Millimeter-Wave High Level and Low Activity Waste Glass Research

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Problem Statement

- Current and planned waste vitrification operations use predictive models without on-line monitoring
- Vitrification efficiencies are limited by uncertainties in models and operating parameters
- Melter operations are vulnerable to disruptive anomalies that cannot be predicted
- Identified monitoring needs:
  - Viscosity
  - Salt layer formation
  - Foaming
  - Liquidus crystals
  - Noble metals buildup
  - Pour spout flow

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Research Objectives

Reduce Immobilization Costs and Risks

- Develop new robust diagnostic tools for glass melt monitoring in high temperature and radioactive environments
- Exploit these new tools to advance vitrification materials science as it relates to nuclear waste and glass melt property modeling
- Progress toward a goal to modernize nuclear waste glass vitrification operations\control to industrial standards

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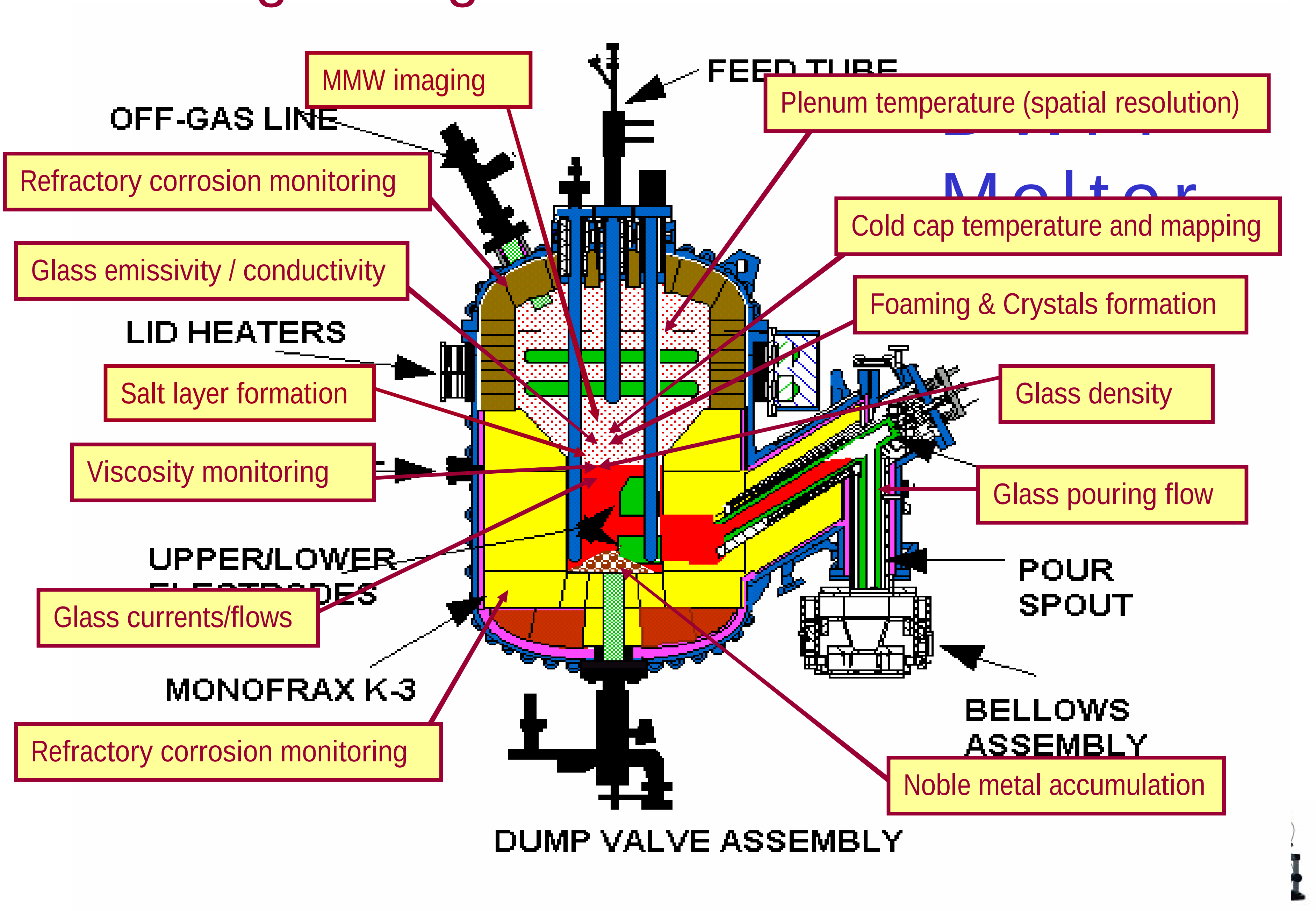
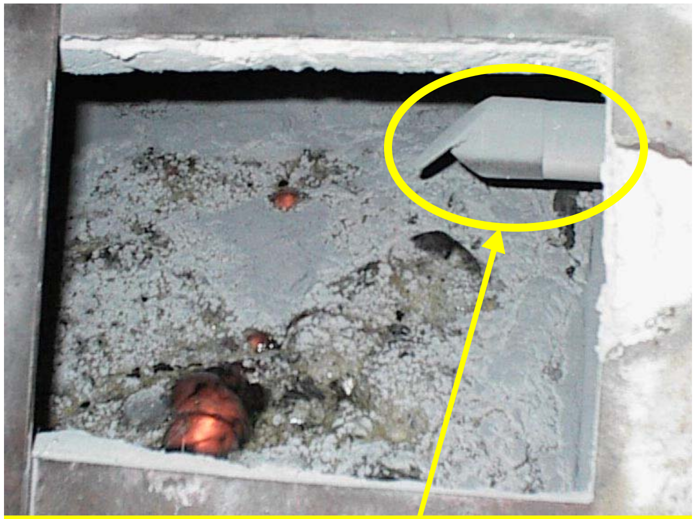
Long Range Vision of Research



