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# Ultrasonic Instrumentation for Waste Feed Delivery Certification

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PNNL

**EM Waste Processing Technical Exchange**
November 16-18, 2010

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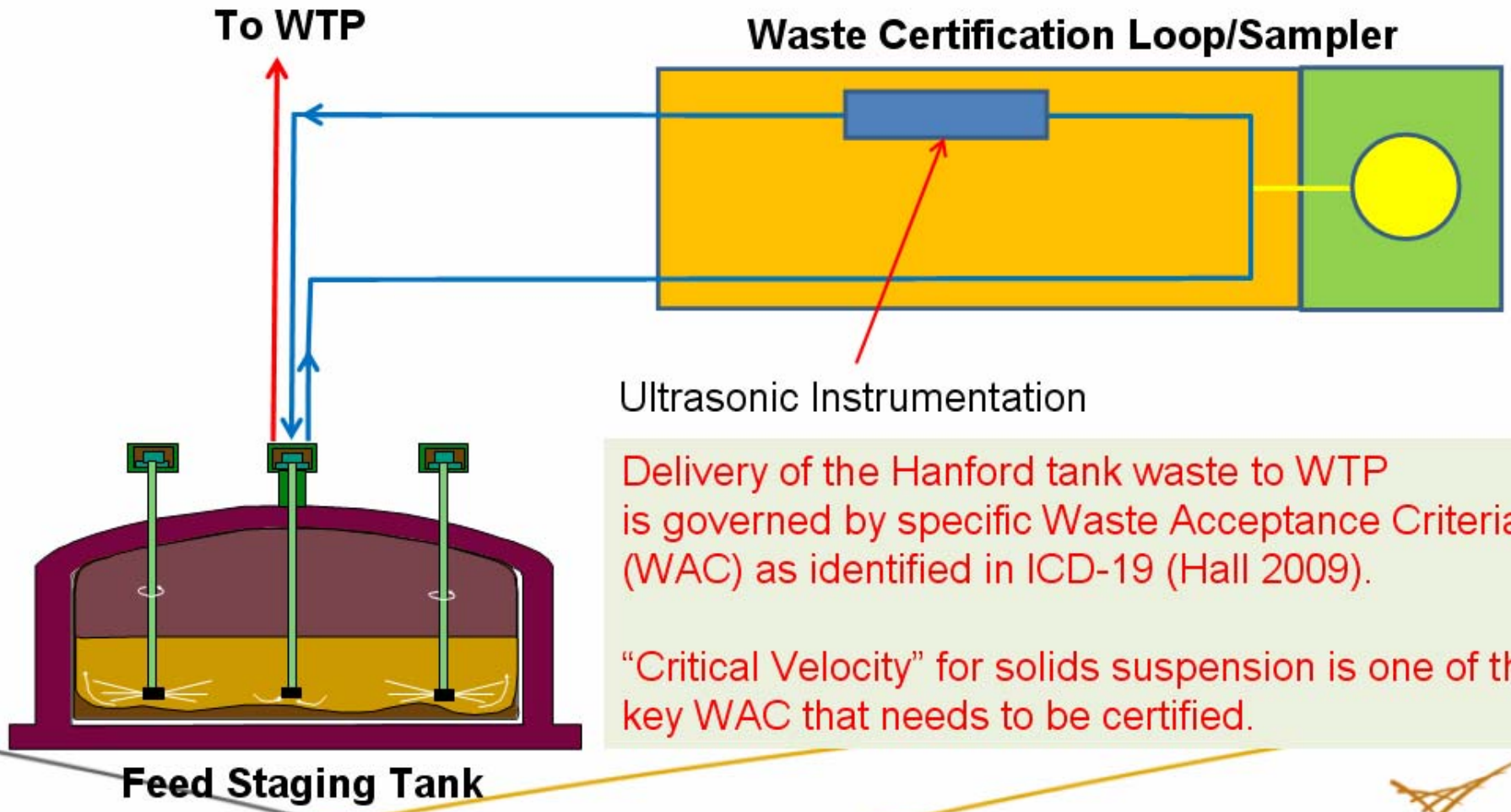
# Hanford Tank Farms - Feed Certification Strategy




Delivery of the Hanford tank waste to WTP is governed by specific Waste Acceptance Criteria (WAC) as identified in ICD-19 (Hall 2009).

"Critical Velocity" for solids suspension is one of the key WAC that needs to be certified.



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# Critical Velocity

***Critical velocity is one of the most significant WTP acceptance parameters identified in ICD-19***
***Currently only theoretically estimated and not measured***

$$v_{cr} = \sqrt{g\, d_p \left(\frac{\rho_s}{\rho_L} - 1\right)}\; 1.85 C_s^{0.1536} C_L^{0.3564} \left(\frac{d_p}{D}\right)^{-0.378} \left(\frac{D\rho_L \sqrt{g\, d_p \left(\frac{\rho_s}{\rho_L} - 1\right)}}{\mu_L}\right)^{0.09} \chi^{0.30}$$

Analytical Measurement

$d_p = median\ particle\ diameter, d_{50}$

$\rho_L = liquid\ density$

$\rho_s = solids\ density$

$C = solids\ volume\ fraction$

$C_L = liquid\ volume\ fraction\ (1 - C_s)$

$\mu_L = liquid\ viscosity$

$v_s = particle\ settling\ velocity$

Theoretical Estimate

$v_{cr} = critical\ velocity$

$\chi = eddy\ velocity\ factor$

Constant

$g = gravitational\ acceleration$

$D = pipe\ inside\ diameter$

**From RPP-5346**



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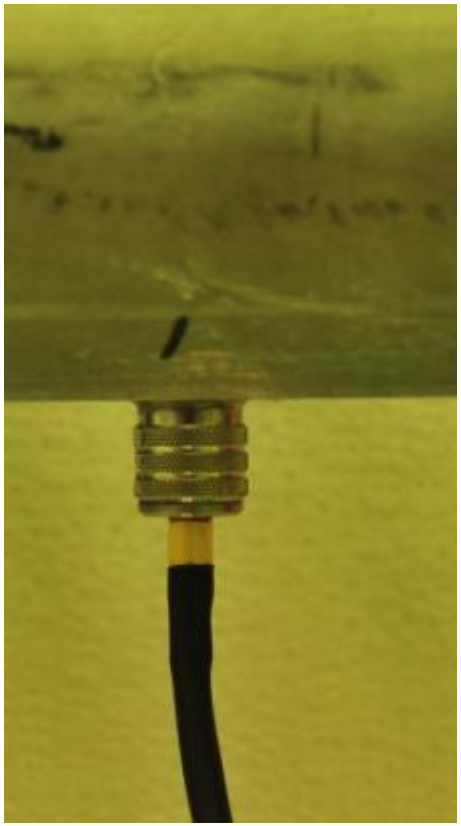
# Objectives

- Evaluate the performance of three ultrasonic instruments detecting "critical velocity" for solids settling using:
  - Prototypic transfer pipe size (3-inch, Sch. 40)
  - Simulants that encompass Hanford high-level waste feed properties with respect to densities, PSD, and rheological properties
- Instruments tested:
  - PulseEcho Ultrasound
  - Ultrasonic Doppler Velocimetry
  - Ultrasonic Attenuation
- Instrument Specification
  - Detection of particles > 50µm

# PulseEcho Ultrasound (PE)

- Detects onset of settling by measuring ultrasound signal amplitude modulation caused by particle movement





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# Ultrasonic Doppler Velocimetry (UDV)

- Detects onset of settling by measuring velocity of particles within the pipe cross-section

