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# Technologies for Fissile Material Detection and Prevention of Fissile Material Introduction into International Shipping

*J. Richardson*

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Lawrence
Livermore
National
Laboratory

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# Technologies for Fissile Material Detection and Prevention of Fissile Material Introduction into International Shipping

J. Richardson
Lawrence Livermore National Laboratory
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Prevention of the introduction of fissile materials into international shipping, and hence into a given country, is a complex problem. Some pieces of the solution to the puzzle are conceptually well defined, but lack definition of a technical pathway and/or operational implementation. Other elements are a little more fuzzy, and some elements are probably undefined at this point in time. This paper reviews the status of the more well-defined elements, and suggests needed additional measures to enhance the probability that fissile materials are not illicitly introduced into distant countries.

International commerce proceeds through a number of steps from point of origin to final destination. Each step offers the possibility of a well-defined choke point to monitor and interdict the illicit shipment of fissile materials. However, because there are so many potential points and venues of entry into a large country such as the United States (e.g., air cargo, shipping containers, truck and rail transport, private vehicles, boats and planes, commercial passenger travel), it behooves the world to ensure that fissile material does not illicitly leave its point of origin.

Consequently, the primary step and first element of the solution should be to improve the physical security, control and accountability of fissile materials at their source. Physical security includes such straightforward steps as secure and alarmed barriers, central monitoring stations and response forces, and secured and guarded transport. Materials control includes monitors to detect material movements, precise and accurate quantitative measurements for inventory values, and operational procedures to enhance control and minimize insider diversion. Inventory data should be accessible at a variety of regional, national, and organizational levels, which implies modern communication links and accessible data bases which can be validated and verified through a regulated process. Such steps are simplified if the amount of material and the number of locations can be reduced through consolidation of the sites and conversion of the material to less attractive forms (e.g., downblending of HEU to LEU, conversion of HEU research reactors to LEU, encapsulation and storage in secure and / or geological repositories). While rapid upgrades, particularly with respect to physical security, bring immediate benefits, the necessary infrastructure has to be established to permit the sustainability of the enhancements. Sustainability varies from power and economic infrastructure to ensure the maintainability of equipment and processes, to training and re-certification to ensure operational congruence with national and international regulations and best practices. While this process has begun with Russia through the DOE MPC&A program, it is clear that much remains to be done in both Russia and other countries which still have fissile materials (if the desire is to prevent the introduction of radioactive materials, the number of countries and sites increases considerably).

With respect to the homeland security of the United States, it is clear that, given initial diversion of fissile material, the highest leverage is to detect illicitly trafficking as the material leaves the country of origin. This element begins to become fuzzy, as there are a variety of potential traffic routes to smuggle fissile material from its country of origin. Consequently, the critical element to (foreign) border security is to develop the trade/smuggling route analysis and corresponding system architecture which maximizes the return on investment for interdiction of illicit trafficking in fissile materials. Because this is not the United States, a variety of methods to enable international cooperation is essential. The international framework includes not only government to government agreements, but also provisions for NGO participation, promotion of regional, multilateral cooperation instead of just bilateral arrangements, carrot and stick incentives, and necessary legal and indemnification support. Specific issues for other, frequently small and / or third world countries are an expansion of the sustainability issues which MPC&A is facing in Russia; namely, infrastructure to minimize corruption and maximizing equipment and operational dependability, mobile technical and operational response capability, training, re-certification, and rule of law.

There are a myriad of technical challenges facing global control of fissile materials: e.g., communication links, data bases of fissile material correlated with commerce data bases, rapid computer search algorithms, pattern recognition, scenario analysis and risk analysis. But because the primary goal is the detection of fissile materials, radiation detection is clearly one of the technical challenges to combating the illicit transportation of fissile materials and subsequent nuclear terrorism. System goals have been approximately defined: 1) detect 5 kg of HEU reliably with low error rates (i.e., to have both few false positives and few false negatives); 2) to perform the detection in a variety of cargos that potentially will shield the fissile materials (i.e., shielding from 0-60 g/cm$^2$ and low to high Z, representative of agriculture, electronic and heavy industry products / components); 3) to perform the detection rapidly (few minutes at the most, seconds is preferable) without disturbing commerce (hence a minimal number of nuisance alarms); 4) while the focus is on fissile materials, the additional detection of high explosives, chemical agents, and even biological agents would be desirable.

