Coupled Neutronics and Thermal Hydraulics Calculations for the MSRE Pump Startup and Coastdown Transients

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ANS Student Conference 2023
University of Tennessee at Knoxville, Knoxville, TN, April 15, 2023

Outline

BACKGROUND AND MOTIVATION

MATHEMATICAL MODEL

MODEL IMPLEMENTATION

RESULTS AND DISCUSSION

CONCLUSION AND FUTURE WORK

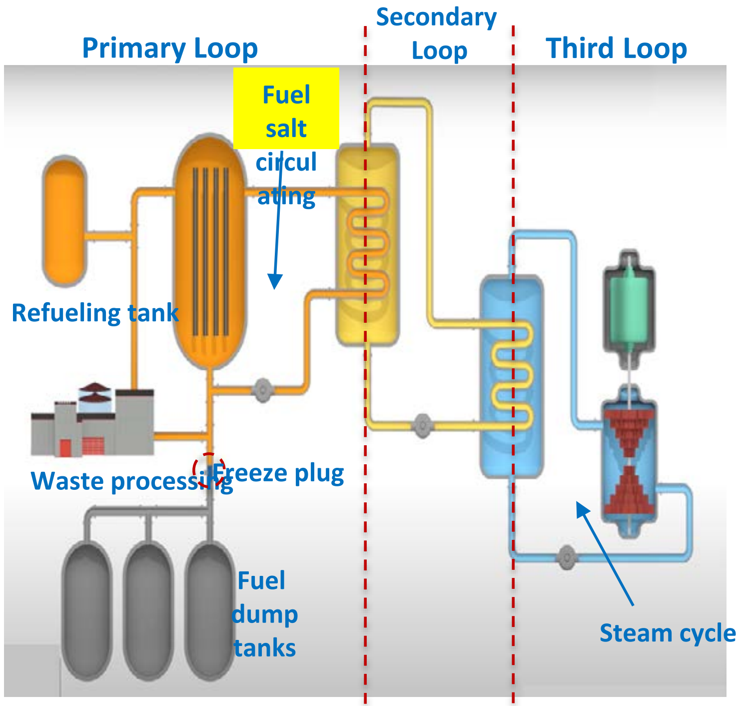
Molten Salt Reactor (MSR)

Advantages of MSR:

- Homogeneous design
- Continuous online refueling
- No fuel melting concern
- High operation temperature
- Low operation pressure
- Burn TRU

Computational Challenges:

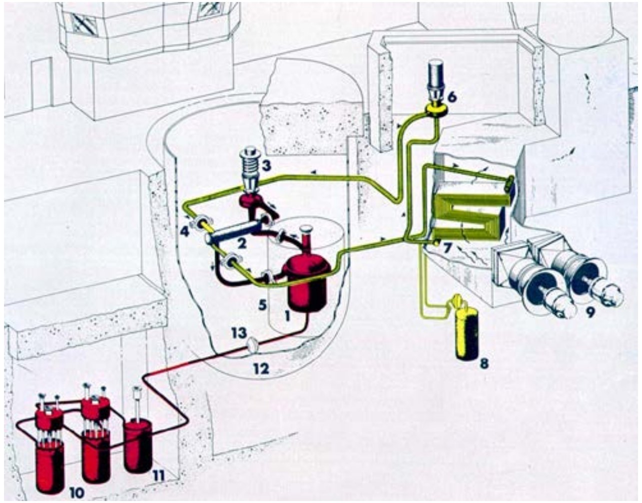
- Fluid flow and delayed neutron precursor (DNP) drift,
- **Lack of experimental data for validation.**



A molten salt mixture is used as both fuel and coolant.

