



U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

Office Of Nuclear Energy

Annual Review Meeting

Dynamic Simulation Modeling Tool

**Lou Qualls
ORNL**

September 16-18, 2014

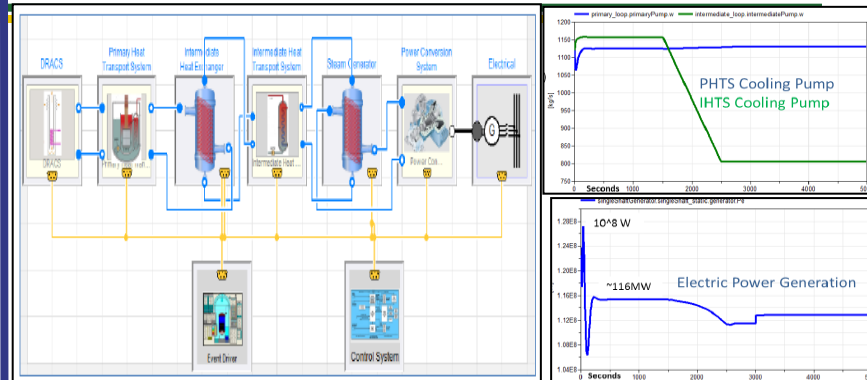
Work Package SR-14OR130108 – Modeling Tools for Dynamic Behavior Simulations of SMRs

Nuclear Energy Task Relevancy

Simplified Dynamic Modeling for Advanced SMRs

- Numerous dynamic models are needed to simulate plant behavior under operational scenarios and in response to transient conditions for advanced SMRs
- Modelica-based models with user friendly interfaces (Excel/Web) allow common simulation environment and simplified/easy access and use for wide range of technical investigators.

ALMR Simulation



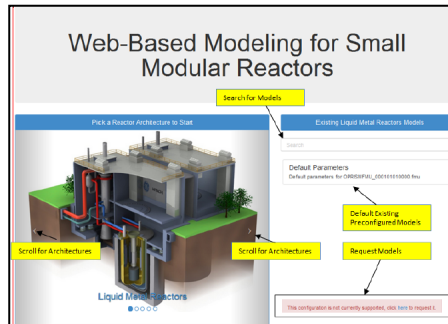
ALMR PRISM Architecture

Excel Based Simulation Results

Technical Approach/Accomplishments/Results

- Modelica modeling architecture implemented
- ALMR PRISM (first) plant model completed
- Excel Based Simulation Tool Completed (see below)
- Web-based Simulation Application prototype developed & User Manual drafted (see below)
- Initial collaborators established with University Partners

Model Name	Model Number	Model Description	Model Status
ALMR PRISM	SR-14OR130108	Advanced SMR Model	Completed
Excel Based Simulation Tool	SR-14OR130108	Simulation Tool	Completed
Web-based Simulation Application	SR-14OR130108	Simulation Application	Prototype



Expected Deliverable & Schedule

- ✓ FY14 molten salt cooled model deliverable due.
- FY15 web application deliverable due.
- FY15 model repository establishment due.
- FY15 working collaboration with University partners.

Project Overview

- **To create a flexible, portable and powerful dynamic system modeling environment**
- **to facilitate investigation of control system strategies for reactor systems in any number of configurations**
 - Facilitate rapid development of models,
 - Ensure consistency among research products,
 - Minimize duplication of effort



Technology Impact

- ***The ORNL ModSim Tool is a development, execution environment and repository for reactor subsystem models and end-to-end reactor system models which allows***
 - *Powerful dynamic simulation in the Modelica environment*
 - *The ability to configure components into new power system arrangements*
 - *The ability to collaborate as a community via the internet*
 - *The ability to export models for analysis within the Excel environment opening affordable collaboration to everyone*

- ***The tool will allow reactor design concepts to be studied***
 - *Without requiring the modeler to develop a unique set of BOP models*
 - *With multiple reactors coupled to shared infrastructure*
 - *With control system implementations modeled separately so that system models do not require modification for different I&C designs*

