Nanoscaled, microelectronic sensor systems for detecting and monitoring of environmental chemical agents

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Community-Based Risk Assessment Workshop

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Where did ORCAS come from?

UT + Battelle + ORAU OAK RIDGE ASSOCIATED UNIVERSITIES = UT-BATTELLE

ORAU OAK RIDGE ASSOCIATED UNIVERSITIES =

Florida State University

Georgia Tech

Vanderbilt

Virginia Tech

Duke University

NC State University

University of Virginia

The Mission…

- ORCAS is a think and do consortium of research universities, government, industry, and non-governmental organizations.

- It is focused on critical issues with strong science and technology content.

- Problems are framed broadly, taking into account their scientific, technical, economic, social, and policy dimensions to develop research and integrated strategies for addressing those challenges.

- We attempt to ensure that our ideas and research are translated into action.

April 2006 Workshop…

Nanotechnology Applications in Environmental Health: Big Plans for Little Particles

- Introduction of two research communities
  - Nanomaterials/nanosensors
  - Environmental health/ecological health
- Exploration of the “art of the doable” on the nano-side
- Discussion of the possible environmental health effects, exposure assessment and ecological health applications
- Better informed communities with likelihood of beneficial interactions in the future

The Case for Nanotechnology – ***Commentary by Michael Strano (Asst. Professor, University of Illinois- Urbana)***

•It has been pointed out that generally the detection limit of a sensor scale approximates the cube of its characteristic length. So smaller sensor elements mean lower detection limits generally.

•The case varies both with the type of material used in its design and the physical and chemical properties of that material.

•Fluorescence-based techniques are some of the most powerful molecular detection methods available. Single molecule fluorescence analysis is a now routine. For optical fluorescence-based sensors, there are classes of nanoparticles that exhibit extremely enhanced photostability in fluorescent emission. This means that for the first time, new types of sensors can be devised with extremely long operational lifetimes. This is not possible with conventional fluorophores (e.g., single-walled carbon nanotubes are infinitely photostable at moderate light fluxes).

•Some nanosystems emit light at longer wavelengths where few conventional materials operate whereas few conventional materials do so. The human body is particularly transparent to near-infrared light in a narrow region of the electromagnetic spectrum. These systems will form the basis of novel detection technologies that can operate in strongly scattering media where fluorescent spectroscopy is limited.

•Nanoparticles can also possess features that are commensurate with biomolecules and other important macromolecular analytes. Electrodes that are narrow enough to fit or conform to biological structures should be capable of transducing subtle changes in these structures**,**

The Case for Nanotechnology – **Sensor shelf-life, Real-time detection, Useful life**

•Shelf Life – varies as a function of the sensing layer. For example, bioreceptors (antibodies, enzymes, lipid layers) are limiting factors because of their inherent short life span under non physiological conditions. On the other hand, aptamer- and polymer-based sensing layers have been used in an effort to extend the lifetime of the device.

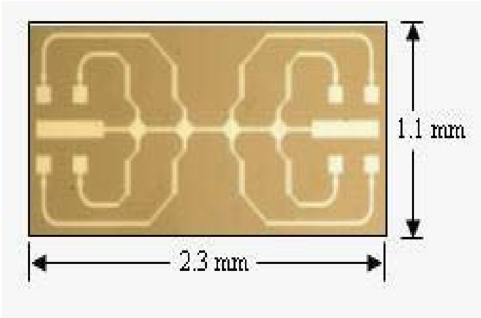
•Real-time Detection - is a common feature of nanosensing technology. The nanosensors described in the meeting all operated on a time scale ranging from seconds to minutes.

•Useful life - The binding mechanisms for the sensor platform can be described as reversible—requiring little or no surface treatment to return the sensor to its steady state—or irreversible where analyte binds with high affinity such that surface treatment is required to remove the bound substrate.

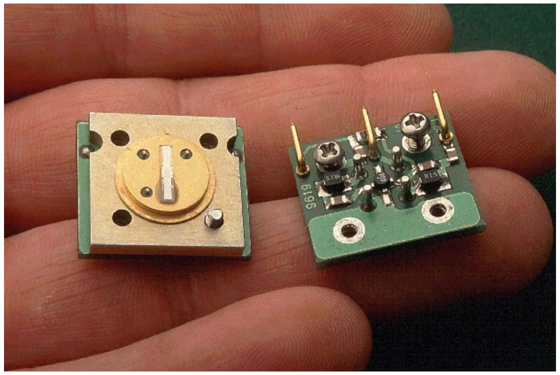
Examples of Technologies Employed in Exposure Assessment

