Commercializing Advanced Nuclear: What's It Gonna Take?: Impact of National Laboratories

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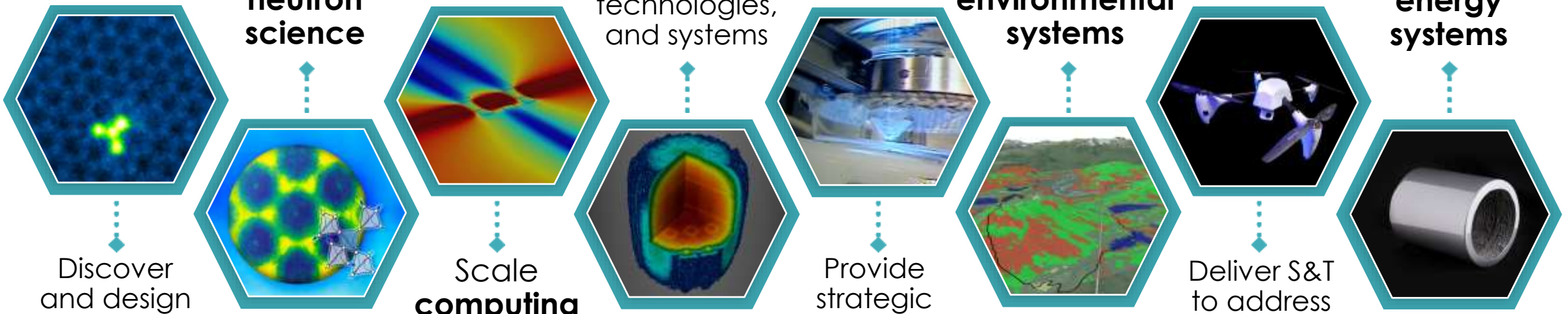
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

The national laboratories have a unique role in energy research in the United States

- The national laboratories perform research for many national interests.
  - Unique facilities and capabilities
  - Basic and fundamental properties
  - New innovations and applied research
- Combining basic to applied research can accelerate innovation and efficiently support deployment for nuclear energy.
- Partnerships, collaborations, and support with industry, the US NRC, and other stakeholders provide an avenue for cost- and time-effective research to make meaningful impacts.

ORNL's major science and technology initiatives provide an opportunity to leverage other areas of science for nuclear



Discover and design next-generation **materials and chemical processes** for energy

Advance the impact and application of **neutron science**

Scale **computing and data analytics** to exascale and beyond for energy

Achieve breakthroughs in **nuclear** science, technologies, and systems

Provide strategic capabilities in **isotope R&D and production**

Understand complexity in **biological and environmental systems**

Deliver S&T to address pressing **national security** challenges

Deliver transformational R&D on integrated **energy systems**

National laboratories have unique capabilities that can be applied to many different applied needs

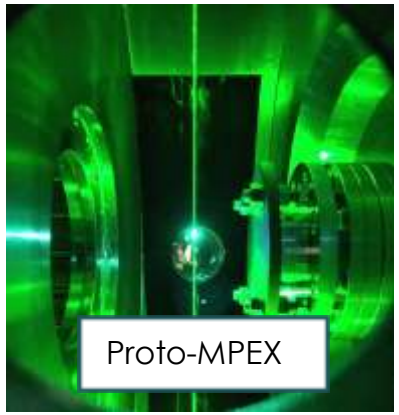
Frontier HPC

Manufacturing Demonstration Facility

HFIR

SNS

High Power Resonant Ring



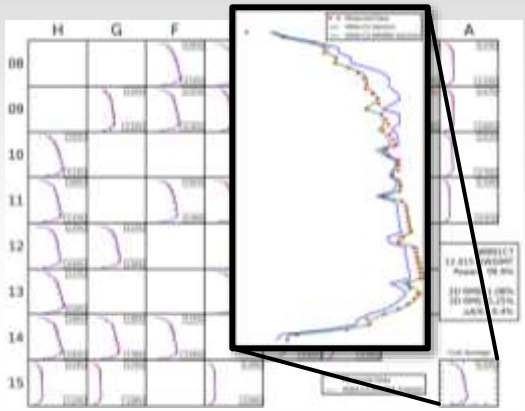
Proto-MPEX

Pellet Lab

National Transportation Research Center

Basic-to-applied research has the power to advance and accelerate reactor technology deployment

VERA Core Simulator uses coupled codes to accurately predict CRUD induced power shift



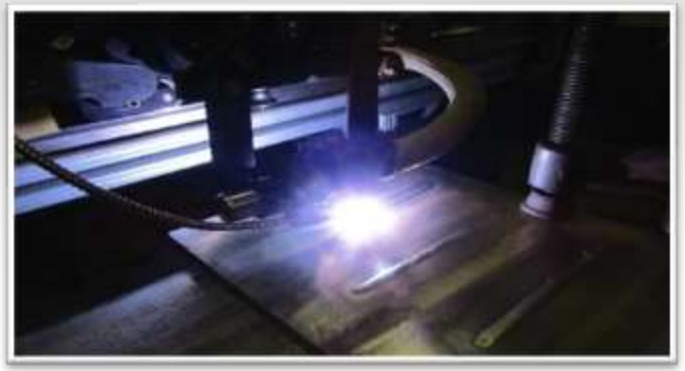
Domestic loss-of-coolant accident test capability was re-established and demonstrated

New approaches shorten the development and qualification cycle

TRIstructural-ISOtropic (TRISO) fuel pebbles

Chloride salt purification system was conceived, built, approved for use, and operated in a 3-month period

