Molten Salt Reactor Test Bed with Neutron Irradiation

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Molten Salt Reactor
Campaign Review Meeting

Thursday April 18, 2024
11:00 am PDT; 2:00 EDT

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Massachusetts Institute of Technology

NC STATE UNIVERSITY

Berkeley UNIVERSITY OF CALIFORNIA

OAK RIDGE National Laboratory

Agenda

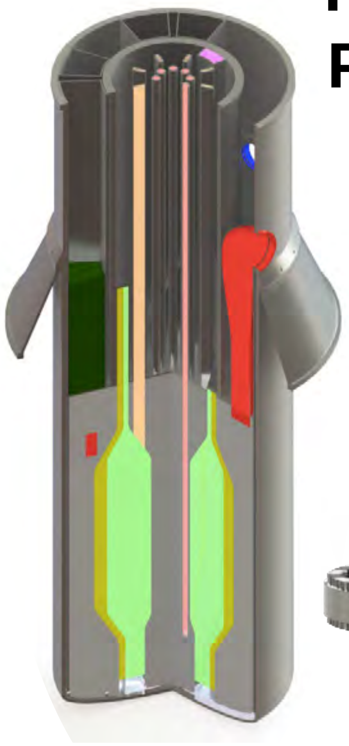
- Molten salt futures (Multiple users and customers)
- IRP: Molten Salt Reactor Test Bed with Neutron Irradiation
- Related Activities

Molten Salt Futures

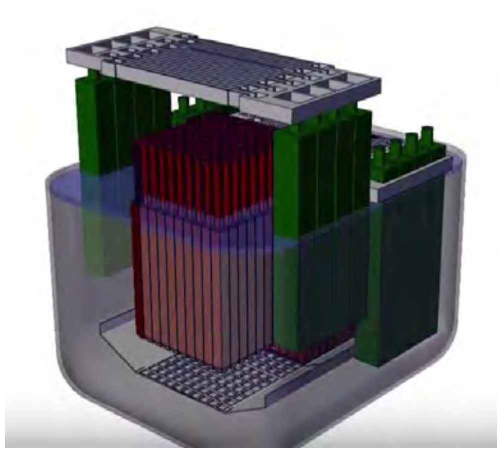
Multiple Applications Drive the Need for Cooperation Between Salt Programs and Salt Irradiation Facilities

Multiple Technologies Dependent on Salt Technology

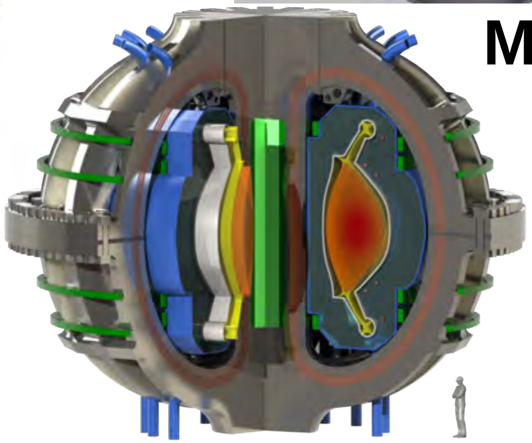
Clean Fluoride Salt Coolant



Kairos Power FHR



Moltex



Commonwealth Fusion

Fuel in Fluoride Salt

MSR: Many variants

Molten Fluoride Salt Fast Reactor (Europe)

Fuel in Chloride Salt

Molten Chloride Fast Reactor

Fuel Salt in Tubes with clean salt coolant (Moltex)

Clean Chloride Salt

Concentrated Solar Power

High Temperature Heat Storage

Fast-Spectrum Fission ?

Applications: Fission, *Fusion*, Solar, Heat Storage

Break-Though In Magnetic Fusion with Commonwealth Fusion (MIT Startup)

- Two billion dollar startup with 650 employees
- Flibe salt fusion blanket—same salt for FHR and many MSRs
- **The Fusion Program Is Having a Major Impact on the Fission IRP at MIT and Elsewhere with Shared Facilities**

SPARC

Devens Facilities

Integrated Research Project

Molten Salt Reactor Test Bed with Neutron Irradiation

Massachusetts Institute of Technology

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Project Goals

- Design, build, and test a general-purpose instrumented molten-salt test loop at the MIT reactor where flowing salt is irradiated by neutrons with temperature variations around the loop to duplicate conditions in a salt reactor.
  - Test bed for chemistry control, salt cleanup, tritium control and instrumentation
  - Loop initially clean flibe salt, capability for uranium salts.
- Provide learning experience (lessons learned) for future salt irradiations and loops at ATR, HFIR and university reactors

Team Members and Responsibilities

- MIT. Design, build, and test a general-purpose instrumented molten-salt test loop at the MIT reactor
- NCSU. Develop, design, build and test off-gas sensor system capable of measuring tritium, fission products and actinides (not installed in MIT loop in this IRP)
- University of California at Berkeley: Develop, design and build instrumentation for measurement and control of redox salt chemistry to be installed in loop
- Oak Ridge National Laboratory. Supporting Role

