Fast Reactors R&D Overview

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Advanced Sensors and Instrumentation (ASI) I&C Review Meeting
Webinar
October 23, 2019

Outline

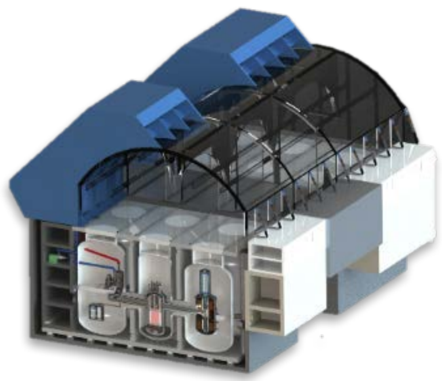
- NE-52 Advanced Reactor Technologies (ART) Program:
  Fast Reactor R&D Overview

- Sensors and Instrumentation
  – Assessment of Advanced Reactor Sensor Technologies
  – ART Fast Reactor RD&D Activities
  – NEUP Program Awards and Calls

ADVANCED REACTOR EXAMPLES

Different Advanced Reactor Designs Being Developed By Industry

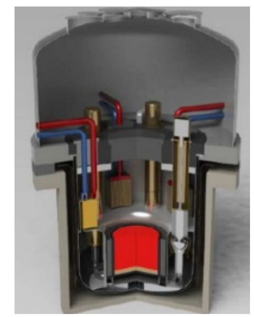
Gas Fast Reactors



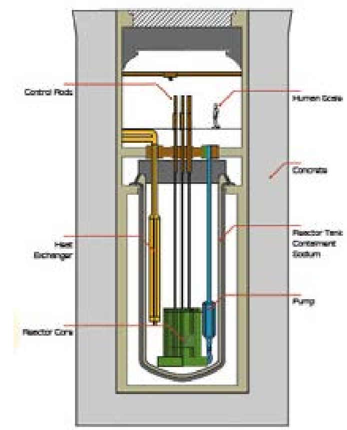
GA Gas-cooled
Fast Reactor

Sodium-Fast Reactors

GE Hitachi
PRISM

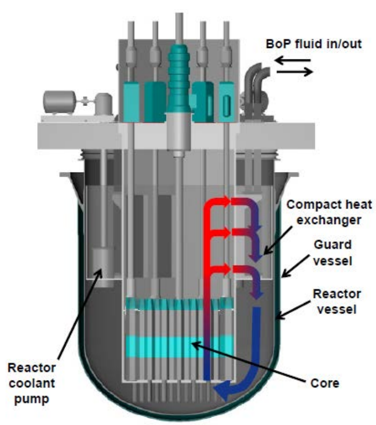


TerraPower
TWR



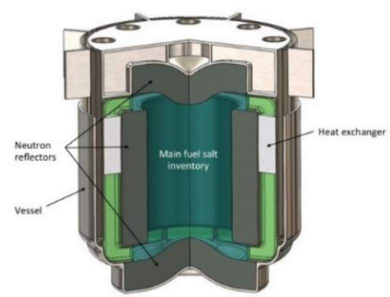
Advanced Reactor
Concepts LLC
ARC-100

Lead-Fast Reactors

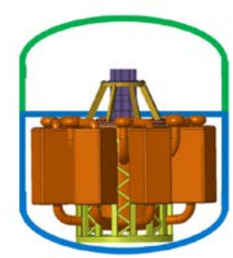


Westinghouse LFR

Molten Salt Fast Reactors



TerraPower
MCFR



Elysium USA
MCSFR

Engagement with Industry

In FY17, DOE-NE established the Gateway for Accelerating Innovation in Nuclear (GAIN) initiative to provide developers with access to technical, regulatory and financial support

U.S. industry self established advanced reactor working groups. The Fast Reactor Technology Working Group consists of diverse concepts:

- **SFR – Oklo, General Electric, TerraPower, Advanced Reactor Concepts**
- **LFR – Westinghouse, Columbia Basin Consulting Group, Hydromine**
- **GFR – General Atomics**
- **MCFR – Elysium, Southern/TerraPower, Flibe**

Group requests are generally broad in scope and identify capabilities useful for multiple technology options

Office of Advanced Reactor Technologies

Mission:

Identify and resolve the technical challenges to enable transition of advanced non-LWR reactor technologies and systems to support **detailed design, regulatory review and deployment** by the early 2030's

Objectives:

- Conduct focused research and development to **reduce technical barriers to deployment** of advanced nuclear energy systems
- Develop technologies that can enable new concepts and designs to achieve enhanced **affordability, safety, sustainability** and **flexibility** of use
- **Collaborate with industry** to identify and conduct essential research to reduce technical risk associated with advanced reactor technologies
- **Sustain technical expertise and capabilities** within national laboratories and universities to perform needed research
- Engage with Standards Developing Organizations (SDO's) to **address gaps in codes and standards** to support advanced reactor designs

U.S. DEPARTMENT OF ENERGY | Office of Nuclear Energy

DOE ART Program - Fast Reactor R&D – Priorities

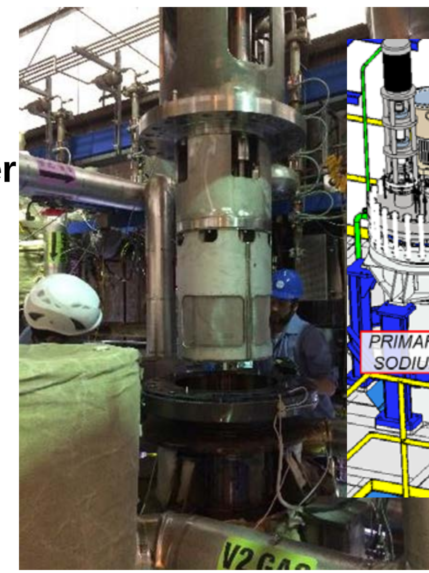
- For the commercial deployment of fast reactor technology, two recurring challenges are identified
  - For advanced fuel cycles, capital investment in reactors is the dominant cost (cost reduction is also vital for electricity production)
  - A pathway must be established for non-LWR licensing
- Therefore, ART Fast Reactor work activities have focused on:
  - Research, development, and demonstration of innovative cost reduction and performance enhancing technologies (e.g., new configurations, materials, energy conversion, etc.)
  - Clarifying fast reactor licensing criteria and science-based approach for demonstration of regulatory compliance – NRC engagement and resolution of regulatory issues

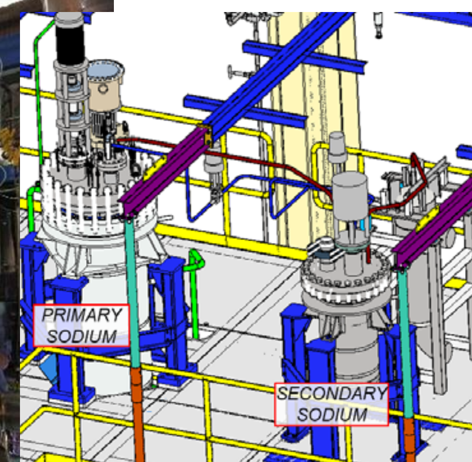
ART Fast Reactor R&D Technical Areas

- Technology Development
- Methods, Modeling, and Validation
- Advanced Materials