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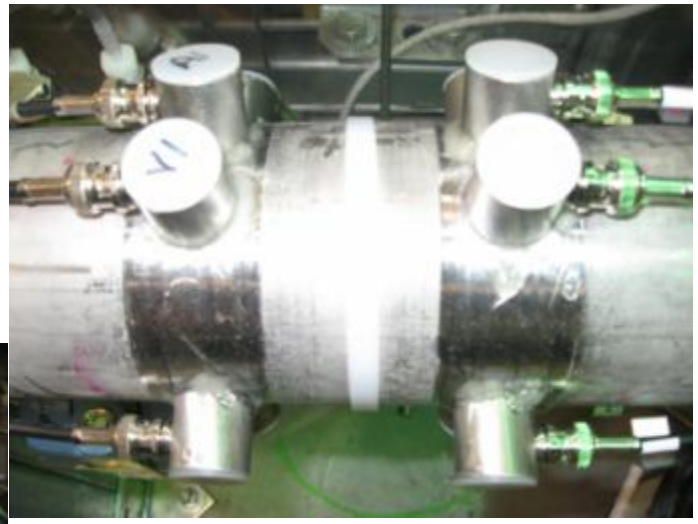
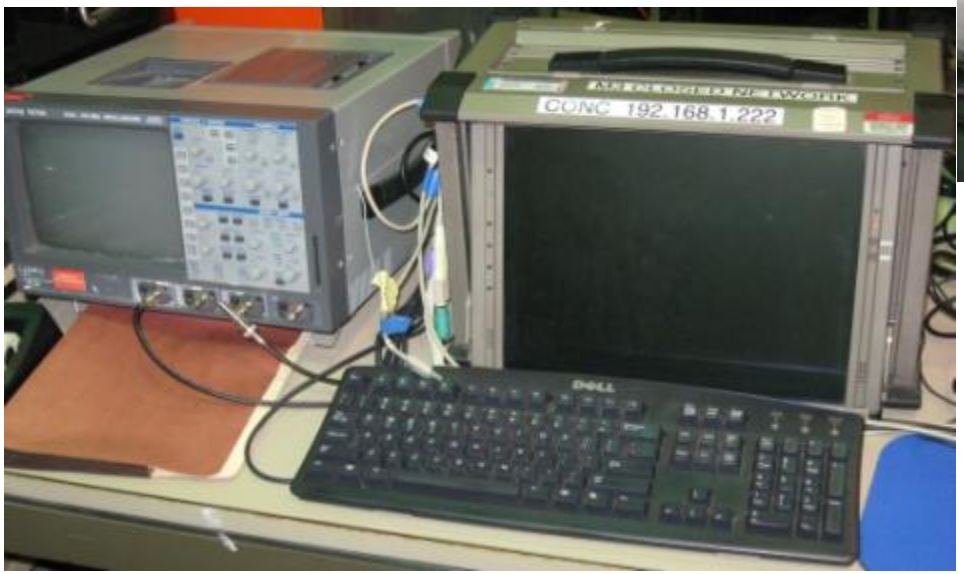
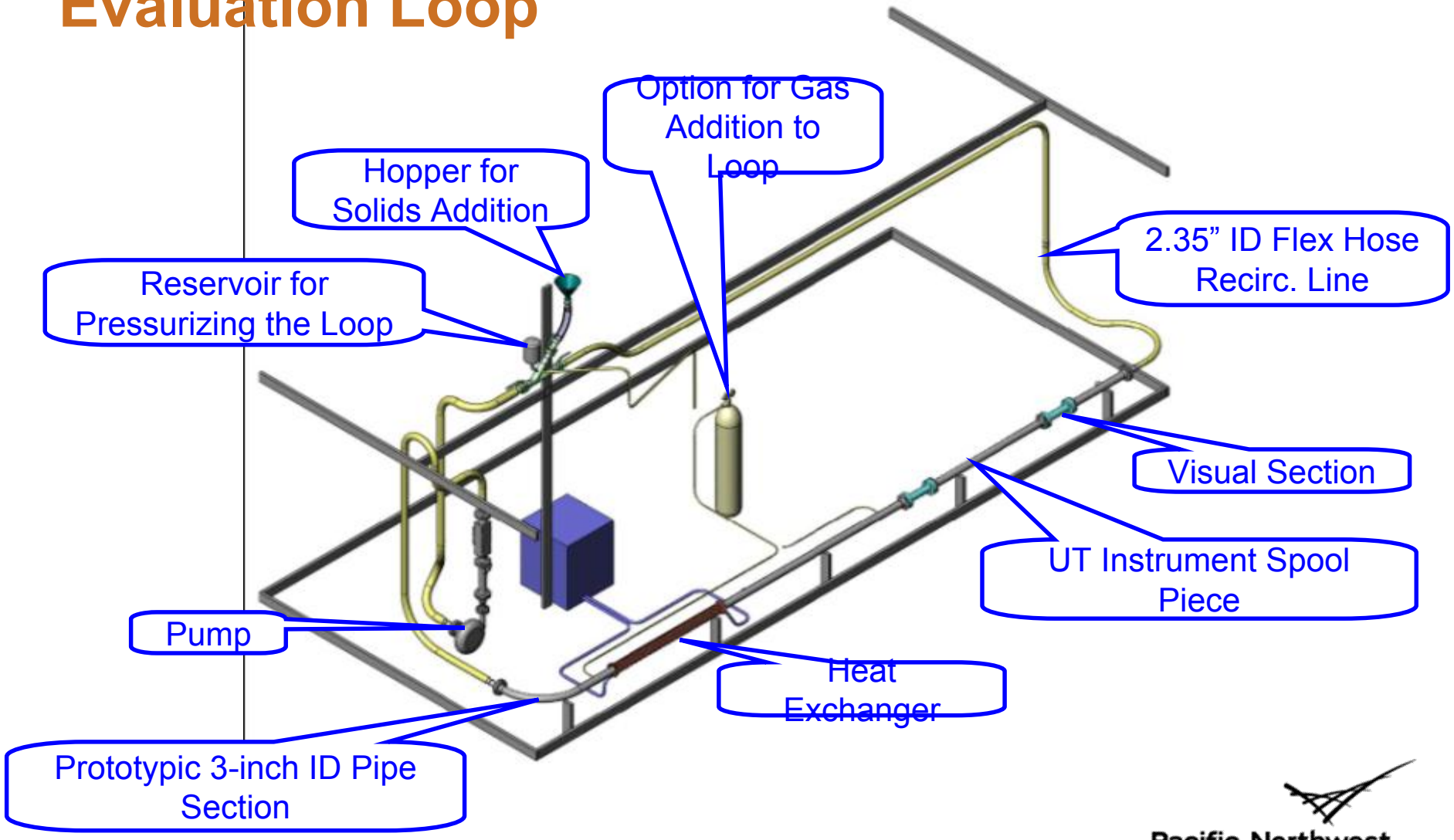
# Ultrasonic Attenuation (UA)

- Detects onset of settling by measuring the attenuation of the ultrasonic signal in the pipe cross-section





