Explosives Trace Detection

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"Putting First Responders First"

Homeland Security
Science & Technology

Explosives and Weapons Detection ‘Bulk and Trace’ Programs

← Bulk →

← Trace →

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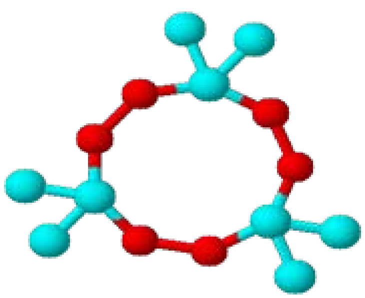
Trace Detection

- Can be solid (particulate) or gas (vapor) phase.
  - ppm, ppb, or even ppt
- Identifies explicit composition



TATP

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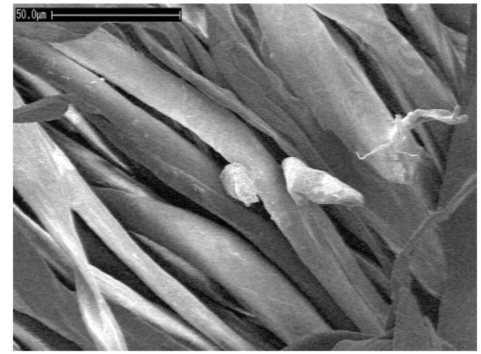
Explosives Detection Overview

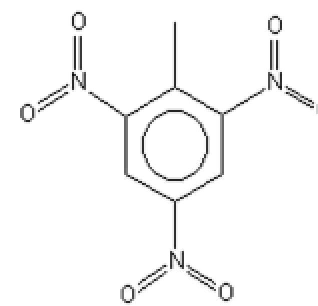
Trace Detection – Chemistry Approaches



C-4 particle on cloth at 400X

- Detection of trace (<ng/ppb) levels of explosive particles *and* vapors resulting from contamination

Vapor signature



Vapor molecule of TNT

Trace Detection - What are we finding?

- 1-100 Nanogram of residue
- On the Concealment (BOMB)
- On the Latches, Handles, etc (bags, cargo, vehicles, people, ...)
- On the Interior of the Surfaces
- On the Exterior of the Surfaces

Where does the Traces of Explosives Come From ?

- Contact with the Bulk Explosive
- Aerosolized Explosive
- Secondary Fingerprints
- Contact with Contaminated Hands (gloves)
- Contact with Surfaces - Tools & Workplace

Explosives Detection Overview

Classification of Explosives

- Explosives Matter
  - Explosives
    - High Explosives
      - **Primary (initiating)**
        - Lead Azide
        - Lead Styphnate
        - Mercury Fulinate
        - Tetryl
      - **Secondary**
        - Military Explosives
          - TNT
          - RDX
          - HMX
          - PETN
          - PBX-*
          - Boosters
        - Industrial Explosives
          - Dynamites
          - Permitted Explosives
          - ANFO
          - Slurries Emulsions
          - Binary
    - Propellants
      - **Rocket Propellants**
        - Double Base
        - Triple Base
        - Liquid
      - **Gun Propellants**
        - Smokeless
        - Black Powder
    - Pyrotechnics
      - Flashes
      - Flares
      - Noise Generators
      - Smokes
      - Fireworks
  - **Industrial Chemicals** which can form Explosive Mixtures
    - Ammonium Nitrate
    - Sodium Chlorate
    - Organic Peroxides
    - NG, PETN (Medical Use)
    - Solid Fuel (camp Stoves)

Characteristics of Explosives

- **Detonation velocity**
- **Intimacy of fuels**
- **Sensitivity to external stimuli**

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Explosives

Standard Explosives

- TNT
- RDX
- PETN
- Nitroglycerin (NG)
- Ethylene Glycol Dinitrate (EGDN)

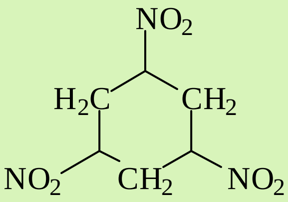
Plastic Explosives

- C-4 (RDX)
- Detasheet (PETN)
- Semtex (RDX + PETN)

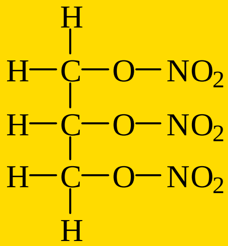
Improvised Explosives

- ANFO (Ammonium nitrate + fuel oil)
- Urea nitrate
- Triacetone triperoxide (TATP)