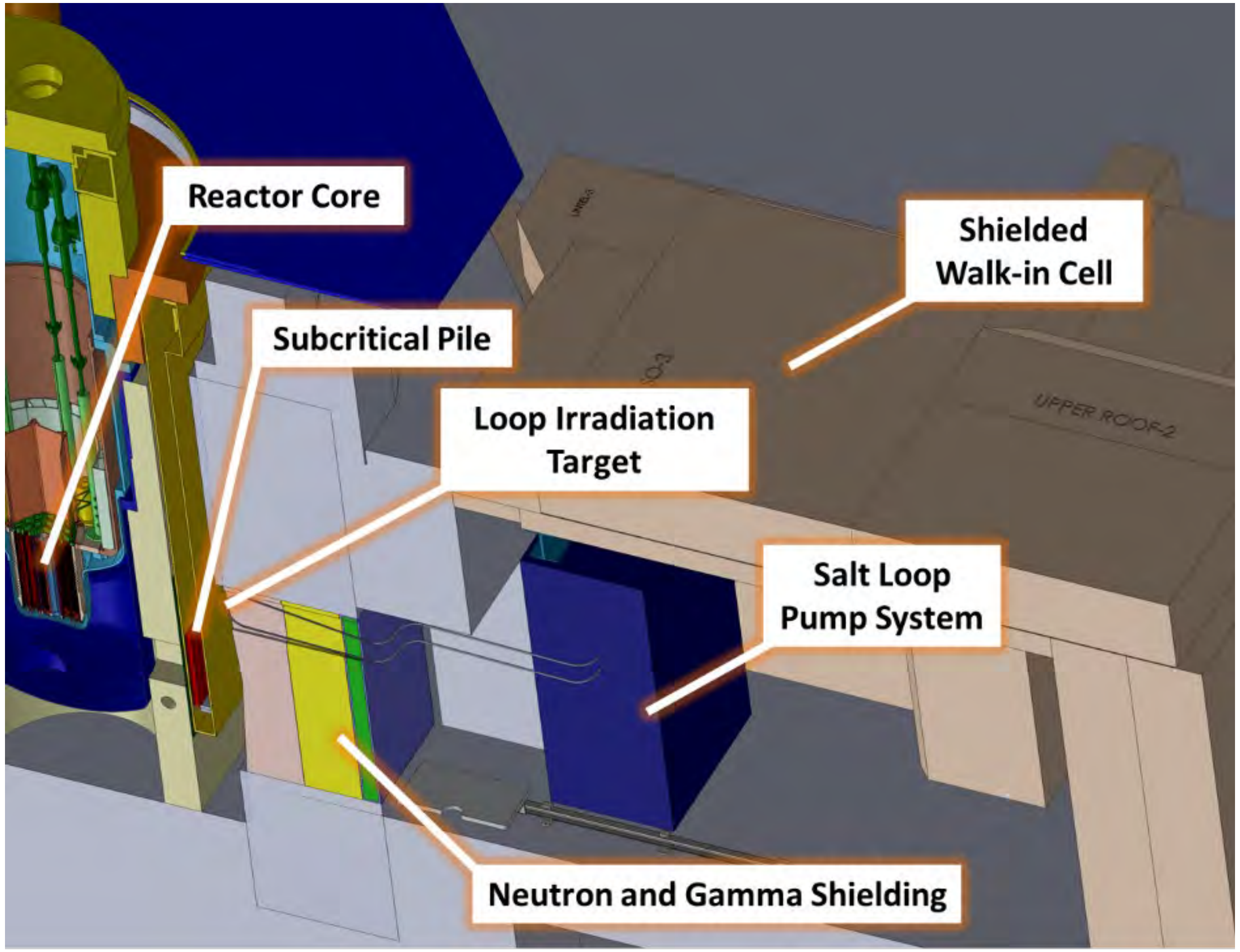
Massachusetts Institute of Technology

Department of Nuclear Science and Engineering
MIT Nuclear Reactor Laboratory

C. W. Forsberg, D. Carpenter

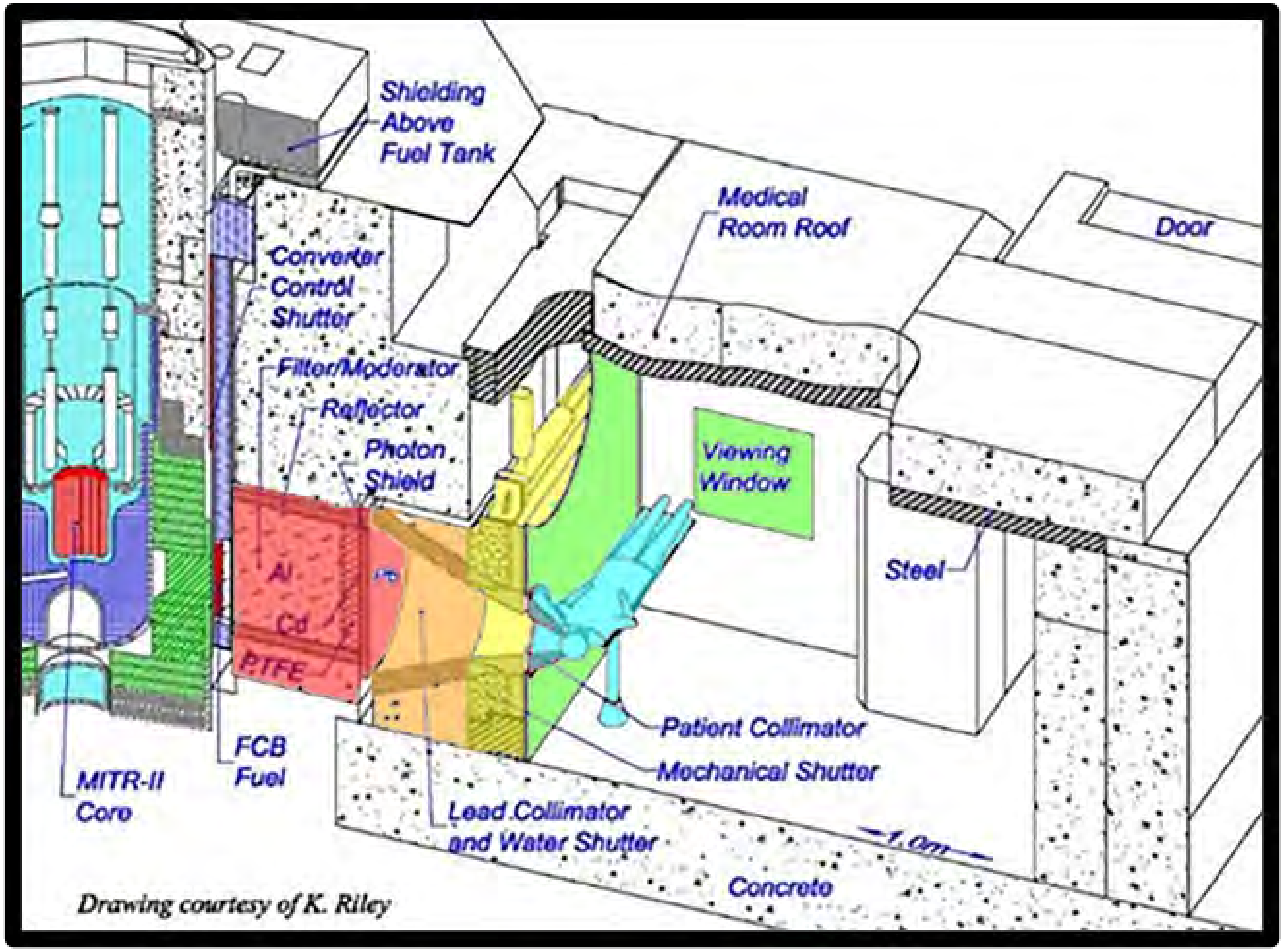
MIT Has Initiated Design and Construction of a Salt Loop at MIT Reactor

