Preliminary Steady State Xenon Transport Benchmark Using MSRE Data

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04/22/2026

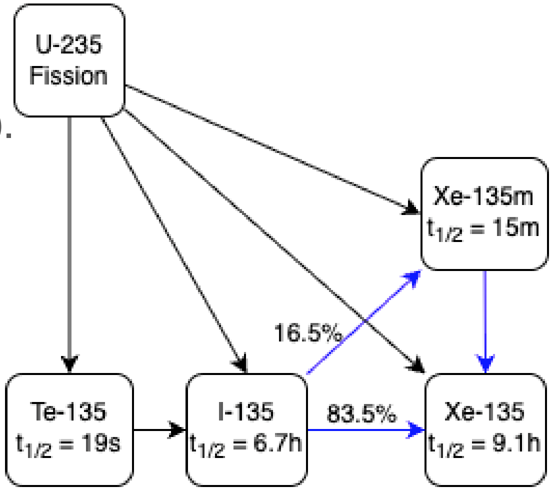
MSR Program Annual Review Meeting

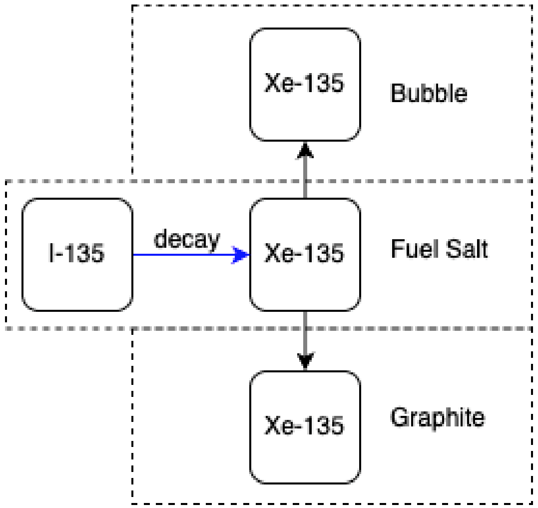
Introduction

- Species transport in MSR is an important phenomenon to be captured for reactor design and operation. Xenon is one of the important species among them due to its large absorption cross section, especially for thermal MSRs.
  - Xenon can have large impact on reactor control, restart restriction (Xenon poisoning), power level change (e.g., load following).
- It is important to have the capability to track Xenon concentration in the MSR primary loop in the NEAMS tool. The objective of this study includes:
  - Understand the basic physics of Xenon transportation in the MSR primary loop.
  - Employ the NEAMS tool to simulate the Xenon transport phenomena.
  - Preliminarily validate the newly implemented capabilities through the MSRE data.

Basic Physics Model

- Xenon concentration in the core at secular equilibrium is low compared to its precursors due to its large absorption cross section (i.e., high removal rate). Xenon concentration builds up due to its precursor decay once the reactor power is reduced or shutdown.
- The main source of Xe-135 is through U-235/U-233 fission in the fuel salt and its precursor I-135 decay in all phases.
- The main transfer mechanism of Xe-135 includes:
  - Salt-to-gas transfer (gas can form from injected sparging gas, dissolved cover gas, or noble gas formation in the salt).
  - Salt-to-graphite (or other solid structures) transfer.
  - Xe in salt/gas would flow in the primary loop and stay in the core if diffuse into core structure.
- The main removal of Xe-135 is through the absorption in the core, removal in the off-gas system, and decay

