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VAPOR DETECTION OF TRAFFICKING OF CONTRABAND MONEY-- A DISCUSSION OF TECHNICAL FEASIBILITY

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Concept Paper

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VAPOR DETECTION OF TRAFFICKING OF CONTRABAND MONEY --A DISCUSSION OF TECHNICAL FEASIBILITY

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Abstract

For every two pounds of cocaine smuggled into the U.S., drug traffickers are being forced to clandestinely ship three pounds of money back out for subsequent laundering. Based on tracer technology developed for validation of long-range atmospheric transport models and other commercial applications, it is shown that U.S. currency can be tagged with a minute amount (about 1 ppm by weight of a bill) of perfluorocarbon tracer (PFT) material that is sufficient to last for about 30 years and yet provide a vapor emission rate suitable for detectability of modest caches of contraband money in vehicles at border crossings, on aircraft at international terminals, and in buildings. The cost of tagging is less than $5 per million bills; the taggant quantity should have no impact on the feel of a bill. The low emission rate would not allow detectability of usual amounts of money in typical scenarios, providing an essential degree of privacy, but extraordinary amounts would be detectable using specialized instrumentation and know-how not easily attainable but commercially in production; an example of sub-part-per-quadrillion detection of a proposed PFT taggant is demonstrated using a prototype commercial unit. An outline of a research and demonstration program to achieve this capability and details of the proposed tagging and detection procedures already indicate that the concept is technically feasible.

Vapor Detection of Trafficking of Contraband Money
--A Discussion of Technical Feasibility

Introduction

The recent tightening of reporting requirements in the electronic transfer of all monies has forced drug traffickers to resort to bulk smuggling of tons of $5, $10, and $20 bills out of the U.S. via Mexico for subsequent laundering *(1)*; typical intercepted shipments have had $5 to $10 million or more in illicit drug-trade revenues.

This paper addresses the technical feasibility of the tagging of all money, prior to issue, for the vapor detection of "large" clandestine caches, when necessary, in vehicles at border crossings, in aircraft, and in homes as well as commercial buildings using instrumentation currently being commercialized for the detection of underground fluid leaks for the utility industry and other commercial activities. Depending on the tagging process, it may be desirable to tag only specific monies for specific situations; in the end, however, that may be more difficult to implement, technically and logistically.

With the U. S. Treasury's plans to redesign U. S. currency starting with $50 notes in a few years after following the efficacy of the new $100 bills being issued this year *(2)*, now may be the time to consider the addition of a cost-effective vapor taggant that should be a "security-enhancing feature . . . (and) acceptable technologically and politically to society."

Background

Starting in the late 1970s, the U. S. Department of Energy (DOE) has been funding the development and application of perfluorocarbon tracer (PFT) technology *(3)* at Brookhaven primarily for tagging and tracing the atmosphere for validation, at up to 3000-km *(4)*, of long-range air transport, dispersion, and dilution models applicable to accident response following incidences such as at Chernobyl and Bopal. As a result of this R&D, however, commercial laboratory and portable field equipment have been produced and commercial tracer services in a number of other areas have been started at Brookhaven and by others worldwide, in cooperation with Brookhaven and independently. Over the ensuing years, the three other major commercial applications of the PFT technology *(5)* that have evolved were: building ventilation measurements *(6,7)*, petroleum reservoir (gas and oil) studies for enhancing recovery from reserves *(8,9)*, and underground cable leak hunting for the utility industry *(10,11)*. Today, these three applications and that of long range atmospheric tracing are practiced, commercial activities throughout the world (e.g., in Australia, Austria, Denmark, England, Finland, Italy, Japan, Netherlands, Norway, Scotland, and Sweden). Numerous additional publications, reports, and articles have been written on each of these applications.

In regard to enforcement-type activities, Brookhaven's Tracer Technology Center (TTC) interacted with and was funded by LEAA, the FAA and AT&F to develop the use of tracer technology to tag explosives for pre-detonation detection *(12,13)* and to perform a thorough evaluation of the several PFT tagging procedures and their detectability in various explosive detection scenarios as indicated by a number of field demonstrations *(14)*. Recently, the Center's Head testified before Congress regarding the potential for detecting concealed firearms in buildings and schools *(15)*. The prepared Statement and the subsequent Testimony further describe the concept of vapor detection and provide additional background on law enforcement applications and the safety of the use of PFTs in such activities.

The approaches, concepts, and technologies from the above applications have the potential to establish a new system for significantly reducing the trafficking in contraband money as well as aiding in other law enforcement areas requiring detection of "large" money caches. This paper emphasizes the concept of tagging money for detection in various scenarios, provides significant detail to support the conclusion of a reasonable suitability for a high likelihood of successful implementaton, and suggests the probable steps to be covered in a research, development, and demonstration program designed to meet the law enforcement needs.

