Advanced Chemical Analyses as Indicators for Coal Fouling and Slagging

Larry Baxter

Brigham Young University

Provo, UT 84602

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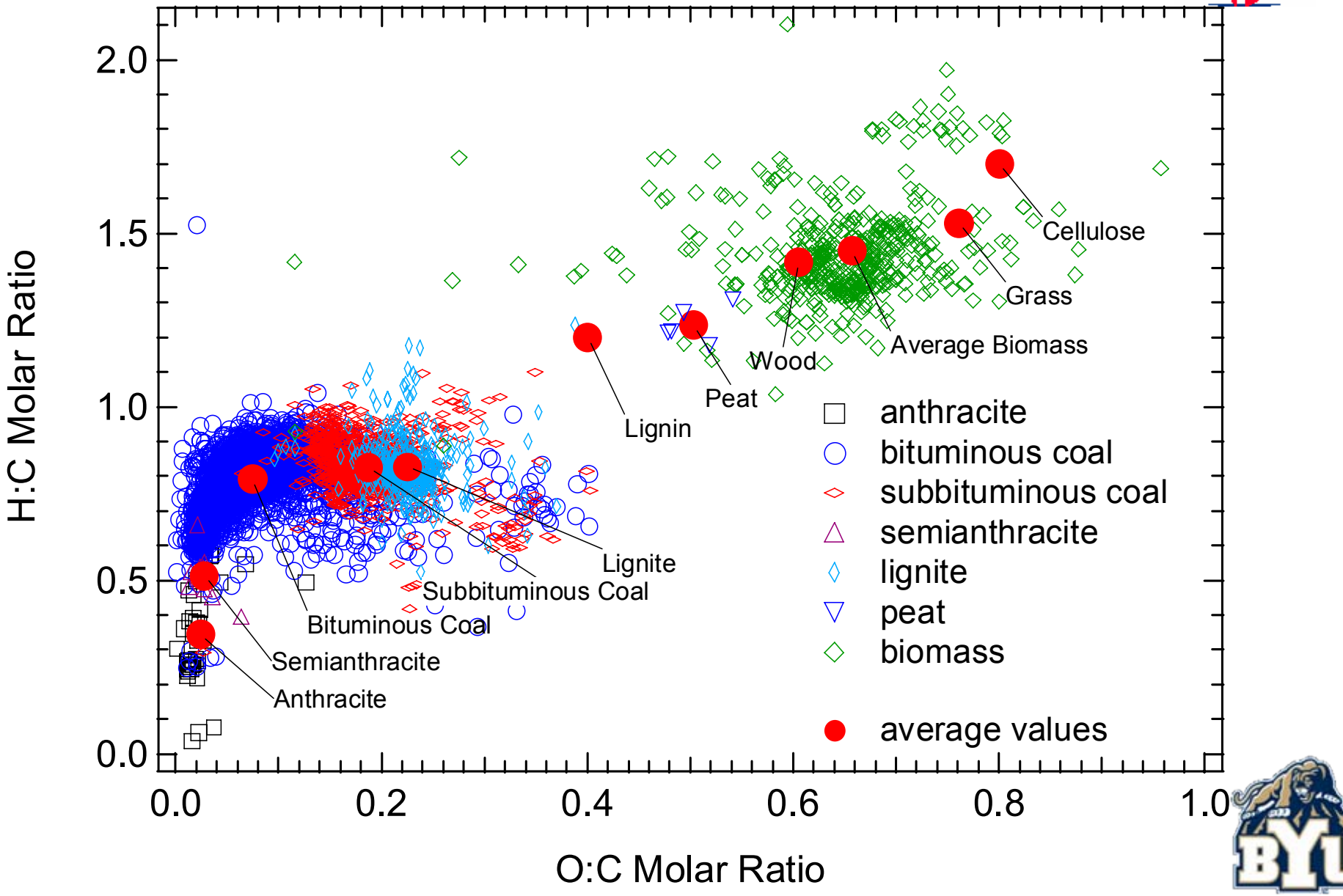
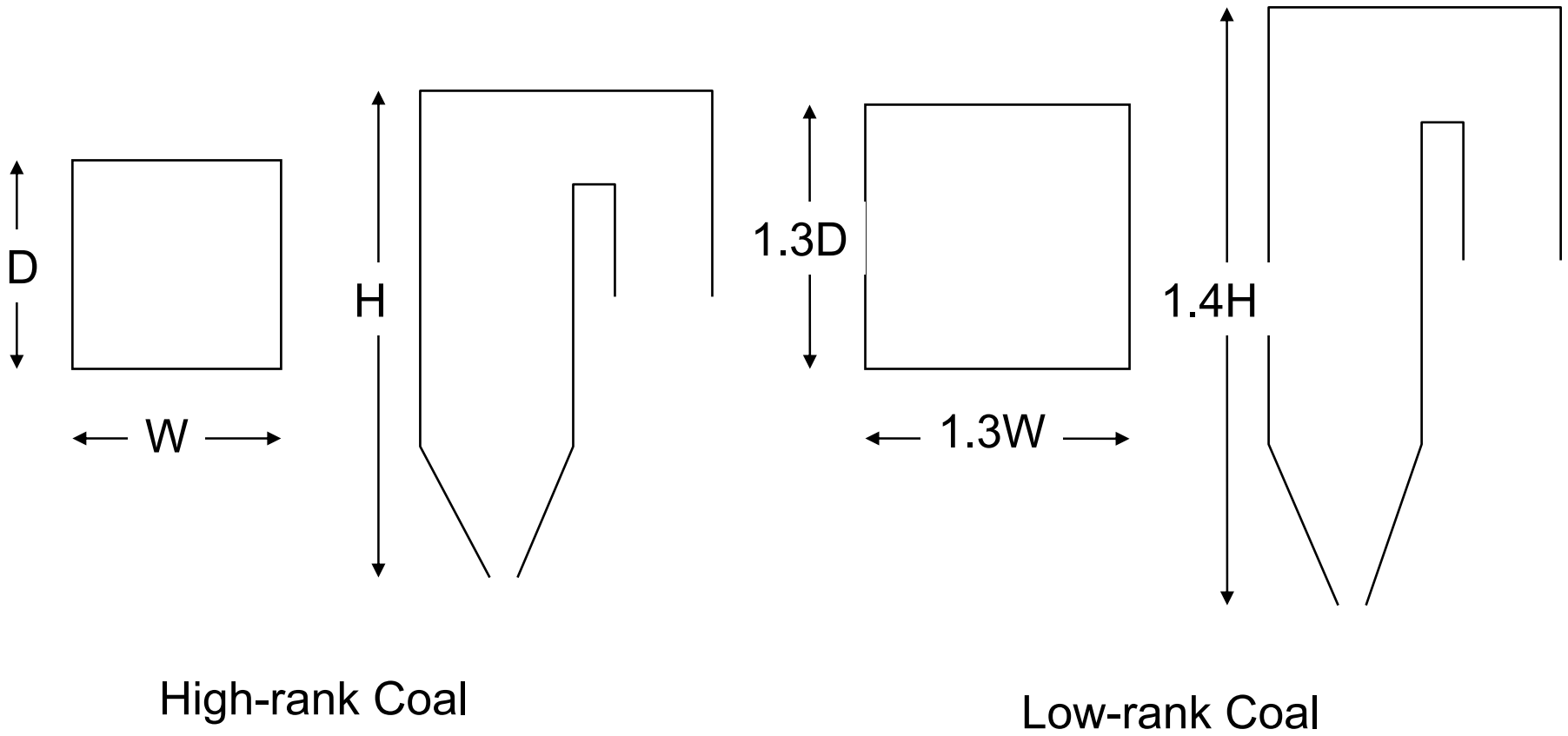
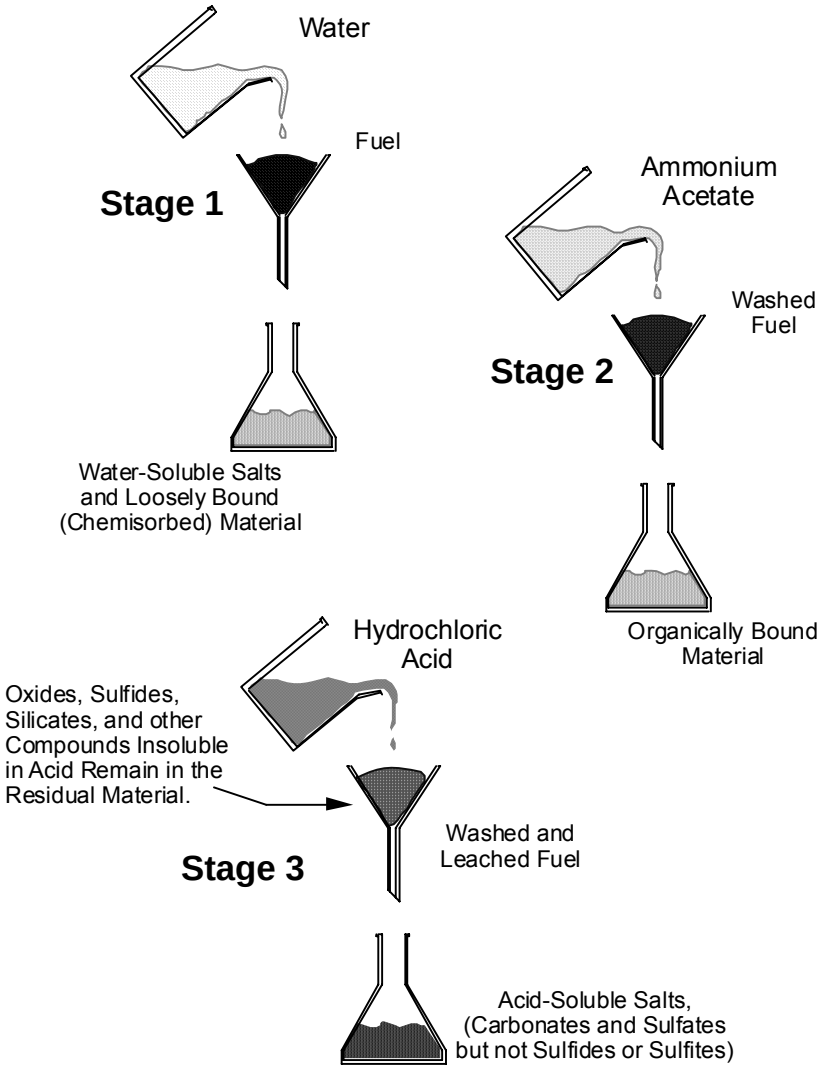
Origins of Coal