Approach

Millimeter-Wave Technology (10-0.3 mm, 30-1000 GHz)

- Wavelengths are long enough to penetrate optical/infrared obscure viewing paths through dust, smoke, and debris
- Wavelengths are short enough for spatially resolved point measurements and profiles
- Waveguide/mirror components can be fabricated from the same refractory materials as the melter



MMW Inconel mirror and mullite guide

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Summary of Achieved Development

New Millimeter-Wave (MMW) Techniques and Technologies Developed for Melter Monitoring

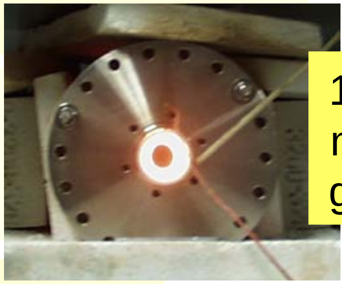
- Thermal Return Reflection (TRR)

  Use thermal emission as a probe to resolve emissivity and temperature

- Reflective Interferometry

  Monitor fluid displacement, fluctuations, and flow (viscosity)

- High Temperature (> 1000°C) Efficient Waveguides



1200 °C mullite guide

- Efficient Quasi-Optical MMW Signal Control components

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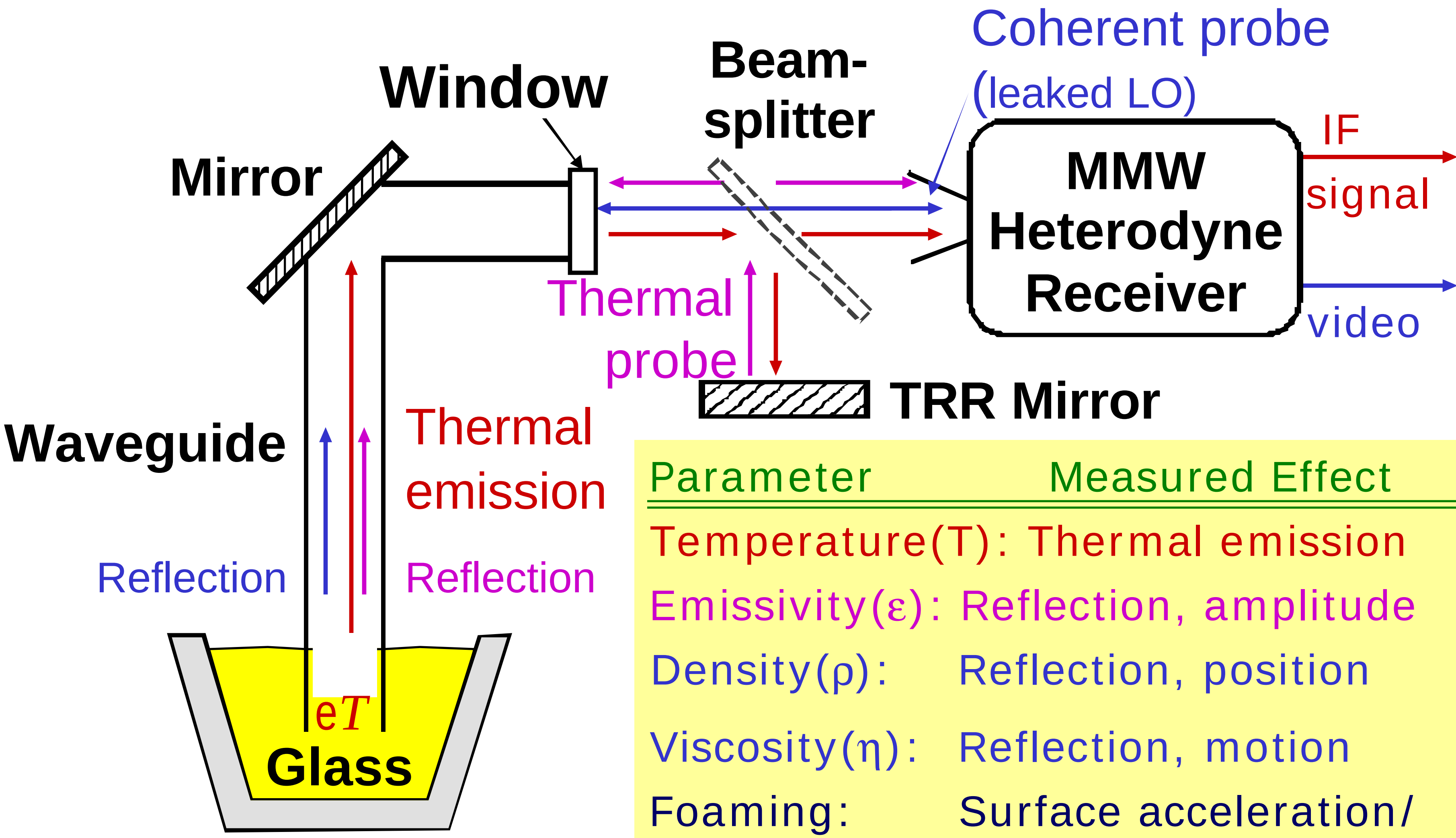
MMW Sensor Configuration