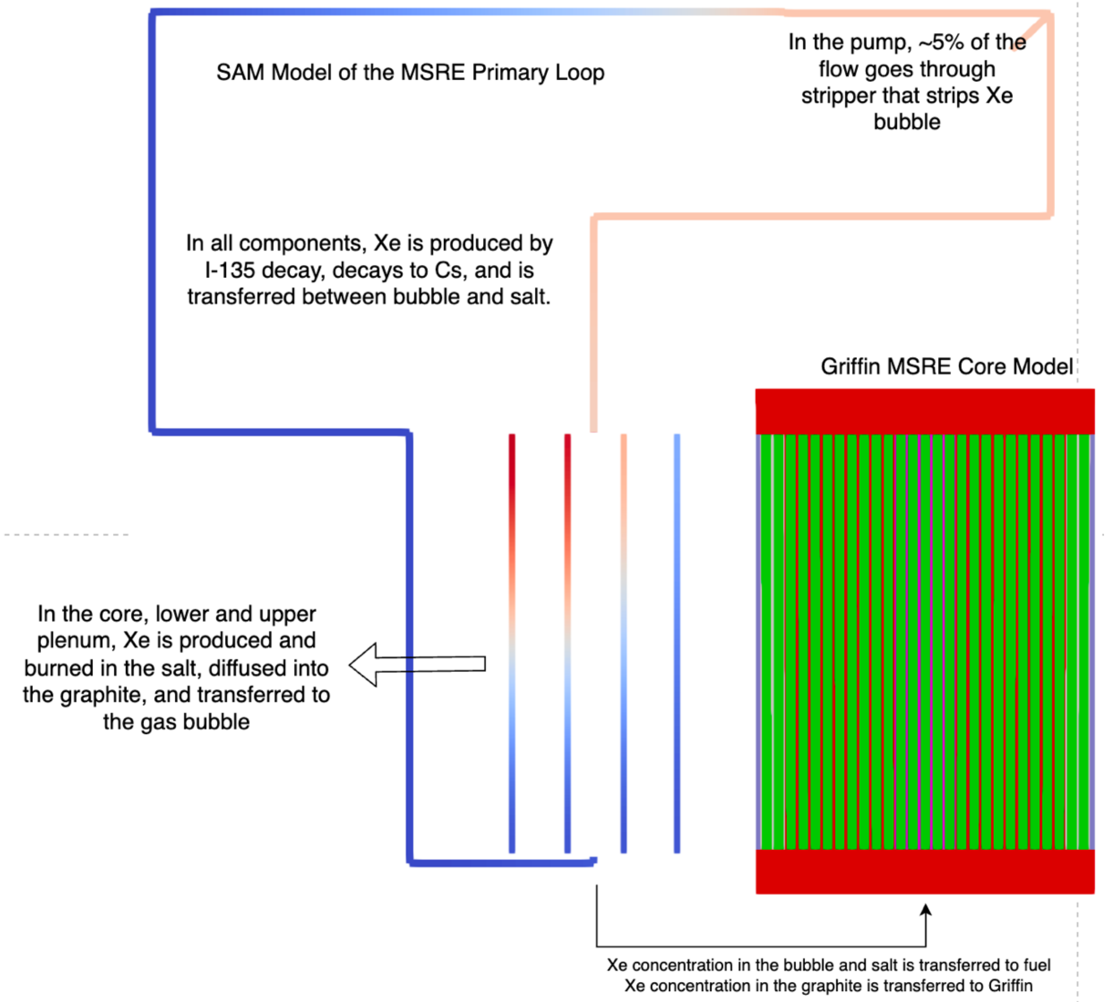




SAM/Griffin Model (I)

- A SAM/Griffin model was developed to demonstrate the Xenon transport simulation using the MSRE reactor.
  - SAM handles the Xenon transport (both I-135 and Xe-135) simulation and sends the Xenon concentration to Griffin to estimate the change in reactivity (i.e., Xenon poisoning).
  - The core contains four channels in the SAM model, and Xe-135 is produced in all channels plus the upper and lower plenum.
  - The void fraction is now controlled by boundary conditions for steady state.

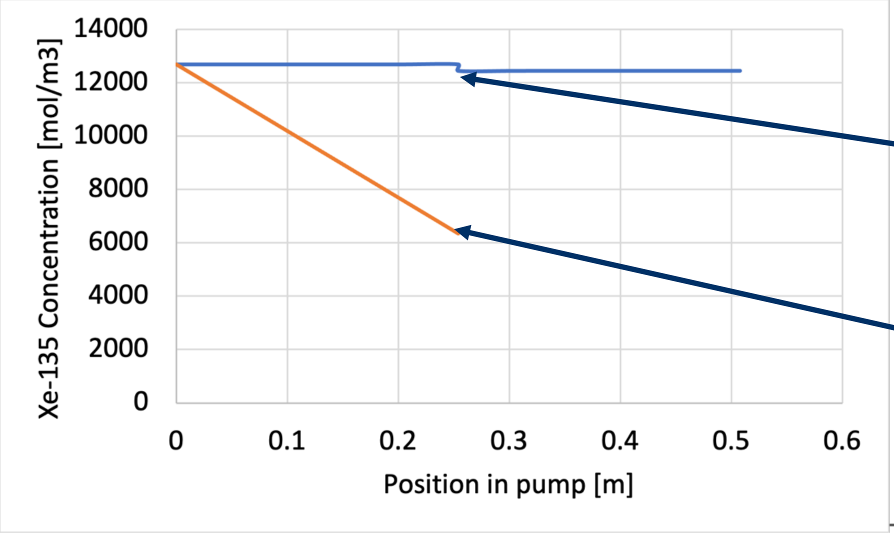
Region	Power fraction
Upper plenum	0.0535
Channel 1[a]	0.0973
Channel 2	0.2495
Channel 3	0.4239
Channel 4	0.1245
Lower plenum	0.0513

