NRIC National Reactor Innovation Center

Digital Engineering

2024 NRIC Program Review

INL Digital Engineering: Chris Ritter || Peter Suyderhoud || Brennan Harris || Nick Crowder

04/24/2024

Agenda

- Digital Engineering Overview
- FY24 NRIC Digital Engineering Review
- Other NRIC Digital Engineering Updates at INL
- Funding and FY25 Look Ahead

Digital Engineering Overview

Why Digital Engineering

- 48% of large projects finish on budget
- 8.5% of large projects finish on budget and on schedule
- 0.5% finish on budget and schedule, while delivering the expected benefits/promises
- Nuclear related infrastructure is one of the worst offenders

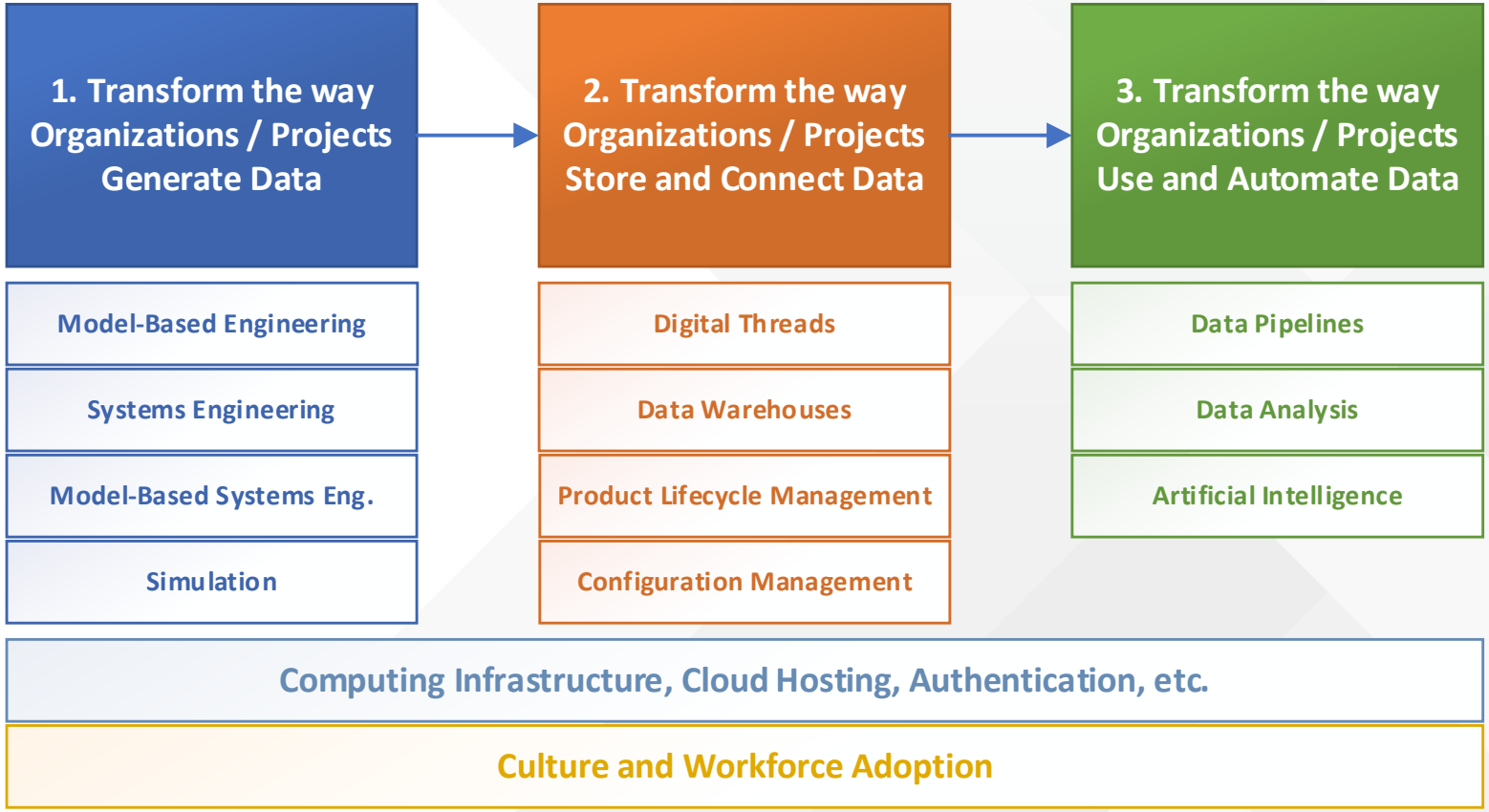
How Big Projects Performed

Source: Flyvbjerg Database

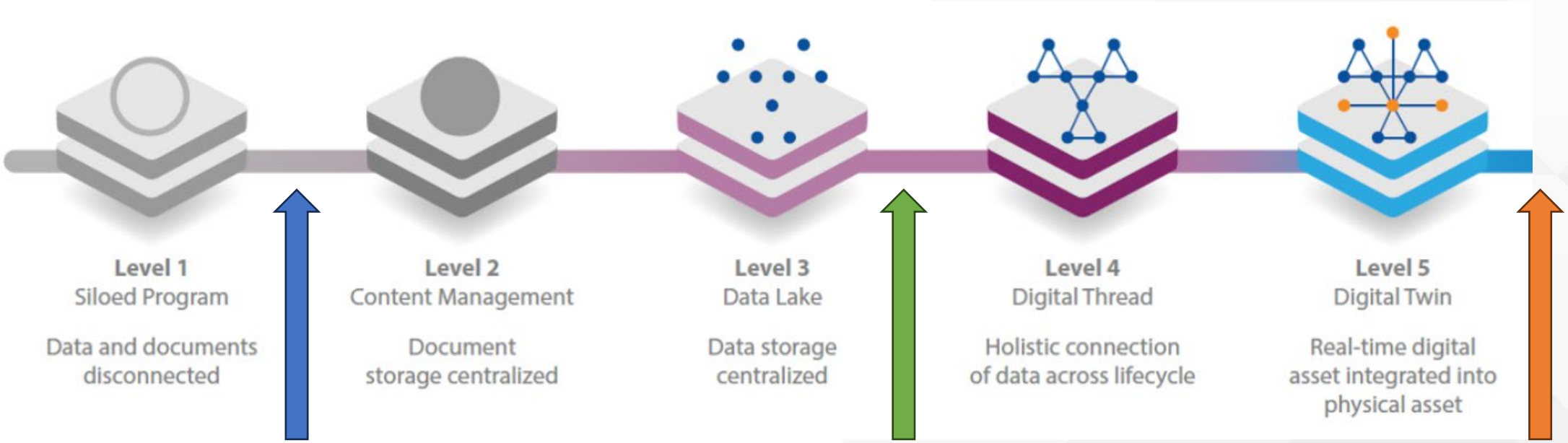
Project type	Mean cost overrun (%)	Projects (A) with ≥50% overruns (%)	Mean overruns of A projects (%)
Nuclear storage	238	48	427
Olympic Games	157	76	200
Nuclear power	120	55	204
Hydroelectric dams	75	37	186
IT	73	18	447
Nonhydroelectric dams	71	33	202
Buildings	62	39	206
Aerospace	60	42	119
Defence	53	21	253
Bus rapid transit	40	43	69
Rail	39	28	116
Airports	39	43	88
Tunnels	37	28	103
Oil and gas	34	19	121
Ports	32	17	183
Hospitals, health	29	13	167
Mining	27	17	129
Bridges	26	21	107
Water	20	13	124
Fossil thermal power	16	14	109
Roads	16	11	102

Digital Engineering Overview

- Digital engineering provides for the most secure, highest quality, most accessible, fastest execution of large scale and complex projects
- NRIC expects to “Do it right” every time and provide the most advanced look at reactor and testbed integration and designs



INL Digital Engineering Program Progress



NRIC National Reactor Innovation Center

FY24 Digital Engineering Review

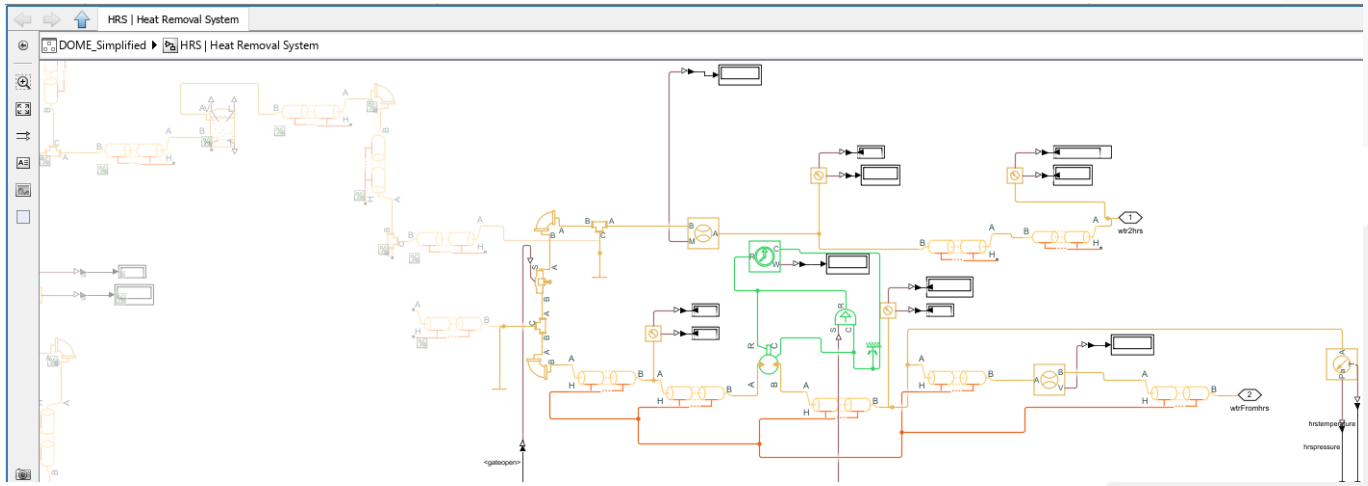
DOME Facility-Level Modeling

Why?

