INL/MIS-23-74030-Revision-1

Release on the Virtual Test Bed of an MSRE thermal hydraulics model

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Changing the World's Energy Future

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Idaho National Laboratory

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Virtual Test Bed Release of a SAM-Pronghorn Coupled MSRE Model using the Domain Overlapping Approach

Foundational work by Mauricio Tano, Sebastian Schunert, Mustafa Jaradat, Guillaume Giudicelli, Samuel Walker, Jun Fang, and Abdalla Abou-Jaoude

THE NATIONAL GEM CONSORTIUM

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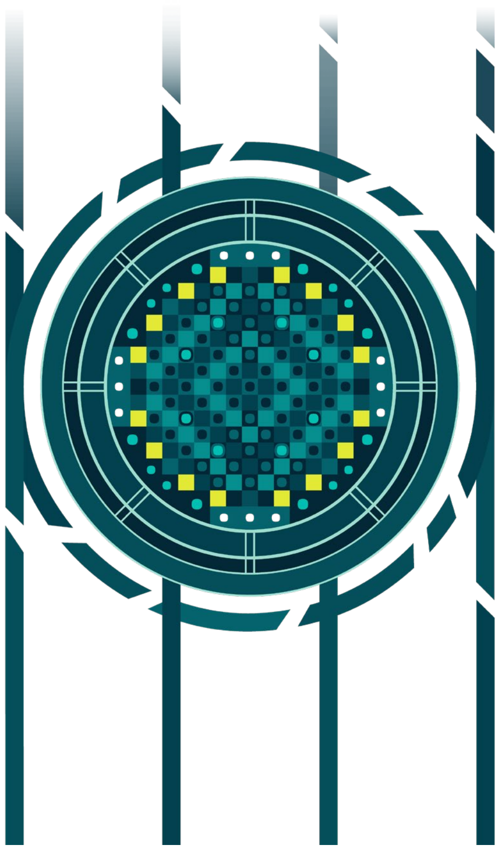
Outline

- Introduce the Virtual Test Bed Models
- Description of the Molten Salt Reactor Experiment
- Introduction to SAM and Pronghorn
- Implementation of Domain Overlapping Coupling
- How other modelers can apply the SAM-Pronghorn DOC for other reactor models

Contextualizing the Virtual Test Bed Models

NRIC National Reactor Innovation Center



NRIC – National Reactor Innovation Center

NEAMS – Nuclear Energy Advanced Modeling and Simulations (DOE)