Concept of Tagging and Detection of Money

In every tagging and detection scheme, whether the tagged item is air (atmospheric tracing and building ventilation), dielectric fluid (cable leak pinpointing), gas (petroleum reservoir studies and gas pipeline leaks), or money, the tagging process and the subsequent PFT emission rate and duration, as well as the practicality and feasibility must be considered in conjunction with the performance of the detection equipment and the actual field situations in which the technology will be used.

Tagging and detection. For this document, some generalizations have been made in order to demonstrate the potential for vapor detection of illicit money shipments or caches. The details used to arrive at the suggested PFT emission rates needed to detect various quantities of bills in different scenarios are given in the attached Appendix A. The conclusion is that only about 1 μg of PFT need be added to each bill in the form of microencapsulated particles or liquid-filled polymer beads with a wall material designed to provide a 10- to 30-year lifetime permeation rate which, as is discussed, appears to be quite attainable. The cost is estimated to be about $10,000 per 2 to 5 billion bills issued per year. Tagging at 1 μg per bill, that is, at 1 part per million by weight of the bill, should have no consequence on the "feel" of the currency.

The minimum limit-of-detection required of the PFT analyzer is in the sub-part-per-quadrillion ($<10^{-15}$) concentration regime, a capability that is already available in a prototype commercial instrument based on a Brookhaven concept. To minimize false alarms, two new PFTs should be developed and used in a known proportion to assure identification. Within less than 6 months following the issue of tagged money, the identification of clandestine caches should be possible; the use of containers, etc., as barriers to militate detection by suppressing emission rates is rarely effective.

Money Detectability. At the tailored emission rates per bill, the usual amount of currency carried by people at normal occupancy levels in buildings and conveyances would not be detectable, thus maintaining an essential degree of privacy, but extraordinary amounts could be detected. Based on the calculations in Appendix A, Table 1 gives the anticipated minimum quantity of bills detectable compared to the usual number expected to be present assuming an average of about 12 bills per person (or 20 when traveling).

For automobiles and trucks, the PFT emission rate, the air exchange rate of the vehicle, and the sensitivity of the PFT analysis instrument would allow about 100 bills in the vehicle to be just detectable, almost equal to the number expected to be present. In airplanes, the amount detectable is about 3 times the expected number of bills to be present; in commercial buildings, about 10 times; and in homes and small buildings, the detectability is about 25 times the expected number of bills. Thus, the most sensitivity for detection is in the scenarios most likely

Table 1

Expected Minimum Detectability of Clandestine Money

	Occupancy (adults)	No. of Bills		Detectable Bills Value
		Expected	Detectable	
Auto/Truck	2	50	100	$1,500
Airplane (727)	150	3,000	10,000	$150,000
Home/Sm. Bldg.	3	40	1,000	$15,000
Commercial Bldgs.				
--4,000 m^3	100	1,200	13,000	$200,000
--40,000 m^3	1,000	12,000	130,000	$2,000,000

requiring uncovering of contraband currency and the least sensitivity is in homes and small buildings (e.g., apartment buildings, etc.) where detection is less likely to be needed (but is still acceptable).

Detection equipment and situations. The basic instrument necessary to measure the presence of tagged money is expected to cost about $100,000 in lots of 1 or 2; such a cost would generally preclude those purchasers other than special law enforcement groups from acquiring the measurement capability. The cost would be substantially less for a larger number of units, perhaps <$10,000 each, when one agency is leasing or buying many for use at multiple sites. However, ancillary equipment, supplies, and operational experience requirements will still keep the cost moderately expensive and the use of the tools difficult for the uninitiated.

A brief description of detection strategies is considered in Appendix A. At border crossings, vehicles would be sampled for the presence of vapor-tagged money as papers are quickly checked. Vehicles pulled aside, either as a routine or because of some suspicion could be more thoroughly but still quickly (less than a minute or so) screened for money vapors. A positive signal would be followed up with additional searching aided by more air sampling with no need to open packages or containers. Pedestrians could also be screened by air sampling much as explosive detection systems perform such screening. Similarly, airplanes, just prior to departure or upon arrival, especially at international terminals, could have the ventilation air checked for contraband money. The verification of money caches not expected to be present could also be quickly assessed by sampling air within a commercial building even in the lobby.

Research, Development, and Demonstration Program Needs

Improving the ability of law enforcement officials to intervene in the trafficking of drug money based on the PFT technology will require a program with the following elements:

1. Review current law enforcement scenarios and strategies designed to intercept contraband money;
2. Develop protocols for enhanced detection consistent with the PFT technology's capabilities and projected tagging concepts;
3. Review current time-release technologies for potential incorporation of the PFT vapor tag;

4. Design, develop, and demonstrate one or more tagging concepts;
5. Develop new PFTs specific for tagging money;
6. Refine the current PFT samplers and analyzers for operation in specific law enforcement scenarios;
7. Design and fabricate ancillary equipment in support of detection protocols; and
8. Field-demonstrate existing and new developments for subsequent detection enhancement.

