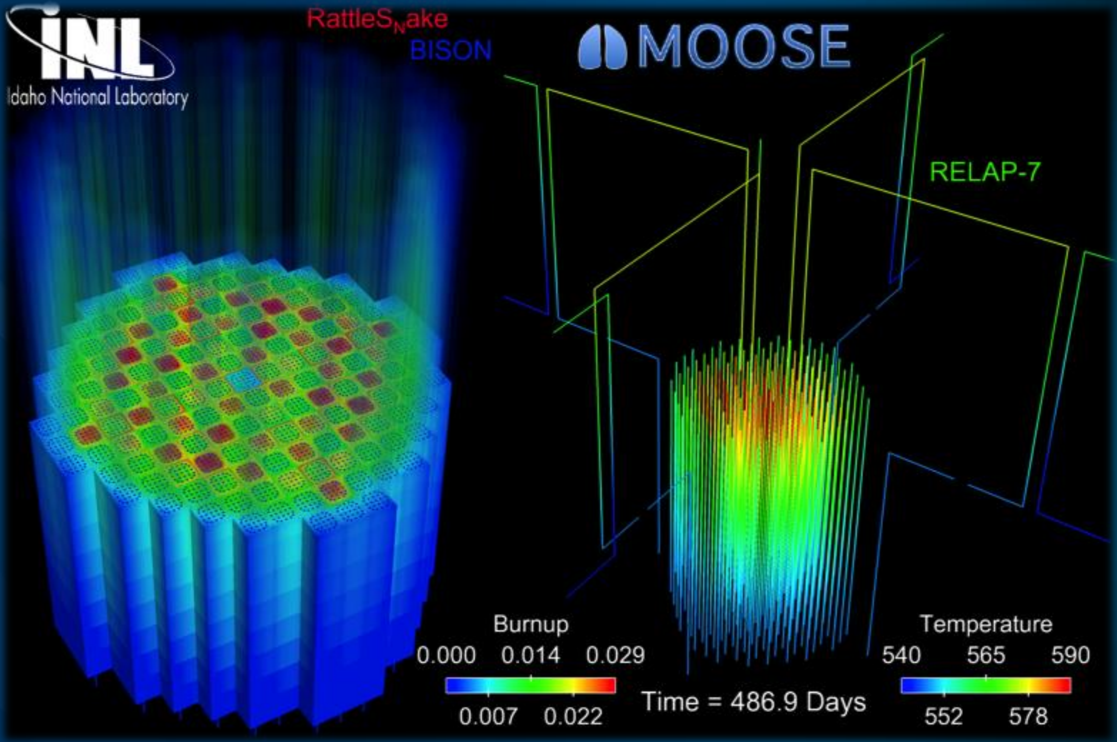
RELAP-7 Code Development Status Update

Presented by Hongbin Zhang, Ph.D.



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Idaho National Laboratory

RELAP-7 Team:

- ***Theory:*** Ray Berry
  Richard Martineau
- ***Simulation:*** Hongbin Zhang
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  Ling Zou
- ***Framework:*** David Andrs

- ***Collaborators:*** Rui Hu - ANL
  Steve Hess - EPRI
  Gregg Swindlehurst - EPRI

