# Ultrasonic Liquid Characterization
## *Container Screening Device (CSD)*

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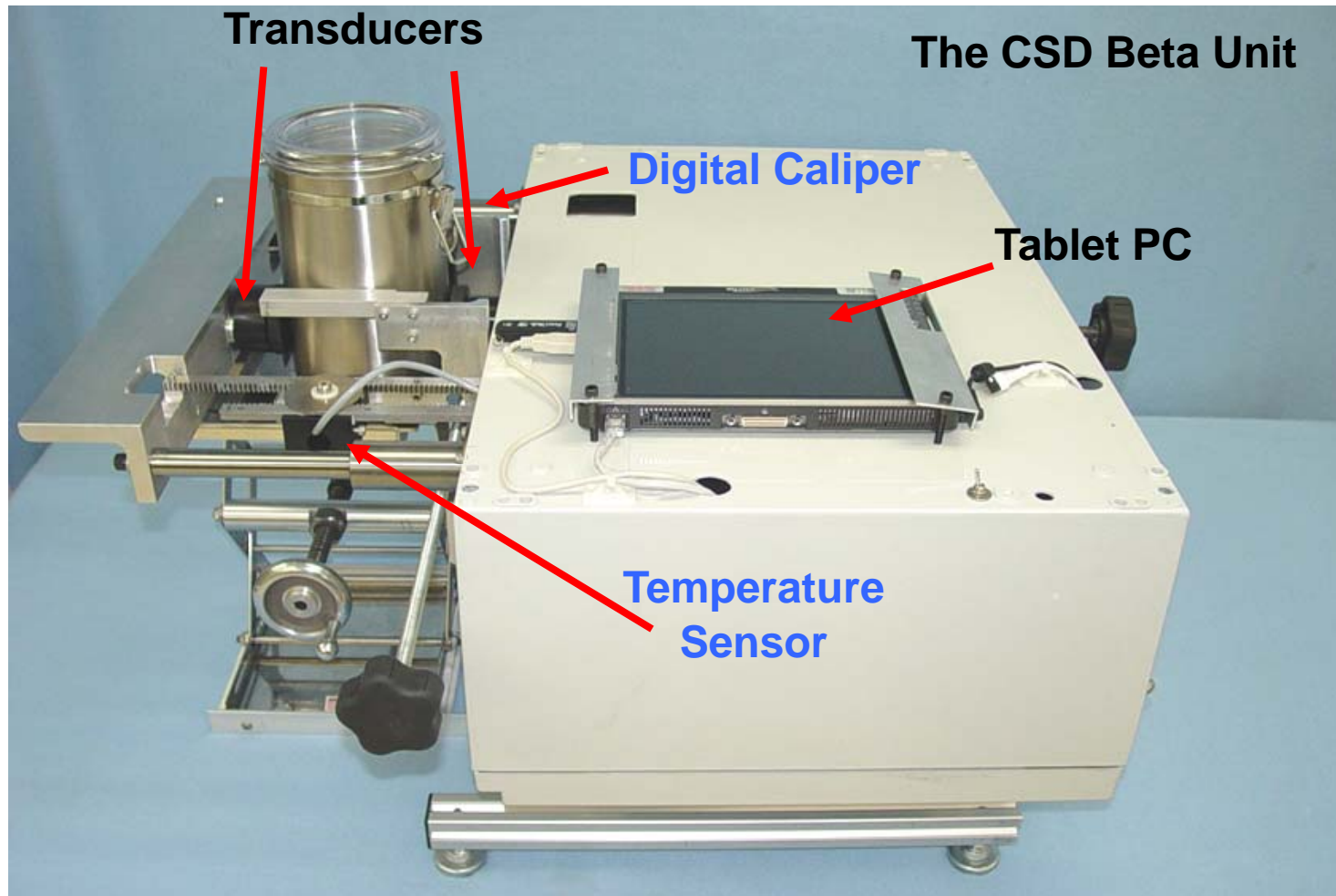Phone: 509-375-2606    Email: aaron.diaz@pnl.gov

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# **Topics of Discussion**

➢ **Introduction**
  ▪ **Historical Background**
➢ **Description of the Technology**
  ▪ **Principles of Operation**
  ▪ **Capabilities and Functionality**
➢ **Applications**
  ▪ **Other Embodiments**
➢ **Advantages of Ultrasound**
➢ **Recent Activities with CSD**
➢ **Estimated Manufacturing Costs**
➢ **Conclusions and Future Work**



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# The CSD Prototype (PNNL Version)



