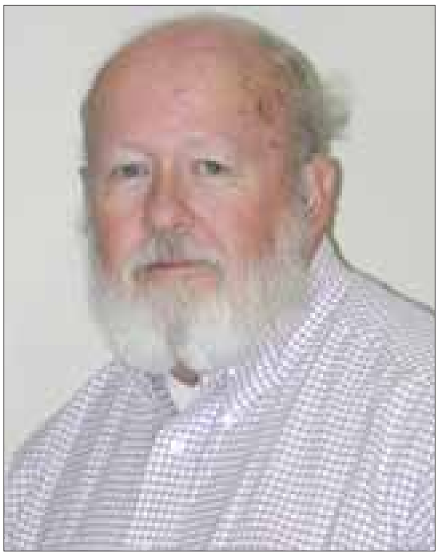
THE *NUCLEAR NEWS* INTERVIEW

Dennis Slaughter: Looking for hidden materials

Researchers at Lawrence Livermore National Laboratory are developing a system to detect radioactive materials hidden in cargo shipments.

Dennis Slaughter's work on developing large-scale radiation-detection devices started soon after the events of September 11, 2001. As a nuclear physicist for the Department of Energy's Lawrence Livermore National Laboratory (LLNL), Slaughter had worked on magnetic fusion diagnostic measurements and laser-induced fusion, and he led the group that built the first high-power femtosecond laser (which for a time was the world's highest-power laser). He was also the technical director of LLNL's 100-megaelectronvolt (MeV) electron linear accelerator facility and head of the low-energy nuclear physics program at LLNL.



Slaughter: "We decided to develop a system that would detect special nuclear material concealed in cargo."

All that changed on 9/11. Slaughter says he and a group of fellow physicists at LLNL were angry and upset over the terrorist attacks and wanted to do something to protect the nation from future incidents. The physicists got together and elected Slaughter as the leader in developing a system that would be employed at seaports to scan commercial cargo crates coming into the United States.

At first the group worked on their own time and without government funding. Subsequently, the work was continued with funding coming primarily from the U.S. Department of Homeland Security (DHS). Slaughter, who is now retired from LLNL, is still involved in the development work. He talked with Rick Michal, *NN* senior editor, about taking his group's system from the drawing board to possible commercial application.

How did you start working on developing nuclear technologies for counterterrorism?

It started soon after the events of 9/11. I was doing research for Lawrence Livermore National Laboratory and was leading a group of nuclear physicists. We were all upset about what had happened that day, and so we called a meeting among ourselves and concluded that we had to do something. We decided to develop a system that would detect special nuclear material concealed in cargo. Nearly 80 percent of the imports that come into the United States enter through maritime ports, so that's the area we concentrated on.

