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Sensors for Screening and Surveillance

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Introduction

Much attention, in fact an entire session at this conference, is being devoted to protecting the United States against human threats—individuals who may pose a danger by their mere presence on US soil. However, tomorrow's terrorists will employ weapons in their attacks, and we must also be diligent in preventing these weapons from reaching their targets. Sensors can play an important role in detecting these weapons before they achieve their desired effects. A sensor system can best be understood as a way of automating search techniques that would normally be carried out by a human's touch and vision senses, or by a dog's sniffing capabilities.

The list of potential threats is long, including nuclear, biological, chemical and radiological weapons, and each presents its own challenges. However, any effective system must meet the following requirements:

- Sensor systems must be operationally practical. Delays must be kept to a minimum. The systems must be safe to operate. Individual privacy and corporate proprietary information must be protected. The systems must be part of a viable concept of operations; i.e., they must provide information that can enable effective, preemptive actions to be taken.
- Sensors systems must be highly sensitive, providing a low probability of missed detections (false negatives). Our adversaries will conceal their device from detection, and they will likely probe our defenses for any weaknesses. Our systems must be robust against these techniques.
- Sensor systems must give a low probability of false alarms (false positives). Our response to the detection of such a weapon will marshal substantial resources and, in many scenarios, be highly disruptive to the general population. Thus a system that gives frequent false alarms will soon be ignored.

No sensor system can provide a "perfect" solution to these competing requirements; the best that can be done will be a compromise that strikes a balance among all three. The compromise will likely entail a layered defense, exploiting a combination of complementary sensor types. By sensing different characteristics of the weapons threats at successive layers, such a system reduces the number of false negatives. One sensor's strengths can be used to offset another sensor's weaknesses. The layers, particularly if they include mobile, agile components, also help to address the threat of "displacement", mitigating our adversary's attempts to probe our defenses for "holes" where they can elude any exposure to our sensors. Likewise, successive layers help reduce false positives. Natural fluctuations in background are less likely to trigger multiple layers than any single detector. A "tiered" approach can be employed, whereby a positive indication from the sensor at one tier prompts a more extensive measurement at the next tier.

There are three natural locations for layers of defense: points of debarkation (in foreign countries), our own borders, and high value targets within the US. Each of these locations offers sites suitable for "portal inspection" as well as natural "choke-points" where covert inspections can be undertaken. To understand the magnitude of the need for efficient sensor technologies, one has to remember that border protection does not just include airport screening of luggage and individuals—it extends beyond those boundaries to include border crossings, ports of entry, train stations, and the expanses of wilderness and ocean that lay in between.

The 5527 miles shared by the US and Canada have long been the largest unprotected border in the world, while the 2079 miles that abut Mexico have been known as the most porous. Add to that the Coast Guard's 12,452 miles of coast with 361 ports of entry, and a non-technology-based security system becomes obviously inadequate. [1]

Each weapon type—nuclear, biological, chemical, radiological, and explosive—presents its own unique challenges in striking the right balance between these three competing requirements. Each threat type will now be treated in turn.

Nuclear/Radiological. Particularly for the nuclear threat, we must detect the weapon prior to its use, as far from its target as possible, ideally before it reaches US soil. To illustrate, Figure 1 (***I'll get the figure***) depicts the effects of a 10 Kt nuclear detonation, centered in the Port of Oakland. Were terrorists to conceal an improvised nuclear device in a CONEX container and detonate it as the container was offloaded from a ship in port, the attack would have devastating consequences on the local population, resulting in 10's of thousands of fatalities and many more casualties. In addition, it would severely disrupt our transportation industry.

Radiological weapons pose far less of a threat to human life—more than likely the only fatalities that would result from such an attack would be those due to the blast of the conventional explosive used in the dispersal. Nonetheless, such an attack could have severe economic consequences, rendering areas uninhabitable until an extensive cleanup effort is completed. Thus the challenge for sensors is to detect the weapon prior to its use. Such a weapon would be likely to have a strong radiation observable, probably stronger than that from a nuclear weapon. The same passive sensor systems useful in detecting a nuclear weapon would be effective in the detection of a radiological dispersal device.

