

Using the PHT3D Reactive Transport Model for In-Situ Recovery ACL Application Predictions

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Micheal Gard - Engineering Analytics, Inc.

John J. Mahoney, Ph.D. - Mahoney Geochemical Consulting LLC

The Cake is in the Can Now What?

- No Longer Generating Revenue
- Restoration Costs Can Be Significant with Some Estimates as High as 50 % of the Total Life Cycle Costs



ISR Restoration Goals

- Clean Groundwater to MCLs or Background
 - Groundwater Sweep
 - Reverse Osmosis Water Rinse (and Repeat)
 - Long Term Monitoring
- What if Background or MCLs Cannot be Achieved
 - Alternate Concentration Limit
 - Long Term Monitoring
 - Roughly Equivalent to Monitored Natural Attenuation

Restoration Pitfalls

- TIME ---- It Take Years
- Expensive (Up To 50% of the Production Costs)
- MCLs or Background May Not Be Economically Obtained
- Concentration Rebound Common in ISR Restoration
- The Mine Unit Has Undergone Permanent Changes to Geochemistry
- The Conditions That Generated the Roll Front Are Gone

ACL Approach

Develop a Plan Based on the Concept that a POC Concentration Can Be Developed That Will Result a POE Concentration Lower Than the MCL

- Alternate Concentration Limits Has Not Been Completed For Uranium ISR
- ACL for ISR is Different From a Mill or Mine
- Illustrate Pitfalls In ISR Restoration
- Hydro-Geochemical Models to Develop ACL Concentrations and POE and Reduce the Cost of Closure

ACL Comparisons

Uranium Mill ACL

- Nearly Homogenous Geochemistry
- Non-Reactive Transport Models Commonly Used
- POC at Toe of Tailings
- POE is Typically At Property Boundary of Mining Company
- Property Transferred to DOE upon Acceptance of ACL and License Termination

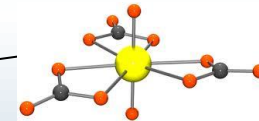
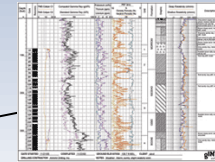
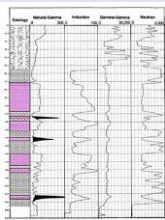
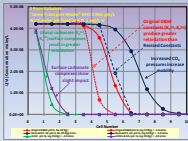
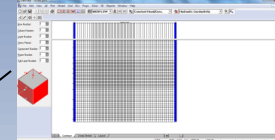
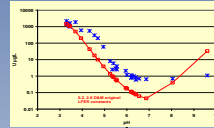
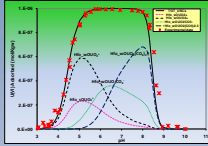
ISR ACL

- Variable Geochemistry
- Reactive Transport Model Required
- POC at Monitoring Well Ring
- It May Take Decades for Geochemistry to Stabilize in Mine Unit
- POE within Aquifer Exemption Ring
- No Long Term Custody

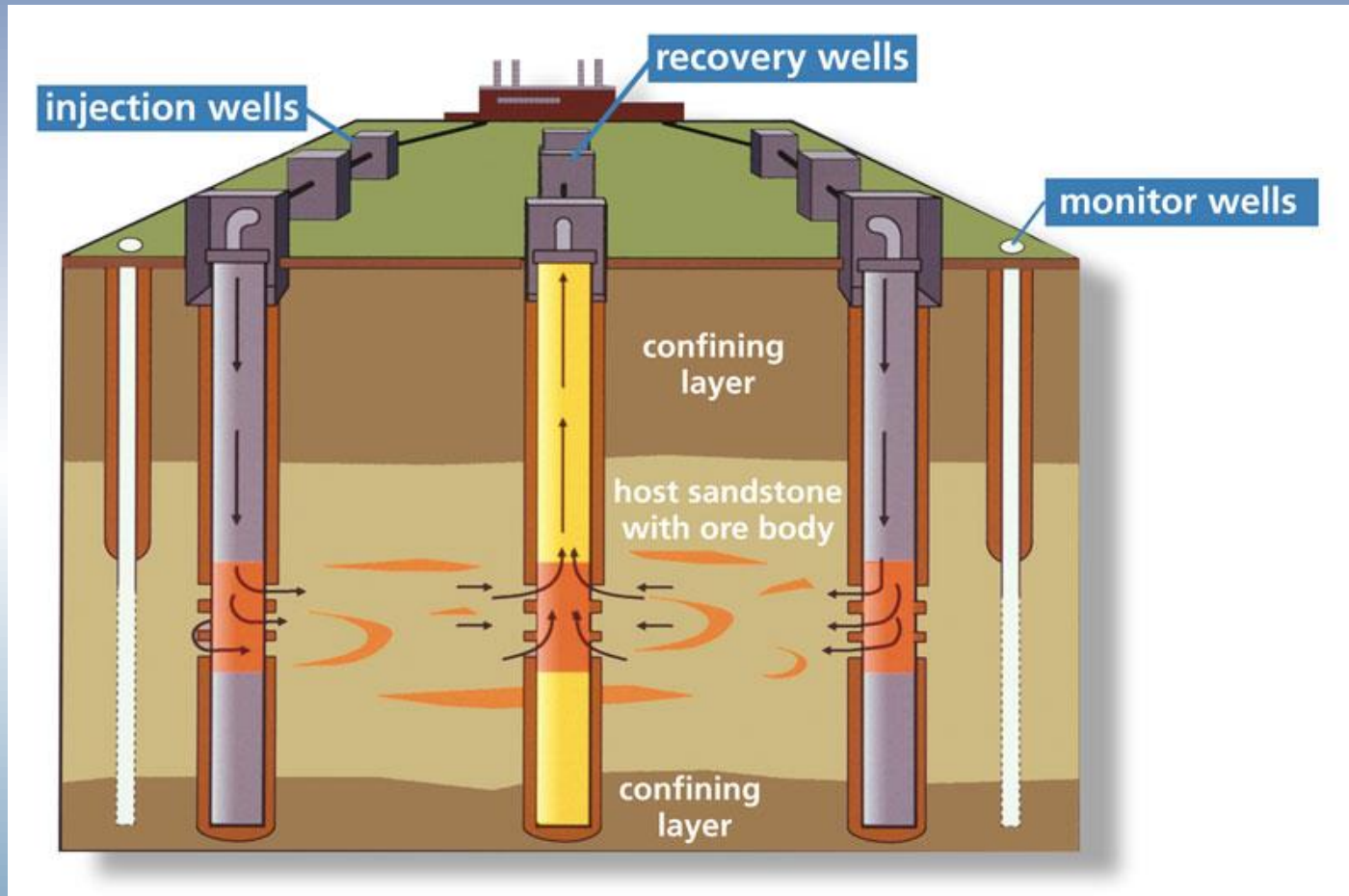
Hydro-Geochemical Models and the ACL Process

- Hydro-Geochemical Models Capable of Simulating All of the Chemical Constituents of Mining Unit
- Current Aquifer Exemption Zones are based on Mining and Possible Excursions
- Aquifer Exemption Zones May Require Amendment if ACL Approach is Implemented
- Hydro-Geochemical Models can be Used to Define the Aquifer Exemption Zone Up Front