Technology Description	Technology Platforms	Value to EPA	Advantages	Limitations
Location and activity sensors	Global Positioning Systems (GPS), Geographic Information Systems (GIS) and Accelerometers.	Provides information on potential sources of environmental exposure (exposure potential).	Provides location and activity information of study participants. Commercially available.	Unable to receive data inside steel and concrete structures.
Electronic Diary	Personal Data Assistants (PDA) devices.	Provides link between personal exposure, daily activities and dietary consumption.	Real-time information, captured in personal diaries, and questionnaires. Commercially available.	Requires a certain level of technology literacy to operate.
Wearable Sensors	Microelectronic Arrays: Cantilever arrays, acoustic sensors, Radio-frequency Identification (RFID) tags, Microelectromagnetic systems (MEMs) sensors.	Provides a less intrusive method of monitoring personal exposure to a variety of environmental pollutants in real-time.	Real-time PM measurements. Size: micro-nano. Sensitivity: ppb/ppt range. Low cost (~$3/chip). Child-friendly design.	Micro- to nano- scale device poses design issues. Still under R&D and not commercially available. Selectivity issues.
Portable Sensors	Fluorometric biosensors, Optical sensors, Potentiometric sensors, Amperometric sensors.	Links personal exposure to environmental pollutants/stressors to health effects.	Near real-time measurements. Links pollutant to health effects. Sensitivity: ppb/ppt range.	Selectivity issues. Not commercially available.

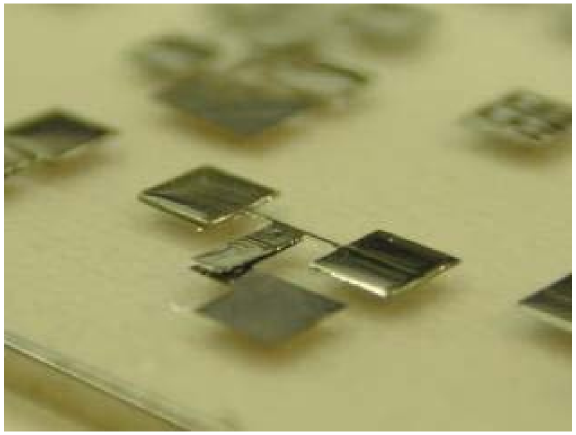
Emerging Technologies in Exposure Assessment



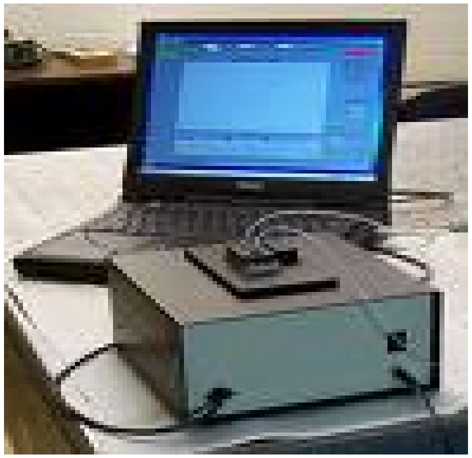
Passive RFID Tag



Electronic nose: “Dog-on-a-chip”