VTB – Virtual Test Bed
www.mooseframework.inl.gov/virtual_test_bed

MSRE – Molten Salt Reactor Experiment

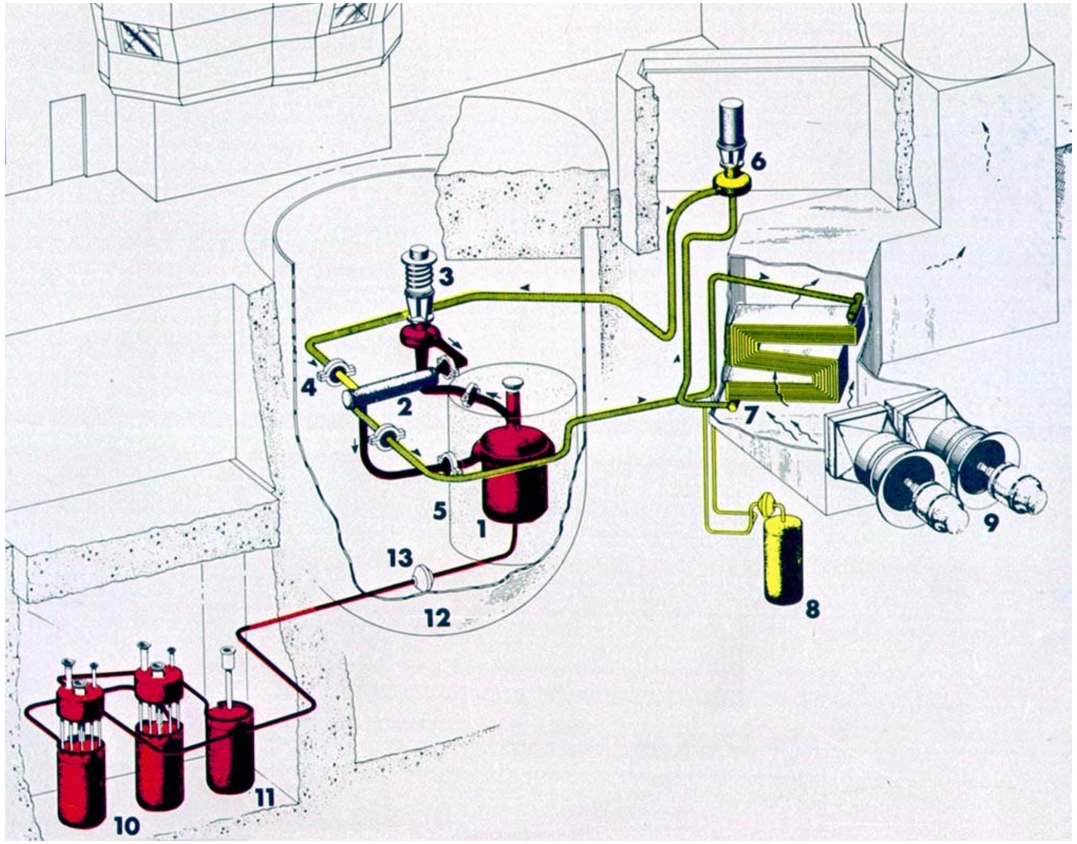


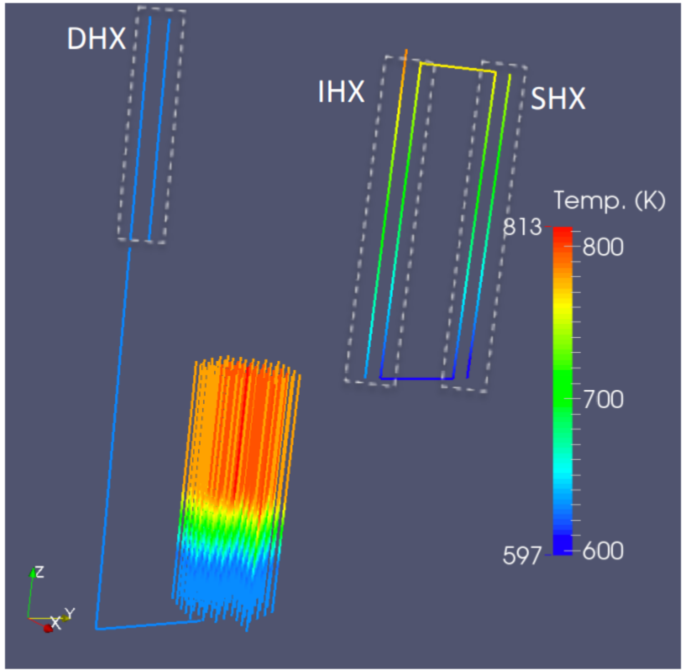
TABLE I: MSRE Reactor Specifications [5]

Parameter	Value
Core Power [MW_{th}]	10
Core height [m]	1.63
Core diameter [m]	1.39
Fuel Salt	$LiF\text{-}BeF_2\text{-}ZrF_4\text{-}UF_4$
Fuel salt molar mass	65.0%-29.1%-5.0%-0.9%
Fuel salt enrichment	33.0%
Channels in graphite moderator	3.05 cm x 1.016 cm
Channels' rounded corners radii	0.508 cm
Vertical graphite stringers	5.08 cm x 5.08 cm

MSRE at ORNL – Oak Ridge National Laboratory
Running Period: 1965 - 1969
More than 13,000 operational hours

'*Mighty Smooth Running Experiment*' – Weinberg (1968)