The fissile material essential to a nuclear weapon emits radiation that can be detected. The two most common materials are Plutonium-239 and Uranium-235. Plutonium emits both neutrons and moderately penetrating gamma rays; Uranium-235 emits very few neutrons and only weakly penetrating gamma rays, although other isotopes that are often present as impurities emit highly penetrating gamma rays. Common neutron detectors are based on helium-3 proportional counters (***Cite suppliers—Gamma Labs, Bicron***) and plastic scintillators (***Cite suppliers--?***). Common gamma-ray detectors are based on Sodium Iodide scintillators (***Cite suppliers—PGT, Ortec, Harshaw***) and Germanium solid-state detectors (***Cite suppliers—Ortec, Canberra***). In the

[1] Estimates of the US coastlines and landlines vary based on the amount of detailed curvature used in the calculation. While the US Coast Guard counts 95,000 miles of US coastlines (including the Great Lakes and inland waterways), the smoothed figure of 12,452 more accurately represents the nation's exterior water border, as compared to the length of land-based borders. Estimates come from the CIA World Fact Book, 2001ed.

absence of intervening materials, detection ranges of 10's of meters are practical, in 10's of seconds, with appropriately sized sensors. However, in the presence of intervening materials, practical detection ranges for Uranium-235 drop to a few meters or less. Thus, passive sensors will be most effective primarily for Plutonium, and for Uranium-235 in situations where only a small amount of intervening material is possible.

In situations where the containers are large enough to provide substantial shielding and standoff from the detectors, it will likely prove necessary to use "active" sensor systems to probe the inspected volume for Uranium-235, to detect the presence of either highly attenuating materials or the fissile material itself. This is the case for CONEX containers widely used on container ships, trains and trucks. For these containers, highly attenuating materials can be detected by gamma-ray transmission measurements; several commercial systems (***Cite suppliers—SAIC, ...***) are available for this purpose. Fissile material can be detected either by similar transmission measurements, as these material are very dense, or by neutron interrogation. When neutrons strike fissile material, they cause (non-explosive) fission, which results in the emission of more neutrons as well as gamma rays. Neutron interrogation systems are also available commercially (***Cite suppliers***), and the refinement of these techniques is still an active area of research (***Cite Labs research***). In practice, the combination of gamma-ray transmission and neutron interrogation measurements can be quite effective in detecting weapons quantities of fissile material, but only in controlled situations where several minutes are available for inspection and provisions for radiation safety can be employed. In particular, one must ensure that no stowaway passengers are inside maritime containers prior to irradiation.

Active systems could be employed at shipping ports, ideally at foreign ports of debarkation. They could also be employed selectively at border crossings, where traffic flow may not allow several minutes for a thorough inspection of every truck or rail car. Passive sensors would provide some assurance for external inspection of CONEX containers, but would be more effective for inspecting the contents of these containers as they are loaded or unloaded. They could thus play a role in a "trusted shipper" system, whereby the shipper would employ them to screen the contents of CONEX containers as they are loaded.

Alternatively, it may prove feasible to instrument "smart" cargo containers with low cost radiation sensors. These low cost sensors would be inherently less sensitive than those employed at portal inspection sites, but would have the advantage of a long measurement time, during the 7-10 day passage across the ocean.