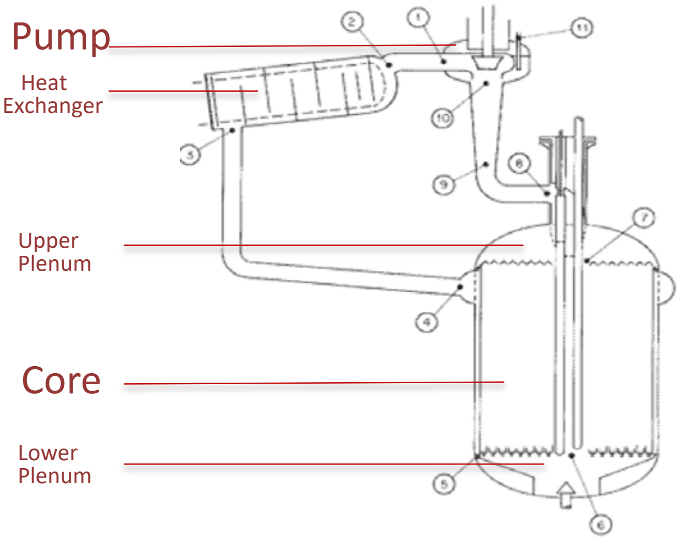
Molten Salt Reactor Experiment (MSRE)

- Performed at ORNL (1960-1970).
- The objective was to verify the safety, and practicality of molten-fluoride, circulating-fuel reactor system.
- Several static, dynamic, and transient tests were performed.
- Two phases of operation:
  - U^{235} (35%)
  - U^{233} (91%)



MSRE Primary Loop Parameters

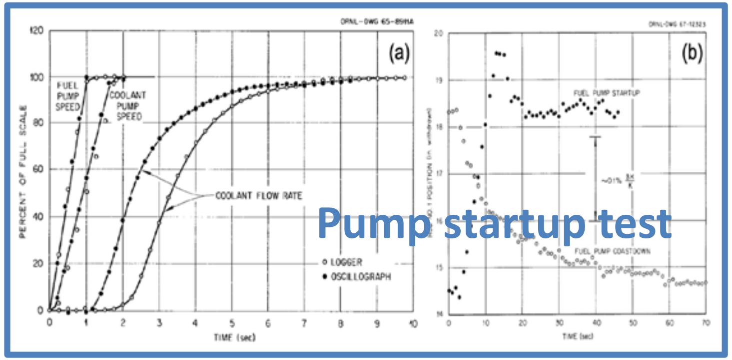
- FLiBe Salt.
- pressure (~3.8 Atm).
- Design Temperature (700 C)

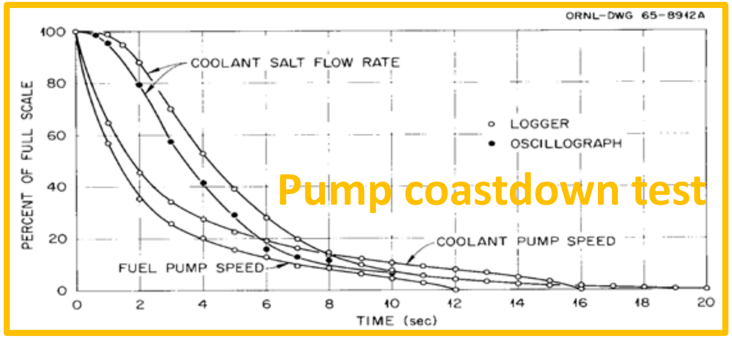


Schematic view of the fuel loop of MSRE

Isothermal MSRE Transient Experiments

- Zero power (~10 W).
- During the pump startup test, the pump speed was increased linearly from zero to 100% in 1s then it was kept constant
- In the pump coat down test, starting from steady state flowing conditions, the pump motor was turned off.





Mathematical Models

Two-group Neutron Diffusion

$$\begin{cases} \dfrac{1}{v_g}\dfrac{\partial \varphi_g}{\partial t} - \dfrac{\partial}{\partial z} D_g \dfrac{\partial \varphi_g}{\partial z} + \Sigma_{r,g}\varphi_g = Q_g \\ Q_1 = \dfrac{(1-\beta)}{k(t)} \sum_g \upsilon \Sigma_{f,g}\varphi_g + \sum_k \lambda_k C_k + \Sigma_{s,2\to 1}\varphi_2 \ , \\ Q_2 = \Sigma_{s,1\to 2}\varphi_1 \ . \end{cases}$$

