Estimating the Molten Salt Flow Rate for the MSRE Isothermal Transient Benchmark Development

Mohamed Elhareef, Dr. Zeyun Wu

Mechanical & Nuclear Engineering,
Virginia Commonwealth University

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Objectives

- **Developing and evaluated transient benchmark for MSRs based on the Molten Salt Reactor Experiment (MSRE).**
- **Regenerating the missing flow rate during the pump transient test.**
- **Simulating the reactivity response to the flow transient.**
- **Identifying the parameters with significant impact on the reactivity response.**

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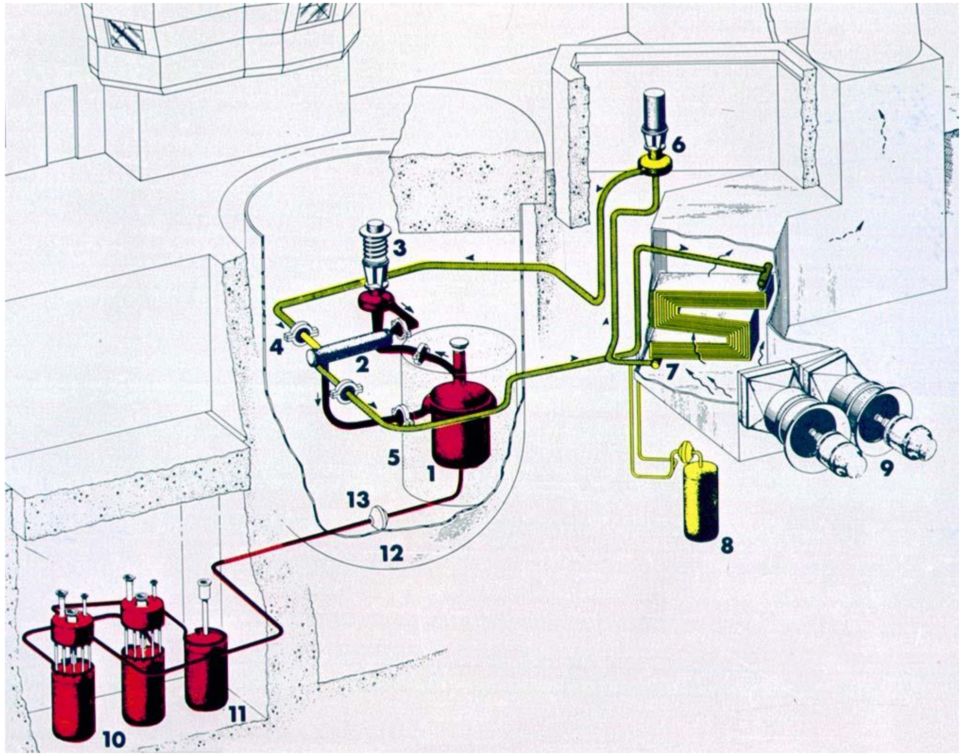
Molten Salt Reactor Experiment (MSRE)

- **Performed at ORNL (1960-1970).**
- **Currently, the only reliable source for experimental data for circulating-fuel MSRs.**

Design power	10 MW
Maximum operation power	7.2- 8.0 MW
Fissile material	^{235}U then ^{233}U
Coolant	FLiBe
Moderator	Graphite
Design fuel temperature	1175-1225 F
Design flow rate	1200 gpm (0.075 m3/s)



MSRE Pump Transient Tests

- **Conducted at zero power.**
- **The aims are:**
  1. **Obtain the fuel pump and coolant pump startup and coastdown characteristics;**
  2. **Infer fuel salt flow rate characteristics during coast down;**
  3. **Determine transient effects of fuel flow rate changes on reactivity.**
- **The pump speed was changed, and a flux servo controller kept the power constant.**
- **The reactivity response is estimated from the control rod position.**
- **Reactivity response is entirely due to fluctuations in DNPs concentration.**