r = *1* - e

Parameter	Measured Effect
Temperature(T):	Thermal emission
Emissivity(ε):	Reflection, amplitude
Density(ρ):	Reflection, position
Viscosity(η):	Reflection, motion
Foaming:	Surface acceleration/ emissivity
Salt Layer:	Emissivity/turbulence

Summary of Accomplished Research

In the Laboratory

- High Temp. MMW properties of materials investigated (chromium oxide (Cr_2O_3), alumina-zirconia-silica (AZS), Monofax K3, $NaSO_4$ salt)
- Melt flow and MMW fluctuations investigated for viscosity (Hanford #7 & #8, DWPF black frit #265, commercial E glass)
- MMW signature of foaming event observed

In the Field (Clemson EV-16 Melter)

- 2-D cold cap temperature profiles measurements
- Viscosity depth profile measurements
- Salt layer formation studied

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Viscosity and Salt Field Test

Clemson Environmental Technology Lab (CETL)

- EV-16 Joule Heated Glass Melter (up to 1150 °C)
  ---- 45.7 cm (18 inch) square melt pool,
  filled to 20.3 cm (8 inch) depth
- Defense Waste Processing Facility (DWPF) black frit #265 glass --- 111 kg (245 lbs)

MMW Measurements:

- Glass flow versus depth and temperature
- Salt layer formation and emissivity of glass and salt --- 1.9 kg (4.2 lbs) sodium sulfate added