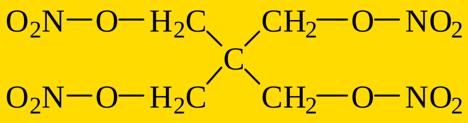
Explosive Compounds



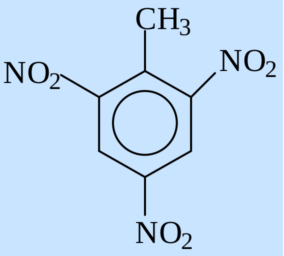
RDX



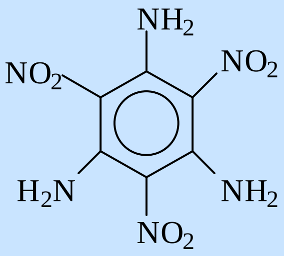
NG



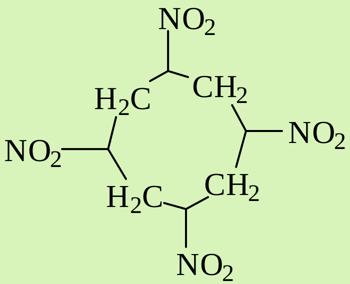
PETN



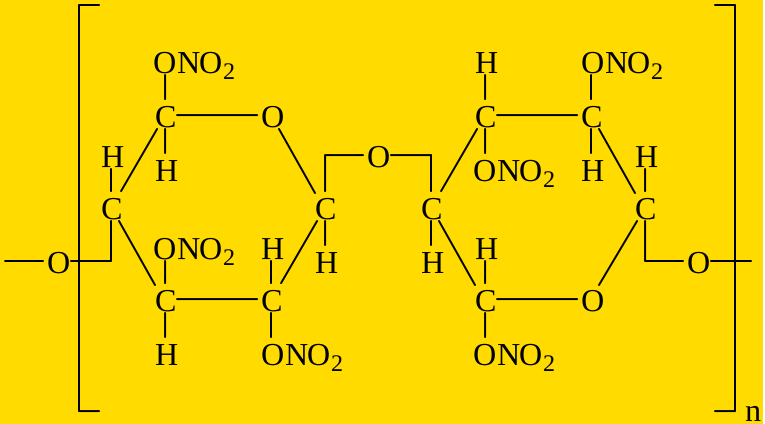
TNT



TATB

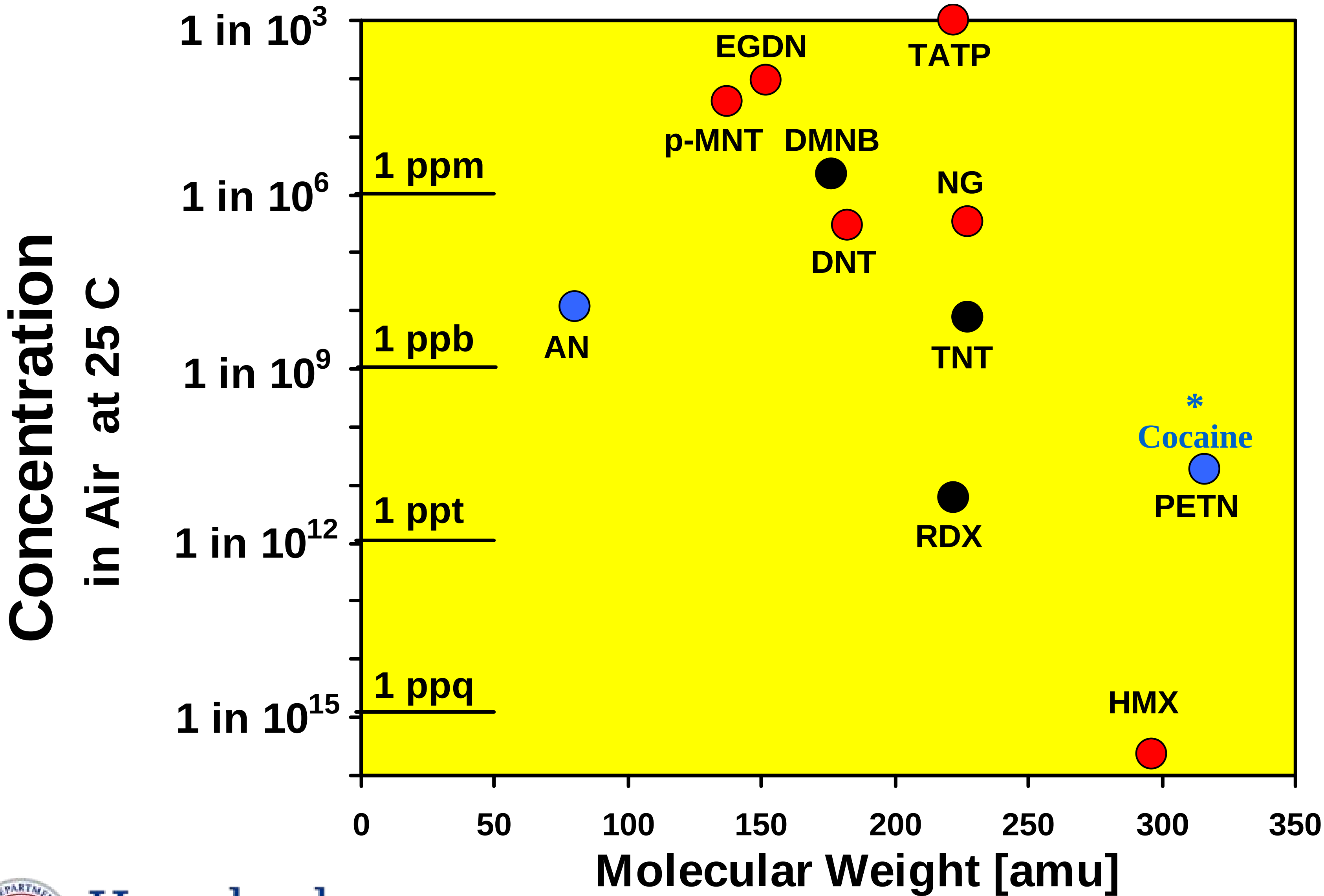


HMX



Nitrocellulose

Vapor Pressure, at Room Temperature . . .



Ref: US DOE study . . .

Trace Detection: Three processes

- Collect - the sampling process…Front-end collection / preconcentration…

- Separate - provides selectivity of threat…

- Detect - provides sensitivity for the threats of interest…

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Particle vs. Vapor Sampling

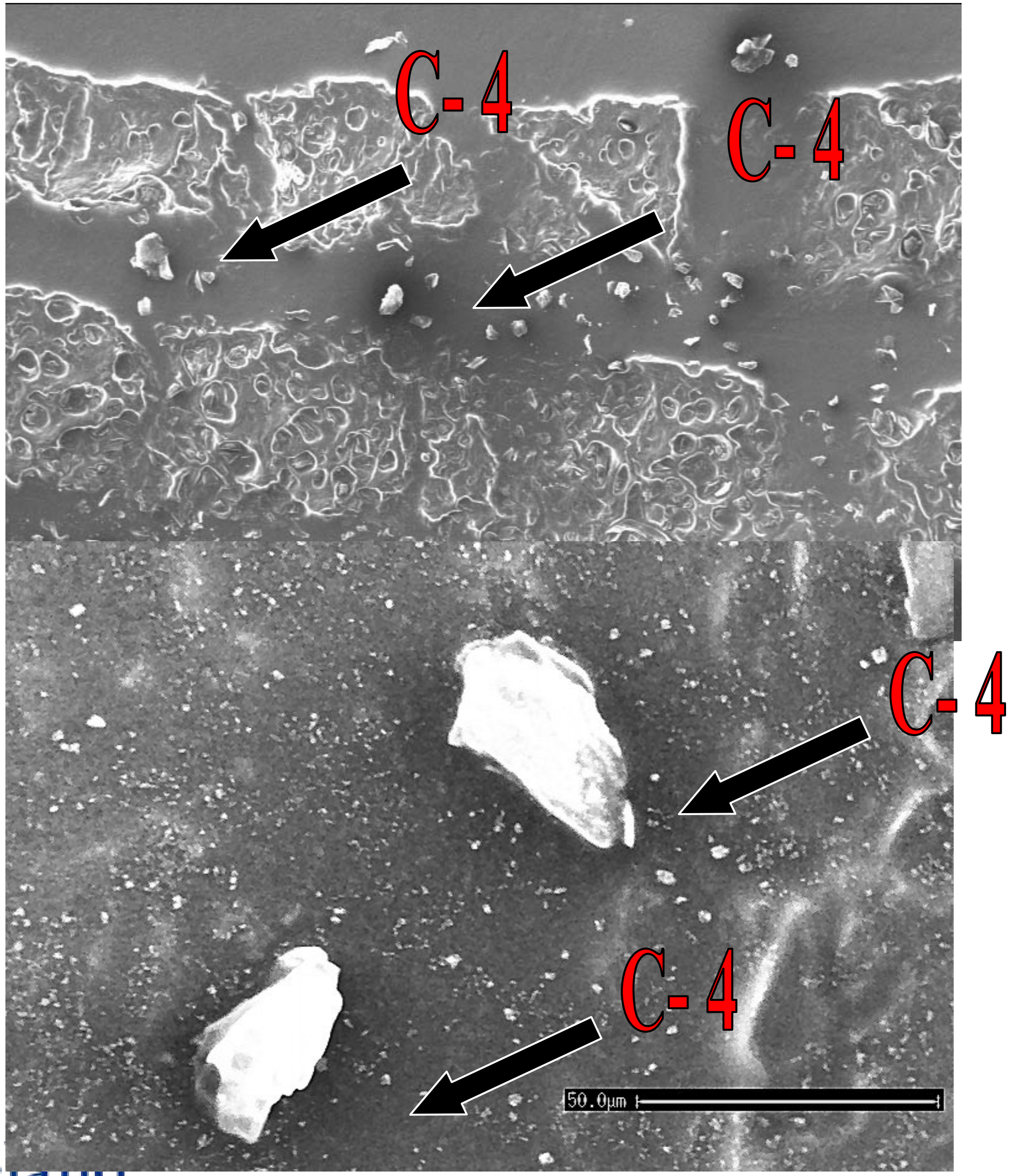
- Most threats only provide spread via particles…
  * exceptions - newer homemade threats…

- Particle - hard, solid surfaces; contact swiping
  - soft surfaces, air jet or vac. sampling

