



An Innovative Method for Mitigating Impacts from Acid-Producing Rock

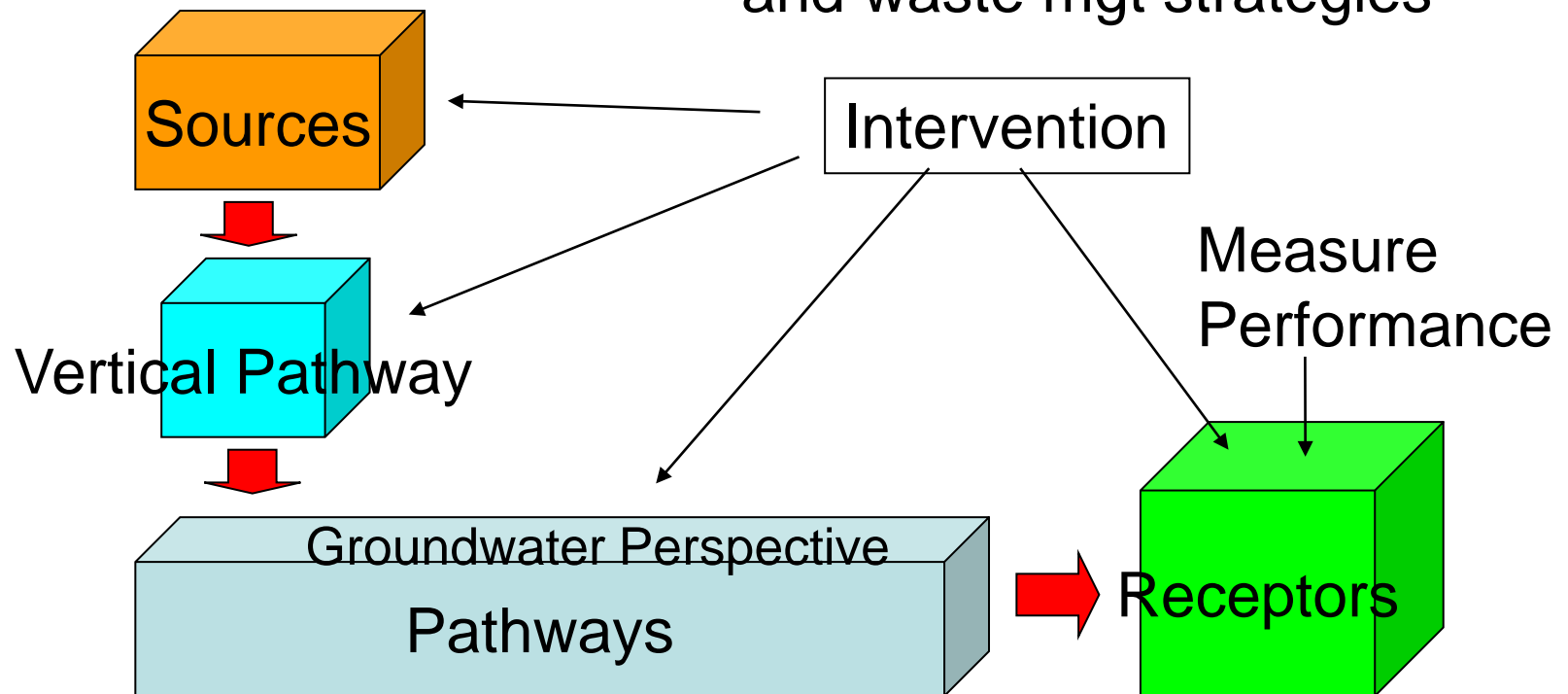
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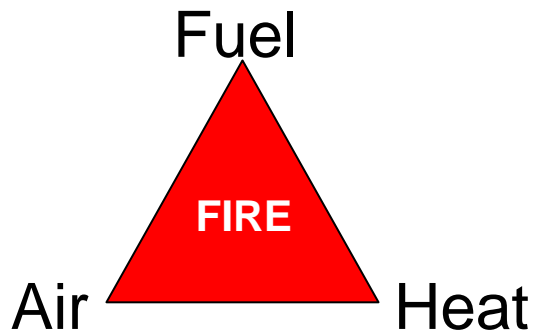




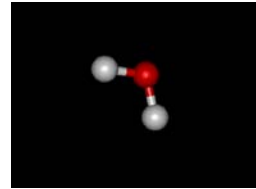
REF: GARD Guide 2010
www.gardguide.com
(Read Chapter 6.0)

Early avoidance of ARD problems is a best practice technique that is integrated into mine planning, design and waste mgt strategies

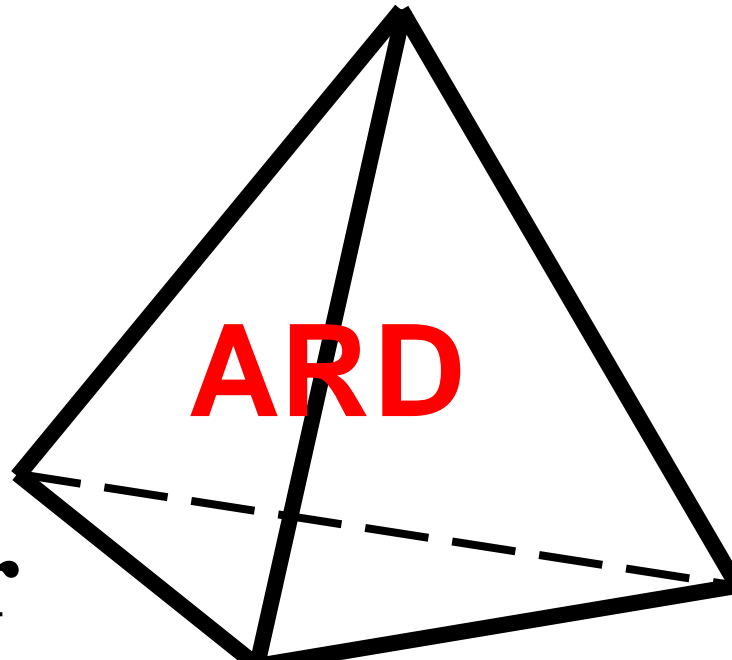




Water



Oxidizer
(Air, Fe^{+3})



Bacteria



Pyrite



ARD is a global **bacterial infection**.

There are plenty of geo-antibiotics available but the current situation is akin to the patient taking a shower with Tums dissolved in orange juice - not very effective or practical.