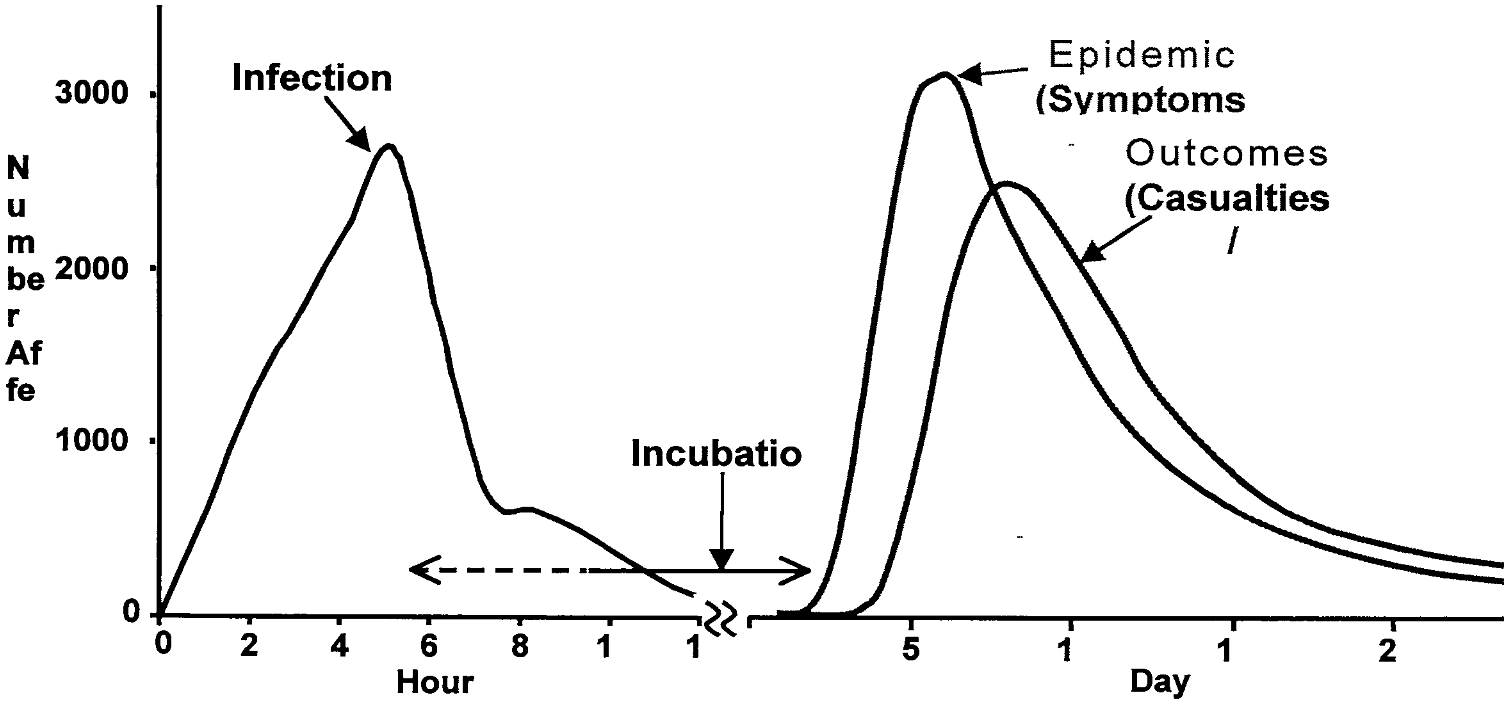
An additional layer of defense could be achieved by the deployment of a mobile network of passive sensors in the area surrounding high value targets such as the Capitol, White House, and Pentagon. The mobility of these sensors would counter any probing of our defenses, while the integrated interpretation of data from the entire network would provide greater sensitivity and fewer false alarms than each individual sensor alone. Such a system would likely provide protection against Plutonium devices, and limited protection for devices using Uranium-235.

At this time, more work is needed to define the most effective system for detection of a nuclear weapon in transport. The performance of passive radiation sensors is quite well understood, but there remain unresolved systems issues. Affordable sensors with better background discrimination are under development, and promise to enhance the performance of such systems. Likewise, more research is needed to optimize active interrogation systems, and to characterize their performance in “real-world” situations.

Biological

Defense against terrorist use of biological weapons presents a unique set of challenges. The detection of the weapon prior to detonation is unlikely for several reasons. First, one must detect extremely small quantities: kilogram quantities, effectively dispersed, would be sufficient to inflict thousands of fatalities. Furthermore, the agent emits no radiation, has an extremely low vapor pressure, and is comprised of roughly the same elements as other organisms. Still, because a biological weapon is designed to be readily dispersed, it is entirely possible that inadvertent dispersal will take place prior to the intended attack, as in the case of the anthrax mail. Under some circumstances it may be possible to detect this inadvertent, limited dispersal and preempt the intended attack. To do so will require sensitive detection, more rapid than is currently feasible.