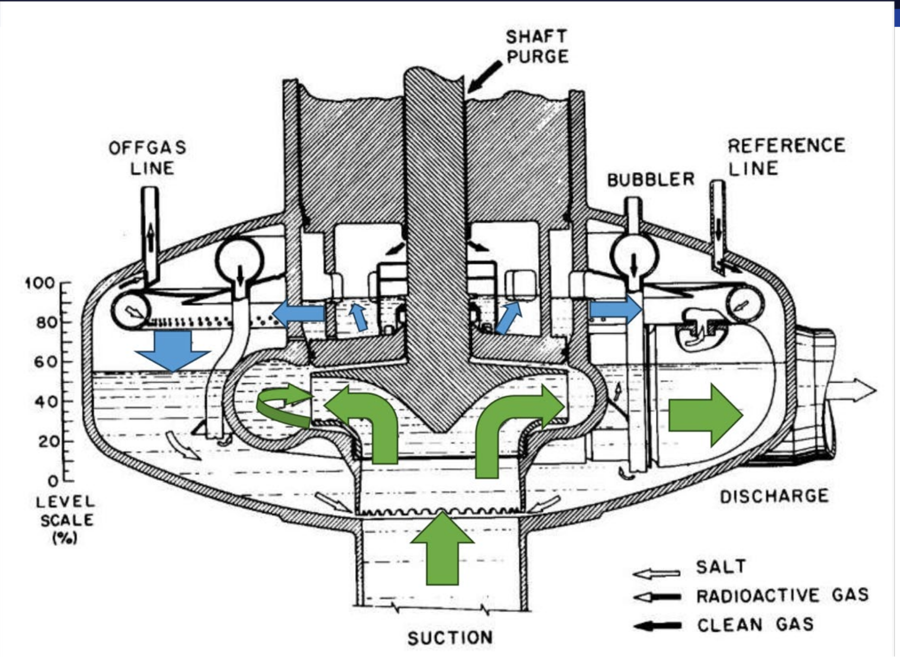


SAM/Griffin Model (II)

- The main Xe-135 removal is through the pump bowl. The pump is modeled as two parts.
  - 5% flow is directed through the bubble stripper. A stripping rate is applied depending on the assumed stripping efficiency η.
  - No Xe-135 removal through bubble removal in the main flow path.

