INL/MIS-24-77127-Revision-0

Virtual Test Bed (VTB): NRIC FY24 Program Review

March 2024

Lise Cecile Madeleine Charlot, Abdalla Abou Jaoude, Emily Shemon

Changing the World's Energy Future

Idaho National Laboratory

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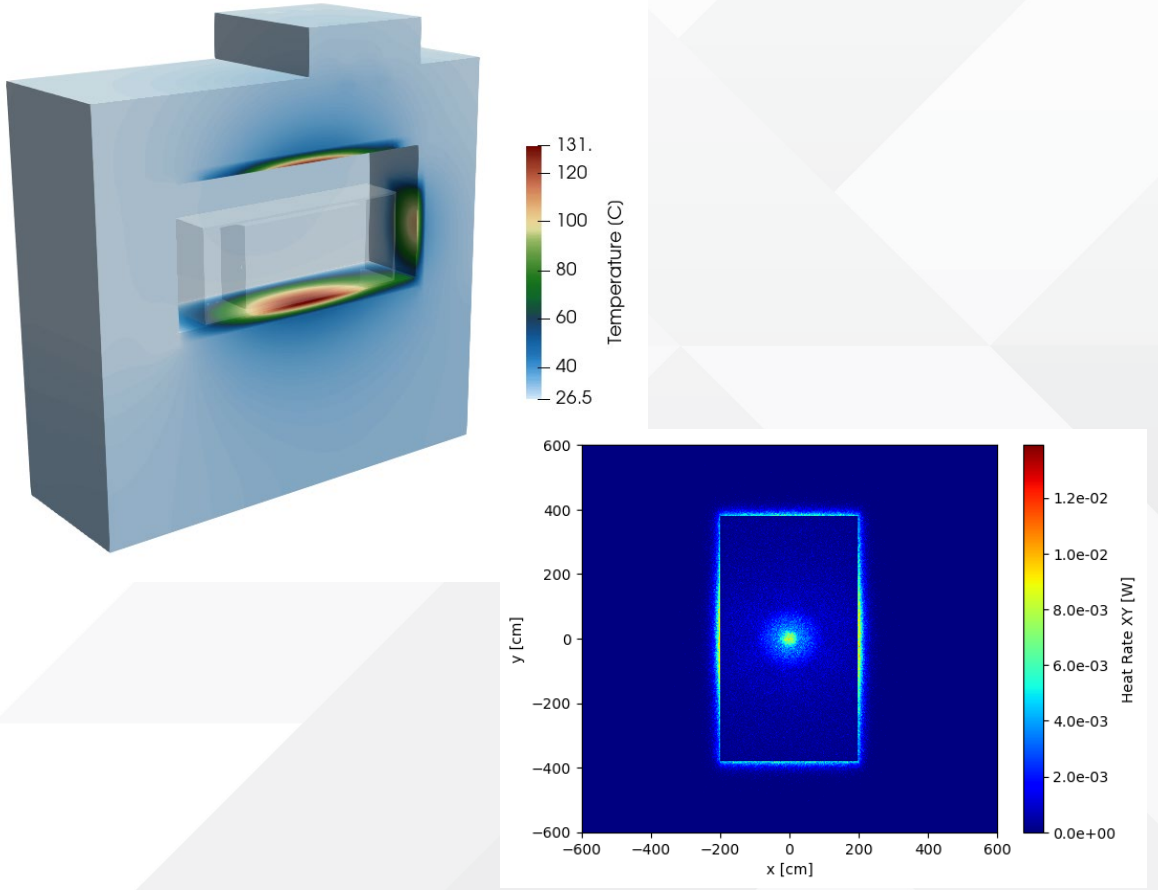
NRIC National Reactor Innovation Center

NRIC Virtual Test Bed (VTB)

NRIC FY24 Program Review

Lise Charlot (INL), Abdalla Abou-Jaoude (INL), Emily Shemon (ANL)