METL Status

- Initial fill of sodium into METL in May 2018.
  - 15 55-gallons drums were heated and transferred to the sodium dump tank.
- Sodium was transferred from the dump tank and into the main loop in September 2018 and sodium purification was initiated.
- *https://www.osti.gov/biblio/1492054-mechanisms-engineering-test-loop-phase-status-report-fy2018-update-fy2017-report*
- Gear Test Assembly (GTA) was fully assembled, water and air tested, and moved to B308 for commission
  - *First test article into METL December 2018*
- *After insertion and initial checkout, it was operated for ~9,800 simulated core assembly removal and insertion cycles under load (Feb-Mar 2019)*
  - *First test vessel removed in August 2019*
  - *Now cleaning in inert enclosure*
- Thermal Hydraulic Test Article (THETA) will use two test vessels to model pool stratification
  - *Complete design/fab in FY19 with startup in FY20*





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Access to FR Databases: https://frdb.ne.anl.gov/

TREXR: TREAT Experimental Relational Database

Website

TREXR

A limited selection of TREXR is available to the public. User registration is required for increased access.

About

TREXR is an organized, searchable collection of information that describes the hundreds of experiments conducted on nuclear reactor fuels in the Transient Reactor Test (TREAT) facility beginning in 1960. The experiments generally investigated the response of nuclear fuel samples to severe conditions similar to those associated with reactor accidents. The TREAT reactor was specifically designed and operated to provide such conditions. TREXR includes a collection of thousands of documents describing the design and operation of these tests as well as measured instrumental data for some of the tests. Reports and records can be viewed and saved, and instrumental data can be plotted live as well as downloaded in CSV format.

Request Access

Requests for user accounts to access the database can be made by visiting the website. Click on "Login" and follow the appropriate link and instructions under "Get an Account." For questions about the database, website, or your access permissions, contact Carolyn Tomchik (ctomchik@anl.gov).

FIPD: EBR-II Fuels Irradiation & Physics Database

Website

FIPD

FIPD is available to registered users.

About

FIPD is an organized collection of EBR-II test pin data and documentation. The database includes pin operation conditions calculated using a collection of ANL analysis codes developed during the IFR program, including axial distributions for power, temperatures, fluences, burnup, and isotopic densities. The database also contains pin measured data from post-irradiation examination, including pin fission gas release and gas chemistry measurements, and axial distributions from profilometry, gamma scans, and neutron radiography. There is also an extensive collection of documents associated with different pins and experiments, including raw PIE data, design

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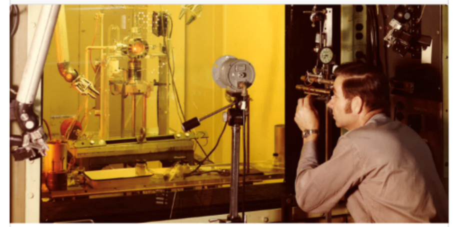
OPTD: Out-of-Pile Transient Database



Website

OPTD

OPTD is still in initial development, and only accessible to the development team.

About

OPTD is an organized, searchable archive of records describing a series of out-of-pile furnace transient tests conducted on metallic fuel samples at the Alpha-Gamma Hot Cell Facility (AGHCF) at Argonne National Laboratory. Fuel pins (or pin segments) previously irradiated in EBR-II were placed into one of two furnace apparatuses constructed in the AGHCF and overheated to examine the fuel-cladding compatibility of each sample, margins to failure, and failure mechanisms. Records describing the design, planning, and execution of the tests are included in the database as well as test summary reports, experimenter's notes, and post-test metallographic examinations of the samples.

ETTD: EBR-II Transient Test Database

Website

ETTD

ETTD is available to registered users.