Computational Tools: SAM and Pronghorn



(a) SAM model with 61 core channels

SAM

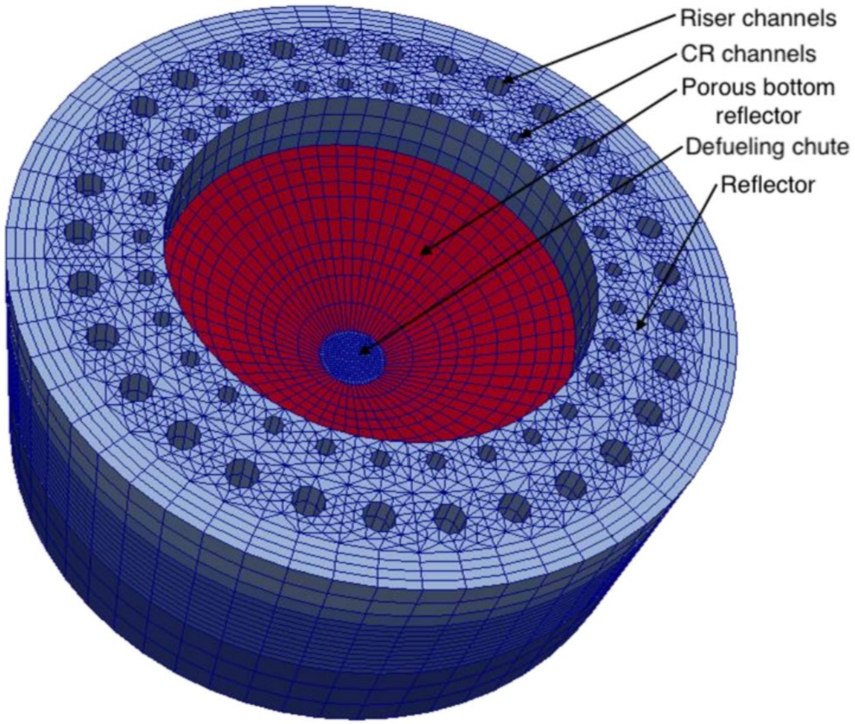
System Analysis Module

- Fast-running, whole-plant transient analyses capabilities

Features:

- 1-D pipe networks
- Point Kinetic model with various reactivity feedback
- Computationally efficient flow model

Computational Tools: SAM and Pronghorn



Pronghorn HTR-PM mesh of the bottom reflector cone region

Pronghorn

- Multidimensional, coarse-mesh, thermal-hydraulic code for advanced reactors
- Main area of application is analysis of accident scenarios

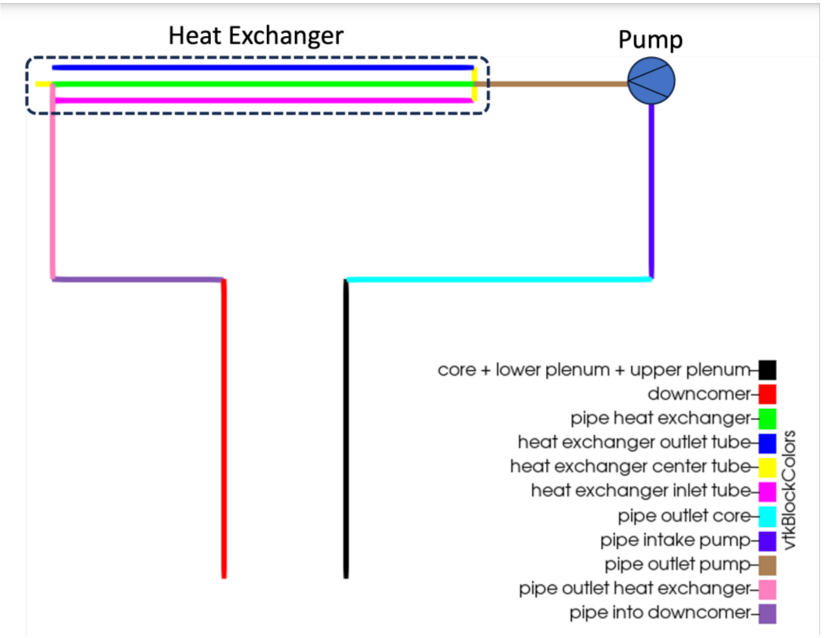
Features:

- Leverages seamless multiapplication data transfer

SAM and Pronghorn Models

SAM – System Analysis Module

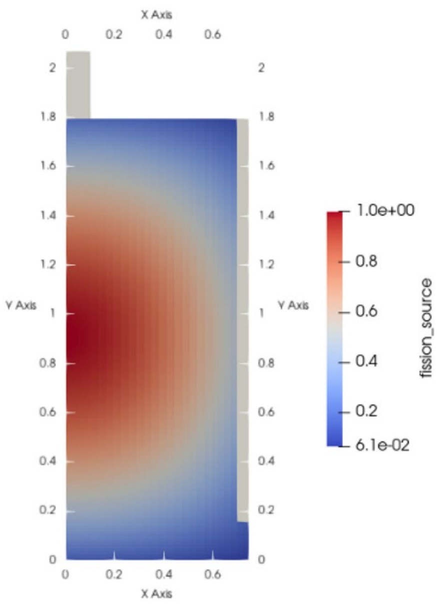
System Level Thermal Hydraulic Analysis Module



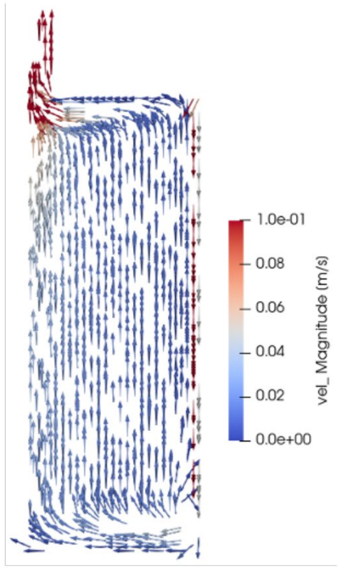
SAM model of the MSRE primary and secondary circuits

Pronghorn

Coarse Mesh Multi-dimensional Thermal-Hydraulics code



(a) Normalized power distribution.



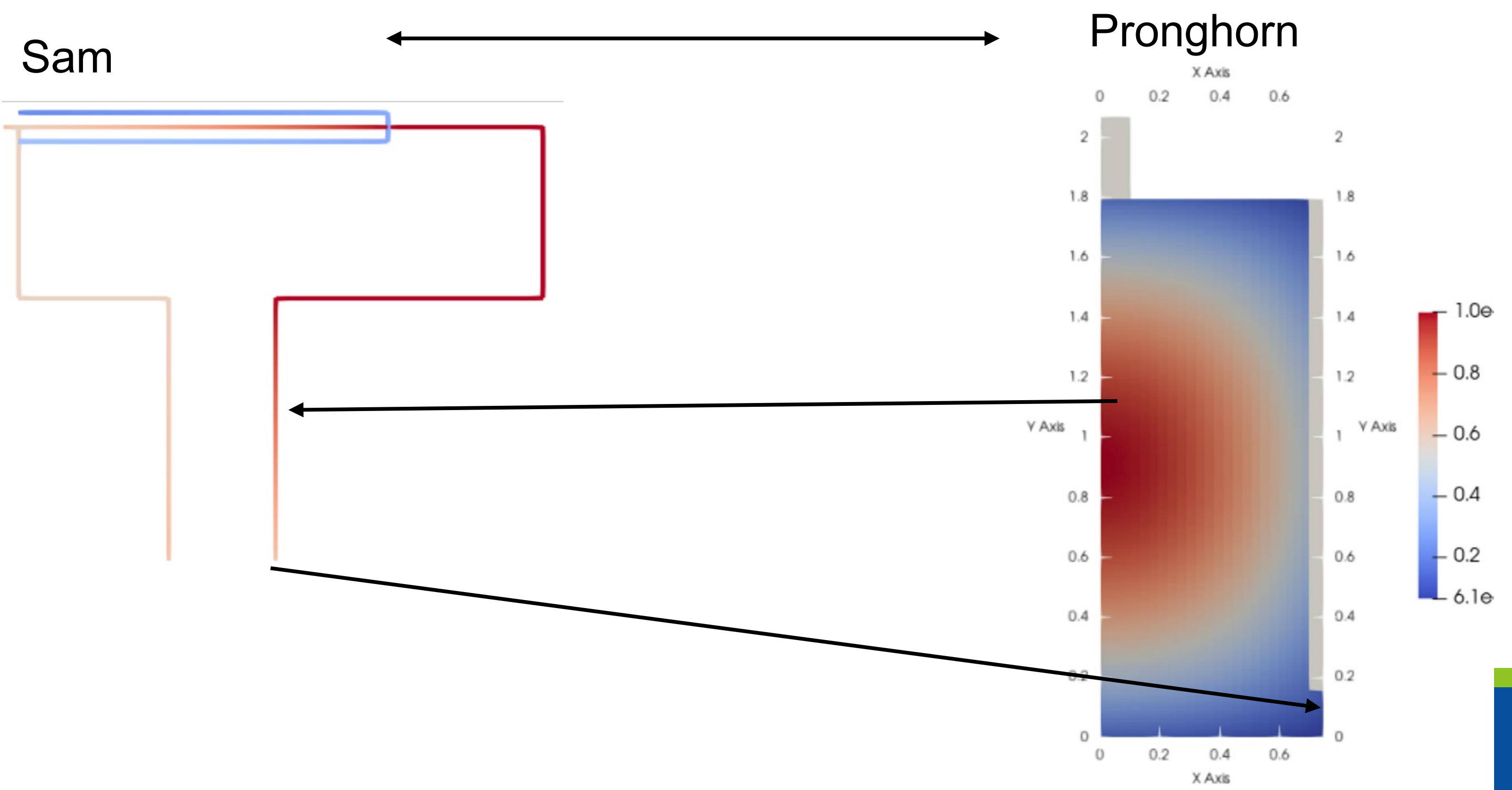
(b) Vector plot of the velocity field colored with the velocity magnitude (m/s).

