U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Molten Salt Reactor PROGRAM

Salt spill testing for MSR accident progression model validation

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Motivation and Objective

Motivation

- Analysis of the effects of postulated accidents on safety is required to obtain NRC license for new nuclear reactors
- There is a lack of experimental data on processes that determine the potential consequences of molten salt reactor (MSR) accidents
  - Experimental data is needed by vendors preparing for the licensing process
  - Experimental data is needed by modelers to guide and advance model development
- Common postulated accident scenario for many MSR concept involves a rupture within the primary loop that leads to hot fuel salt spilling onto the primary containment floor

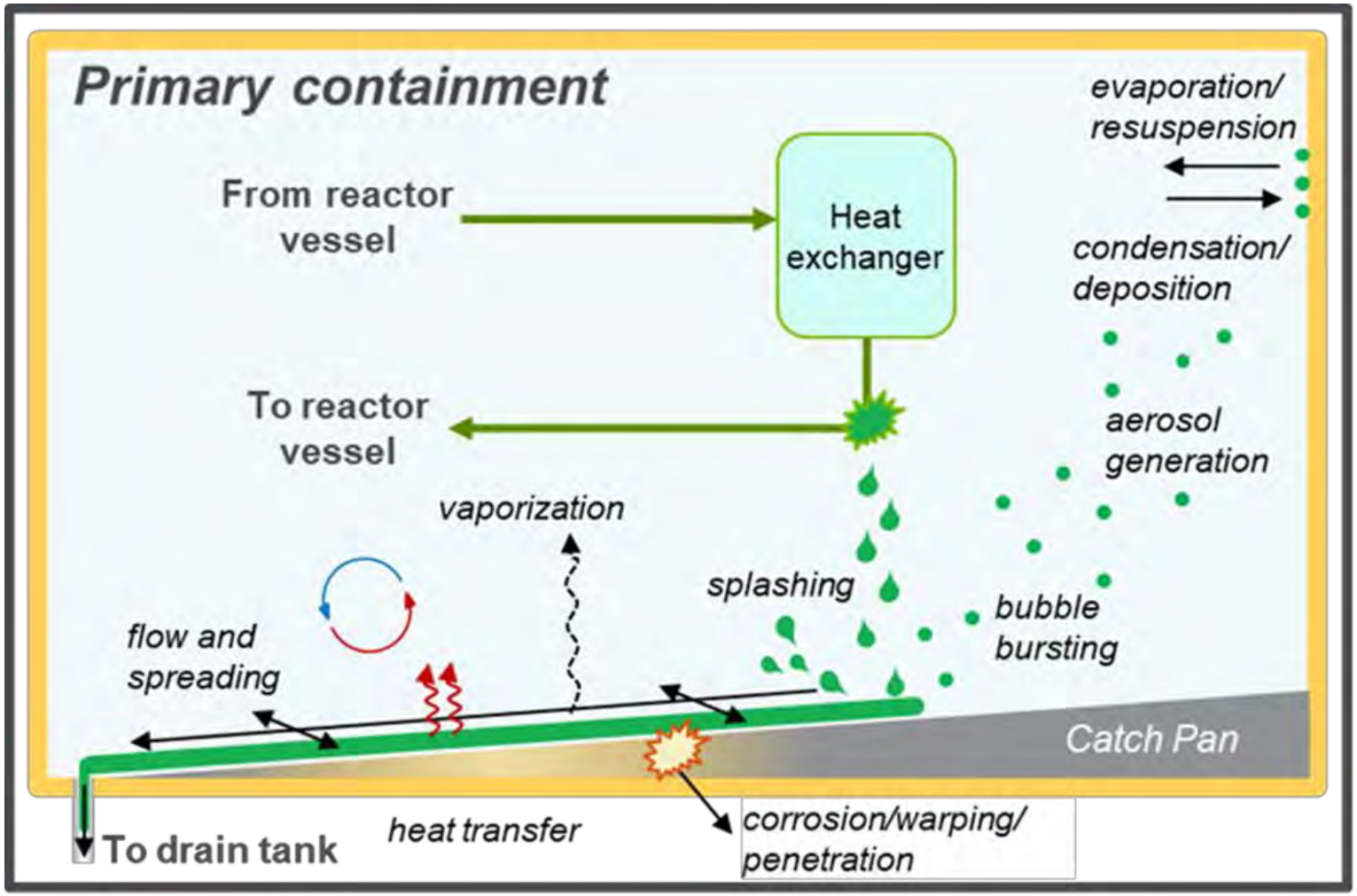
Objective

- To provide the experimental data that are needed to close identified gaps in mechanistic source term and accident progression models for postulated MSR accident scenarios.

