Non-contact explosives detection by means of TDLS

A.G. Berezin, S.L. Malyugin, A.I. Nadezhdinskii,
D.Yu. Namestnikov, Ya.Ya. Ponurovskii, I.P. Popov,
Yu.P. Shapovalov, D.B. Stavrovskii, I.E. Vyazov, V.Ya. Zaslavskii

DLS LAB

A. M. Prokhorov General Physics Institute of RAS
38 Vavilov str., 119991 Moscow, Russia.
E-mail: Nad@nsc.gpi.ru

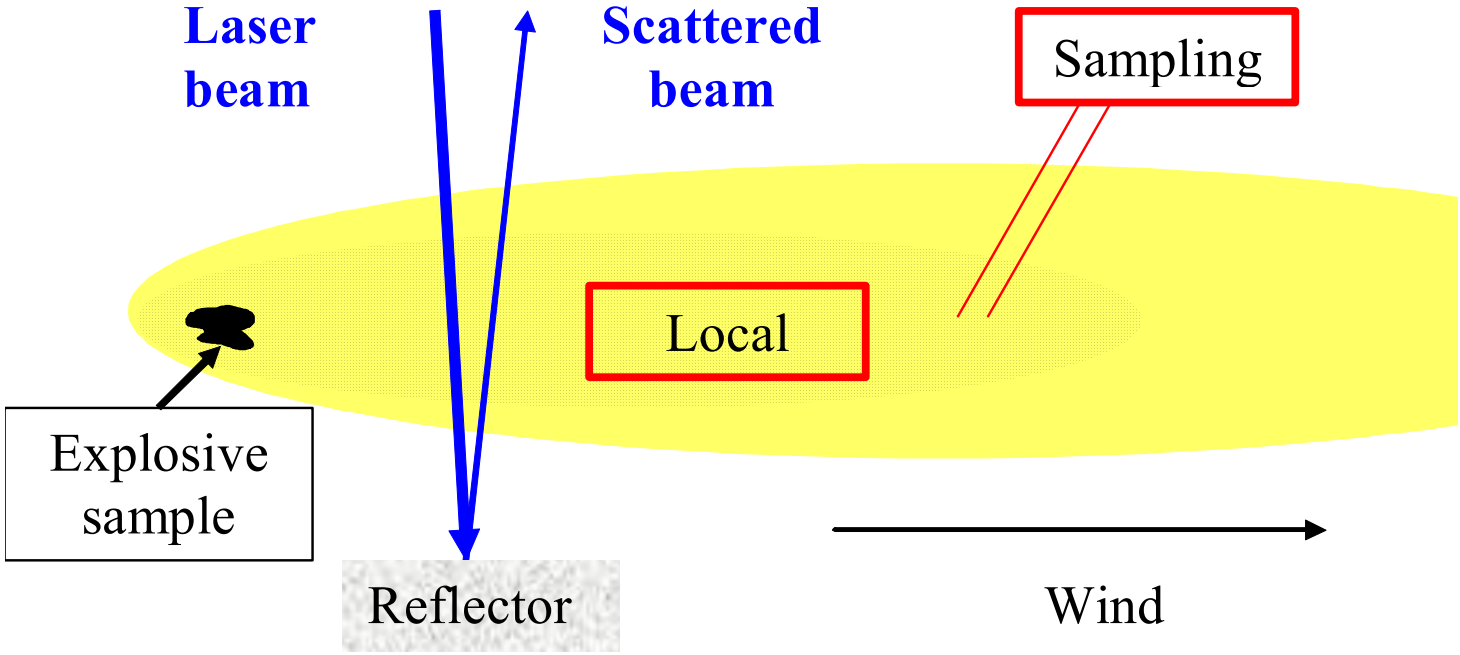
Abstract

A majority of the explosives detection techniques now in use, such as gas-chromatography or ion-drift spectroscopy, need sampling and sample preparation and can not be used for stand-off detection. The optical methods, such as TDLS, allow remote sensing. Saturated vapor pressures of many explosives at room temperatures are too small and that gives almost no chances to detect them directly by optical methods. However, explosives are metastable compounds and their presence could be found by detection of their decay products.

In this report we demonstrate possibility of non-contact explosives detection by measuring their decay products concentration in atmosphere. As example, ammonia detection is presented. Ammonia is decay product of ammonium-nitrate based explosives. For safety reasons most of experiments were conducted with explosives substitute: ammonium fertilizer (in many cases it is one of the components of ammonium-nitrate based explosives). The decay rates of samples under investigation were measured. Influence of different wrappings and humidity on ammonia measurement is presented.

Explosive sample remote detection

Possible objects of remote detection: explosive sample (black figure), explosives micro-particles (black points), gaseous cloud above the sample

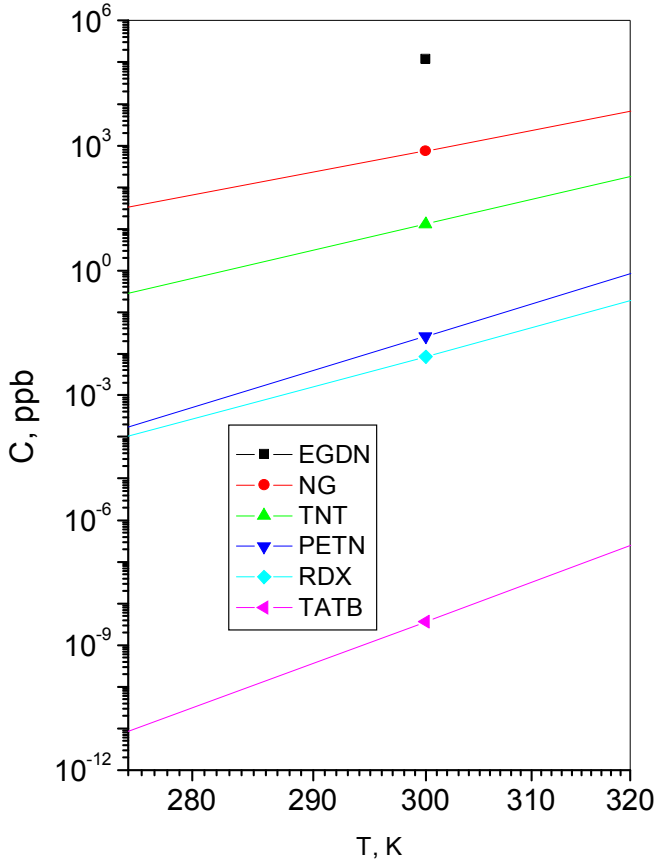


Possible scenarios of explosives remote detection using TDLS technique:

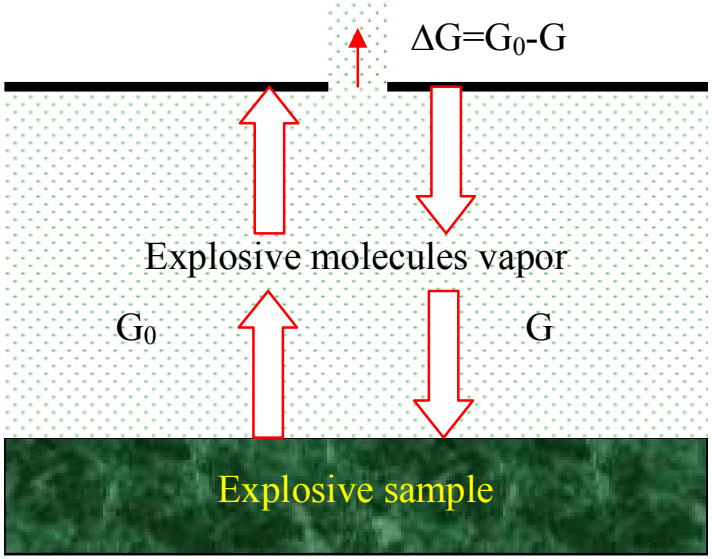
1. Sampling for future analysis (gaseous and micro-particles fragmentation) using TDLS with multi-pass cell.
2. Local measurements using TDLS with multi-pass cell installed in the cloud.
3. System with reflector.

Explosives vapor detection

Traditionally is considered as main approach



Explosives vapor cloud formation above explosive sample in wrapping



Explosives saturated vapor concentrations

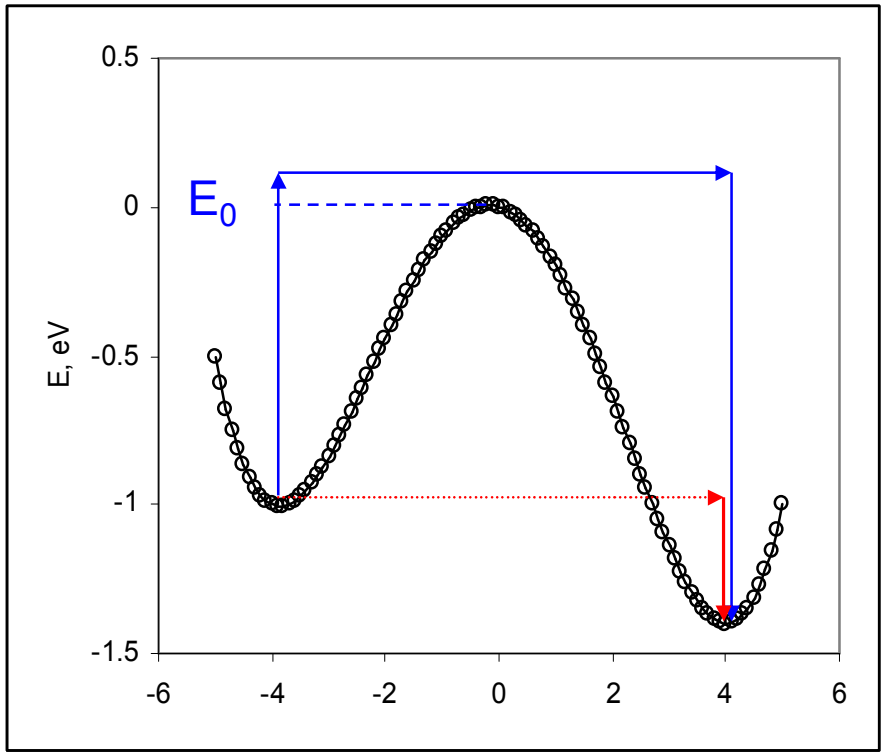
Molecules flow through hole having diameter d in wrapping

$$\frac{\partial N}{\partial t} = \pi D d N_0 = 10^5 \text{ mol/sec}$$

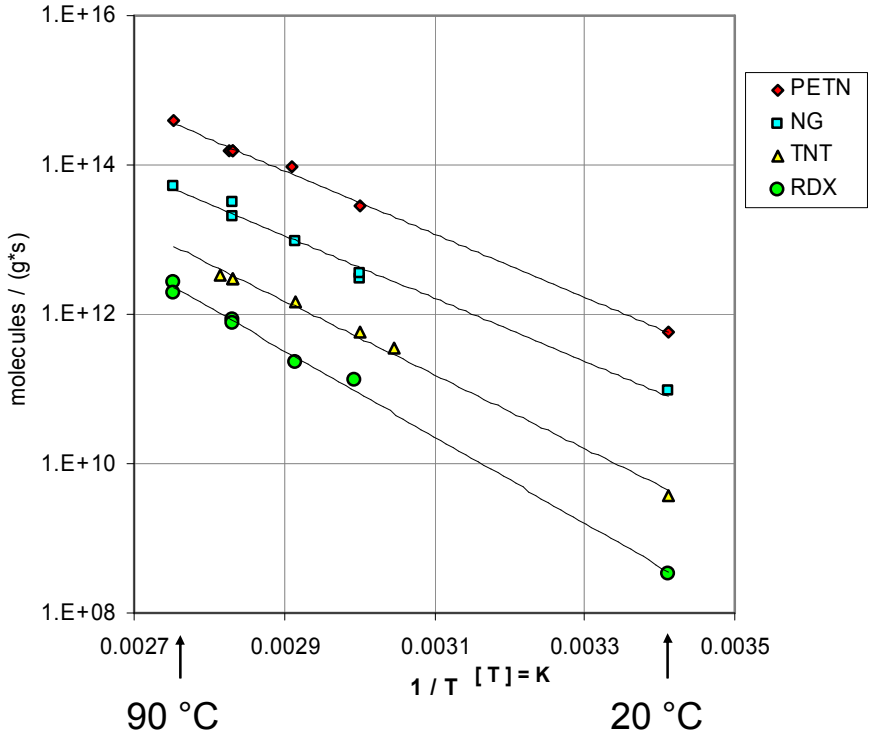
It can not be detected

Resume: Remote detection of explosives vapor is impossible

Back to Basic: explosives decay



Explosives (metastable molecule) energy diagram in configuration space.