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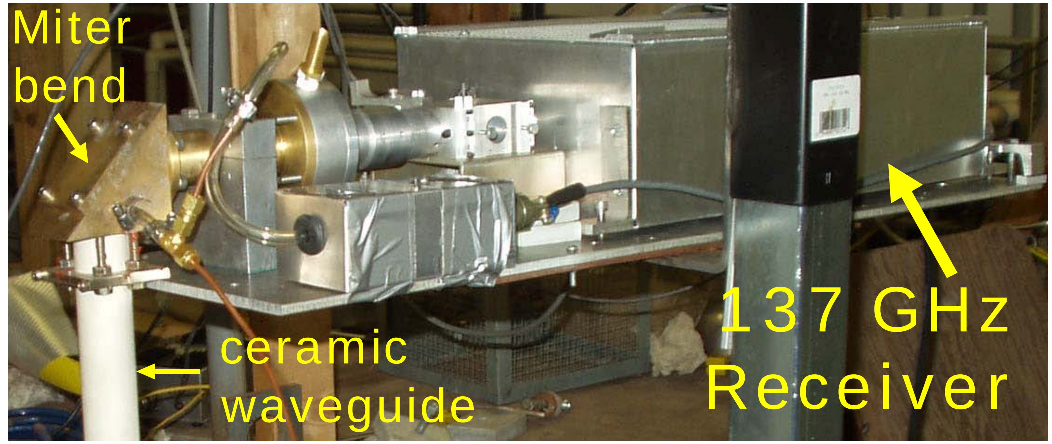
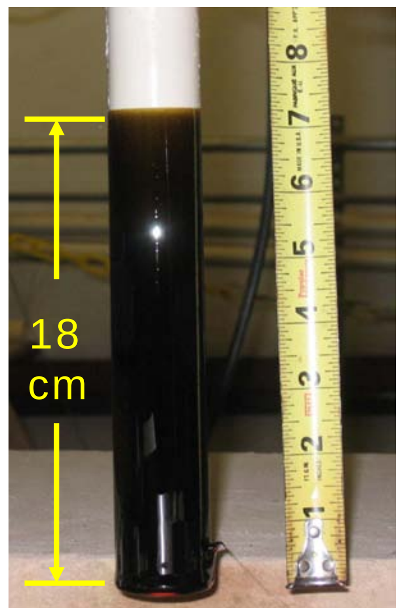
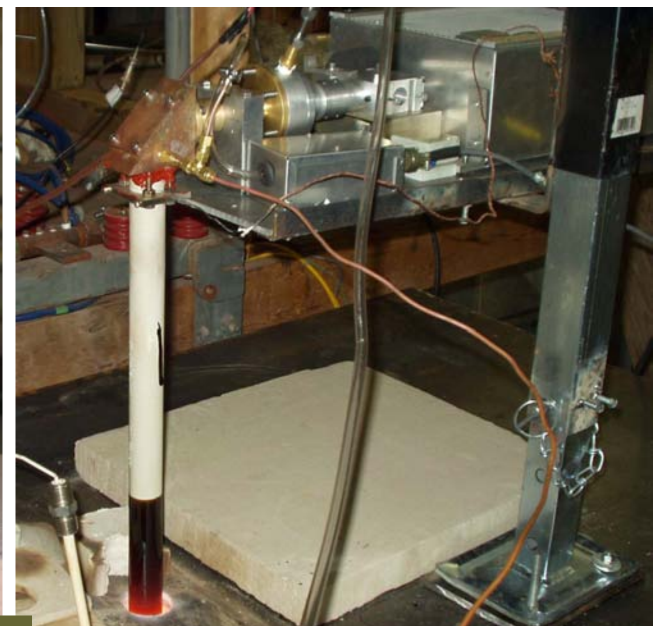
Experimental Setup