Appendix A provides a description of how the PFT technology would fare in envisioned scenarios. Under Elements 1 and 2, Brookhaven would meet with appropriate officials and develop concepts more consistent with the user's needs and the technology's capabilities. From previous work, microencapsulation products appear viable as a means to provide the correct tailored emission rates; their disadvantage may be the need to survive the integlio printing process. Subsequently, the microparticulate capsules must also survive normal usage and exposure elements. Other alternative forms of tagging, such as solubilization into substrates already incorporated or easily modified into the printing paper will be examined in Element 3; a disadvantage is the age-dependence of the emission rate. This element would require a detailed examination of commercial technologies in these areas. Brookhaven would work closely with a number of developers and manufacturers during Element 4 and carefully test the proposed systems in cooperation with the Bureau of Engraving and Printing (BEP).

Element 3 and 4 can be explored using existing PFTs. At the same time, Brookhaven would work with the PFT manufacturer, BNFL Fluorochemicals (Element 5) to develop PFTs tailored to meet the emission rate needs and the inherent multi-tracer quality-assurance detection capabilities. Simultaneously, working with the current commercial manufacturer of the Brookhaven DTA as well as new partners in the horizon for an even further improved detectability at reduced cost, the Tracer Technology Center at Brookhaven will thoroughly test the new concepts to be implemented commercially (Element 6).

In Elements 3 to 6, there will be a close interaction and dependence upon the most competent and relevant commercial partners such that at the completion of those tasks, commercial products and protocols for tagging bills and for detecting clandestine money caches are available for immediate implementation in the current proposed time frame for introducing the next-generation U. S. currency. To test those products and facilitate that implementation, necessary ancillary equipment will be developed (Element 7) and demonstrated (Element 8).

Further elaboration of each of these elements would be needed to completely define this R, D, and D program and the costs for such a research endeavor.

Benefits of Brookhaven's PFT Technology

The capabilities of the PFT technology and the skills applied in the last 15 years by Brookhaven's Tracer Technology Center (TTC) in the development of the several successful and ongoing commercial activities, lend an assurance that the technology's ultimate capability to reduce trafficking in drug money will be thoroughly investigated. In March of 1983, the TTC first proposed the concept of tagging dielectric fluid for leak detection; today, more than 20 leaks have been pinpointed and user's of such fluid-filled high voltage cables are seeking to acquire the commercial capability.

Vapor detection of money looks equally promising. The only real uncertainty is exactly how the money tagging process will be implemented, but there are several candidate approaches to be studied in detail.

Vapor detection of tagged money will give the law enforcement investigator another tool to detect or "see" a cache of money without having to first search the vehicle or facility. Additionally, sniffing air expelled from such sources may not be constituted as an illegal search.

There is little risk in exploring this application. The PFT manufacturer is willing to work with Brookhaven to explore new products which could be applied to tagging money; the tagging product (microcapsules, microparticles, etc.) with different PFTs (money PFTs should be unique) could be viable for other tagging applications, both in law enforcement and environmental (e.g., subsurface transport of bacteria and pollutants) situations. There are a number of existing and new microencapsulation industries. The instrumentation is proven and there have been very few situations worldwide where vapors other than PFTs have interfered with their detection; new approaches and industrial partners will only further improve the detection of PFTs, the speed of analyses, and the rejection of interferences. Collecting a sample of air can be done very quickly, inconspicuously, and unobtrusively.

There may be other direct benefits of having vapor-tagged currency. Large transactions could be deliberately monitored; delivered quantities of money should have certain vapor emission levels. Tagged money in banks would produce characteristic vapor patterns when vaults are opened in the morning and when money is returned to the vault in the evening. With future-generation analyzers (not something on the immediate horizon), millisecond processing might be viable for detecting counterfeits.

Project Organization and Key Participant Experience

For a program conducted at Brookhaven, overall project performance would make use of existing technology, instrumentation, and know-how within the TTC as well as new technologies from relevant industrial partners. Project management and technical direction would be the responsibility of Dr. Russell N. Dietz, Head of the TTC. The project would require active participation of a number of federal agencies and the industrial partners.

As the overall project coordinator, Dr. Dietz (Polytechnic Institute of NY, B. Ch. E., 1960; Ph.D., 1964) has 25 years of tracer technology experience in both laboratory and field programs. His chief associate, Dr. Gunnar I. Senum, has 20 years of tracer experience including being project manager of the AT&F program on tagging explosives. Each of the other staff of the Center have worked under Dr. Dietz for no less than 15 years.

