

# Remote (more than 100 m) explosives detection using TDLS

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*A. Nadezhdinskii*

**DLS**  

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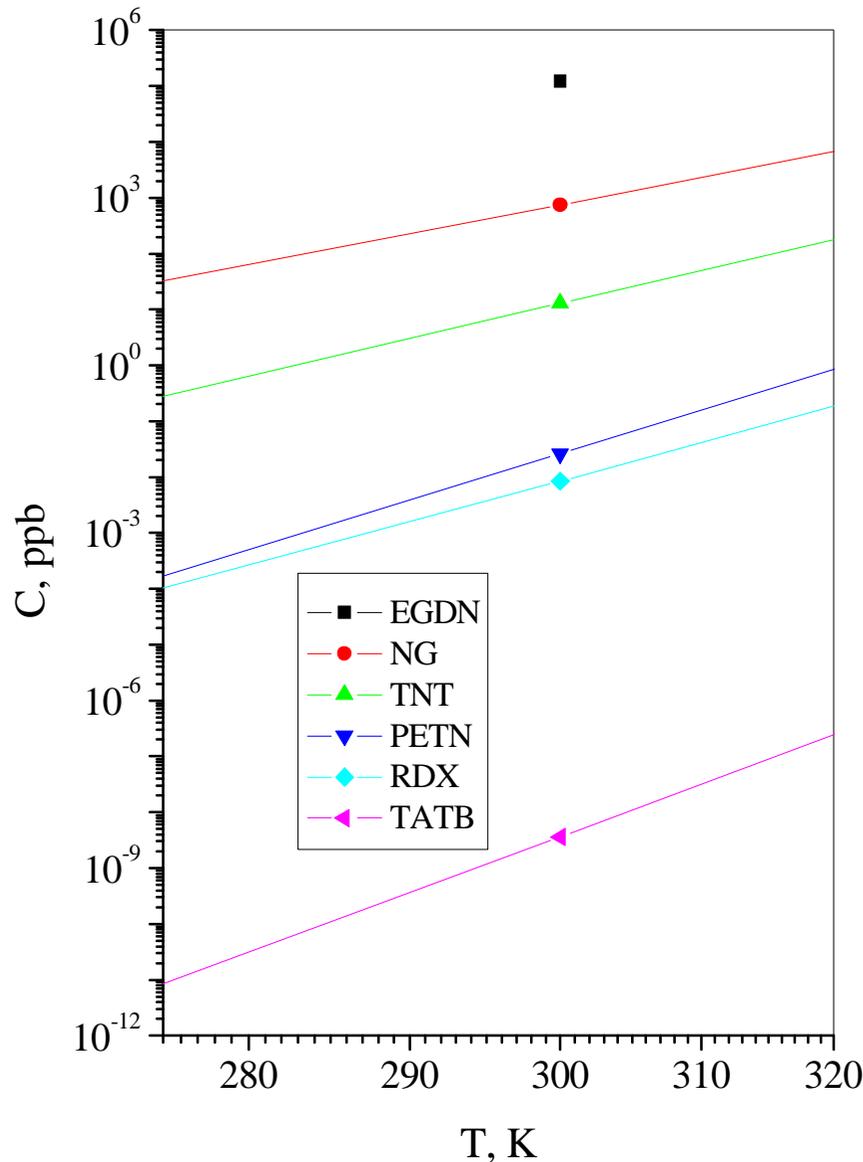
**LAB**

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# History

|               | Contractor/<br>partner | Our milestones   |
|---------------|------------------------|--|
| ~1985         | A.Zhitov               | Spectra of explosives and their vapor. Below detection limit.  |
| 1998          | P.Franken              | Idea of explosives decay products was discovered.  |
| 2000          | Russia                 | Explosives decay products spectra with FTS (NO, N <sub>2</sub> O, CO).   |
| 2002-<br>2003 | ISTC,<br>Aquila        | TDLS instrument to measure NO <sub>2</sub> from explosives. Below detection limit.   |
| 2003-<br>2005 | Russia                 | FTS of decay products. NH <sub>3</sub> – decay product of AN explosives. Successful non-contact AN explosives detection.   |
| 2005-<br>2007 | Aquila<br>S.Kadner     | Analysis of explosives remote detection scenarios. Transfer of technology developed at GPI to manufacture prototype for field tests at Aquila. Successful field tests in US. |
| 2007          | Russia                 | TDLS instrument for field tests. Successful field tests in Russia.   |
| 2008          | Aquila<br>S.Kadner     | HNCO – product of secondary chemical reactions for all N containing explosives. NH <sub>3</sub> – signature of these explosives.   |

# Explosives vapor



Explosives molecules presence in atmosphere traditionally is considered as main signature for explosives detection.