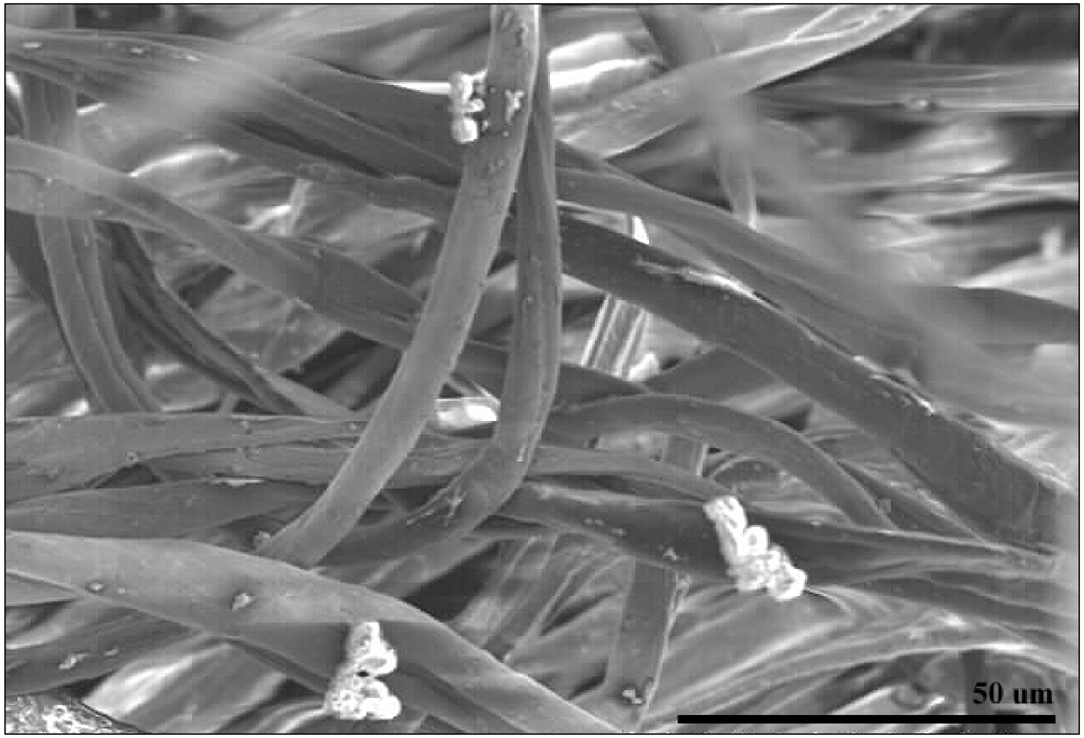
- Vapor - High and low volume air collection.

- Today - need for both, simultaneous…

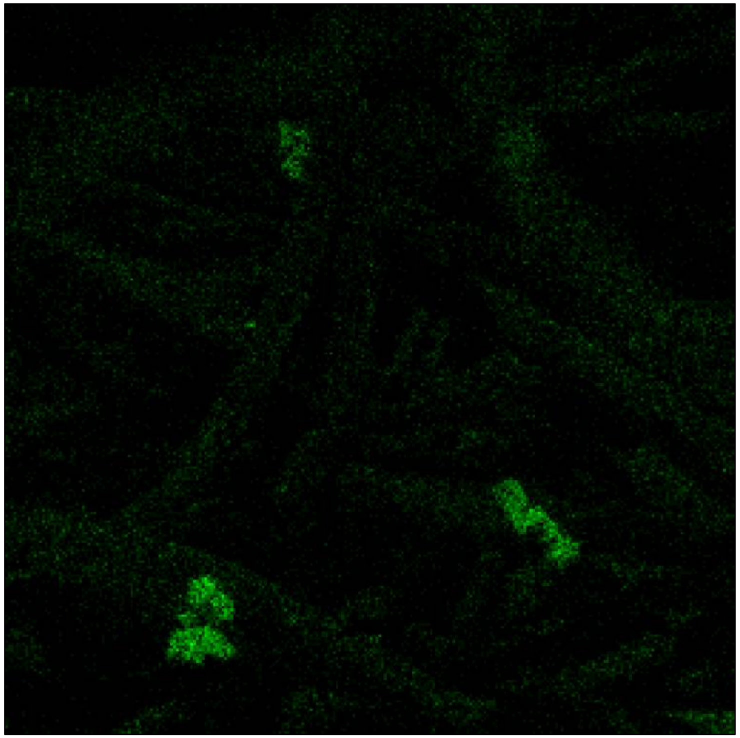
C-4 Fingerprint



X-RAY MAPPING OF C-4



SEM of C-4 on Muslin



X-ray Nitrogen Map

Particle Sampling

- How to remove from surfaces;

- First, need to know physical and chemical properties of the threat of interest … particle size, stickiness, binding forces, vapor pressure, etc.

- Sample Swiping method - efficiency of collection; careful selection of material, collection via hand wiping or sampling wand, area per collection and pressure to be applied, etc.

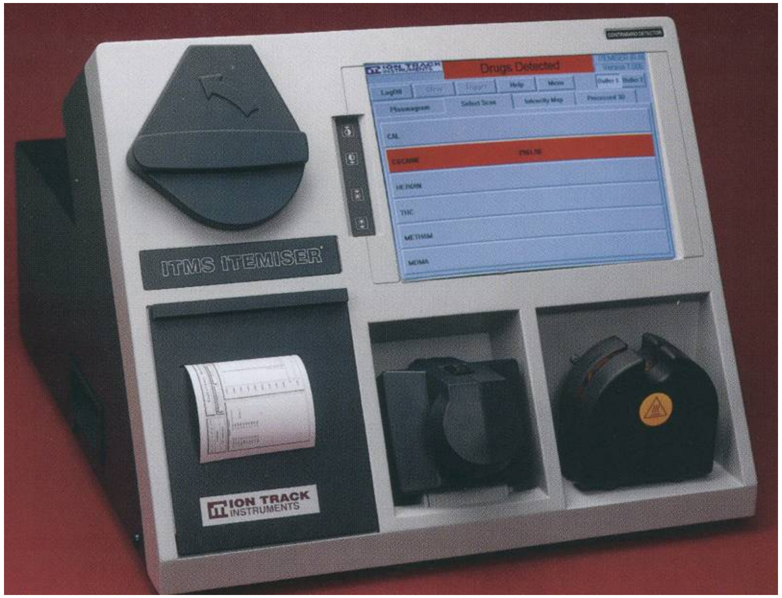
.

-Enviromental effects; dry vs. wet surface (vs. type of sample swipe), clean vs. dirty surfaces, etc.

Reference herein to any specific commercial products, processes, equipment, or services does not constitute or imply its endorsement, recommendation, or favoring by the United States Government or the Department of Homeland Security (DHS), or any of its employees or contractors.

