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Modern Error Scaling

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Outline

- Representativity
  - Methodology
  - Implementation
- Application of representativity to TREAT TWERL loop
  - TREAT and TWERL overview
  - Prototypical PWR and TWERL model
  - Simulation results
- Conclusions and future work

Representativity

Representativity Methodology

- **How "representative" is my experiment with respect to a full size facility?**
- What does "representative" mean?
  - Capturing the Figures of Merit?
  - Capturing the derivatives of the FoMs?
  - ?

- Traditionally studied in ***scaling theory***
  - Big experiments that are very close to the full-size plant → Expensive
  - Small experiments → Involves expert judgement
  - Validation extrapolation problem → Model before data before..

- ***How to mitigate these shortcomings through modern modeling and simulation techniques?***

→ One proposed option: **Representativity theory**

Representativity Methodology

- Data adjustment technique
  - **Goal**: Maximum reduction in simulation error for FOMs (not necessarily measurable) for plant model
  - Make the best use of measured values F^m in order to reduce the uncertainty/error in the calculated FOM_k^cs.
  - Likelihood maximization with constraint treated with Lagrange multipliers.
    - Maximizing the joint probability density function (maximum likelihood) of the measured values $\overrightarrow{P^m}$ and $\overrightarrow{F^m}$.
    - Constraint $\vec{F} = f(\vec{P})$

$\overrightarrow{P^t} \rightarrow$ **Experiment model**

$$F_l^t = F_l^c\left(\overrightarrow{P^t}\right)$$

$$FOM_k^t = FOM_k^c\left(\overrightarrow{P^t}\right)$$

Experiment $\rightarrow$ $\overrightarrow{P^m}$ $\boldsymbol{C}_{\overrightarrow{P^m}}$ F^m

Find best estimate of *P*

$$\overrightarrow{\widetilde{P^t}} = f\left(\boldsymbol{C}_{\overrightarrow{P^m}}, F_l^m\right)$$

$\overrightarrow{\widetilde{P^t}} \rightarrow$ **Plant model**

$$\widetilde{FOM}_k^t = \widetilde{FOM}_k^c\left(\overrightarrow{\widetilde{P^t}}\left(\boldsymbol{C}_{\overrightarrow{P^m}}, \overrightarrow{F^m}\right)\right)$$

Representativity Methodology

- Small U_{Exp}^{FOM} and $\left(\overrightarrow{S_{Exp}^{FOM}} \circ \overrightarrow{\Delta P_{Sim}{}^{1/2}}\right) \parallel \left(\overrightarrow{S_{Plant}^{FOM}} \circ \overrightarrow{\Delta P_{Sim}{}^{1/2}}\right)$ leads to biggest reduction in uncertainty

- Defining representativty

$$R^{FOM} = \left| \frac{\left(\overrightarrow{S_{Exp}^{FOM}} \circ \overrightarrow{\Delta P_{Sim}{}^{1/2}}\right) \cdot \left(\overrightarrow{S_{Plant}^{FOM}} \circ \overrightarrow{\Delta P_{Sim}{}^{1/2}}\right)}{\left\|\left(\overrightarrow{S_{Exp}^{FOM}} \circ \overrightarrow{\Delta P_{Sim}{}^{1/2}}\right)\right\| \left\|\left(\overrightarrow{S_{Plant}^{FOM}} \circ \overrightarrow{\Delta P_{Sim}{}^{1/2}}\right)\right\|} \right|$$