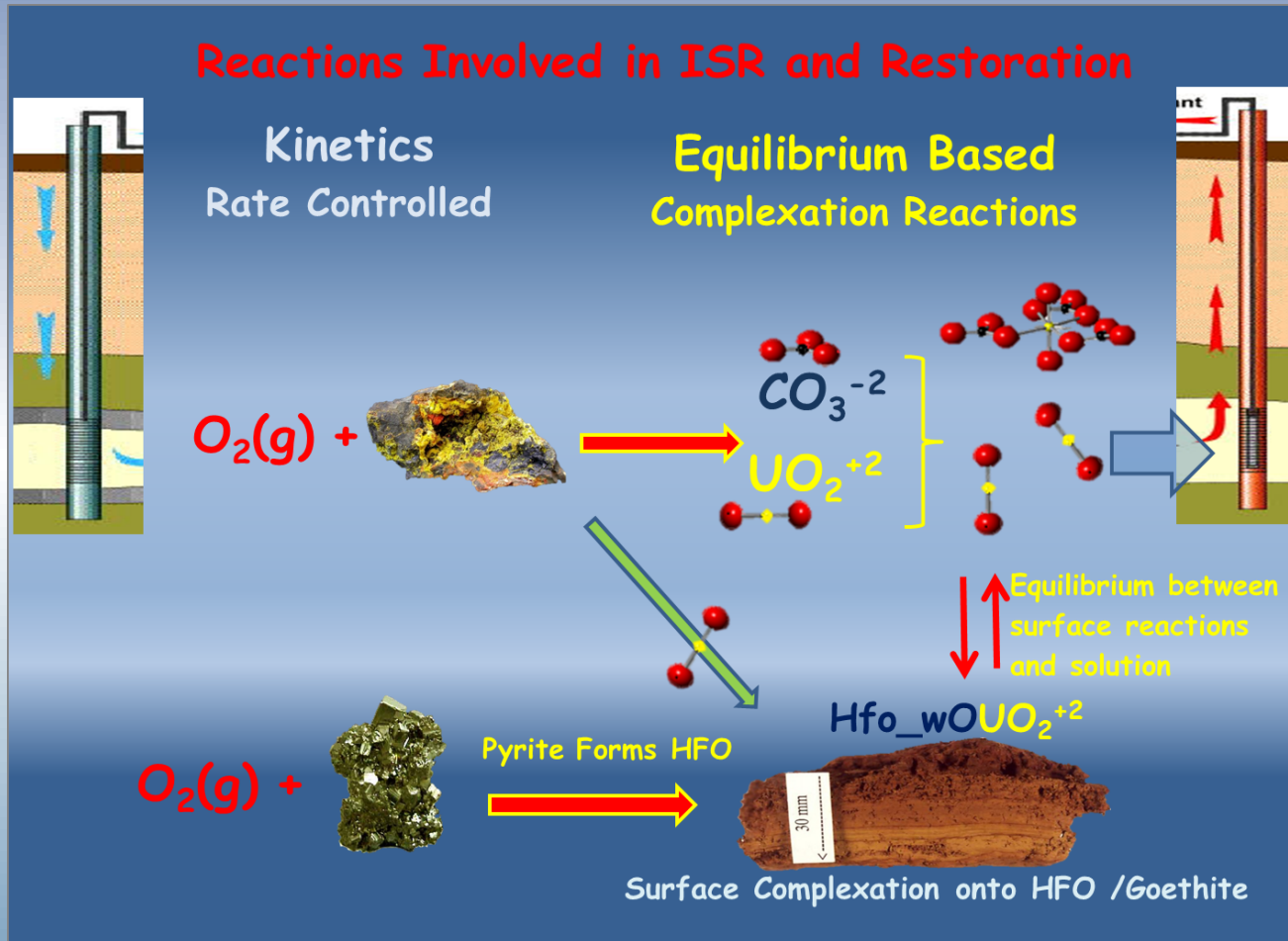
Hydrogeologic and Geochemical Modeling



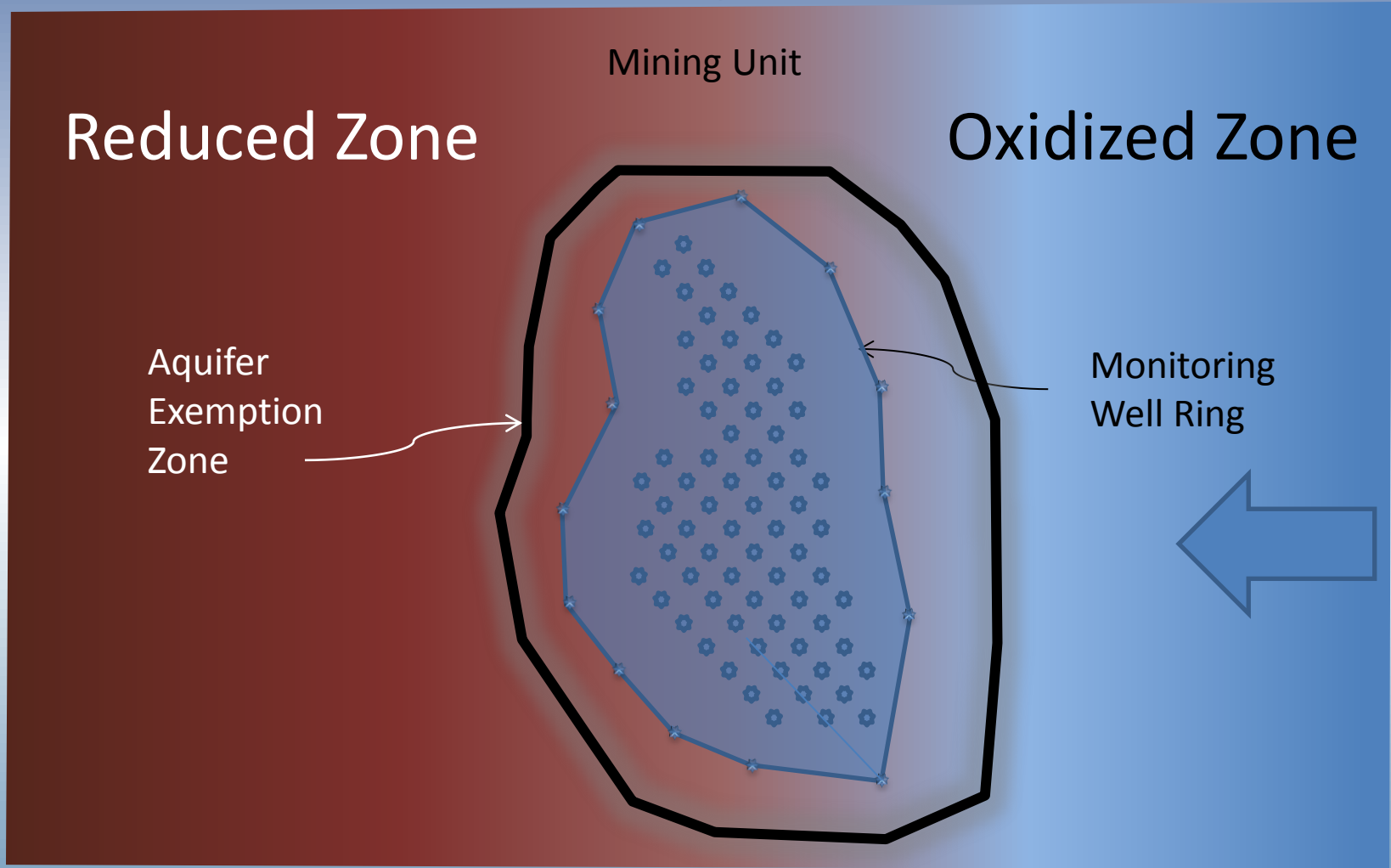
ISR Hydrogeologic Process



ISR Geochemical Process

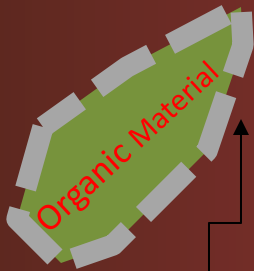


Mining



Post Restoration

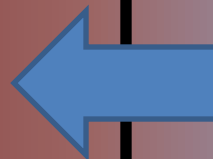