# PNNL's Material Transport Evaluation Loop



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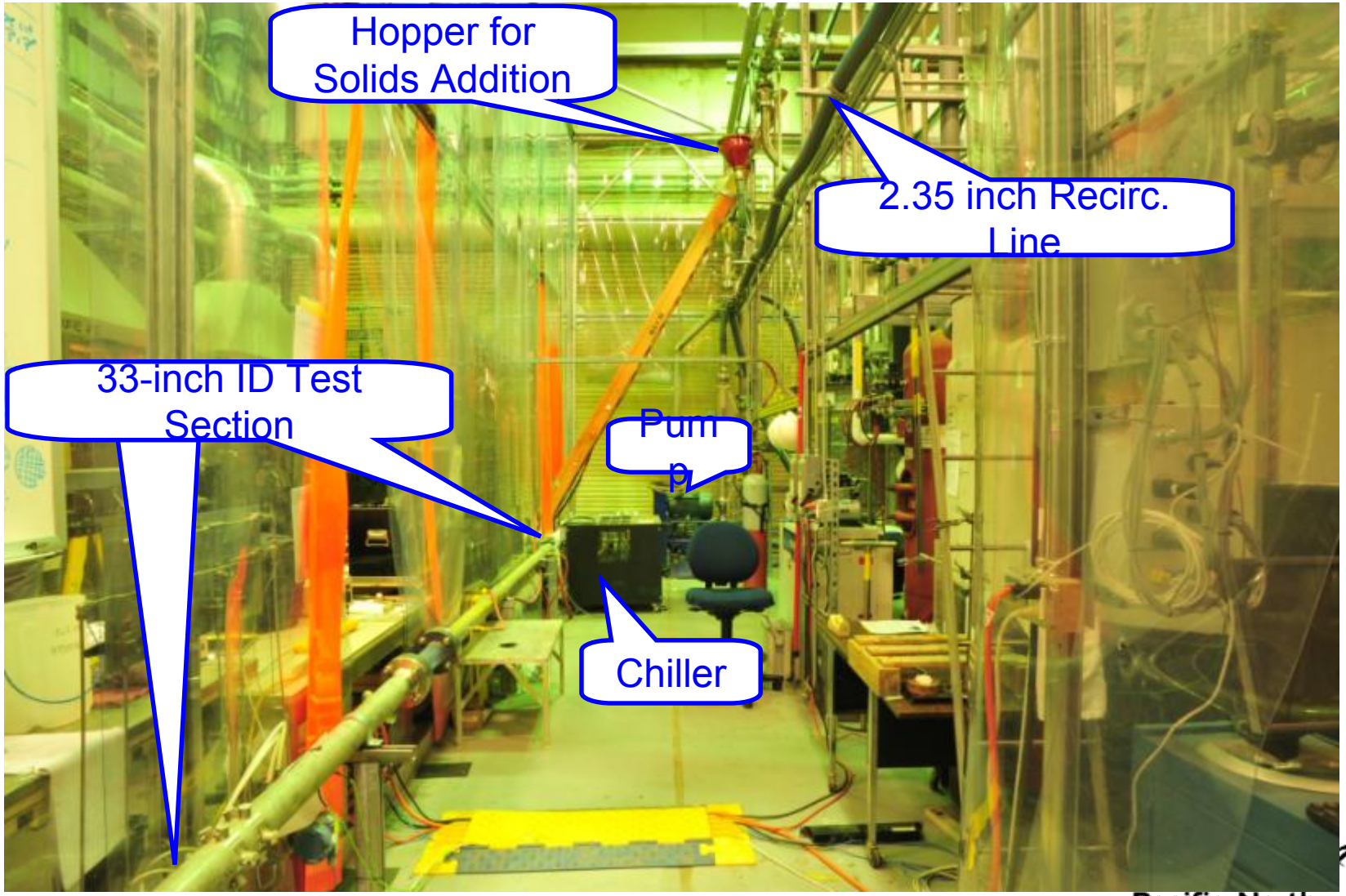
# PNNL's MTE Loop, contd.



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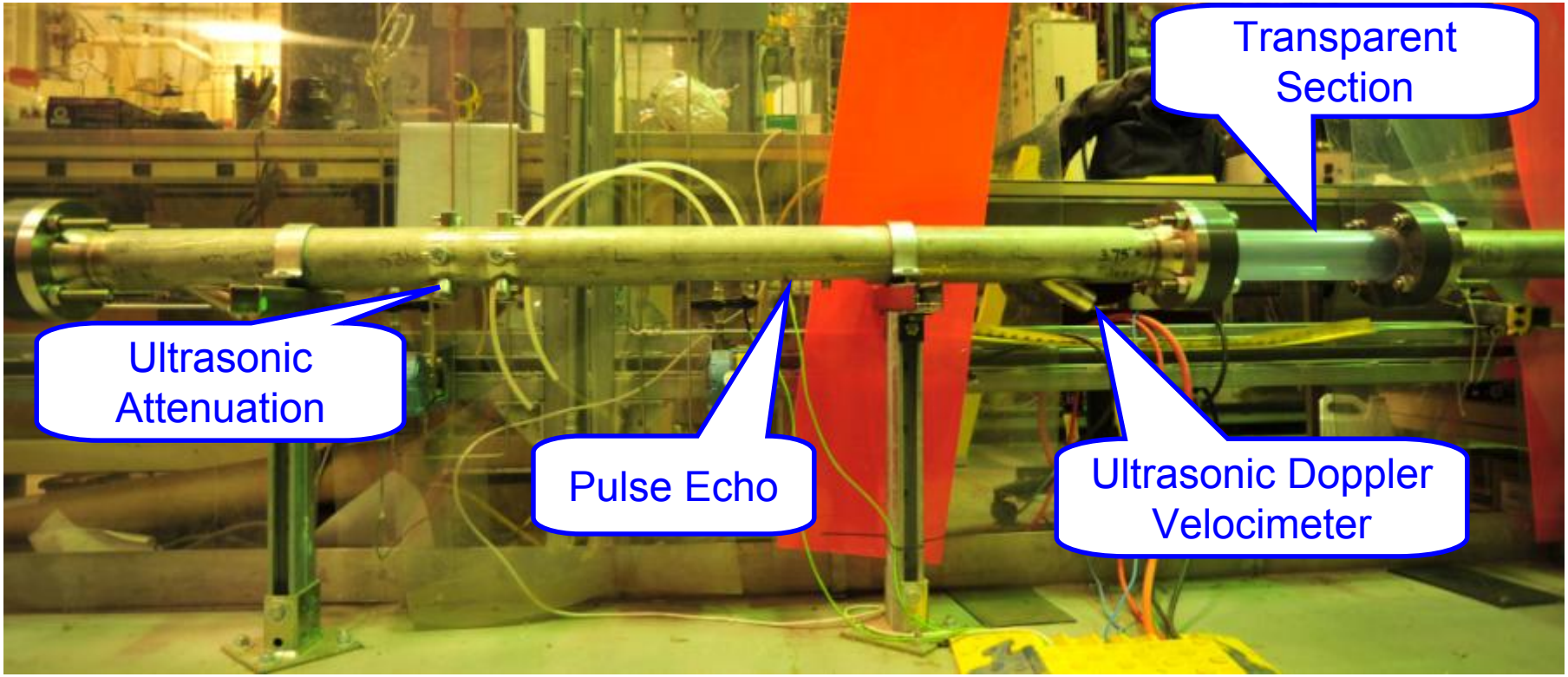
# Instrument Spool Piece



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# Simulants Tested

- Carrier Fluid Property Range
  - Density (1 – 1.25 g/cm$^3$)
  - Viscosity (1 – 11.7 cP)
  - Yield Stress (0 – 11 Pa)
- Solid Property Range
  - Density (2.5 – 4.2 g/cm$^3$)
  - PSD (1 – 500 µm)
  - Wt% (5 – 20%)
- Simple Newtonian
  - Narrow PSD
  - Broad PSD
  - Binary Size
  - Binary Density
  - Binary Density Broad PSD
- Non-Newtonian
  - Mono Dispersed
  - Broad PSD
  - Complex



