TRANSFORM

A Vision for Modern Advanced Reactor System-Level Modeling and Simulation Using Modelica

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The Future of Nuclear Energy is New & Diverse Applications

What will be required of modeling and simulation tools?

Flexible and Adaptable

- Tools must be able to be used for a variety of applications
- Tools must be modifiable for new uses

- Advanced Reactor Technologies
  - HTGRs, LMRs, MSRs
- Integrated Energy Systems
  - Desalination, Hydrogen, Oil-recovery

Rapid Development

- Users need the ability to "fail fast" and mature analysis
- Modeler has control over level of fidelity

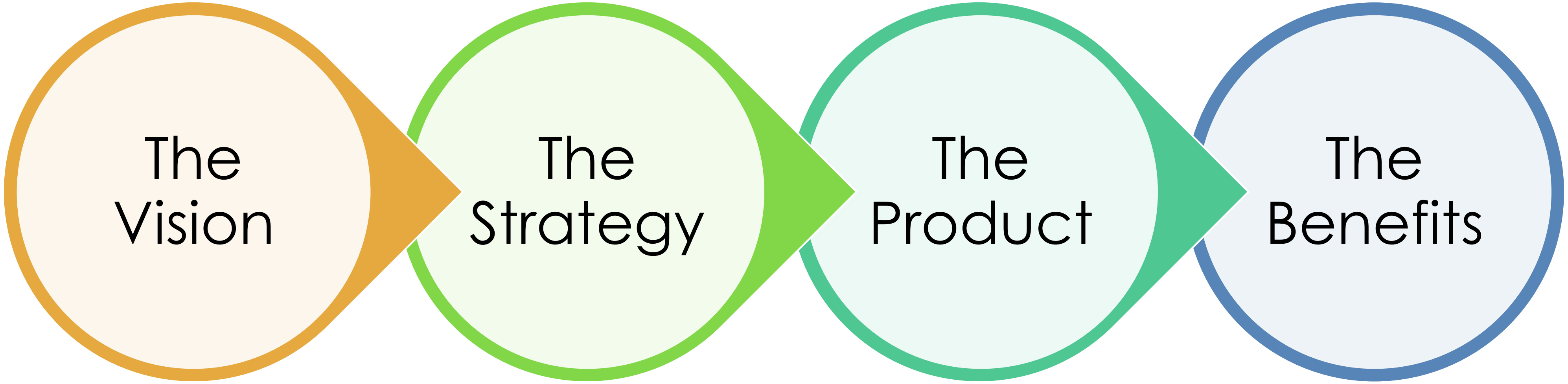
- Deployable on a range of machines
  - PCs, clusters
- Advanced languages and features
  - Python, Modelica
  - Acausal, object-oriented

Collaborative

- Domain expertise shareable to leverage skill sets
- Models able to communicate with other tools and frameworks

- Models should be shareable/exportable
  - Open-source or "black-box" capable
- Ability to integrate at different "scales"
  - System, CFD

The TRANSFORM Enterprise



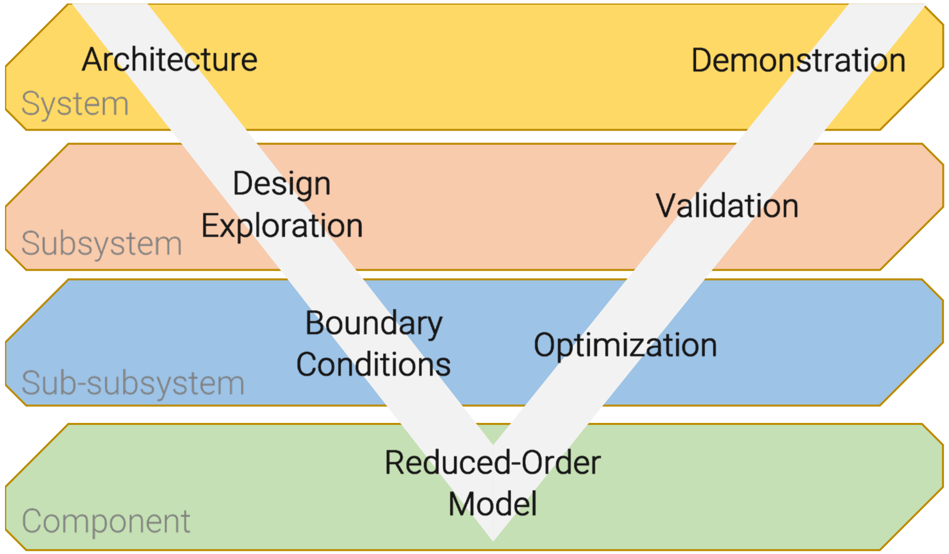
The Vision

To accelerate the design, analysis, and deployment of advanced nuclear reactors

by enabling rapid, collaborative, and adaptable exploration of design and analysis

via a modern, system-level engineering ***<u>enterprise</u>***

which delivers a vertically integrated suite of Modelica focused design and analysis tools



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The Strategy

The pillars upon which all activities will be focused

- Enabling Rapid Development
  - Enable graceful progress through the levels of system development and analysis demanded of the application
- Collaborative
  - Community participation in development and capability extension
  - Advisory council collaborations to help guide research and development effort
- Adaptable
  - Generic modeling approaches allowing underlying capability that can later be extended and adapted to meet a variety of application demands

How does TRANSFORM support Rapid Development?