The CSD Beta Unit

Transducers

Digital Caliper

Tablet PC

Temperature Sensor

US Patent #7,246,522 issued in July, 2007

# Introduction

- ➢ **Driven by FBI, DHS, DoD and DoJ**
  - ▪ **Border and Transportation Security**
  - ▪ **Security at High Profile Venues and Events**
  - ▪ **Emergency Preparedness and Response**
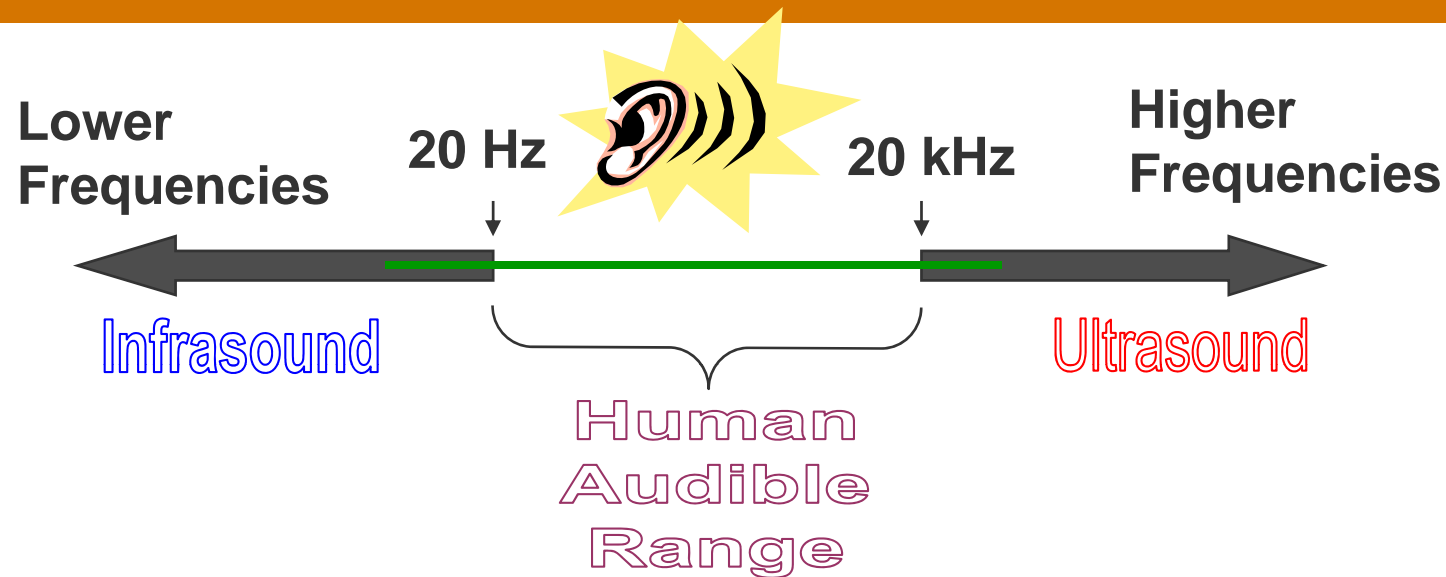  - ▪ **Vulnerabilities to Liquid-Based Homemade Explosives (HMEs)**

- ➢ **The CSD addresses container screening for liquid threats (chemical weapons agents, liquid explosives, precursors, etc.)**

- ➢ **An effective acoustics-based approach offers a non-invasive, nondestructive method for screening or characterizing liquids rapidly and reliably.**

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# Introduction
# (Historical Background)

- ▶ Dr. Brian Eckenrode, FBI

- ▶ Counter-terrorism and Forensic Sciences Research Unit (CFSRU)

- ▶ Funding for the initial development effort was coordinated with others at the FBI in the Hazardous Materials Research Unit (HMRU)

- ▶ Initial project was funded for two years from 2004-2005 and again in 2005-2006

- ▶ Internal Battelle investment has also been made

- ▶ Currently the FBI has the initial prototype device and are testing it at FBI Academy Labs in Quantico, VA.