About

The EBR-II Transient Test Database (ETTD) is an archive of data and documents describing transient tests performed in the EBR-II reactor during the 1984-1987 time period. The database provides links to tests that are grouped in five testing periods (each with different core load configuration) under which they were conducted, or several testing categories including:

- Reactivity feedback characterization tests
- Loss of flow with scram and transition to natural circulation
- Loss of flow without reactor scram with different levels of severity
- Dynamic frequency response tests
- nk tests (with or without scram)
- ssure reduction tests
- ontrol tests (to demonstrate features of the reactor)

bility to download and/or plot up
DAS channels (broadly grouped
power, control and safety rod
, intermediate sodium coolant
erheater steam temperatures,
e and balance of plant flow rate

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Sodium System and Component Reliability Database (NaSCoRD)

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Code Qualification for Alloy 709

Background:

- Alloy 709 (20Cr-25Ni) is an austenitic stainless steel with significant time-dependent strength advantage over 316H stainless steel as a SFR construction material
- Enhanced time-dependent strengths of Alloy 709 with respect to 316H can reduce commodity requirements, and thereby decrease the capital cost of the reactor plant
- Can also permit structural components to withstand higher cyclic and sustained loading, leading to higher safety margins, and the prospect of eliminating costly add-on hardware instituted in past designs, and other design innovations and simplifications

Status:

- Qualification efforts for ASME Division 5 Code Case for 100,000 h and 760C are ongoing
- Tests include tensile, creep, fatigue, and creep-fatigue

Alloy 709 plates fabricated from 45,000 lb commercial heat

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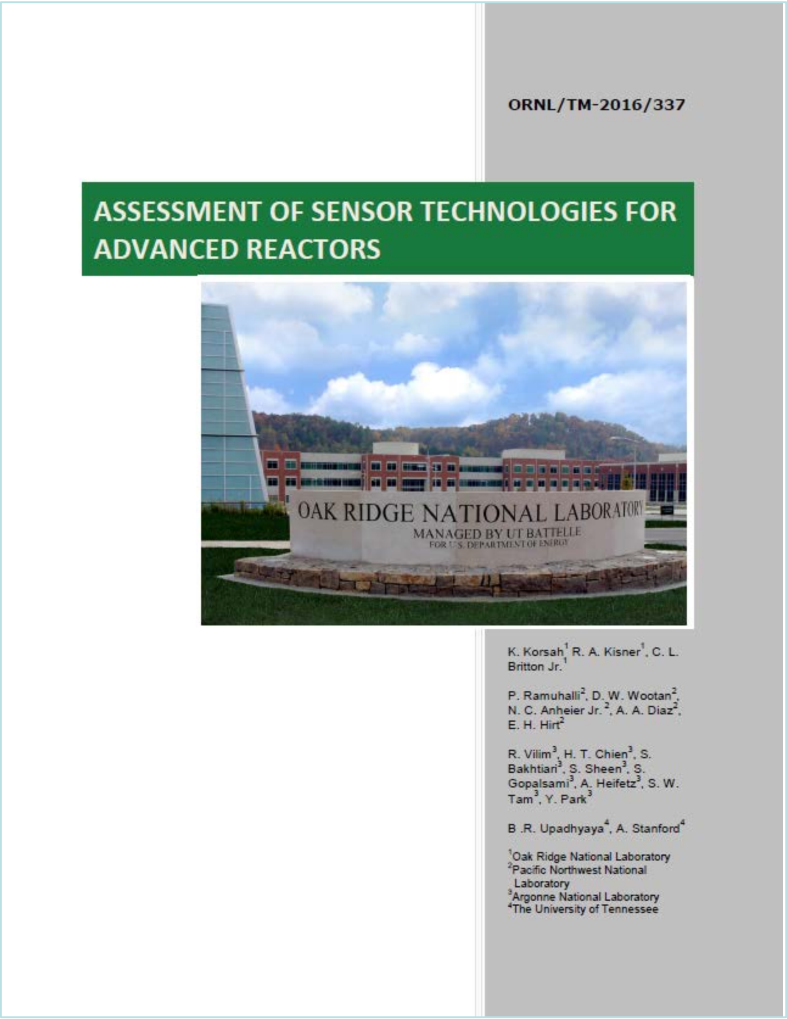
Advanced Reactor ASI Needs

- Assessment completed in 2016
  - High Temperature Reactors (gas, salt)
  - Fast Reactors (liquid metal)
- Operational characteristics and operating regimes identified
- Limitations of previous techniques
- State-of-the-art and technology gaps identified (see next viewgraphs)
- Summary and general prioritization

https://info.ornl.gov/sites/publications/files/Pub68822.pdf


ORNL/TM-2016/337

ASSESSMENT OF SENSOR TECHNOLOGIES FOR ADVANCED REACTORS

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[3]Argonne National Laboratory
[4]The University of Tennessee

What Constitutes a Measurement Gap?