What's needed is a mining-analogue to an I-V drip of tetracycline and/or oral antibiotics.

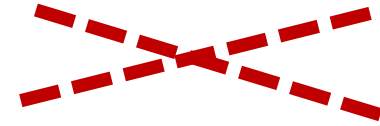
And then there's the question: Do we need to **Vaccinate** or **Medicate**?

**What is currently available in the ARD prevention
“pHarmacy”?**



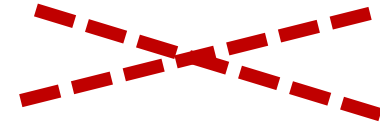
- Sodium lauryl sulfate (EPA-endorsed)
- Alkyl-benzene sulfonate (laundry soap)
- Waste milk (heterotrophic bacteria out-complete *acido-thiobacillus*)
- Sodium Thiocyanate (NaSCN)
- Bi-Polar Lipids

Note: We need to consider the *physics* of delivering and distributing a weak bactericide solution into a porous, **unsaturated** medium (it's been done, but it wasn't easy)



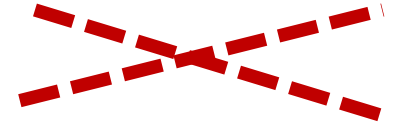
- Limestone (quarried) – crusher fines?
- Dolomite
- Lime kiln dust or cement kiln dust
- Steel slag
- Sodium bicarbonate

Note: We need to consider the *physics* of delivering and distributing a solid into a porous **unsaturated** medium



- Sawdust (the finer, the better)
- Paper (newsprint, office waste [shredded])
- De-inking residue
- Biosolids (see GARD Guide, Ch. 6)
- MicroCgTM, LactoilTM, others?

Note: We need to consider the *physics* of delivering and distributing a solid into a porous, **unsaturated** medium



- Keeco Mix (micro-silica)
- Potassium permanganate (Glen Miller, UNR)
- Potassium humate (commercial agricultural amendment)
- Others?

Note: We need to consider the *physics* of delivering and distributing a coating into an **unsaturated** porous medium



- Red Mud (Bauxsol or nano-scale ferric oxy-hydroxide)
- Enviroiron (Bob Hedin's ferric oxy-hydroxide)
- American Peat products
- Others?

Note: We need to consider the *physics* of delivering and distributing a adsorptive material into an **unsaturated** porous medium



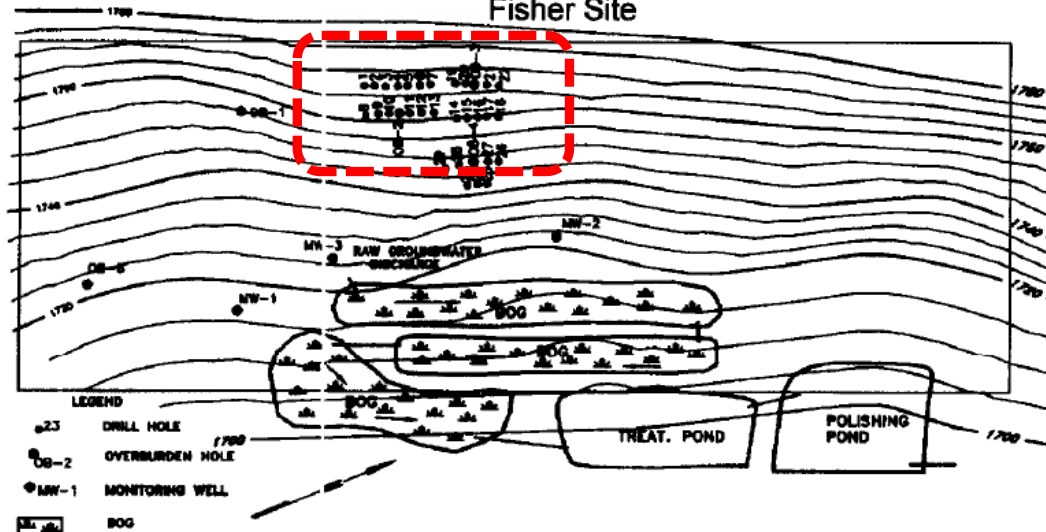
Treating existing waste rock dumps

- Deliver bactericides without complete flooding of waste rock mass
- Focus the delivery of alkalinity in the “hot zones”
- Deliver organics in hot zones and without complete flooding

■ Fisher Coal Mine, PA – 1995 Vapco Engineering

- ❑ Geophysics targets 3 ARD-generating zones
- ❑ Multiple injection boreholes on a tight spacing
- ❑ Injection of 20% NaOH solution simultaneously into 12 shallow (3 m deep) boreholes with packers
- ❑ Injection of 2% sodium lauryl sulfate bactericide
- ❑ Seepage continues to be net alkaline 16 years later, bond release is reportedly imminent

Figure 5 - Location of Wells on Fisher Site





■ Sequatchie Coal Mine, TN – 2008 Western Research Institute

- ❑ Geophysics used to target ARD
- ❑ Two doses - drip application of waste **milk** and biosolids (as inoculant)
- ❑ Seepage reportedly net alkaline after four years.
- ❑ Patent issued January, 2012
- ❑ Check out ITRC website

http://www.itrcweb.org/miningwaste-guidance/cs31_sequatchie.htm

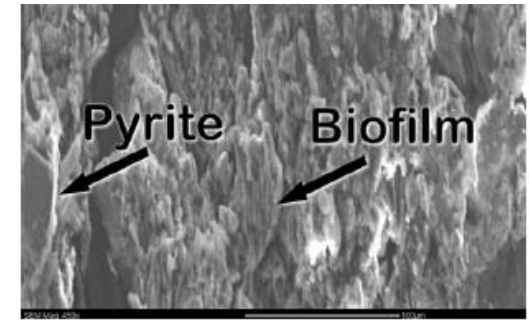
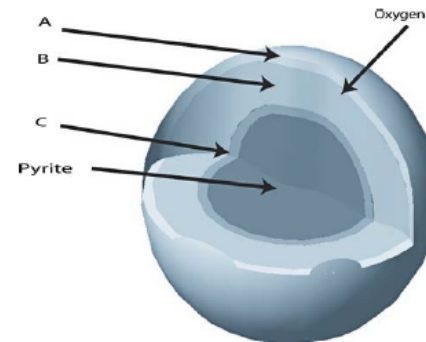