# Description of the Technology

Lower Frequencies

20 Hz

20 kHz

Higher Frequencies

**Infrasound**

**Ultrasound**

**Human Audible Range**

**Measured Characteristics**

- Path Length (Distance)
- Echo Detection
- Time of Flight/Temperature
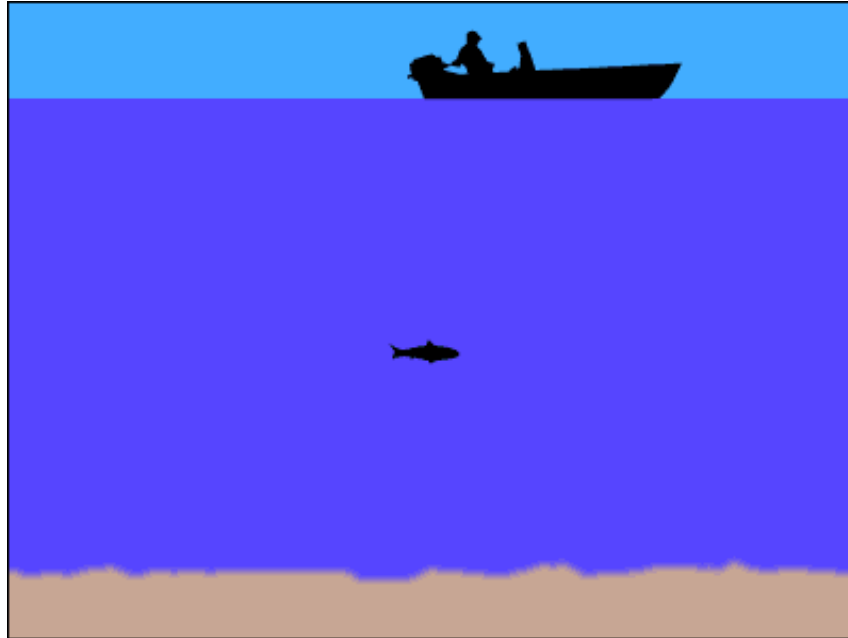- Signal Amplitude/Phase
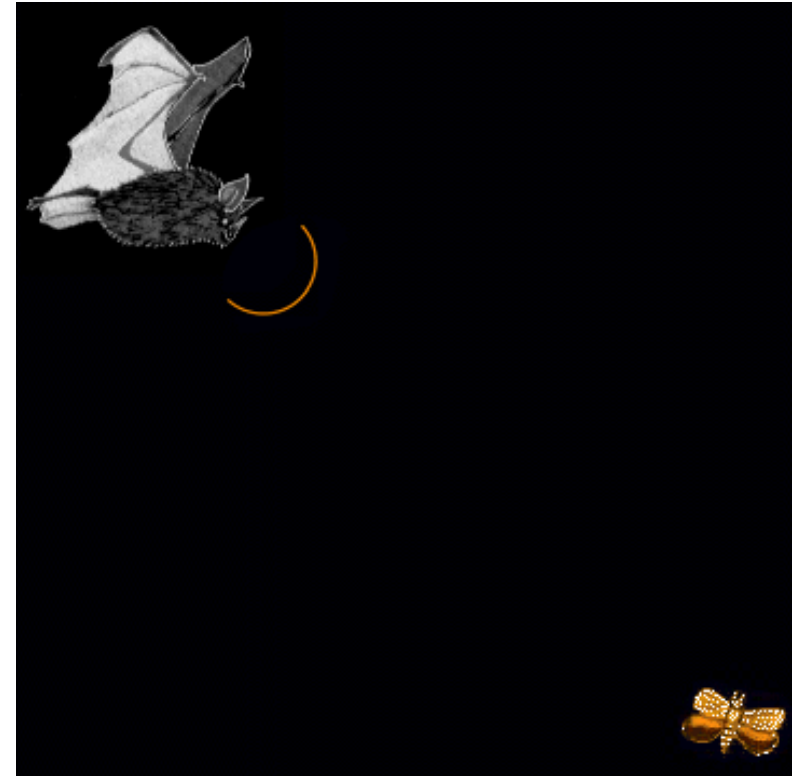- Frequency Content

**Resultant Properties**

- Acoustic Velocity
- Relative Attenuation
- Absorption Spectra
- Liquid Density
- Resonance Spectra

?

# Principles of Operation
# (How does the CSD Work?)

▶ The term 'ultrasound' is commonly associated with things such as bat echolocation and fishfinders.

▶ Common theme: object detection

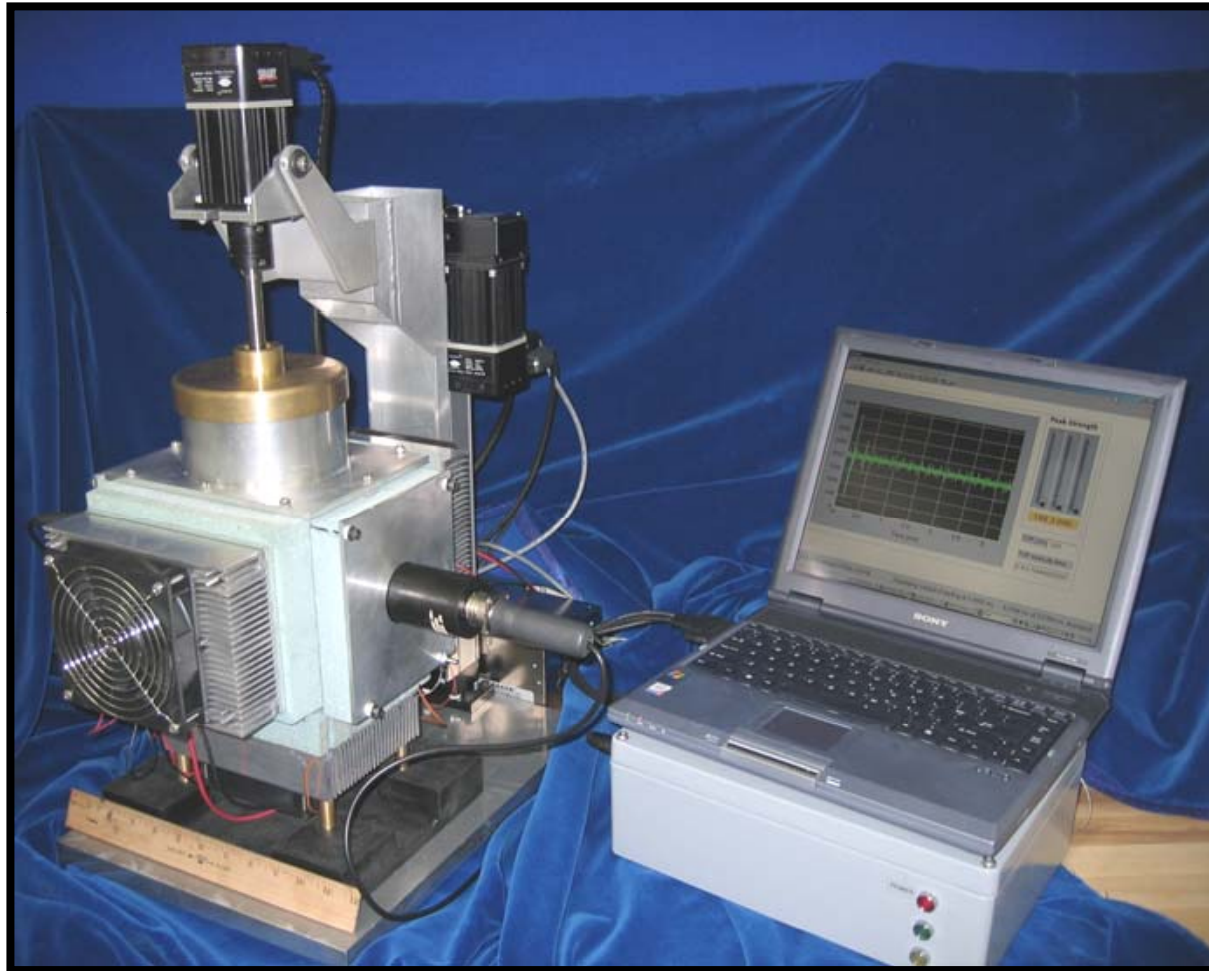▶ The CSD uses ultrasound to accomplish Detection and Liquid Characterization.