$$Stripping\ rate = v_g \alpha A C_{g,phase} \eta,$$



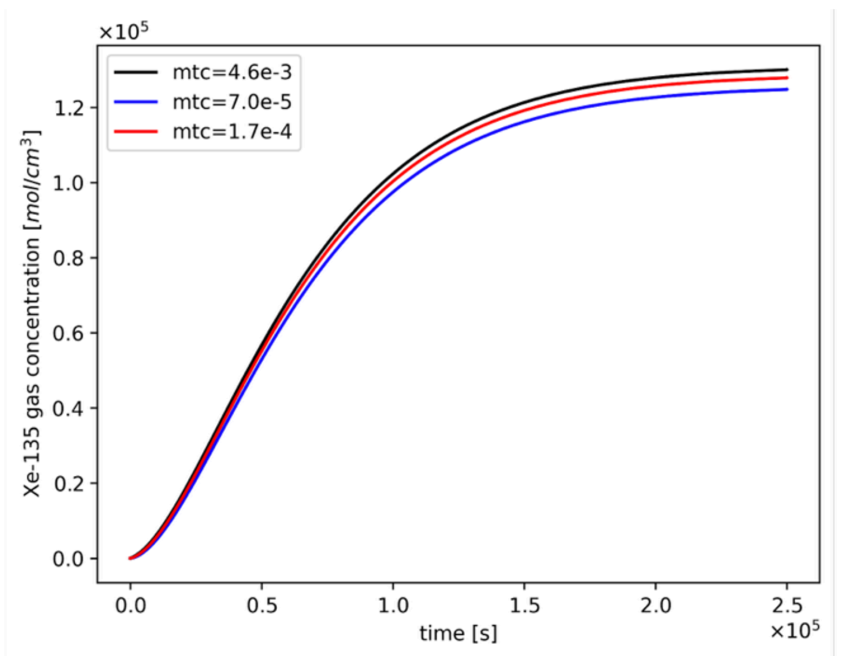


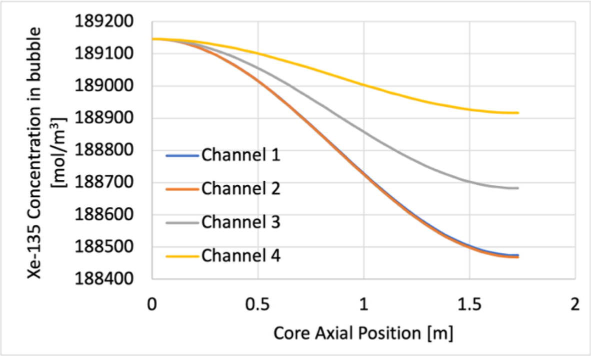
The overall reduction in Xe-135 is small as only 5% flow is diverted to the bubble stripper.

Stripping efficiency is defined as the fraction of Xe-135 removed in the bubble stripper. In this case, 50% Xe-135 is removed in the bubble stripper.

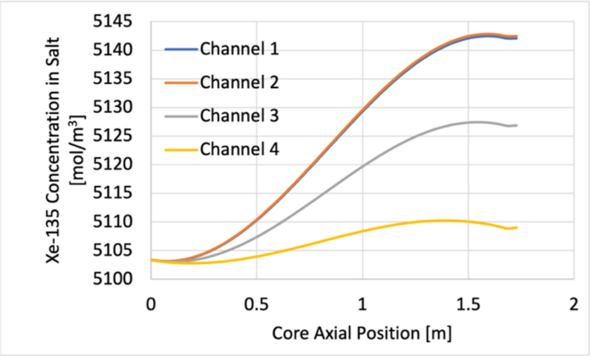
Parametric Study

- Parametric study was performed on mass transfer coefficient, Henry's constant, and void fraction.
  - Most Xe-135 is contained in gas bubble.
  - Dependence on Henry's constant and MTC is small.
  - The concentration in each channel is relatively flat, and the difference is small (due to mixing at the core inlet plenum and long half life comparing to the transit time).





(a)

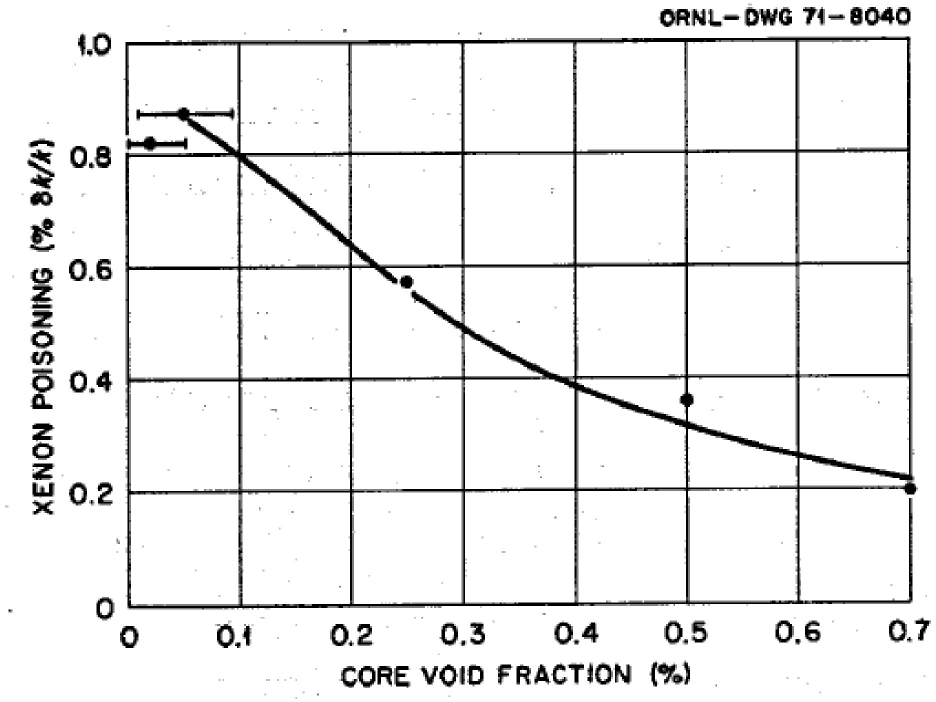


(b)