Experimental data are needed to fill data gaps in key processes:

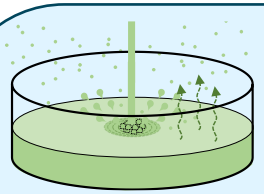
- Spreading and flowing behavior of the bulk salt
- Heat transfer between the salt and its surroundings
- Interactions between the salt and structural materials
- Vaporization and condensation of radionuclide species
- Formation of radionuclide-bearing aerosol and splatter particles

Molten salt spilling from primary loop onto containment floor



Approach to generating experimental data for accident progression model development and validation

- Model simulations of postulated accident scenarios for MSRs will require experimental validation using datasets generated at a relevant scale



Salt spill scenario

Interaction with stakeholders
(model developers and MSR vendors)

Conduct individual process tests at laboratory scale

Conduct integrated process tests at laboratory scale

Design and construct engineering-scale test system for integrated processes

Conduct engineering-scale tests

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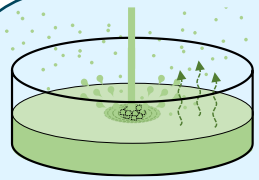

Salt spill scenario

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Rationale for starting at a laboratory scale:

- Identify processes to measure
- Develop methods to simulate processes
- Develop measurement techniques
- Fill data gaps in process models
- Gain experience measuring processes simultaneously

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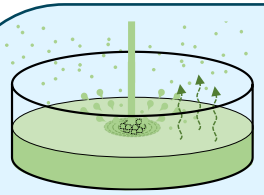


Salt spill scenario

Interaction with stakeholders
(model developers and MSR vendors)

Conduct individual process tests at laboratory scale

FY21

Conduct integrated process tests at laboratory scale

FY23

Design and construct engineering-scale test system for integrated processes

FY23

Conduct engineering-scale tests

FY24 Work Scope

Develop method for real-time measurements of concentration and size of salt aerosol particles

Motivation and Background

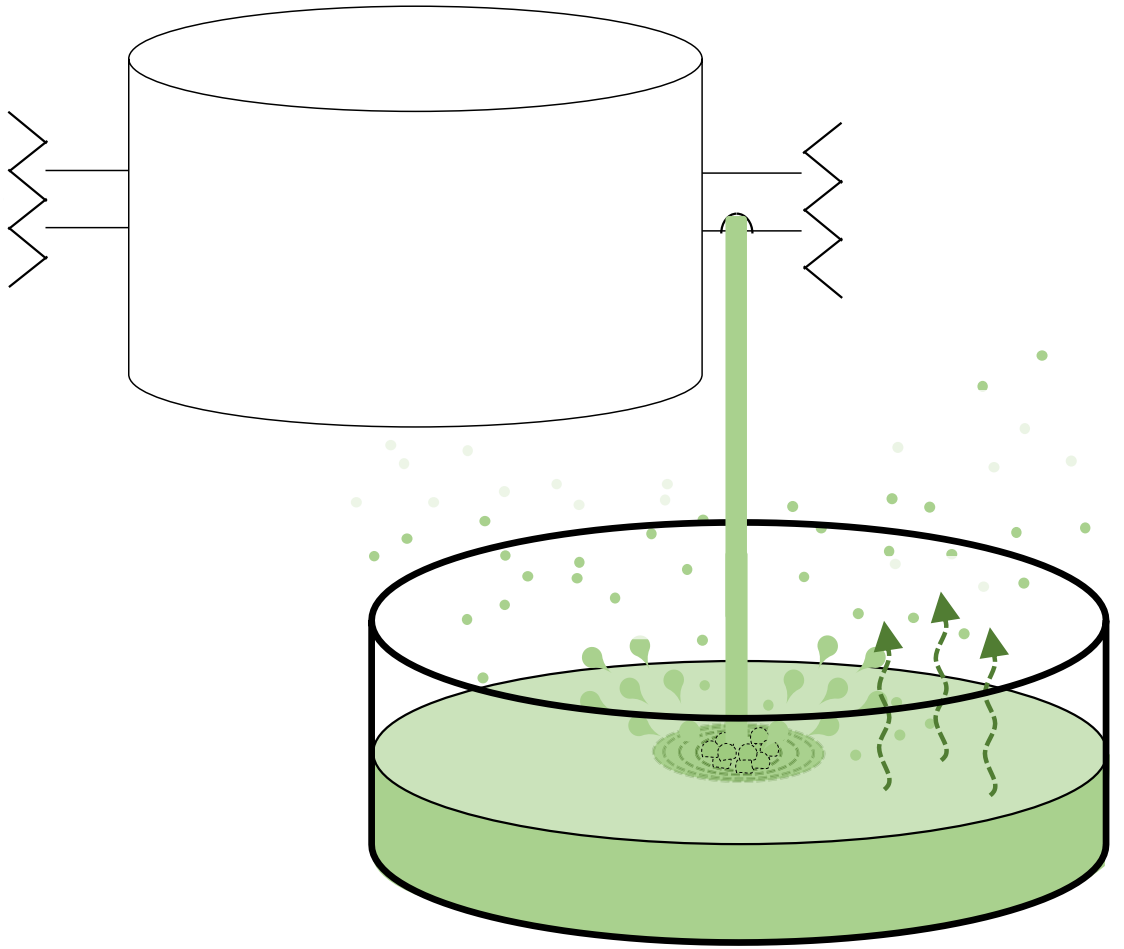
Formation of radionuclide bearing aerosols is particularly important to accident consequence