New remote weld repair developed to remediate nation's aging spent nuclear fuel canisters



Accident-tolerant fuel (ATF) FeCrAl cladding

ORNL (and all national laboratories) work with (and for) many different partners to support development and deployment of nuclear energy


HITACHI
Westinghouse
Commonwealth Fusion Systems
EPRI
TERRESTRIAL ENERGY
framatome
Flibe ENERGY
TerraPower
NUSCALE Power for all humankind
BWXT BWX Technologies, Inc.
TRISO
energy
Kairos Power
GENERAL ATOMICS
Southern Nuclear
DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA
TVA
U.S.NRC
NASA
OAK RIDGE National Laboratory

ORNL is addressing multiple challenges for new nuclear fission deployment and sustaining the current fleet

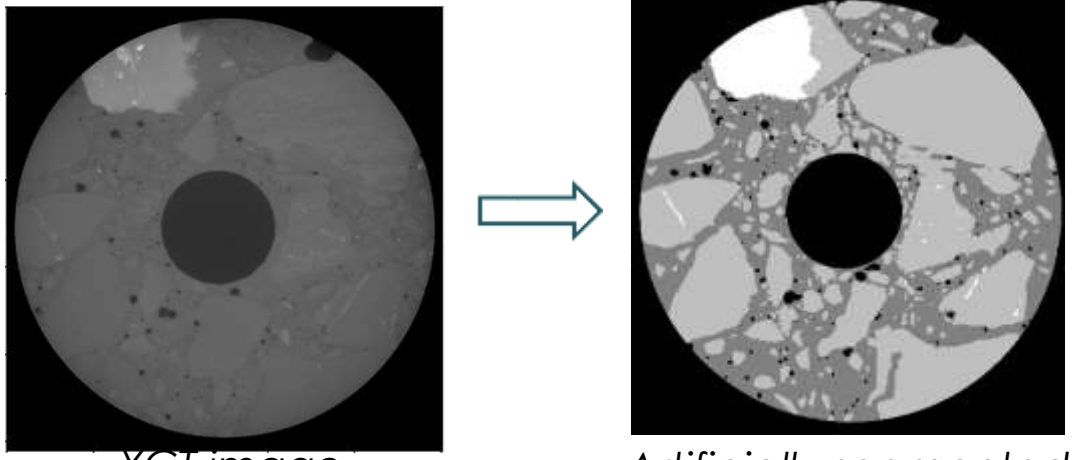
- Supporting DOE's Advanced Reactor Demonstration Program (ARDP):
  - Multiple demonstrations within 7 years
  - 10 advanced reactor designs
  - TRISO fuel line development for X-Energy
  - PIE for Natrium (TerraPower LLC) fuel
- Enabling improvements to and extended operations for current fleet
  - Developing advanced repair techniques (with EPRI)
  - Leadership in evaluating high-burn up fuel options
- Analyzing PIE of fuel from two commercial power plants (accident tolerant clad concepts for Westinghouse and GNF)
- Supporting TVA's evaluation of SMR deployment at Clinch River site

Enclosed welding system in REDC hot cell

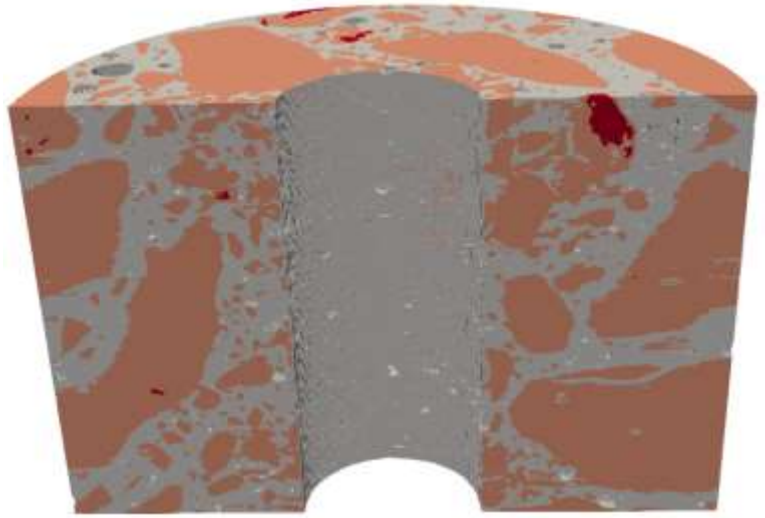
Modern tools are being used to further understanding of critical structures: towards 3D concrete microstructure modeling

- In addition to 2D phase map reconstruction, we employ **nondestructive 3D characterization techniques** (x-ray computed tomography (XCT), neutron imaging) to reconstruct the full volume of a specimen.

- We then employ **artificial intelligence** techniques to 'read and label' the XCT images. This enables the generation of a realistic 3D domain for our microstructure simulations in MOSAIC.