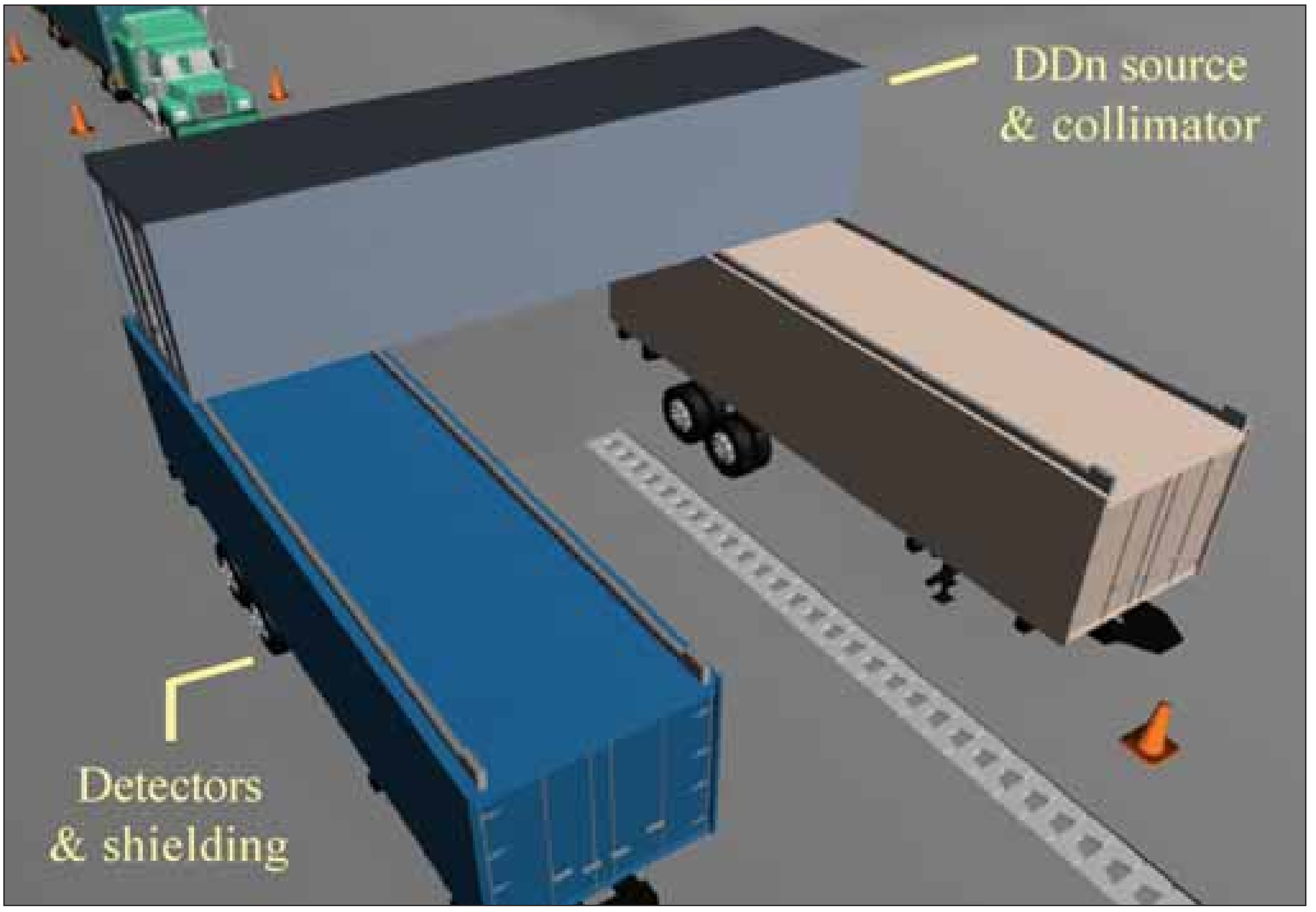
What kind of system did you develop?

It is a radiation detection system that uses a low-intensity neutron beam. The first lesson we learned is that while a plutonium-based weapon has a fairly high level of natural radiation, which facilitates its detection using ordinary neutron and gamma-ray detectors, a uranium-based weapon is a different situation. The uranium produces essentially no neutrons in its normal radioactive decay, and the principal gamma rays are at very low energy—below 200 kilovolts. Shielding by cargo or other materials compounds the challenge.

Our next decision was that if we could amplify the signal by inducing fission in that nuclear assembly, it would produce a lot more radiation and be easily detectable, even if it were buried in cargo. So that's the path we took. The system we developed puts a low-intensity neutron beam into a cargo container. If there is uranium or plutonium, the neutron beam will thermalize in the cargo and produce fission. The result is a really bright signal of fission product decay.

How did you come up with your idea?

We just brainstormed until we hit upon it. Rick Norman [who formerly worked at Lawrence Berkeley National Laboratory and now works at LLNL] and Stan Prussin [of the University of California at Berkeley and LLNL] introduced the idea of looking at high-energy fission product gamma rays. The technique, which facilitates the detection of heavily shielded nuclear material, hadn't been tried before. What had been tried was producing fission in a bare target and then detecting delayed neutrons from it, because there aren't a lot of delayed



Shown is a mobile version of the active neutron interrogation system configured in three truck containers—a source module, a detector module, and an operator/control module. As a part of the active neutron interrogation process, a 4-MeV beam of deuterons is generated to strike a deuterium gas target. The resulting nuclear reaction produces neutrons that are directed toward the cargo. (This process is abbreviated as DDn in the graphic.) A collimator reduces the size of the beam. (Graphic: LLNL)

neutron sources in nature. This traditional technique has been around for more than 30 years. The problem with it is that delayed neutrons have a very low yield in fission and are very low energy. And so, instead, we looked at delayed gamma rays from the fission products.

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Was there ever a worry that your instrument reading could pick up normal background radiation?