Temperature dependence of Decay Rate (DR) for different explosives see poster D11

$$DR \approx \int_{E_0}^{\infty} \exp\left[-\frac{E}{kT}\right]\sigma(E)v(E)dE \approx \exp\left[-\frac{E_0}{kT}\right]\sigma(E_0)v_T$$

E_0 ~ 1 Ev = 12000 K
v_T ~ 300 m/sec
DR ~ 10^9 – 10^{14} mol/g sec

Ammonium Nitrate

Ammonium Nitrate (AN) is component of several widely used explosives: ammonite (AN with TNT), ammonal (AN with aluminum powder), ANFO (AN with fuel oil), etc. For safety reasons most of experiments were conducted with explosives substitute (ammonium fertilizer). However, samples of real explosives were investigated also.

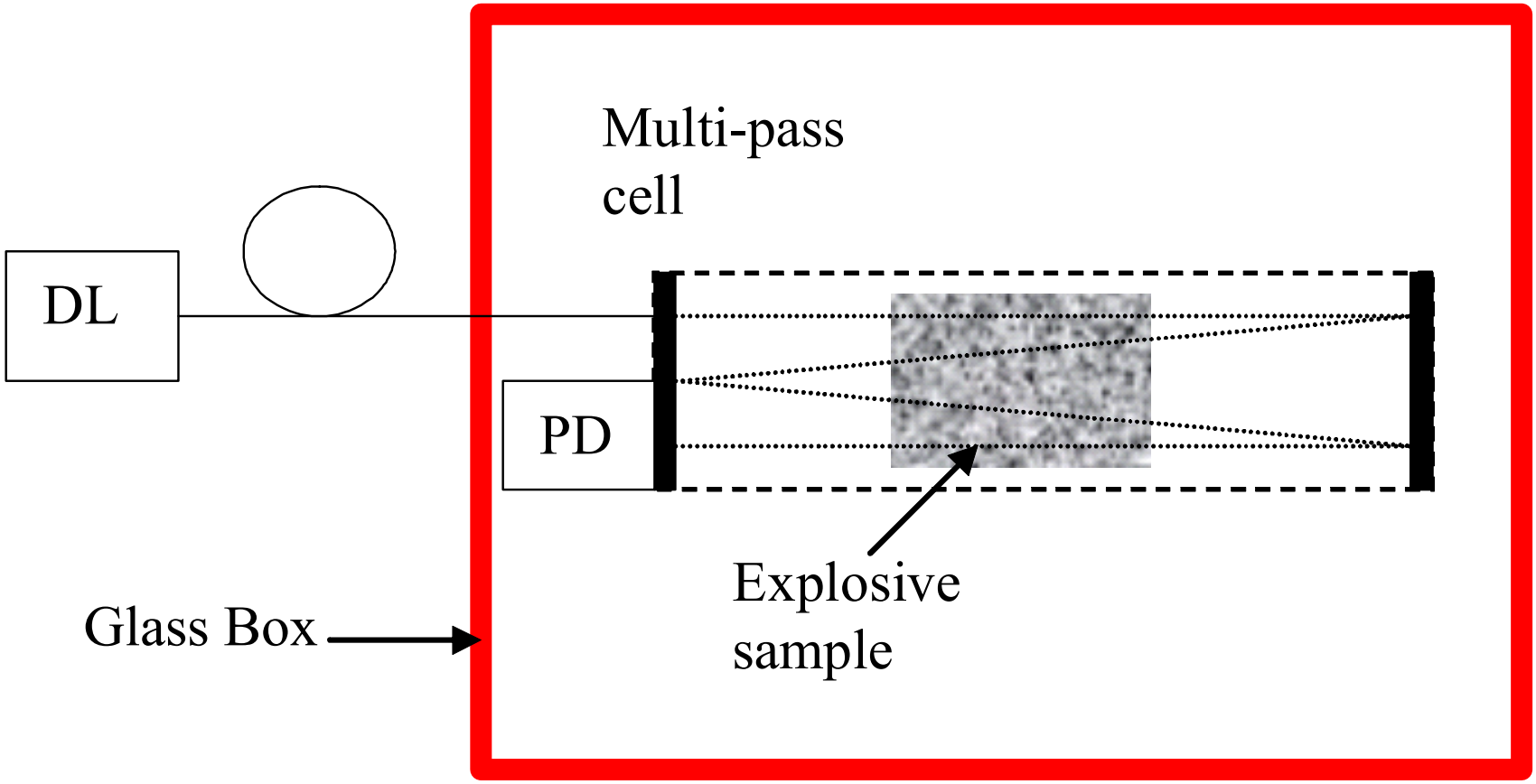
Ammonia is one of decay products of ammonium nitrate:

$$NH_4NO_3 \rightarrow NH_3 + HNO_3$$

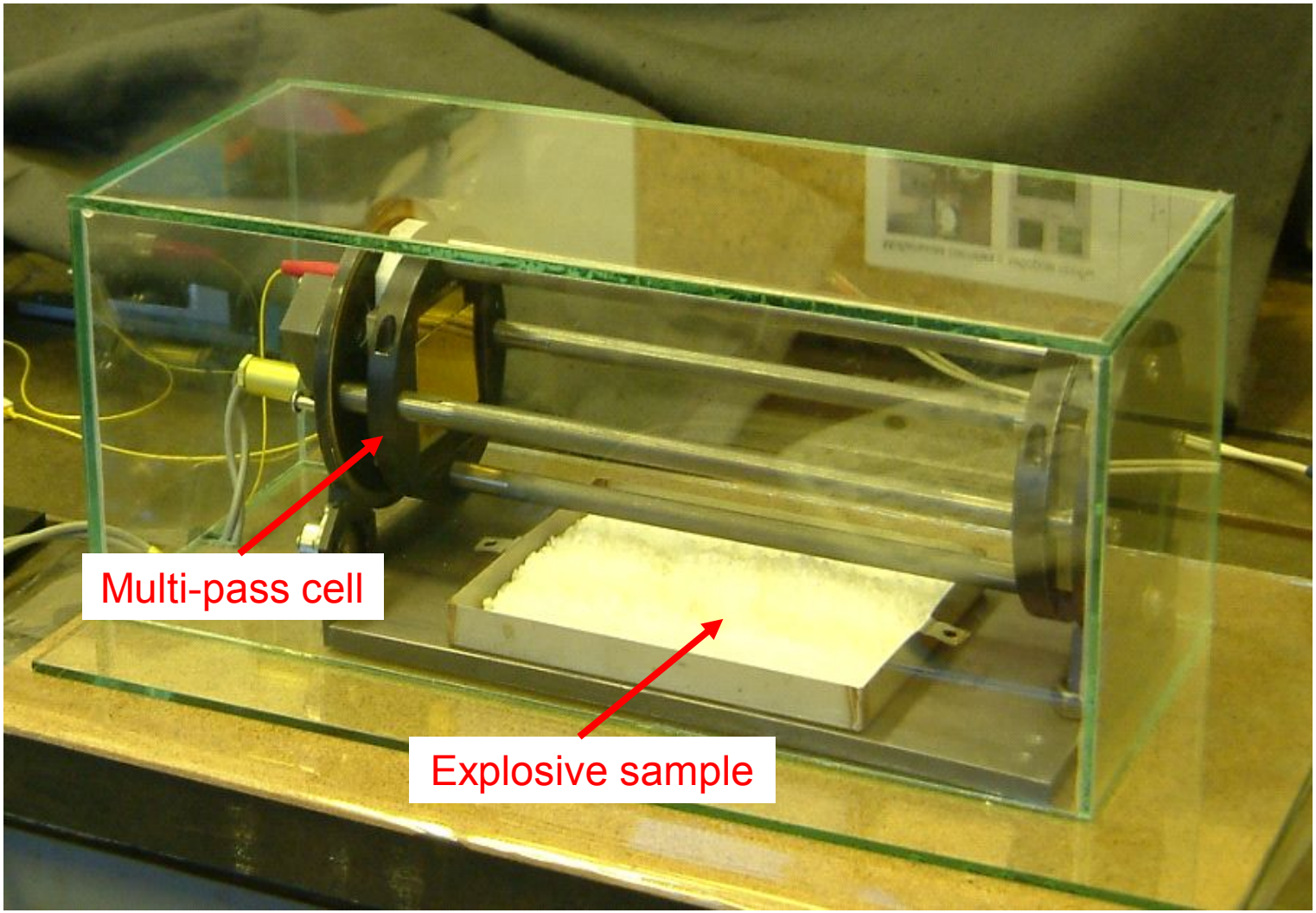
Ammonia can be detected with high sensitivity using TDLS. Moreover, ammonia is product of secondary chemistry reactions of some other explosives.

Role of atmosphere humidity in secondary chemistry reactions is also subject of investigation.

Experimental set-up



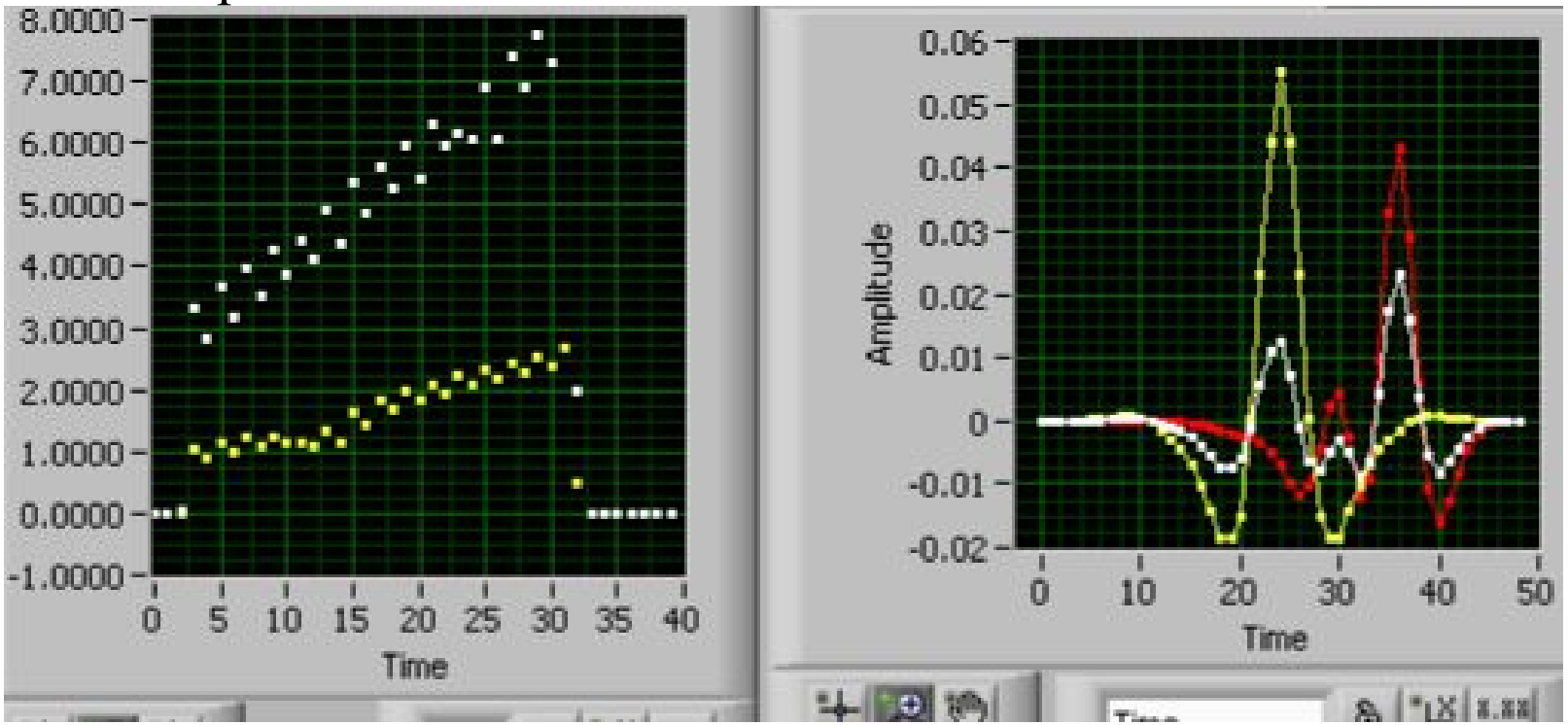
Experimental set-up



View of experimental set-up: multi-pass cell and explosive sample in glass box

Program interface

Simultaneous measurements of ammonia and water concentrations are important for present work. For laser in use both molecules can be detected.