Courtesy of bats4kids.com

Courtesy of Johnson Outdoors, Inc.

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# Principles of Operation
# (How does the CSD Work?)



**Liquid Characterization System**

# Principles of Operation
# (How does the CSD Work?)

| Liquid | Second Order Polynomial Fit; where X = Temperature in °F | $R^2$ Value |
|---|---|---|
| 50% Acetic acid in water solution | $y = -0.0033x2 - 0.373x + 1535.5$ | 0.9995 |
| Toluene (Toluel - commercial brand) | $y = 0.0026x^2 - 2.8287x + 1509.6$ | 0.999 |
| Chloroform | $y = 0.001x^2 - 2.046x + 1144.660$ | 1.000 |
| Xylene | $y = 0.002x^2 - 2.634x + 1515.228$ | 1.000 |
| Paint Thinner (commercial brand) | $y = 0.0014x^2 - 2.4731x + 1457.7$ | 1.000 |
| Water | $y = -0.011x^2 +3.098x + 1322.839$ | 1.000 |
| Gasoline Additive (STP - commercial brand) | $y = 0.0011x^2 - 2.3835x + 1484.7$ | 1.000 |
| Acetone (commercial brand) | $y = 0.0017x^2 - 2.7694x + 1371.7$ | 0.999 |
| Ethanol | $y = 0.001x^2 - 2.107x + 1304.761$ | 0.999 |
| Methanol | $y = 0.001x^2 - 2.102x + 1261.274$ | 1.000 |

**Example of Liquids Database
(Sound Speed and Temperature)**

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# Capabilities and Functionality

**CSD Provides the Capability to:**

▶ Detect Contraband, Objects, Anomalies, or Hidden Compartments in Liquid-filled Containers, Pipes or Vessels

▶ Rapidly Sort Liquid Types (and many Solids) into Groups of Like and Unlike (or Threat versus Non-threat)

▶ Classify/Characterize Liquids in Sealed Containers, Pipes or Vessels (*and some un-contained solid materials as well*)

▶ Determine Liquid Fill Level in a Sealed Container or Vessel

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# Potential Applications
## (Liquid Characterization, Monitoring and Detection)

➢ **Food Processing and Quality Control**

➢ **Chemical and Industrial Liquid Process Streams**

➢ **Pharmaceutical Liquid Process Streams**

➢ **Petro-Chemical, Oil and Gas Liquid Process Streams**

➢ **Homeland Security and National Security Applications**

➢ **Law Enforcement - Intelligence Community (Liquid Forensics)**

➢ **Military Applications**

➢ **Transportation Security (Airport Screening)**

➢ **Inventory Control and Validation**

➢ **Hazardous Materials (HAZMAT) Assessments**

➢ **Fuel Compliance Evaluations**

➢ **Environmental Applications and Waste Management**

# Potential Applications
## (Liquid Characterization, Monitoring and Detection)

**Food Processing/Quality Control Consumer Applications:**

- Tomato products (consistency)
- Steak sauce (consistency)
- Mustard (consistency)
- Pudding (consistency)
- Gelatin (degree of gelation)
- Cake/brownie/cookie/bread mixtures (detection of missing ingredients)
- Shampoo (consistency)
- Ground beef (%fat)
- Chicken (anomaly/bone detection)
- Cereal rice and grains (degree of cooking)
- Potatoes (degree of cooking)
- Beer (degree of fermentation)
- Milk and diet shakes (septic vs. good)
- Liquid holding tank fill level (inventory control)
- Container inspection (inventory control, anomaly detection)