XCT image *Artificially segmented image*



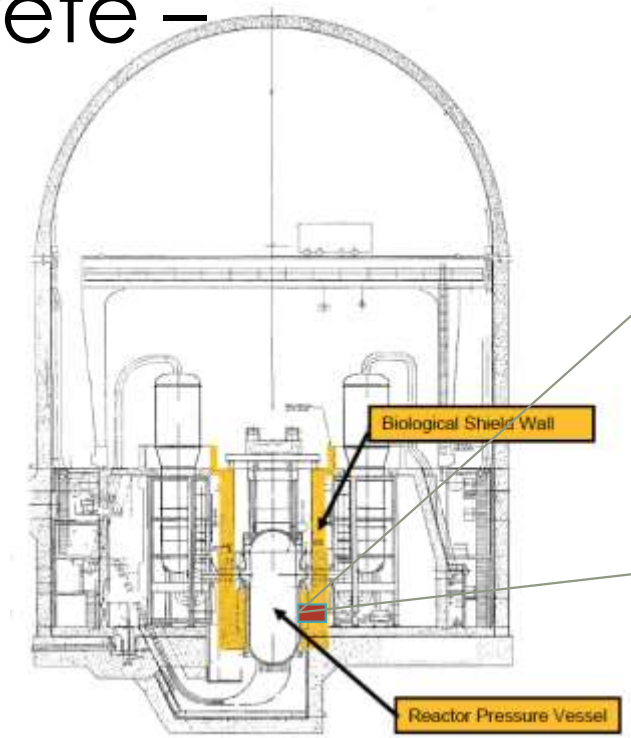
Reconstructed full volume

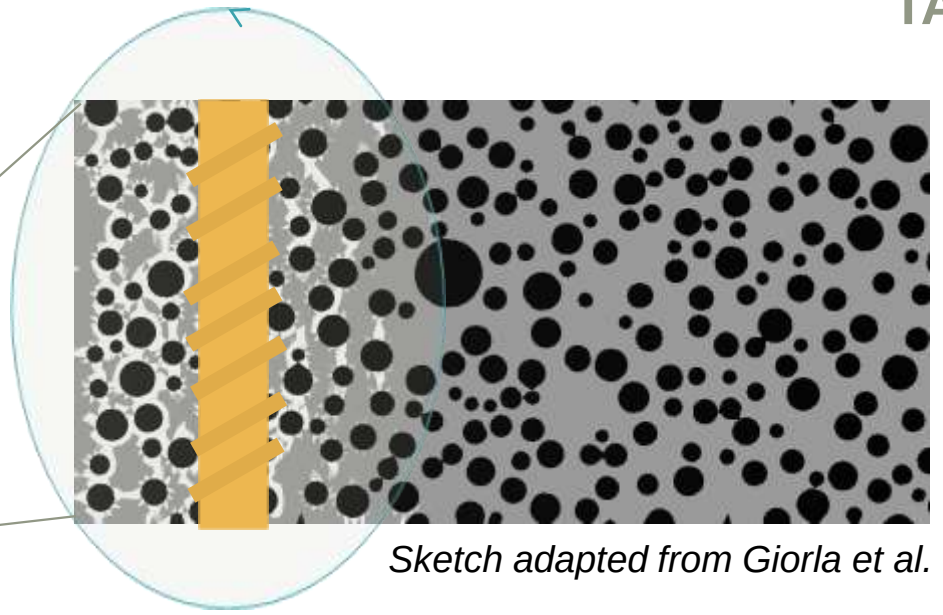
Effects of Irradiation on the Bond Strength of Steel in Concrete – Research Significance

In-service irradiation-induced concrete damage possibly extending beyond rebar

Impact on structural integrity during accidental conditions

TASK 2



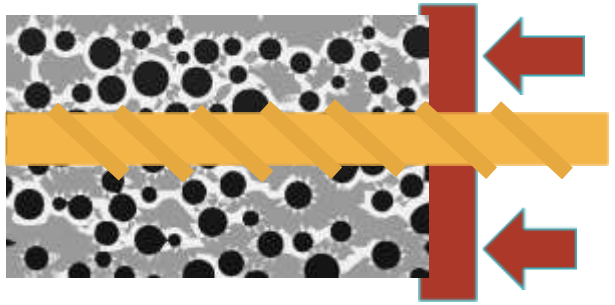


Sketch adapted from Giorla et al. (2016)

Feeds

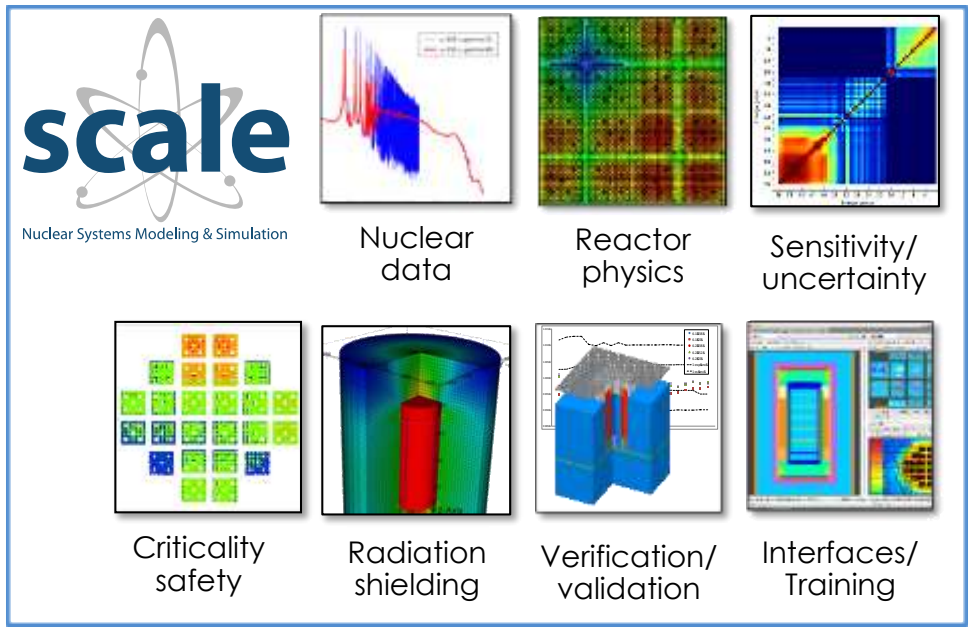
Need for data to support structural analysis

