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Salt spill testing and sampling

Experiments to Advance and Validate Mechanistic Source Term Models for MSRs

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This work was conducted for US DOE Office of Nuclear Energy Advanced Reactor Technologies Molten Salt Reactors Campaign.

MSR Campaign Review Meeting

Motivation and objectives

Motivation

- Analysis of postulated accidents is required to obtain NRC license for new nuclear reactors
- There is a lack of experimental data on the potential consequences of MSR accidents
  - Experimental data needed by vendors preparing for the licensing process[1]
  - Experimental data needed by modelers to guide model development[2]

Objectives

- Provide technical bases for key processes in mechanistic source term and accident progression models by conducting suite of laboratory-scale "salt spill" tests
- Perform analyses using existing models to determine the sensitivity of molten salt heat transfer and spreading towards thermophysical property uncertainties

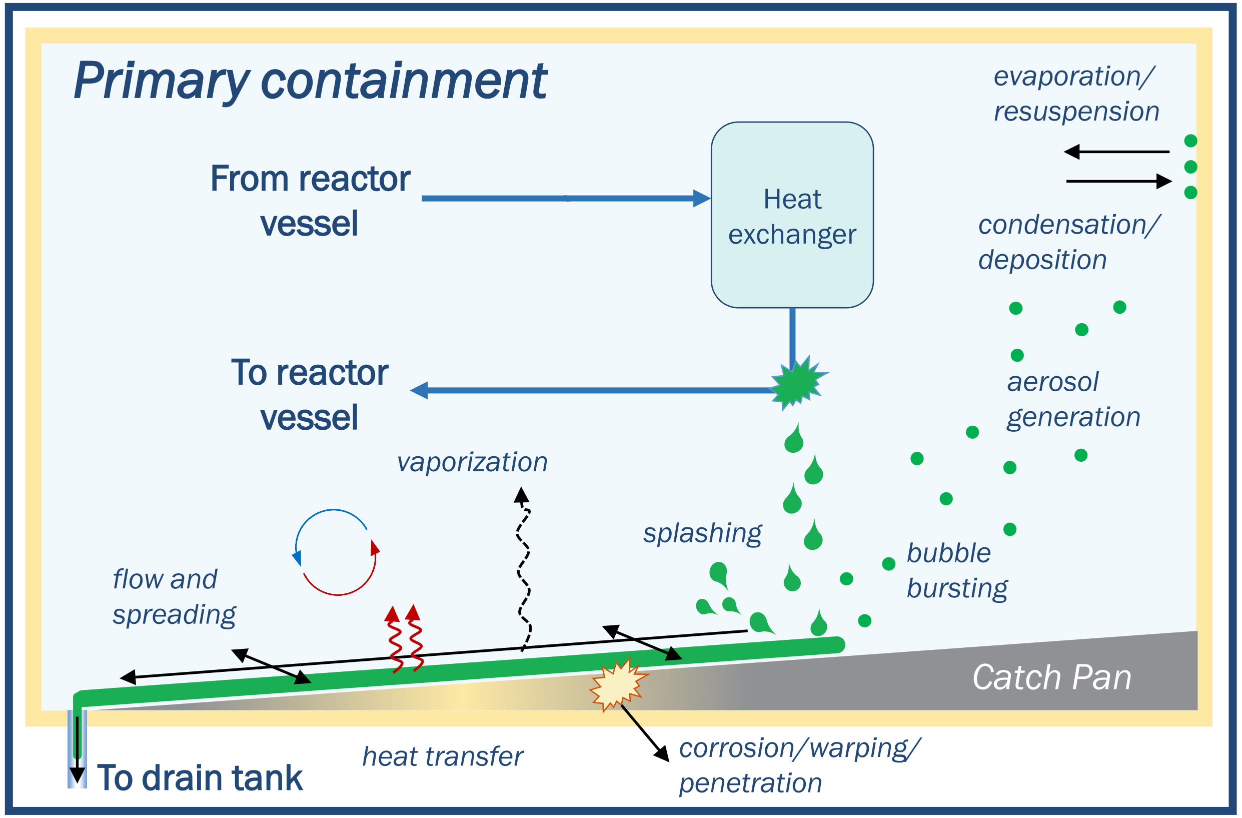
[1]S. Shahbazi and D. Grabaskas, "A Pathway for the Development of Advanced Reactor Mechanistic Source Term Modeling and Simulation Capabilities," Argonne National Laboratory, ANL/NSE-21/21, May 2021. (under review).