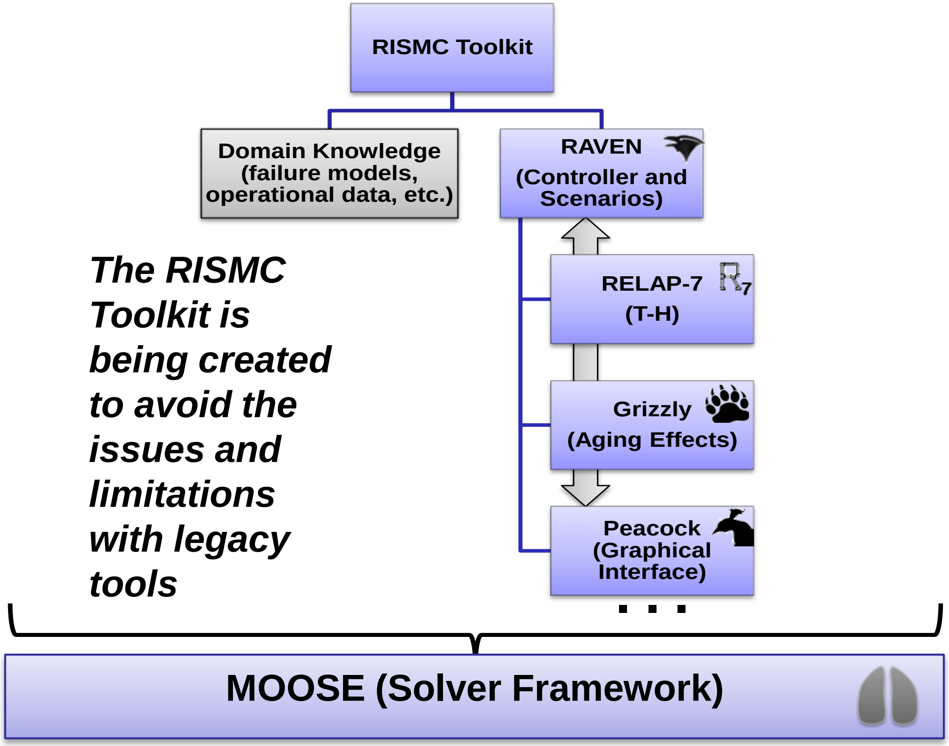
RELAP-7 Overview

- *RELAP-7* is the next generation nuclear reactor system safety analysis code
- The code is being developed based upon the *MOOSE (Multi-Physics Object-Oriented Simulation Environment) framework*: continuous finite element method (CFEM), fully coupled components with implicit solver, mesh and time adaptivity, parallel software
- Fully implicit solver achieved by *Jacobian-Free Newton Krylov (JFNK) method* (MOOSE's main solver).
- 2nd-order accurate temporal and spatial discretization (reduces the traditional numerical errors)
- Flexibility in fluids models: single phase, homogeneous equilibrium model (HEM), 7-equation two-phase flow model, drift flux models (future)
- Ability to couple to multi-dimensional reactor simulators through MOOSE
- Main reactor systems simulation toolkit for LWRS (Light Water Reactor Sustainability) program's RISMC (Risk Informed Safety Margin Characterization) pathway

Risk-Informed Safety Margin Characterization (RISMC) Pathway

- **Support plant decisions for risk-informed margins management to support improved economics, reliability, and sustain safety of current nuclear power plants**

- **Goals of the RISMC Pathway:**
  - Develop and demonstrate a risk-assessment method coupled to safety margin quantification that can be used by nuclear power plant decision makers as part of their margin recovery strategies
  - Create an advanced "**RISMC toolkit**" that enables more accurate representation of nuclear power plant safety margins



The RISMC Toolkit is being created to avoid the issues and limitations with legacy tools

METHODS + TOOLS + DATA

Components Completed

Component Name	Descriptions
Pipe	1-D fluid flow within 1-D solid structure with wall friction and heat transfer
PipeWithHeatStructure	Simulating 1-D pipe fluid flow coupled with 1-D/2-D conduction through the pipe wall; can take Adiabatic, Dirichlet, or Convective boundary conditions at the outer surface of the pipe wall
CoreChannel	Simulating flow channel and fuel rod thermal hydraulics, including 1-D fluid flow and fuel rod heat conduction for either plate type or cylinder type of fuel
HeatExchanger	Co-current or counter-current heat exchanger model, including fluid flow in two sides and heat conduction through the solid wall
Subchannel	Simulating 3-D channel flow with 1-D/2-D fuel rod heat conduction

Components Completed

Component Name	*Descriptions*
TimeDependentVolume	Time Dependent Volume to set pressure and temperature boundary conditions
TimeDependentJunction	Time Dependent Junction to set velocity and temperature boundary conditions
TDM	Time Dependent Mass flow rate (TDM) to set mass flow rate and temperature boundary conditions
Branch	Multiple in and out 0-D volume/junction, which provides form loss coefficients (K), for either isothermal flow or non-isothermal flow
Pump	Simple pump model to provide a head and reverse flow form loss coefficients (K), for either isothermal flow or non-isothermal flow
Valve	Simulate control mechanisms of real valves in a hydrodynamic system
CompressibleValve	Simulate valve open and close behavior for compressible flow, including choking for single-phase gas; can be used as safety relief valve (SRV)
CheckValve	Simulate the check valve behavior with the form loss calculated by the abrupt area change model

