# Countering Terrorism: The Role of Science and Technology

## A Personal Perspective

IMAGE NOT LICENSED FOR WEB USE

Los Angeles Times photo by Luis Sinco

by Jesse L. (Jack) Beauchamp

*On January 1, airports all over the country began sprouting SUV-sized CT scanners to screen passengers' checked baggage for explosives, part of a federally mandated plan to beef up aviation security. Los Angeles International Airport was up and running, with 58 of the new CT screeners and 270 smaller scanners to detect traces of explosives, on the first day of the new year. The lines at the Tom Bradley Terminal stretched out the door (above). Jack Beauchamp's October Watson Lecture foreshadowed this next level of security and explained the research that went into these machines (and subsequent instruments still in development)—and how they work.*

The terrorist threat is a real one. The ease of travel and the access to explosives technology make the terrorist's job a fairly easy one, especially when he's willing to die to accomplish his objectives. And there's a broad spectrum of financial supporters for terrorist activities, which gives factions the ability to strike at any desired target.

In countering such threats, we have so far been mainly reactionary—responding to wake-up calls when terrorists strike. It would be better if we could get out of this mode, if we could anticipate the bad guys and prevent them from carrying out

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their intended activities. This is a tall order, but it's clear from the intentions of Congress and the White House that we're embarking on an enormous program with an R&D budget of around $36 billion to do the best we can.

We have had several wake-up calls already. In 1988, an explosion blew Pan Am Flight 103 out of the skies, killing everybody on board. Forensic work, including careful reconstruction of the aircraft, determined the amount of a common type of explosive that was able to destroy the plane. This information has helped define some of the parameters that are used in the certification of explosive-detection systems in airport security today.

A second alarm went off in February 1993, when a first attempt to bring down the World Trade Center failed. Ramzi Yousef, the mastermind behind this scheme, was also implicated in a complex plot to blow up as many as 11 U.S. aircraft simultaneously over the Pacific Ocean. This wasn't even a suicide mission (nor was Pan Am 103). The terrorists practiced on a flight in Southeast Asia; the bomb was to be planted by a passenger flying a short leg of a flight before the aircraft's departure to either Hawaii or the continental United States. Those involved with the plot were aware of the security precautions and planned their attack to avoid detection. They carried the components on board and assembled the bomb in the bathroom; it was then left in the life preserver under a seat. On the next leg of the flight it exploded, killing a Japanese businessman. But the aircraft was not destroyed, and the larger plot was discovered and thwarted.

Another significant event occurred in 1995, when the Aum Shinrikyo group planted sarin gas, a nerve agent, on five Tokyo subway trains. Only a dozen people died, but several thousand were hospitalized, and it's fortunate that the event did not lead to far more deaths than it did. But we also need to note that this group experimented with a variety of biological agents, as well, and carried out one anthrax attack. Aum Shinrikyo was even able to finance a group of doctors and nurses to bring back the Ebola virus from Africa. It's not known whether or not they succeeded, but this is pretty scary stuff.

When the Murrah Federal Building in Oklahoma City was destroyed by a truck bomb in 1995, 168 died. And in 1998, terrorists were able to mount a coordinated attack, ramping up the stakes in this game by simultaneously bombing two United States embassies in Africa and killing 224. Then terrorists attacked the USS *Cole* while it was refueling in Yemen in 2000.

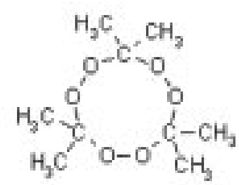
And then came September 11, 2001. About 2,800 people died (compared to 2,400 at Pearl Harbor). I think this event is going to continue to have an impact on the way we live for the next few decades. Potential targets are abundant.

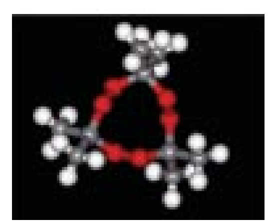
All involved with security have their own favorite list of targets. I have some of my own that I won't even mention here; they would be so disastrous and so easy to do that I'd feel terribly responsible if someone actually went out and did one of them. Among potential objectives already widely known, big buildings will continue to be tempting, easy targets. The Federal Aviation Administration (FAA) provides a conveniently downloadable map on the Internet of numerous other sites, called "temporary flight restrictions." They include nuclear power plants, national laboratories, even the president's ranch. Then there are dams, large airports, the air-traffic-control system, large public gatherings, public figures, the banking and economic sector (remember *Goldfinger*?), energy supplies (for example, the unprotected pumping stations along the Alaska pipeline, a map of which you could find on the Internet until a year ago), and last but not least, the Internet itself.

As for the latter, we're becoming increasingly dependent on the Internet for absolutely everything. Unfortunately, "everything" includes material that actually aids terrorism. If you want to read what the bad guys read, you can search for *The Terrorist's Handbook* and download a copy of it. It will tell you how to build bombs and how to make the explosives that go into them (if you can't acquire them elsewhere). It will also tell you *how* to acquire them elsewhere: just walk over to the chemistry laboratory at any nearby university, go into the stockroom, and load up your backpack with all the ingredients you need to make high explosives.