- A measurement gap exists and can be filled when a new sensing technology can

  1) Produce the measurement with
     - greater reliability
     - smaller form factor
     - greater accuracy
     - reduced cost, or

  2) Make feasible a desired but previously unrealizable measurement, or

  3) Make feasible a measurement for which a sensor is no longer commercially available.

Measurement Gaps Identified FR (1/2)

Process Variable	Measurement Location and Type	Past Sensing Technology	Measurement Gap	New Sensing Technology	Utility/Advantage
Mass Flow Rate	Heat transport system pipe	Magnetic flow meter	Insufficient sensor life	Acoustic transmission through coolant	Improved accuracy and lifetime; reduced maintenance
Level	Sodium level in cold and hot pools and expansion tank	EM level gauge	Bulk	Acoustics	Standoff (wireless) measurement and small form factor
Temperature	Heat exchanger flow channel length profile	None	Unavailable measurement	Bragg fiber in capillary	Control of thermal fatigue. Prediction/extension of service life. Detection of component faults.
Temperature	PHTS cold pool axial profile	Thermocouple tree	Bulky with many wires and individual TCs	Acoustic transmission along notched rod	Smaller form factor; fewer connections and components; improved reliability
Temperature	Heat transport system pipe	Resistance temperature detector	Insufficient reliability wrt calibration and integrity of physical boundary	Focused rare earth permanent magnet	No coolant boundary penetration
Fission Products	Fuel pin release upon failure	None	Seek rapid detection but long mass spec detection time is too long	Detection of organic molecule complexes in purification system	Organic molecule complexes quickly detected eliminating mass spec time delay

Measurement Gaps Identified FR (2/2)

Process Variable	Measurement Location and Type	Past Sensing Technology	Measurement Gap	New Sensing Technology	Utility/Advantage
Fission Products	Fuel pin release upon failure	None	Seek rapid detection but long mass spec detection time is too long	Detection of organic molecule complexes in purification system	Organic molecule complexes quickly detected eliminating mass spec time delay
Weld Integrity	Dissimilar weld materials in structures	None	Unavailable measurement	Magnetic metal memory	Assurance of structural integrity and prediction of useful service life
Concrete integrity	Primary vessel support structure	None	Unavailable measurement		Assurance of structural integrity and prediction of useful service life
Hydrogen concentration	Sodium exit from steam generator; expansion tank cover gas	Commercial production discontinued	Unavailable measurement	Ni membrane	Detection of steam generator tube leak for early isolation
SG tube integrity	Tube mechanical condition	None	Unavailable measurement	Eddy current	Investment protection by avoidance of premature failure
Mechanical vibration	Housing of rotating machinery	Accelerometer	Multiple sensors with physical leads	Standoff microwaves	Single sensor and wireless
SG Acoustic Signal	SG tube bundle	None	Unavailable measurement	Acoustic localization	Detection of steam generator tube leak for early isolation

