# RIC 2024 Hybrid

U.S. Nuclear Regulatory Commission 36<sup>th</sup> Annual Regulatory Information Conference

# ADAPTING TO A CHANGING LANDSCAPE

# MARCH 12-14, 2024

Bethesda North Marriott Hotel and Conference Center Rockville, Maryland

#nrcric2024

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## RIC 2024 Hybrid

U.S. Nuclear Regulatory Commission 36<sup>th</sup> Annual Regulatory Information Conference

T5: Advancing Small Modular Reactor (SMR) Safety through Global Collaboration: International Research and Regulatory Research

MARCH 12-14, 2024

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# *NRC Readiness for Advanced Reactor Independent Analysis*

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#### ADAPTING TO A CHANGING LANDSCAPE



### **Exciting Times for Nuclear**

# Many designs under developmentMultiple technologies





Fuel Kernel (UCO, UO<sub>2</sub>)
Porous Carbon Buffer
Inner Pyrolytic Carbon <sup>(IPyC)</sup>
Silicon Carbide
Outer Pyrolytic Carbon <sup>(OPyC)</sup>



Key mission for the NRC is to be prepared . . . for any & all









## **SMR Landscape & Challenges**

# Light-Water Reactors (LWRs)

- Large "Conventional"
- Conventional Oxide Fuel

Small "Passively Cooled"HALEU and Accident Tolerant Fuel

# Non-Light-Water Reactors (non-LWRs)

- Gas Cooled: Pebble Bed Hydraulics, TRISO Fuel
- Liquid Metal: Fast Spectrum, Metallic Fuel, Mechanical Expansion
- Molten Salt Cooled: Pebble Bed Hydraulics, TRISO Fuel
- Molten Salt Fueled: Fluid Properties, Neutronics, Corrosion
- Microreactors: Heat Pipes, Heat Removal Mechanisms

U.S.NRC UNITED STATES NUCLEAR REGULATORY COMMISSION Protecting People and the Environment

#### SMRs (LWRs with Passive Cooling)

- Independent analysis of SMRs performed with "conventional" codes (TRACE, FAST, SCALE, PARCS, MELCOR)
- Previous work for AP600, AP1000, and ESBWR provided initial validation and data
- Additional validation performed as needed, with experimental data provided by the applicant, from international collaboration (ATLAS, PKL, PANDA, PERSEO), or by the NRC (Rod Bundle Heat Transfer)
- Global cooperation through the Code Application and Maintenance Program (CAMP)







#### **Independent Analysis Capability**

# Advanced Reactor Code Development Reports

- These Volumes outline the <u>specific</u> <u>analytical tools</u> to enable independent analysis of non-LWRs, <u>technical "gaps"</u> in capabilities, <u>V&V needs</u>.
- Gaps in experimental data are currently being identified.





#### "Modeling Gaps" Identified by PIRTs

- Phenomena that are significant and "new" with increased importance for non-LWRs relative to conventional LWRs include but are not limited to—
  - Thermal stratification and thermal striping
  - Thermo-mechanical expansion and effect on reactivity
  - Large neutron mean-free path length in fast reactors
  - Transport of neutron precursors (in fuel salt MSRs)
  - Solidification and plate-out (MSRs)
  - Three-dimensional conduction/radiation (passive decay heat removal)

"Modeling Gaps in NRC Codes"

Plant Type No.	Description
1	HTGR; prismatic core, thermal spectrum
2	PBMR; pebble bed core, thermal spectrum
3	GCFR; prismatic core, fast spectrum
4	SFR; sodium cooled, fast spectrum
5	LMR; lead cooled, fast spectrum
6	HPR; heat pipe cooled, fast spectrum
7	MSR; prismatic core, thermal spectrum
8	MSPR; pebble bed, thermal spectrum
9	MFSR; fluoride fuel salt, thermal spectrum
10	MCSR; chloride fuel salt, fast spectrum