What brought this to everyone's attention was the shoe bomber, Richard Reid, who claims that he used a recipe from the Internet to fashion his infamous sneaker bomb. It has been reported that the molecule he prepared—we'll do a little chemistry now—is triacetone triperoxide (TATP). It can be made from hydrogen peroxide, which you can buy from the local pharmacy; acetone—not the type for fingernails, but the paint-thinner

**Triacetone triperoxide, or TATP, the shoe bomber's explosive of choice, is easily concocted at home.**





Above: The author and his wife, Patricia (also a pilot), love to fly to remote places. Here they camp under the wing of their Cessna 172 in Alaska's Denali National Park. Below: The virtual cockpit of a Cessna 172 on Microsoft Flight Simulator, which can teach you how to fly a plane with your feet still on the ground.

variety available in any hardware store; and a small amount of hydrochloric acid (sulfuric acid will also do). Then you can log onto the Internet and easily find several procedures for combining these ingredients to synthesize TATP. Some are, I would say, quite a bit safer than others, so you might want to consult with your chemist friends. So you don't need a Caltech degree in chemistry to make a compound that has essentially the same power as RDX, the principal component of plastic explosives. What Richard Reid didn't know, as he tried to strike a match to ignite his TATP-lined shoes, was that it's very shock-sensitive. If he had simply stamped his foot, he and the plane might have been history.

I find it interesting that the Bureau of Alcohol, Tobacco and Firearms (ATF), which has responsibility for classifying explosive materials, added this chemical to its list of explosives only this past year, even though it's been used by terrorists and others for nearly two decades and has been known for more than a hundred years. But they finally admitted that, yes, this is a dangerous explosive.

If science and technology are, to some degree, at the terrorist's disposal, what can science and technology contribute to *prevent* or mitigate future terrorist attacks? This is a broad field that I can't begin to cover here, so I'm going to limit myself to the threat to commercial aviation, in which I have some experience.

How did I get involved with aviation security? I'm a chemist. Right now my main interests lie in developing advanced methods for sequencing proteins in the gas phase. But my wife and I are both pilots. We love to fly, and we keep our little airplane at the El Monte Airport.

So, how hard is it to actually fly an airplane? Can anybody—a terrorist, say—just climb into an airplane and learn to fly it? Well, if you'd like to give it a try without the expense of buying a plane or even renting one, you can get yourself a copy of Microsoft Flight Simulator. This is advertised as being as real as it gets, and it's extremely good. The behavior of the "airplane," when you "fly" it, is very close to the real thing. And the simulator gets terrific gas mileage compared to my plane.

One of my graduate students accompanied me on a trip from Pasadena to northern California for a meeting. He had never been in a small plane before, but he had played with Microsoft Flight Simulator. He got in the plane, took off, and flew it all the way to Monterey, performing the navigation as well. And the flight simulator isn't just based on a Cessna 172 like mine, but also includes large aircraft such as a Boeing 737.

Are small planes tools for terrorism? We've seen that a 757 can cause significant damage, but what might one do with a small aircraft? A 1993 Office of Technology Assessment report published a study of the dispersal of 100 kilograms of anthrax spores, which a crop duster could carry on a single flight. The researchers estimated about half a million deaths would result from spraying that amount of anthrax over Washington, D.C. So the answer is yes. The news media reported that four of the hijackers involved in the September 11 attack actually applied for a loan—I think it was from the Department of Agriculture for about half a million dollars—to modify a crop duster. I've never seen a copy of that loan application, but I'd be interested in what they said they were planning to do with it and what the modifications were.

In the early 1990s, having been a pilot for a decade and interested in aviation and the air-traffic-control system, I got involved in developing new mass-spectrometry methods for the detection of explosives. (I'll tell you more about this later.) This combination led to my nomination as chairman of the National Research Council Committee on Commercial Aviation Security, a post I held (succeeding John Baldeschwieler, the Johnson Professor and Professor of Chemistry, Emeritus) from 1993 to 1997. When the explosion on TWA Flight 800 was initially thought to be a terrorist event, President Clinton formed the White House Commission on Aviation Safety and Security, also known as the Gore Commission, after its chairman. I was also appointed to that group, which focused on three specific areas: improved

The National Research Council Committee on Commercial Aviation Security (Beauchamp is in dark shirt, bottom row, left), established in the early '90s, convened here in Atlanta during the 1996 Olympic Games.

aviation security, improved aviation safety (reduction in fatalities due to pilot or crew error and air-traffic-control failures), and improved aircraft reliability (reduction in failures of components and systems). On the whole, aircraft are extremely reliable. Pilot error is a problem; over the last 20 years, pilots have actually killed more people than terrorists have, including all the deaths at the World Trade Center and the Pentagon. But aviation security was our most urgent focus.

We spent six months traveling all over the world, studying what other countries do to protect their aircraft. I spent a week in Israel learning what they do. Theirs is a very different problem, but they have a lot of experience and know-how that we have been able to benefit from.