- Large selection of multi-physics generic models
  - Fluid: Lumped & 1-D
  - Heat and Mass Transfer: Lumped & multi-D
  - Control logic and sensors
  - Nuclear kinetics
- Object-oriented and Acausal
  - Drag and drop
  - Allow computer to rearrange and solve equations
  - Quickly move from model to results

Exhibit A

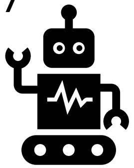
2 years
+ 1 Postdoc

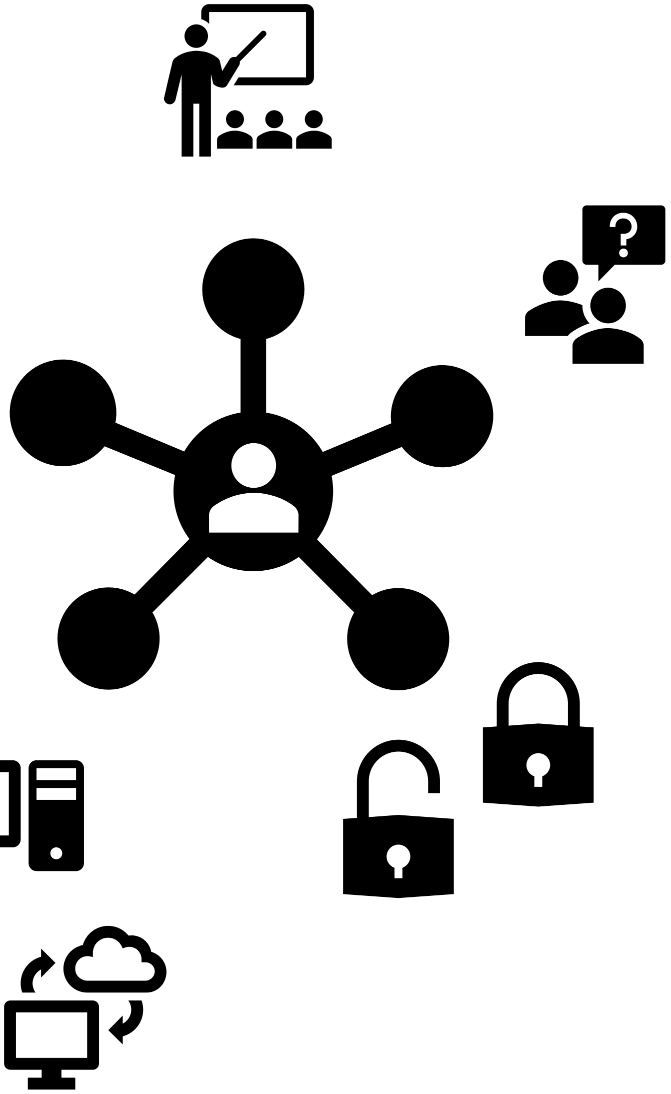
TRANSFORM

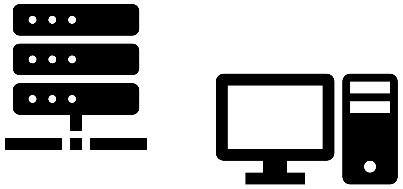
AdvSMR	NHES	TRANSFORM	MSR Models & SMR-GAIN	NTP & More
2013	**2015**	**2017**	**2018**	**2019**

How is TRANSFORM Collaborative?

- TRANSFORM is Open-Source
  - https://github.com/ORNL-Modelica/TRANSFORM-Library
- Readable source code
  - Like "textbook" or engineering representation
  - Easier communication/debugging
- Export models to other environments and users (FMI)
  - Standard interface for receiving/sending data
    - https://youtu.be/A-3iIot0fO8
- Engage with users