Modeling Tools for Dynamic Behavior Simulations of SMRs FY14 Achievements

FY14 Achievements

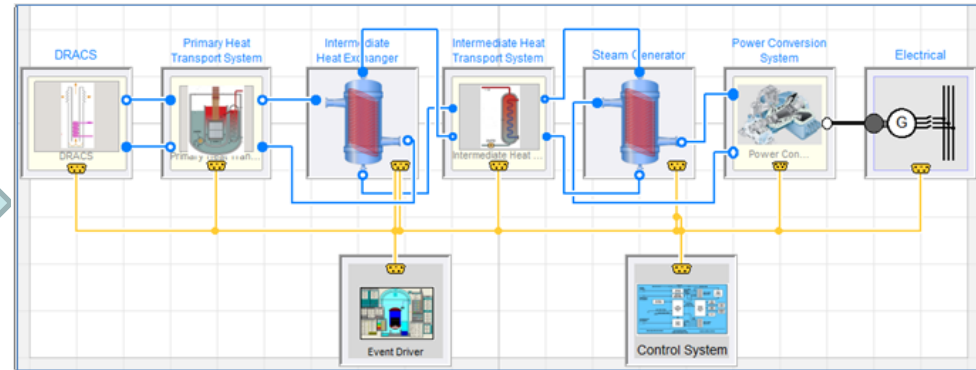
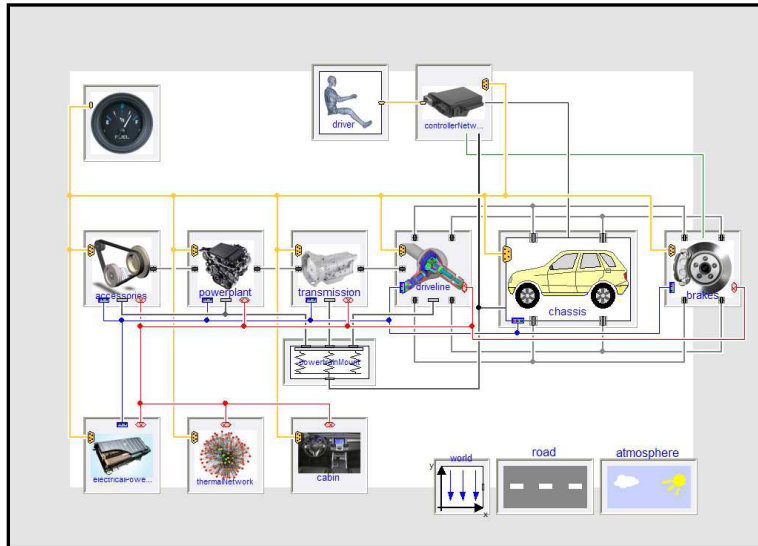
- improved Flexible Model Architecture
- Updated all models to fit within Flexible Model Architecture
- User's Manual
- FHR reactor architecture
- Collaborative efforts initiated
 - Supervisory Control
 - Advanced PRA
 - Universities

FY14 Milestones

- M3SR-14OR1301086 Level 3 Milestone for Work Package SR-14OR130108, Aug 2014
 - *"Extend Modeling Tool Architecture to Molten Salt Cooled Reactor"*
- M2SR-14OR1301085 Level 2 Milestone for Work Package SR-14OR130108, March 2014
 - *"Update on Small Modular Reactors Dynamic System Modeling Tool"*



Approach Based on Proven Science

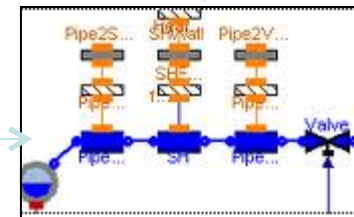
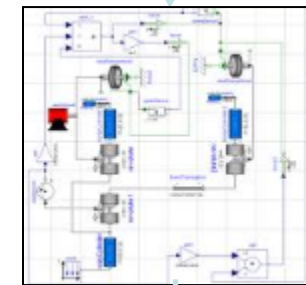
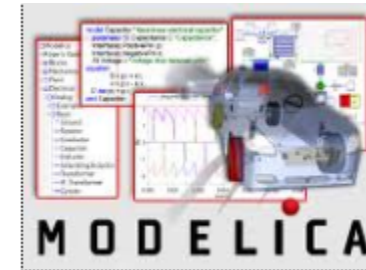


Modelica System Model for Advanced Reactors



How do we do this?

