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Fast Reactor Research Capabilities and Need

Moderator: Tanju Sofu

Panelists:

Bo Feng, Emily Shemon, Steve Novascone, Gary Hu, Changho Lee, Dillon Shaver



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DOE-NE Fast Reactor Program

Bo Feng (National Technical Director)

Argonne National Laboratory

DOE-NE NEAMS Program Annual Review Meeting

February 10-11, 2026, Idaho National Laboratory



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Program Mission Statement and Priorities

Mission Statement

“Anticipate, confirm, and develop the technical elements needed by industry to enable and sustain successful large-scale commercialization of fast reactors”

For commercial deployment of fast reactors, stakeholders have identified two recurring needs:

- Addressing technical challenges to [reduce capital costs](#) and improve economic competitiveness
- Providing validated experimental and operational data [supporting fast reactor licensing](#) cases

High-priority R&D areas:

- [Technology Development](#): Sodium experiments in METL, component design and testing
- [Methods, Modeling, and Validation](#): Safety and physics software and legacy fast reactor databases
- [Advanced Materials](#): ASME code qualification of Alloy 709 for structural materials (100,000-h code case)

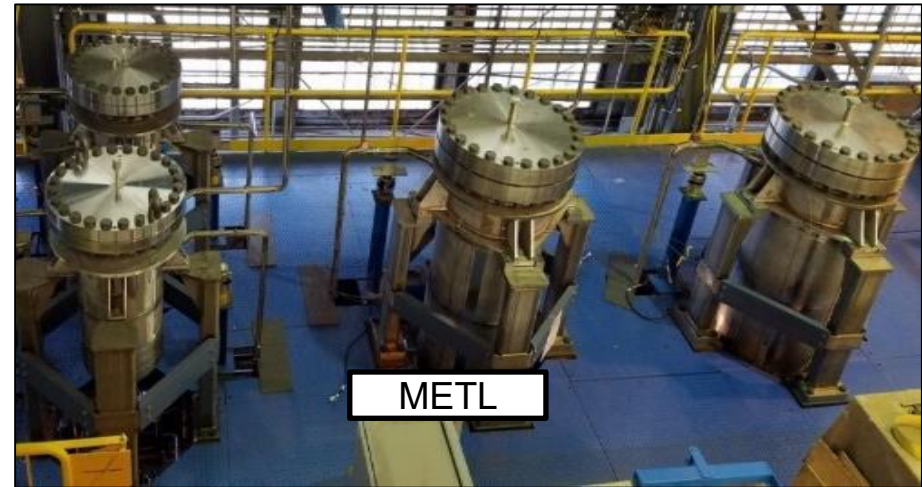


Technology Development

Focuses on designing, fabricating, and testing fast reactor component technologies and experiments in the Mechanisms Engineering Test Loop (METL):

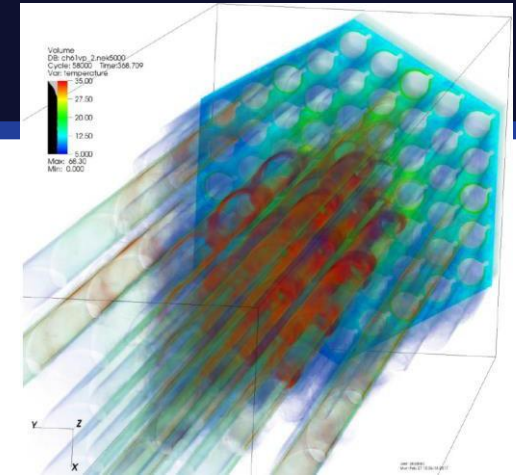
- Gear Test Assembly (GTA)
- Thermal Hydraulic Experimental Test Article (THETA)
- Gripper Test Article (GrTA)
- Flow Sensor Test Article (F-STAr)
- Bearing Test Article (BTA)

These test articles either enable cost reductions and improved performance in SFRs or provide valuable experimental data under sodium for software validation, sensor design, etc.



Methods, Modeling, and Validation

- Verification and Validation of Fast Reactor Software:
 - Domestic and International fast reactor benchmarks (IAEA, GIF, bilateral agreements)
 - Examples: SAS4A/SASSYS-1 (systems/safety) and MFUEL (metallic fuel performance), DIF3D/REBUS (neutronics and fuel management), SRT (source term), SPCA-ANL (Na fire), NUBOW (core bowing), NEAMS tools (SAM, Nek, PyARC), etc.
- Collect, organize, and perform quality assurance on fast reactor databases <https://frdb.ne.anl.gov/> with data from: EBR-II, FFTF, TREAT, ZPR/ZPPR, out-of-pile and sodium experiments
- Industry needs for data and software quality assurance is growing as more license applications are underway



Nek5000 CFD simulation of flow in non-uniformly heated 61-pin assembly

FIPD: Metallic Fuels Irradiation & Physics Database

FIPD is an organized collection of metallic fuel 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 descriptions, safety analysis, and operational reports.