While daunting, the technical challenge of radiation detection is being engaged on several fronts to improve signal-to-noise and identify fissile materials from the background radiation and legitimate radiation-emitting commerce in which the world is awash. To satisfy the system goals, technical approaches involve improvements in radiation detection:

- more particle detections through bigger and more efficient detectors
- more and better data from each particle to aid in identification of the important events (spatial and temporal resolution, angular and energy resolution, correlations in time, space and energy)
- simplified detection through threshold detectors
- enhancement in the number of important events through well defined, minimally invasive active interrogation
- cheap, robust and simple to use

While there is no silver bullet, large volume imaging detectors offer many advantages in both passive and active modes.

The most direct method for detecting radiation from fissile materials is through the use of passive detectors. In principle this works well, as the signatures of fissile (and radioactive) materials is virtually unique. In practice it has many potential pitfalls: source strength is weak, the environment alters the signature, and hence fissile materials of interest cannot be detected quickly, at distance, and uniquely with simple passive detectors. HEU is particularly difficult because of the low activity and the low energy of the emitted gammas (although trace amounts of $^{232}U$ in many samples does provide a high energy line which is more penetrating). There are many developments, which are improving the capability of passive detection.

1) Enhanced sensitivity through modern computing capability and multi-element detectors. Increasing the volume of detector material, the number of detectors, and the speed of spectral identification algorithms enhances the ability to isolate weak signals from background and reduce nuisance alarms without compromising sensitivity. Arrays of CZT detectors can be mounted on a cell phone, and small clusters of NaI detectors can provide enhanced sensitivity compared to plastic scintillators, plus provide rapid spectral identification. The net effect is to reduce a two step process taking minutes (alarm on gross counts and subsequent spectral identification) to a matter of seconds in a drive by mode.

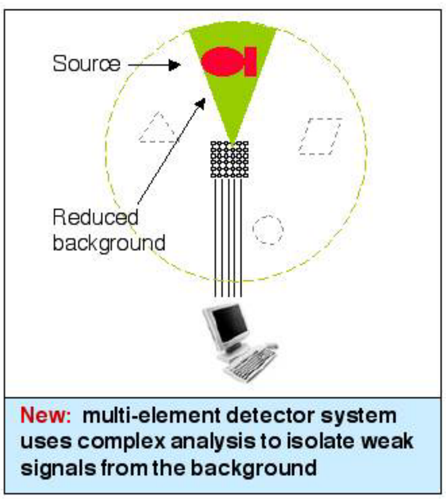



Fig. 1. The use of modern computing and materials processing has enabled detector arrays to provide spectral information which enhances sensitivity and reduces nuisance alarms.

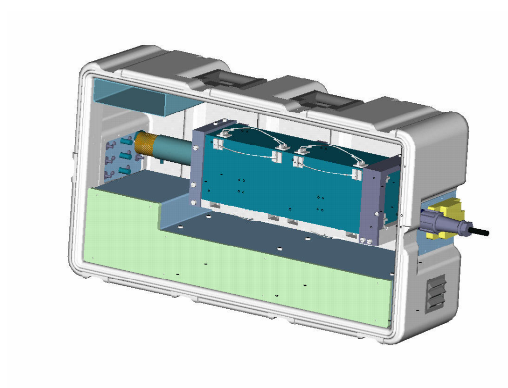


Fig. 2. Adaptable radiation area monitor (ARAM) is a portable radiation monitoring system that is state of the art and can be used in both stand alone and networked monitoring applications and allows the user to configure it to the specific monitoring application

2) Imaging offers improved gamma and neutron detection for monitoring and search. Merely increasing the detector size does not alleviate the background problem, as background scales with detector size. Spatial imaging can improve S/N by over

two orders of magnitude, thereby enabling weak sources to be detected at distances of tens of meters. There are a variety of imaging approaches, [1,2] for both gammas and neutrons, depending on the application and operational requirements.