- MIT reactor: 6 Megawatts
- 24/7 operation, 70-day cycles
- Beamline facility "M^3" enables decoupled setup and operation
- Goal is forced circulation salt loop
  - Neutron & gamma irradiation
  - Heated and cooled
  - Fully instrumented
  - 1000 hours operation



MIT Facility Enables Loop Design with Fissile Material

- Deconstruction of epithermal medical beam and replacement with <u>general purpose irradiation facility</u>
- Avoids large feedback effects and enables use of fissile materials in loop
- Can adjust fissile and lithium-6 content of salt to obtain desired salt behavior
  - High level of circulating activity, tritium generation is ok
- IRP project will be clean salt but system designed for salt with uranium



Project Strategy: Two Loops

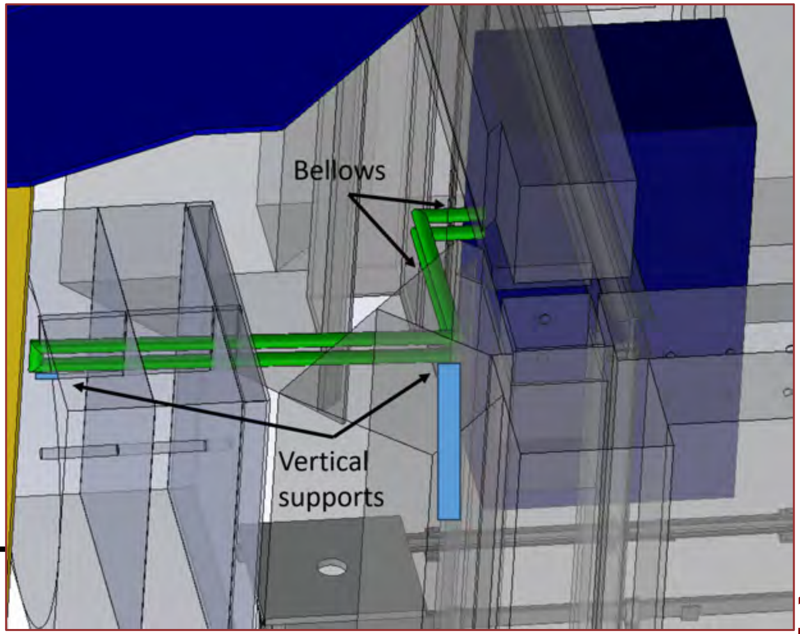
Non-radioactive full loop with:

- variable temperatures
- forced circulation using flinak
- gain practical O&M experience
- integrate UCB sensors

Second reactor-coupled loop with:

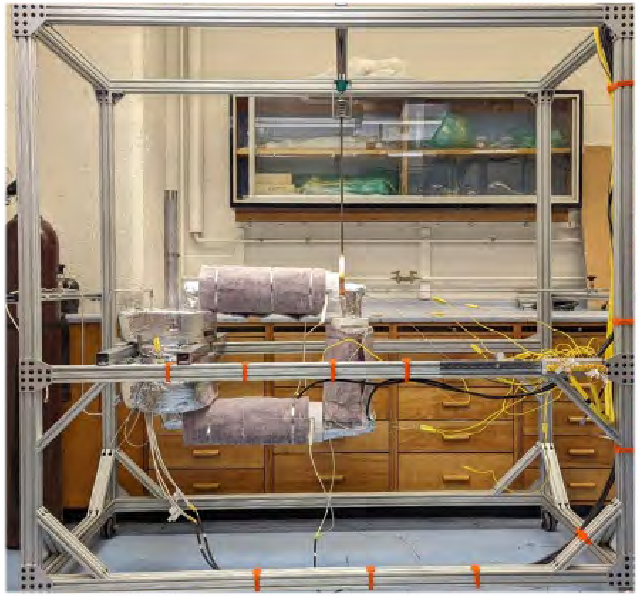
- flibe salt
- off-gas monitoring
- activity monitoring

