Emerging Trends in Sensor Technology: Sensors and Instruments for the Future

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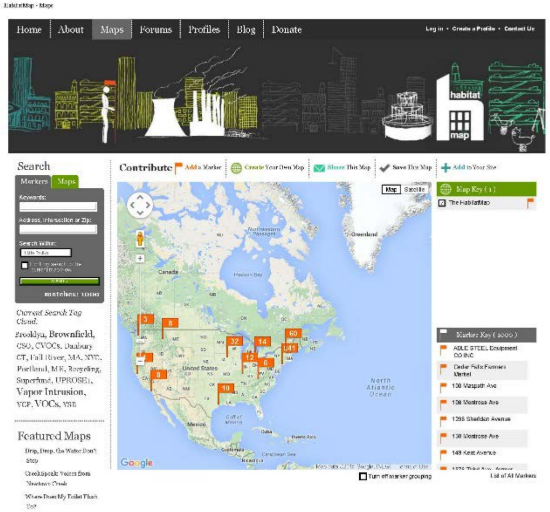
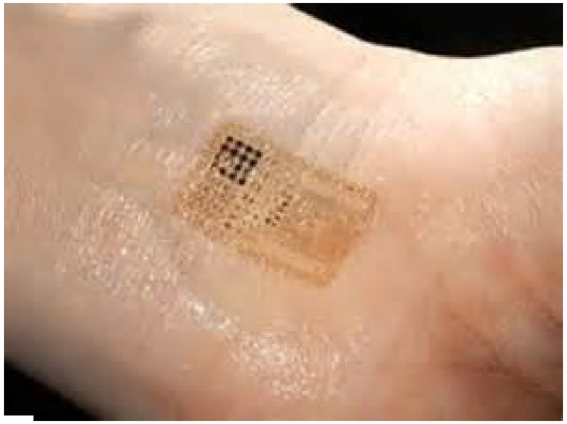
The Future of Sensors:
for anything, anywhere, everywhere

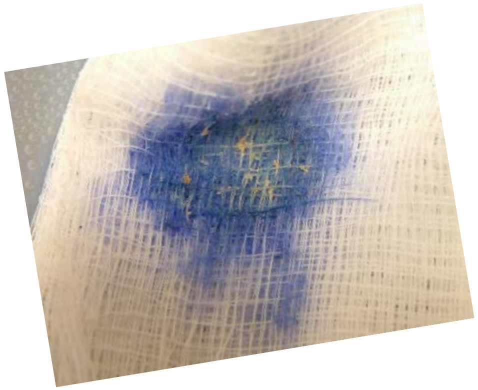
- Wearable Technology
- Embedded Sensors
- Smartphone Apps
- Sensor Arrays
- Self-powered Arrays

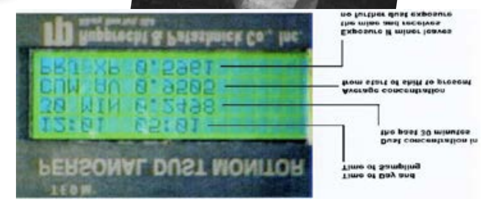




http://habitatmap.org/markers

NIOSH Center for Direct Reading and Sensor Technologies





Enabling safety, health, well-being, and productivity

How do we define and advance the life-cycle for *Turning Numbers into Knowledge?*

TURNING NUMBERS INTO KNOWLEDGE

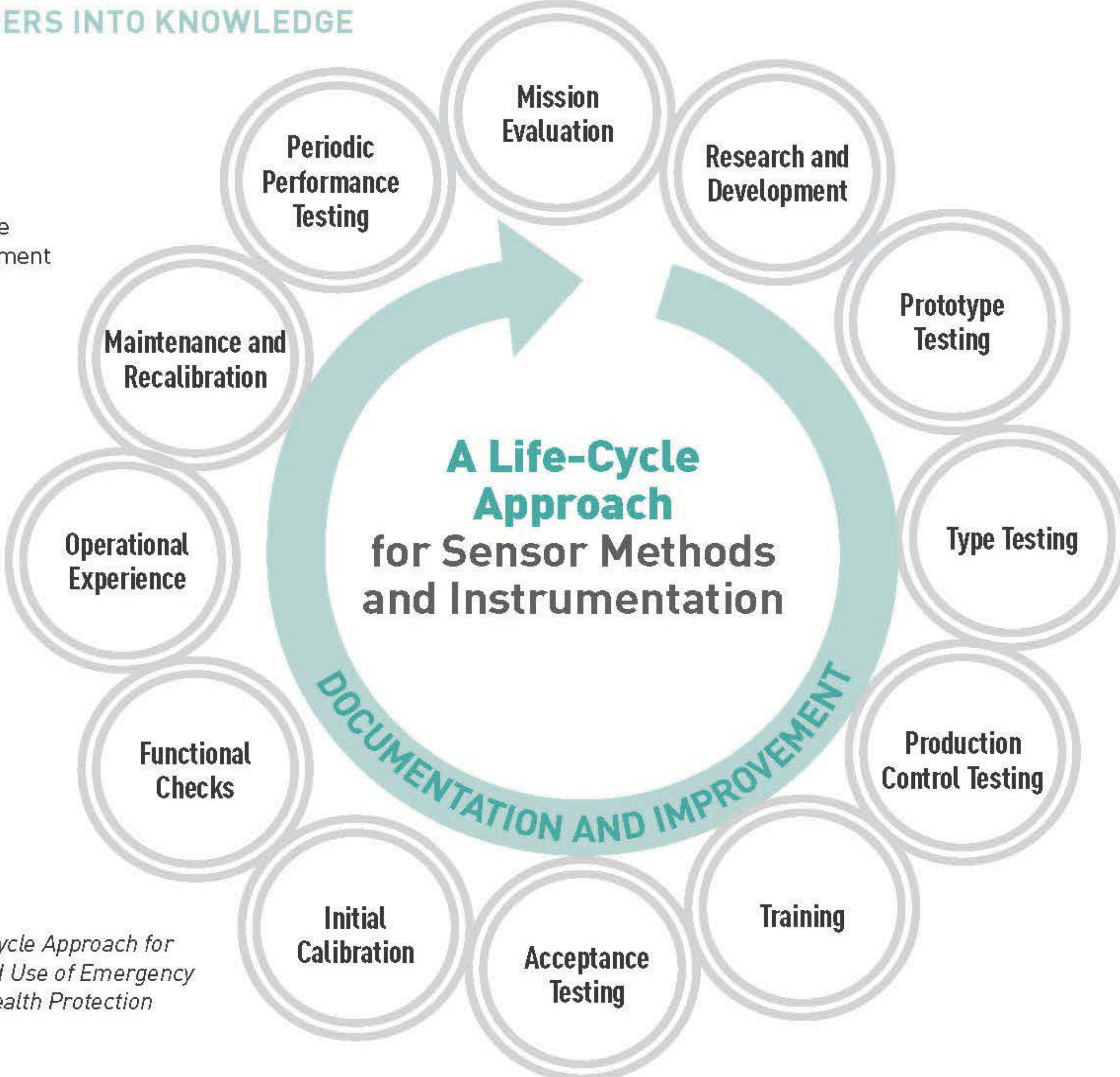
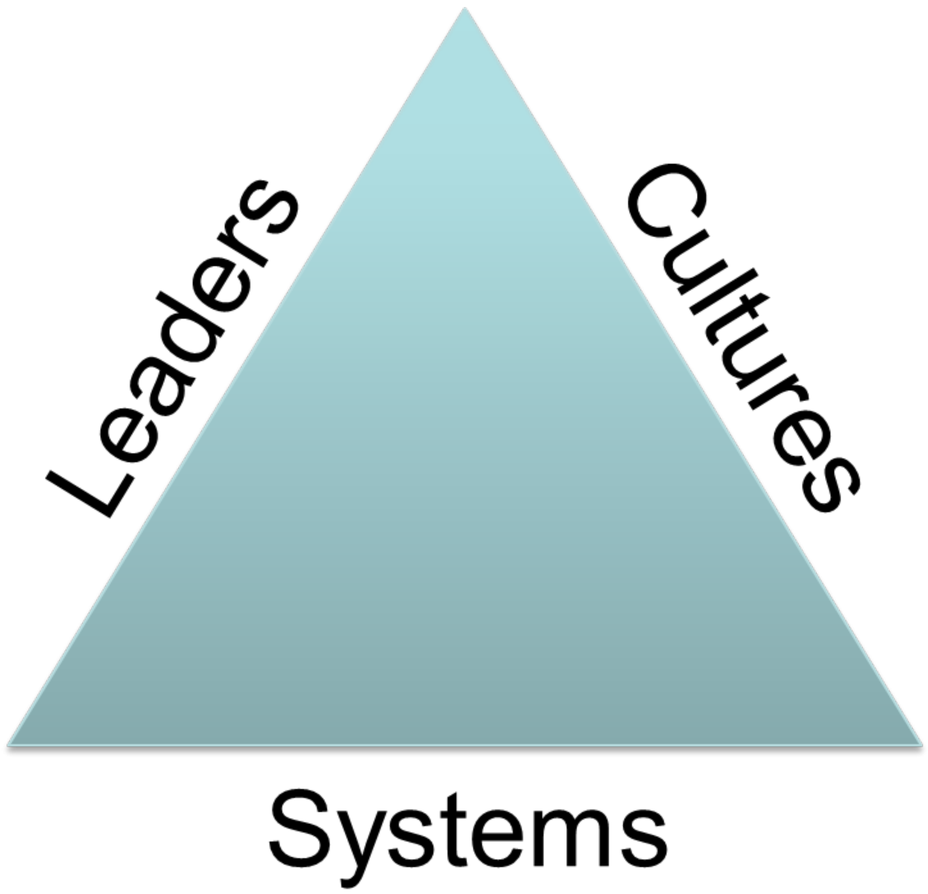


Figure 1. Life-cycle stages for development and application of sensors.