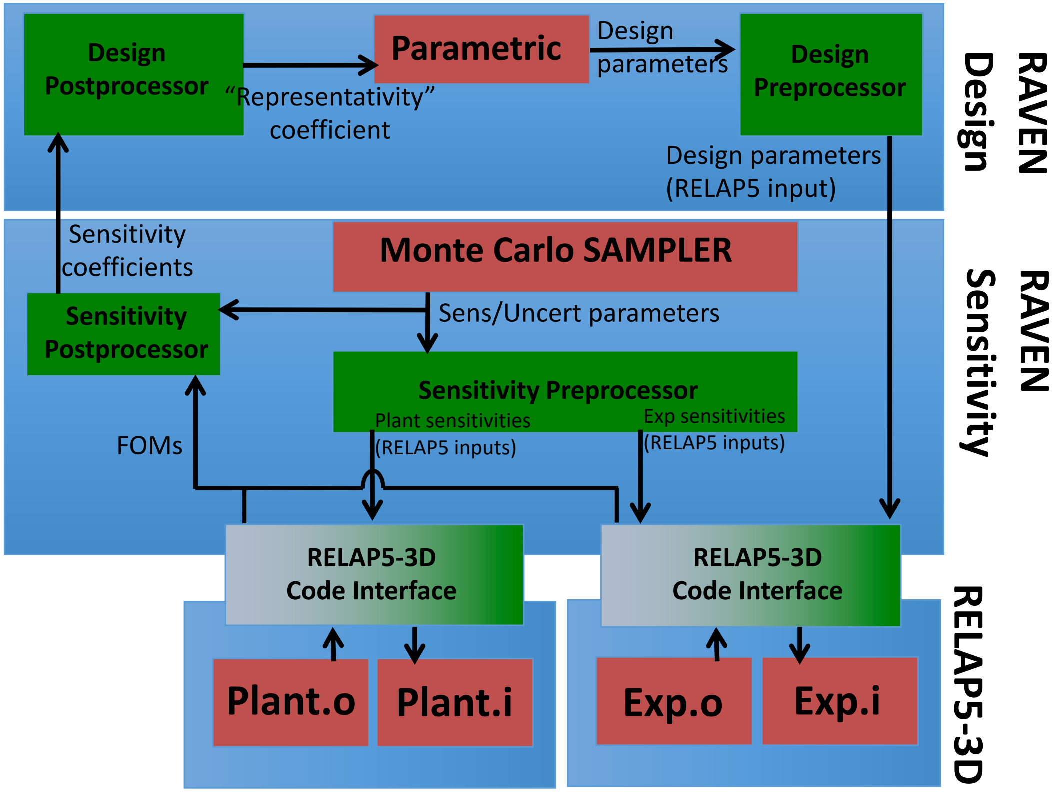
R=0 Experiment is ***not*** representative of plant, ***no reduction*** in simulation error possible with measurements form the experiment.

R=1 Experiment is ***most*** representative of plant, ***no more reduction*** in simulation error possible with measurements form the experiment.

Computational Framework

- **RAVEN**
  - Parametric and probabilistic analysis
  - **Workflow manager**
    - Input sampling
    - Running Model/Surrogate
    - Output post-processing
  - **Coupled** to RELAP5-3D

- Two layer "**RAVEN running RAVEN**" workflow for TWERL analysis

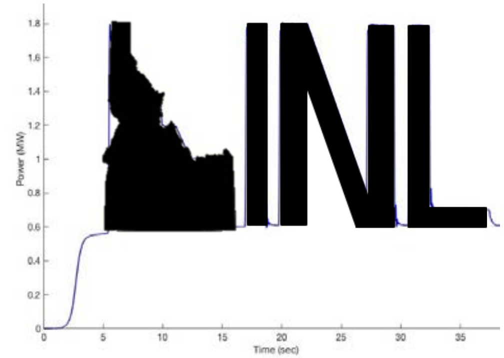


Application of representativity to TREAT TWERL loop

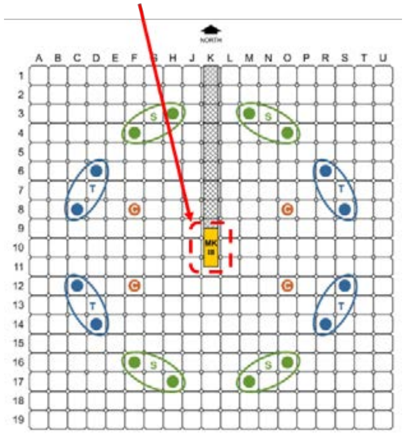
TREAT – Overview

- **Transient Reactor Test (TREAT) has resumed operations in order to support fuel safety testing and other transient science**
- **TREAT: Zircaloy-clad graphite/fuel blocks comprise core, cooled by air blowers**
  - 120 kW steady state, ~20 GW peak in pulse mode
  - Virtually any power history possible within 2500 MJ max core transient energy
  - No reactor pressure vessel/containment, facilitates access for in-core instrumentation