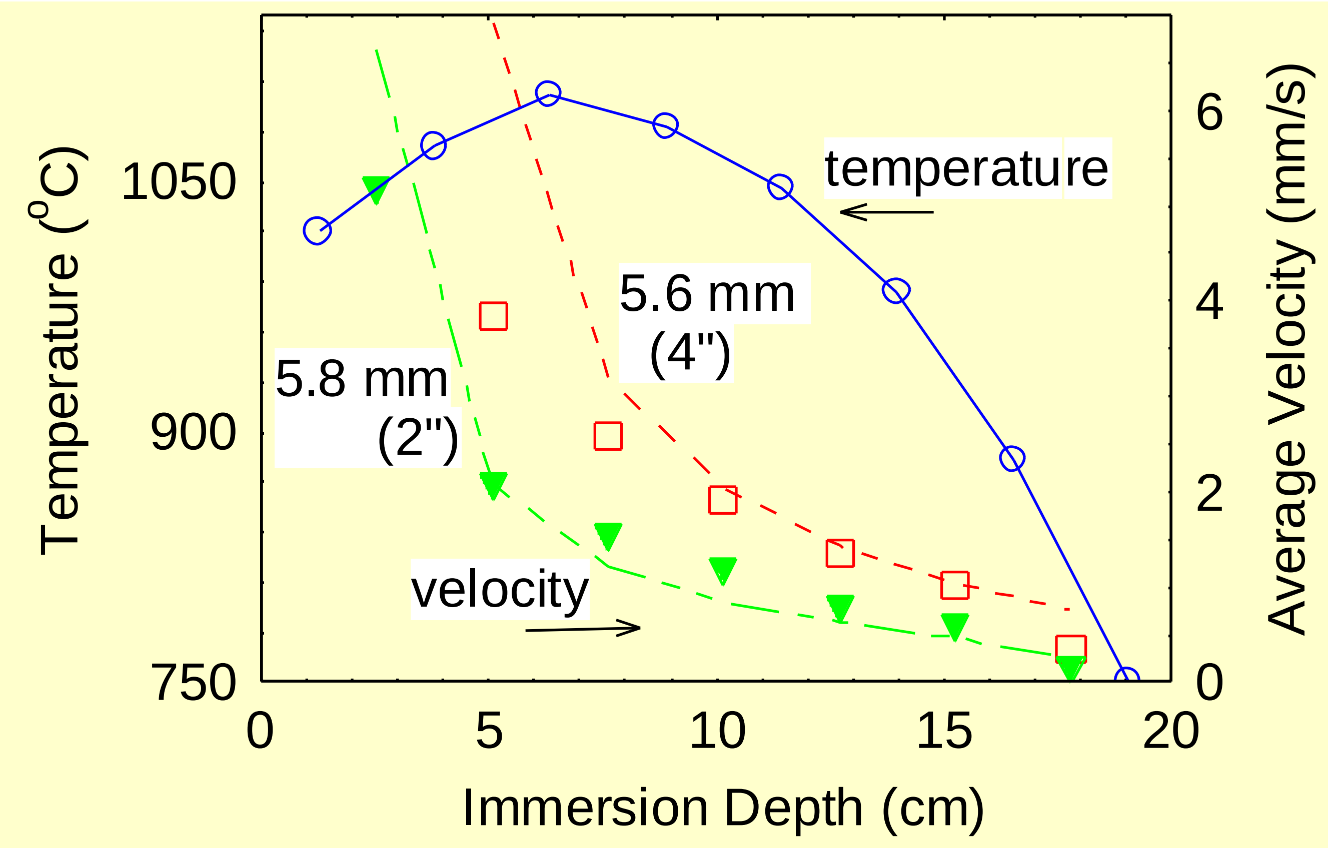


Waveguide
after immersion



Glass Flow Measurements

- Waveguide flow measured as a function of immersion depth for 2.8 mm and 5.6 mm Hg pressurizations



Points are measurements

Dashed lines are theory

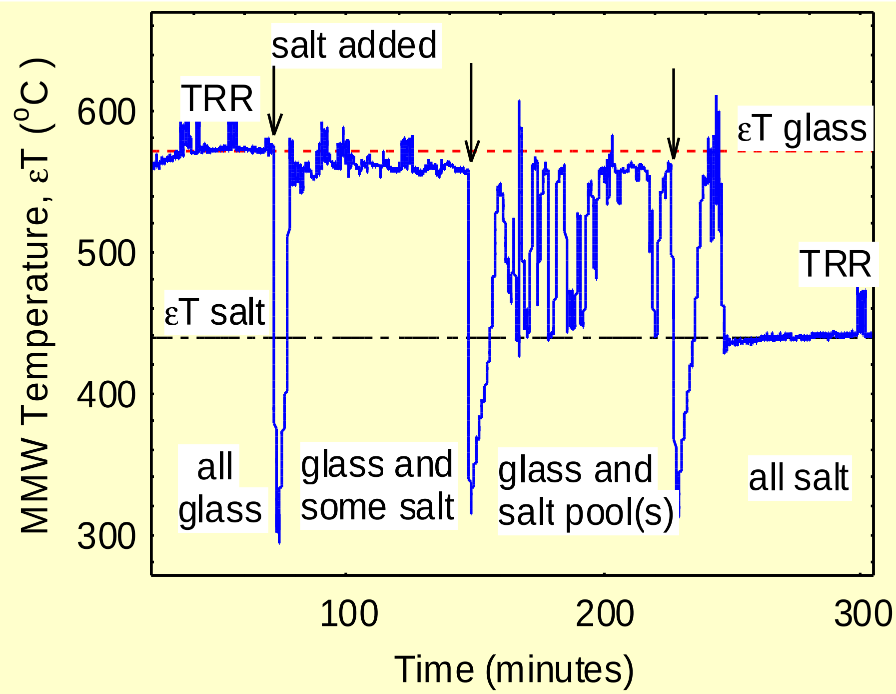
$$v_{ave} = A\,r\,\frac{z_o}{(L - z_o)\,h}$$

1/T scaling of viscosity (η) assumed

Good agreement between theory and experiment for large depths

Salt Experiments

MMW Temperature Signal proportional to eT



- Salt ($NaSO_4$) added at 3 times shown
- Thermocouple temperature steady between additions