Early in 1997, the White House Commission submitted its report to the president, who asked the secretary of transportation to implement the recommendations. There's a lot of inertia in Washington's bureaucracy; things get done slowly, if at all. One of the recommendations was to complement technology with automatic passenger profiling. The idea is that most passengers, frequent fliers and families, can be easily defined as being of little or no risk, leaving just a small group of people who merit additional attention. For the most part, this can be done using computer databases. Although progress has been made on this recommendation, the system was not to my knowledge implemented on September 11.

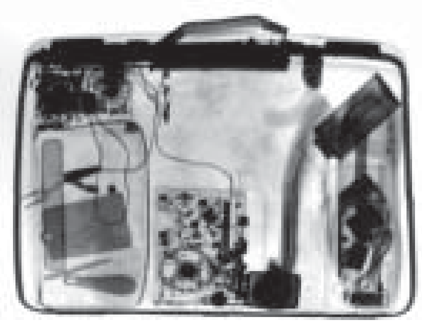
If science and technology are, to some degree, at the terrorist's disposal, what can science and technology contribute to prevent or mitigate future terrorist attacks?

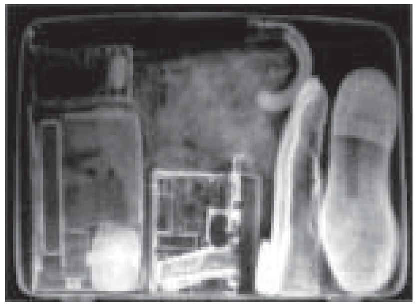
Another of the recommendations was to give properly cleared airport security personnel access to classified information that they need to know. Airlines have been told what to do and not why they're being asked to do it. There needs to be something in between to provide airlines with more information about the nature of a threat so that they can design more effective responses. And that's still a problem.

Let's take a look at aviation security, some of the issues involved, and some of the newer technology. I'll try to explain how some of the security equipment works so that you can impress your friends the next time you're in line at the airport. Aviation security mainly involves screening passengers, their carry-on bags, and checked luggage. Each poses different problems. We need to screen passengers for weapons or explosives. Passengers and carry-on luggage need to be checked rapidly because people tend to board aircraft at the last minute. Checked luggage offers the best opportunity to put a large explosive device onto an airplane. There are a lot of issues associated with checked luggage that I'm not going to discuss here. One of the most important is determining that every suitcase belongs to someone who is also on the plane. Referred to as bag-matching, this is a very difficult problem. Cargo and mail carried on an aircraft also need to be checked.

Detection of explosives in the airport environment presents two distinct problems: bulk detection and trace detection. You need some means to detect a big chunk of explosives and to say, "Yes, there is very likely a bomb there. Let's not let that suitcase or that person on board the plane." Trace detection, on the other hand, involves looking for evidence of bomb making, such as small bits of explosives remaining on a person's hands or clothes. And we'd like to be able to detect chemical and biological weapons as well.

What are the recent scientific and technological developments that enhance aviation security? We are all familiar with the monitors that have been x-raying our carry-on bags ever since airport





**Most x-ray scanners currently in use in airports employ an x-ray source on one side of a bag and a detector on the other to generate what is called a transmission image (left). X-rays bounced back (backscattered) through the same bag to a second detector provide much more information, in this case a plastic gun (right).**

**Backscattered x-rays aren't used on airline passengers in the United States (most people would object to an instrument that can essentially strip them naked), but they can illuminate hidden weapons very clearly, as the man above demonstrates—a metal gun and and a scalpel blade in the front view and a metal file, plastic knife and plastic gun (a Glock 17) in the back. Backscattered x-rays can also pick out illegal aliens being smuggled in a truckful of bananas (right). (Images on this page courtesy of American Science and Engineering.)**

screening procedures were established as the result of the hijackings in this country in the '70s. The screeners look at a bag in a single-view x-ray image in *transmission*. This means you have an x-ray source on one side of the bag, a detector on the other, and you look at the transmitted x-rays, just as with a chest x-ray.

Technology has brought a lot of improvements in x-ray equipment. We now have inexpensive, high-resolution displays and also false-color images. The latter doesn't display a greater amount of information, but it's less boring to look at and helps keep the screeners on their toes. Another technique to maintain operator alertness is called TIP—Threat Image Projection—in which an image of, say, a gun, is inserted into a bag electronically, just to see if the operator is awake. The system allows the operator to determine that the object is not real (a green light flashes when a button is pushed) before he calls the security guards over.

Monitoring equipment can also use x-rays of two wavelengths, which allows you to discriminate based on atomic number. It's more complex, but you get more information out. This would be useful, for example, for finding a detonator based on a lead salt. Unfortunately, you can now buy organic detonators that don't even have metal housings. They're made of paper.

Backscattered x-rays are extremely useful to augment the information you get in an x-ray image. Instead of looking at the x-rays transmitted through the bag, you look with a second detector at the x-rays that are bounced back through the bag again. If you look at the bag with a transmitted x-ray (far left), you can make out various things—a radio, a shoehorn, shaving cream. But can you see a gun? If you look at the same suitcase with backscattered x-rays (left), you can see a plastic pistol. More information is always a good thing. We will start to see more of these scanners in airports soon.