Experiment Operating Data

Browse experiment operational data:

- Experiments
- Subassemblies
- Runs
- Pin Designs
- Reactor Power/Fission Gas History
- Subassembly Coolant Flow Rates



Digitized PIE Collection

Browse digitized PIE by type:

- Gas Release
- Gas Chemistry
- Irradiated Length
- Irradiated Weight
- Contact Profilometry
- Laser Profilometry
- Gamma Scan
- Neutron Radiography



Document Library

Browse documents by type and content:

- Content Types 13
- Document Types 11
- Posttest Examinations 17
- Fabrications 10
- Authors 25
- Open Literature Resources



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Advanced Materials

- Code qualifying **Alloy 709** to replace 316H stainless steel for SFR structural materials
- Higher creep strength of Alloy 709 can result in decrease in capital cost and increase in safety margins
- FRP will see through 100,000 hour code case submission to ASME; all other Alloy 709 scope has shifted to AMMT program: 300,000h - 500,000h cases, non-plate forms, sodium compatibility testing, neutron irradiation, *etc.*



3rd heat of A709



Creep test frames

Same Starting Point	4-Year mechanical properties and creep testing	100,000-hour ASME, Section III, Division 5 Code Case (Data package ready by Dec. 2024)
	7-year limited creep testing	300,000-hour Division 5 Code Case
	11-year selective creep testing	500,000-hour Division 5 Code Case



Fuels Technical Area Fast Reactor Highlights

Topher Matthews

Stephen Novascone

With contributions from:

Jacob Hirschhorn, Yinbin Miao, Shipeng Shu, Aaron Oaks, Kun Mo, Adam Zabriskie,
Latif Yacout, Larry Aagesen, Chao Jiang, Boone Beausoleil, Michael Cooper



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Fast Fuel Highlights

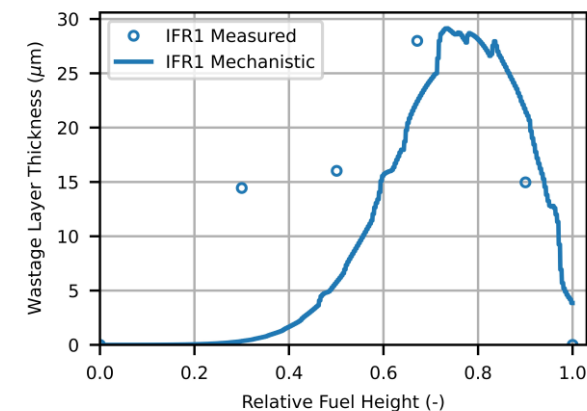
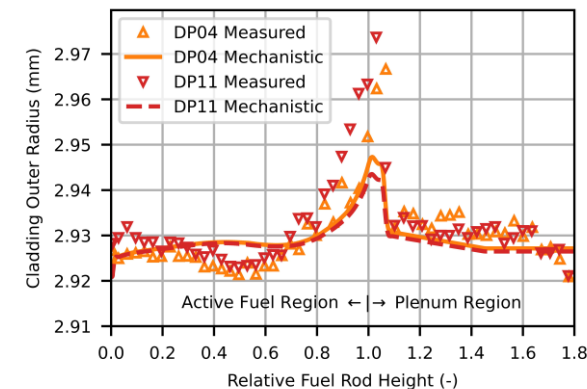
Baseline capabilities in BISON

- Mechanistic FGR and swelling
- Zr migration
- Thermomechanical models
- FCCI model development
- Extended assessment cases and FIPD database