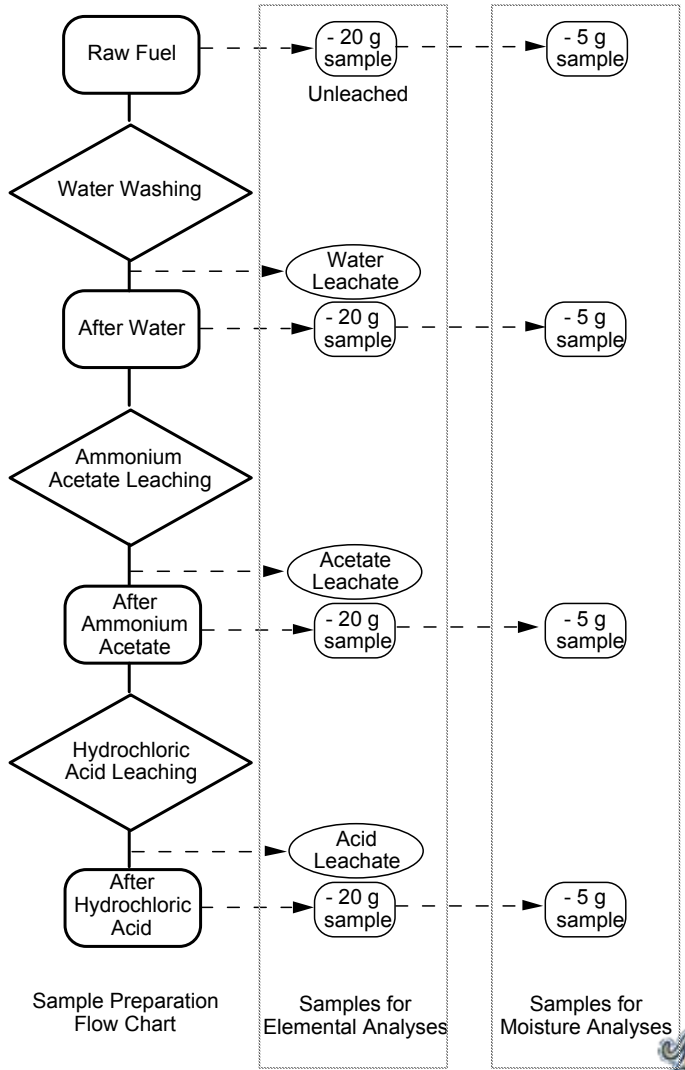


Ash Impacts Boiler Design

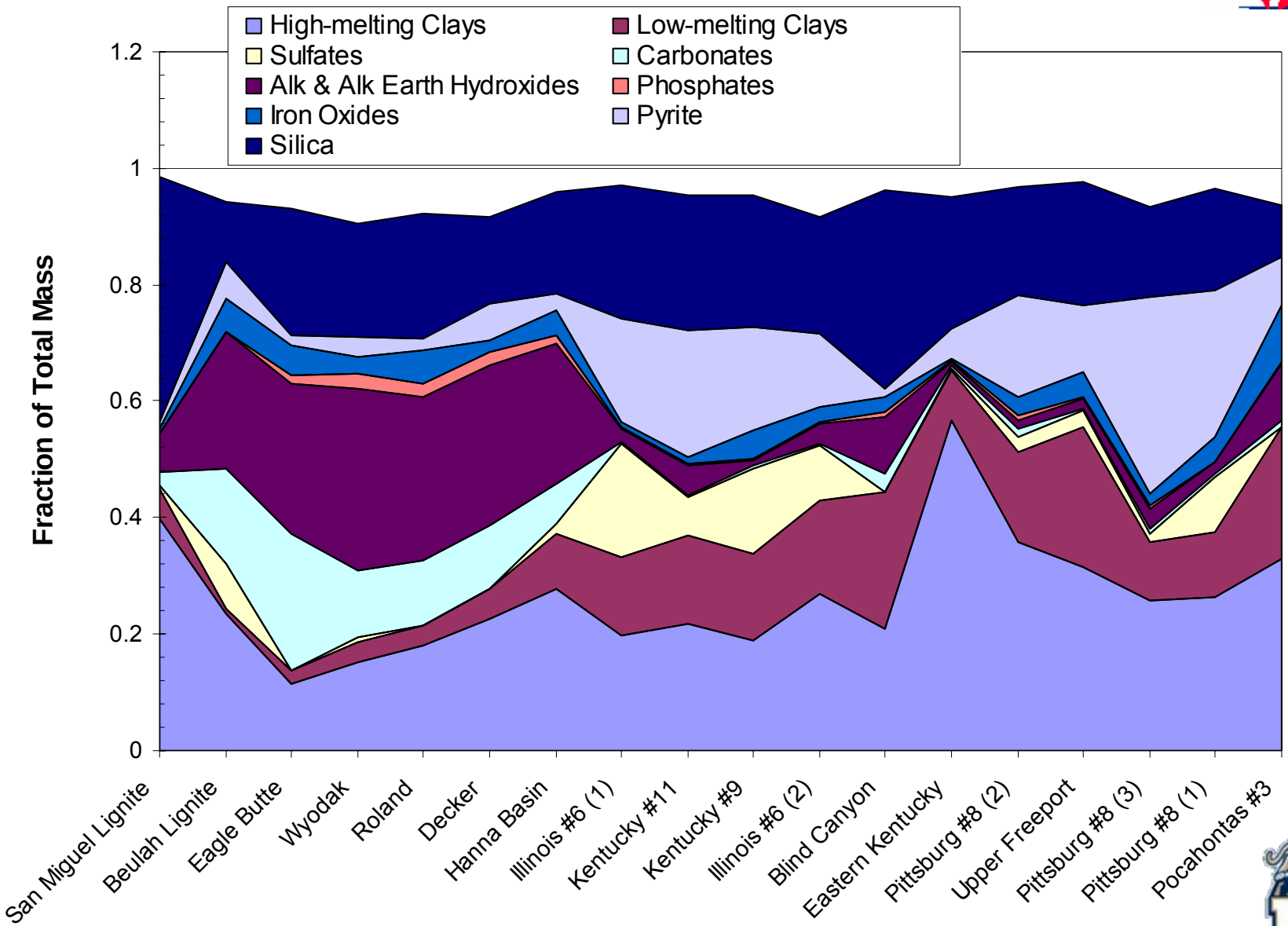


Chemical Fractionation

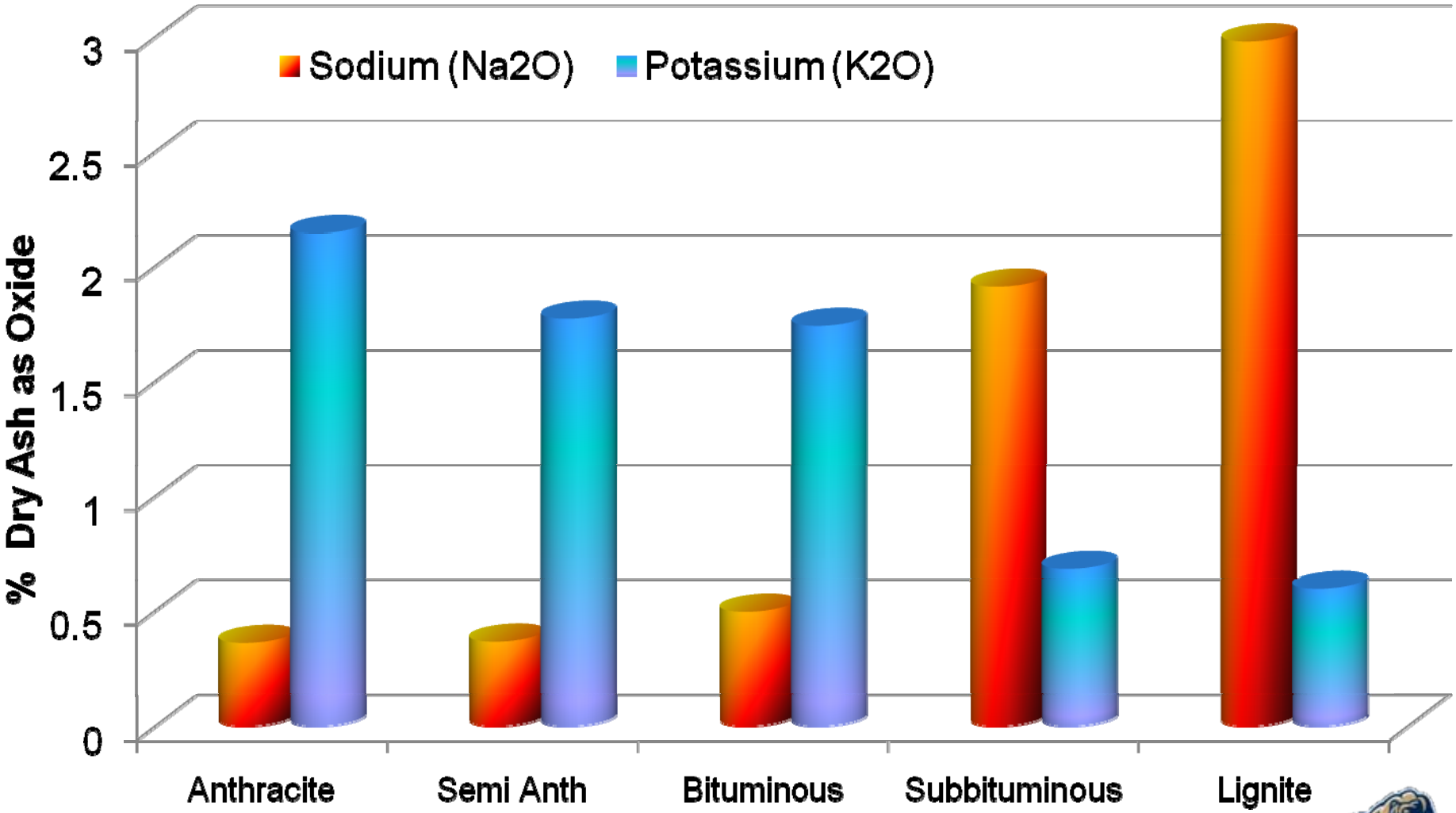




Inorganic Classes

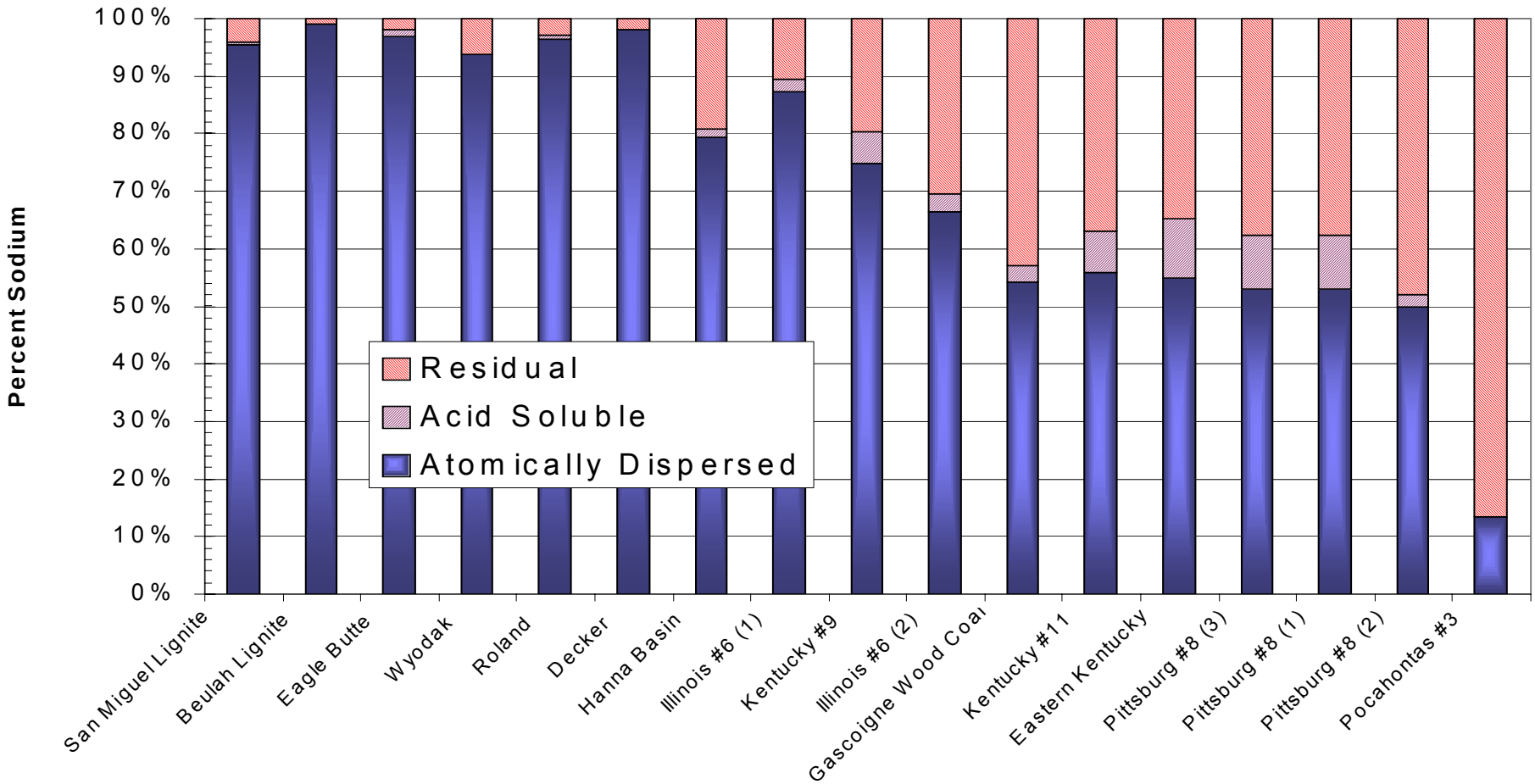


Alkali Metals in Coals

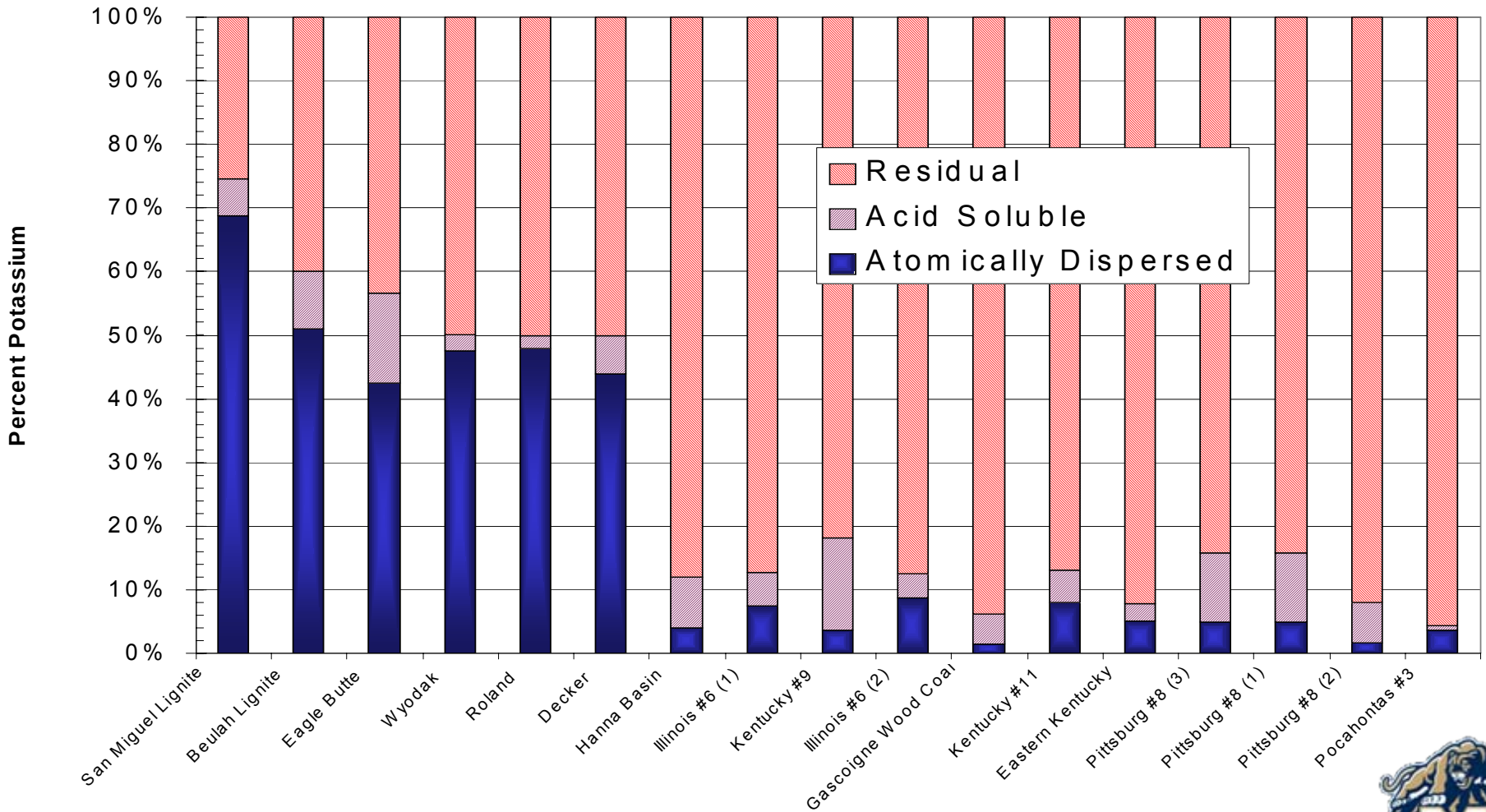


Averages of 6696 Fuel Analysis

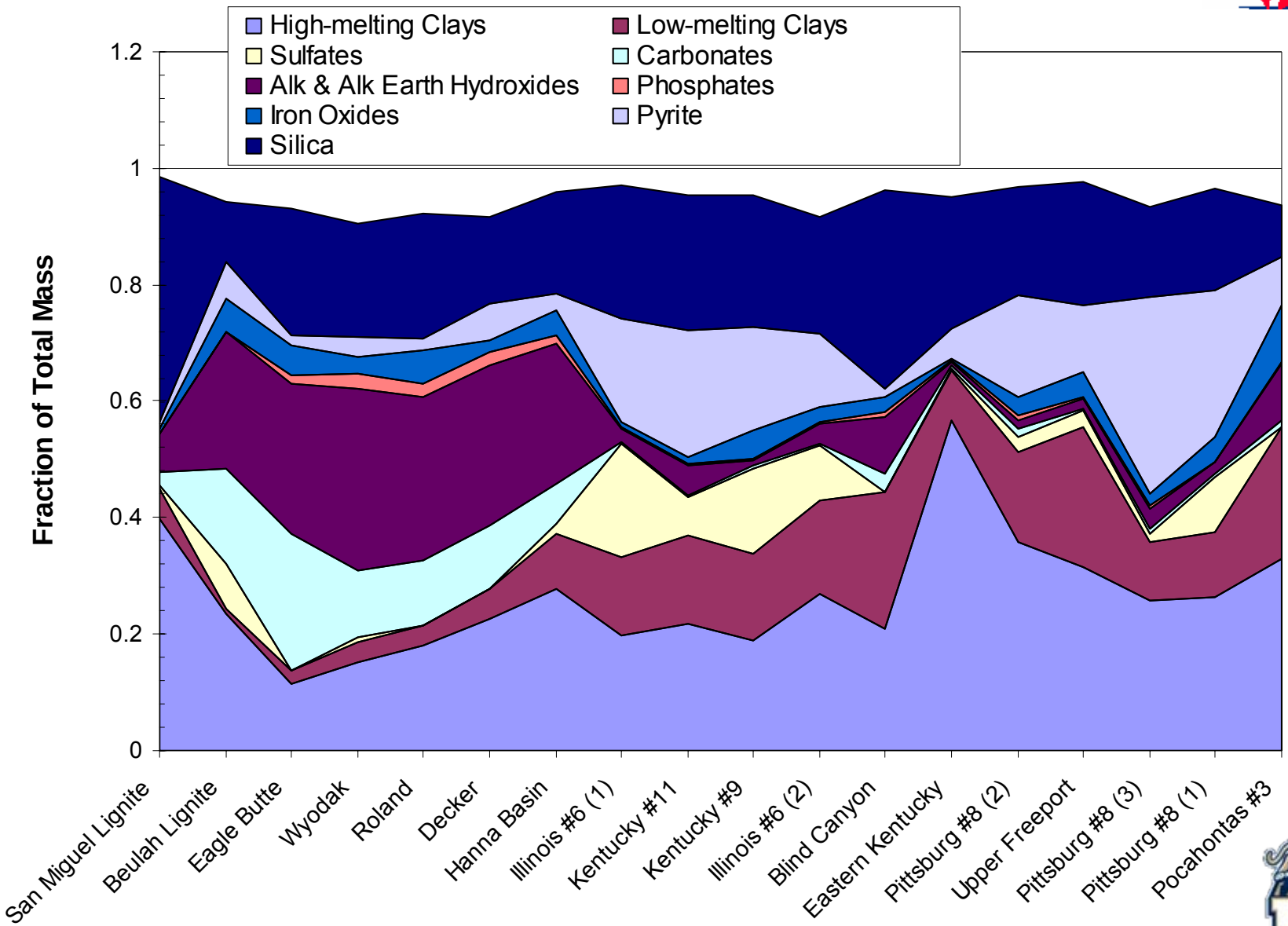
Atomically Dispersed Sodium



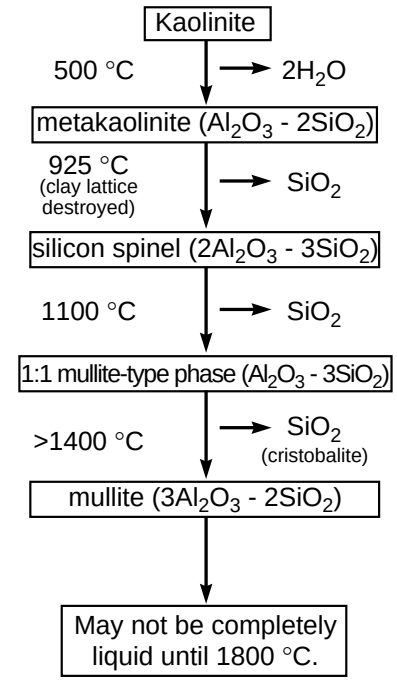
Atomically Distributed Potassium



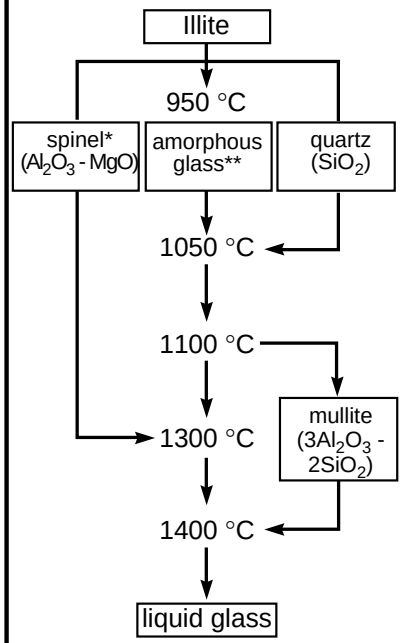
Inorganic Classes



Major Transformations Summary

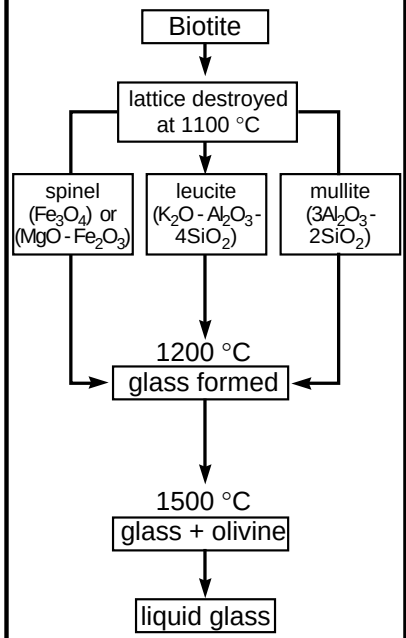


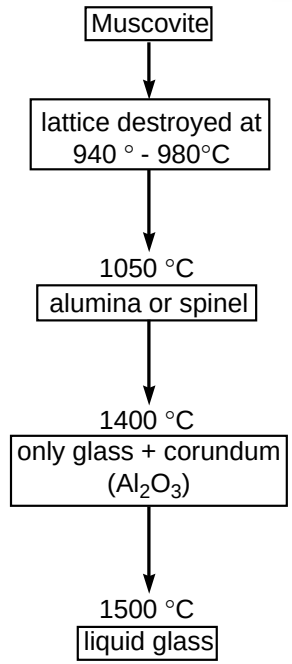
Other members in the kaolinite group, (i.e. livesite and metahalloysite) are thought to undergo similar changes.

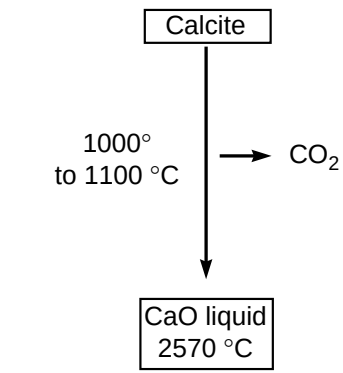


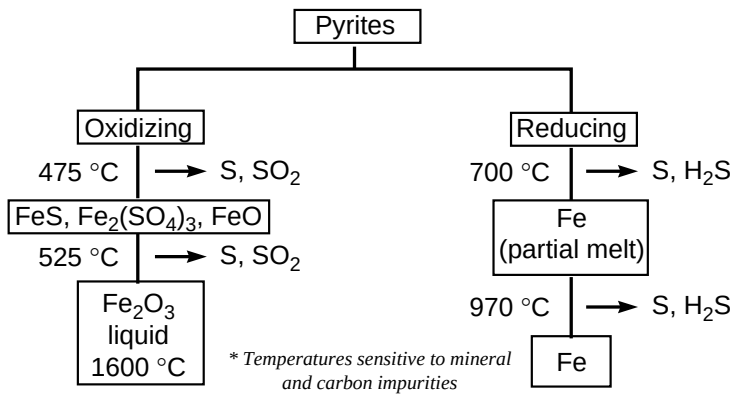
** Formed from aluminum and magnesium from middle layers of lattice.*

*** Formed from alkali and SiO_2 from the outer layers of lattice.*

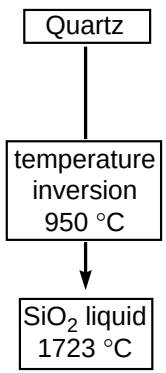




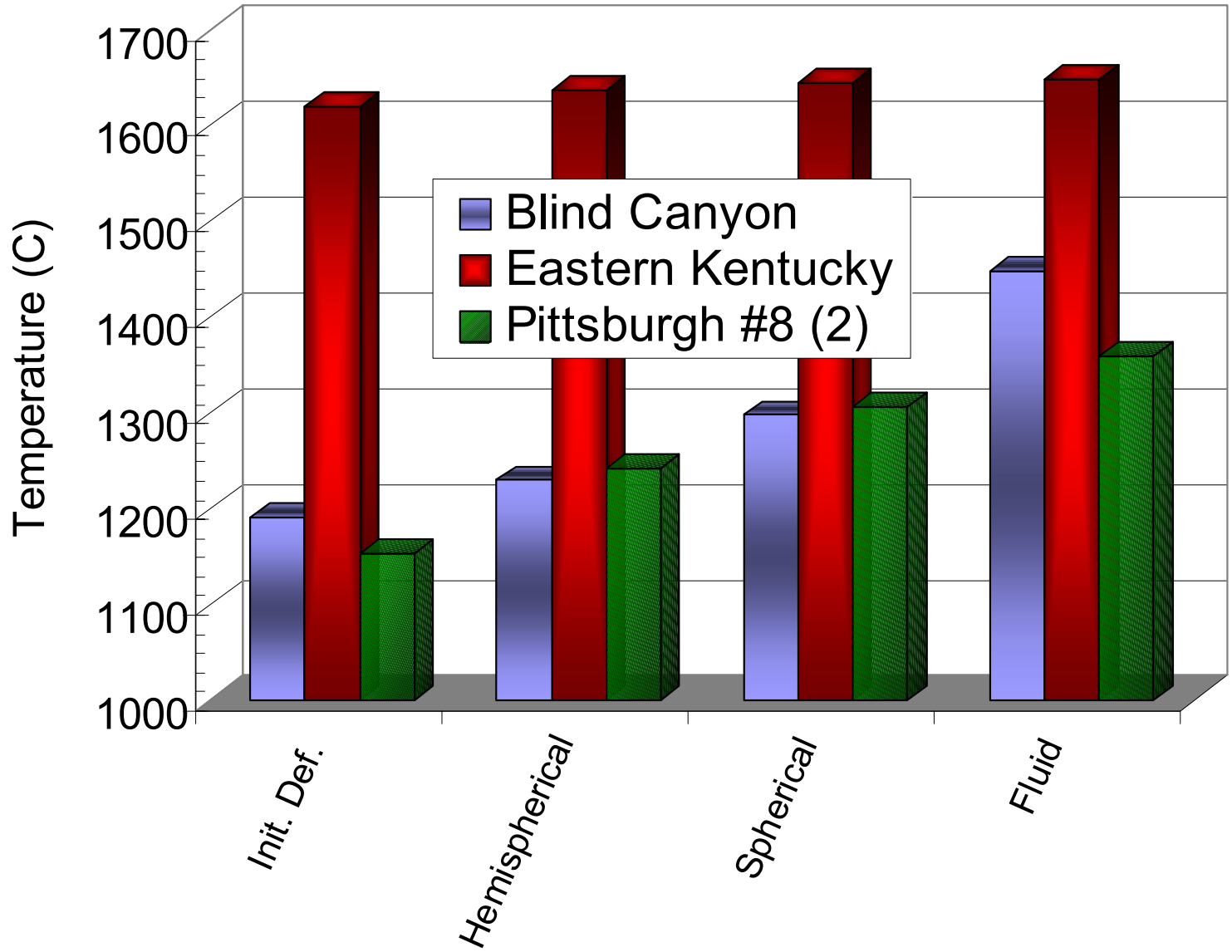




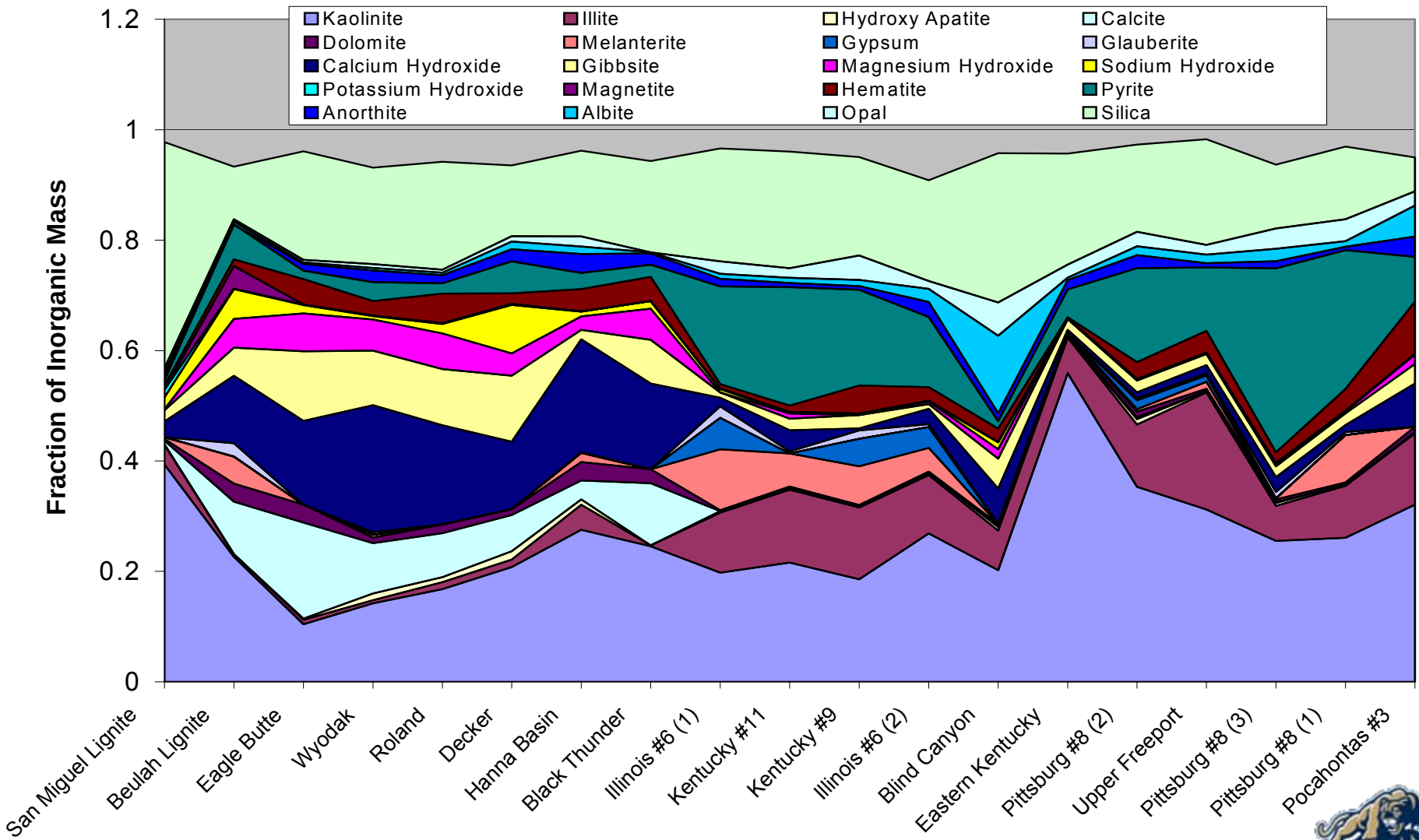
** Temperatures sensitive to mineral and carbon impurities*