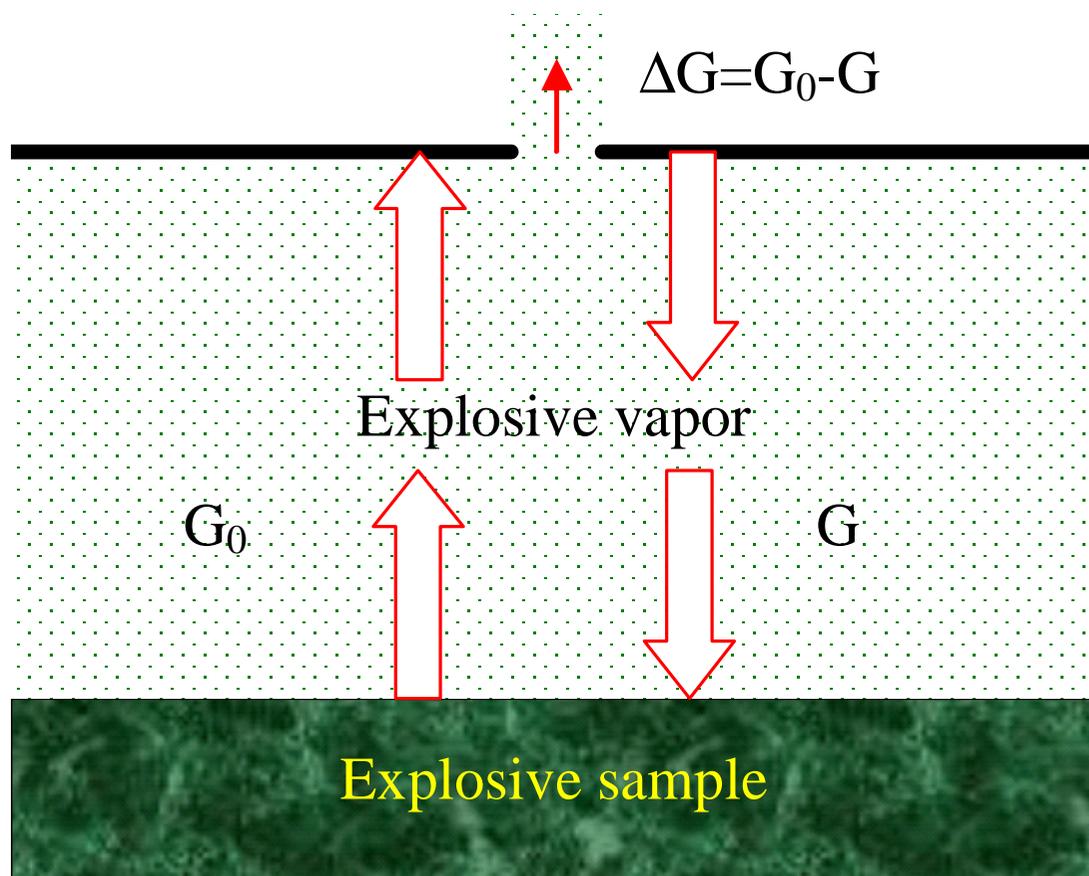
Several explosives saturated vapor concentrations as function of temperature.

**Difference in activation energy can be observed.**

**Concentration of explosives molecules in atmosphere is significantly smaller its saturated value and is below detection limit for detection techniques majority.**

# Explosive sample in wrapping

In real life situation is more complicated because of explosive sample wrapping.



Inside wrapping explosive evaporation and condensation processes take place leading to explosive molecules number density inside wrapping close to saturated one. Next process is diffusion of explosive molecules through hole in wrapping. This flow can be calculated:

$$\frac{\partial N}{\partial t} = pDdN_0 = 10^5 \text{ мол / сек}$$

Here  $D$  – diffusion coefficient,  $d$  – hole diameter,  $N_0$  – molecules number density.

**Physics is saying: this flow can not be detected.**

**However, sniper dogs can detect explosives. What sniper dogs smell?**

# Explosives are metastable objects

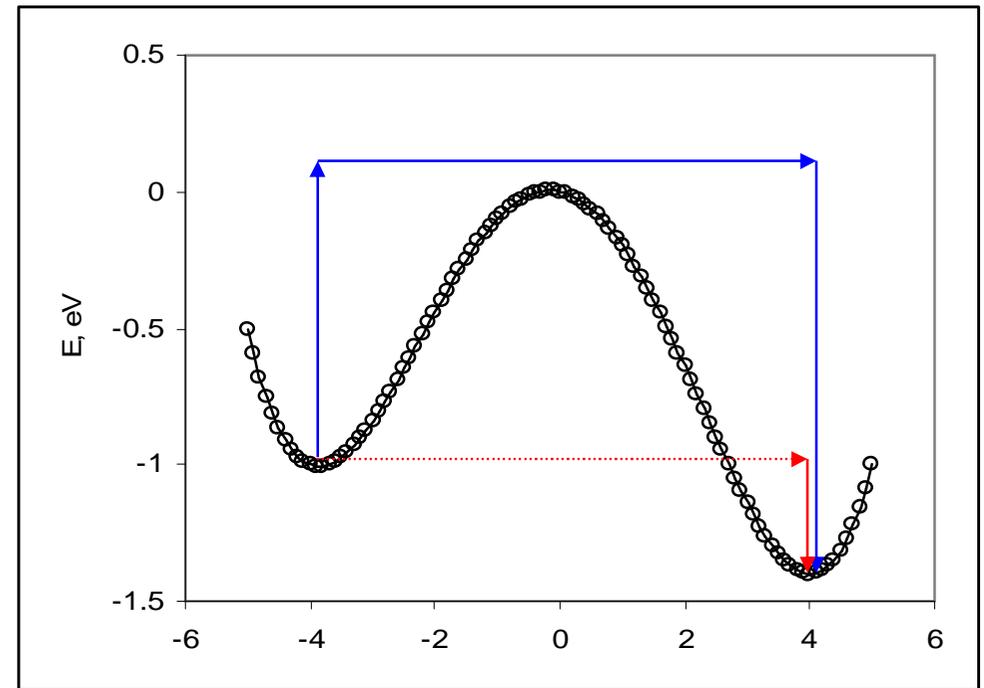
Explosives belongs to energetic materials producing energy after defragmentation (for TNT it is 4.2 MJ/kg or 10 eV/mol). Hence, their energy is higher than energy of defragmentation products.