Source: *A Life-Cycle Approach for Development and Use of Emergency Response and Health Protection Instrumentation.*

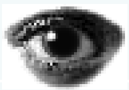
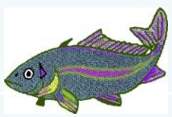
OUR OVERALL OBJECTIVE

Build and sustain leaders, cultures, and systems



for *safety, health, well-being, and productivity*

A Perspective from Sensors developed by Evolution for Safety and Survival

	Biological Sensor	Sensitivity
	Sight (dark-adapted eye)	10 photons/sec-cm^2
	Infrared (snake)	10^{-4} W/cm^2 @ 300 K
	Acoustic (ear)	0.5-angstrom vibrations
	Electric field (fish)	10^{-2} μV/m
	Displacement (scorpion)	1 angstrom
	Smell (moth)	1 molecule
	Ultraviolet radiation (bird)	10^{10} photons/sec-cm^2
	Seismic (frog)	1 micro-g
	Magnetic (pigeon)	10^{-2} gauss
	Smart sensor (frog's eye)	algorithms for array processing, edge enhancement, and changing contrast (i.e., "on-chip" processing)

multiple sensors are needed

Adapted from a slide kindly provided by Ernest Streicher of John Deere

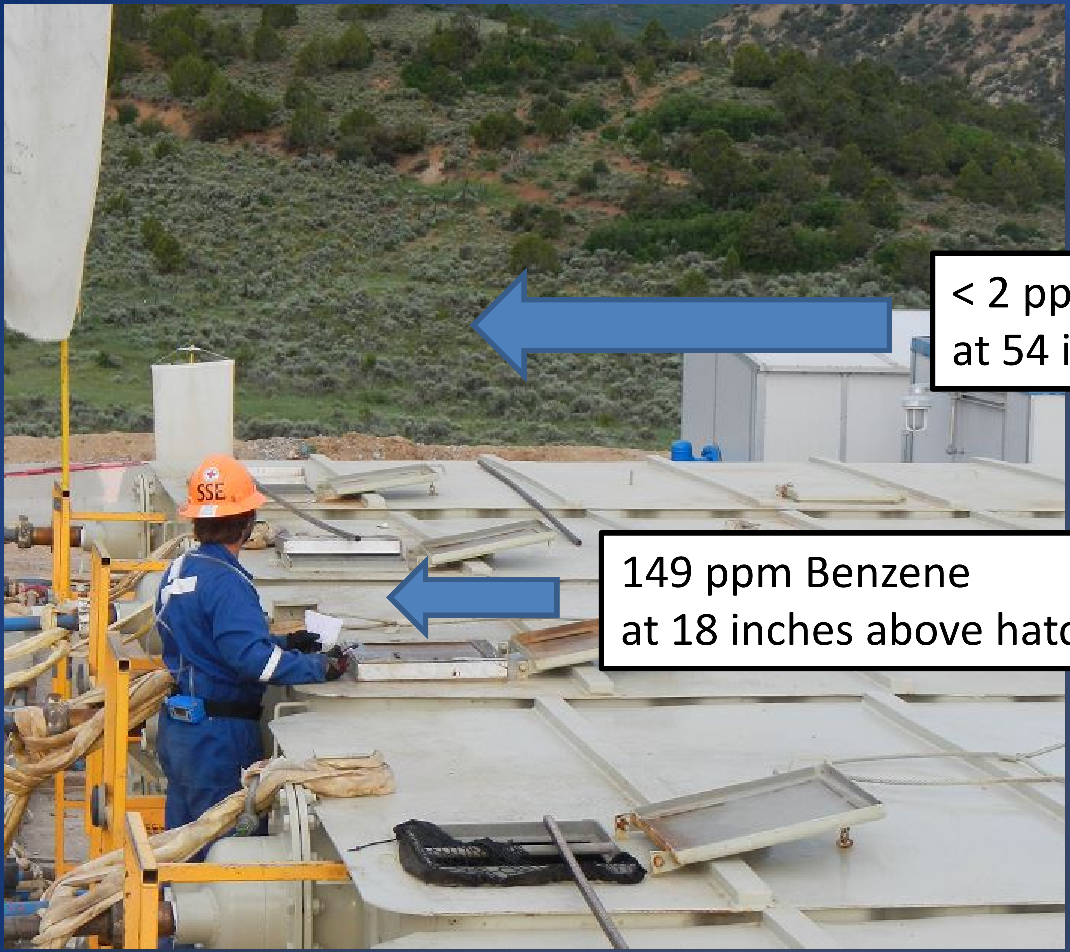
Helmet CAM and EVADE software

Personal monitoring system comprised of a helmet mounted video camera and a continuous real time dust monitor.

Target - Mobile workers
Goal - Evaluation tool to determine “sources of exposure” and “control technology effectiveness”.
Applications – Respirable dust, Noise, Diesel Particulate Matter, Chemical compounds

EVADE - (Enhanced Video Analysis of Dust Exposures). Software available for download http://www.cdc.gov/niosh/mining/Works/coversheet1867.html

A Lesson on Patterns of Exposure: Spatial Variation



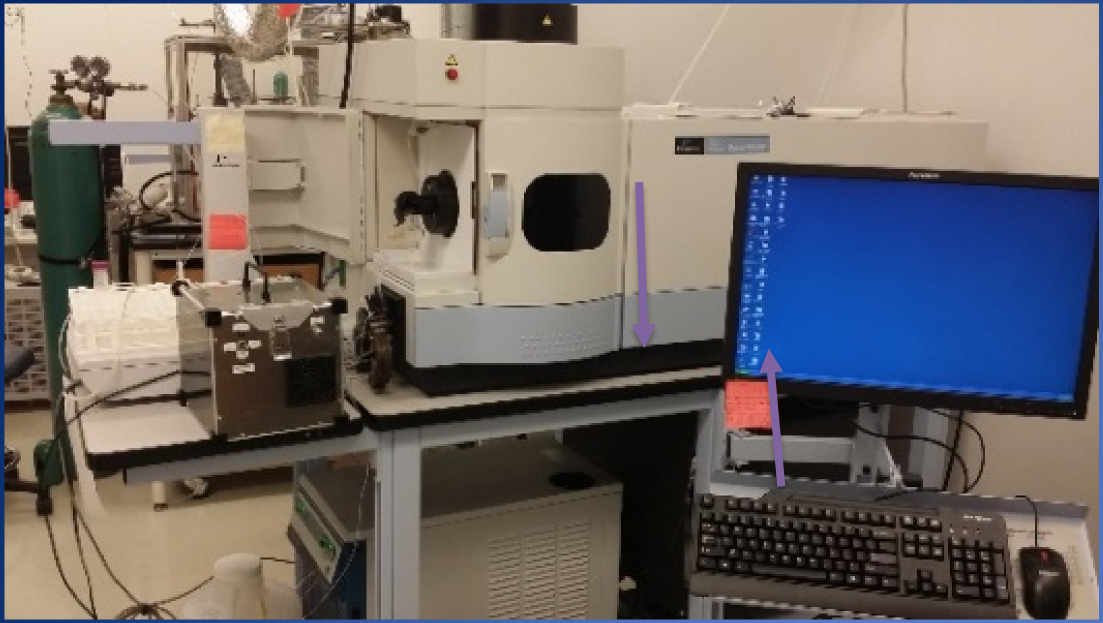
< 2 ppm Benzene
at 54 inches above hatch

149 ppm Benzene
at 18 inches above hatch

Workers did not consistently stand atop the tank to gauge.

Gauging from the ladder platform resulted in higher exposures.

Aerosol Spark Emission Spectrometer (ASES)