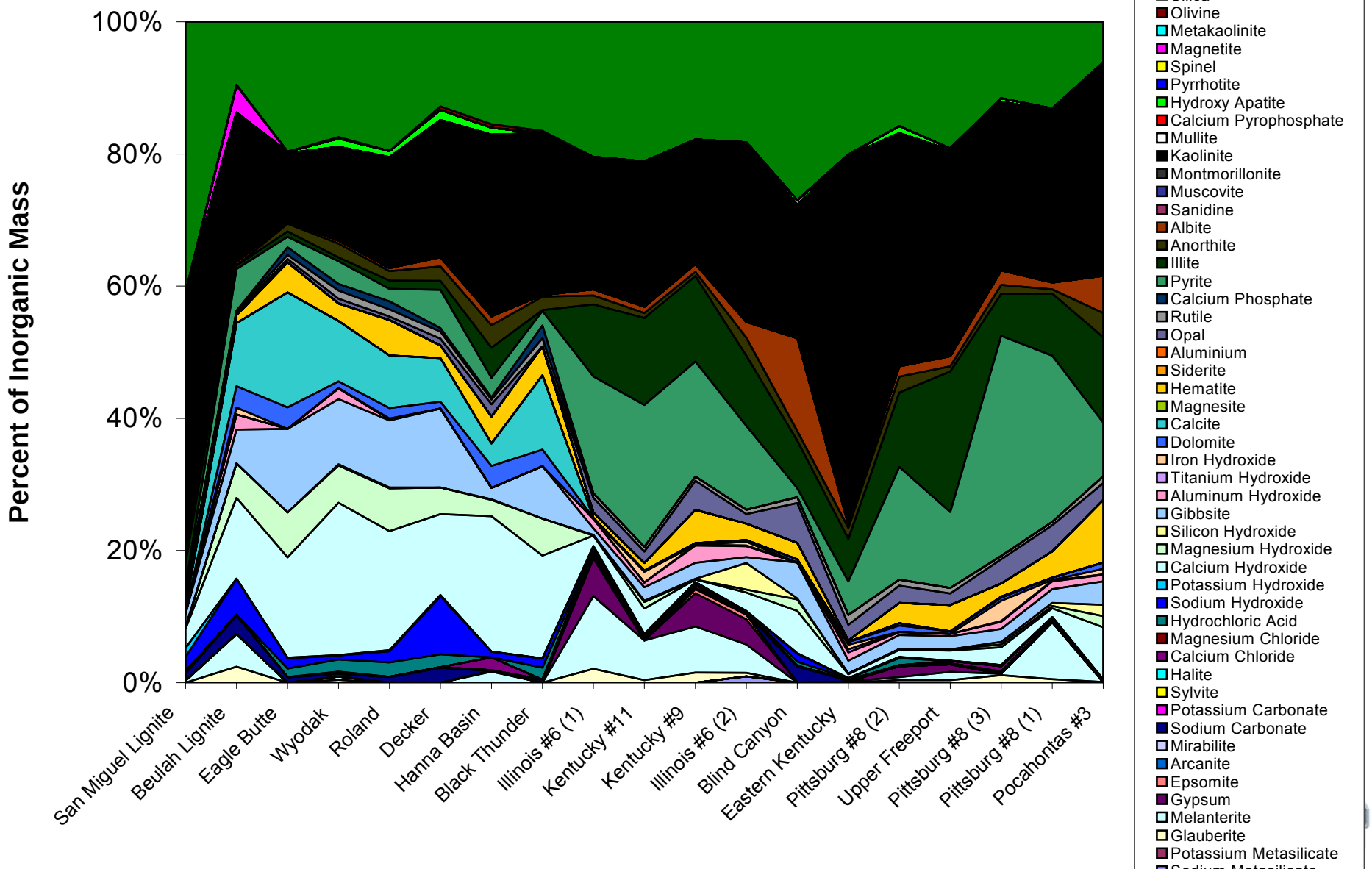
Traditional Analyses



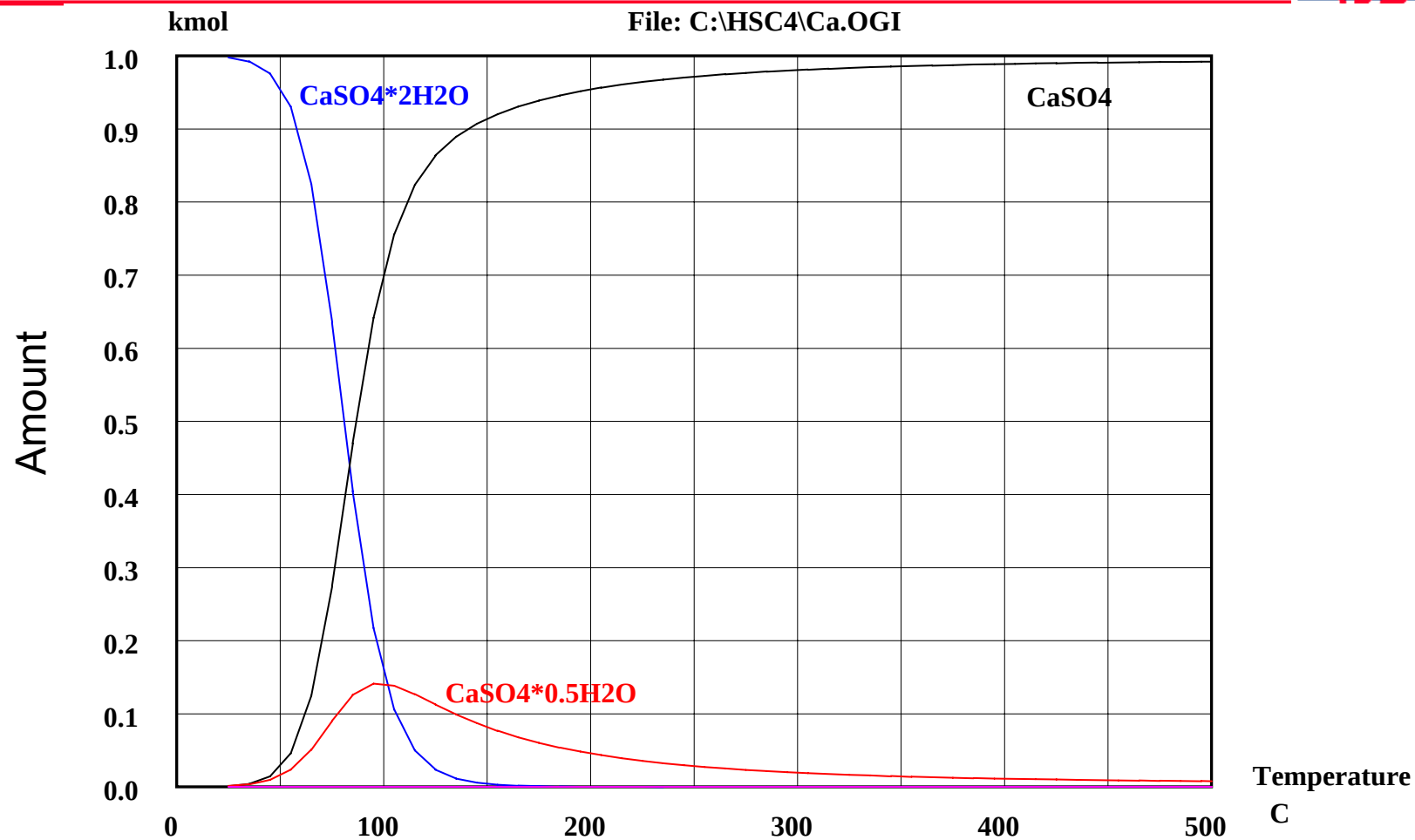
Major Chemical Species



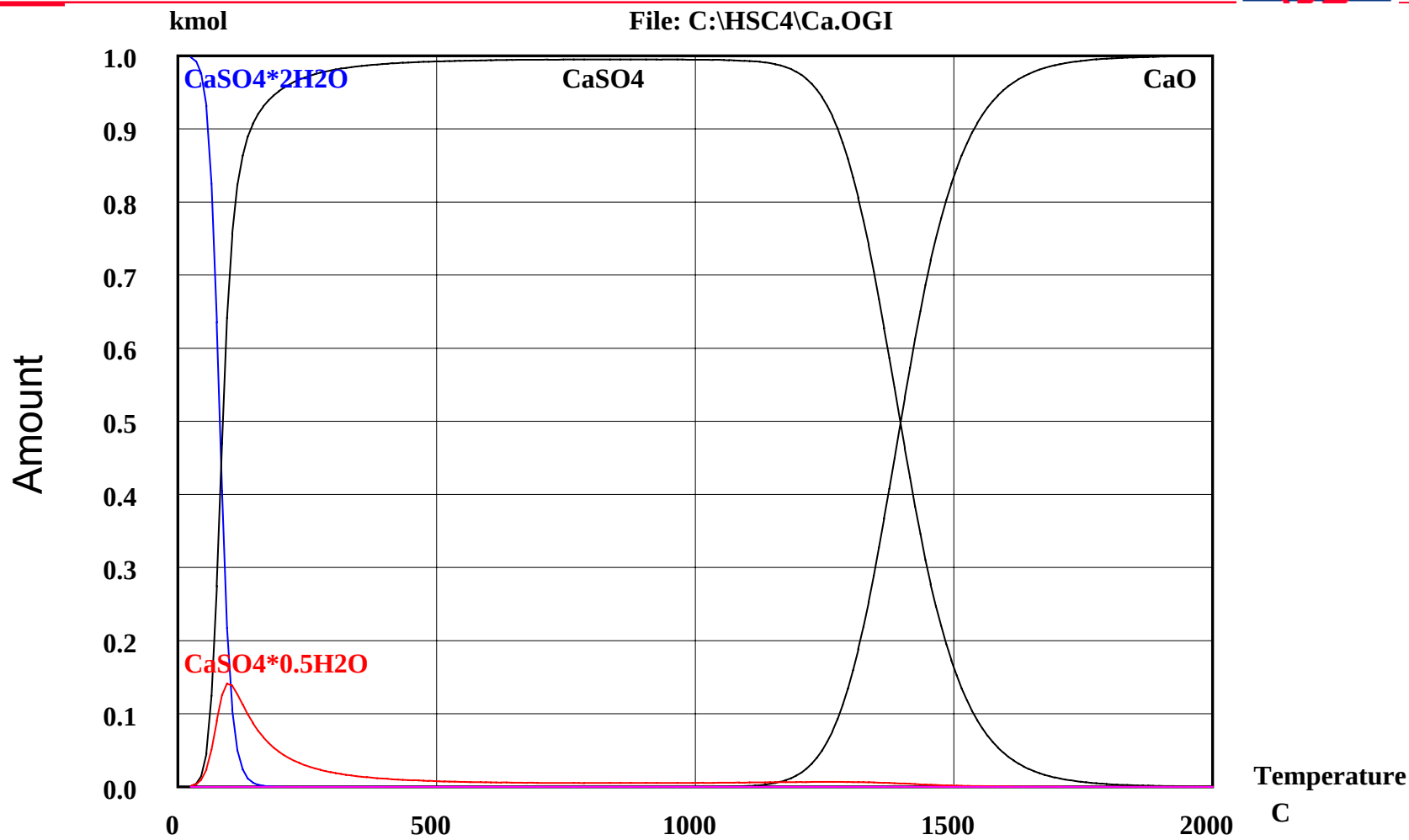
Complete Species Descriptions



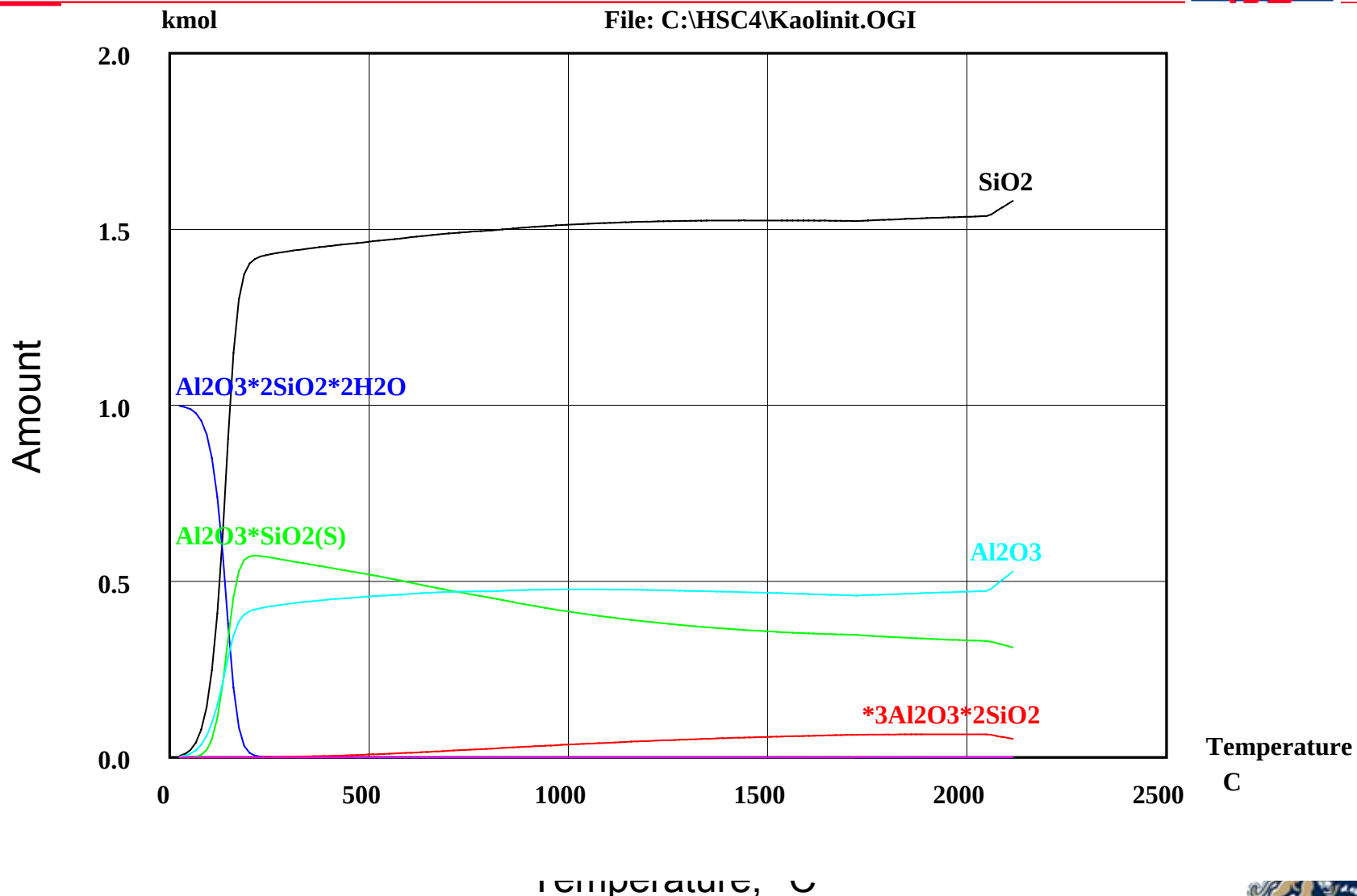
Individual Species Reactions



Gypsum Typifies Sulfates

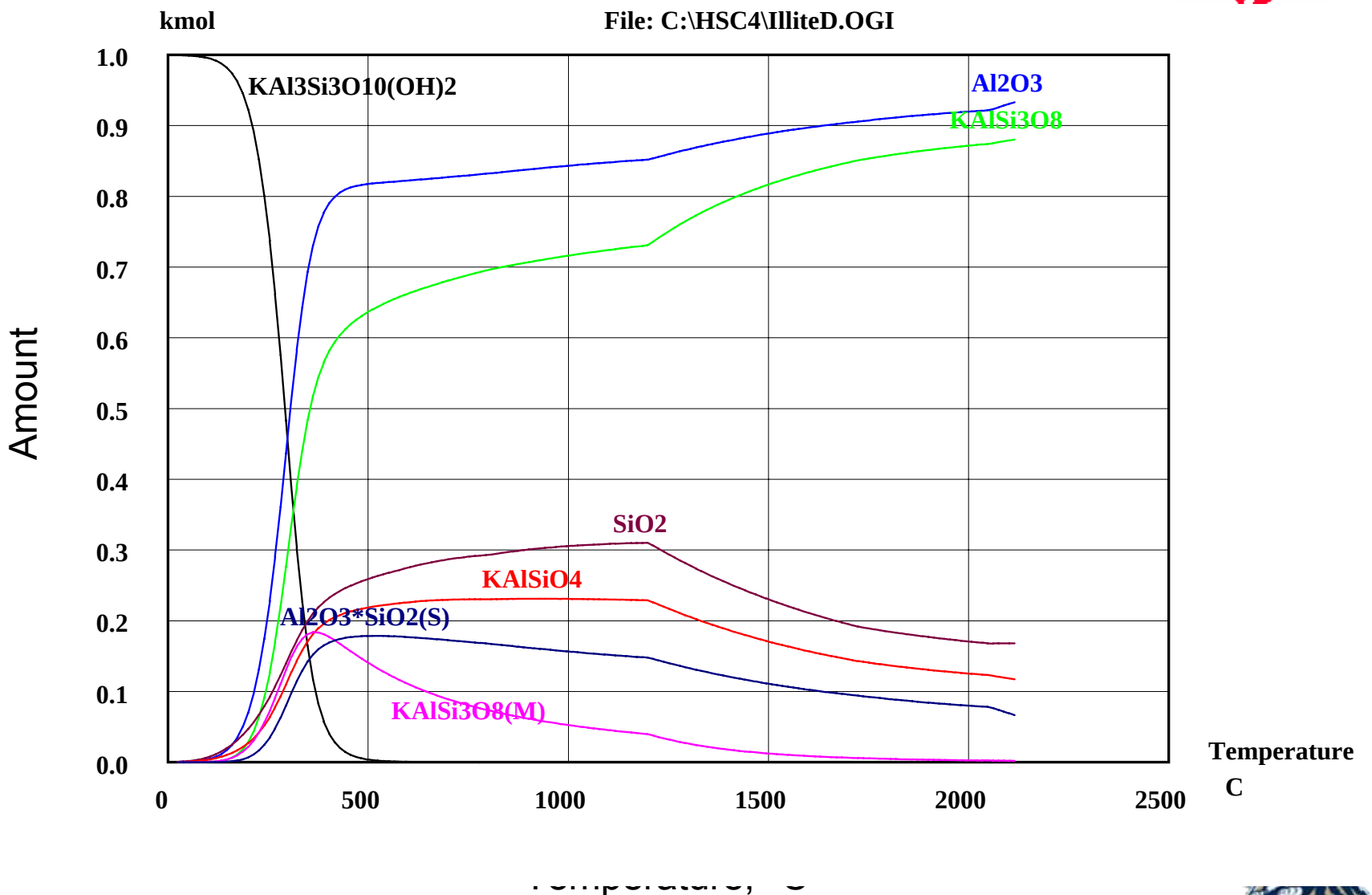


Kaolinite Forms Little Liquid

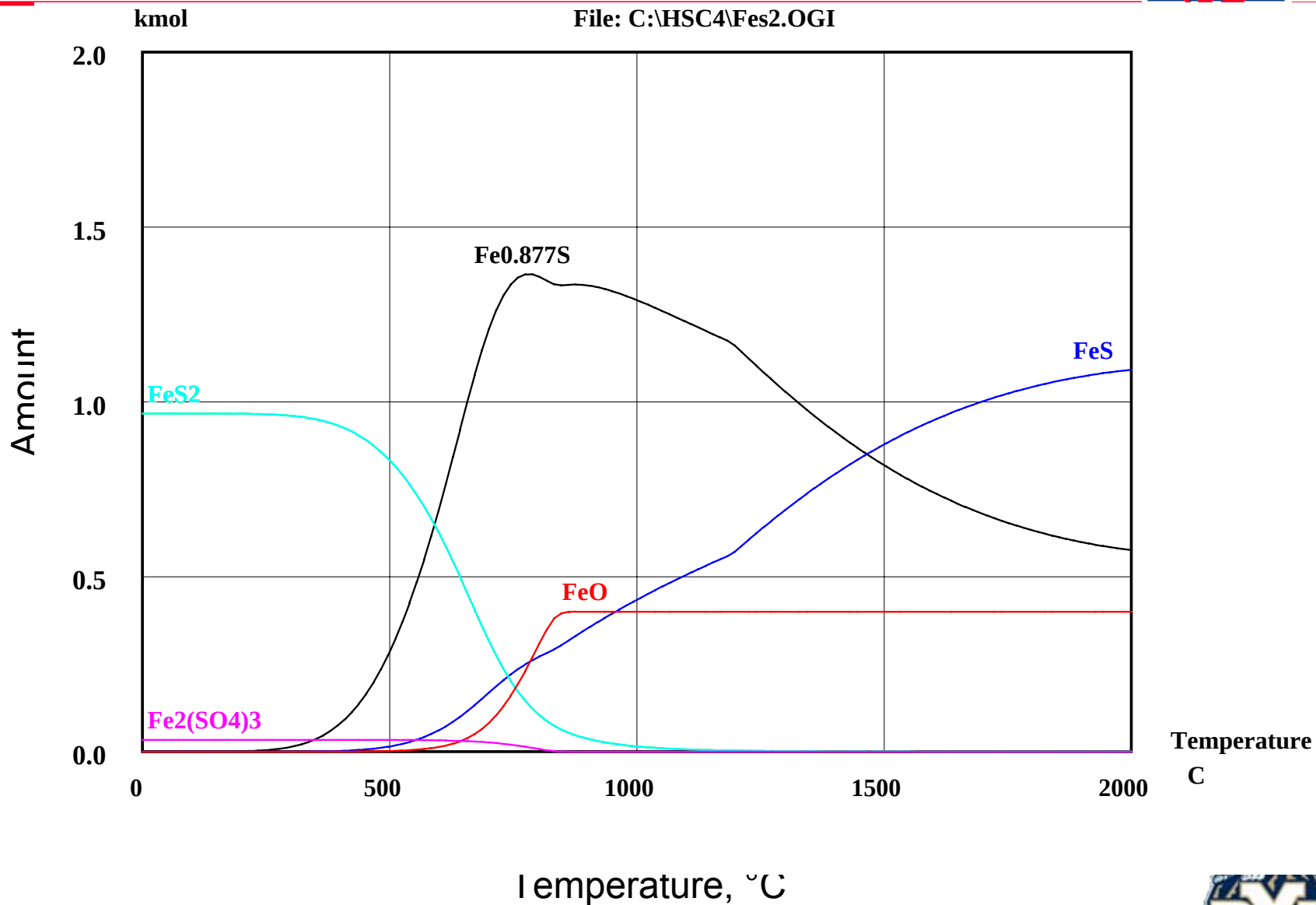


Temperature, °C

Illite (Muscovite)