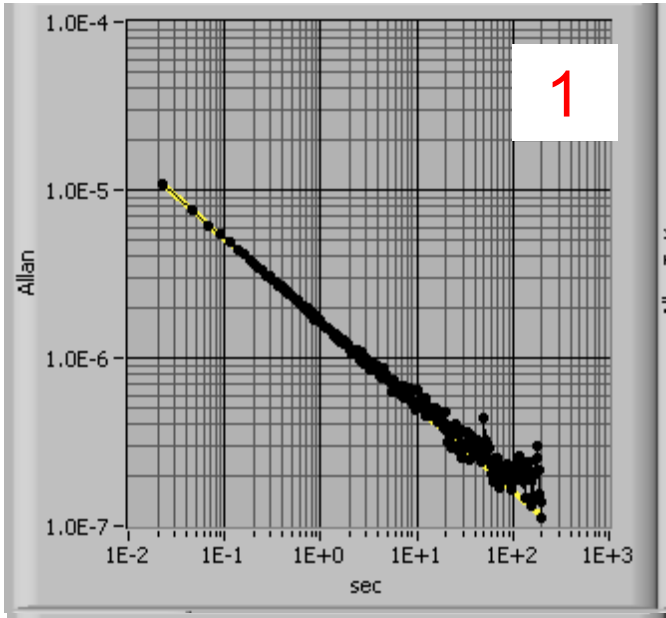


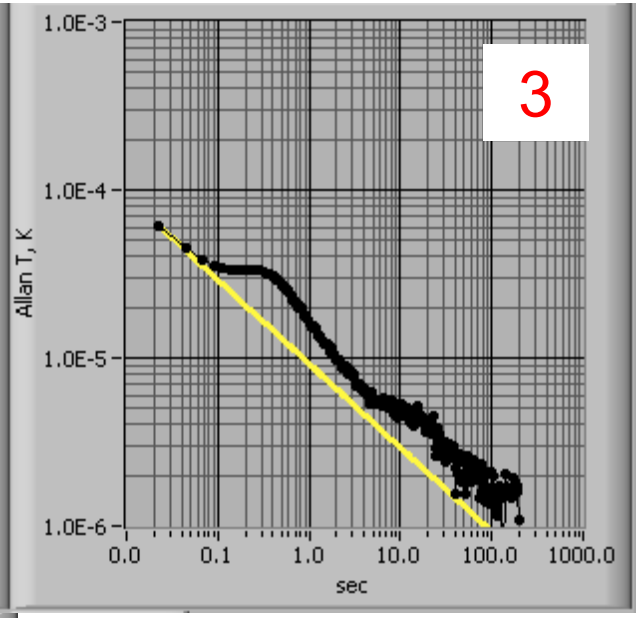
Program interface developed for simultaneous measurements of ammonia and water concentration.

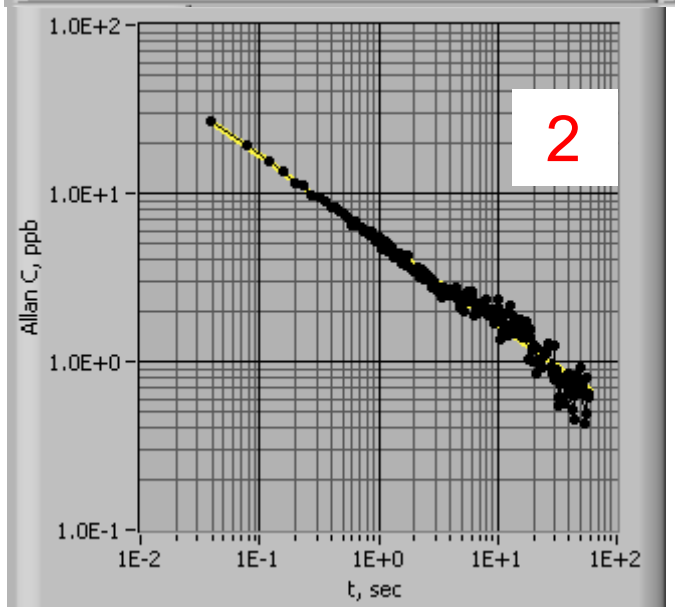
Left graph – signals in analytical (white) and reference (yellow) channels.

Right graph – correlation functions of absorption in analytical channel (white), of ammonia (yellow) and water vapor (red).