Yes. In the normal radiation environment that we live in, the highest gamma ray is 2.6 MeV. But fission products and their decay products produce gamma rays all the way up to about 8 MeV. We decided to look for the high-energy part. It turns out that the yield of high-energy gamma rays in fission product decay is quite high, about a factor of 10 higher than delayed neutrons. More important, the high-energy gamma rays that are produced in the decay of the fission products penetrate all cargos quite easily. For 3 to 5 MeV, the attenuation in all materials up to lead is entirely by Compton scattering—which is the decrease in energy of an X-ray or gamma-ray photon when it interacts with matter—and it doesn't depend on energy or the attenuating material. So there is not only the least amount of attenuation, but the attenuation is the same in all materials.

We decided to look at the high-energy delayed gamma rays produced by the decay of fission products. The technique we developed is one in which we go in with a low-intensity beam of neutrons. After a neutron pulse, we look for the decay of fission products—specifically just the high-energy gamma rays in the range of about 3 to 7 MeV. There's really not much else in nature that does that except for fission products.

Is your system currently in use or is it still being developed?

It is still under development. We built the laboratory prototype with funding from DHS, and we've been doing experiments at LLNL and determining the sensitivity by using the neutron source that we bought and the detectors that we installed for the testing. We are working with a fraction of a kilogram of enriched uranium. During tests, we readily detect the uranium. We have a cargo container that we loaded with either wood or steel. Wood is actually one of the hardest tests for our system because it is a hydrocarbon. With the enriched uranium buried at various locations in the wood, we irradiated it for about 5 to 30 seconds and looked at our instruments for 20 to 100 seconds, and we could detect fission quite reliably.

How does your system handle varying weather conditions?

Once commercialized, our system will

have to be robust against a wide range of weather conditions.

How does your system deal with false alarms?

False alarms are a problem for radiation detectors. We need false alarms to be very rare, and right now we're looking for a very high detection probability. In the lab prototype, we think we're there. Fortunately, the short decay time and high gamma-ray energy of the fission products make them very distinct from normal radioactivity and from activation products, and so we can readily distinguish a real threat from normally occurring materials nearly all of the time.

"If there is uranium or plutonium, the neutron beam will thermalize in the cargo and produce fission."

What is the name of your system?

For the moment, it is the 7-MeV Neutron Interrogation System. That's an interim name, and we're hoping to come up with something that is more descriptive.

What are the physical dimensions of your system?

That will be easier to answer when a commercial firm gets involved. If it were up to me, I think that we could put our system—the neutron source and the detectors—into a 40-foot cargo container, which is something the ports certainly know how to handle. The cargo container would be portable, so the port could move it if necessary. It might be simpler if the detector were separate from the source, so there might actually be two containers, and perhaps a third one to house the operators.

Have you estimated a cost per unit?

We would like to have our system come in under $3 million. If I look at what we've put together in our system, we could certainly buy all the pieces and assemble them into something that works for that amount of money. But at LLNL we make systems that might not be considered cosmetically attractive. For example, if you were to ask the medical community what they want, it might be something that is in a nice, smooth package, color-coordinated, and doesn't have a lot of instrumentation on the front panel. We don't do that at LLNL. I think I could put together a system that would work for probably somewhat less than $3 million, but it would be run by physicists, and that's not what you want at a port. We are now engaging a commercial partner with whom we hope to work to properly package the system, make it robust in the operational environment, including weatherproofing, and develop an estimate of the cost of a manufactured unit.

What's the next step for getting your detector out into the field?

We've basically demonstrated in lab experiments that our system detects uranium. And, certainly, plutonium is easily detected the same way, although we've not used plutonium in the experiments. But we've shown that this thing works and we do have reliable detection. The next step is up to DHS. If DHS were to pick the technology for future use, LLNL could license it to a commercial firm that would make it into a machine that could be sold to seaports.

What systems are being used today to detect nuclear materials in shipping containers?

Deployed out there today are passive gamma-ray detectors and neutron detectors that give a pretty good shot at identifying a plutonium-based weapon. There also are X-ray systems that offer images of cargos. These passive detector systems do a good job of detecting radioactivity, but the problem is that a significant fraction of cargo is naturally radioactive. There are a lot of agricultural products such as bananas that are very high in potassium. While there are many radioactive materials being shipped that the passive detectors are detecting, the problem is in discriminating all of it from a nuclear weapon. That requires either spectroscopy or something better than that, which is why we felt it important to develop our system.

The DOE's National Nuclear Security Administration [NNSA] recently announced that scientists at Brookhaven National Laboratory are making detection devices that can be operated at room temperature, making them more practical and cost-effective than existing, comparable detectors. Do the Brookhaven devices differ from yours?