Still, as Figure 2 shows, the effects of biological weapons based on microorganisms can be significantly mitigated even after an attack, if the attack is detected early.



For those agents that are treatable (Anthrax, Plague, Smallpox, …) detection of the attack during the first day can enable those who have been exposed to be treated, prior to the expression of symptoms, with a high recovery rate. However, not all possible bioagents based on microorganisms are presently treatable (Ebola, EEV,…). Biological toxins, such as botulinum toxin, act much faster than organisms, resulting in incapacitation or death in minutes to hours, and are essentially untreatable.

Immediately after a release, infections will typically rise steadily for several hours, due to the time required for the agent to disperse, and the time required for exposed individuals to uptake a sufficient dose to become infected. If the attack can be detected in these first few critical hours, responsive actions can greatly reduce the number of individuals whose exposure is sufficient to become infected. Automated, rapid detection systems based on both immunoassay and DNA analysis are now under development. (Autonomous Pathogen Detection System, Lawrence Livermore National Laboratory). Such systems will enable the detection and identification of many bioagents within roughly 30 minutes. This response time will enable people to be evacuated from the affected area prior to receiving an infective dose. The response time for systems based on immunoassay are now limited by diffusion and binding tome constants. The response time for DNA-based analyses is limited by the cycle time of Polymerase Chain Reaction (PCR). Dramatic increases in speed will probably require the development of new techniques.

As Figure 2 illustrates, still faster detection would further reduce the number infected. Other applications require even more rapid response. For example, to screen containers for bioagent contamination without disrupting their normal flow requires faster systems. For CONEX containers, results are needed in roughly 5 minutes, for envelopes moving through a mailroom, a detection is needed in a mere fraction of a second. Smart buildings can close down their ventilation systems upon receiving an alarm. However, to minimze the contamination of such a building requires an alarm within minutes, if not seconds, after the introduction of a bioagents into the system. Aerosol mass spectrometry (***Reference—Eric Gard, LLNL***) is one technique that offers the potential for near-instantaneous (`10 millisecond) response time. However, further research is needed to determine whether the technique can achieve the specificity of more established techniques for the full range of bioagents of concern.

Another fundamental limitation of all systems currently in use is that they can only detect bioagents that are present in the system's "library". Thus new, "bioengineered" agents can avoid detection by these systems. Perhaps the best hope for a universal bio-detector is a system based on the host response to the pathogen. If the host response can be detected, prior to the expression of symptoms, with sufficient specificity to prescribe treatment, this approach could offer "universal" detection of bioagents.

Today's biosensors are "point sensors"; i.e., they can only sense agents with which they come in direct physical contact. This trait limits their effectiveness in characterizing the spatial extent of a dispersing plume. Remote sensing technologies will be well suited to mapping the spatial extent of a dispersing plume, if they can achieve adequate performance (high sensitivity, low false positives, low false negatives). Approaches exploiting UV fluorescence and IR absorption are presently under development.

Finally, current systems are too costly to truly function as "bio smoke alarms", widely used in hotels and office buildings, let alone family dwellings. Production costs for APDS or the Aerosol Mass Spectrometer will likely run well over $100,000 each. New phenomenologies, materials, and/or fabrication techniques must be devised to achieve this goal.

Chemical

Defense against chemical weapons presents its own unique set of technical challenges to sensor systems. The most common chemical agents are the nerve agents, GA (Tabun), GB (Sarin), GD (Soman), GF, and VX; the blister agents, HD (sulfur mustard) and HN (nitrogen mustard); and the arsenical vesicants, L (Lewisite). In contrast to biological weapons, the quantities of chemical agent that constitute a lethal dose are 100 to 1000 times greater. The effects of chemical nerve agents are far more rapid than those of biological agents, causing incapacitation and death in a matter of minutes after exposure. Thus a "detect to treat" strategy is far less viable for chemical weapons than for biological weapons, particularly for the civilian population. Sensors must therefore detect the chemical weapon either prior to use, or rapidly enough to enable actions to reduce exposure of the civilian population to the dispersed agent.