Explosives energy diagram (right) in some configuration space.

Such systems are known as metastable.

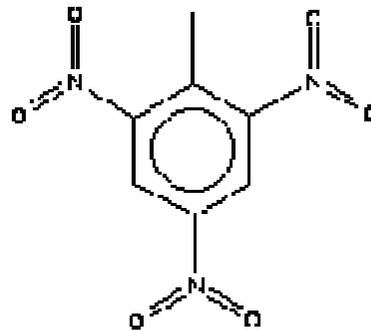
Decay channels are shown by arrows.

Explosives are metastable objects with characteristic half life time around 10 years.



## Decay channel:

Quantum chemical calculations performed showed that for TNT decay channels are  $N_2O$  or NO groups dissociation with activation energy close to 1 eV.



TNT

## Decay rate:

For 10 years explosive life time one can estimate its decay products rate as  $3 \cdot 10^{13}$  mol/g/sec.

**For 100 kg sample it leads to decay molecules flow  $3 \cdot 10^{18}$  mol/sec.**

# Explosive in wrapping decay products detection

Detection of decay products of explosive in wrapping is determined by totally different process in comparison with detection of explosives molecules from explosive in wrapping.

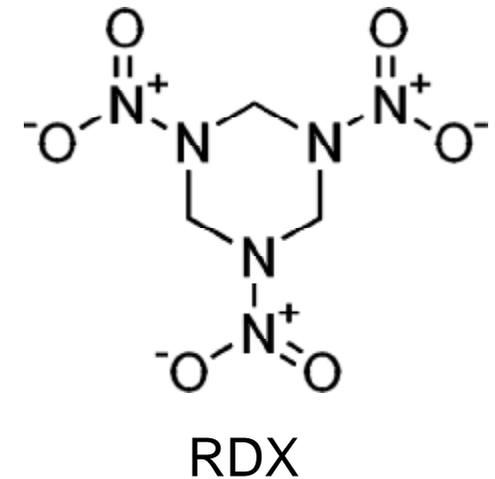
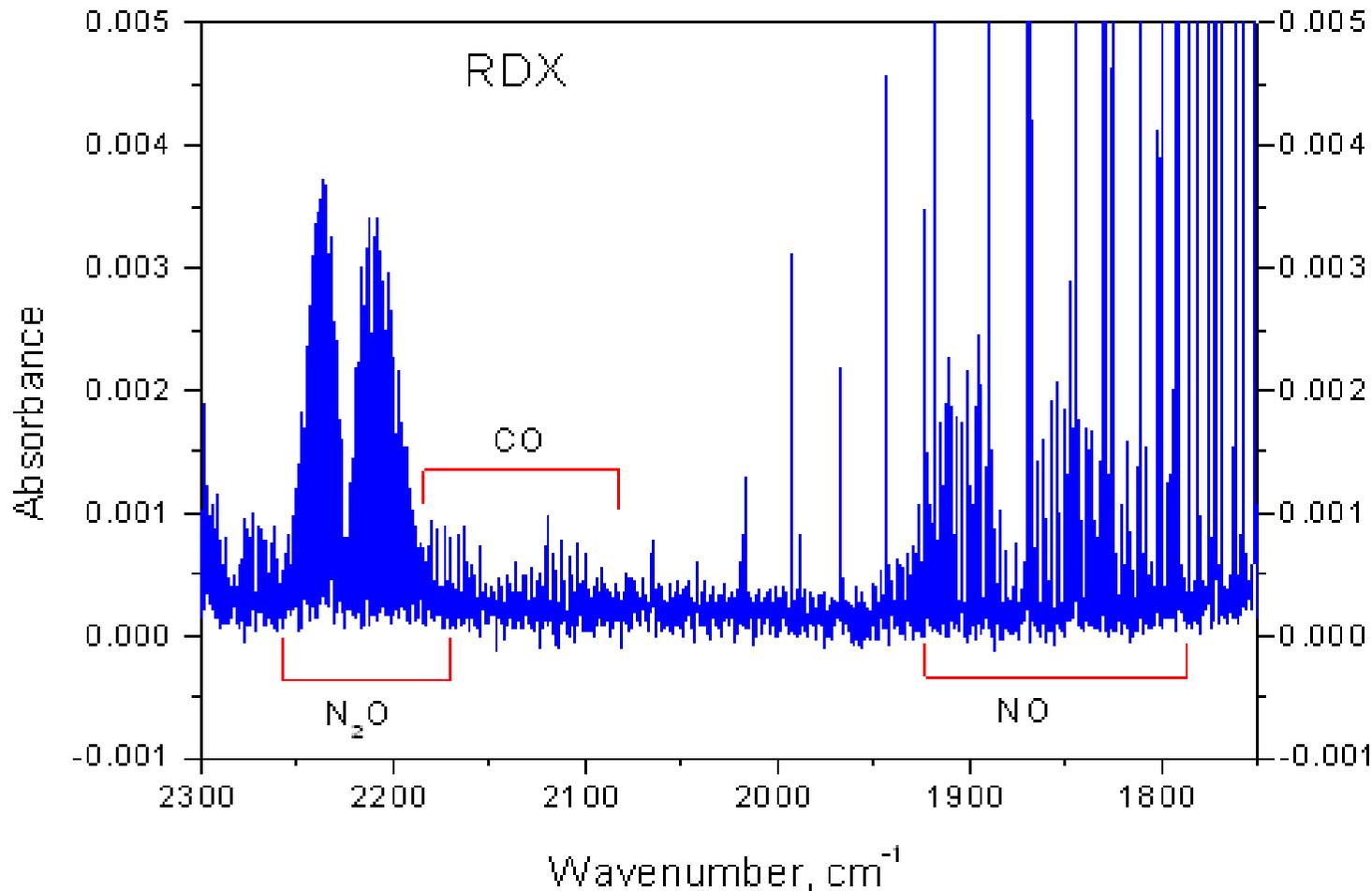
**Concentration of explosive decay molecules inside wrapping will increase until their flow through wrapping hole will be equal to decay rate. For 100 kg explosive sample it means:**