Fig. 6 Substrate dosage experiment: biofilm growing on pyrite after 213 days in a microcosm filled with ground water impacted with acid mine drainage, pyrite, 3 wt% effluent solids (ES) and 5× the required stoichiometric concentration of C (as returned milk) that bacteria would consume while reducing all the SO_4^{2-} in the microcosm. This image was taken at $\times 450$ magnification with a scanning electron microscope



Ref: Jin et al., 2007

Fig. 7 Conceptual model of the community structure of biofilm growing on pyrite in microcosms. Layers A and B of the biofilm are composed of aerobic and facultatively anaerobic bacteria that consume oxygen (O_2) diffusing through the biofilm from overlying water. Layer C is an anaerobe-dominant layer containing sulfate reducing bacteria and other facultative anaerobes; therefore, oxygen diffusion to the pyrite and generation of acid mine drainage is prevented



Use engineered FOAM as a delivery medium for bactericide “cocktail”

- Use waste milk (biocide) in the liquid phase
- Use sodium lauryl sulfate (bactericide) as part of the surfactant mix
- Add powdered limestone or sodium hydroxide for alkalinity
- Add paper, sawdust, or **biosolids** as the organic



Use engineered FOAM as a delivery medium for bactericide “cocktail”

*This process is very similar to pressurized grouting, only the grout mass is mostly gaseous, engineered to be **temporary**, and designed to deposit a coating of active ingredients*



Two-phase “colloid”, the gas phase is separated by a liquid phase



Foam can contain a third phase – ***suspended solids***

- ☐ “Dry” foam (e.g., shaving cream)
- ☐ “Wet” foam (e.g., hand soap)





Limestone-Coated Gravel



Garden hose tremmie pipe





foam

pHoam™

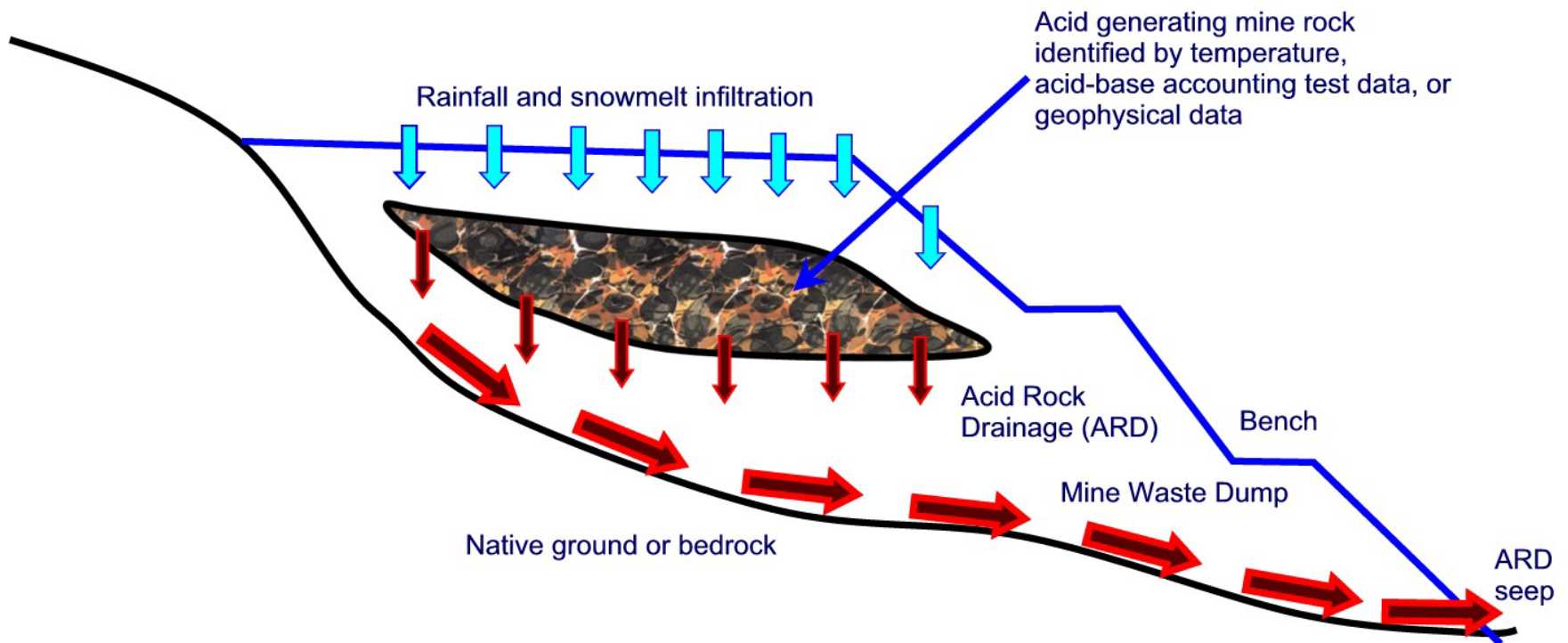
pHoam™ is a mixture of traditional foam plus one or more “active ingredients” that ***induce*** a desirable biological, geochemical, or process-related reaction