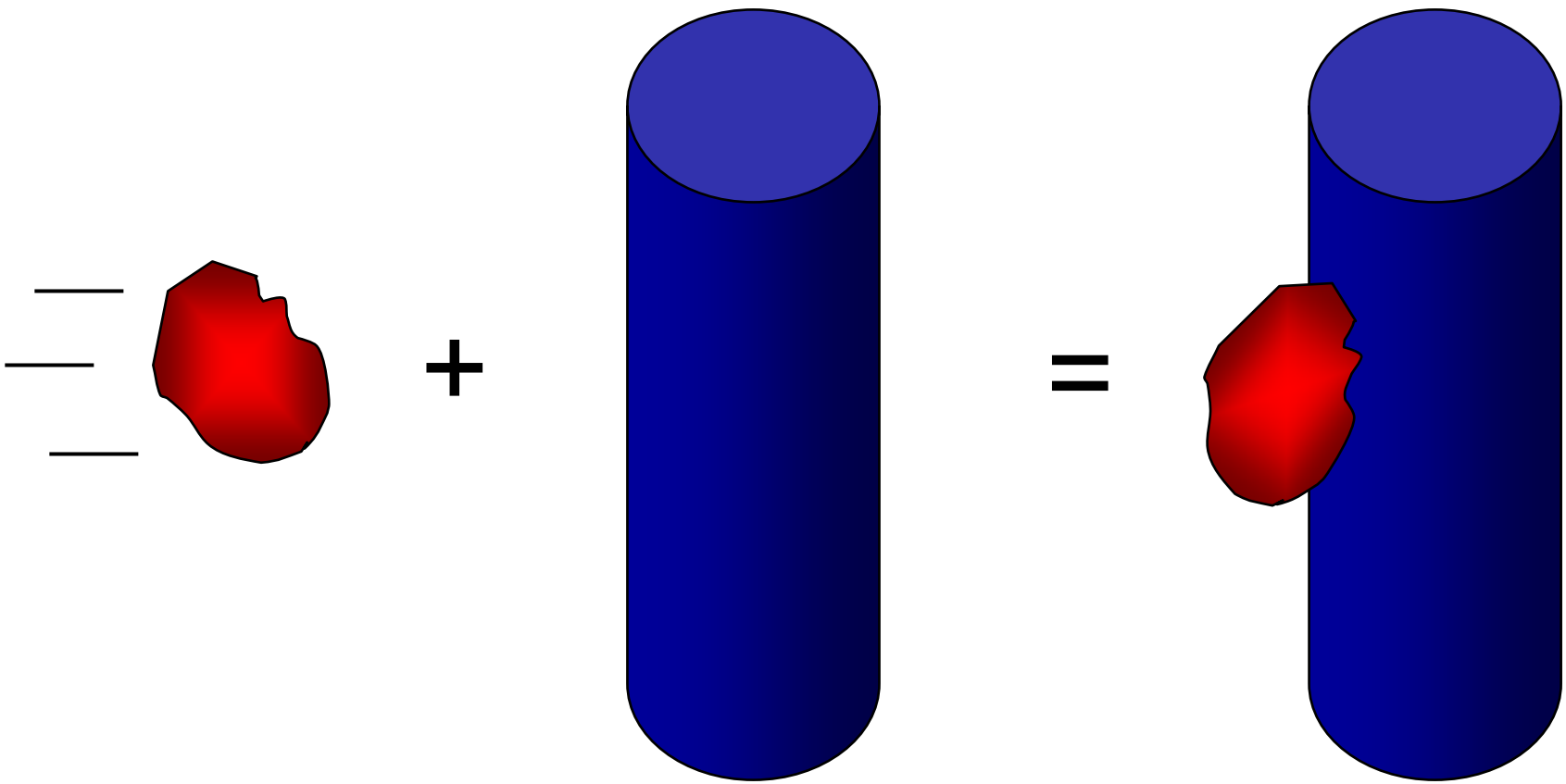


Pyrite Forms Liquid



Deposition Mechanisms

Inertial Impaction

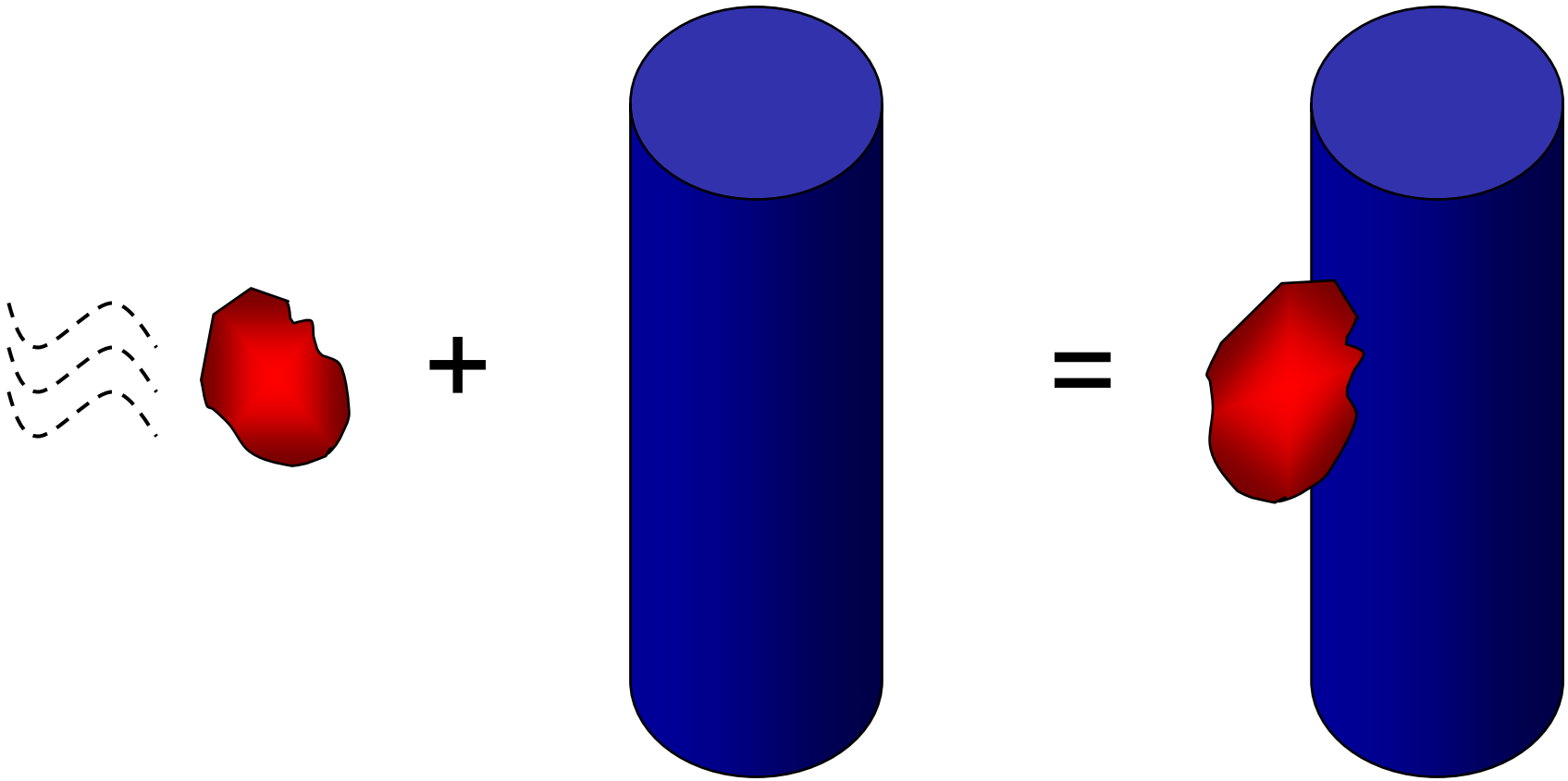


moving particle

steam tube

deposit

Eddy Impaction

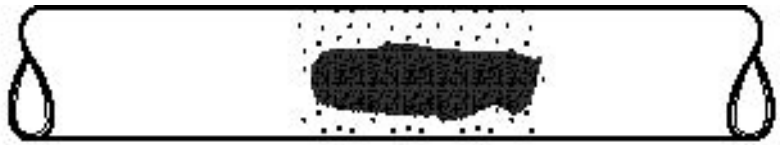


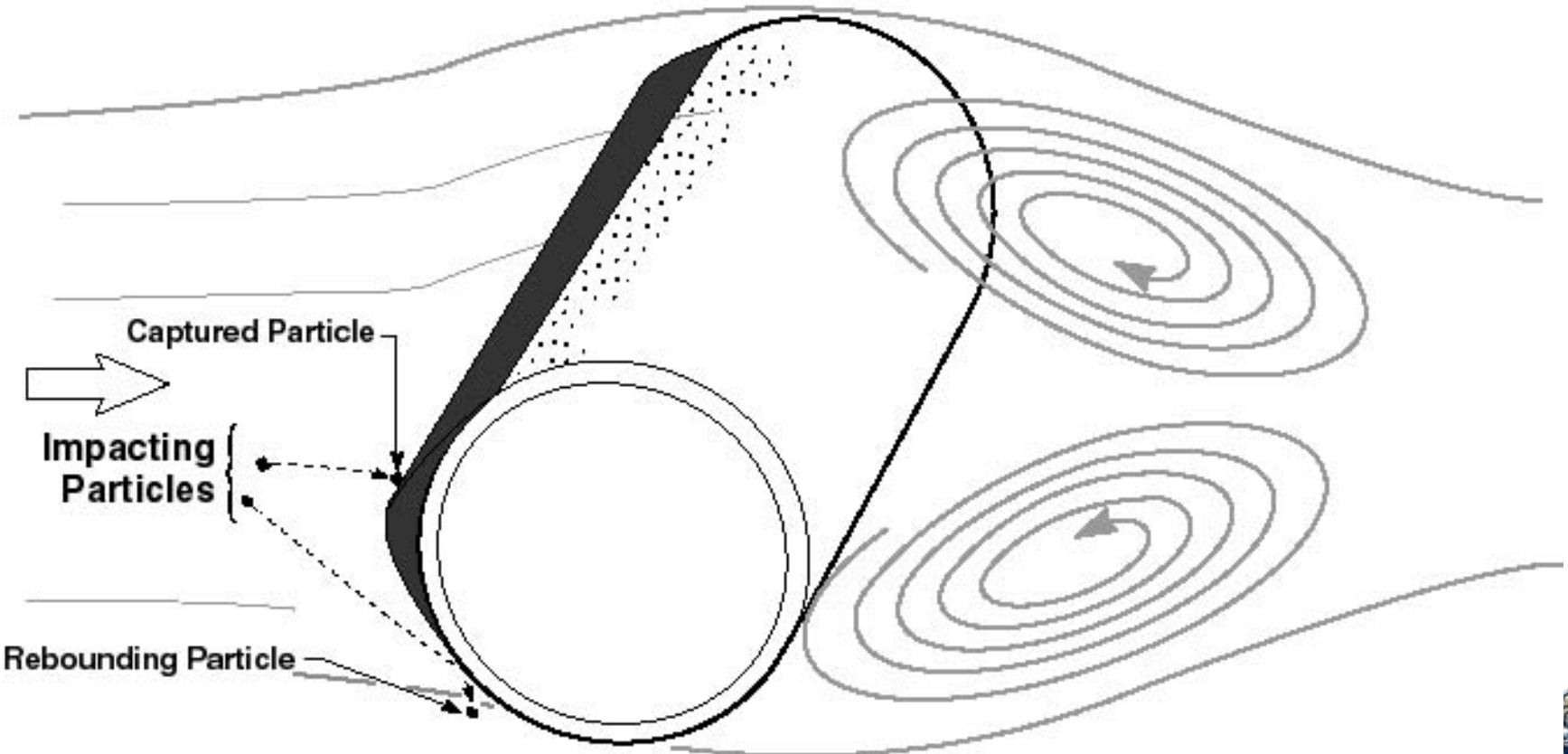
moving particle

steam tube

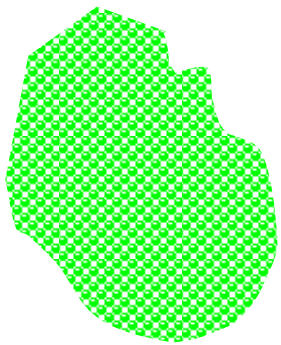
deposit

Most Mass Impacts



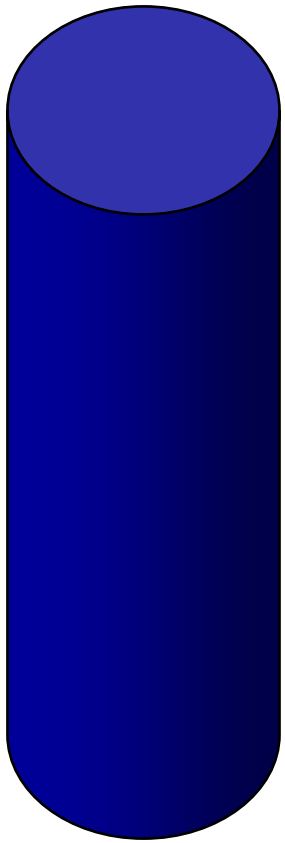


Thermophoresis



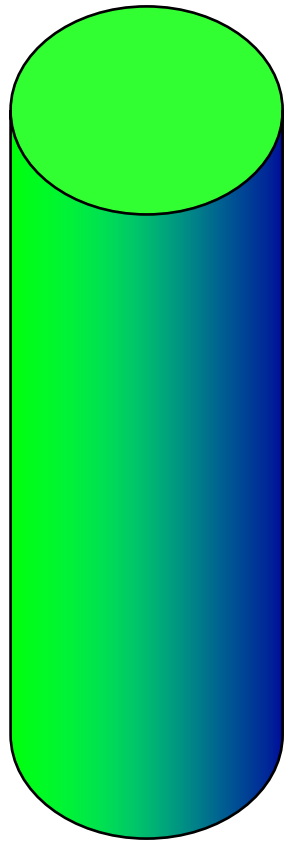
small
(< 5 μm)
particles

+



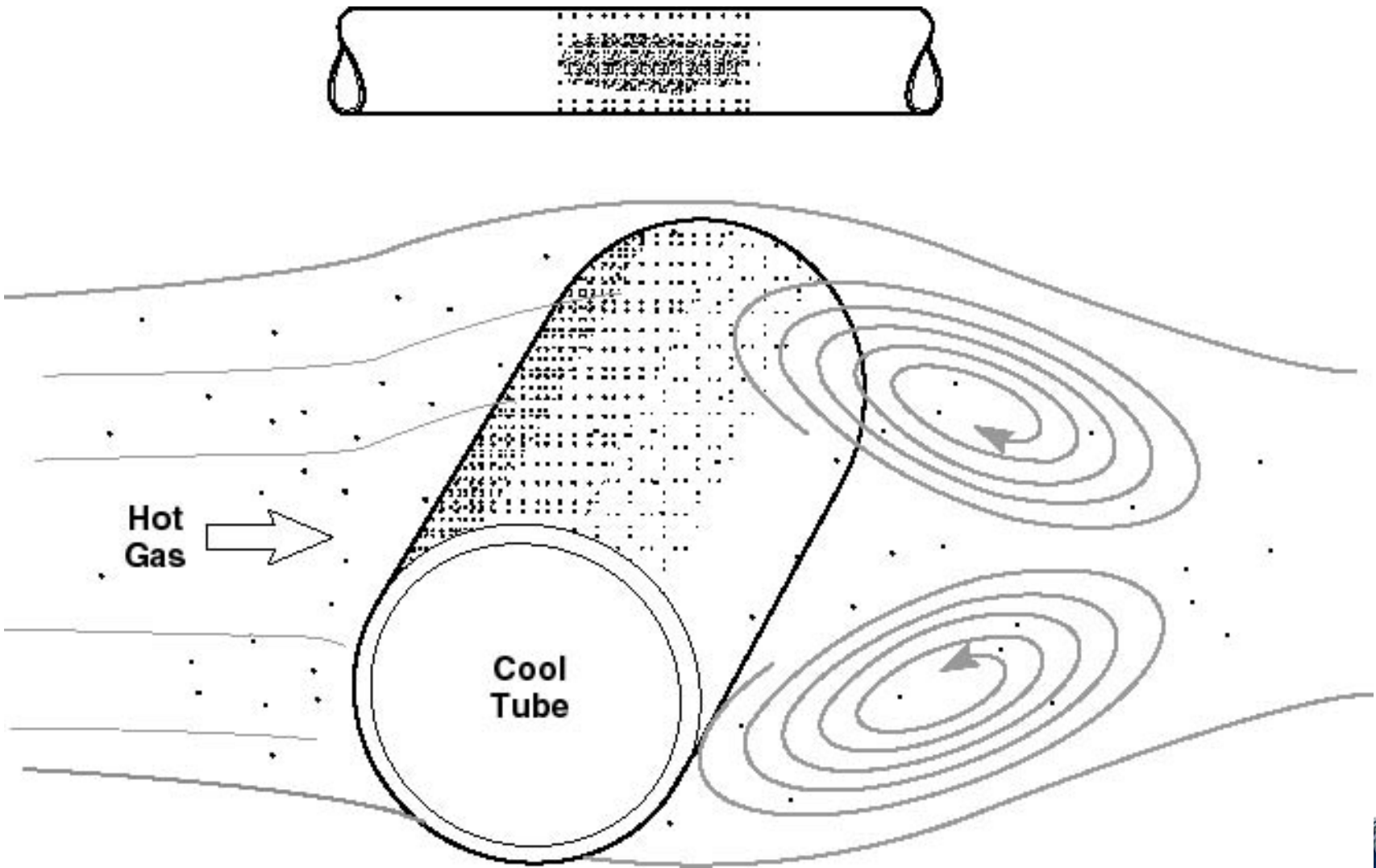
steam
tube

=

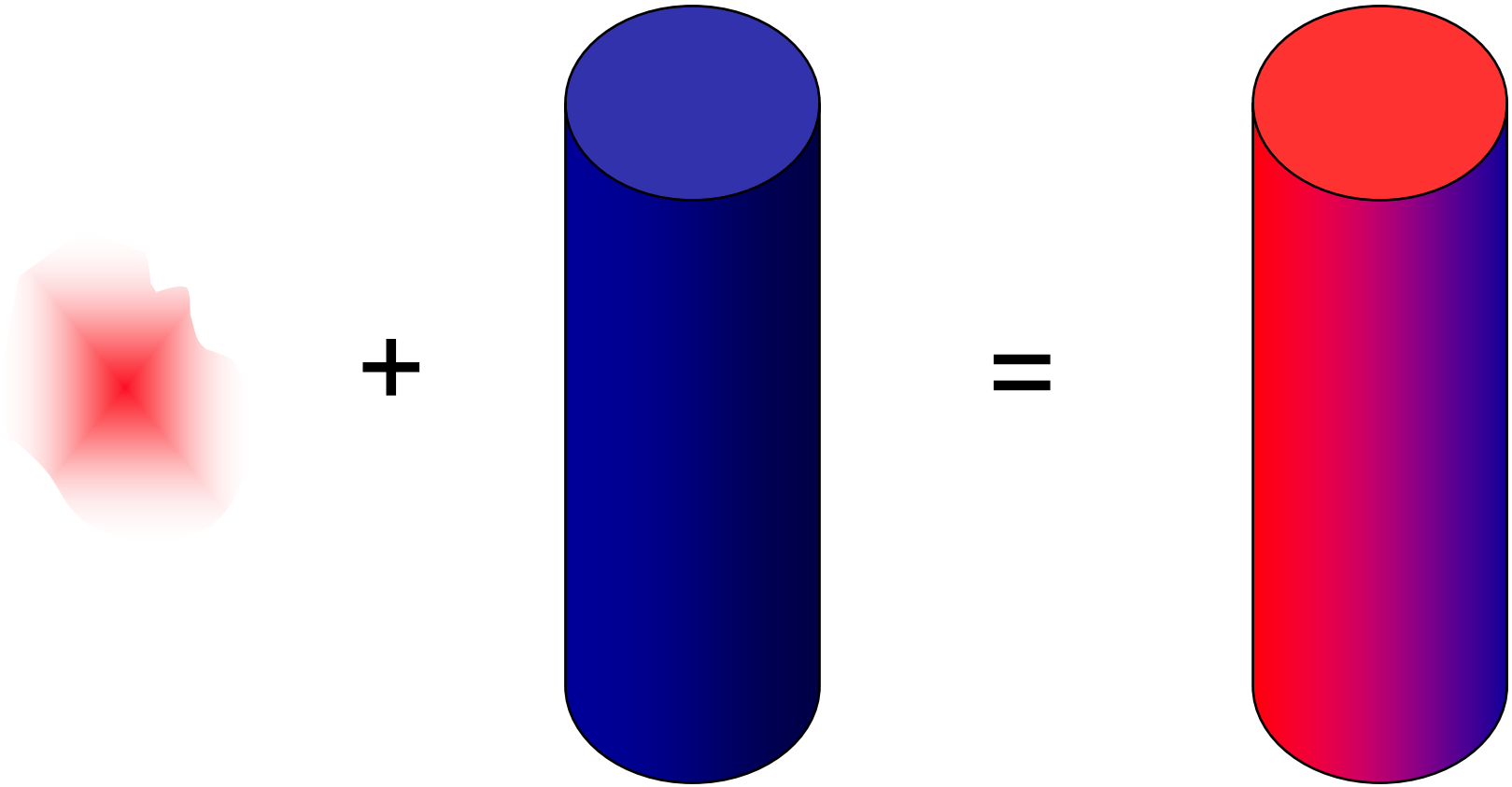


deposit

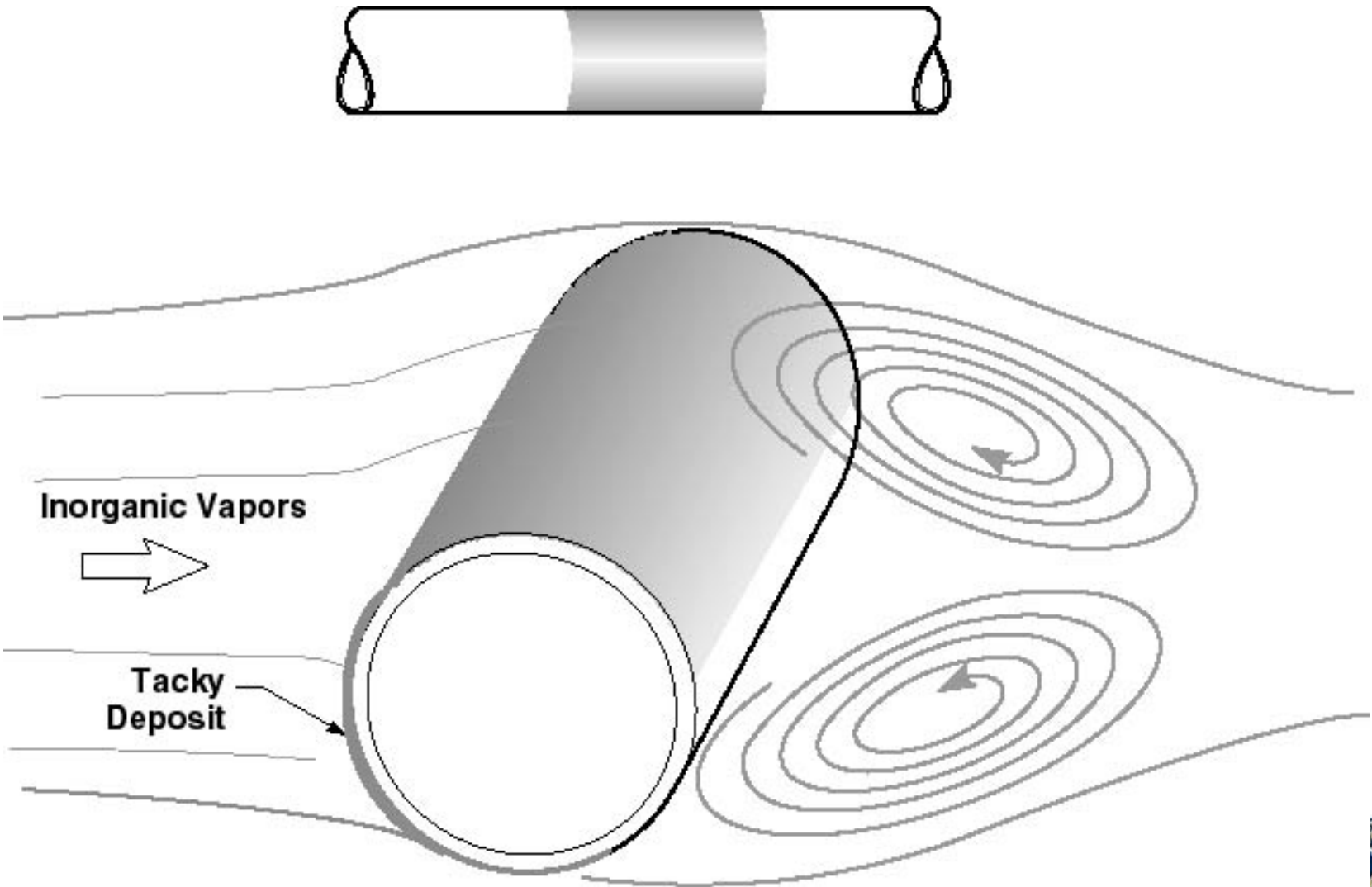
Thermophoresis?