Commercial Trace Sampling Wands

Explosives Detection Overview
Trace Detection – Deployed Particle Equipment



Smiths Detection

IonScan 400B

GE-Ion Track

Itemiser^2

Vapor Sampling

- **How to collect from surfaces;**
- **First, need to know physical and chemical properties of the threat of interest … vapor pressure, sublimation rate, etc. --------->>>**
- **Sample method - efficiency of collection; careful selection of collection via low volume or high volume sampling, distance to suspect item critical, etc.**
- **Enviromental effects; temperature (range of temp), clean vs dirty surfaces (amount of other non-threat vapor), etc.**

Sampling for Explosive Vapors

Reynolds Averaged Navier-Stokes

$$\frac{\partial U_i}{\partial x_i} = 0 \qquad \frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{\partial \hat{p}}{\partial x_i} + \frac{1}{Re}\frac{\partial^2 U_i}{\partial x_j \partial x_j} - \frac{\partial}{\partial x_j}\overline{u_i u_j} + \delta_{i3}\frac{Gr}{\mathrm{Re}^2}\Theta$$

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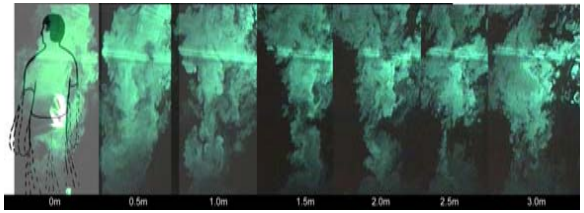

Explosives Detection Overview
Trace Detection – Vapor Detection Equipment

GE – IonTrack

VaporTracer2

Smiths Detection

Sabre 4000

Explosives Detection Overview

Trace Detection – Whole Body Screening

GE – IonTrack

EntryScan³

Syagen

Guardian

Smiths Detection

Sentinel

Explosives Detection Overview
Trace Detection – Canines

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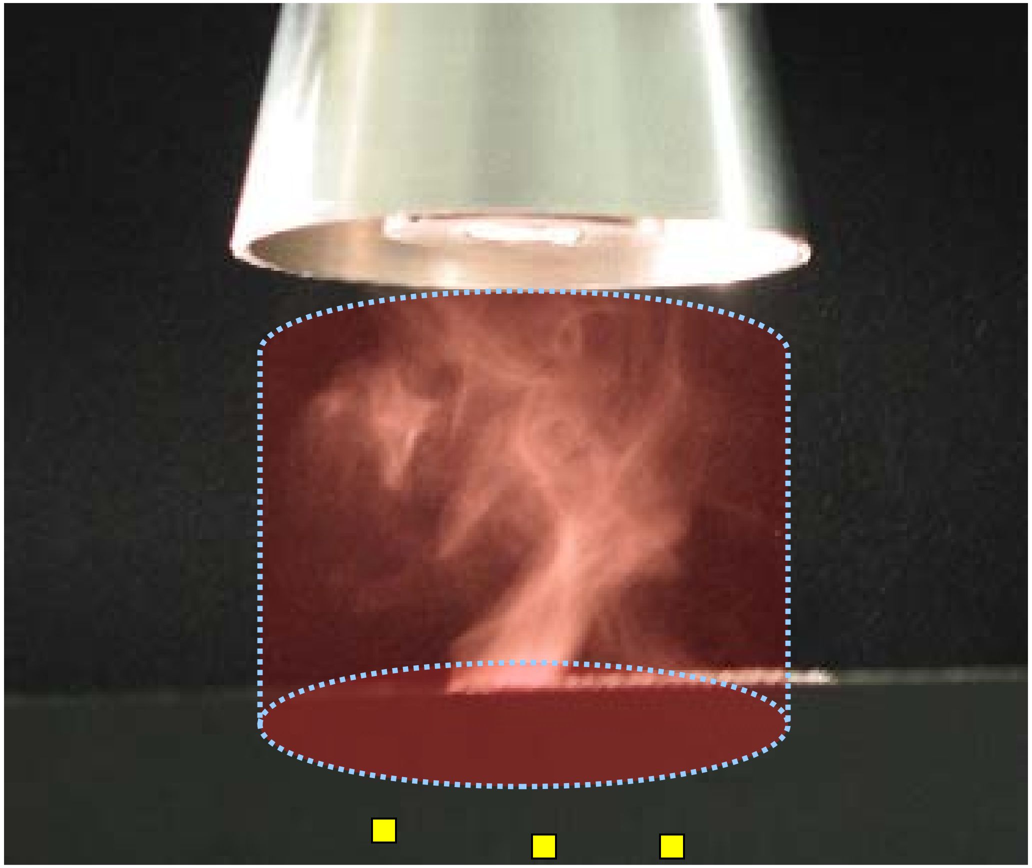
Vortex Sampling System



Axial cyclone with return flow designed to generate an artificial tornado and pick up vapors of explosive materials without physical contact with a surface.

Sampling distance is ½"-13½".

Trace Explosive Detection Technologies

- Electronic/Chemical: Picogram sensitivity
  - Ion Mobility Spectrometry : Widespread use: Separates and Analyzes in seconds
  - Chemiluminescence: Extremely sensitive, need to separate explosives from other compounds
  - Electron Capture Detection: Sensitive, but needs separation step
  - Surface Acoustic Wave: Trade off between specificity and sensitivity
  - Thermo-Redox: Sensitive, needs separation step
  - Mass Spectrometry: Requires high vacuum, is fragile but very sensitive
- Colorimetric (Chemical): Sensitive only to micrograms to nanograms
- Biosensor
  - K-9s: Sensitive, versatile, must train to application
  - Antigen Antibody: Very sensitive, but very specific

Technology Requirements

- Meet Detection Specification for Sensitivity and Selectivity for Specified Threats.
- Very Low False Alarm Rate
- Very High Probability of Detection
- Minimal Decision Making by Human
- Automated
- Robust
- Can Be Operated by Screeners (Not the Ones That Have a Masters Degree in Physics)
- Not Too Expensive (ETD, consumables, etc.)
- Privacy Concerns Addressed

Deployed Trace Detectors

- BARRINGER
  - Technology - Ion Mobility Spectrometry
  - Approved models - IonScan Models 400 and 400B

- IONTRACK
  - Technology - Ion Mobility Spectrometry
  - Approved models - Itemizer-DOS &   Itemizer-W

- THERMODETECTION
  - Technology - GC/Chemiluminescense
  - Approved models - EGIS Models 3000 & II

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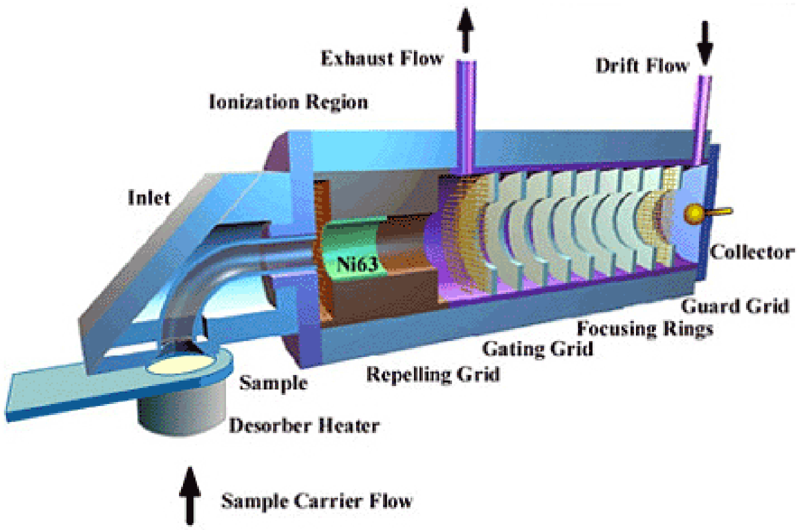
ION MOBILITY SPECTROSCOPY (IMS)



- Substrate heated to vaporize particles
- Molecules are ionized by a weak radioactive source and drift through a weak electric field
- Particle time of flight is a distinct fingerprint, enabling detection

Applications:

- Explosives detection on both luggage and people
- Detection of narcotics

Technical Barriers:

- Dependent on screener sampling
- Susceptible to atmospheric changes
- Calibration requirements
- Saturation possible