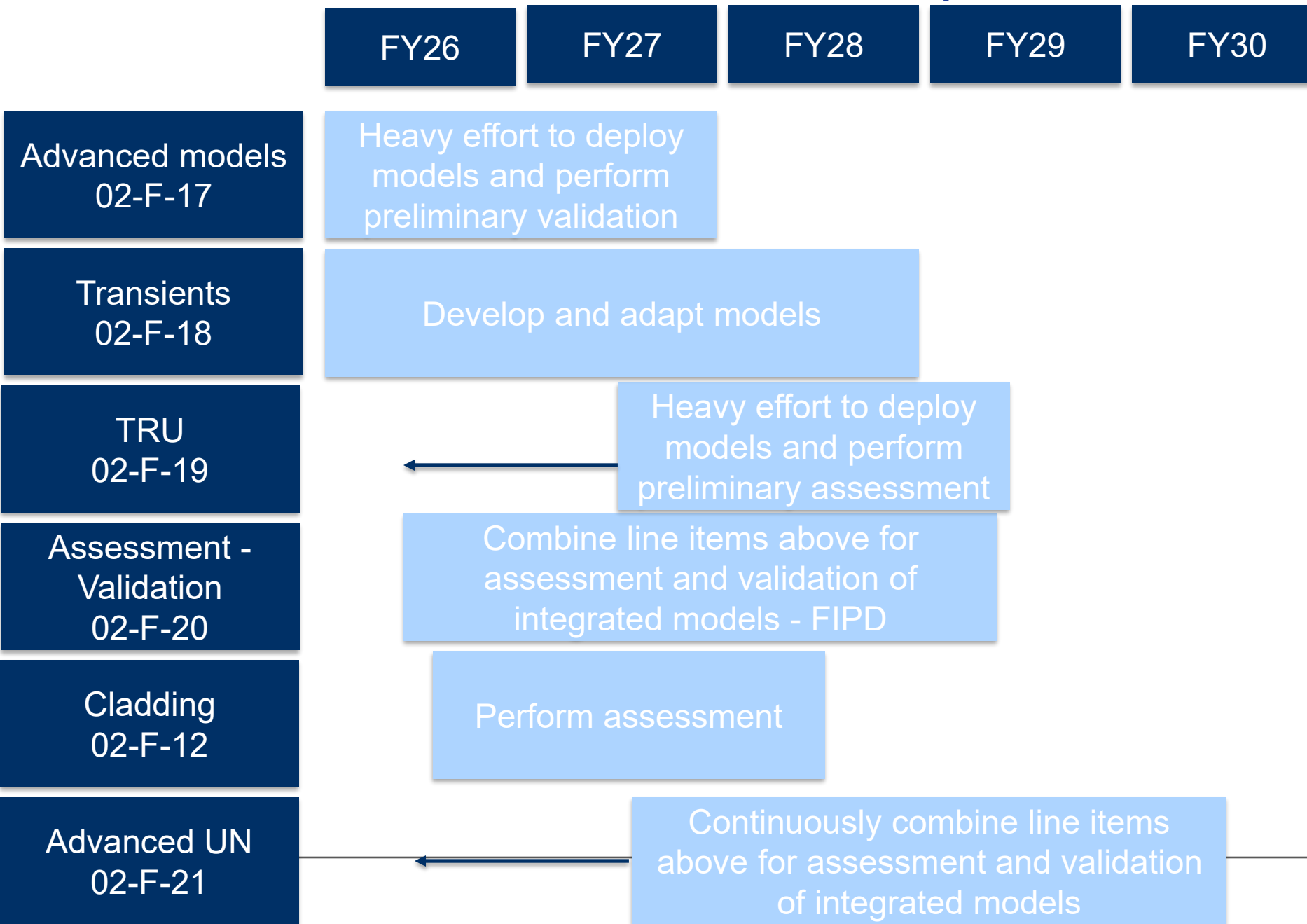
Next steps (FY26)

- Ramping up metallic fuel investment
- Responding to stakeholder input
- Demonstrate integration of recent advanced metallic fuel models through comparisons with EBR-II measurements and first-generation models
- Hot pressing
- Review, develop, and implement BISON models for alpha-Zr and U-Pu-Zr-TRU performance to support near-term industry objectives
- Assessment and Validation of BISON's Next-Generation Metallic Baseline Modeling Capability Using FIPD
- Complete mechanistic model for impurity effects in uranium nitride swelling model

- Multiscale modeling was used to develop a mechanistic framework for cladding-side FCCI in BISON
- Atomistic studies provide transport properties
- Mesoscale studies capture microstructural effects and inform engineering scale model form
- The engineering scale model accounts for reactant conservation and material degradation due to chemical reactions
- Preliminary demonstrations and validation studies are promising, but there is room for improvement
- Quantifiable features of this modular framework can be refined, and expanded
- High-priority future work will focus on refining reactant source terms, conducting broader validation, and investigating potential FCCI rate-limiting processes



