Molten Salt Reactor
PROGRAM

Effect of Impurities on Molten Salt Properties

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Effects of Impurities in Fuel Salts

Changes in fuel salt composition over time are expected due to:

- Fission reactions
- Periodic refueling
- Chemical adjustments for redox control
- Ingression of contaminants

FY23[1] and FY24[2] work at Argonne focused on the impact of fission products on properties of molten FLiNaK

FY25[3] work at Argonne focused on quantifying the uncertainties in derived property values

- The effects of composition on the measured values must be distinguished from instrumental and environmental effects to accurately quantify the salt properties

FY25[4] and FY26 work focuses on determining the effect of corrosion products and oxides on properties of molten FLiNaK

[1] M.A. Rose, L.D. Gardner and T. Lichtenstein. Property Measurements of NaCl-UCl3 and LiF-NaF-KF Molten Salts Doped with Surrogate Fission Products. ANL/CFCT-23/23. September 2023

[2] L.D Gardner, K.A. Chamberlain and M.A. Rose. Property Measurements of LiF-NaF-KF Molten Salts Doped with Surrogate Fission Products. ANL/CFCT-24/23. September 2024.

[3] L.D. Gardner and M.A. Rose. Uncertainty Analyses of Molten Salt Property Measurements. ANL/CFCT-25/5. March 2025.

[4] L.D. Gardner, E.A. Dowding, J. Rojas and M.A. Rose. Property Measurements of LiF-NaF-KF Molten Salts Doped with Corrosion Products and Oxygen. ANL/CFCT-25/22. September 2025.

Impact of Fission products

Measurements of fission product doped-FLiNaK salts were compared with measurements of FLiNaK without dopants.

- Compositions were inspired by depletion calculation results for MSRE

DSC was used to measure the melting temperature and heat capacity of the molten salts

- Measurements were compared to previous measurements of FLiNaK synthesized with as-low-as-achievable concentrations of contaminants to assess the impact of impurities

Doped FLiNaK Compositions (mol %)

Component	Composition 1 (low burnup)	Composition 2 (high burnup)
FLiNaK	99.65	98.23
ZrF_4	0.05	0.25
Mo	0.05	0.25
NdF_3	0.05	0.25
CeF_3	0.05	0.25
CsF	0.05	0.25
CsI	0.005	0.025
SrF_2	0.05	0.25
Ru	0.05	0.25
Te[a]	0.005	0.025

[a] Added as Na_2Te

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Fission Products Depress Melting Point

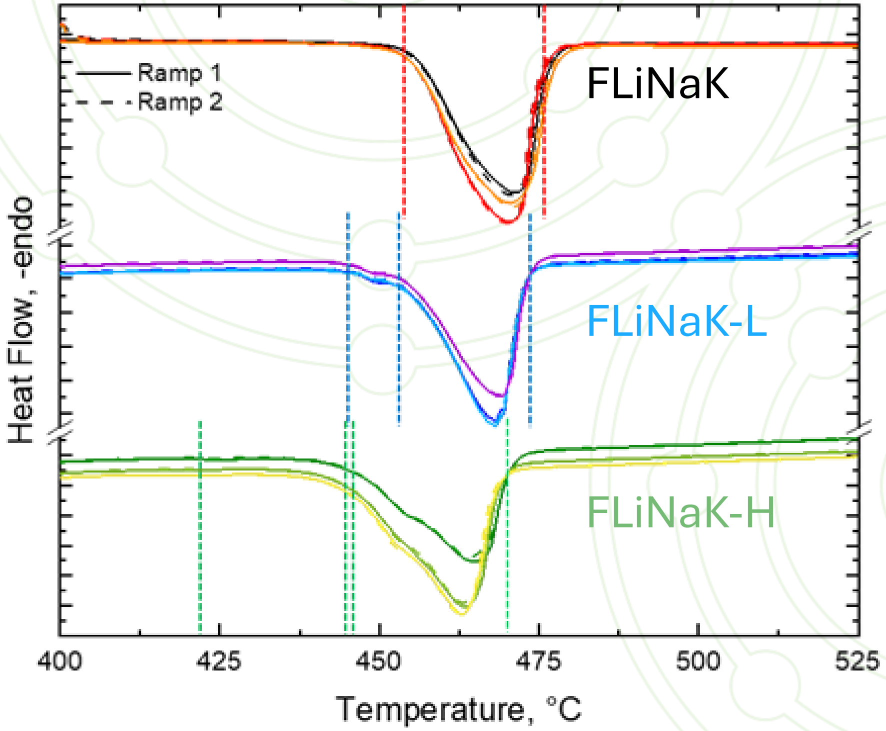
Measured by using a Differential Scanning Calorimeter (DSC)