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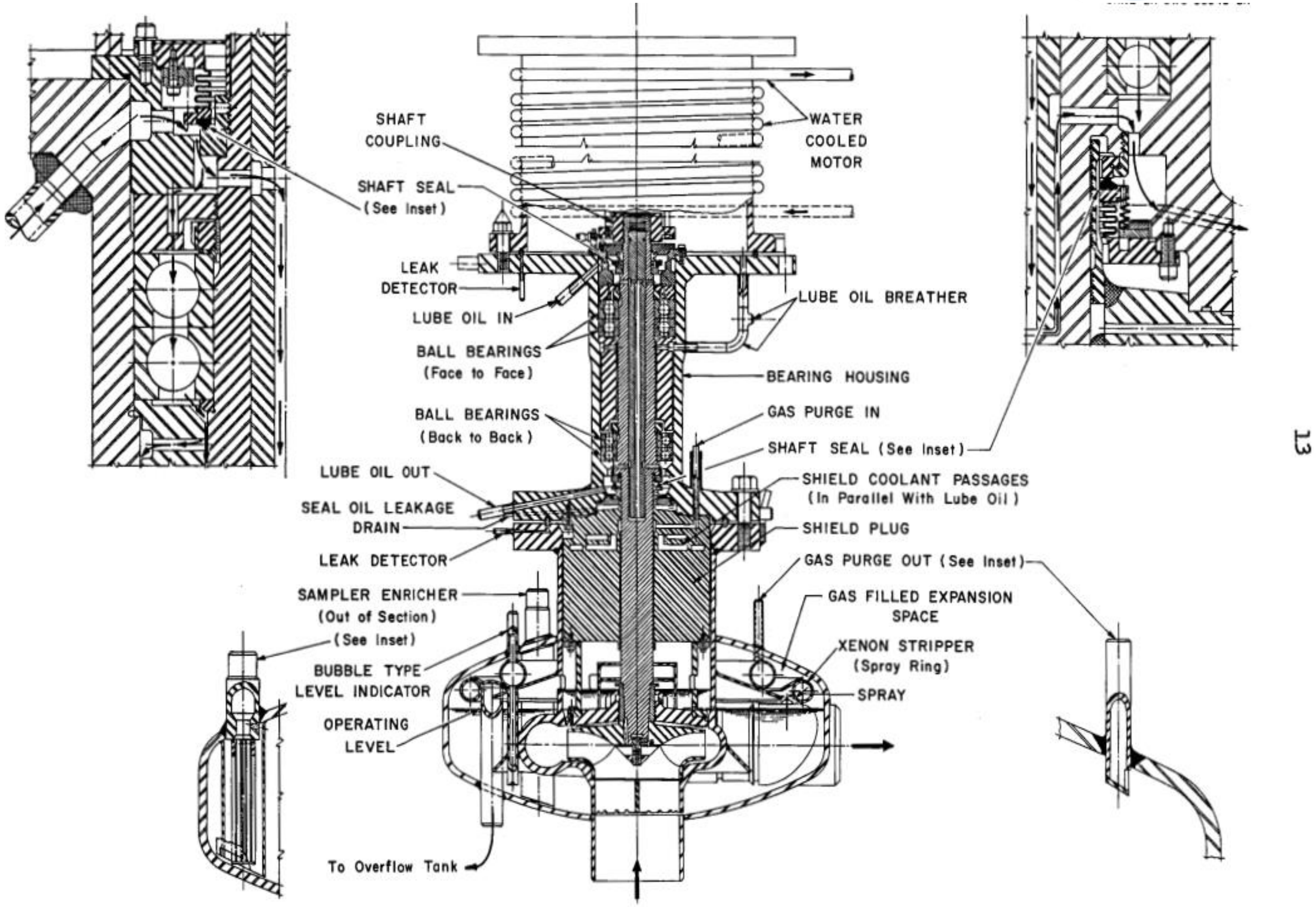
MSRE Pumps

- **The MSRE pumps are almost identical.**
- **Sump-type centrifugal pumps**

Parameter	Primary pump	Secondary pump
Rated head $h_{p_R}\left[m\right]$	14.8	23.8
Rated mass flow rate $q_R\left[kg/s\right]$	172.8	103
Rated impeller speed $N_R\left[rpm\right]$	1160	1750
Impeller Diameter $\left[in\right]$	11.5	10.33
Specific Speed ω_s	0.7998	0.7111
Nominal hydraulic torque $M_0\left[N\cdot m\right]$	206	131
Fluid inertia $\sum\frac{L_i}{A_i}\left[m^{-1}\right]$	3.34E3	8.47E3