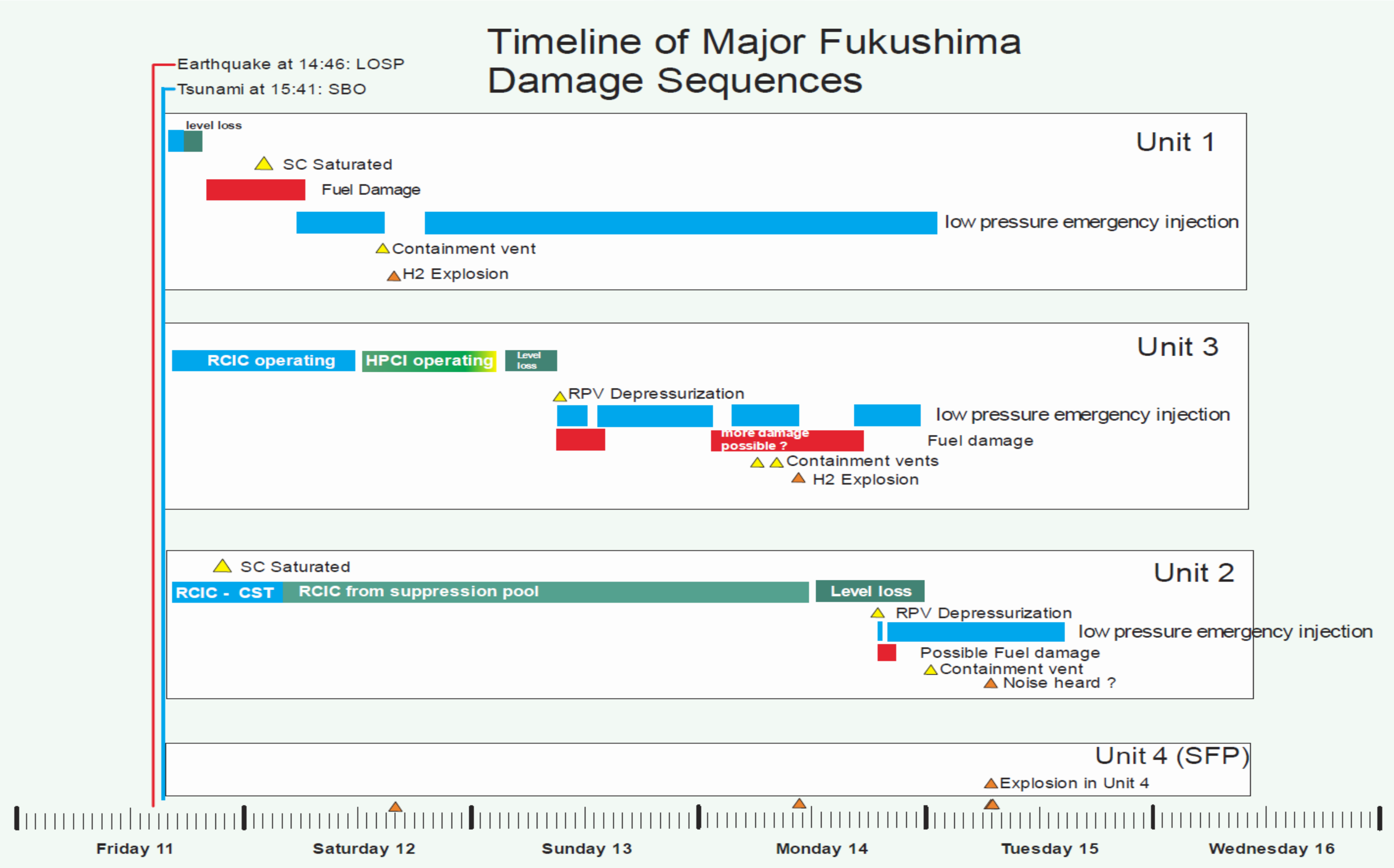
Components Completed (Continuation)

Component Name	*Descriptions*
DownComer	Large volume to mix different streams of water and steam and to track the water level
Turbine	A simplified dynamical turbine model to simulate a reactor core isolation cooling (RCIC) turbine, which drives the RCIC pump through a common shaft
WetWell	Simulate a BWR suppression pool and its gas space
