Aug 20, 2024

Matthew Anderson
Manager, High Performance Computing

Nuclear Reactor Butterfly Valve Analysis with MVAPICH

Idaho National Laboratory

Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

Idaho National Laboratory

Nuclear Reactors and HPC Datacenters

HOME › NEWS › THE INVESTMENT & MARKETS CHANNEL

AWS acquires Talen's nuclear data center campus in Pennsylvania

Cloud company pays $650 million – plans 960MW campus

March 04, 2024 By: Dan Swinhoe Have your say

Amazon Web Services (AWS) has acquired Talen Energy's data center campus at a nuclear power station in Pennsylvania.

Talen Energy Corporation this week announced it has sold its 960MW Cumulus data center campus in Pennsylvania to a 'major cloud service provider' – listed as Amazon in a Talen investor presentation. Amazon is yet to comment on the news.

Nuclear microreactors are coming! HPC are expected end-users

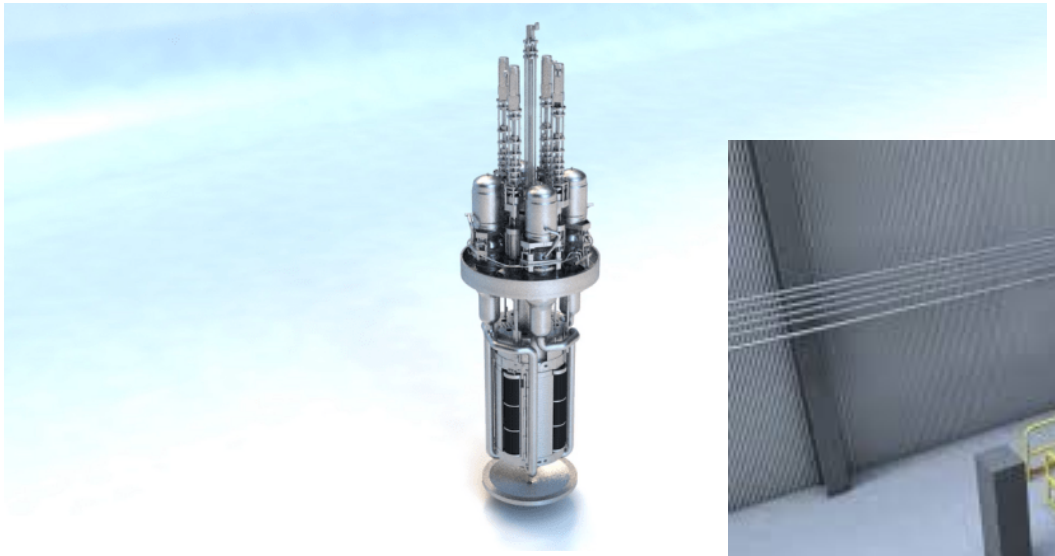
Developer	Name	Technology Type	Power Output [MW(electric)/ MW(thermal)]	Fuel	Coolant	Moderator	Refueling Interval
Alpha Tech Research Corp.	ARC Nuclear Generator	MSR	12 MW (electric)	LEU	Fluoride salt	—	—
BWXT	BANR	HTGR	17 MW(electric)/ 50 MW(thermal)	TRISO	Helium	Graphite	5 years
General Atomics	GA Micro	HTGR	1 to 10 MW(electric)	—	Gas	—	—
HolosGen	HolosQuad	HTGR	13 MW(electric)	TRISO	Helium/ CO_2	—	10 years
Micro Nuclear, LLC	Micro Scale Nuclear Battery	MSR/HP	10 MW(electric)	UF4	FLiBe	YH	10 years
NuGen, LLC	NuGen Engine	HTGR	2 to 4 MW(electric)	TRISO	Helium	—	—
NuScale Power	NuScale Microreactor	HP	<20 MW(electric)	Metallic	Liquid metal	Liquid metal	10 years
Oklo	Aurora	SFR/HP	1.5 MW(electric)	Metallic	Sodium	—	10+ years
Radiant Nuclear	Kaleidos Battery	HTGR	1.2 MW(electric)	TRISO	Helium	Graphite	4 to 6 years
Ultra-Safe Nuclear	MicroModular Reactor	HTGR	5 MW(electric)/ 15 MW(thermal)	TRISO	Helium	Graphite	20 years
Westing house	eVINCI™	HP	1 to 5 MW(electric)	TRISO	Sodium	Graphite	3+ years
X-Energy[33]	Xe-Mobile	HTGR	7.4 MW(electric)/ 20 MW(thermal)	TRISO	Helium	Graphite	—
Nano Nuclear Energy Inc.	NANO Nuclear	FR	0.5 to 1 MW(electric)	—	—	—	10 years