The backscattered technique can also be used to examine large things, such as cargo pallets. Typically, unless you have very high-energy x-rays, you can't penetrate a truck or cargo pallet sufficiently to look inside for the presence of bombs or weapons. But backscattered images can be quite revealing. The image below is from an x-ray system installed at a border-crossing checkpoint between Guatemala and Mexico. The driverless truck has moved through the scanner on a conveyor belt to give it a smooth transit speed past the x-ray source and the detectors. Hidden in the load of bananas in the truck, you can see compartments containing people being smuggled across the border and unknowingly receiving a dose of x-rays.

You *can* use backscattered x-rays on people at very low intensity. They're reflected by the skin and penetrate clothing reasonably well. They're used in prisons to prevent the importation of drugs and weapons, but we haven't yet put them in airports in this country. Since the scanner can see through your clothes, there's a privacy issue to be considered. But in the image at left, you can see that this person has a gun on his thigh; he has a file on the back of his thigh; and in the small of his back he has a Glock 17—a favorite plastic weapon used to avoid metal detectors. Other technologies provide similar imaging capabilities without employing x-ray exposure, which would likely not be accepted by the general public. One such approach generates an image using millimeter waves, but it's expensive and still in development.

Luggage is easier to bombard with radiation than humans are, and suitcase scanning has seen many improvements in the last decade. After Pan Am 103, the FAA Technical Center began investing $20–50 million per year in research and development, doing some of it in-house but mainly providing grants to small businesses and to university researchers to develop the technology and equipment for detecting explosives and weap-

ons. What came out of all this is based on medical technology, specifically CAT scans.

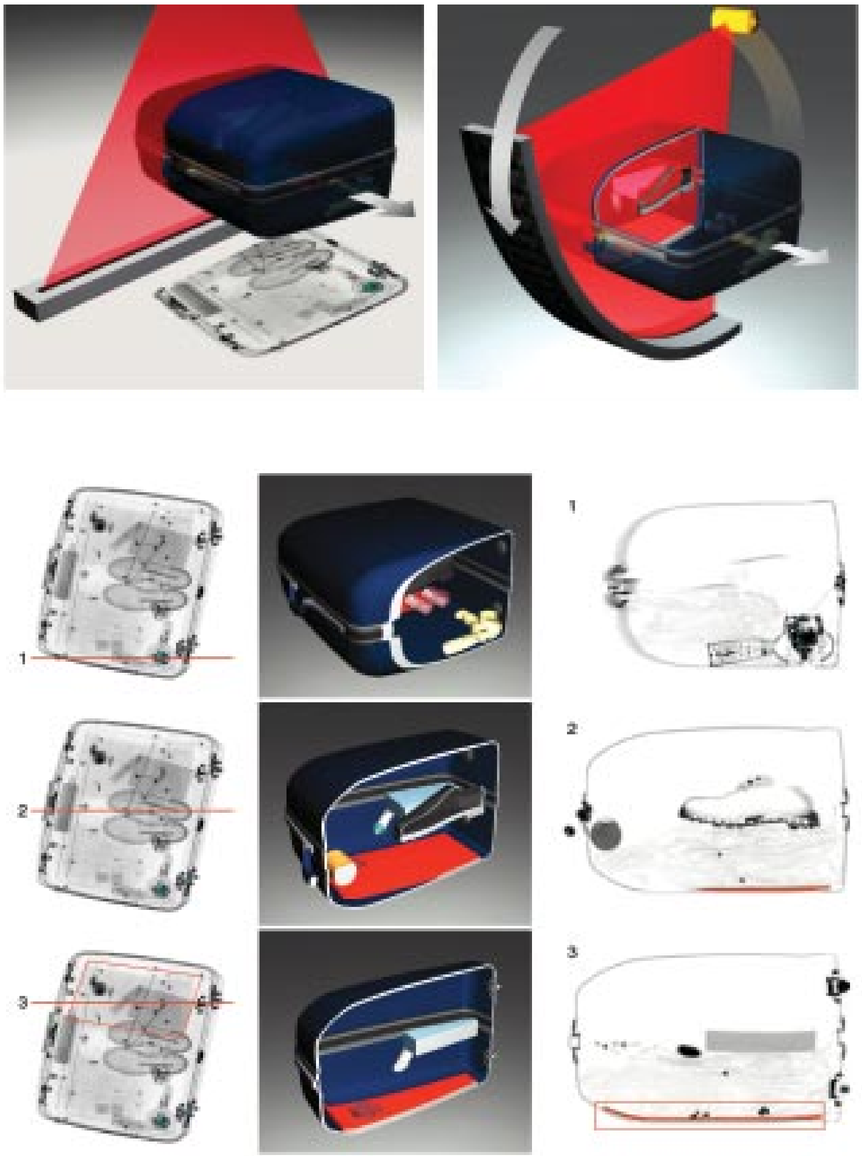
The InVision CTX 5500 x-ray scanner, an automated explosive-detection system, gives the operator a red light if it observes what might be a bomb in the suitcase. This could be a false alarm. For certification of automated explosive detection equipment for checked baggage, the FAA requires high throughput; a high probability of detection for different explosives in different configurations (some are very easy to detect, while others are difficult); and a low probability of false alarms. If you crank up the probability of detection, you're also going to increase the probability of false alarms. If you want to reduce false alarms, you pay the price of a lower probability of detection.