Use this to progress to successful irradiation loop



MIT Is Working in Multiple Areas to Build Loop

Large glove box furnace for large-scale **salt transfer**



High temperature dry test facility for **insulation, heaters and flanges**

Liquid **salt metering** and loading system

Improvements in local **beryllium monitoring and control**

Schedule: Project Completion Late 2024

- Delays procurement from Covid-19 on deliveries (MIT/NCSU)
  - One loop delivered, second “in the mail”
  - MITR irradiation facility utilities upgrade completed
- MIT reactor unscheduled maintenance shutdown
  - Leak December 2022, restart January 2024 with full operation April 2024
  - Limited access to MIT reactor containment for required modifications of hot cell and other facilities
- Completed test fit of UCB sensors in loop
- Obtained no-cost extension

North Carolina State University

Nuclear Reactor Program,

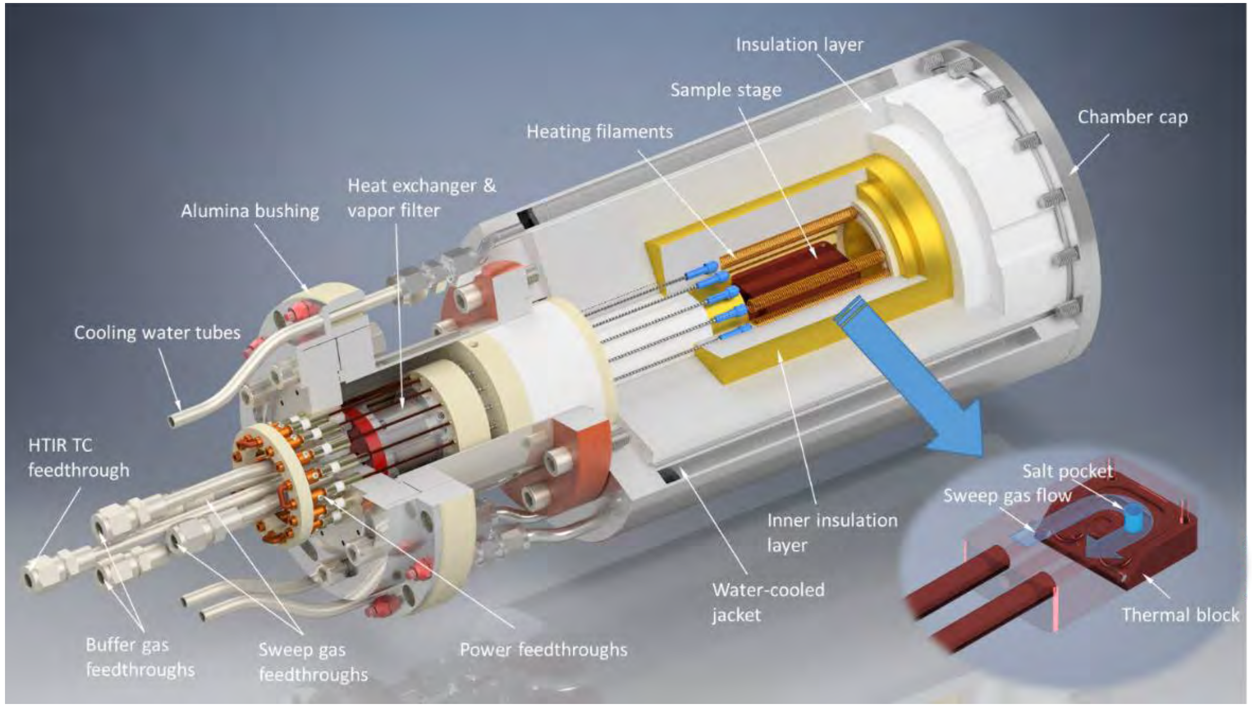
Department of Nuclear Engineering

Ayman Hawari (PI), Ming Liu (project manager), Austin Wells (project engineer), Nicholas Pool (PhD student), Matthew Schweitzer (PhD student), Aidana Bauyrzhan (PhD student)

NC STATE UNIVERSITY

North Carolina State University is Developing an Off-gas Monitoring System

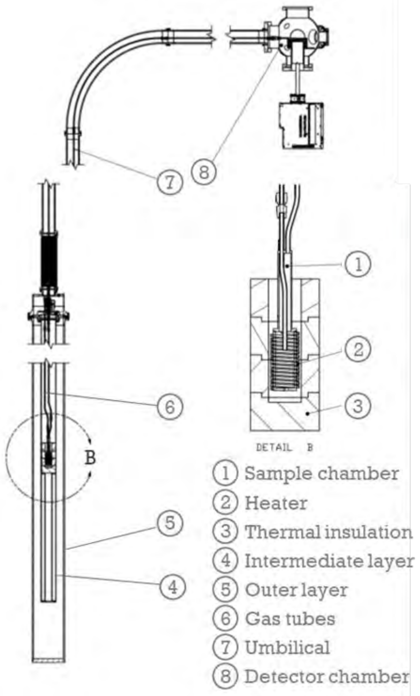
- Measure full MSR fission product spectrum with off-gas between 600 and 700°C
- Initial testing in NCSU PULSTAR reactor with salts containing uranium