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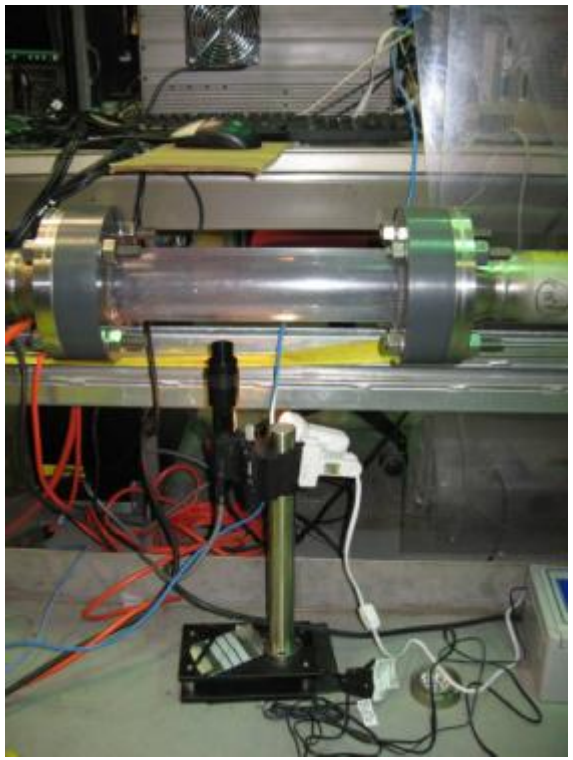
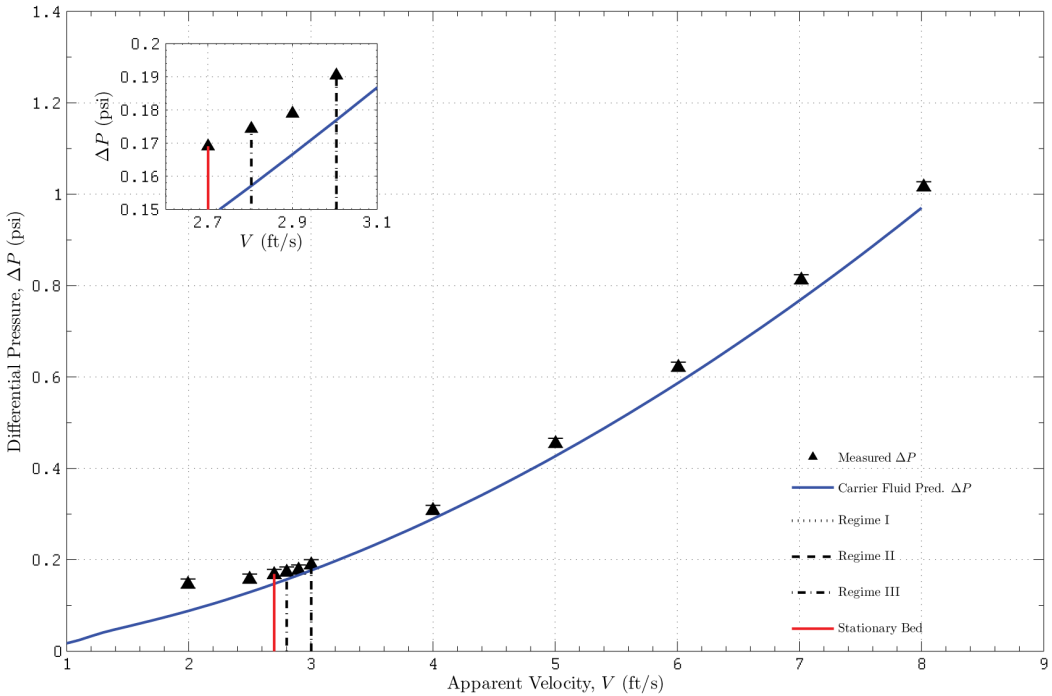
# Experimental Approach

- Add simulant to loop
- Mix contents at high velocity (8 ft/sec)
- **Coarsely identify the region of critical velocity** was by decreasing the fluid velocity in steps of 1 ft/sec until a stationary bed was observed.
- **Precisely determine critical velocity** by zooming into the region where the settled bed was observed at 0.1 – 0.2 ft/sec steps
- At each velocity:
  - Wait until steady state in $\Delta P$ and $\rho$ are noted
  - Visually observe the solids flow behavior and a stationary bed formation
  - Record data from the three sensors

# Exp. Approach – $U_{crit}$ with Ref. Methods

- High Resolution Video
- $\Delta$P Measurement





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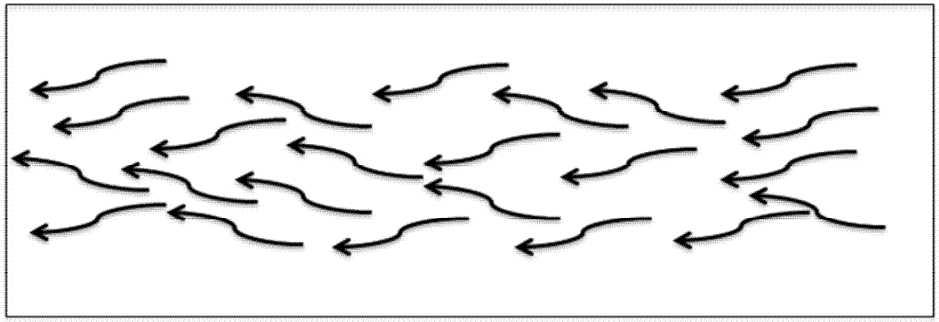
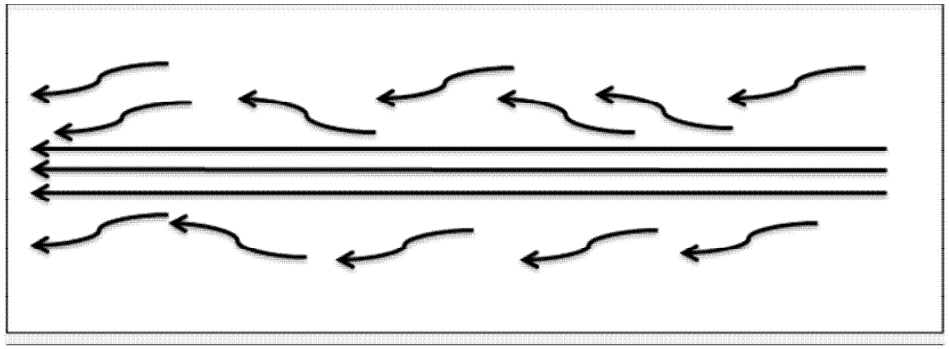
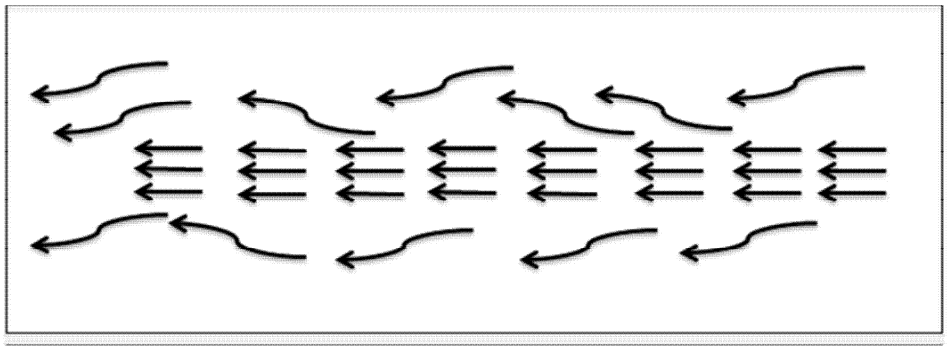
# Flow Observed Regimes Near Critical Velocity