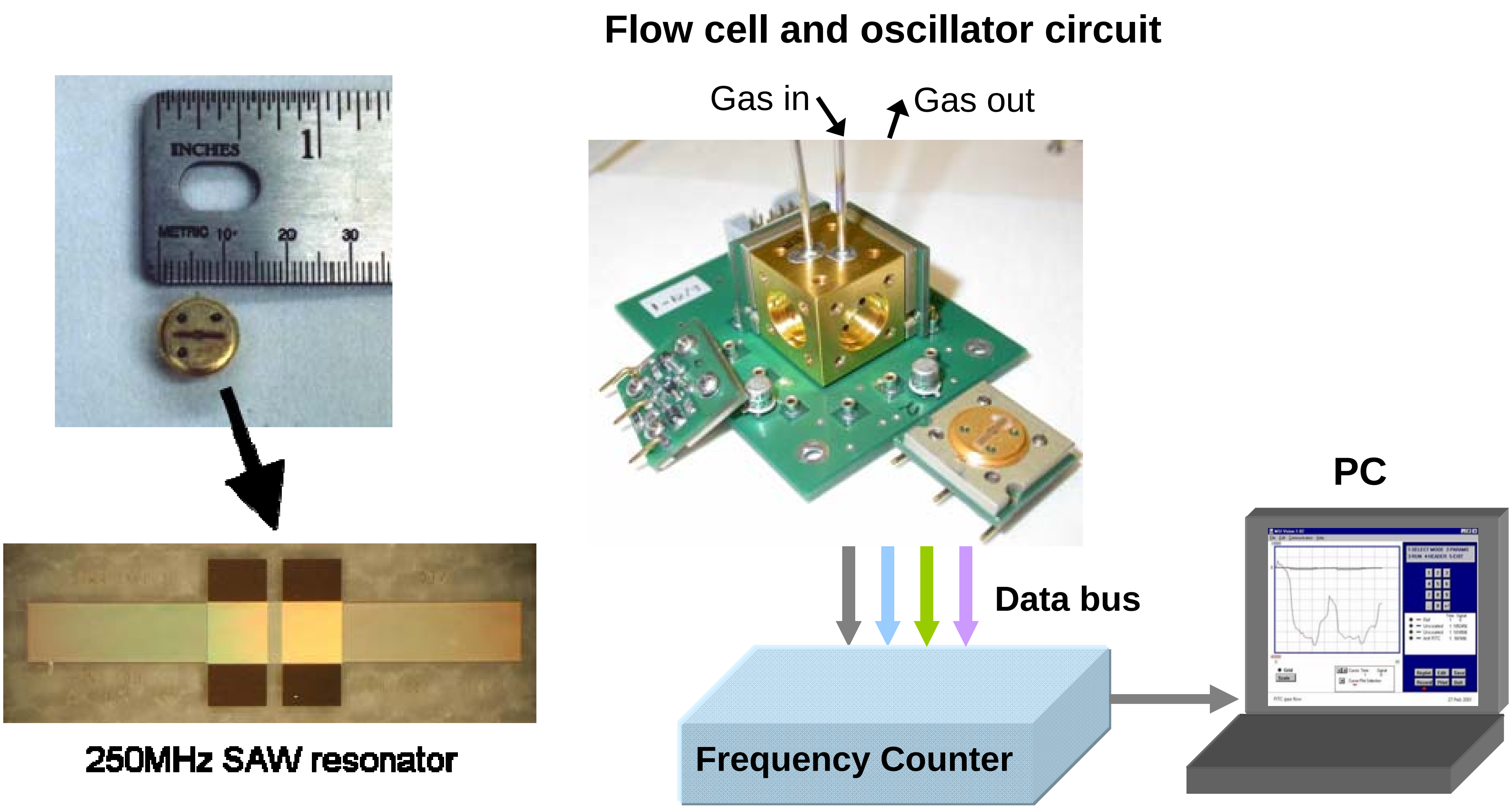


Microelectromagnetic Sensor

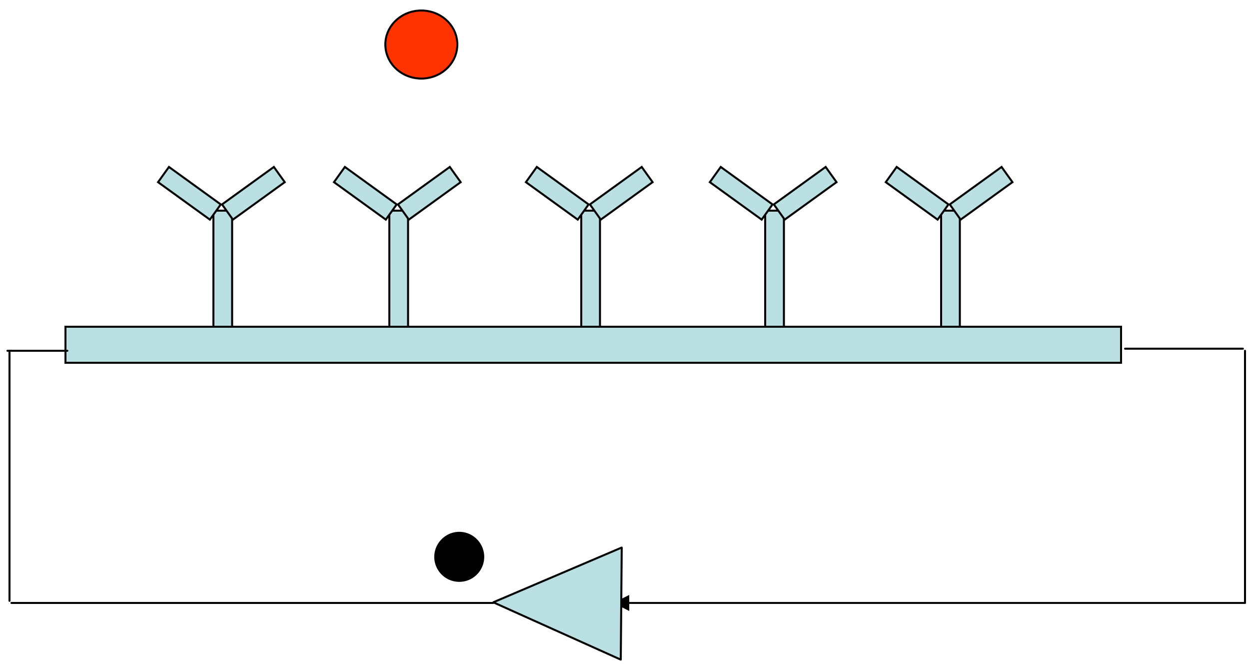


Interferometric Optical Sensor

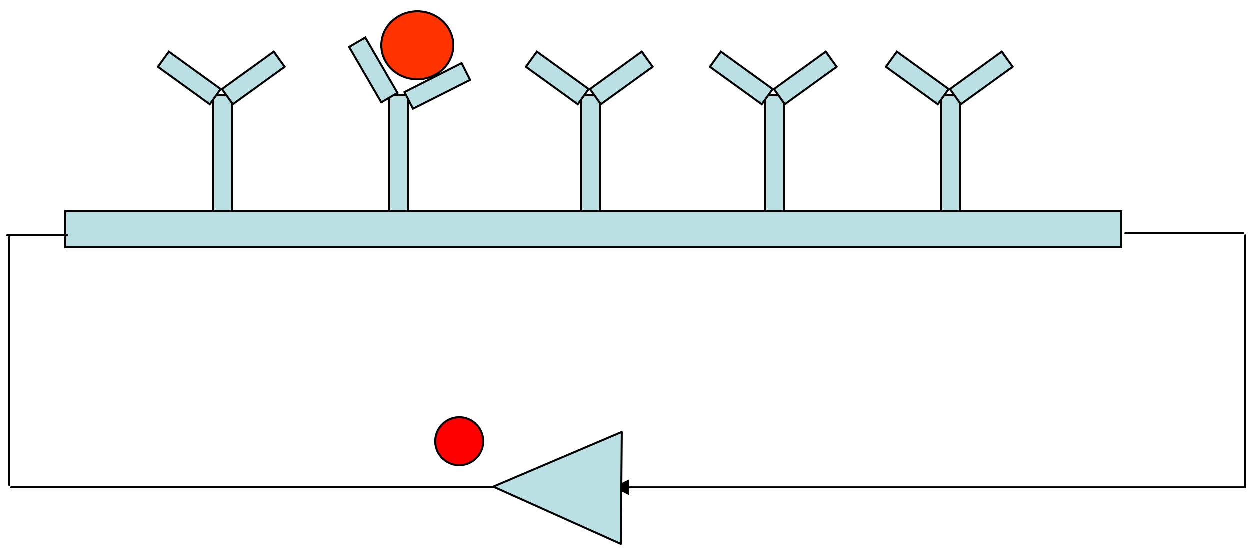
Vapor phase sensor system



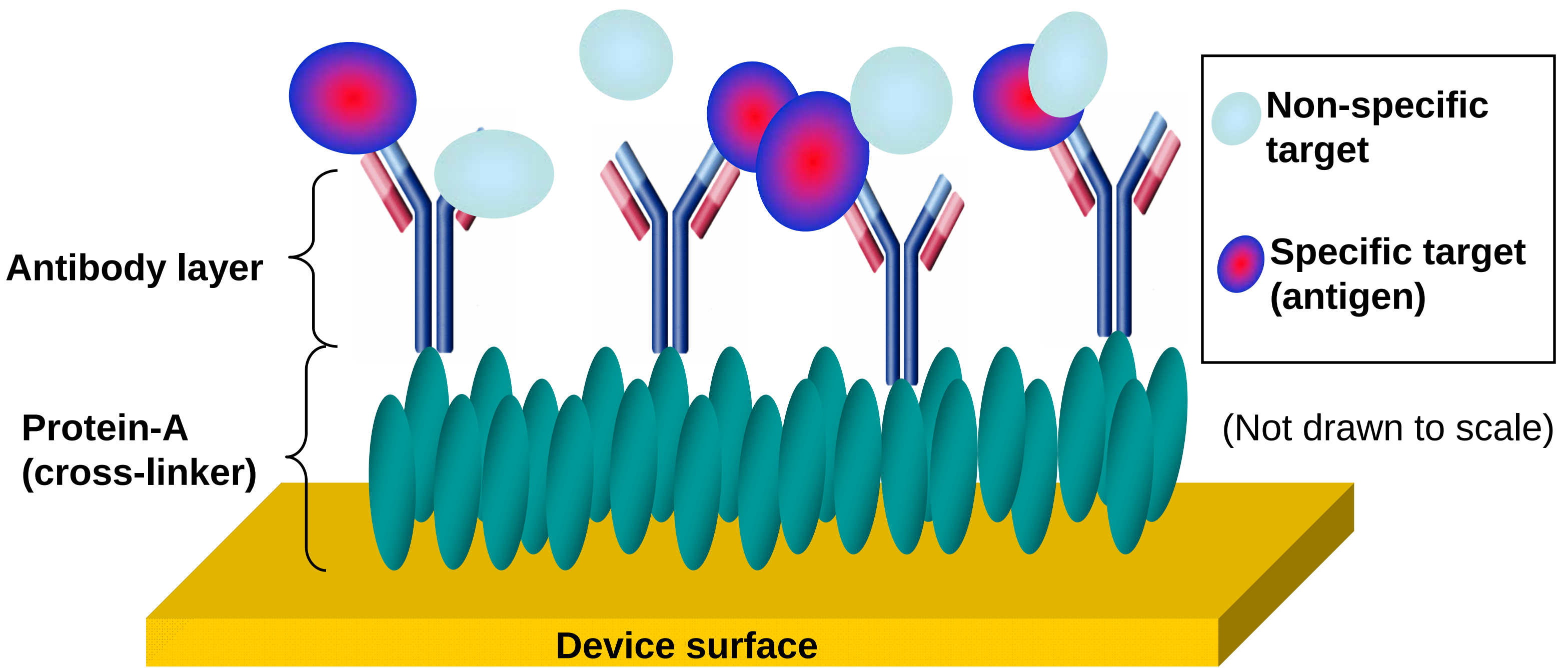