Interactions between line items in IPL, Metallic Fuel



Thermal Fluids Technical Area Fast Reactor Highlights

Dillon Shaver, ANL

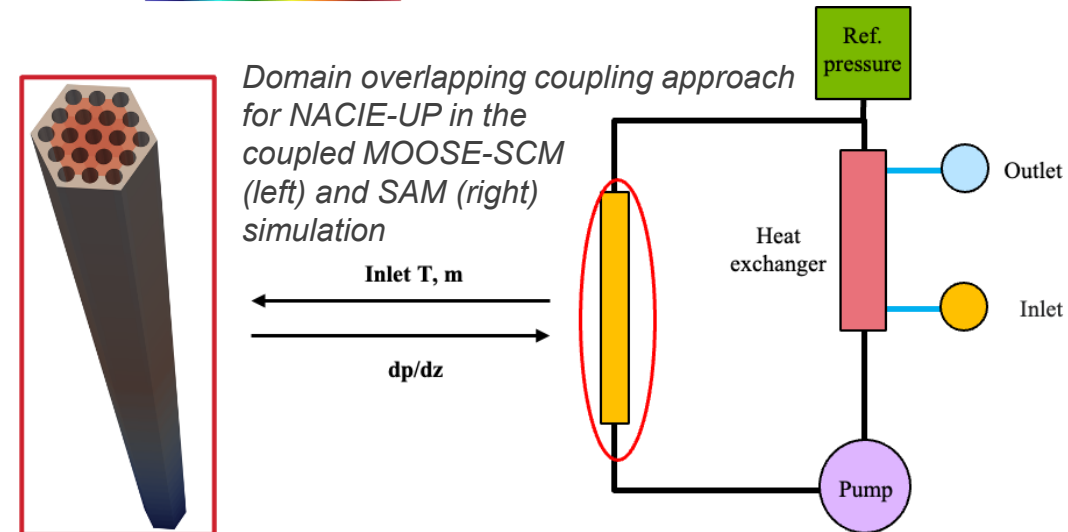
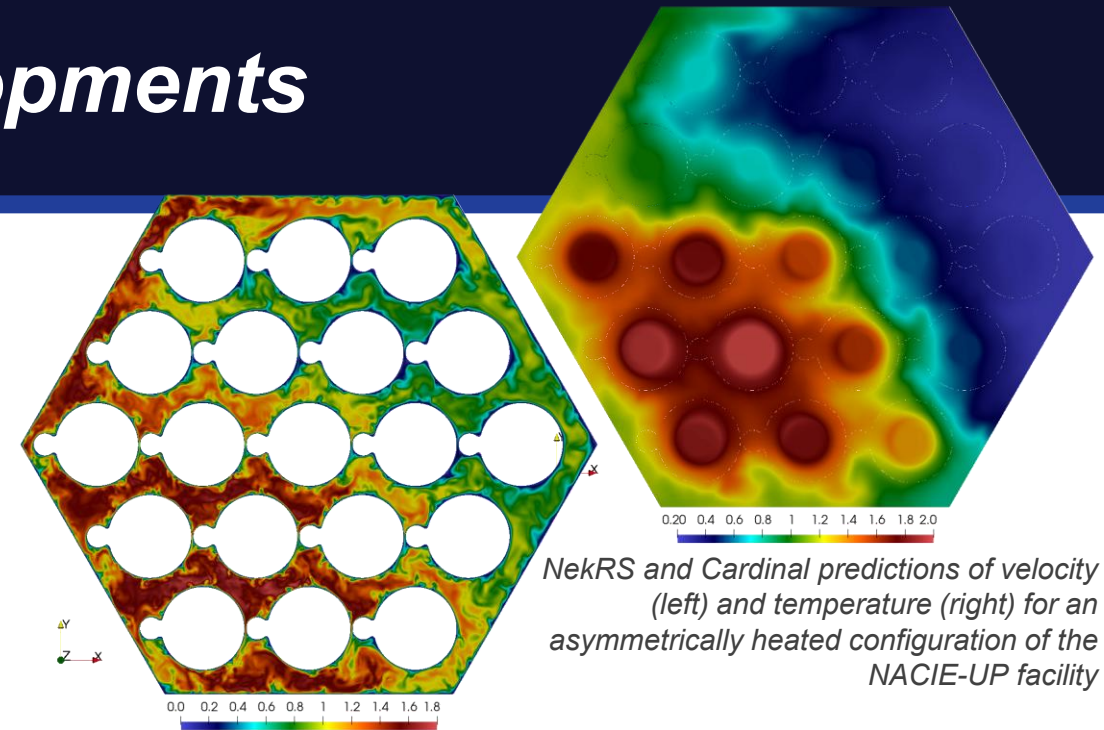


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Thermal Fluids Area: FY25 Developments

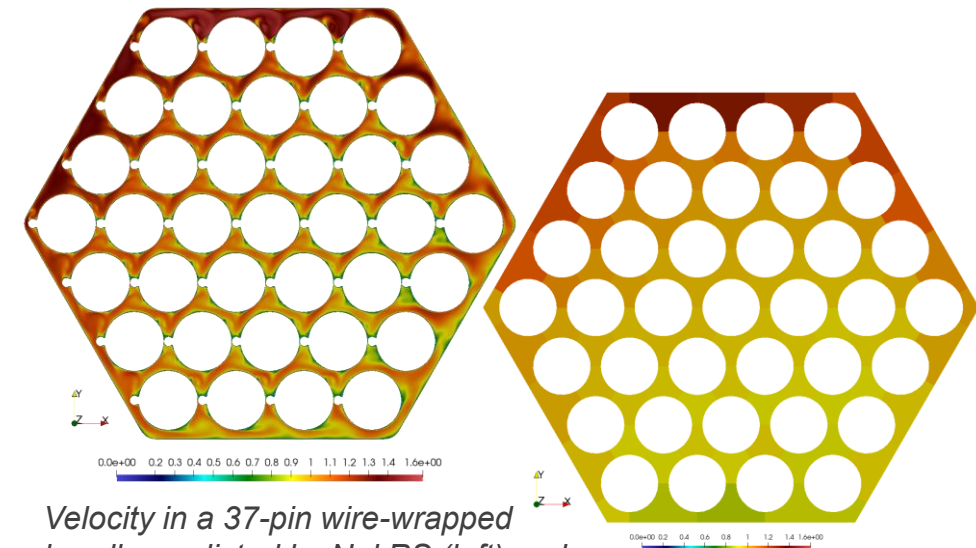
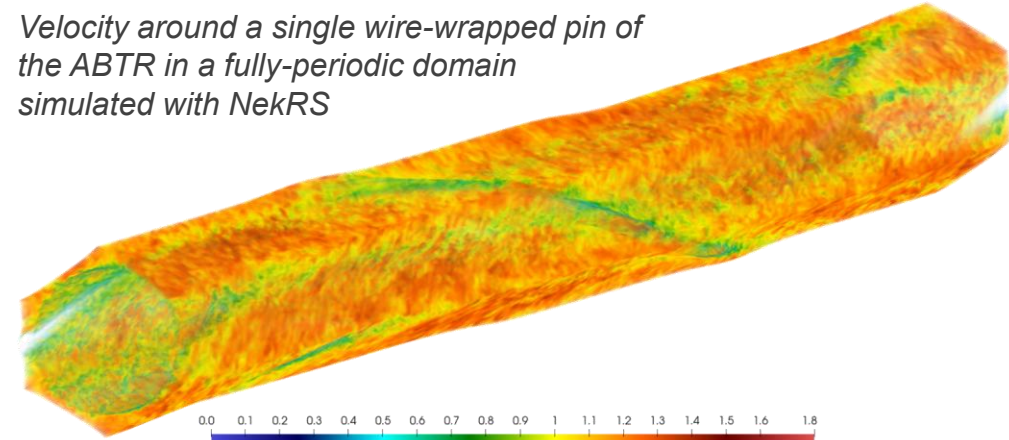
- **NekRS/Nek5000/Cardinal** (*Lower length scale*)
 - Benchmark for LMFR heat transfer with NACIE-UP (supported by ART-FRP)
 - Validation for LMFR flow-split and friction factors (supported by Natrium ARDP)
- **Pronghorn** (*Engineering scale*)
 - Development of additional models based on EBR-II
 - Fast spectrum MSR demonstrations
- **SAM** (*System scale*)
 - Improvement of 1-D axial mixing model for modeling of thermal stratification and mixing in large enclosures
 - Coupled SAM and MOOSE SCM simulations for EBR-II (CoE project with Oklo) and NACIE-UP (supported by ART-FRP)



