PNNL-SA-159006

Size Does Matter! Testing with Simulated Hanford Tank Waste

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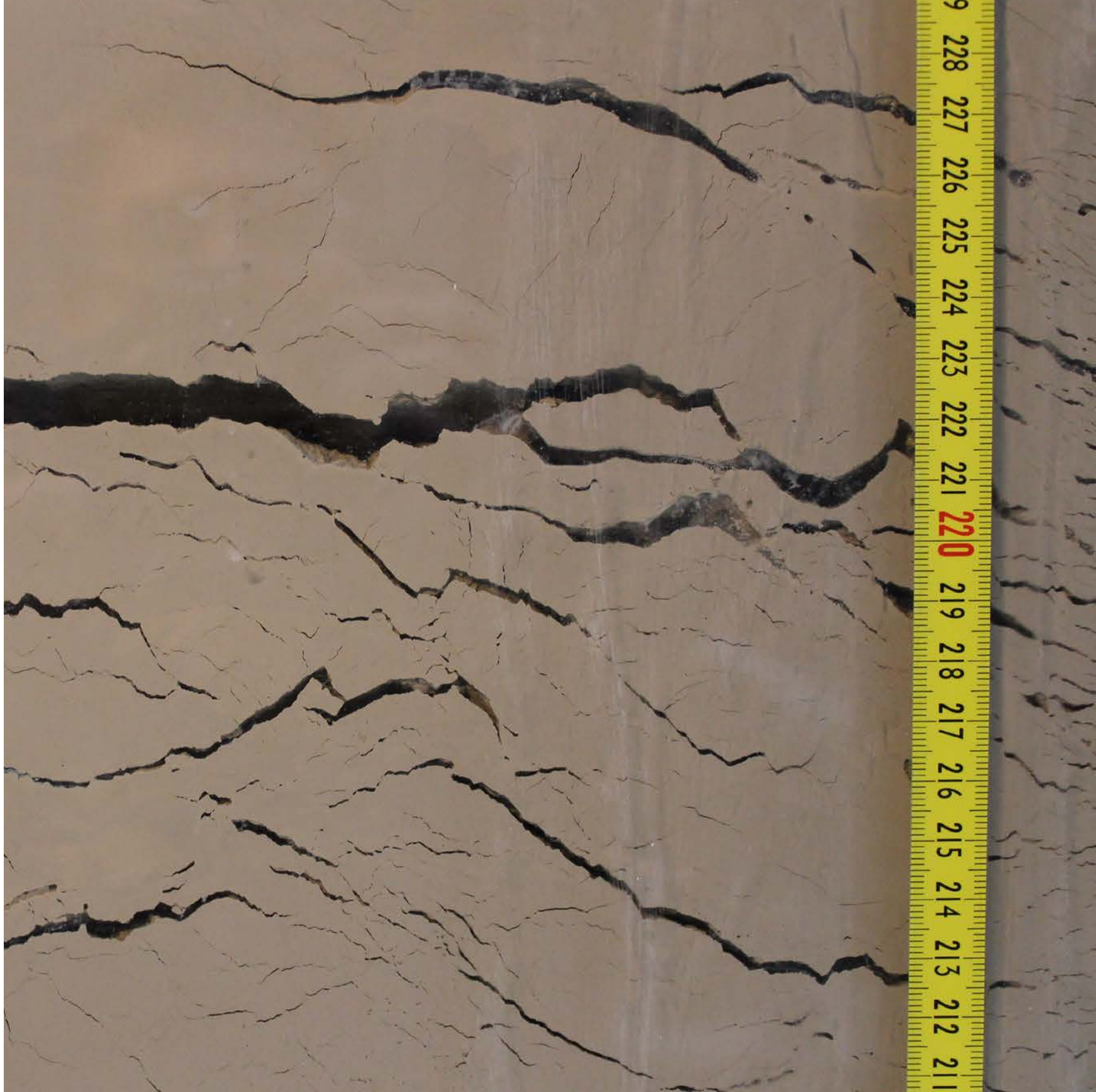

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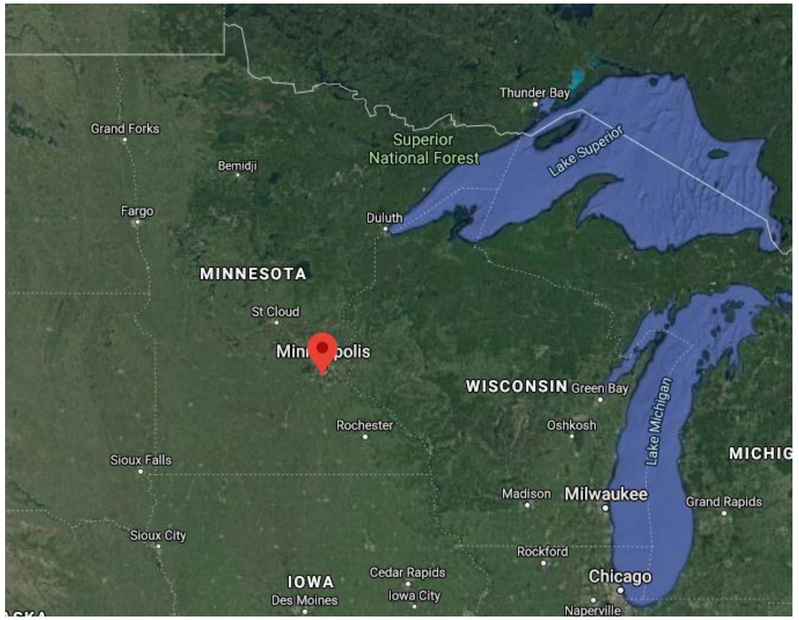
About Me



Science is a team sport

HE Adkins Jr.	CW Enderlin	PJ MacFarlan
EJ Berglin	RL Erikson	LA Mahoney
JM Billing	LS Fifield	MJ Minette
J Blanchard	CM Fischer	RA Peterson
GK Boeringa	SK Fiskum	RP Pires
JR Bontha	MS Fountain	MR Powell
GN Brown	PA Gauglitz	SA Sande
WC Buchmiller	DJ Heldebrant	RW Shimskey
CA Burns	JJ Jenks	JI Shutthanandam
CE Charron	NK Karri	DM Smith
RC Daniel	ML Kimura	L Snow
JM Davis	GR Kulkarni	C Song
KM Denslow	DE Kurath	DN Tran
MK Edwards	JB Lang	BE Wells
M Elmore	CD Lukins	M Zumhoff

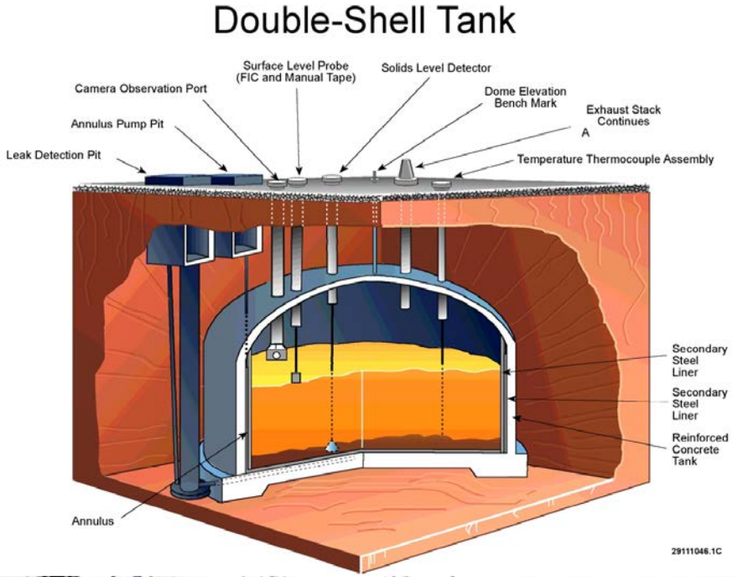
The Central Argument

My goal is to convince you that...

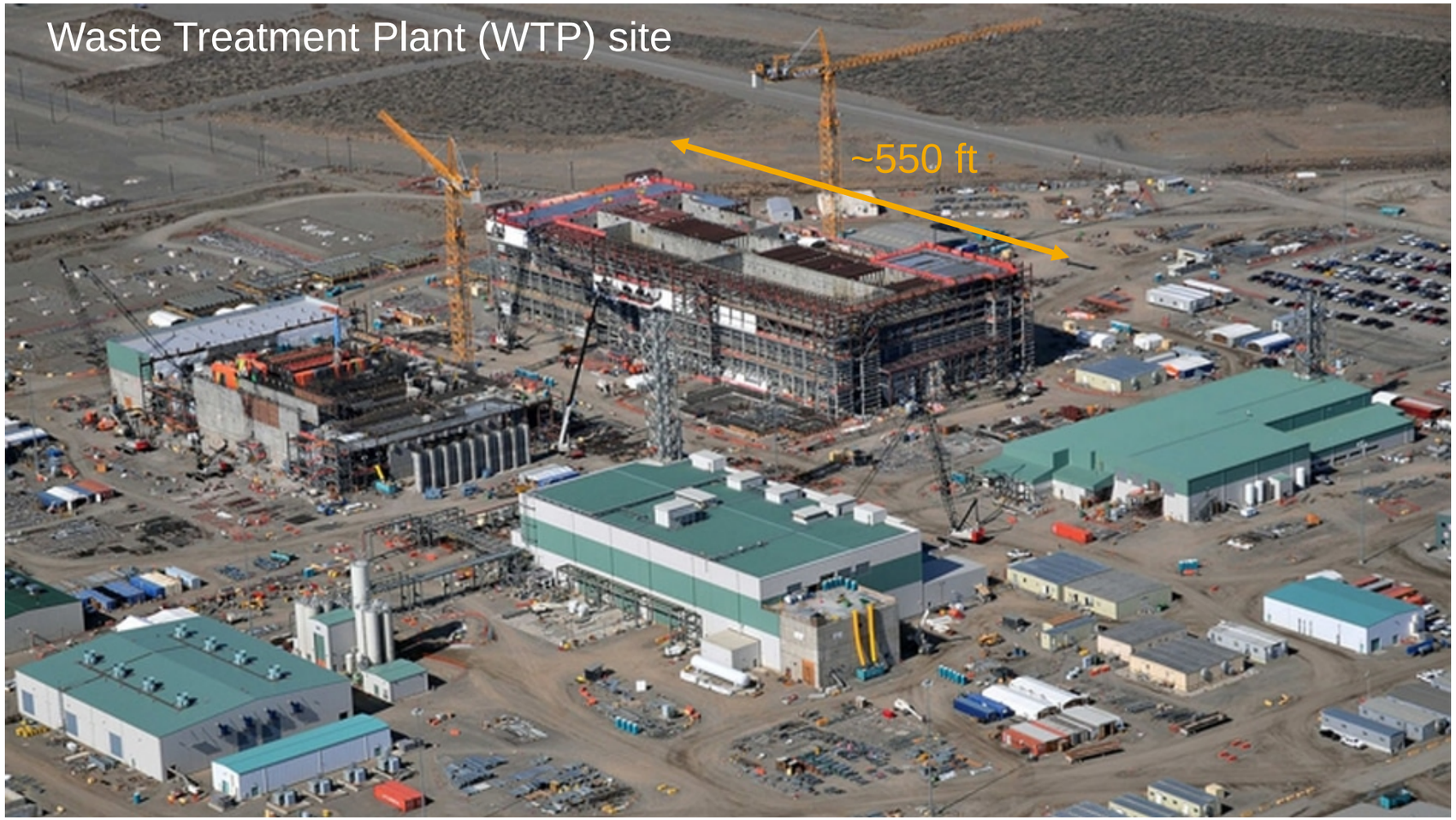
1. Experiments at large sizes are sometimes necessary
2. Large-scale experiments are challenging
3. Creative multi-disciplinary teams can overcome the challenges
4. Testing at large scale is lots of fun!

