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Changing the World's Energy Future

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Idaho National Laboratory

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INTRODUCTION

The National Reactor Innovation Center (NRIC) was established to accelerate the deployment of novel reactor concepts. This is achieved by providing physical and virtual spaces for building and testing various components, systems, and complete pilot plants. The Virtual Test Bed (VTB) represents the virtual counterpart to the physical test bed.[1] It is in development in collaboration with the Department of Energy's (DOE) Nuclear Energy Advanced Modeling and Simulation (NEAMS) program.

The mission of the VTB is to accelerate the deployment of advanced reactors by facilitating the adoption of advanced modeling and simulation (M&S) tools developed by the DOE NEAMS program. This is accomplished by two primary means: (1) storing example challenge problems in an externally available repository and (2) developing models to fill the M&S gaps needed by industry. The VTB repository consists of two sub-entities:

1. A documentation website detailing the models (https://mooseframework.inl.gov/virtual_test_bed).
2. A GitHub repository that hosts the corresponding files (https://github.com/idaholab/virtual_test_bed).

Previous documentation on the models hosted in the VTB can be found in [1,2,3]. This paper primarily provides a status update of the most recent additions to the repository.

Overview of Models Hosted

The VTB hosts 21 distinct models, eight of which were recently developed in 2022 and will be discussed in more detail here. Figure 1 provides an overview of the various models and their capabilities. Part of the intent of the VTB is to showcase a 'block' style approach to modeling and simulation: if a capability is not showcased for a specific reactor type, it could, in theory, be easily ported/replicated from another. The breadth of advanced reactor types considered is representative of the large variety of concepts being proposed for demonstration.

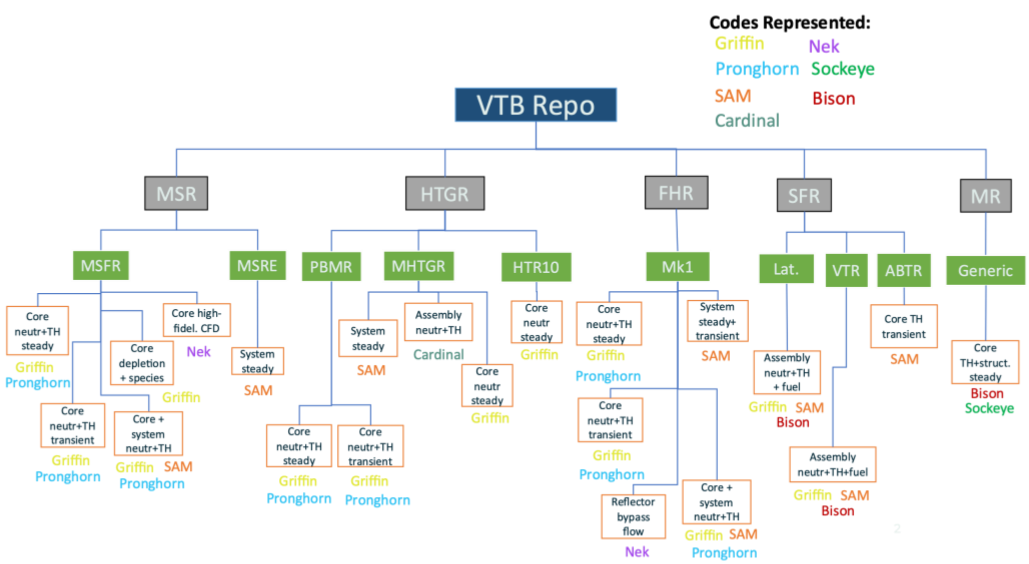

Fig. 1. VTB model tree showing various models hosted

[1] All input files and documentation developed are available via the VTB website: mooseframework.inl.gov/virtual_test_bed

Overview of Codes Used

Eight codes from the NEAMS programs are currently showcased on the VTB for advanced reactor modeling and simulation. For additional background on each code and its capabilities, readers are referred to the references in Table I.

TABLE I. Overview of the codes showcased on the VTB

Code	Usage	Ref.
MOOSE	Multiphysics code coupling framework	4
Griffin	MOOSE-based neutron transport solver with various techniques	5,6
SAM	MOOSE-based 1-D thermal hydraulic system code	7
Pronghorn	MOOSE-based coarse mesh thermal hydraulic solver for intermediate fidelity	8
NeK	High-fidelity Computational Fluid Dynamics (CFD) solver	9
Sockeye	MOOSE-based heat-pipe simulator and analysis tool	10
Bison	Nuclear fuel performance and thermo-mechanics code	11
Cardinal	Application wrapping Nek, MOOSE, and OpenMC tools	12

Multiphysics workflows are constructed using the MOOSE MultiApp System to couple codes together into loosely or tightly coupled multiphysics workflows which transfer information seamlessly between codes. New documentation added to the VTB during 2022 describes the use of MultiApps to construct nuclear reactor analysis workflows and walks the reader through basic multiphysics concepts, input syntax, and the steps to create and test a multiphysics reactor simulation.