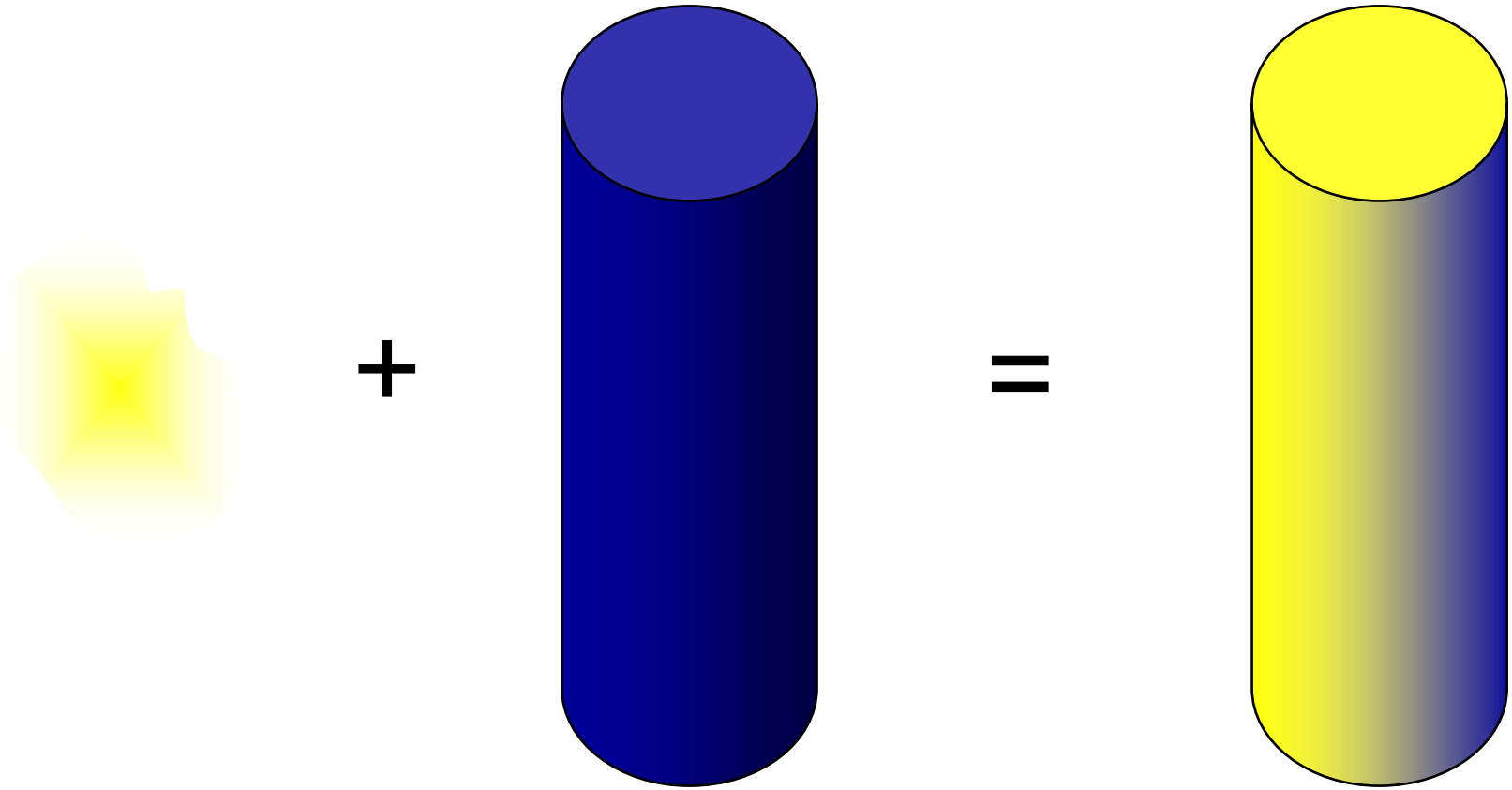
Condensation



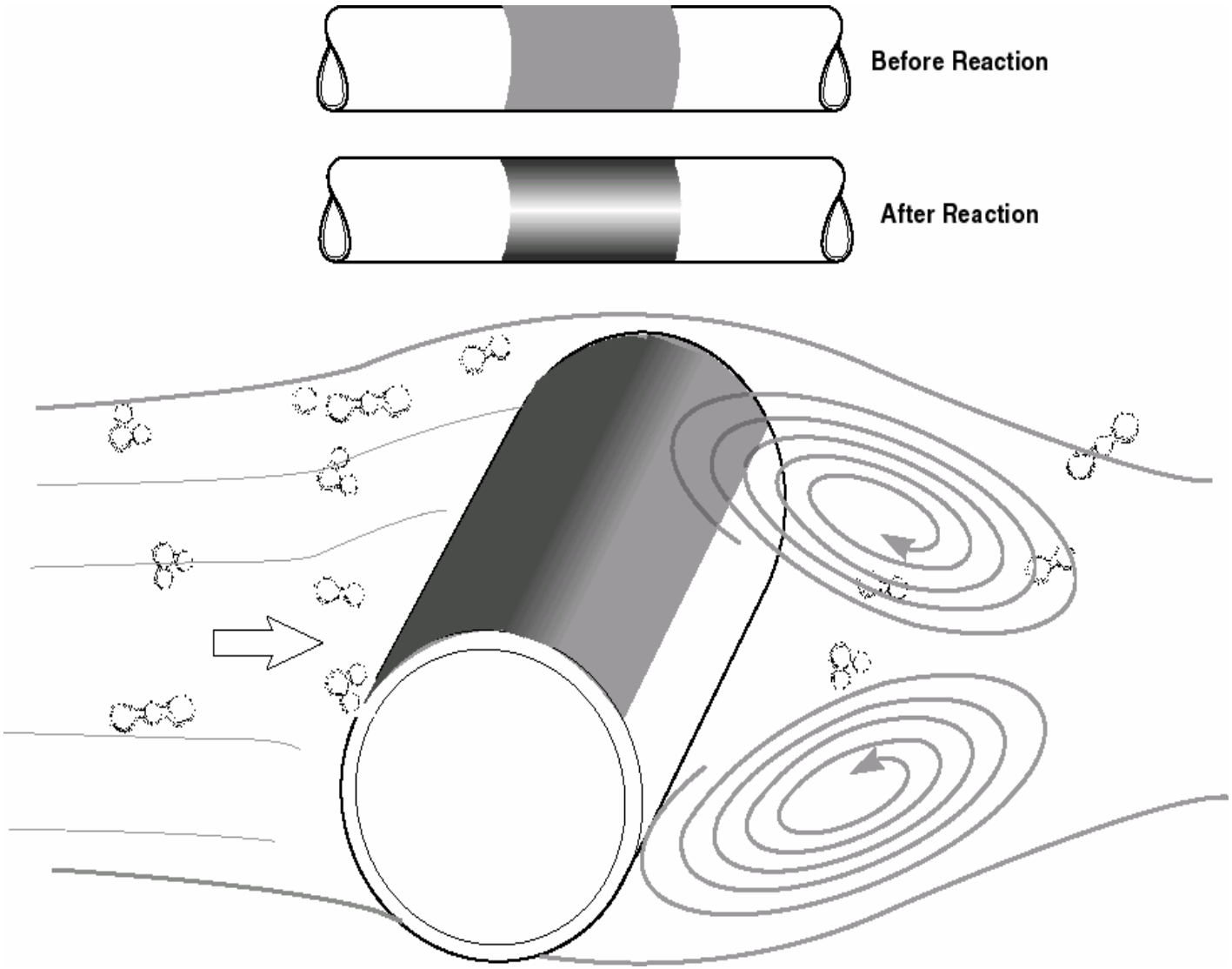
Condensation



Chemical Reaction



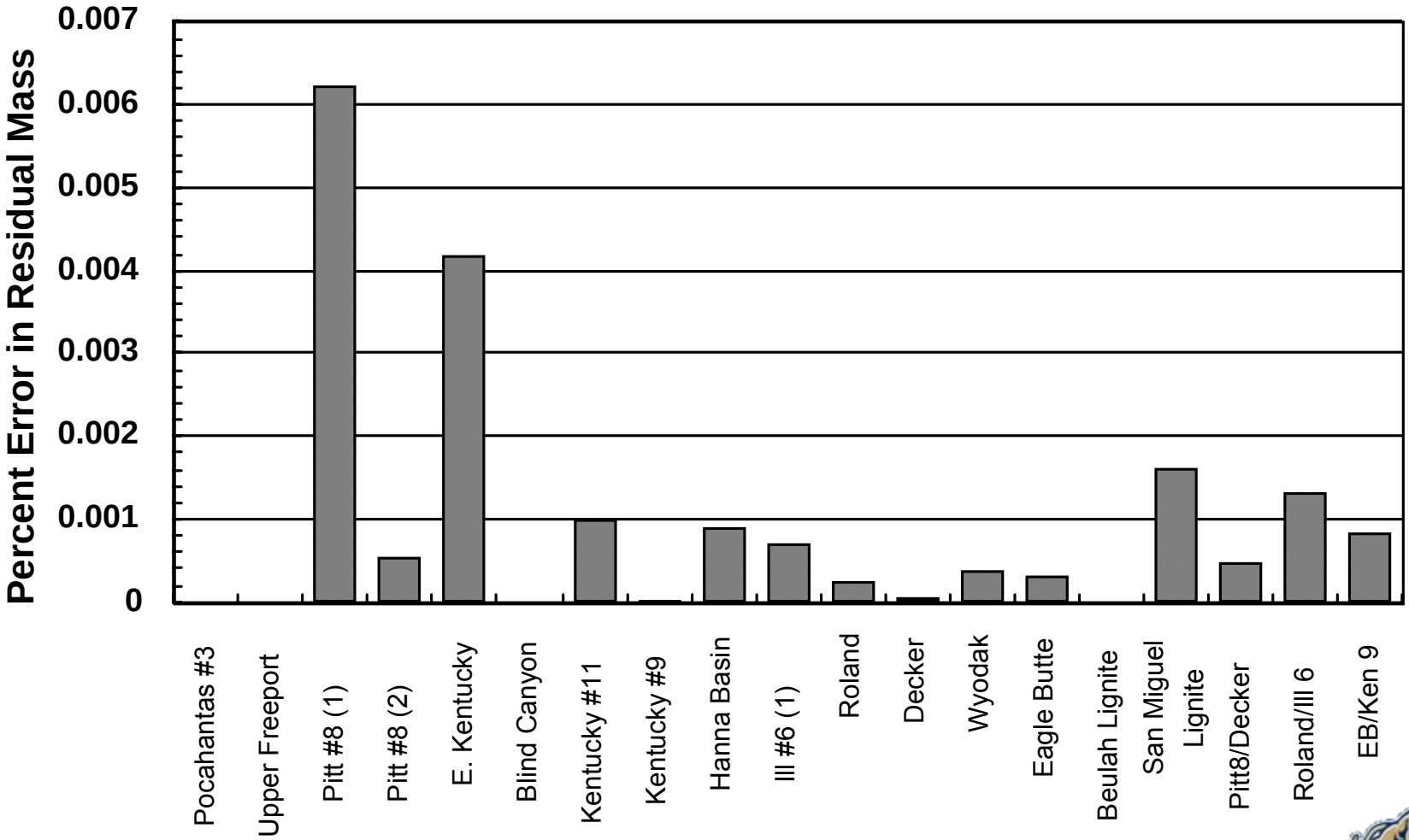
Gases React with Deposits



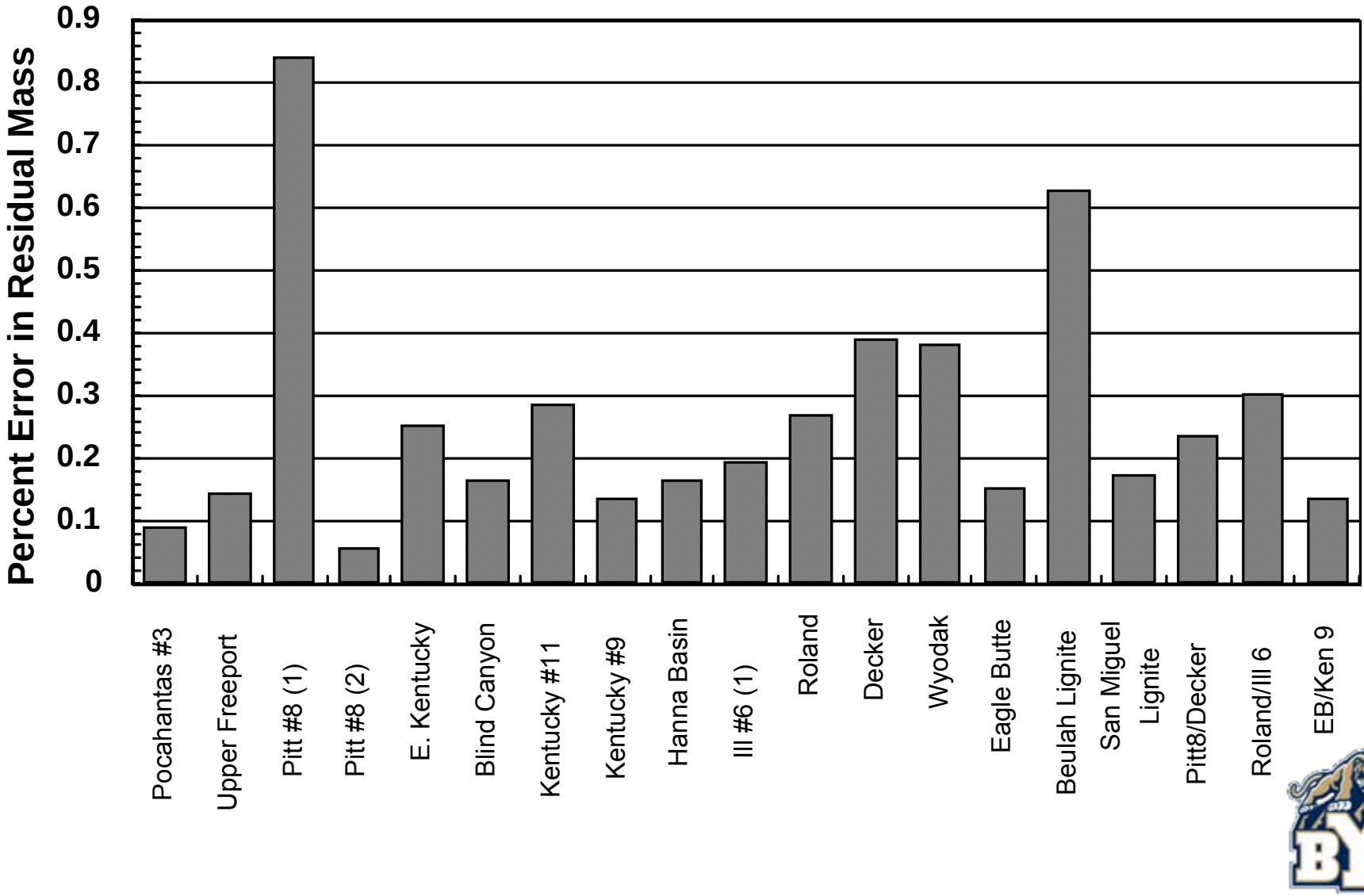
Status of Chemical Fractionation

- Incorporated into (nearly) commercial software
- Analysis developed as VBA code and incorporated into Access – could easily be incorporated into Excel
- ASTM Ruggedness tests
  - Repeatability (ability of a single lab to get similar results) done
  - Reproducibility (ability of different labs to get similar results) underway – welcome volunteer labs (need about 6 more)
- Have database of about 50 coals representing most ranks, mostly bituminous and subbituminous, and mostly US fuels.