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# Potential CSD Physical Embodiments (What Might the CSD Look Like?)
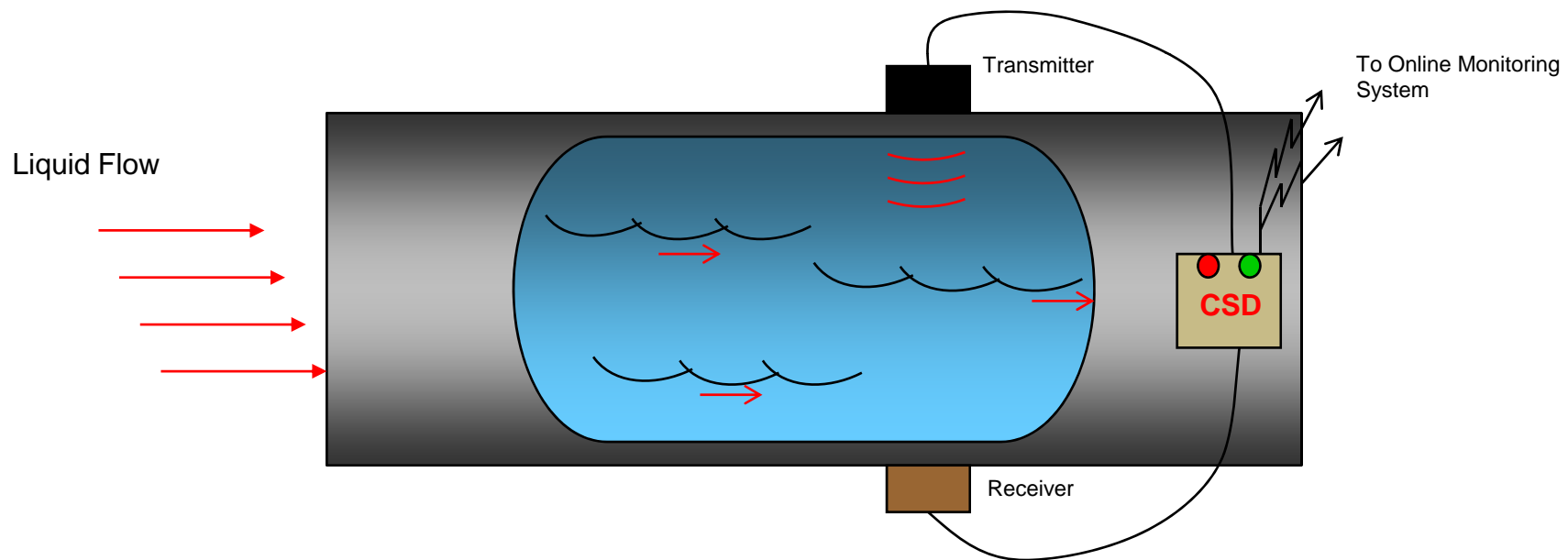
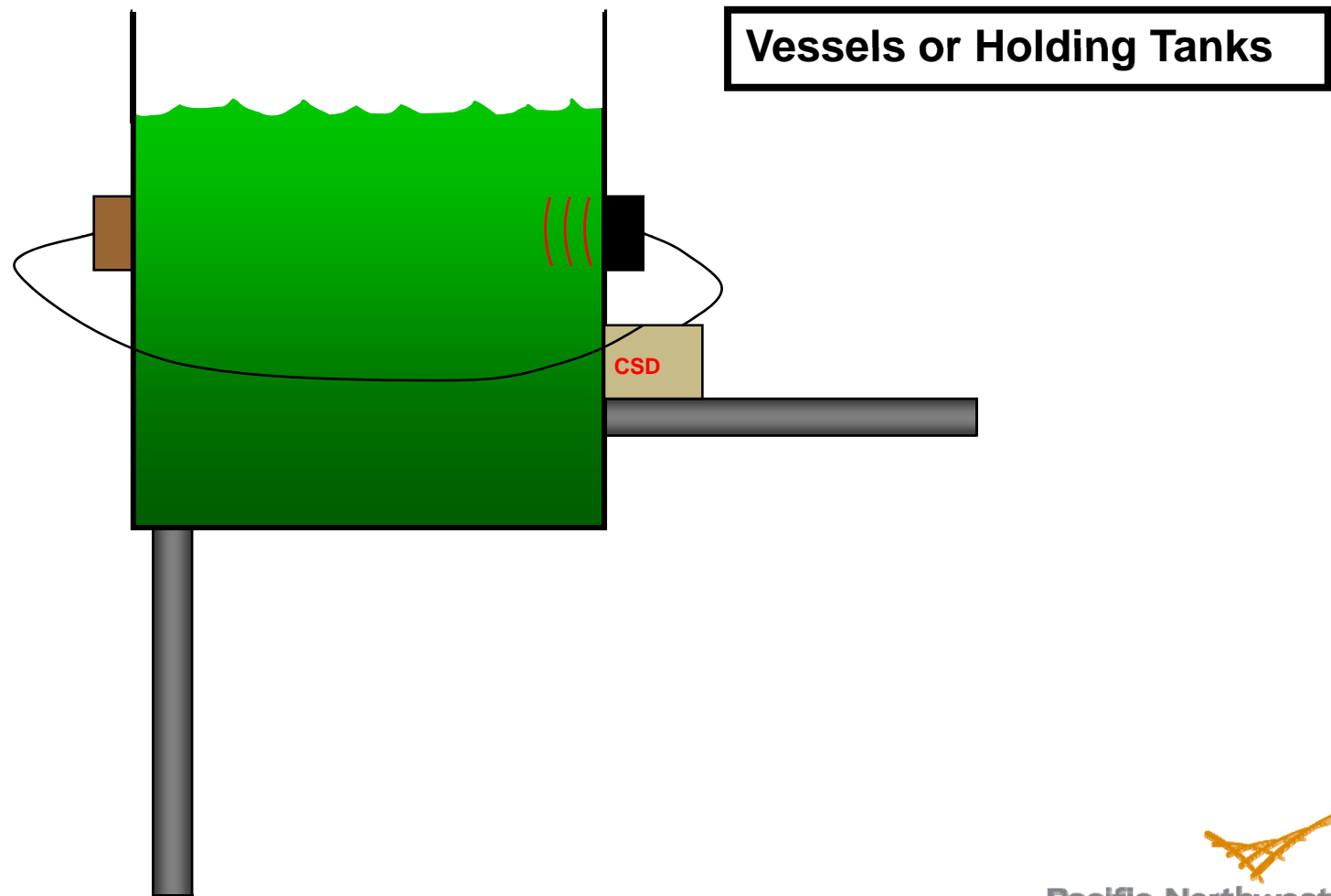**Current Bottle Screening Configurations**
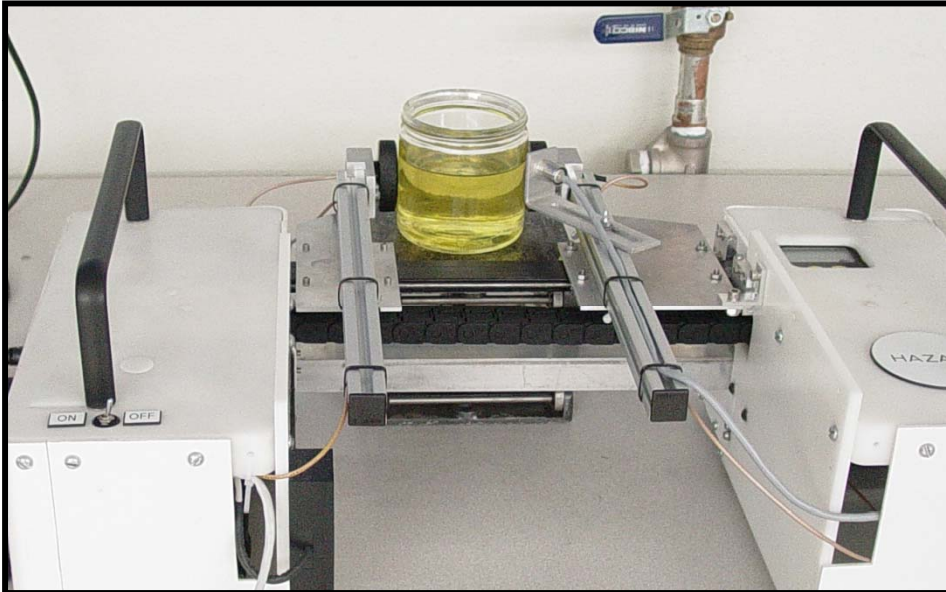