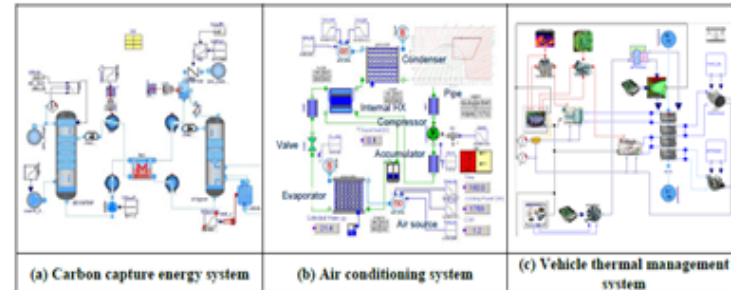
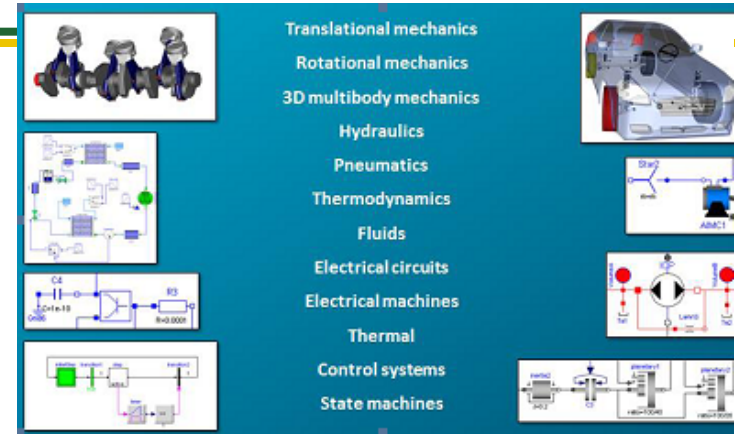
- We are modeling complex advanced reactors in the MODELICA language
- We are solving MODELICA models with DYMOLA solver
- We are leveraging the MODELICA ThermoPower library for reactor systems





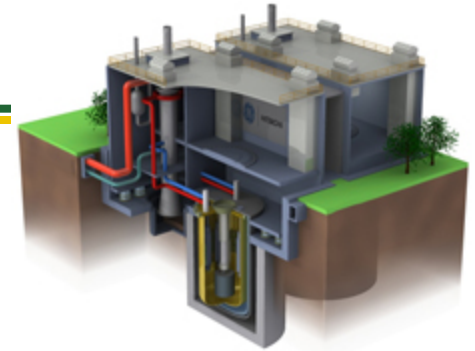
Modelica: Using the Emerging Open-Source Modeling Standard

- Modelica is a nonproprietary, object-oriented, equation-based language used to model complex physical systems.
- Modelica is free, open source, object oriented and has multi-domain libraries that already exist and can readily be modified
- Modelica is a multi-domain modeling language and can handle mechanical, electrical, electronic, fluid, thermal, hydraulic, pneumatic, magnetic, and control systems and their interactions
- Been adopted by other industries for fast turnaround design studies (automotive/aerospace)