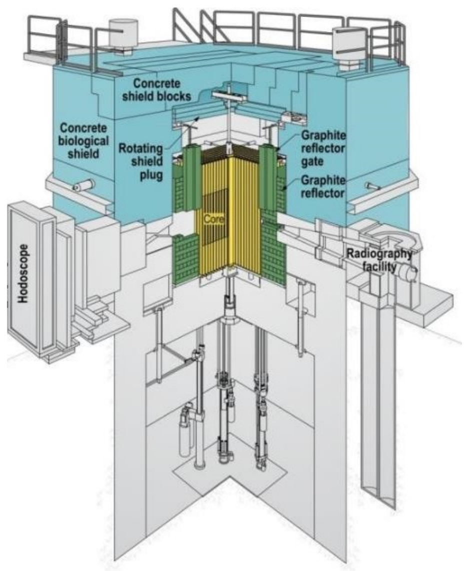
Complex Shaped Transient



Typical Experiment Location

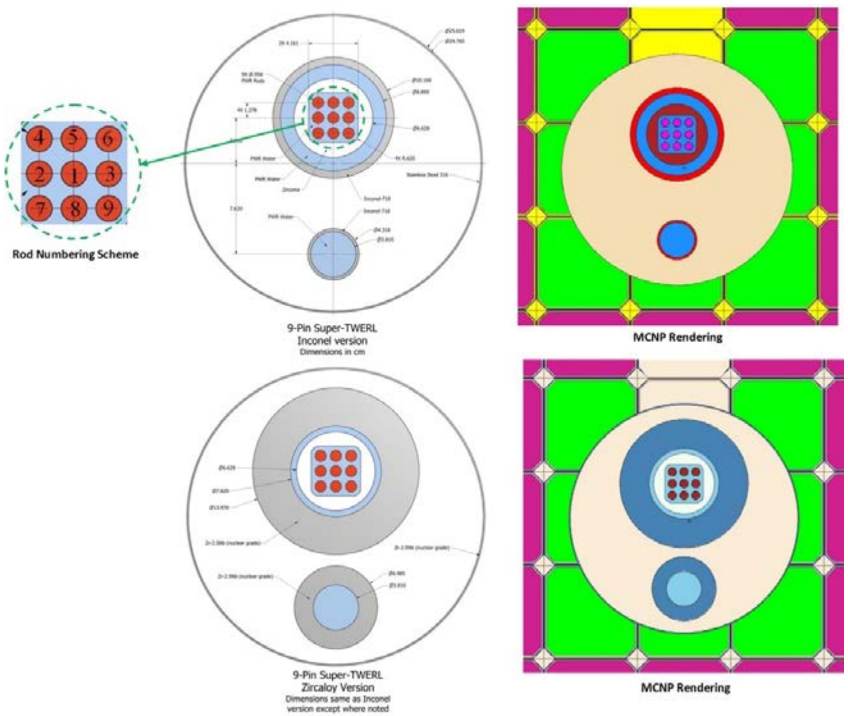


- **Experiment design**
  - Reactor provides neutrons, experiment vehicle does the rest
  - Tests displace a few driver fuel assemblies, handled in cask outside core
  - Recoverable historic designs don't include water-environment vehicles, new designs needed
- **4 slots view core center**
  - 2 in use for fast neutron hodoscope, neutron radiography
- **Collocated at INL with other complimentary facilities**
  - ATR and HFEF
  - Fuel fab and characterization