Lower onset of melting and liquidus point temperatures were measured for both low-burnup FLiNaK and high-burnup FLiNaK compared to those of pure FLiNaK

- A small peak detected with an onset at 445 °C in analyses with both doped FLiNaK salts
- Additional pre-peak with an onset near 419 °C is observed in high-burnup FLiNaK measurements

Differences in liquidus end point temperatures are greater than the expanded uncertainty of 4 °C determined from temperature calibration

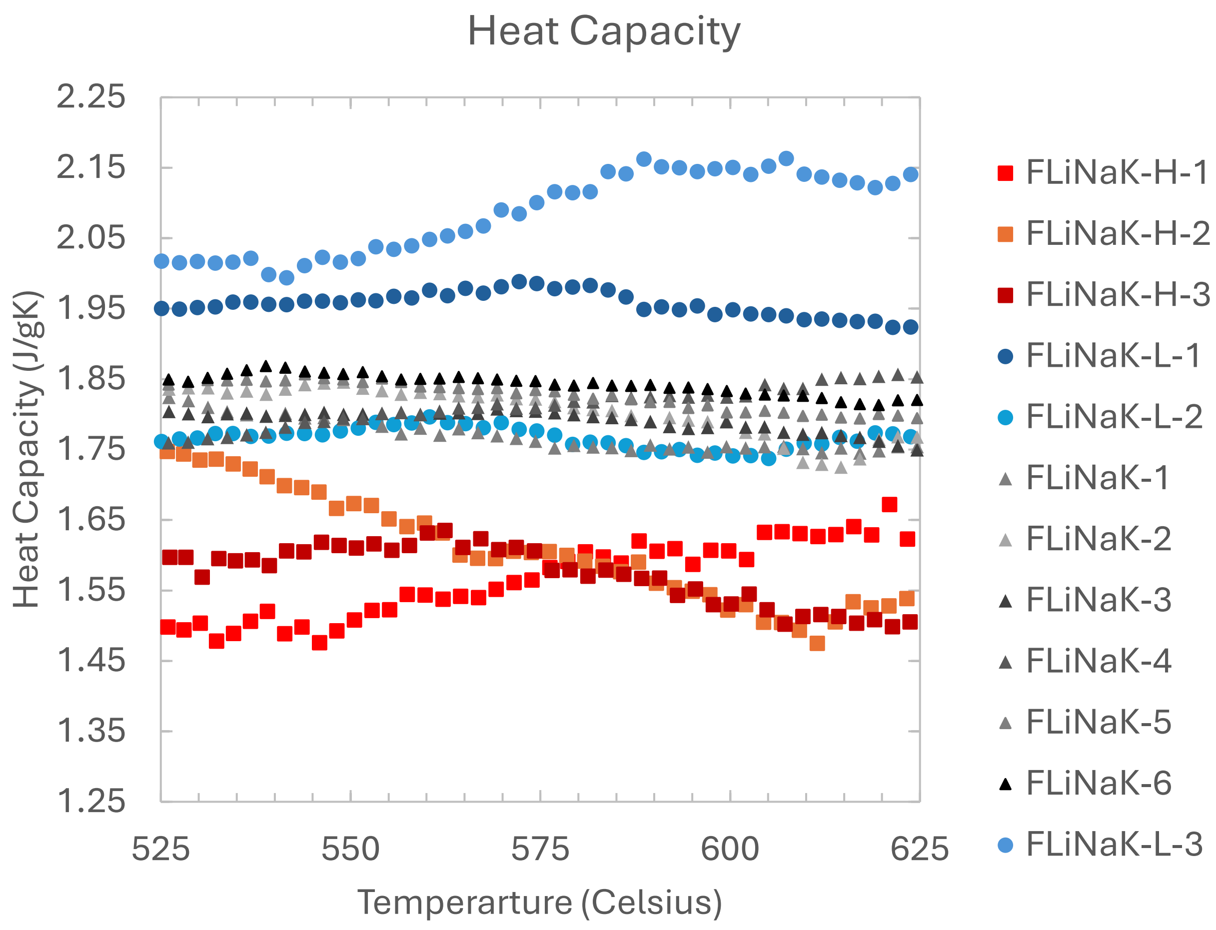
Decrease in melting temperatures and presence of low-temperature transitions due to addition of surrogate fission products