Regime I – Chaotic Motion

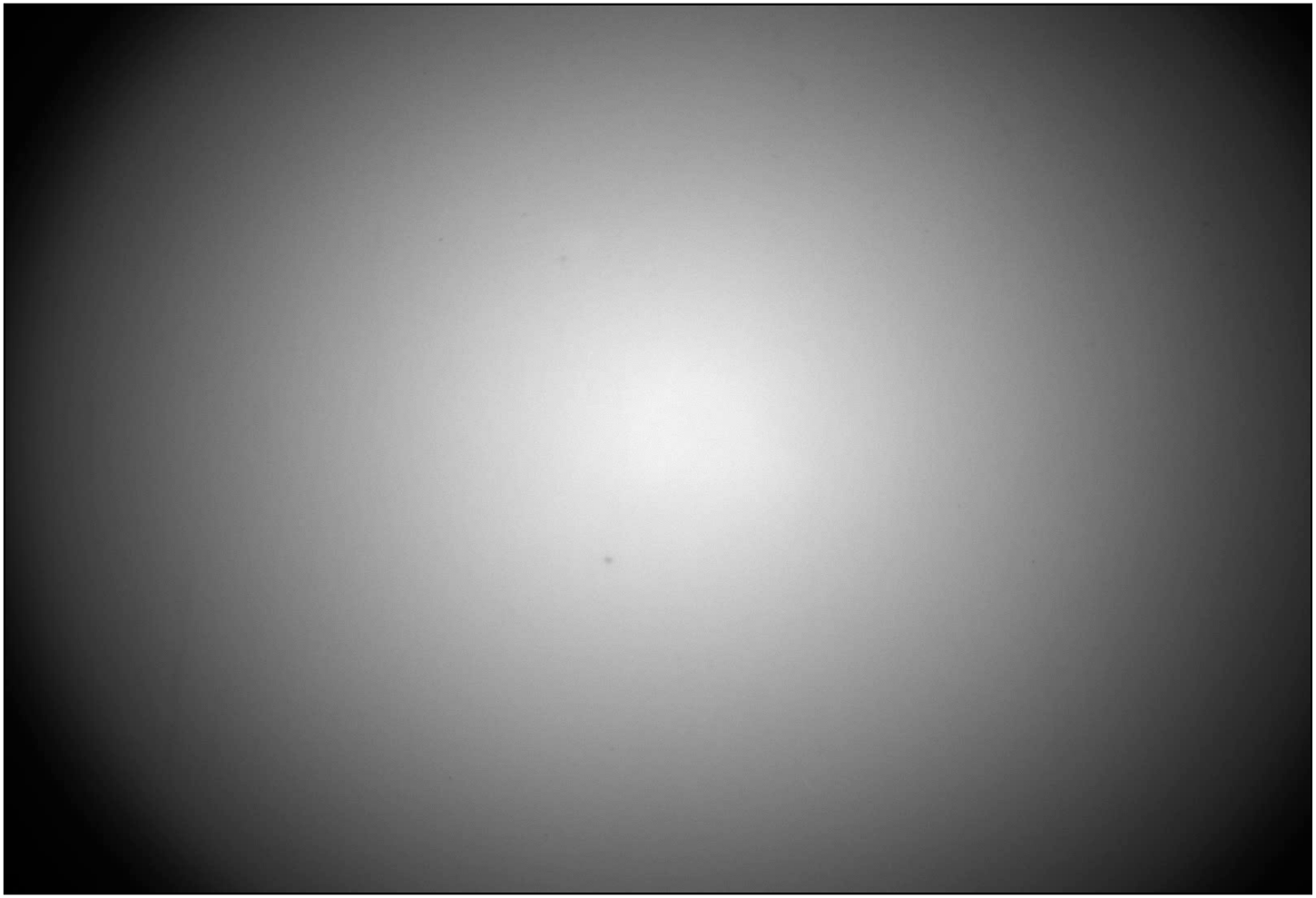
Regime II – Focused Axial Motion





Regime III - Pulsating Bed

# $U_{crit}$ Using High Resolution Video



Bimodal distribution with 65 and 170 µm, 2.5 g/cm$^3$ particles @ 4.0 ft/s

**Click on Photo Above to Play Video.**

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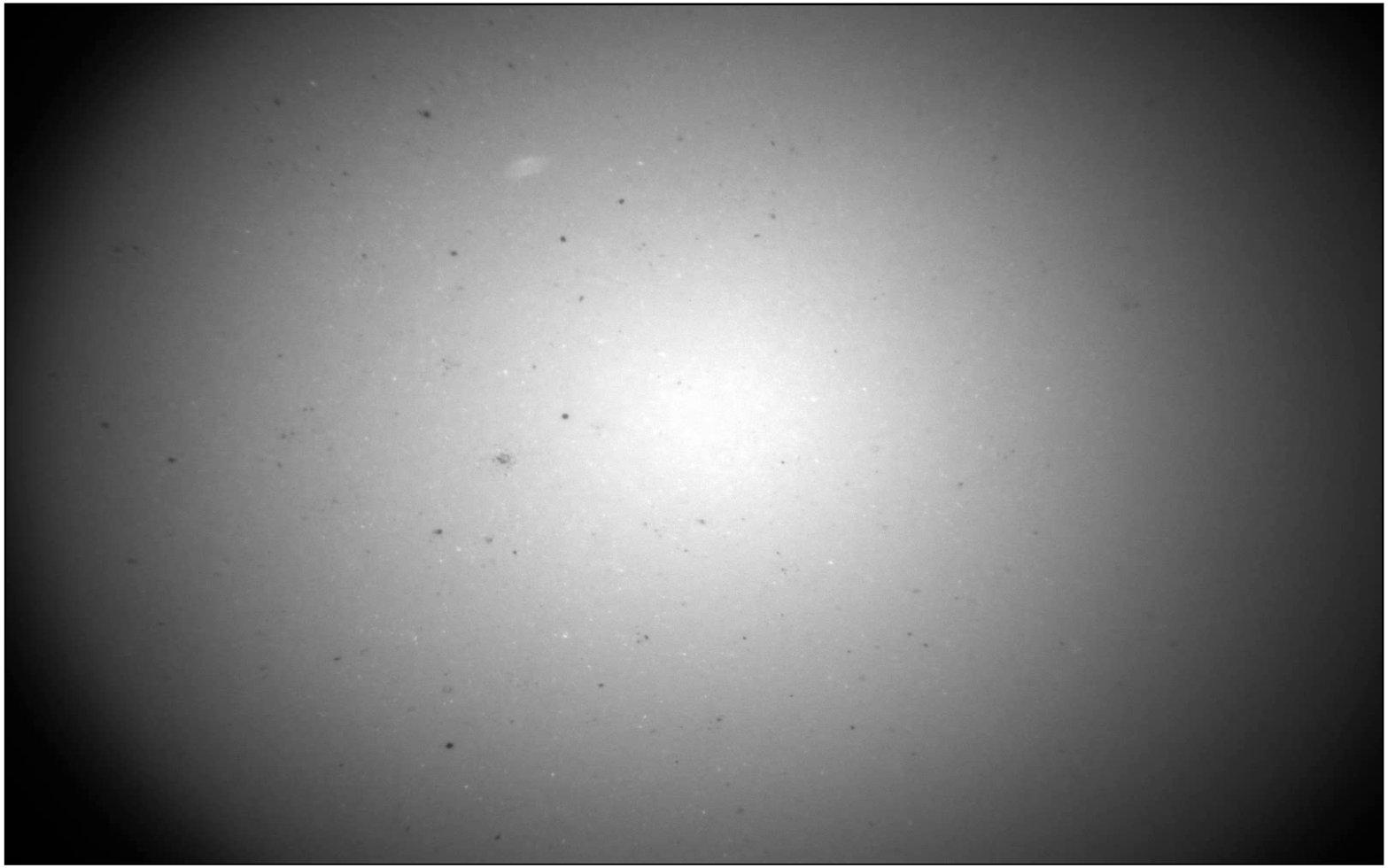
# $U_{crit}$ Using High Resolution Video