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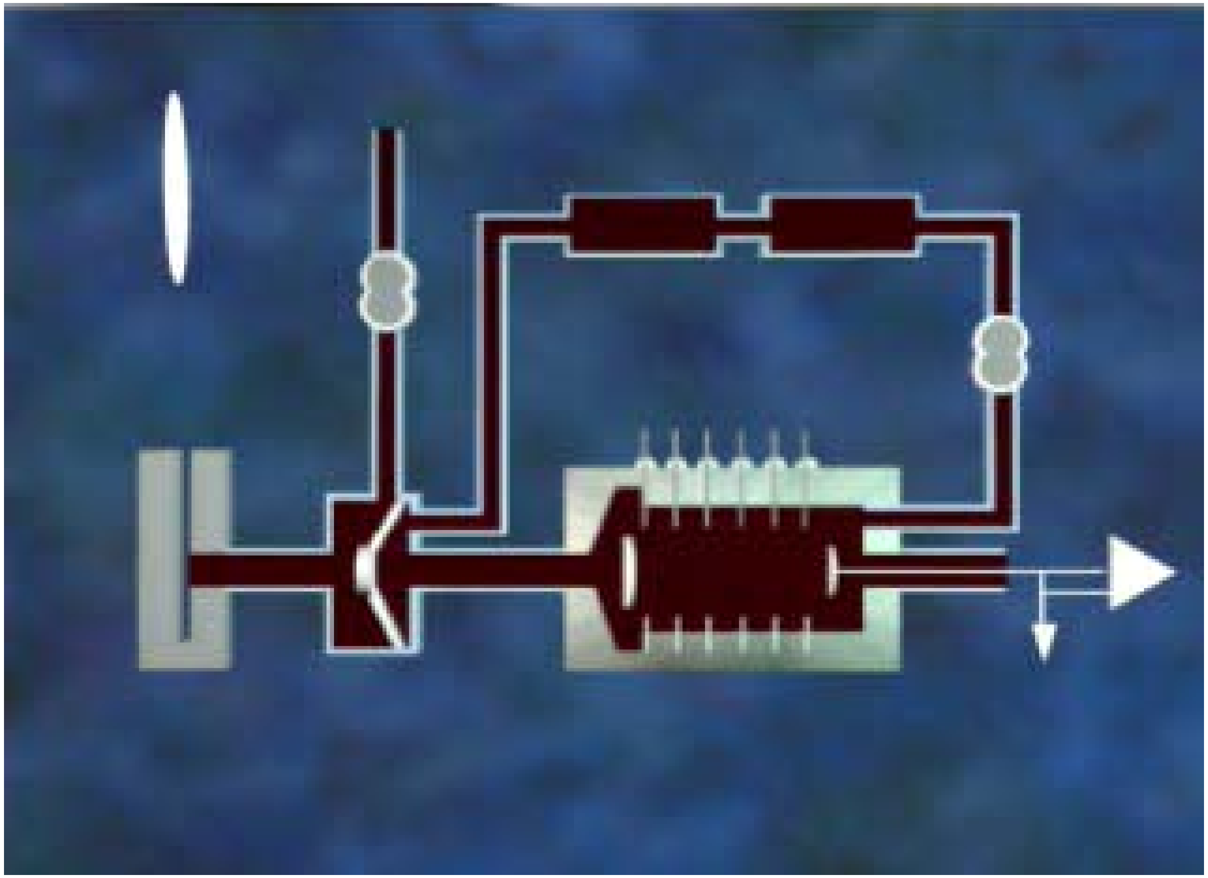
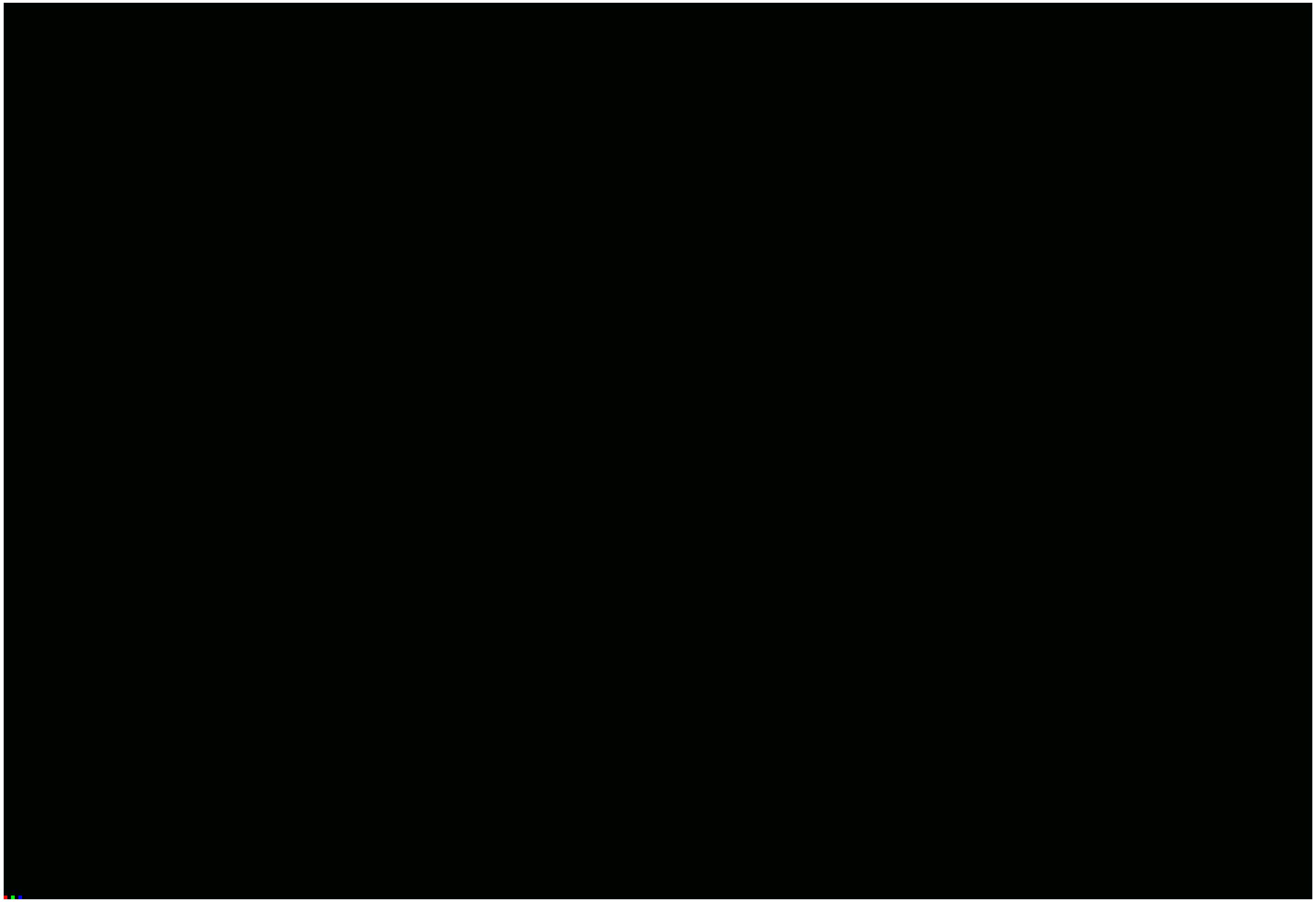
ITMS Detector
How It Works



Simultaneous, Dual-Mode Detector



Challenges to Trace Detection

Interferential Only

An alarm does not necessarily mean a bomb if sampling for particles but you need a good reason to be contaminated! **If you see vapor, YOU HAVE A BOMB!**

Sampling

True vapor and particle sampler does not exist

Its about getting the sample!!