DNP Drift

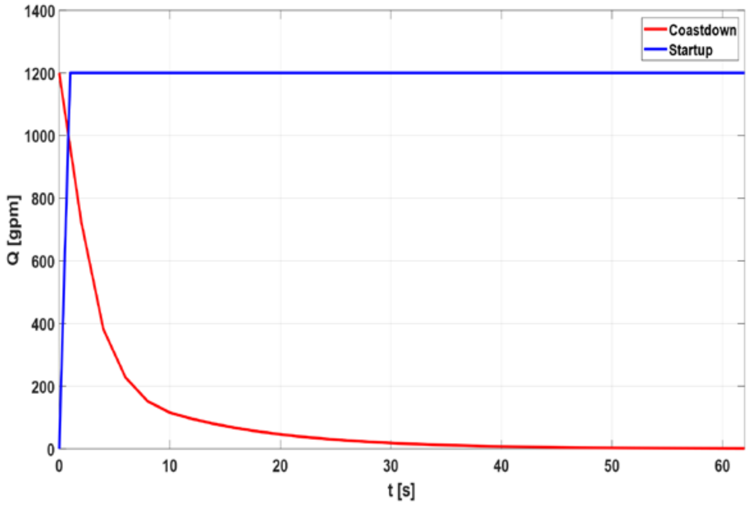
$$A\frac{\partial C_k}{\partial t} + Au\frac{\partial C_k}{\partial x} = -A\lambda_k C_k + \frac{\beta_k A}{k(t)} \sum_g \upsilon \Sigma_{f,g}\varphi_g$$

1D Pipe Flow

$$\begin{cases} \nabla(Au) = 0 \\ \rho\dfrac{\partial u}{\partial t} + \rho u.\nabla u = -\nabla p - \nabla p_{friction}, \end{cases}$$

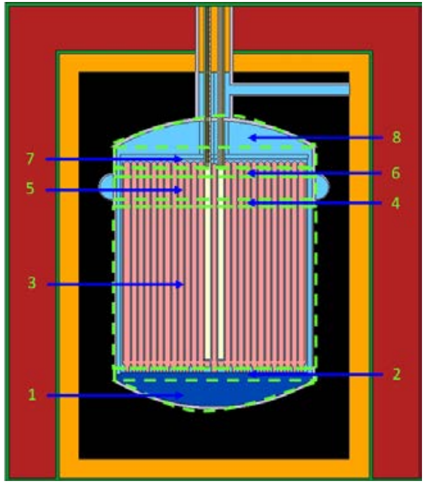
Model Assumptions

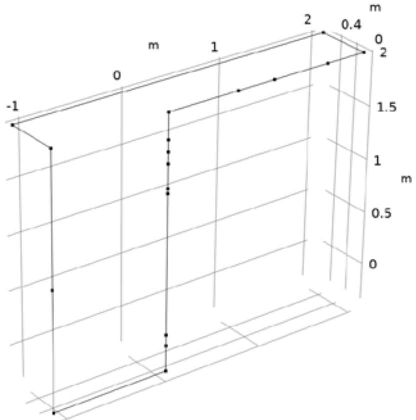
- Incompressible flow.
- No Circulating voids.
- Negligible DNP Diffusion.
- Transient initiating event:
  - Startup: $Q\alpha\ \omega$
  - Coastdown: $\Delta p_{pump} = \Delta p_0 e^{-t/\tau}$



Implementation

- Serpent 2 for XS generation
- COMSOL Multiphysics for the coupled calculations.
- Pump was molded as point momentum source.
- IC for pump startup: Eigenvalue solution of the static configuration.
- IC for pump coastdown: SS conditions of the pump startup simulation.