Sensors can play a role in the detection of a chemical weapon in transport, prior to its dispersal. Active interrogation systems similar to those described for the nuclear problem can also be applied to detecting a chemical weapon. X-ray images of containers may disclose suspicious-looking objects. The inelastic gamma rays that are emitted from a chemical agent as a result of neutron interrogation will reflect its elemental composition and can provide another indicator. Similar systems have been demonstrated for use in the characterization of unexploded ordnance, distinguishing between conventional and chemical munitions (INEE, http://www.inel.gov/featurestories/8-99pins.shtmlL).

Once the agent has been dispersed, prompt, accurate detection and identification will be essential to reducing the number of casualties. A preliminary system concept for subway systems is being developed by the NNSA Chemical and Biological National Security Program, in collaboration with the Washington Metropolitan Area Transit Authority. The program, called PROTECT (Program for Response Options and Technology Enhancements for Chemical/Biological Terrorism) has established a station testbed, and selected 3 commercial sensors (***list here***) for use in the concept evaluation phase. The "gold standard" for volatile chemical detection and analysis is the Gas Chromatograph/Mass Spectrometer (GC/MS) (***Cite suppliers—HP, ***) These instruments can provide definitive multi-species identification, at concentrations as low as 1 part per billion. Some chemical agents have fairly low volatility and thus will not flow through the GC. For such agents High Pressure Liquid Chromatography (HPLC) can be employed, avoiding the need for chemical "derivitization" of the analyte to a form that can be analyzed by the GC/MS. These are both laboratory instruments, although fieldable versions of the GC/MS are becoming available (***Cite LLNL/TSWG/DOE program***). A wide range of portable chemical detectors is available commercially. These detectors are based on several technologies: ion mobility spectrometry, gas chromatography, infrared spectroscopy, surface acoustic waves, electrochemistry, and chemresistor arrays, to name a few (**Cite a couple references for each***). As field instruments, they naturally cannot match the performance of laboratory instruments. In many cases they can be quite sensitive, but will generally not offer the selectivity of a GC/MS. Depending on the background environment and how the detection thresholds are set, they will generally provide higher false positives than the larger, more complex and expensive laboratory instruments. False positives may be reduced by using several different types of chemical sensors in concert. In any case, they can serve a useful role as a first screen, to be followed up with more extensive examination by GC/MS when warranted.

For dispersion in large open areas, standoff sensors offer the ability to image the spatial extent of the plume in near real time. Data from such systems, coupled with a small number of point sensors on the ground, would provide a much more complete picture for crisis managers, enabling them to reduce the number of casualties. Such systems could be deployed on helicopters, or positioned on high rise buildings with a view of the affected scene. The technology to enable such systems applications, infrared absorption imaging spectroscopy, is reaching maturity in several research labs across the country. (AFRL, LLNL, …)

Attribution

In addition to detecting a weapon system prior to its use, and mitigating its effects, sensors can play an important role in the "attribution" of such an attack, whether or not the weapon is actually employed. Trace chemical and isotopic analyses would provide valuable clues in determining the origin of the material that comprised the weapon. Definitive attribution could aid in marshalling world support for retaliation, to prevent further attacks. Knowledge that such attribution capabilities exist may also serve as a deterrent to future terrorist acts.

Summary

Tomorrow's terrorist has a wide range of options available, in weapons, targets, and pathways. Sensors alone cannot counter the full diversity of the threat, but they can narrow the range of options, and increase the chances that any future attack will be preempted, or mitigated to greatly reduce its effects. Field evaluations with the participation of law enforcement and first responders will be essential in developing not only technologies, but also viable concepts of operation to meet these challenges.