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# Portable Thin Layer Chromatography for Field Detection of Explosives and Propellants

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## ABSTRACT

A field deployable detection kit for explosives and propellants using thin layer chromatography (TLC) has been developed at Lawrence Livermore National Laboratory (LLNL). The chemistry of the kit has been modified to allow for field detection of propellants (through propellant stabilizers), military explosives, peroxide explosives, nitrates and inorganic oxidizer precursors. For many of these target analytes, the detection limit is in the  $\mu\text{g}$  to  $\text{pg}$  range. A new miniaturized, bench prototype, field portable TLC (Micro TLC) kit has also been developed for the detection and identification of common military explosives. It has been demonstrated in a laboratory environment and is ready for field-testing. The kit is comprised of a low cost set of commercially available components specifically assembled for rapid identification needed in the field and identifies the common military explosives: HMX, RDX, Tetryl, Explosive D or picric acid, and TNT all on one plate. Additional modifications of the Micro TLC system have been made with fluorescent organosilicon co-polymer coatings to detect a large suite of explosives.

Keywords: Explosive detection, propellant detection, Thin Layer Chromatography, field detection

## 1. INTRODUCTION

There are several methods for explosives detection in the field, ranging from simple colorimetric kits to sophisticated spectroscopic methods. All these methods define some type of explosives detection—from screening to speciation of the exact material. One such technology that is mature for laboratory use, and performs very well is thin layer chromatography (TLC). TLC is fairly simple, has few power requirements, is very accurate in separation and detection, and can have very low limits of detection.

TLC has been utilized in chemical separation and detection since the mid 20<sup>th</sup> century [2]. It has been employed for a variety of applications, and has been a proven technique for separation and detection of chemicals. Extensive treatments of the application of the technique applied to a wide range of chemicals can be found elsewhere [2]. Briefly, TLC utilizes separation of individual compounds based on differing partition coefficients for each compound between the mobile liquid phase (solvent) and binding sites on the (stationary) solid phase (the adsorbant on the TLC plate). The solvent gradually moves up the plate via capillary action, and the analytes move along the stationary phase at different rates. The desired result is that each component moves a different distance up the plate, resulting in a series of spots at different locations up the plate. Substances can be identified by their  $R_f$  values, which are characteristic for a given mobile and stationary phase. The  $R_f$  value for a substance is the ratio of the distance that the substance travels to the distance that the solvent travels up the plate. For example, an  $R_f$  value of 0.5 indicates the spot corresponding to the substance travels exactly half as far as the solvent travels along the plate. Various methods can be used to visualize the different components once separated. The classic example is the separation of inks where the components are already colored in the visible range, so they can be seen without assistance. However, many chemical components are not colored in the visible range, so alternative methods are needed for detection, including chemical developers or UV light sources. The ease of using TLC is shown in Figure 1. Making a direct drawing of the plate performs the documentation of the position of the mixture components for an issued US Patent on a TLC method for separating explosives [1].

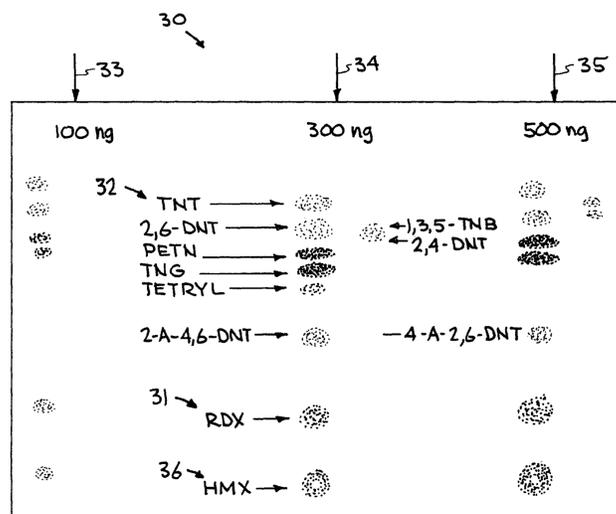


Figure 1. Drawing of position of components separated by TLC in an explosive mixture from US Patent 7745227 B2 [1].