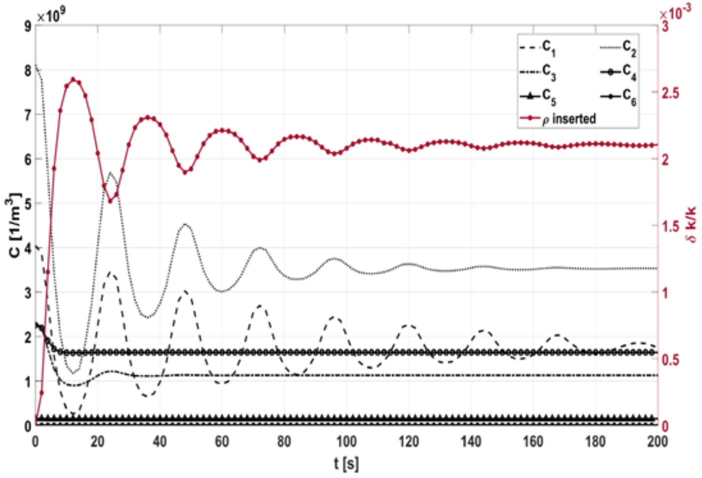




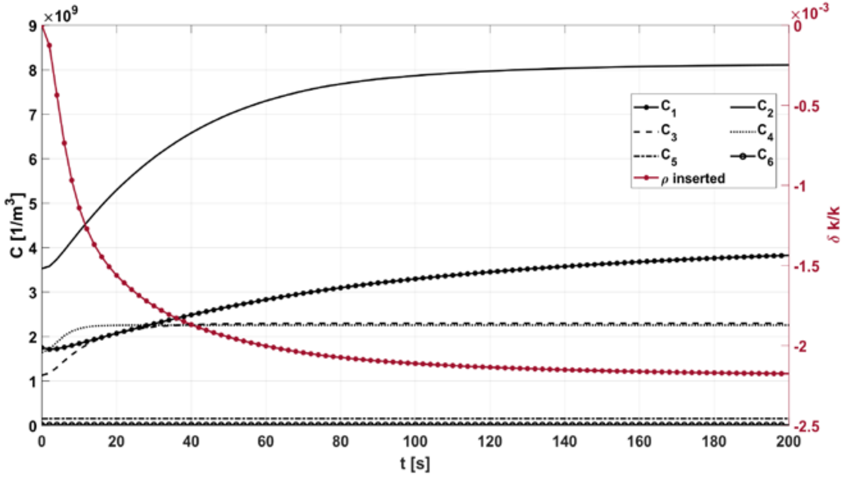
[6] D. SHEN et al., *Nucl. Sci. Eng.*, **195**(8) (2021).