[2]J. Leute, B. Beeny, F. Gelbard, and A. Clark, "Identification and Resolution of Gaps in Mechanistic Source Term and Consequence Analysis Modeling for Molten Salt Reactors." 2021. M2RD-21SN0601061

Motivation and objectives

- Common postulated accident scenario for many MSR concepts involves a rupture within the primary loop that leads to hot fuel salt spilling onto the reactor containment floor

For MSR: salt spilling onto primary containment floor



Data needs to quantify associated phenomena

- Spreading and flowing
  - On containment floor
  - Through tubing into drain tank
- Heat transfer
  - Convection
  - Conduction
  - Radiation
- Interactions with structural materials
  - Warping
  - Corrosion
- Vaporization and condensation
- Splashing and aerosol formation

Experimental approach

Separate modular laboratory-scale tests used to:

- Develop methods
- Identify key factors and priorities for integrated tests
- Provide data for individual process models

Test descriptions:

Test 1: Spreading and heat transfer of molten salt on sloped stainless-steel sheets

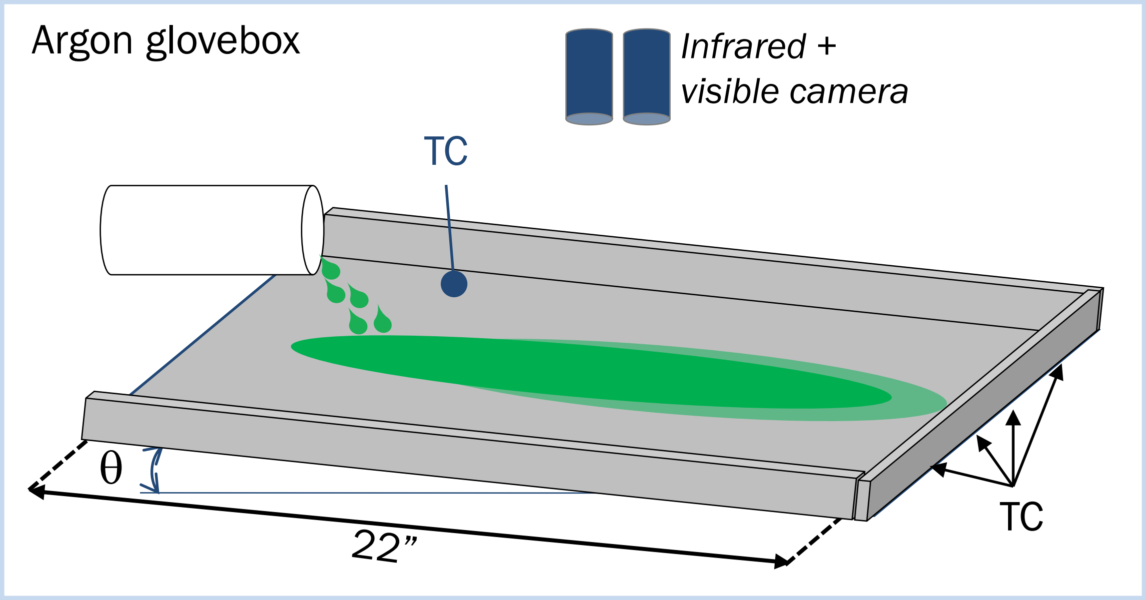
Test 2: Splashing, vaporization/condensation, and aerosol generation from spilled molten salt