$$3 \cdot 10^{18} \text{ mol/sec}$$

**It is 13 orders of magnitude higher than explosive molecules flow.**

**Conclusion: sniper dogs smell explosives decay products.**

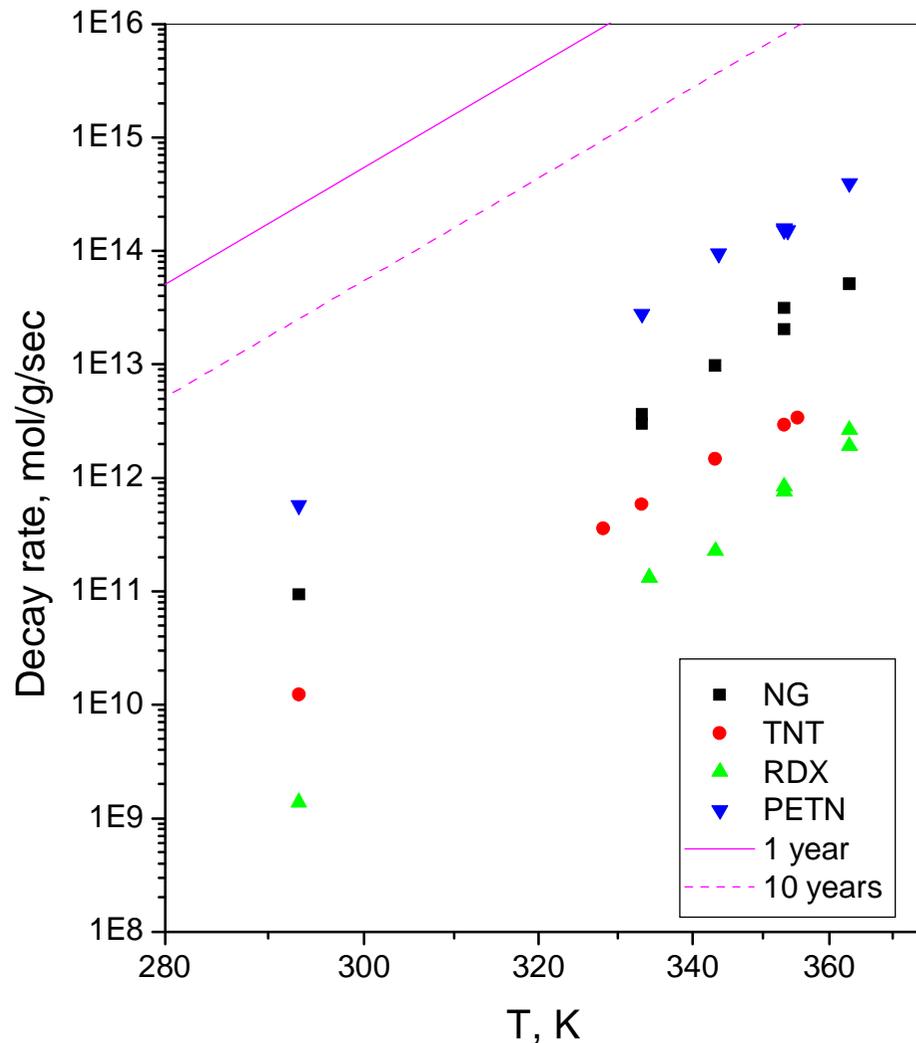
# Explosives decay products



Small (~1g) explosive samples were installed in container at elevated temperature for several hours to investigate their decay products.