MTC [m/s]	Henry's constant [mol/m³-Pa]	Notes
4.62E-3	1.85E-4	Both values are obtained from the example in Ref. (Mui et al. 2024)
7.00E-5	1.85E-4	The MTC is obtained from Ref. (Wu et al. 2024).
1.69E-4	1.85E-4	The MTC is obtained from Ref. (Kedl and Houtzeel 1967)
1.69E-4	2.90E-8	The Henry's constant is obtained from (Engel and Steffy 1971).

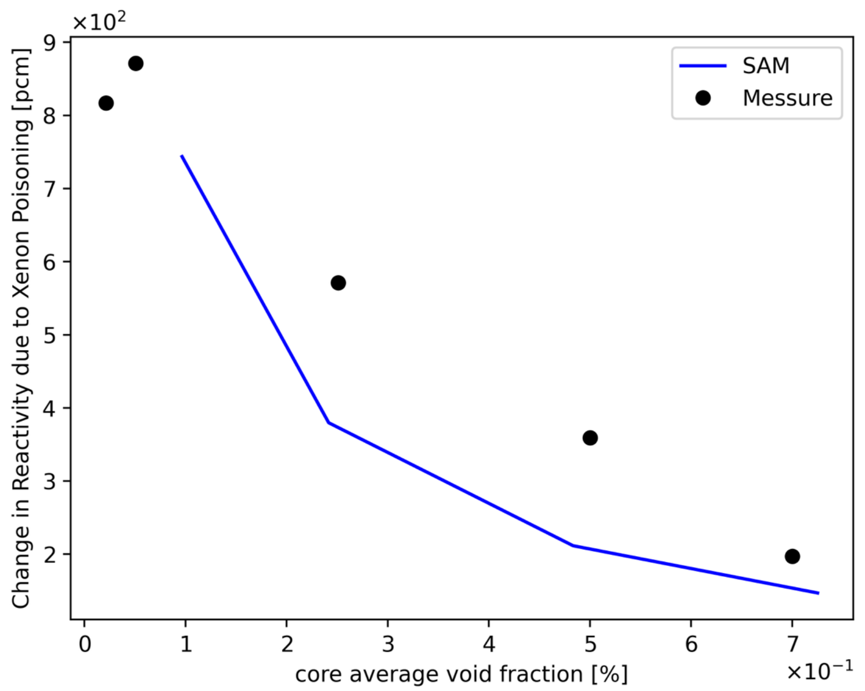
MSRE Xenon Poisoning Experiment

- The Xenon poisoning data was mainly collected through the reactivity balance.
  - Most reactivity feedback was measured at the zero power. At higher power level, the only additional reactivity feedback is due to Xenon presence.
- The experimental data used for the preliminary benchmark was obtained during the U-233 operation.
  - In August 1969, a series of experiments was performed to evaluate the void behavior with various fuel pump speeds and Xenon poisoning.
  - The operation power was 5 MW. Both He and Argon cover gas were tested. The Argon gas data was selected due to its low solubility (current SAM model does not include cover gas dissolution).
  - The reactivity change (Xenon poisoning) was measured at different core void fraction.



Results (I)