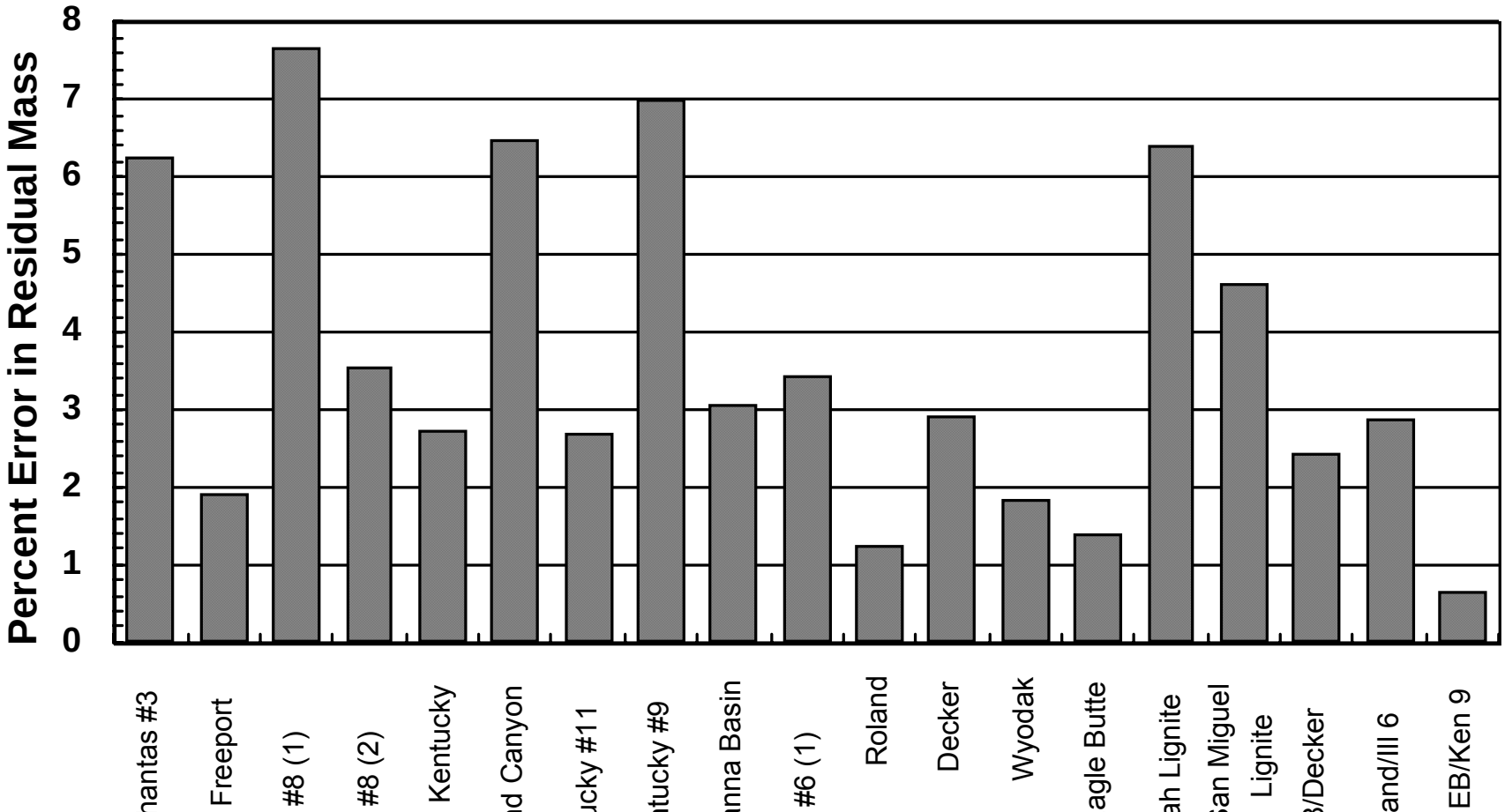
Si Tracer Errors in H_2O Step



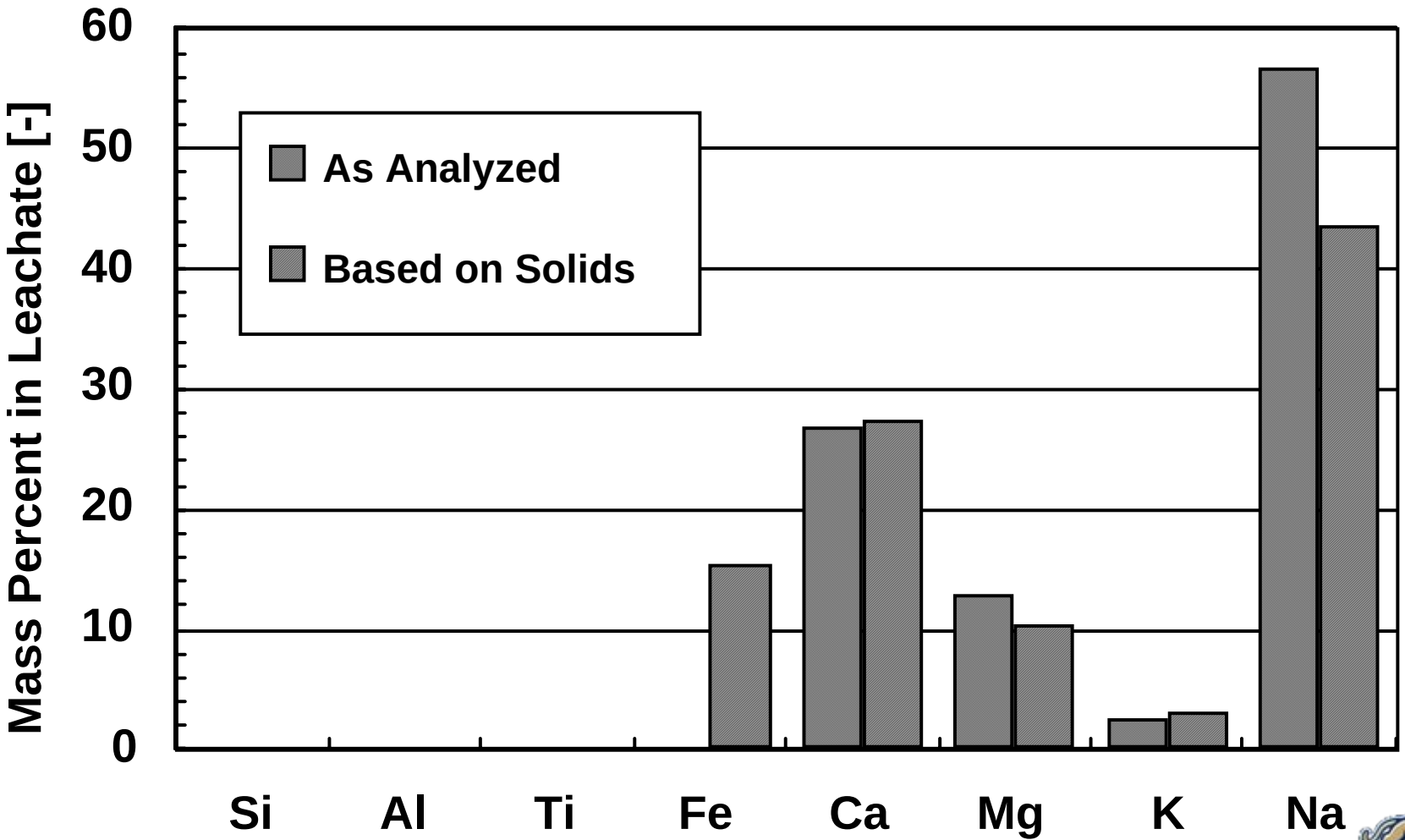
Si Tracer Errors in AmAc Step



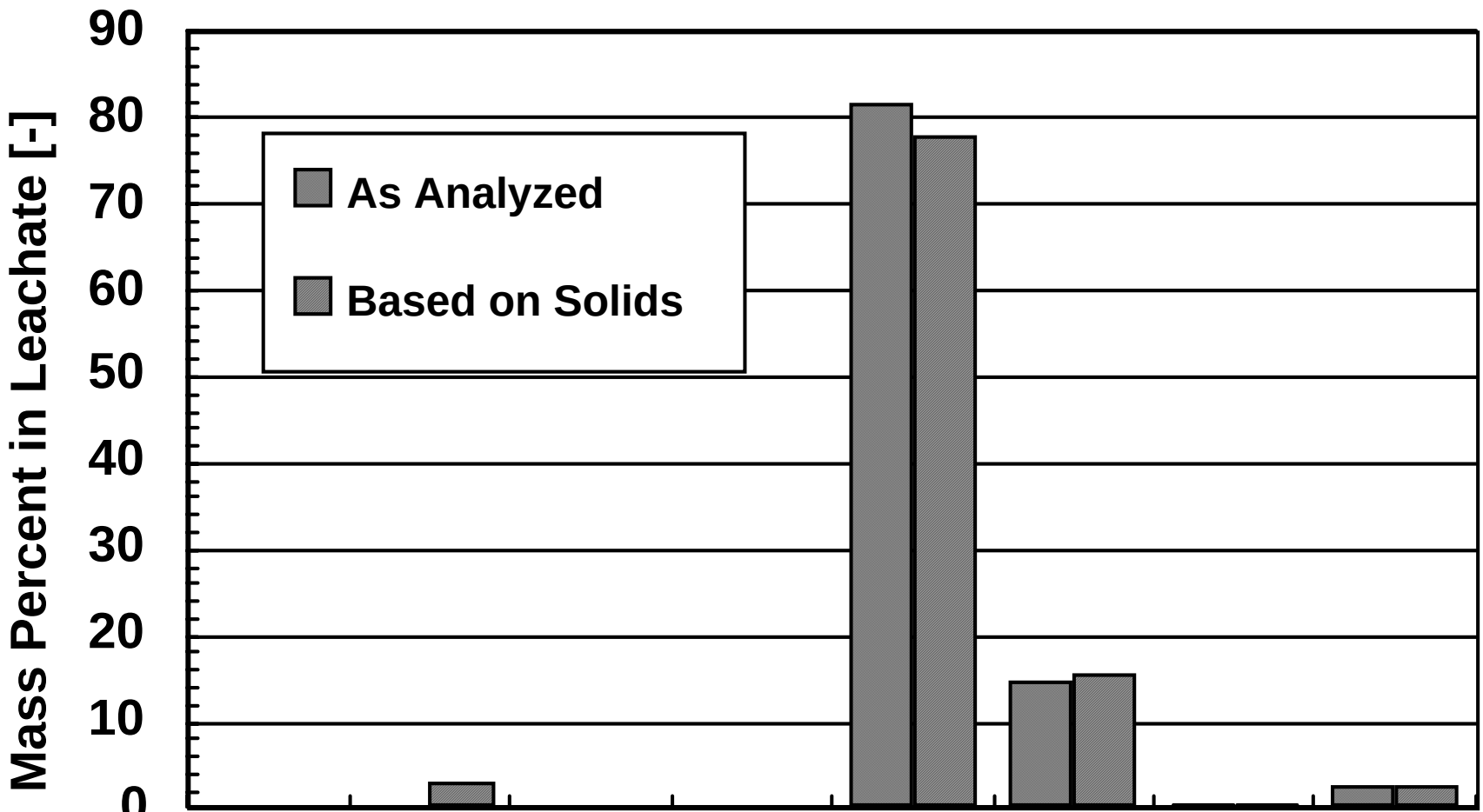
Si Errors in HCl Step



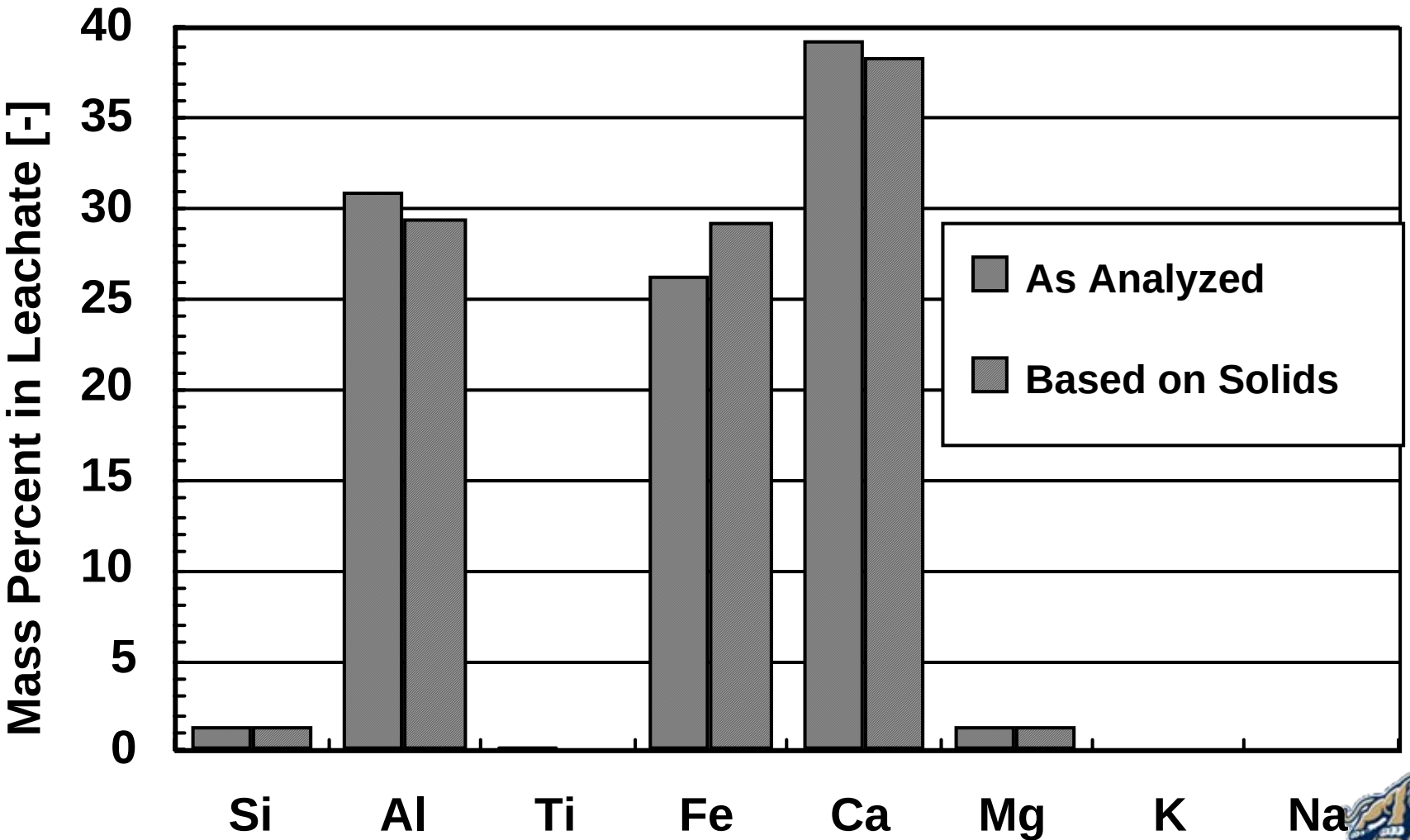
Leachate vs Solids Analysis: H_2O



Leachate vs Solids Analysis: AmAc

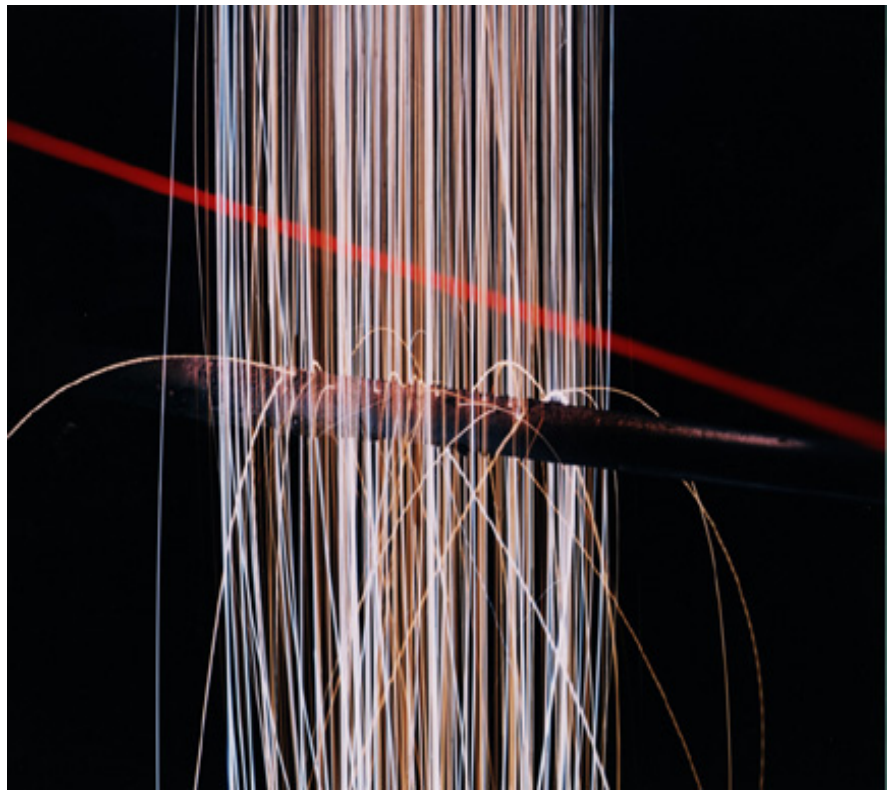


Leachate vs Solids Analysis: HCl



Deposition Rates Are Modeled

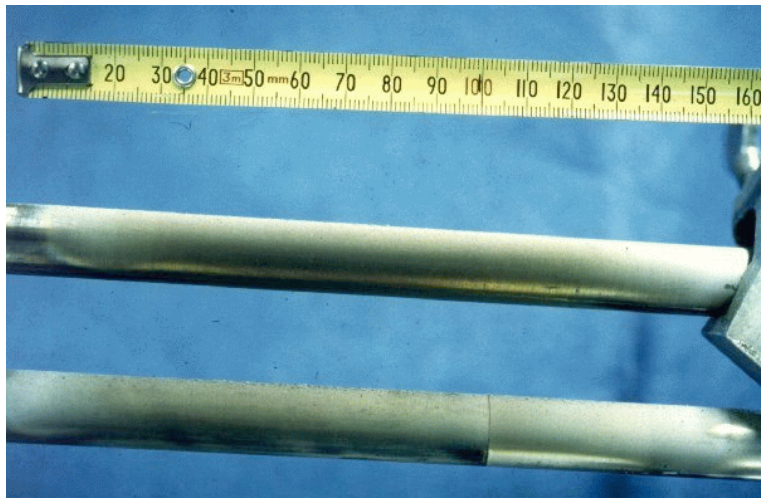
- Inertial impaction
  - Important for deposit mass
  - Best quantified
- Eddy impaction
  - Generally small contributor
  - Largely empirical models
- Thermophoresis
  - Huge theoretical literature
  - Data comparisons not satisfying
- Condensation
  - Good theory, but complex for practical conditions
- Chemical reaction
  - Complex in condensed phase



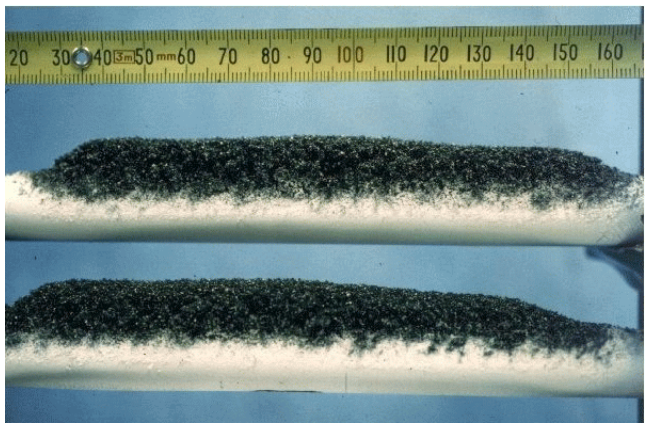
Cofiring Deposition

1

3



2



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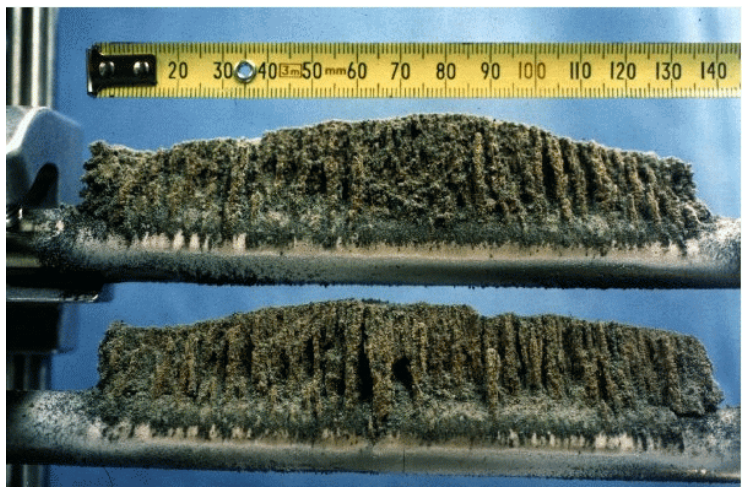
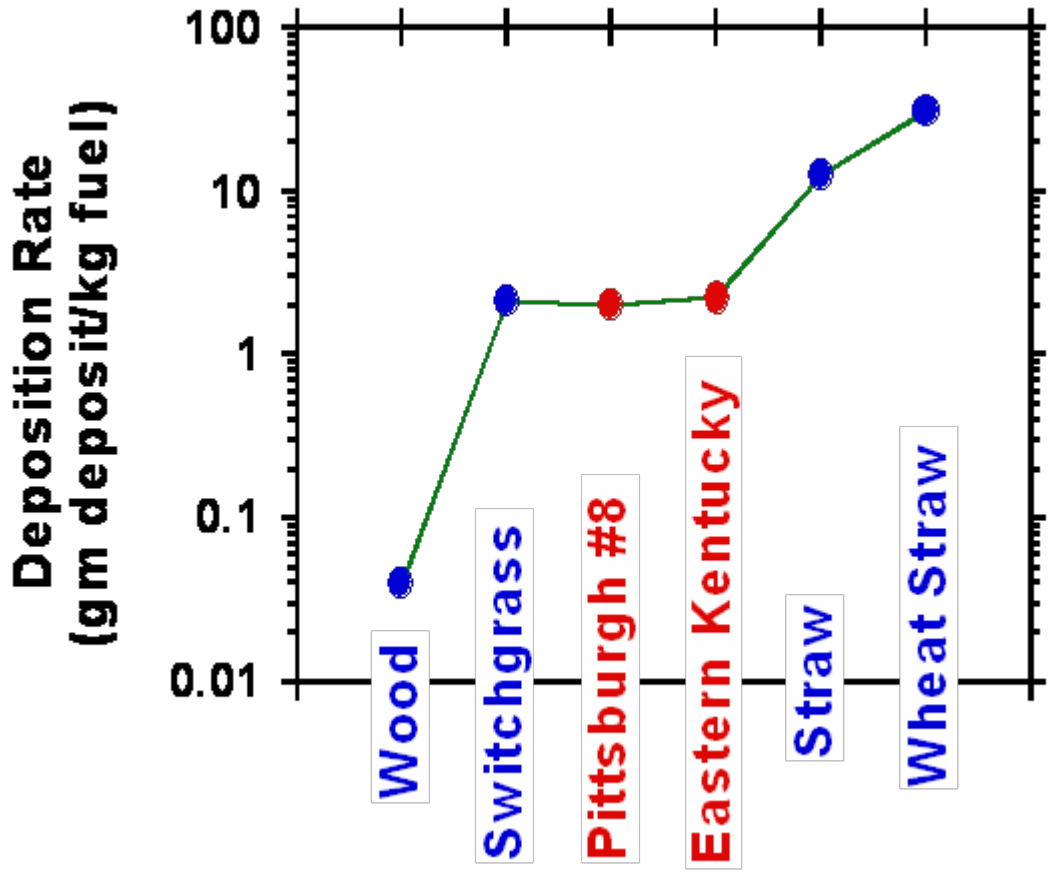
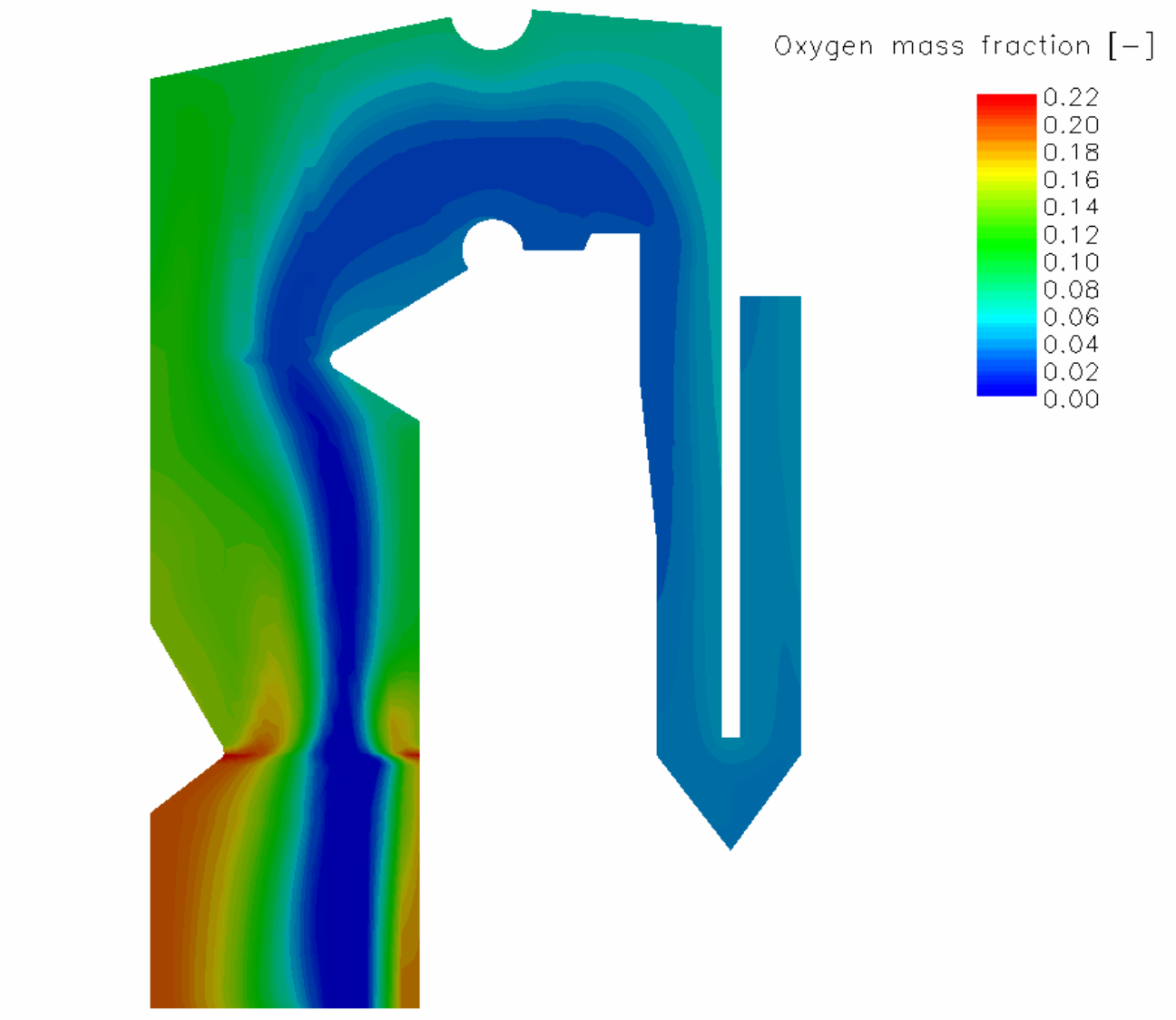


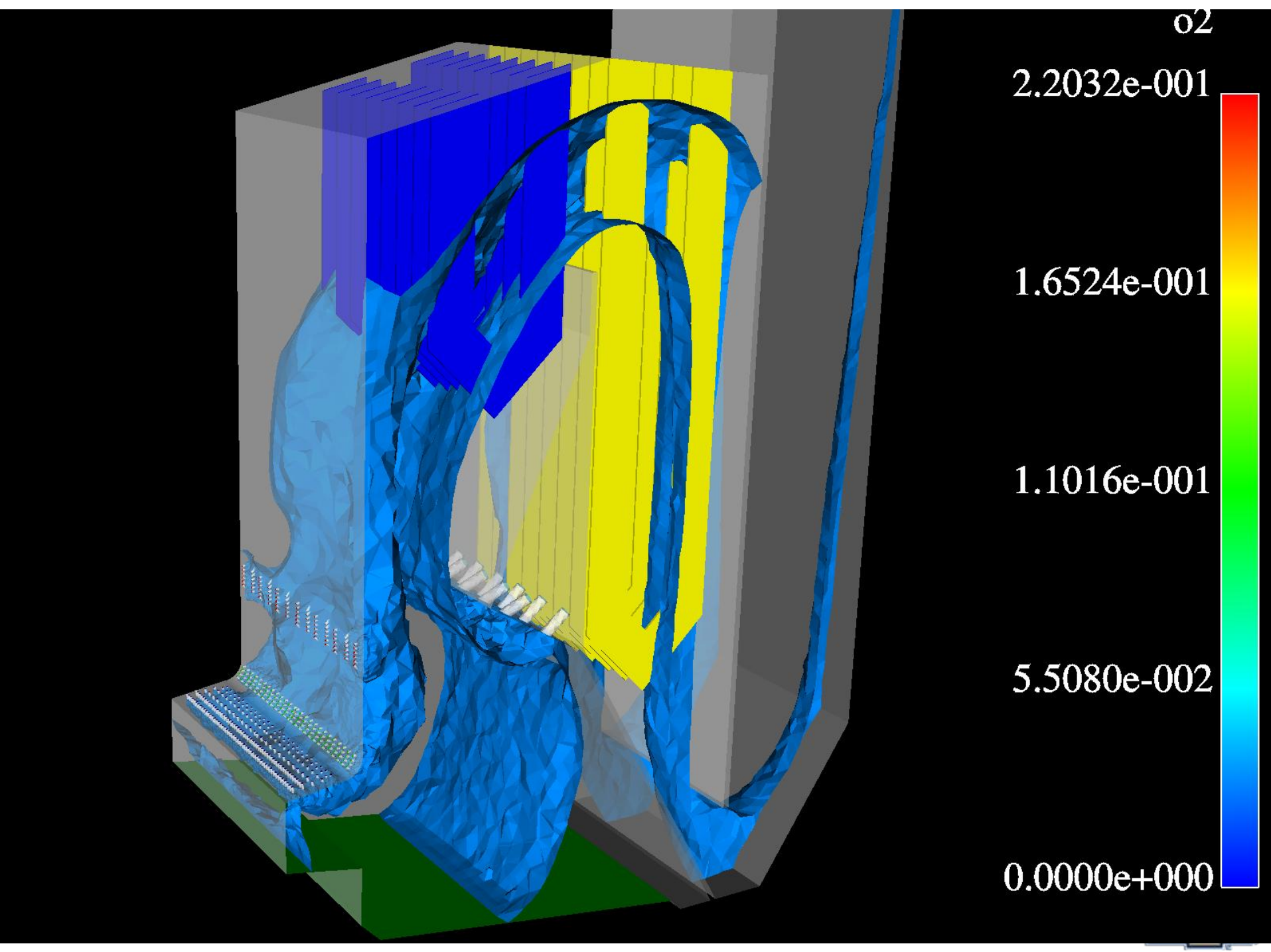
Deposition Rates Vary Widely

- Cofiring biomass can lead to either decrease or increase in deposition rates.
- Cofiring decreases deposition relative to neat fuels.