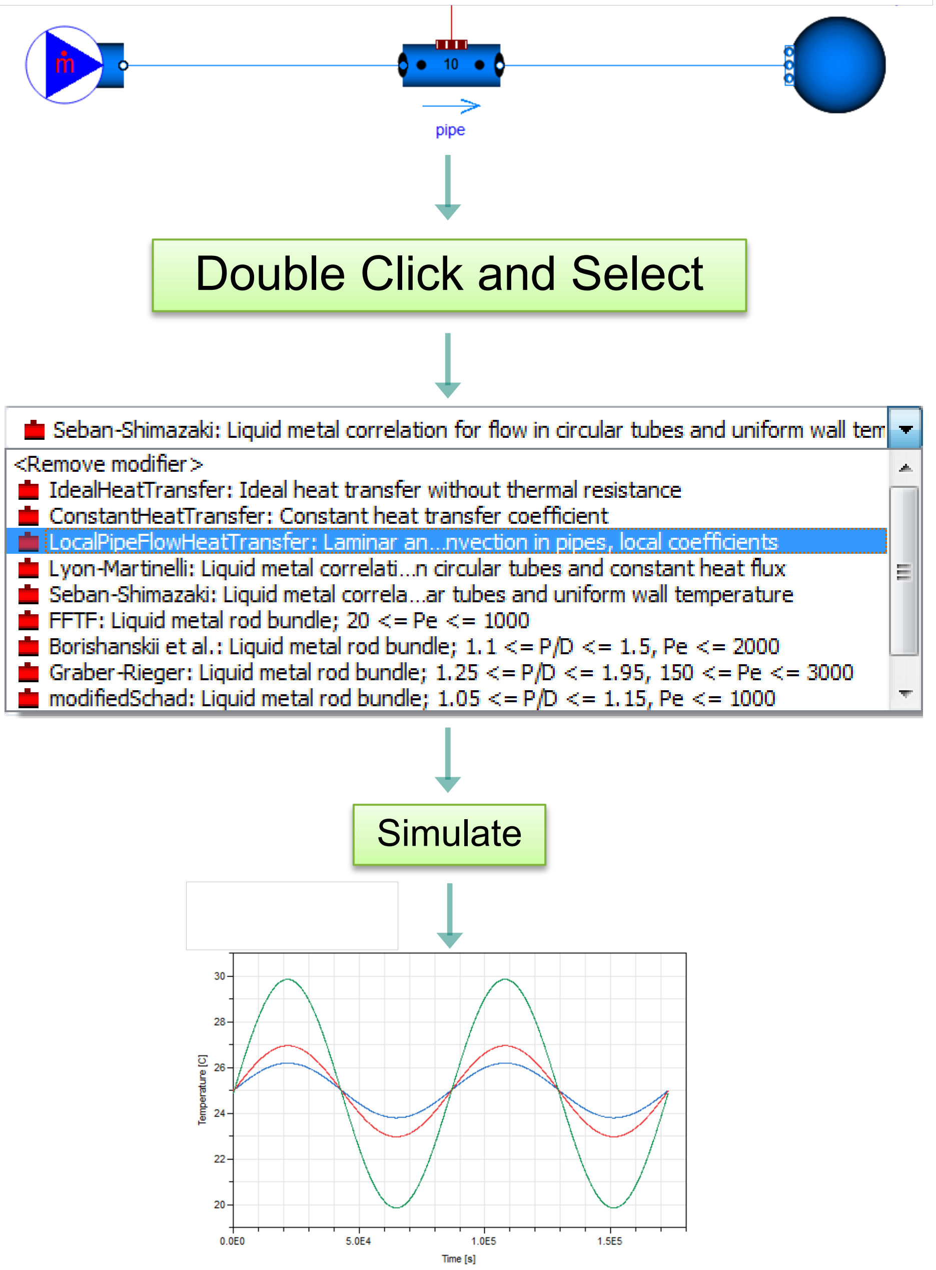




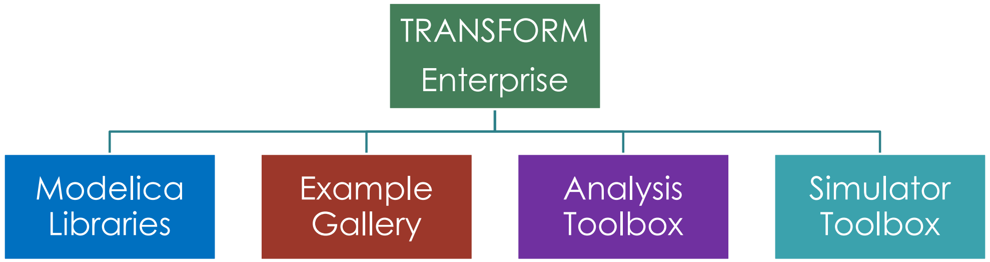


How is TRANSFORM Flexible and Adaptable?

- Components are modifiable
  - Extend models to add capability
  - Adapt or modify for new applications
  - Incorporate new models
- Replaceable physics
  - E.g., heat transfer, fluid media



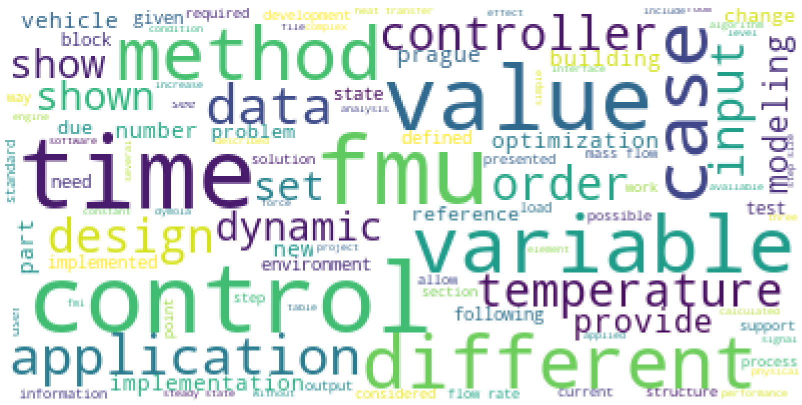
The Product



- Modelica Library
  - Components for system modeling
- Example Gallery
  - Curated examples, templates, and training material
- Analysis Toolbox
  - Toolset for data analysis such as optimization and regressions tests
- Simulator Toolbox
  - Toolset for creating simulators and model integrations using FMI

TRANSFORM Modelica Library

- Current TRANSFORM capabilities include:
  - Nuclear energy and auxiliary systems
  - Thermal-hydraulics, heat transfer, and control systems
- Built using the Modelica programming language
  - A powerful and modern dynamic system modeling language
  - Time-dependent system modeling
  - Ideal for rapid, flexible, and collaborative system modeling
- Part of an “economy” of modeling
  - Leverage other Modelica libraries
  - A growing number of tools directly support Modelica and FMI



The Benefits

- Immediately Useful
- Customizable to needs
- Will grow and adapt base on “customer” needs
- Supported by industry and their workflows and toolchains
- Will meet expectations of how modeling and simulation should be performed

The TRANSFORM Enterprise

- Delivering a robust toolchain for modelica based development and analysis of advanced reactors
  - Enables rapid development and is collaborative and adaptable
- Built on the emerging standard of Modelica in physics-based system modeling
- Integrates with modern MBSE workflows and toolchains
- Foundational to realizing the demands of a complex and integrated energy future

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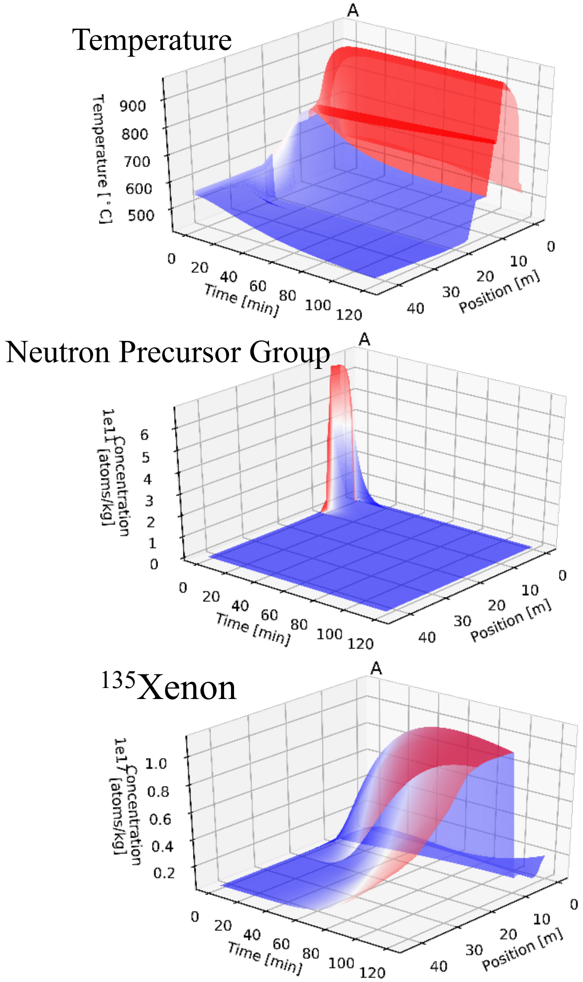
Examples of projects leveraging TRANSFORM