Reduced Zone



Organic Carbon
Remineralized Uranium

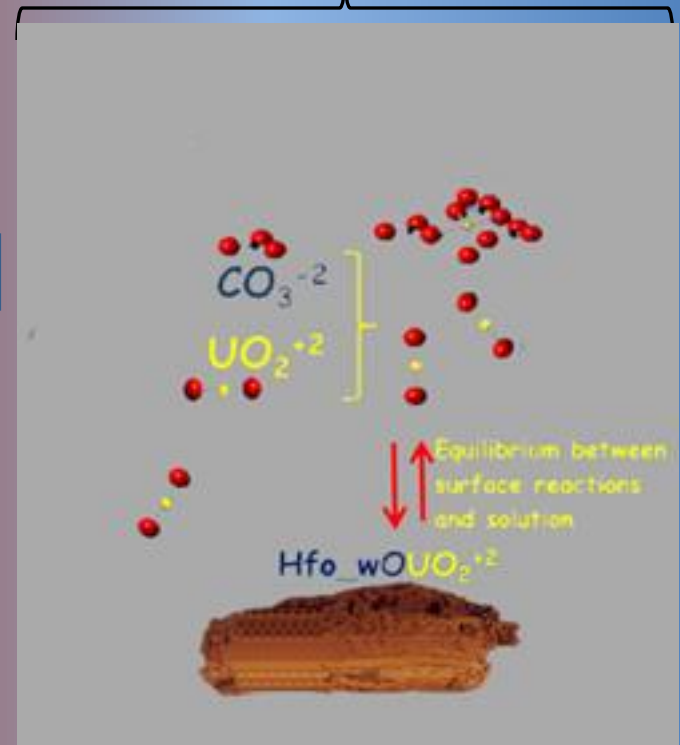


Pyrite
Consumes Residual Oxygen
Remineralized Uranium

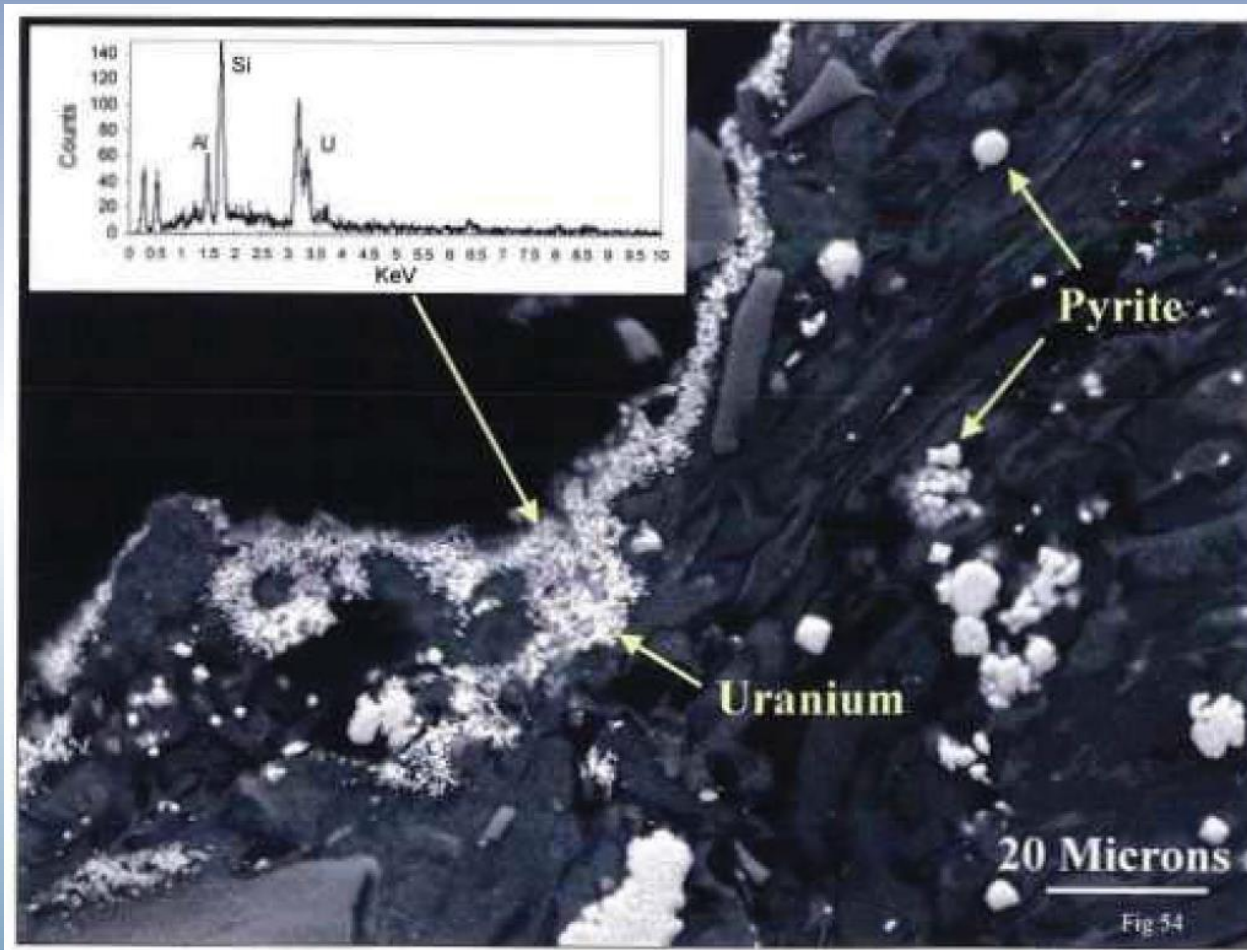


Oxidized Zone

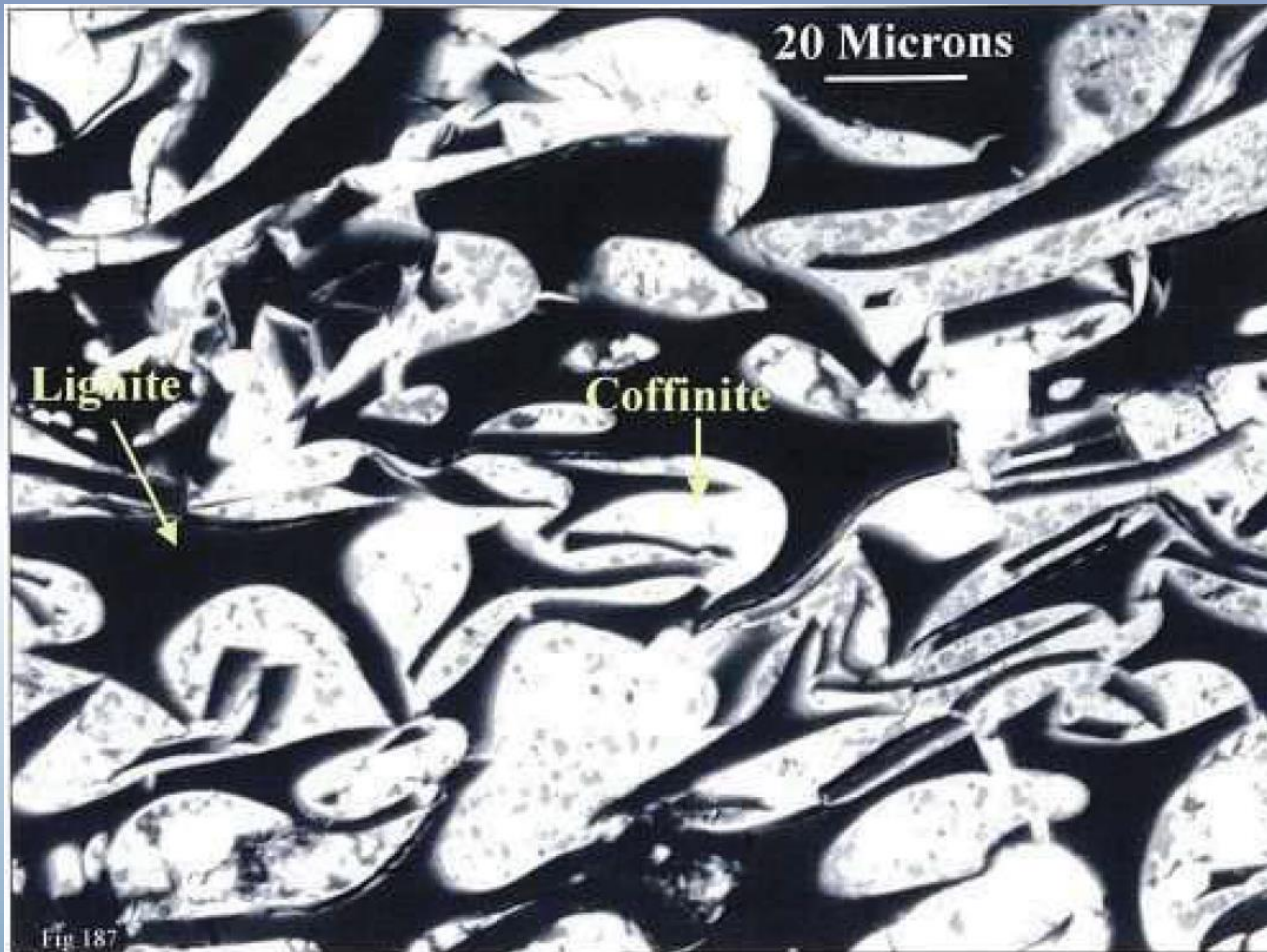
Mining Zone



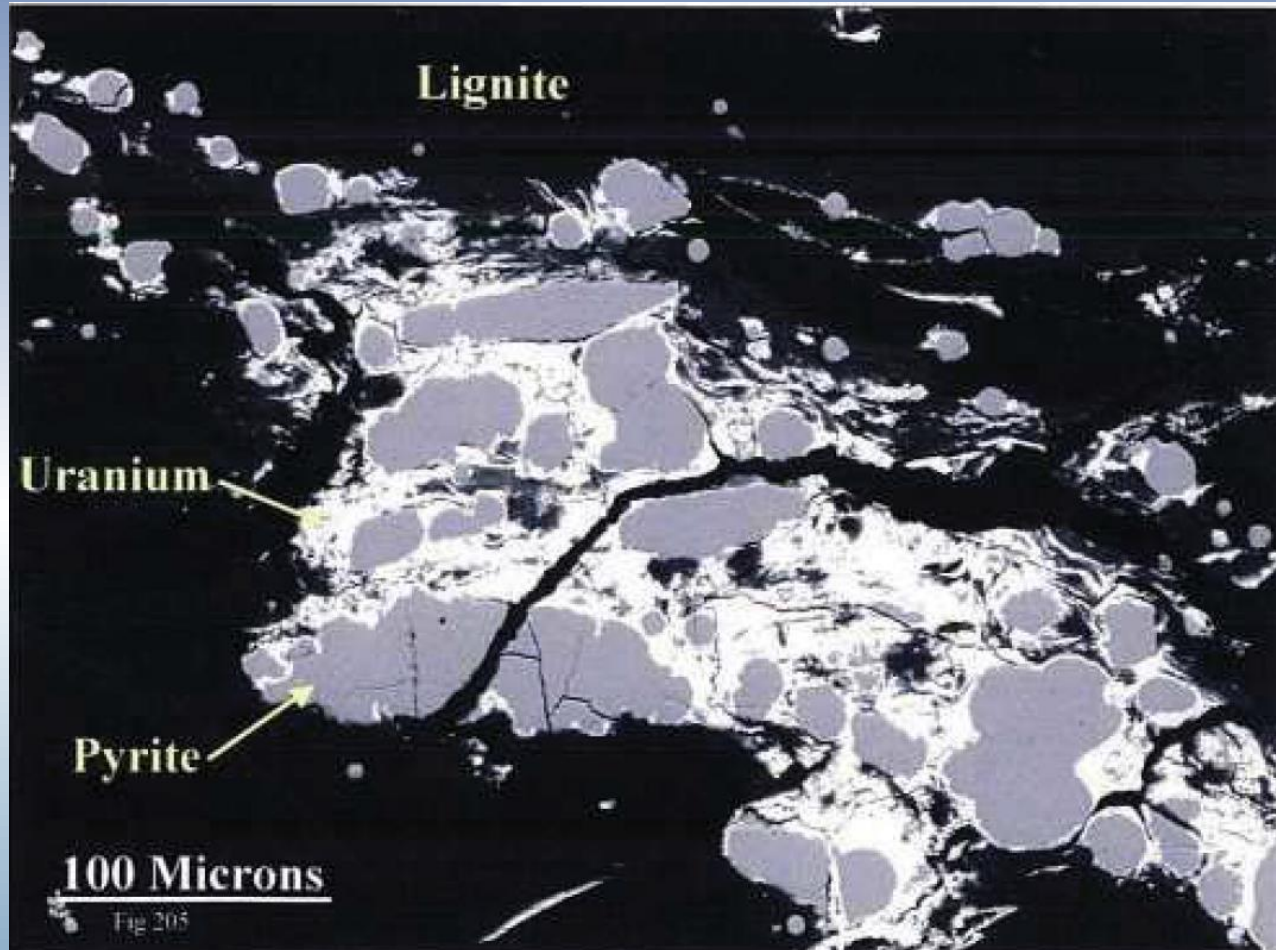