**FBI Device**

**PNNL Device**

# Potential CSD Physical Embodiments
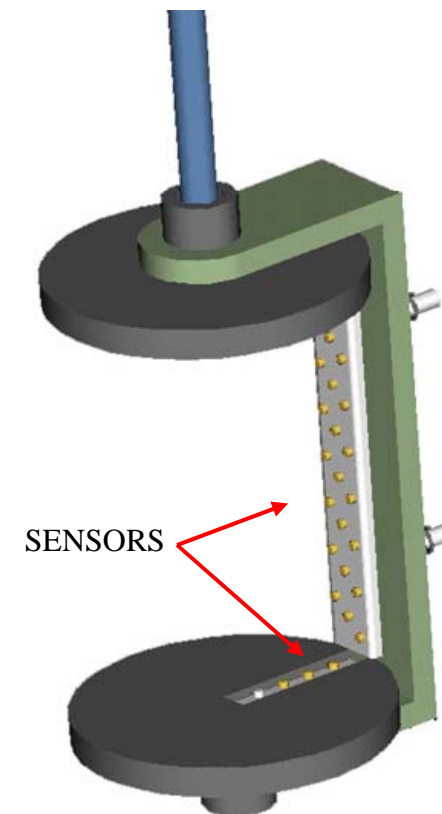# (What Might the CSD Look Like?)

Process Stream Monitoring



Transmitter

To Online Monitoring System

Liquid Flow

CSD

Receiver

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# Potential CSD Physical Embodiments
## (What Might the CSD Look Like?)