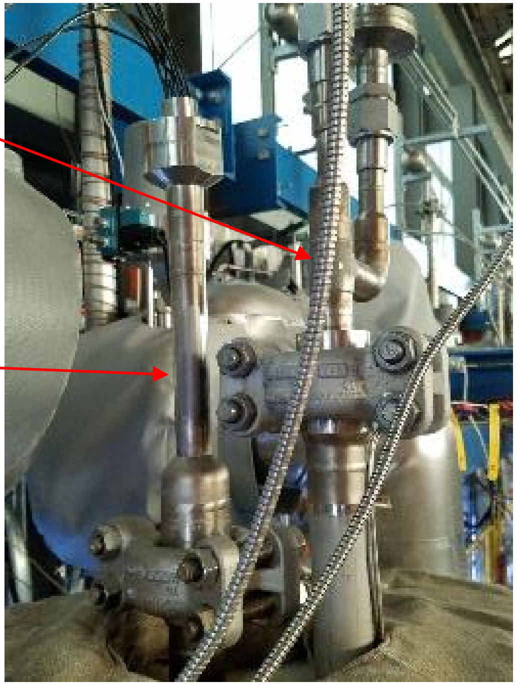
Instrumentation - Level Inductive Level Probes - development for METL

- **Currently testing a number of instruments to measure level in the METL sodium vessels**
  - Using differential pressure indicators for height difference.
  - Inductive probe

- **Working to develop inductive level probes**
  - Located in dump tank
  - Located in expansion tank
  - Used during the sodium fill of the dump tank and the sodium fill of the main loop and expansion tank

DP Instrument

Inductive Level Instrument



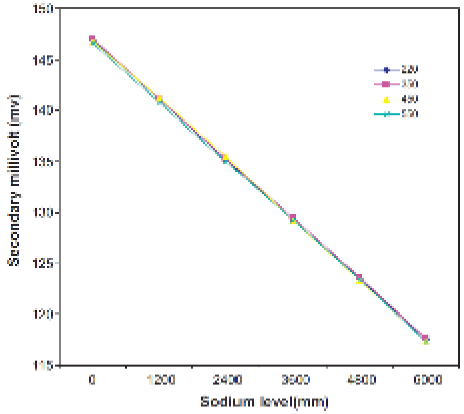


Fig. 8. Secondary output with temperature compensation using external resistor.

Diffusion-type Hydrogen Meters

To develop diffusion-type hydrogen meters (DTHMs) for steam generator leak detection system (SGLDS) with quick response, high sensitivity, and sufficient stability and reliability to detect leak, to prevent leak propagation, and to protect SG and IHX systems of a SFR.

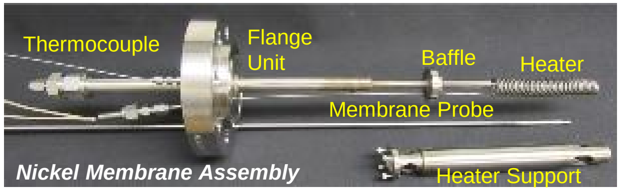
Challenges

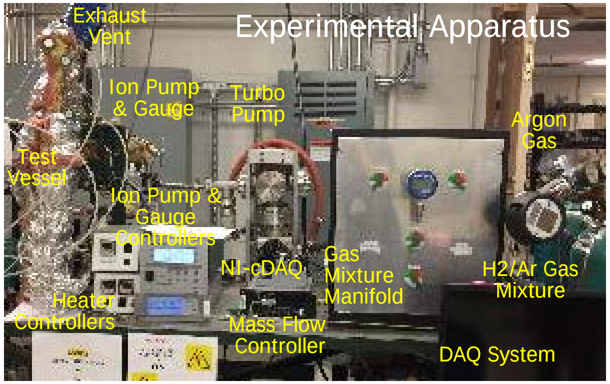
- Heat: local temperature could reach >1,200^{o}C due to sodium/water reaction
- Reaction products: NaOH, NaO_2, and H_2
- Threats: corrosion, stress-corrosion cracking, plugging, pressure, overheating

Impacts:

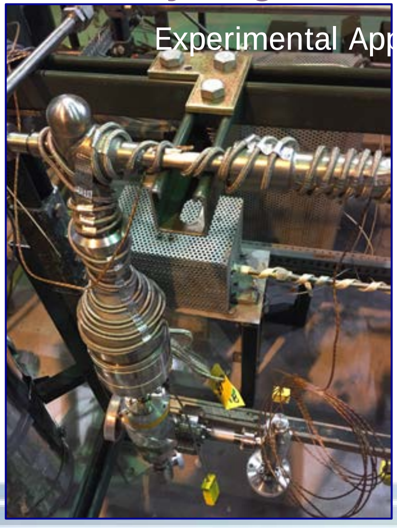
- Have demonstrated as the most reliable technology for steam/water leak detection of SG.
- Will improve reliability, ensure safety, and reduce operational costs for nuclear energy stakeholders.

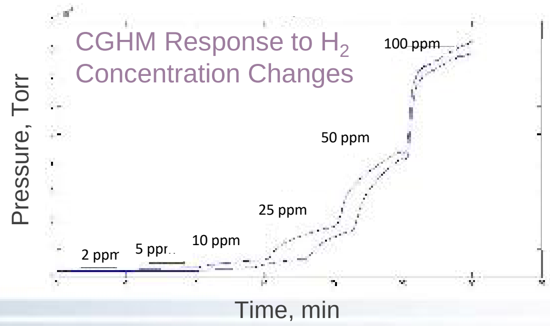
Cover-gas Hydrogen Meter

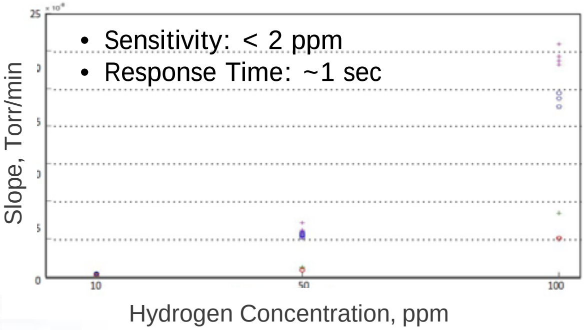




In-Sodium Hydrogen Meter







Thermoacoustic Power Sensor

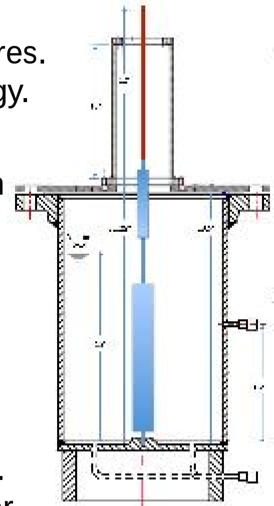
To develop TAPS for *in-situ*, in-core, real-time reactor power and temperature monitoring.

TAPS is a device that produces sound waves of an assigned frequency (proportional to temperature) with an amplitude (loudness) proportional to the fission heat input without a need for applied electrical power or signal transmission cables. Acoustic output signals are measured outside the reactor vessel.

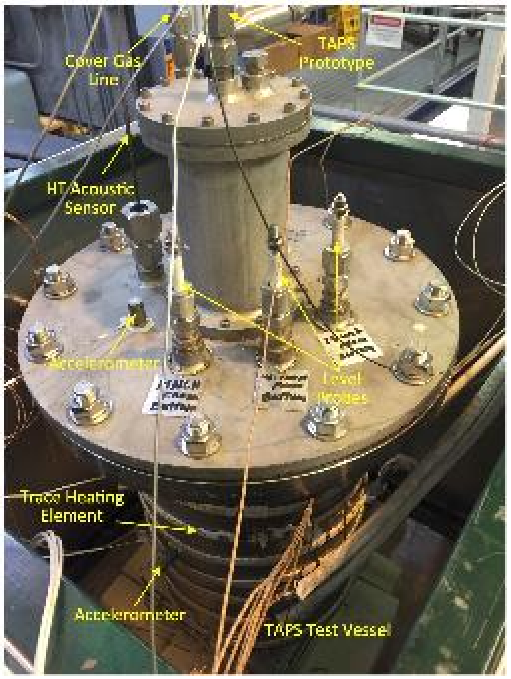
Simpler design:
- Reduced number of reactor vessel penetrations and associated structures.
- Reduced number of cabling due to the wireless nature of the technology.