Uranium Re-Mineralization



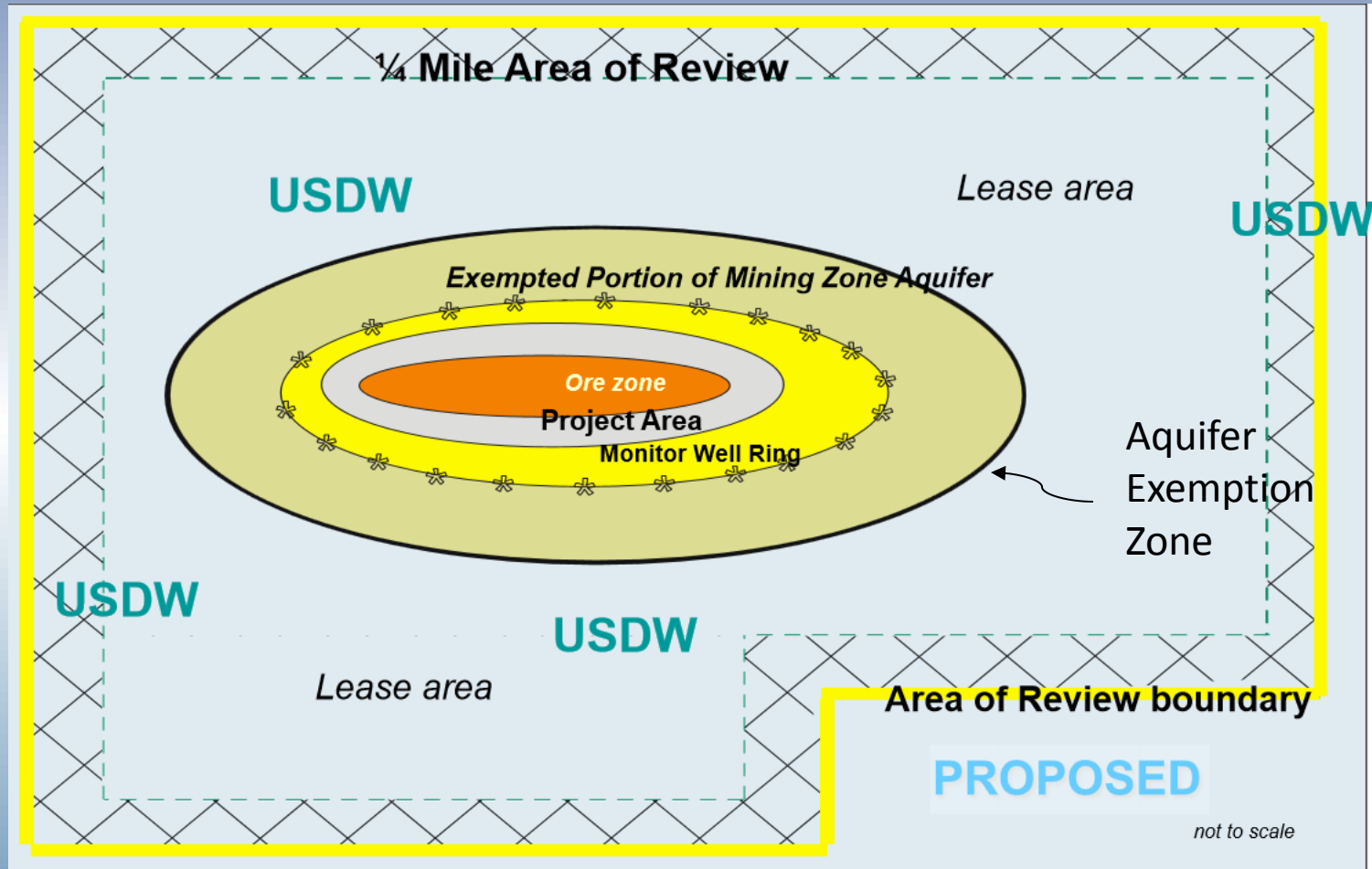
Uranium Re-Mineralization



Uranium Re-Mineralization



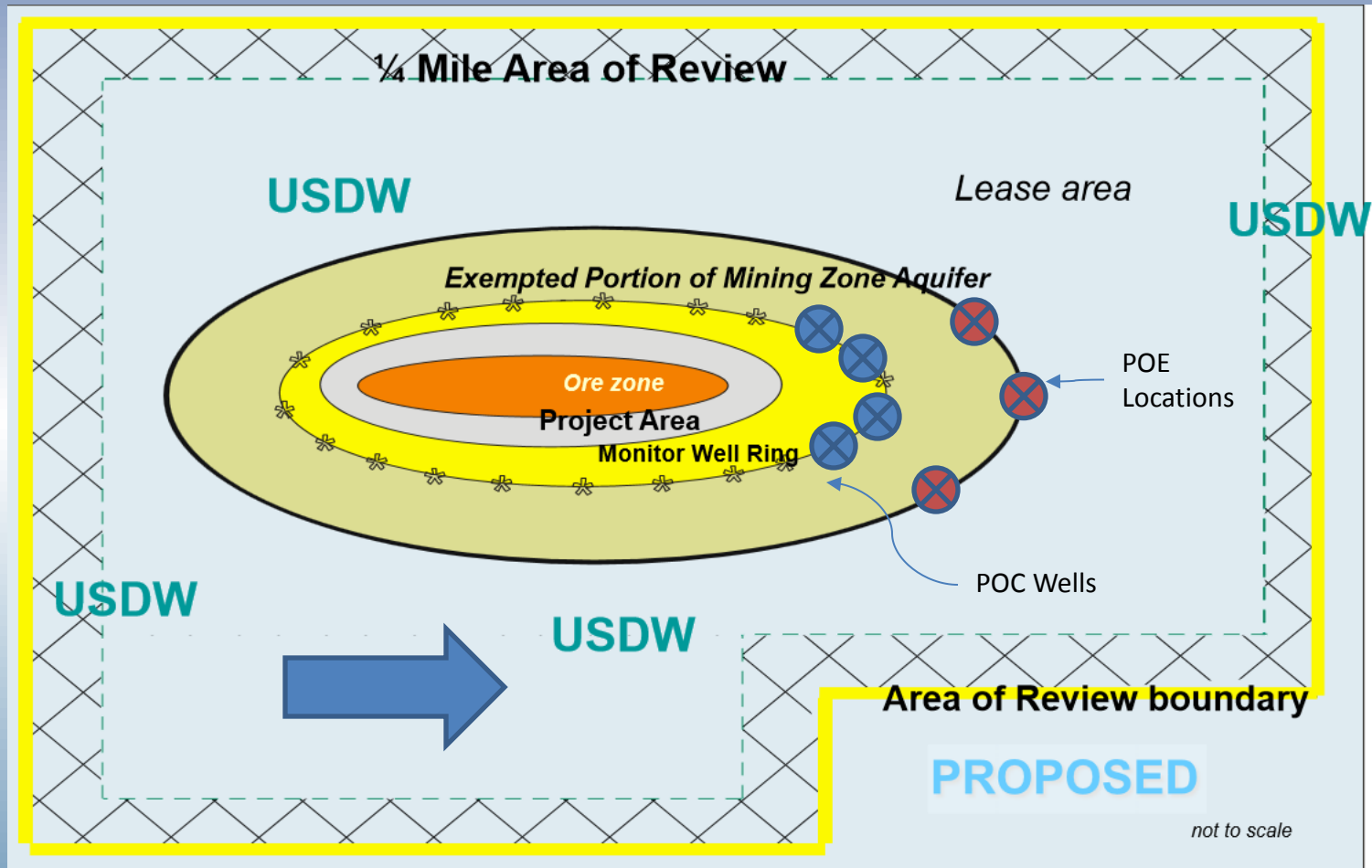
Regulatory Designations



ACL Process

- Point of Compliance (POC)
- Point of Exposure (POE)
- POC Coincident With the Monitoring Well Ring
- POE Coincident With the Aquifer Exemption Area
- Concentration of Contaminants of Concern (COC) Must Be Below MCL or Background Concentration at the POE
- Use Modeling to Estimate the COC Concentration at the POC that Results in Below MCL At POE