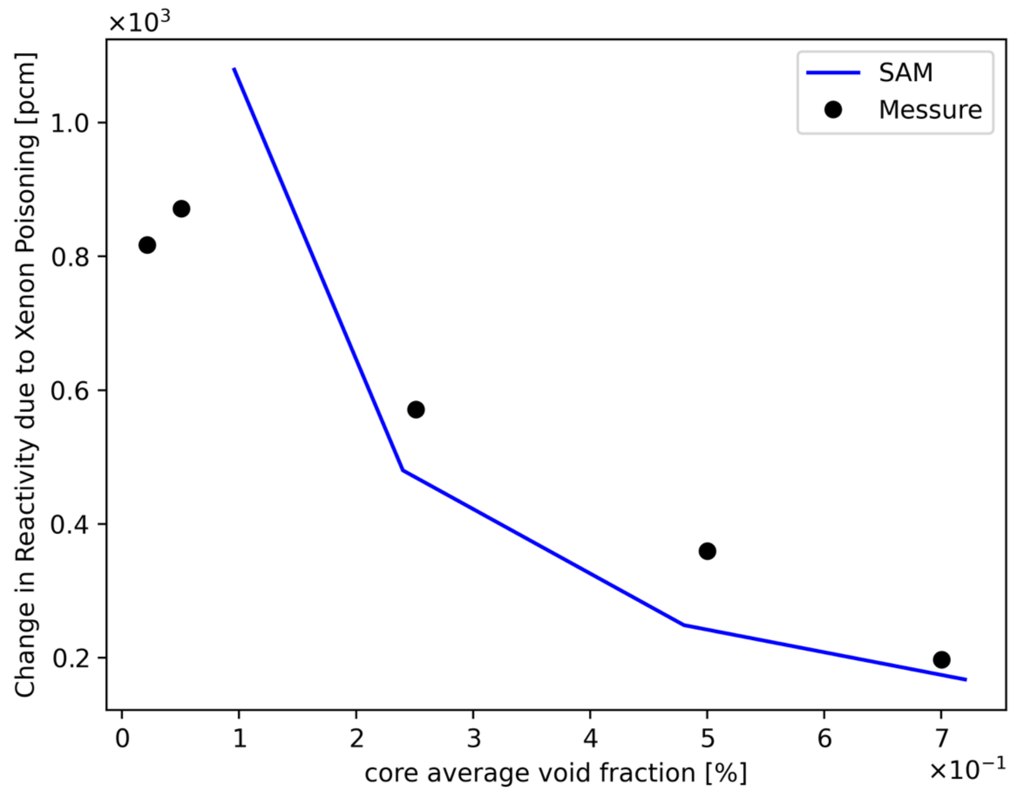
- Using the Kress correlation for salt-to-bubble mass transfer coefficient and a stripping efficiency of 10%, good agreement with the experimental is achieved.
  - This is consistent with the data used in the legacy report (Engel and Steffy 1971).
- The Xe-135 concentration in the bubble is much greater than that in the fuel salt and in the graphite.
  - As the void fraction increases, more Xe-135 would be removed from the primary loop of MSRE in the pump bowl, and the Xe-135 in all parts of the core would decrease accordingly.



Void fraction [%]	Xe-135 Concentration [mol/m³]		
	Bubble	Salt	Graphite
0.1	1.29E+05	1.80E+04	2.43E+04
0.25	7.41E+04	7.39E+03	9.95E+03
0.5	4.31E+04	3.72E+03	5.01E+03
0.75	3.04E+04	2.49E+03	3.35E+03

Results (II)

- Higher stripping efficiency (50%) was indicated to be possible. For this case, a lower mass transfer coefficient can also match the experiment data well.
- Comparing to the low-stripping-efficiency case, the Xe-135 concentration in the graphite and in the fuel salt is about three times larger.
  - This means the Xenon poisoning effect may be larger due to the higher reactivity feedback coefficient for Xenon in the graphite.



Void fraction [%]	Xe-135 Concentration [mol/m^3]		
	Bubble	Salt	Graphite
0.1	3.33E+04	5.80E+04	7.95E+04
0.25	1.62E+04	2.55E+04	3.50E+04
0.5	8.64E+03	1.32E+04	1.80E+04
0.75	5.87E+03	8.84E+03	1.21E+04

Conclusion and Future Work

- The SAM-Griffin MSRE model is being developed with the state-of-the-art capability for Xenon transport calculation. This model is preliminarily validated against the MSRE experiment for a steady state case.
  - The main basic physics are captured in this model.
- Good agreement is achieved for two cases: one with a high stripping efficiency and a low salt-to-bubble MTC, and the other with a low stripping efficiency and a high salt-to-bubble MTC.
  - Validated against the Xenon poisoning (reactivity change).
- There are still potential improvements of the modeling and methods needed.
  - Transient experimental data are available. Performing transient benchmark may shed light on the MTC and stripping efficiency.
  - Better understanding and modeling of the stripping efficiency.
  - Validation of the bubble flow model.
  - Resolving the overestimation of the Xenon poisoning effect at low void fraction.
- Contact me at tfei@anl.gov if you have more questions.

Acknowledge

- This work was made possible with funding from the DOE-NE NEAMS program and with the help from the SAM development team.

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