FTS spectrum for RDX (85%) based plastic explosive ( $M = 1.5$  g,  $T = 90$  °C,  $t = 2.5$  h,  $L = 4$  m). RDX decay products: NO, N<sub>2</sub>O, CO. We never saw NO<sub>2</sub> as explosives decay product except NG decomposition by high temperature.

# Explosives decay rate



Decay rate temperature dependence of several explosives measured using NO (see previous slide).

Activation energy is practically the same for all explosive samples under investigation (compare with saturated explosive vapor) and is in good agreement with quantum chemical calculations.

However, decay rate is significantly (several orders of magnitude) smaller than one predicted by explosives life time.

Explosives decay products ( $\text{NO}_2$  and NO) are chemically active and interact with explosive material.

**Resume: products of secondary chemical reactions have to be considered as explosives signatures.**

# Secondary chemistry products

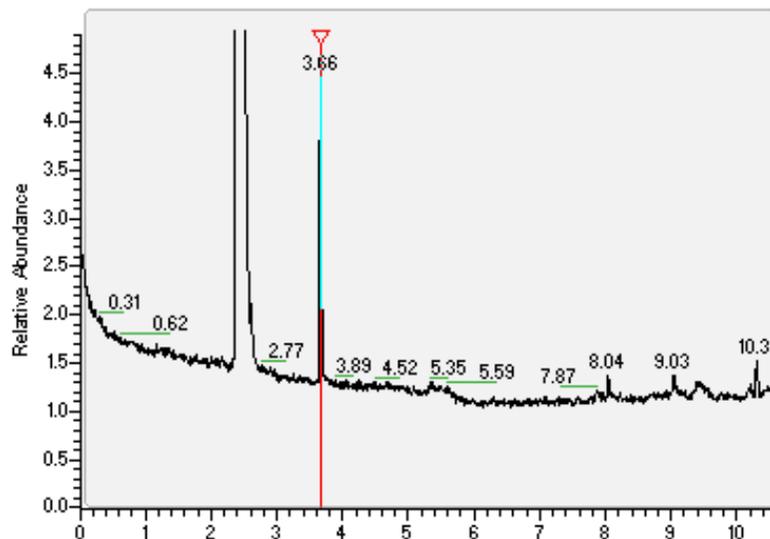
To investigate secondary chemistry products of explosives decay Energetic Materials Research and Test Center (EMRTC) in Socorro, NM was contracted.

Six explosives samples were investigated:

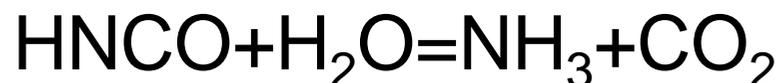
| # | Sample  | t, h |
|---|---|------|
| 1 | ANFO  | 24   |
| 2 | Detacord (HMX based)  | 6    |
| 3 | Primacord (PETN based)  | 6    |
| 4 | Detagel (slurry explosive; ammonium nitrate and hexamine based) | 24   |
| 5 | Dynamite  | 6    |
| 6 | TNT (flake)   | 6    |

Small explosives samples (~ 1g) were installed in container and remained in it at 60 °C for several hours. Secondary chemistry products in atmosphere above samples were investigated using GC/MS technique.

# GC/MS of secondary chemistry products



For all samples under investigation 3.66 min peak (marked by arrow) was observed (upper picture). Lower picture this peak MS. Refer to MS library it is identified as HNCO – isocyanic acid. Its interaction with atmosphere water leads to [1]:



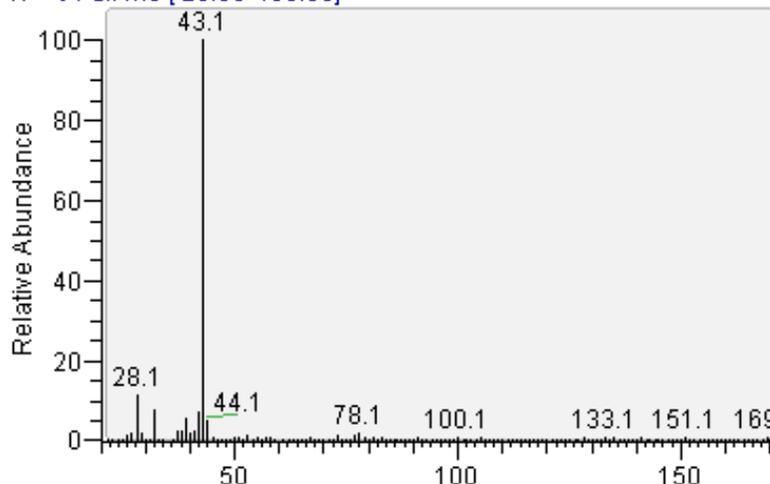
1. Fearon, Wm. Robt. And G.C. Dockeray, “A Note on the Hydrolysis of Cyanic Acid.” *BioChem Journal*, November, 1925.