- Prolonged suspension in atmosphere
- Human health hazard when inhaled

Significant data gaps on aerosol formation mechanisms during and after salt spill accidents

- Effect of initial conditions of accident
- Effect on aerosol size, concentration, and composition

Relevant aerosol formation processes during fuel salt spill accident



FY24 Work Scope

Develop method for real-time measurements of concentration and size of salt aerosol particles

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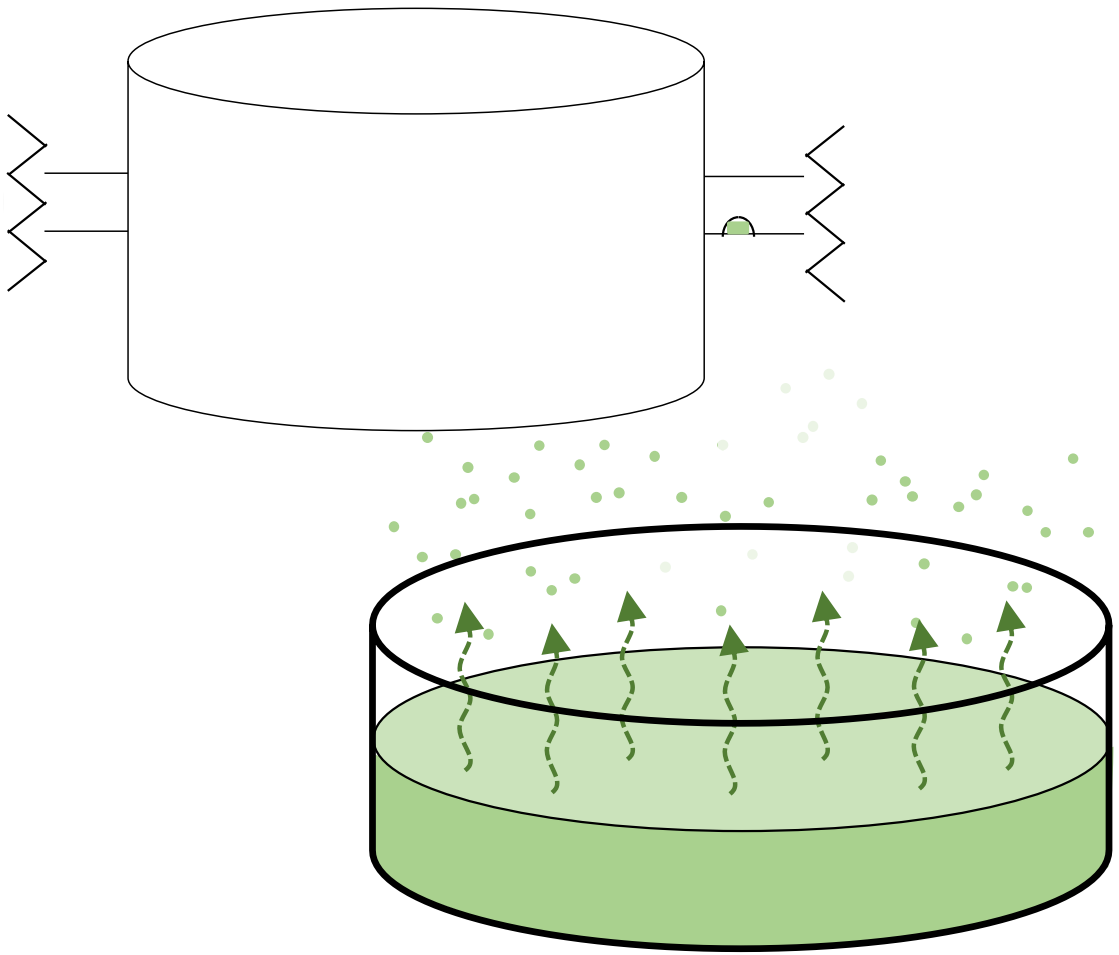
- Effect of initial conditions of accident
- Effect on aerosol size, concentration, and composition