This scanner weighs about a ton and has a gantry that rotates at 60 rpm. It has an x-ray source and a series of detectors that allow it to look at the absorption of x-rays simultaneously over a broad fan. The instrument is rotated around the target, recording data as a function of angle; then you use that information in a fast computer to reconstruct an image of the object, just like a medical CAT scan looking at cross sections of a brain. The quantity of interest is actually the linear attenuation coefficient of the object, which you can obtain for each "voxel," or volume element.

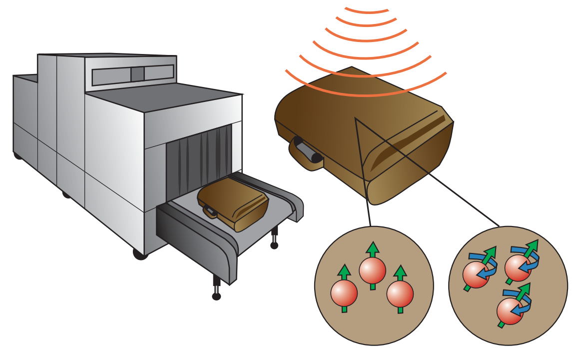
These coefficients are then used to calculate what is known as the CT number—an arbitrary definition that just gives you a scale. Some common CT numbers are: air, –1,000; water, 0; dense bone and metal would have CT numbers of around 3,000. You can determine certain types of bone disease by looking at the CT number. Explosives also have specific CT numbers, which I'm not allowed to tell you here, but they fall in a fairly narrow range. We would like it very much if these CT numbers didn't overlap with the CT numbers of any other common substances.

At left are CT images of a suitcase, showing cross-sectional slices of it as it moves through the CT scanner. You can see a sheet of plastic explosive in the bottom. This is one of the most difficult types of explosive to detect, because it usually conforms to the shape of the suitcase and it's sufficiently thin that it doesn't attenuate x-rays to any significant amount in a transmission image. Once you have identified a suspicious object, you can go back and take many more slices and reconstruct the full shape of the suspected explosive.

The latest version of the CT scanner is the InVision CTX 9000. This particular instrument has been certified at 542 bags per hour, to my knowledge the world's fastest. That means that it has about six seconds to detect a bomb reliably. I know it's been certified for this speed, but I think it's unlikely that this performance will be achieved in actual airport use. One of the reasons I'm doubtful is that the bags the FAA uses at their test center are lost luggage kept in storage lockers. As




**A transmission x-ray image of a suitcase (left) produces a flat, two-dimensional view of the contents and cannot detect the sheet of explosives lining the bag. In the InVision CTX 5500 scanner, the x-ray source and detectors are rotated around the suitcase (top, right), creating multiple slices of data that a computer can reassemble into a three-dimensional image. These data also deliver information on the composition of the bag's contents; the characteristic "CT number" of plastic explosive exposes the hidden sheet of this material on the bottom of the piece of luggage (red). (Illustration courtesy of InVision Technologies.)**



Left: A quadrupole resonance scanner, a variant of an MRI scanner, bombards a suitcase with radio frequency pulses, which excite the quadrupolar nuclei (among them nitrogen and chlorine, common in explosives) and cause them to align and precess at a particular frequency. When these relax back to equilibrium, an echo signals a receiver coil. Each explosive's signal is unique (left, below), as is that of heroin.

you might guess with unclaimed luggage, they don't contain a lot of consumer electronics. This removes much of the clutter that makes it difficult to tell whether an object that has been flagged as a bomb is, in fact, a bomb. In a real situation, you're looking for components—the detonator, the timer, the power supply for the detonator—and when you have electronic clutter, it's difficult and more time-consuming to pick out those components.

Another thing removed from these lost suitcases is food. Unfortunately, it turns out that a number of food products have CT numbers similar to common explosives. Clearing false alarms from, say, smoked salmon from the duty-free shop, may mean significant delays.

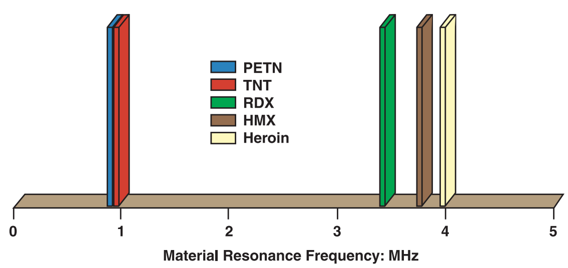
There are also other technologies that could be employed, but there are problems of practicality with all of them. One that still looks promising (although it requires a controlled temperature-and-humidity environment to function well) is a device called a quadrupole resonance scanner. It doesn't make an image like an x-ray scanner; it detects the total amount of substances that have quadrupolar nuclei. That includes nitrogen and chlorine, chemical components of numerous explosive materials. The instrument bombards the bag with radio frequency signals at a particular frequency, causing the alignment of quadrupolar nuclei. An echo occurs as these relax back to a thermal population distribution, inducing a signal in a receiver coil. You can see resonances (right) associated with a fairly wide range of explosives, including PETN, TNT, RDX, and HMX. Certain drugs, such as heroin, can also be detected—a convenient byproduct of numerous explosive-detection technologies.