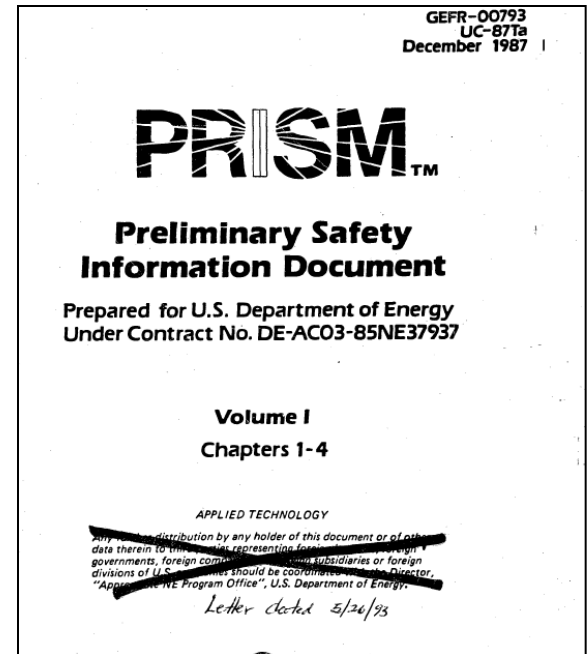
ALMR Concept Modeled



■ PRISM¹ ALMR End-to-End System model created from previous models that include:

- Reactor
- Primary System
- Intermediate System
- Power Conversion
- Grid (Generic model)

¹The S-PRISM represents GEH's [Generation IV reactor](#) solution to closing the [nuclear fuel cycle](#) and is also part of its Advanced Recycling Center (ARC) proposition^[1] to U.S. Congress to deal with [nuclear waste](#).^[2] It is a [sodium-cooled fast breeder reactor](#), based on the [Experimental Breeder Reactor II](#) (EBR-II) design, scaled up by a factor of ten. [Wikipedia]



GEFR-00793
UC-87Ta
December 1987

PRISM™

Preliminary Safety Information Document

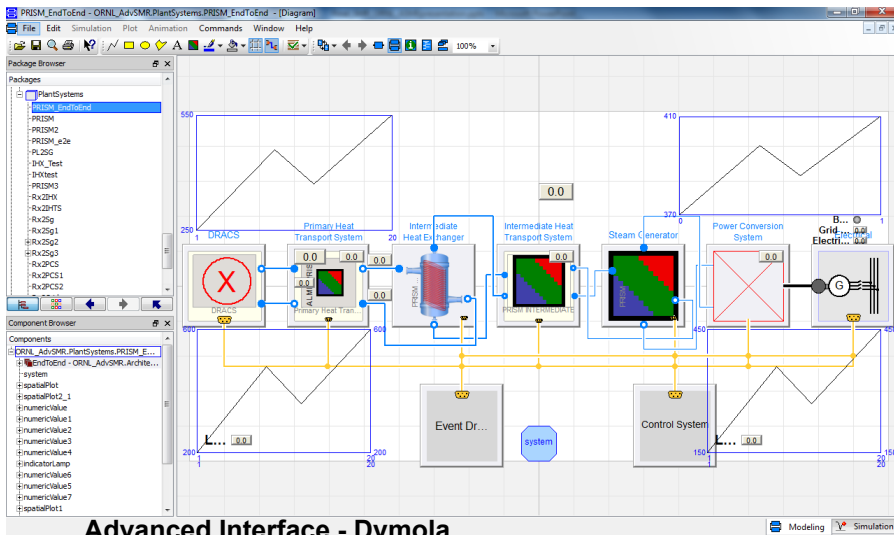
Prepared for U.S. Department of Energy
Under Contract No. DE-AC03-85NE37937