Relevant aerosol formation processes after fuel salt spill accident

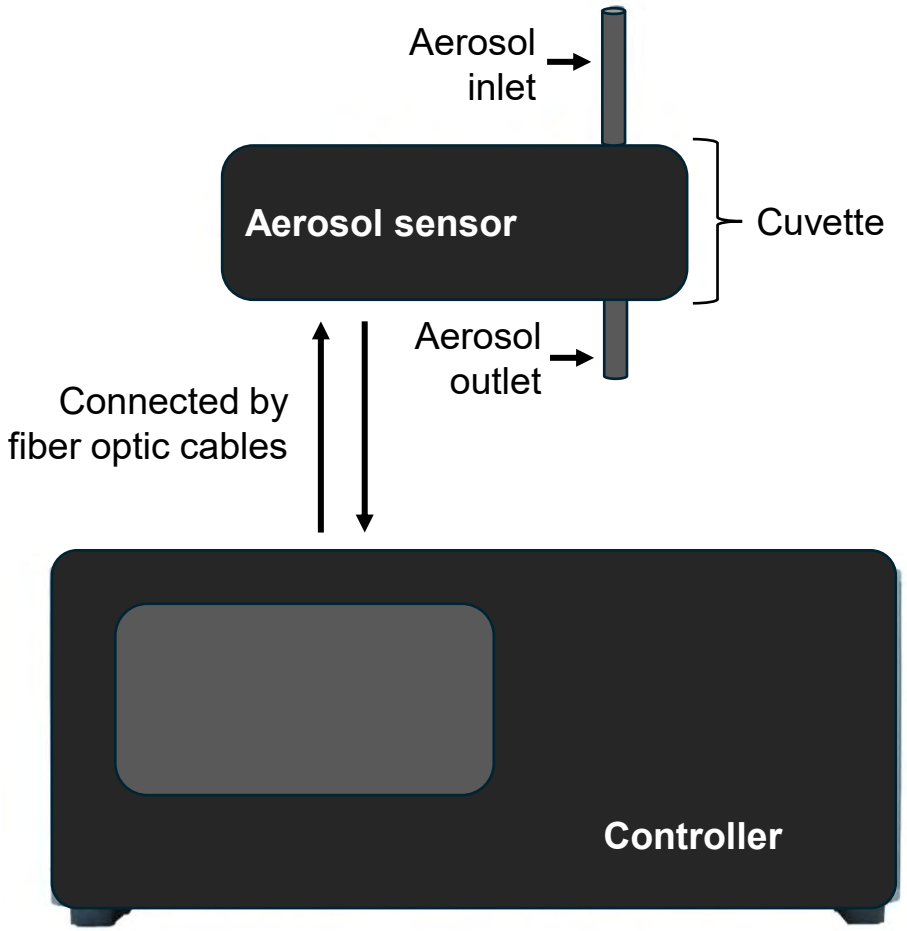


Requirements for aerosol sensor

- Able to measure aerosol size and concentration in gas stream in real-time
- Non-destructive so particles can be collected for post test imaging and composition analysis
- Provide accurate measurements in air and argon atmospheres at multiple temperatures
- Ab wi d ig r r r ri r g (≥ 100 °C)
- Able to withstand corrosive carrier gases
- Able to be easily cleaned and calibrated by user
- Compact and portable