Another method, impractical for a variety of reasons, involves coherent x-ray scattering, which gives information on molecular structure that can then be used as a fingerprint to characterize different explosives. This might turn out to be quite useful for resolving false alarms.

Neutron scattering is very appealing, especially to physicists, because it would likely provide employment for a PhD physicist in every airport in the country. But for practical reasons, you don't want to have neutron sources in airports because they are large and require shielding. And the quality of the images and the information is still not quite good enough to be useful.

One simple solution is just to contain a potential explosion in checked luggage with containers made of high-tech polymers instead of the flimsy containers that you see being pushed around airports today. This would significantly increase the cost of the containers, but it's a one-time investment that could save lives.

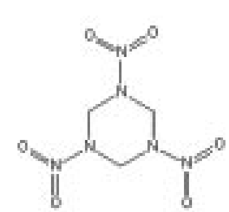
I don't think dogs are very practical for detecting explosives in airports. It remains controversial what they actually "smell." I think, though, that they have a tremendous deterrence effect, and for that reason alone it's probably worth having them. Now, if you could figure out the olfactory process and mimic it with an electronic nose, you'd save a lot on dog food. And electronic noses would work 24 hours a day without trainers. Nate Lewis, Argyros Professor and Professor of Chemistry, is working on just such a device, but an airport model is still on the horizon.

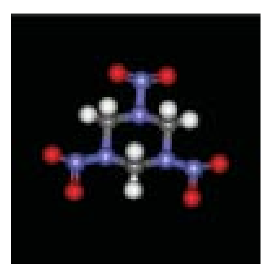



An electronic nose might also be useful in screening passengers for trace amounts of explosives. A trace amount doesn't necessarily mean that a person has been involved with making an explosive device that he's trying to sneak on board. He might be a law-enforcement agent or somebody who loads his own shells for hunting; plastic explosives are also used in some mining operations.

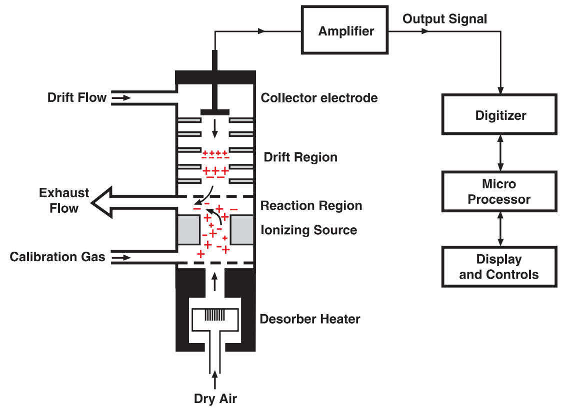
Now, in trace detection there's one molecule that's important to target: RDX, or cyclonite, which is the main component of plastic explosives. It's very involatile. In air at room temperature, it's only one part per trillion, so you have to have a very sensitive detector to be able to spot it. What's used in airports is an ion mobility spectrometer. It works incredibly well in detecting and identifying both explosives and narcotics. A pad that's been wiped on your computer or your suitcase is then heated to release the sample into

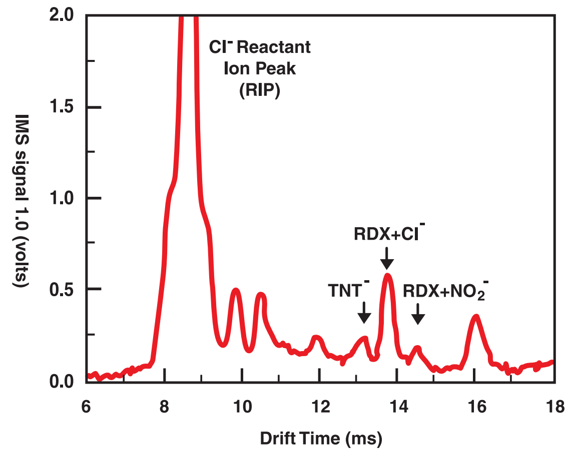
RDX, or cyclonite, $(CH_2)_3N_3(NO_2)_3$



Right: An ion mobility spectrometer can detect traces of explosives. The sample, wiped from a suitcase, is heated, ionized, and sent through a drift tube, which sorts the ions by size. The data from the detector (far right) show the presence of RDX, which attaches a chloride ion in the ionizing source.