Things on the Hanford site are BIG

Hanford Double Shell Tanks
75 ft in diameter
Maximum depth of 454 in (~38 ft)
1,000,000-gallon capacity



Things on the Hanford site are BIG



Things on the Hanford site are BIG

Process vessels for WTP facility

Melter unit for WTP LAW facility

Largest in the world (20’ × 30’ × 16’)

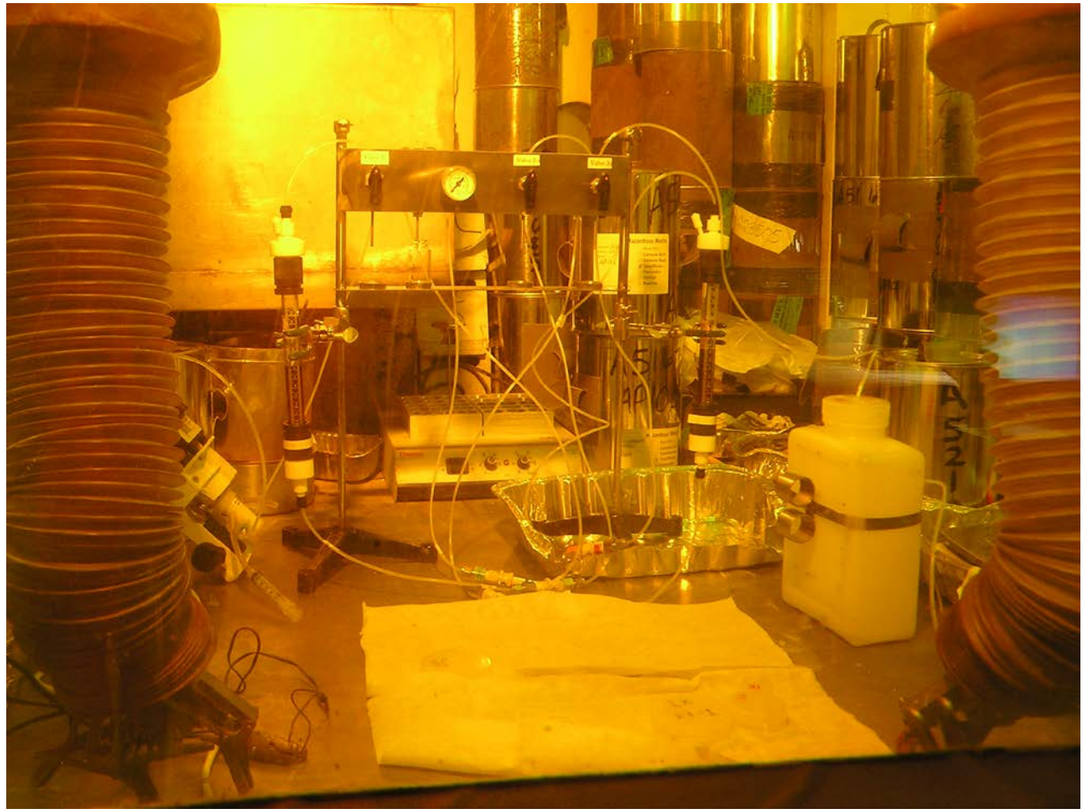
Ion exchange column for TSCR

Even modest-sized equipment is fairly large

TSCR IX column (right panel):
3.5 ft diameter
7.5 ft tall
~1300 lbs of media

Testing with Waste is Best…However…

Hot cells at PNNL in Radiochemical Processing Laboratory



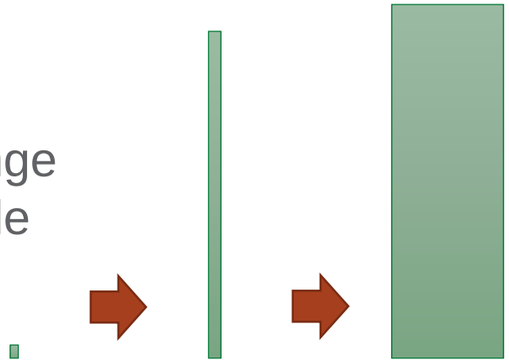
Limited in size and waste sample availability!

Why Do We Want to Scale?

Actual waste data
Small size
Limited amount
Expensive

Hanford system
Large size
Expensive
Needs to be safe, reliable
Difficult to modify

Ion exchange example



V = 0.01 L	~1 L	600 L
D = 1 cm	2.5 cm	106 cm

Scaled test system
Allows collection of sufficient data
Preserves important mechanisms
Test variations
Inexpensive

Sidebar: Enter Simulants

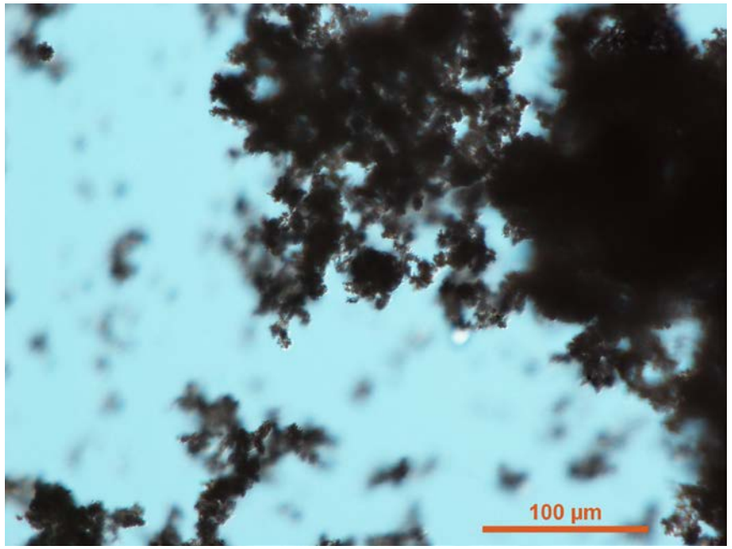
Simulants are intended to “represent” the waste without the radiological hazard

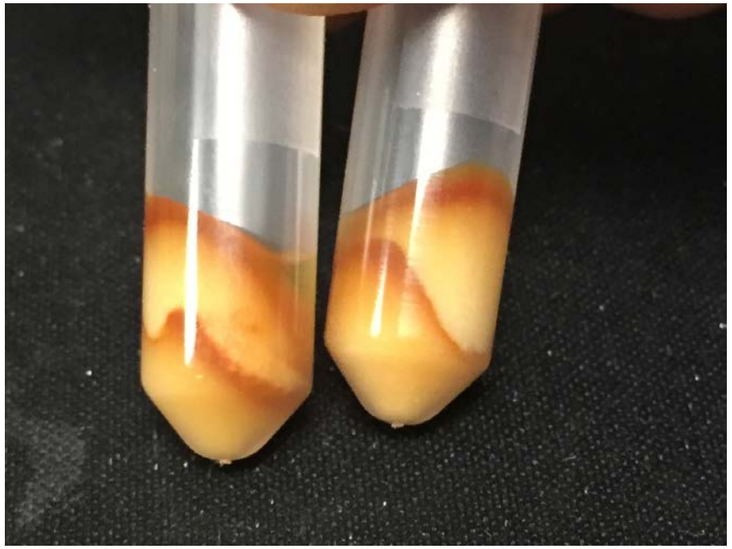
Enable scaled testing to achieve its intent → performance-based development

For successful use:

- Firm grasp of Hanford waste
- Good characterization information
- Understand what is important

Major limitation: real waste history cannot be duplicated (radiation, recombination, aging)