<http://www.biochemj.org/bj/020/0013/0200013.pdf>

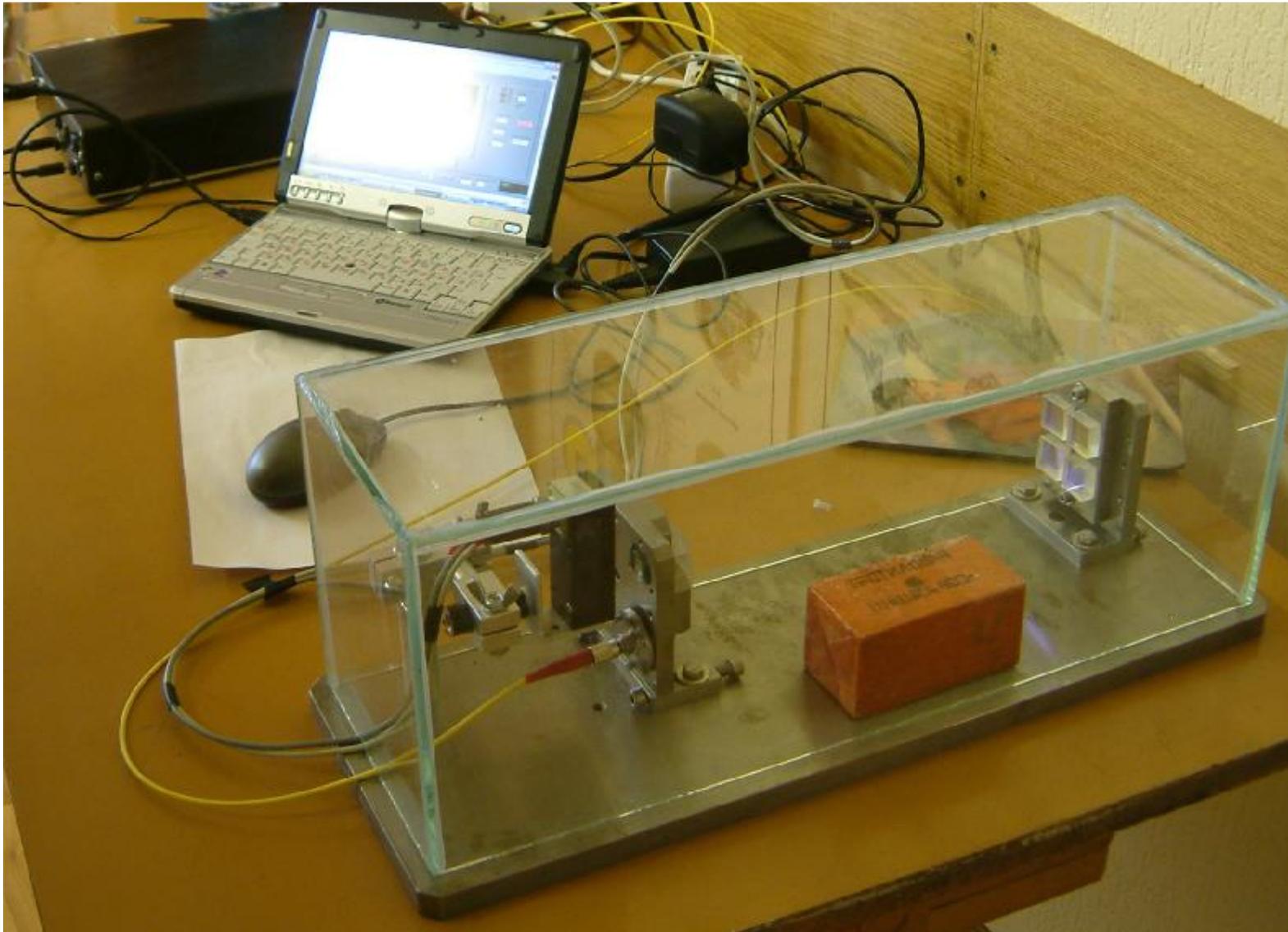
**Resume: ammonia is signature of all N containing explosives.**

Some other peaks common for different samples were observed but not yet identified.