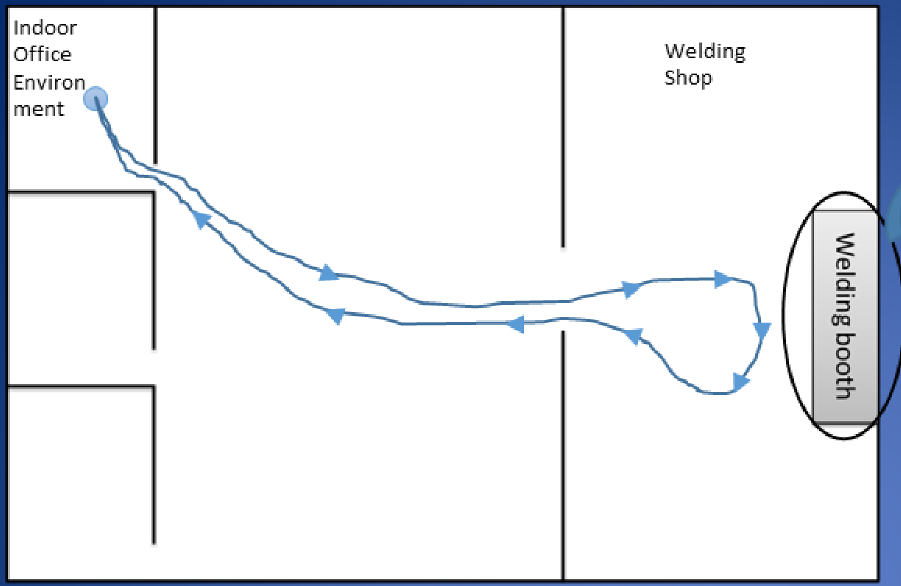


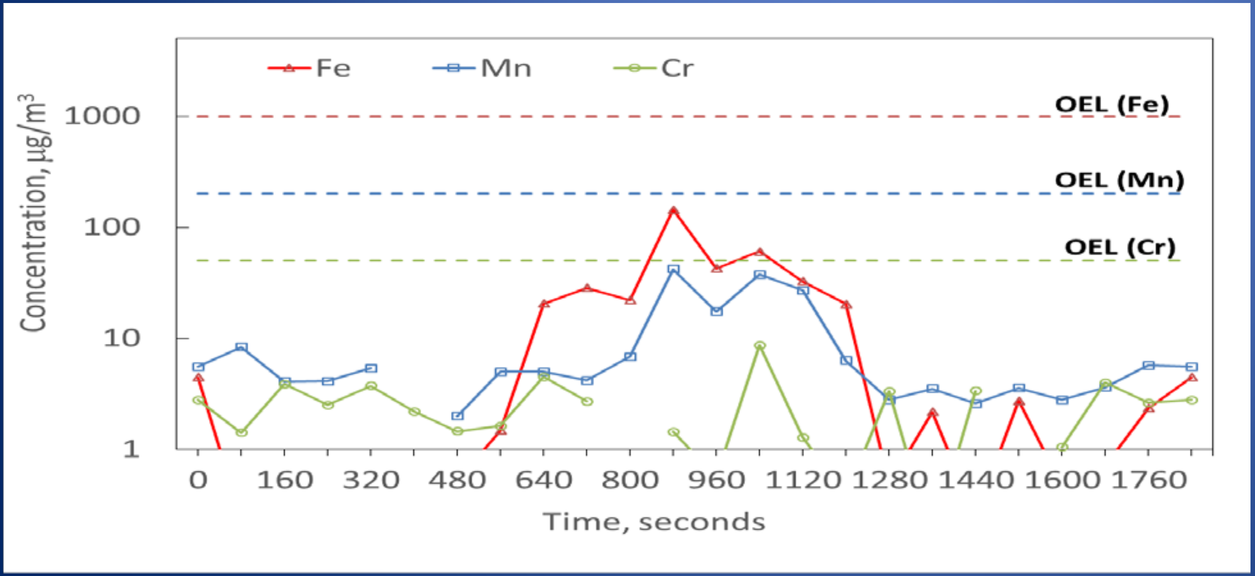
Laboratory ICP-OES

ASES

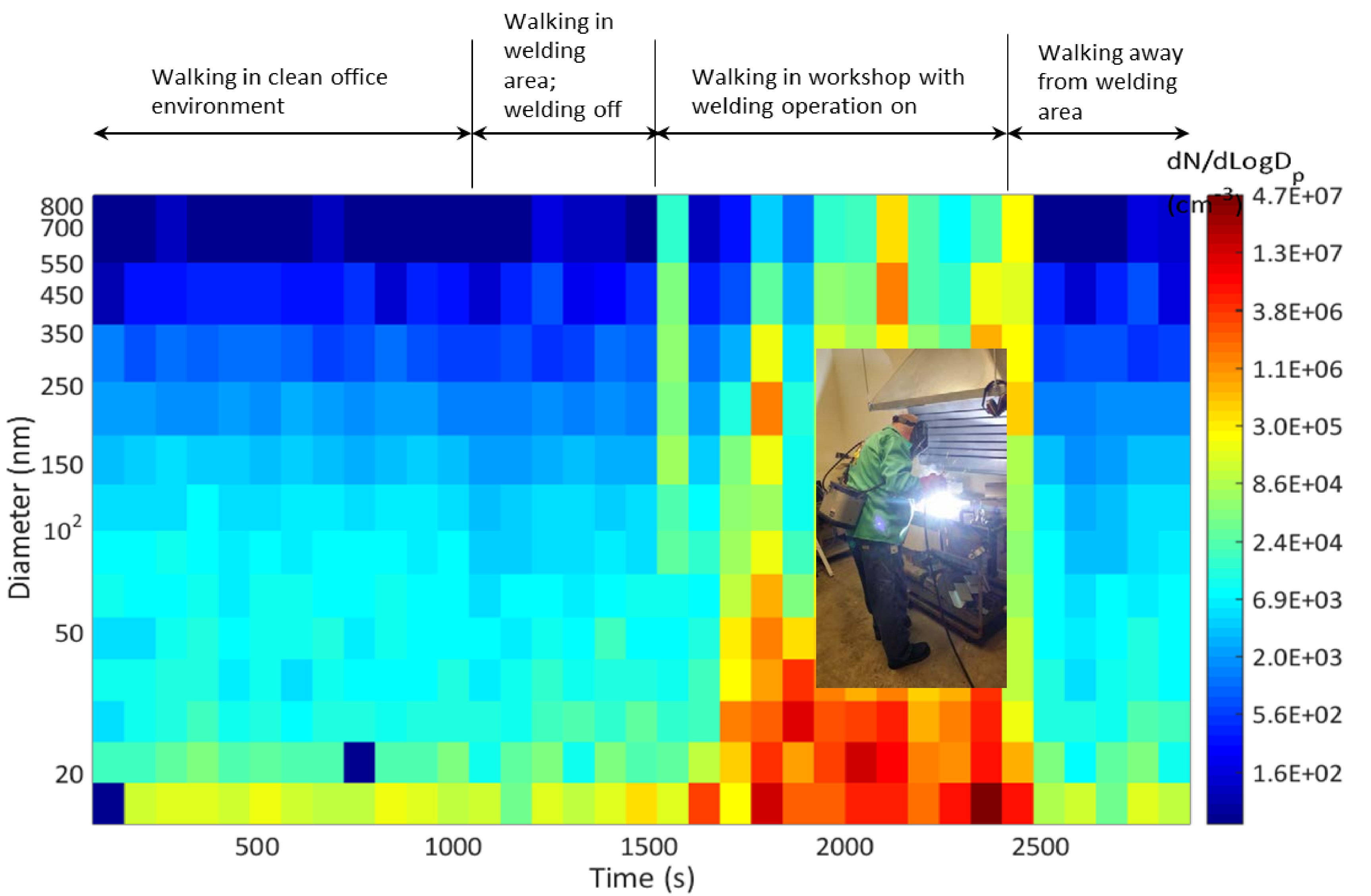
- ASES can measure simultaneously measure almost all metals at LOD of ~1 $\mu g/m^3$ with about 1 min time resolution
- Features:
  - Hand-portable, < 8 lb
  - Battery-operated, stand-alone continuous operation
  - Can simultaneously measure most metals of interest
  - LOD~1 $\mu g/m^3$ at ~1 min collection for most metals
  - Allows continuous mobile measurements, personal exposures