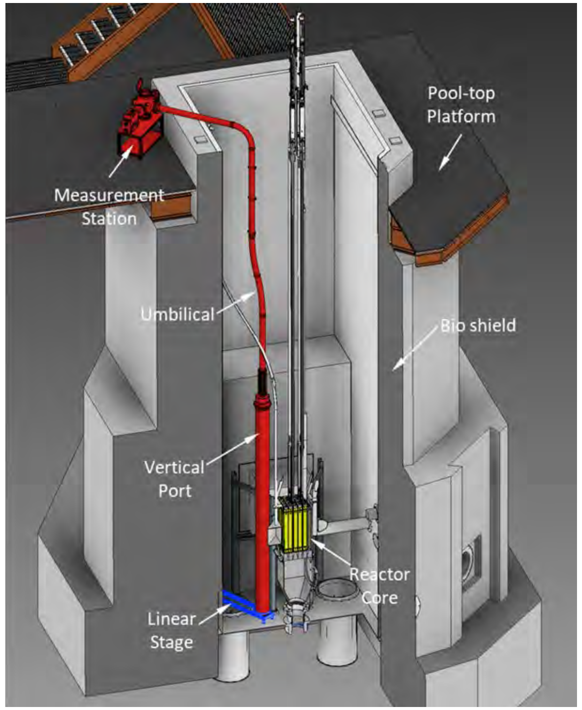


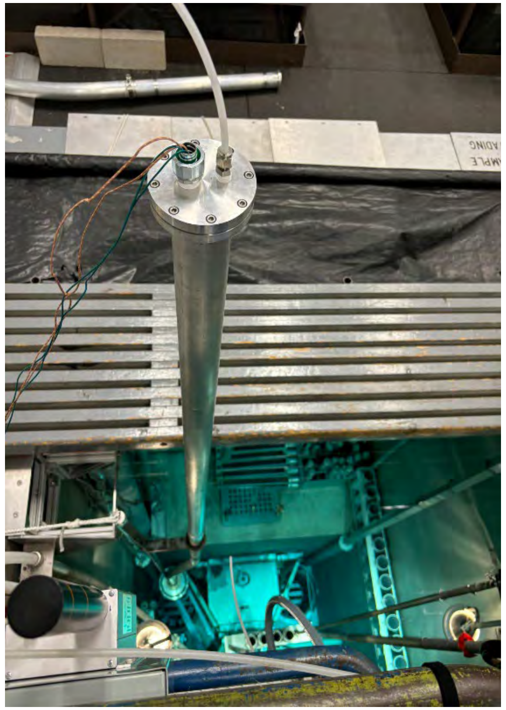
Conceptual design of the fission gas and tritium measurement irradiation chamber

NCSU Building Off-gas Sensor System and Off-gas Source (Molten Salt Materials)

- Sensor system
- Irradiation of molten salt reactor (MSR) materials in intense irradiation and high temperature environments
- Capsule system outside reactor core with off-gas to sensor system



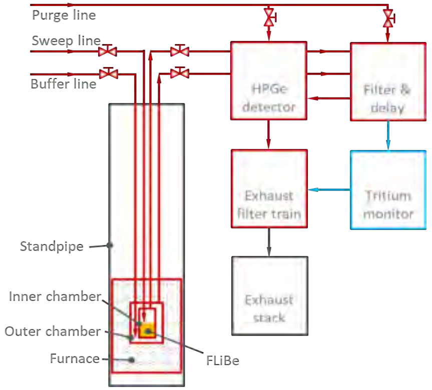


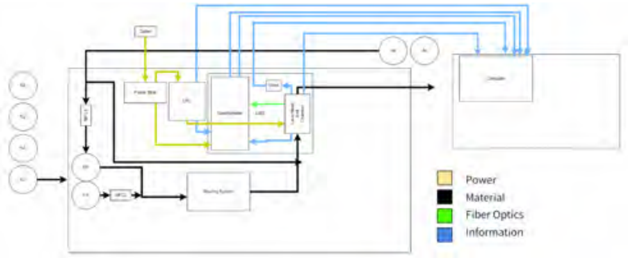


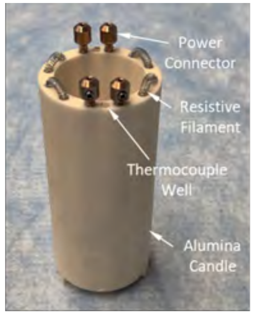
In the reactor pool

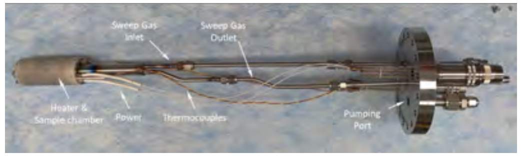
Multiple Sensors to Analyze Off-Gas

- On-line gamma spectroscopy for radionuclides
- On-line tritium analysis
- Off-line Laser Induced Breakdown Spectroscopy (LIBS) for chemical analysis









On-line system

Off-line system

The University of California at Berkeley

Department of Nuclear Engineering

R. O. Scarlat (Co-PI), L. Vergari (PhD student), Michael Borrello (PhD student), Haley Williams (PhD student), Colton Bruni (Undergraduate)