- Operational digital twins need some concept of how a facility or system is “supposed to work”
- Our INL engineering practices suffer from not incorporating system-level modeling

What?

- Use Matlab/Simulink tool suite to replace drawings with models and demonstrate how DOME is designed to work
- Systems are complete to model the high-level function of the physical assets and control logic associated with facility thermal management.
- Will be able to transfer this model to operations and leverage for the predictive side of the facility digital twin



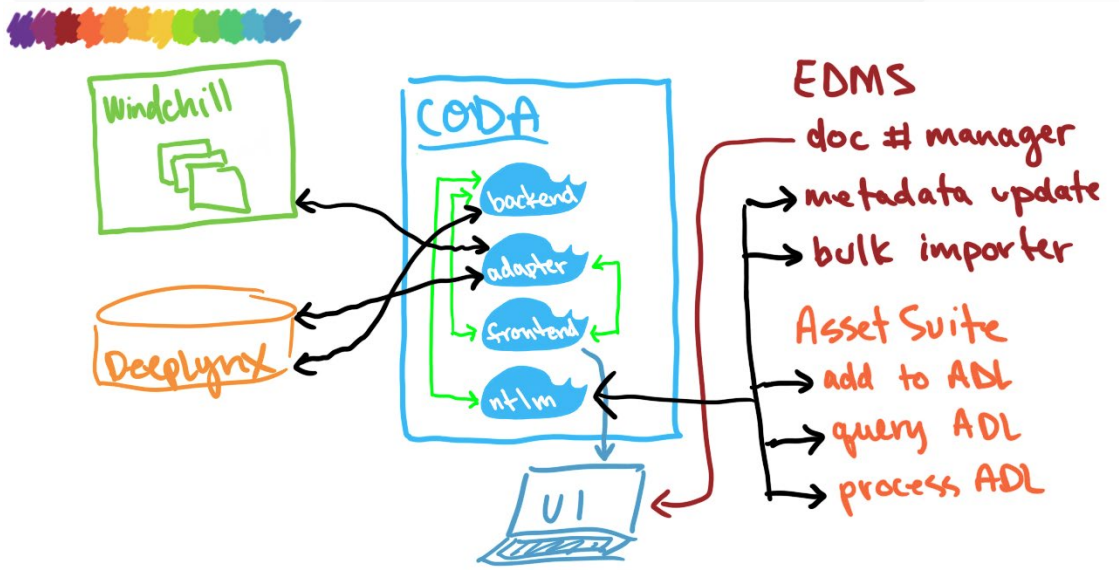
Windchill and Document Automation

Why?

- INL does not have a product lifecycle management (PLM) tool
- At the end of the design phase, engineers manually copy documents from multiple sources into our legacy systems

What?

- Deploy Windchill as an INL production system
- Automatically transfer completed engineering outputs from Windchill to INL Legacy Systems and Record Repositories



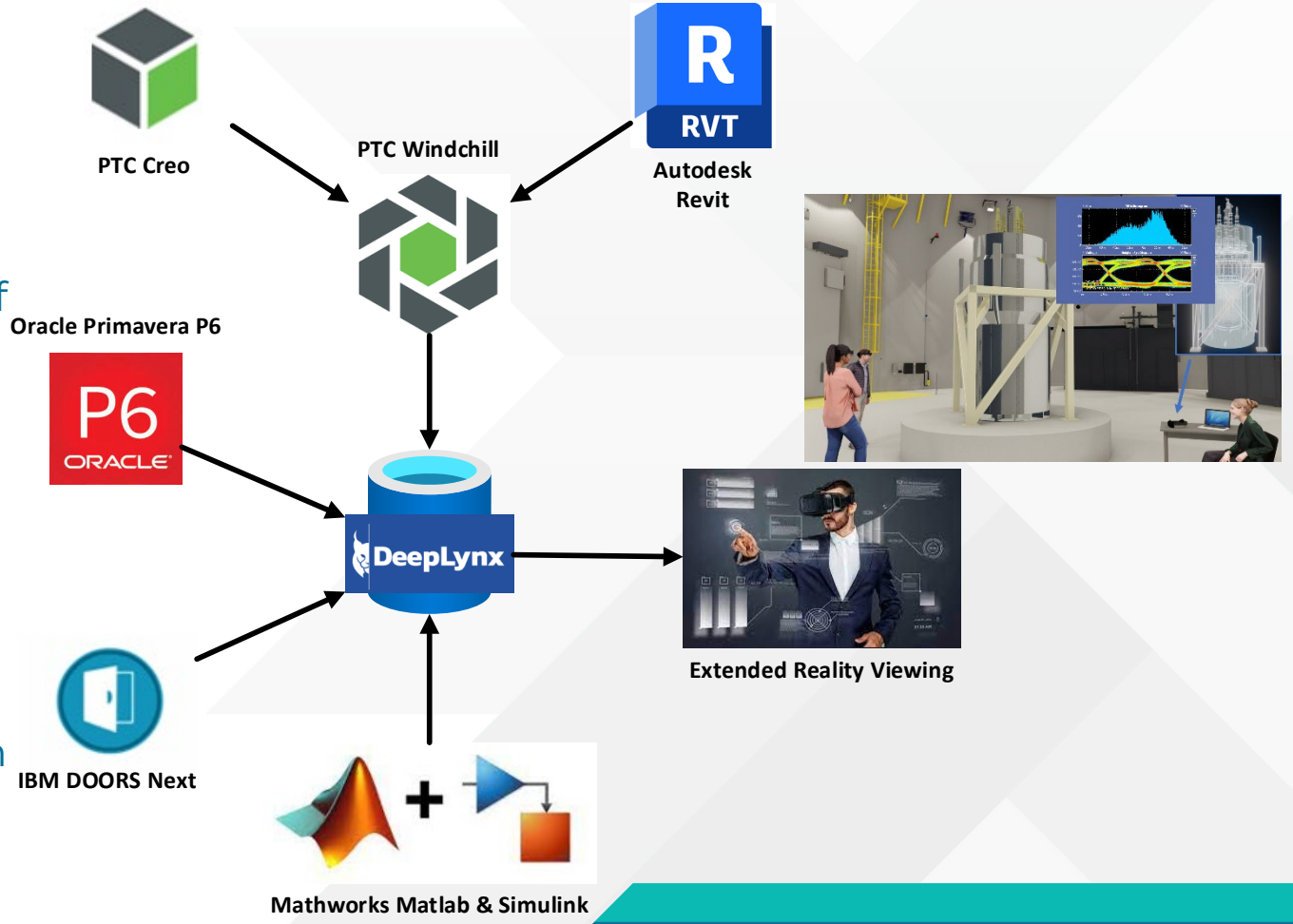
DOME Informational Digital Twin

Why?

- Digital Threads (connected data) is incredibly useful, but the mechanism by which we review it is outdated
- Review of a design is always “static” and never real-time from the source of truth

What?

- Connect requirements, P6 Schedule, Creo models, simulation results into a single “Viewing” platform that is real-time and leverages Deep Lynx
- Users will be able to inspect the model, move objects, traverse through the design using their computer or holographic glasses



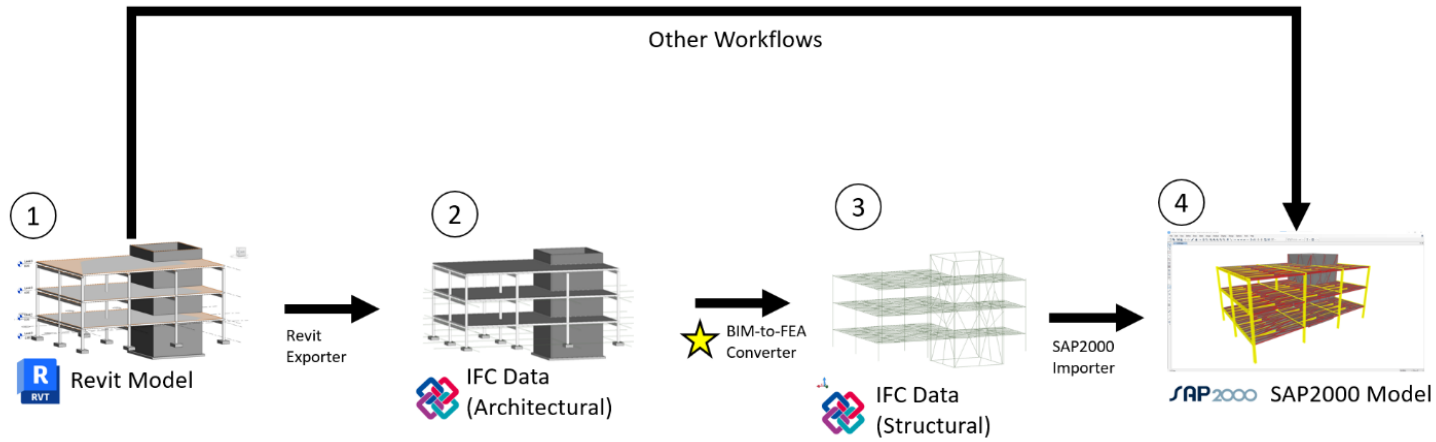
BIM to FEA Data Conversion

Why?