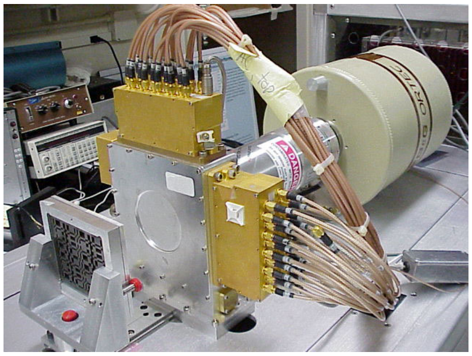


Fig. 3 Coded aperture with hybrid Ge detector (a planar, 19x19 cross strip with standard coaxial unit). One of many approaches to developing a variety of imaging technologies to eliminate background and enhance S/N in search applications.

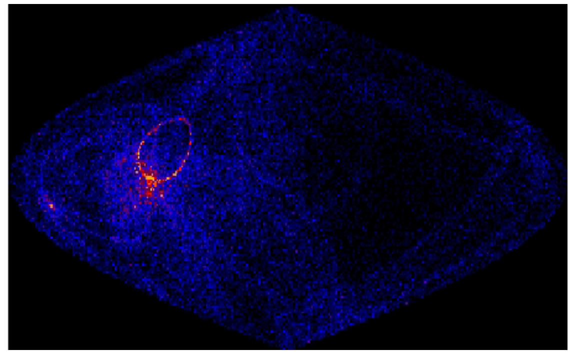


Fig 4. Simulation of detection of less than a significant quantity of HEU with single segmented Compton imager measured for 10 sec from 50 feet away.

3) Improved energy resolution reduces nuisance alarms and contributes to attribution. For decades the standard material for the highest energy resolution has been liquid nitrogen cooled high purity Ge. The difficulty with such an instrument has been the size and the issue of providing liquid nitrogen in the field. Recent developments have led to electro-mechanically cooled Ge, which are much smaller in size (< 10 pounds), run for many hours on batteries, and have expected lifetimes of years.


Fig. 5. The RadScout is being commercialized by ORTEC, ruggedized, 25 pounds and 6 hr battery life.

Fig. 6. The Cryo3 is being adapted for maritime use, with 2.6 keV FWHM at 660 keV, <10 pounds, > 8 hr battery life

An even better approach is to develop new materials which do not require cooling

[1] K.P. Ziock and W.W. Goldstien, "The lost source, varying backgrounds and why bigger may not be better." Proc. URSSRA Workshop, Wash. DC. April 2002.
[2] K. Vetter, High Sensitivity Gamma-ray Imaging with Hybrid Deetectors, NA-22 report.

but deliver the same spectral resolution as Ge. One such candidate material is AlSb, which only recently has been grown in large crystal sizes with resolution approaching that of Ge. Finally, superconducting materials for both gammas and neutrons have enabled energy resolution more than an order of magnitude better than Ge. Such energy resolution makes it possible to conceive of exquisite fingerprints of fissile materials, with sufficient resolution to detect trace contaminants which are unique to source location and history.

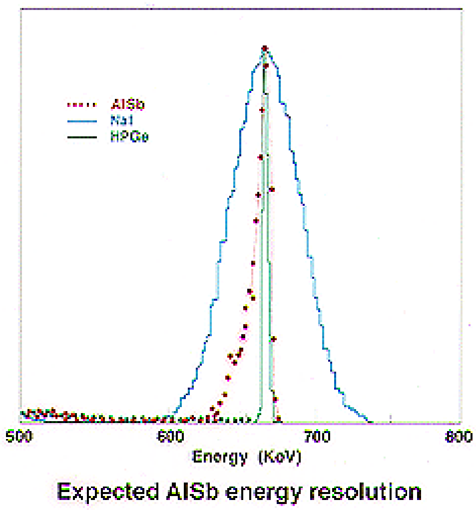



Fig 7. AlSb has the potential of Ge resolution at room temperature. Careful control of stoichiometry, crystal processing, and trace dopant introduction expects to result in achieving the resistivity (ca. $10^9$ ohm-cm) necessary for room temperature operation.