POC and POE Locations



Transport Model Used to Estimate ACL Concentrations

- MT3DMS
 - Used Where Geochemistry is Stable
 - No Reaction
 - Retardation based on K_d
 - Can be Used in Conventional Uranium Mill Settings
- PHT3D
 - Used where Geochemistry is Variable
 - Fully Reactive Transport
 - Re-precipitation Removes Uranium From the Solution
NOT Merely Retard Transport

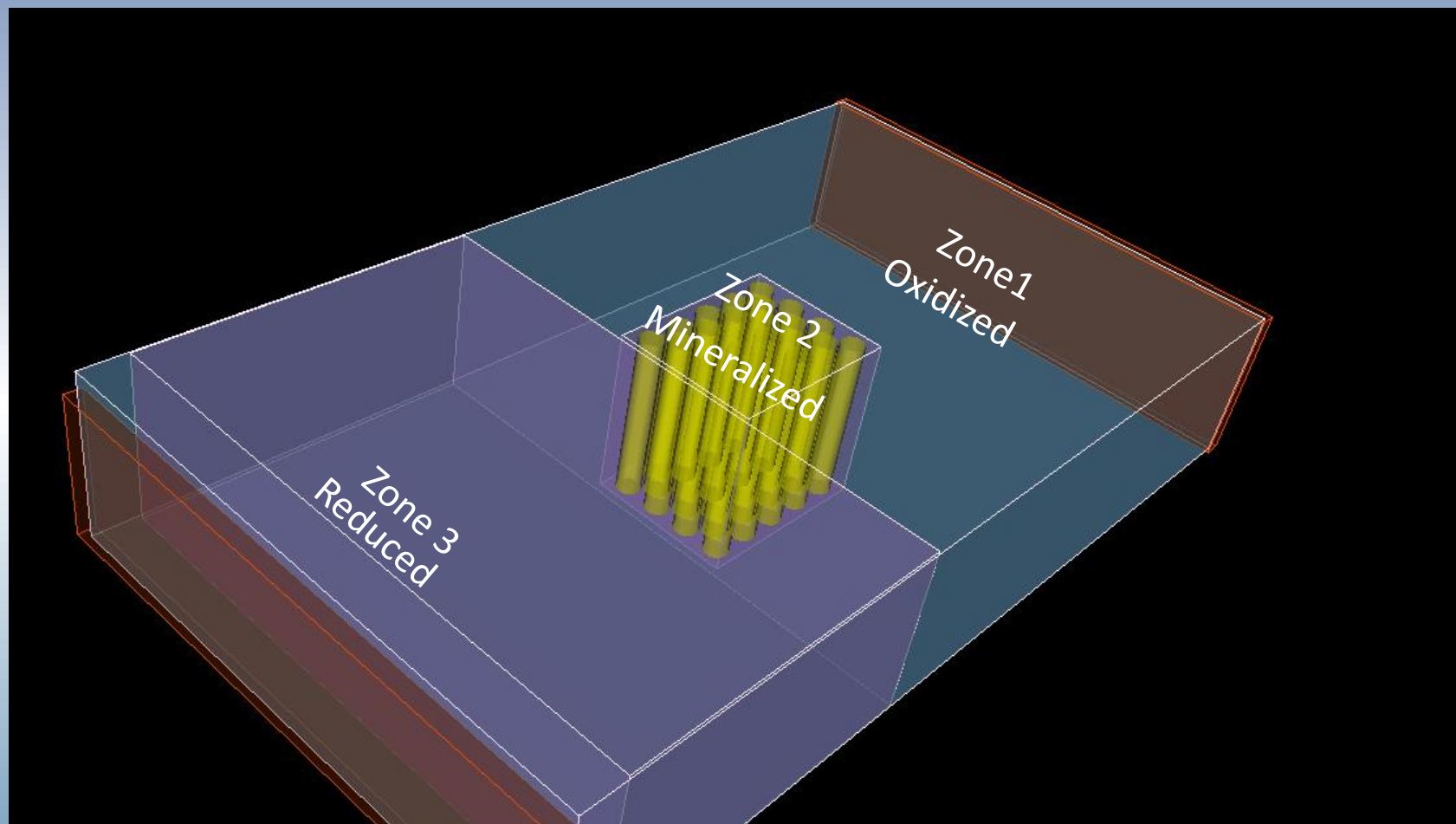
PHT3D Modeling

- Combines MT3DMS and PHREEQC
- Flow Field Generated By MODFLOW
- Industry Standard Models
- Updated PHREEQC Database
- Fully Three-Dimensional

Modeling Parameters

- Generic Data Collected From Adams (NRC) Using Several Sites in Wyoming and Nebraska
- Organic Carbon Mineralization Inferred From University of Wyoming Claudia Stewart Thesis
- Modified Geochemical Database
 - Uranium Dissolution Calibrated to Site Data