- Engineering design and analysis are historically siloed domains in nuclear
- One engineer spends time creating a model in Building Information Modeling (BIM) software and then another engineer recreates the exact same model in a structural analysis tool like SAP-2000

What?

- Automatically convert engineering design models (BIM) into compliant analysis models (FEA)
- Eliminate ~50% of the time it takes to generate a model for seismic analysis
- Currently working with several industry partners

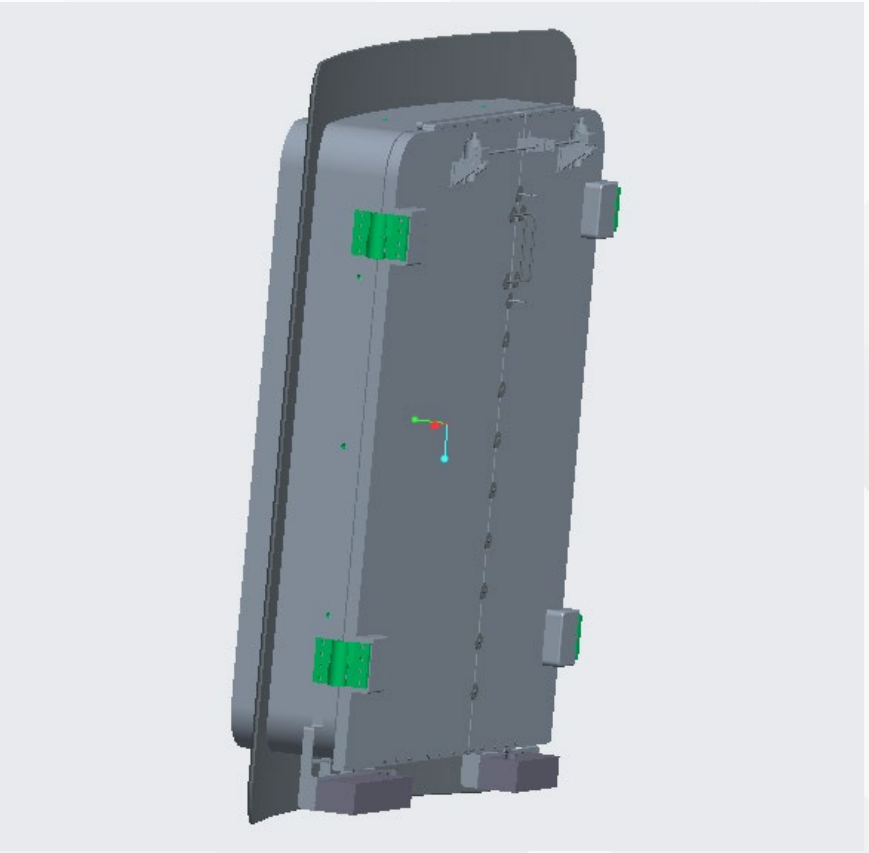


NRIC National Reactor Innovation Center

Other NRIC Digital Engineering Updates

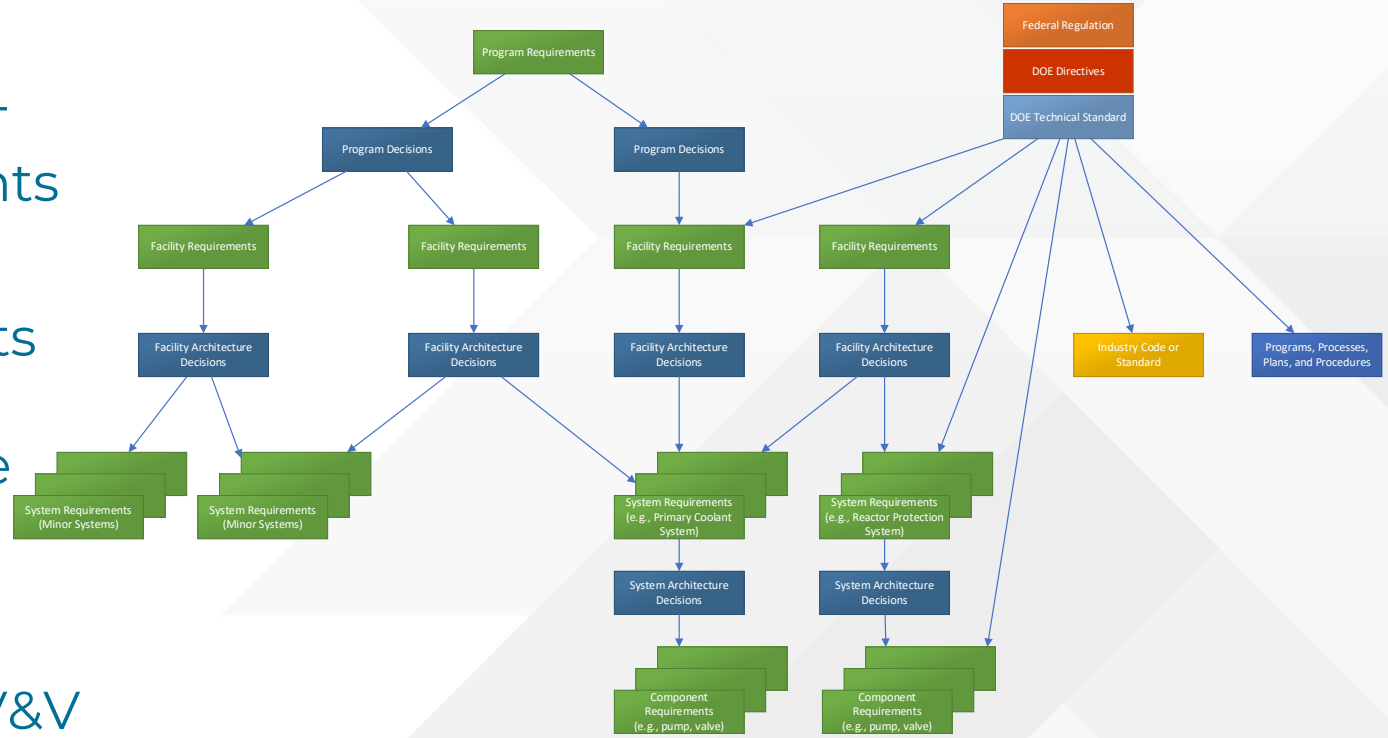
Model-Based Definition (MBD)

- Reworked DOME models to implement rigorous MBD and integrate with Windchill
- Mapping parameters embedded in the model to Windchill so that all bill of material (BOM) data is available to the user without access to CAD
- Instituting best practices with regard to identification (numbering), parameters, vendor/supplier collaboration, redlining, RFIs, etc.



Model-Based Requirements Engineering (MBRE)

