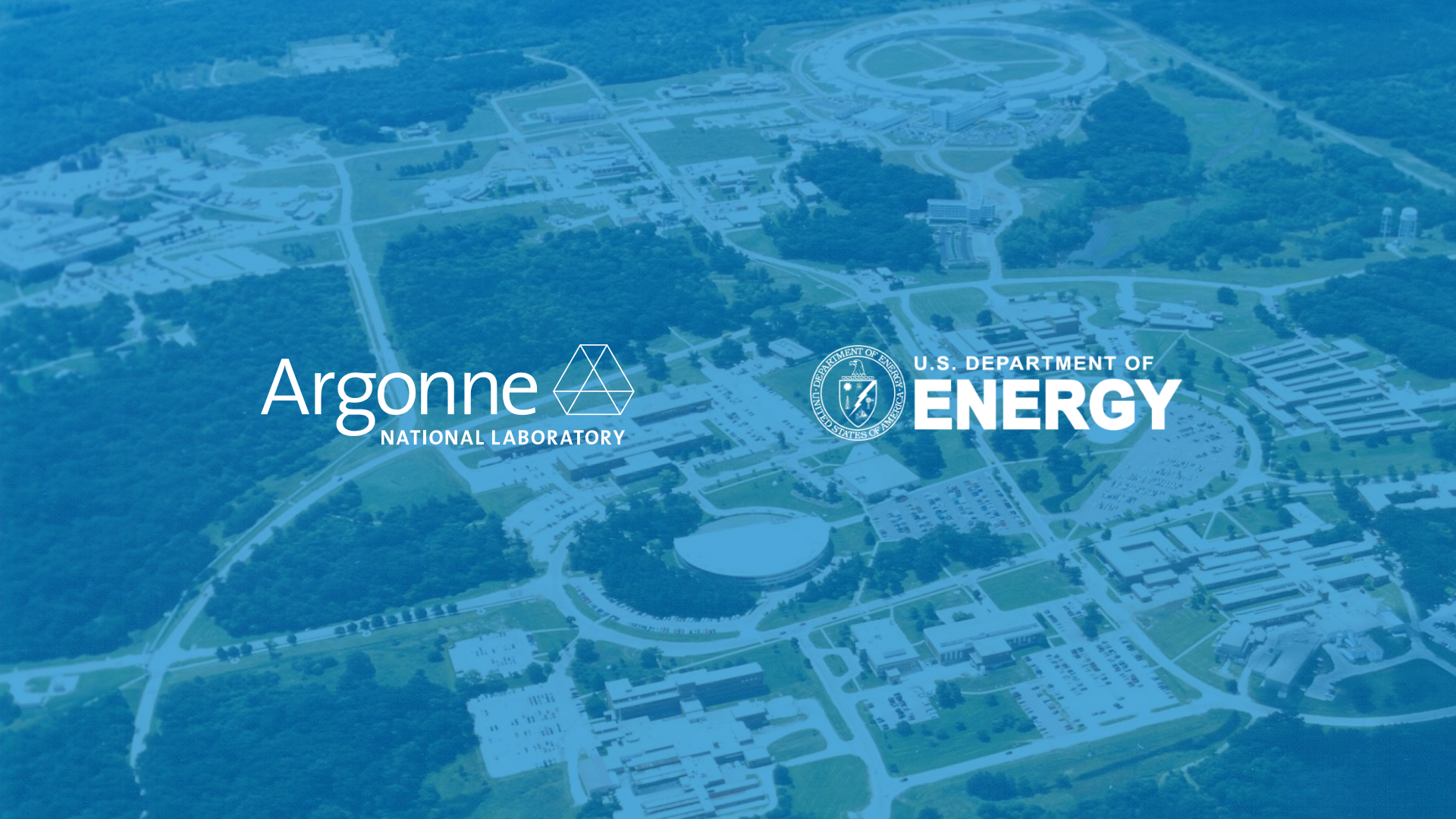
Install, integrate, and assess a wide variety of safeguards relevant sensors (including Argonne-derived designs and externally-provided sensors) across a complete range of representative flow conditions

- *Salt depth*
- *Salt sampling*
- *Particle detection*
- *Optical spectroscopy*
- *Etc.*

CONCLUSIONS

- Flow-tolerant electrochemical sensors for MSR applications are being developed.
- A modular testbed for assessment of the electroanalytical sensors and other safeguards-relevant sensors is in the final design and construction phase.
- The main tanks, heaters, and most of the flow components have arrived at Argonne.
- Shakedown testing will be performed with coolant salts prior to moving to U-bearing fuel salts.
- The sensors will assist MSR vendors in meeting challenging NRC licensing requirements for mass accountancy, criticality safety, and corrosion monitoring.

GOVERNMENT LICENSE NOTICE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