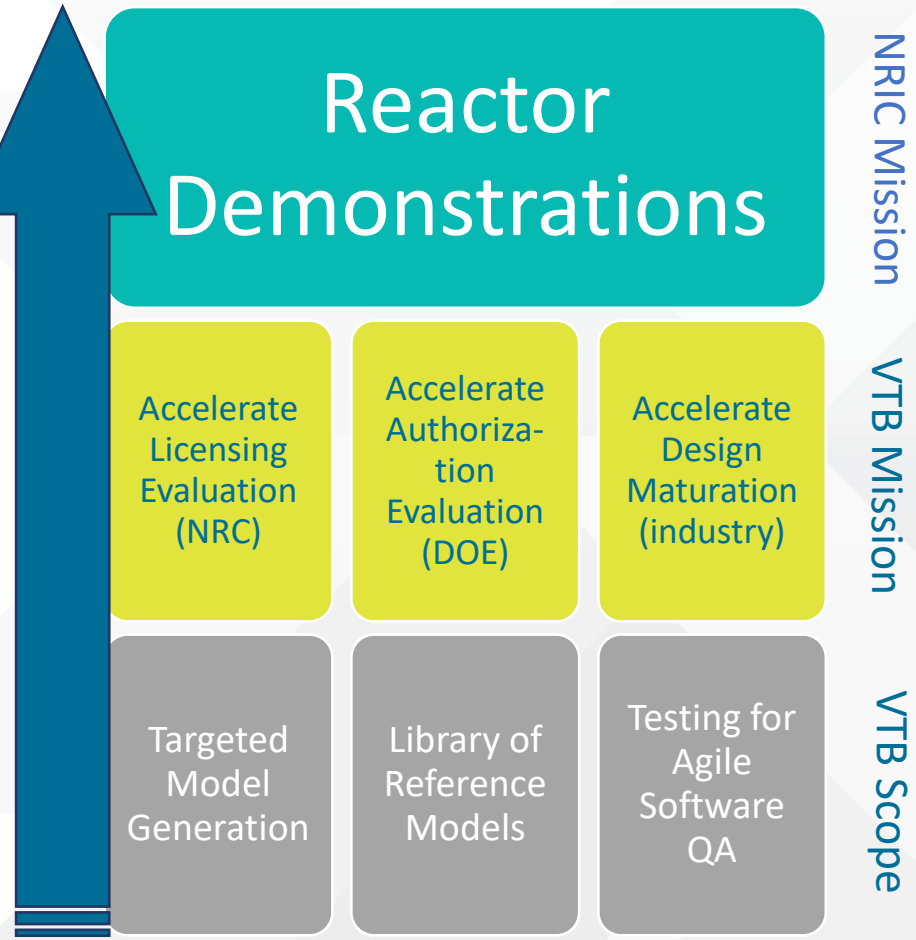
5/21/2024



Mission Statement

NRIC: Deliver successful demonstration and deployment of advanced nuclear energy

- **EBRII Test Bed (DOME)**
- **ZPPR Test Bed (LOTUS)**
- **Virtual Test Bed (VTB)**: Accelerate deployment of advanced reactors by leveraging state-of-the-art ModSim tools to evaluate performance and safety



Ok, but what is it?

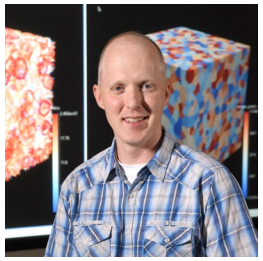
- **Library of Reference Model**: database of advanced multiphysics advanced reactor models that users can download, edit, and re-run
- **Continuous Software QA**: linking repository to software development to avoid legacy issues while enabling rapid code development
- **Virtual models of the test bed:** developing demonstration-relevant models (e.g., candidates for DOME/LOTUS) to accelerate safety evaluations

VTB Team

INL Team

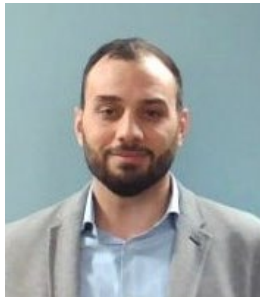
Abdalla Abou-Jaoude
Former VTB Workpackage Manager; *PI salt irradiation LDRD; SA&I Techno-economics Lead*

Lise Charlot
New VTB Work Package Manager;
Computational scientist



Cody Permann
VTB department support; *Computational Framework Dep. Manager*

Guillaume Giudicelli
VTB Infrastructure Lead; *MOOSE Developer*



Mustafa Jaradat
VTB DOME model developer;
Computational scientist

Samuel Walker
VTB External Model Lead; *Pronghorn Developer*

ANL Team

Emily Shemon
VTB Work Package Manager; *NEAMS Multiphysics Applications Technical Area Lead*

Jun Fang
VTB Model Developer;
ANL Nek+SAM analyst

Shikhar Kumar
VTB DOME model developer
Griffin developer

Joffrey Dorville
VTB DOME model developer
OpenMC Developer

Additional Contributors:

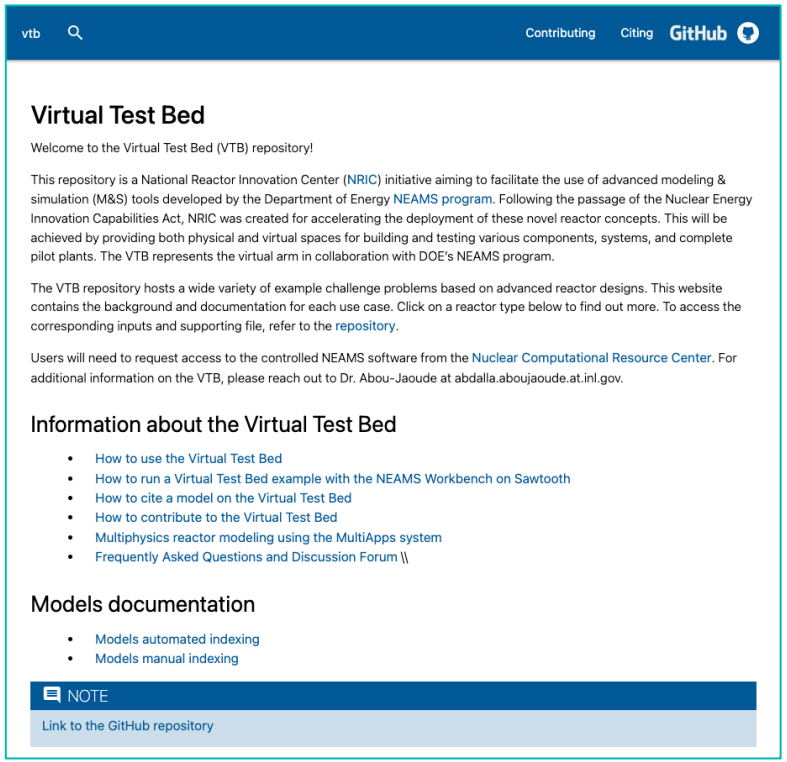
Nicolas Martin, Jason Miller, Logan Harbour, Paolo Balestra, Nicolas Stauff, Dillon Shaver, Rui Hu, Ling Zou, Thanh Hua, Yinbin Miao, Ahmed Abdelhameed, Ting Fei, Zhiee Jhia Ooi, Nick Wozniak, Hansol Park, Marco Delchini, April Novak, Derek Gaston, Mauricio Tano, Stefano Terlizzi, Vincent Laboure,Namjae Choi, Sebastian Schunert, Javi Ortensi, Vasileios Kryiakopoulos, Yan Cao, Joshua Hansel, Zach Prince, Pierre-Clément Simon, Ben Spencer, Kylee Swanson, Andres Fierro Lopez, Isaac Naupa, Ramiro Freile, Thomas Folk, Liam Martinez and others.