Allan plots







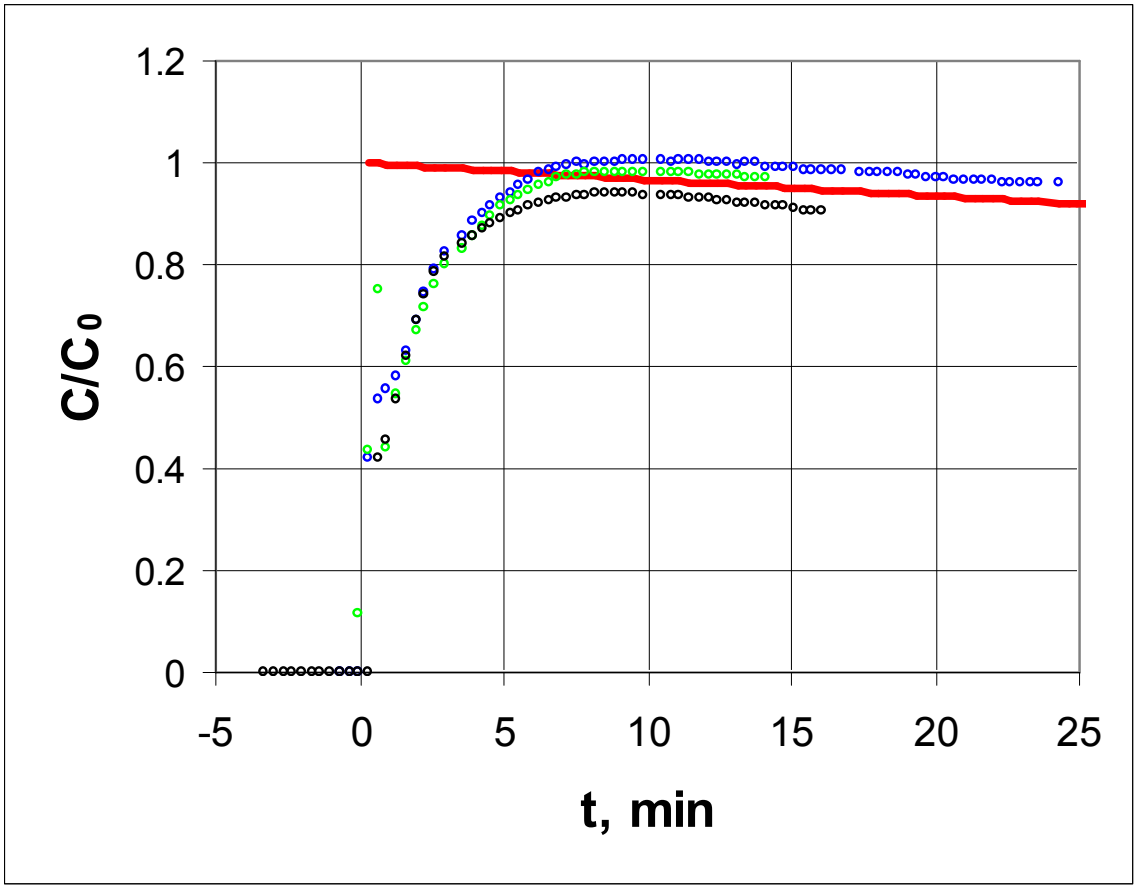
1. Minimum detectable absorption
2. Minimum detectable ammonia concentration
3. DL temperature stability

For laser in use water line is located close to ammonia analytical one. Hence, very good temperature stability is required to achieve good detection sensitivity. DL frequency tuning cycles stabilization using water line as reference one was included in operation regime.

At present time sensitivity obtained is 5 times above fundamental limit due to DL quantum noise, subject for future improvement

Calibration test

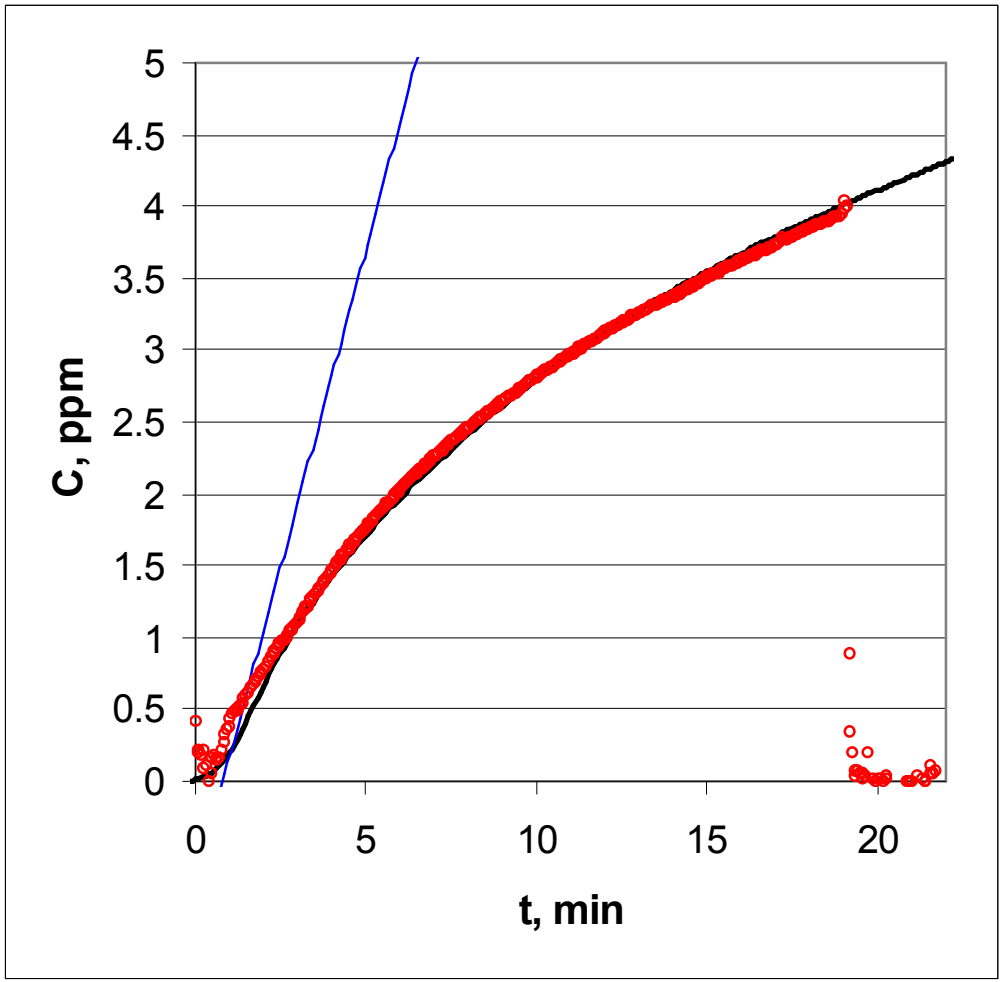
To determine accuracy of measurements, calibration test was performed when known volume of gaseous ammonia was injected in glass box.



Time dependence of normalized concentration C/C_0 (open cycles) after injections of v=10 ml of gaseous ammonia in volume - V of glass box. $C_0 = v/V$.

Injection took place at t = 0. Then during 7 min turbulence of injected plume and ammonia diffusion in box can be observed. Red line - ammonia concentration decreasing due to its leaks from box determined from independent experiment.