The utility of TLC is found in the ease of application. It is easy to use by as witnessed by the introduction of TLC techniques early in chemical education [3]. The following are some of the positive features of TLC:

- The process is fairly simple—place the material to be separated on the solid surface and then expose the surface to solvent in such a way that the solvent wicks across the surface through capillary action. The components to be separated are dragged across the surface at different rates and therefore are separated.
- TLC is easy to maintain—the working components are very few. Generally a non-reactive solid is used for the porous surface, such as paper, silica or alumina. (Note, some surfaces can be extremely complicated chemically, but this is the exception, not the rule.) The solvents tend to be mixtures of stable, common liquids such as water, alcohols and acids, requiring little special preparation or storage.
- The components have low power requirements—the separation step of TLC is driven by capillary action of the solvent interacting with the solid surface, requiring no external power. Once the separation is completed, often times the application of the indicator chemical (development if necessary) is usually done by a hand operated sprayer. A common visualization light system is the UV lamp. This requires power. Also, developed TLC plates tend to fade with time, so if a permanent record is needed, a storage device, such as a camera or image recorder is needed. This also takes power.
- TLC can quantitate—although not widely appreciated, TLC is capable of quantitating that is comparable to some more sophisticated methods, such as GC-MS and is superior to IMS [4].
- TLC can speciate—the premise of TLC is to separate and detect the individual components by co-eluting with standards. By definition, the separation into components and identification by standards is speciation. If suitable effort is made, some of the components can be unequivocally identified.
- The components are durable—based on the few moving components and the lack of complicated electronic equipment, TLC is a rugged, durable technology. In some applications, the surface or developers (indicators) can be sensitive to air, presenting an operational challenge, but this is rare for most TLC.
- TLC generally is inexpensive—many of the solid phases used for TLC are fairly common materials, such as paper, silica, and alumina. These are quite inexpensive in bulk quantities. In the case of solid powders, these are deposited on a substrate (usually small pieces of glass or metal), in a simple, cost effective process that can be done by the operator. The technology is so widely used that separation surfaces (plates) can be purchased in bulk and are inexpensive enough to be disposable. Many of the solution phases are common solvents that can be purchased in large quantities and can be used without further or minimum purification. The technology is so routine that many chemical companies produce chromatography-grade chemicals in bulk.
- TLC technology can be field usable—although mostly used in laboratory settings, with appropriate modifications, TLC can be taken to the field. All the factors above coalesce to be a small, portable system with the durability that few alternate separation-detection methods can offer.

All these features present an optimum platform for separation and identification of energetic materials, if the appropriate solid and liquid phases and developing methods can be combined. If the size of the components can be reduced without loss of performance, then the system can be miniaturized.

## 2. LLNL PORTABLE TLC FIELD KIT

**2.1 Overall Structure and Components.** The TLC technology at LLNL was originally developed for the application of propellant stabilizer separation and detection [5], then later for the application of explosive detection. Figure 2 shows the overall kit housed in durable pelican cases. The kit weighs about 70 pounds and is contained in the large case (25" by 20" by 14"). Supplies for consumables are stored in the small cases (16" by 10" by 7").



Figure 2. Full size LLNL TLC Field kit.

The inner components of the TLC kit are shown in Figure 3. These components are more or less the same for all applications (including explosives detection). Shown from left to right in the figure are: 1) a balance for weighing, 2) small portable light for field lighting, 3) shears for cutting, 4) a timer for tracking elution, 5) a mixer and vials configured to be stable for field work, 6) syringe filter for separating solids during solvent extraction, 7) a black plastic tray, 8) a plate holder with separation plate, 9) a developing tank, 10) a sealed package with plate (sealed to keep plates clean and fresh), 11) the development chamber with UV light (optional), 12) a camera for recording a permanent record, 13) and computer to store images and track data. Depending upon the type of separation and detection method, some of these components can be excluded from the kit.



Figure 3. Components of the full size TLC Field kit for Propellants and Explosives.

Overall, the kit separates and detects propellants and explosives, although the development of the kit to meet specific applications has been a step process. In general, the kit uses standard stationary phases deposited on glass or aluminum-backed plates, where the compositions of these phases (plates) depend upon the target analyst. For many of the applications, the detection method uses colorimetric chemistry, and the detection level is on the ng scale. The kit is completely self-contained (hardware, elution solvents, detection reagents and light box), and requires no external power in most configurations (computer assisted record keeping requires power). The kit operates typically for TLC technology—fast separations and multiple analytical samples at one time; little training required.