or

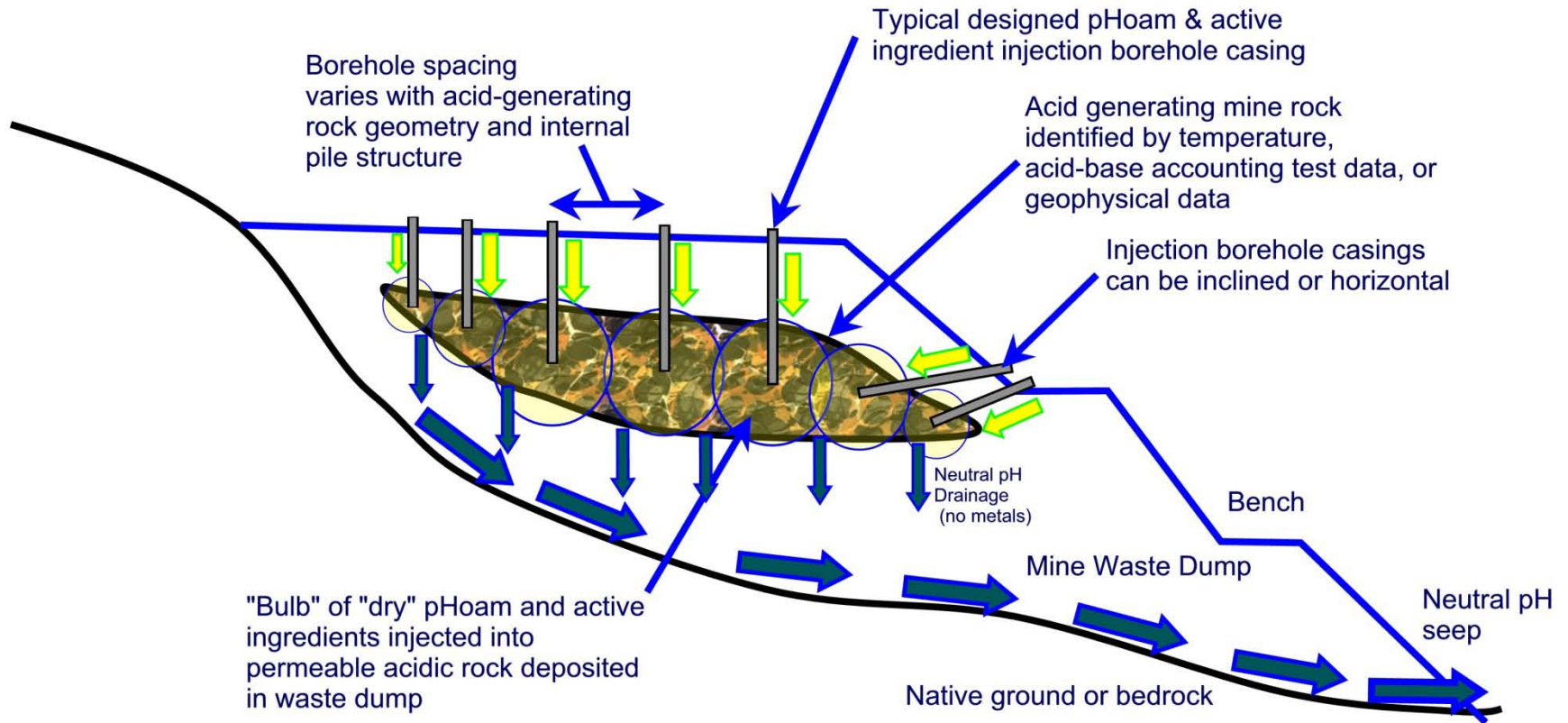
Foam + active ingredients that suppress an undesirable reaction.



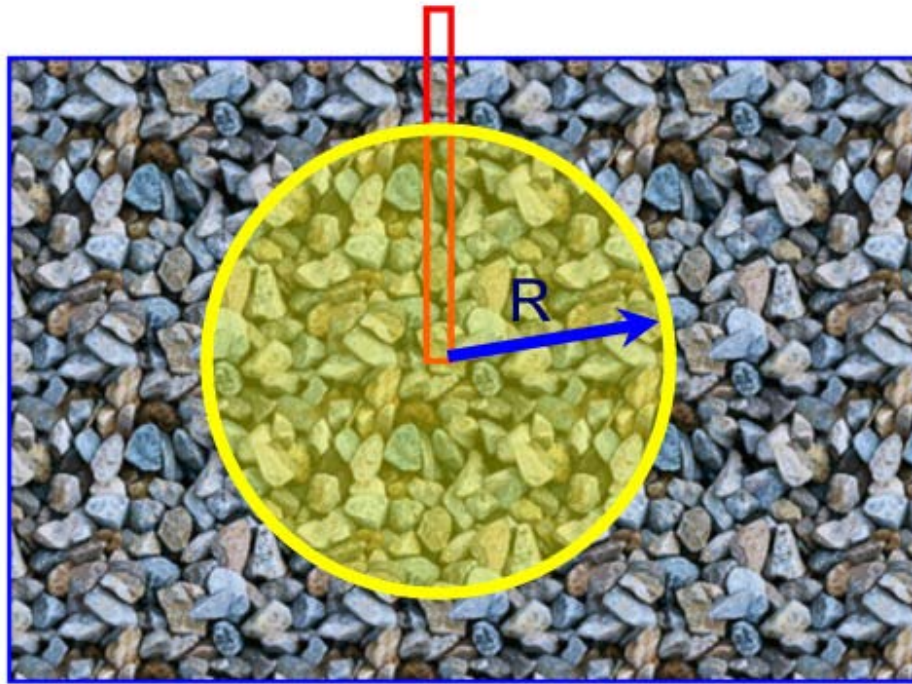
Vaccination (Prevention)	Medication (Mitigation)
Waste rock dumps at active mines ("sterilize" ARD rock by the truckload before it is placed in the dump)	Small-scale "dog hole" abandoned underground mines that produce ARD
Active coarse coal refuse piles (sterilize refuse by adding a "wet" pHoam™ in the feed hopper of a conveyor belt)	Waste rock dumps or coarse coal refuse facilities at abandoned mines (even if they are capped)
Active tailings storage facilities (sterilize the cycloned coarse tails in the embankment – the material most likely to form ARD before capping and revegetation)	Abandoned underground mine stopes (use geophysics for targeting and inject pHoam™ through bore holes) – use mine fire/foam equipment?
Active underground mine stope backfill materials	Backfilled pits (coal or metal) that are poorly capped



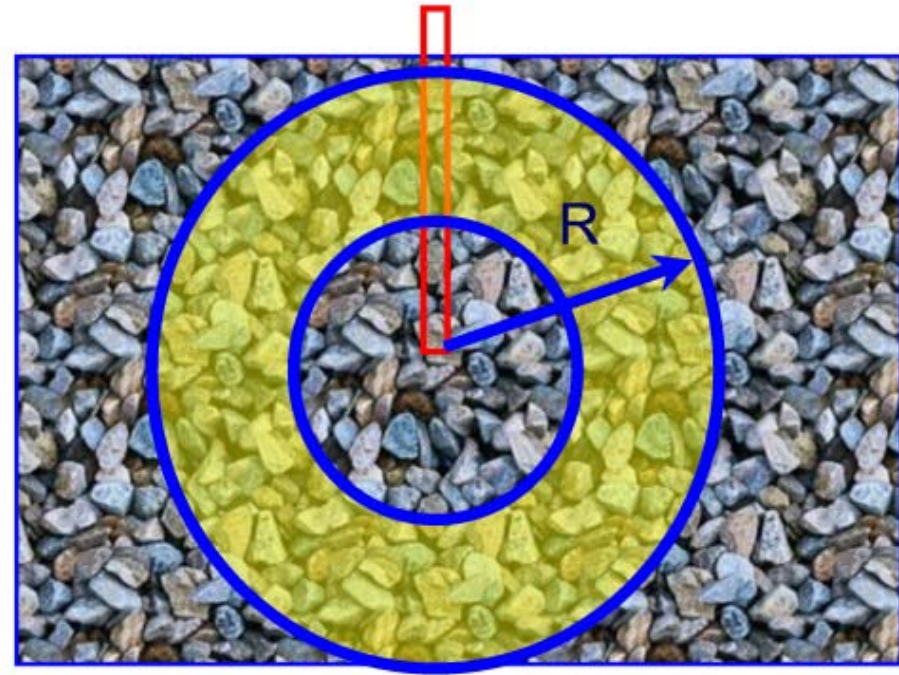
Waste Rock Dump = Big Humidity Cell



Waste Rock Dump



The “Balloon” Effect...