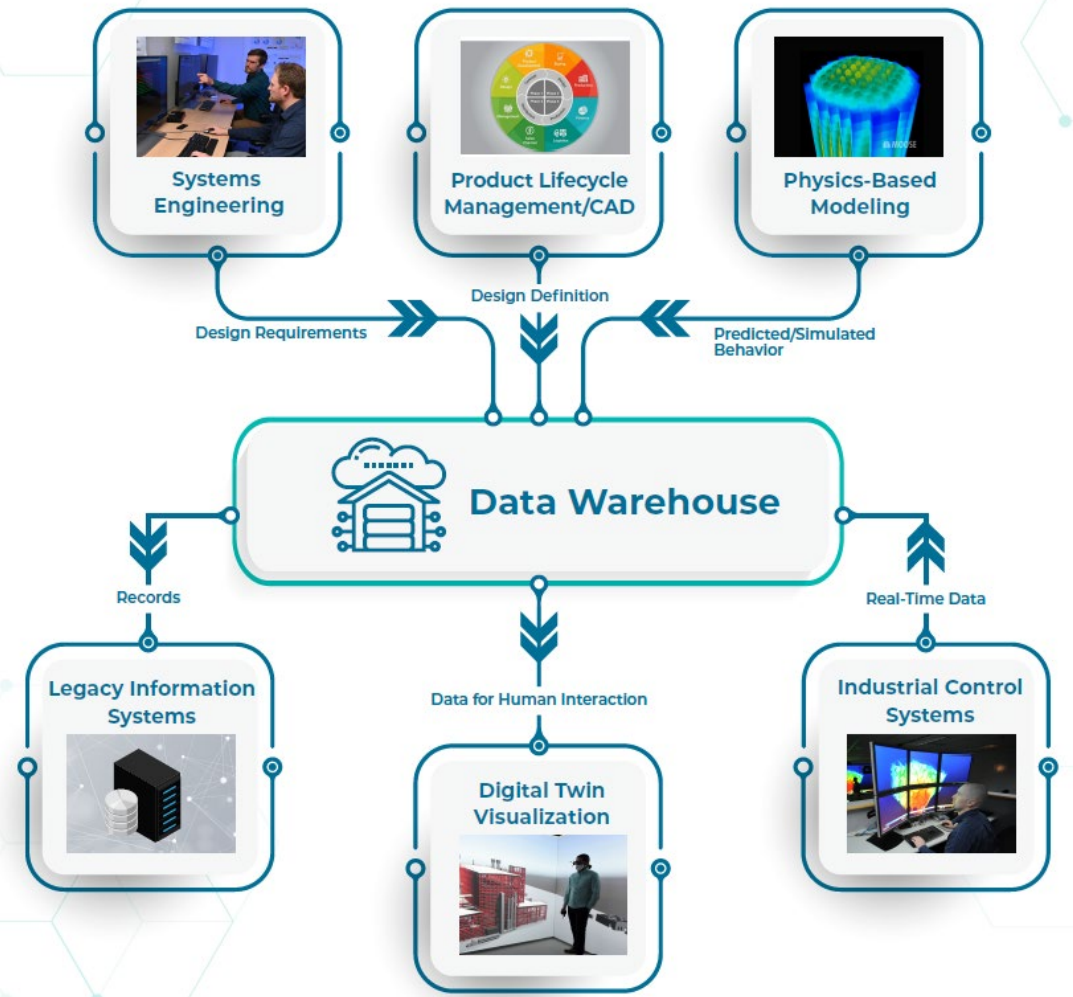
- Continued adoption of IBM Engineering Lifecycle Management (ELM) [a.k.a. DOORS Next] for requirements management at INL
- Templatized a generic requirements structure
- Able to generate Word/PDF reports and documents conforming to almost any formatting or template
- 20+ NRIC projects using for Action Tracking
- Piloted use for field/construction V&V



NRIC National Reactor Innovation Center

Deep Lynx

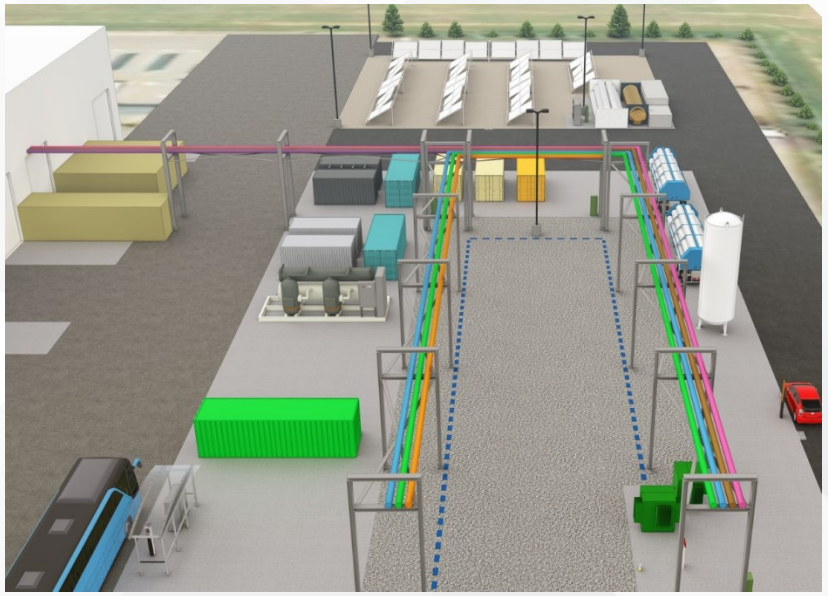
- INL is investing more in Digital Thread technology and the Deep Lynx data warehouse
- INL has R&D mission, meaning that software typically gets funded to TRL 6 without a path towards TRL 9
- Working with stakeholders and partners to stabilize the product and progress to TRL 9 and the standards expected of a commercial product
- Starting taking an internal SE approach to the M&O of the platform, established roles and responsibilities, enhanced documentation
- Some industry support and engagement



NRIC National Reactor Innovation Center

Artificial Intelligence

- Submitted two Digital Engineering-led LDRDs to Nuclear Call
  - AI for Regulatory Process Transformation
  - AI for Microreactor Operations
- AI Chat Deployed on the INL HPC and Ready for Use Cases: https://chat.hpc.inl.gov/
- Prototype MBSE -> CAD Generator (Auto Plant Design)

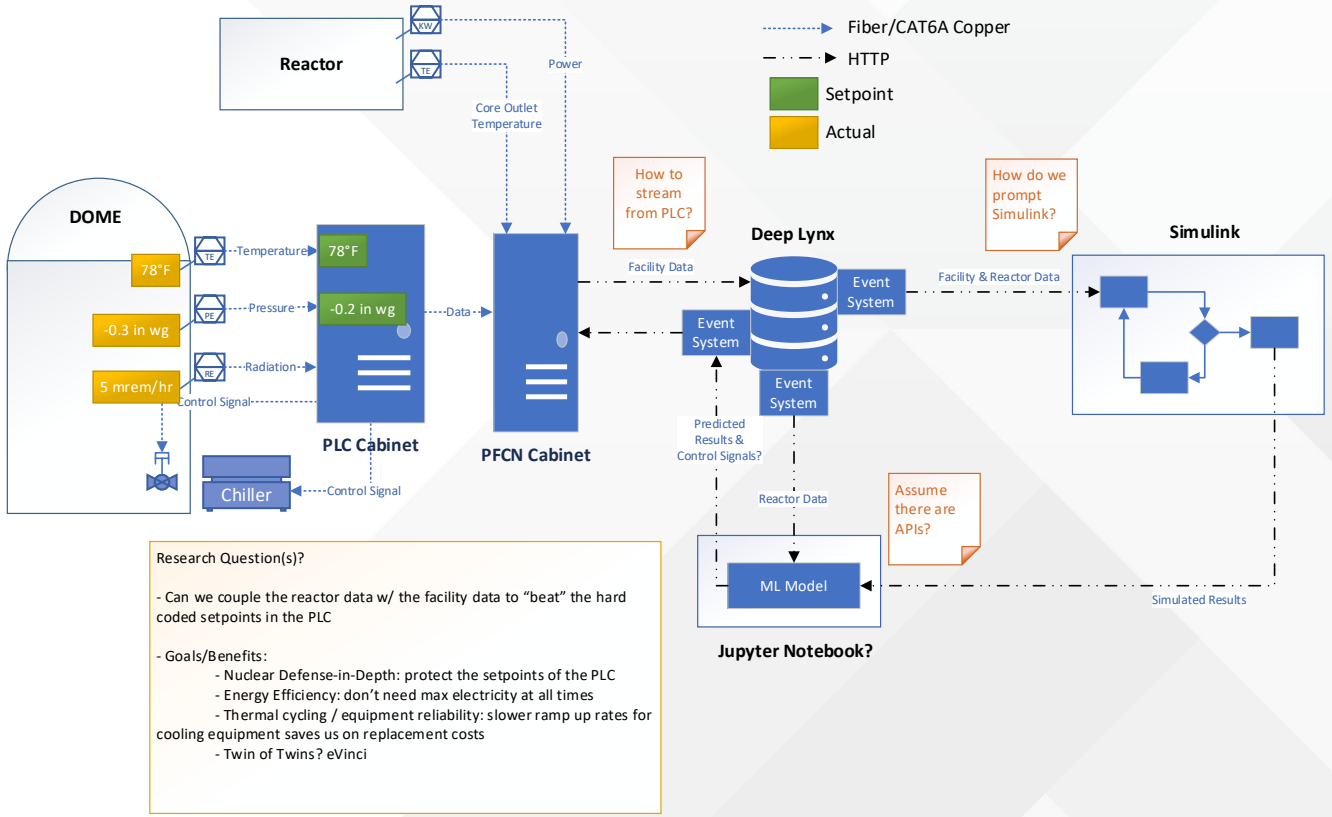


Funding and FY25 Look Ahead

FY25

FY20	FY21	FY22	FY23	FY24
$600K	$989K	$742K	$500K	$1.1M

- Release Beta Version of Auto Plant Design Application using AI
- Continued Development of DOME Digital Twin, incorporating hardware feedback
- Release Deep Lynx 2.0 at TRL 9 Level



Questions?