TASK 1

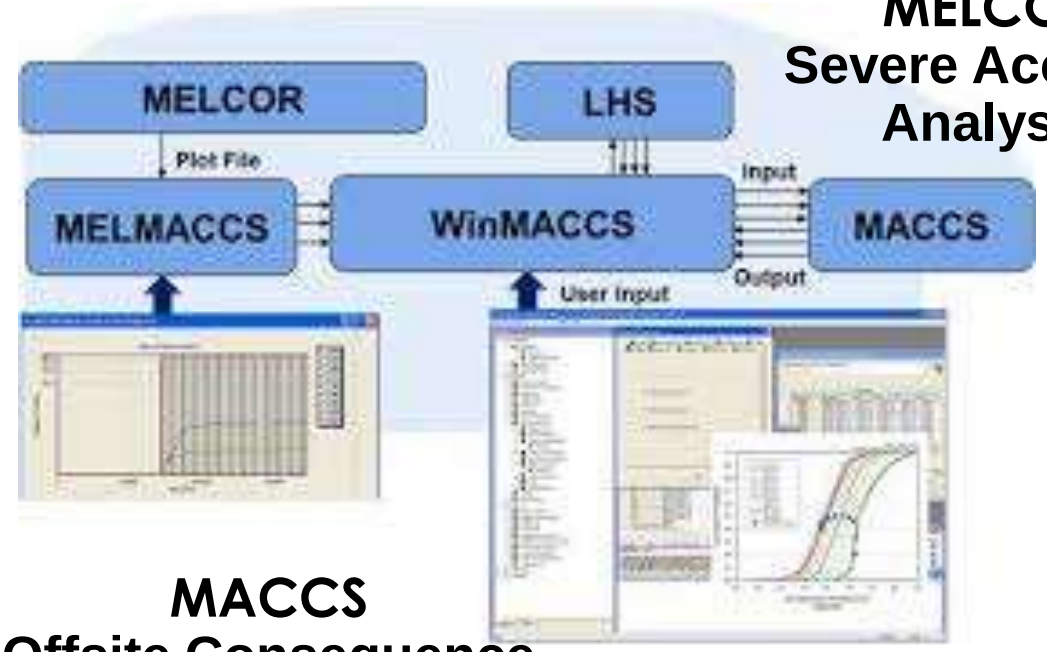


Conceptual sketch of pull-out testing

National laboratories are partnering with NRC to extend codes, data, validation, and methodologies to enable reviews of accident tolerant fuels and non-LWRs



MELCOR
Severe Accident Analysis

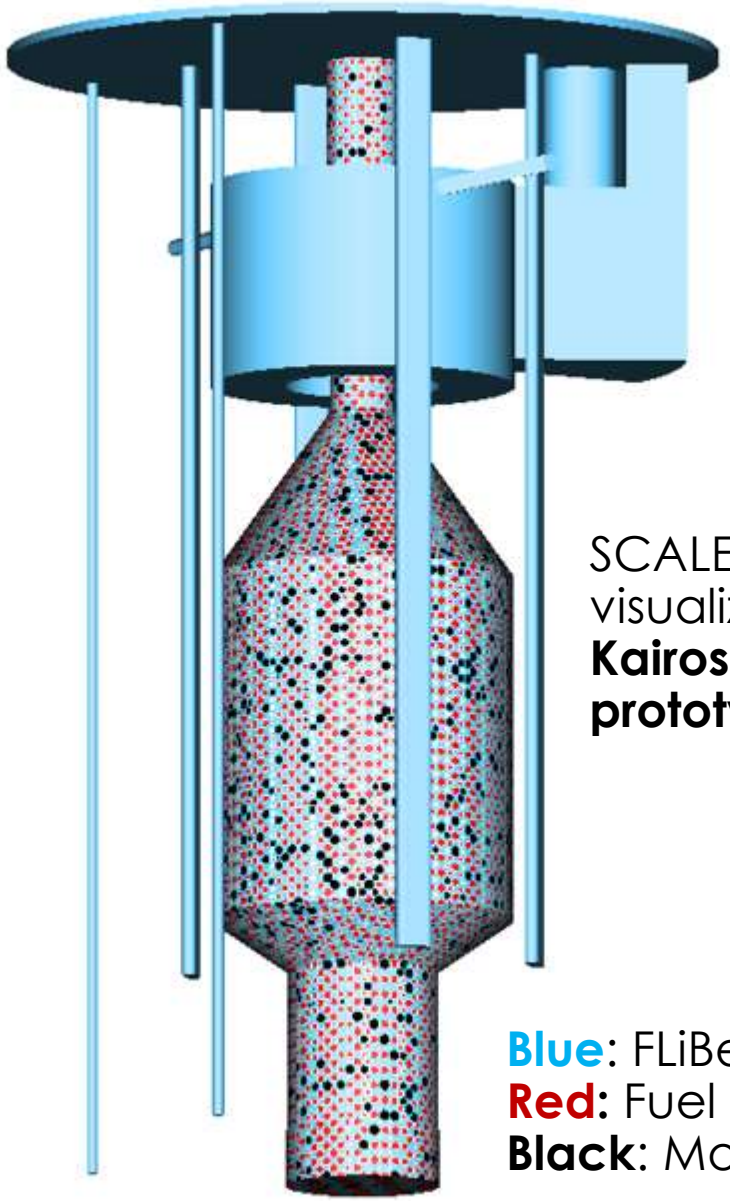


MACCS
Offsite Consequence Analysis

- Experimental coupling and validation are essential to any tool development.
- Combined, these validated codes provide tools for understanding, mitigating, and preventing accident scenarios.