SeparatorDryer	Separating steam and water with mechanical methods, 1 in and 2 outs, 0-D volume
PointKinetics	0-D point kinetic neutronics model to simulate reactor kinetics and decay heat generation
Pressurizer	Simulate pressurizer dynamic behaviors with the 3-zone model.
Reactor	A virtual component that allows users to input the reactor power

Simulation Capability Demonstration

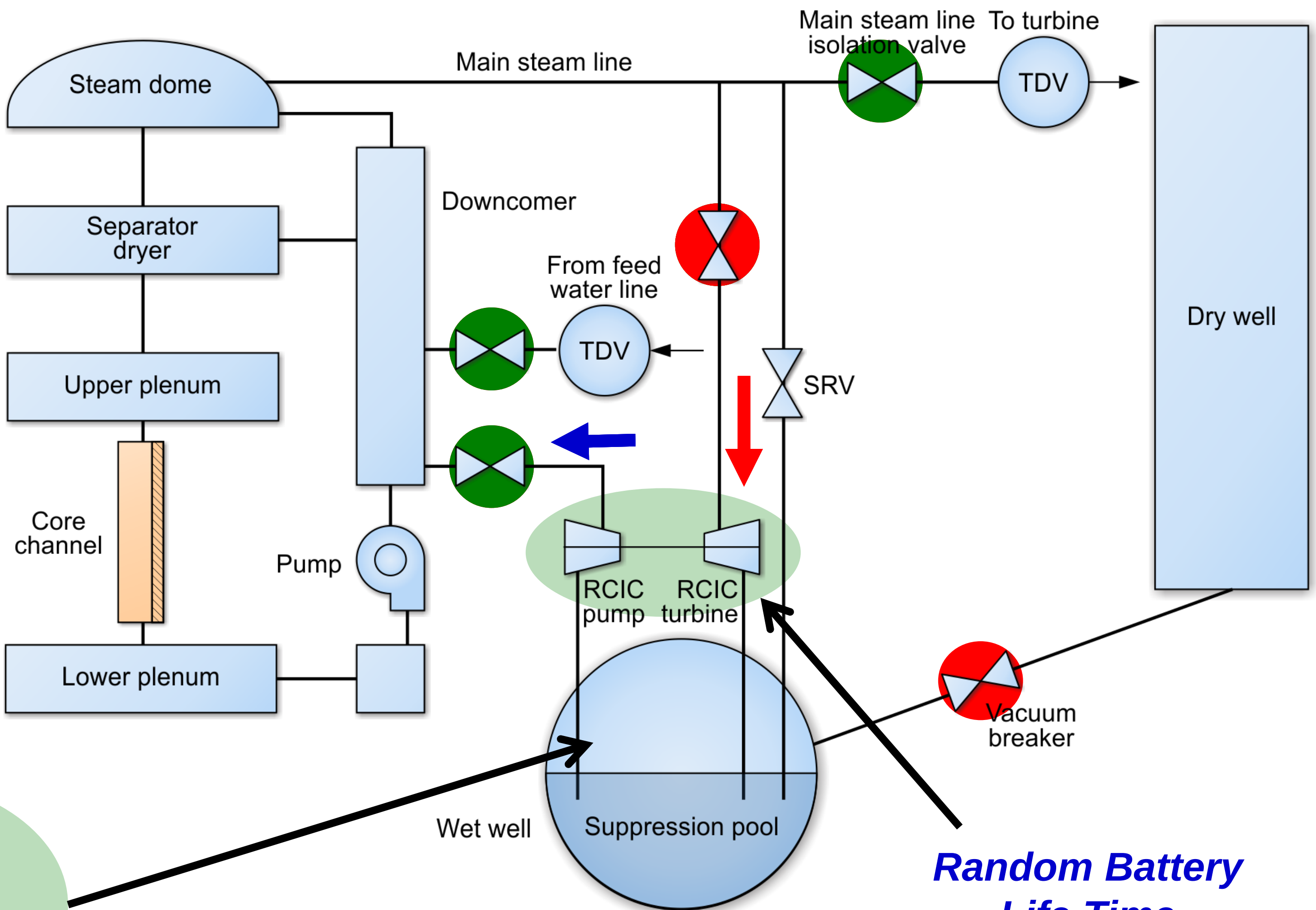
BWR SBO with RCIC and SRV Systems Dynamically Modeled and Fully Coupled