**Vessels or Holding Tanks**

CSD

# Potential CSD Physical Embodiments (What Might the CSD Look Like?)
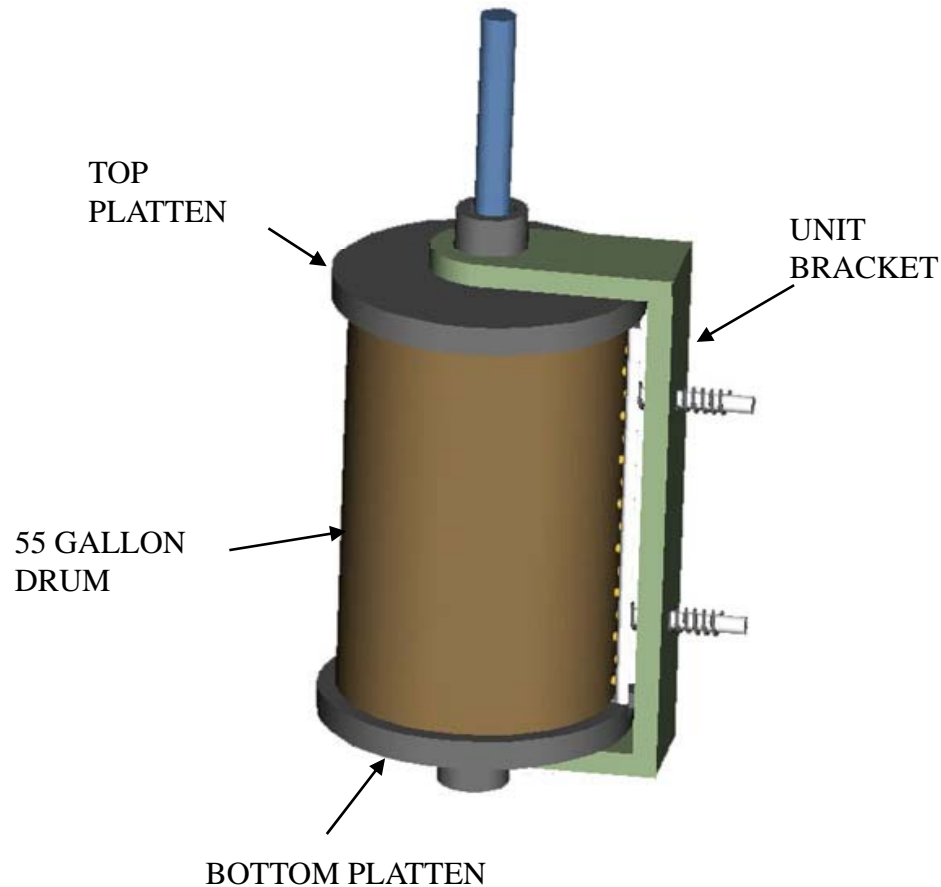
# Advantages of Ultrasound
## (Why Use Ultrasound and What is the Value Added?)

▶ *Safe* to operate and requires access to only one surface
▶ *Non-invasive* and non-intrusive
▶ *User-friendly* and reduced level of complexity
   ■ Technical perspective (mature technology)
   ■ Operational perspective (training and use)
▶ *Robust* in the field and long-term system stability
▶ *Rapid*, real-time response
▶ *Penetrating power* (larger vessels or attenuative materials)
▶ *Cost effective* (equipment)
   ■ Relative to X-ray, Laser-based systems and other non-invasive approaches
   ■ System can be reduced in size relatively easily w/low power consumption
▶ *Wide variety* of liquids and solids applicability
▶ *Volumetric* examinations of containers