Aerosol sensor system from PALAS

- ✓ Measures aerosol size and concentration in gas stream in real-time using optical light scattering technology
- ✓ Sensor is portable and connected to controller by fiber optic cables
- ✓ Particles are collected on filter downstream of sensor for gravimetric concentration determination (validation) and composition analysis
- ✓ Sensor cuvette can be customized for particularly difficult measurement conditions
  - ✓ Highly corrosive gases
  - ✓ High temperature gases (up to 450 °C)
- ✓ Compatible with multiple gas compositions and gas temperatures
- ✓ Sensor can be easily calibrated and cleaned by user
- ✓ Particle size range: 0.2 µm to 10 µm particle diameter



FY24 Project Phases

1 Method validation using standard particles

- Confirm accurate **particle size** measurement using standard particles of known size
  - Monodisperse polystyrene latex
  - Monodisperse silica
- Demonstrate quantitative accuracy in both **air** and **argon** atmospheres at **room temp.** and **elevated temp.** (e.g., 50 °C & 100 °C)
- Confirm accurate **particle concentration** measurement by comparing light-scattering results to gravimetric results

2 Method demonstration with salt aerosol particles

- Generate molten salt aerosols by vapor condensation mechanism and quantify concentration and size distribution using aerosol sensor
- Simultaneously measure salt aerosol concentration gravimetrically to compare to aerosol concentration measured by sensor
- Simultaneously collect aerosols on coupons and quantify size distribution using SEM to compare to measurements made by sensor

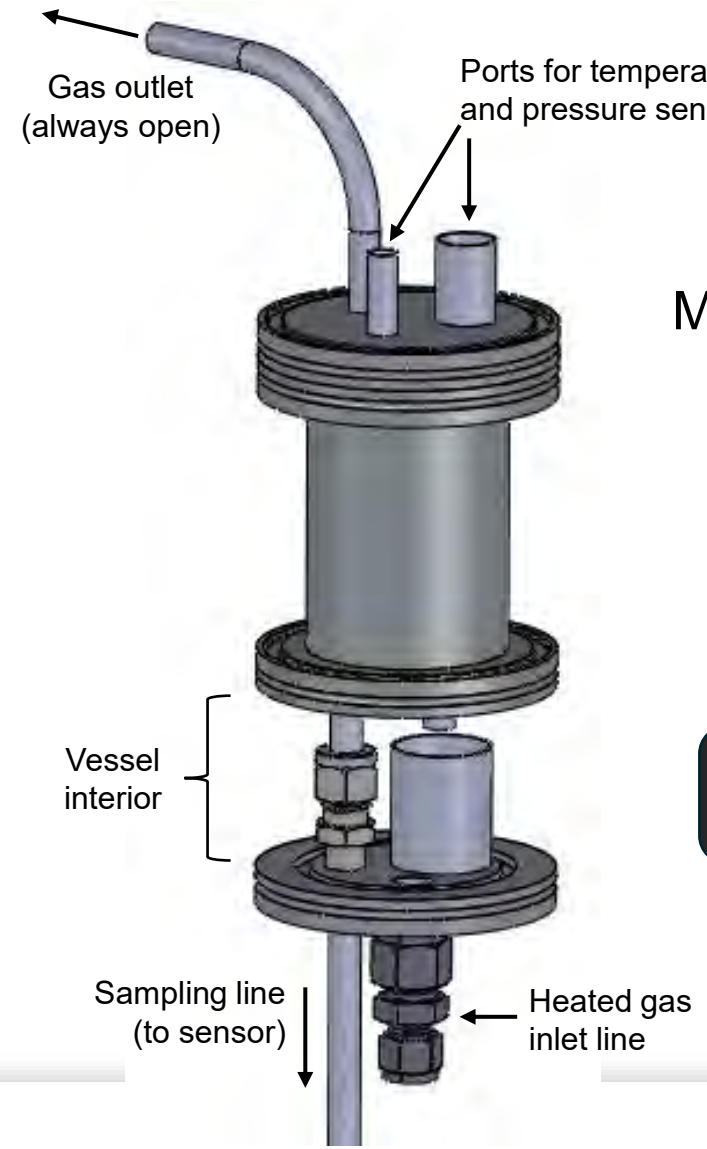
Calibration test system design

Sensor must be calibrated under same conditions as test conditions (i.e., gas composition and temperature)