Fukushima Accident Timeline (SAND2012-6173)



BWR SBO Scenario – Fully Coupled RCIC & SRV Systems

RCIC off but SRV functioning until the end of simulation



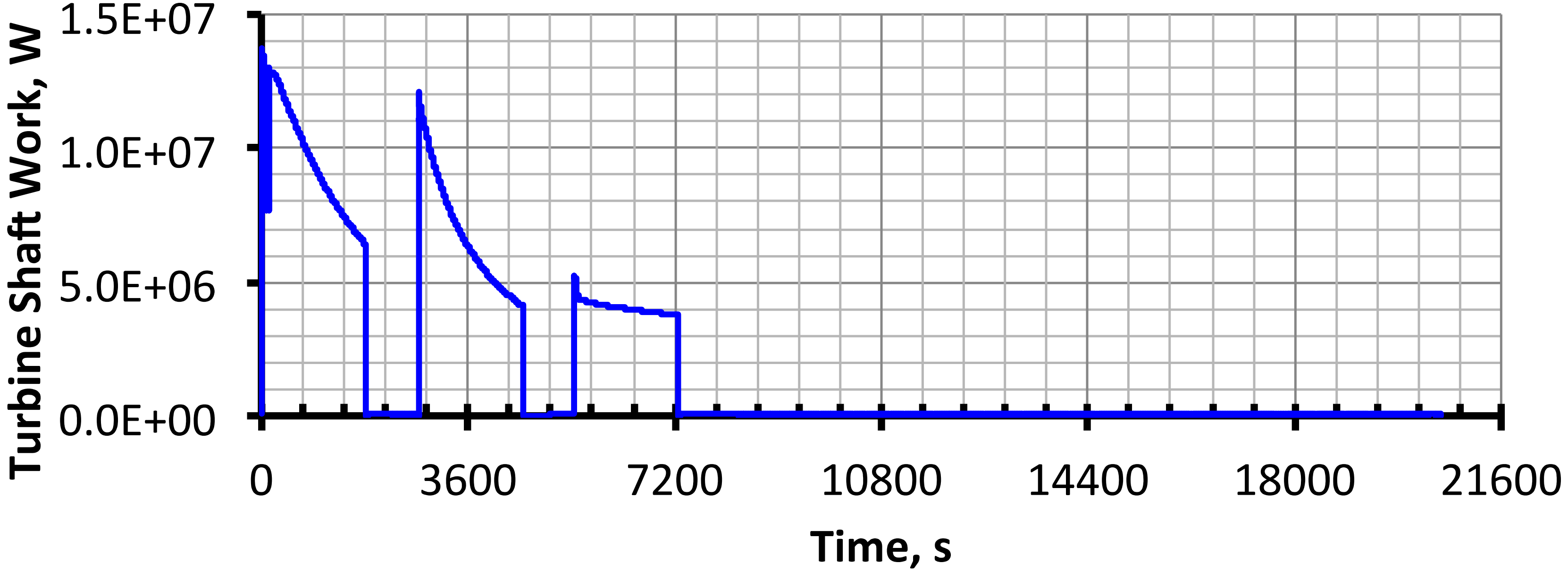
Open

Close

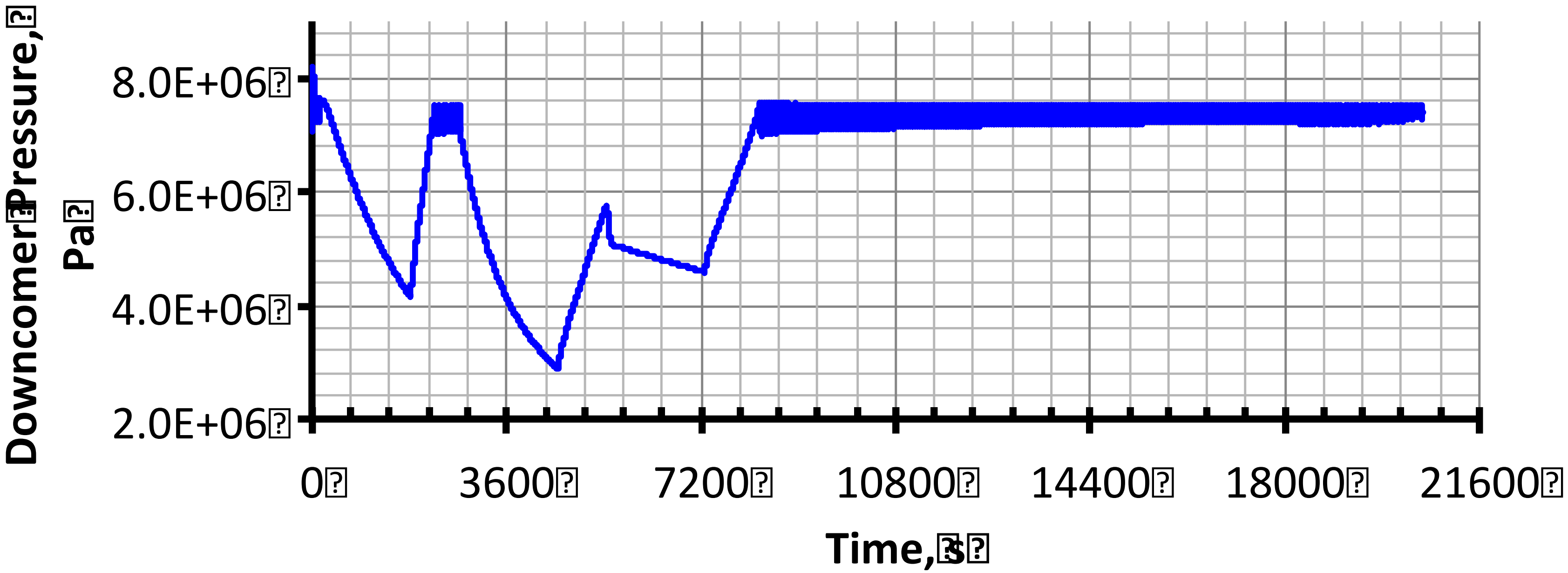
Net Positive Suction Head

Random Battery Life Time

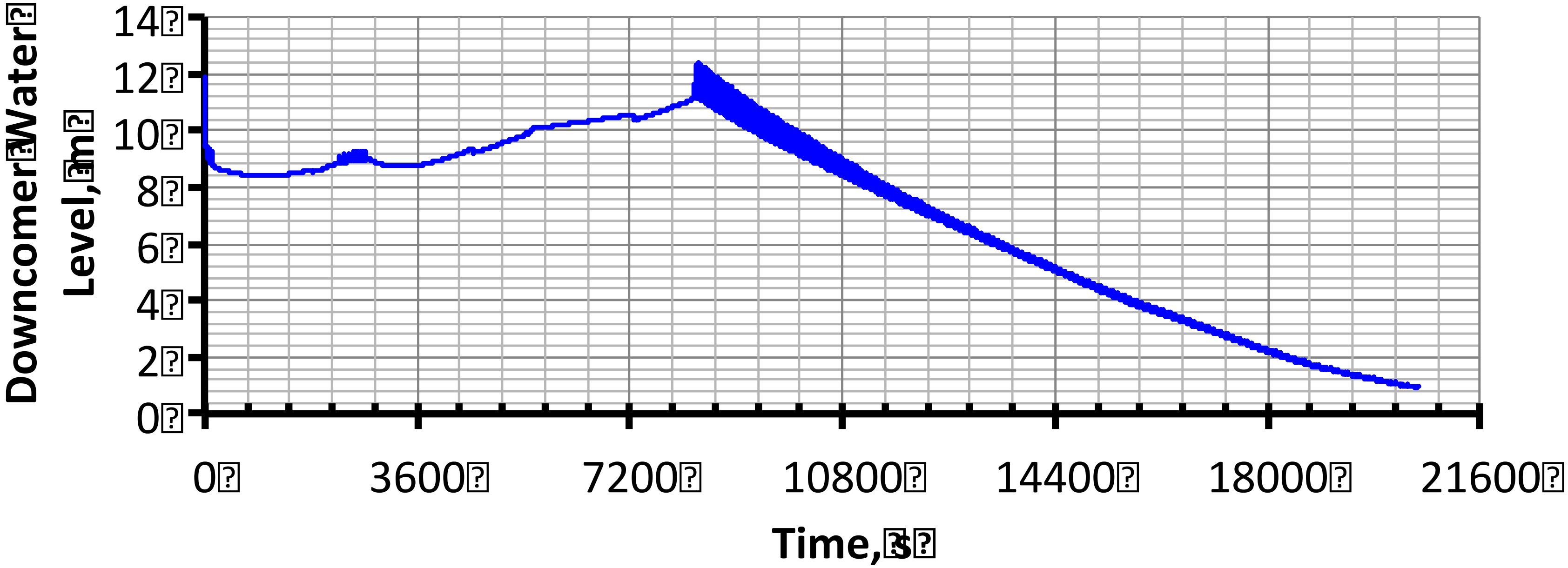
RCIC Turbine Shaft Work



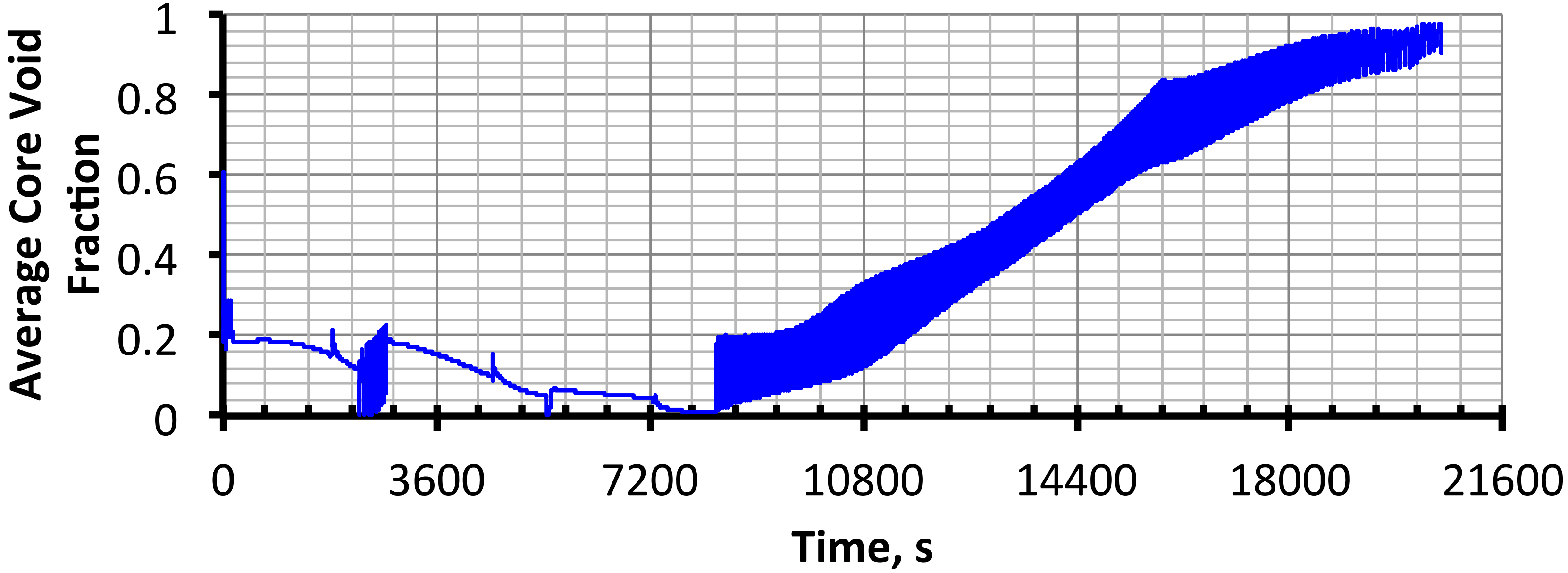
Reactor Vessel Pressure



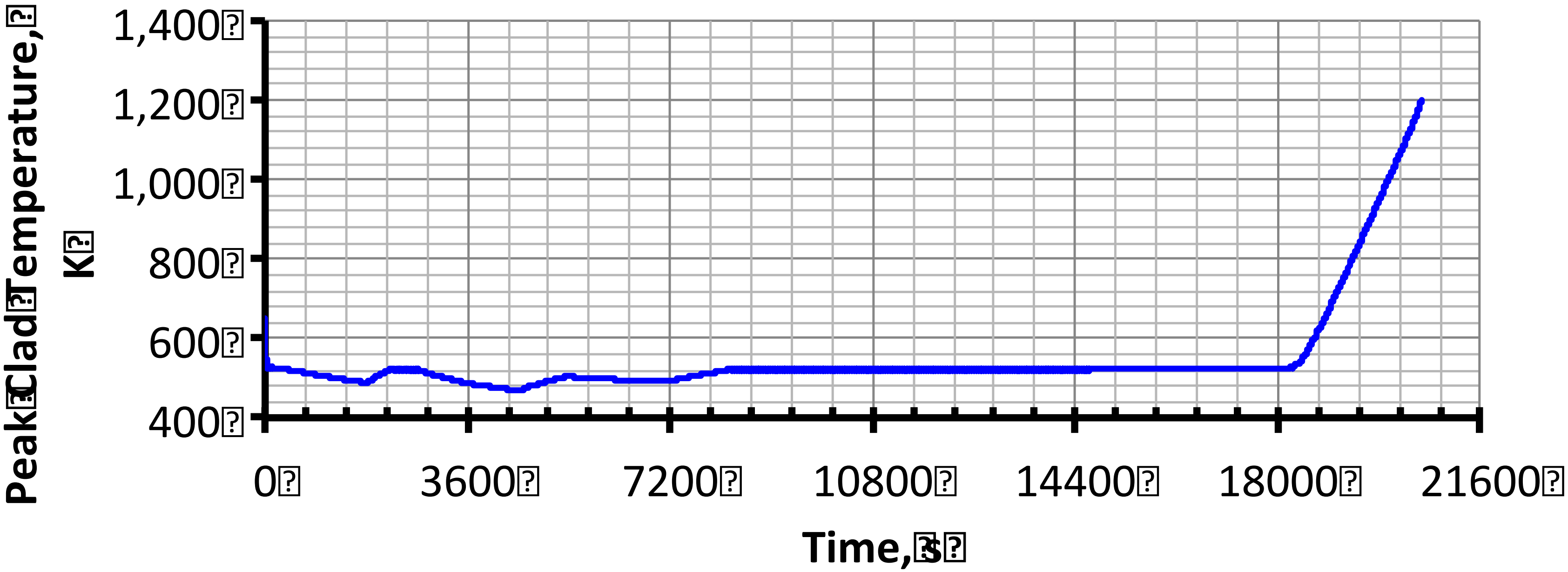
DownComer Liquid Level



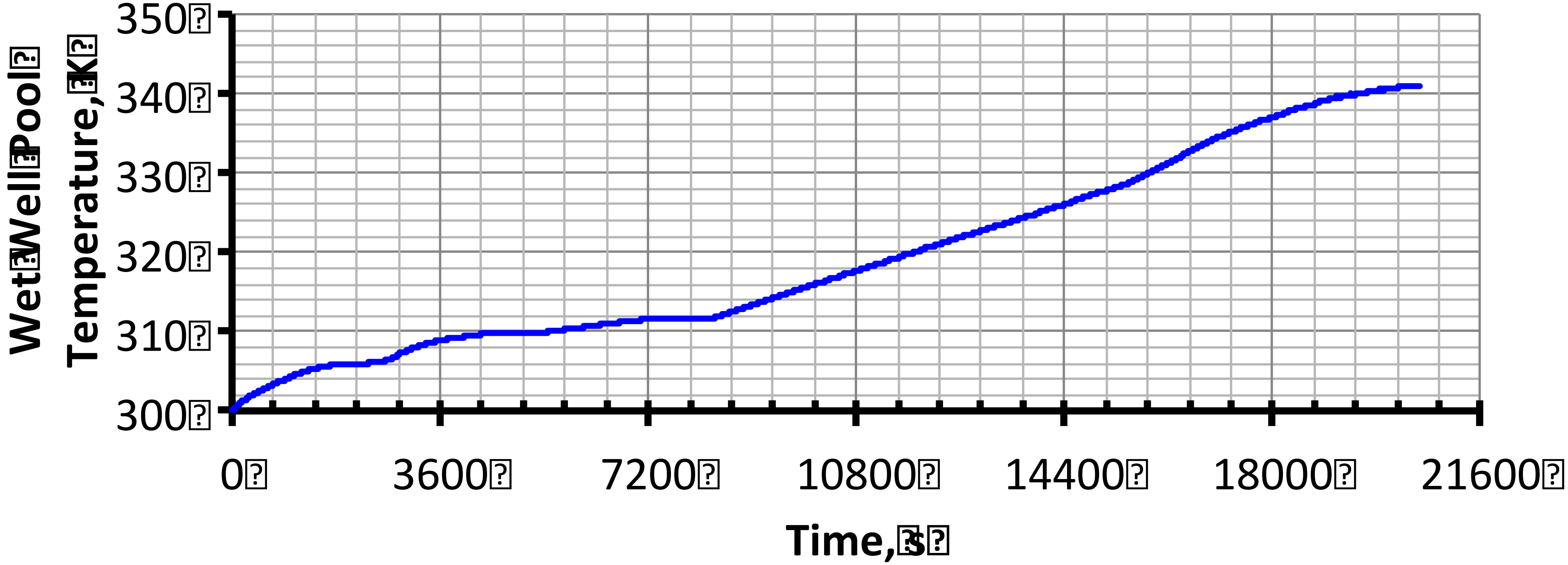
Average Core Void Fraction