The VTB Repository

https://mooseframework.inl.gov/virtual_test_bed

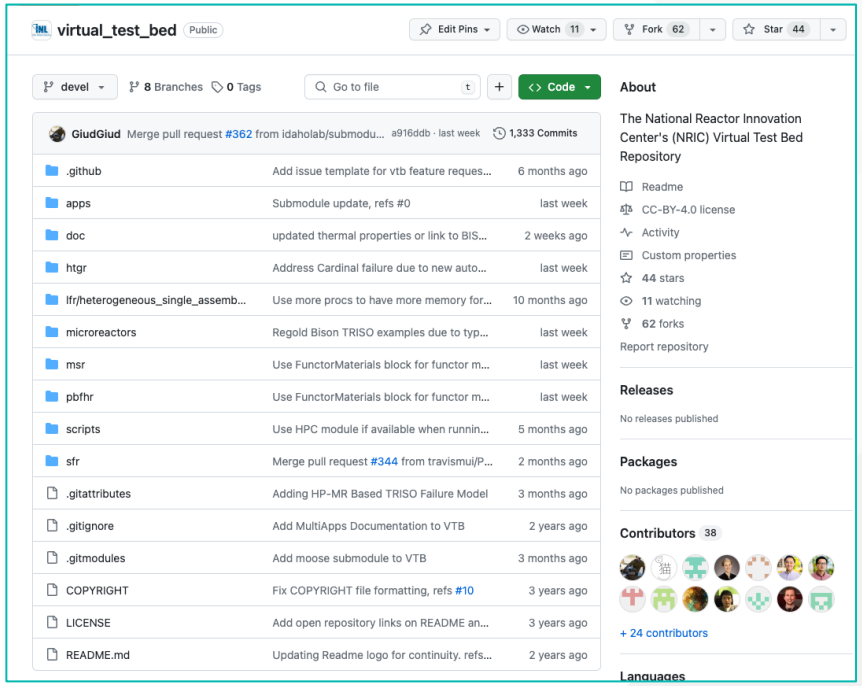
1. Documentation

Detailed explanation of models



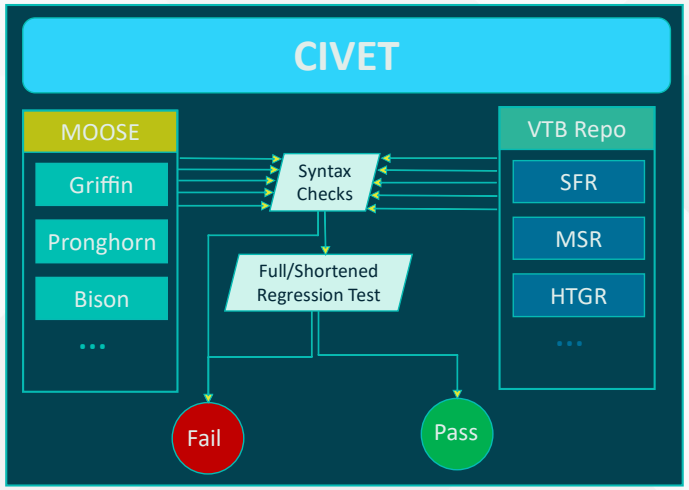
2. GitHub Repo

Ability to clone and contribute to models



3. Integration with Code Development

Continuous testing of models against codes using CIVET



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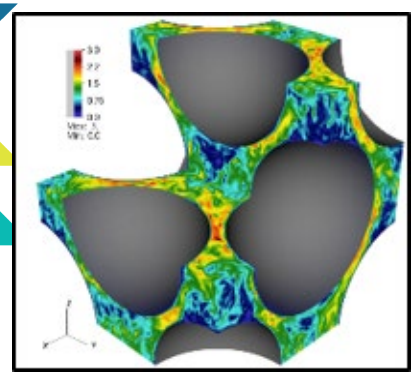
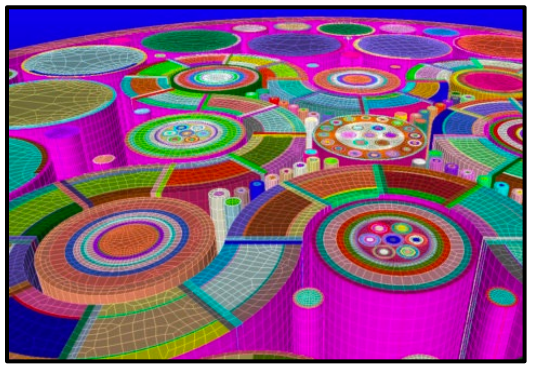
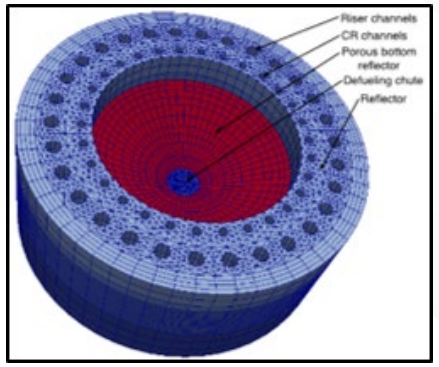
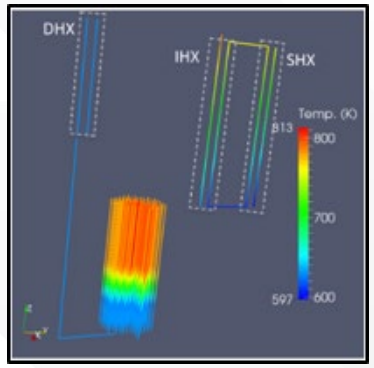
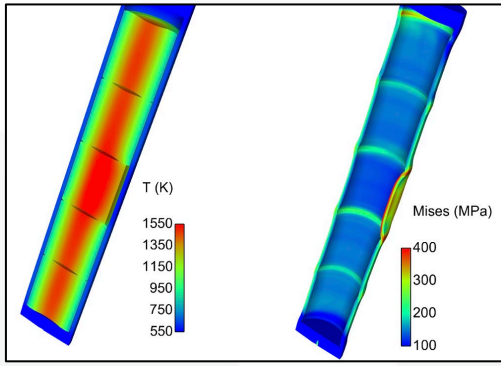
Advanced Reactor ModSim Suite











NEK-5000 + GRIFFIN + PRONGHORN + SAM + Bison/ Yellowjacket

High Fidelity

2D/3D Multiphysics Transients

System-level Simulation

Depletion & Fuel Performance

Fuel Performance/ Thermochemistry

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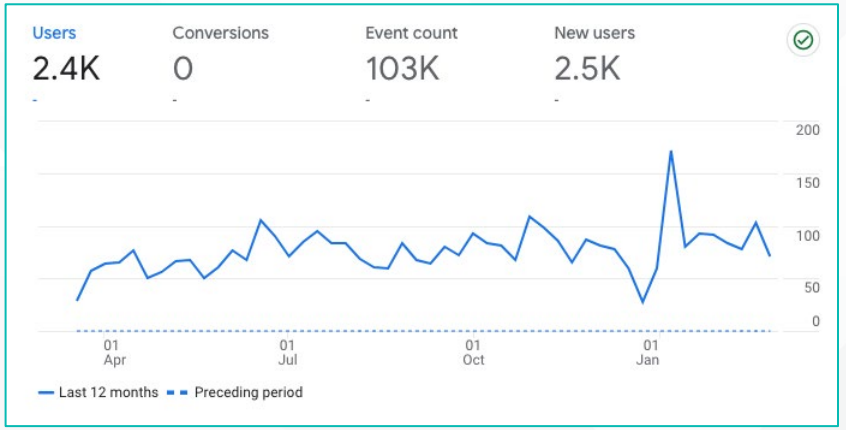
VTB Benefits to Stakeholder

- VTB models can downloaded and repurposed model for specific need/designs
- Hosting open benchmark problems
- Showcasing challenge problems
- Coordination of teams working on similar reactor type