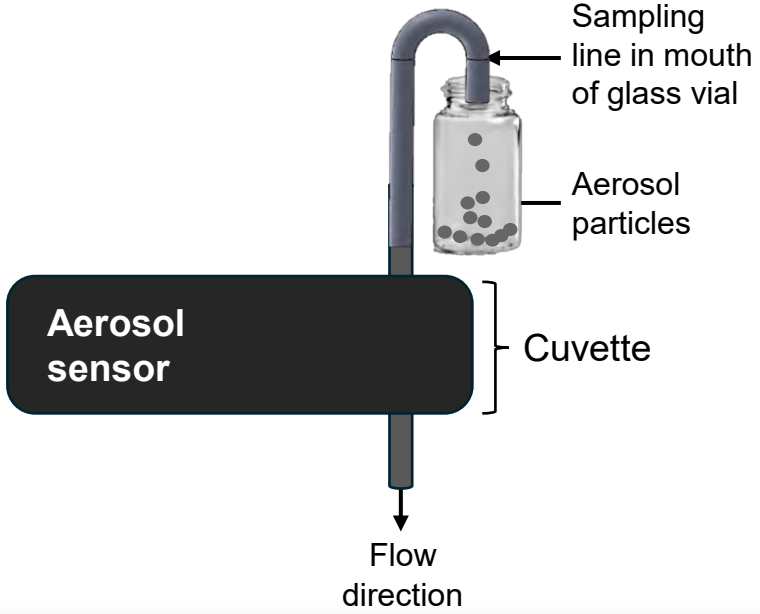
Calibration procedure

1. Flow room temp. or heated gas through vessel
2. Allow vessel to reach a constant temperature and pressure
3. Gently tap vessel to suspend particles in container and start gas flow through aerosol sensor