Measurement of Welding Aerosol Using ASES

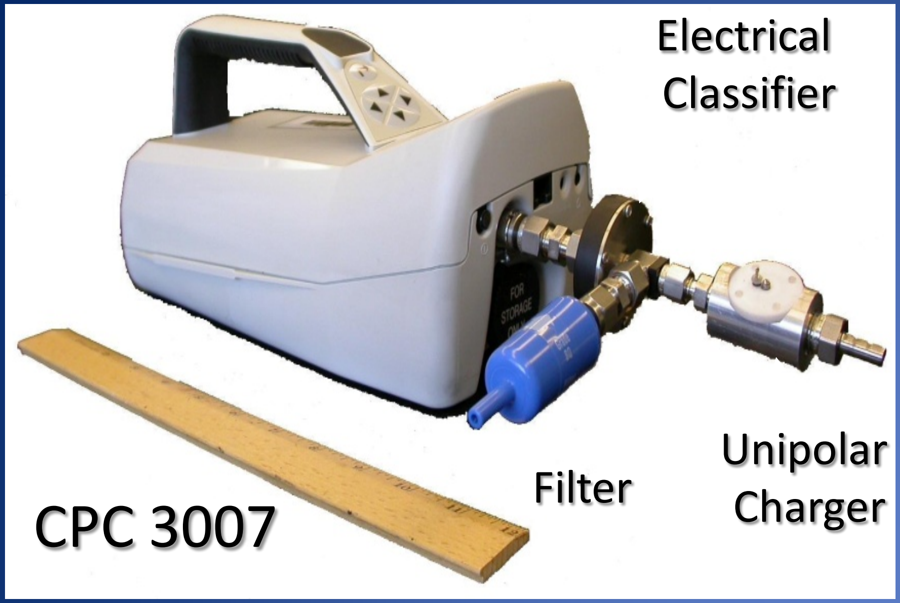


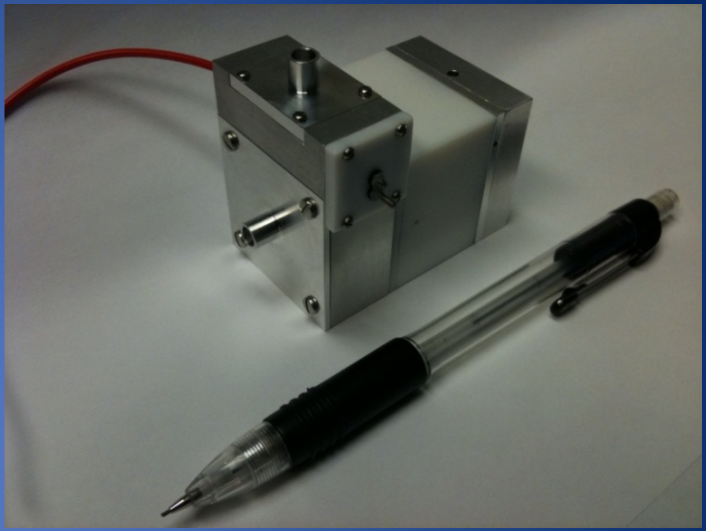


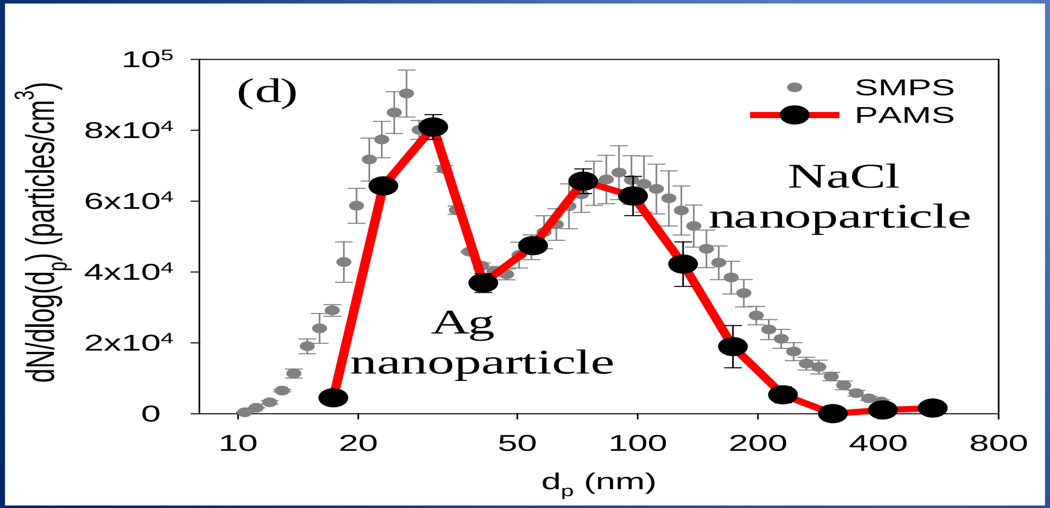
Measurement of Welding Aerosol Using ASES



Nanoparticle Monitors







- Size range: 15 – 633 nm
- Resolution: 8 channels per decade (13 channels total)
- Measurement time: 30-50 s
- Dynamic range: 1-10^5 particles/cm^3
- Total flow: 0.7 lpm

Personal Dust Monitor (PDM)

- The PDM **continuously** monitors the worker’s personal exposure to respirable dust and it displays cumulative, current (i.e. last 30 minutes) and shift limit information in numeric and graphical formats
- **At the end of the shift**, the PDM provides a true mass measurement of the dust collected. The data are automatically converted into average shift respirable dust concentration.
- The real time data stored in the instrument can be downloaded and analyzed at the end of the shift. The data can be used for identification of dust sources, optimization of mine ventilation or control technologies.

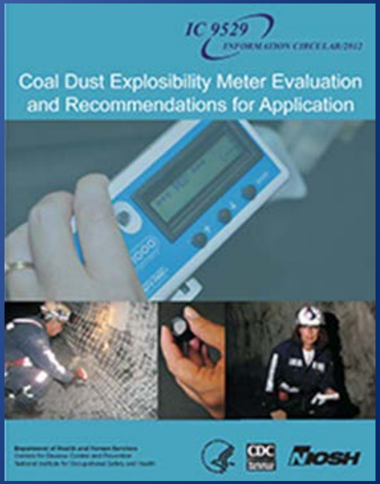
Coal Dust Explosibilty Meter (CDEM)

Allows for immediate identification and mitigation of an area deficient in rock dust – rock dust is needed in coal mines over coal dust to mitigate the risk of explosion

Accounts for the particle sizes of the coal and rock dust
Based on:

- optical reflectance
  determines the ratio of rock dust to coal dust surface area (% RD)
- full-scale experiments on flame propagation
- use of well mixed and dry dust mixture

For more in-depth information: Coal Dust Explosibility Meter Evaluation and Recommendations for Application. NIOSH [2012].
http://www.cdc.gov/niosh/mining/Works/coversheet1843.html



NIOSH Intelligent Proximity Technology

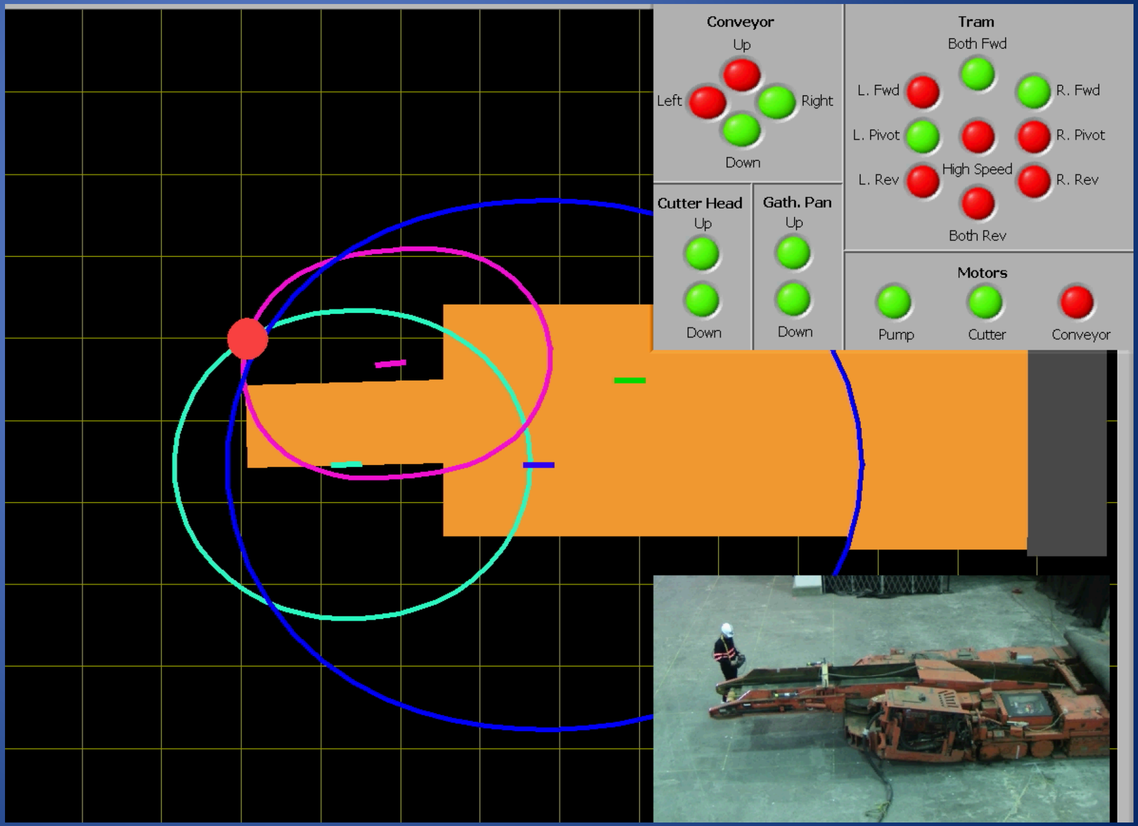
Proximity detection systems are ***required*** to protect miners near continuous mining machines (MSHA rule)

Conventional systems stop machine motion completely when a person is detected in the danger zone

The NIOSH-developed system only disables potentially dangerous motions.

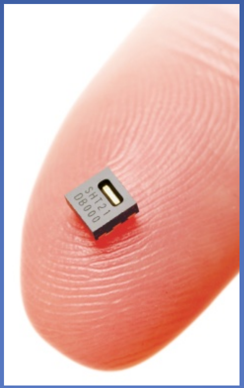
This allows the operator to:

- Avoid other hazards
- Better see necessary visual cues
- Minimize nuisance alarms