NEW MODELS ON THE VTB

A summary of the new models will be provided here. They are discussed within the same reactor type groupings of Fig. 1: High-temperature gas, molten salt, fluoride high-temperature, and sodium fast reactors. Table II provides a matrix-overview of codes versus reactor type, highlighting upcoming capabilities that are still under development.

TABLE II. Status of models in the VTB repository based on examples being available (A), coming in near-term (N), and not applicable (N/A).

	Griff.	Prong.	SAM	Nek	Sock.	BISON
HTGR	A	A	A	A	N/A	N
SFR	A	N	A	N	N/A	A
FHR	A	A	A	A	N/A	N
MSR	A	A	A	A	N/A	N/A

High-Temperature Gas Reactor (HTGR)

Three new gas-cooled reactor models were recently added to the VTB. The first consists of a Cardinal model of a prismatic fuel assembly [13]. Cardinal allows coupling of Monte Carlo codes and high-fidelity CFD to the MOOSE framework. This is a novel capability to the VTB. As shown in Figure 2, the coupled neutronic, thermal-hydraulic, and conduction model can derive solid/fluid temperatures.

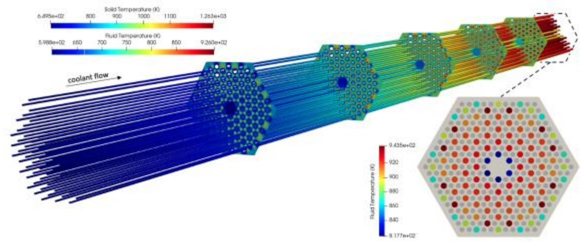

Fig. 2. Cardinal model of an HTGR assembly on the VTB. Taken from [13].

The other two HTGR models added to the VTB were solely MOOSE-based. The first is a neutronic benchmark of the HTR-10 reactor. The initial critical configuration, the full core configuration, and control rod insertions are all modeled [14]. The resulting power distribution of the full core configuration is plotted in Figure 3. The second model is an OECD benchmark problem for the MHTGR [15].

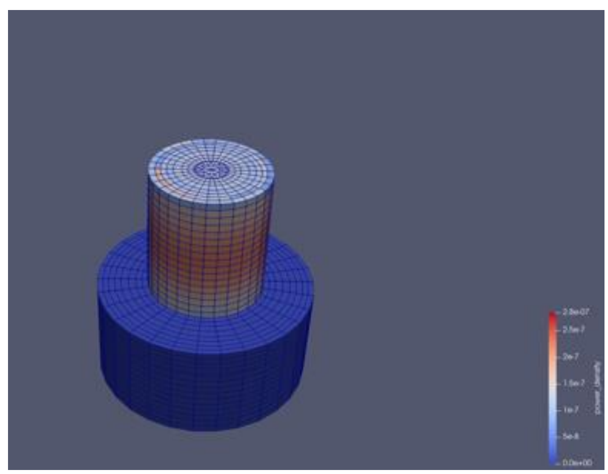

Fig. 3. Power distribution in the HTR-10 VTB full configuration model.

Molten Salt Reactor (MSR)

Two new MSR examples are included on the VTB. The first leverages a novel depletion capability within Griffin which enables mass transfer of species from one region to another with burnup. The results are discussed in greater detail in another article in this session (see [16]).

The second model consists of a Griffin-Pronghorn-SAM coupled simulation [17]. Both a steady-state and a transient model are included. The multiphysics transient simulation studies how change in pump flow on the secondary side impacts the primary loop, with the resulting temperature oscillation in the fuel salt for an overspeed transient shown in Figure 4.

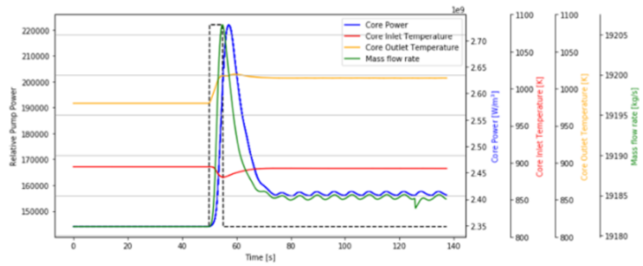

Fig. 4. Temperature evolution in the VTB Griffin-Pronghorn-SAM MSR model following a pump overspeed in the secondary side. Taken from [17].