Thermal Fluids Area: Looking Ahead

- **NekRS/Nek5000/Cardinal** (*Lower length scale*)
 - Completion of NQA-1 compliance for Cardinal
 - Streamlined interface for post-processing and multiscale coupling via Cardinal
 - Additional validation cases for LMFRs
- **Pronghorn** (*Engineering scale*)
 - Development of SFR subchannel capabilities in collaboration with Oklo
- **SAM** (*System scale*)
 - Develop modeling methodology for SFR inter-wrapper flow and inter-assembly heat transfer during transients
 - Develop advanced data-driven models for thermal mixing/stratification in large plena, such as a transformer-based machine learning turbulence model

Velocity around a single wire-wrapped pin of the ABTR in a fully-periodic domain simulated with NekRS



Velocity in a 37-pin wire-wrapped bundle predicted by NekRS (left) and subchannel-averaged with Cardinal (right)

Reactor Physics Technical Area

Fast Reactor Highlights

Changho Lee, ANL

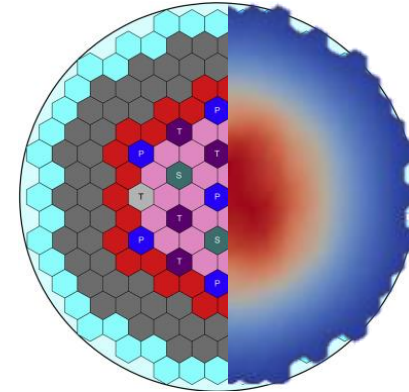


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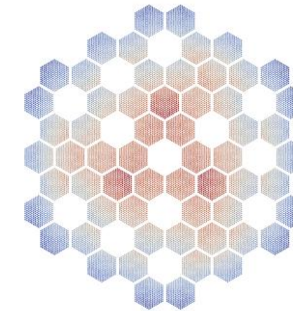
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NEAMS Reactor Physics: Baseline Capabilities

- **Goal:** develop and deploy codes for modeling neutral particle transport and nuclide depletion/decay
- Griffin
 - DFEM-SN and HFEM-PN transport solvers for steady-state & transient
 - Cross section generation workflow using built-in MC²-3 (similar to PyARC)
 - Pin power reconstruction
 - Fuel management capability for shuffling and fuel cycle calculations (no external cycle)
 - Verification using ABTR and ABR-1000 compared against Serpent and DIF3D
- Shift
 - Standalone Monte Carlo reference solutions with Shift
 - Two-step neutronics workflow for Shift-Griffin calculations