Radionuclide Mass Accountancy

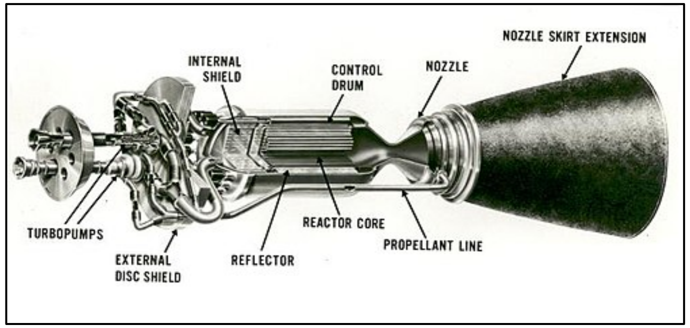


Transient behavior as a function of position

Model of the fluoride salt-fueled, thermal MSDR

Source
Greenwood, M.S., Betzler, B.R., Qualls, A.L., Yoo, J., Rabiti, C.: Demonstration of the Advanced Dynamic System Modeling Tool TRANSFORM in a Molten Salt Reactor Application via a Model of the Molten Salt Demonstration Reactor. Nuclear Technology. 1–27 (2019). https://doi.org/10.1080/00295450.2019.1627124

Dynamic Model of a Nuclear Thermal Rocket

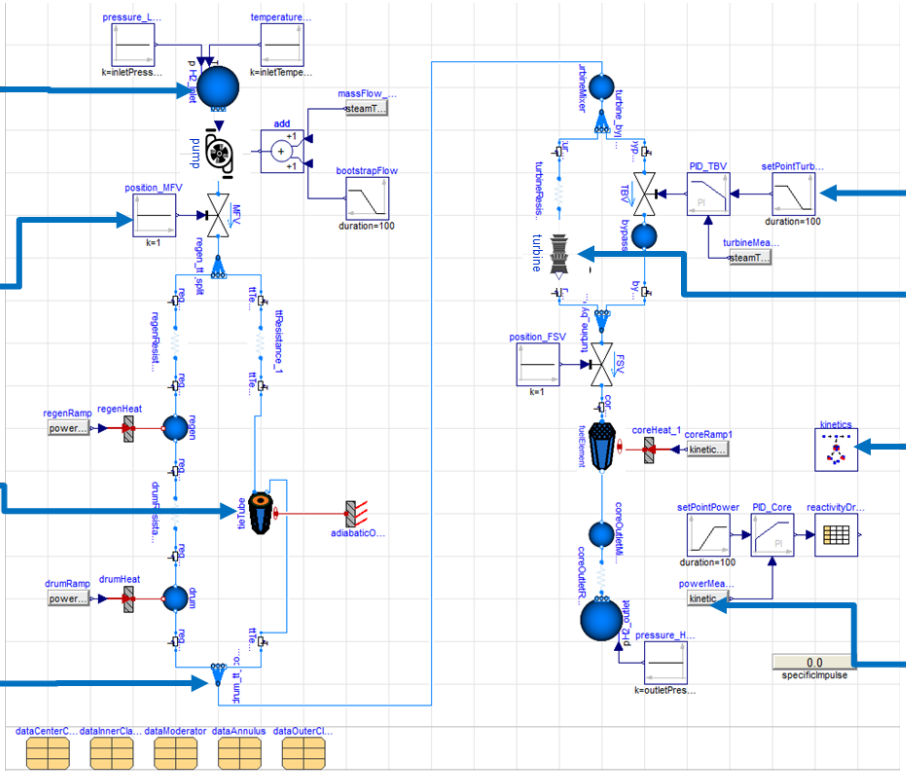


Temperature sensor performance

Valve control

Core instrumentation

Fluid flow measurement performance



Valve position sensor performance

Turbine instrumentation

Drum control

Neutron monitor performance

Source

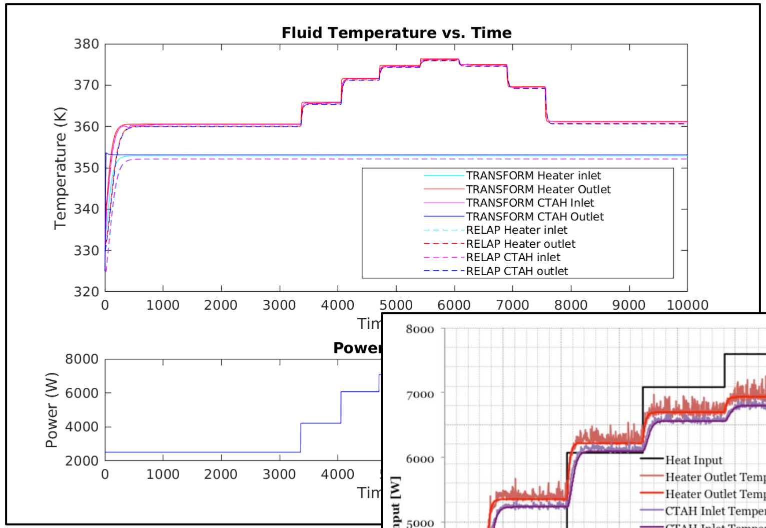
J. D. RADER et al., "Nuclear Thermal Propulsion Dynamic Modeling with Modelica," in Proceeding of Nuclear and Emerging Technologies for Space (NETS), Las Vegas, NV (2019).