**2.2 Propellant identification.** The targets for propellant detection by the full size LLNL TLC field kit are stabilizers commonly put into propellants. The total suite of stabilizers are 2NDPA; NNODPA; DPA; 2,4- 2,2'-, 2,4'-, 4,4'-

DNDPA and 4 NDPA [6]. Conditions for TLC of propellants stabilizers are: 1) dissolve in a solution of 60:20:20 v/v acetone, methyl nonafluoroisobutyl ether, and methyl nonafluorobutyl ether; elute with a mixture of 90:6:4 v/v of cyclohexane, methanol, and isopropanol; develop with hydrogen tetrachloroaurate (III)/zinc chloride and sodium hexachloroiridate (III) hydrate (1:1) in H<sub>2</sub>O [7].

Figure 4 shows a field study that utilized the propellant TLC kit. This particular field study was for detection of propellants in approximately 6 million pounds of propellants confiscated by the ATF, where only 90,000 pounds were legally tracked. Several lots were unidentified. The operator finds a flat stable surface to use the kit (in this case, the back of a truck). The figure shows a typical developed TLC plate with propellant stabilizer standards 2NDPA, DPA, AK II and EC. Note: many of the stabilizers were identified at amounts less than 200 ng.

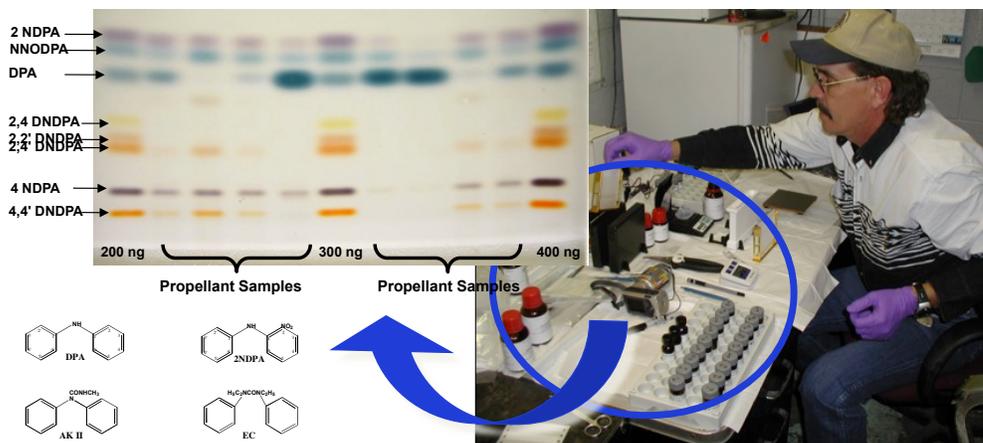


Figure 4. Field application of the LLNL TLC Field kit for propellant identification.

**2.2 Military Explosives Identification.** The LLNL TLC Field kit has been adapted for a suite of explosives [8]. The original chemistry utilized silica plates for separation of the various components with identification of the various components (spot development) by colorimetry. The nitroaromatics were developed as the highly colored Meisenheimer complex and nitramines and nitrate esters with the Griess reagent [1]. Over the years, the colorimetric methods have been optimized for speed of detection and chemical stability.

The identity of the TLC adsorbant, elution solvent and colorimetric methods vary with the target analyte. For the military explosives, HMX, RDX, Tetryl, Explosive D, picric acid, CL-20, TNT, NG, and PETN, normal-phase silica-gel TLC plates (HPTLC nanoSilgur-20/UV<sub>254</sub> plates from Machery-Nagel) are used. The elution solvent is an 8:4:3 v/v mixture of toluene, hexanes, and acetone. Detection is performed in steps—irradiating with 254 nm UV light to identify the nitroaromatic and nitramine compounds; followed by treatment with 1% diphenylamine (DPA) in hexane with irradiation with 254 nm UV light to identify the nitrate esters. Figure 5 shows the separation of several standards at different concentrations. Clearly, most materials are visible in the 100 ng range.

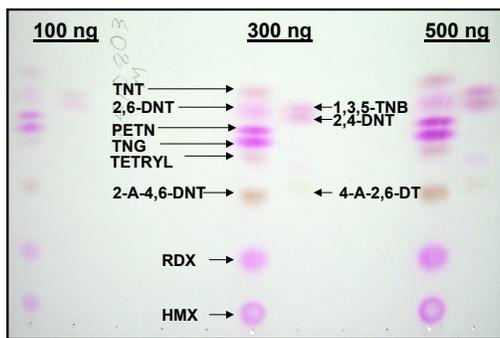


Figure 5. LLNL TLC Field kit applied to explosives to determine limits of detection.