PETN\_hs\_60heat\_1 #430 RT: 3.65 AV: 1 NL: 1.56E5  
T: + c Full ms [ 20.00-400.00]



# Explosives detection in laboratory



**Field test in  
Russia.**

**Non-contact  
TNT sample  
detection in  
laboratory  
environment,  
 $M = 400\text{ g}$**

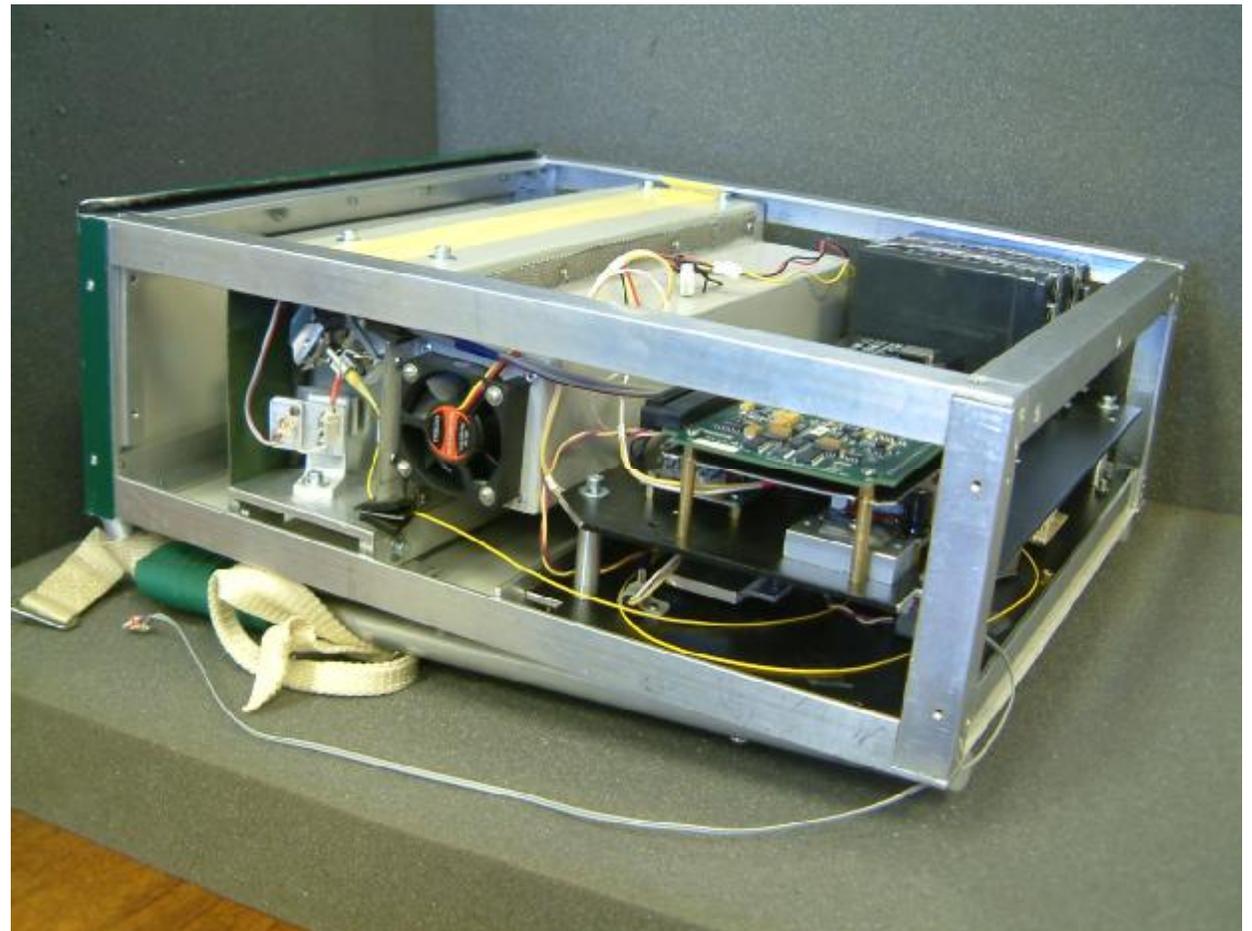
# Albuquerque, USA

Backpack prototype for remote explosives detection was jointly developed by Aquila (Canberra) and GPI (DLSLAB).