NRIC National Reactor Innovation Center

www.nric.inl.gov

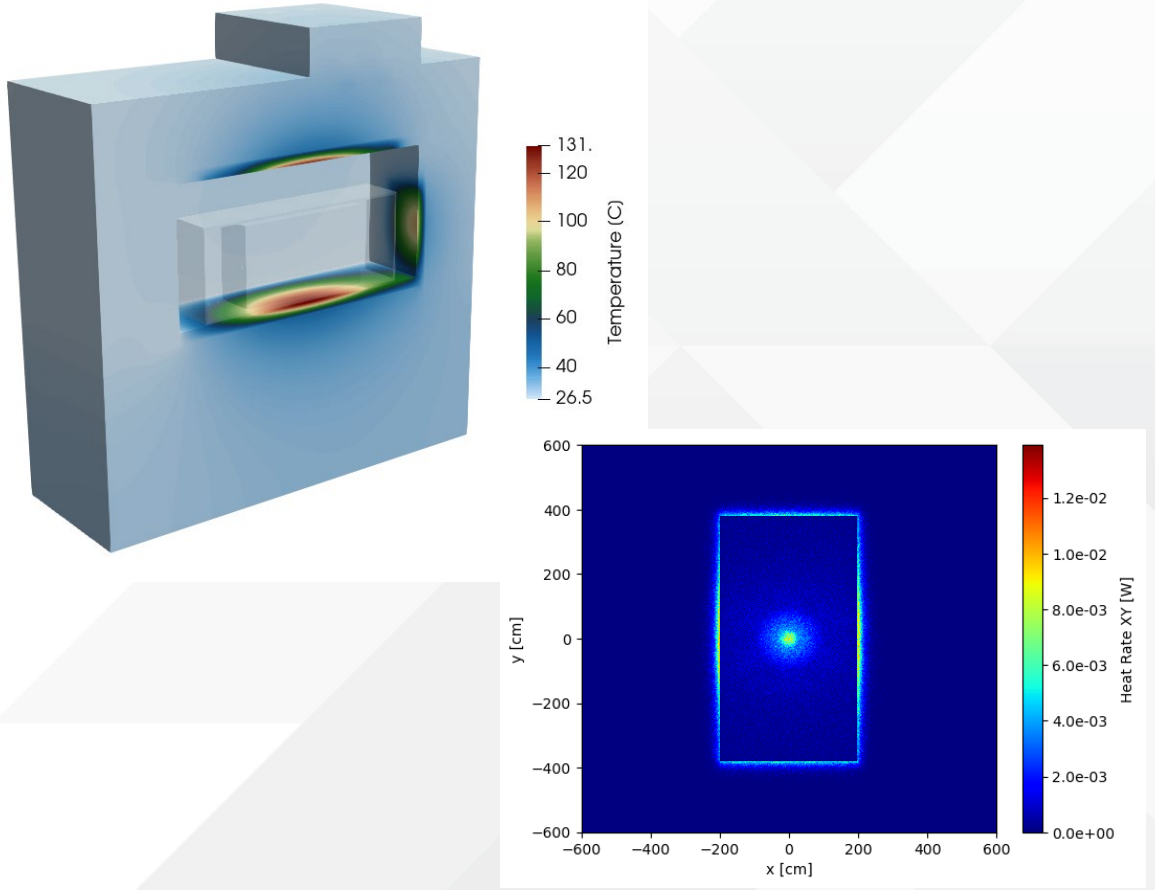
NRIC National Reactor Innovation Center

NRIC Virtual Test Bed (VTB)

NRIC FY24 Program Review

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

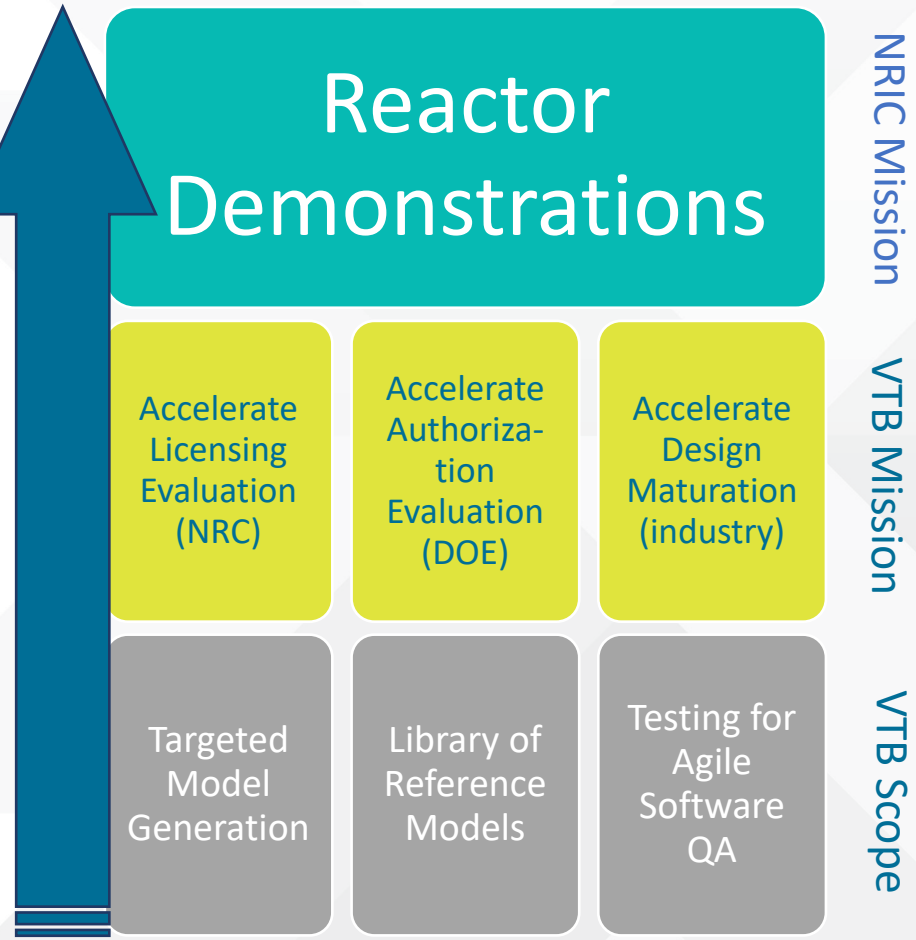
4/29/2024



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?

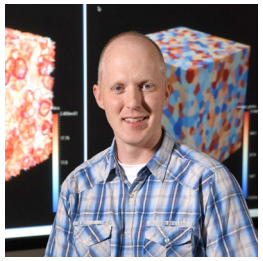
- **Library of Reference Model**: database of advanced multiphysics advanced reactor models that users can download, edit, and re-run
- **Continuous Software QA**: linking repository to software development to avoid legacy issues while enabling rapid code development
- **Virtual models of the test bed:**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

VTB Team

INL Team

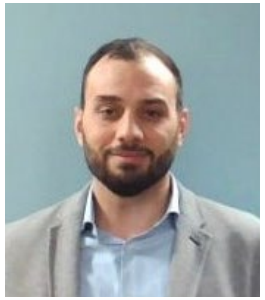
Abdalla Abou-Jaoude
Former VTB Workpackage Manager; *PI salt irradiation LDRD; SA&I Techno-economics Lead*

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:

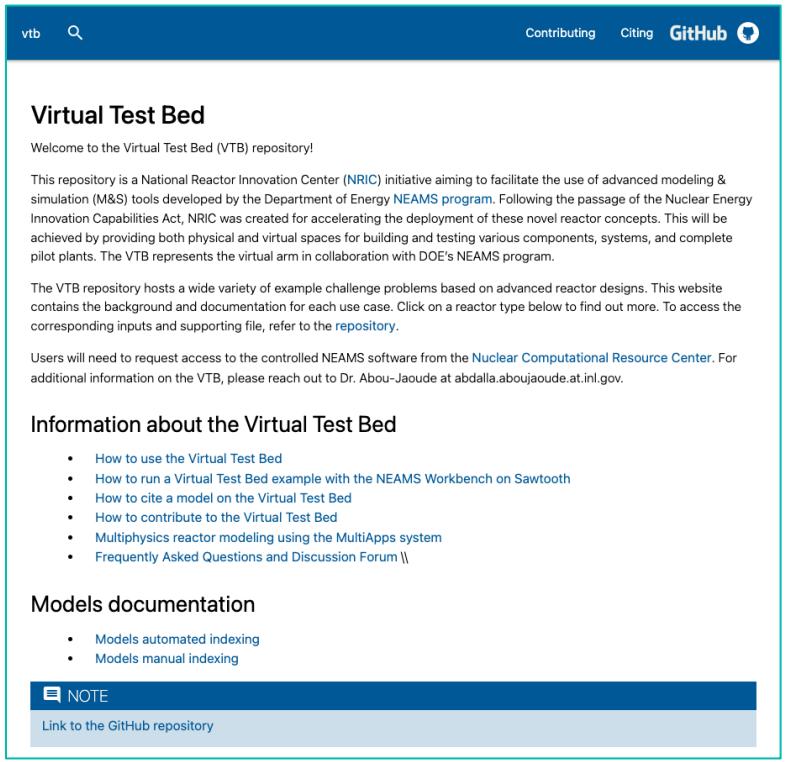
Nicolas Martin, Jason Miller, Logan Harbour, Paolo Balestra, Nicolas Stauff, Dillon Shaver, Rui Hu, Ling Zou, Thanh Hua, Yinbin Miao, Ahmed Abdelhameed, Ting Fei, Zhiee Jhia Ooi, Nick Wozniak, Hansol Park, Marco Delchini, April Novak, Derek Gaston, Mauricio Tano, Stefano Terlizzi, Vincent Laboure ,Namjae 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