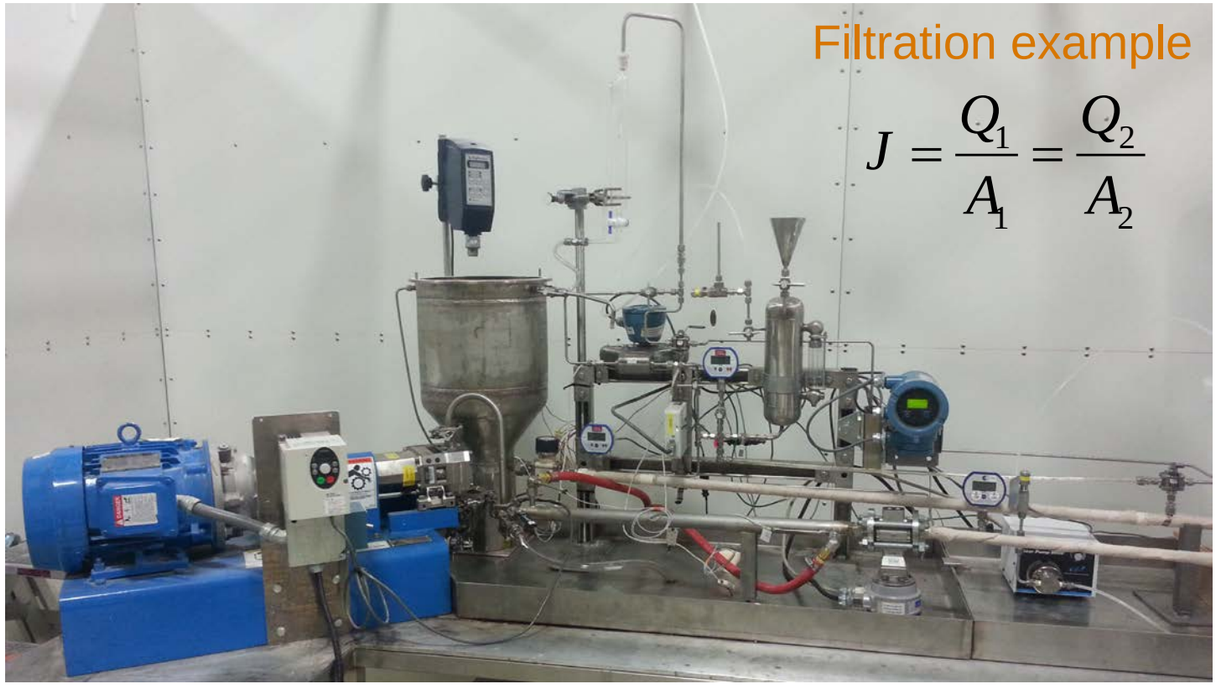
How Do We Scale (Typically)?

Premise of scaling: valuable source of additional information

More nuanced than selecting sizes that are “in-between”

Configuring test systems that:

- Hold relevant parameters constant (similarity)
- Match operational elements of the full-scale system (prototypic)
- Prioritizing the key parameters → hard choices



Three “Real-Life” Examples

1) Spray Aerosols Generated in Proposed Nuclear Facility Accident
   [**Spray Release**]

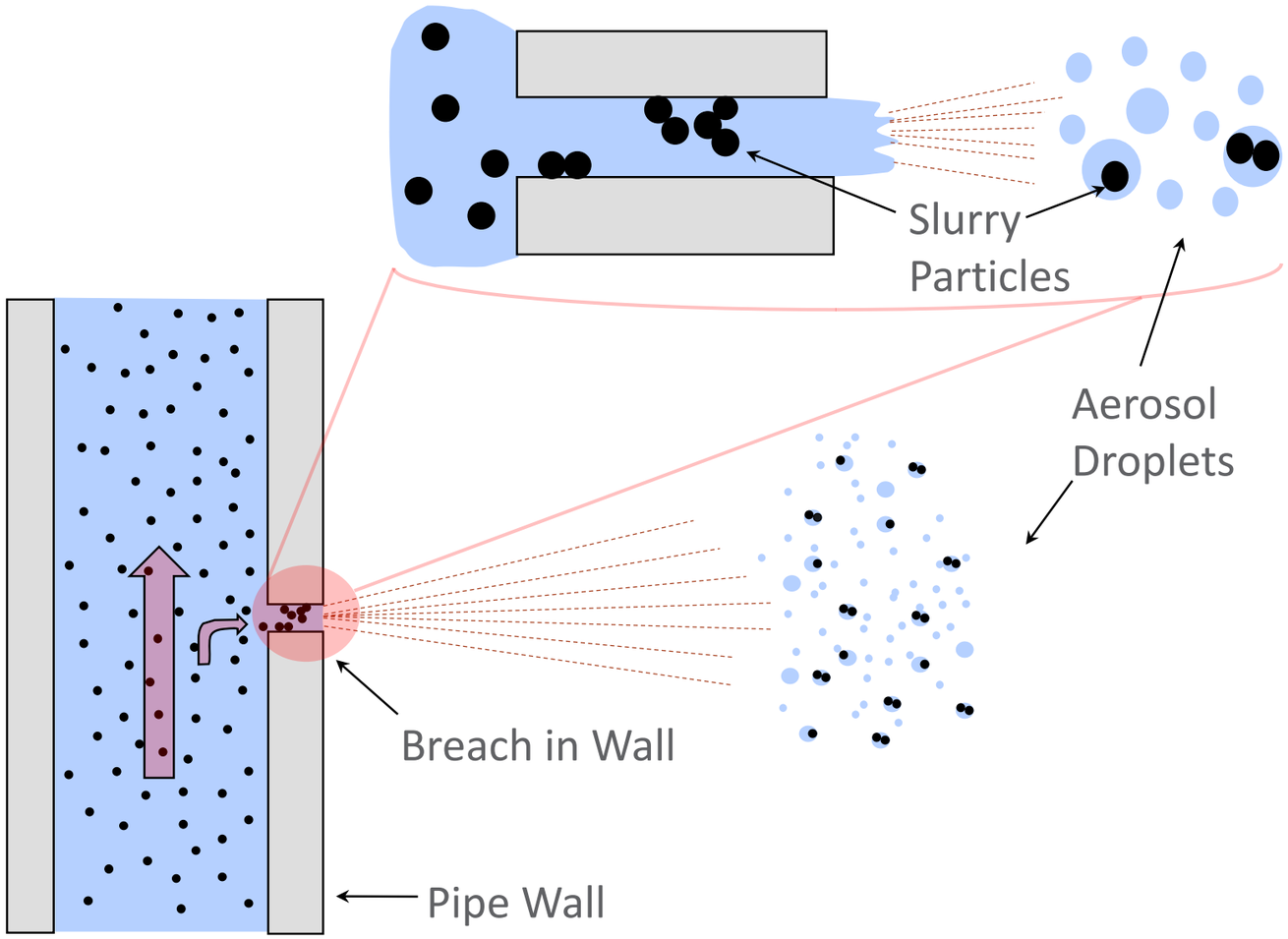
2) Supplemental Mixing in a Waste Treatment Plant Vessel
   [**Airlift Circulator**]

3) Flammable Gas Retention and Release in Sludge Waste
   [**Tall Column**]

<u>Bird’s Eye View</u>
The Problem
What’s Important
Sense of Scale
Fun Stuff
What We Learned

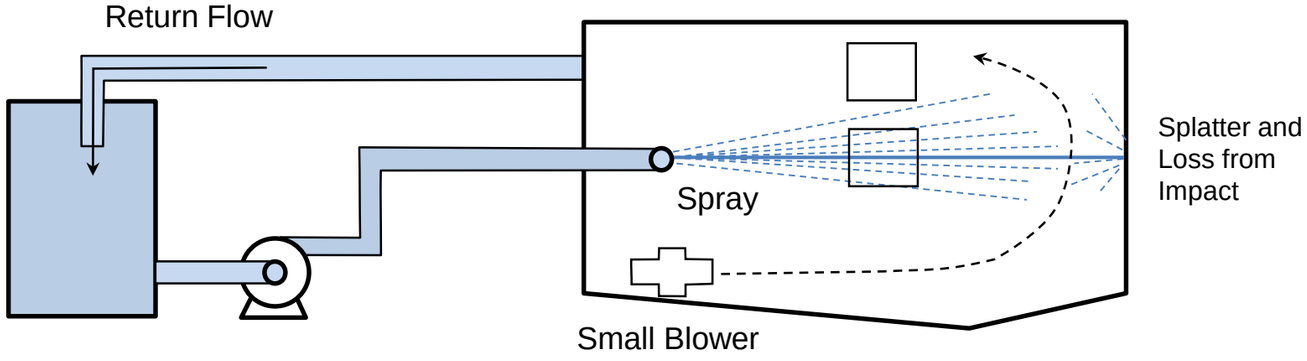
Example 1: Spray Release

- Nuclear facility, e.g., WTP
- Flowing fluid in a pressurized pipe
- Postulated failure in pipe
  - Crack, breach, pinhole, etc.
  - Of sufficient size to generate a spray
- Spray generates aerosol, which is a hazard
- Uncertain if available information was comprehensive

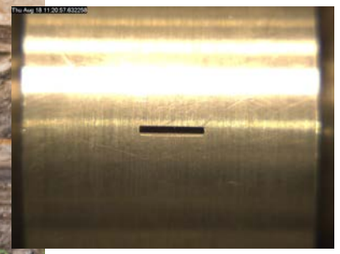


Spray Release: What's Important?