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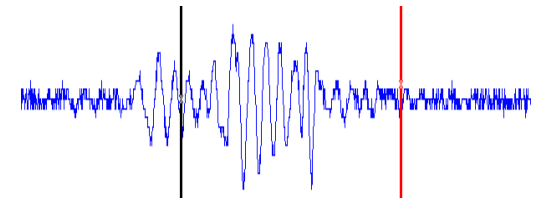
# Recent CSD Activities
## (Current User Interface - Research Purposes Only)
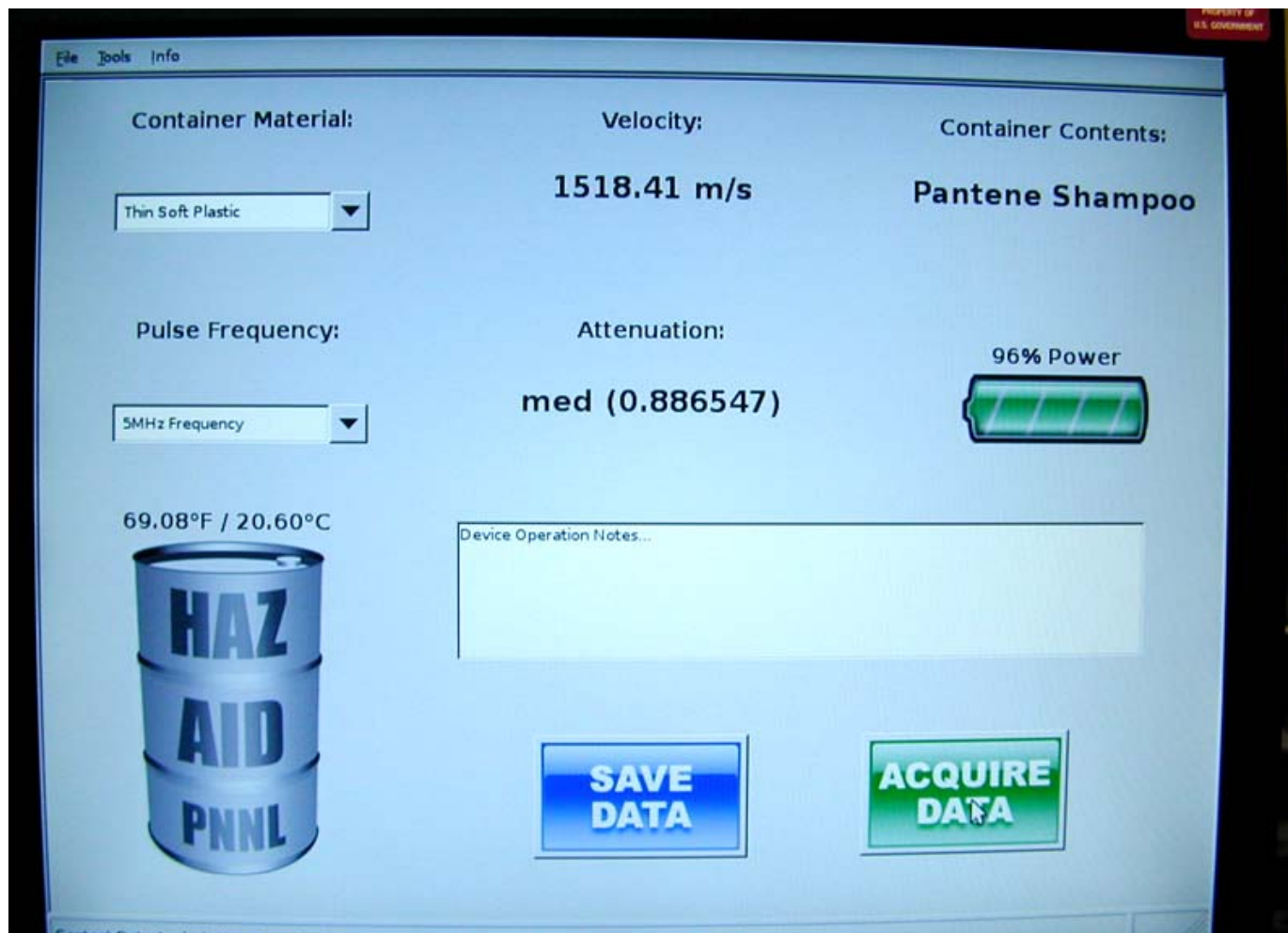
# Recent CSD Activities

| Liquid Category | Total Number of Liquids in Category | Examples of Liquids |
|---|---|---|
| Hair Care Products | 14 | Shampoos, Conditioners, Gels, etc. |
| Automotive Products | 18 | Octane booster, Antifreeze, etc. |
| Liquors | 7 | Whiskey, Scotch, Liquor |
| Toiletries | 8 | Colognes, Perfumes, After Shave, Pre Shave |
| Cleaners | 22 | Floor Cleaners, Wood Cleaners, Detergents, etc. |
| Medicine | 12 | Cold Medicines, Allergy Medicines, Children's Medicines |
| Food | 57 | Juices, Syrups, Vinegars, Marinades, etc. |
| Skin Care Products | 18 | Body Wash, Lotions, Facial Products, Body Oils, etc. |
| Threat Liquids and Flammables | 24 | Fuel, Liquid Explosives, Acids, etc. |
| TOTAL NUMBER OF LIQUIDS | 180 | 24 Threat Liquids, 156 Non-Threat (Benign) Liquids |

# Driving Factors that Impact Estimated Device Costs

➤ **Application** (fixed geometry such as a pipe versus varying geometries) translating into different physical form requirements, algorithm requirements and electronics requirements.

➤ **Measurement Speed and number of sensors** required for application (translates into different algorithm and electronics requirements)

➤ Accommodating **environmental variables** (applications requiring measurements in high temp or pressure environments), etc. Possibly requiring mil-spec testing and validation.

➤ **Database requirements** (applications focused on a small set of liquids versus applications requiring a much larger set of liquids)

➤ **Market need** (fields of use where only 10's or 20's or 30's of these devices are needed, versus 1000's)

➤ **End-User operational requirements** (such as red-light/green-light operation versus a more select or customized user interface)

**ROM Estimated Device Cost Range: $7K to $40K per Unit**

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# Conclusions and Future Work

➢ Developing Additional Acoustic Signatures

➢ Decreasing Measurement Variability

➢ Addressing Measurement Physics Issues

➢ Incorporating Complementary Measurement Modalities

➢ Incorporate advanced statistically-based analytical and decision algorithms

**The CSD is Currently Available for Licensing Across All Fields of Use.**

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