Salt	Onset, °C	Liquidus End Point, °C	Additional Transitions, °C
FLiNaK	455	476	-
FLiNaK-L	454	473	445
FLiNaK-H	446	469	445, 419

Effect of FPs on Heat Capacity

- Thermal responses of FLiNaK, FLiNaK-L, and FLiNaK-H were measured by using DSC and used to calculate heat capacity by the ratio method
- Three samples of each doped salt mixture were measured and six of FLiNaK without dopants



FLiNaK-L has high variance between samples while FLiNaK-H has better between sample precision – reflects ability to uniformly distribute a constituent at a larger concentration

FPs at higher concentrations measurably depress heat capacity

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Effect of Corrosion Products

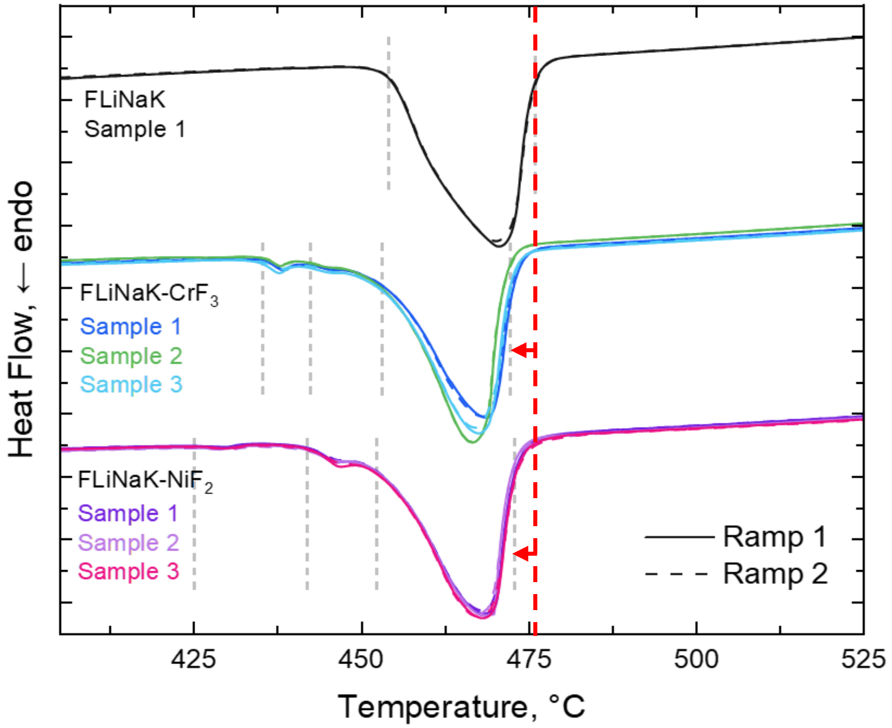
- Determining the effect of corrosion products on the properties of molten salt

Doped individual batches of FLiNaK salt with 1 wt % each of nickel fluoride and chromium fluoride