Tools like SCALE have the potential to assess advanced reactor design and conditions

- Provide comprehensive assessment of nuclear data quality through validation across all components of the fuel cycle
  - Criticality safety
  - Radiation shielding
  - Spent fuel inventory
  - Reactor physics/operation
  - Isotope production
  - Leverage near-term reactor deployment activities

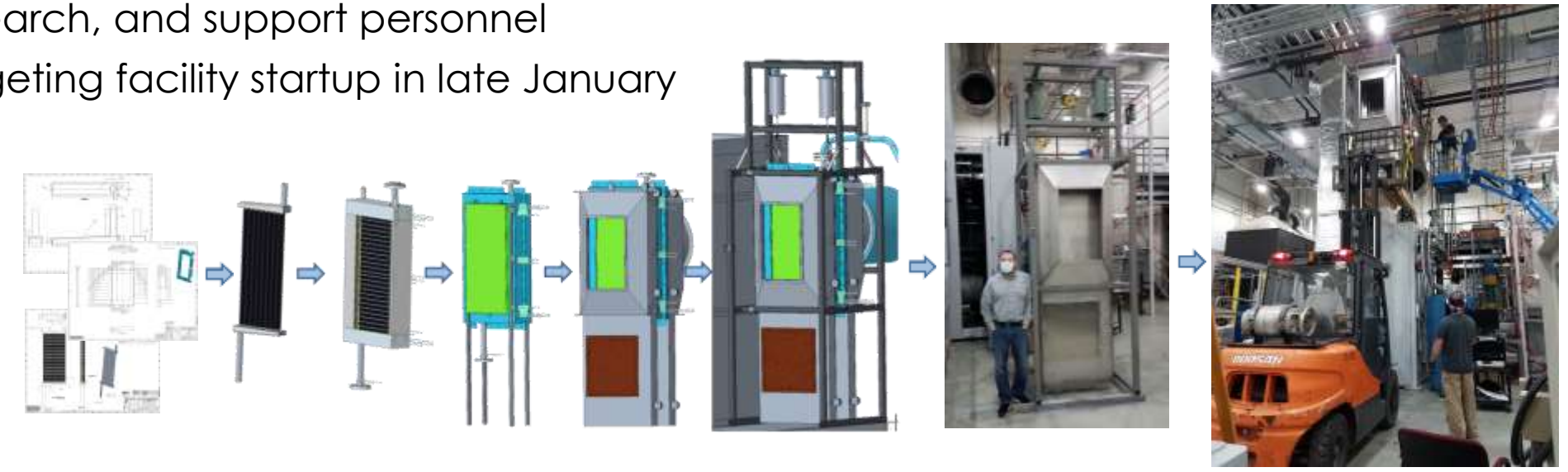


SCALE v6.3.0 3D visualization of **Kairos Hermes prototype reactor**

Blue: FLiBe Coolant
Red: Fuel Pebble
Black: Moderator Pebble

Facility to Alleviate Salt Technology Risks (FASTR) is a versatile, high-temperature (>600°C) molten chloride salt test facility

- FASTR is a chloride salt facility under construction. It will be the largest, non-private, chloride salt facility in U.S. once operational.
  - Custom heat exchanger arrived onsite, culminating 3 y of effort
  - Heat exchanger was lifted 12 ft into place
  - Top pipe segment was lifted and installed
  - Required coordination and support from multiple crafts, research, and support personnel
  - Targeting facility startup in late January



Molten Salt Thermal Properties Database (MSTDB) Released

Scientific achievement

- MSTDB is a database of key models and model parameters that represents key properties as a function of temperature and composition.

Significance

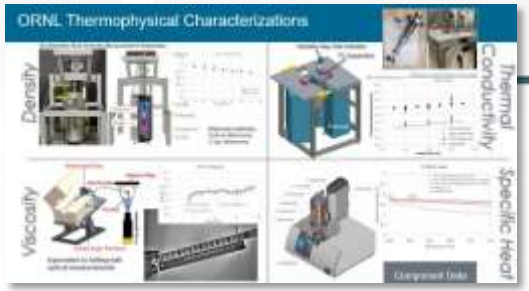
- This data is highly sought for design safety calculations, critical for deployment of molten salt reactors

Research Impact

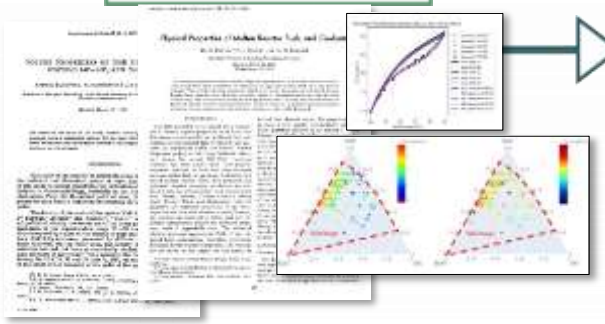
- Within one day of release, over 25+ requests for data were received by industry, universities, and other national laboratories.