Drawing of vessel for sensor calibration



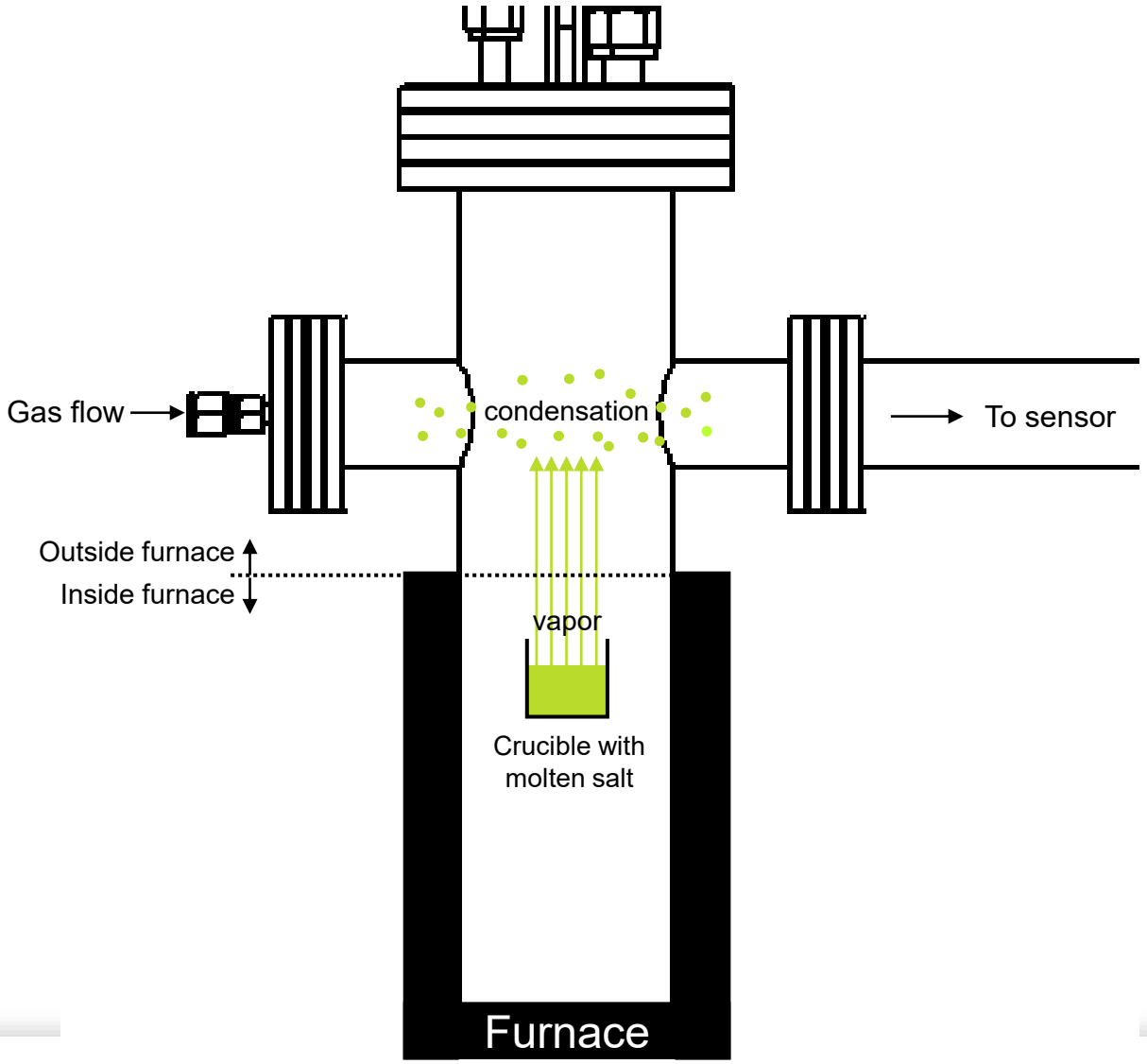
Micrometer-sized particles transported to sensor through U-shaped tube



Salt aerosol test system design concept

- Salt vapor that evolves from molten salt condenses in a cool gas stream and forms small suspended particles (aerosols)
- Initial method demonstration uses:
  - CsI as salt aerosol source
  - Argon as carrier gas
- Vessel can be used in future separate effects tests
  - Salt temperature
  - Salt composition
  - Carrier gas composition (i.e., dry air, humid air)