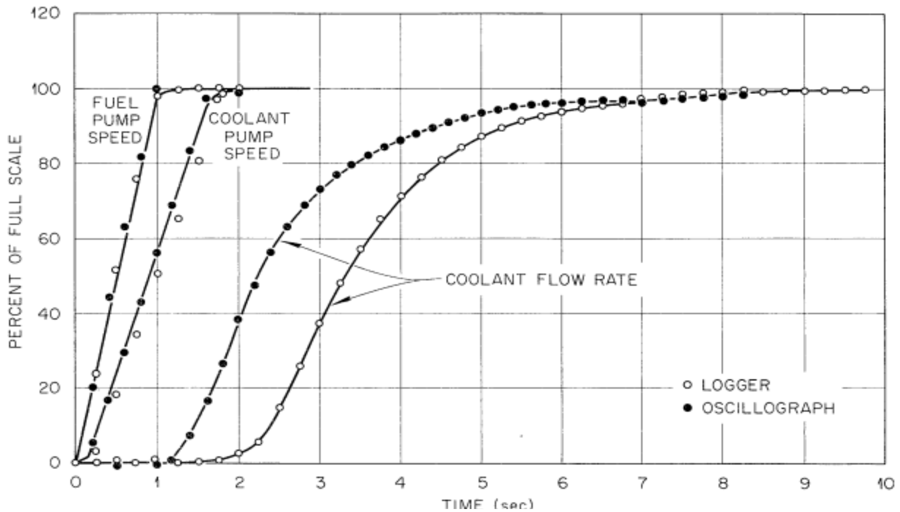


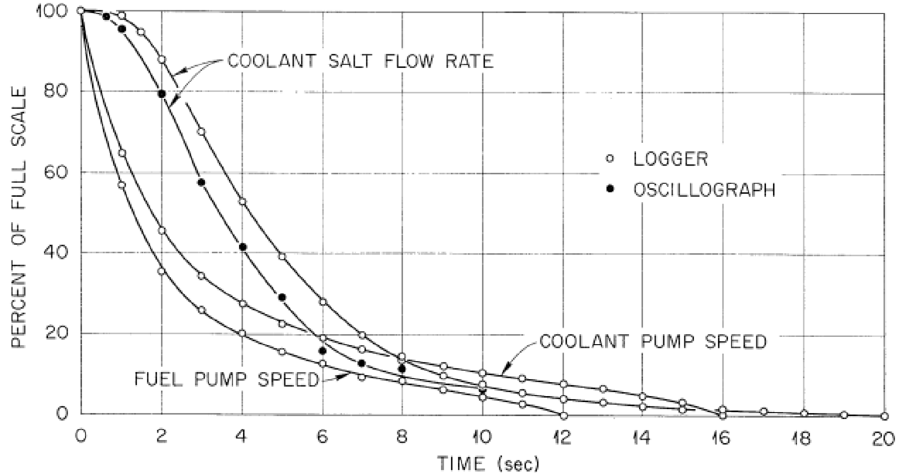
Pump Transient Tests (cont.)

- **What We know:**
  - ✓ **Fuel pump speed**
  - ✓ **Coolant pump speed**
  - ✓ **Coolant flow rate**

- **We don’t know the transient fuel rate**

Can we use the measured parameters to estimate the missing flow rate?