- Direct sharing of models and new capabilities developed through DOE programs
- Industry relevant through active collaborations
- Model used for student training



2400+ distinct users with 100,000+ counts over a year

Success stories:

- The MCRE ARD team is using VTB models by building on them for the final proprietary design analysis.
- VTB models are being referenced in an upcoming NRC report on verification and validation of NEAMS tools

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Oregon State University

U.S.NRC

TerraPower
Kairos Power
NATRIUM
Southern Company
AlphaTech RESEARCH CORP
RADIANT

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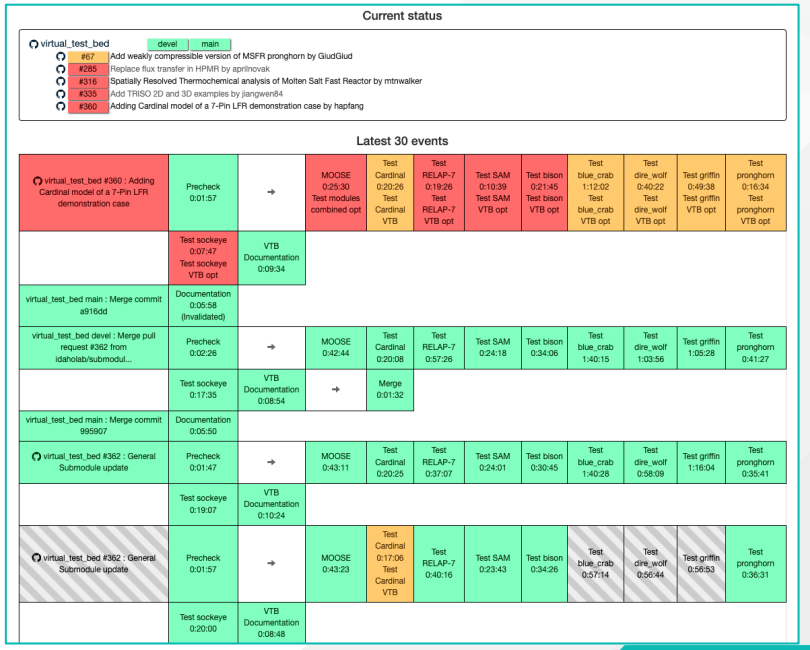
VTB Repository Maintenance

While most of the process is automated there are some manual interventions required

- Reviews of input file modifications tied to code updates: 14 in FY23
- Maintenance operations through pull requests to the repository: 40 in FY23
- Documentation improvements operations on existing models: 15 in FY23
- Google Analytics user tracking added March 23
- Search engine created and expanded to replace manual sorting of models (reactor type/physics solved/laptop vs HPC..)