mstdb@ornl.gov

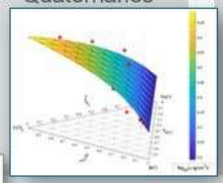
Experiments



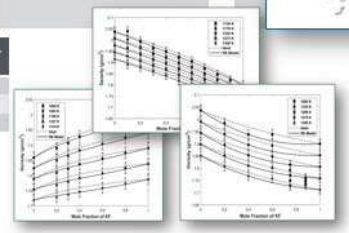
Literature



Component Data	Modeling	Extrapolation	MSTDB-TP	Saline
• Estimation from databases • Multicomponent system behavior estimated by extrapolation of lower order systems (pseudo-binary) • Databases contain pure and binary mixture properties	• Redlich-Kister Expansion • Corrects for interaction in binary system • Accuracy depends on pure and binary component data	• Extrapolate expansion and fit to higher order systems • Ternaries • Quaternaries	• Database of models/ model parameters that will represent salt solution thermal property behavior as a function of temperature and composition	• Application Programming Interface • Provides a stable C++ interface for obtaining supported properties



Pure Salt	Density Equation (g/cm³), T in K
KF	2.6616 – 6.6500 x 10⁻⁴ T
LiF	2.3289 – 4.6803 x 10⁻⁴ T
NaF	2.6820 – 6.1510 x 10⁻⁴ T



- Melting/Boiling Temperatures
- Density
- Thermal conductivity
- Viscosity
- Heat Capacity
- Optical Properties

MSTDB-TP

N. D. Ezell et al., 2022

ORNL Coated Particle Fuel Development (CPFD) Lab

- Established in 2002 with a mission to advance US capabilities for fabrication and characterization of tristructural-isotropic (TRISO) particle fuel.
  - US TRISO coating and quality control (QC) characterization methods modernized.
  - TRISO particles and fuel compacts fabricated at laboratory-scale for the DOE-NE Advanced Gas Reactor (AGR) Fuel Development and Qualification Program's first three irradiation tests.
  - Multiple US industries engaged and supported for scale-up of TRISO fuel fabrication and QC methods.

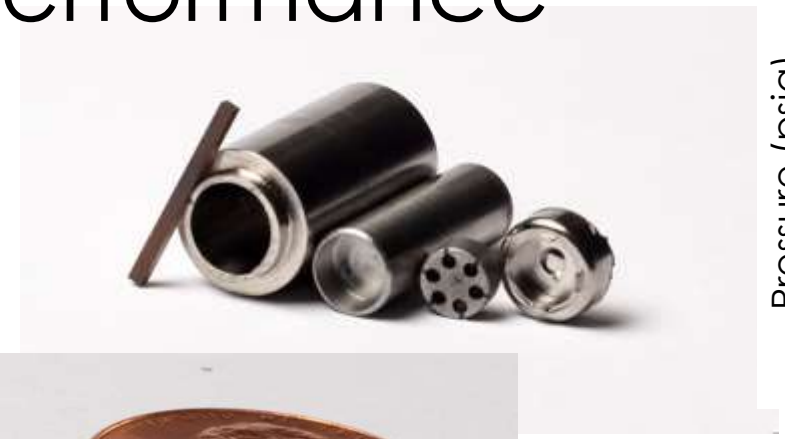
TRISO-X Pilot Line Operating in CPFD Lab

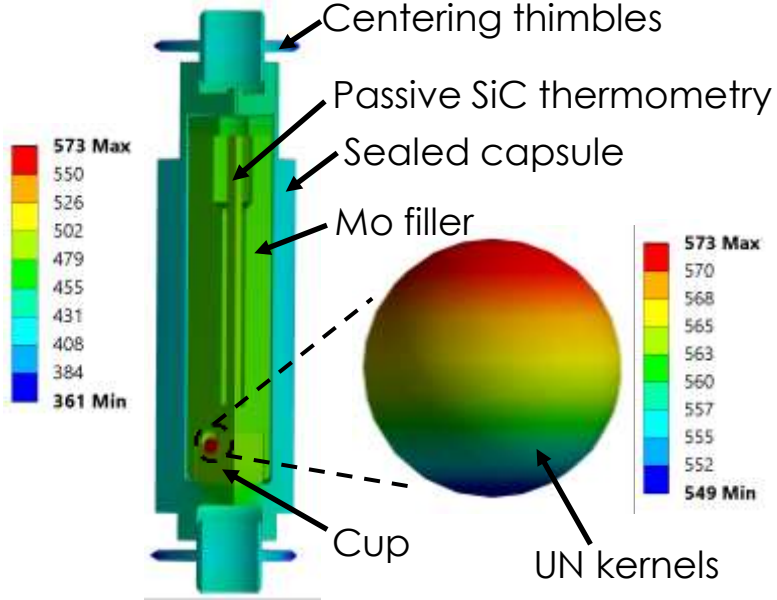
- An X-energy / ORNL collaboration established in 2015 has led to a new US capability for making fuel pebbles and creation of a pilot line for fabricating fuel kernels, TRISO particles, and pebbles with equipment and processes that will be used in the TF3 TRISO-X Fuel Fabrication Facility coming to Oak Ridge in 2025.