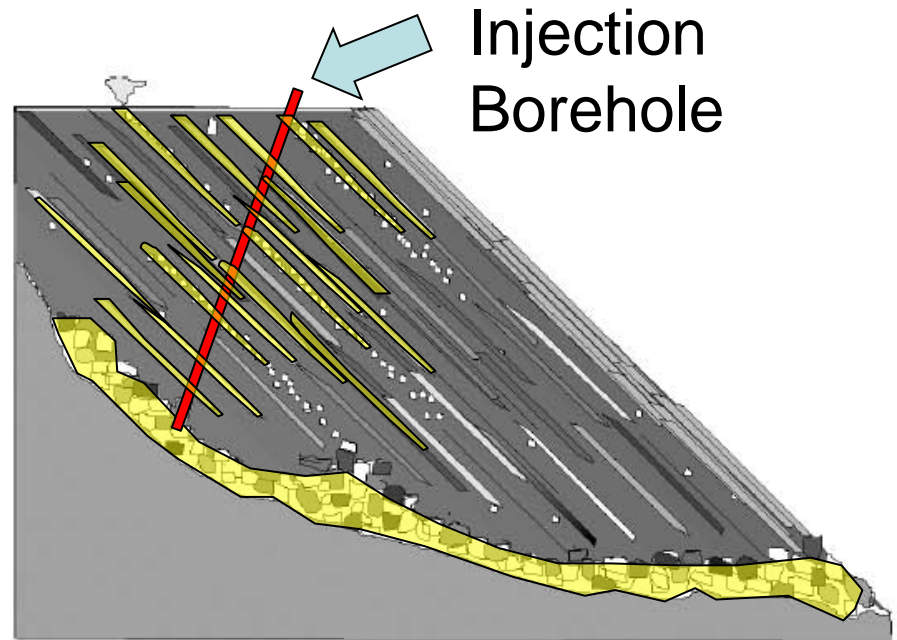
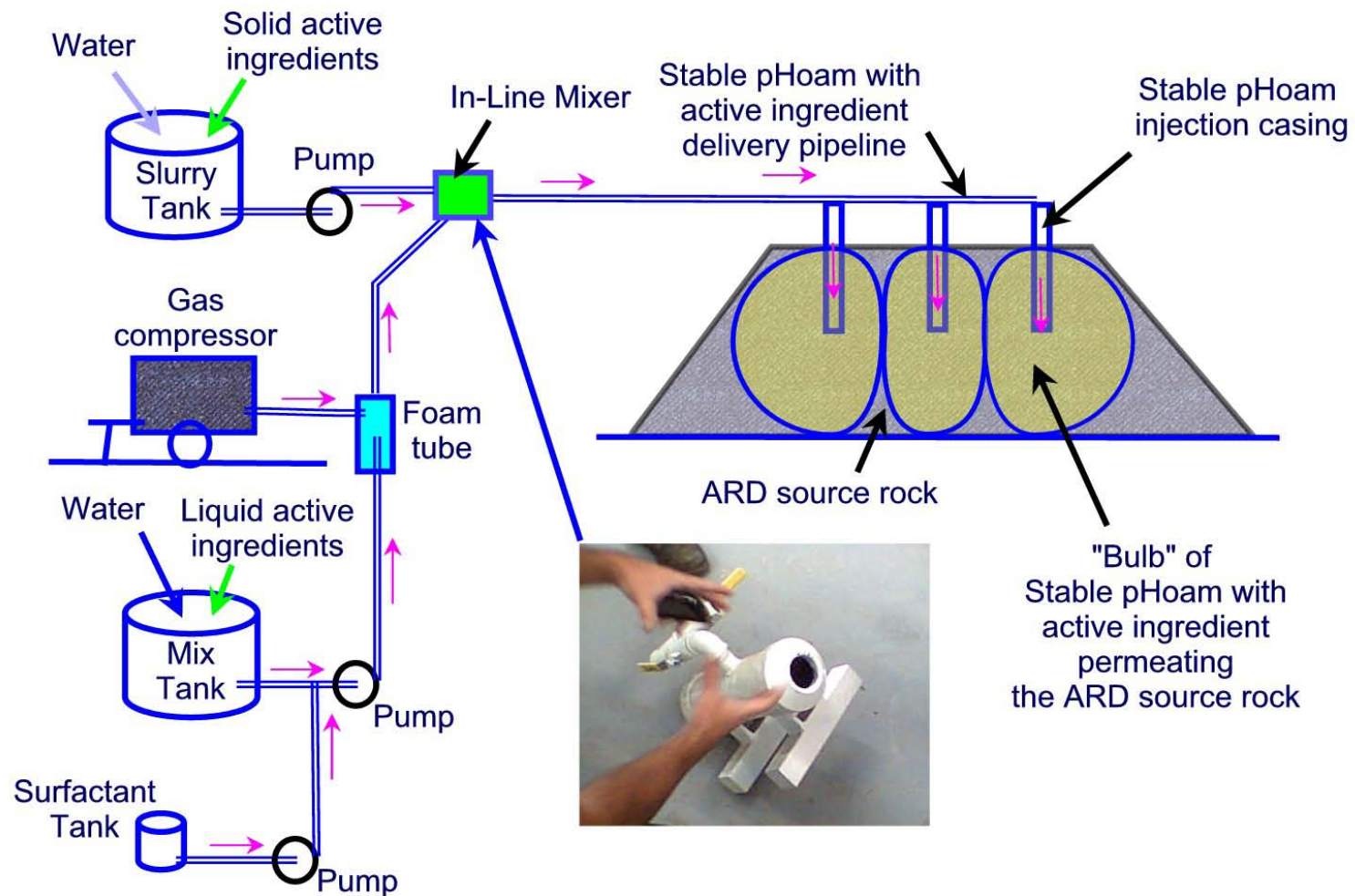


Figure 1. Gravity segregation and resulting interbedded structure in waste rock dumps.