Positioning System Coupled to a Personal VOC Exposure Monitor

RF positioning tag



Micro Temperature And Humidity Sensor

Micro Volatile Organic Compound Sensor

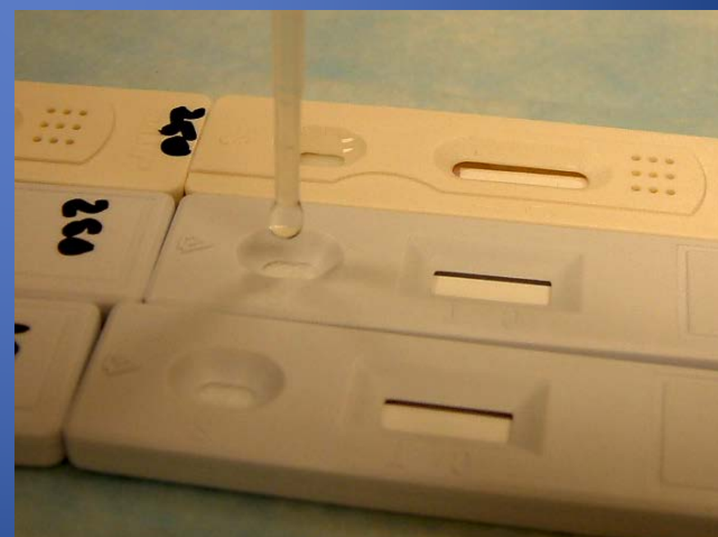
Lead Wipe Test Kits

Lead Wipe Test Kit U.S. Patent #*6,248,593*

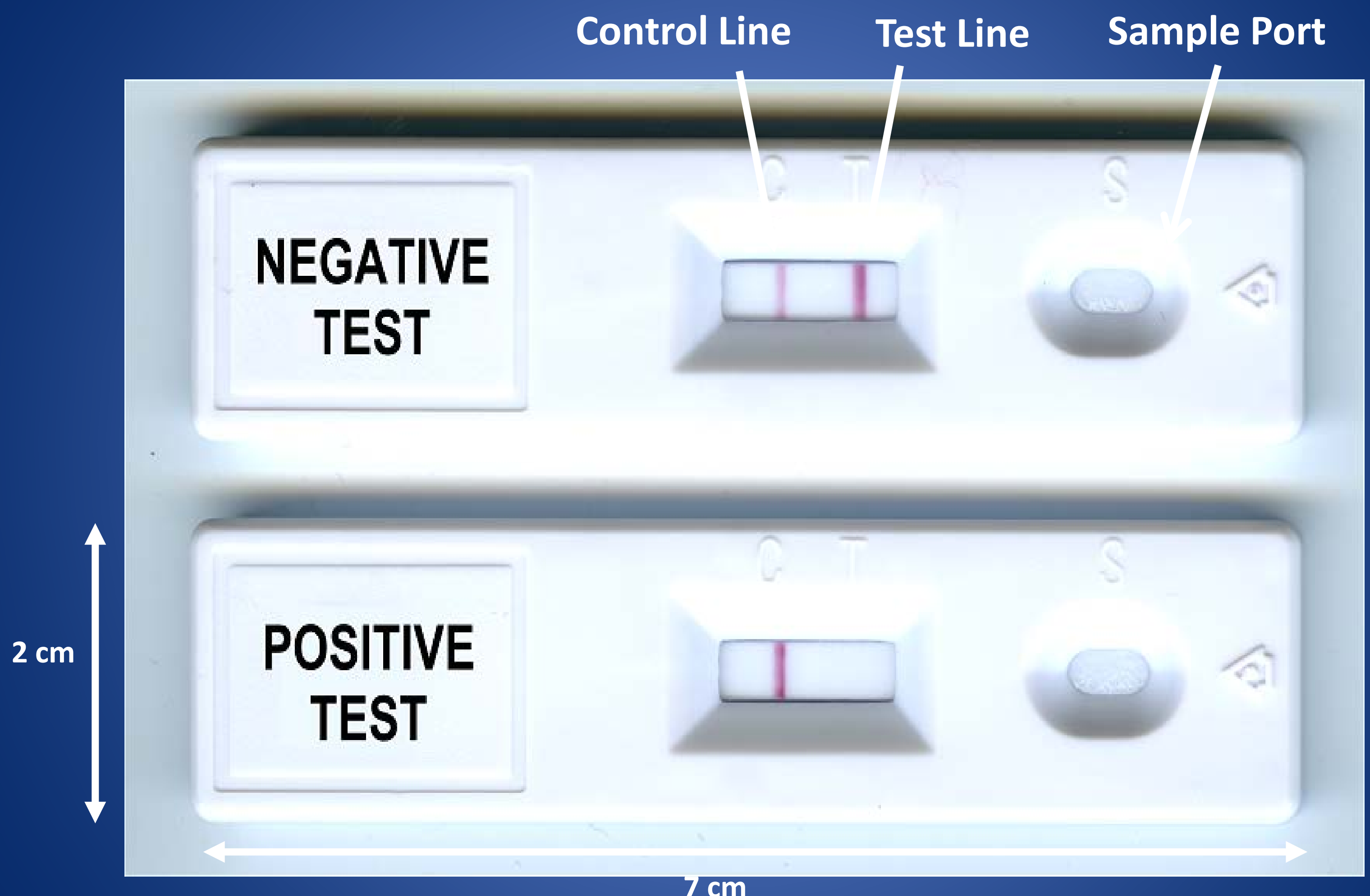
Methamphetamine Test Kits

Two Direct Reading Methods: Colorimetric and Immunochemical

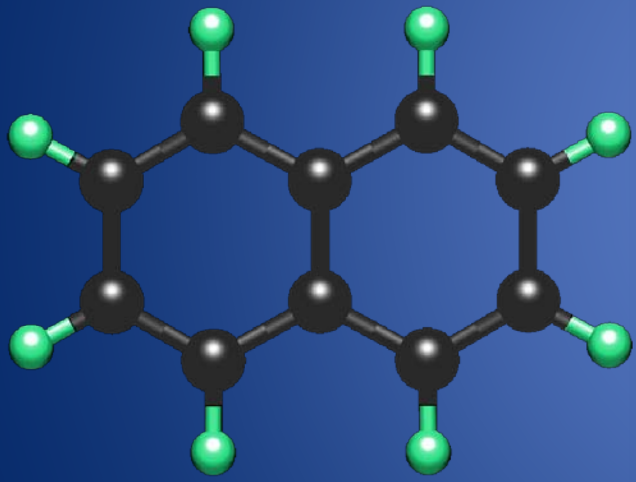
Licensed to SKC as "MethAlert" "MethChek"



Methamphetamine Test Kits



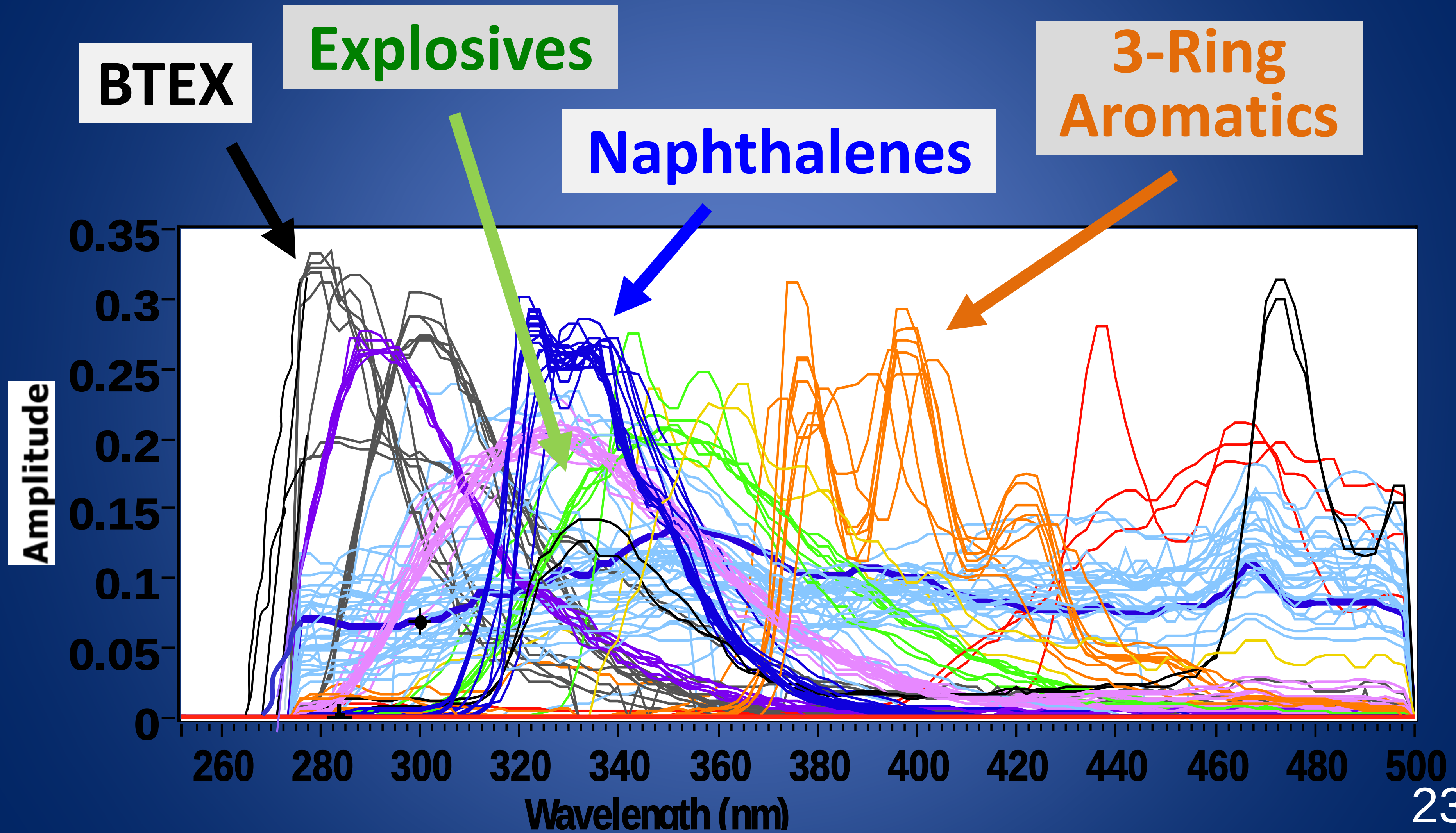
Development and Validation of a Wearable, Real-time Ultraviolet Native-Fluorescence-Based Monitor