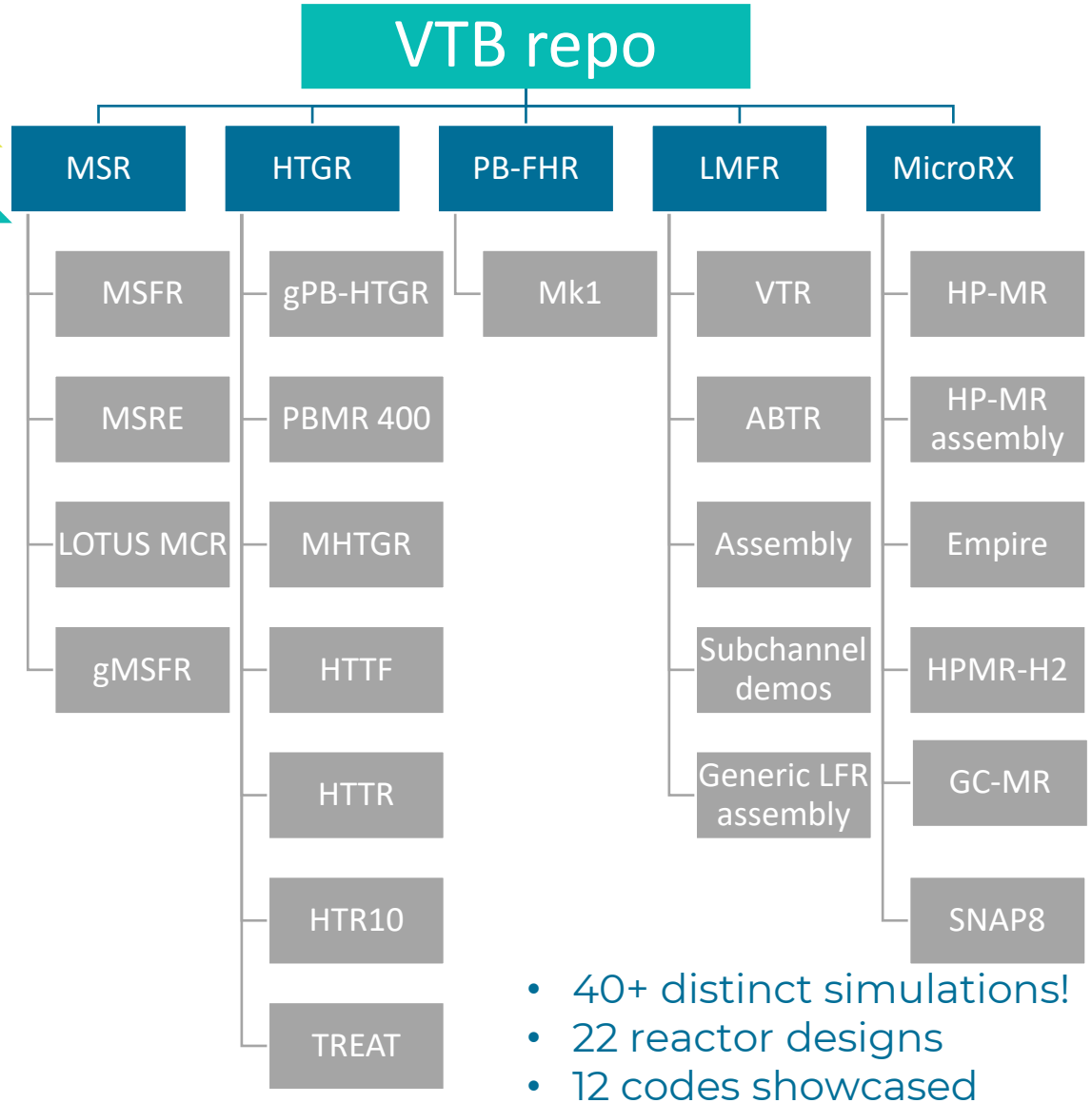
Planned Improvements

- Deployment of VTB Continuous Integration to INL High Performance Computing for expensive model testing (CFD calculations, large transients etc)
- Continuous improvement of the search engine feature

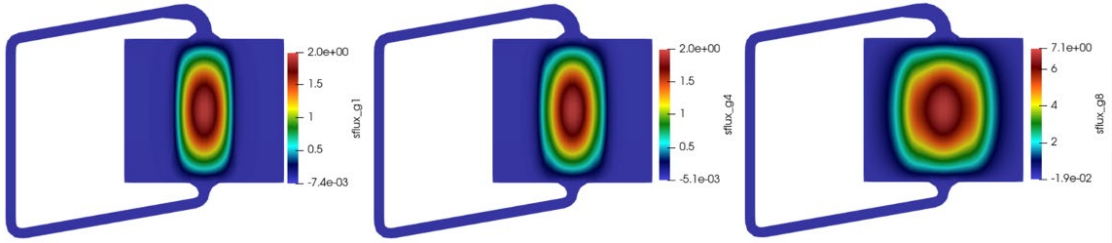


Snapshot of the VTB testing dashboard on 03/01/2024 (Red is an external pull request, current status on 3rd line)