DOI: https://doi.org/10.1080/00295450.2022.2118626S1

Small size
May be mobile
Produce <10 MWe
Operate Autonomously
Refueling interval as much as 10 years
Load follow limited (< 10%/minute)

MARVEL is an example of a prototype microreactor

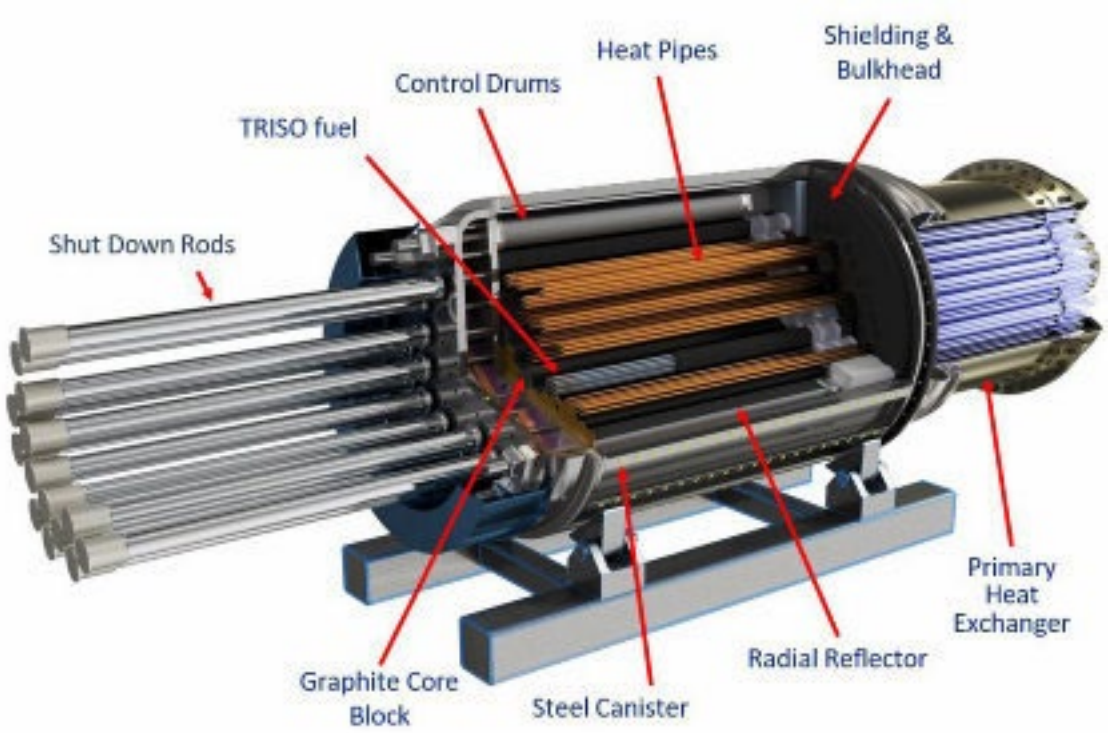
Marvel Microreactor at Idaho National Laboratory



Under construction at INL
Expected output: 50 kWe
Ready ~2026

eVinci Microreactor

Westinghouse
5 MWe
8+ year fuel cycle
No water required for operation
Above ground installation



https://www.westinghousenuclear.com/flysheet-directory/evinci-microreactor-the-next-generation-nuclear-research-reactor