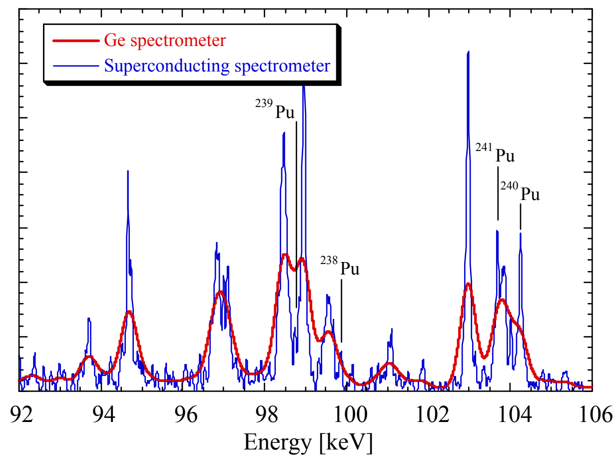



Fig 8. An ultra-high resolution gamma spectrometer has been developed using a microcalorimeter and superconducting materials as the key element in a transition edge sensor. Energy resolution nearly 10X better than Ge has been achieved, and demonstrated with Pu in the 100 keV region. Similar technology is being applied to energy resolved neutron spectroscopy.

4) Sensor networks extend the range of detection and avoid one-point failures. The most straight-forward application of networks is a series of fixed detectors. Depending on the characteristics of the network, additional enhancement in sensitivity can be achieved by correlation of sensor hits to track the radioactive shipment. Enhanced detector capabilities can significantly reduce false positives and false negatives, and is, along with optimal configuration of the network and additional data acquisition (e.g., video, license plates, intelligent transportation data), a current subject of much system analysis.

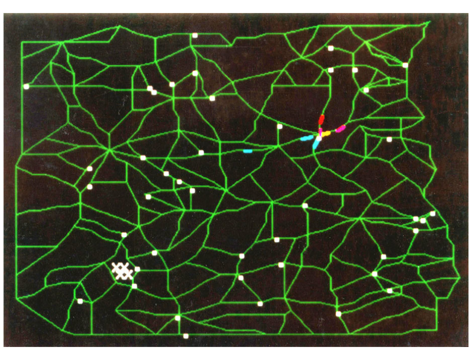


Fig. 9. Field demonstrations and computer simulations of distributed sensor networks refines required communication links, signal processing and detector performance requirements, tracking algorithms, benefit of additional data integration, and system analysis of configuration as a function of threat scenario.

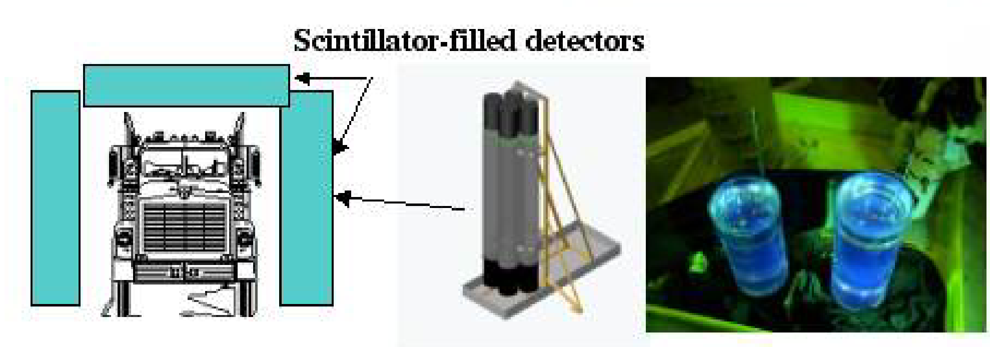
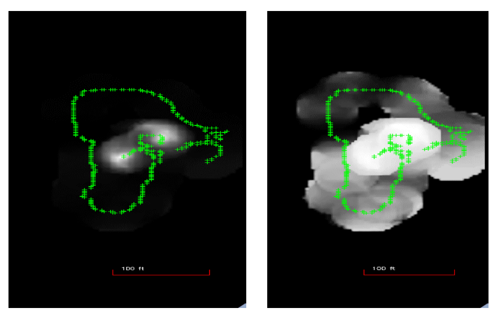