Principle of Operation



Principle of Operation



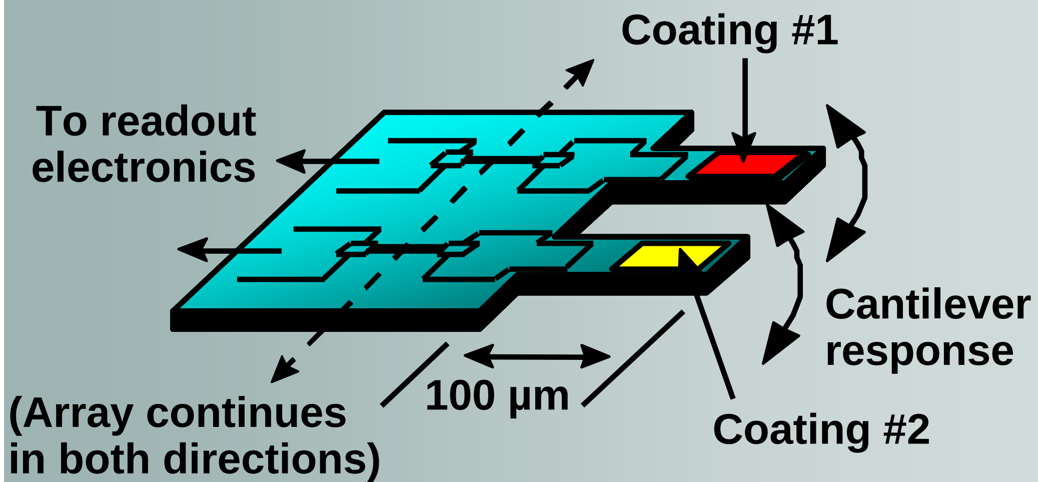
Antibody Immobilization on Au Electrodes

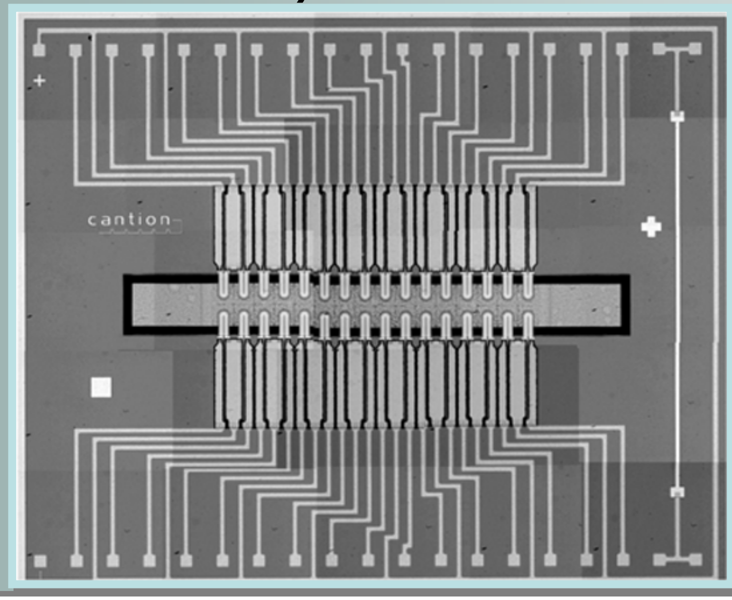


Courtesy Sang Hun Lee

Multi-Analyte Detection - Arrays

- Arrays of sensors on a *single chip* with *selective coatings for* application-specific programmable sensors
- Arrays give more information than separate sensors
- Coupled to *custom* readout electronics
- Telemetry
- Mass production
- Inexpensive