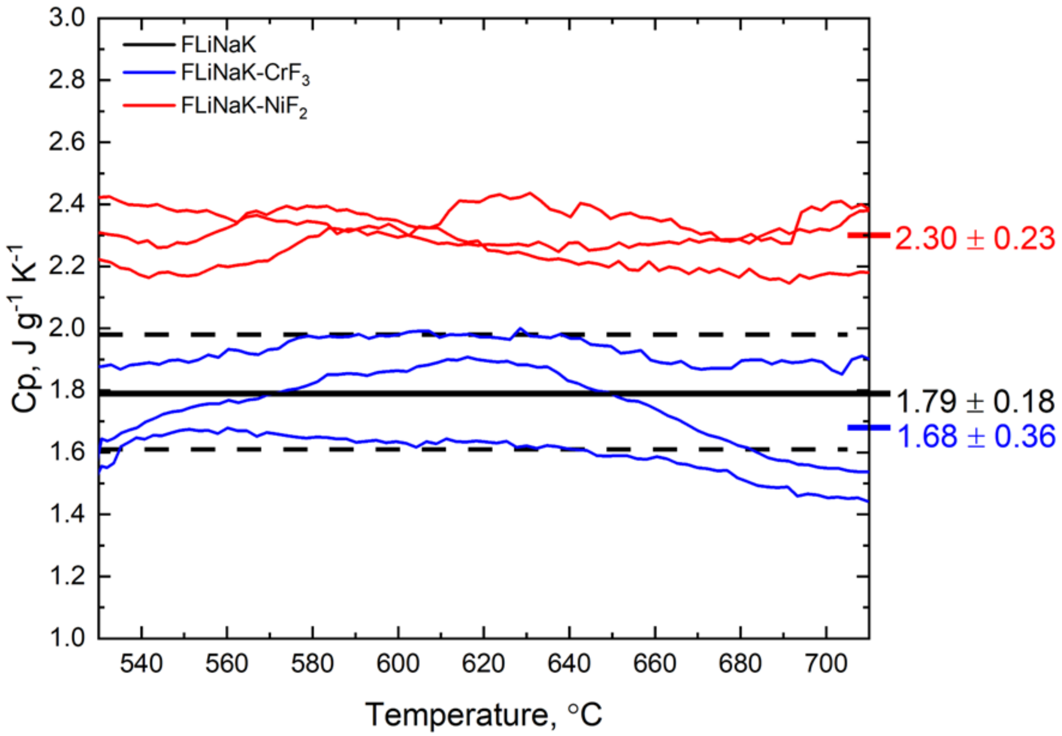
- DSC was used to measure the melting temperature and heat capacity of the molten salts
- Laser flash analysis is being used to determine the thermal diffusivity of the molten salt
- Density is being measured by a hydrostatic method
- Viscosity is being measured by rotational viscometry

Measurements will be compared to previous measurements of FLiNaK synthesized with as-low-as-achievable concentrations of contaminants to assess the impact of impurities

Measured effect of corrosion products



Measured thermal behavior of FLiNaK with and without 1 wt % corrosion product dopants measured by DSC.



Measured heat capacity of FLiNaK with and without 1 wt % corrosion product dopants, measured by the ratio method by using DSC.

Decrease in melting temperatures and additional low-temperature transitions due to ~1 wt % corrosion products

Increase in heat capacity due to ~1 wt % NiF_2

[1]L.D Gardner, E. Dowding, J. Rojas and M.A. Rose. Property Measurements of LiF-NaF-KF Molten Salts Doped with Corrosion Products and Oxygen. ANL/CFCT-25/22. September 2025.

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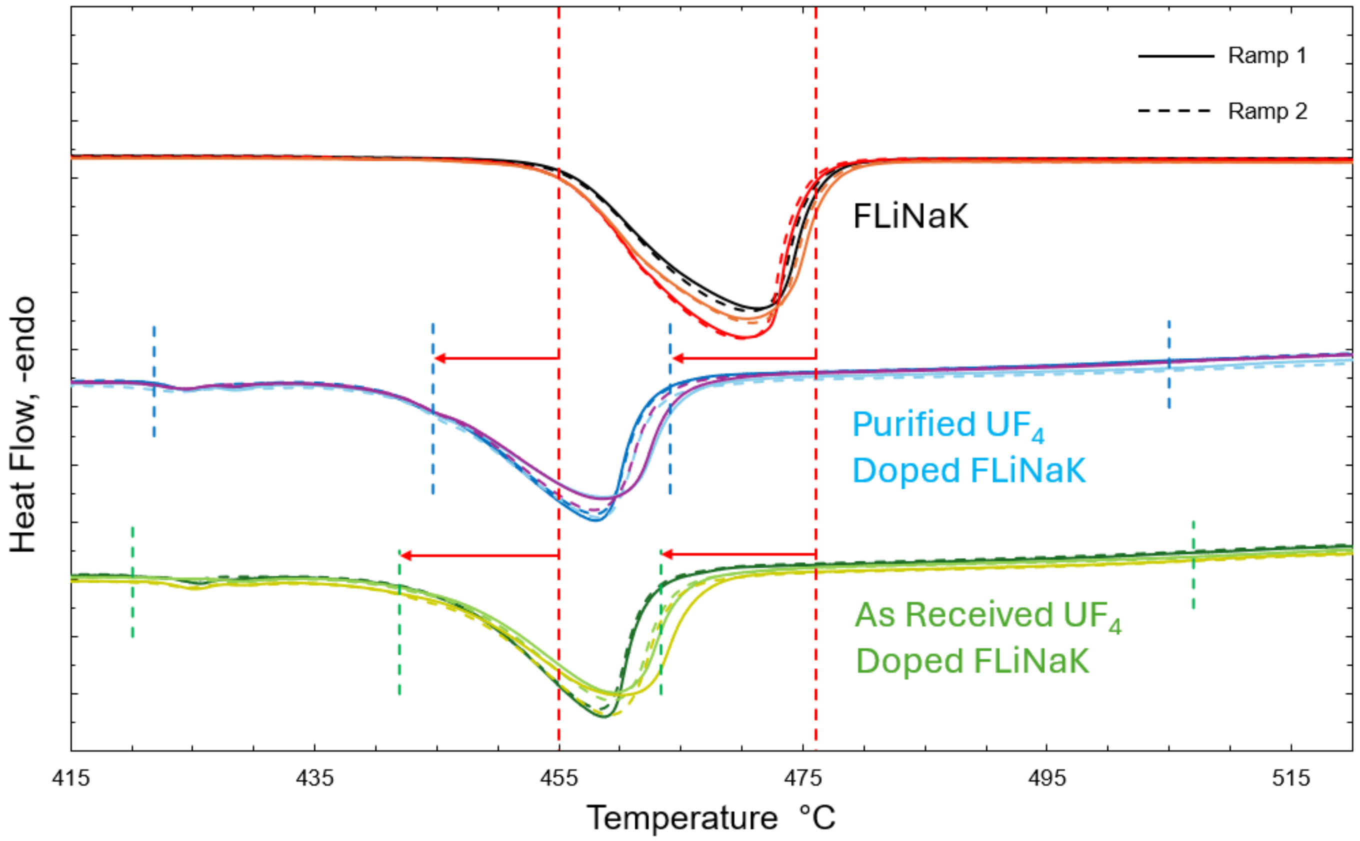
Effect of Oxide impurities