- Spray releases involve complex physics
  - Function of pressure, breach geometry, fluid and particle parameters
  - Transition from bulk spray to individual aerosol extremely chaotic
  - In addition, aerosol measurements are challenging to make and interpret
  - Unclear that spray "behavior" from smaller scales could be used to predict
- PNNL test system designed to have full-scale aspects:
  - Aerosol drop-out is hard to scale
  - Breach size (based on 3-in pipe)
  - Variable distance to impact

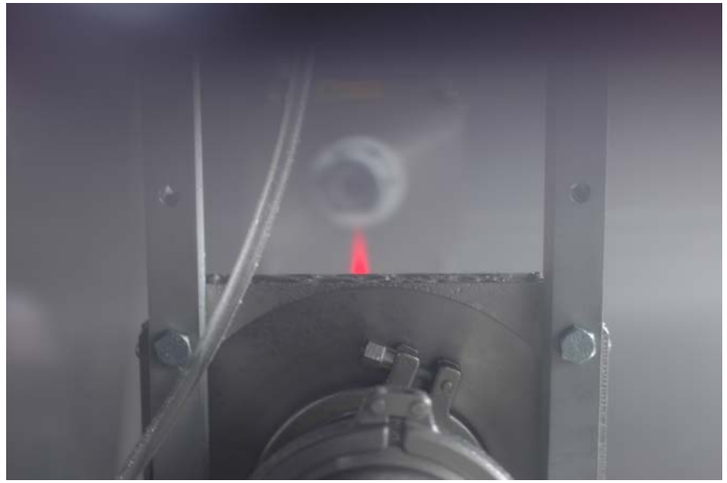


Spray Release: Method

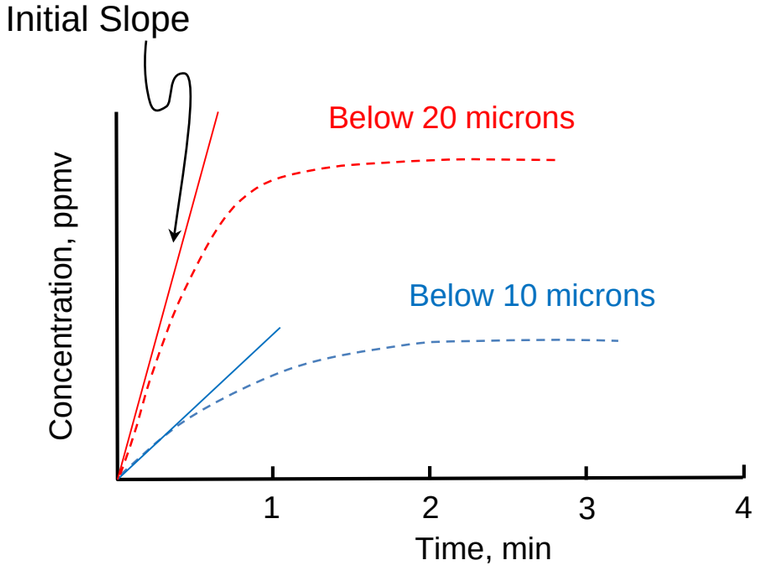


Breaches in pipe

Spray in Chamber



Laser Diffraction Aerosol Measurement



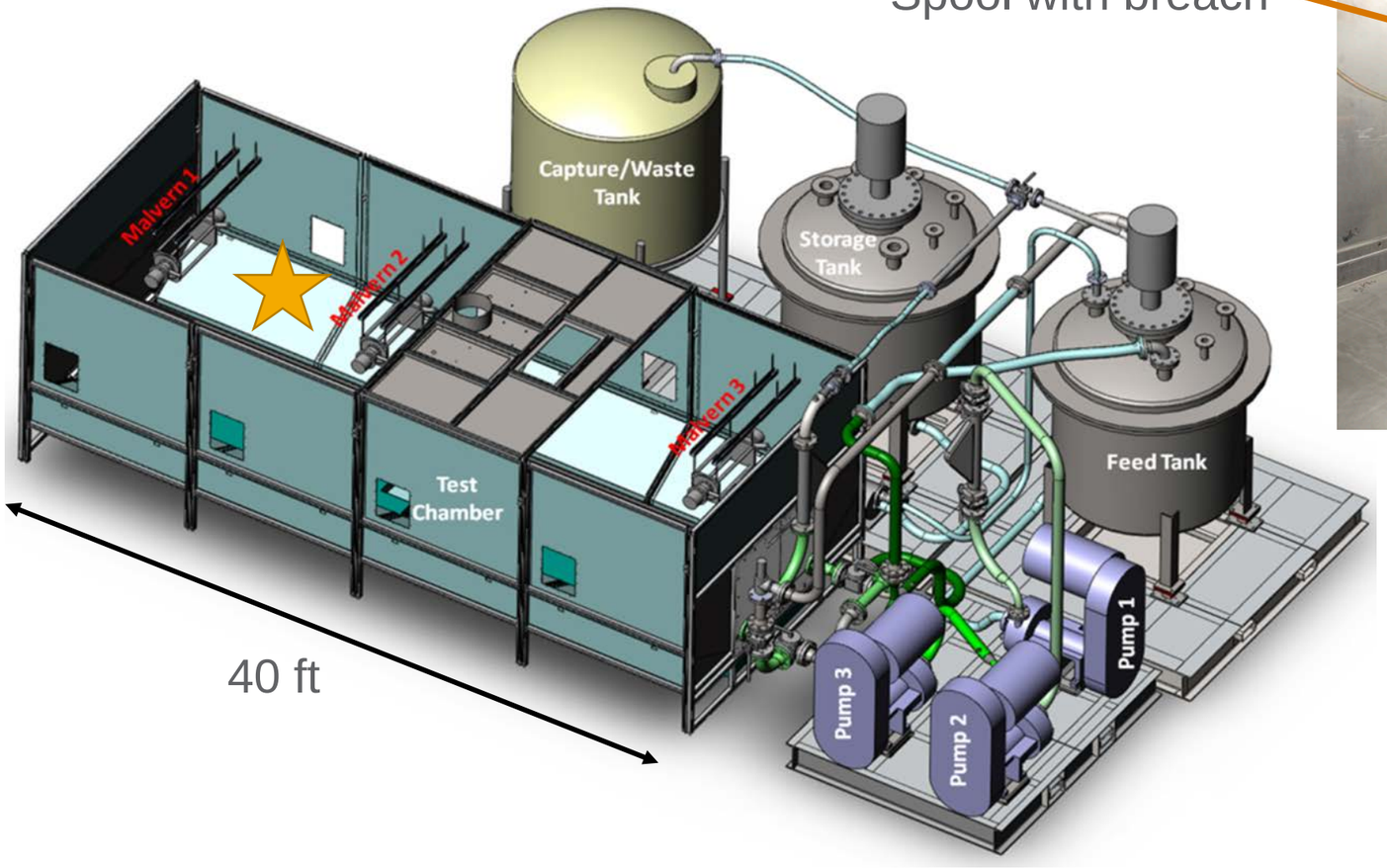
By this method, well over 1,000 tests were performed:

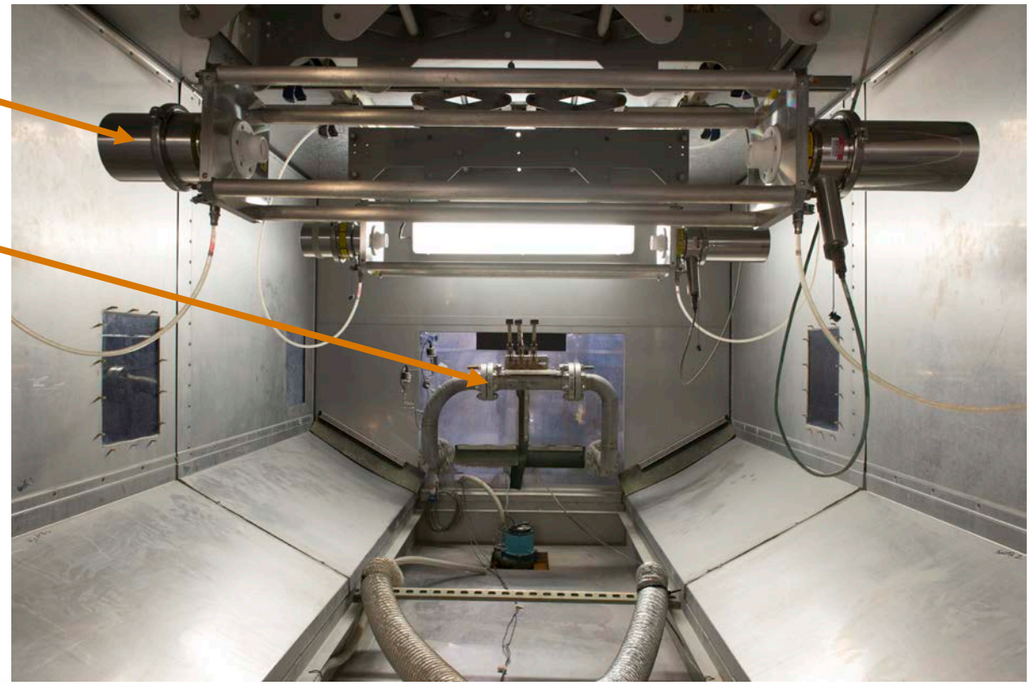
- Several different simulant fluids
- Tested an entire range of breaches (round and rectangular)
- Tested a range of spray lengths/chamber sizes

Spray Release: Testing Scale

Laser diffraction aerosol instrument

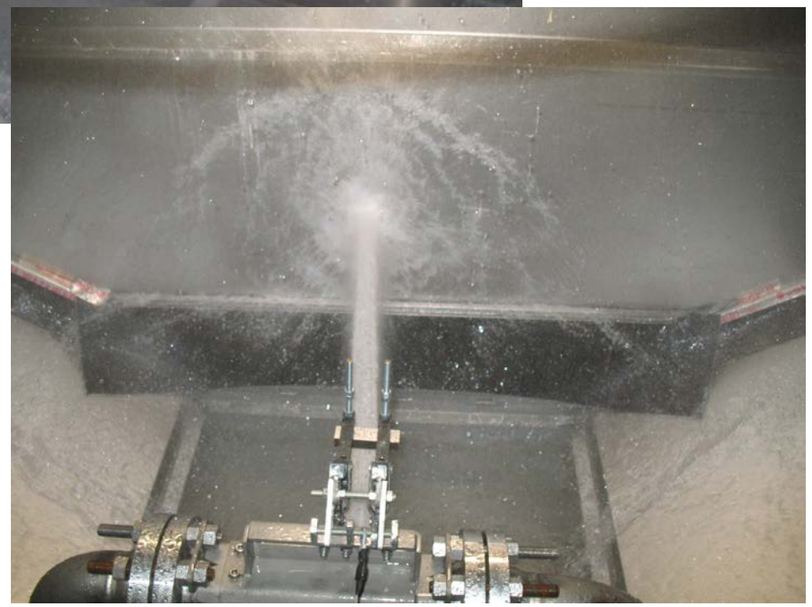
Spool with breach





View towards the chamber front (from the star shown at left)