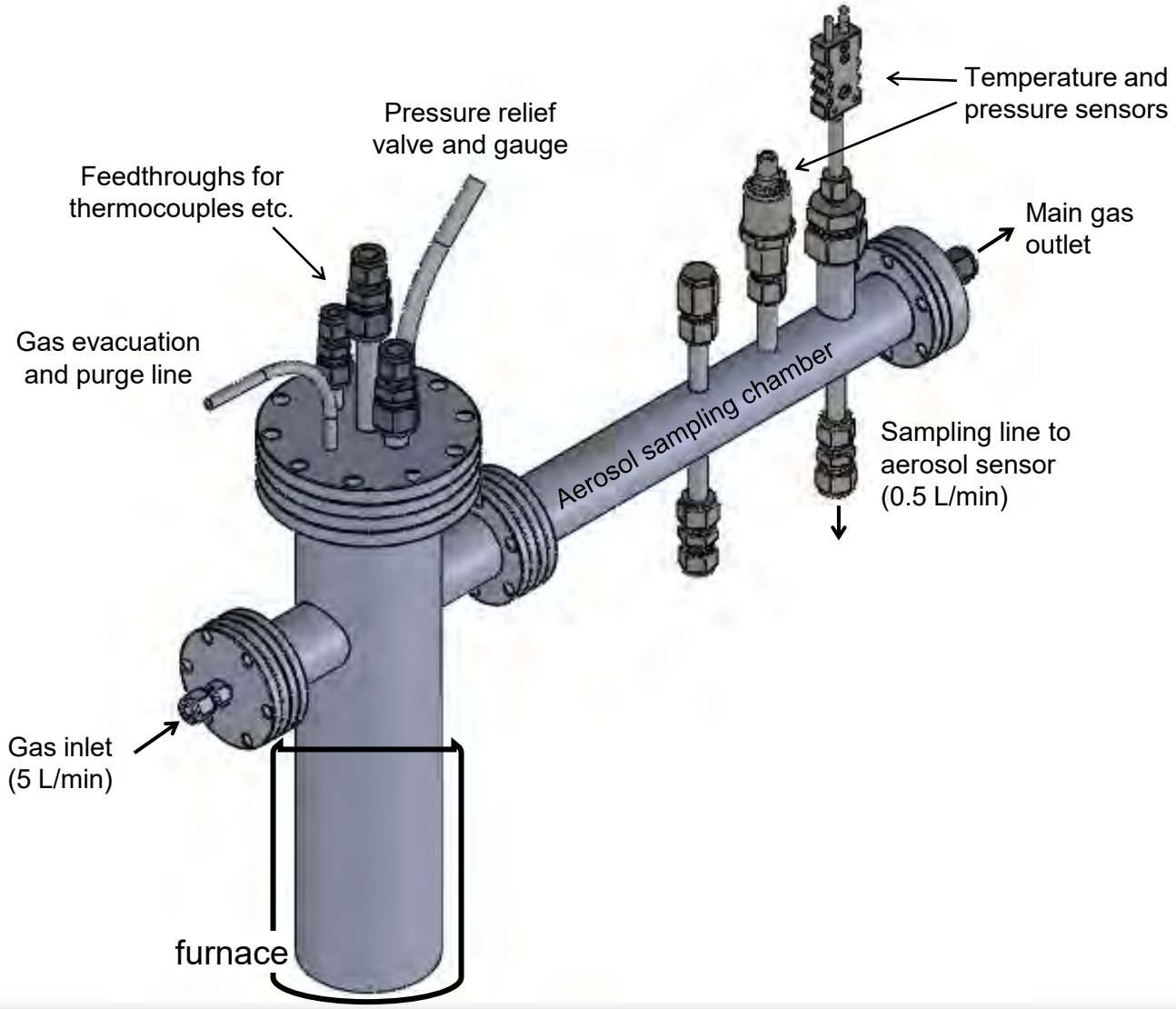
Design concept for salt aerosol generation



Salt aerosol test system design

- Molten salt is heated to target temperature within vessel
- Gas flows through vessel and over salt surface at constant flow rate determined by mass flow controller
- Salt particles formed by vapor condensation are transported to aerosol sampling chamber by carrier gas
- Aerosol sampling chamber serves multiple purposes
  - Enables independent flow rate control through sampling line
  - Allows carrier gas to cool prior to flowing through sampling line

Drawing of salt aerosol generation vessel



Summary of accomplishments and milestones

Task		Status
1	Identify and purchase aerosol sensor capable of non-destructively measuring salt particle size and concentration in gas stream in real time	Complete
2	Design and construct aerosol sensor calibration system	In progress
3	Design and construct salt aerosol generation system	In progress
4	Complete internal safety reviews for calibration and salt aerosol generation systems	Complete
5	Demonstrate accuracy of sensor measurements in air and argon atmospheres at multiple temperatures using standard particles of known size	Starts after Task 2 completion
6	Demonstrate accuracy of sensor measurements in argon atmosphere using salt particles	Starts after Task 3 completion

Upcoming milestones – on schedule

Milestone Number	Title	Due
M3RD-24AN0602061	Complete development of method for real-time salt aerosol concentration and size measurements for molten salt reactor safety assessments	9/17/24

Future work

- Continue to develop and confirm test methods and measurement techniques for future use in engineering scale integrated test system
- Conduct separate effects tests on aerosol formation to generate experimental data that can be used to parameterize process models (coordinate with modelers to ensure testing highest priority variables)
  - Static versus agitated salt
  - Salt and gas temperature
  - Salt compositions that contain actinides and surrogate fission products
  - Presence of humidity and oxygen in atmosphere
- Design and construct engineering scale salt spill test system with input from MSR campaign participants, modelers, and MSR developers
  - Integration of methods and measurement techniques that were developed individually
  - Automated molten salt transfer device that enables spilling kilograms of salt and allows for control of flow rate and flow velocity
- Conduct engineering scale salt spill tests to provide validation datasets for accident progression models (MELCOR)

Thank you

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