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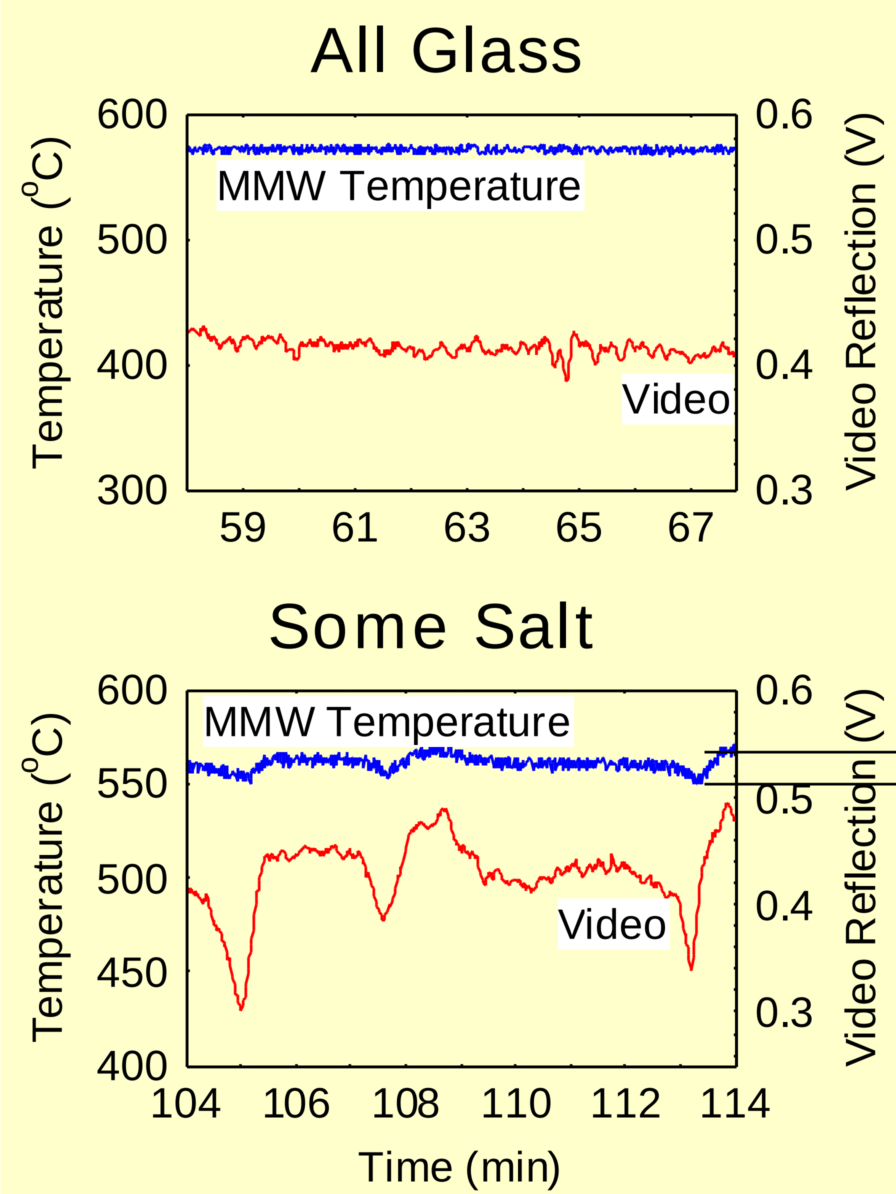
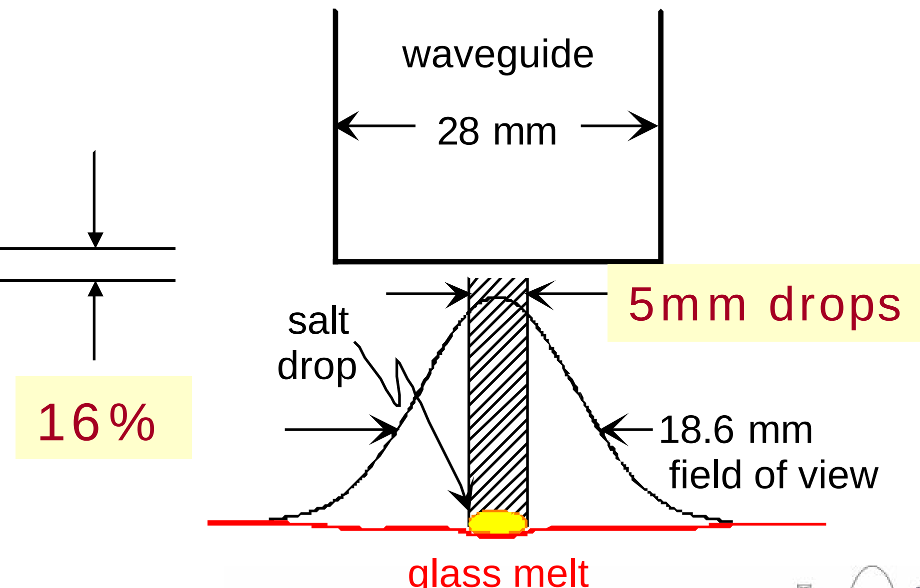
Salt Data Analysis



- MMW surface fluctuations occur with salt
- Salt in discreet drops
- Drop size can be estimated from data