Results from the Pronghorn model

Domain Overlapping Coupling

- Numerically Stable
- Converges faster and is more accurate that domain-segregated approach
- Supports multiple boundaries

- Volumetric source terms match the variables of interest
  - Ex: friction factor, volumetric heat transfer, pressure, passive scalars



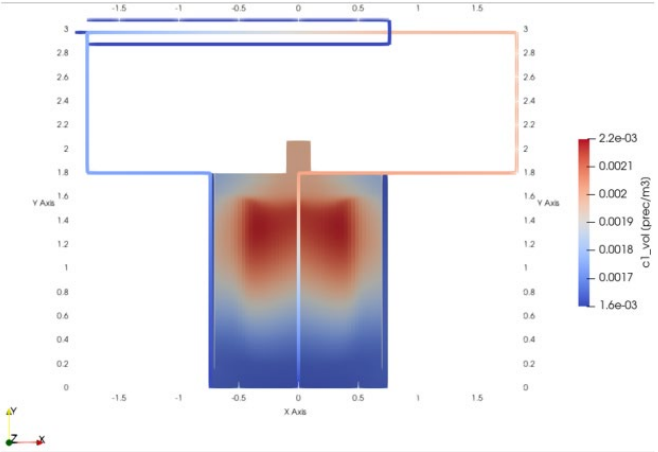
Input File Syntax

[OverlappingDomainCoupling]

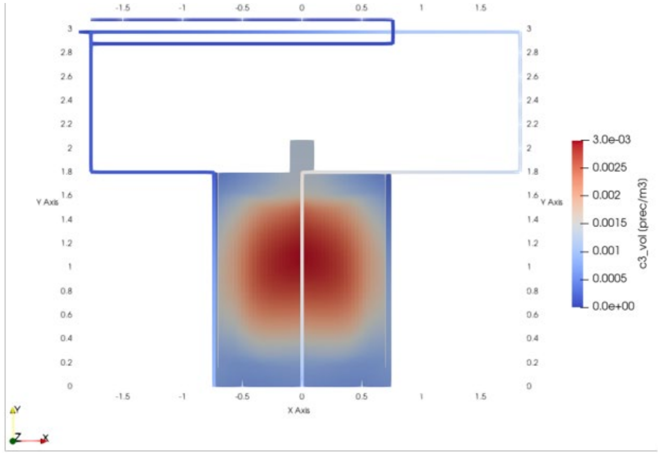
```
[OverlappingDomainCoupling]
 # MD side boundary information. PP values are received from SAM
boundaries = 'left right'
boundary_massflowrate_names = 'from_sam_mfr_left from_sam_mfr_right'
boundary_pressure_names = 'from_sam_pressure_left from_sam_pressure_right'
initial_boundary_massflowrate = '0 0'

# SC side: components overlapped
subapp_filename = 'overlapped_pipe_sc.i'
component_names = 'pipe_left pipe_right'

# SC side: branch overlapped connecting overlapped component
# pressure is matched there between MD and SC
overlapped_branch_name = j_left_right
reference_pressure = reference_plane_pressure

# duplicated component information
component_orientation = 'in out'
component_area = '1 1'
component_length = '5 5'

# Energy coupling
enthalpy_functor = cp_temp
boundary_temperature_names = ${energy_inlet_pps}
initial_boundary_temperatures = '${T_initial} ${T_initial}'

# Algorithm parameters
hydrodynamic_iteration_type = update
hydrodynamic_startup_time = 1
thermal_iteration_type = update
thermal_startup_time = 1
show_pps = true
```