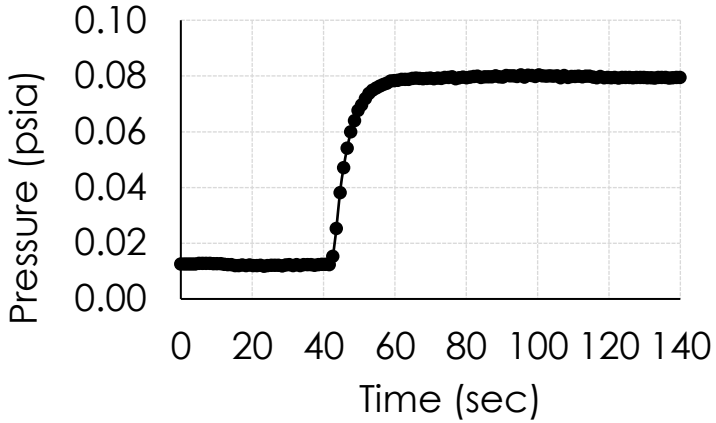
2019 TRISO-X Pilot Line ribbon-cutting ceremony

New "mini-fuel" experiments may provide insights into high-burn up performance

- The new testing capability simplifies experiment design and analysis—accelerating fuel qualification and enabling understanding of basic nuclear fuel behavior.
- Approach minimizes variables and experimental uncertainty, leading to higher quality data.
- First tests focused on fission gas release and swelling of uranium nitride fuel for light water reactors—a fuel lacking any current performance data.







Pressure rise during puncturing

In-cell puncturing apparatus for measuring fission gas release of first MiniFuel capsule

Rapid deployment of cost-effective solutions is key to advanced nuclear deployment

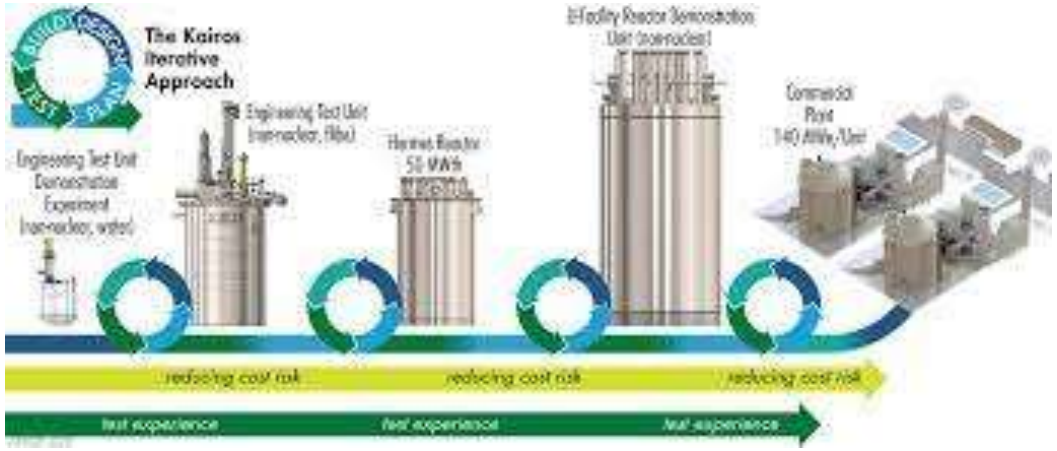
- Delivering first-of-a-kind 3D-printed qualified components for current nuclear power plant (Transformational Challenge Reactor Program)
- Technology development and transfer with key partner Kairos
  - 3-D printed closed pump impeller
  - Must withstand temperatures up to 600 degrees C
  - Rapid manufacturing turnaround
- A partnership with TVA is evaluating performance of 3D-printed fuel assembly brackets for service in an operating power plant.
- Multiple ARDP activities build upon additive manufacturing potential

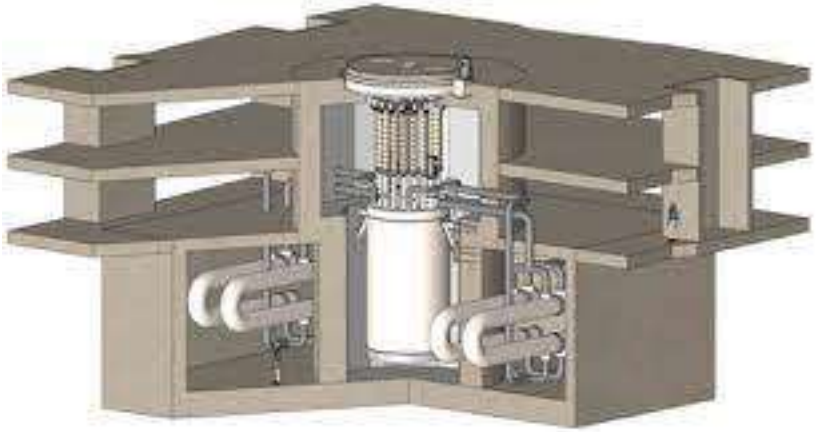
Artistic rendering of HERMES low power demonstration reactor. Credit: Kairos