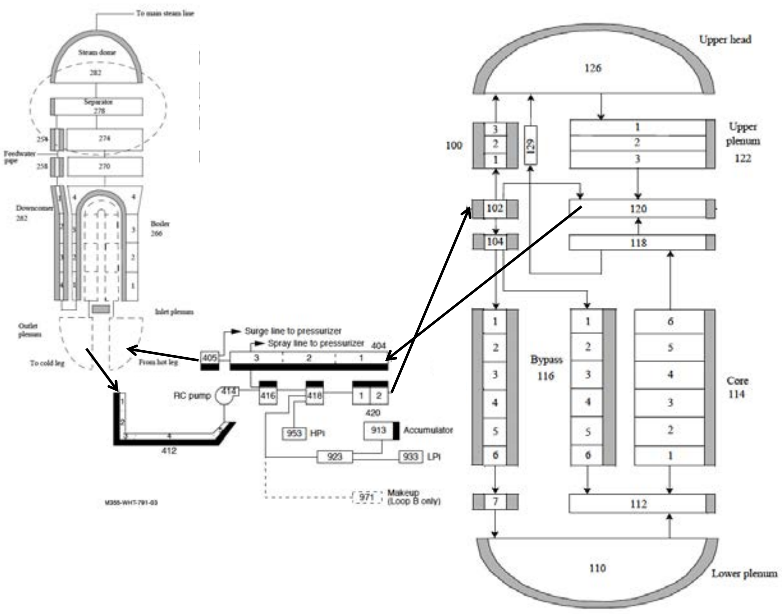
TWERL – Overview

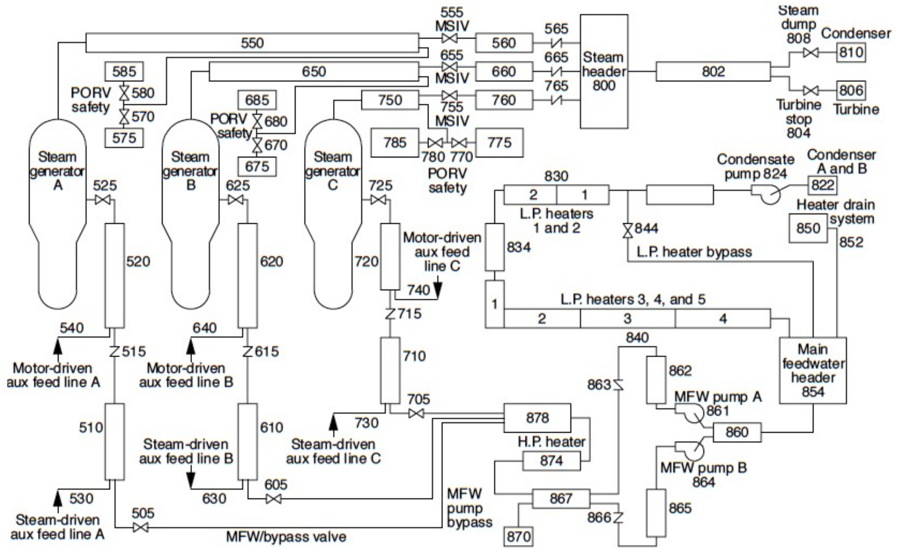
- TREAT Water-Environment Recirculating Loop (TWERL), pump-forced convection ultimately needed to simulate:
  - LWR steady **temperature distribution** prior to accident
  - Flow/temperature distribution in small bundles (TREAT is neutronically capable of driving high burnup **9-rod bundle** to failure limits)
  - Post failure fluid-assisted behavior (**fuel sweep out**)
  - Timing of thermal hydraulic events (dry-out duration, life **after DNB**)
- Current efforts focused around thermal hydraulic performance comparison
  - **System codes simulation of loop options** and typical LWRs
  - Benchmarking against prototype loop recently built at OSU
- Building heavily upon Super-SERTTA design for 2022-2023 deployment



PWR – RELAP5 Model

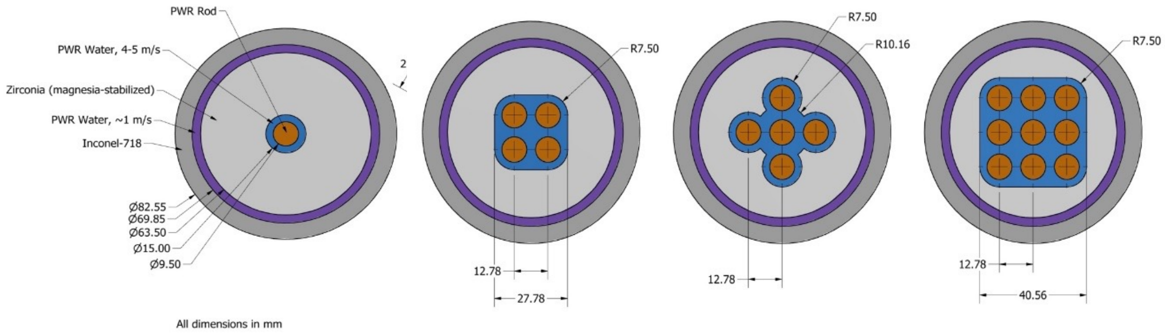
- **Includes one 17x17 pin fuel**
- Core, primary and secondary loops are included in legacy RELAP5-3D model