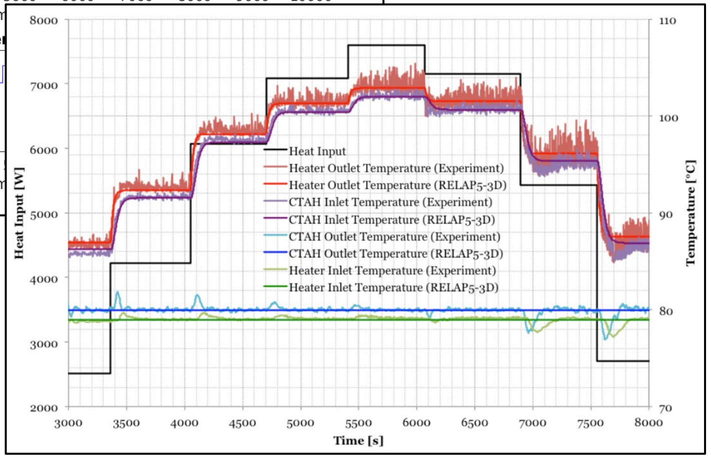
Transformational Challenge Reactor

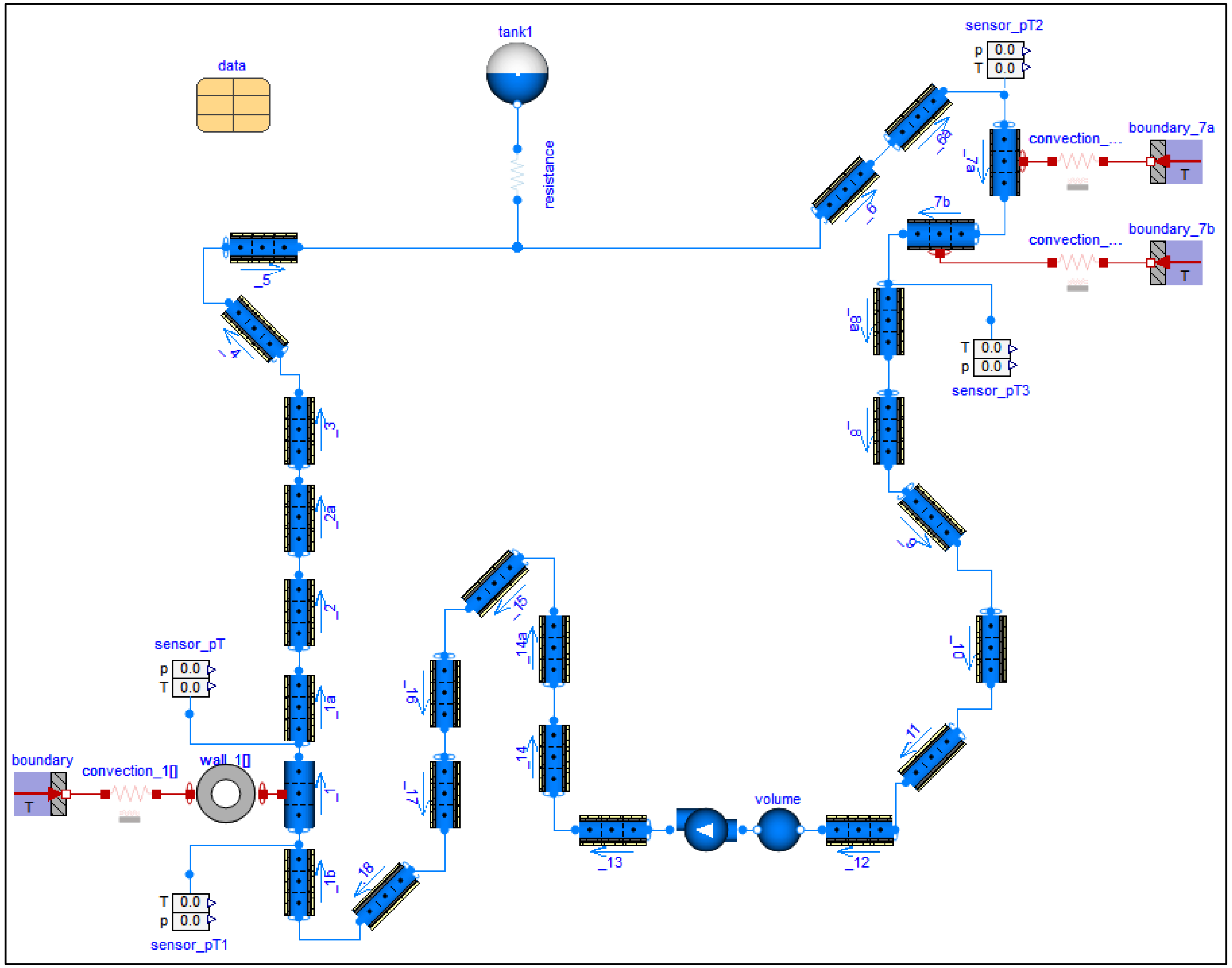
- Project is designing and building an advanced manufactured nuclear reactor
- Accident event analysis verification of a novel gas-cooled nuclear reactor
- See their presentation in the American Nuclear Society Winter meeting ☺
  - Wysocki, A.J., Jain, P.J., Rader, J.D.: Transformational Challenge Reactor Accident Analysis. In: Proceeding of the American Nuclear Society. , Chicago, IL (2020)

UC Berkeley CIET benchmarking

- Performed an experimental benchmark of a simulant fluid facility for salt-cooled reactors using frequency analysis.