**2.3 Military Explosives and Peroxides.** With the increase in use of Home Made Explosives (HMEs), the TLC kit has been adapted to separate and identify peroxide explosives, TATP and HMTD [9]. The configuration has been changed without the loss of the ability to detect the military explosives—HMX, RDX, Tetryl, Explosive D, picric acid, CL-20, TNT, NG, and PETN, TATP and HMTD. In this adaptation, the reverse-phase C18 TLC plates (RP-18) gave the best results. The elution solvent mixture is a 16:1 v/v toluene and isopropanol. After elution, detection is performed in steps—exposure to 254 nm UV light to identify nitroaromatics and nitramine compounds; followed by spraying with 0.02% diphenylbenzidine in ethanol to detect the peroxide explosives; then irradiation with 254 nm UV light to identify the nitrate esters.

The utility of using the reverse-phase plates is that a second eluting solvent mixture also gives adequate, but different separation of the target analytes, providing a confirming analytical method. By using the solvent mixture of 11:9:2 v/v water, methanol, and acetonitrile, the analytes elute in a different order. After elution, detection is performed in steps—exposure to 254 nm UV light to identify nitroaromatics and nitramine compounds; followed by spraying with 0.02% diphenylbenzidine in ethanol to detect the peroxide explosives; then irradiation with 254 nm UV light to identify the nitrate esters.

Table 1. Observed  $R_f$  values of the standard explosives on the RP-18 plate using the two solvent systems.

Explosive	Toluene:Isopropanol (16:1) solvent	Water:Methanol:Acetonitrile (11:9:2) solvent
picric acid	0.09	0.76
Exp D	0.09	0.76
HMX	0.31	0.41
RDX	0.39	0.44
Tetryl	0.61	0.16
NG	0.73	0.28
HMTD	0.43	0.63
TATP	0.45	0.36
CL-20	0.28	0.01
PETN	0.78	0.08
TNT	0.86	0.23

Table 2. Detection limits (LOD) and the response of explosives to the different visualization techniques.

Explosive	UV response	DPB response*	UV +DPB response	LOD, ng
picric acid	+		+	25
Exp D	+		+	25
HMX	+		+	50
RDX	+		+	50
Tetryl	+		+	50
NG			+	100
HMTD		+	+	10
CL-20	+	+	+	50
TATP		+	+	25
PETN			+	100
TNT	+		+	100

\*Spray with 0.02% diphenylbenzidine in ethanol for peroxide explosives

Table 1 shows the  $R_f$  values for the reverse-phase separation using two solvent systems. The orders of elution are essentially opposite of each other. Table 2 shows the detection limits and response spot development using reverse-phase plate system.

Figure 6 shows the application of the technique to an old munitions site in Hawai'i. These are soil samples extracted with acetone, and then separated on the reverse-phase plates using the water, acetone, and acetonitrile eluent mixture. The plate on the left side is an example of the extract eluted and viewed with 254 nm UV light. The plate on the bottom

right is an example of the extract eluted, the developer applied and viewed with visible light. The top plate on the right side is an example of the extract eluted, the developer applied and viewed with 254 nm UV light. The only detectable material in the soil samples is HMX.

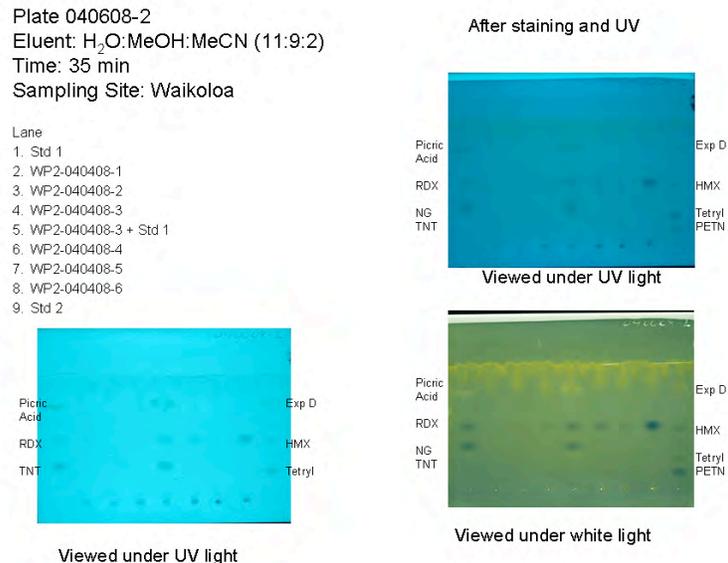


Figure 6. Application of LLNL TLC Field kit to Waikoloa munitons site.