Bimodal distribution with 65 and 170 µm, 2.5 g/cm$^3$ particles @ 3.2 ft/s

**Click on Photo Above to Play Video.**

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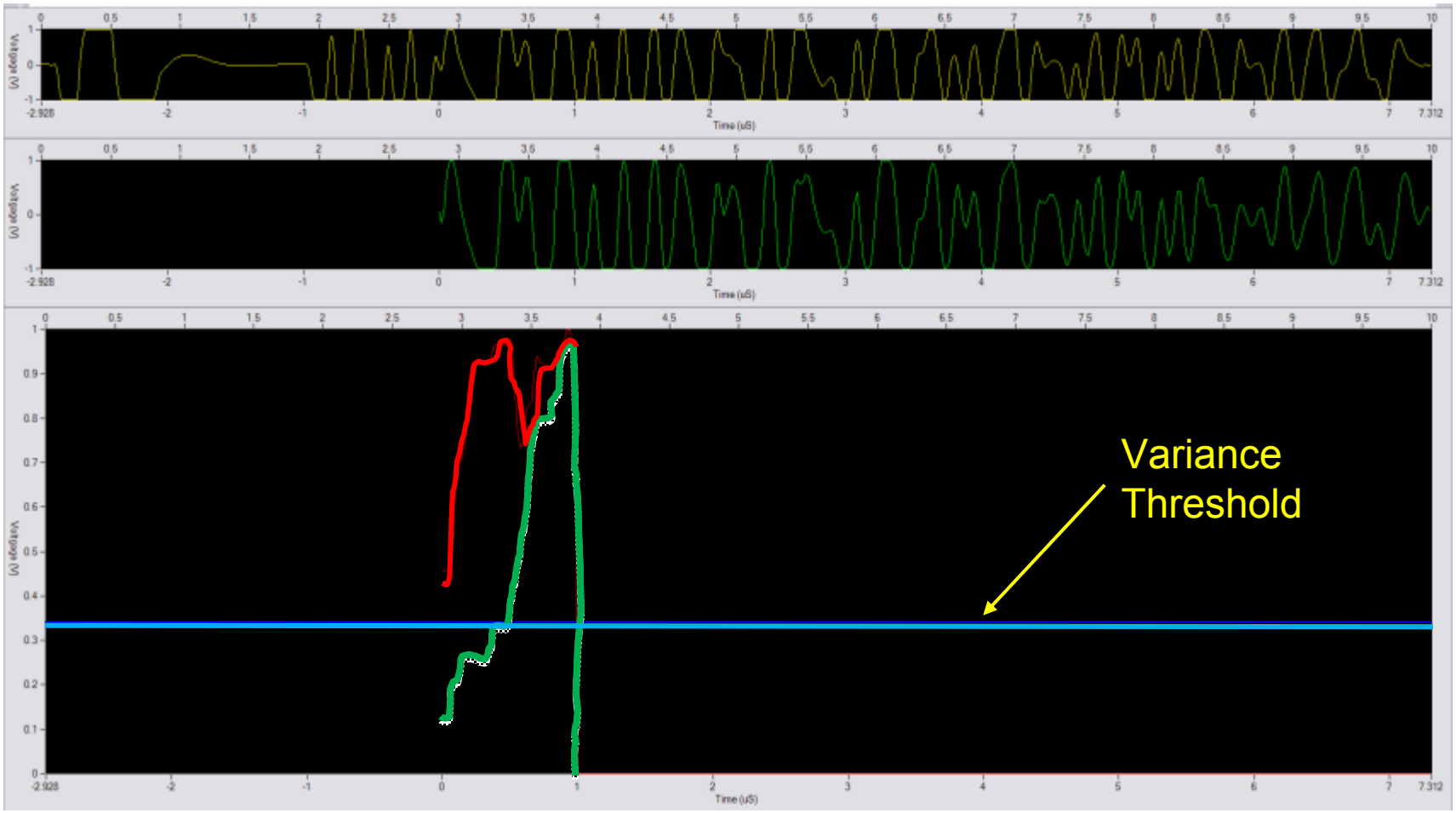
# Exp. Approach - $U_{crit}$ With PE



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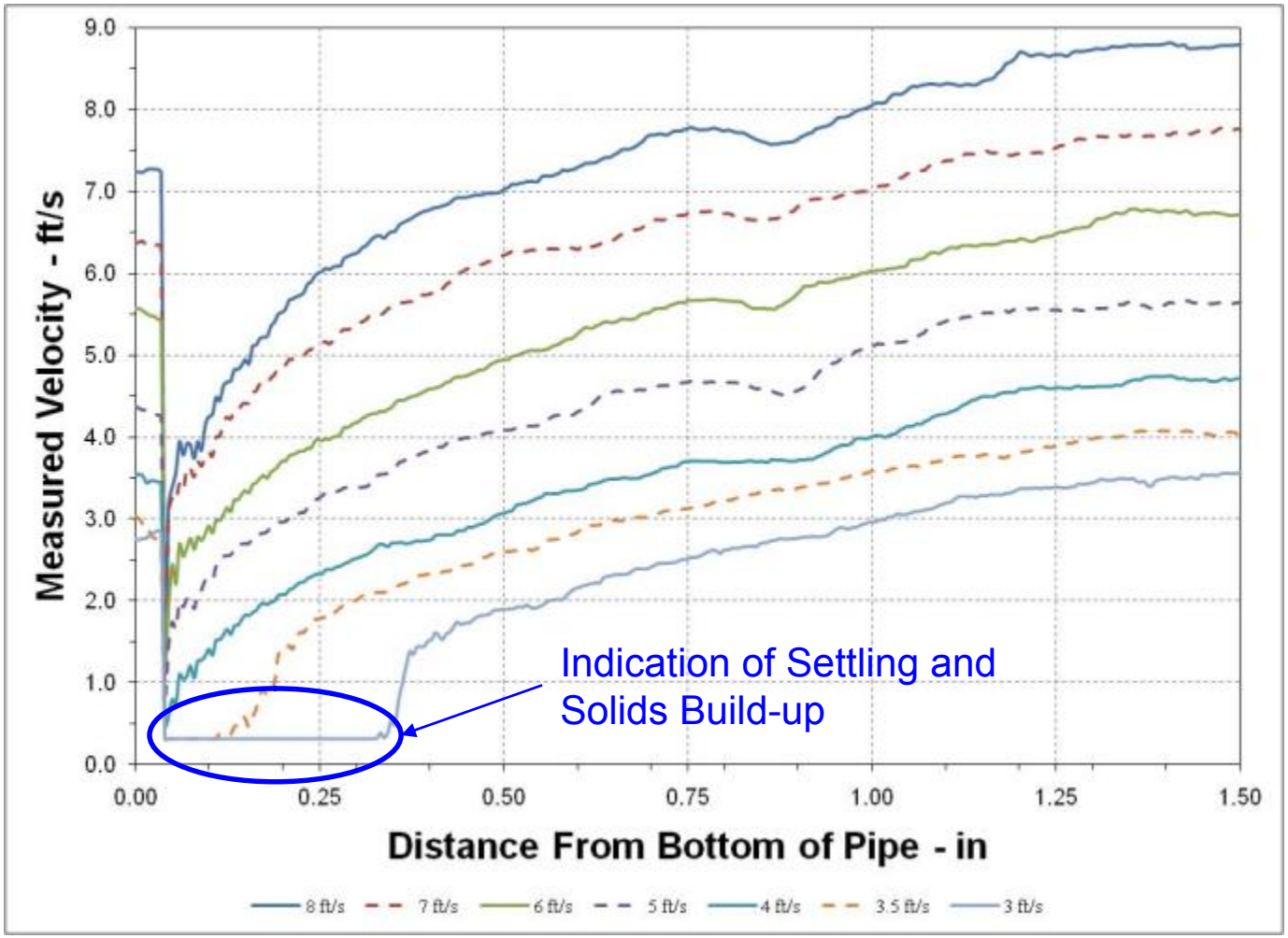
# Exp. Approach – $U_{crit}$ With UDV



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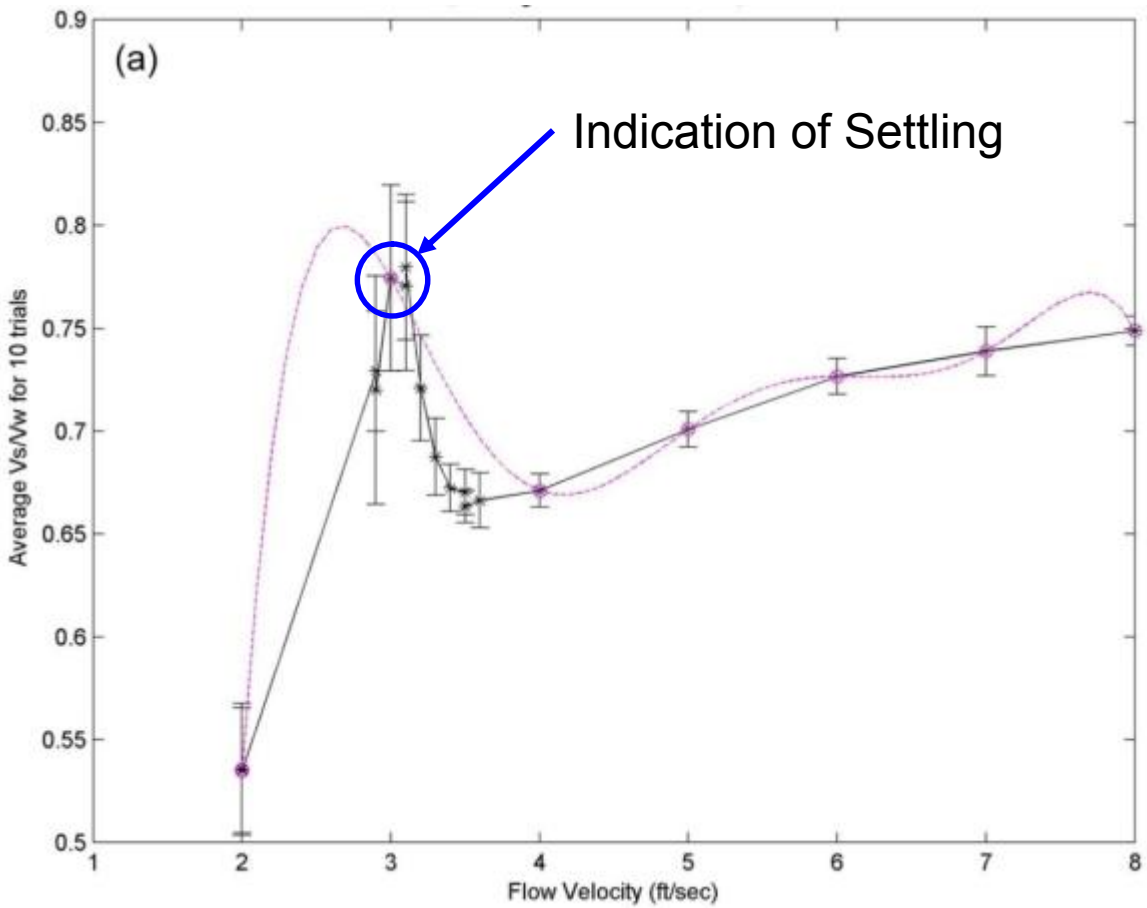
# Exp. Approach – $U_{crit}$ With UA