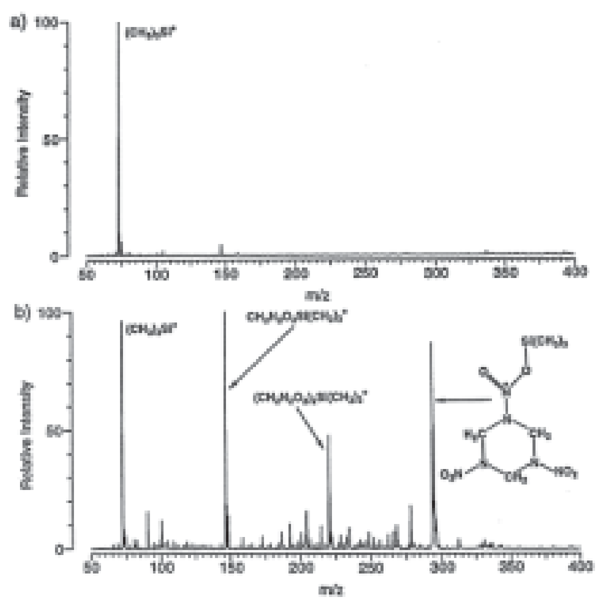



the instrument. The molecules enter a region where they become ionized; they then move through a drift tube under a constant electric field. The small ions encounter less resistance from the gas, so they arrive at the detector first, and the heavier ions arrive later. So the instrument sorts things out at the detector based on their size. You can see above what the data look like, as a function of drift time. The particular experiment above shows the presence of RDX, which attaches a chloride ion in the ionizing source and gives rise to the characteristic peaks in the spectrum. The technique does have its limitations. The resolution is not very good. It's subject to contamination and to interferences, creating a lot of unidentified peaks. For example, a perfume might overlap the main RDX peak. But it does work and is widely used.

A better method for trace detection is mass spectrometry. Earlier this fall, John Fenn, professor of analytical chemistry at Virginia Commonwealth University, shared the Nobel Prize in chemistry. Fenn made very important contributions to the use of mass spectrometry for looking at biological molecules—the molecules of life. In his own words: "Mass spectrometry is the art of 'weighing' individual atoms and molecules to determine their masses or molecular weights. Such weight information is sometimes sufficient, frequently necessary, and always useful in determining the identity of a species." There you have it from this year's Nobel Prize winner in chemistry. And it just happens to work really well for explosives.

I'll give you an example of work that we've done in my lab developing sensitive, selective methods for mass-spectrometric detection of explosives. RDX has oxygens that just love to bind to silicon, so if you use trimethylsilyl cations as an ionizing reagent, they selectively attach to the RDX, leading to characteristic peaks in the mass spectrum that can be used to identify explosive material. In the experiment below, the reactive ion is stored in a device called an ion trap. After many collisions with gas molecules passing through the trap, eventually the reactive ion finds the RDX and sticks to it. So, after one second of reaction time, you see the spectrum on the bottom instead of the one on the top. You can see the RDX and you can see two fragments that come from cleavage of the ring. These data provide forensic evidence for the presence of RDX.



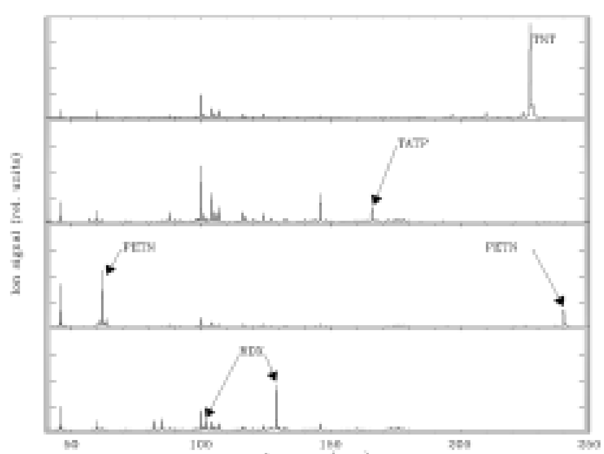

In mass spectrometry work done in the author's Caltech lab, RDX is chemically ionized with trimethylsilyl cations—$(CH_3)_3Si^+$. When these collide with trace amounts of RDX, a stable compound forms, which can be characterized using mass spectrometry, giving the spectrum in the lower graph. Within a second, you can see the RDX at the right, with peaks of the two dissociation products in the center.

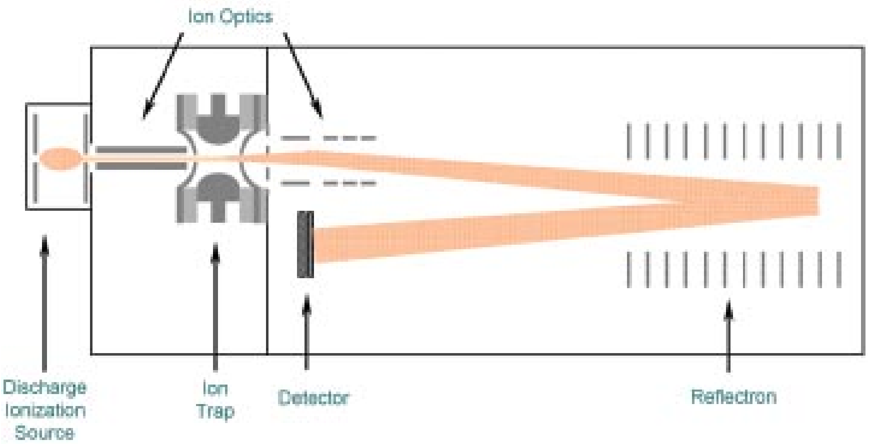
[We should] continue to support research and development related to new technologies for the detection of weapons, explosives, and chemical and biological weapons. I have to say this because I'm a research person, right?