Pump Transient Modeling

- **Pump transients are governed by the fluid and the rotating parts momentum balance**

- **Two approaches for solving this system:**
  1. **Affinity law approximation**
  2. **Pump homologous curves**

- **The coolant pump data can be used to validate the assumption or to estimate the homologous relations**

$$\sum \frac{L_i}{A_i}\frac{dq}{dt} + \rho g \frac{q^2}{q_0^2} h_{p0} - \rho g h_p = 0$$

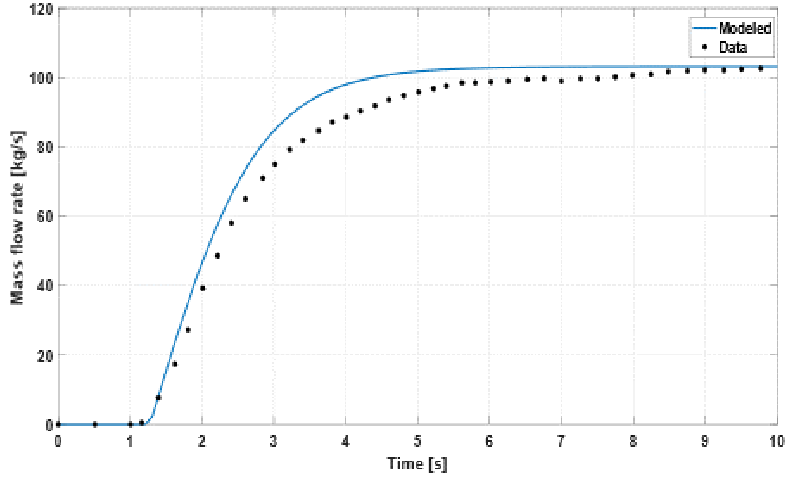
$$I\frac{d\omega}{dt} = M_{em} - M_h - M_f$$

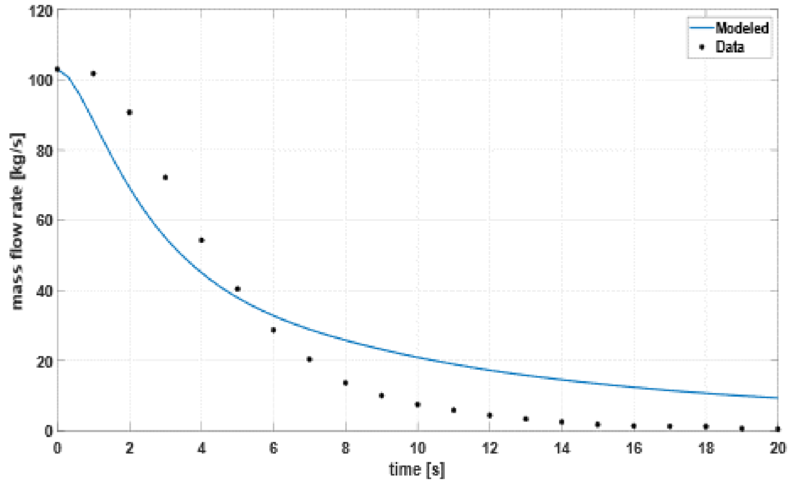
Affinity Law Approximation

- **Assuming that the pump head is proportional to the square of the pump speed.**

$$\sum \frac{L_i}{A_i} \frac{1}{\rho g h_{p0}} \frac{dq}{dt} = \left(\frac{\omega}{\omega_0} \right)^2 - \frac{q^2}{q_0^2}$$

- **Conclusion: the affinity law approximation is adequate for the startup transient.**