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# Results

| Newtonian Simulant Tests | | | | |
|---|---|---|---|---|
| Test | Exp. $U_{crit}$ | PE | UDV | UA |
| 1 | 2.4 | 2.4 | 2.4 | N/A |
| 2 | 2.55 | 2.65 | 2.65 | N/A |
| 3 | 4.2 | 4.1 | 4.3 | 5.0 |
| 4 | 3.3 | 3.3 | 3.3 | 4.5 |
| 5 | 4.0 | 4.1 | 4.1 | 4.2 |
| 6 | 3.9 | 3.9 | 4.1 | 4.1 |
| 7 | 2.7 | 3 | 2.8 | 2.4 |
| 8 | 2.35 | 2.35 | 2.35 | 2.1 |
| 9 | 3.1 | 3.5 | 3 | 3.0 |
| 10 | 4.1 | 4.5 | 4.1 | 4.1 |
| 11 | 3.8 | 4.1 | 3.8 | 3.6 |
| 12 | 2.7 | ~2.6 | >2.0 & < 2.5 | 2.6 |
| 13 | 4.6 | 4.9 | >4.0 & <4.6 | 4.3 |
| 25 | 3.7 | 4 | 3.8 & 3.9 | N/A |

# Results, Contd.

| Non-Newtonian Simulant Tests | | | | |
|---|---|---|---|---|
| Test | Exp. $U_{crit}$ | PE | UDV | UA |
| 15 | 2.1-2.3 | 2.1 | 2.1 | N/A |
| 16 | 2.6-3.0 | 3.2 | 3.2 | N/A |
| 17 | 3.6 | 4.1 | 3.6 | 4.2 |
| 18 | 3.0 | 3.3 | 3 | 2.8 |
| 19 | 0.2 | 0.5 | 1 | 0.4 |
| 20 | <1.0 | 1.5 | 1.5 | 1.2 |
| 21 | 3.1-3.3 | 3.2 | 3.1 & 3.2 | 2.8 |
| 22 | 3.1-3.3 | 3.3 | 3.3 | 3.3 |
| 23 | 3.6-3.8 | 3.9 | 3.9 | 4.4 |
| 24 | 4.1-4.7 | 4.3 | 4.6 | 4.4 |

# Conclusions

- The performance of three ultrasonic instruments was evaluated for applicability to detect critical velocity during Hanford waste transfers
- Pulse Echo and UDV systems performed exceptionally well
  - In most cases the measured $U_{crit}$ is within $\pm 0.1$ ft/sec of the experimentally determined values
- Ultrasonic Attenuation system performance was good but interpretation of data was difficult
- Both PE and UDV are recommended for further evaluation and consideration for field deployment
  - PE system **is the preferred** because of simplicity of design but can yield false indications at low concentration of solids (i.e. concentration of solids in detectable size range of > 50 μm)
  - UDV system is not limited by solids concentration but requires additional design features as the sensor installation requires breaching the pipe

# Acknowledgements


**PNNL Key Contributors**

- Kayte Denslow (PE)
- Gerald Morgen (UDV)
- Margaret Greenwood (UA)
- Harold Adkins
- Jeromy Jenks
- Carolyn Burns
- Phil Schonewill

**WRPS**

- Mike Thien
- Ted Wooley

# QUESTIONS?

# Contact Information

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# BACK-UP SLIDES



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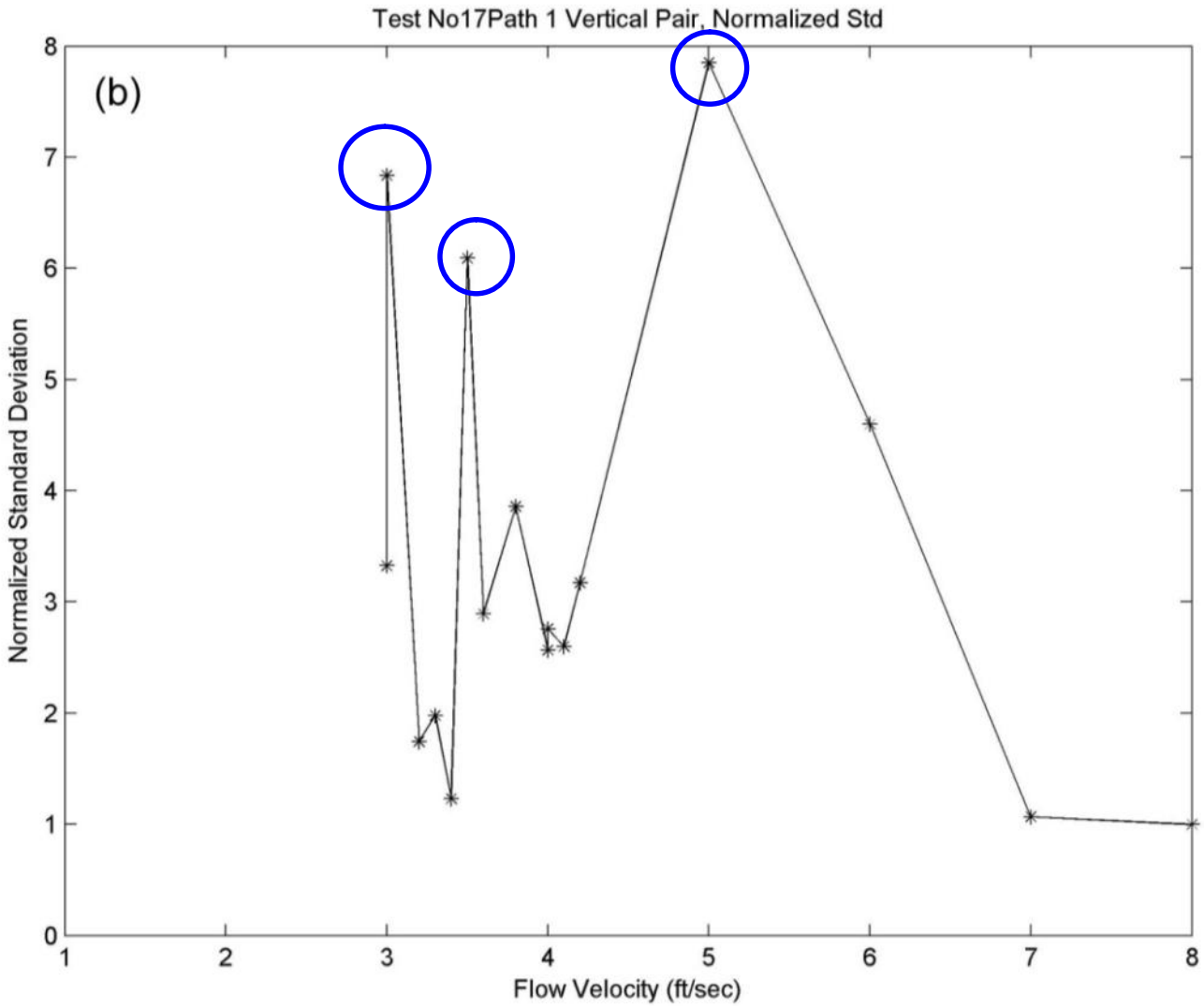
# UA Data