APPENDIX A

Parameters Guiding Tagging and Detection of Money

This appendix considers the details of constraints regarding tagging quantities and costs, instrument sensitivity, and particular scenarios to arrive at practical thresholds for the detectability of clandestine money caches. The following sections consider:

- Tagging and detection requirements and guidelines;
- Quantity of money detectable, in various scenarios, and;
- Potential tagging and detection strategies and costs.

Tagging and Detection Requirements and Guidelines

A U.S. bill weighs 1 g and thus the amount of vapor taggant and its carrier components (e.g., microscopic capsules or polymer beads) must weigh very significantly less than 1 mg in order not to affect the "feel" of the bill and yet the vapor emission rate should be sufficient for detection in each scenario, reasonably constant with time, and able to last for perhaps 10 years or more (30 years would cover multiple bill lifetimes). The purpose of this section is to define the tagging and detection constraints with respect to the envisioned law enforcement situations.

For every detection scenario envisioned, the relationship between the PFT emission rate from a single bill, the number of bills present, the ventilation rate in the facility or vehicle being searched, and the concentration level attained is given by:

$$nS = R_v \Delta C \qquad \text{(A-1)}$$

where
- n = number of bills
- S = PFT emission rate per bill (pL/h • bill)
- R_v = rate of ventilation of vehicle, building, etc. (m^3/h)
- ΔC = increase in PFT concentration above ambient background (pL/m^3)

Note 1: pL is picoliters or 10^{-12} liters by volume and fL is femtoliters or 10^{-15} liters by volume.

Note 2: pL/m^3 is equivalent to fL/L or ppq (parts per quadrillion).

To determine the minimum PFT emission rate for one bill from Eq. A-1, one must have an estimate of the expected ventilation rate of structures in which the illicit money is being cached (for buildings, homes, and airplanes, this value is well-known; for vehicles, good estimates are available), the number of bills to be detected (which can be set to 10 times the number of bills normally expected to be present based on the number of occupants), and the minimum reliable signal required for detection of PFT vapors above background (i.e., ΔC_{min}).

Minimum PFT detectability (ΔC_{min}). An example output from a multiple PFT analyzer, produced commercially according to Brookhaven specifications for PFT-tagged dielectric fluid leak detection for the utility industry, is shown in Fig. A-1. Five (5) PFTs were quantified in less than 1.5 min at their normal ambient background levels ranging from 0.5 to almost 12 fL/L or ppq; the speed of analyses can be adjusted for each detection scenario to accommodate both necessary response time and limits of detectability. The lower chromatogram shows air spiked with one tracer (ocPDCH), increasing its concentration to 3.5 fL/L or 8 times background.

As an example of detectability, ocPDCH, the lowest background PFT, has an analysis precision of ±12% to ±15% depending on the instrument operating conditions. This means that for this PFT as a vapor taggant, a signal greater than 1.45 times background is greater than 99% certain to be a real "alarm". Since this potential money-tagging tracer has a 0.4 fL/L background, then ΔC_{min} is 0.2 fL/L which is equivalent to 0.2 pL/m^3 or about 3 pg/m^3 (a very small quantity). As will be shown, this level of PFT sensitivity leads to a very cost-effective tagging formulation. The last section discusses instrumentation costs and possible detection strategies and systems.

Reliability of positive identification. To minimize false alarm, two (2) PFTs in a set ratio would be used to tag money; if both were detected above a certain threshold and within a specified ratio of each other, then a detection would be considered positive. Precision of each PFT's determination is also improved by measuring its response relative to another PFT which is not present in money nor usually in any other application and comparing that ratio to the ratio obtained when no money is present; this ratioing is possible only if the instrumentation being used measures down to the ambient PFT background, as does the Brookhaven-designed equipment.

To further minimize false signals, Brookhaven would again work with the primary PFT manufacturer, BNFL Fluorochemicals Ltd. in the U.K., to develop new tracers not previously manufactured; this was done by the Brookhaven/BNFL team in 1986 for the development of two new PFTs for 3000-km atmospheric tracing applications. New candidates have been identified.

Minimum PFT emission rate. Detecting contraband money in vehicles at border crossings may be the most important scenario. Assuming the average person carries 12 bills at any one time (~\$100 to \$180), 4 people in a car would have about 50 bills. The tagging level should be set to adequately detect the presence of about 1,000 bills (~\$15,000) in a vehicle at a border crossing; detecting the presence of 100 bills, which might be considered an intrusion of privacy, would be just at the threshold of detection. From Eq. A-1, then,

$$S_{min} = R_v \Delta C_{min}/n \qquad \text{(A-2)}$$

If the air change rate in a closed vehicle is about 2 to 4 times per hour and its volume is about 150 ft^3 (4.2m^3), then R_v is about 10 to 15 m^3/h. Using an average of 12.5 m^3/h and the minimal detectability from earlier of ΔC_{min} = 0.2 pL/m^3, then, for n = 100 bills, Eq. A-2 gives:

$$S_{min} = R_v \Delta C_{min}/n = (12.5)(0.2)/100 = 0.025 \text{ pl/h} \cdot \text{bill}$$

for the threshold detection of 100 bills in a vehicle.