Decrease in melting temperature and low-temperature transitions due to UF_4



DSC was used to measure thermal transitions of three samples each of FLiNaK doped with ~12 wt % UF_4 with different levels of UO_2 contamination:

- **As-received UF_4 containing ~10 wt % UO_2**
- **Purified UF_4 containing < 1.5 wt % UO_2**

Addition of ~12 wt % UF_4 to FLiNaK caused expected changes in thermal behavior :

- **Lowers melting temperature**
- **Introduces low temperature features**
- **Produces extended shouldering of liquidus**

The differences in the transition temperatures (> 4° C) measured with different samples of FLiNaK doped with UF_4 from both sources indicates compositional non-uniformity of salt mixtures

- **Effect is more pronounced in salt with higher oxide content**
- **Oxide is not soluble in salt and is likely not distributed homogeneously**

[1]L.D Gardner, E. Dowding, J. Rojas and M.A. Rose. Property Measurements of LiF-NaF-KF Molten Salts Doped with Corrosion Products and Oxygen. ANL/CFCT-25/22. September 2025.

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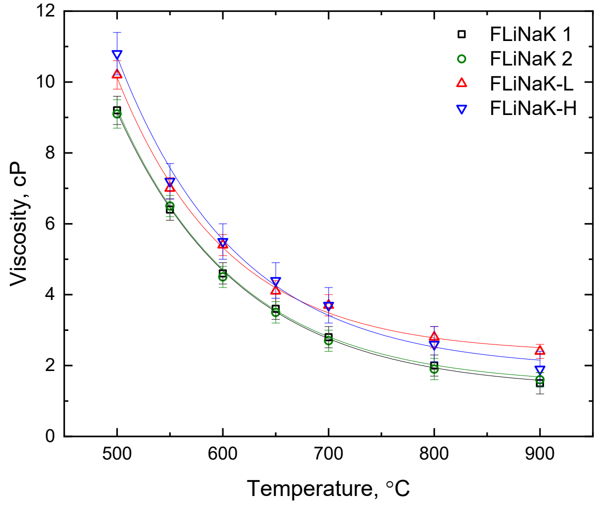
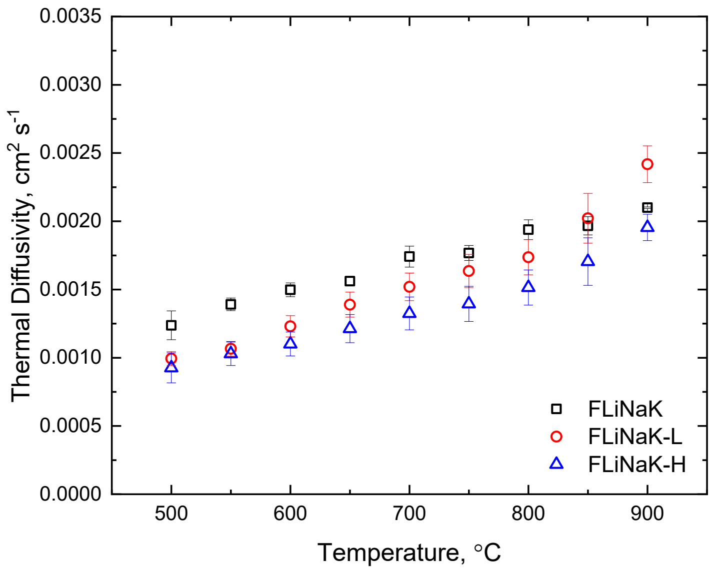
Determining the effect of Corrosion products and oxides on thermophysical properties