Homogenized
Core Flux Distribution



Reconstructed
Pin Power



NEAMS Reactor Physics: FY25, FY26 & Future

- FY25 Accomplishments

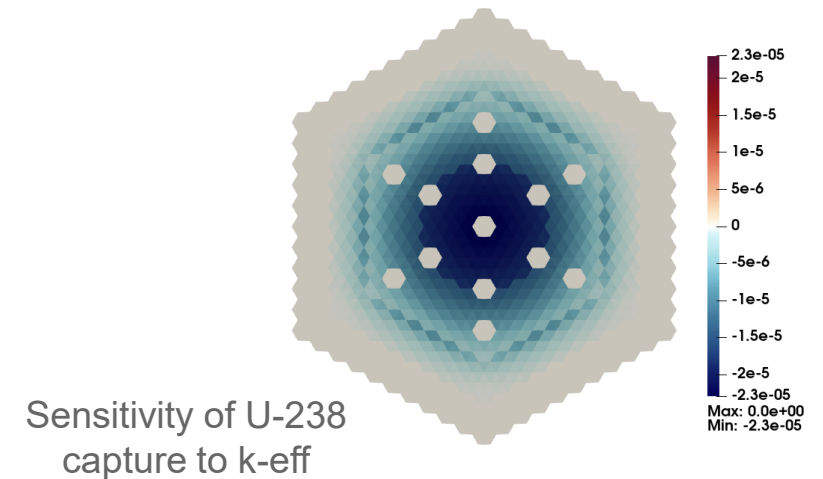
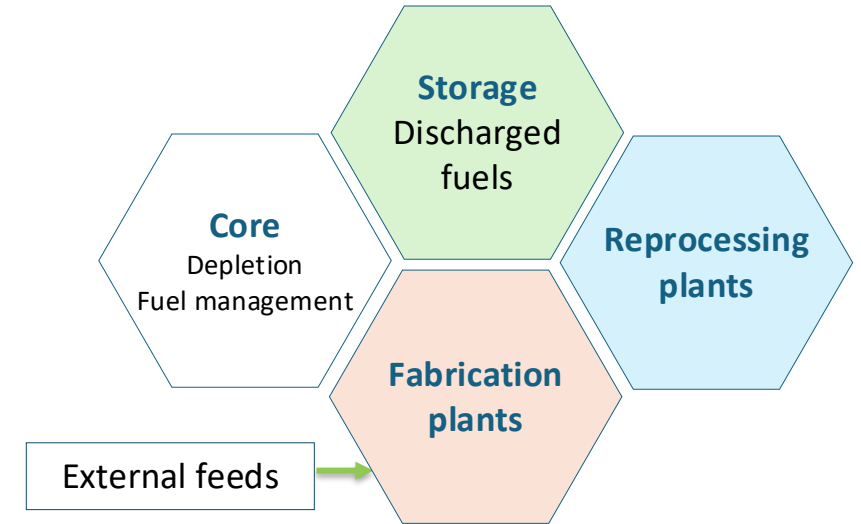
- Started adding **external fuel cycle** options to fuel management (similar to REBUS)
- Started GPT-based **sensitivity capability** (completed in Dec. 2025) and **uncertainty capability** for fast reactor problems (similar to PERSENT)
- Started capabilities (sodium backfill, updated pin powers) supporting **core bowing** multiphysics (completed in Dec. 2025)
- (Shift) Deployed improvement of multigroup **scattering cross sections** for trace nuclides using the virtual collision
- (Shift) Continued research on **anisotropic scattering** moments

- FY26 Goals

- Deploy fuel management scheme including external cycle capability
- Deploy the uncertainty calculation capability
- (Shift) Start on automated MOOSE-to-Shift reference solutions

- Future Work

- Perform validation using fast reactor experiment data
- Add similarity (representativity) calculation to the sensitivity capability



Structural materials modeling Fast Reactor Highlights

Gary Hu and Mark Messner, ANL



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Structural Materials & Chemistry for Fast Reactor

Alloy 709 development and qualification

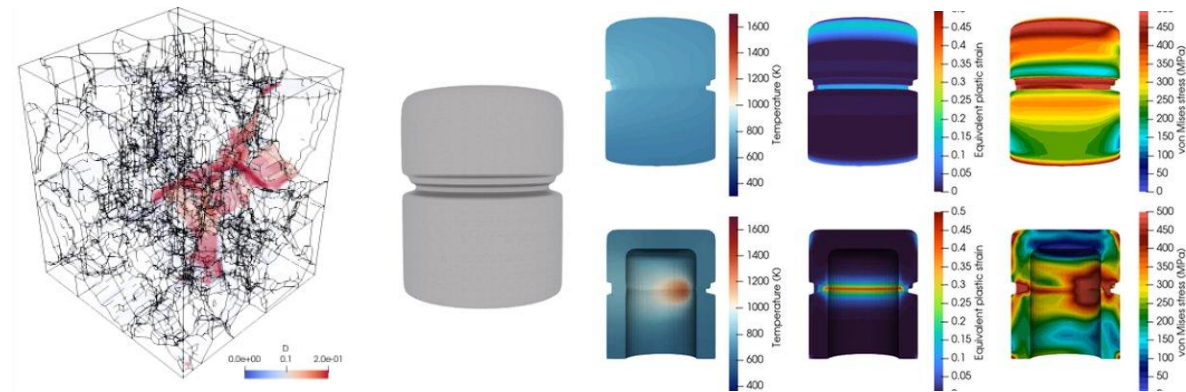
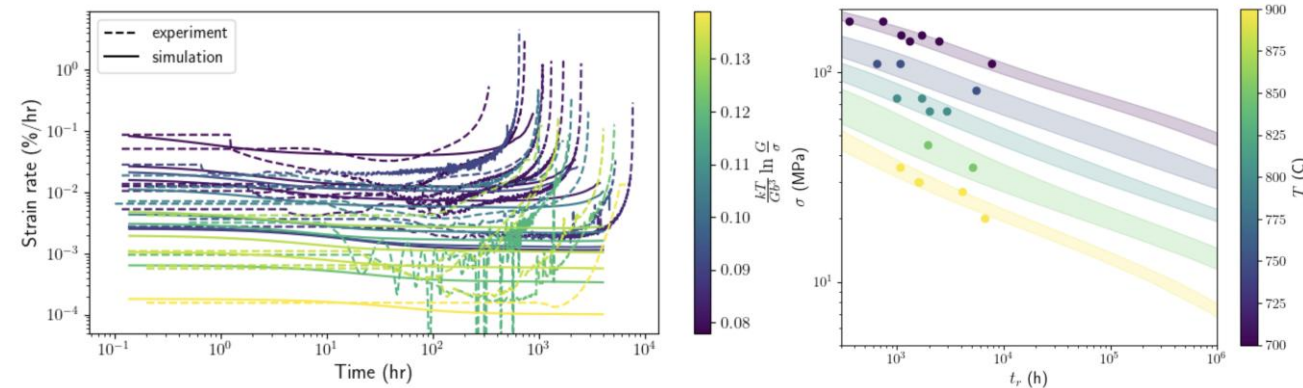
- Developed physics-based [creep/thermal aging](#) model accelerating long-term property prediction.
- Investigated [stress-relaxation](#) and [multi-axial creep](#) relevant to high-temperature fast-reactor alloys.