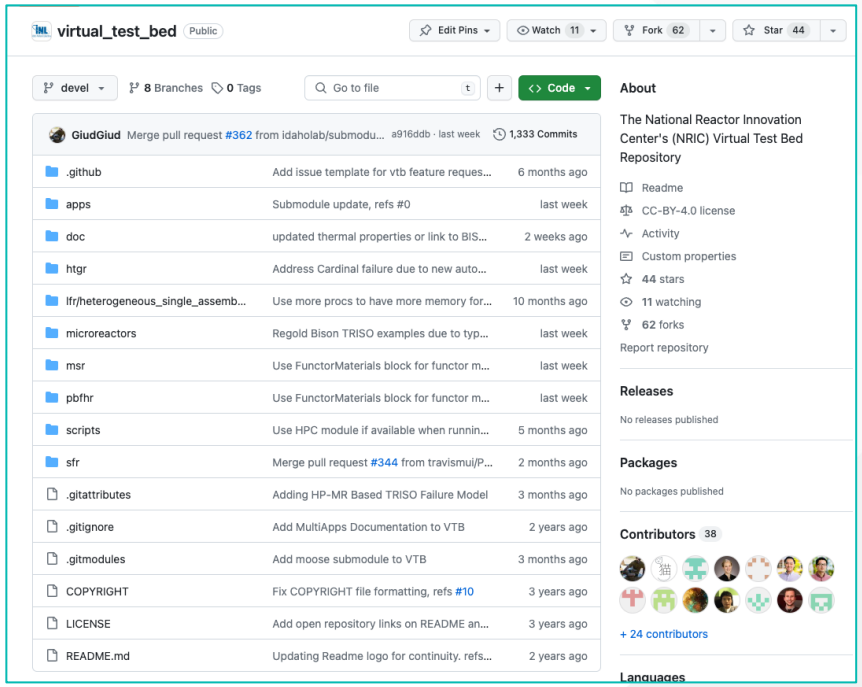
1. Documentation

Detailed explanation of models



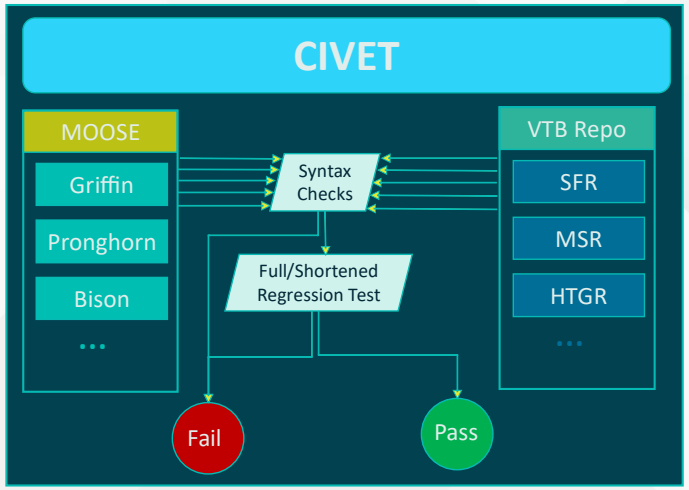
2. GitHub Repo

Ability to clone and contribute to models



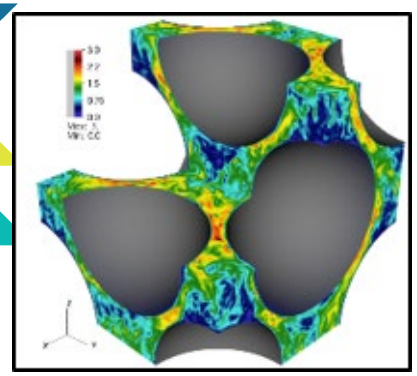
3. Integration with Code Development

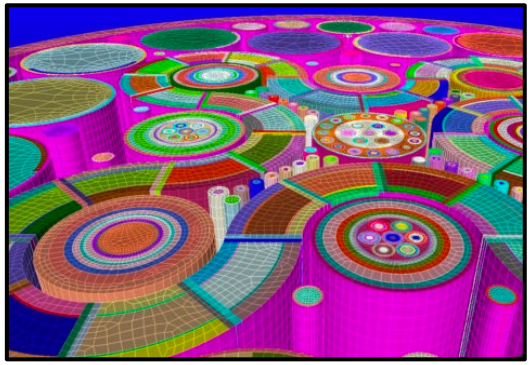
Continuous testing of models against codes using CIVET

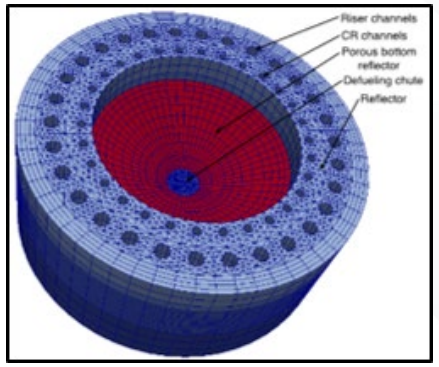


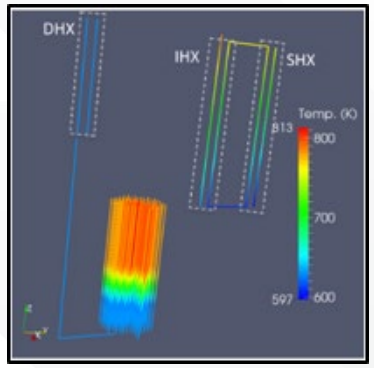
NRIC National Reactor Innovation Center

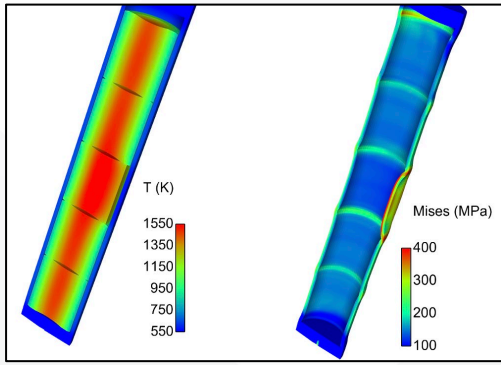
Advanced Reactor ModSim Suite











NEK-5000 + GRIFFIN + PRONGHORN + SAM + BISON

High Fidelity

2D/3D Multiphysics Transients

System-level Simulation

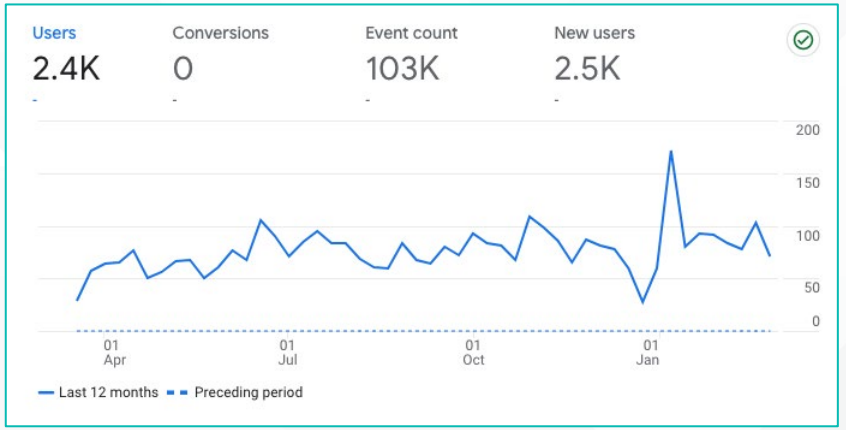
Depletion & Fuel Performance

Fuel Performance/ Thermochemistry

NRIC National Reactor Innovation Center

VTB Benefits to Stakeholder

- Maintain models that can be downloaded and repurposed for specific need/designs
- Host open benchmark problems
- Showcase challenge problems
- Enable coordination of teams working on similar reactor type
- Share 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

NRIC National Reactor Innovation Center

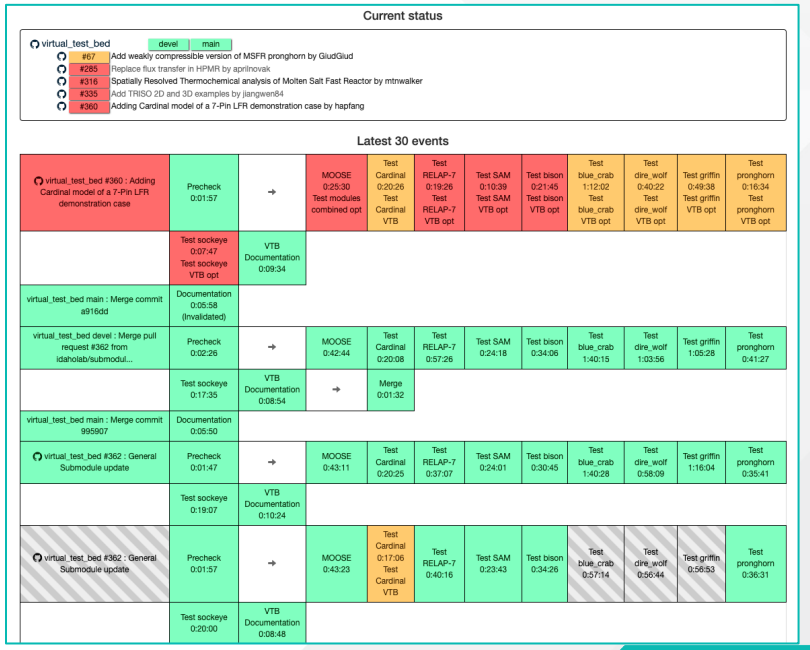
VTB Repository Maintenance

The repository is maintained to ensure models stay up to date (40 pull requests in FY23):

- Reviewed input file modifications tied to code updates (14 in FY23)
- Improved documentation on existing models (15 in FY23)
- Added Google Analytics user tracking (March 2023)
- Search engine created and expanded to replace manual sorting of models (reactor type/physics solved/laptop vs HPC..)