THE SALT RESEARCH GROUP

Berkeley UNIVERSITY OF CALIFORNIA Nuclear Engineering

U.C. Berkeley Is Developing Chemical Control Strategies for Salt Systems

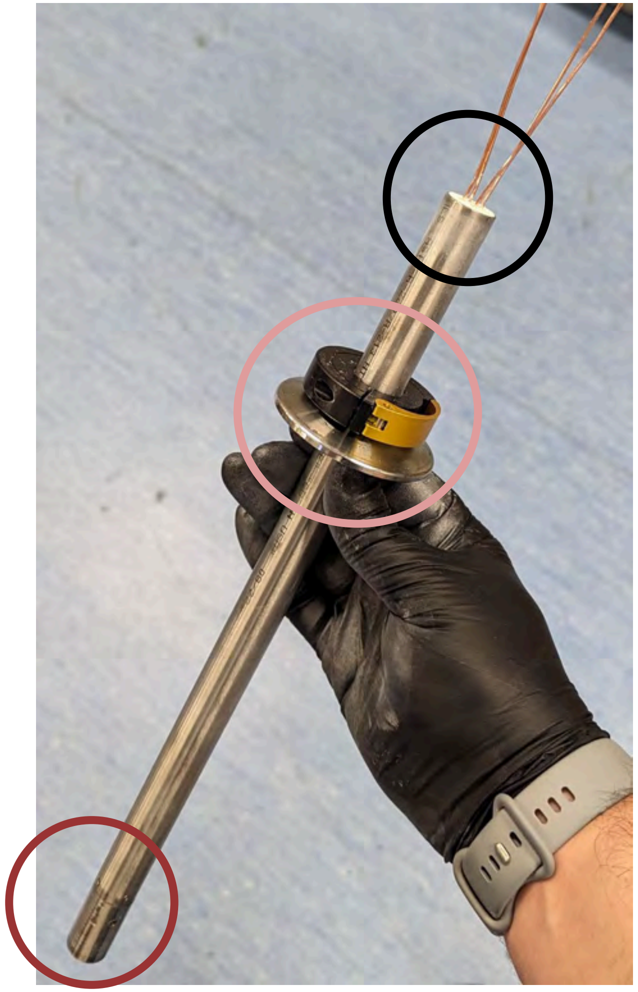
Redox Chemistry Control Determines Corrosion Rates and What Fission Products are Metals versus Fluorides

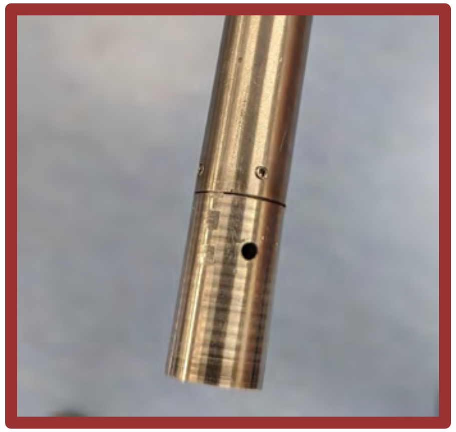
- Tritium and fission product transport experiments
- **Development of on-line redox measurement probes for loop—required to control redox**
- Incorporate sensors into the MIT loop
- Basis for use in salt reactors

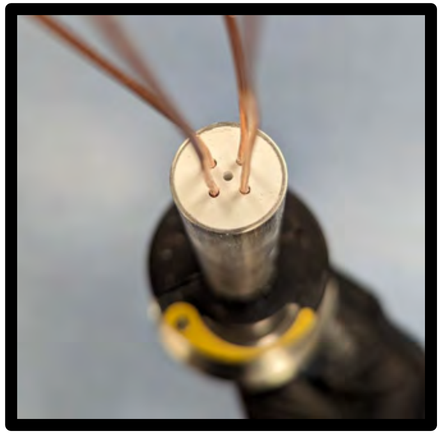
Sensor Probe Configuration and Dry Run at MIT After Full Testing at UCB

Functional Requirements

- Redox measurements
- Oxide quantification
- Corrosion product indication







Increases in Tritium Inventory to be Measured by Electrochemical Thermal Desorption Spectroscopy

- Uses a graphite working electrode to measure the electrochemically-enhanced desorption of tritium at temperature.
- Lab scale experiments of H_2 desorption from graphite in FLiBe have been performed at UCB.
- The nearby electrochemical signals of oxide and hydride, as well as complex formation, can complicate interpretation.

A graphite sample will be integrated into the MIT loop as a trapping site for tritium. ETDS will be run to quantify tritium.

Project Goal 2: Provide learning experience for future loops at ATR, HFIR and university reactors

- Workshop on lessons learned in how to conduct salt irradiation experiments

- Second workshop November 2024 before or after ORNL Molten Salt Reactor Workshop

- Quarterly reports are widely distributed including lessons learned—what not to do