**2.4 Oxidizers.** Further modification of the TLC has been made to accommodate the detection of perchlorates, nitrites, nitrates, chlorates and bromates. The solid phase is HPTLC cellulose plates from EMD Chemicals. The mobile phase is 3:3:2 v/v *n*-BuOH, acetone and NH<sub>4</sub>OH mixture (although other ratios can be used). The development solution is 0.1% sodium 2,6-dichloroindophenol hydrate as the colorimetric reagent. Figure 7 shows the response of various concentrations of the target analytes indicating LOD levels of 2 µg or less.

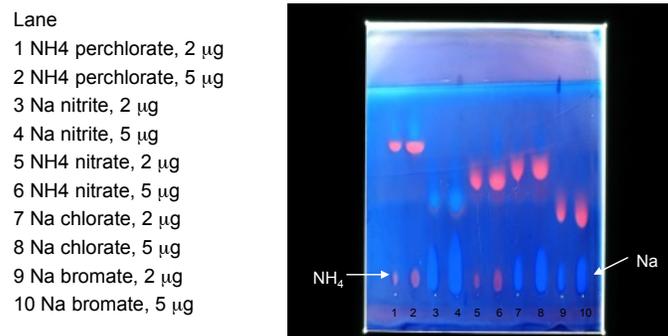


Figure 7. LLNL TLC Field kit applied to solid oxidizers.

For Urea Nitrate, (NH<sub>2</sub>)<sub>2</sub>COHNO<sub>3</sub>, a new system has been developed. The stationary phase is Machery-Nagel RP-18W UV<sub>254 nm</sub>, 10 x 10 cm plates. The mobile phase is a mixture of 3:3:2 v/v of *n*-BuOH, acetone, and NH<sub>4</sub>OH, and 0.5% dimethylaminobenzaldehyde (DMBA) in ethanol containing 0.5% sulfuric acid is the colorimetric reagent. Urea nitrate is first separated into its components; then the urea is detected by the colorimetric reagent.

### 3. MICRO TLC Field Kit

There are many reasons for reducing the size of the TLC kit:

- Reduces the cost—if the components are off-the-shelf, smaller components tend to cost less.

- Current systems are too big for some applications—the smaller unit is easier to transport and, if small enough, could be carried in a back pack.
- Easier to use in the field—smaller size and weight makes field portability more tractable.

Making the TLC kit easier to use in the field is not a trivial task. Several issues must be addressed to attain size reduction:

- Physically reducing plate size without losing separation resolution is a primary concern—the separation is critical to identification with  $R_f$  values being limiting factor. Reduced plate size has the benefit of reducing the size of development tanks and using less solvent, etc.
- Simplify colorimetric chemical reagents—reducing the quantity of chemicals to fit on the smaller platform reduces the size; having multiple plates and reagents increases weight and size.
- Simplify colorimetric chemistry—potentially allows the analysis of more types of analytes per plate; can also reduce the number of chemical components in the kit.
- Improve liquid handling—elution and development chemicals are by far the hardest component to deal with. An improvement in storage and application would help increase speed of detection and reduce the size of the kit and the amount of consumables.
- Reduce hardware size—along with smaller plates, reducing size of UV lamps and other components will help reduce case size, etc. and sometime power requirements.
- Faster detection—smaller plates translates into less solvent development time and have less resistance to capillary action. Reducing the plate size reduces the chromatography time and detection time.

**3.1 LLNL Micro TLC Field Kit.** Figure 8 shows the results of the size reduction, considering the points above. The Micro TLC Field kit is 10” by 10” by 2” deep and weighs about ½ pound when fully equipped [10]. This is a substantial reduction in physical dimensions compared to the full size kit. The Micro TLC kit also does not need accessory cases for consumables. The figure shows not only substantial reduction in size of the TLC plates, but also in the supporting hardware such as the UV light, drying and solvent systems.