- Laser flash analysis is being used to measure the thermal diffusivity of doped salts
- Density of doped salts is being measured by a hydrostatic method
- Viscosity of doped salts is being measured by rotational viscometry

Average viscosities and expanded uncertainties for FLiNaK 1, FLiNaK 2, FLiNaK-L, and FLiNaK-H[1]



Average thermal diffusivities and expanded uncertainties for FLiNaK, FLiNaK-L, and FLiNaK-H



Similar comparisons between fission product-doped and fresh salts will be made for corrosion product and oxide doped salts.

Vapor Pressure Measurements

- Constructed instrument for measuring the vapor pressures of molten salts

Coupling a differential scanning calorimeter – thermogravimetric analyzer (DSC-TGA) and quadrupole mass spectrometer to measure vapor pressure by the transpiration method

- DSC-TGA is being used to record mass loss of molten salts during isothermal holds at selected temperatures
- Mass spec is being used to analyze evolved gases during heating

Vapor pressure measurements are being performed on reference materials and pure salts in preparation for measurements of salt mixtures

Remaining FY26 Work

- Determining the impact of corrosion products and oxides on molten salt thermophysical properties
  - Measuring thermal diffusivity, density and viscosity of doped batches of FLiNaK
  - Comparing measurements of doped salts to FLiNaK synthesized with as-low-as-achievable concentrations of contaminants to assess the impact of impurities

Items planned to be completed in FY27:

- Testing a custom apparatus for measuring vapor pressure of molten salts.
- Host a workshop to refine technological gaps in supply, use and reuse of molten salt fuels

Recent Reports

L.D Gardner, K.A. Chamberlain and M.A. Rose. Property Measurements of LiF-NaF-KF Molten Salts Doped with Surrogate Fission Products. ANL/CFCT-24/23. September 2024.

M.A. Rose, Quality Ranking of Unary Chloride Salt Property Data Included in MSTDB-TP. ANL/CFCT-24/34. December 2024.

L.D. Gardner and M.A. Rose. Uncertainty Analyses of Molten Salt Property Measurements. ANL/CFCT-25/5. March 2025.

L.D. Gardner, E.A. Dowding, J. Rojas and M.A. Rose. Property Measurements of LiF-NaF-KF Molten Salts Doped with Corrosion Products and Oxygen. ANL/CFCT-25/22. September 2025.

Summary of accomplishments and milestones

Task		Status
1	Measure effect of corrosion products and oxides on density and viscosity of FLiNaK salt	In Progress
2	Develop a method for vapor pressure measurements by transpiration	On Hold
3	Host a workshop to refine technological gaps in supply, use and reuse of molten salt fuels	On Hold
4	Support the update of the MSR molten salt chemistry and overall MSR program roadmaps	In Progress

Milestone Number	Title	Due
M3AT-26AN0705011	Effects of environmental contaminants on viscosity and density of FLiNaK salt	9/30/26 *on schedule*
M4AT-26AN0705012	Vapor pressure of standard materials and unary molten salts	12/18/26 *Revised completion date*
M3AT-25AN0705013	MSR Fuel Cycle Chemistry Technological gap identification	3/31/27 *Revised completion date*

Future Work

Impacts of impurities on thermal transition temperatures, viscosity, and heat capacity have been observed to exceed measurement uncertainties.

Additional measurements are needed to determine which impurities must be removed and to what levels to maintain acceptable fuel salt properties

- Effects of other impurities (Fe, moisture, noble metals)
- Tolerances to concentrations of impurities to establish purity standards

Knowing which impurities should be removed and setting purity standards will inform developers as they work to define their fuel cycle strategy.

Acknowledgements

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Thank you

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