Figure 10. Improved portals employing liquid scintillators will employ correlation techniques and energy discrimination to reduce background by >10X, thereby enhancing sensitivity and providing improved input to network decision process.

Alternative networks employ mobile detectors. One approach is to build the detector into a cell phone with GPS. Such a system provides constant background monitoring, spectral identification, greatly enhances the number of potential nodes in the network, and provides flexibility for consequence management.

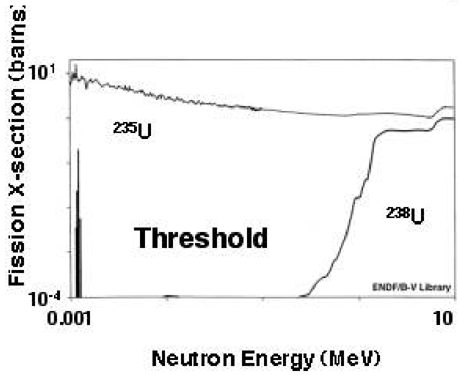
(a)



(b)

Figure 11. A CZT pixilated array with dedicated ASIC readout has been incorporated into a cellular phone package with GPS and smart processing; expected additional cost is *ca*. $100 (a). Demonstrations have been successfully completed to monitor background and locate a hidden 10 μCi $^{137}$Cs source (b).

Active interrogation with either neutrons or photons provides the potential for a great enhancement in the probability of detecting fissile materials. Selectivity is provided by initiating fission events, and monitoring delayed neutrons or gammas. Selecting the energy of the initiating particle, and by temporally and energetically filtering the detected particle can eliminate most potential interferences. Unlike passive detection, active interrogation provides some variables to accommodate various shielding. Gammas are highly penetrating through low Z materials, and neutrons are highly penetrating through high Z material. Delayed neutrons or gammas provide temporal discrimination, and delayed gammas from HEU have a higher yield and are more capable of escaping than neutrons. Coupling of active interrogation with radiography (X-rays or gammas) provides additional data with which to discriminate illicit fissile materials from NORM and legal shipments.



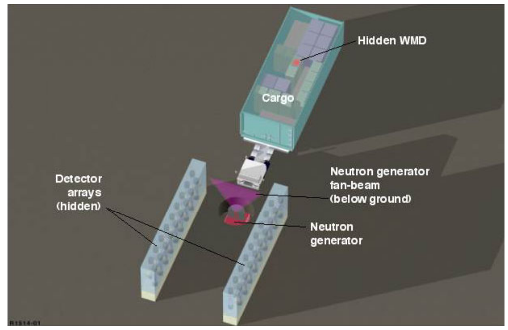




Fig. 12. Fissile materials and potential interferences have specific fission or reaction energy thresholds. By selecting tuning the interrogation beam (gammas or neutrons) and using time and or energy resolution on the signature (neutrons or gammas), it is possible to discriminate against chemical and isotopic interferences.

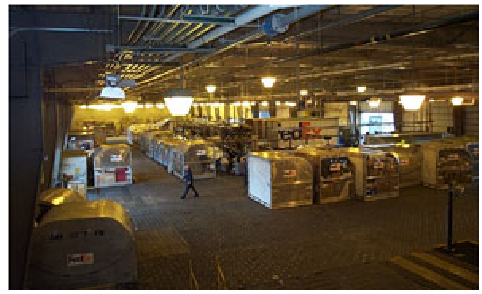
Fig. 13. A preliminary approach to scanning cargo for WMD has been established using tunable sources, improved detectors, and enhanced signal processing to minimize commerce disruption.