Status update on code cases for ASME Boiler & Pressure Vessel Code, Section III, Division 5

- [Alloy 709](#): submitted (in collaboration with [ART/FR](#))
- [AM 316](#): drafted, pending submission (with [AMMT](#))
- [Alloy 625](#): experiment/simulation campaigns (with [AMMT](#))

Software capability developments

- Expanded solid mechanics with new Lagrangian kernels enabling [efficient, scalable large deformation simulations](#).
- Integrated [cohesive zone method](#) for interface traction-separation mesoscale fracture modeling.
- Strengthened dynamic subdomain modification capabilities in support of [welding](#) simulation workflows.
- Ongoing integration of NEML2 material models into MOOSE enabling [GPU](#) utilization.



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Structural Materials & Chemistry for Fast Reactor

Achievement	NEAMS Tool
High-temperature alloy creep models	
Mesoscale models for deformation, damage, irradiation effects in Grade 91	LApX
Surrogate creep models for microstructure-aware component-level modeling	LAROMance, MOOSE
Phenomenological models for high-temperature creep	NEML2
Mesoscale models for deformation, damage in Alloy 709	NEML, NEML2, MOOSE
Support for accelerated qualification of Alloy 709	NEML, NEML2, MOOSE
Core duct deformation modeling	MOOSE
Prediction of weld residual stress prediction and subsequent stress-relaxation cracking	MOOSE

Future work

- Continue collaboration with AMMT on accelerated material qualification
- Scale to full-core LMFR core duct deformation modeling
- Validate weld residual stress prediction against established benchmarks
- Enable end-to-end solid mechanics simulation on GPUs



Multiphysics Applications Fast Reactor Highlights

Emily Shemon, ANL

FY25-26 Contributors:

*ANL: Ahmed Abdelhameed, Yan Cao, Kalin Kiesling (WPM), Kyle Ramey, Emily Shemon (WPM),
Nick Wozniak, Gang Yang, Yiqi Yu*

ORNL: Eva Davidson (WPM), Donny Hartanto

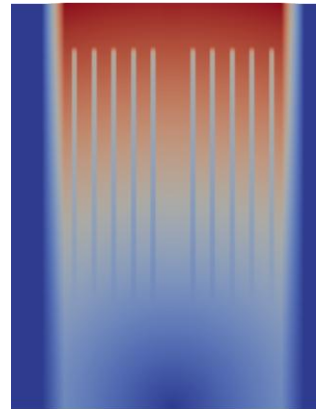
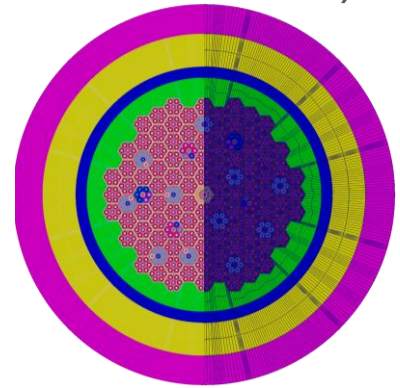
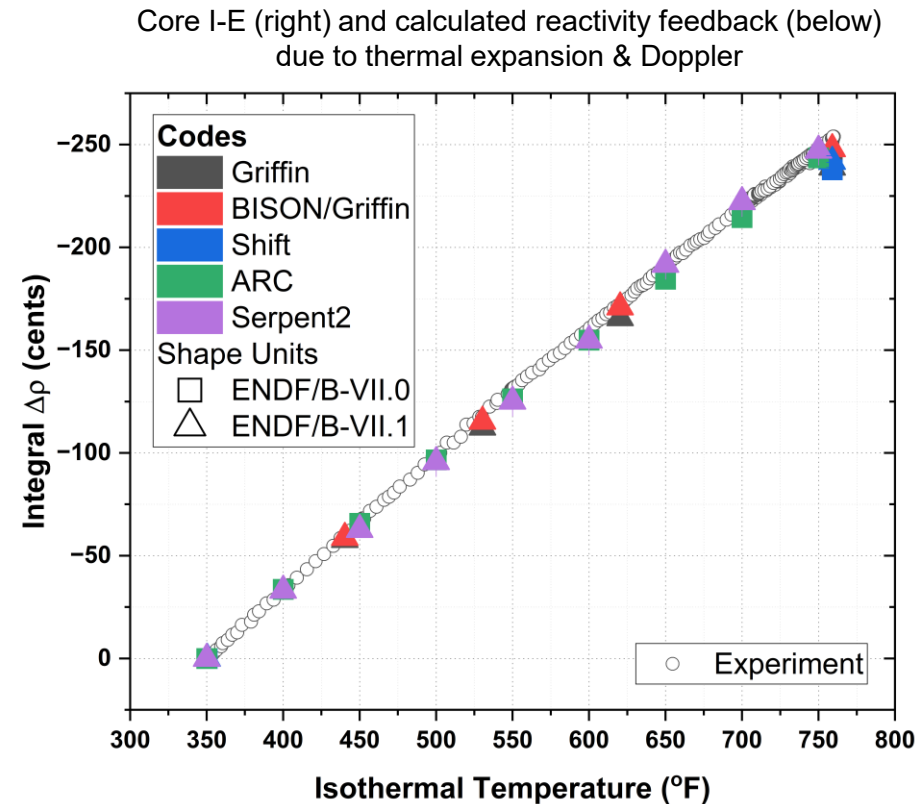