Transient Results

Pump Startup



Pump Coastdown

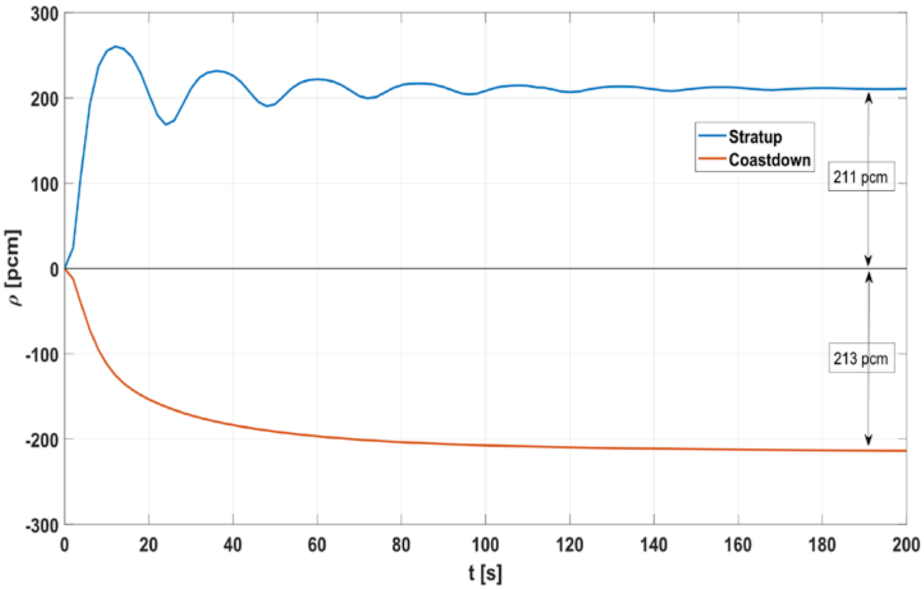


Discussion-1

Prediction of reactivity loss due to fuel circulation

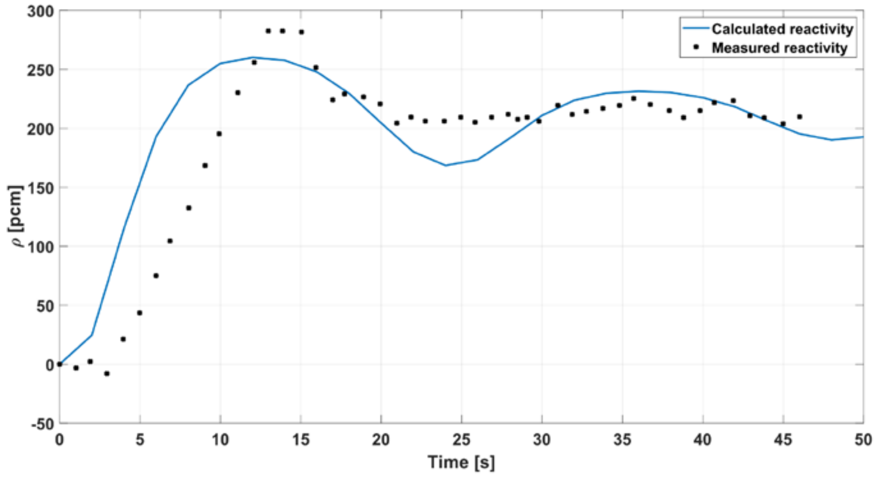
Startup	Coastdown	Measured
211	213	212

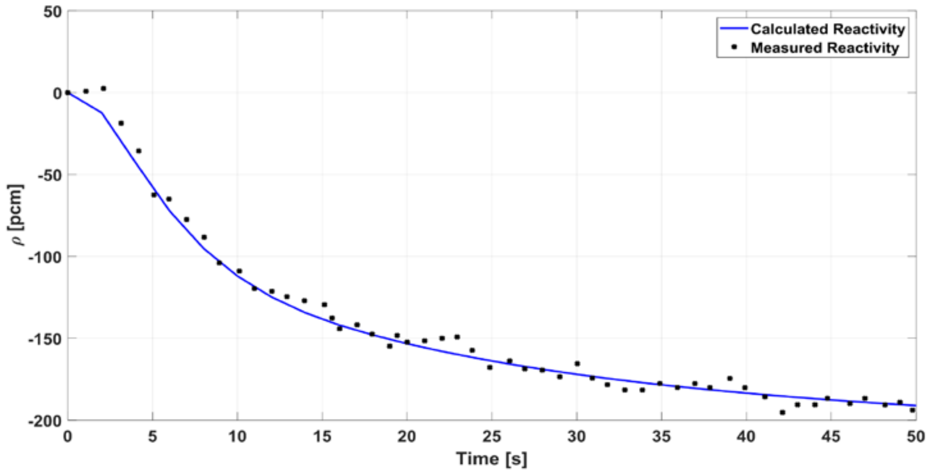
R. B. BRIGGS, Molten-Salt Reactor Program Semi-annual Progress Report, ORNL, Oak Ridge, Tennessee, ORNL-3872 (1965).



Discussion 2

- Oscillation frequency
- Initial reactivity change



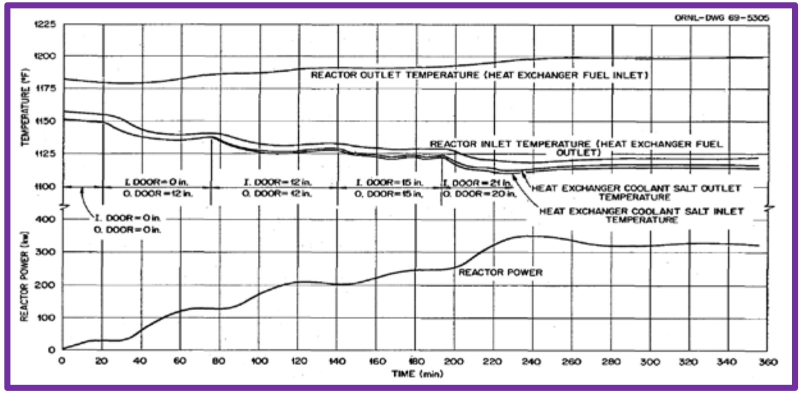


Conclusions

- The 1D model successfully captured the essential features of the time evolution of the MSRE isothermal transients.
- The assumption about the time evolution of flow rate during the pump startup test is not adequate.
- The assumption about the pump head decay during the pump coastdown test is reasonable.
- The model did not capture the reactivity oscillations during the coastdown test.