Spray Release: Images



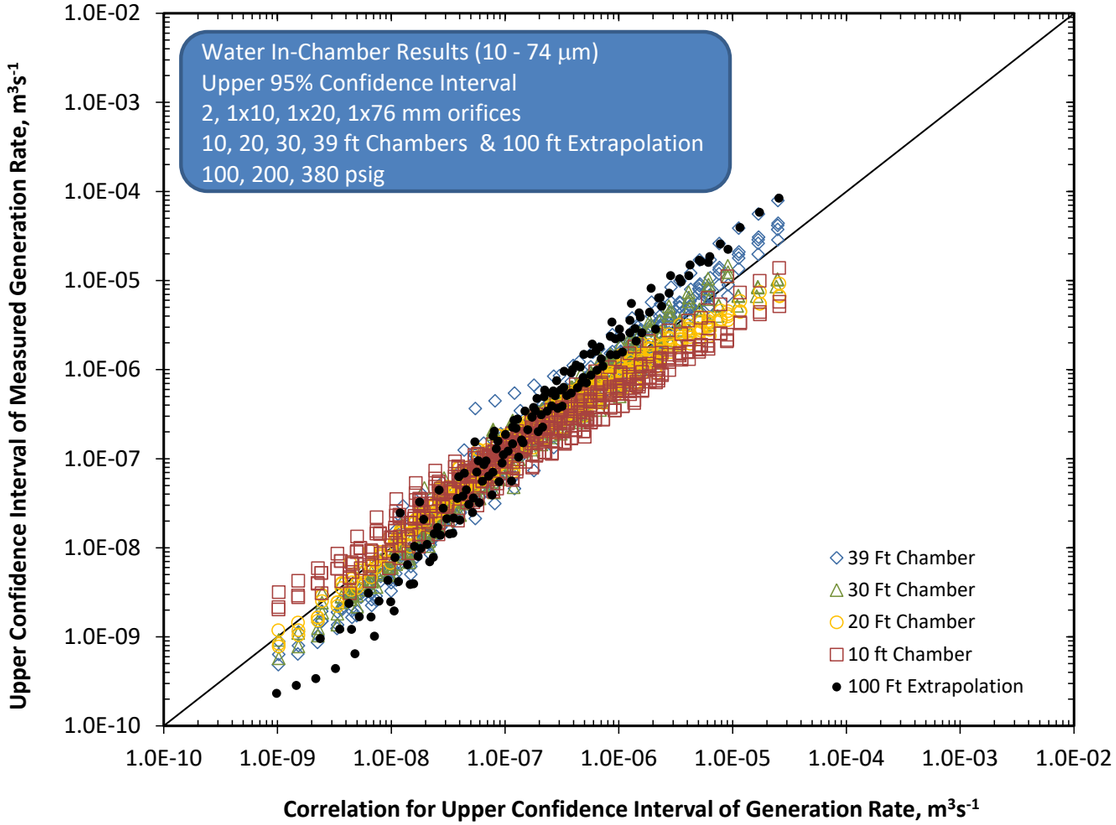
Spray Release: Spray Video

Spray Release: What We Learned

$$GR = c(A)^{a1}(P_s)^{a2}(d_p)^{a3}$$

where

GR	=	cumulative droplet generation rate (m3/s)
A	=	orifice areas (mm^2)
P_s	=	spray pressure (psig)
d_p	=	aerosol droplet diameter (µm)
c	=	leading constant
$a1$	=	coefficient for orifice area
$a2$	=	coefficient for spray pressure
$a3$	=	coefficient for droplet diameter

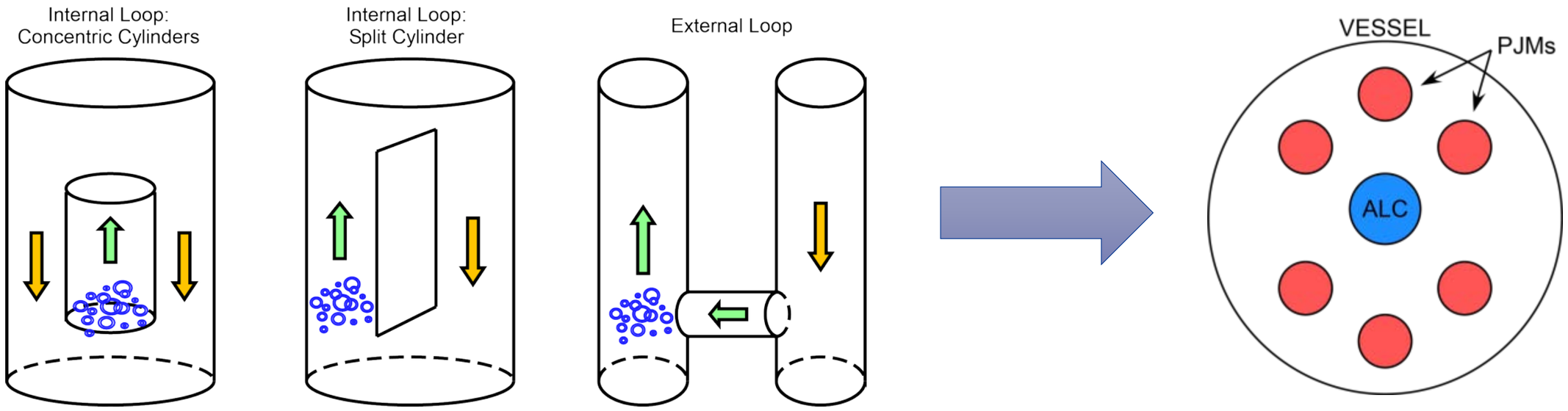


PNNL-developed correlation (at right) recommended for use by Department of Energy in 2019 technical report

Adjust leading coefficient to bound all data above:

$$GR_C = \left(3.3\times10^{-16}\right)A^{0.79}P_s^{2.2}d_p^{2.4}$$

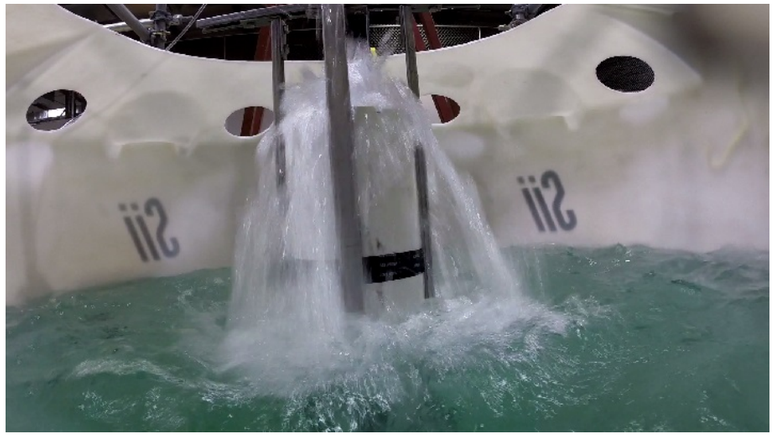
Example 2: Airlift Circulator Study



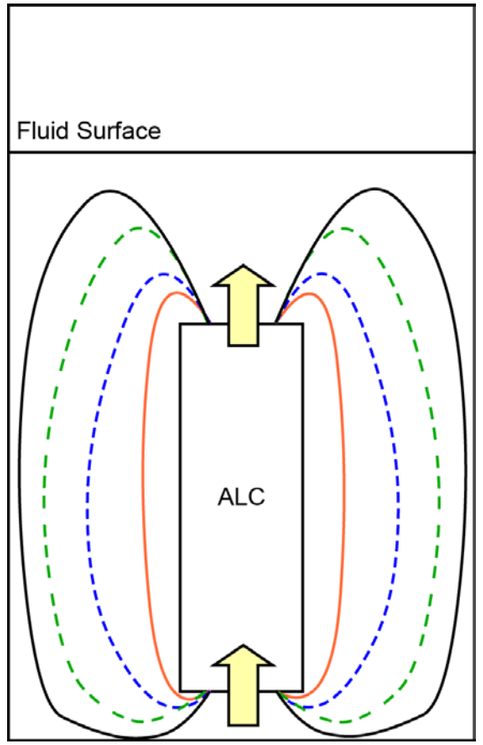
Does an Airlift Circulator (ALC) provide adequate supplemental mixing in a vessel?

ALC needed to be effective for both Newtonian and non-Newtonian fluids.

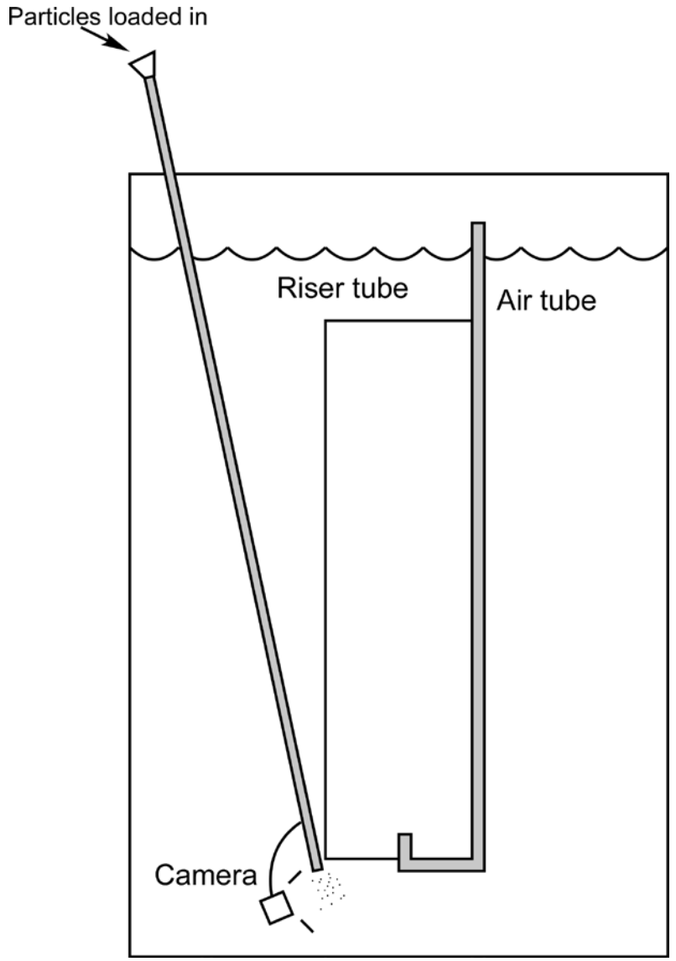
ALC: What's Important?