Non-contact explosives detection



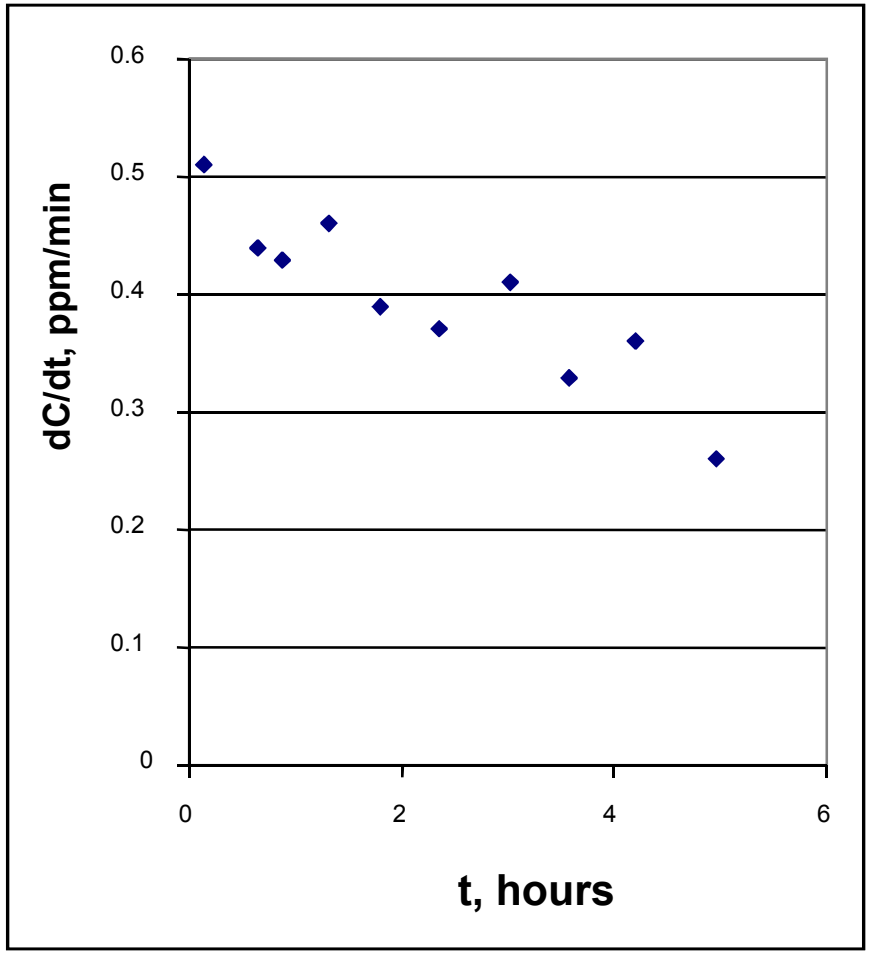
t = 0 - ammonium nitrate (AN) sample was installed in glass box. Ammonia concentration increase (open red cycles) because of AN decay can be observed as well as time delay due to ammonia diffusion in air. After 19 min glass box was removed and measured ammonia concentration dropped to 0.
Solid curves - models of ammonia diffusion in air.
From results obtained ammonia diffusion coefficient in air and decay rate were determined.

For the first time non-contact detection of explosives decay products was demonstrated

Secondary chemistry

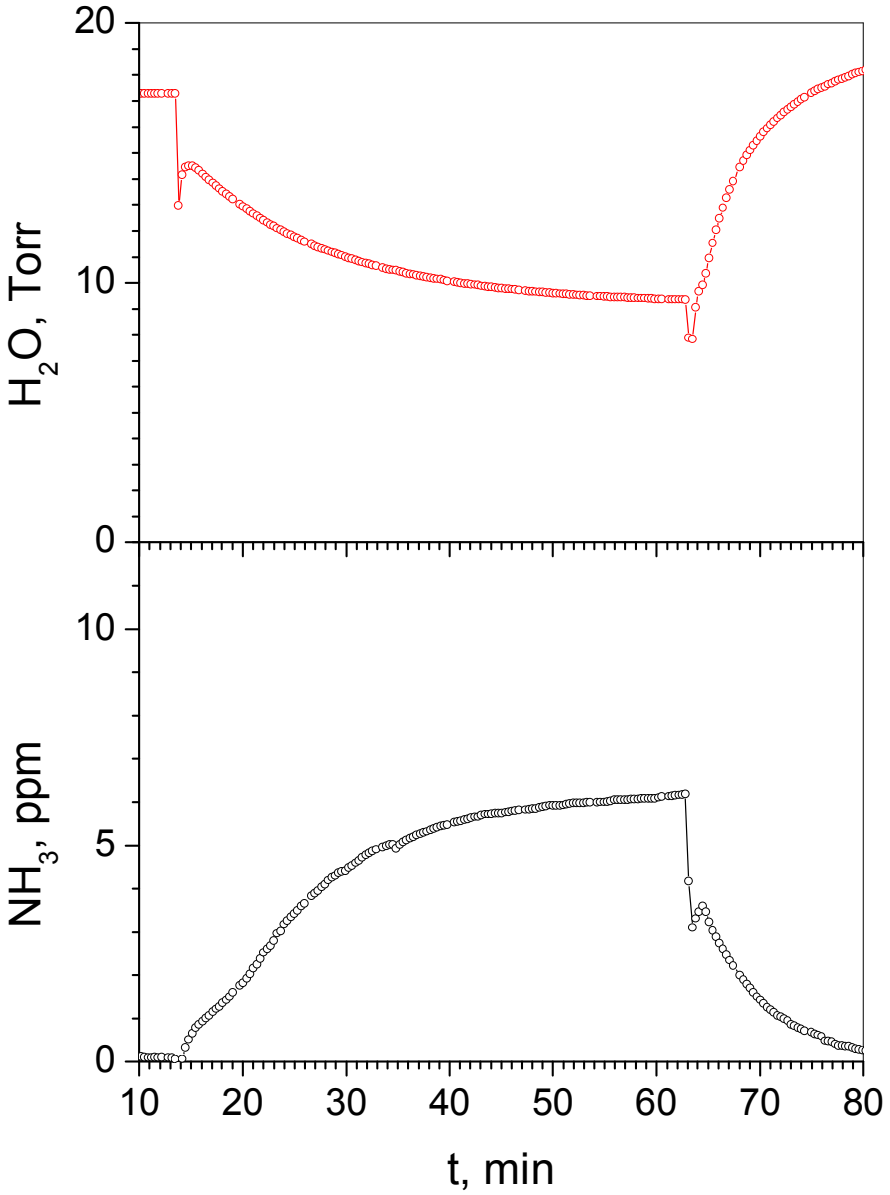
Process of explosives decay products measurement is rather complex.