Volume I
Chapters 1-4

APPLIED TECHNOLOGY

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Letter dated 5/26/93



Advanced Interface - Dymola

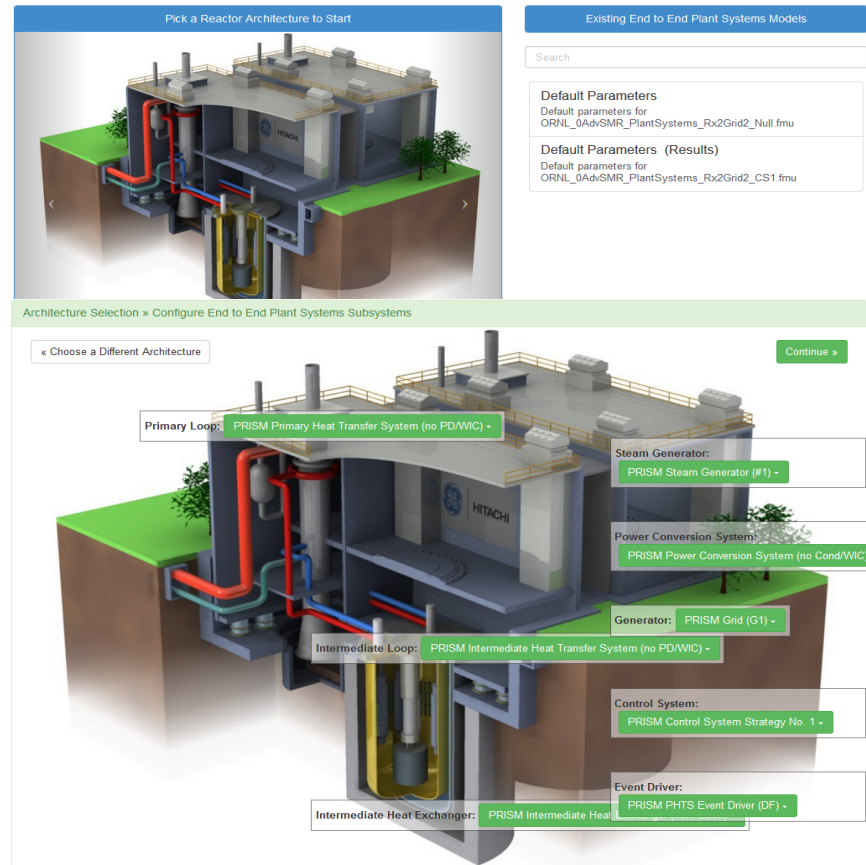
Settings	Default	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Start time	0										
Stop time	1000										
FMU	C:\Users\jbatteh\AppData\Local\Temp\VMU012C.tmp\K158T1U3\H6N7.fmu										
Log level	Info										
Enable	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Output points	100										
Timeout	0										

Indata	Variable	Type	Unit	Default	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
reactor.rod.T	reactor.rod.T	continuous	Real	K	293.15		300							
reactor.Q_reactor	reactor.Q_reactor	parameter	Real	W	2500		1750							
reactor.C_rod	reactor.C_rod	parameter	Real	J/K	10									
coolant_loop.radiator.length	coolant_loop.radiator.length	parameter	Real	m	10									
coolant_loop.radiator.diameter	coolant_loop.radiator.diameter	parameter	Real	m	0.01									
coolant_loop.heat	coolant_loop.heat	parameter	Real	1	1000									
coolant_loop.valve_pos	coolant_loop.valve_pos	parameter	Real	1										
coolant_loop.T_amb	coolant_loop.T_amb	parameter	Real	K	293.15									
coolant_loop.cooling_factor	coolant_loop.cooling_factor	parameter	Real	1										
controller.mflow_pump	controller.mflow_pump	parameter	Real	kg/s	0.01									

Outdata	Name	Variable	Type	Unit	Default	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
reactor.rod.Q_flow	reactor.rod.Q_flow	continuous	Real	W		1499.94	1749.93								
reactor.rod.T	reactor.rod.T	continuous	Real	K		486.637	519.181								
coolant_loop.tank.level	coolant_loop.tank.level	continuous	Real	m		1.0038	1.00455								
coolant_loop.coolant_bus.T_rad_in	coolant_loop.coolant_bus.T_rad_in	continuous	Real	K		336.643	344.188								
coolant_loop.coolant_bus.T_rad_out	coolant_loop.coolant_bus.T_rad_out	continuous	Real	K		307.847	310.412								
coolant_loop.coolant_bus.mflow_pump_sensed	coolant_loop.coolant_bus.mflow_pump_sensed	continuous	Real	kg/s		0.01	0.01								
coolant_loop.coolant_bus.mflow_pump	coolant_loop.coolant_bus.mflow_pump	continuous	Real	kg/s		0.01	0.01								
controller.controlbus.coolant_bus.mflow_pump	controller.controlbus.coolant_bus.mflow_pump	continuous	Real	kg/s		0.01	0.01								