Quantity of Money Detectable in Various Scenarios.

Using the appropriate tagging components and procedures to achieve the suggested minimal PFT emission rate given above, it is informative to use Eq. A-1 to calculate the estimated PFT concentration increases that would occur at steady state in different facilities or vehicles for several magnitudes of bill-quantities being illicitly secreted or smuggled. The facilities and vehicles being considered along with their assumed ventilation rates and volumes are shown in Table A-1. The ACR rate of 6 h^{-1} for auto/trucks is with windows partly open, that for homes/small buildings (0.5h^{-1}) is for naturally ventilated buildings, and that for commercial buildings (1.35 h^{-1}) is the published recommended rate for occupancy at 40m^3/person.

Table A-1

Facility and Vehicle Parameters

Facility/Vehicle	Volume, m^3	Air Change [a] Rate, h^{-1}	Vol. x ACR = Rv, m^3/h
Auto/Truck	4.2	6	25
Home/Sm. Bldg.	500	0.5	250
Building "A"	400	1.35	540
Building "B"	4,000	1.35	5,400
Building "C"	40,000	1.35	54,000
Boeing 727 Plane	240	10.7	2,500

[a] Estimated from published sources

Using these values for R_v and the minimum emission rate above of $S_1 = 0.025$ pL/h · bill, as well as a five-fold higher value ($S_2 = 0.125$ pL/h · bill), the increase in PFT concentration, ΔC, was computed for various quantities of bills, n. The normalized expected concentrations to be found in each situation are then

$$C^* = \frac{C_{meas}}{C_{bkd}} = \frac{\Delta C + C_{bkd}}{C_{bkd}}$$

which are given in Table A-2 as multiples of the assumed background concentration ($C_{bkd} = 0.4$ fL/L) for the various scenarios.

Table A-2

Detectability of Contraband Vapor-Tagged Money in Various Scenarios (Expected PFT concentrations are normalized to background)

No. of Bills	1,000		10,000		100,000		1,000,000	
Value	$15,000		$150,000		$1,500,000		$15,000,000	
PFT Conc. (C*), x Bkd [a,b]	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
--In Auto/Truck	3.5	13.5	26126		251	1251	2501	--
--In Home/Sm. Bldg.	1.25	2.25	3.5	13.5	26126		251	1251
--In Commercial Bldg. [c]								
...400 m^3	1.12	1.58	2.16	6.8	12.6	59	117	580
...4,000 m^3			1.12	1.58	2.16	6.8	12.6	59
...40,000 m^3					1.12	1.58	2.16	6.8
...Room in 4,000 m^3 Bldg.			1.5	3.5	6.0	26	51251	
--In Airplane								
...Boeing 727-100			1.25	2.25	3.5	13.5	26126	

a Limit-of-Detection (LOD) = ~1.5 x Background (Bkd) at 3 sigma

b Tagging levels per 1000 bills: $S_1 = 25$ pL/h, $S_2 = 125$ pL/h

c At 40 m^3/person, the 400m^3 building has 10 people with 120 bills (12 bills/person); the 4000 m^3 bldg, 100 people, 1200 bills; 40,000 m^3 bldg., 1000 people, 12000 bills

With a C* limit-of-detection of about 1.5 times background, the S_2 tagging emission rate improves the detectability in most cases. For detection of 1000 bills or more in a vehicle, either rate is adequate. With 10,000 bills present, the S_2 rate gives a signal greater than 100 times background; clearly $1 million or more in monies being smuggled would easily be detected. For a naturally ventilated home or small building, the S_2 rate allows the detection of 1000 bills (a $15,000 cache); 10,000 bills ($150,000) could be readily detected (the S_2 rate gives 13.5 times background).

In commercial buildings, the detectability of a cache scales with the building size. Almost all such buildings have air handling systems with recirculation of some return air; in essence, the building has well-mixed air such that tagged money in any room on any floor will, within a few hours, establish a uniform concentration at all floors. For a 4,000 m^3 building (1-2 stories), detection begins with slightly more than a $150,000-cache. Most of that building would have a concentration of 1.6 times background; a room in the building would be at 3.5 times background, so pinpointing the cache is possible. With 100,000 bills (a $1.5 million cache) in the 4000-m^3 building, the PFT concentrations in the building and the room with the cache would be 6.8 and 26 times background, respectively, that is, easily detectable. On a Boeing 727, a $150,000 cache could be readily detected in the ventilation exhaust from the plane's outflow valve.

Note that in each of the scenarios above, the effect of placing money in a container of any sort will delay the attainment of these steady state concentrations, but, as discussed next, in most cases and with most barriers the delay is not consequential.