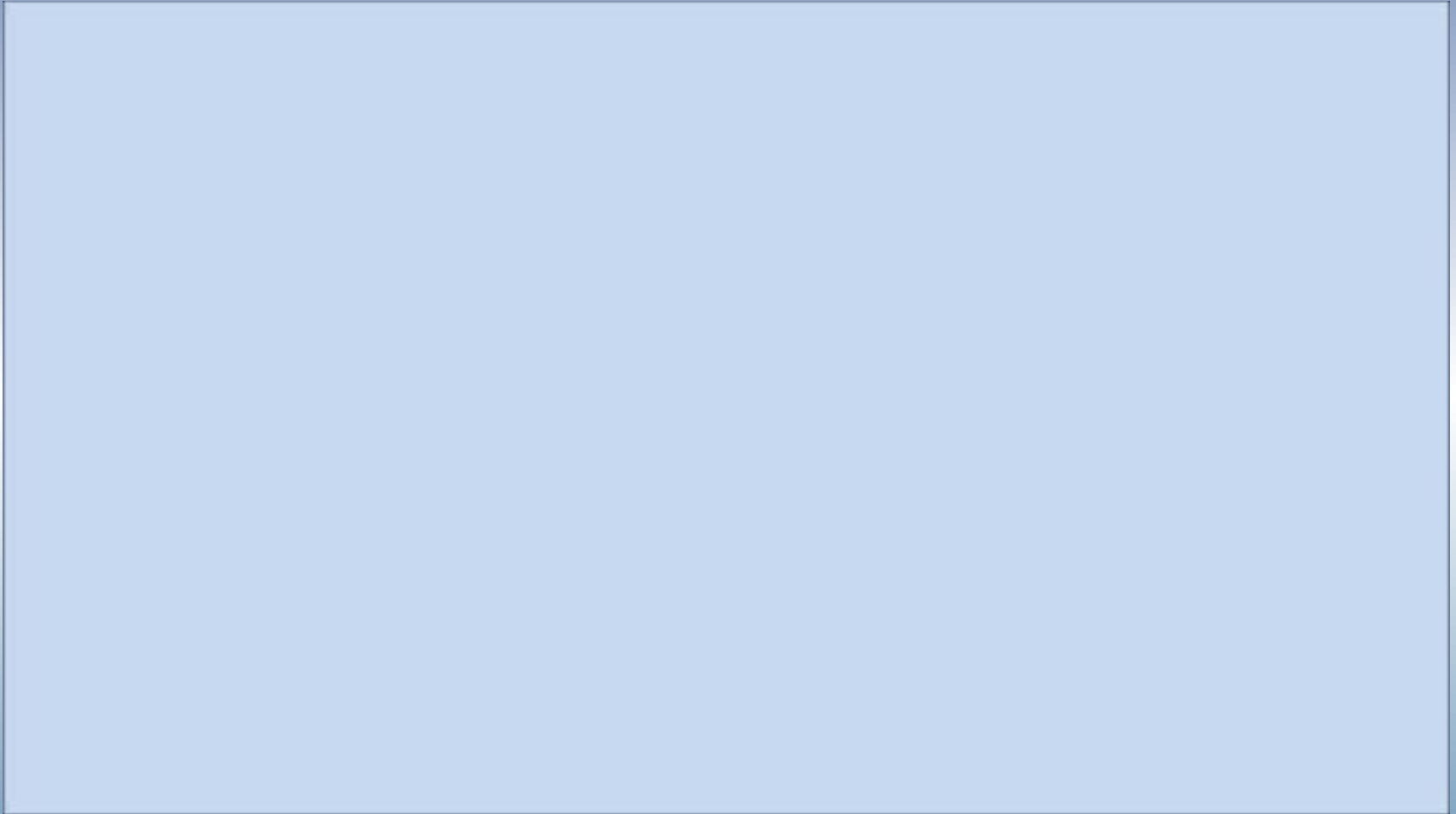
Geochemical Zones



Zone Definition

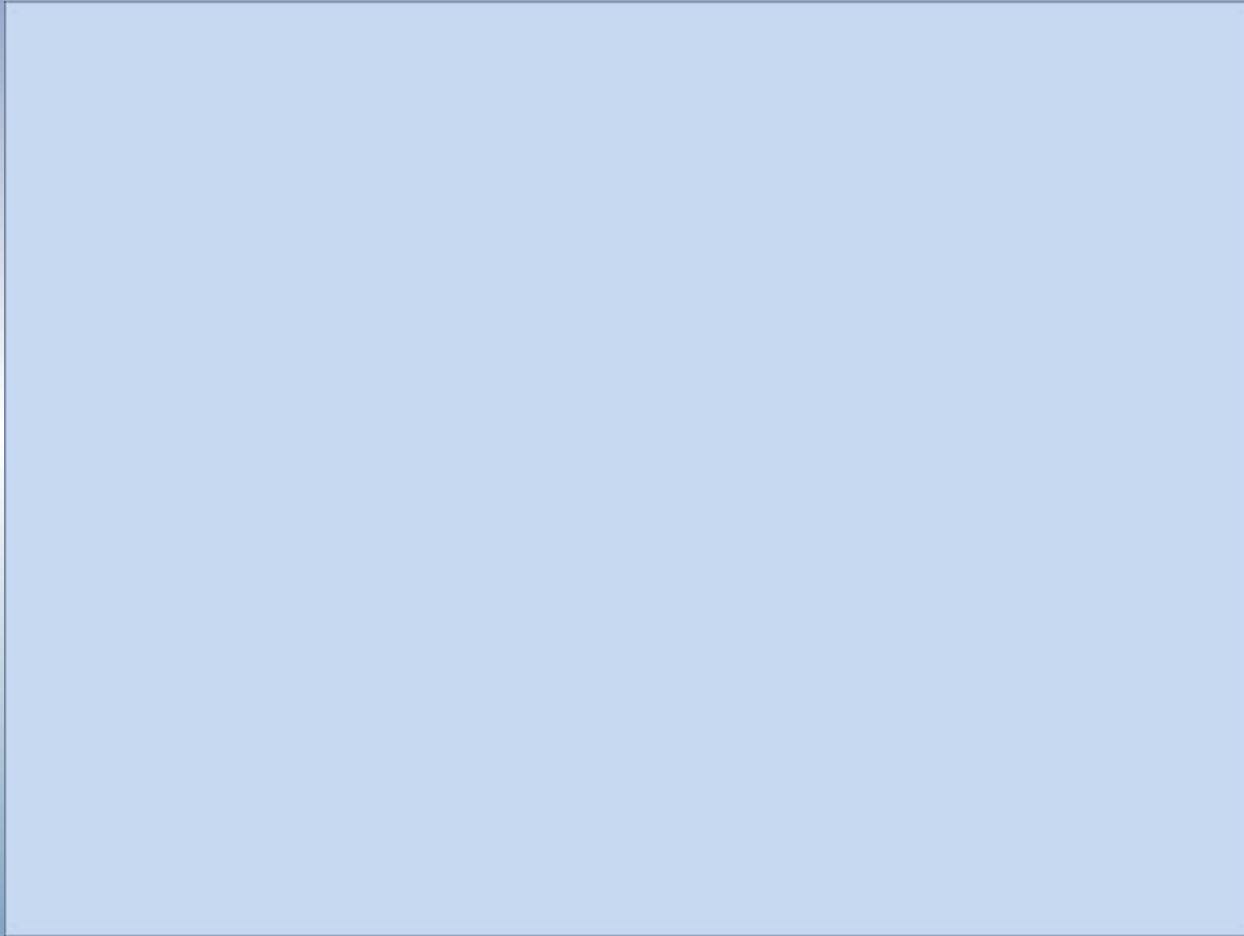
Zone 1 Oxidized Zone	
No Pyrite	Background Oxygen
No Organic Carbon	High pe
Zone 2 Mineralized/Mining Zone	
Ambient Water Into Zone	Dissolve Pyrite
Dissolve Uraninite	
Zone 3 Reduced Zone	
Pyrite	Low pe
No Oxygen	Uraninite Precipitates
Organic Carbon	

Uranium In Solution (ppm)