Test 3: Flowing and freezing of molten salt in tubing

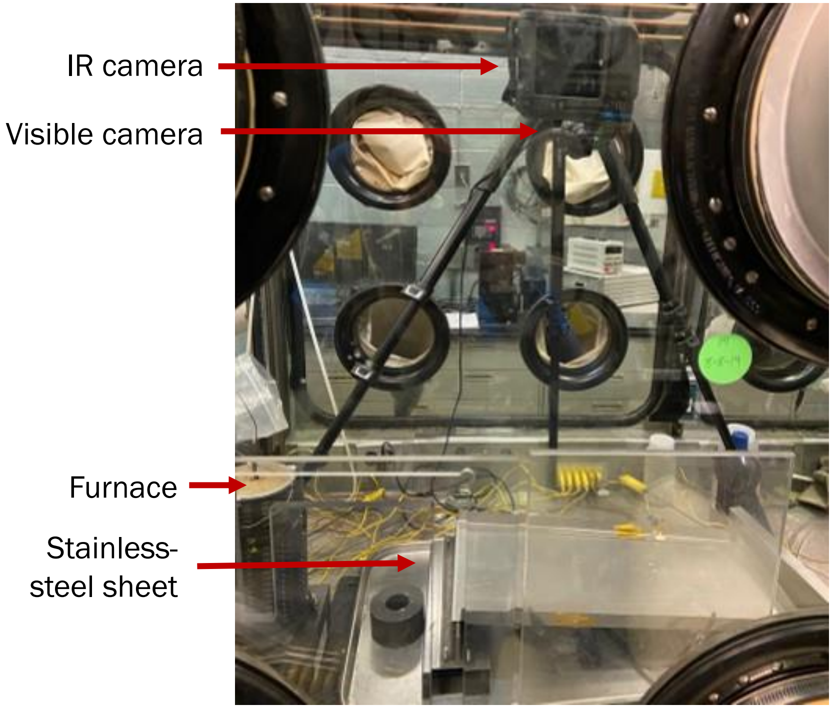
Test 4: Corrosion of stainless steel in molten salt

Molten salt spreading and heat transfer

Objective: To measure the flow rate, flow morphology, compositional heterogeneity, and heat transfer of molten salt that is poured onto a stainless-steel substrate as a function of initial salt temperature, pour mass, pour rate, and salt composition.