Peak Clad Temperature



Wet Well Suppression Pool Temperature



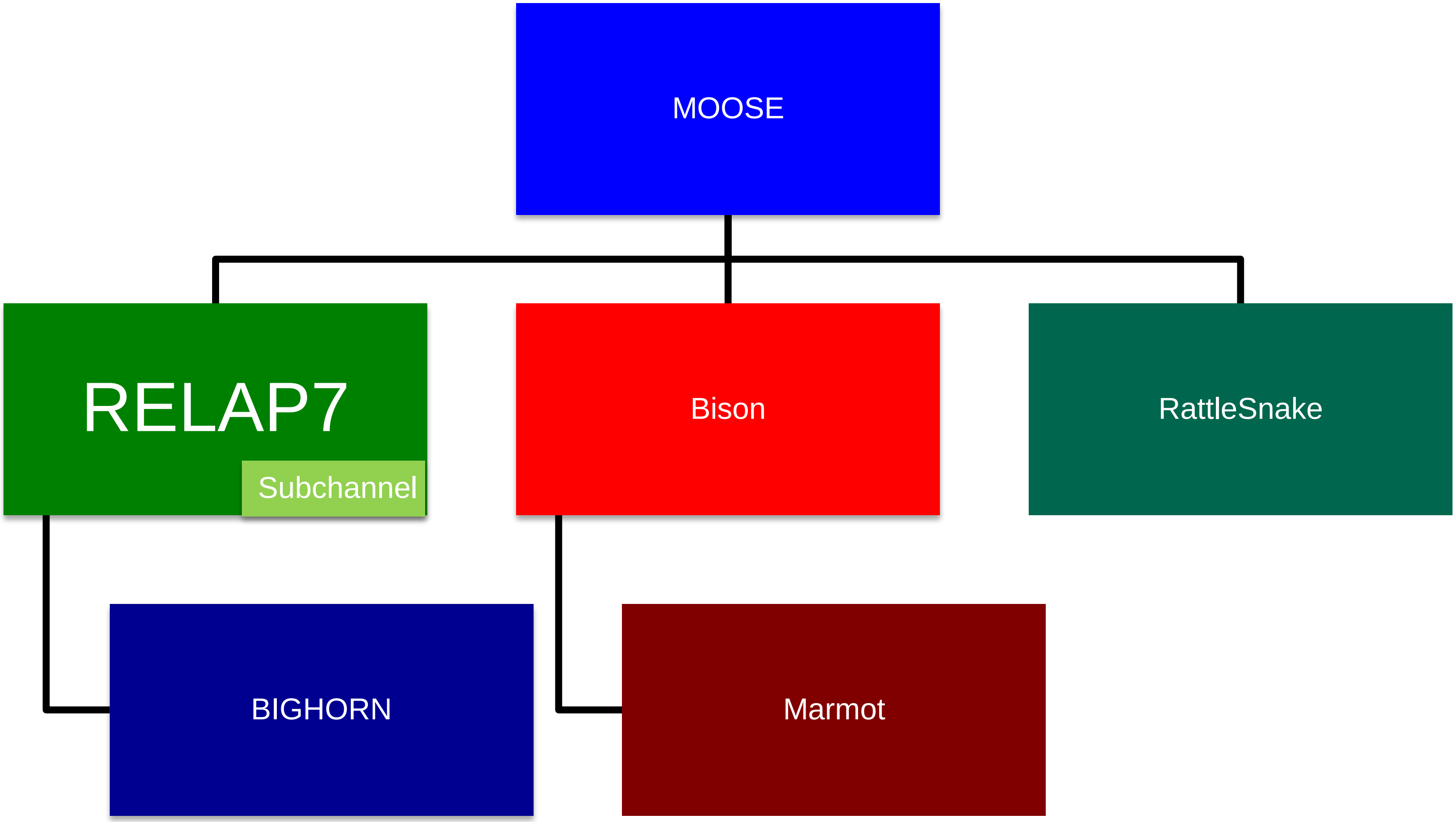
Key Takeway Points

- The behavior of safety components, such as RCIC and SRV systems, under BDA is not well understood. However, such behaviors must be understood to provide risk assessment to ensure plant safety post Fukushima era.
- RELAP-7 (designed as a RISMC ready tool) has the opportunity to answer such questions through fully implicit, fully coupled, higher fidelity and dynamic modeling and simulation of safety components.
- Our simulations indicate such simulations are doable.
- This kind of simulations would reduce the uncertainties associated with user's experience which normally assumes certain boundary conditions in the analysis such as assuming RCIC turbine & pump mass flow rates, etc.
- In RELAP-7, we are working toward higher fidelity models and enhanced capability (e.g. UQ for all the models and parameters) to enable RISMC analysis.

RELAP-7 Timeline

FY 2012	FY 2013	FY 2014	FY 2015 and beyond
- 3 equation single phase - Heat structures - Basic components	-HEM & 7 equation two phase flow - Additional relevant components and physics for SBO	- Develop the full set of components to perform SBO for a BWR - Prepare the code for the initial beta release	- Develop and upgrade closure laws. Improve physical modeling of equation parameters - Extend the number of available components
Demonstration of a steady state PWR simulation	BWR SBO simulation on simplified system with relevant components	- Initial beta release - Refined BWR SBO	- Comprehensive Verification & Validation (V&V) & Uncertainty Quantification (UQ) - Delivering a large set of validating benchmarks

Multi-Dimensional Capability



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