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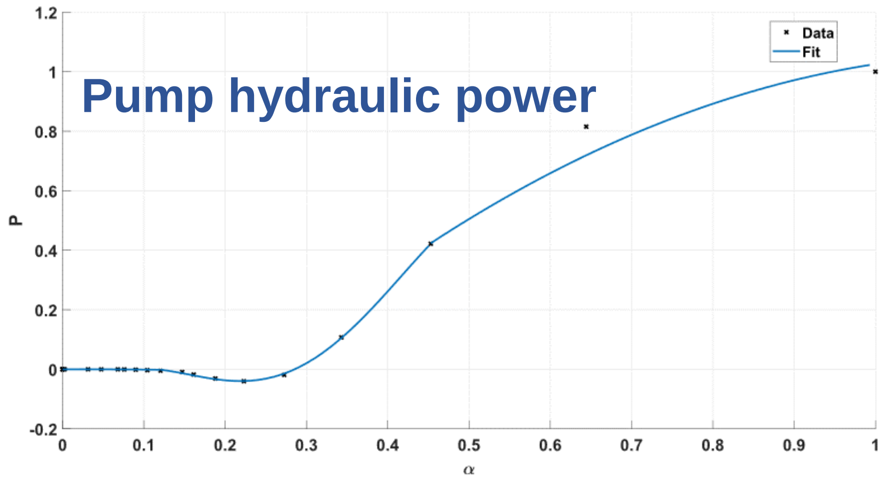
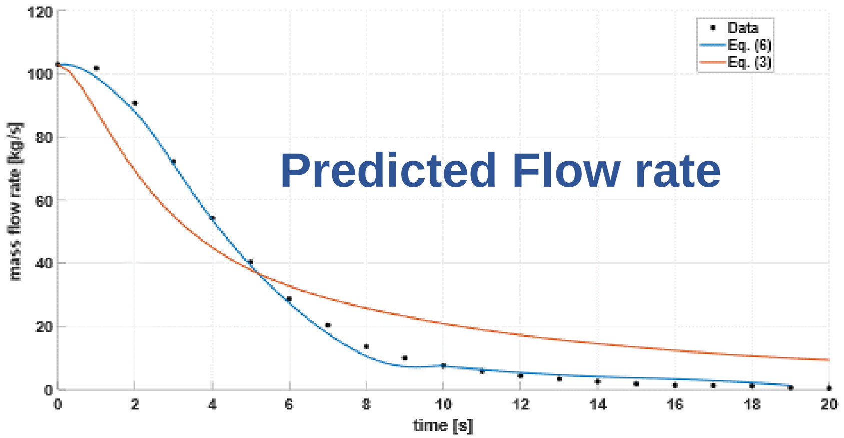
Pump Homologous Relations

- **Trying to find a non-dimensional quantity that is transferable between the two pumps and can be used to give the functional relation between the pump head and pump speed.**

- **Pump hydraulic power** $P(\alpha)$



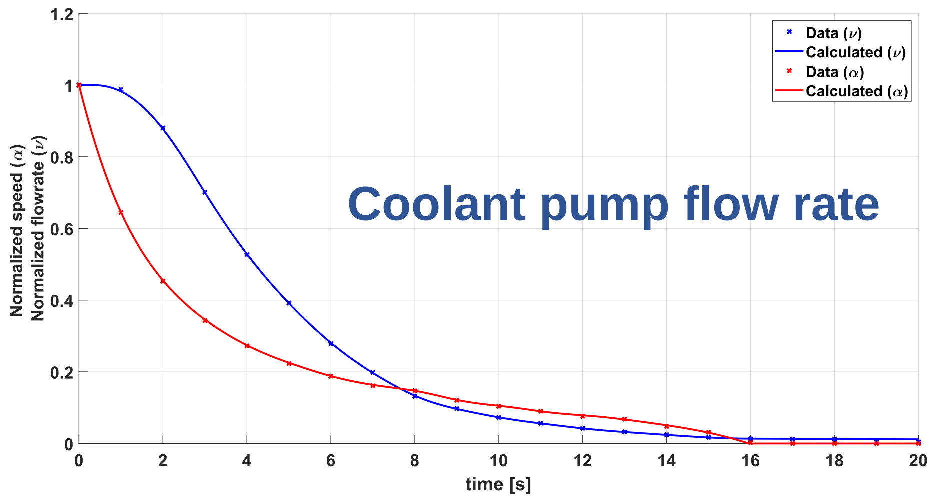


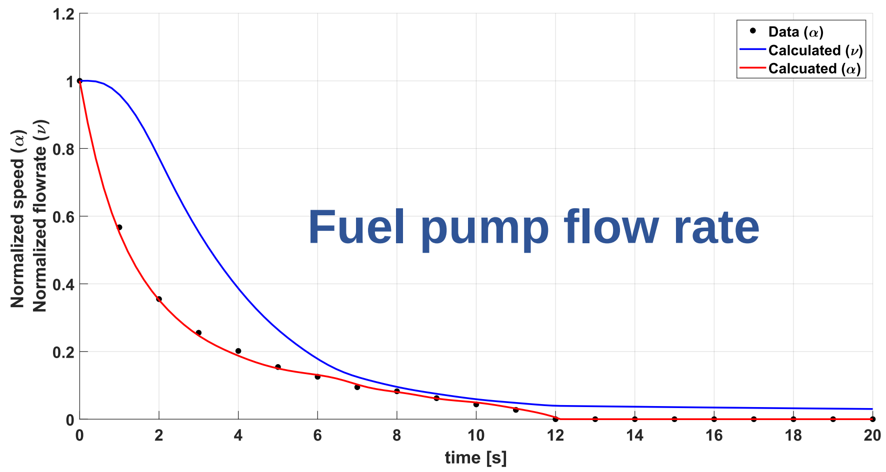
How can we validate this model?