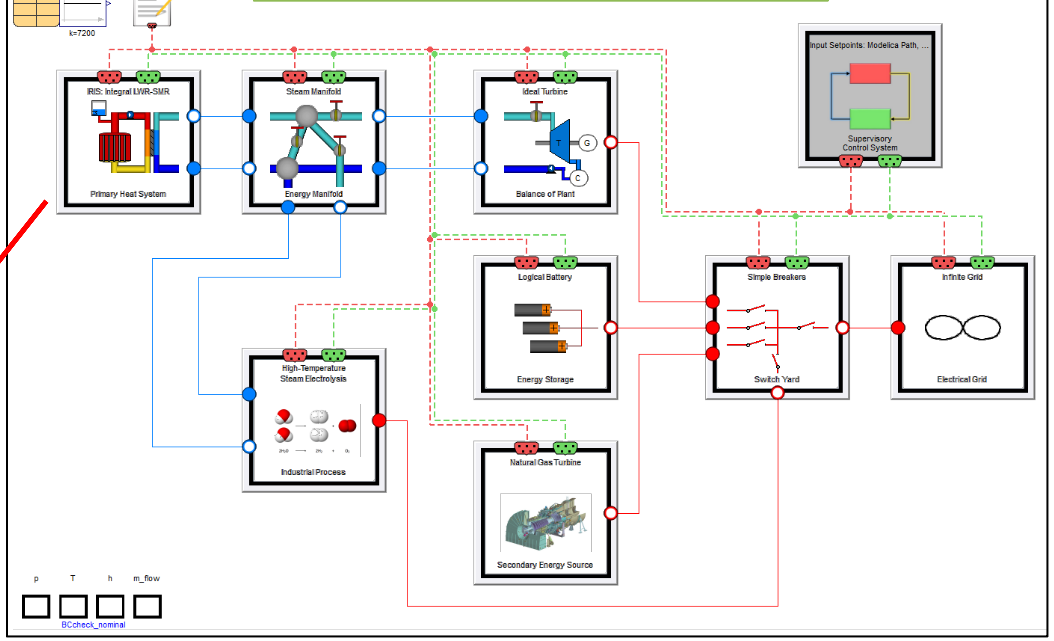
Model of the UCB CIET Facility

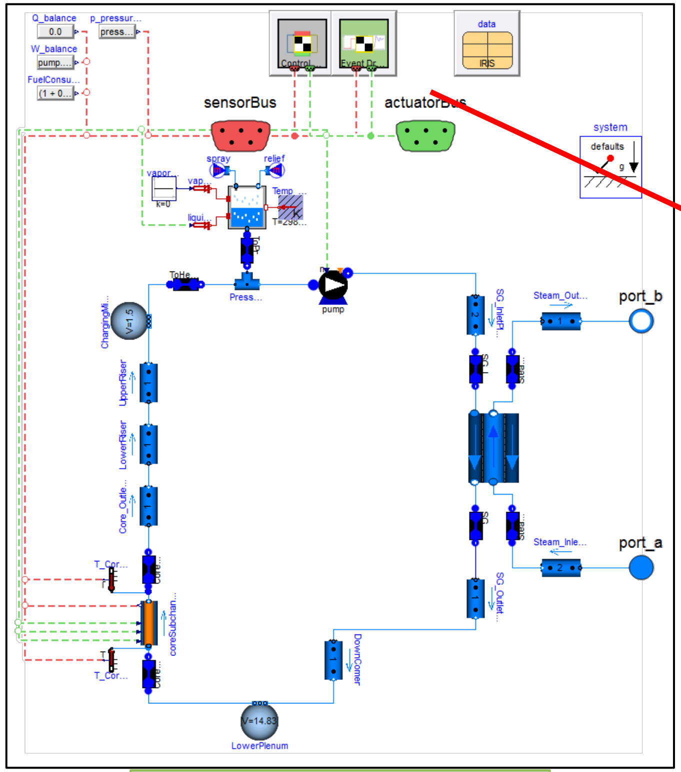
Source
D. de Wet, "A Frequency Domain Approach to Characterizing and Modeling Single Phased, Forced Circulation Advanced Nuclear Reactor Designs," University of California, Berkeley, Berkeley, CA, 2020.

Integrated Energy Systems

- Create physics-based models of nuclear reactors coupled with energy generation, energy storage, and industrial users for subsequent analysis and optimization.