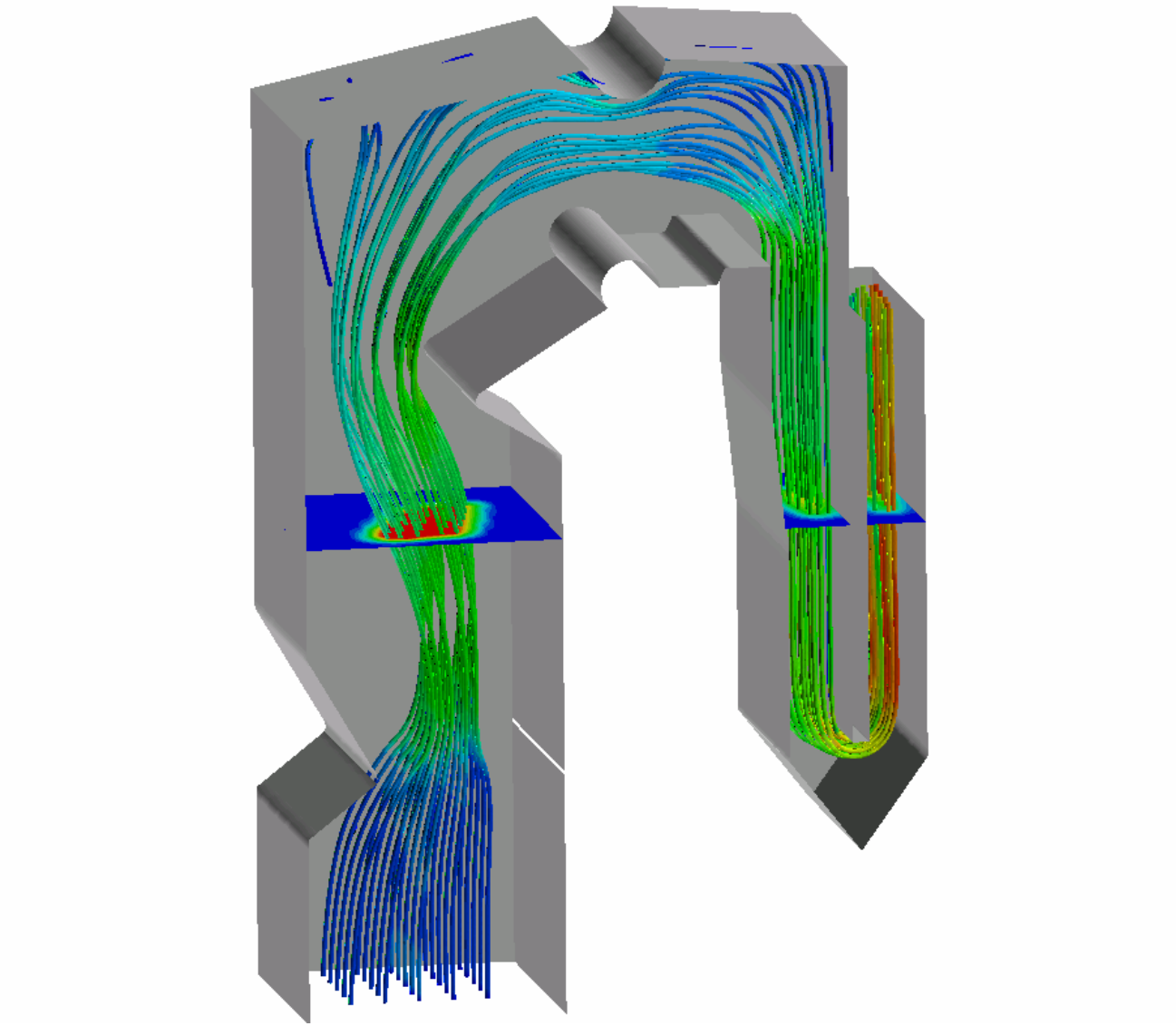


Oxygen Mass Fraction Contours

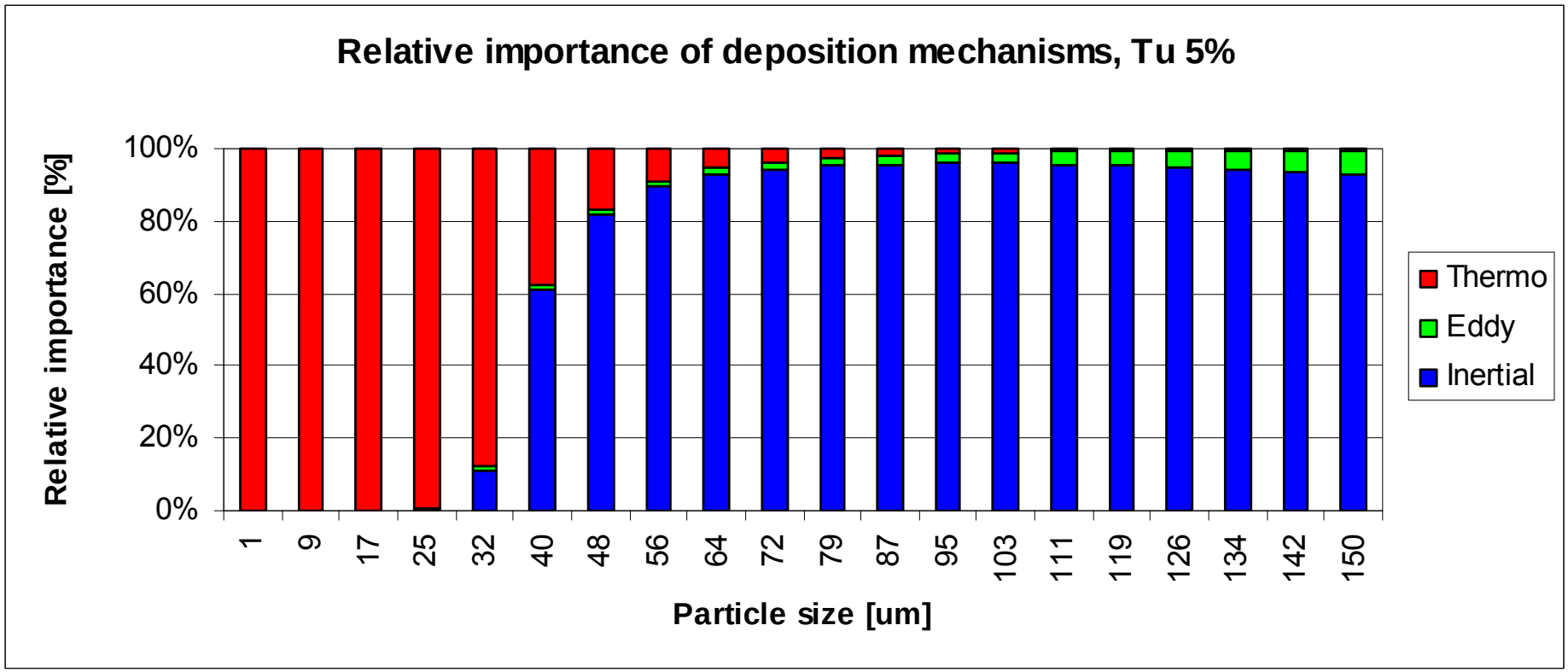



o2
2.2032e-001
1.6524e-001
1.1016e-001
5.5080e-002
0.0000e+000

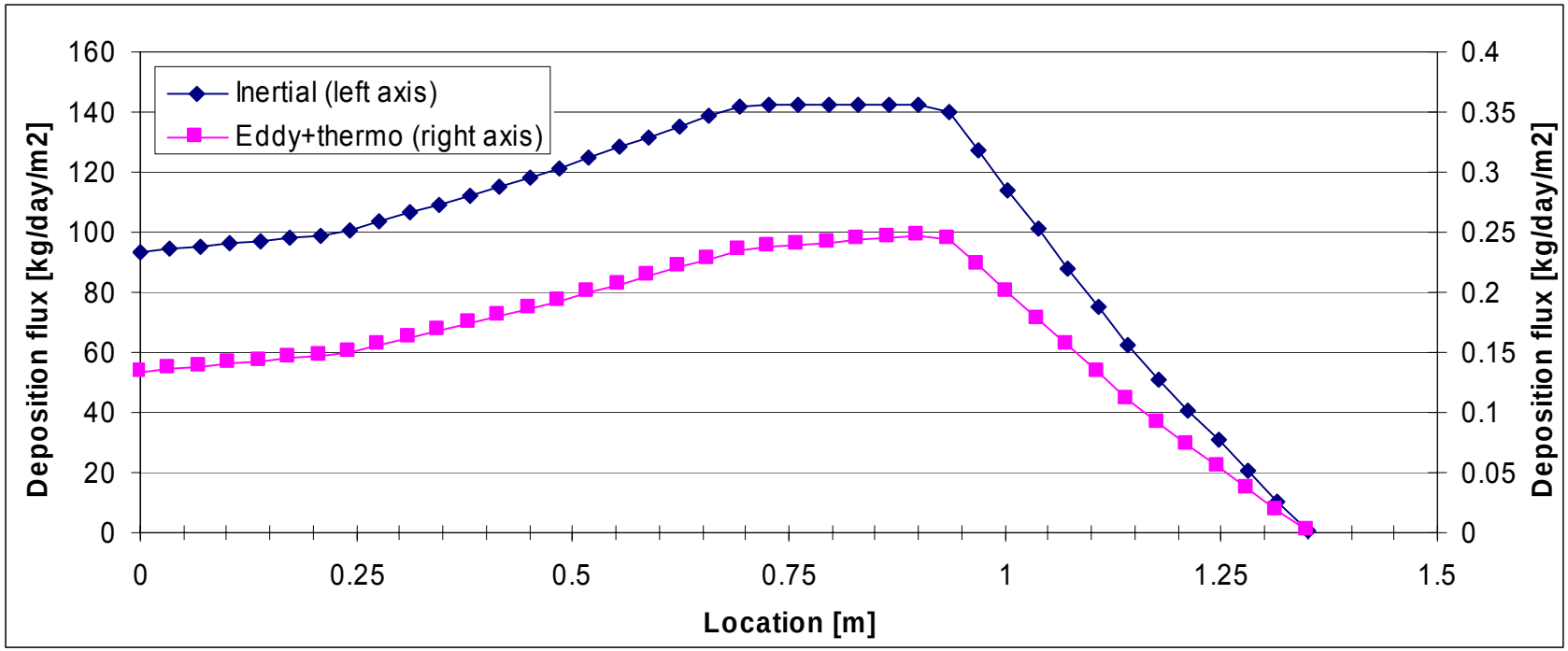
Cloud (Particle) Trajectories



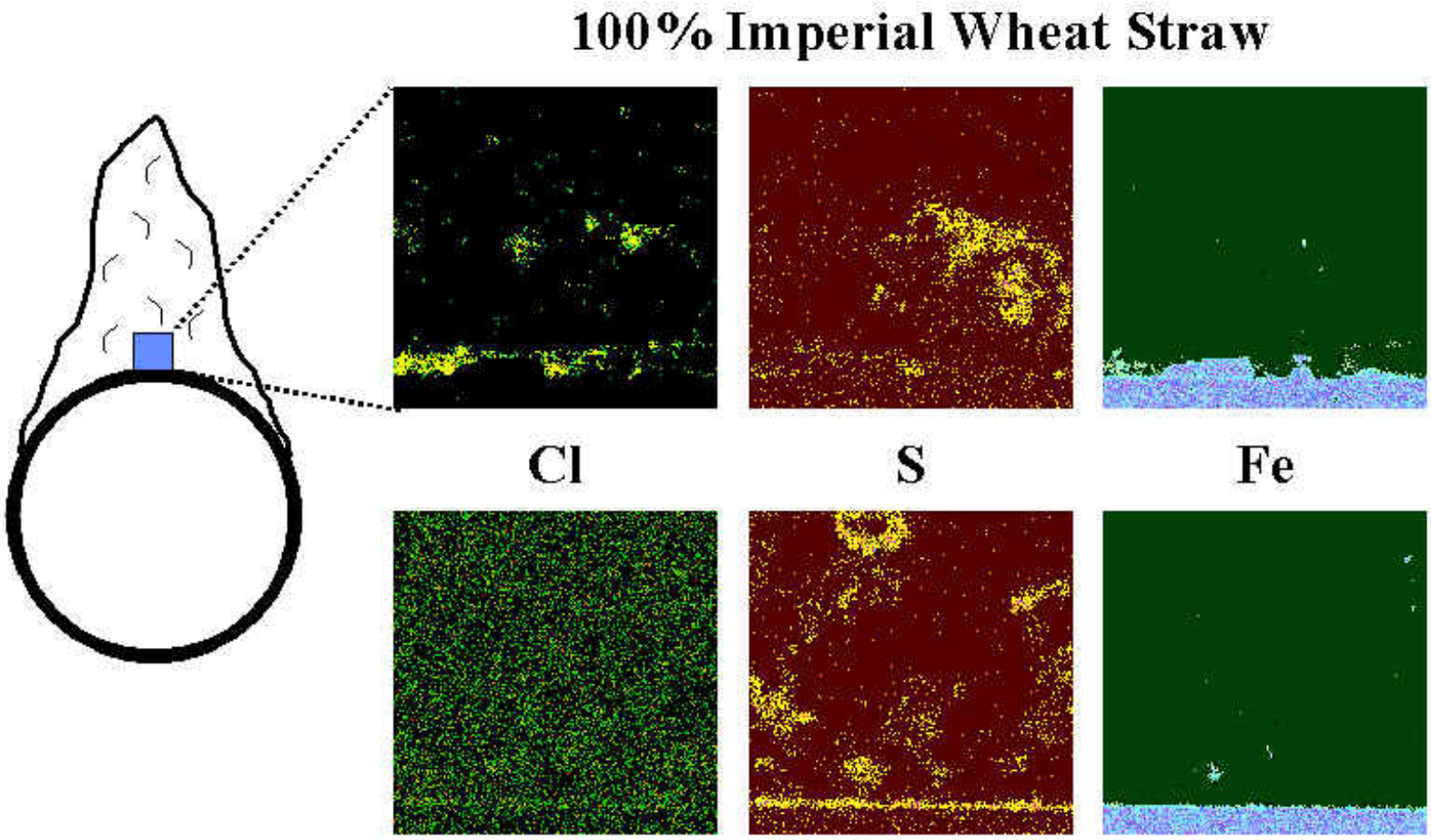
Mechanisms Shift With Size



Deposition Rate: First SH

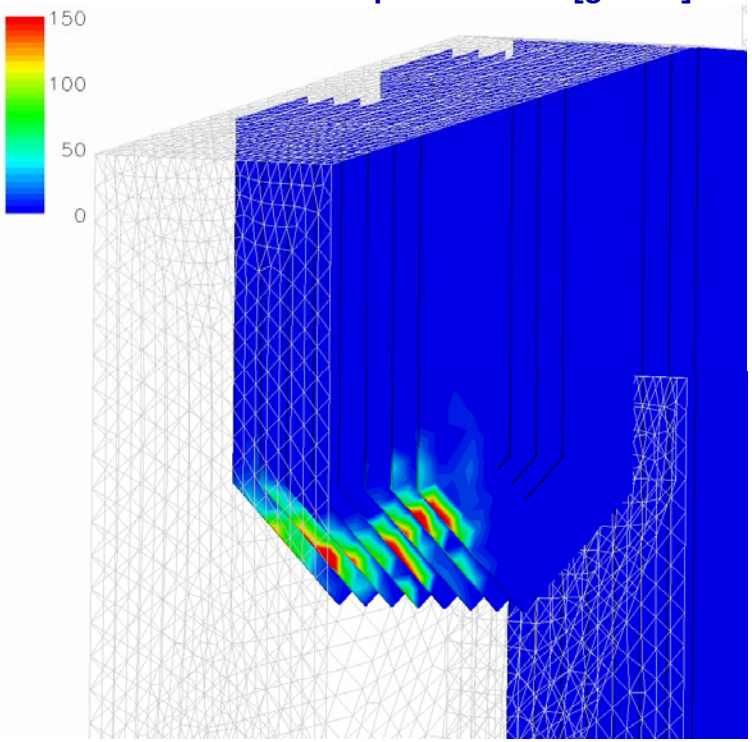


Sulfur Affects Chlorine Exposure

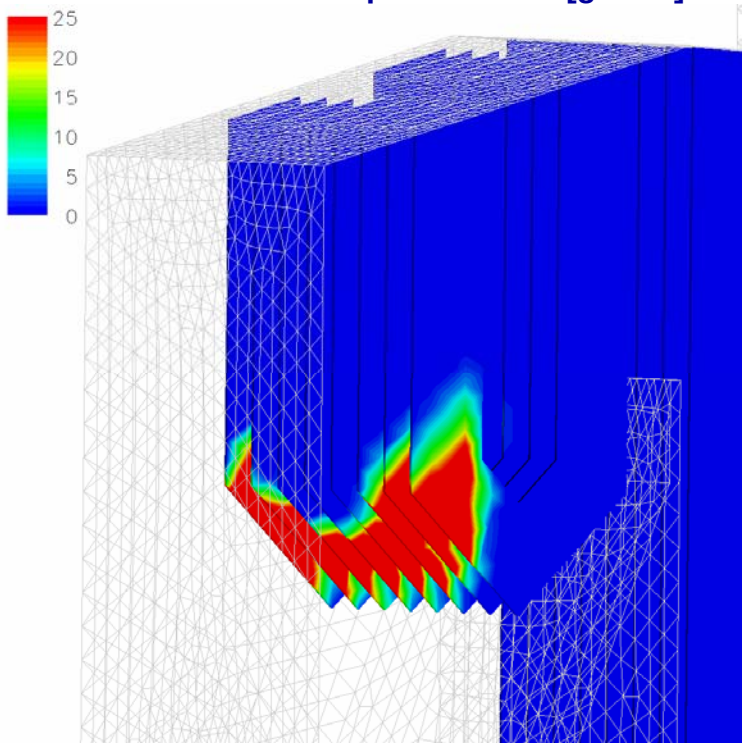


BL Mechanisms

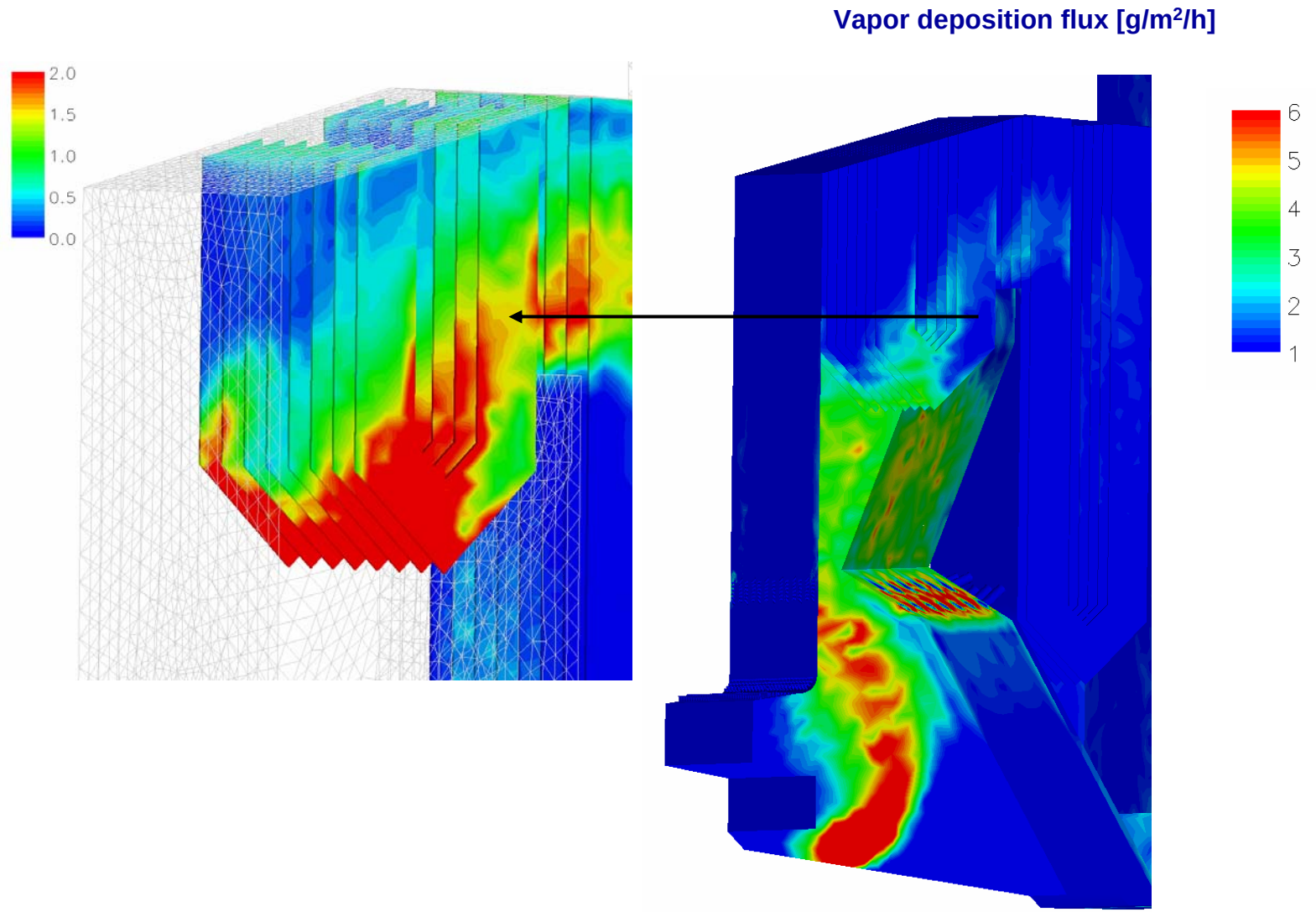
Inertial deposition flux [g/m^2/h]



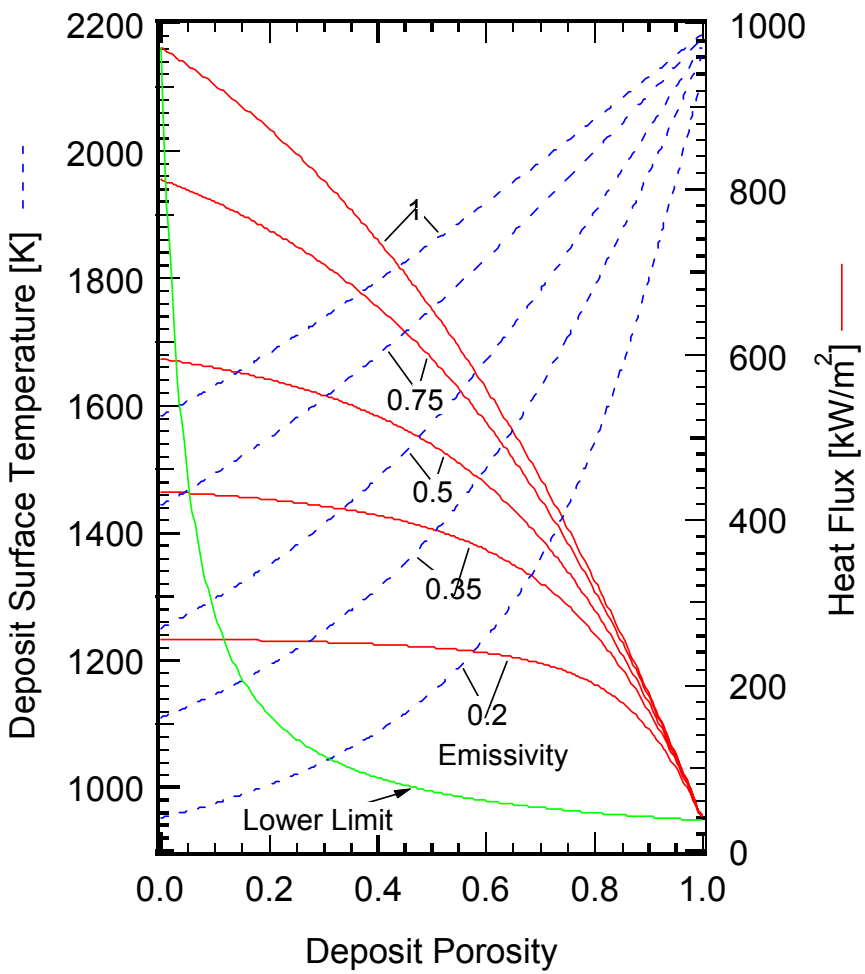
BL deposition flux [g/m^2/h]



Vapor Deposition

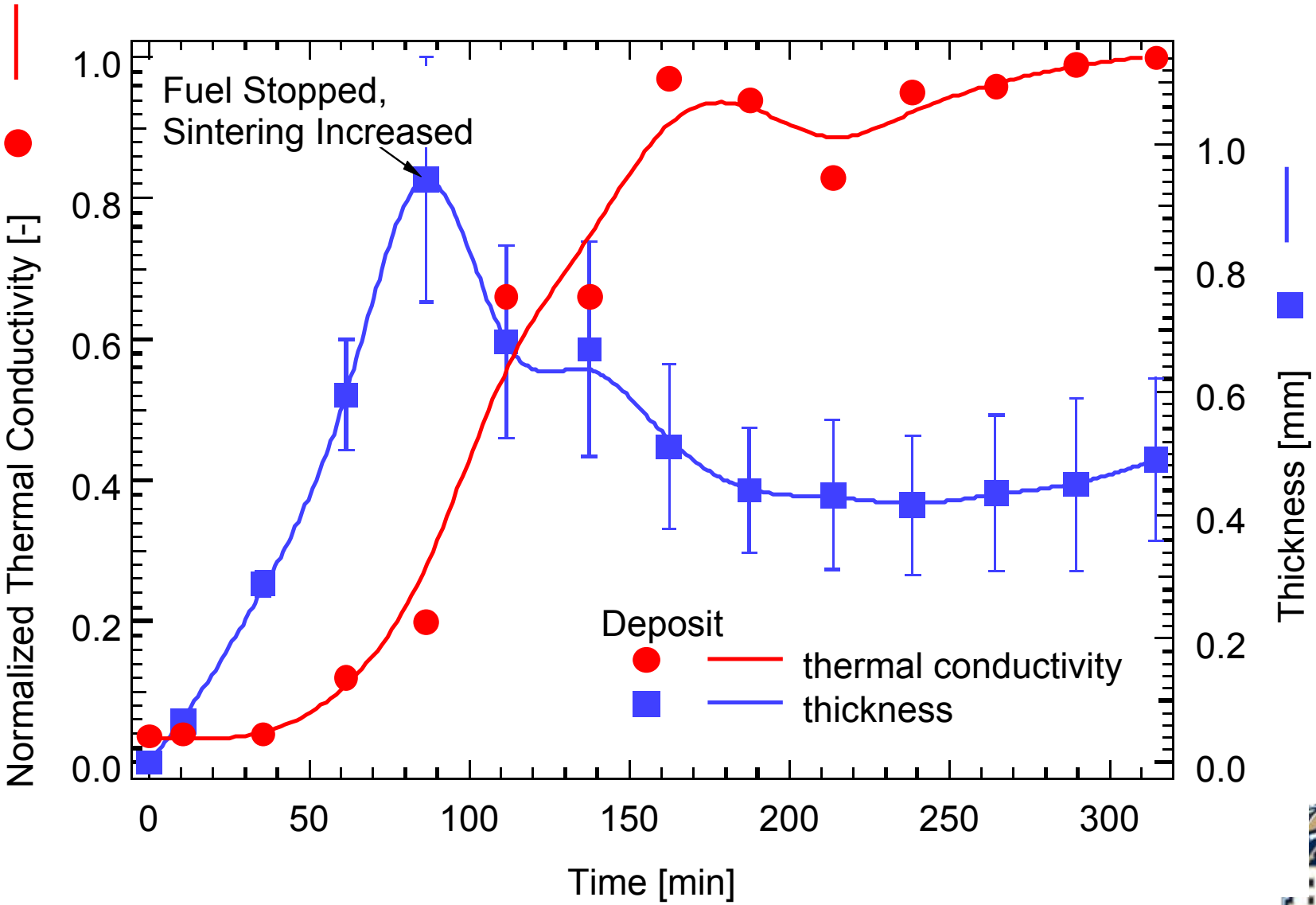


Radiative Properties Are Important

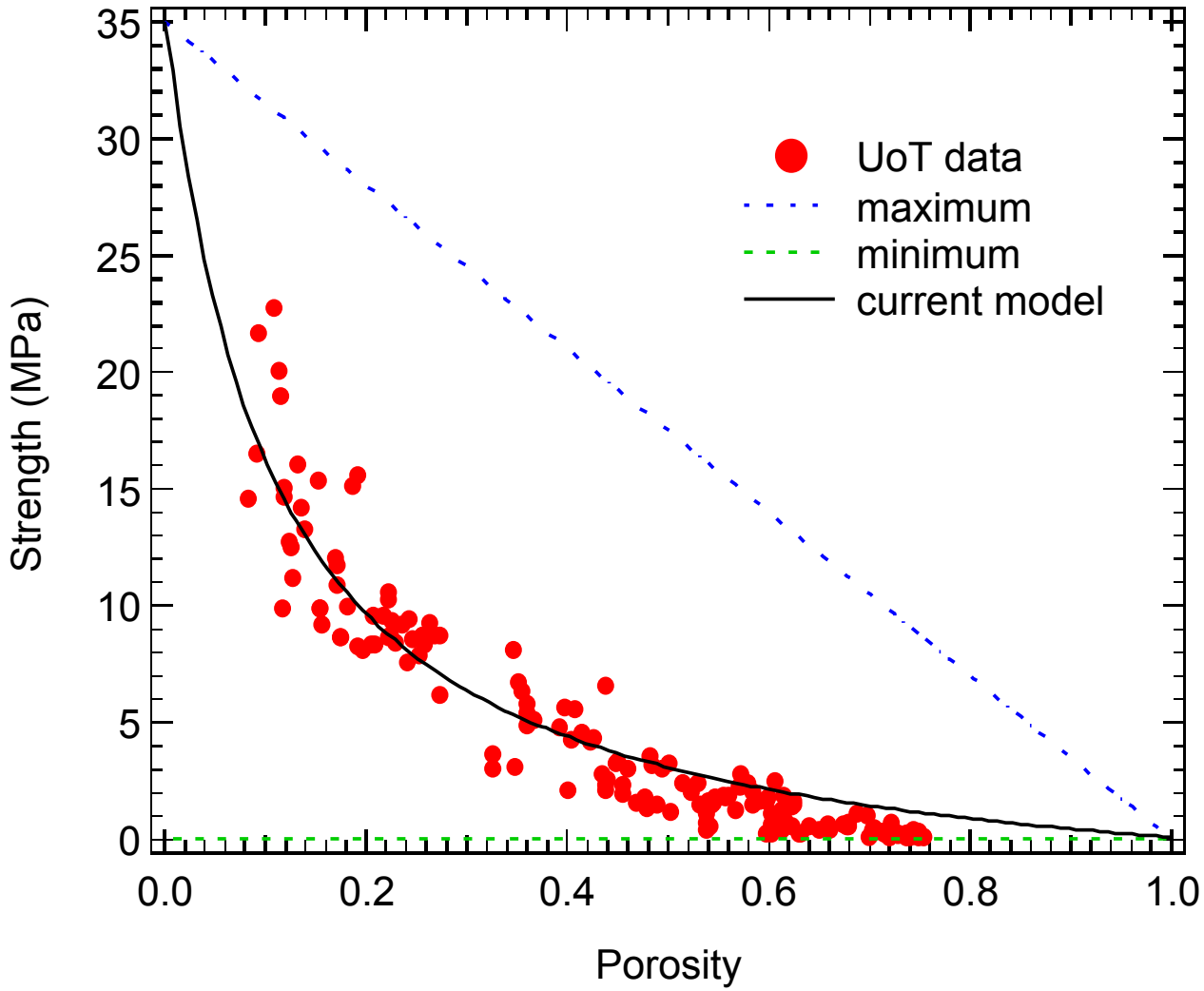


- **Deposit surface temperature and heat flux depend strongly on thermal conductivity and emissivity.**
- **Between the theoretical bounds or thermal conductivity lies a large variation in performance.**
- **It is essential that in situ thermal conductivity data are collected.**