Domain Overlapping Coupling Results on the MSRE

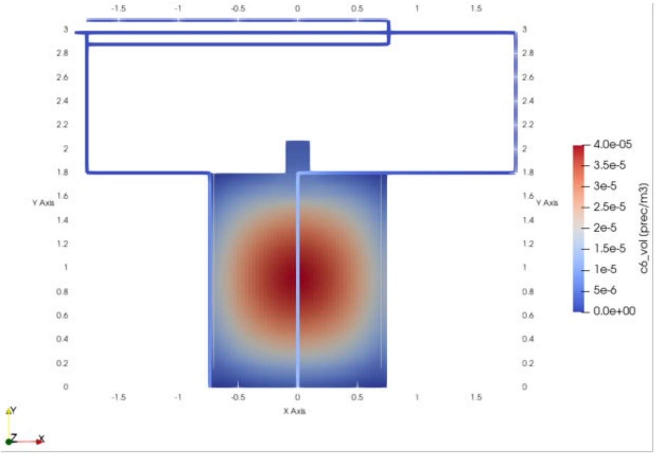
Neutron Precursors



(a) c_1 - Decay Constant = $0.013336 \frac{1}{s}$.



(b) c_3 - Decay Constant = $0.1208 \frac{1}{s}$.

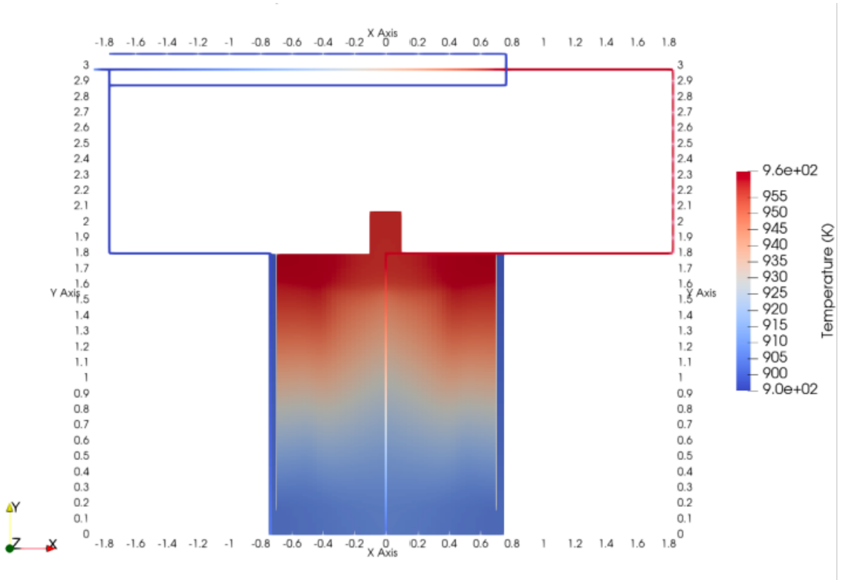


(c) c_6 - Decay Constant = $2.8530 \frac{1}{s}$.