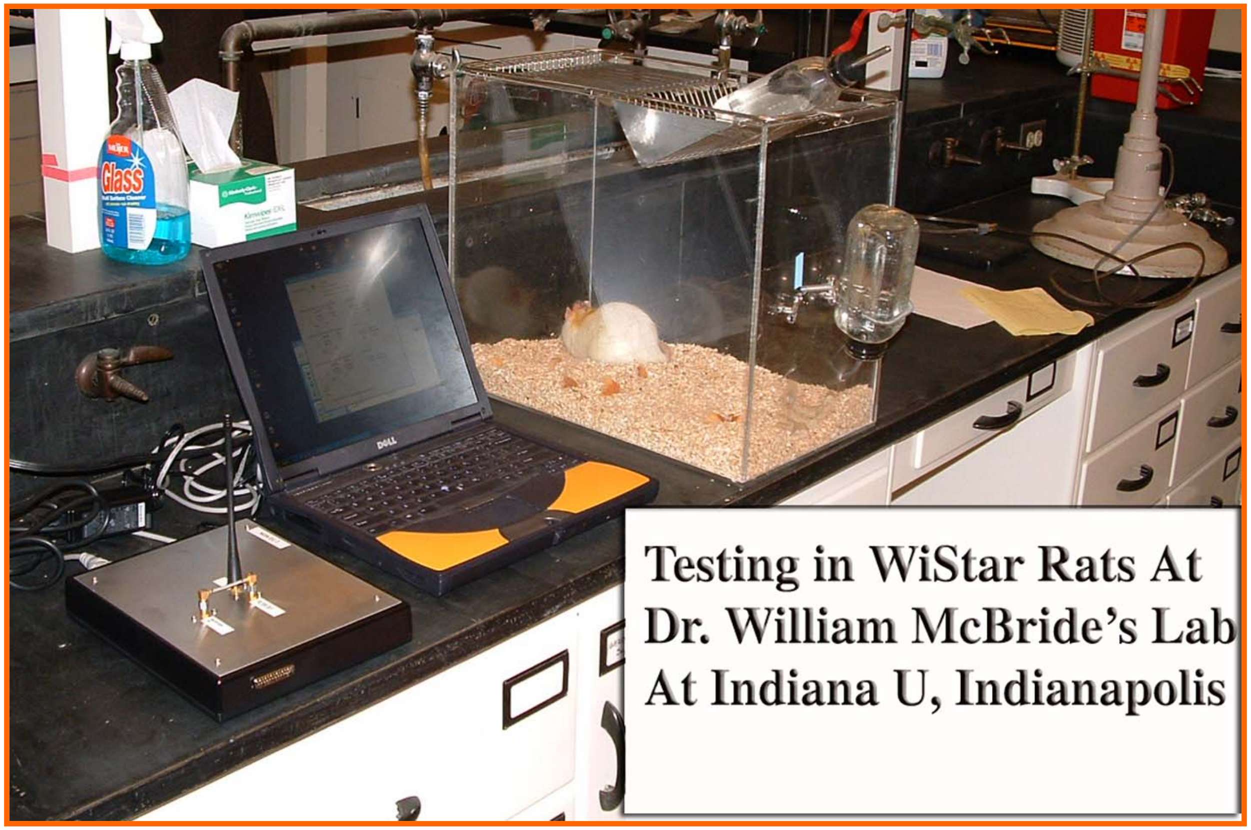


Implanted Behind Neck in WiStar Rats to Measure Ethanol Levels

Rats Injected with One g/Kg of Eth

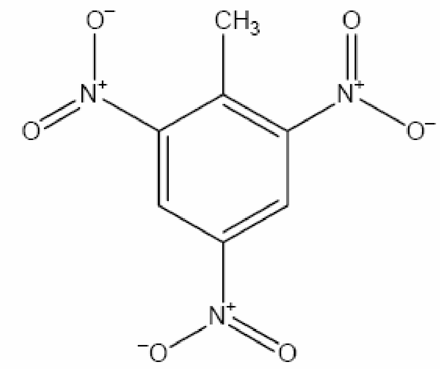
Body Temperature & Eth Monitored For Several Hours

Data from Interstitial Fluid Tracked Blood Lvl



Testing in WiStar Rats At Dr. William McBride's Lab At Indiana U, Indianapolis

Why TNT?