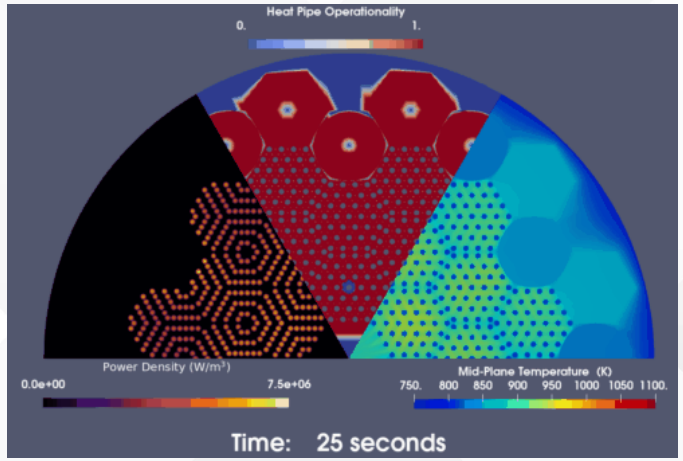
VTB Model Tree



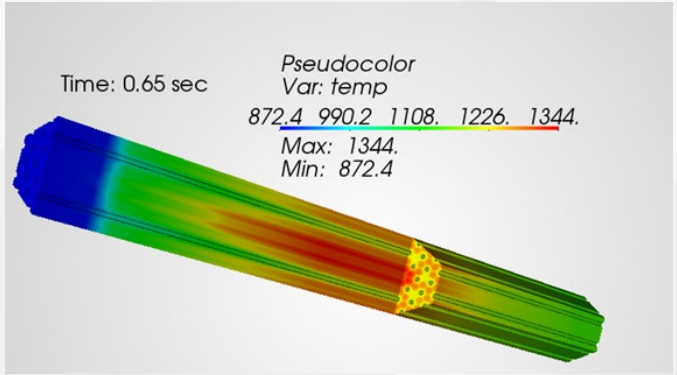
- 40+ distinct simulations!
- 22 reactor designs
- 12 codes showcased



Normalized steady-state neutron fluxes for 3 selected groups in the LOTUS Molten Chloride reactor



Cascading heat pipe failure in an overpowered heat pipe micro reactor



3-D temperature distribution during RIA in a gas-cooled microrx assembly

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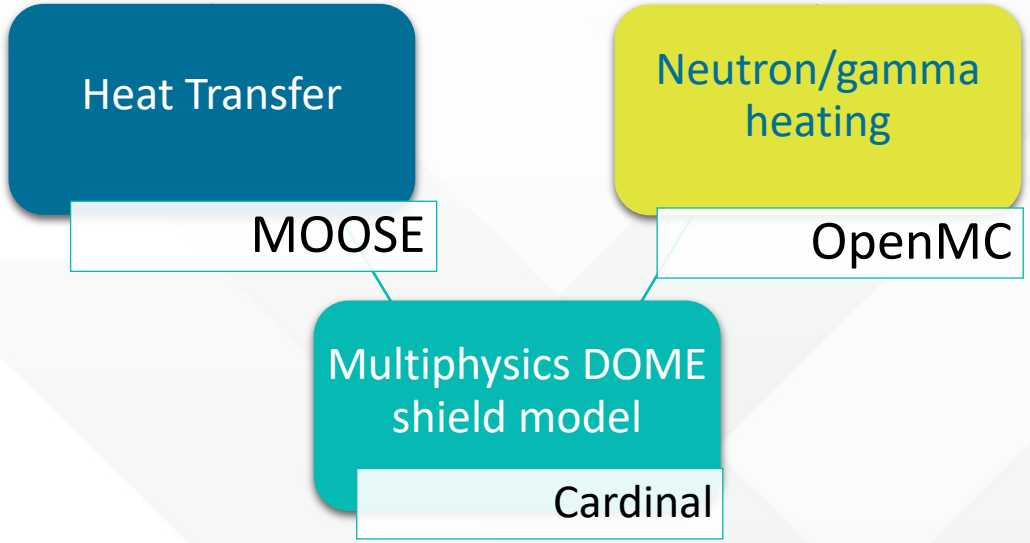
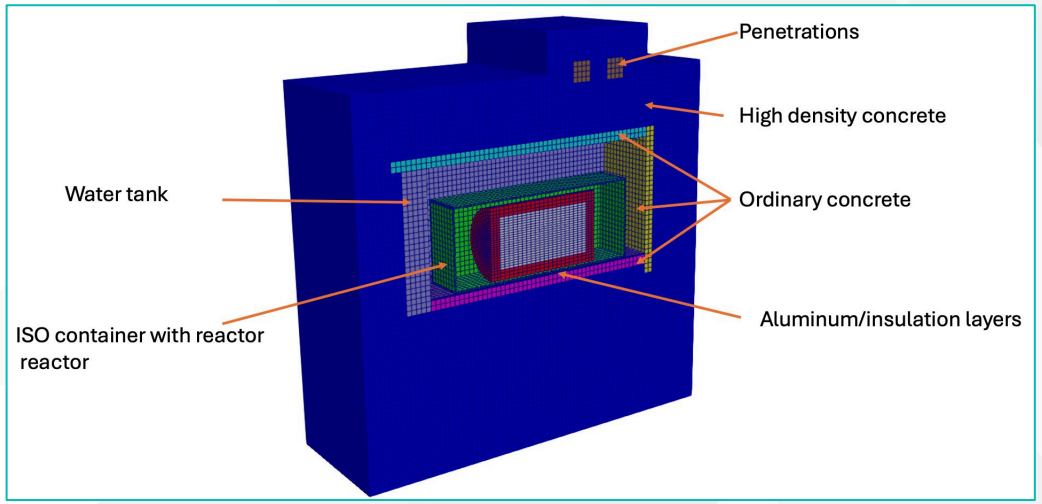
DOME shield virtual Model