The typical portals to screen passengers aren't designed to sniff for explosives on a person; they failed, for example, to detect the shoe bomb on Richard Reid. One advanced system has been developed by Syagen (a Tustin firm founded by Jack Syage, who was a postdoc at Caltech with Pauling Professor of Chemical Physics and Professor of Physics Ahmed Zewail) and Sandia National Laboratory. Syagen's expensive portal can screen people for traces of explosives, chemical weapons, and narcotics without direct contact or x-rays. One of the first such systems for an airport, it's now undergoing testing at Idaho National Laboratory. This super-high-tech device uses mass-spectrometric detection. When you're standing in the portal, it takes your picture so that it has a record of every individual passing through (that's the easy part). In the picture at right, laminar flow of ionized air is shown by the red arrows; the blue arrows indicate other air flows from pulsed nozzles that ruffle your clothing to dislodge particles; and the white arrows indicate injection of ionized air to assist in collecting the particles. Once collected, the particles are passed into a mass spectrometer with an atmospheric-pressure discharge ion source. Ions are extracted and accumulated for a short period of time in an ion trap and then injected into a time-of-flight mass spectrometer. All the ions here initially have the same energy, causing the light ones to arrive at the detector first and the heavy ones last, providing a mass spectrum. In addition to having excellent sensitivity to explosives, the portal can also detect chemical agents such as VX, a potent nerve gas.

In addition to chemical weapons, much progress has been made on rapidly determining the presence of pathogens, or biological agents. For example, the Ebola virus has a particular protein in its coat that can easily be detected and analyzed with mass spectrometry. Depending on how the analysis is performed, you get not just the molecu-


**Above: In the Syagen portal, the main stream of air flows past the subject (red arrows), as pulses of air (blue arrows) puff his clothing to liberate particles, while other jets of ionized air help collect them (white arrows). Next the particles pass into a time-of-flight mass spectrometer (opposite page), which delivers the mass spectrometric fingerprints for several common explosives (below). (Illustrations courtesy of Syagen Technology, Inc.)**






**Above: After the particles are collected in the portal, they are heated to release explosive vapors, which are then ionized and collected in an ion trap, before being ejected into a time-of-flight mass spectrometer. The lighter ions arrive at the detector first and the heavier ones later, producing a mass spectrum. The orange band indicates the path of the ions; the reflectron enhances the mass resolution of the device.**

lar weights but the actual sequence of amino acids, which are unique signatures. Scott McLuckey, professor of analytical chemistry at Purdue University, is one of the leading researchers working on this technology.

In closing, I'll give you my 10 recommendations for countering terrorism. They're not too different from some of the conclusions of the recent National Academy of Sciences report.

- Make effective use of intelligence information.
- Make effective use of deterrence. Nobody holds up a doughnut shop with a police car in front, even if there's no policeman around.
- Promote coordination and communication between agencies responsible for security at all levels. People need to talk to one another.
- Promote public education and vigilance. If I were flying a plane out of some small airport and saw a guy taking out his backseat and loading in cases of TNT, I'd call the police and then see what I could do to stop this guy from leaving the airport. If you see somebody unloading canisters of gas at 3 a.m. into a neighbor's garage, call somebody to come take a look at it.
- Support the public-health infrastructure and research related to infectious diseases. I think the best thing we can do in response to the threat of biological attack is to start doing a better job of protecting ourselves from known diseases.
- Equip and train first-response teams to deal with emergencies. The faculty at Caltech spends a lot of time doing K–12 education; the National Science Foundation requires us to do it. I think the NSF and other agencies should require us to spend a certain amount of time working with hazmat teams. We can do a lot to help these teams learn how to use the equipment they already have and to help make some of the newer technologies available for their use.
- Avoid complacency by recurrent training of airport screeners. Pay attention to human factors, such as boredom. I don't think it matters whether the screeners are private or federal; it's performance that's important.
- Continue to support research and development related to new technologies for the detection of weapons, explosives, and chemical and biological weapons. I have to say this because I'm a research person, right? But I also think that, more than tomorrow's detectors, we need to implement in the field the technology that's already available right now.
- Restrict access to materials likely to be employed in terrorist acts. I know it's a free country and we can't keep stuff off the Internet (although we can try to stifle information on how to make explosives). But we should take measures to limit access to, say, chemistry-department stockrooms at Caltech and other universities.
- Do what we can to restrict access to tempting targets. Sometimes this can be accomplished by some pretty simple means. □

*Jesse L. (Jack) Beauchamp earned his BS from Caltech in 1964. After graduate school at Harvard and a PhD in 1967, he returned to Caltech to join the faculty. He has been professor since 1974 and was named the Ferkel Professor of Chemistry in 2000. For his decades-long work on the structure and reactions of molecules and ions in the gas phase, he has been recognized with numerous awards, including three from the American Chemical Society: the ACS Award in Pure Chemistry and the Peter Debye Award in Physical Chemistry, and he will be receiving the 2003 Field and Franklin Award for Outstanding Achievement in Mass Spectrometry. He is a member of the National Academy of Sciences—and the Aircraft Owners and Pilots Association.*

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