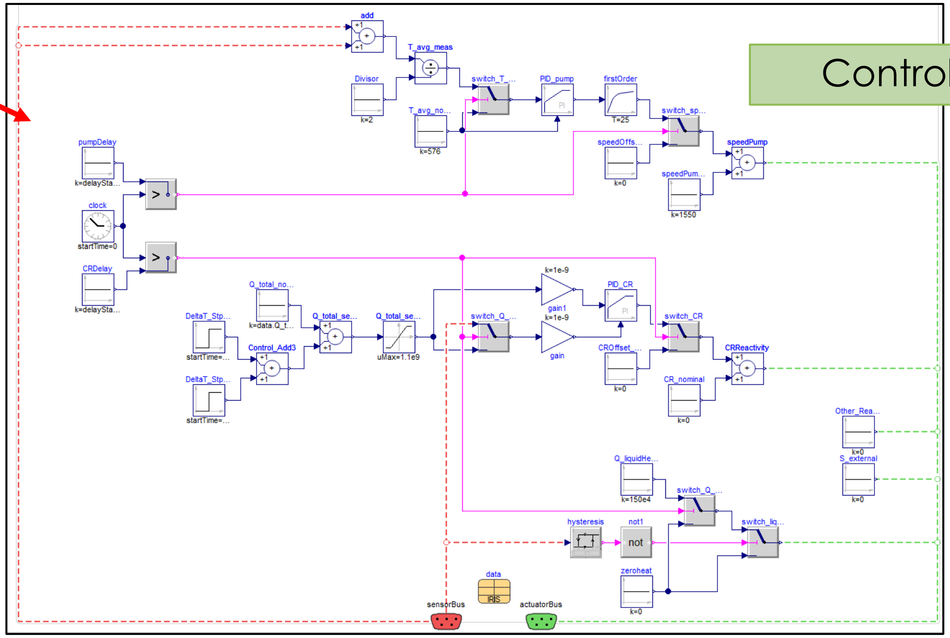
Hybrid Energy System





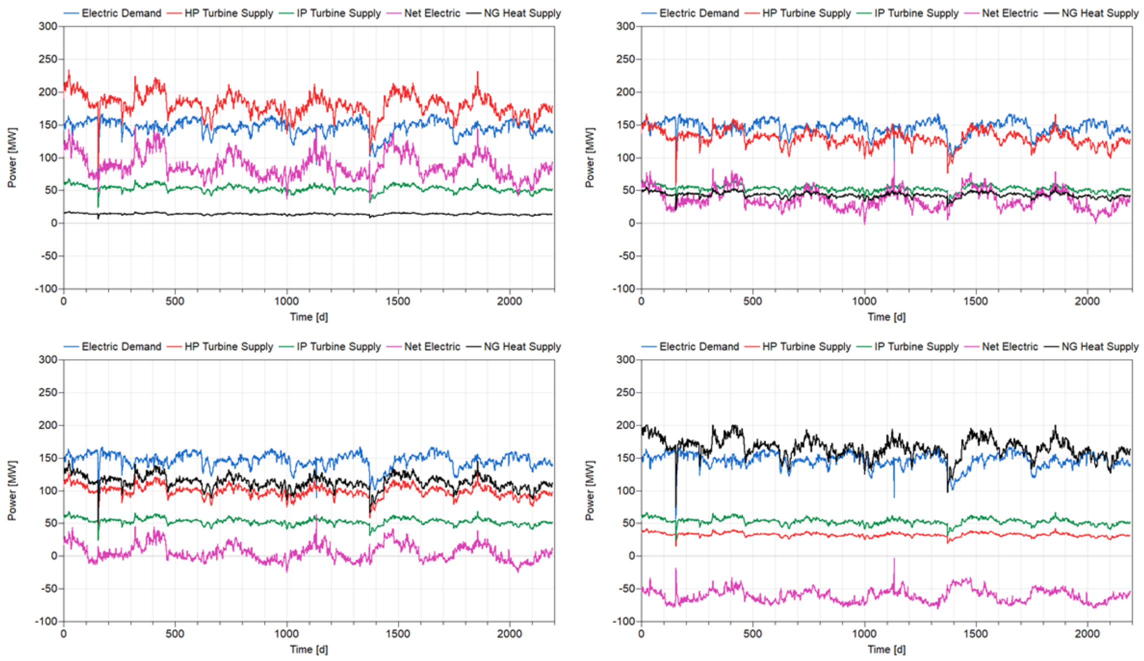
Light Water Reactor

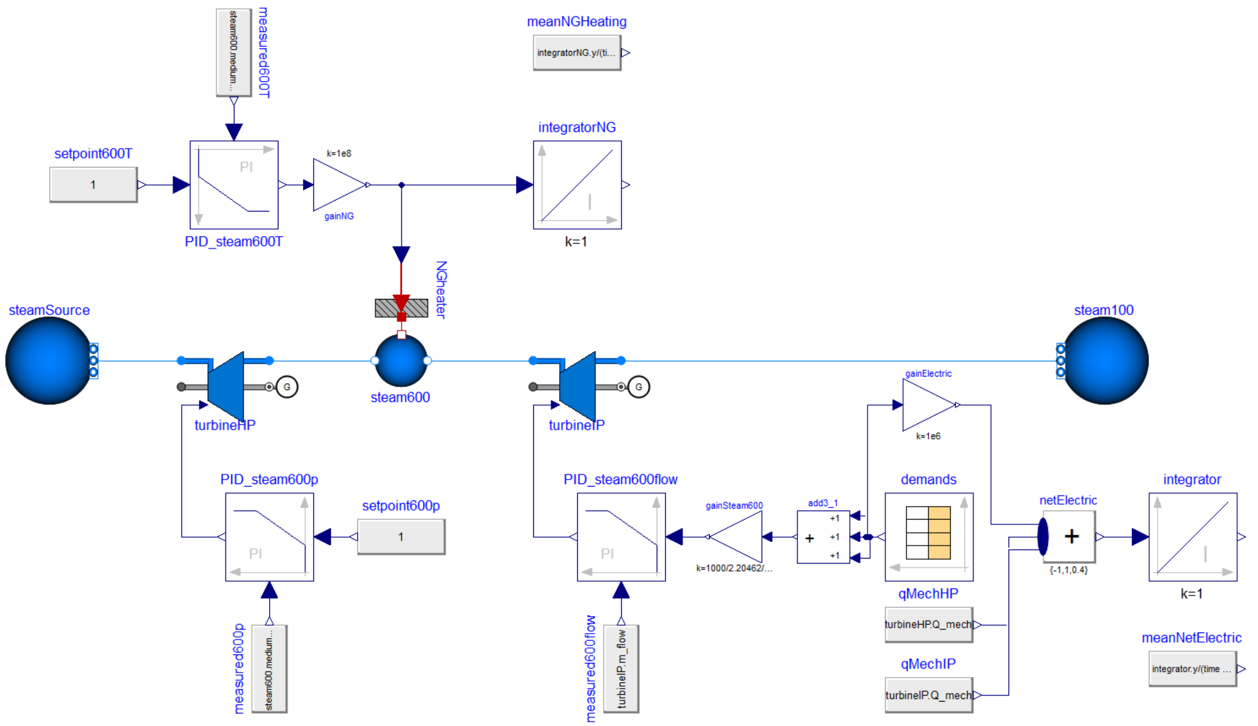
Control Logic



Eastman Integrated Energy System Investigation

- Study ability of advanced reactors to deliver high-quality steam to the steam distribution network of an industrial chemical facility.