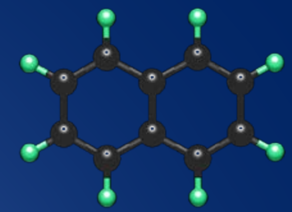
NaDOS Anatomy

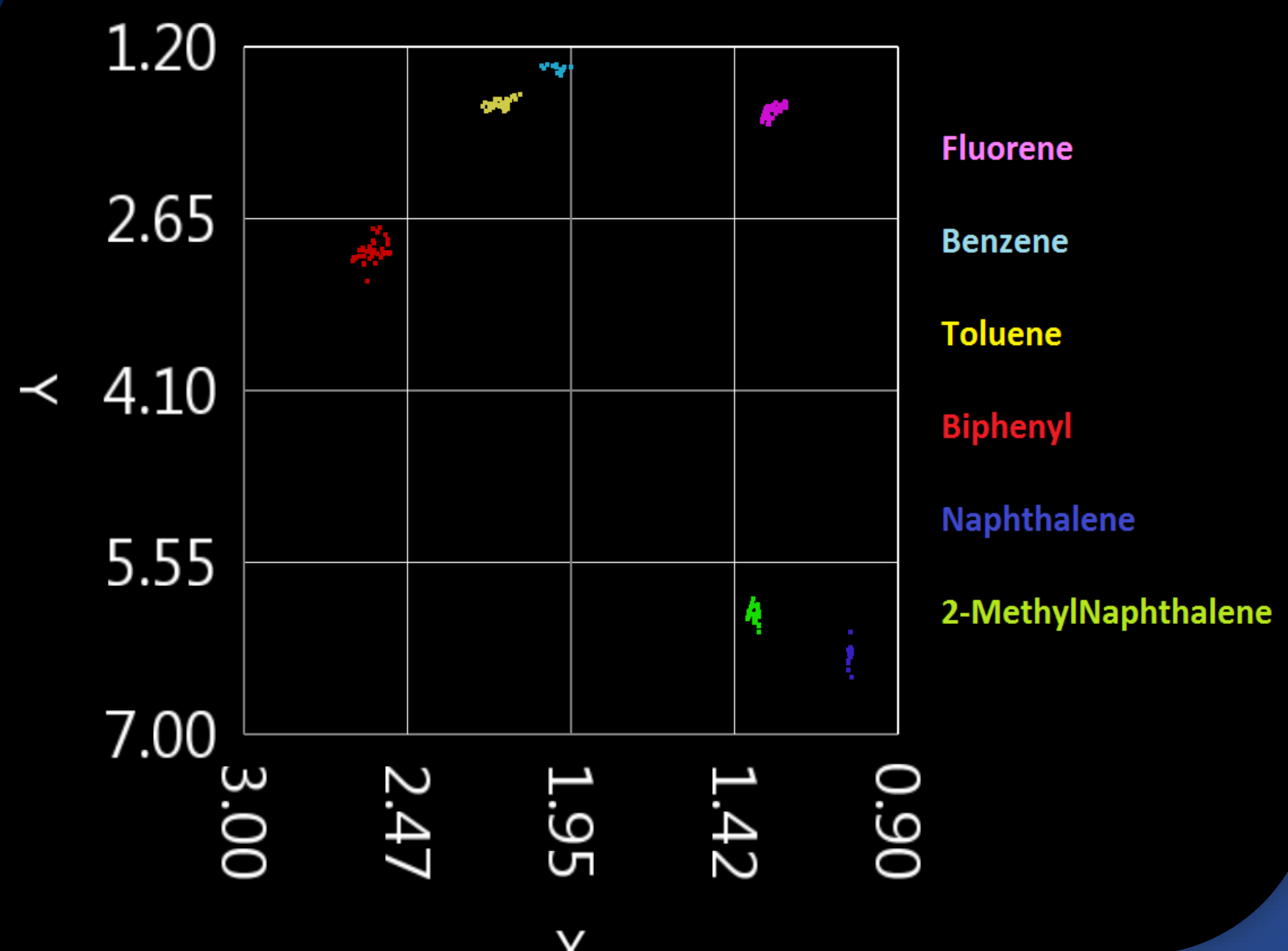
- Native fluorescence of molecules excited by pulsed UV light (280-320 nm) to perform qualitative and quantitative analysis.
- Air enters sample chamber and the compound is concentrated and exposed to UV light.
- The UV light excites the molecules of the gas or vapor and the molecule emits a compound specific-spectral signature.
- The emitted signal strength corresponds to the chemical concentration.

Emission spectra for most organics is limited to wavelengths above 260 nm.



NaDOS Chemometric comparison





Y axis is the ratio 320/340 and the x axis is 340/360. Notice the tight cluster of the ratios for an individual chemical compared to the large spread on the axis. All of these chemicals are easily differentiated.

Laboratory Validation

Develop methods for delivering known concentrations of naphthalene to the NaDos, PID and Gas Chromatograph to reach the goal of detecting and identifying naphthalene vapor densities as low as 100 µg/m3 and as high as about 1.5 g/m3 in a time period of about 2-3 minutes.

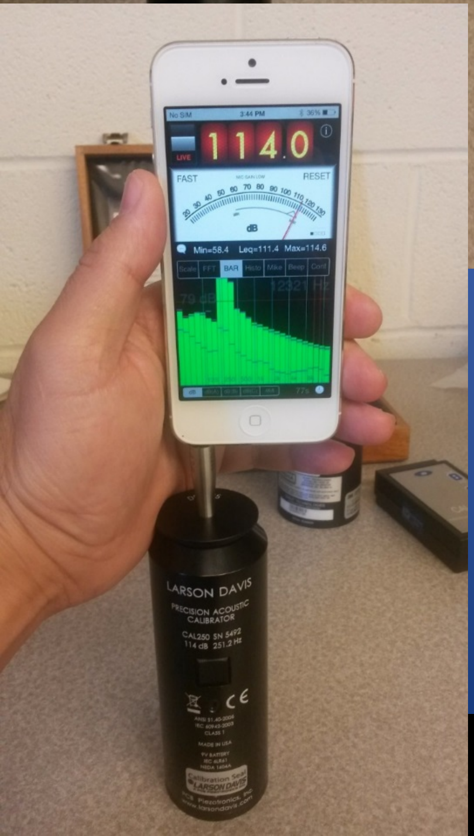
Field Validation

Data Collection Conducted US military base locations (Army and Air Force)

Working with warfighters working different job types: fuel cell (5), POL (4), vehicle mechanics (3), refuelers (2), helicopter crew chief and pilots (2)

NIOSH Sound Level (SLM) Meter App

- Study on smartphone sound meter apps examined accuracy and functionality of 192 iOS and Android apps
  - Kardous CA, Shaw PB [2014]. Evaluation of smartphone sound measurement applications, J. Acou. Soc. Am., 135 (4).
  - NIOSH science blog: http://blogs.cdc.gov/niosh-science-blog/2014/04/09/sound-apps/
- 4 iOS apps had mean differences within ± 2 dBA w/SLM
- NIOSH SLM App based on tech from one of the 4 apps developer
- Available for free – Worker empowerment, job exposure database, calibrated in our labs
- Currently in beta testing – Not yet approved for distribution



Use w/ External Mic (Type 2)

Significant Advantage: Ability to calibrate app using regular acoustic calibrators!

Noise App Impact and Challenges

- **Adoption of more smartphones =**
  A noise dosimeter in every pocket

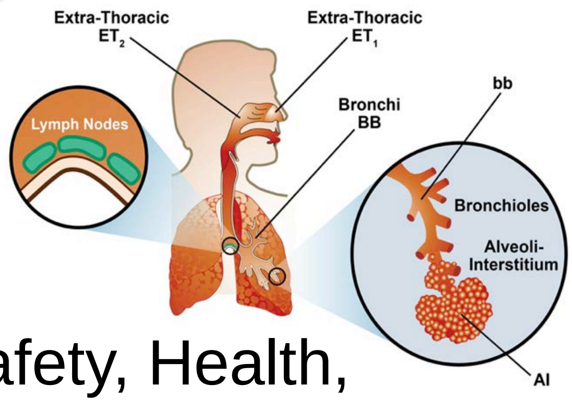
- Better **worksite management** and occupational safety and health **staff involvement**

- Residents' and citizens' **awareness** of noise pollution leads to better **involvement** of city planners and regulators.

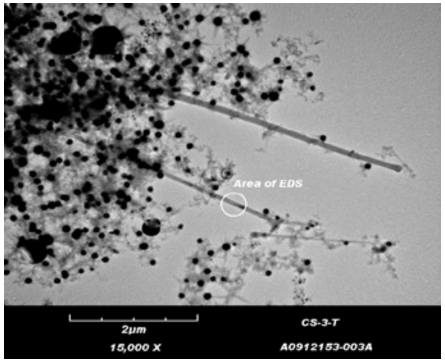
- **Buying and using quieter equipment**

Challenges remain: Accuracy, privacy, corrupt data, data storage, calibration standard

A Convergence for Information Sharing

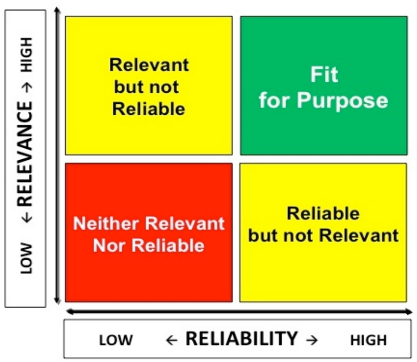


Safety, Health, Well-being, and Productivity



New Technologies

*



Risk Management

Focus on the Convergence = Focus on Success.