Intermediate Interface - FMIE

Web-Based Modeling for Small Modular Reactors



Existing End to End Plant Systems Models

Search

Default Parameters
Default parameters for ORNL_0AdvSMR_PlantSystems_Rx2Grid2_Null.fmu

Default Parameters (Results)
Default parameters for ORNL_0AdvSMR_PlantSystems_Rx2Grid2_CS1.fmu

Architecture Selection » Configure End to End Plant Systems Subsystems

« Choose a Different Architecture

Continue »

Primary Loop: PRISM Primary Heat Transfer System (no PD/WIC) -

Steam Generator: PRISM Steam Generator (#1) -

Power Conversion System: PRISM Power Conversion System (no Cond/WIC) -

Generator: PRISM Grid (G1) -

Intermediate Loop: PRISM Intermediate Heat Transfer System (no PD/WIC) -

Control System: PRISM Control System Strategy No. 1 -

Event Driver: PRISM PHTS Event Driver (DF) -

Intermediate Heat Exchanger: PRISM Intermediate Heat Exchanger

Beginning Interface – Web Application

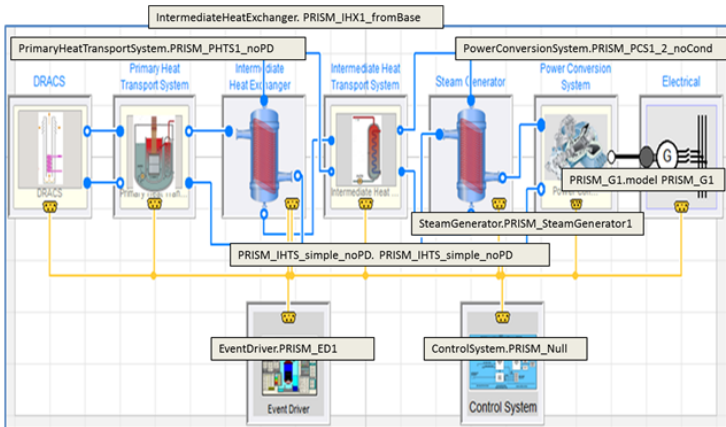
<http://smr.apps.xogeny.com/#/>

Interfaces exist for all user levels.

Goal is to lower threshold for simulation and modeling use.