Currently highly dependent on skilled operator

Selectivity/Sensitivity

- A wider range of threats (cross-applications) needs to be addressed and developed for Trace Detection, eg. Chemical agents, transparent Extremely sensitive explosive detectors exist, but ability to detect more compounds, lower false alarm rate needed.

- Operational alarm rates are "reasonable" for many of the current applications; but are prohibitively high in others.

Explosive Trace Detectors
The Future …

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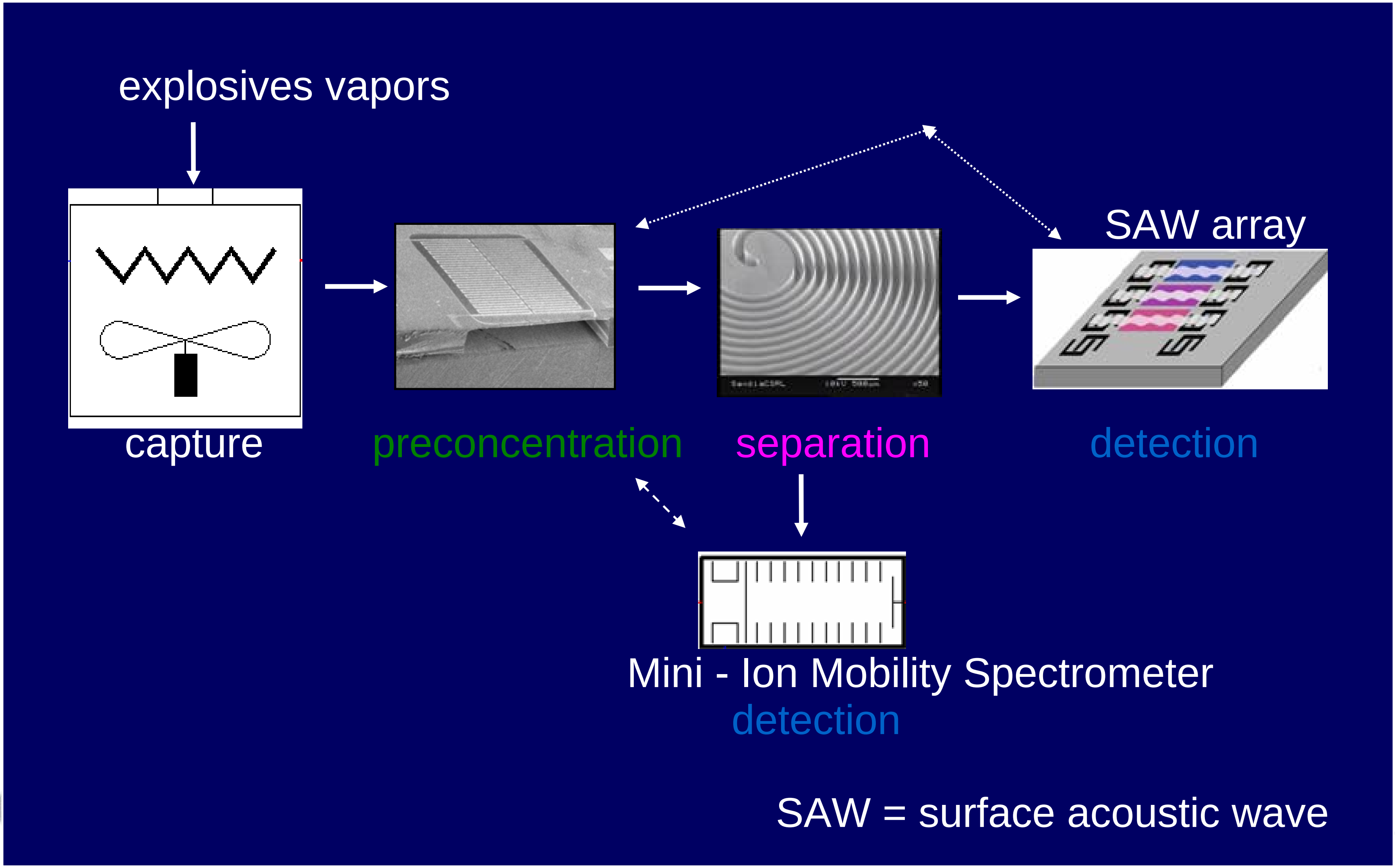
Near – term ETD's . . .
and improvements to sample collection . . .

MicroHound III

MicroHound™ Concept



Microsensors

Requirements for Detection of Explosives for First Responders

- Small and portable
- Specific to one or more explosives
- Array of Sensors – provides full threat coverage, and Improved alarm statistics.
- Sensitive (and Selective).
- Low cost

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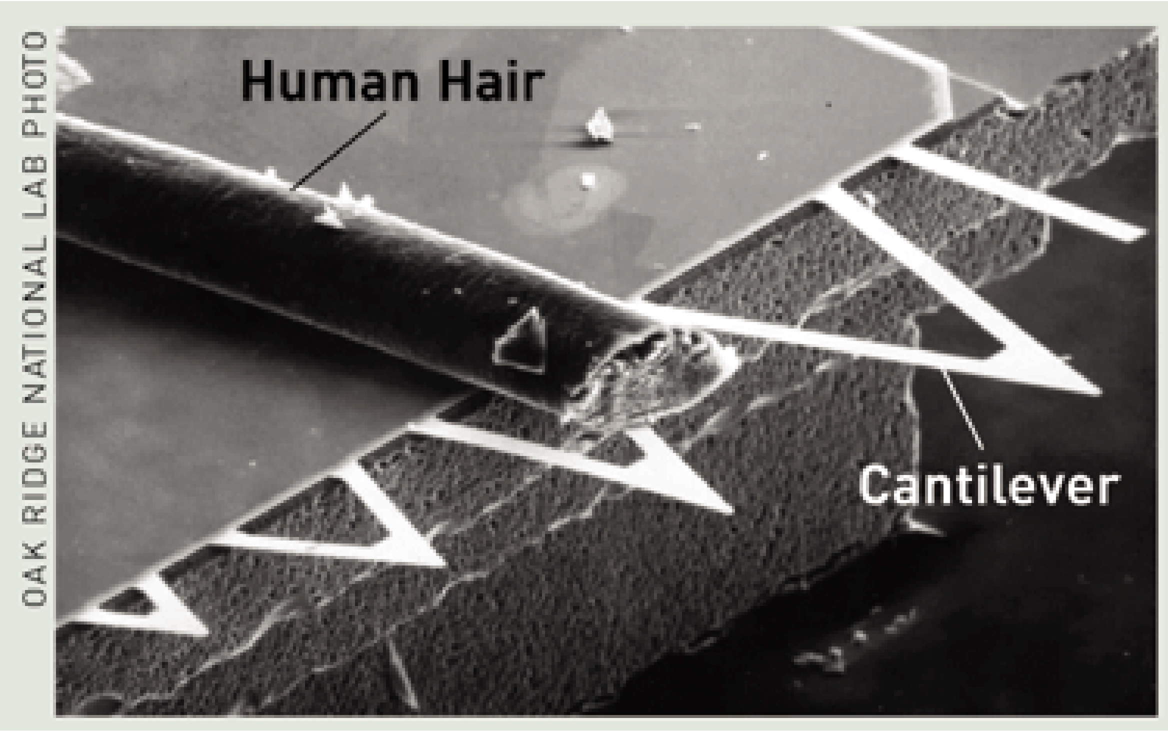
Micro-electromechanical System (MEMS) Cantilever