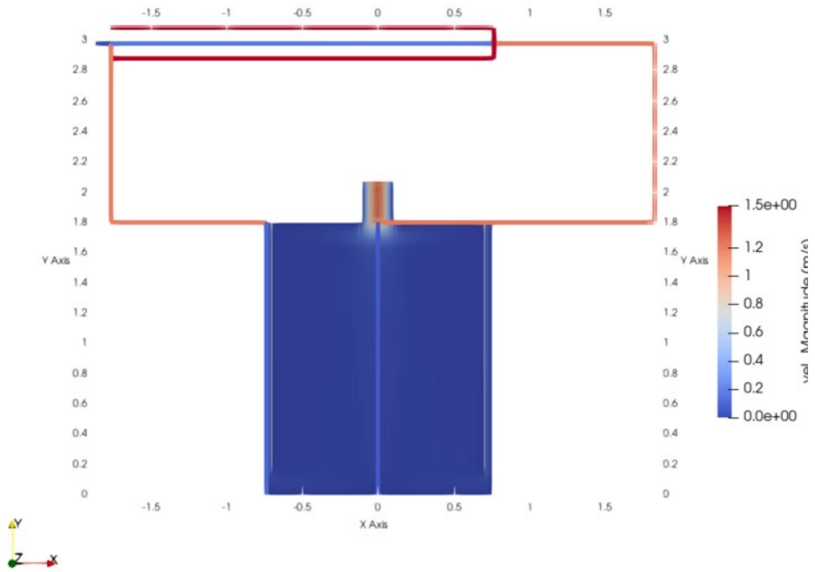
Fig. 7: Coupled Pronghorn-SAM normalized neutron precursors concentration results for steady-state primary circuit of MSRE [1].

Domain Overlapping Coupling Results on the MSRE

Thermal-Hydraulics



(a) Temperature (K).



(b) Velocity (m/s).

Fig. 6: Coupled Pronghorn-SAM thermal-hydraulics results for steady-state primary circuit and secondary cooling of MSRE [1].

Domain Overlapping Coupling Results on the MSRE

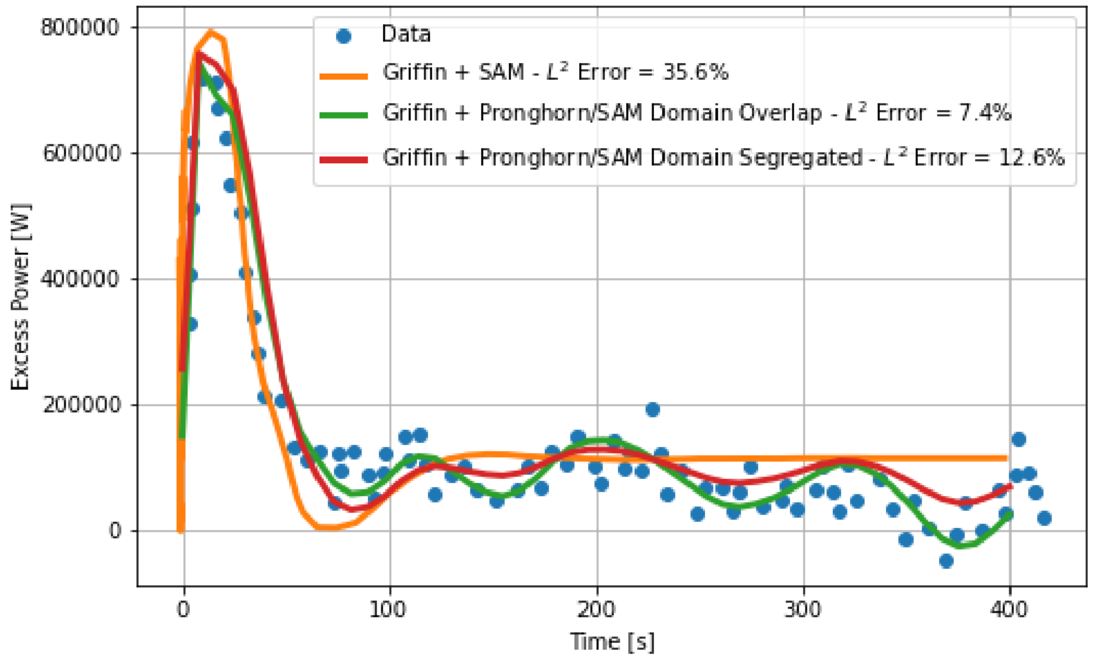


Fig. 5: Griffin coupled to thermal-hydraulics model results for reactivity insertion transient at 5 MW for MSRE [1].