2,4,6-Trinitrotoluene (TNT)
Low vapor pressure ~ 1.99 x 10^{-4} Torr

Ability to detect trace levels of TNT is key to:

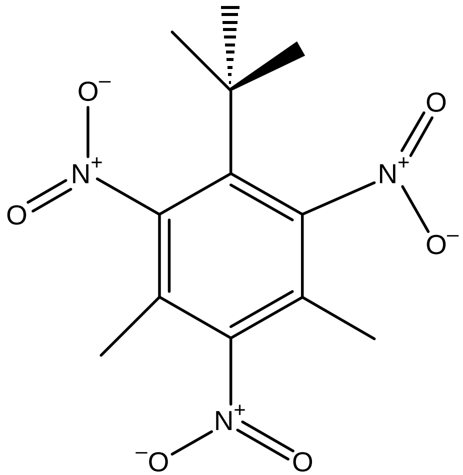
•Reducing fatalities from land mines (TNT constitutes 80% of all land mines -there are over 100 million scattered across the planet)

•Tracking explosives materials (Anti-terrorism)

•Environmental concerns (water and soil contamination)

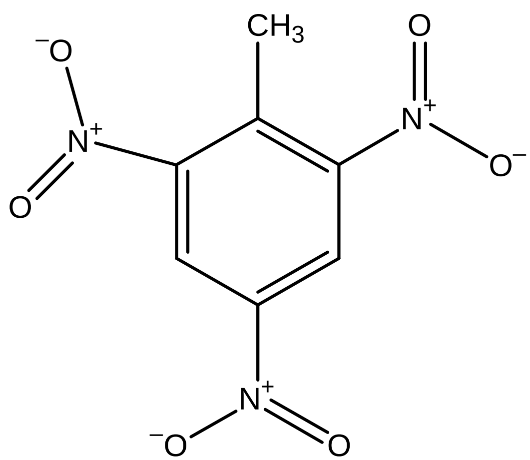
TNT Analogs

Musk Oil (Musk Xylene)



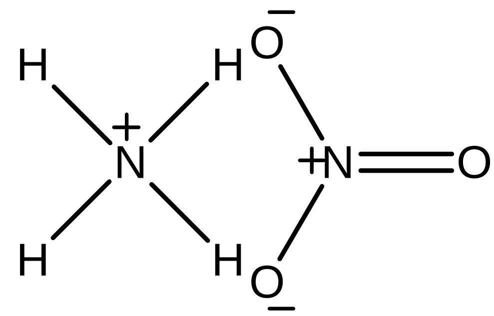
1-*tert*. -Butyl-3,5-dimethyl -2,4,6-trinitrobenzene