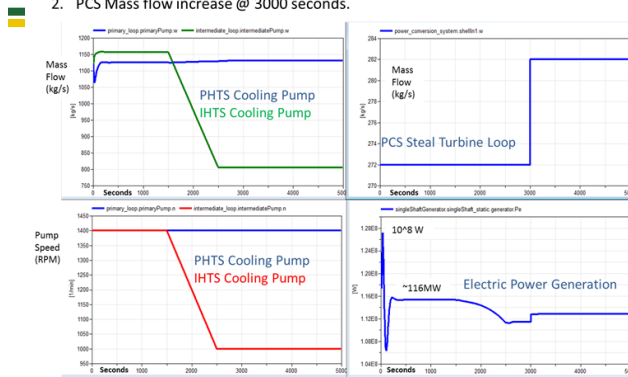


Baseline "Null" Configuration without control
ORNL_AdvSMR.PlantSystems.Rx2Grid2



Baseline "Null" Configuration without control

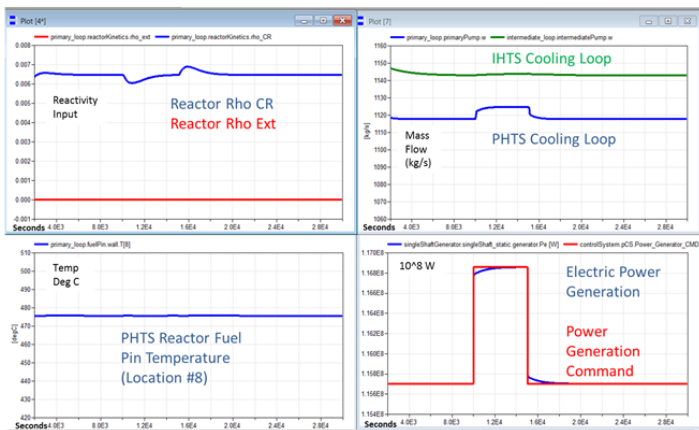
- Two Events:
1. IHTS Intermediate Pump Speed Change @ 1500 seconds.
 2. PCS Mass flow increase @ 3000 seconds.



- Two control strategies associated with a single transient
- Transient is simulated step change in reactivity

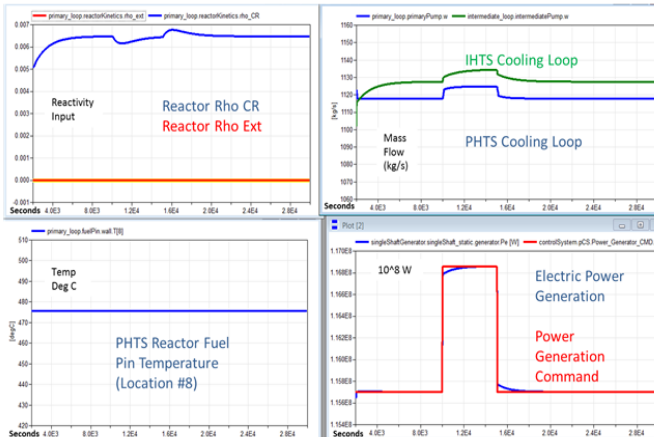
Baseline "Null" Configuration with Control Strategy #1

Trapezoid Power Generation Command Profile – 1.2MW Ramp, Hold, Negative Ramp over 5000 seconds



Baseline "Null" Configuration with Control Strategy #2

Trapezoid Power Generation Command Profile – 1.2MW Ramp, Hold, Negative Ramp over 5000 seconds



- #1 is controlling outlet temperature
- #2 is controlling differential temperature

The initial transients step change in reactivity with subsequent control system evaluation.

No detailed analysis has been performed goal was to demonstrate the tool.



Modifying and Executing Models Outside of Dymola



- **FMI Excel** Tool Allows sophisticated compiled models to be modified and executed through an Excel Interface, without a Dymola License

Functional Mockup Interface Add-in for Microsoft Excel® enables steady-state and dynamic simulation of physical models integrated in a spread sheet environment.