- ALC mixing had two focus areas
  - Lifting solid particles in Newtonian fluid (water)
  - Yielding regions of non-Newtonian fluid (clay slurry)
- Opportunity to influence mixing design choice was time-sensitive
- Direct comparison with WTP test vessel could expedite decision-making
- Therefore, PNNL test system used a full diameter
  - Benchmark against historical Hanford data
  - Dynamic similarity is hard to achieve
  - Solid particles have limitations for scale

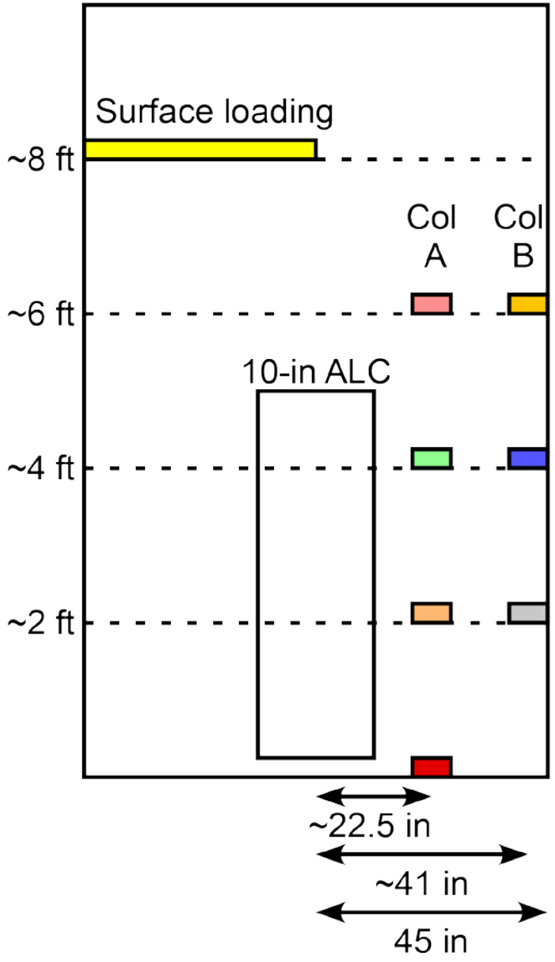


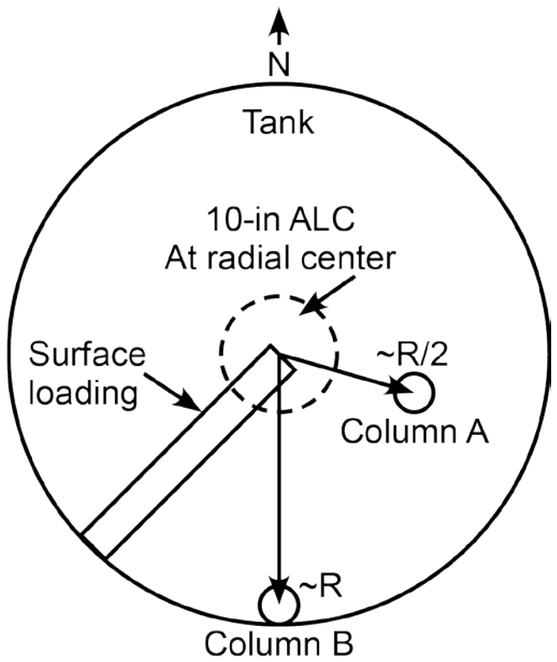
ALC: Method

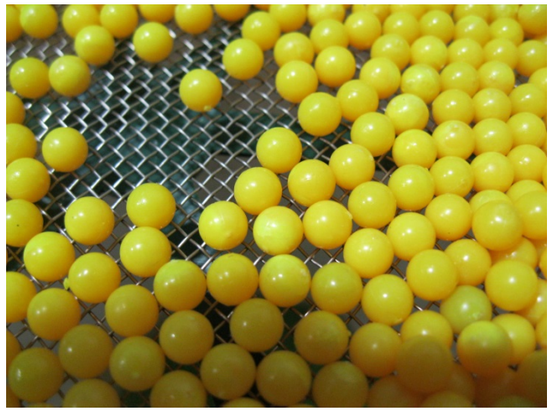


Newtonian (water) particle lifting

Non-Newtonian (clay slurry) mobilization testing

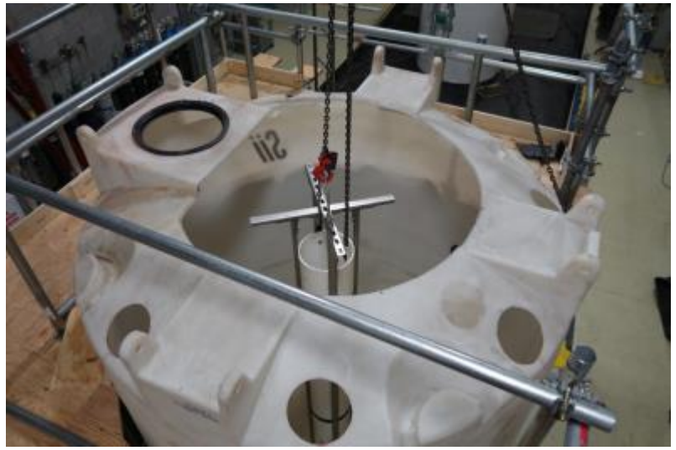






ALC: Testing Scale

8-ft test vessel with scaffolding
When full, nearly 3,000 gallons



Looking into empty vessel

Airlift circulator assembly

ALC: Lifting Solids in Newtonian Fluid

ALC: Mobilizing Non-Newtonian Fluid

ALC: What We Learned

"Sampling" clay simulant

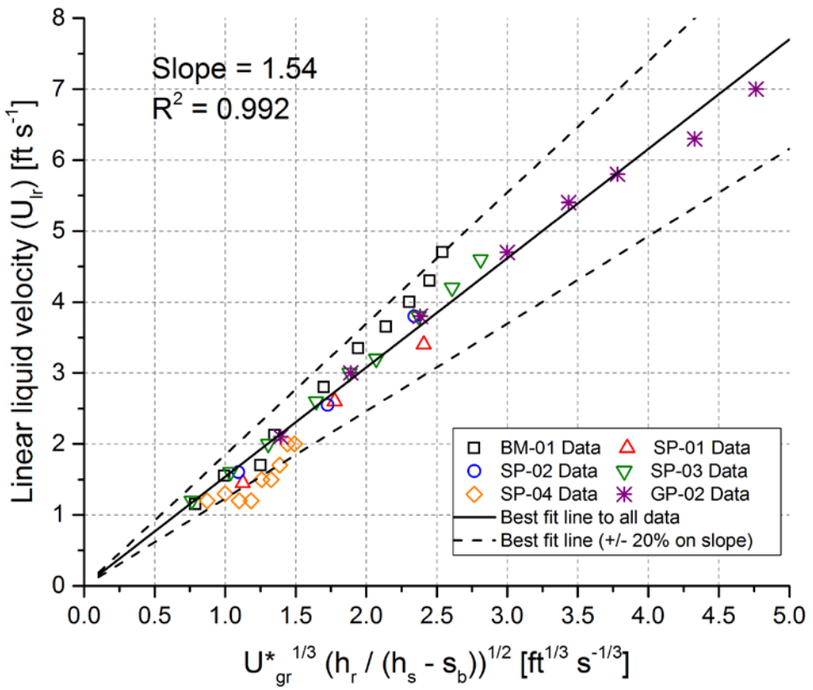
ALC can lift particles like pea gravel (~6 mm) with only modest air input (<20 cfm)

ALC can yield most of the top part of the vessel, with slightly higher air requirement (~30 cfm)

Modifications, like pulsing the air flow, are more effective for the non-Newtonian case

Promising potential WTP vessel alternative (low air usage)

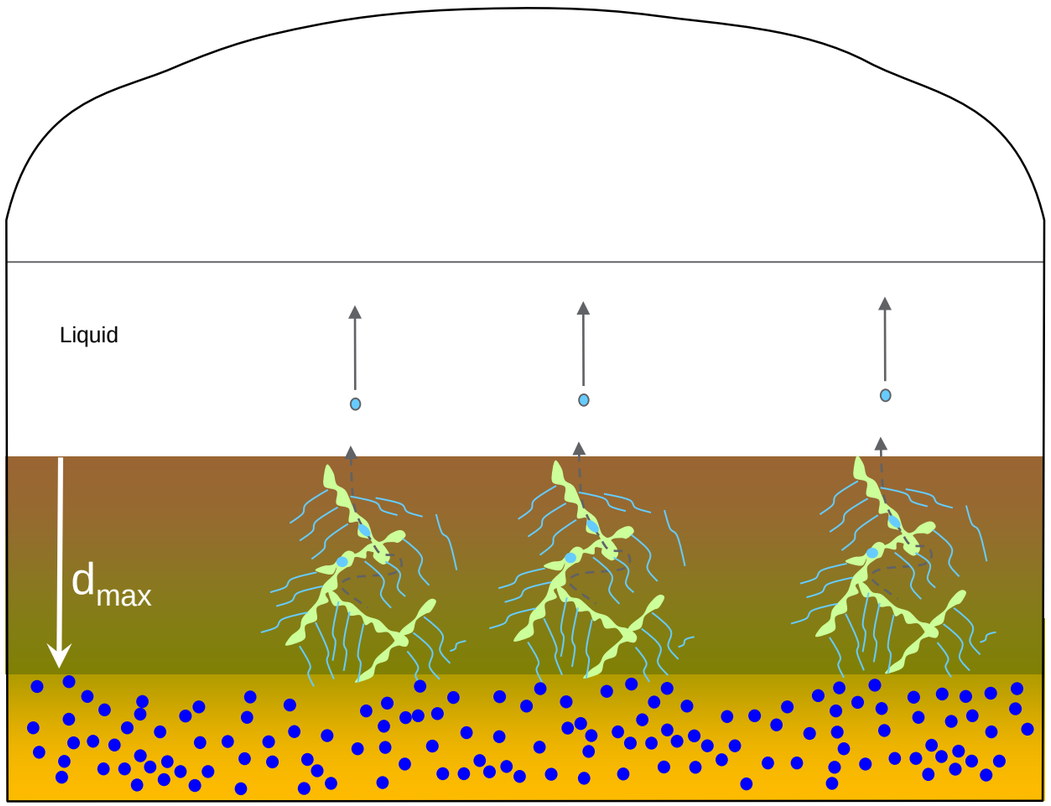
Collapse of data with different ALC configurations



Example 3: Tall Column

- Flammable gas is an important hazard in the Hanford tank farm
- Gas (primarily H_2) is continuously generated due to the presence of radiation
- Small amounts of gas bubbles are retained in the waste during day-to-day operations
- Concern arose that gas retention in a DST could lead to a deep sludge gas release event
- Relevant literature supported the concern, but no direct measurements in “Hanford-like” scenarios had been made
- Operations halted until concern was addressed

Double-Shell Tank



Tall Column: What's Important?