Experimental setup inside argon glovebox

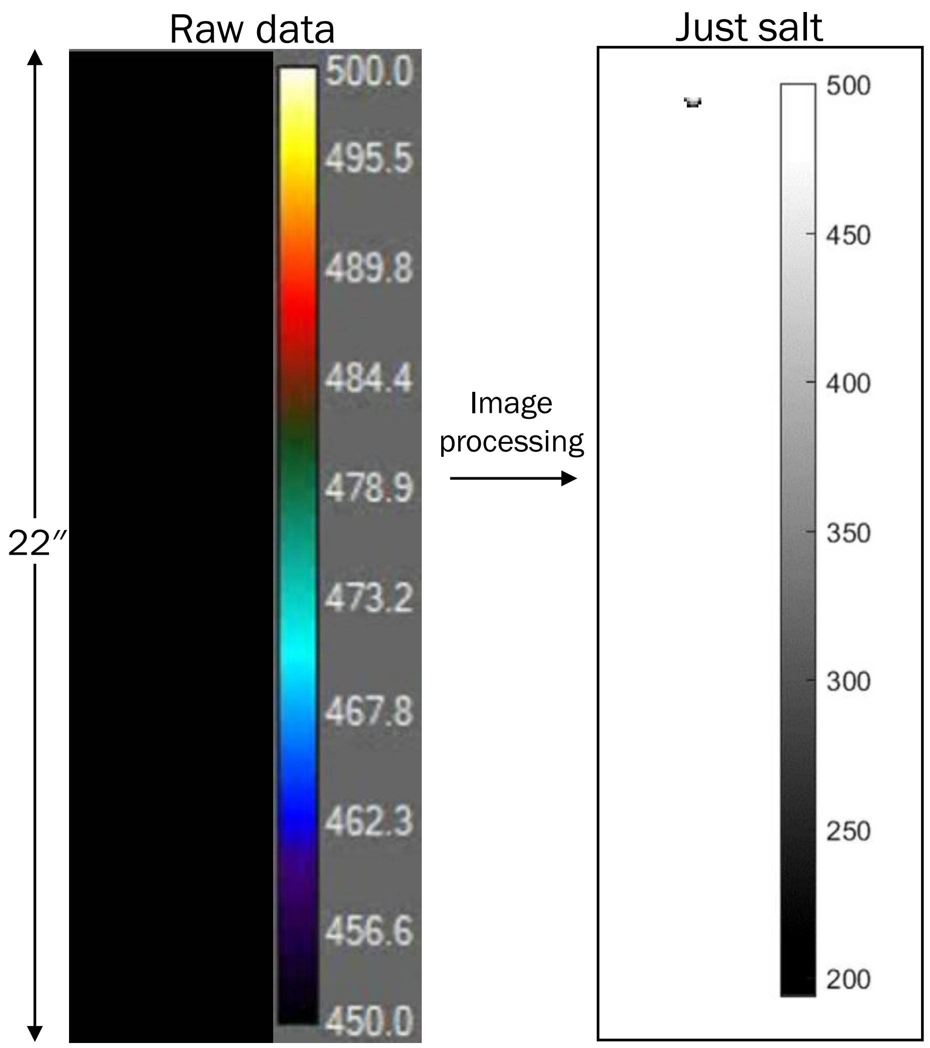


Measurements

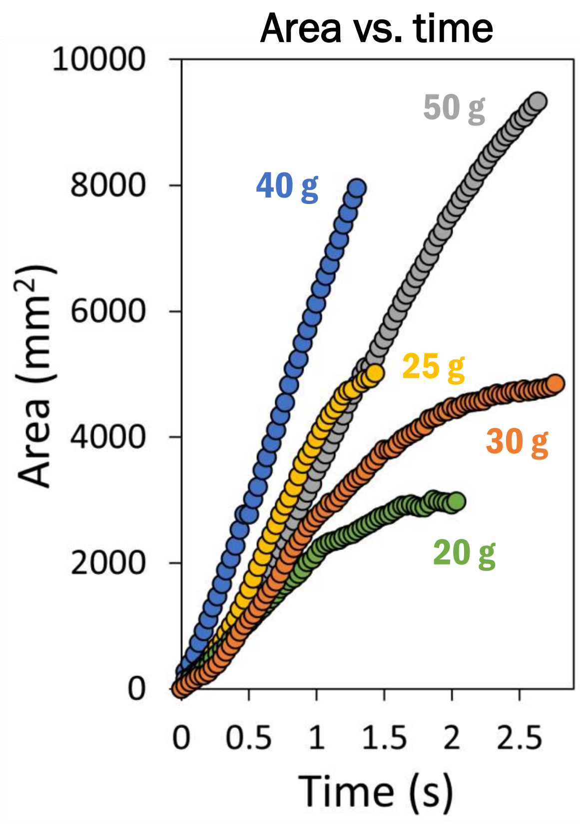
- Flow rate of pour
- Visible camera video
- IR camera video for flow velocity and covered area
- Temperature of substrate underside, substrate surface, salt surface, and atmosphere
- O_2 & H_2O contents of glovebox atmosphere
- Composition of salt after pour

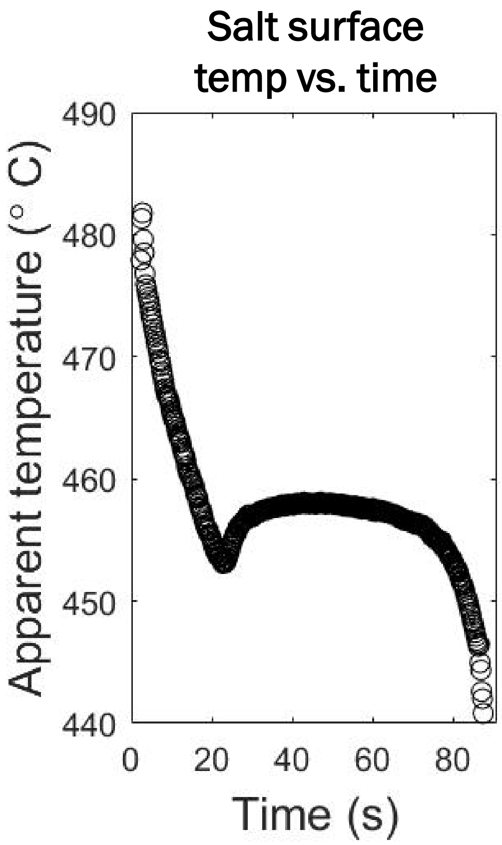
FLiNaK flowing on stainless-steel sheet

Initial salt temp: 500 °C, Mass poured: 40 g



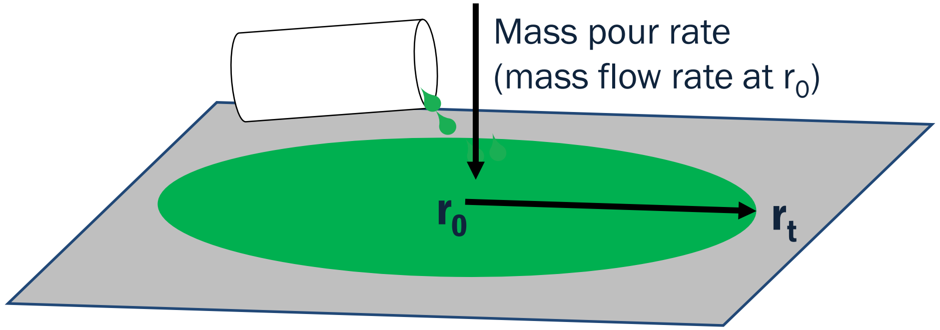
- Results from IR video analysis provide data that can be directly compared with results from spreading and heat transfer models:
  - Leading edge vs. time
  - Covered area vs. time
  - Salt surface temperature vs. time