Ref: T. Thundat et al, ORNL

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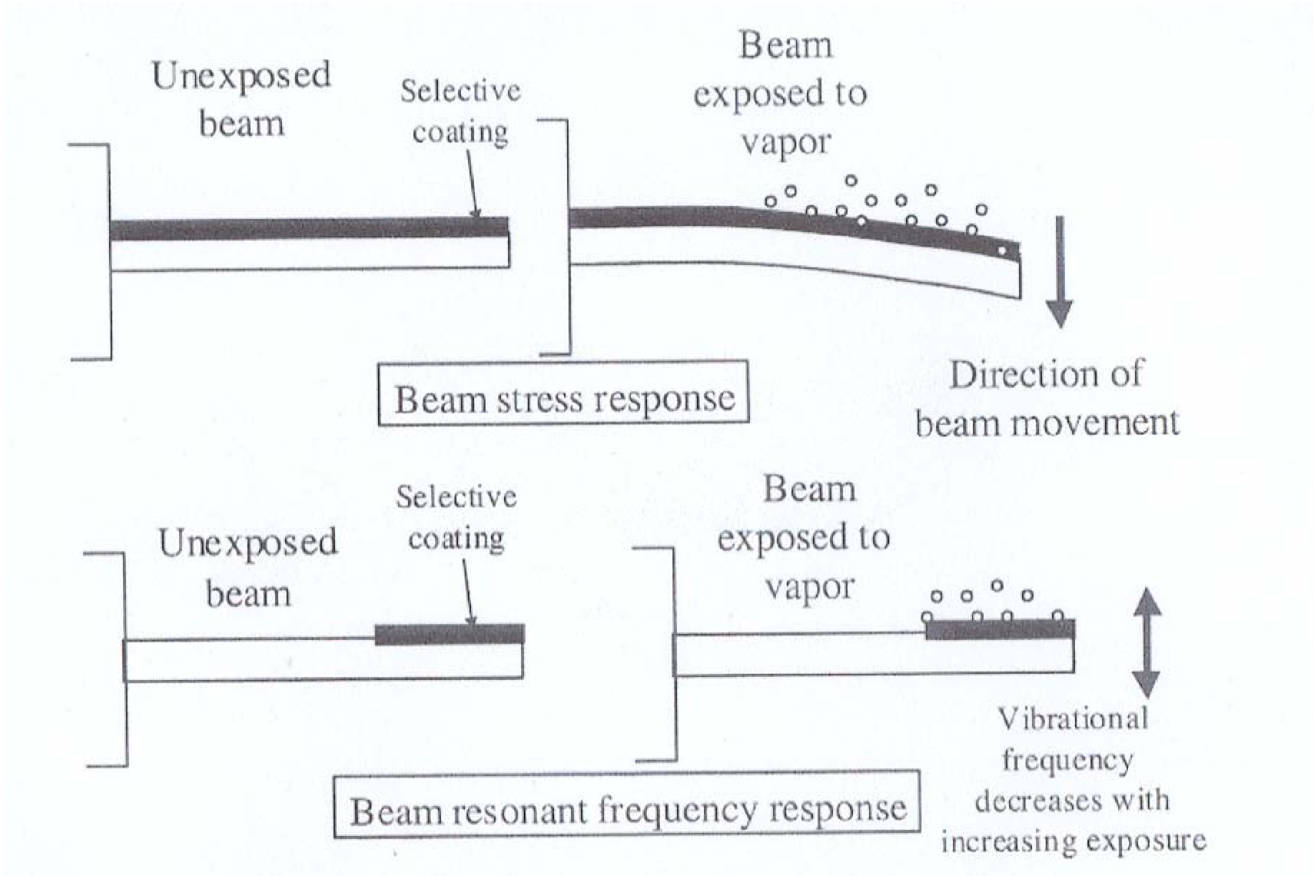
Micro-electromechanical System (MEMS) Cantilever



Ref: Coatings NRL & ORNL

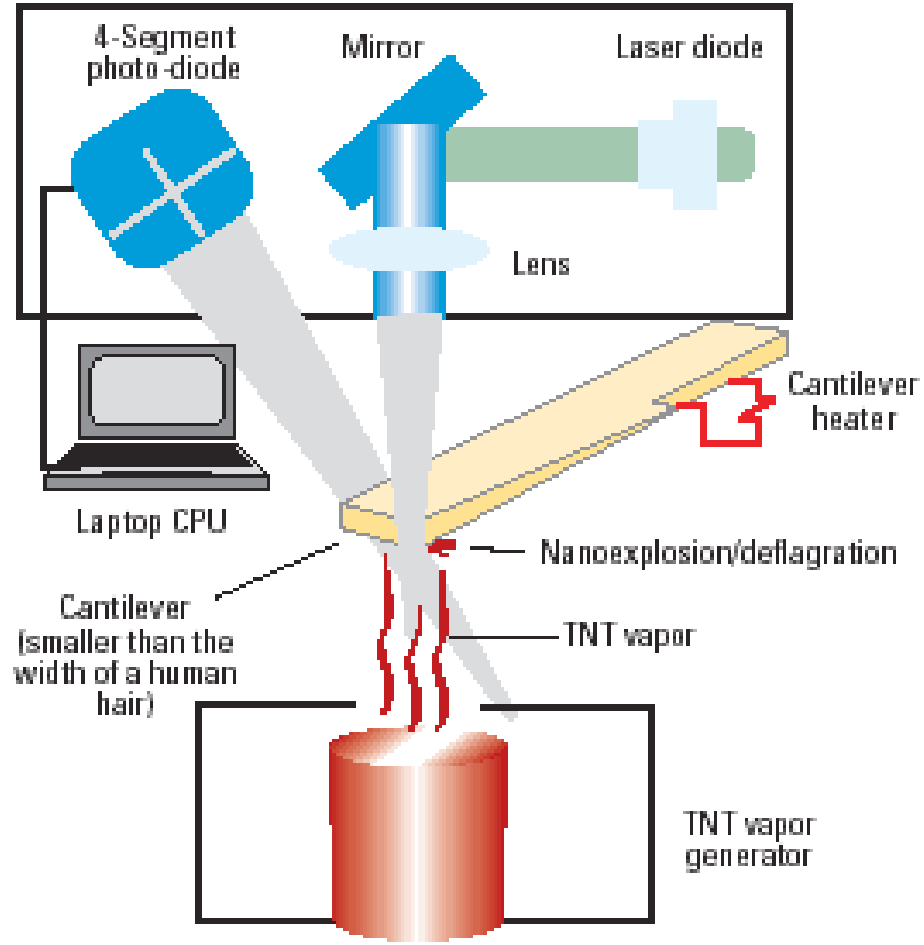
ATF /TSA
uCantil. Progm.

Micro-electromechanical System (MEMS)

Is based on miniature micro-machined silicon cantilevers (a few hundred μm long and 1 μm thick) that can detect tiny forces caused by heat-induced nano-explosions. The silicon material absorbs the explosive vapor, which is heated and undergoes tiny explosions that are detected by an optical beam. Scanning the temperature of the cantilever allows detection of various explosives, according to their temperature of deflagration.