Pump Homologous Relations (cont.)

- **Simultaneously solving for the pump speed and flow rate.**
- **Using the measured pump speed to validate the results.**
- **The homologous pump head and the homologous friction torque are estimated.**

$$H(\alpha,\upsilon)$$
$$F(\alpha,\upsilon)$$





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Reactivity Response

- **The generated flow rate is used as input for the coupled N/TH calculation.**
- **COMSOL was used to solve the model.**

G	Set 1		Set 2	
	λ_i	β_i	λ_i	β_i
1	1.24E-02	2.11E-04	1.25E-02	2.09E-04
2	3.05E-02	1.40E-03	3.18E-02	1.07E-03
3	1.11E-01	1.25E-03	1.09E-01	1.04E-03
4	3.01E-01	2.53E-03	3.17E-01	2.96E-03
5	1.14E+00	7.40E-04	1.35E+00	8.66E-04
6	3.01E+00	2.70E-04	8.64E+00	3.05E-04

$$\frac{1}{v_1}\frac{\partial \varphi_1}{\partial t} - \frac{\partial}{\partial z} D_1 \frac{\partial \varphi_1}{\partial z} + \Sigma_{r1}\varphi_1 = (1-\beta)\sum_g \nu\Sigma_{fg}\varphi_g + \sum_{k=1}^{6}\lambda_k C_k,$$

$$\frac{1}{v_2}\frac{\partial \varphi_2}{\partial t} - \frac{\partial}{\partial z} D_2 \frac{\partial \varphi_2}{\partial z} + \Sigma_{r2}\varphi_2 = \Sigma_{s,1\to 2}\varphi_1,$$

$$A\frac{\partial C_k}{\partial t} + Au\nabla_t \cdot C_k = A\beta_i \sum_g \nu\Sigma_{fg}\varphi_g - A\lambda_k C_k, \quad k = 1,\cdots 6,$$

$$A\frac{\partial \rho}{\partial t} + \nabla_t \cdot (A\rho u) = 0,$$

$$\rho\frac{\partial u}{\partial t} + \rho u \cdot \nabla_t u = -\nabla_t p - f_D \frac{\rho}{2d_h} u|u| + F.$$