MELTSPREAD modeling

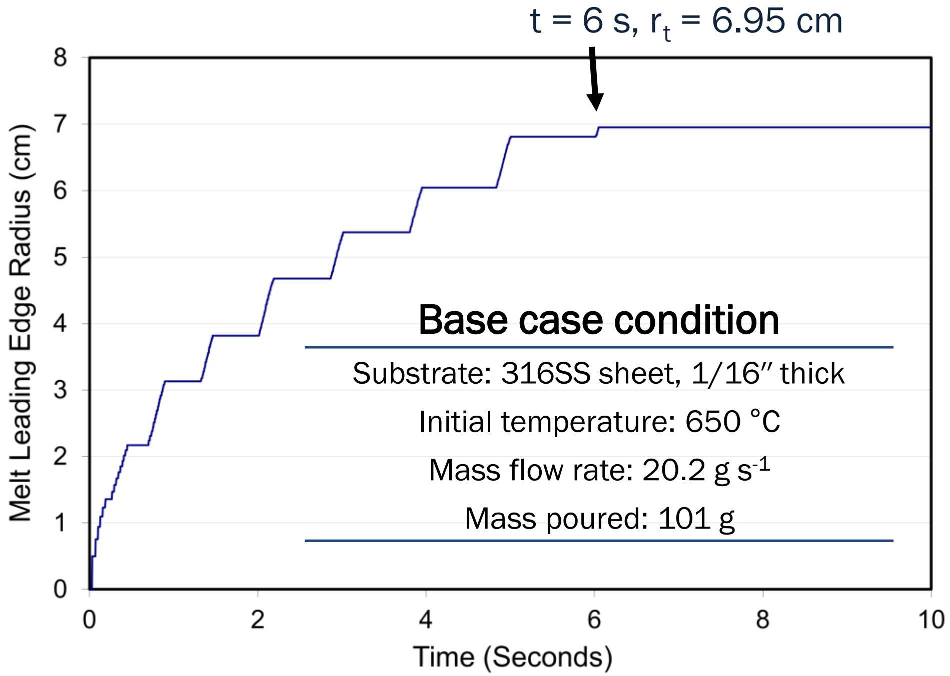
- Modeled gravity-driven spreading and freezing of FLiNaK poured onto a flat stainless-steel sheet
- Initial calculations performed to compare experimental observations to model results and determine model sensitivity to parameter values



radial spreading of FLiNaK poured onto flat sheet

Results from base case

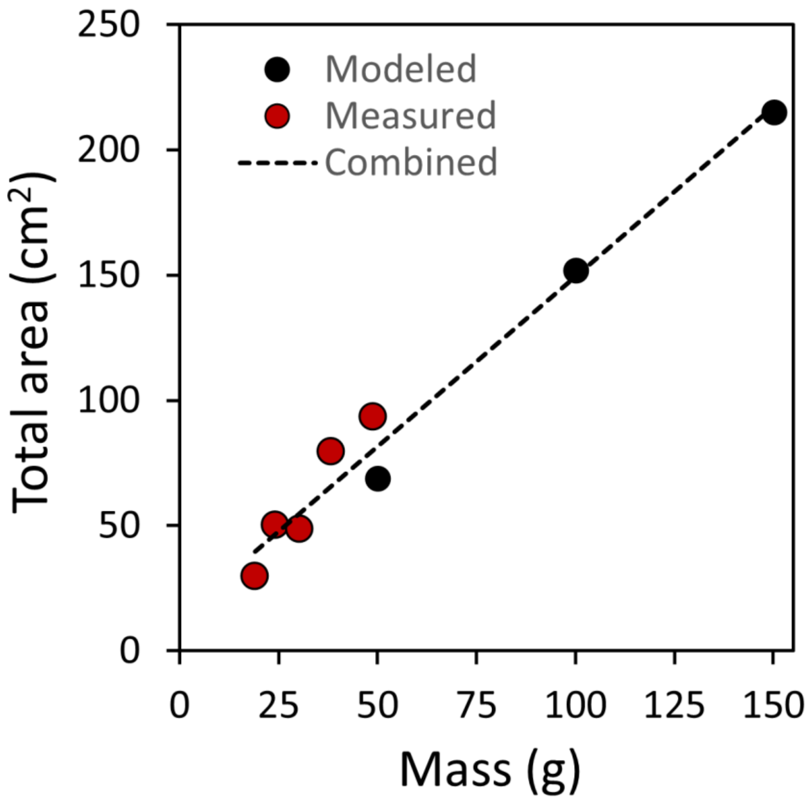
- Salt is still molten 2 minutes after spreading stops; this indicates inefficient heat transfer.
- Spreading stops due to the balance between surface tension and gravity