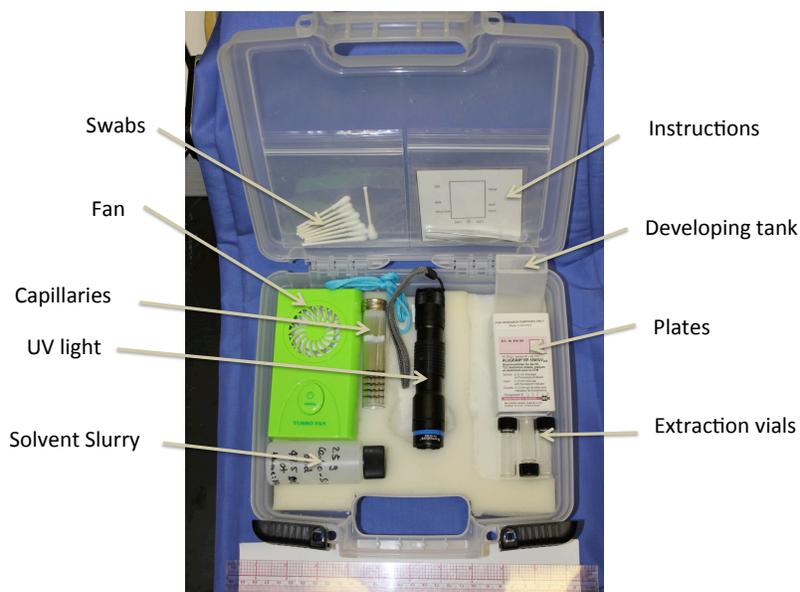


Figure 8. LLNL Micro TLC Field Kit.

**3.2 Micro TLC Field Kit Components.** Figure 9 shows a close-up of some of the components of the system. The Micro TLC has improved performance over the full size TLC Field kit. The separation and detection process takes less than 3 minutes from start to finish. The pre-spotting of the TLC plates with conventional standards before deployment facilitates this time. These pre-spotted plates are stable for a year or more. The Micro TLC kit is also easier to use because there are far fewer components and a more straightforward sampling approach, taking less training.

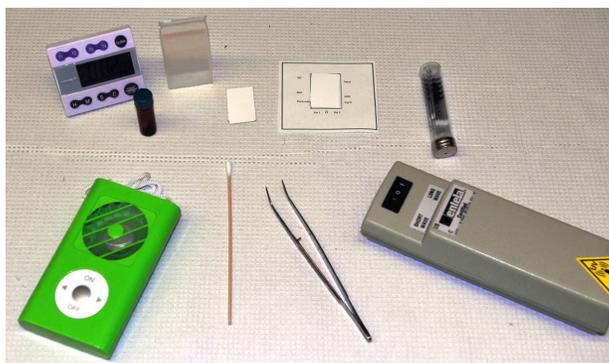


Figure 9. Selected components of the LLNL Micro TLC Field kit.

**3.3 Micro TLC Field Kit Operation.** The operation of the Micro TLC Field kit parallels that of the full size TLC Field kit, but some of the concept of operations has changed to accommodate the smaller design and different chemistry. Samples are taken with a swab or swipe that are extracted with acetonitrile in the vials provided. If the sample is a solid, such as soil, the extraction is handled the same way as the full-size kit. The solvent containing the analyte is transferred from the vial to the pre-spotted plates using micropipettes. If the analyte is suspected to be very dilute, the solution is applied to the plate multiple times (with quick drying in between) as in normal TLC. A notable improvement is the use of the gelled developing solvent. This allows for easier transportation of the kit because the gelled mixture may be treated as a solid instead of a flammable liquid. The plate is developed (elutes) with a gelled slurry of 16:1 v/v toluene and isopropyl alcohol and Cab-O-Sil® 6 wt. % on the bottom of the developing tank. The TLC plate is placed in the gel (the gel will hold it in place), and the container capped. The solvent is eluted to ~ 5 mm from the top that takes about 2 to 3 min. The plate is dried with a battery operated portable fan (3 min) and detection of the analytes uses a by 254 nm UV light. For record keeping, the results are recorded (cell phone camera or PDA) because TLC spots tend to fade with time. The Cab-O-Sil® mixture can be used 2 or 3 times, but it loses enough solvent after the 3<sup>rd</sup> use that it needs to be replaced.