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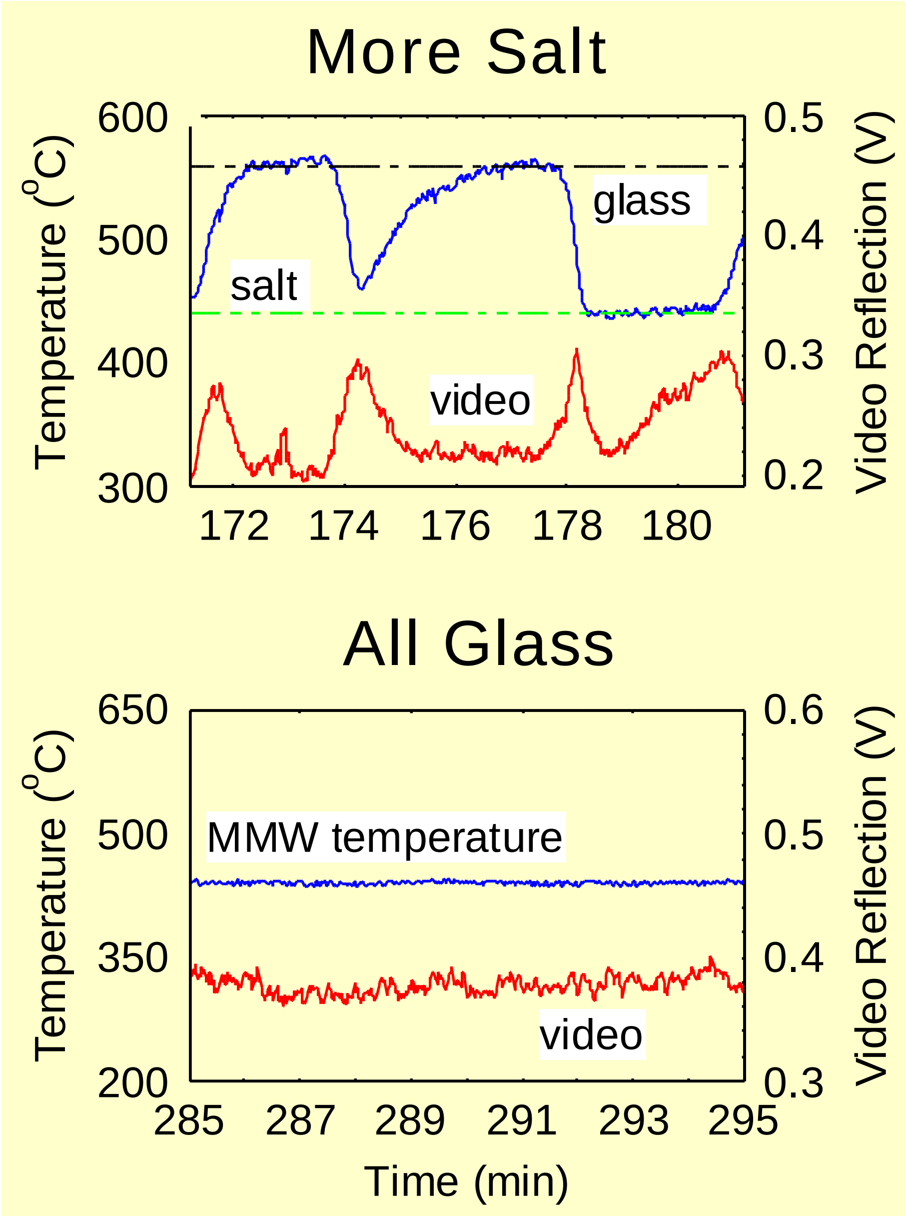
Salt Data Analysis



- With more salt drops grow into larger pools > 28 mm diameter
- Salt pools are in constant flow on melt surface
- 4.2 (1.9 kG) of $NaSO_4$ established continuous layer on 18^2 in^2 (46^2 cm^2) glass surface --- layer depth ~3.3 mm