MELTSPREAD modeling: sensitivity analysis

Which properties/conditions effect radial spreading of FLiNaK poured on flat stainless-steel sheet under inert atmosphere?

- No effect:
  - Emissivity, heat of fusion, heat capacity, thermal conductivity, initial salt temperature, SS plate thickness
- Slight effect:
  - Viscosity and density
- Strong effect:
  - Pour rate: positively correlated with spread velocity but has minimal effect on spread area
  - Pour mass: positively correlated with total spread area but no effect on spread velocity
  - Surface tension: negatively correlated with spread radius



Data needs: The effect of chemical composition (e.g., actinide-bearing salts, chloride vs. fluoride salts, fission product-bearing salts, contaminants), environmental conditions (i.e., air atmosphere), and different substrate materials (roughness) on spreading behavior

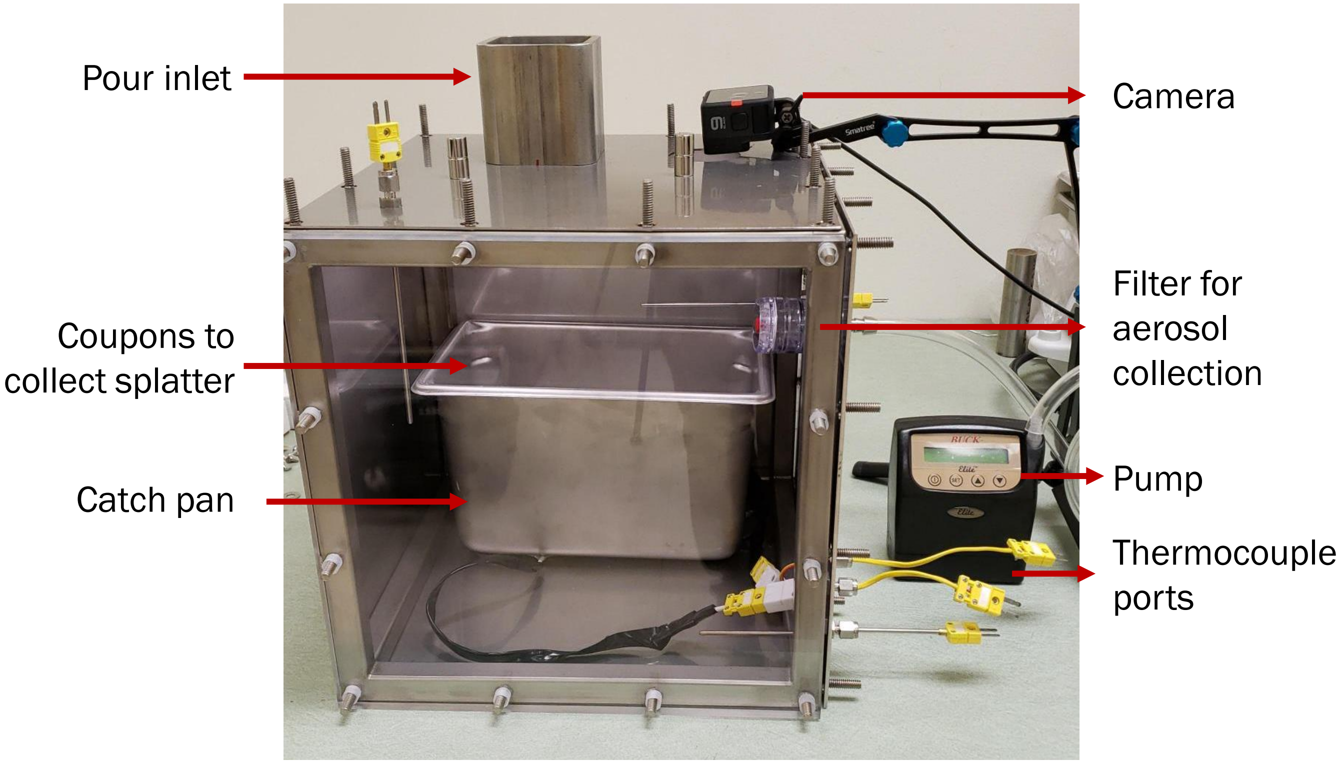
Summary of FY21 accomplishments

- Conducted spreading and heat transfer tests of FLiNaK on stainless-steel sheets
- Performed sensitivity analyses of thermophysical properties on spreading and freezing behavior of FLiNaK on stainless steel
- Corrosion studies of stainless steel in FLiNaK in progress
- Tests to study molten salt splashing and aerosol generation in progress
- Tests to study molten salt flowing and freezing in tubing in progress

Presentations

"Proposed lab-scale salt spill experiments" working group meeting December 21, 2020

"Salt Spill Experiments" at MSR PIRT Meeting on March 17, 2021



Spill containment box for splash tests

Funding and milestones

- Project commenced in FY2021
  - $410k for spill tests
  - $250k for uncertainty assessment

Upcoming milestones

Milestone Number	Title	Status
M4RD-21AN06010511	Annotated outline of salt spill model report	7/21/21
M2RD-21AN0601059	Report for modeling salt spill tests	9/22/21
M3RD-21AN06010512	Uncertainty assessment	9/30/21
M3RD-21AN06010510	Data package for laboratory-scale salt spill tests	10/29/21

All Milestones On Schedule

3-year plan and budget request

Significance of research: This work provides essential experimental data on phenomena pertinent to molten salt spill accidents that is needed by model developers and industry to advance and validate mechanistic source term models for MSR licensing purposes.

- FY2022 $600k
  - Perform suite of lab-scale process tests with chloride salts bearing uranium and surrogate radionuclides ($450k)
  - Iterate with modelers to advance development of process models and guide design of integrated tests ($100k)