After G.W. Wilson, 2008

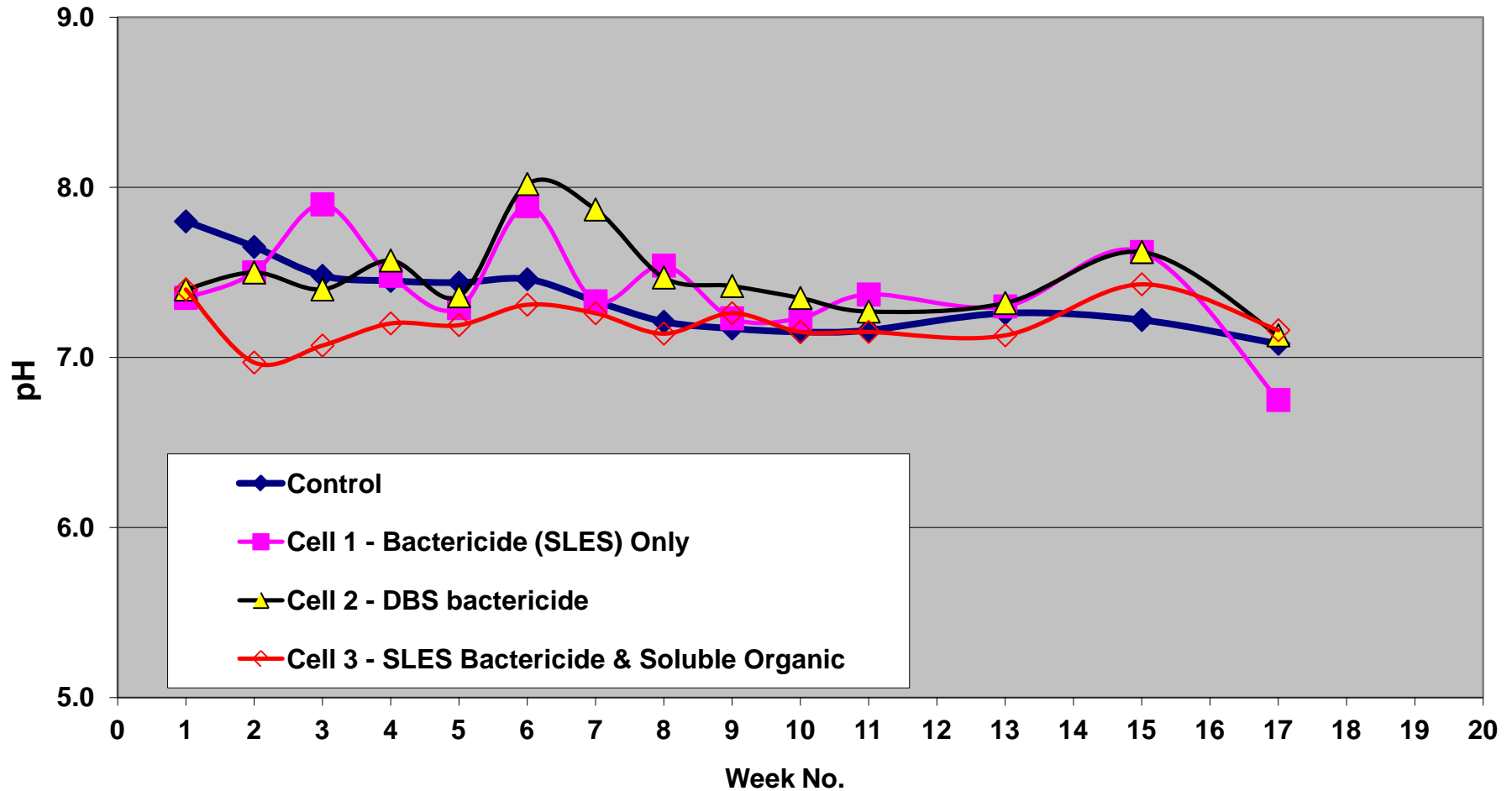


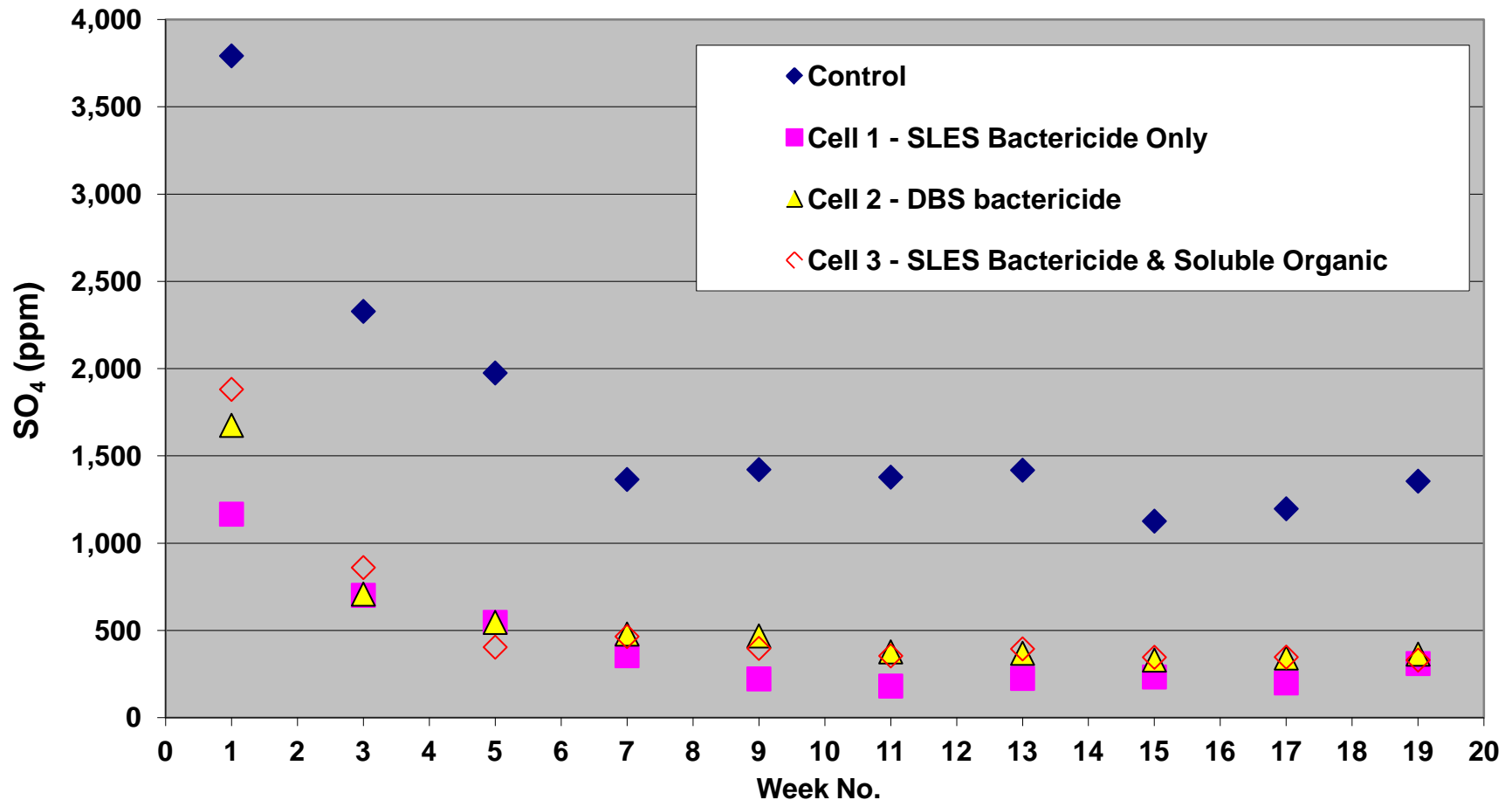
- Pyrite oxidation is exothermic
- If a pHoamTM encounters a “hot zone” with elevated pyrite, the bubbles should collapse and preferentially deposit the “active ingredients”
- This feature could potentially give pHoamTM a “***heat-seeking missile***” capability that could automatically deliver more ARD-suppressing active ingredients to a mine waste site in the zones where it is needed the most.