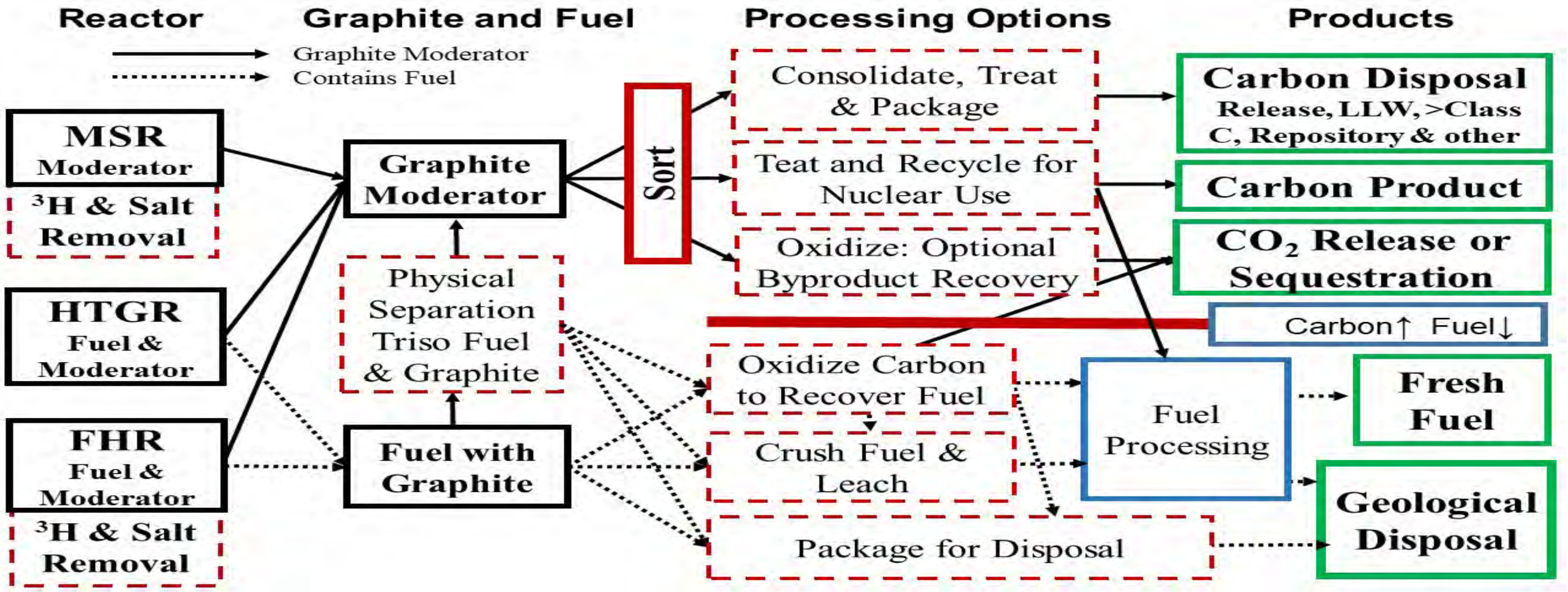
Related Activities

Coupled (Partly Enabled) but Not IRP Activities

Initial Conclusions of Studies

Roadmap of Graphite Moderator and Graphite-Matrix TRISO-Fuel Management Options

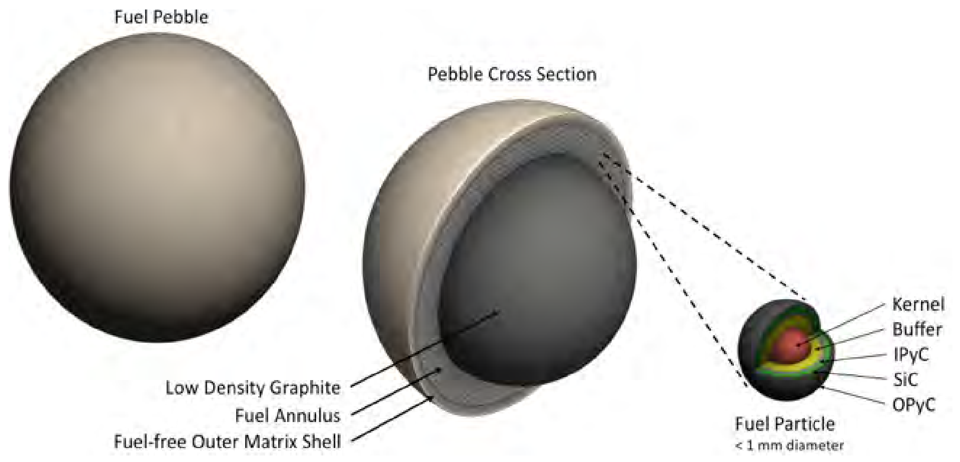
The Low-Cost Disposal Route For Nuclear Graphite May be to Oxidize Graphite and Sequester CO_2 with Fossil CO_2 Sequestration



C. Forsberg, Roadmap of Graphite Moderator and Graphite-Matrix TRISO-Fuel Management Options, *Nuclear Technology.* 10.1080/00295450.2024.2337311

Safeguards and Security for High-Burnup TRISO Pebble-Bed Spent Fuel and Reactors (FHR and HTGR)

- Can eliminate weapons safeguards for pebble bed SNF with burnups greater than 150,000 MWd/ton (limited safeguards for other purposes)
- Faster, quicker and less technical risk building weapon starting with uranium mine
- **May Be Preferable Reactor for Export**