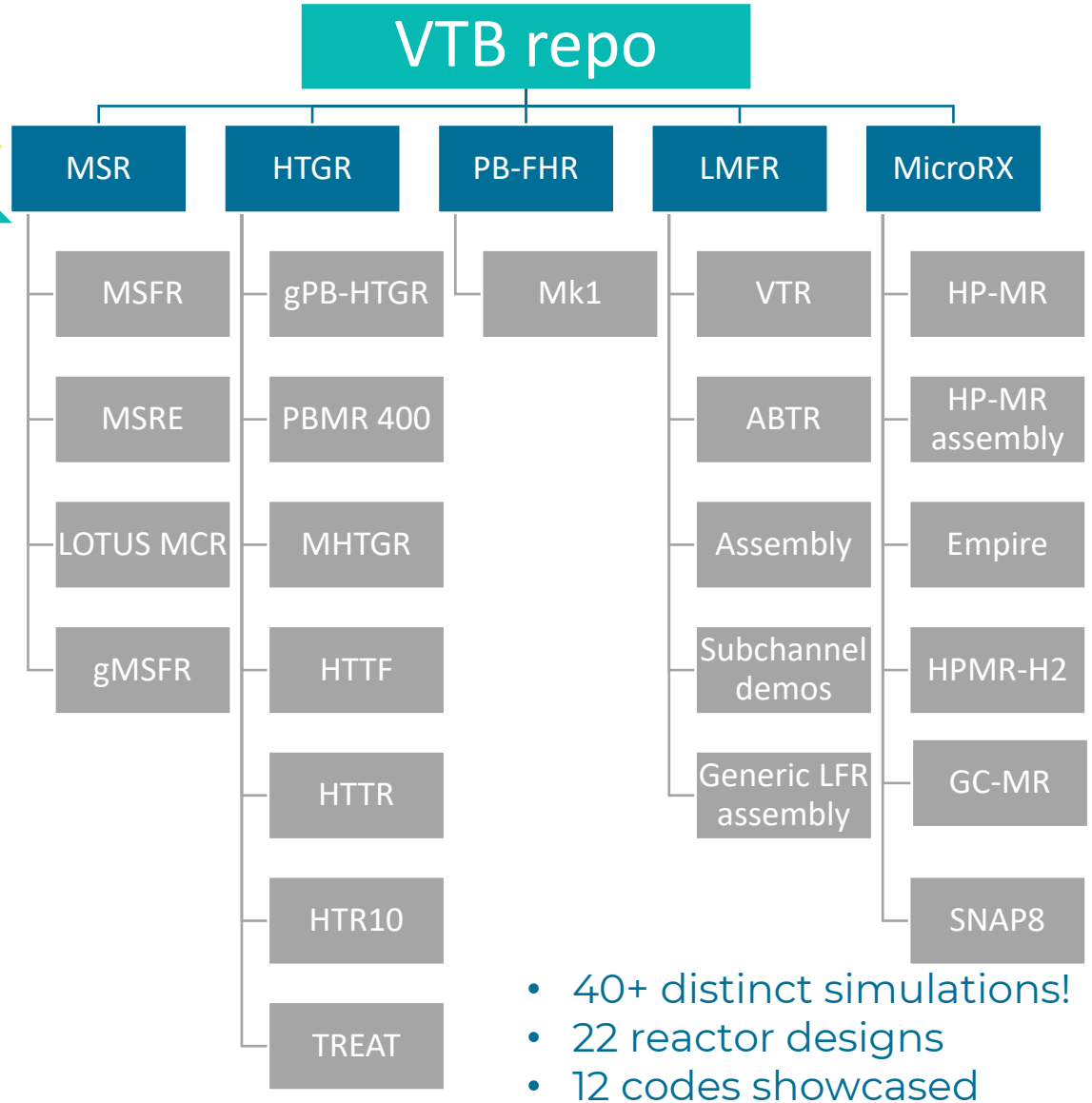
Planned Improvements

- 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

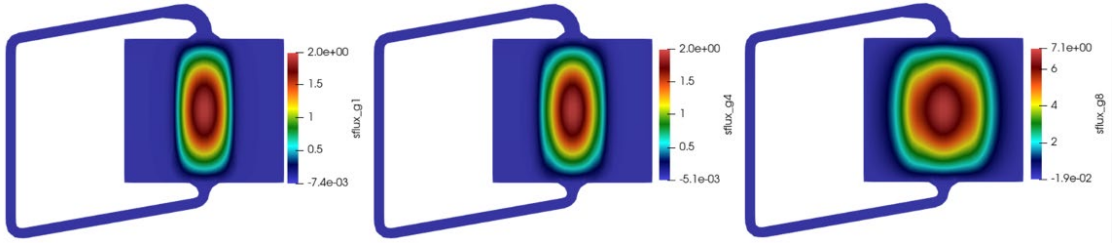


Snapshot of the VTB testing dashboard on 03/01/2024 (Red is an external pull request, current status on 3rd line)

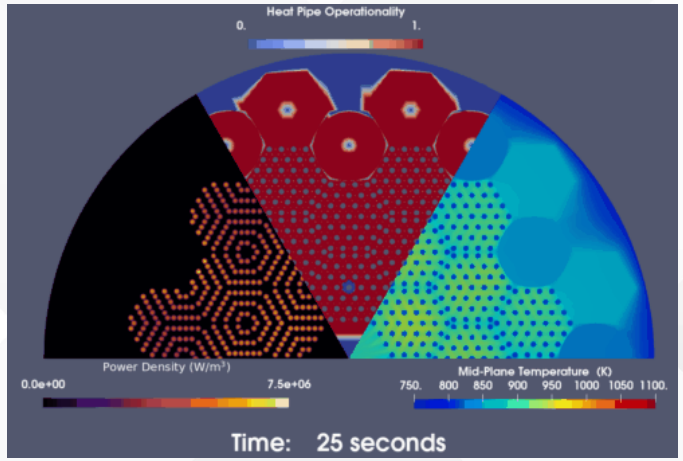
VTB Model Tree



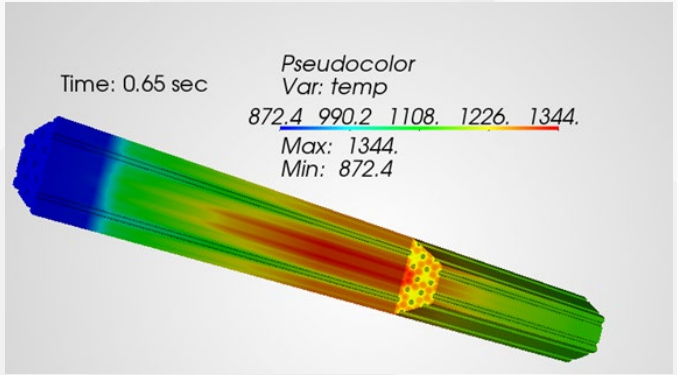
- 40+ distinct simulations!
- 22 reactor designs
- 12 codes showcased