- Add a virtual model of the DOME shield to the VTB repo
- Goal: Accelerate confirmatory analysis by providing a model of the DOME shield that can interface with a DOME user reactor model
- Model requirements:
  - Coupling with any reactor design
  - Evaluation of the maximum concrete temperature in the shield for both steady state operation and transient scenarios.
  - Use open-source codes
  - Model should be easy to modify to accommodate shield configuration changes

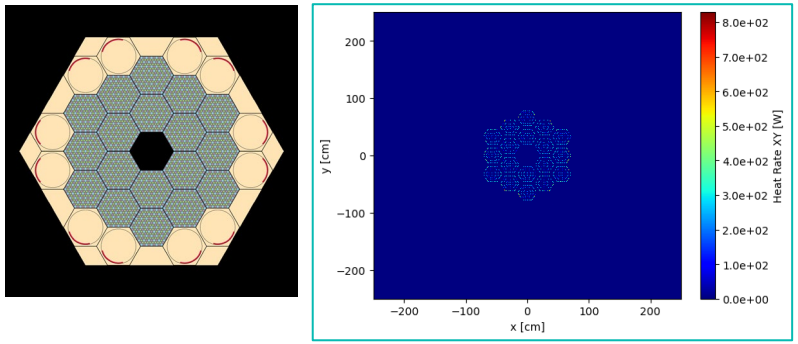




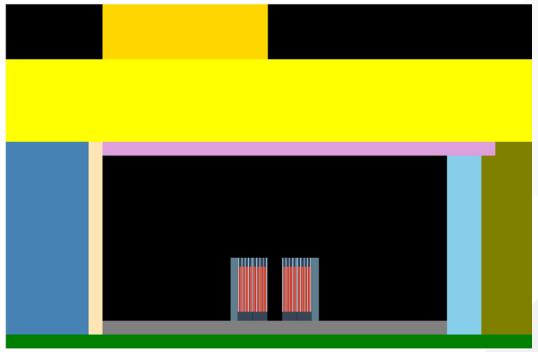
DOME shield model (Conceptual design)

DOME shield model-accomplishments

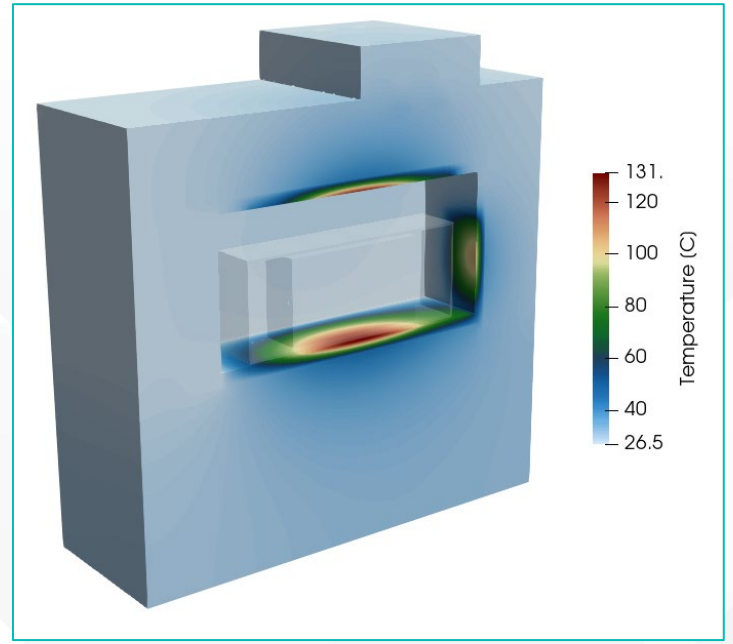
- MOOSE thermal analysis of the DOME shield using FY23 design.
- OpenMC model of a heat pipe reactor to obtain a physical source term
- Model of the shield with a fixed source
- DOME shield models will be released on the VTB repo when the design is finalized



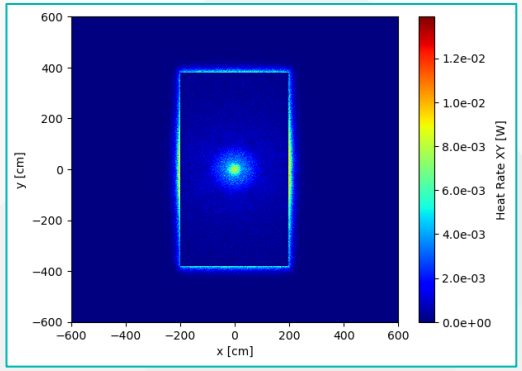
OpenMC model of a heat pipe reactor



Preliminary OpenMC setup of a reactor inside the shield structure



Temperature distribution in the shield concrete (FY23 design)