Mobile Datacenter

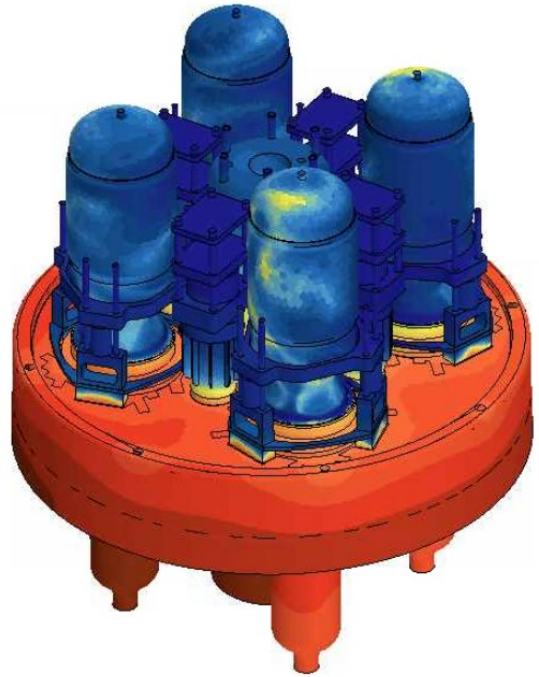
Self-contained system for HPC

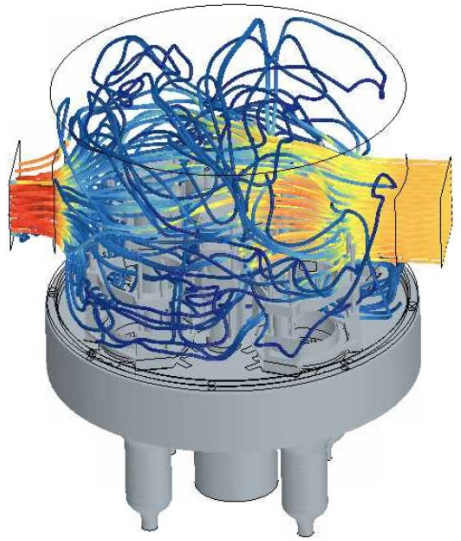
Bard B-410A/@36H Wall-Mount Heat Pump with 3 Tons cooling capacity

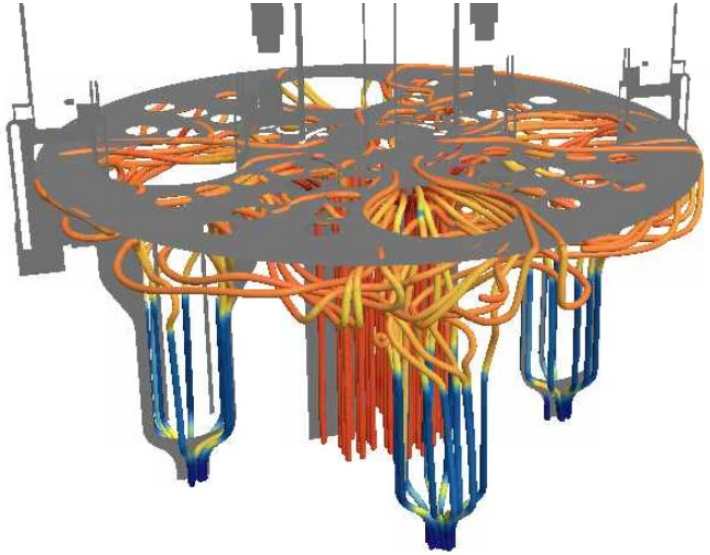
3 compute racks

UPS

Provide nuclear energy modeling and simulation via open source frameworks







INL High Performance Computing Resources

- NSUF HPC systems support a wide range of users and programs as a shared-use resource for national laboratories, universities, and industry
- WindRiver (2024)
  - 843 nodes, 94,416 cores
  - Arriving 23 Sep 2024
- Bitterroot (2024)
  - 374 nodes, 41,888 cores
  - Powered on 16 April 2024
- Sawtooth (2020)
  - 6 Petaflops performance
  - 2,079 compute nodes, 99,972 compute cores
  - #37 on November 2019 TOP500 list
  - Open for users: 17 March 2020
- Lemhi (2018)
  - 1 Petaflop performance
  - 504 compute nodes, 20,160 compute cores
  - #427 on November 2018 TOP500 list
  - Open for users: 28 Feb 2019