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Software Validation using SEFOR Data

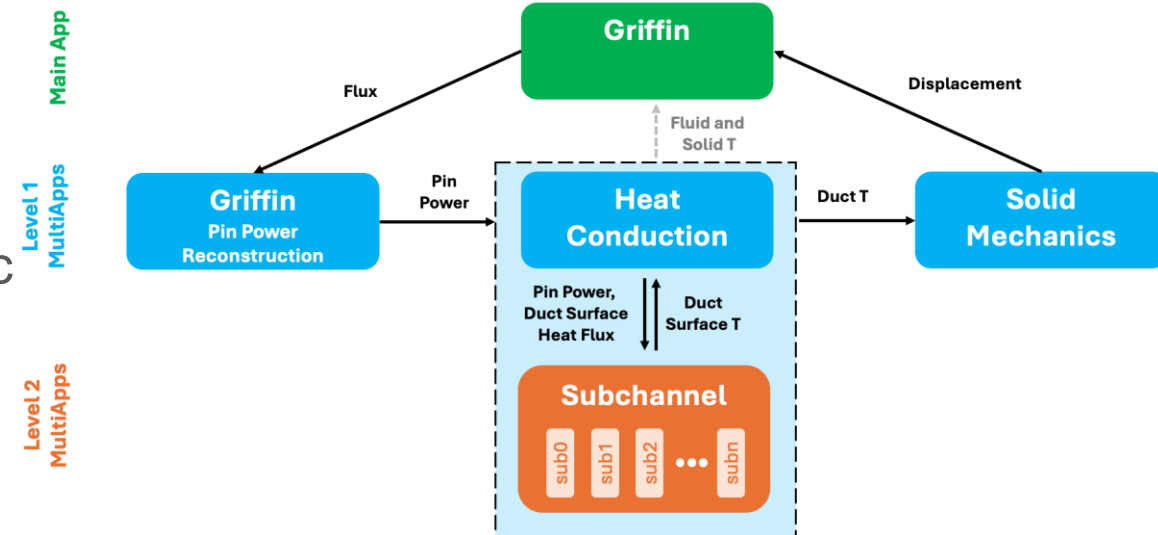
- Collaboration with ART FRP & France's CEA to validate fast reactor software using Southwest Experimental Fast Oxide Reactor (SEFOR) data (isothermal, power ascending, and transient tests)
- **Complete:** **MC²-3/Griffin** & **Shift** validation for Doppler reactivity feedback (isothermal tests) in Core I-E (*shown right*) & Core I-I
- **In progress:** Integrate **BISON** for automatic thermal expansion; model reflector worth tests
- **Publications:** [Joint milestone report](#); upcoming PHYSOR 2026 papers; Core I-E & Core I-I Griffin models on [NRIC VTB](#)



BISON thermal displacement prediction (room temp to 350 F)

Progress on Multiphysics SFR Core Bowing Methodology

- Multiyear project to model SFR core bowing & reactivity feedback directly (in collaboration with ART FRP & Japan's JAEA)
- **Complete:** Preliminary integration of **Griffin** reactor physics, **SCM** thermal fluids, and **MOOSE** solid mechanics on steady state mini ABR-1000 core
- **In progress:** Incorporate advanced reactor physics capabilities (sodium backfill, PPR), assess neutronic & TH fidelity sensitivities, expand grid plate on-the-fly; develop V&V plan
- **Publications:** [Joint milestone report](#), verification of multiple MOOSE thermo-mechanical models ([VTB](#))
- *Other:* PyARC open source software upgrades (joint with FRP); enable fast reactor workflows with MOOSE meshing capabilities (e.g. restraint ring geometries)





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