1. Explosives molecules decay.
2. Decay products interaction with explosive body.
3. Interaction with wrapping materials.
4. Decay products interaction with atmosphere molecules.
5. Decay products sorption by environment.
6. Atmosphere molecules (water) sorption by explosive sample.
7. Decay products sorption by absorbed water.
8. Etc.



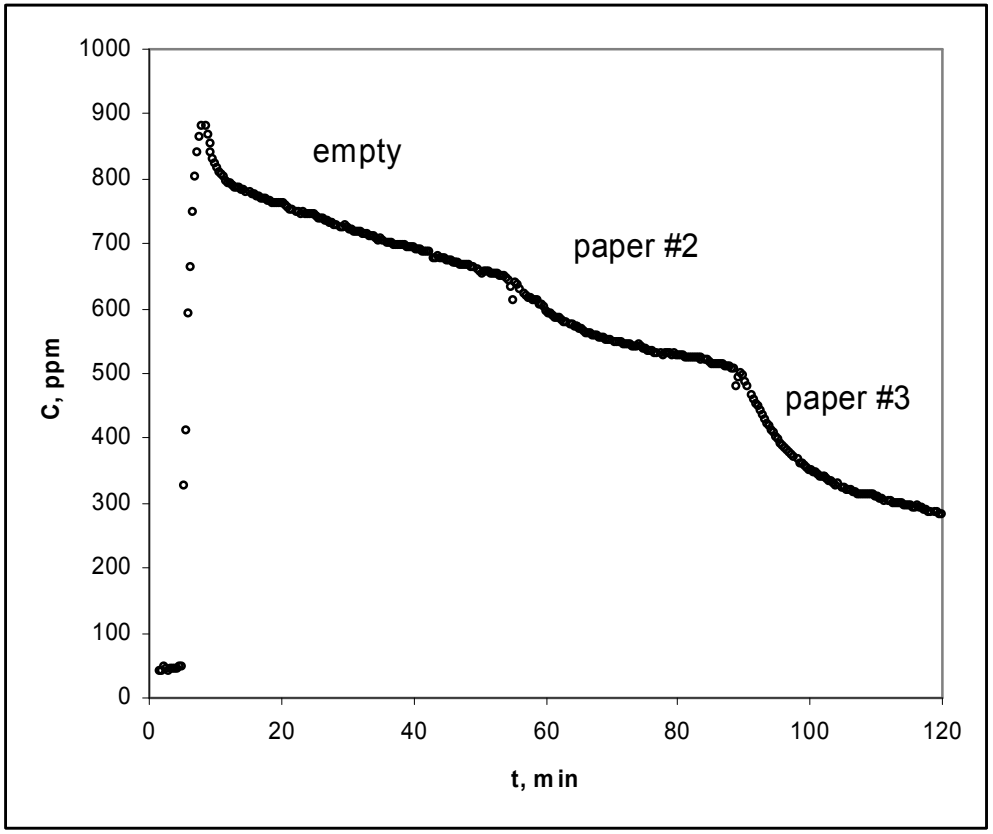
Decrease of measured ammonia concentration rate as function of ammonium fertilizer exposition in atmosphere.

NH_3 and H_2O measurement

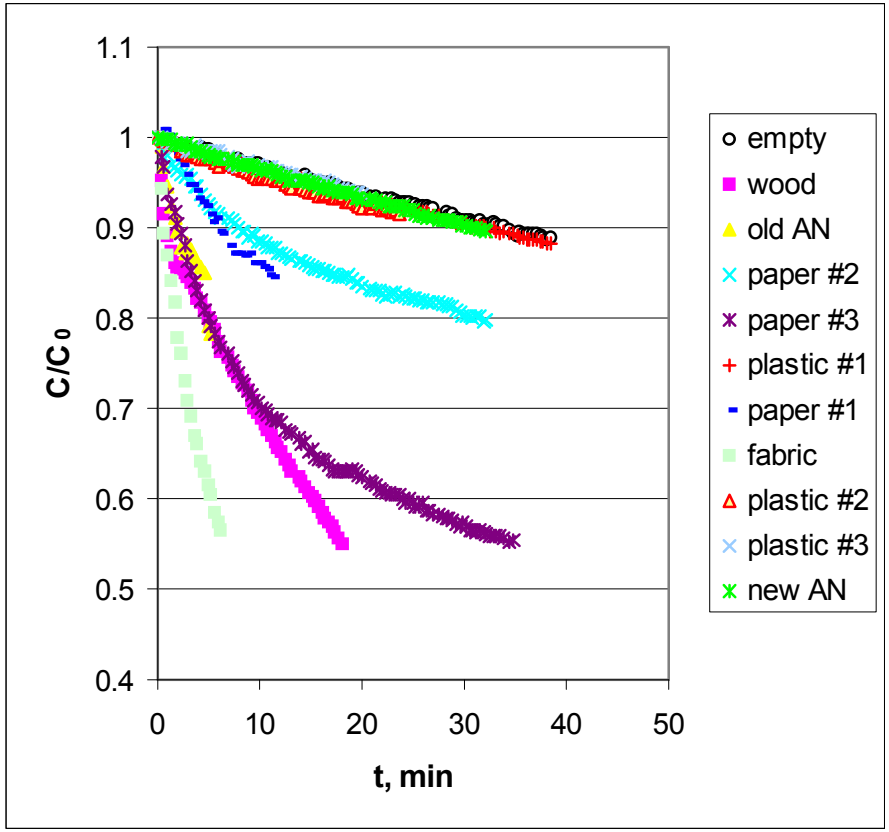


Simultaneous measurement of ammonia and water concentrations in glass box.
At the beginning instrument measured atmosphere humidity and absence of ammonia.
t = 14 min – ammonium titrate (AN) sample was installed in glass box. Ammonia concentration increases due to AN molecules decay. Water partial pressure decreases because of water sorption by AN sample.
t = 62 min – AN sample was removed from glass box and box with water was installed in it. Water concentration increases approaching to saturated vapor pressure. Ammonia concentration decreases due to ammonia sorption by liquid water.

Wrapping materials



Investigation of ammonia interaction with different wrapping materials



Decrease of ammonia caused by sorption of different materials

Conclusion

1. DL based instrument was developed having minimum detectable concentration of ammonia below ppb level.
2. Concept of explosives detection by measuring decay products of explosive material was proved.
3. Non-contact explosive sample detection was experimentally demonstrated.
4. Field tests of standoff explosive sample detection were successfully performed recently.