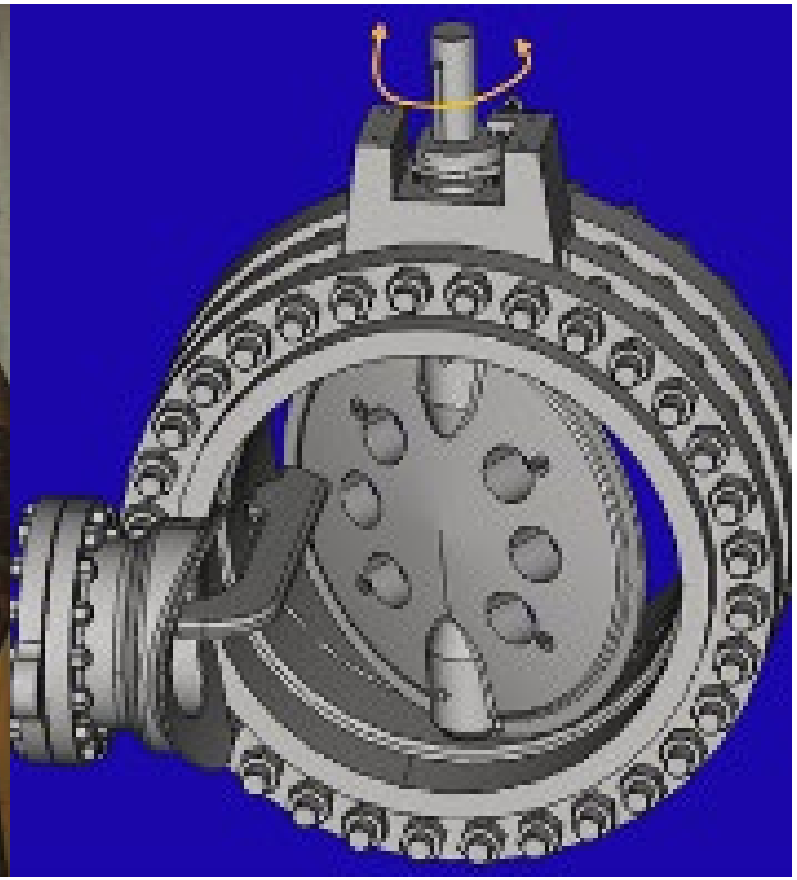
Bitterroot

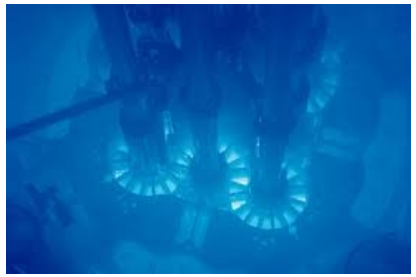
Sawtooth

Lemhi

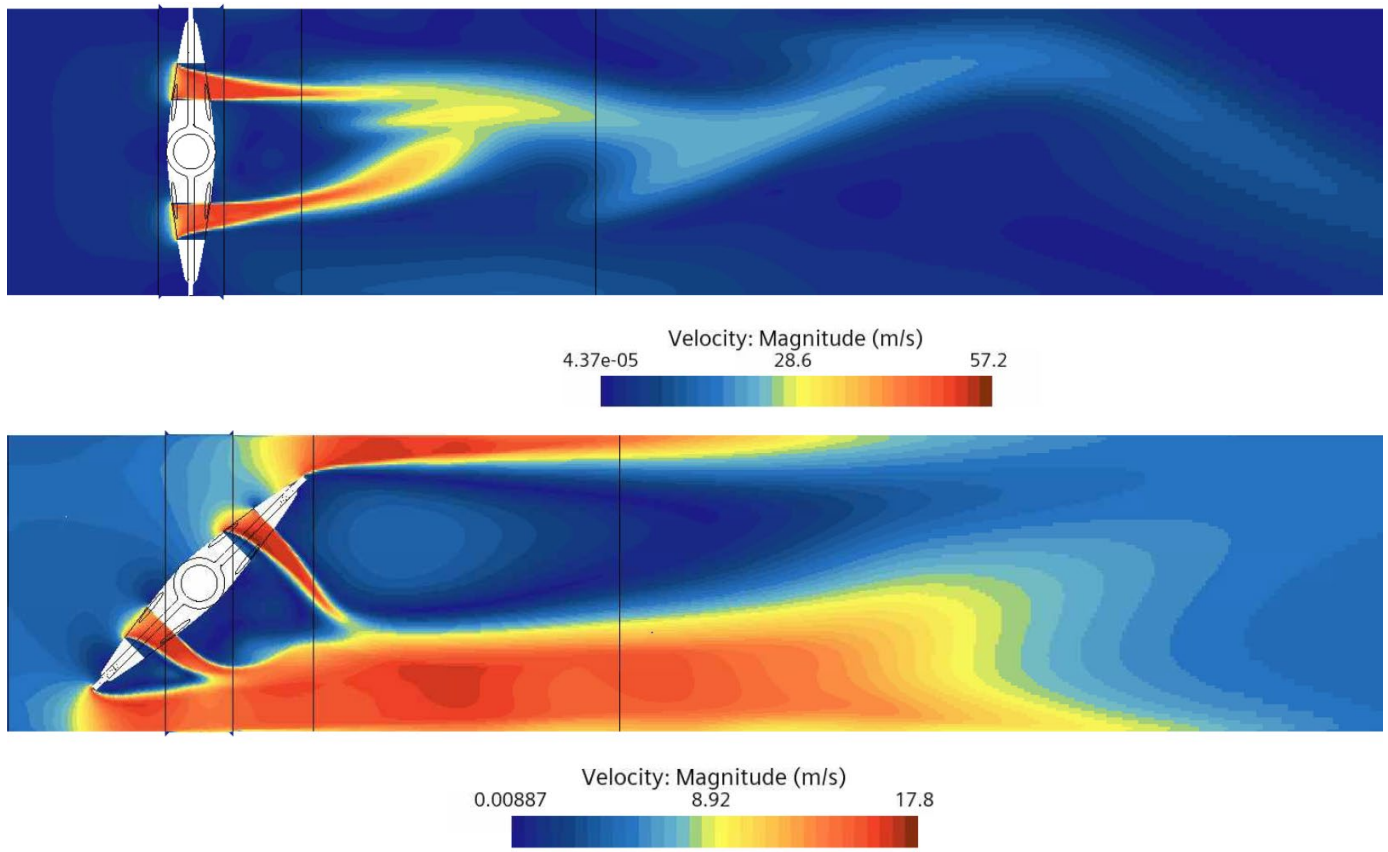
Butterfly-Valves and Nuclear Reactors

- Each PWR reactor has about 1500 valves; simulating their behavior (and failure) is common in nuclear energy
- Example PWR butterfly valve:
- = 0.9144m (36 in) across





STAR-CCM+ Results



MOOSE Framework

- MOOSE is an open-source multi-physics simulation environment
- Relies on MVAPICH2
- Pros:
  - 100% open-source!