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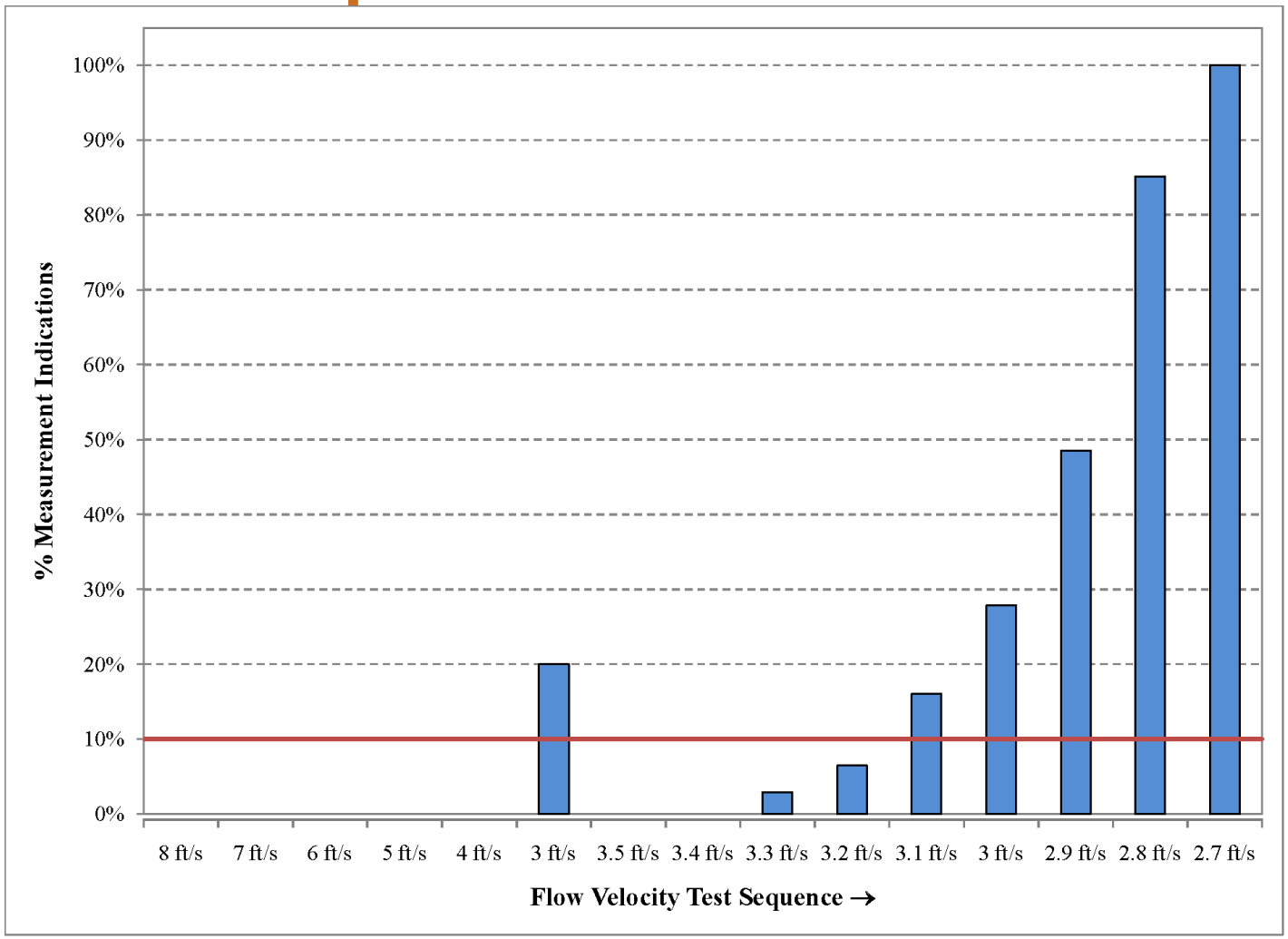
# PE Data at Moderate Concentrations of Particles > 50 µm



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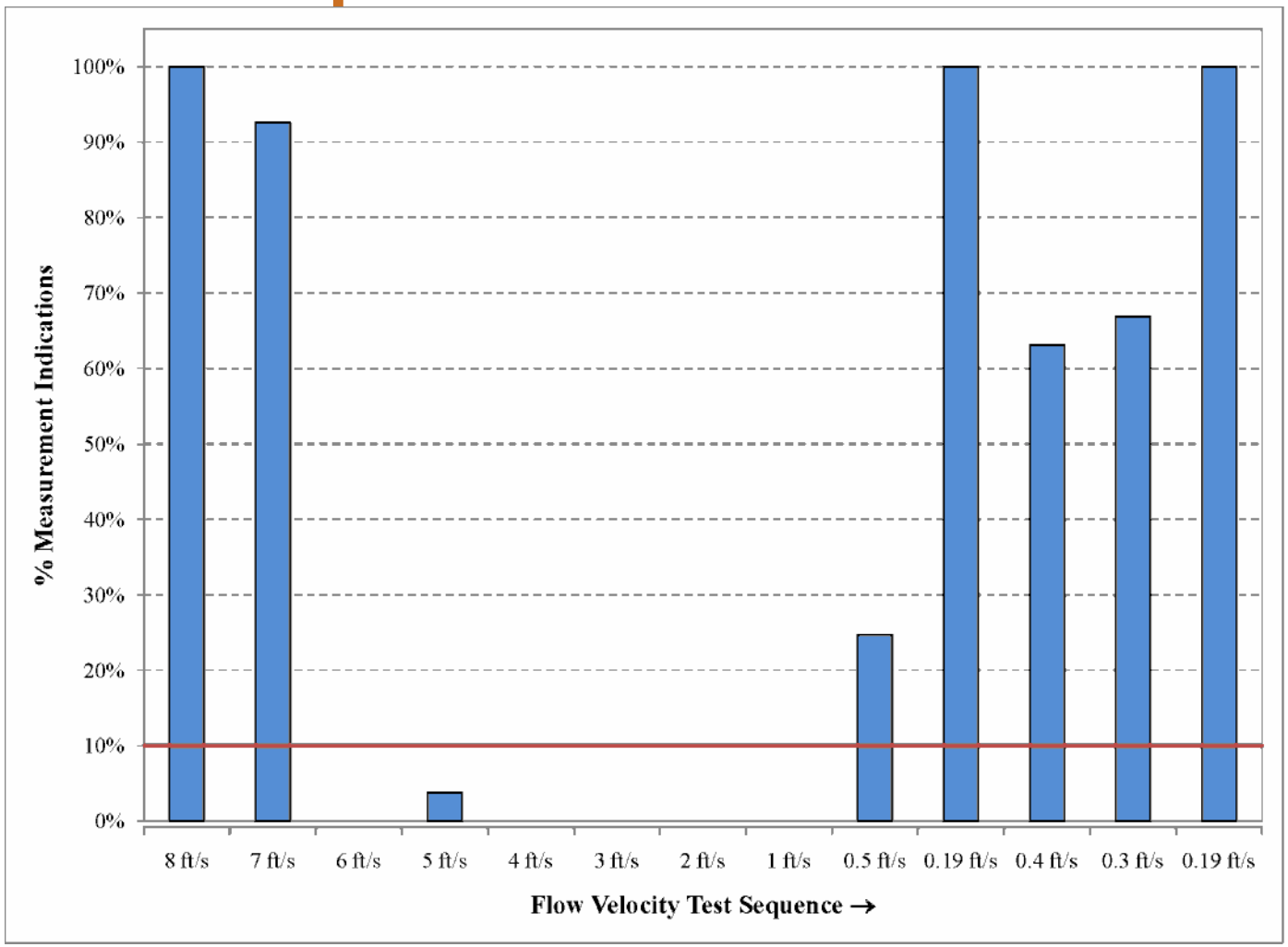
# PE Data at Moderate Concentrations of Particles > 50 µm



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