Reduced costs:
- Improvement in reactor operating margins through higher resolution in power distribution monitoring.
- Reduced outage and operating costs associated with maintaining and inspecting equipment and penetrations.

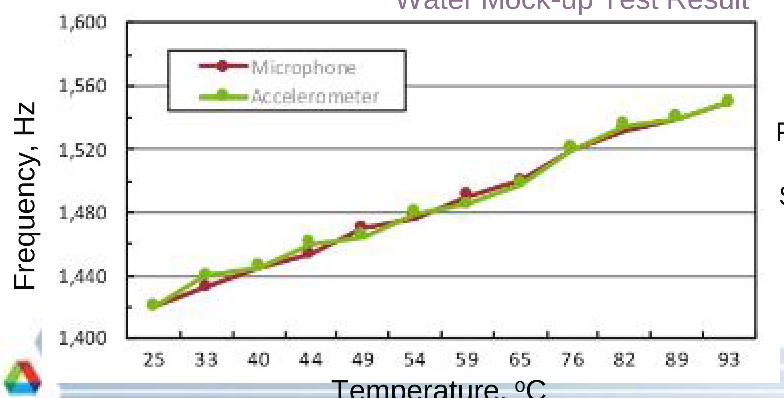
Enhanced safety:
- Less reliance on electric power sources due to self-powered nature of TAPS and possibility to harvest gamma energy to power receivers.
- Ability to monitor for unacceptable temperature increases in spent fuel.
- Reduced likelihood for loss of coolant due to reduced number of reactor vessel penetrations.



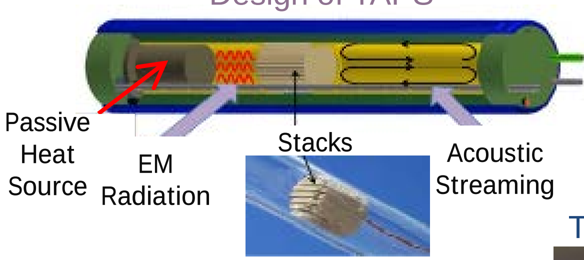
TAPS In-sodium Setup



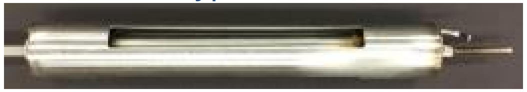
Water Mock-up Test Result



Design of TAPS



TAPS Prototype for In-sodium Test



Collaboration with Westinghouse Electric Company LLC and U. of Pittsburgh

NE University Program - NEUP Awards

FY19 Awards

LMFR Instrumentation and Technology Development (UW)

Corrosion/Irradiation Testing in Lead and LBE (MIT)

Versatile Heavy Liquid Metal (Lead) Testing Loop (UPitt)

NEUP Call FY20 – [RC-3] LMFR Technology

Background

- **Advanced Non-Light Water Reactors (Liquid Metal Cooled: Na or Pb) Cooled Fast Reactors offers the potential for significant improvements to safety, economics and environment stewardship while increasing energy security and reliability.**
- **The Mechanisms Engineering Test Loop (METL) located at Argonne National Laboratory (ANL) is a sodium test facility that is designed to test small to intermediate-scale components and systems in order to develop advanced liquid metal technologies.**

Focus/Objective

This work scope seeks proposals to develop experiments, instrumentation, control strategies, and performance enhancing technologies for the METL facility that have the potential to subsequently be deployed and used by liquid metal (sodium or lead-cooled) fast reactor concepts proposed by U.S. nuclear industry. Experiments that offer the potential for significant overall benefits to reactor capital or operating cost reductions are of particular interest.

Questions?