  - Easy to learn
  - Well documented
  - **Can be easily containerized**
  - Makes simulations easy to reproduce

For more information please click the above image to go to the conference website.

An open-source, parallel finite element framework

Proven Capability
- Scalability to over 30,000 cores
- R&D 100 winner in 2014
- Wide variety of applications

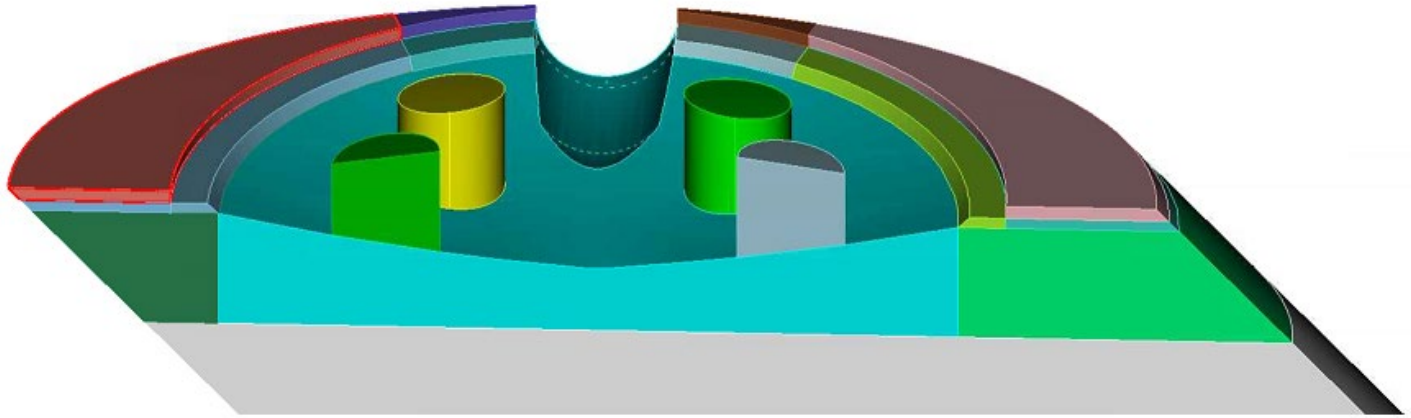
Rapid Development
- Simple installation
- Extensive tutorials
- Built-in physics modules
- Natural multi-scale capability