Retention of flammable gas in waste is based on shear strength and the material load as a function of height

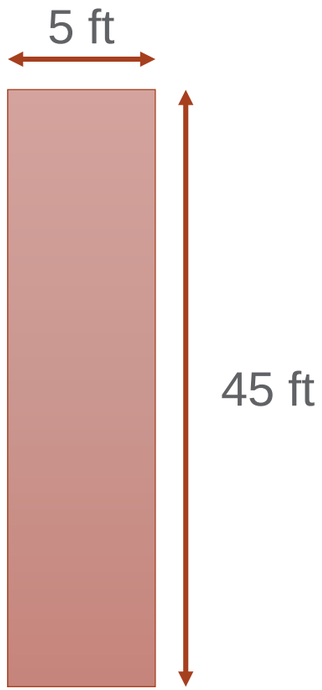
$$d_{max} = \frac{c_u(1+e)}{K_0(\rho_s - \rho_w)g}\left[1 + \ln\left(\frac{r_0^2 - d_f^2}{d_f^2}\right) + \ln\left(\frac{E}{2c_u(1+\nu)}\right)\right]$$

Smaller diameter columns can support bubbles that span the entire cross-section

$$Y_G = \frac{\tau_s}{\rho_s g D}$$

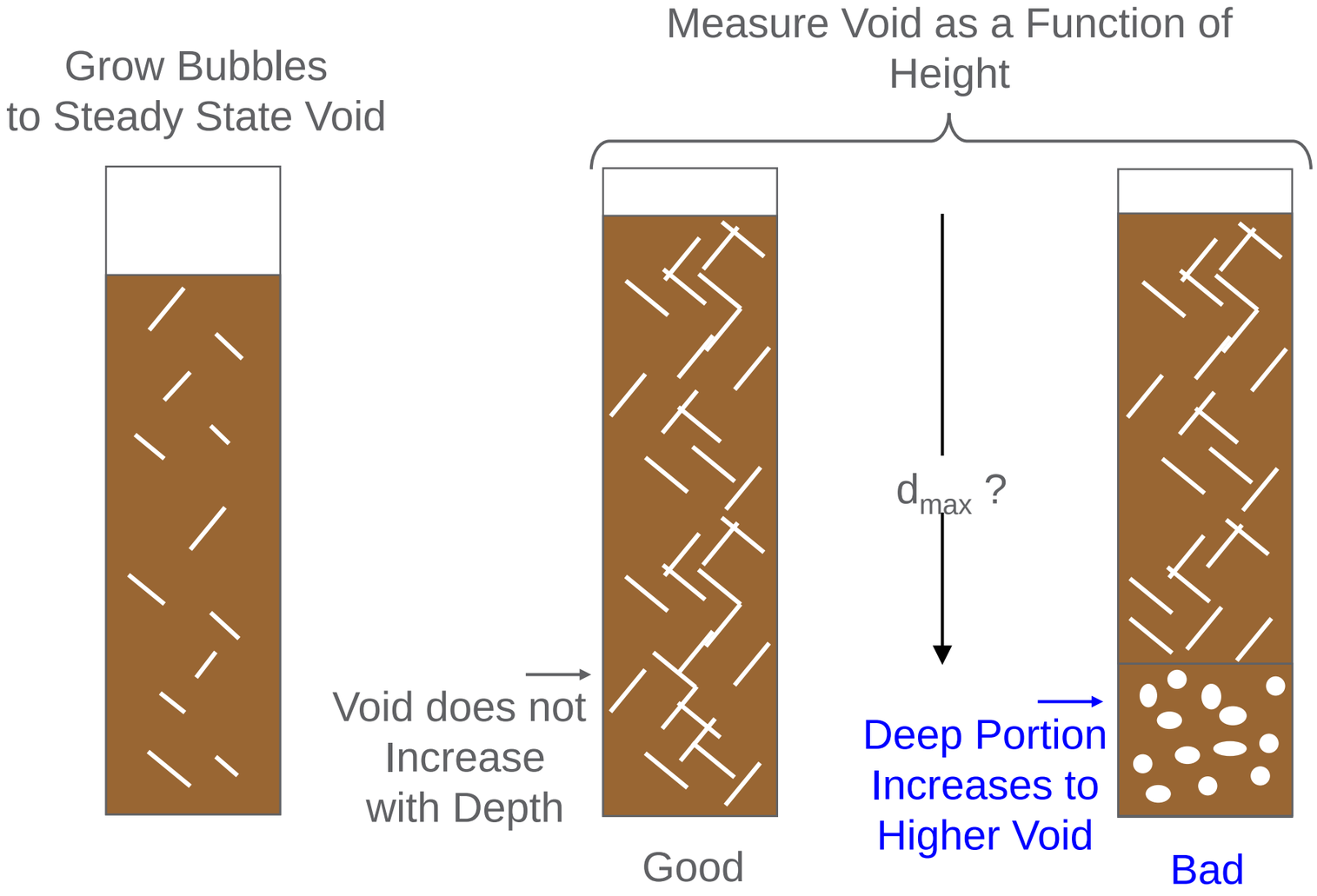
Therefore, PNNL test system used a full DST height column, i.e., the "tall column"

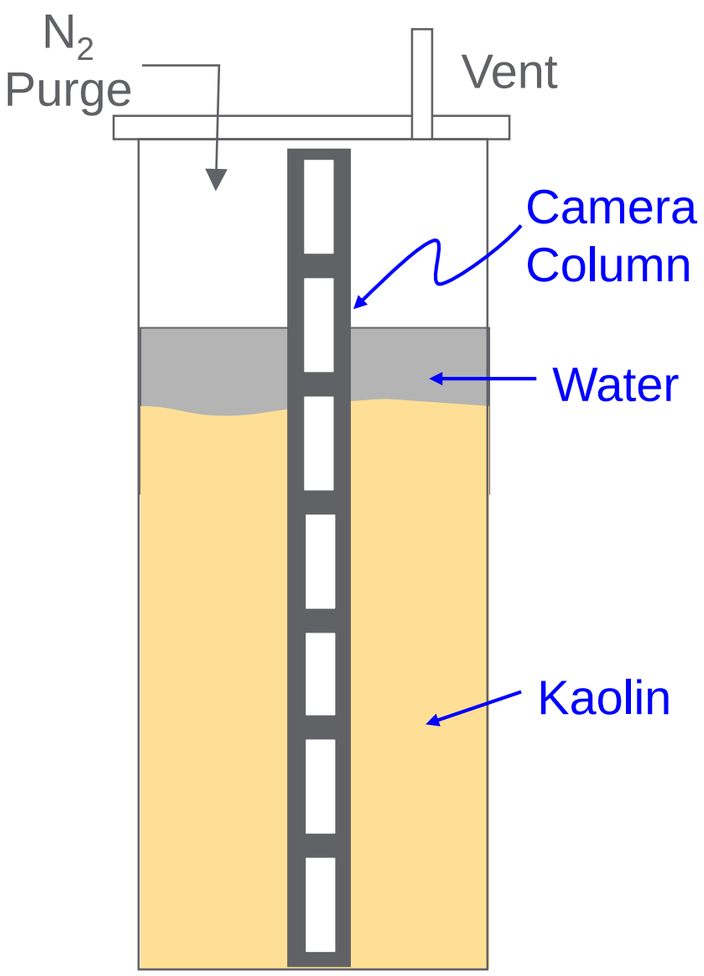
- Safety concern directly related to depth of waste
- Theoretical prediction based on fluid weight (density, gravity)
- Large enough diameter needed to minimize risk of unhelpful test