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

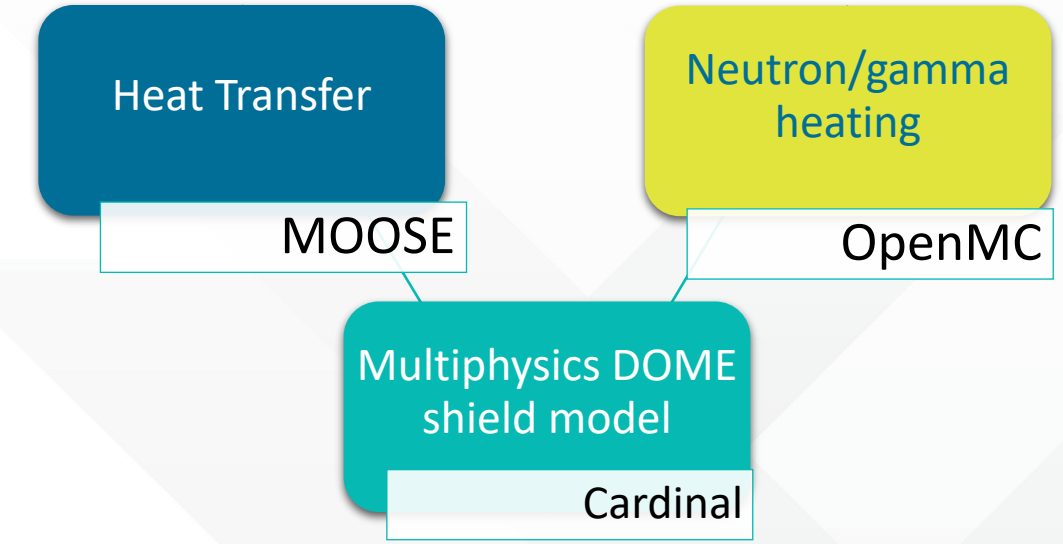


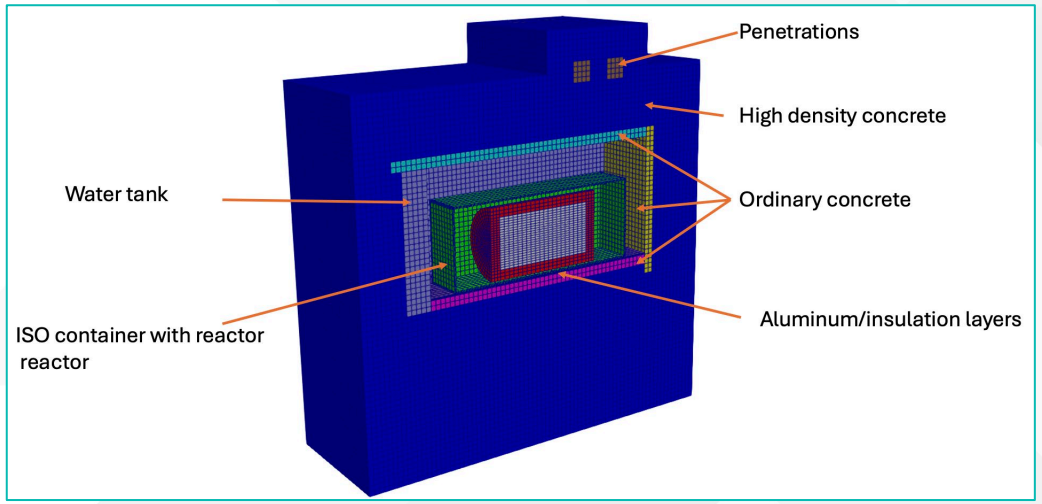
3-D temperature distribution during RIA in a gas-cooled microrx assembly

NRIC National Reactor Innovation Center

DOME shield virtual Model

- 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

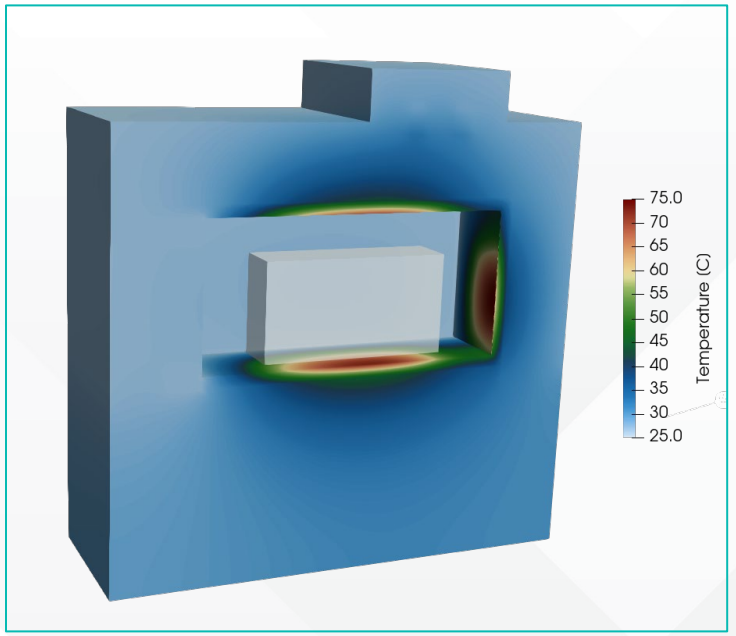




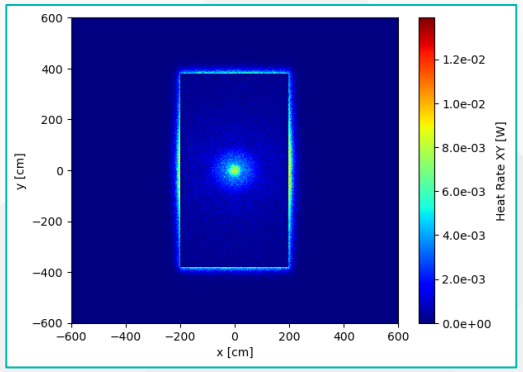
DOME shield model (Conceptual design)

DOME shield model-accomplishments

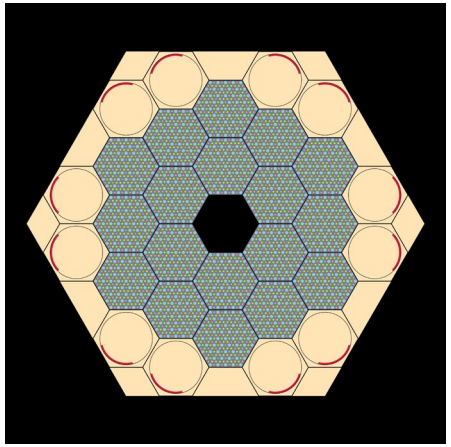
- MOOSE thermal analysis of the DOME shield using FY23 design.
- OpenMC model of a heat pipe reactor to obtain a physical source term
- Model of the shield with a fixed source
- DOME shield models will be released on the VTB repo when the design is finalized

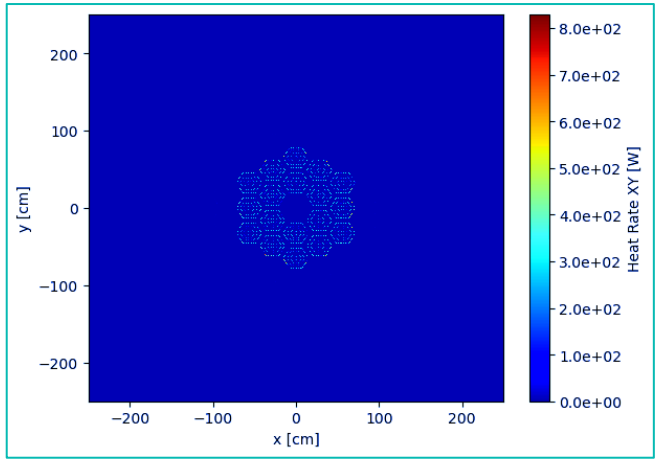


Temperature distribution in the shield concrete (FY23 design)



Predicted heat rate in the shield structure using a fixed source

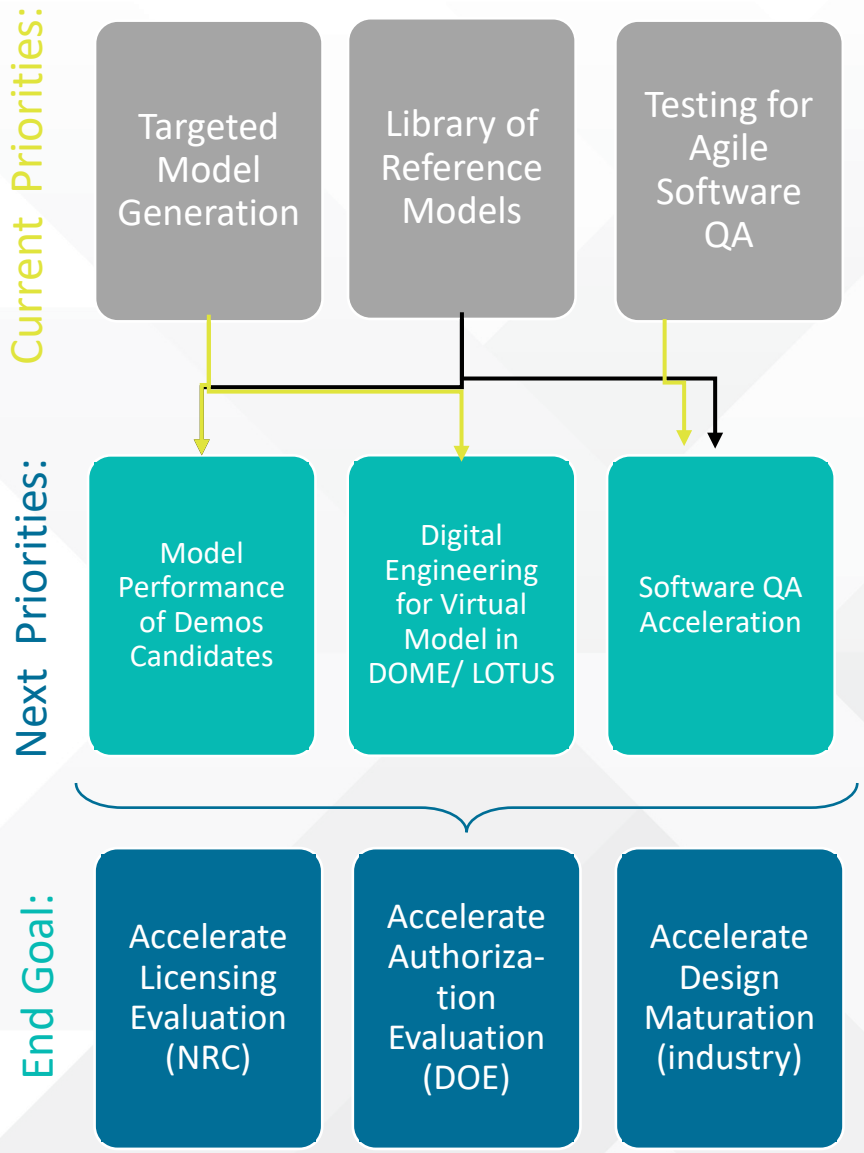




OpenMC model of a heat pipe reactor

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 streamlined 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

NRIC National Reactor Innovation Center