5 MW of Power, 19 pcm, are inserted at 0 seconds.

All three models report the subsequent power drop due to the density-Doppler effect.

However, the subsequent thermal oscillations of the neutron precursors completing the primary loop circuit is best captured by the Pronghorn-Sam DOC

Didactical Documentation on the Virtual Test Bed

https://mooseframework.inl.gov/virtual_test_bed/msr/msre/msre_sam_model.html

Executioner

This block describes the calculation process flow. The user can specify the start time, end time, time step size for the simulation. Other inputs in this block include PETSc solver options, convergence tolerance, quadrature for elements, etc., which can be left unchanged.

```
[Executioner]
  type = Transient
  dt = 0.2
  dtmin = 1.e-3
  dtmax = 10.0
  nl_rel_tol = 1e-8
  nl_abs_tol = 1e-6
  nl_max_its = 10
  l_tol = 1e-6
  l_max_its = 200
  start_time = 0
  end_time = 300
  num_steps = 100000
  [./Quadrature]
    type = SIMPSON
    order = SECOND
  [../]
[]
```

(msr/msre/steady_state/msre_loop_1d.i)

Takeaways and Conclusions

- The MSRE model was released to the VTB with didactical documentation
- The ODC method is easily appliable to other reactor types
  - Framework allows arbitrary geometries
  - No assumption is made about the reactor being modeled

1. S. SCHUNERT, et al., “Overlapping Domain Coupling of Multidimensional and System Codes in NEAMS - Pronghorn and SAM,” Tech. Rep. INL/RPT-23-72874, Idaho National Laboratory (2023).
2. P. N. HAUBENREICH et al., “Experience with the Molten-Salt Reactor Experiment,” Nuclear Applications and Technology, 8, 2, 118–136 (1970).
3. I. DAVIS et al., “High-fidelity multi-physics coupling for determination of hydride distribution in Zr-4 cladding,” Annals of Nuclear Energy, 110, 475–485 (2017).
4. H. E. MCCOY et al., “Postirradiation examination of materials from the MSRE,” (12 1972).
5. M. FRATONI et al., “Molten Salt Reactor Experiment Benchmark Evaluation,” (5 2020).
6. M. JARADAT et al., “Thermal Spectrum Molten Salt-Fueled Reactor Reference Plant Model,” Idaho National Laboratory, INL/RPT-23-72875 (07 2023).
7. D. R. GASTON et al., “2.0 - MOOSE: Enabling massively parallel multiphysics simulation,” SoftwareX, 20, 101202 (2022).

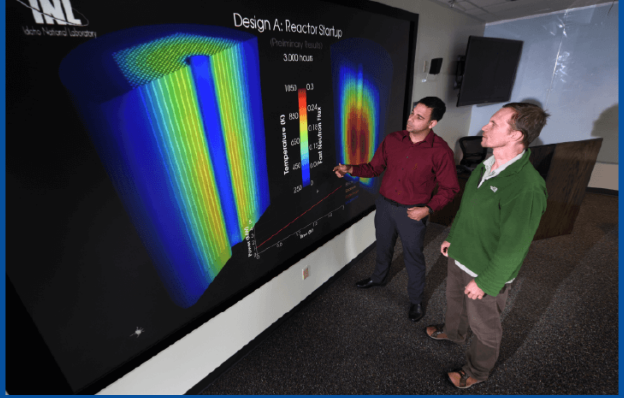


Image Sources

NRIC -

- https://nric.inl.gov/#:~:text=NRIC%20is%20a%20national%20Department,the%20U.S.%20National%20Laboratory%20System.

MSRE -

- https://www.wikiwand.com/en/Molten-Salt_Reactor_Experiment#Media/File:MSRE_Diagram.png

NEAMS -

- https://neams.inl.gov/about-us/

SAM -

- https://publications.anl.gov/anlpubs/2021/05/166771.pdf

Pronghorn -

- https://www.ne.ncsu.edu/wp-content/uploads/2019/10/S5_Balestra_NUC_workshop_sep_2019_PB1.pdf

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