Future work

- Further investigation of the discrepancy between measurements and calculations.
- Inference of undocumented data.
- Extending to non-isothermal transients (i.e., thermal-convection heat-removal test)



Acknowledgments

NEUP Nuclear Energy University Program

U.S. Department of Energy

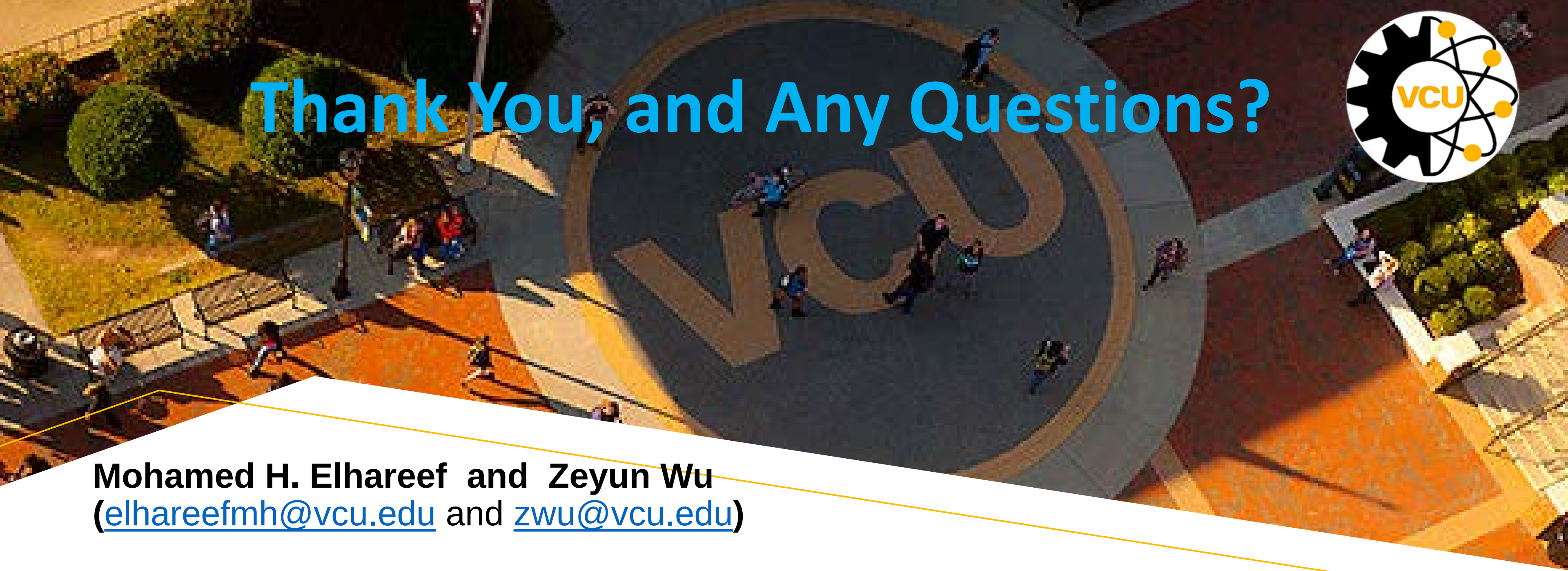
"Regenerate Undocumented Data in Historical Experiments for MSRE Transient Benchmark Development"

Award No. DE-NE0009162

All Collaborating Partners:

- Virginia Commonwealth University
  - Zeyun Wu
  - Mohamed Elhareef
- University of California Berkeley
  - Massimiliano Fratoni
- Argonne National Laboratory
  - Tingzhou Fei
- Oak Ridge National Laboratory
  - Eva Davidson
- Flibe Energy
  - Kurt Harris

Thank You, and Any Questions?



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