Application of radiation detection technology has to be done at several points along the flow of commerce, from source, through borders, in transit, to point of entry and to final destination. The highest leverage point is at the source or embarkation point; the longest interrogation time is during transit. Monitoring during transit requires smart solid state detectors which are very inexpensive, monitor a variety of signatures, have dual communication links to a central receiver/transmitter, and an appropriate con ops for handling detection.

Fig. 14. Monitors for cargo in transit have to add only ca. \$300 to the container cost (maximum). Candidates include doped GaAs neutron detectors, TLD, and optical materials. The communication links between a given container and a central station have been developed.

In order to develop these technical and operational measures, a multi-phase approach is required: 1) Laboratory R&D improves upon COTS equipment and provides understanding of the art of detection for realistic threats with a variety of test cargos; this is at the single instrument scale. 2) Field experiments and test beds test multiple instruments, in small networks or systems, and provide a basis for developing con ops. 3) Mass deployment depends on transferring technology to the commercial sector and developing the international agreements necessary to share data and operations. Test beds are already being evaluated for a variety of venues and potential chokepoints: land (bridges, tunnels, parcel shipping), maritime (commercial ports, limited non-commercial facilities), and air.

(a)



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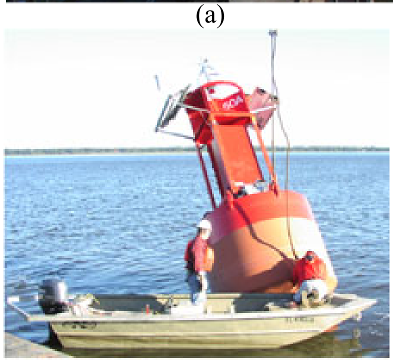

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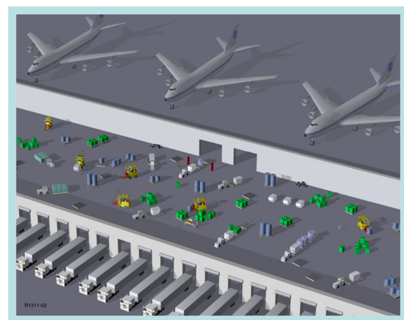

(d)

Figure 15. Test bed venues: (a) bridges and tunnels; (b) central parcel shipping facilities; (c) commercial and non-commercial maritime choke points (e.g., ports, channels); (d) air cargo terminals.

At some of these test beds, advanced detection concepts are being evaluated.


(a)


(b)

Fig. 16. (a) Advanced imaging is being evaluated in realistic scenarios to determine enhancement in processing for illicit trafficking in fissile materials. (b) active inspection with commercial systems (e.g., VACIS) provides input for con ops for more selective interrogation and requirements for nesting several detection technologies in proximity.

In summary, there are many steps to ensuring that fissile materials do not enter international commerce, or, if they do illicitly, are detected in a timely and safe manner.

- Control of the material at the source
- Prevention of material illicitly leaving the country of origin

- R&D to develop orders of magnitude improvement in radiation detection technology, both passive and active. Pathways which have already demonstrated 2 orders of magnitude in S/N improvement, reduction in analysis time by one order of magnitude, and improvement in energy resolution and hence selectivity by one order of magnitude, have already been demonstrated at the laboratory scale. But this effort needs to be continued and enhanced, with the metrics of cost / reliability, throughput, and sensitivity / selectivity, being foremost in evaluation of new technologies, associated con ops, and there transition to the commercial sector.
- Global data fusion to correlate manifest, sensor, intelligence, law enforcement, commercial and personal information (e.g., medical treatments)
- System analysis to determine optimal configurations for priority threat and vulnerability analysis.
- Risk and cost benefit analysis, with the recognition that zero risk for the illicit trafficking of fissile materials is unobtainable.

Acknowledgement

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