- **Batch-simulations**
- **parameter sweeps**

Meta Data							
Sheet version				Generated by Modelon FMI Add-In for Excel version 1.0			
Model name				PowerPlantControlTest_0v2			
Generation tool				Dymola Version 2013 (32-bit), 2012-03-28			
FMU kind				CoSimulation_StandAlone			
Settings				Default	Case 1	Case 2	Case 3
tstart				-10			
tstop				10	800	800	800
FMU				C:\Users\stdf2\Documents\Dymola\PowerPlantControlTest_0v2.fmu			
log level				Info			
enabled				TRUE			
output points				100	800	800	800
Indata							
Name	Variability	Type	Unit				
steamPlant_Sim1_1hRSG.drums.HPd_Tmstart	parameter	Real	K	300			
steamPlant_Sim1_1.sourceGas.w0	parameter	Real	kg/s	585.5			
w'att_t_Gas.k	parameter	Real		5.4E-06			
ramp.height	parameter	Real		-10			
ramp.duration	parameter	Real	s	50			
ramp.offset	parameter	Real		110			
ramp.startTime	parameter	Real	s	500			
PI.k	parameter	Real	1	250	250	25	10
PI.T	parameter	Real	s	100	100	100	200
ramp1.height	parameter	Real		10			
ramp1.duration	parameter	Real	s	10			
ramp1.offset	parameter	Real		0			
ramp1.startTime	parameter	Real	s	700			
Outdata							
Name	Variability	Type	Unit				
steamPlant_Sim1_1hRSG.GasOut.w	continuous	Real	kg/s		-591	-590	-587
steamPlant_Sim1_1hRSG.HeatExchangersGroup.Ec2_HP_waterI	continuous	Real	kg/s		63.2	63.64	63.77
steamPlant_Sim1_1hRSG.HeatExchangersGroup.Ec1HP_EcIP.g	continuous	Real	kg/s		590.6	590.3	587.3
steamPlant_Sim1_1hRSG.HeatExchangersGroup.Ec_LP_gasOut	continuous	Real	kg/s		-591	-590	-587
steamPlant_Sim1_1hRSG.HeatExchangersGroup.Ec_LP_waterDi	continuous	Real	kg/s		-85	-85.7	-85.2
steamPlant_Sim1_1hRSG.HeatExchangersGroup.mixIP.T	continuous	Real	K		631.7	631.7	632
steamPlant_Sim1_1.sTG_3LRh.steamTurbines.valveIP.Tin	continuous	Real	K		858.8	859	859.3
steamPlant_Sim1_1.sTG_3LRh.totalFeedPump.feedWaterPump.	continuous	Real	K		307.4	307.4	307.4
steamPlant_Sim1_1.sTG_3LRh.totalFeedPump.pumpSpeed_rpm	continuous	Real			1422	1431	1424

Model Configuration/Case Settings

Adjustable Model Inputs

Resulting Model Outputs

Recall we discussed missing pieces. The first piece was the ability to simulate outside of the proprietary solver. To do this we cheat and use another proprietary tool – but one that is much cheaper and easier.



Sharing and Collaboration

Nuclear Energy

Web-based model development collaboration through Github with open and secure repositories for proprietary and non-proprietary work



GitHub **A project to build a web-based analysis tool for small, modular nuclear reactors**

72 commits 2 branches 0 releases 3 contributors

branch: master **ORNL-WebSMR** /

Improved layout		
mtiller	authored a month ago	latest commit cd329eb04a
Documentation	incorporating Mike's edits and a few of my own	8 months ago
Examples	minor changes to models	8 months ago
Models	Sample generated HTML.	7 months ago
fms	Pre conference material	a month ago
images	Forgot to add John's reactor image	8 months ago
schemas	Adding optional Title property	8 months ago
util	Another syntactic change to architectures.yaml	8 months ago
.gitignore	Improved .gitignore	8 months ago
README.md	Demonstrating making changes	8 months ago
architectures.yaml	Improved layout	a month ago
fms.yaml	More tweaking based on compiler feedback	a month ago
subsystems.yaml	More tweaking based on compiler feedback	a month ago

Code

Issues 0

Pull Requests 0

Wiki

Pulse

Graphs

Network

HTTPS clone URL

You can clone with [HTTPS](#), [SSH](#), or [Subversion](#).

Clone in Desktop

Download ZIP

GitHub is a web-based hosting service for software development projects that use the Git revision control system.



Conclusion

- ***The ORNL ModSim Tool creates a set of common tools to investigate advanced reactor concepts and applications***

- ***The tool saves time and money by giving researchers libraries of functioning models to begin with, modify and share***

- ***ModSim facilitates collaboration by***
 - *Using an open-source and emerging simulation environment*
 - *Having access via the internet*
 - *Having the ability to create models that operate within the Excel environment*

Modeling Tools for Dynamic Behavior Simulations of SMRs FY14 Achievements

FY14 Achievements

- improved Flexible Model Architecture
- Updated all models to fit within Flexible Model Architecture
- User's Manual
- FHR reactor architecture
- Collaborative efforts initiated
 - Supervisory Control
 - Advanced PRA
 - Universities

FY14 Milestones

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- M2SR-14OR1301085 Level 2 Milestone for Work Package SR-14OR130108, March 2014
 - *“Update on Small Modular Reactors Dynamic System Modeling Tool”*