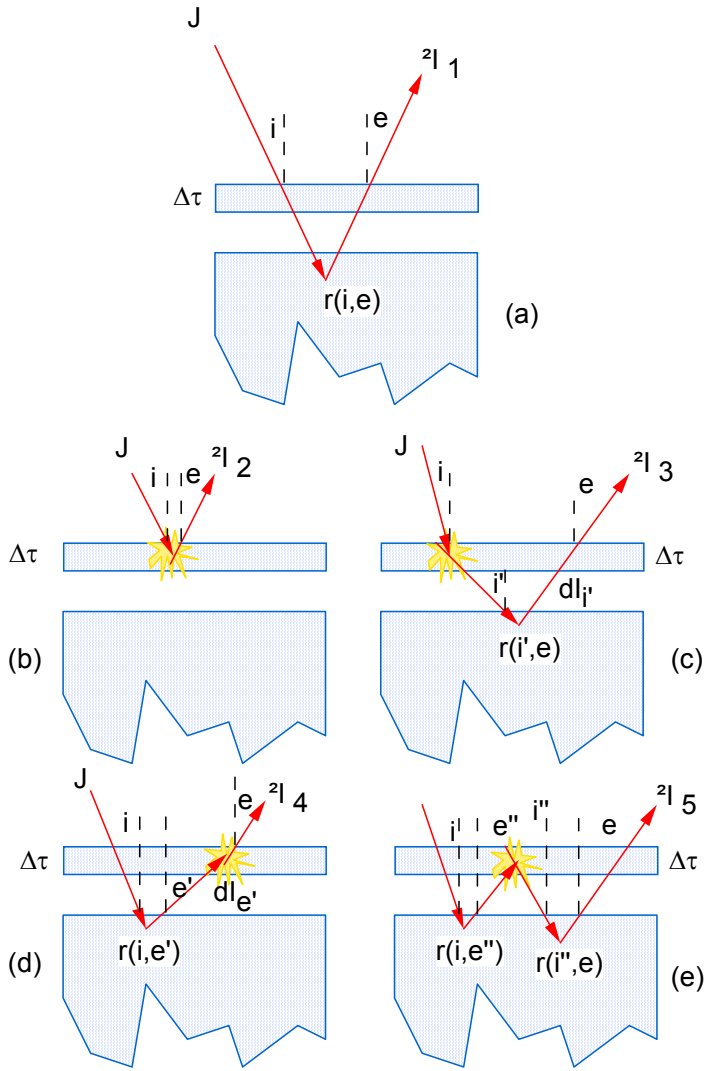
In Situ Conductivity Data



Strength vs. Porosity

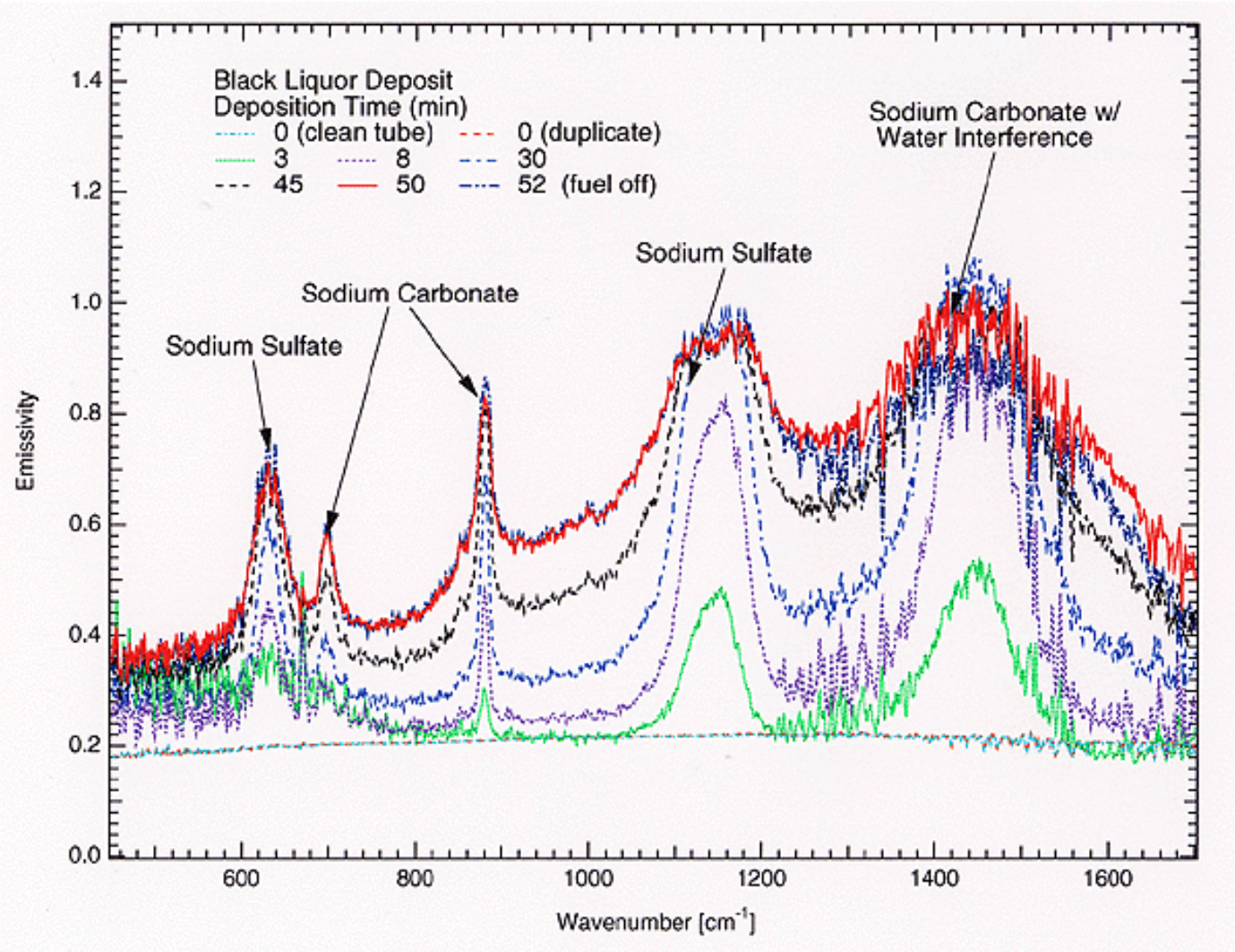


Emissivity Is Difficult

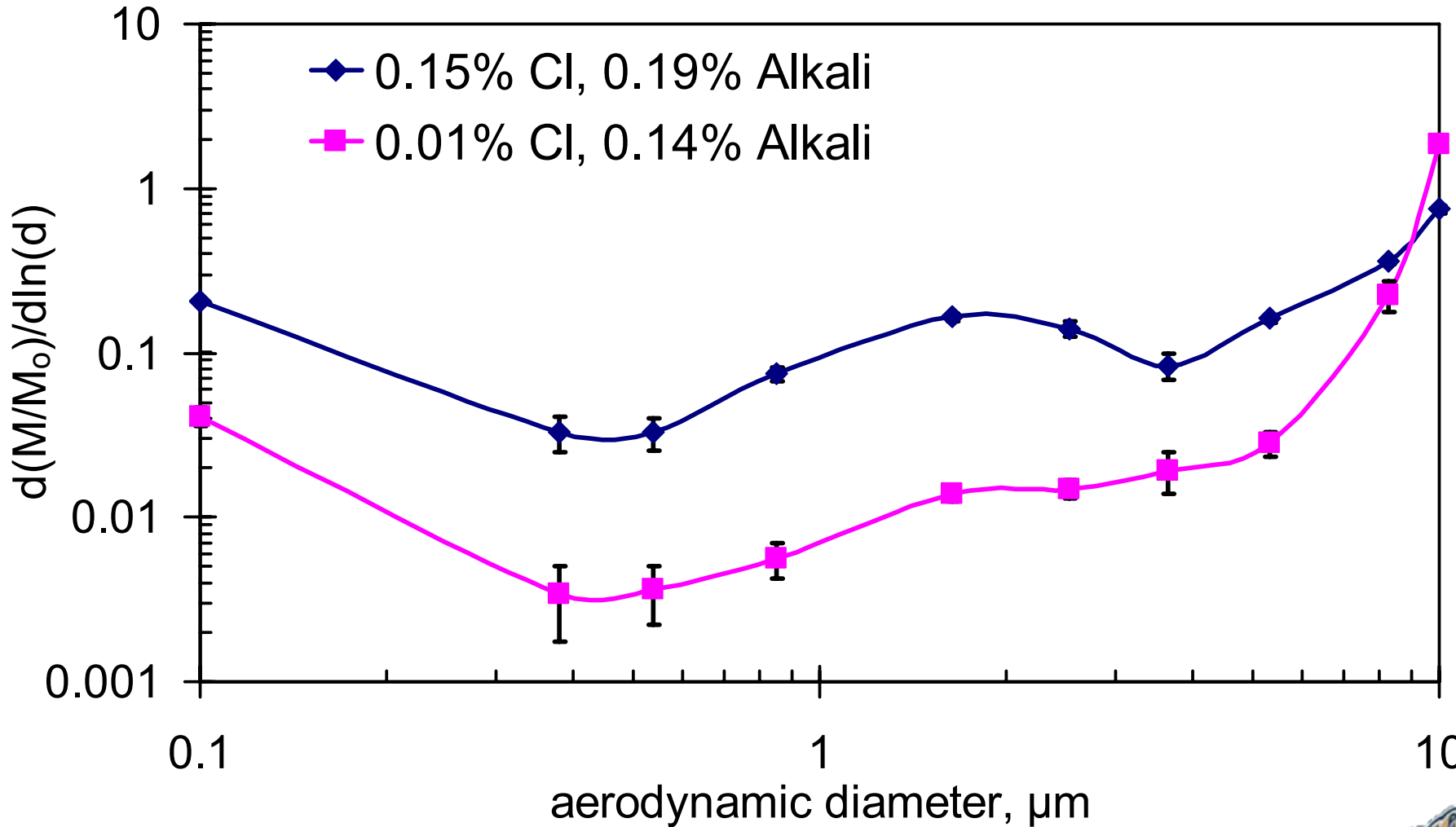


- **Theoretically rigorous approaches are being attempted to describe emissivities.**
- **Fundamental data (optical constants) are in significant disagreement.**
- **New optical constants are being calculated using several approaches.**

In Situ Experimental Data



Chlorine Dominates Aerosol Formation



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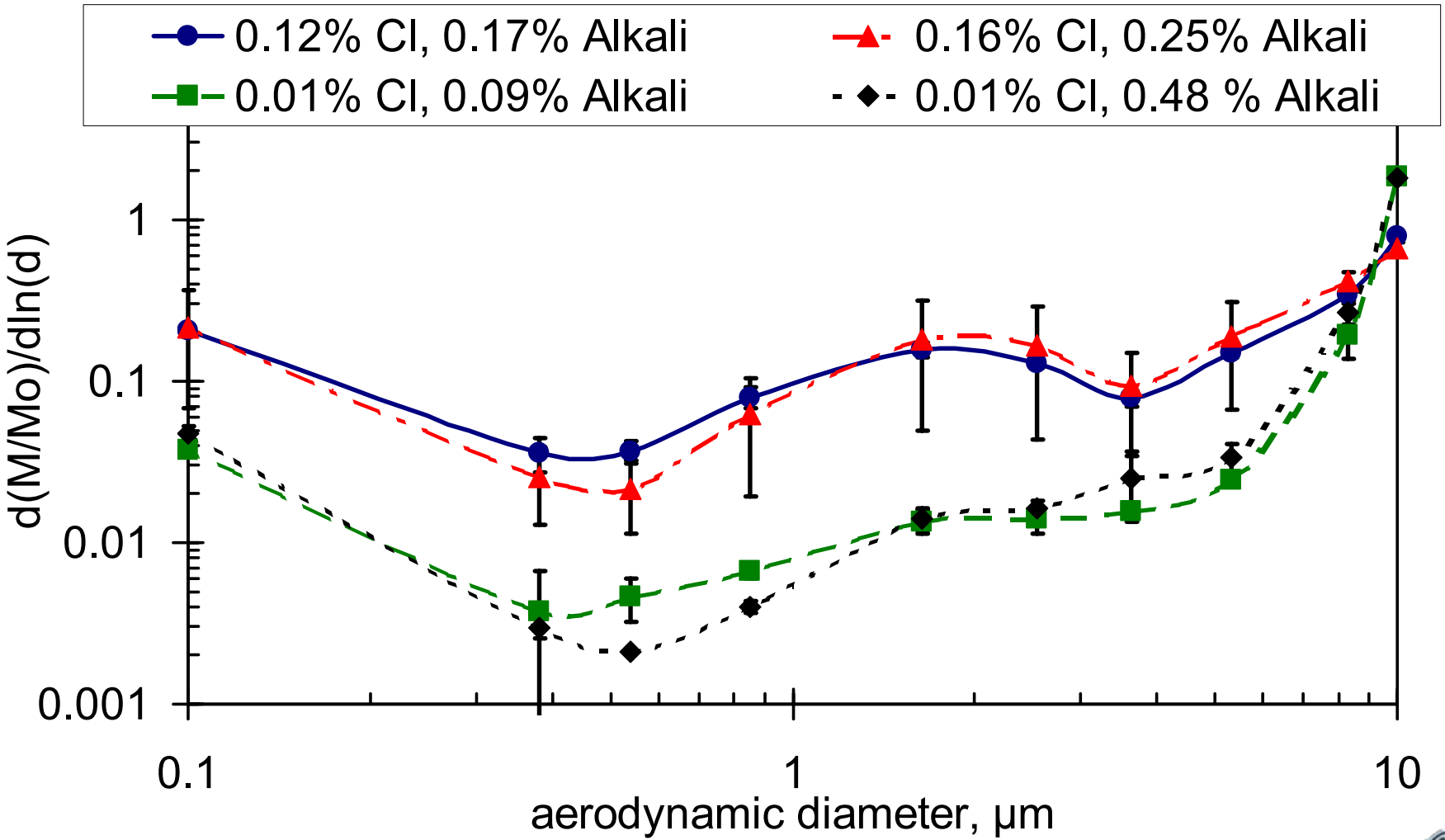
Chlorine Controls Aerosol Amount



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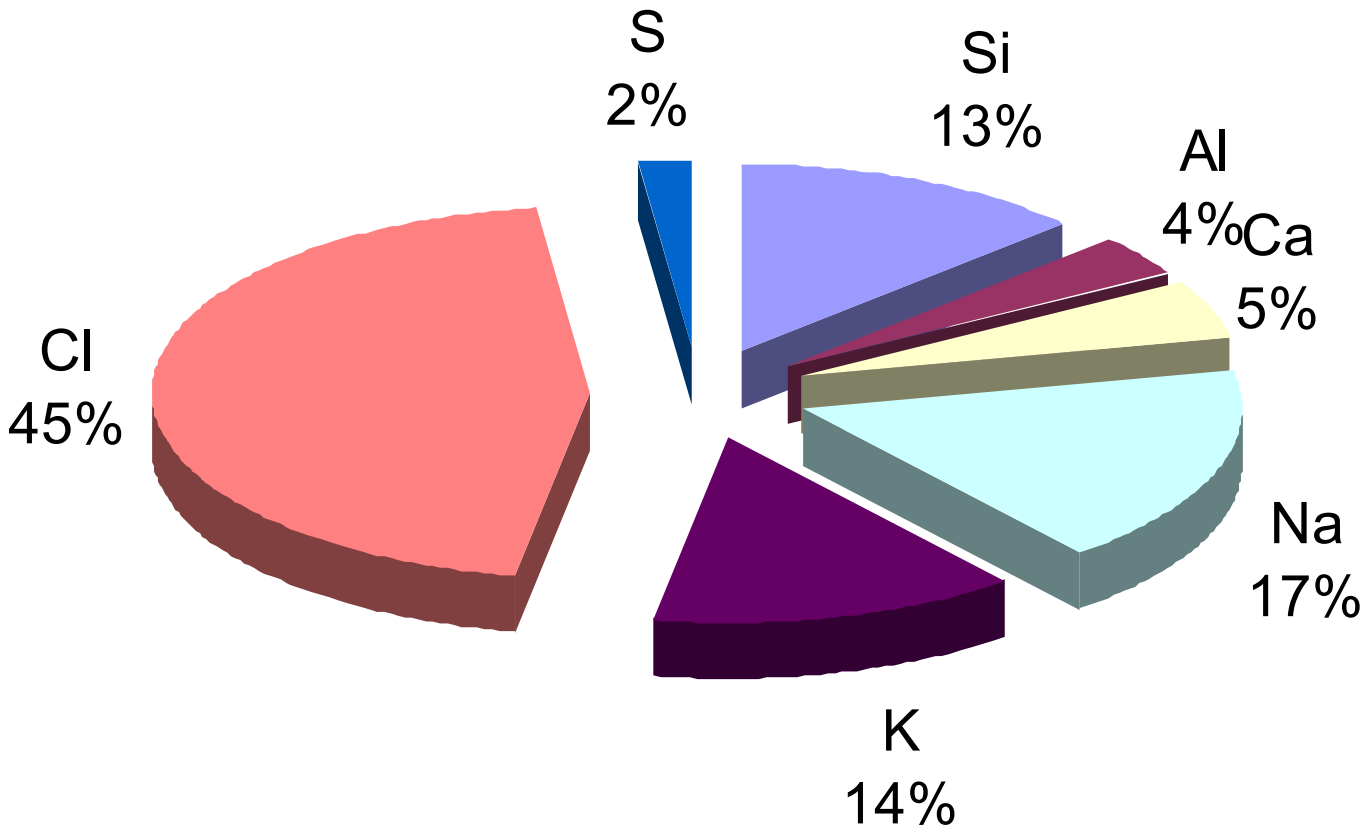
High-chlorine Aerosol Composition



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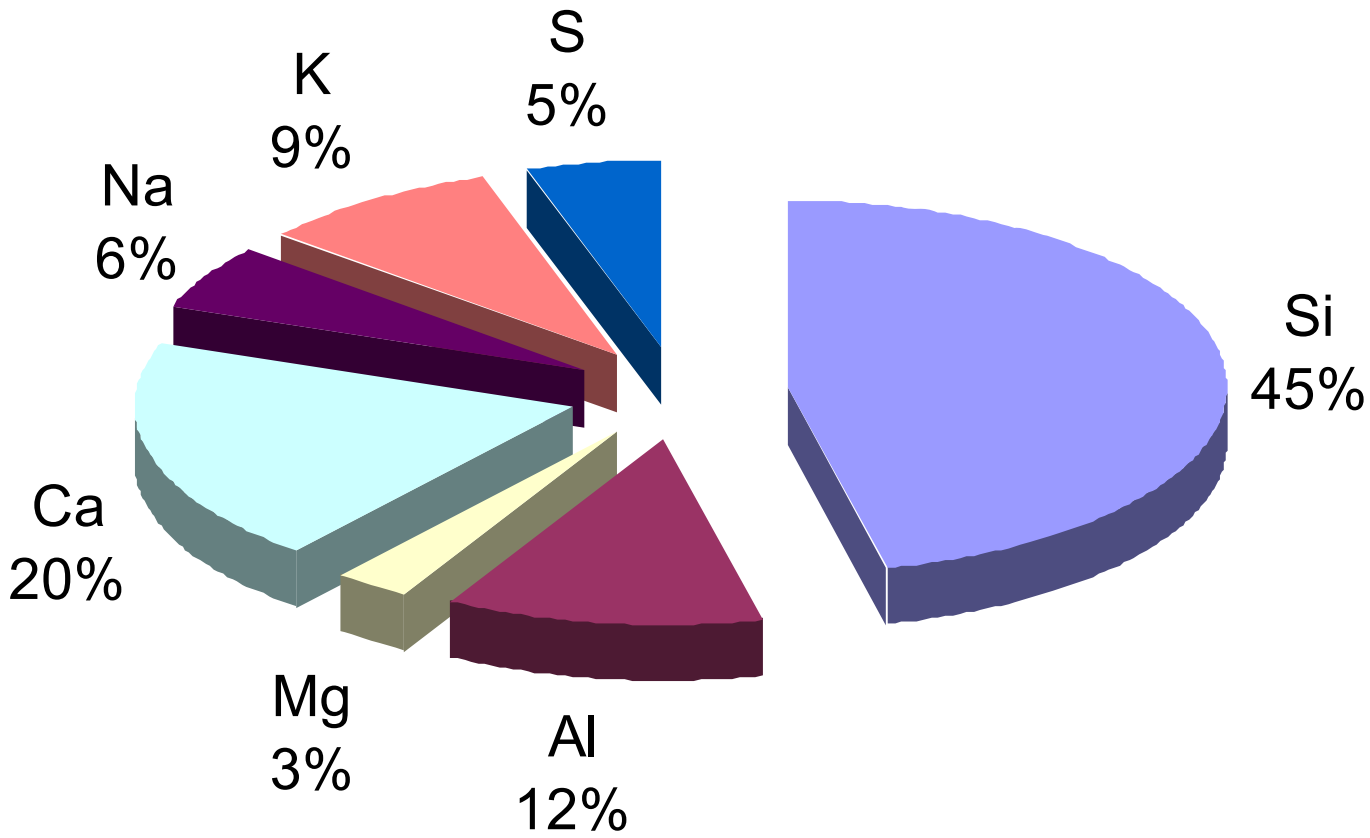
Low-chlorine Aerosol Composition



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Mechanisms Combine