**3.3 Chromatography.** Figure 10 shows the chromatographic separation in more detail. The TLC plate size has been reduced substantially compared to the full size kit to 1" from 6" across with commensurate reduction in plate height. The overall hardware to support the TLC plate and elution solvent has also been reduced in height as well as weight with concomitant reduction in developing solvent volume. The solvent system has been replaced by a gelled system described above. From a performance perspective, the reduction in size of the stationary phase reduces the amount of elution solvent, and, more dramatically, the time required for elution time to 2 to 3 minutes from 20 minutes.

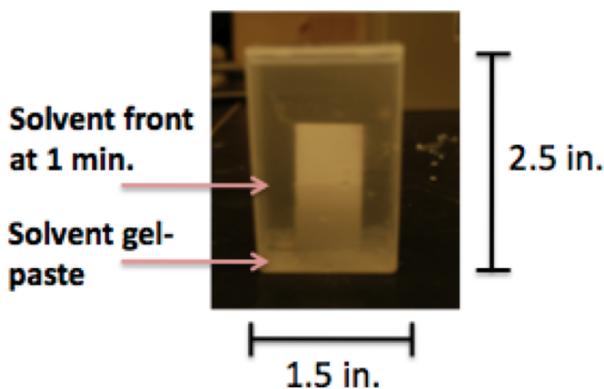


Figure 10. Close up of LLNL Micro TLC Field kit separation system.

**3.4 Micro TLC Field Kit Plate Performance.** Figure 11 shows an example of a developed plate from the Micro TLC Field kit used to separate and identify an unknown explosive. The plates used are the reversed-phase TLC plates described above and were pre-spotted with the standards. For clarity, the left side of the plate was pre-spotted with TNT,

RDX and picric acid, and the right side of the plate was pre-spotted with tetryl, HMX and Explosive D. In this example, the unknown is a mixture of TNT and RDX.

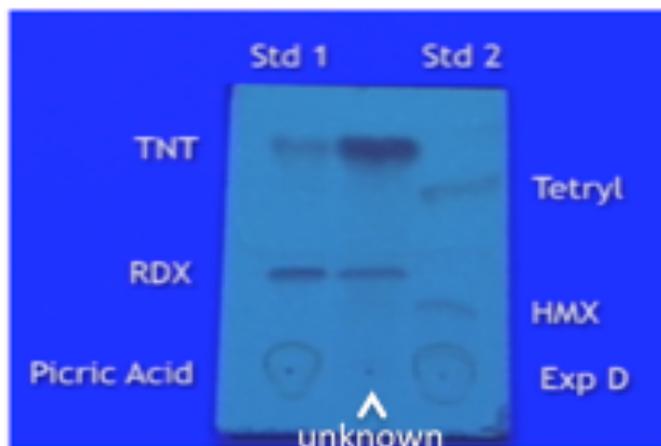


Figure 11. Developed plate from LLNL Micro TLC Field kit viewed with 254 nm UV light illumination.

#### 4. ANALYTE SPECIFIC POLYMER COATINGS

Efforts continue to improve the performance of the LLNL TLC Field kit systems. Comparison of the Micro TLC Field kit to the full size TLC Field kit shows that the Micro TLC Field kit needs to be adapted to accommodate a large suite of explosives. Because of size and operational constraints, these modifications are not just simply miniaturizing the full size TLC components. One approach is to develop new types of coatings for the TLC plates that are more specific or give a broader range of explosives.

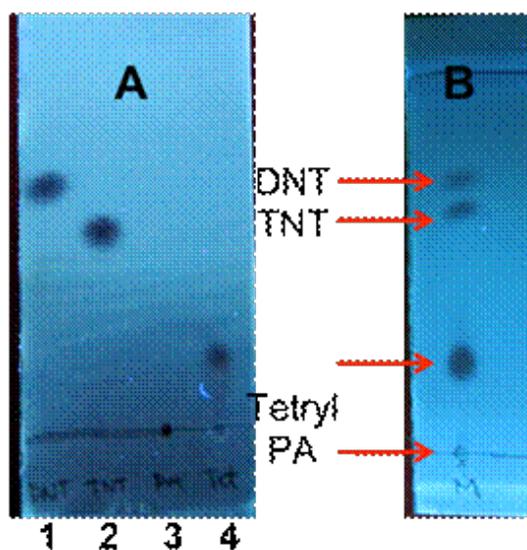


Figure 12. Developed plate from LLNL Micro TLC field Kit viewed with 360 nm UV light illumination using fluorescent organo-silicon co-polymer coating.