<u>Time required to be effective.</u> There are two periods of time which will effect the detectability versus quantity of money in various scenarios shown in Table A-2--namely, the time since the issue of new tagged bills and the lag time of a barrier (14). The former would reduce the attained steady state concentration values shown in the table and the latter would delay that attainment.

Small denomination bills have the least circulation lifetime--about 18 months for $1 bills *(2)* but probably less than 3 to 4 years for $10 and $20 bills. If money were tagged at the S_2 rate, then the S_1 rate in Table A-2 is equivalent to the presence of 20% of all money in a cache as tagged money. Thus, the concentration numbers under the S_1 rate represent the detectability if tagged bills were introduced at the replacement rate and about 1 year or so had elapsed. The conclusion is that money caches should be detectable in all scenarios in one year or less--even much less time in circulation for detection in automobiles and trucks.

The lag-time effect of various barriers--items such as suitcases, boxes, plastic bags, etc., in which the cached money was placed before occupying the conveyance or building, was studied in detail earlier (14). It is beyond the scope of this paper to discuss all the variables affecting the time to achieve detectability, but the conclusion of the earlier study is that normal items in which large caches of money would be placed effectively have no impact on detectability unless very extreme measures were taken by the perpetrator, and even then it is difficult to be certain one has been effective in that task.

<u>Potential Tagging and Detection Strategies and Costs</u>

This last section addresses the feasibility of tagging money by providing an example using technology demonstrated almost twenty years ago and shows that the cost of implementing the tagging of all bills is essentially trivial. Also addressed is a description of the PFT analyzer and its estimated cost as well as a brief discussion of detection strategies and systems which could be developed for the relevant law enforcement scenarios.

Tagging feasibility and cost. The minimum desired emission rate from one bill, S_1=0.025 pL of PFT vapor per hour, as derived above, may need to last for 30 years and should have an insignificant cost. The example PFT from Fig. A-1, oPDCH, consists of about 50% as the ocPDCH isomer. The total mass of that tracer required to give the S_1 rate over 30 years is only 0.2 µg; the S_2 rate, 0.125 pL/h•bill, would require a total of 1.0 µg of PFT to last for 30 years. Note that this mass is only 1 part-in-a-million of the 1-gram weight of a bill, thus ensuring negligible impact on the "feel" of a bill.

The current commercial cost of this PFT is about $350 per kilogram from the manufacturer (BNFL). The preparation of the PFT in the form of microencapsulated particles might bring the cost to $1,000 per kilogram of PFT which would tag 1 billion bills at 1 µg each; if this was implemented several years from now when, in each ensuing year, a different denomination bill (from $50 down to $1) is to be issued, the estimated 2 to 5 billion bills each year would require less than $10,000 in tagging material costs.

However, can a tagging composition of 1µg of PFT microcapsules per bill be formulated to give the desired rate, about 0.1 pL/h•bill? About 18 years ago, Brookhaven, with AT&F support, worked with such capsules used to tag explosives for the potential pre-detonation detection of clandestine bombs; papers were given in a 1978 workshop *(16,17)*, at which, SRI International presented work with the REGEMA microencapsulation system *(18)*. An isomer of the PFT example above, in this case, mPDCH, was made into 20-28 µm diameter capsules containing 82% by weight as mPDCH; the permeation rate at about 50% humidity was 2 to 4 ng per min per gram of capsules. Using an average value of 3 and assuming the PFT was 45% ocPDCH, this rate is equal to 5.0 nL/h/g or equal to the S_1 rate of 0.025 pL ocPDCH/h•bill with just 5 µg per bill containing about 4 x 10^5 capsules per bill; with this formulation, the S_2 rate would require 25 µg or about 2 x 10^6 capsules per bill at a cost of about $25 per million bills and would last for 750 years.

For a more reasonable 30-year lifetime with minimal cost, a microencapsulation formulation giving a vapor rate of about 0.1 ng per min per gram of capsules needs to be developed. Certainly, in the last 18 years, significant improvements have been made in the tailoring of microencapsulation systems which would allow optimum performance for tagging money. The preparation of microcapsules and other tagging approaches must be studied in some detail, but a feasible approach would seem possible.

Description of PFT analysis system and cost. The new commercial version of the original *(19)* Brookhaven dual-trap analyzer (DTA) is being produced for detecting the underground dielectric fluid leaks that occur in buried high-voltage transmission lines belonging to the electric utility industry. Currently, a prototype unit, built according to Brookhaven design by Sentex Systems Inc., has been residing at BNL since September 1995, undergoing installation of components and testing. The present system, SDTA1, is capable of analyzing for PFTs in air down to the background level as shown in Fig. A-1 in about a 1.5-min cycle time. While air is sampled on one trap, the other trap is desorbed, processed and treated, retrapped, and finally analyzed; output results such as those shown can be provided every 1.5 min.