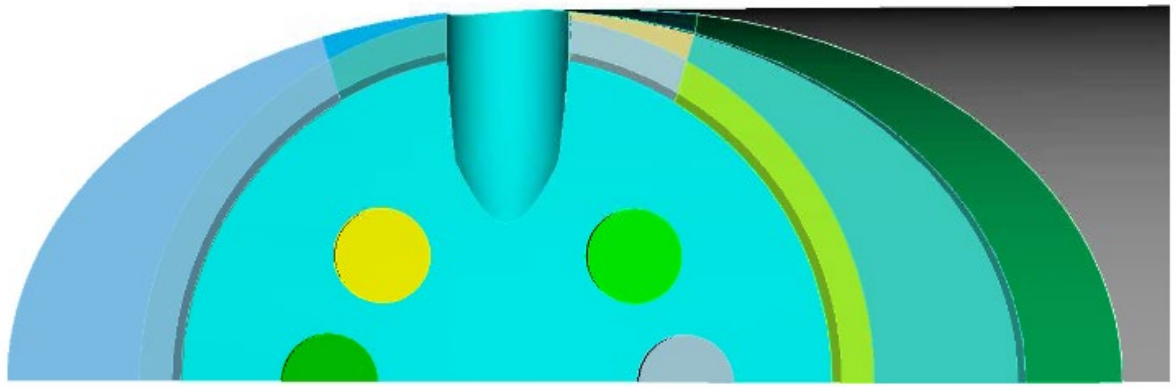
Active Community
- Active discussion forum
- Over 200 contributors
- Over 500 publications
- Over 10 million tests run per week

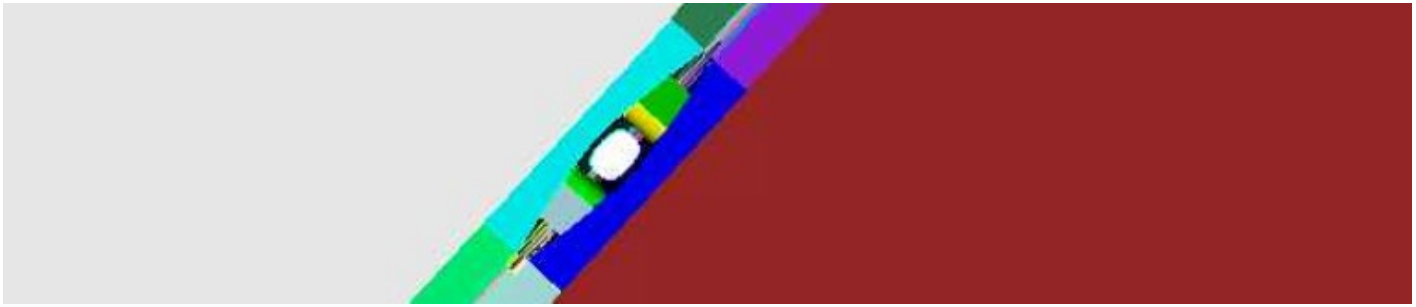
INL Idaho National Laboratory · Argonne NATIONAL LABORATORY · Los Alamos NATIONAL LABORATORY · OAK RIDGE National Laboratory | LEADERSHIP COMPUTING FACILITY

MOOSE Pipeline: Meshing

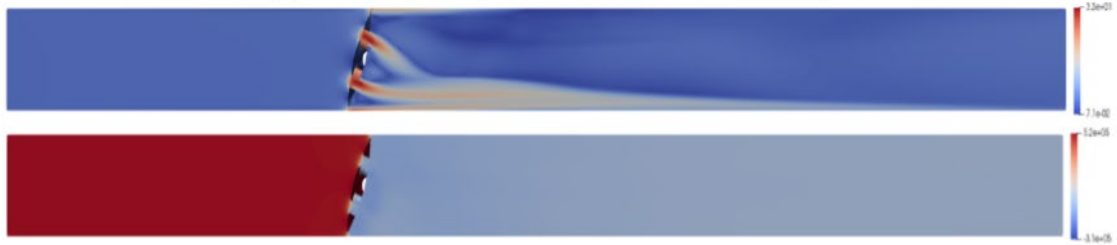
- Meshing was performed using Cubit
- MOOSE requires conformal meshes