Sulfate In Solution

Uranium Mineral Dissolution During Mining



ELECTRON ACTIVITY

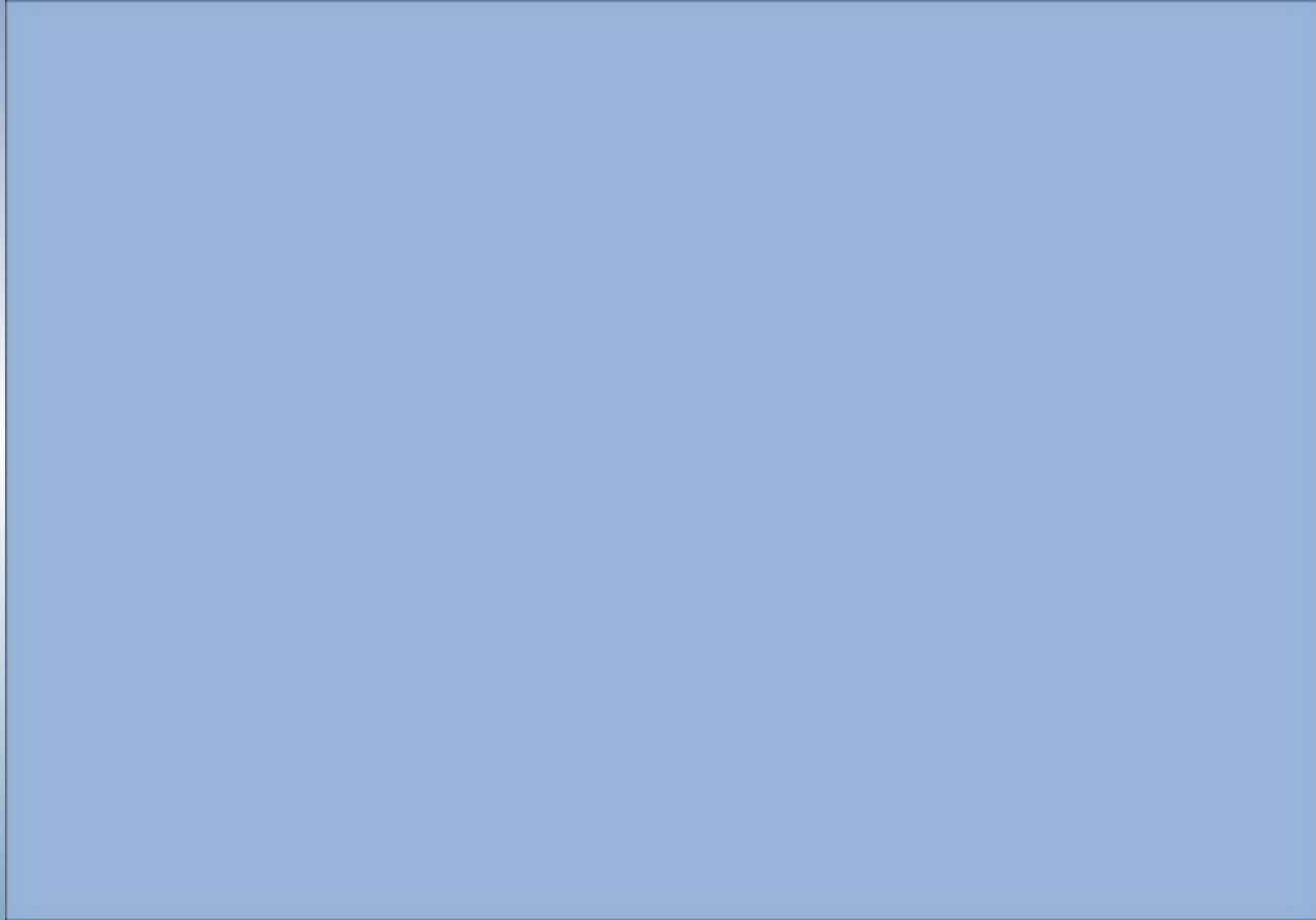
$$pe = -\log a_{e^-}$$

- The pe Indicates the Tendency of a Solution to Donate or Accept Electrons
- If pe Is Positive, There Is a Strong Tendency for the Solution to Donate Electrons - The Solution Is Oxidizing
- If pe Is Negative, There Is a Strong Tendency for the Solution to Accept Electrons - The Solution Is Reducing.
- LEO Says GER

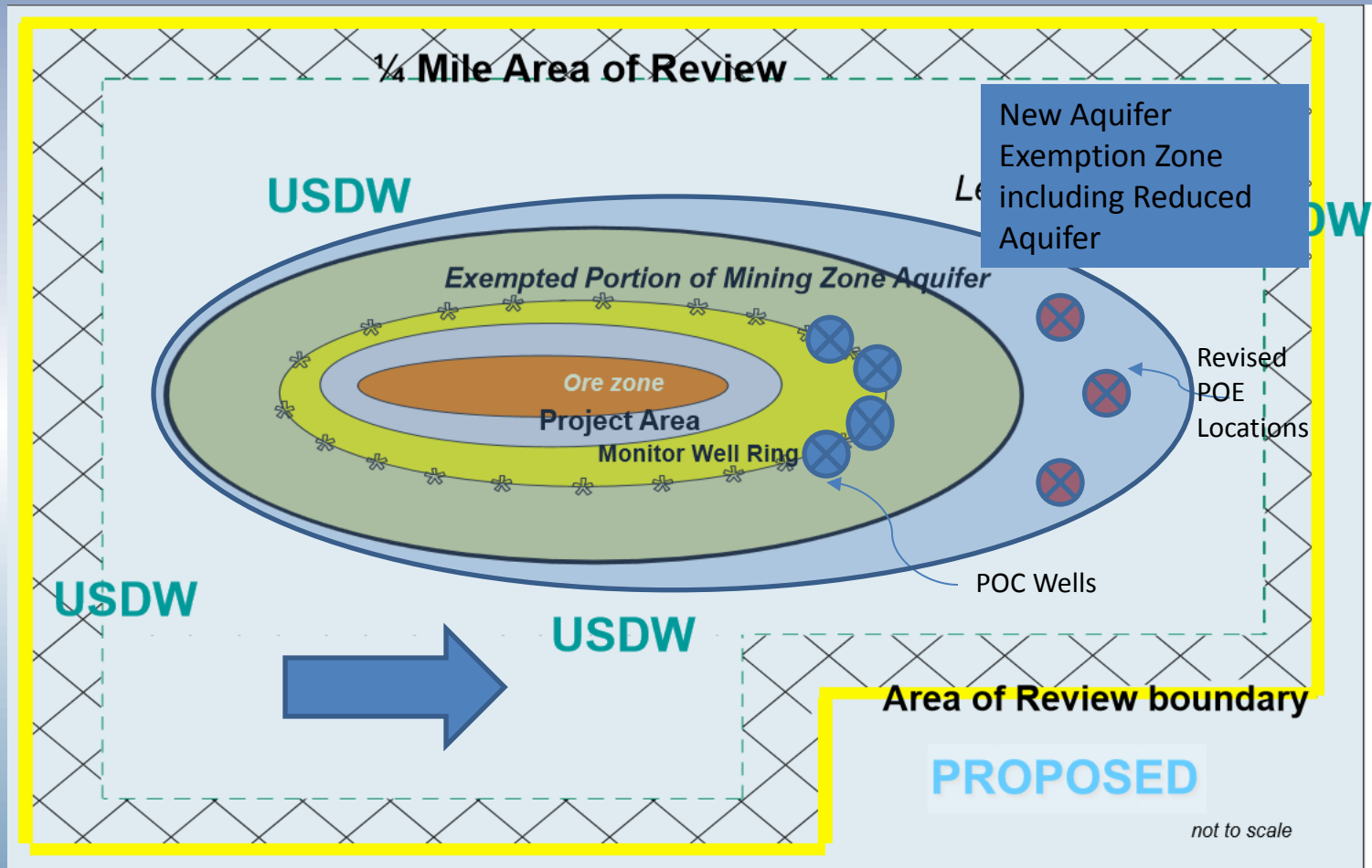
Modeled pe Distribution



Uranium Re-Precipitation After Restoration



POC and POE Locations



Conclusions

- Modeled Residual Oxygen In Well Field is Quickly Consumed In Pyrite and Organic Carbon Reactions in Down-Gradient Reduced Zone
- Modeled Residual Uranium In Well Field Quickly Re-Precipitated in Down Gradient Reduced Zone
- Generic Kinetic Rates Were Used In the Model
 - Actual Kinetic Rates Will Require Calibration

Conclusions

- Calibrated Hydro-geochemical Model Can Be Implemented To Establish Defensible POC Alternate Concentration Limits
- Reduction In Closure Costs
- Excursion Analysis Can Be Implemented To Establish Defensible Aquifer Exemption Boundaries

Thank You
Questions?