The PFT technology developed at Brookhaven also includes sampling devices such as glass adsorbent tubes (about the size of a cigarette) and air sampling bags (a few liters), which can be quickly filled with air from various detection scenario locations and returned to a centrally-located analyzer for PFT determinations. The new SDTA system is being designed to include analysis of sampling tubes and bags automatically as well as real-time analysis of air delivered by a pump; instrument control and data processing are via a lap-top computer which will also communicate to an expert system for decision-making.

An even newer version of this commercial prototype is on the drawing board at Brookhaven with new components and approaches being developed and tested now which could lead to another further improvement in sensitivity with a significant reduction in analysis time--possibly down to a 10- to 30-second cycle time. The cost of such a system would depend on the ancillary equipment desired and further simplifying commercial developments that are on the horizon for other market applications of the technology. One-of-a-kind systems with appropriate support material would probably be $100,000 to $150,000. On the other hand, certain design considerations imply that, in modest quantities, costs could be under $10,000.

Detection strategies and systems and costs. Brookhaven's Tracer Technology Center has employed PFT technology in numerous applications requiring different tagging and sampling tools and strategies as well as laboratory and real-time field analyzers *(3,5)*. It is beyond the scope of this document to consider the complete details of law enforcement situations to which the detection of tagged money could be applied, but some generalizations can be made.

At busy border crossings, there are a number of potential scenarios. Of course, any car or tractor-trailer pulled aside for a more thorough inspection could easily have one or more air samples collected and analyzed within minutes; a positive signal, especially if reconfirmed, would provide much encouragement for a follow-on thorough search. To assist in that process, air samples would be collected from each crate or carton in a truck and analyzed within seconds; in this way, only the positively identified crate(s) would need be opened to confirm the presence of contraband money.

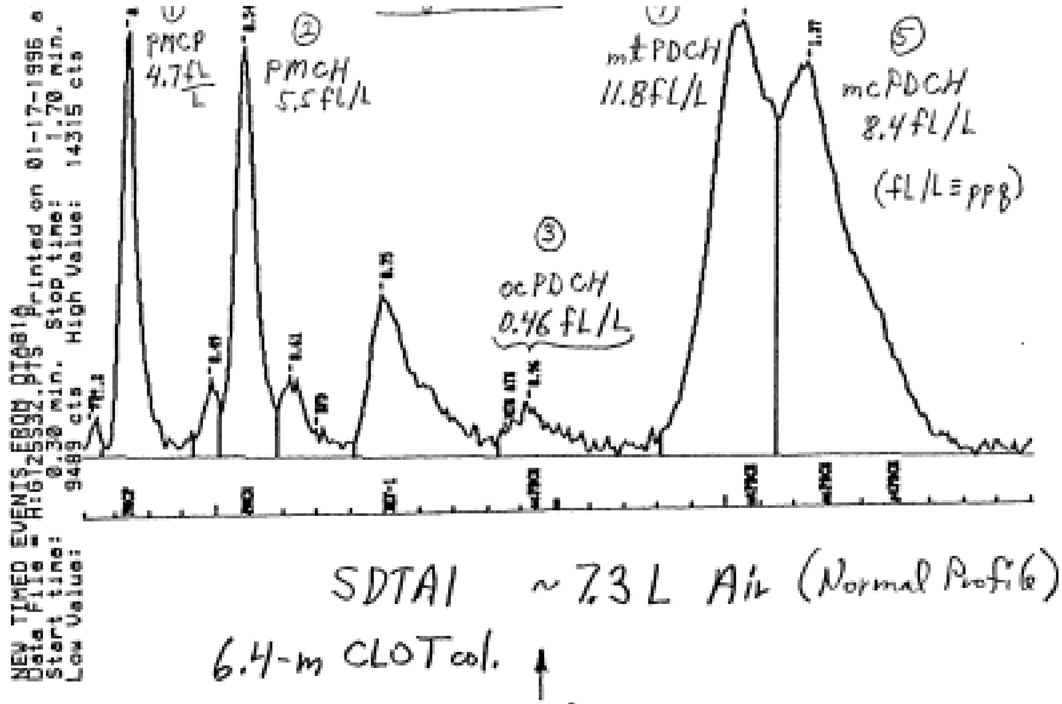
For pedestrians walking across the border, or for vehicles being waved through, passageways can be devised to sample air continuously, much like is done on an automated baggage examiner *(20)*. A Plexiglas walled-in drive-through, with air being extracted below and on both sides of the vehicle, might allow rapid screening for detection with no apparent intrusion of the vehicle; even with dilution factors of 100- to 1000-fold, large caches of money (>$1 to $5 million) would be detected. More effectively, especially for trucks, when the driver's border papers are examined, techniques and procedures could be devised to quickly sample the cab air and the trailer air.

