# The X Files: Part 3

*In this final part of a three-part series, Paul J. Bjorkholm and James Johnson of Varian Medical Systems, Security & Inspection Products, discuss the future of high-energy X-ray systems used for cargo security screening.*

Part 1 of "The X Files" reviewed the history and development of high-energy X-ray cargo screening. Part 2 of the series discussed the current state of the art of high-energy X-ray screening. In this final article we discuss ways in which the technology and the economics of high-energy cargo inspection may develop in the future.

Previously we noted that high-energy X-ray inspection systems have the capability to image the entire contents of a fully loaded sea cargo container with sufficient spatial and density resolution to allow an operator to understand the contents of the container. The challenges in expanding the use of high-energy X-ray screening more universally in ports are related to materials handling and port design issues. The next major changes in container inspection must be in the automation of the inspection process, and in tight integration with the normal shipping processes and procedures. This will require innovative port designs.

We can imagine the path these changes could follow by looking at how airport security inspection has evolved. The first X-ray systems produced black and white images. Then, dual energy systems were quickly adopted, and these produced colored images depending on the scanned material. Next, sophisticated algorithms were added to detect explosives. Finally, these systems were tightly integrated into the normal baggage flow in an airport. Today's high-energy X-ray inspection systems are similar to the early black and white systems used in airports. But high-energy inspection is poised to make substantial leaps in the near future. Some of these will dramatically change how containers are inspected.

## Technology

Future generations of high-energy imaging systems will be based on dual energy linear accelerators capable of switching energies pulse to pulse. Since linear accelerators made by Varian Medical Systems are capable of switching at several hundred pulses per second, two independent images taken at different energies can be acquired in a short time (10 to 30 seconds for a sea container). These data can then be interpreted by automatic algorithms for the detection of specific materials.

## Automation

A major goal of high-energy X-ray inspection that is already amenable to automation is the detection of nuclear based Weapons of Mass Destruction (WMDs). If a container is imaged at two different high energies, it is possible to compare the images and automatically detect sub-critical masses of uranium or plutonium, or of lead that might be used as a shielding material. This is possible because X-rays interact with high atomic number materials in two ways, Compton Scattering and pair production. While the details of these interactions are unimportant to this paper, what matters is that these interactions are different functions of the energy of the photons and the atomic number of the material being X-rayed. Therefore, the transmissions through the cargo as measured at two different energies can be solved simply to yield the average atomic number of the material in the cargo.

Varian is already developing a linear accelerator for cargo screening that can allow simultaneous measurement of the transmission at two energies. These data can then be used to identify any high atomic number material. Figure 1 shows a simulation of the results expected for various materials. Note how easily uranium can be differentiated from more normal materials such as iron, aluminum, and water. Since all nuclear-based weapons of mass destruction and "dirty bombs" contain significant amounts of high atomic number materials, the detection of such items can be completely automated. While stream of commerce measurements have not been made yet, simulations indicate that true detection rates of >99% and false alarm rates of <0.1% are possible with full automation in real time, permitting examination of a much higher percentage of containers without significant time delays.

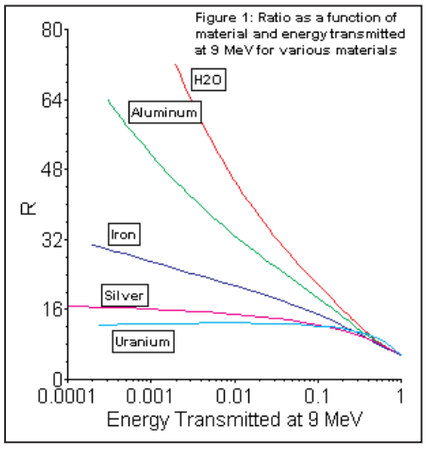


Figure 1: Ratio as a function of material and energy transmitted at 9 MeV for various materials

To date, most investigators have considered WMD detection the most important task for dual energy imaging. It will also be useful for more normal detection tasks.

Other automation techniques will follow soon after. Combining dual energy imaging with image post-processing, manifest information and target modeling, it will be possible to dramatically extend the accuracy of the atomic number detection process. It may also be possible to use these techniques to detect chemical and biological WMDs. However, it is likely that this will remain an operator assisted feature, at least for the near term future.

## Economics

The future of cargo inspection will be driven by economics as much as technology. The economics discussion can be broken into two components: integration and financial rationalization.

## Integration

To date, X-ray inspection systems have required that containers be brought to, and taken away from, the inspection system. This means containers must be moved out of the flow of commerce. In order to achieve the goal of screening a higher percentage of containers, the screening process will have to be more tightly integrated into the intermodal system, minimizing delays and disruption.

There are a number of possibilities for integrating the inspection process into the normal cargo commerce stream. One possibility is to integrate the inspection system into the loading/unloading process. This will require extensive process mapping of the existing flow within any given port or terminal. For existing sites this may require renovation or modification of existing infrastructure. For new ports or terminals, this will require that new designs and container flow patterns be considered during the design phase.

Normally, container transport trucks receive a container on a roadway built directly under the gantry cranes. These vehicles then transport the containers to a storage area and, if necessary, to an inspection area. Unfortunately, the container and its cargo are vulnerable to interference during these movements. The container as inspected may not be the same as the one that was unloaded from the vessel.

New inspection systems should be integrated to accomplish the inspection as soon as the container is offloaded or during the process of offloading. A similar requirement exists for sites where inspection occurs for exported containers.

The integration necessary to accomplish this requires close cooperation between manufacturers of handling equipment, terminal operators, port authorities and the manufacturers of the screening and IT systems. This level of cooperation and coordination does not exist in most instances today, and consequently, many of these stakeholders find themselves operating at cross- purposes. What will bring them together are the common goals of automating the security process and improving productivity.

## Financial Rationalization

In addition to advances in technology and integration with the intermodal system, next generation inspection will have to justify its existence through increased productivity as well as other economic benefits. As already suggested, this will largely be achieved through high-level automation and the related improvement in productivity.

Cargo transport stakeholders are all interested in securing the homeland through more effective container inspection. However, due to the sensitive nature of the intermodal system, even minor disruptions can have significant negative impacts on efficiency, delaying transportation to the final destination and increasing costs. By having a highly automated imaging system more tightly integrated into the flow of containers through the intermodal system, productivity can actually be improved. This would eliminate the delays associated with inspection as it exists today, as well as losses due to damage or theft. Current attempts in this direction include passive radiation detection and other technologies that monitor container location, but cannot positively identify container content.

Rapid identification of container contents combined with automatic detection of threat quantities of nuclear materials can be achieved with the next generation of high-energy linear accelerator imaging systems combined with intelligent integration. This solution can be the key element to securing the intermodal system, increasing productivity and reducing costs for all stakeholders.

## Summary

State of the art high-energy X-ray inspection systems have the capability to screen fully loaded containers and generate images with resolution high enough to easily identify all materials in the container. The future will see dramatic developments: Dual energy linear accelerators will soon be available that make possible the automatic, real-time detection of nuclear-based weapons of mass destruction. Highly integrated inspection systems will be designed to achieve 100% inspection with little impact on existing inspection procedures. New port and terminal design and renovations must include integrated high-energy X-ray inspection technology. New economic models are being developed to ensure that the technology can be self-sustaining. The future for cargo screening is certainly bright.

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