INFORMATICS 4 IMPACT

A critical point of view

*The "**I**"s are in the eye of the beholder.*

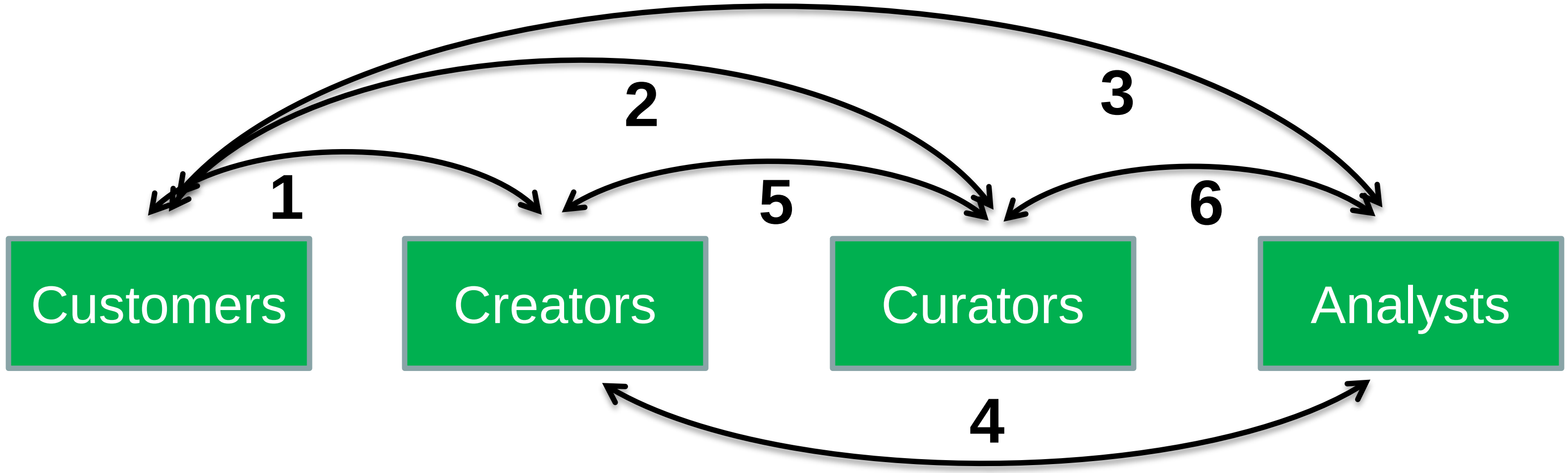
One size does not fit all...

A Matrix View of “Who we are” and “What we need”

	Workers	Health and safety practitioners	Managers	Policy makers and regulators	Equipment and facility providers	Materials suppliers	Financiers	Insurers	Legal community	Researchers	Educators	Students	Emergency Responders	Media	Consumers	Society
Literacy and Critical Thinking Skills																
Real Life Examples																
Understanding (not rote application)																
Continuous Improvement																
Modeling and Sharing																
Assessment																

Specific messaging and actions in each element of the matrix must be based on (a) what knowledge and understanding each stakeholder needs and (b) what knowledge and understanding each stakeholder can provide.

Informatics Roles and Responsibilities



	Set Mission Objectives	Determine Relevance	Collect	Validate	Store	Share	Analyze and Model	Apply	Confirm Effectiveness	Convey Experience	Generalize	Update Guidance
Customers	X	X						X	X	X	X	X
Creators		X	X	X					X			X
Curators		X		X	X	X			X			X
Analysts		X		X			X		X		X	X

Communication and understanding are essential at all steps.

The IH Decision-making Framework and Process

Anticipate and Recognize → Evaluate → Control and Confirm Protection

Constant communication, continuous improvement

Risk Assessment

Hazard Assessment

Identify and define dose-response relationships and "*Hazard Criteria*"

- Occupational Exposure Limits
- Skin Notations, …
- Hazard Bands

Exposure Assessment

Collect all "relevant and reliable" exposure information for assessment against and refinement of the "*Hazard Criteria*"

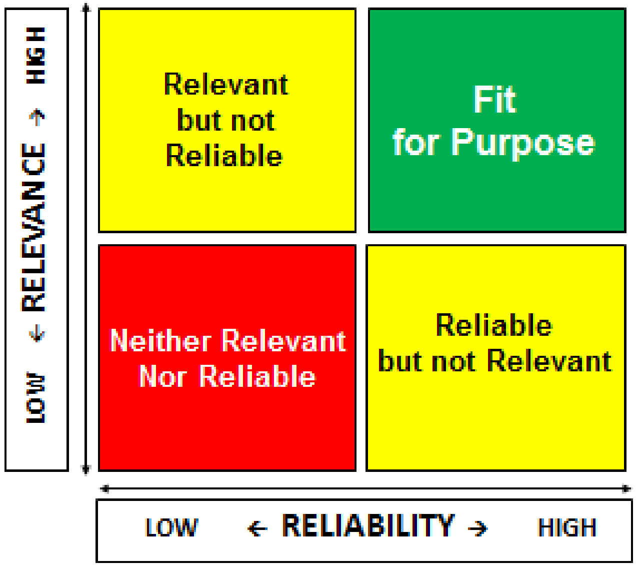
Risk Characterization

Characterize risks associated with "realistic" combinations of hazards and exposures

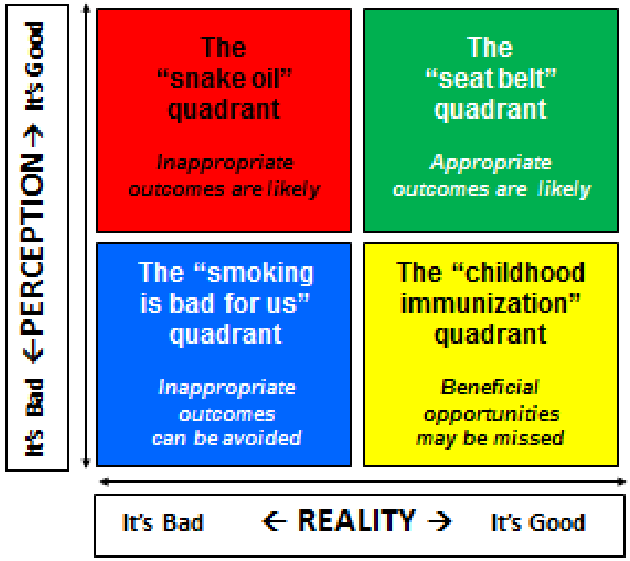
Risk Management

Use the Hierarchy of Controls to apply "appropriate" controls and programs and confirm protection

Relevance-versus-Reliability Assignment



Perception-versus-Reality Refinement

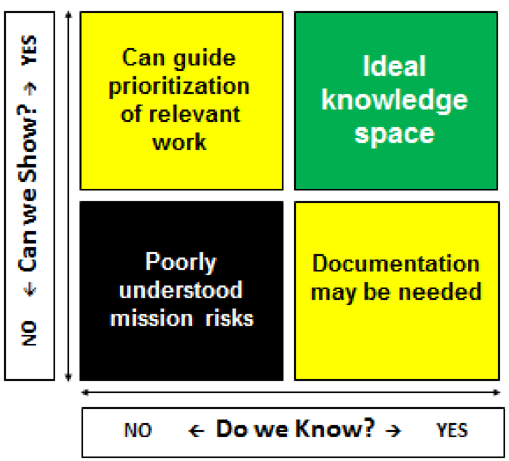


"Compliance" is the third dimension:

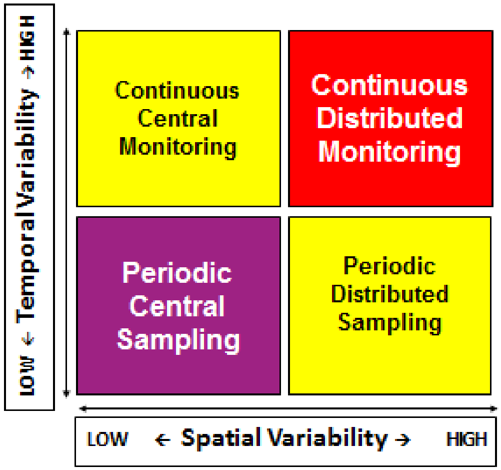
Why doesn't everyone wear seat belts?

Why do many continue to smoke?