- Initial patent filing (16 August 2011)
- Initial demo – injecting into a gravel-filled pipe (done)
- Lab Testing (4Q 2011 to 4Q 2012)
 - ❖ Entity provides pyrite samples (done)
 - ❖ CCS treats samples with foam & amendments (done)
 - ❖ Golder/CCS conducts humidity cell tests in-house (**ongoing**)
 - ❖ Golder conducts mini-leach tests on acidic metal mine waste rock site [24 pHoam recipes] (**ongoing**)
- Demonstration Site (planned in Pennsylvania in Aug-12)
- Monitor demo site 2012 and beyond

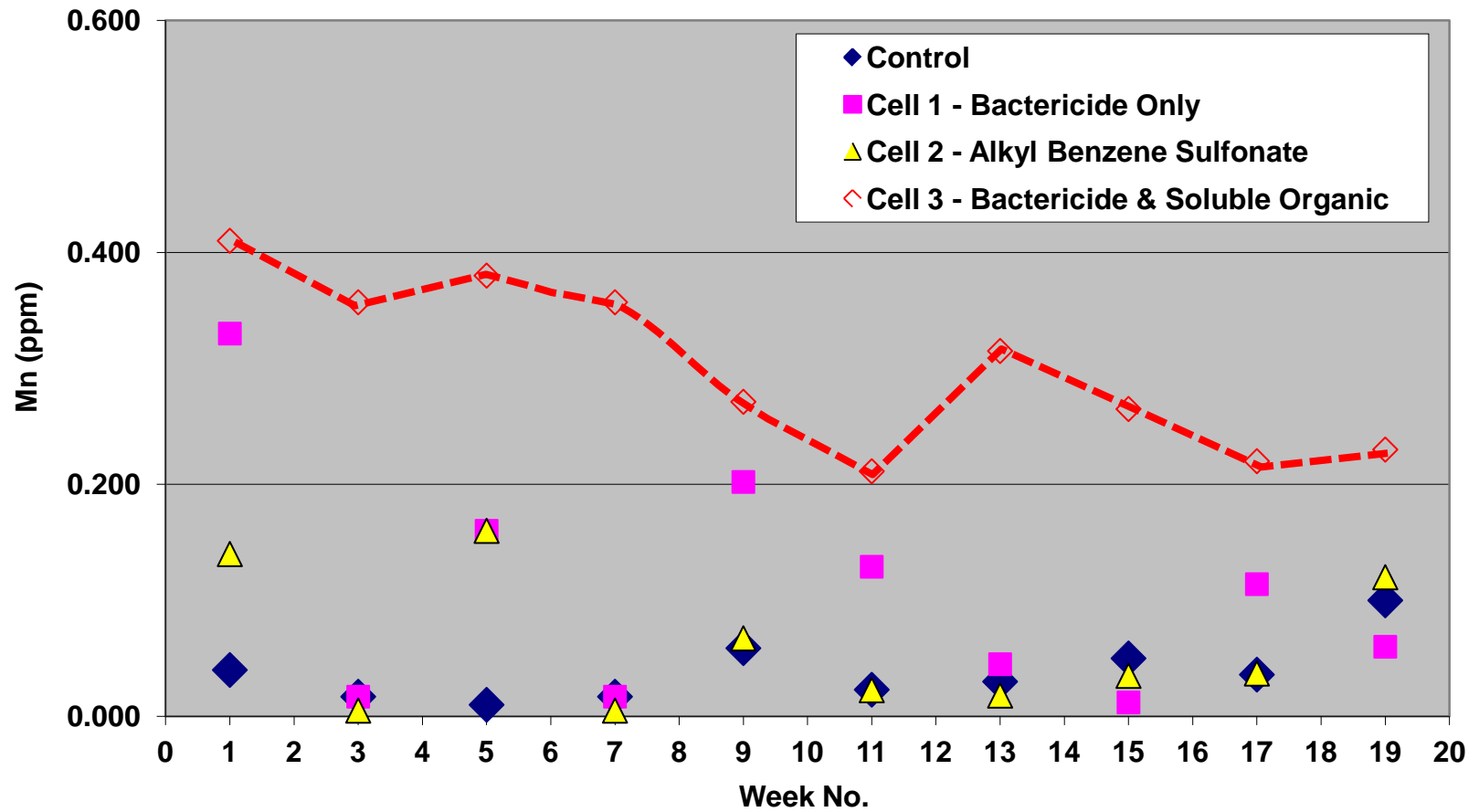






**Bactericide concentration ~0.06% by volume
(33x more dilute than 2% solution)
Organic ~0.7% by volume**







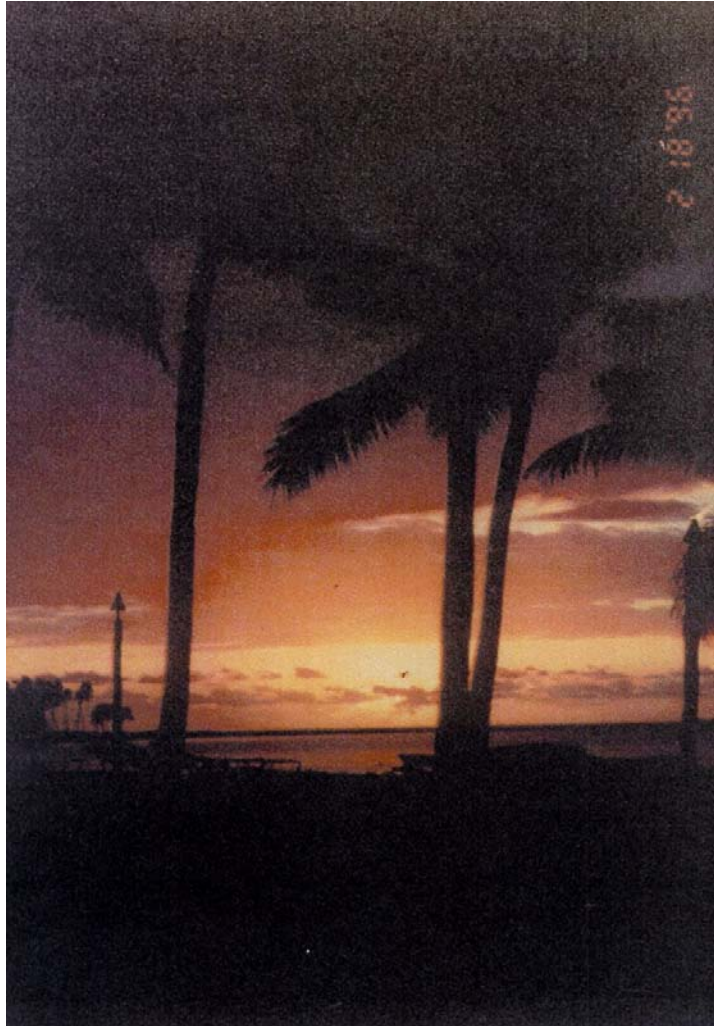
- Need to do comparison with perpetual ARD treatment (either active or passive technologies) or other remedies
- We have a cost model but it has **not** been validated/calibrated, **so we need demonstration sites**
- In an upcoming field test, we anticipate the cost of a liquid-based pHoam™ (no solid phase) to be about \$2.00 per cubic yard. Assuming a 30% void ratio, this would treat 6 cubic yards of mine waste (or \$0.33/cy of waste). **This doesn't include potential savings from the "balloon" effect.**