With the projected real-time analyzer capability, the air in the exhaust vent of an airplane could be checked for a tagged-money cache in about 30 seconds or less. It is unlikely the analyzer would be built into the airplane, unless the PFT technology was being used also to detect the presence of smuggled tagged explosives, firearms, or other items of law enforcement concern *(14,15)* that had also been tagged. Alternatively, one or two central locations at an airport could be equipped with the latest real-time money analyzer (MDTA) version capable of analyzing collected samples and a sample of vent outflow air could be collected just before departure or on arrival if there was suspicion of a large money cache; results would be available in minutes for further decision. International arrivals and/or departures might be a location for routine checking.

A commercial building suspected of containing a large cache of money could, in most cases, quickly and inconspicuously have a sample of air collected and then processed in a nearby passenger van equipped with the MDTA; presumably a court order to collect a liter of air in the lobby of a building may not be needed. If a signal were detected, it may also be feasible to sample air on some floors within the building without entering particular units or suites on that floor.

Homes and small buildings, on the other hand, could have air collected from penetrations, especially in basements and crawl spaces, but permission to search (i.e., take air from within the home or building) might be needed.

Details of these and other scenarios would need to be defined and expanded within the proposed R,D, and D program.


NEW TIMED EVENTS FROM DTABIA
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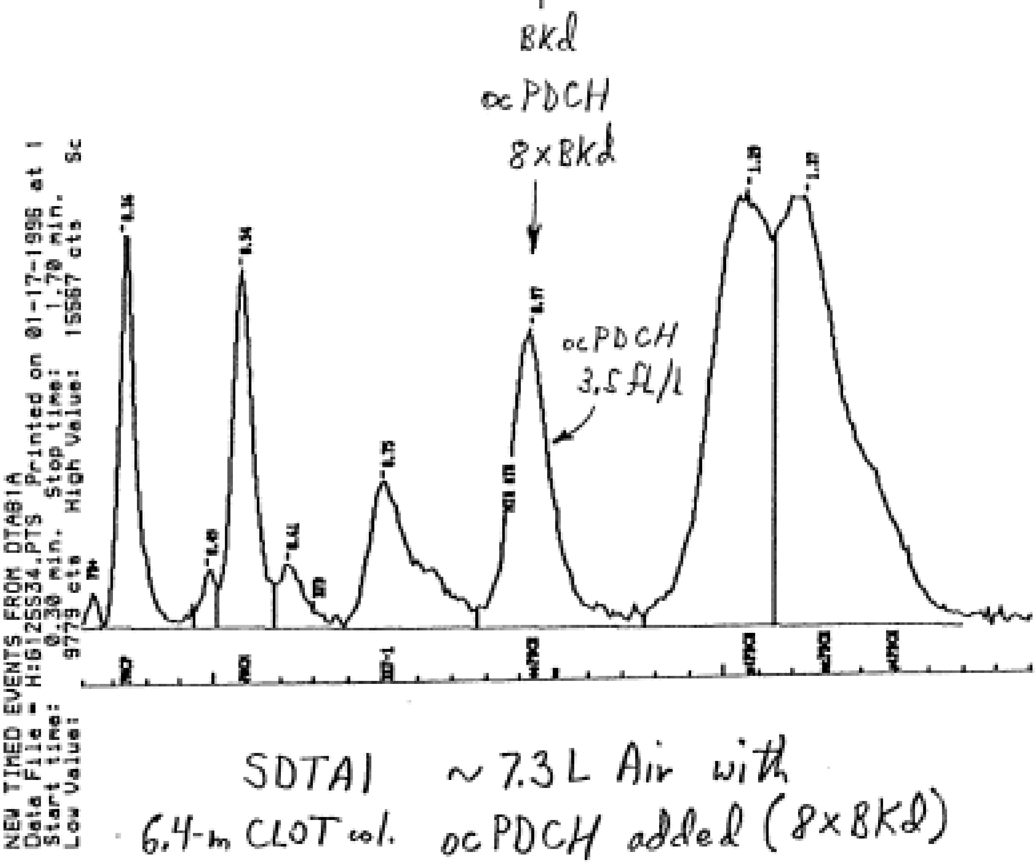
① PMCP 4.7fL/L
② PMCH 5.5 fL/L
③ ocPDCH 0.46 fL/L
mtPDCH 11.8fL/L
⑤ mcPDCH 8.4fL/L
(fL/L ≡ ppq)
SDTAI ~7.3 L Air (Normal Profile)
6.4-m CLOT col.


BKd
ocPDCH
8×BKd
NEW TIMED EVENTS FROM DTABIA
Data File = H:612S534.PTS Printed on 01-17-1996
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Low Value: 9773 cts High Value: 15567 cts
ocPDCH 3.5 fL/L
SDTAI ~7.3 L Air with
6.4-m CLOT col. ocPDCH added (8×BKd)

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