Tall column size

Tall Column: Method

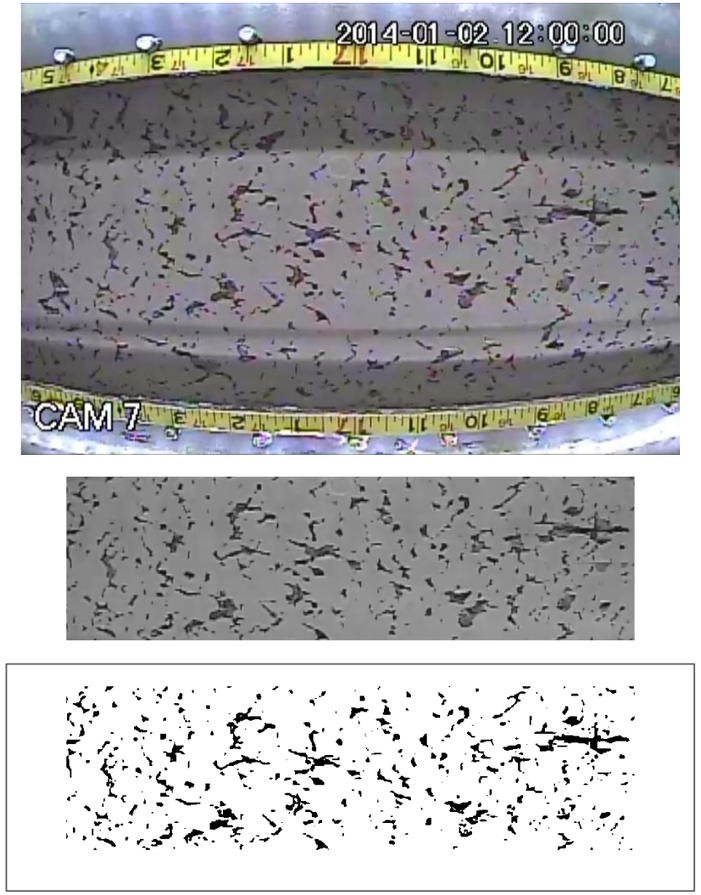




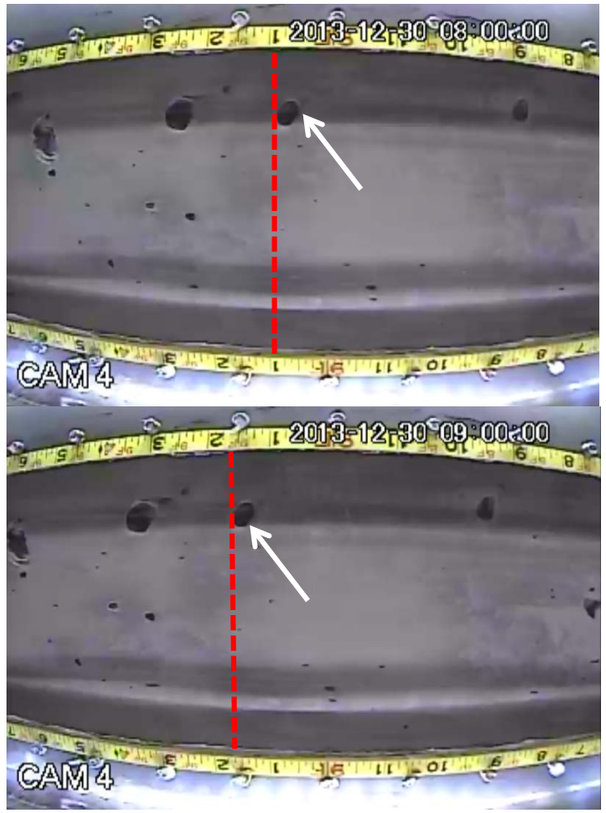
Tall Column: Testing Scale

Tall Column: Executing The Test

Tall Column: Measuring Gas Void in the Column



Void by image analysis

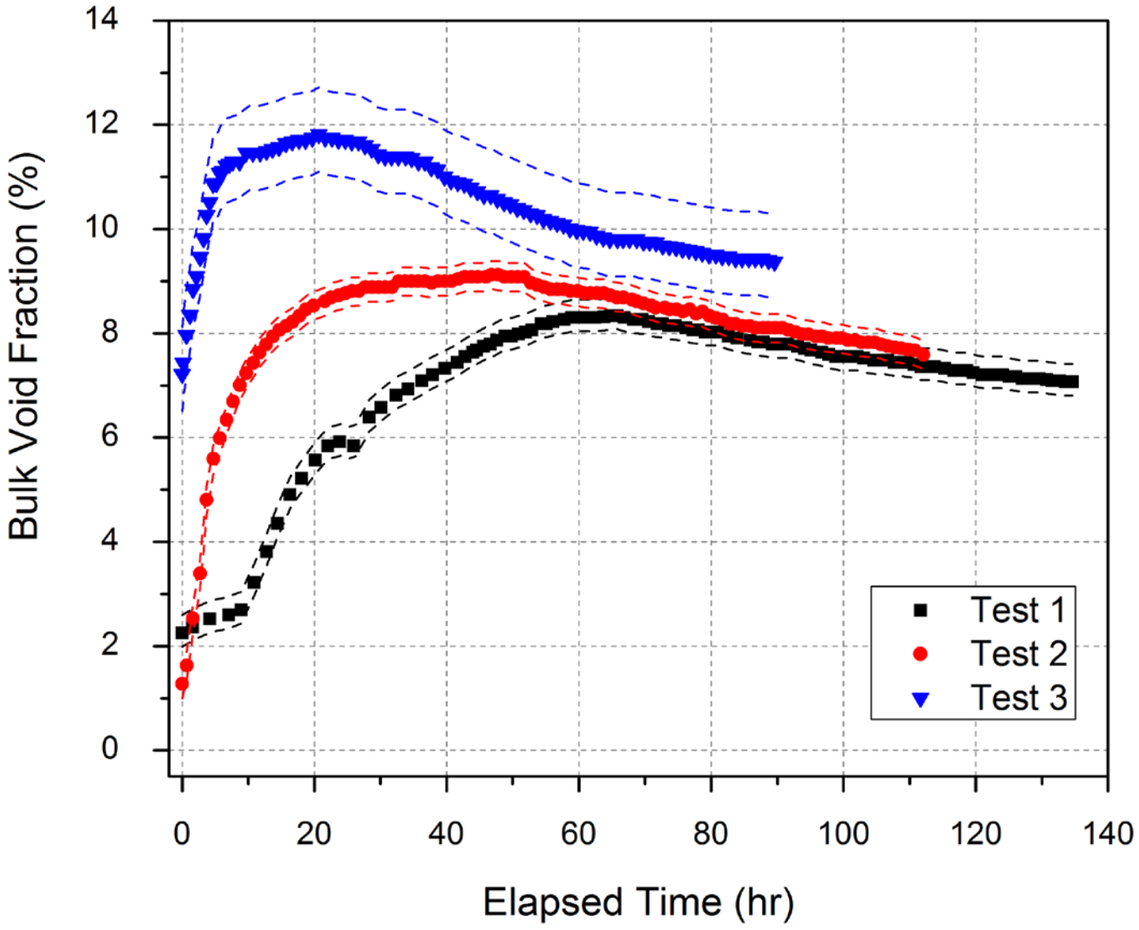


Void by feature tracking

Void by ultrasonic attenuation

Tall Column: What We Learned

- Gas generated within the clay simulant was transported from the lowest elevations to the surface
- Differences in bubble density and morphology were not observed between various elevations in the column
- All the empirical evidence suggests the d_{max} theory does not accurately describe the gas retention behavior
- Testing supplied Hanford with evidence to justify adding more waste to DSTs

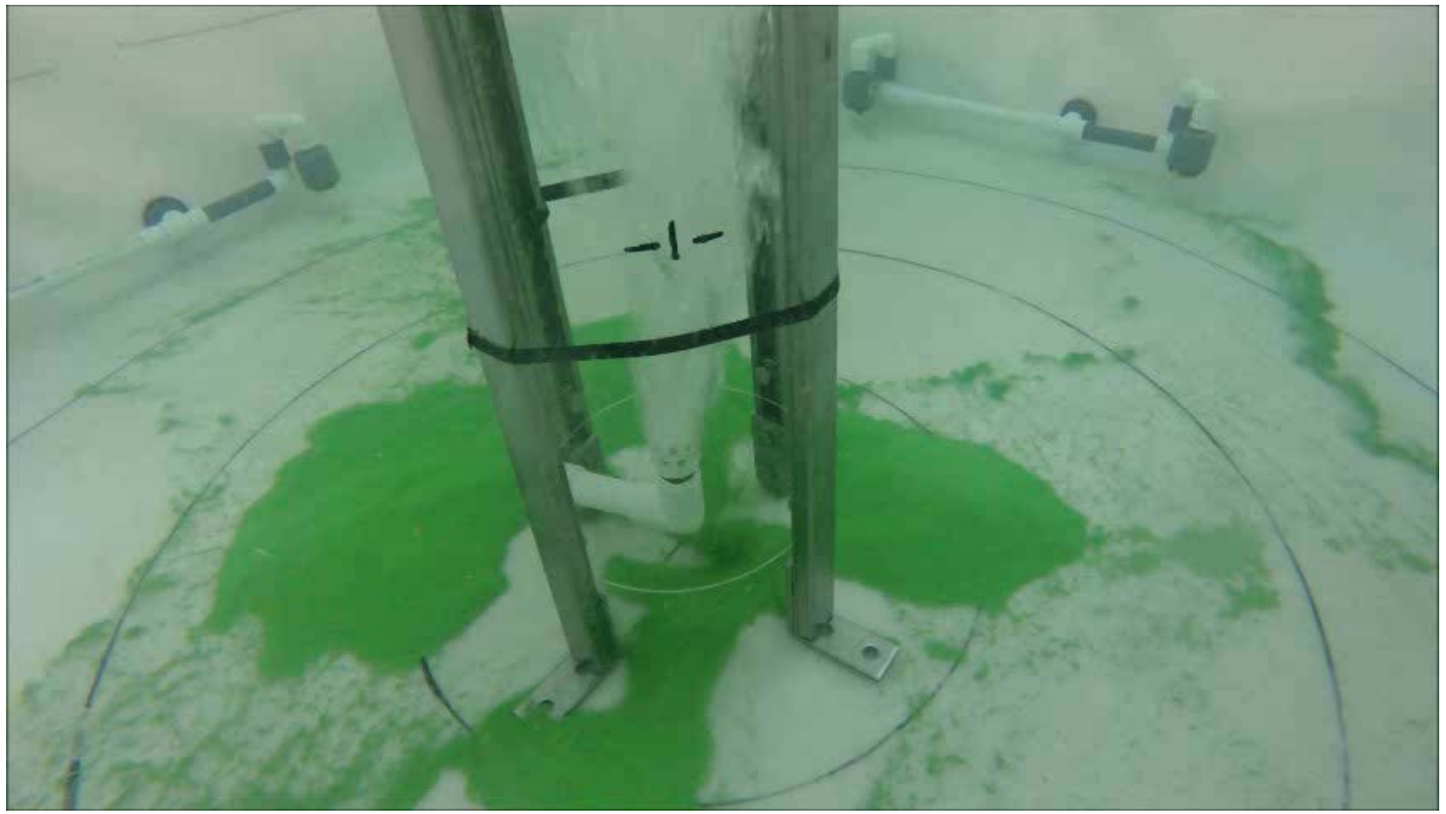


Summary

Testing with simulants to support Hanford operations is necessary

Some problems require testing at large scale to get answers

Testing at large scales is difficult, but also collaborative and fun



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THANK YOU!

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