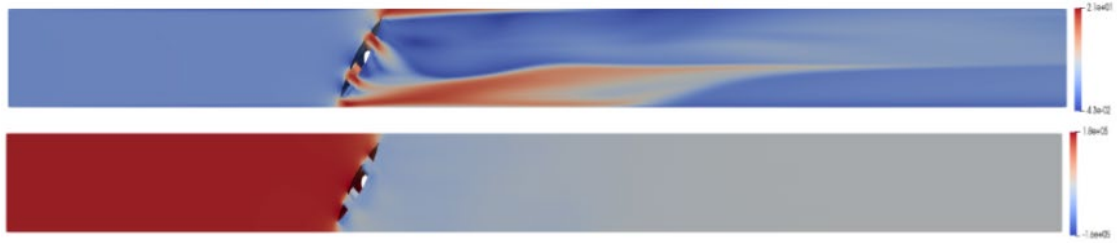


(a) 0° velocity and pressure profile. $V_{inlet} = 2.051m/s$

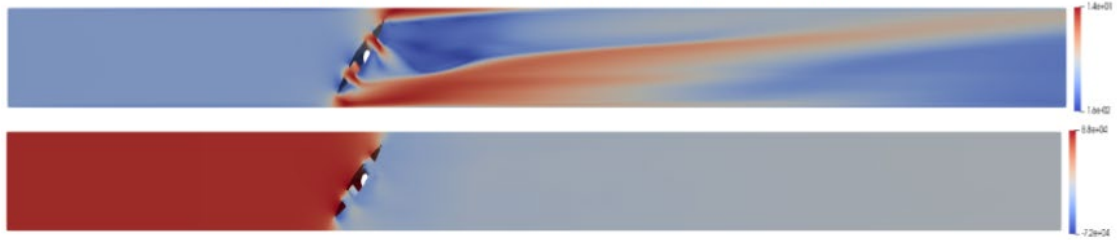


(b) 19.7° velocity and pressure profile. $V_{inlet} = 4.195m/s$

(c) 22.5° velocity and pressure profile. $V_{inlet} = 4.318m/s$



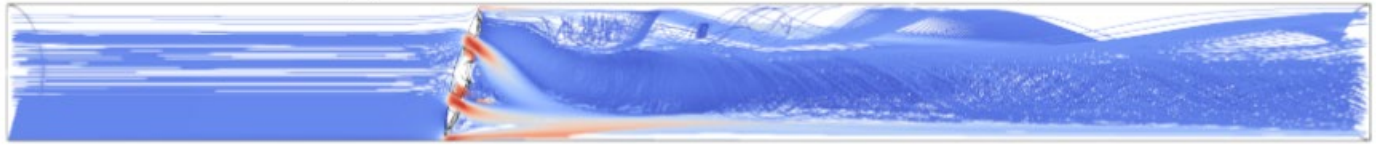
(d) 36.3° velocity and pressure profile. $V_{inlet} = 4.836m/s$



(e) 42.7° velocity and pressure profile. $V_{inlet} = 4.190m/s$

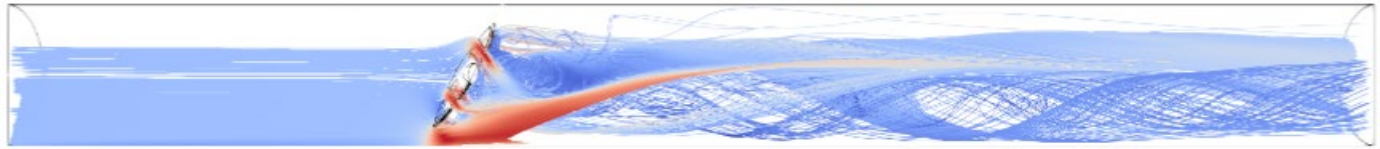
(a) 0° velocity streamline plot. $V_{inlet} = 2.051m/s$