$$\rho(t) = \frac{\theta_0 - \theta(t)}{\theta(t)}$$

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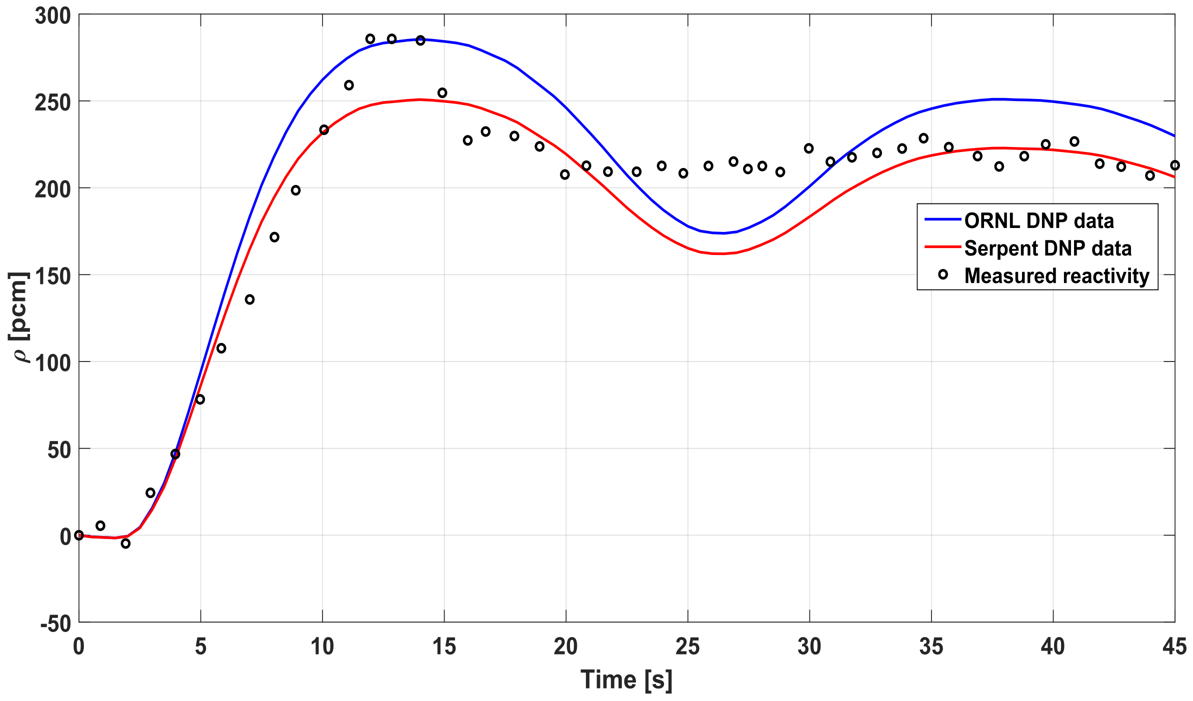
Pump Startup Test

- **As the flow rate increase, DNP concentration decrease, and positive reactivity is needed to keep the reactor critical.**

- **With the recirculation of the salt that initially filled the core, this reactivity demand in reduced.**

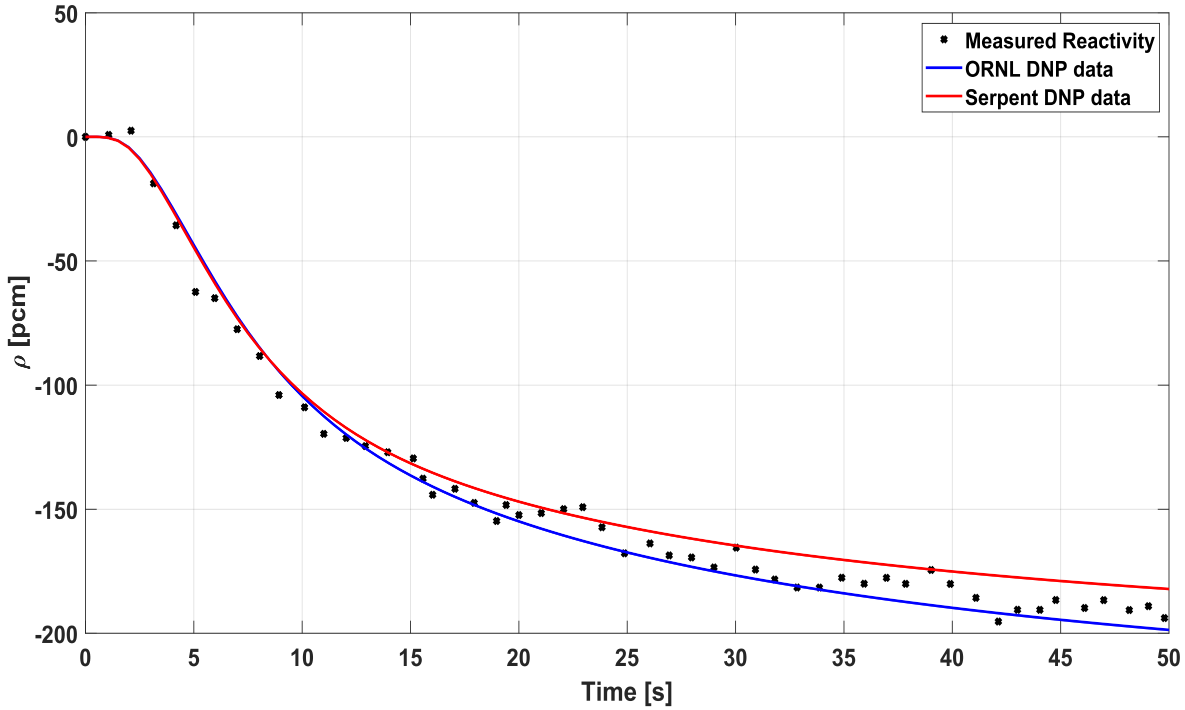
- **Damped oscillation with period of 25s.**