The luminescent organosilicon copolymers poly(silafluorenyldiethynylspirobifluorene) and poly(tetrasilolethynylspirobifluorene) have been covalently linked to a silica gel TLC support [11]. This modified support has been coated onto plates that fit within the Micro TLC Field kit. Figure 12 show the separation and detection of a suite of explosives using this modification to the plates. A 360 nm UV light is used for detection. Explosives detected are TNT, DNT, PA (picric acid), Tetryl, HMX, RDX, CL-20, PETN and NG. Detection limits are between 4 to 750 pg, depending upon the

efficiency of the explosive to causing fluorescent quenching of the polymer. The detection results obtained by using these polymers show that the Micro TLC can be adapted to include a wider range of explosives, yet retain the positive attributes of using the miniaturized configuration.

## 5. SUMMARY

TLC has been adapted for the explosives detection of propellants, military explosives, peroxides, oxidizers and urea nitrate. The TLC system has been reduced in size to much smaller TLC kit, which offers advantages in faster detection, lighter platform, less solvent and improved ease of use. The Micro TLC Field kit is currently being adapted to detect a larger suite of explosives.

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## REFERENCES

- [1] Hass, J. S., "System for Analysis of Explosives," U. S. Patent 7745227 B2, June 29, 2010.
- [2] Scott, R. P. W., [Thin Layer Chromatography], Library4Science Publisher, <http://www.chromatography-online.org/TLC/publisher.html>.
- [3] Malins, D. C. and Wekell, J. C., "TLC—Versatile Tool," J. Chem. Educ. 40(10), 531 (1963).
- [4] Caster, W. O., "An optical imager for the quantitation of TLC," J. American Oil Chemist Soc. 43(3) A139 (1966).
- [5] Whipple, R. E., "Field Analysis of Propellant Stabilizers and their Daughter Products in any Propellant Formulation by Thin-Layer Chromatography Year End Report 2003," UCRL-TR-201359, December 9, 2003.
- [6] Pelatron Inc., "Thin Layer Chromatography TLC Field Kit, Operators Manual for Analysis of Propellant Stabilizers," revised 4/15/07, <http://WWW.PELATRON.COM>.
- [7] Kim, H. and Church W., "Field-Portable Thin Layer Chromatography Propellant Stability Test Kit, Moving Forward PIKA – Pelatron Consortium," 2007 Global Demil Symposium, [http://www.dtic.mil/ndia/2007global\\_demil/SessionVIA/1435Church.pdf](http://www.dtic.mil/ndia/2007global_demil/SessionVIA/1435Church.pdf)
- [8] Hass, J. S. and Gonzalez, M. A., "Rapid on-site environmental sampling and analysis of propellant stabilizers and their decomposition products by portable sampling and thin-layer chromatography kits," in [Chemistry for the Protection of the Environment], R. E. Mournigham, M. R. Dudzinska, J. Barich, M. A. Gonzalez, and R. K. Black, Eds. Springer Science 2005, ISBN 0-387-23020-3.
- [9] Whipple, R. E., Klunder, G., Carman, M. L., Nunes, P. J., Chiarappa-Zucca, M. and Bazan, J., "Thin-Layer Chromatography a Field Technique for Propellant Stabilizers and Explosives Analysis," Global Demilitarization Symposium Reno, NV May, 2007; Lawrence Livermore National Laboratory, UCRL-PRES-230934, [http://www.dtic.mil/ndia/2007global\\_demil/SessionVIA/1320Whipple.pdf](http://www.dtic.mil/ndia/2007global_demil/SessionVIA/1320Whipple.pdf)
- [10] Carman, M. L., Whipple, R. E., Pagoria, P. F., and Satcher, J. H., "Rapid Identification of Explosives Using Thin-Layer Chromatography and Colorimetric Techniques," Patent applied (2012).
- [11] Martinez, H. P., Grant, C. D., Reynolds, J. G., and Trogler, W. C., "Silica anchored fluorescent organosilicon polymers for explosives separation and detection," J. Mater. Chem. 22, 2908-2914 (2012).

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