(b) 19.7° velocity streamline plot. $V_{inlet} = 4.195m/s$



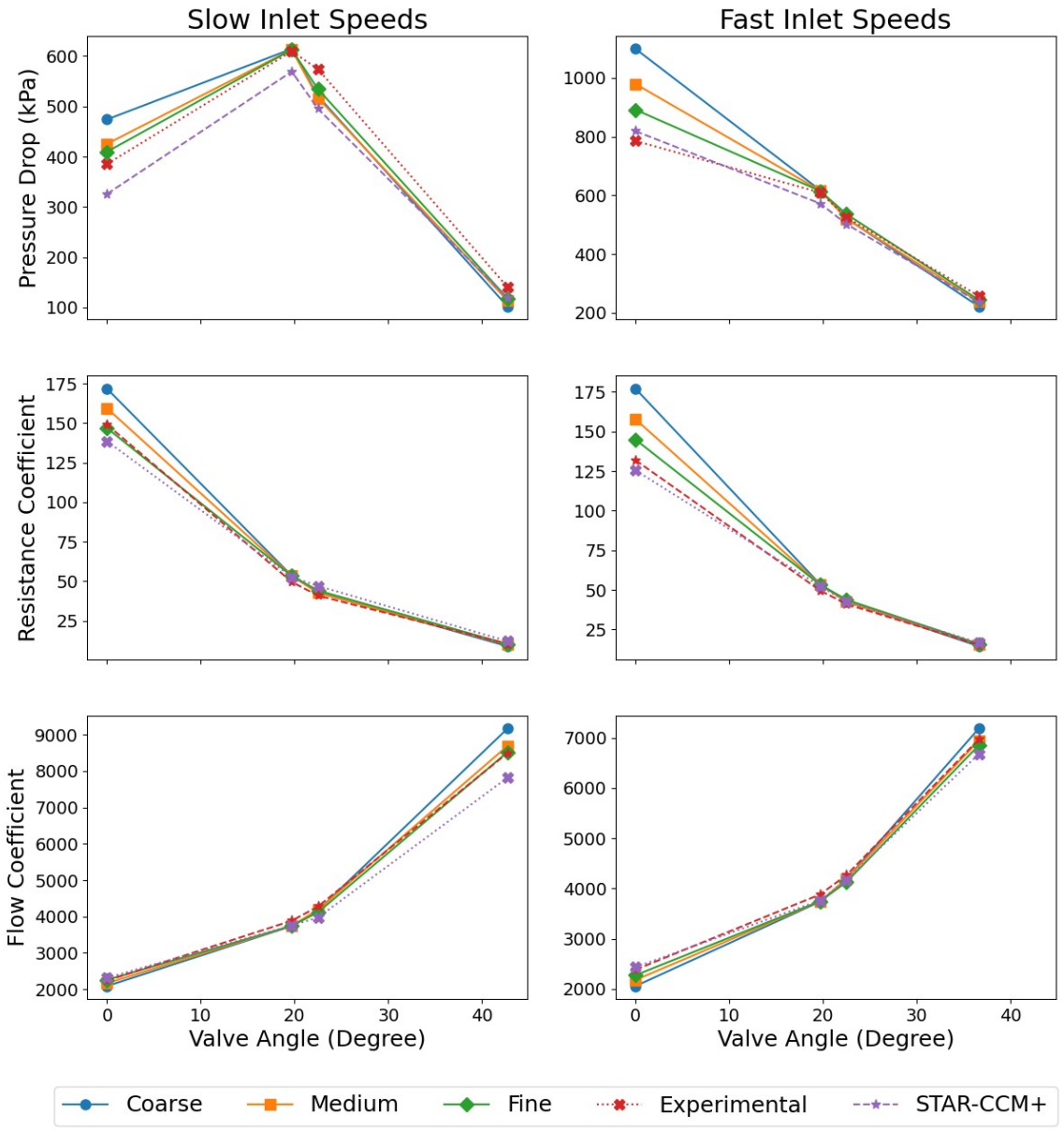
(c) 22.5° velocity streamline. $V_{inlet} = 4.318m/s$

(d) 36.3° velocity streamline plot. $V_{inlet} = 4.836m/s$



(e) 42.7° velocity streamline plot. $V_{inlet} = 4.190m/s$

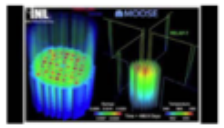
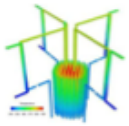
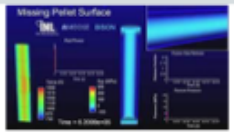
Butterfly-Valve Performance Factors



Challenges

MOOSE herd apps

Application	Domain	More information
Bison	Nuclear fuel performance	https://mooseframework.inl.gov/bison/index.html
Blue crab	Nuclear plant systems analysis	https://www.osti.gov/servlets/purl/1766199
Dire Wolf	Heat-pipe microreactor analysis	https://gain.inl.gov/MicroreactorProgramTechnicalReports/Document-INL-EXT-20-59691.pdf
Griffin	Neutron diffusion solver	https://doi.org/10.1016/j.anucene.2021.108546
Marmot	Mesoscale fuel performance	https://mooseframework.inl.gov/magpie/getting_started/Marmot.html
Mastodon	Multiscale Hazard Analysis	https://mooseframework.inl.gov/mastodon/
Pronghorn	Advanced reactor thermal hydraulics	https://doi.org/10.1080/00295450.2020.1825307
Sabertooth	Fuel performance and thermal hydraulics with neutronics	https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_41824.pdf
Sockeye	Heat-pipe analysis	https://doi.org/10.1080/00295450.2020.1861879

Performance issues with MOOSE sparse communication routines impacting application performance

Challenges

- Nuclear Energy modeling and simulation requires extensive verification and validation
- Most applications are being containerized via apptainer
- Long term guidelines needed for supporting mvapich with containers on hosts with IB and OPA; to provide a unified container that works for hosts with different fabrics

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.