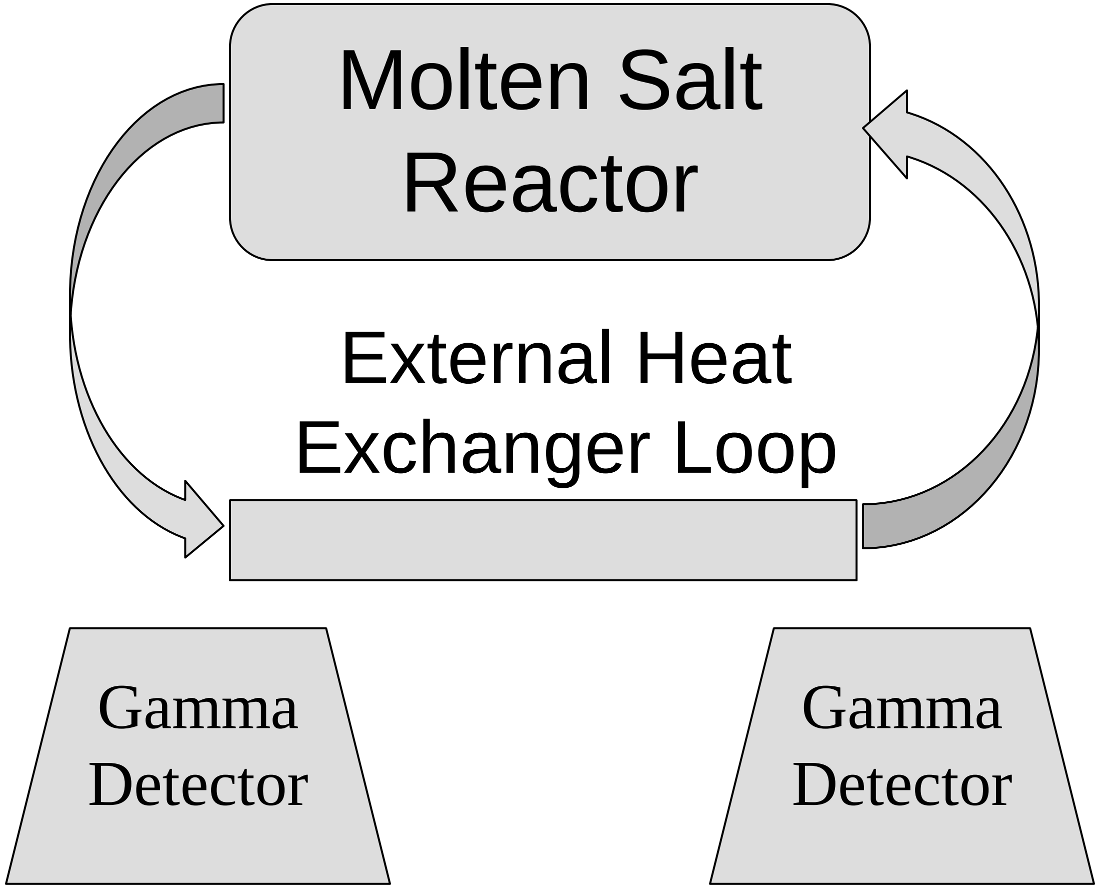


C. Forsberg and A. Kadak, "Safeguards and Security for High-Burnup TRISO Pebble-Bed Spent Fuel and Reactors', *Nuclear Technology*. Published on-line 22 February 2024. https://doi.org/10.1080/00295450.2023.2298157

With Flowing Fissile Salt, Gamma Detectors May Measure Flow Velocity, Mass Flow and Xenon Concentrations

- Simplify salt reactor instrumentation, nothing in salt
- Joint effort MIT and U. of Texas (Austin)

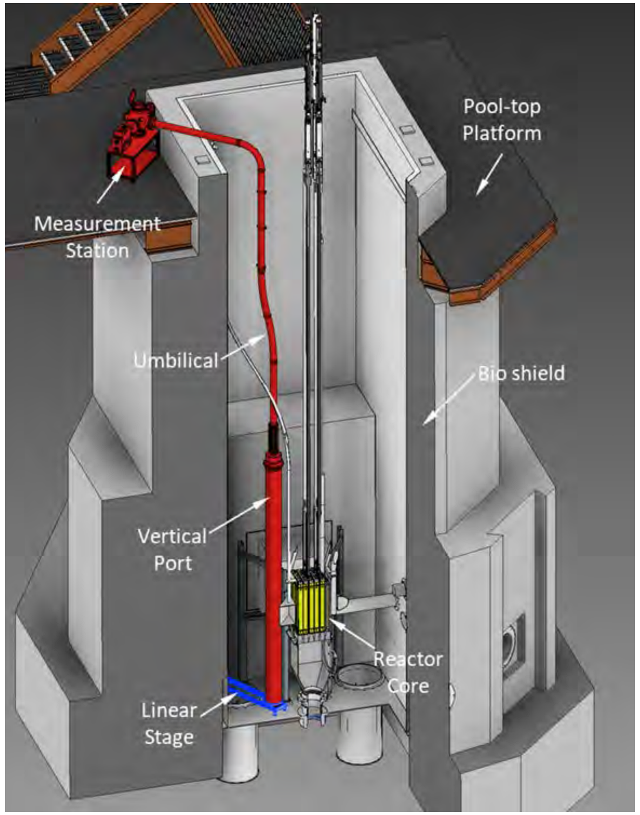
C. Forsberg, D. Carpenter, S. Dayawansa and K. T. Clarno, “Measuring Flow Rates and Compositions in Salt Reactors with Gamma Spectroscopy”, Transactions of the American Nuclear Society, American Nuclear Society Annual Meeting, Las Vegas, June 16-19, 2024.



Can Measure Flow in Clean Salt with 11 Second F-20, 1633 KeV

Questions

MIT (Salt Flow Loop at MIT Reactor)



NCSU (Off gas Sensors at NCSU Reactor)

UCB (Redox/Other Sensors at MIT Reactor)

Biography: Charles Forsberg

Dr. Charles Forsberg is a principal research scientist at MIT. His current research areas include Fluoride-salt-cooled High-Temperature Reactors (FHRs), hybrid energy systems, utility-scale 100 GWh heat storage systems and nuclear biofuels systems. He is one of the three inventors of the FHR. He teaches the fuel cycle and energy systems classes. Before joining MIT, he was a Corporate Fellow at Oak Ridge National Laboratory. Earlier he worked for Bechtel Corporation and Exxon.

He is a Fellow of the American Nuclear Society (ANS), a Fellow of the American Association for the Advancement of Science, and recipient of the 2005 Robert E. Wilson Award from the American Institute of Chemical Engineers for outstanding chemical engineering contributions to nuclear energy, including his work in waste management, hydrogen production and nuclear-renewable energy futures. He received the American Nuclear Society special award for innovative nuclear reactor design and is a Director of the ANS. Dr. Forsberg earned his bachelor's degree in chemical engineering from the University of Minnesota and his doctorate in Nuclear Engineering from MIT. He has been awarded 12 patents and published over 300 papers.