Yes. Brookhaven's devices are very helpful for the detection of radiation that escapes the cargo. Our system has been developed to address those cases where a massive cargo prevents the escape of radiation from uranium or plutonium decay.

Are there other techniques under development that would interest DHS or NNSA?

Yes. Another approach is being developed by Rapiscan Systems, in California, with funding from DHS and the Domestic Nuclear Detection Office [DNDO]. Rapiscan's technique interrogates with neutrons at 14 MeV and produces fission. It doesn't look for the delayed high-energy gamma rays, but instead looks for the decay of the prompt neutrons produced by fission. There are some fairly good data from testing it, and I think Rapiscan is at a reasonable level of maturity with it.

There is also another group of researchers funded by DHS/DNDO from Idaho National Laboratory that is using a small electron accelerator for photon interrogation, producing Bremsstrahlung radiation up to about 10 MeV. Bremsstrahlung radiation is electromagnetic radiation produced by the deceleration of a charged particle, such as an electron, when deflected by another charged particle, such as an atomic nucleus. Their system also produces fission in any uranium or plutonium that may be concealed in the cargo, thus amplifying the radiation output. In that case, delayed and prompt neutrons are detected, indicating the presence of nuclear weapons or their component parts. In a field application, their system would work much like ours, with greater sensitivity in hydrocarbons such as wood but with less in dense cargos of metal or machinery.

Could these various technologies be used in combination at seaports?

Frankly, I think they should be. There is a report commissioned by DNDO that has evaluated all the relevant technologies. I was one of the scientists selected to do the evaluations. Thirty-four different systems were considered for review, but that number was reduced to 12. Those systems that were more than five years away from being usable were set aside. Others that we eliminated were nonstarters to begin with. And others looked as if they would be extraordinarily expensive to use. We established six "difficult cargo scenarios" that each system had to deal with. Instead of asking the system developers to show us their best experimental data, we asked Los Alamos National Laboratory to run Monte Carlo simulations to predict performance. After the simulations, we ranked the systems. The good news is that by using multiple systems together, all of the problems were solved. For example, if we took the photon interrogation system that worked on one set of problems and combined it with the neutron interrogation system that worked on a different set of problems, they overlapped, which was good. The bottom line is that if we put the two together, we worked out all of the problems.

Would the systems be deployed at U.S. ports or worldwide ports?

That is to be determined. The best place to scan cargo is at the point of origin, not at the point of arrival. If this cargo arrives at a U.S. shipping port, it may already have reached the destination that the terrorists have in mind. The U.S. Coast Guard is already setting up field personnel at some of the foreign ports that have the largest amounts of traffic to the United States. They're getting ready to start scanning cargo headed our way. Of course, the foreign ports of origin would like to see us scanning cargo headed their way. There is reciprocity involved.

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Could these devices be used at land crossings, in addition to seaports?

We would do exactly the same thing at a truck port that we would do at a seaport. We haven't looked there, but the traffic is the same and the kind of real-estate environment is the same. At seaports, for example, trucks come through a gate to pick up cargo offloaded from ships. Each truck stops at a gate as it is leaving the port, and someone scans a manifest so that the driver knows where he's headed and that he has picked up the correct load. We could have a scanning system right there. A seaport gate looks virtually the same as the gate at a border crossing.

Are there drawbacks to using your system?

I think there are two issues that will require public discussion. The first is that we're detecting uranium by irradiating the cargo container. The unfortunate truth is that some of these containers have people in them who are being smuggled in. The radiation dose in our beam at the lab is small enough to walk through without harm. We wouldn't walk through it intentionally, but it could be done without consequence. For the general public, however, once we start talking about irradiating people in containers, it becomes a big issue. I think it is worth discussing that the job of X raying all these containers should be required before anything else is done. The X rays would establish whether or not there are people inside. If there are no people, then the container could be hit with the neutron beam.

The second issue is related to the first one. Anytime an energetic photon beam or neutron beam is put into a cargo, there is going to be a small amount of activation. It's very short-lived and is not at a high level. The Department of Transportation [DOT] has one picocurie per gram as the threshold below which a cargo is not radioactive. The activation that we produce, even for the scan where we're looking for a small amount of uranium, drops below that DOT threshold in less than one hour, probably before the container leaves the port. Nevertheless, I think the public is going to want to discuss that, because a lot of the cargo being scanned will be food.

How soon before any of these techniques are deployed?

The head of DNDO testified before Congress recently and said that he wants to have prototype systems ready for evaluation in 2009. That's not far down the road. NN