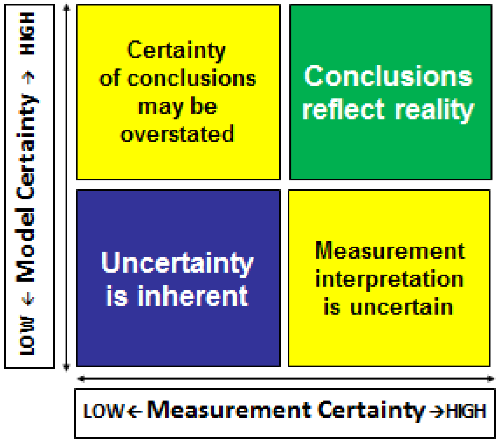
Know-versus-Show Alignment



Temporal-versus-Spatial Variability

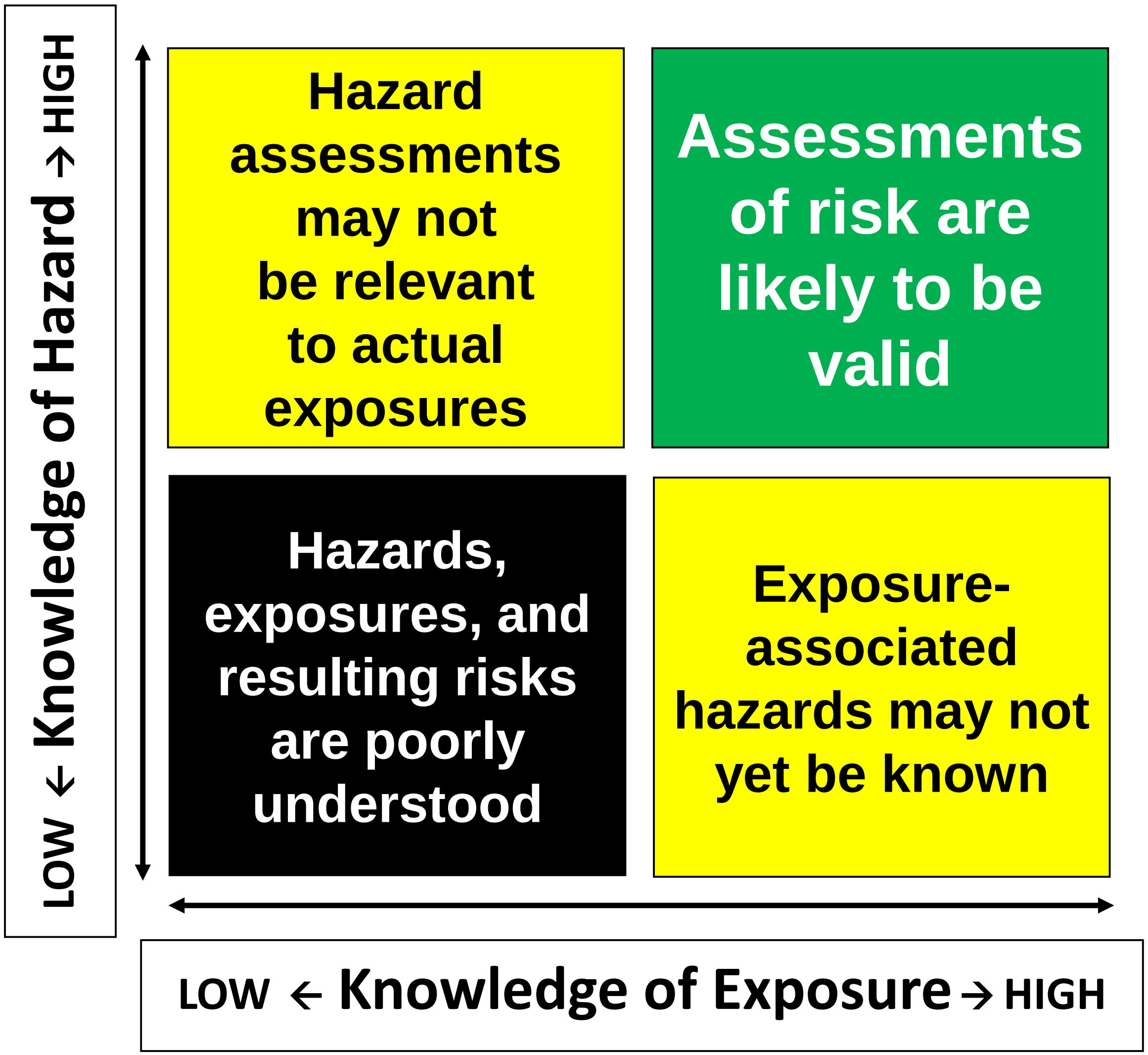


Model-versus-Measurement Certainty



Hoover et al., 2015

Knowledge Spaces for Hazard-Informed and Exposure-Informed Risk Assessment



Key ingredients:

- Hazard-Informed Exposure Assessment
- Exposure-Informed Hazard Assessment

Nanotechnology Signature Initiatives

- Nanotechnology for ***Solar Energy Collection and Conversion***

- ***Sustainable Nanomanufacturing***:
  Creating the Industries of the Future

- ***Nanoelectronics*** for 2020 and Beyond

- Nanotechnology ***Knowledge Infrastructure***:
  Enabling National Leadership in Sustainable Design

- Nanotechnology for ***Sensors and Sensors for Nanotechnology***: Improving and Protecting Health, Safety, and the Environment

- Related initiative: ***Materials Genome Initiative***

Our Premise:

We can ***accelerate discovery***,
revolutionize design,
and ***sustain innovation*** through a

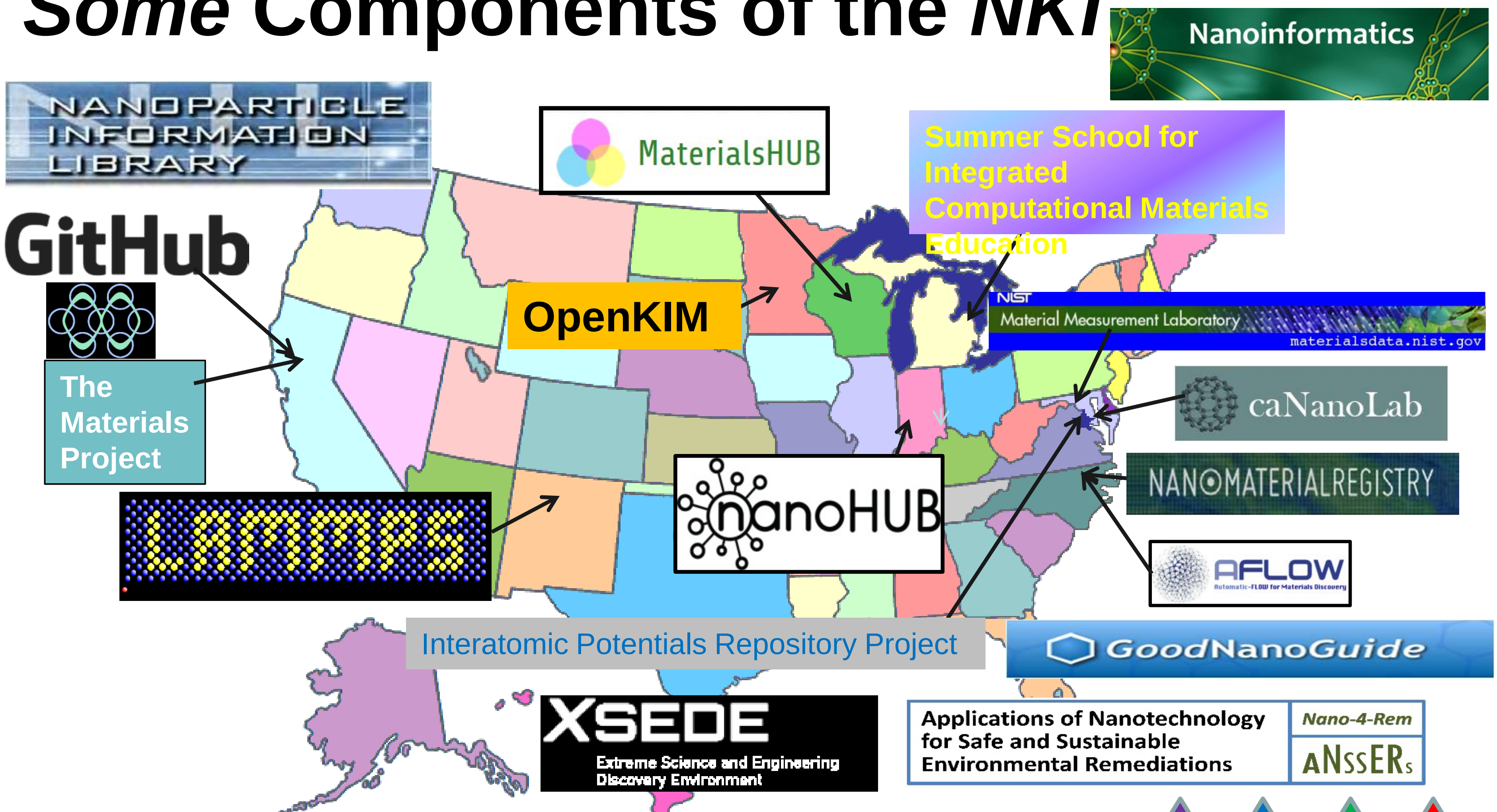
Knowledge Infrastructure

Grass roots involvement is required!

Nano.gov
U.S. National Nanotechnology Initiative

Opportunities to Partner

Some Components of the *NKI*



- Supported by NIH, NIOSH, NIST, NSF, ONR, DOE, EPA …

A wide array of nanoinformatics activities are already underway.

Data Readiness Levels

Summary of DRLs Versus Data Attributes

Attribute	DRL 0	DRL 1	DRL 2	DRL 3	DRL 4	DRL 5	DRL 6
Units		maybe	yes	yes	yes	yes	yes
Precision and Noise				either	both	both	both
Independent Confirmation				possibly	yes	yes	yes
Related to Larger Body of Scientific Knowledge					no	yes	yes
Measurement Uncertainty					specula-tive	high	low
Example or use	little to none	unscaled sensor data	scaled sensor data	scaled data; noise levels defined	major scientific advances	coarse validation of theory	theory refinement and methods validation

Data attribute details are application-dependent.

Four Steps for Community Action

to build and sustain **leaders, cultures, and systems** for **safety, health, well-being, and productivity**

Thank you for partnering with us for success.

Steps to Data Readiness for Decision-Making

Step	Attribute
00	Establish CLEAR objectives
0	Address uncertainty
1	Address false positive conclusions
2	Address false negative conclusions
3	Apply appropriate decision levels
4	Apply appropriate evaluation methods
5	Differentiate correlation from causation
6	Apply appropriate extrapolations
7	Develop adequate documentation
8	Address mishap or misconduct

Focus on doing the right things right.

Adapted from Hoover et al., 2014

Focus of the NIOSH Sensor Center

- **Coordinate a national agenda** for direct-reading methods and sensor technologies
- **Develop guidance** documents pertinent to direct-reading methods and sensors, including validation and performance characteristics
- **Develop training protocols**
- **Establish partnerships** to collaborate in the Center’s activities





Questions ?

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