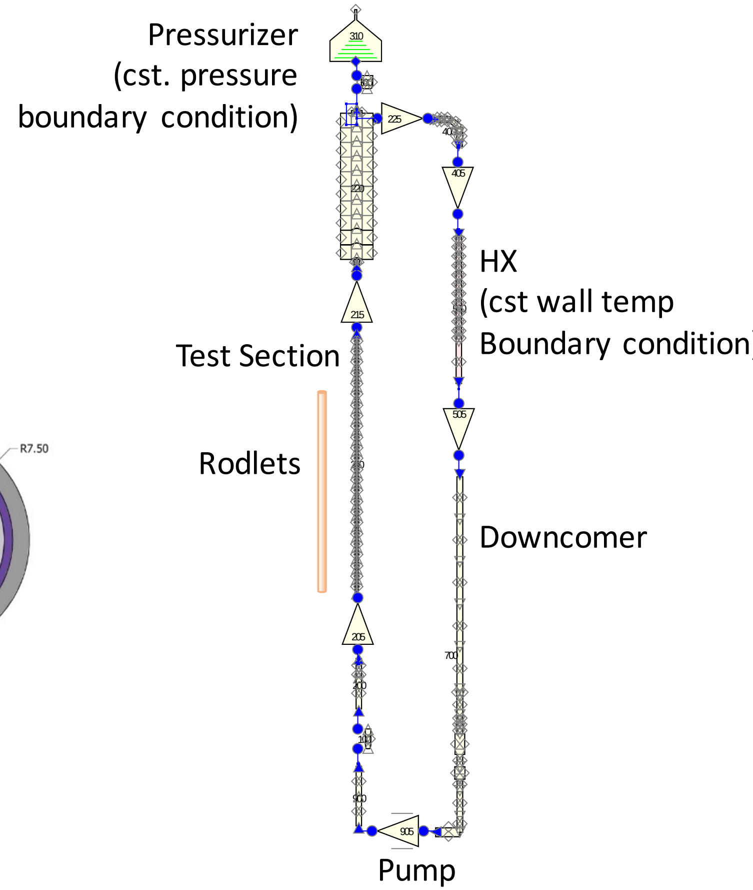


TWERL - RELAP5 Model

- **RELAP5 hydraulics** only **model** set up
  - **Test Section:**



  - **Heat exchanger:** Fixed BC.
  - **Pump:** Time Dependent Junction, imposing fluid velocity.
  - **Pressurizer:** Time Dependent Volume, constant pressure of 155 bar is imposed.



Results - Inputs

Selected Uncertainty parameters

Parameter	Accuracy	PDF	Applicability
Coolant velocity in channel	±1%	Normal	Exp.
Coolant inlet temperature	±1.5K	Uniform	Exp.
Power	±1.5%	Normal	Exp. and plant
Heat transfer coefficient	±24%	Normal	Exp. and plant
Rod pitch	±0.5%	Normal	Plant