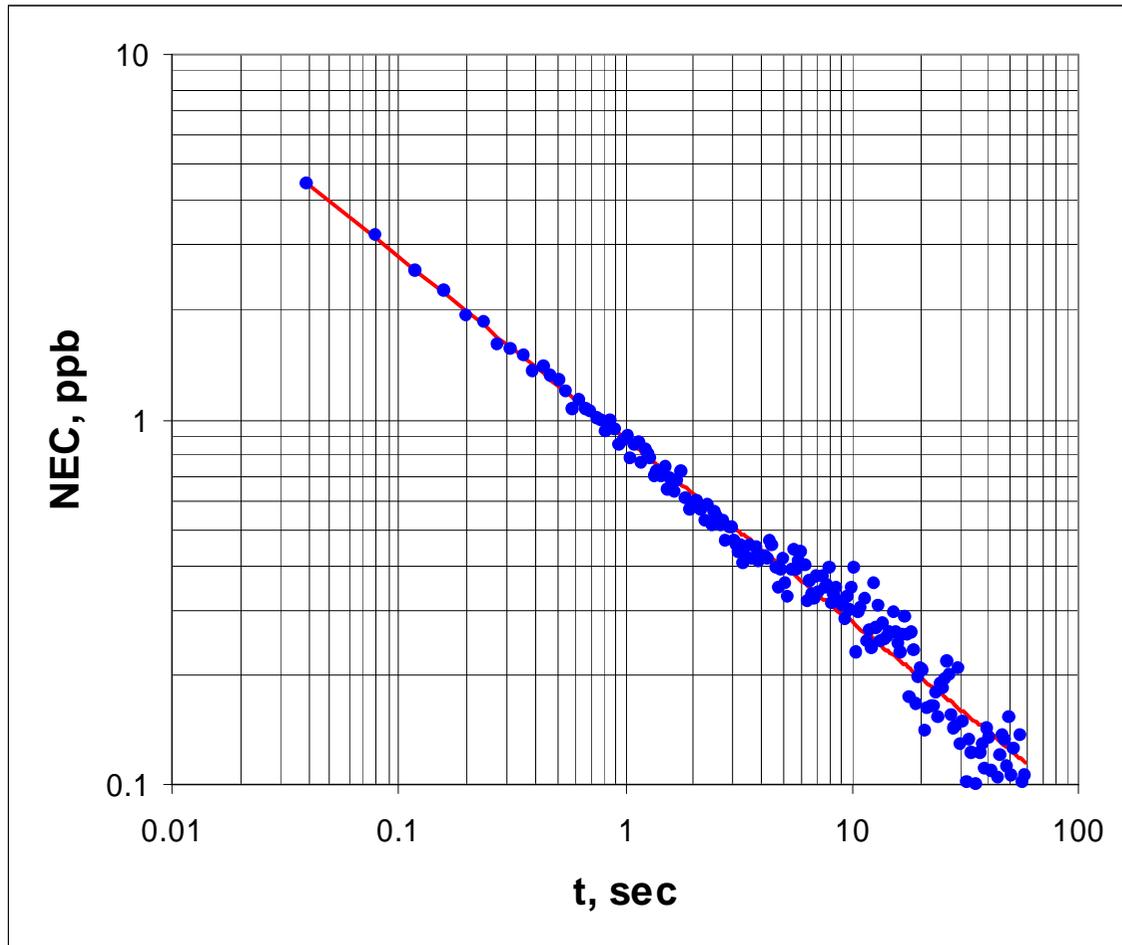


# Moscow, Russia

Backpack prototype for remote explosives detection was developed by GPI (DLSLAB) (see B3) using electronics manufactured by Aquila (Canberra).



# Minimum detectable concentration



NEC (Noise Equivalent Concentration of  $\text{NH}_3$ ) as function of averaging time as it was measured in Moscow.

For both instruments under consideration, NEC was determined by DL quantum noise.

**NEC together with explosive decay rate determine minimum detectable explosive mass inside moving vehicle and distance at which sample with given mass can be detected down wind.**

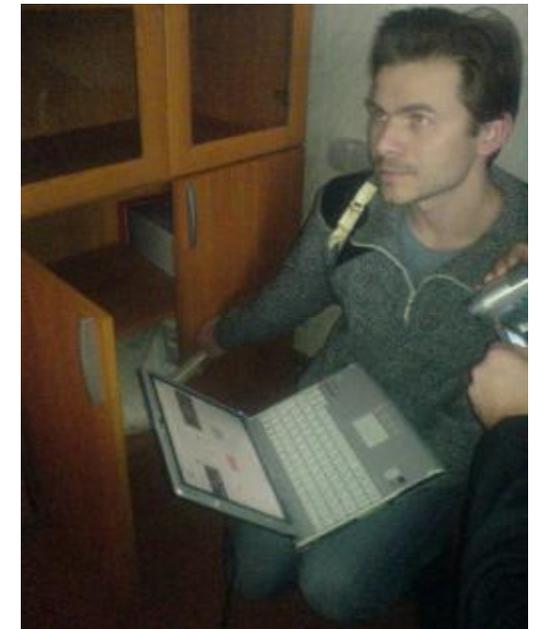
# Remote explosives detection

Several remote explosives detection scenarios can be considered.



**Field test: remote explosives detection inside moving vehicle.**

**Field test: non-contact 2 kg explosive sample finding inside building using gradient of measured explosives signature concentration.**



**Field test: 300 kg explosive sample in wrapping was detected at 120 m down wind.**

# Conclusion

**10 years ago it was realized that explosives molecules from explosive in wrapping can not be detected because of very low molecules flow  $\sim 10^5$  mol/sec. At the same time alternative method of explosives detection was discovered – explosives decay. Several explosives samples were investigated using GC-MS demonstrating the same GC peak. It was identified as HNCO – isocyanic acid. HNCO interaction with atmosphere water leads to ammonia. Hence,  $\text{NH}_3$  is signature of nitrogen containing explosives.**

**TDLS based backpack prototypes were developed and field tests were performed. Several test scenarios were investigated. Samples of all explosives available were detected. 10 kg explosive sample was detected inside moving vehicle. 2 kg explosive sample was found inside building using gradient of measured explosives signature concentration. 300 kg explosive sample in wrapping was detected at 120 m distance down wind.**