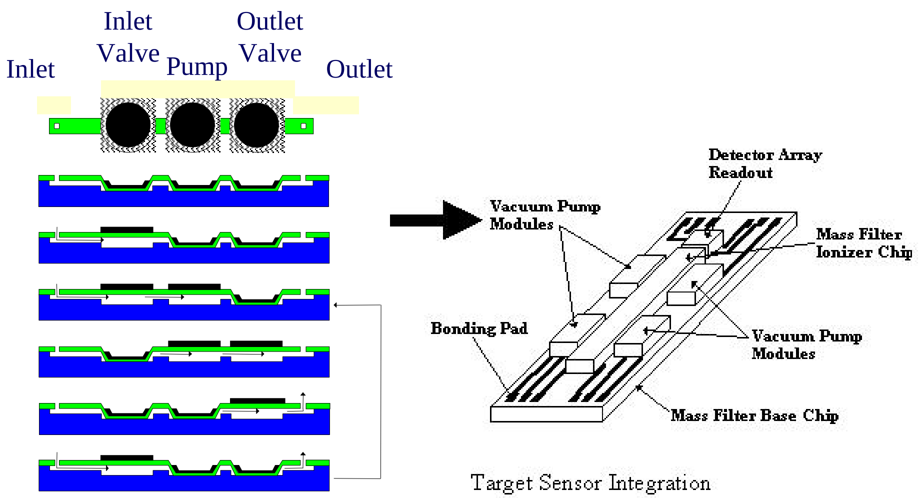
Sensitivity: 10-30 ppt of RDX and PETN (femtogram range)

Cantilever detection system



T. Thundat et al., Ultramicroscopy, 97, 433, 2003

Mass Spec on a Chip/MEMS



- R&D of a front end Chemical sensor for the MEMS based MS on a Chip (and support of MS development project).

MS on a Chip

- Partnership with NG/ARL/DARPA

- Report with evaluation of one type of front end chemical sensor (gas centrifuge separator).

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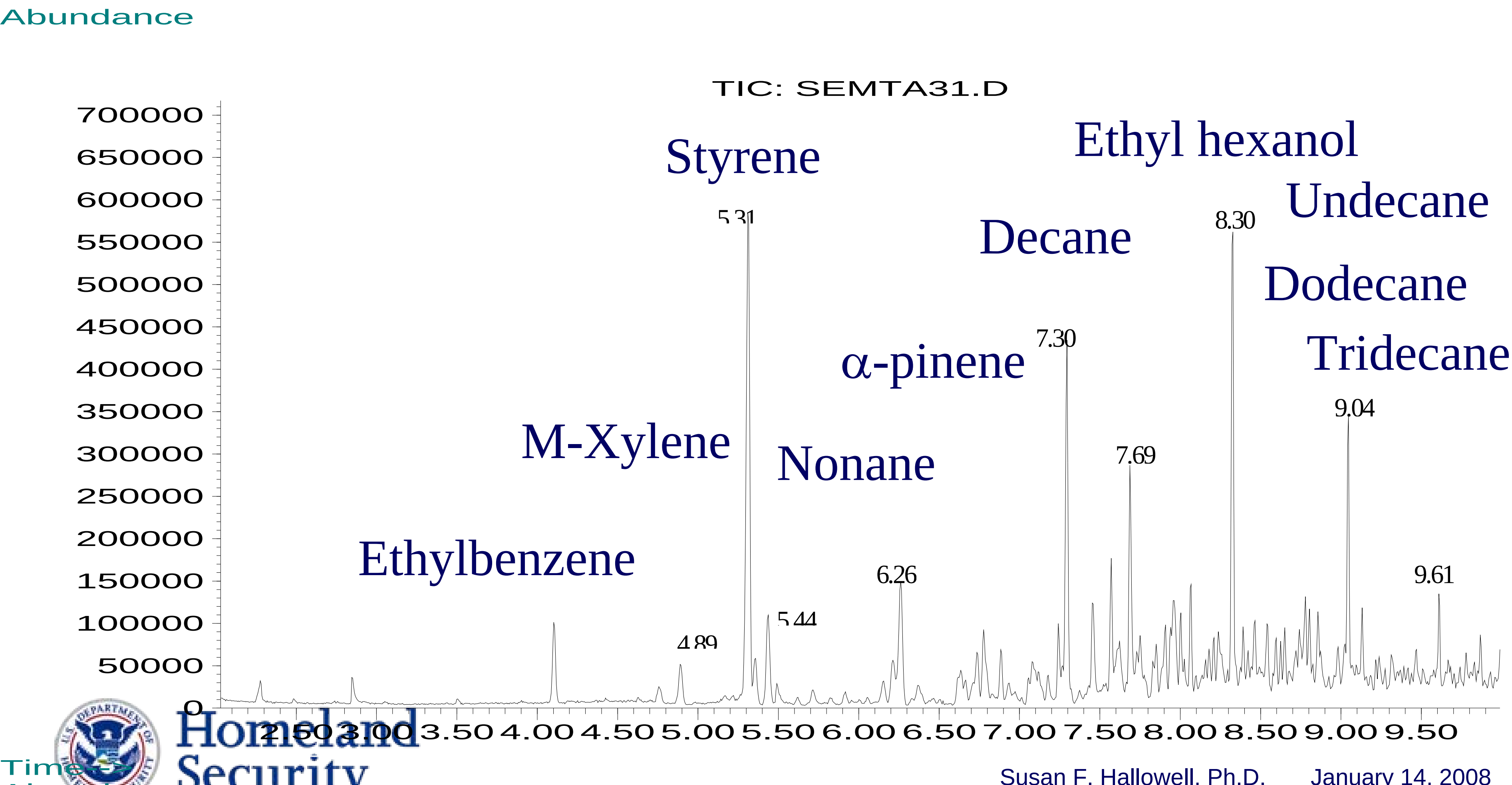
What analyte is a detection dog signaling on?

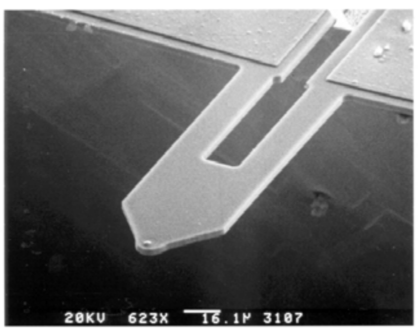
Semtex H Headspace Analysis



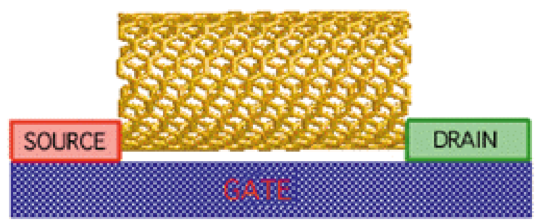
Time (minutes)

The Future of Trace?

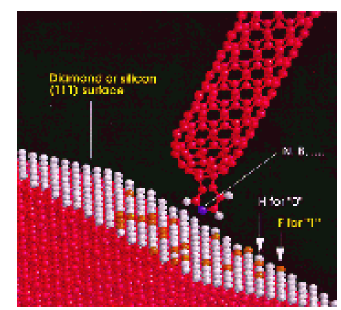
- **Automated Samplers: The key is the front end!**
- **Trace Explosives and CW/BW Sensor Development, Metal Detection, etc.**
- **Embedded Detectors in containers/walls.**
- **Nanotechnology: sources and detectors**



Nano detection on micro systems



CNT – nano explosives Det.



CNT – nano wire sensor

Effort with NASA Ames Research Cntr.

Future Prospects

- Novel Collection/Sampling Systems, New ETD's – including other technologies like MS, Spectroscopy (THz, CRDS, ...), etc.
- Microsensors/electronic noses – as Array Detectors.
- Nanotechnology will become the major driver for microsensors, and certainly a long-term future development.

Conclusions…

- Today/Future - need to efficiently sample both vapor and particle at same time…

  - Automated - to eliminate or reduce human training and human ability to sample.

  - Non-contact (if possible) - to reduce interaction with surfaces and eliminate wiping of surfaces (manual sampling issues, cost of consumables, etc.).

- Ability to detect threats with Trace Explosive Detection is a combination of Sampling and Detection…both critical processes.

Questions?

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