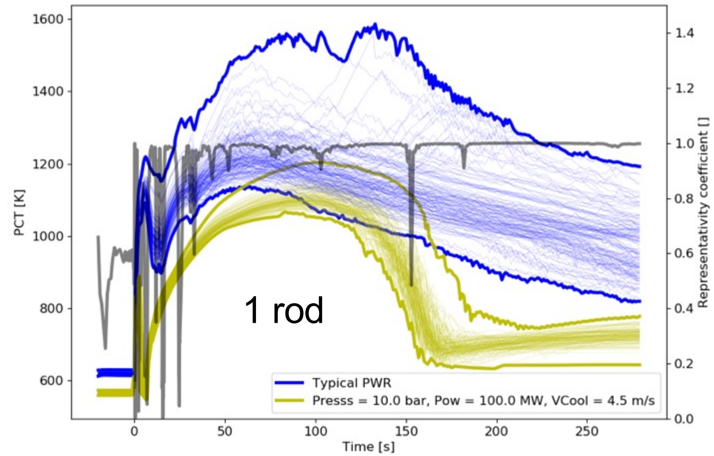
LOCA transient

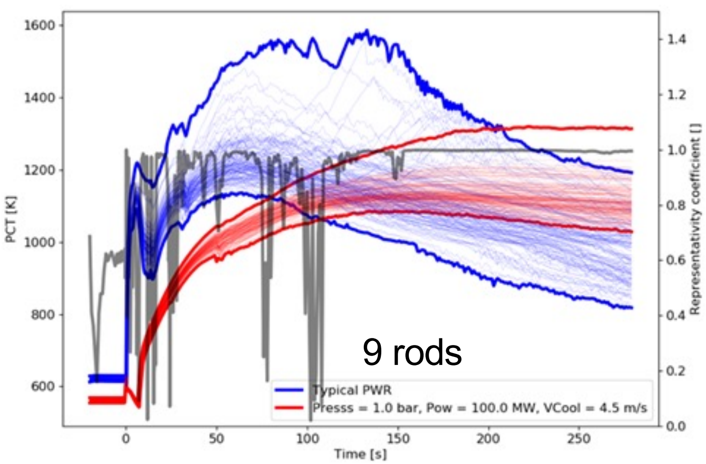
- PWR
  - Find plant steady state
  - Start LOCA (time reset to zero)
  - Plant protection system is working (SCRAM, ECCS)
  - Power follows PWR decay heat curve
- TWERL
  - Experiment set to HX outlet temperatures (cold stand by)
  - TREAT power plateau (different power levels investigated)
    - Fuel heats up
  - PCT at 626.5K, LOCA starts (time reset to zero)
    - TREAT follows PWR decay heat power shape
    - TWERL coolant pump is tripped

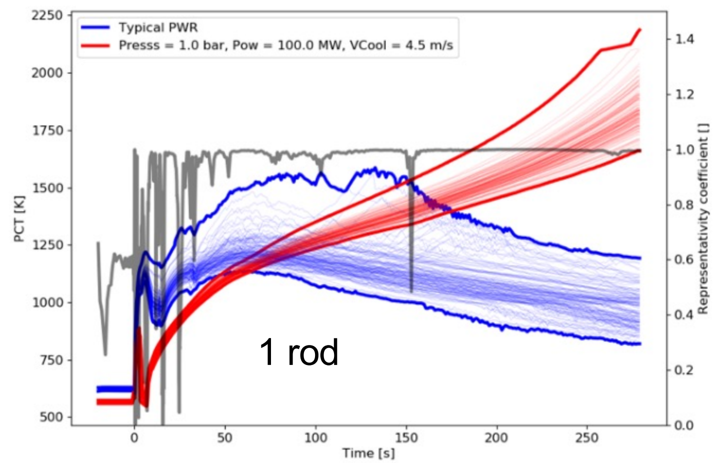
- Design parameters
  - Number of rods in section (1, 4, 5, 9)
  - TWERL back-up pressure (1 bar, 10 bar)
  - TREAT heat-up power (100 MW, 500 MW)
  - Coolant velocity (4.5 m/s, 5.5 m/s)

Results - PCT

- PCT
  - The coolant velocity has a very limited impact on the evolution of the transient
  - The TREAT power level to heat-up the fuel in the experiment has a limited impact on the evolution of the LOCA transient







Conclusions and future work

Conclusions and Future Work

- ***Representativity***
  - Current limitation: Linearization of the transfer operator for TH problems
    - Extend Sensitivity coefficients to higher order
    - Piece wise linear
  - Compare to scaling theory

- ***TWERL LOCA***
  - **Coolant velocity** and the **TREAT power level to heat-up** have **limited impact** on the transient behavior (PCT and MaxCtoF) for all test section designs.
  - The PCT are **most influenced by the back-up pressure**.
  - The **LOCA parameters** investigated (back-up pressure, TREAT power and coolant velocity) have all a **limited impact on MaxCtoF**.

  - All test section designs, the **representativity** is somewhat fluctuating between 0.0 and 1.0 at the beginning of the transient and then becoming very good (close to 1.0) for the rest of the transient. This indicates that the experiment design in general is very representative.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