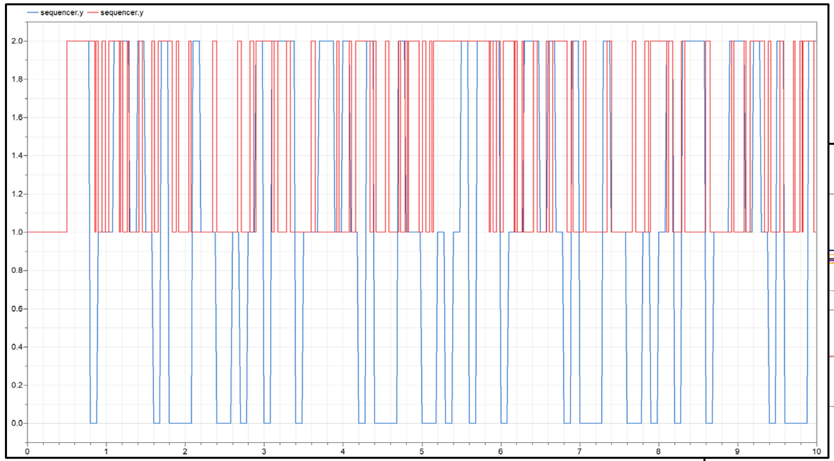


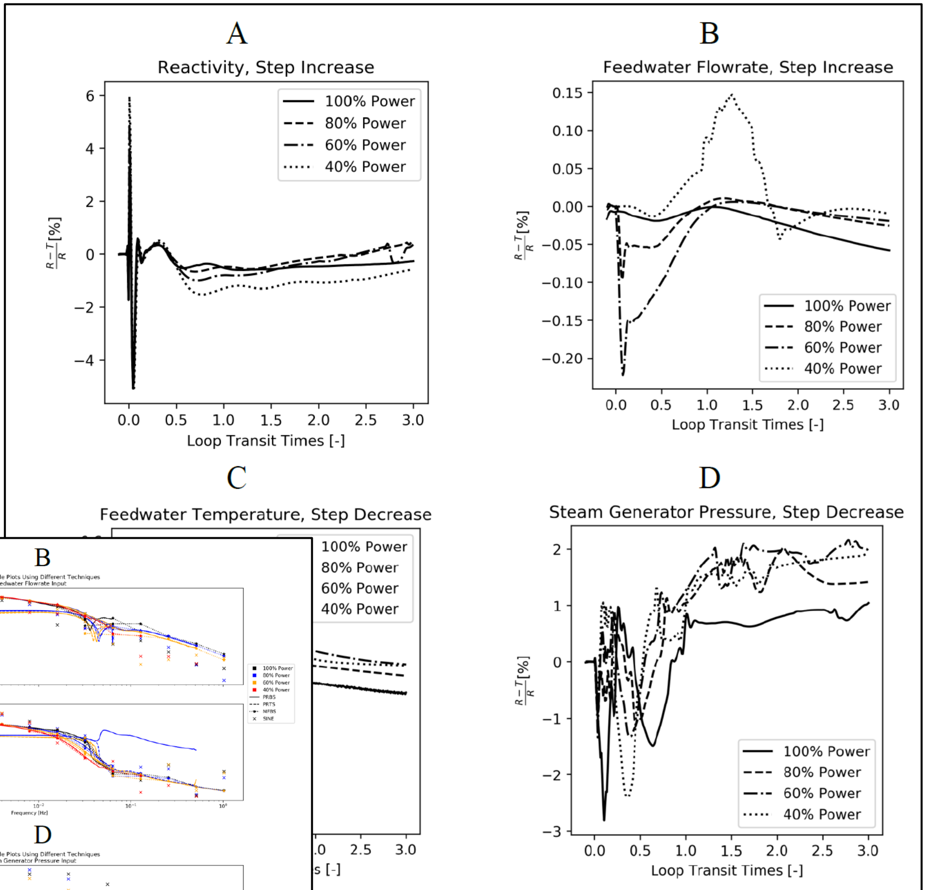


Source
Greenwood, M.S., Yigitoglu, A.G., Rader, J.D., Tharp, W., Poore, M., Belles, R., Zhang, B., Cumberland, R., Muhlheim, M.: Integrated Energy System Investigation for the Eastman Chemical Company, Kingsport, TN Facility. ORNL/TM-2020/1522; CRADA/NFE-19-07651, Oak Ridge National Lab. (ORNL), Oak Ridge, TN (United States) (2020)

SMR-160 Primary Flow Stability

- Linear stability studies of a natural circulation pressurized water small modular reactor.





e comparisons of core power time histories for tivity (A), feedwater flow rate (B), feedwater G pressure (D) for different initial power levels.

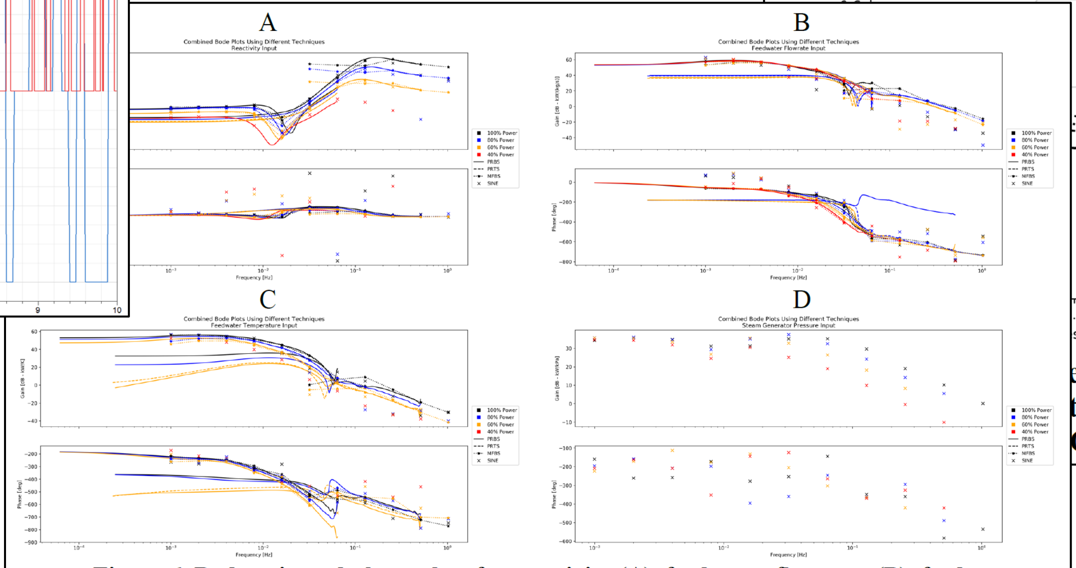


Figure 6. Bode gain and phase plots for reactivity (A), feedwater flow rate (B), feedwater temperature (C), and SG pressure (D) for different initial power levels.

Source
J. D. RADER et al., "Linear Stability Studies of a Natural Circulation-Based Small Modular Reactor," presented at NPIC HMIT 11, 9 February 2019, Orlando, FL.

Thank you.

TRANSFORM Github
https://github.com/ORNL-Modelica/TRANSFORM-Library

TRANSFORM Video:
https://youtu.be/esUoh9zBK-M

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