Fluoride High-Temperature Reactor (FHR)

Similarly, as for the MSR case, a Griffin-Pronghorn-SAM coupled model was also added for FHR reactor types [18]. While the model above only demonstrated heat transfer between SAM-Pronghorn, this model also utilizes mass and momentum transfer between the two codes. The resulting steady-state salt temperatures across the system are shown in Figure 5.

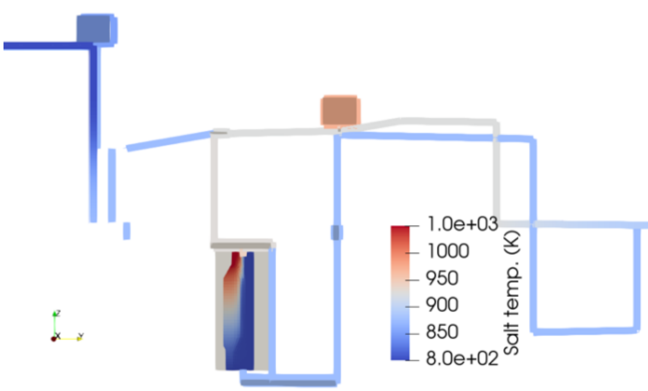

Fig. 5. Steady-state salt temperature in VTB FHR primary loop model. Taken from [18].

Sodium Fast Reactor (SFR)

Two new SFR models were added to the VTB. The first is a SAM system model of the ABTR concept. Both steady-state and transient inputs are hosted. The temperature evolution during an unprotected loss of flow (ULOF) transient is shown in Figure 6.

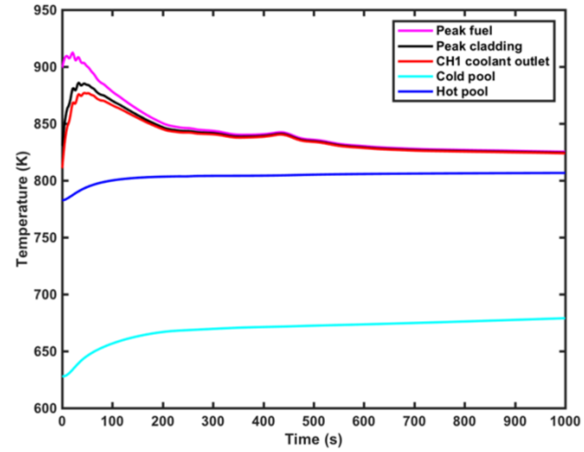

Fig. 6. Temperature evolution in an unprotected ABTR transient using SAM on the VTB. Taken from [19].

The second SFR case included in the repository is a multiphysics core-level simulation based on the Versatile Test Reactor (VTR) [20, 21]. The model couples the various physics of interest in a SFR such as the thermal expansion of a core support plate and fuel assemblies. The resulting power density and axial displacements are illustrated in Figure 7.

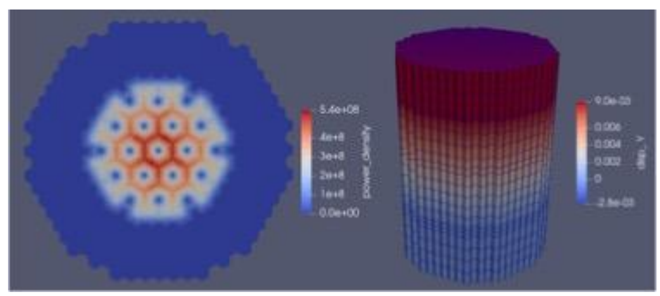
Fig. 7. Power distribution (left) and axial displacement (right) in the coupled multiphysics VTR core model.

SUMMARY

A total of eight new NEAMS-based models were added to the NRIC Virtual Test Bed (VTB) repository in 2022. The capabilities include high-fidelity CFD, full core multiphysics, coupled SAM-Pronghorn simulations, and standalone physics benchmarks, among others. The use cases spread among four advanced reactor types.

The VTB repository is entirely open to the general public. Users are widely encouraged to download/clone the models and build on them. External contributions to the VTB repository are also welcome and can benefit the community at large.

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