Predicted heat rate in the shield structure using a fixed source

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Funding Timeline & FY24 Tasks

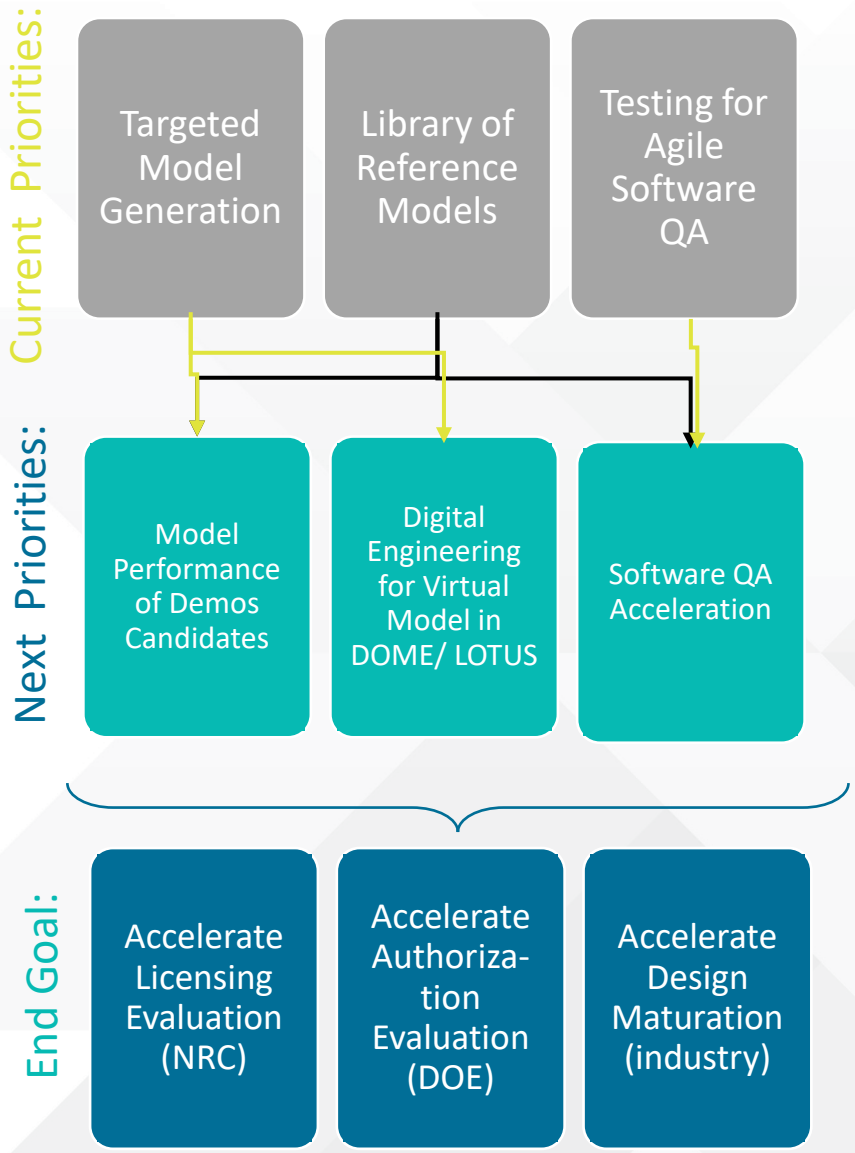
- FY24 Tasks:
  1. Repo improvements: Search, HPC testing
  2. External models: NRC, NEAMS, ART-GC/MSR, etc.
  3. Model development: DOME Shield Virtual model
- Proposed Additional scopes:
  - See Nov M4RC-24IN0206022
  - Cost range: historical + [$0.6M - $1.5M]
  - Priorities:
    - Expand DOME shield virtual model
    - Link VTB with Digital Engineering
    - Involve ORNL as key partner
    - Improved cross-section workflows
    - Simplified reduced order models
  - Can start in FY24 or push to FY25

Funding:

	FY21	FY22	FY23	FY24
INL	$400k	$350k	$400k	$430k
ANL	$200k	$200k	$200k	$275k

Future Vision of VTB

- Continue existing efforts with a focus on acceleration of licensing (NRC), authorization evaluation (DOE), and industry design maturation
- Support DOE Authorization at DOME:
  - Virtual model of DOME on the VTB repo
  - Leveraging Digital Engineering for automated safety evaluation
- Accelerate Software QA Process:
  - Prioritize V&V problems on VTB
  - Feedback from industry (Westinghouse, USNC, etc.) and NRC
  - Work towards Commercial Grade Dedication of tools
- Once Demos are built: VTB can act as vessel for validation benchmark exercises
- Expand VTB scope to include Fusion ModSim Engagement with ORNL



Summary

- VTB Goal: Support deployment of advanced reactor by building a database of models & simulations integrated with software QA
- VTB Benefits: Accelerate timeline for NRC/DOE review of candidate demos, support maturation of industry designs
- VTB Stakeholder engagements: Government (DOE, NRC), Industry (Terrapower, Radiant, Natrium, etc.), Academia (MIT, TAMU, UCB, U of Idaho, etc.)
- FY24 Tasks: (1) repo improvements, (2) hosting external models, (3) generating models for DOME Shield
- Future Scopes: Expand DOME models, Linking with Digital Engineering, Support Commercial Grade Dedication

Questions?

https://mooseframework.inl.gov/virtual_test_bed

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