- Longevity of the treatment is a big issue. The non-pHoam™ treatment at the Fisher Coal Mine in 1995 with NaOH and bactericide is still effective after 17 years.



- Has research funding available
- Contains mine waste that is fully characterized, mapped, and is acid-generating
- Is relatively small in scale (1 to 2 acres) (<1Ha)
- Is relatively accessible by conventional construction equipment
- Is amenable to “dissection” after pHoam application
- Has documented ARD impact
- Is on publicly-owned land (USFS, USBLM, USEPA Superfund)
- Is not a part of or contingent upon ongoing litigation



- **Uses very little water**
- **Flexible design (wet/dry/stiff/flow-able)**
- **Flexible longevity (hours to days)**
- **Flexible active ingredients for suppressing ARD – whatever is inexpensive locally**
- **Easy to manufacture with traditional equipment**
- **Heat-seeking missile and “balloon” effects**
- **Pumpable or flow-able**
- **Biodegradable surfactants can double as bactericides**
- **Permeates unsaturated zones of mine waste to deliver anti-ARD “cocktail” that could last for decades, maybe longer**



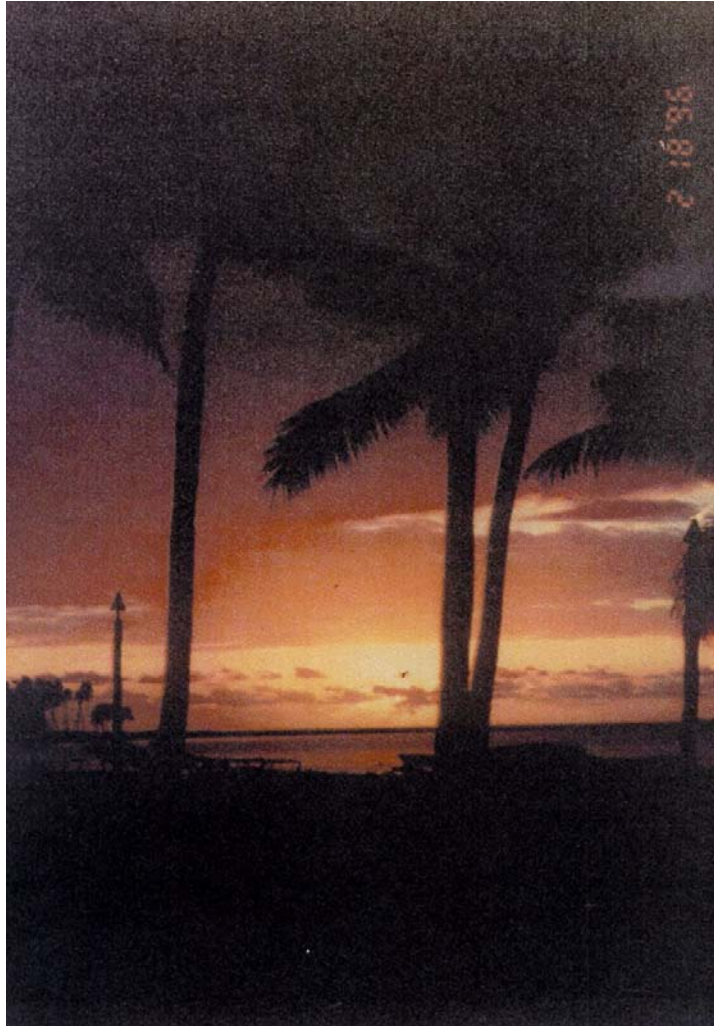
Nihil simul inventum est et perfectum

Latin Proverb

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invented and
perfected at the
same time

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