Pump Coastdown Test

- As the flow rate Decrease, DNP concentration increase, and negative reactivity is needed to keep the reactor critical.

- In steady state, DNP are distributed throughout the circulation loop. Thus, there is no bulk of salt that contain higher concentration of DNP.

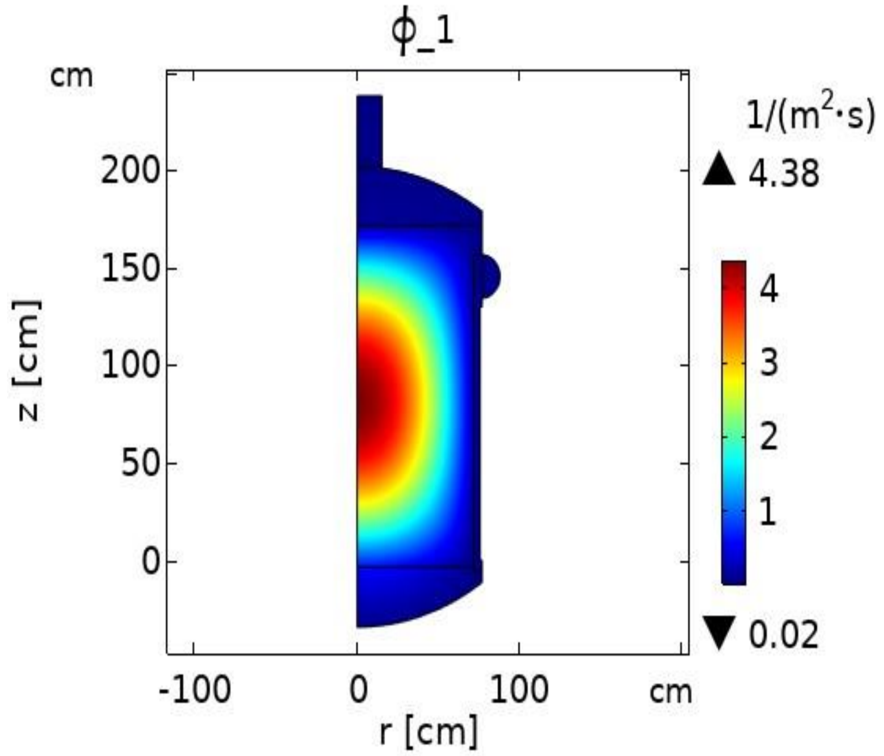


Discussions

- **Potential causes of discrepancy with experimental data:**
  - **Modeling approximations:**
    1. **2G diffusion model**
    2. **Scaling the fission source uniformly over the reactor vessel.**

  - **3D effects:**
    1. **Radial distribution of flow**
    2. **Radial distribution of DNPs**
    3. **Lower flow mixing in the 1D model**

  - **Experimental setup**
    1. **Dead band on the flux servo controller setpoint**
    2. **The flux servo controller was installed at the outer region of the core**



Conclusions & Future Work

- The transient flow rate of the MSRE fuel pump during the pump transient test was regenerated.

- The reactivity response to the flow transient was modeled using a 1D, fully coupled neutronics/fluid flow model.

- Good agreement was achieved with the experimental data.

- For future work:
  - The discrepancy with the experimental data will be investigated,
  - Uncertainty quantification.

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Thank You, and Any Questions?

Mohamed H. Elhareef, Zeyun Wu
elhareefmh@vcu.edu, zwu@vcu.edu

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VCU College of Engineering
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