### <u>Comprehensive Reactor Analysis Bundle</u> BlueCRAB









### **Multiphysics Coupling**

**Griffin: Reactor Kinetics** 

#### SAM: System-Level Thermo-Fluids



**Tensor Mechanics Module** 



#### Codes Supporting Non-LWR Licensing (Volume 3 & 5)



The NRC's comprehensive neutronics package:

- Nuclear data and cross-section processing
- Decay heat analyses
- Criticality safety
- Radiation shielding
- Radionuclide inventory and depletion generation
- Reactor core physics



The NRC's comprehensive severe accident progression and source term code:

- Characterization of accident progression
- Thermal-hydraulic response of the reactor
- Core heat-up, degradation, and relocation
- Fission product release and transport behavior



#### **Reference Plants**

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Туре	Reference Design	Accomplishments
GCR	HTR-PM (250 MWt)	2D Porous Media, Pebble Tracking, Reactor Cavity Cooling System
SFR	ABTR (250 MWt)	60 Chan Model with DRACS, Core Plate Expansion
MSR (cooled)	PB-FHR (320 MWt)	2D Porous Media, Pebble Tracking, Reactor Cavity Cooling System
MSR (fueled)	MSRE (10 MWt)	Neutron Precursor Tracking
MicroRx	~ SPR A	Heat Pipe Modeling, 3D Heat Conduction
MicroRx	~ eVinci	Heat Pipe Modeling, 3D Heat Conduction

#### **Other Available Reference Plants**

Туре	Reference Design	Comments
GCR	HTTF, PBMR-400	Benchmark Participation, Validation
SFR	FFTF	Benchmark Participation, Validation
MSR (fueled)	EVOL	Internal Circulation (i.e., requires ~ CFD)



# Advanced Reactors Three-Phased Approach for Confirmatory Models



<u>Stage 1</u> – Generic Readiness for a Reactor Technology Code infrastructure development, reference plant model/source term demonstration, generic models that benefit all non-LWR designs (IAP Strategy 2 Volumes)



<u>Stage 2</u> – Readiness for a Specific Application

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<u>Stage 3</u> – Model build, Analysis, and Review of a specific application under licensing review

Conduct confirmatory analysis, generation of RAIs, and input to SER



## **Non-LWR Progress and Next Steps**

#### Completed

- Non-LWR Code Development Reports
- Reference Plant Models
  - o 6 for systems analysis (Vol. 1)
  - $_{\circ}$  5 for severe accident and source term analysis (Vol. 3)
  - 2 for nuclear fuel cycle analysis (Vol. 5)
- SCALE/MELCOR Demonstration Public Workshops
  - 5 for source term (Vol. 3)
  - 2 for fuel cycle (Vol. 5)
- MACCS assessments and updates (Vol. 3)
  - Near-field atmospheric transport and dispersion model
  - Radionuclide and physiochemical methodology
- Code Assessment Reports for Metallic and TRISO Fuels (Vol. 2)
- Training on BlueCRAB Codes (Vol. 1)

#### **Under Development**

- New and Updates to Existing Reference Plant Models (Vols. 1, 3, 5)
- Verification and Validation Report for Systems Analysis (Vol. 1)
- Assessment of MACCS Capabilities to Model Physiochemical Transformations during Atmospheric Dispersion (Vol. 3)
- Development/Consolidation of Radiation Protection Codes for Non-LWR Analysis (Vol. 4)
- Fuel Cycle Demonstration Project Public Workshop for Molten Salt Reactors (Vol. 5)



#### Summary

- Code development and preparation for independent analysis of SMRs are well underway. Analysis codes have been identified and are being improved by application to reference plant models
- International collaboration is welcome through participation in code assessment and international benchmark studies
- Code validation and quantification of uncertainties remain as important topics to be resolved
- The NRC is prepared for independent analysis of SMRs to support the licensing and evaluation process

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