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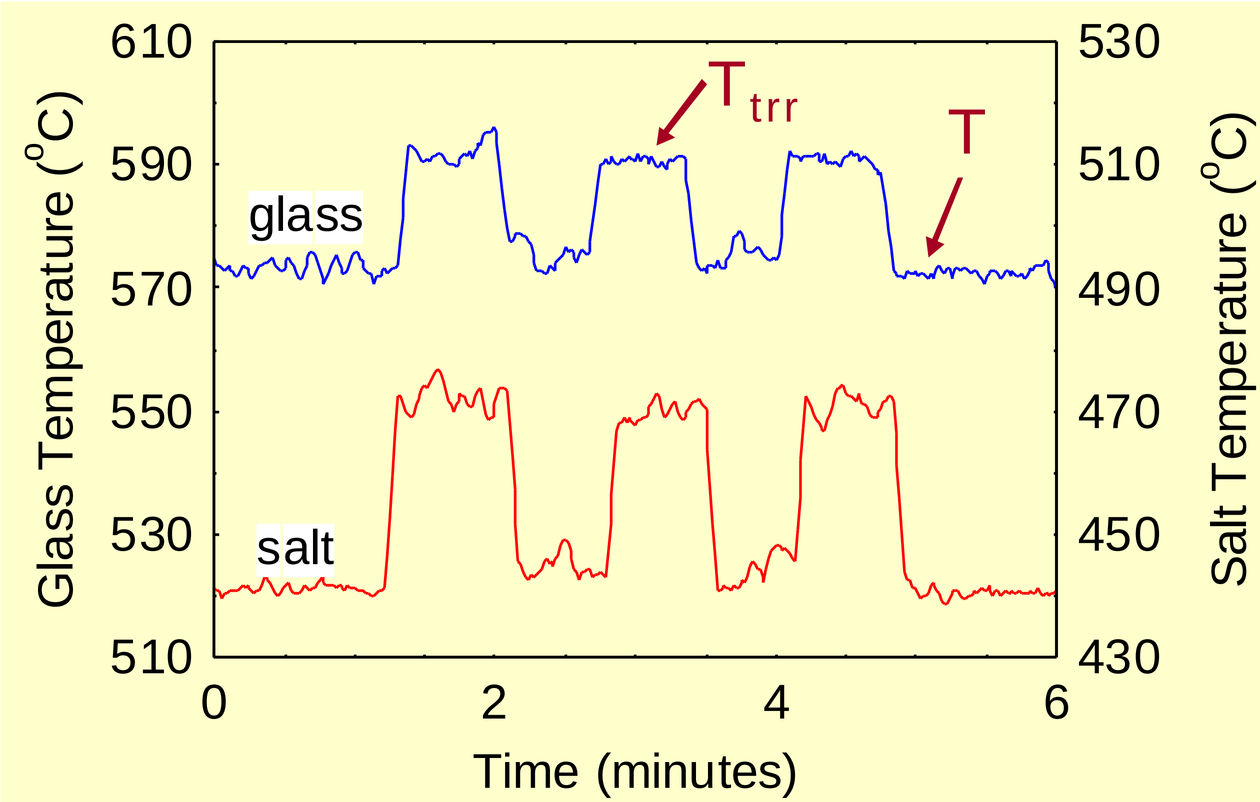
Salt and Glass Emissivity

- Emissivity and surface figure determined by thermal return reflection method and thermocouple



At 950°C & 137 GHz

DWPF Glass:

ε = 0.64 ± 0.05

κ = 0.46 ± 0.05

$NaSO_4$ Salt:

ε = 0.44 ± 0.05

κ = 0.60 ± 0.05

$$e = 1 - \frac{1}{k r_{bs}^2 t_{wg}^2}\left(1 - \frac{T}{T_{trr}}\right)$$

Woskov & Sundaram, J. Appl. Physics, **92**, 6302, 2002.

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Planned Research

- Obtain more data on salt layer formation with future planned waste glasses (regular and bulk vitrification processes)
- Compare MMW glass flow measurements with other viscosity data, improve modeling, and research limits of melt viscosity and specific gravity measurements
- Obtain more data and model foaming of melts and correlate foaming to processing conditions and glass chemistry
- Research measurements and interpretation of melt surface fluctuations (Maragoni force)

Planned Research continued

- Investigate more sensitive emissivity monitoring for melt parameters such as liquidus (duel receiver system, in situ reference)

- Implement MMW receiver system for more laboratory research at ACTL (run melt tests at ACTL)

- Carry out additional tests relevant to DWPF/WTP

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Further Reading

"**Millimeter-Wave Monitoring of Nuclear Waste Glass Melts – An Overview**", *P. P. Woskov, J. S. Machuzak, P. Thomas, S. K. Sundaram, and W. E. Daniels, Jr.*, in Environmental Issues and Waste Management Technologies VII (*Ceramic Transactions, Volume 132*) pp. 189-201, 2002.

"**Cold Cap Monitoring using Millimeter Wave Technology**", *S. K. Sundaram, P.P. Woskov, J.S. Machuzak, and W.E. Daniel, Jr.*, in Environmental Issues and Waste Management Technologies VII, Editors: G. L. Smith, S. K. Sundaram, and D. R. Spearing (Ceramic Transactions, Volume 132) pp. 203-213, 2002.

"**Thermal return reflection method for resolving emissivity and temperature in radiometric measurements**", *P. P. Woskov and S. K. Sundaram*, J. Appl. Physics, vol. 92, 6302-6310, 2002.

"**Molten salt dynamics on glass melt using millimeter-wave emissivity measurements**", *P. P. Woskov, S. K. Sundaram, W. E. Daniel, Jr., D. Miller*, J. of Non Crystalline Solids, vol. 341/1-3, 21-25, 2004.

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