  - Develop roadmap for performing integrated accident scenario tests applying insights from small scale tests and modeling ($50k)
- FY2023 $600k
  - Conduct lab-scale integrated accident scenario tests and interface with modeling approaches
  - Design large-scale integrated test apparatus
- FY2024 $1000k
  - Construct apparatus for large-scale integrated accident scenario tests and perform shake-down tests

Towards large-scale, integrated tests

Salt spill tests - ANL

OVERVIEW

Purpose: Provide technical bases and data for modeling key processes in mechanistic source term models

Objectives:

- Generate data package to quantify key phenomena that can occur during a molten salt spill accident for use in the development and validation of models.
- Establish testing and analytical methods for use in integrated accident scenario tests to generate quality data.

IMPACT

Logical Path:

- Develop experimental and analytical methods to quantify processes using well-characterized reference salt
- Demonstrate suitability of test data for use in process models
- Conduct tests using representative chloride and fluoride salts with surrogate fission products and actinides
- Perform integrated tests using knowledge and experience gained from tests on individual phenomena to assess process interactions

Outcomes:

- Quantification of molten salt spreading and flowing behavior, heat transfer, vaporization/condensation, interactions with structural materials, splashing, and aerosol generation.
- Strategy for conducting, assessing, and modeling integrated spill tests
- Programmatic presentations, conference presentations, and reports

DETAILS

Principal Investigator: Sara Thomas
Institution: Argonne National Laboratory
Collaborators: modelers at Argonne and other national labs

FY 2022 Total Funding Requested: $600k

Scenario 1: ($600k) Perform tests on a surrogate chloride salt bearing uranium and fission products for flow, aerosol generation, corrosion, and composition changes. Apply MELTSPREAD to test results. Design integrated lab scale tests.

Scenario 2: ($500k) Perform tests on a surrogate chloride salt bearing uranium and fission products for flow, aerosol generation, corrosion, and composition changes. Apply MELTSPREAD to test results.

Scenario 3: ($400k) Perform tests on a surrogate chloride salt for flow, aerosol generation, corrosion, and composition changes.

DELIVERABLES

FY22

- M3: Report on results of spill tests and MELTSPREAD modeling for chloride salts
- M3: Data base of test results for use in process models
- M3: Roadmap report on pathway towards conducting integrated tests

Questions ?

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