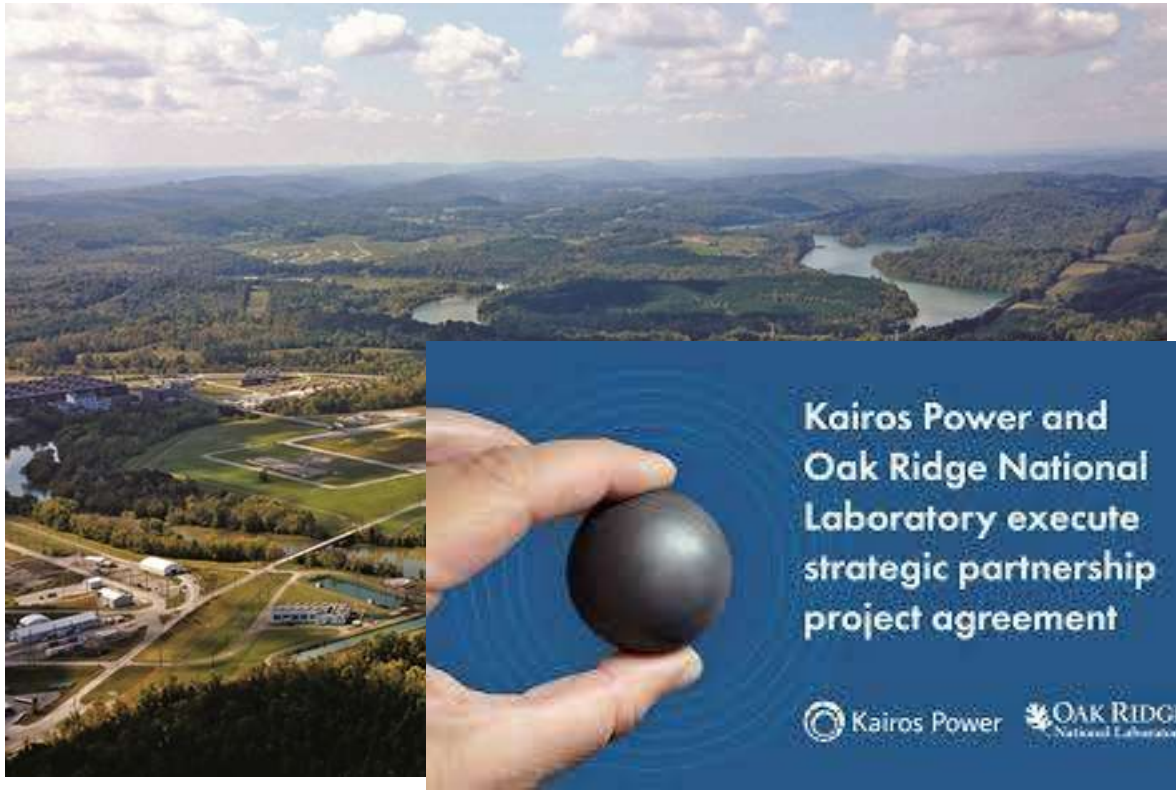
3D printed impeller, (Kairos Power)

3D-printed fuel assembly brackets in TVA Browns Ferry Plant, produced at MDF

Kairos Power has committed to building their prototype Hermes reactor in east TN



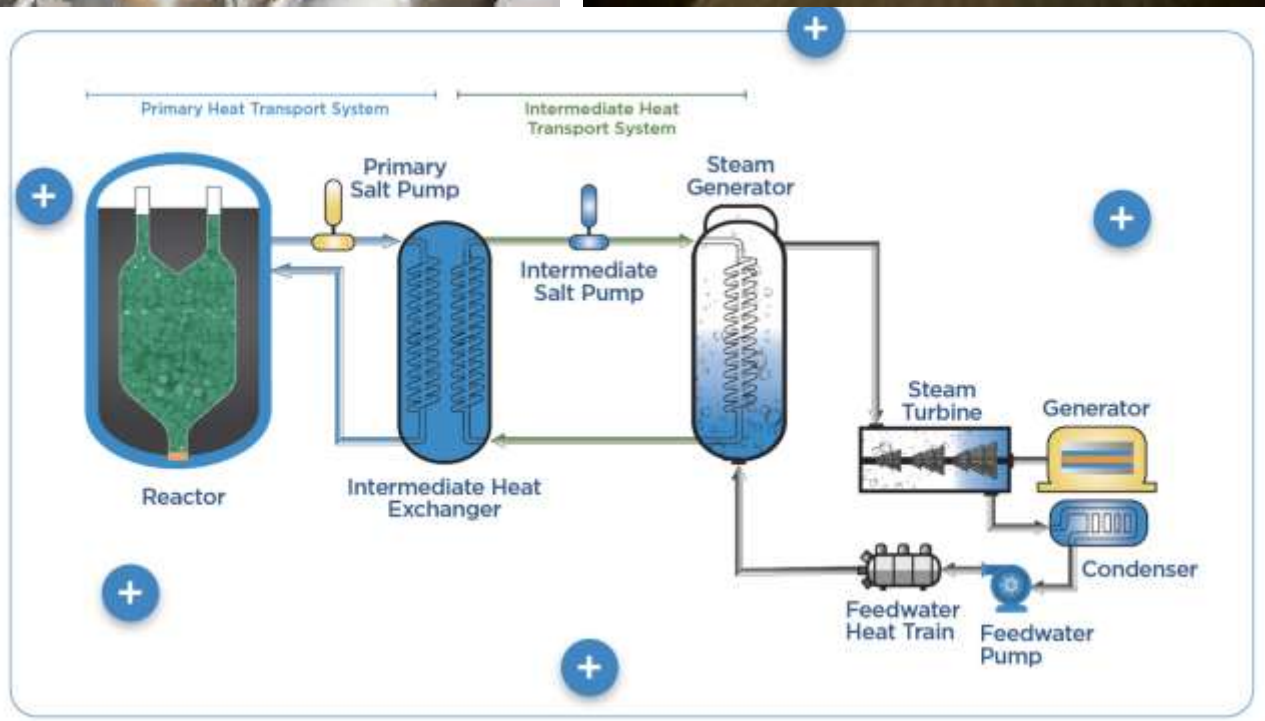




OAK RIDGE National Laboratory

The ORNL/Kairos collaboration is multidisciplinary

- Fuel development
- Materials qualification
- Used fuel storage/transportation options
- Additive manufacturing
- Siting options
- Residual stress management
- Operational experience



The US National Laboratories are excited to help deploy advanced reactors