TNT

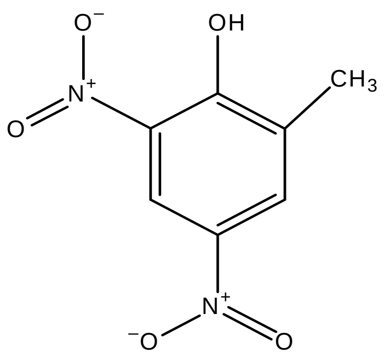


2-Methyl-1,3,5-trinitro-benzene

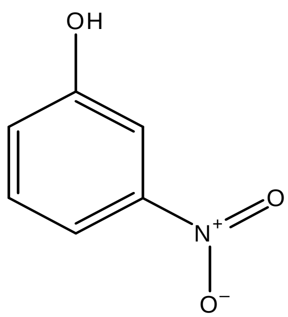
Ammonium nitrate



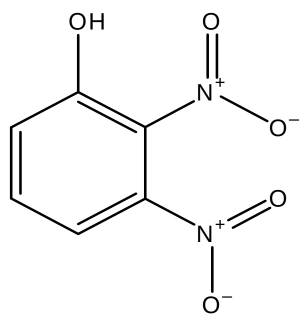
TNT Analogs



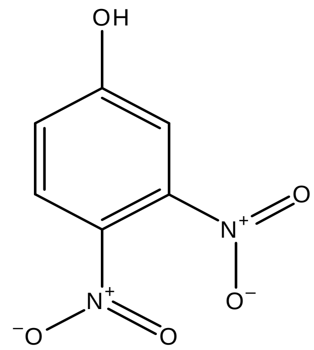
2-Methyl-4,6-dinitro-phenol



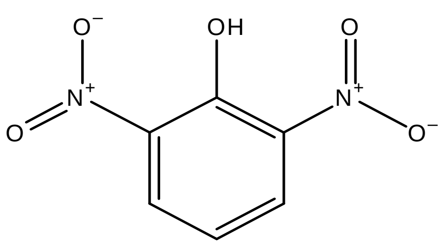
3-Nitro-phenol



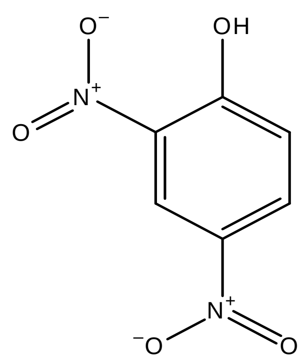
2,3-Dinitro-phenol



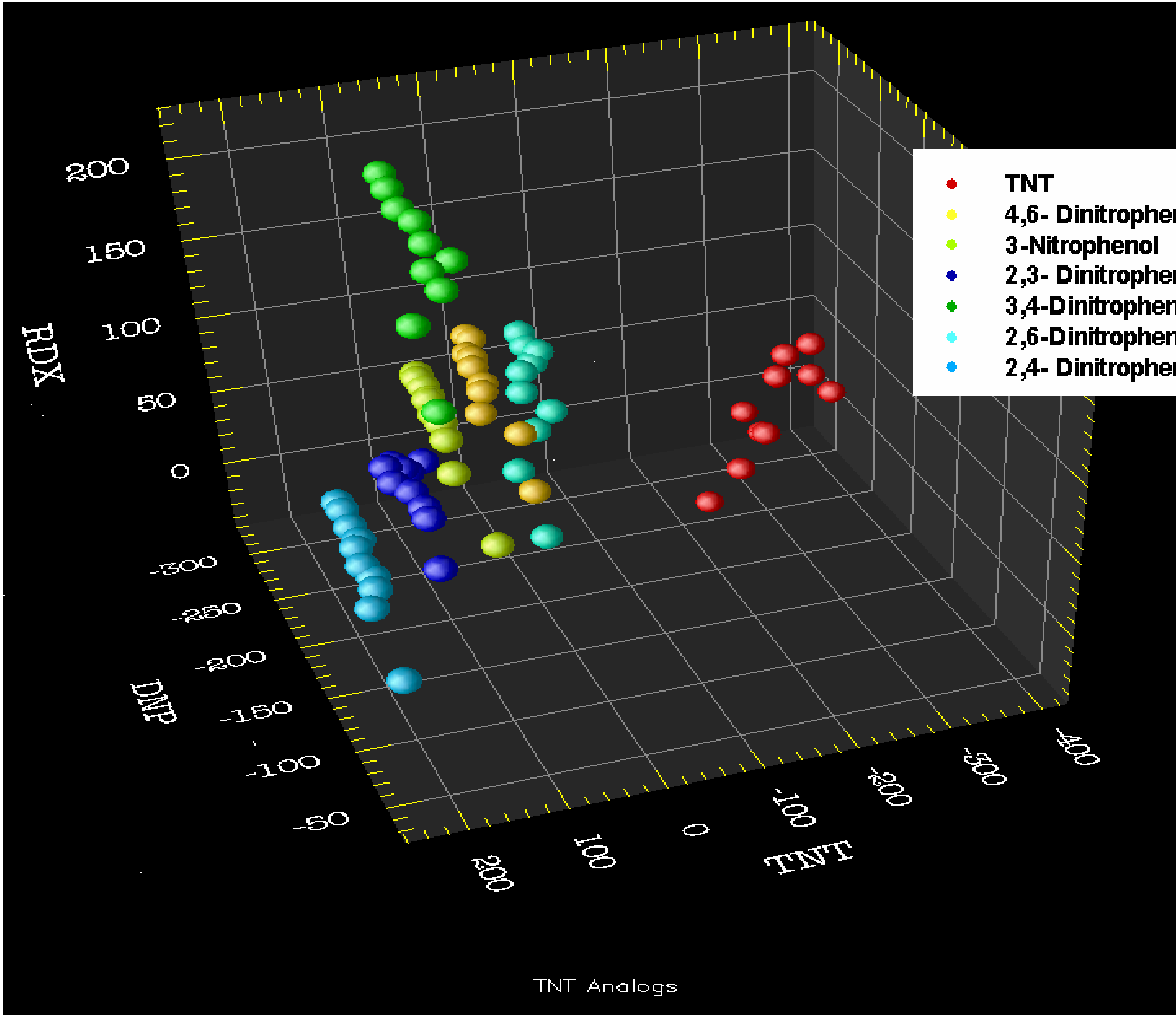
3,4-Dinitro-phenol



2,6-Dinitro-phenol



2,4-Dinitro-phenol


TNT
4,6- Dinitrophenol
3-Nitrophenol
2,3- Dinitrophenol
3,4-Dinitrophenol
2,6-Dinitrophenol
2,4- Dinitrophenol
RDX
200
150
100
50
0
DNP
-300
-250
-200
-150
-100
-50
TNT
200
100
0
-100
-200
-300
-400
TNT Analogs

Questions?