Realistic Modeling of Radiation Transmission Inspection Systems*

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Abstract

We have applied Monte Carlo particle transport methods to assess a proposed neutron transmission inspection system for checked luggage. The geometry of the system and the time, energy and angle dependence of the source have been modeled in detail. A pulsed deuteron beam incident on a thick Be target generates a neutron pulse with a very broad energy spectrum which is detected after passage through the luggage item by a plastic scintillator detector operating in current mode (as opposed to pulse counting mode). The neutron transmission as a function of time information is used to infer the densities of hydrogen, carbon, oxygen and nitrogen in the volume sampled. The measured elemental densities can be compared to signatures for explosives or other contraband. By using such computational modeling it is possible to optimize many aspects of the design of an inspection system without costly and time consuming prototyping experiments or to determine that a proposed scheme will not work. The methods applied here can be used to evaluate neutron or photon schemes based on transmission, scattering or reaction techniques.

I. Introduction

Detection of hidden explosives and other contraband materials is a high priority in several branches of the government and civilian organizations. Examples of desired detection capabilities include sub-kilogram quantities of high explosive material in checked or carry-on airline luggage, illicit drugs in cargo containers, or a nuclear warhead entering or leaving the U.S. Other tasks in which nuclear interrogation methods may be of use include detection of land mines and the determination of whether a piece of ordnance contains a chemical warfare agent or only ordinary high explosives. Several nuclear physics based methods for detecting contraband have been proposed [1].

The technical problems that must be overcome to implement any of the proposed nuclear-based detection and identification schemes are formidable. Here only the detection of high explosives in checked airline luggage will be considered.

*Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48

II. The Proposed Method

The detection scheme that is investigated here is based on fast neutron transmission. It, along with several other nuclear-based schemes are reviewed in reference [1]. A schematic view of the set-up that has been modeled is shown in Figure 1. A deuteron beam of about 5 MeV energy is incident on a Be target that is thick enough to stop it. A strongly forward peaked neutron beam with a wide energy range (0 to ~8 MeV) impinges on the item to be inspected. A neutron detector on the opposite side of the item detects the neutrons that are transmitted. A view of the system, generated by COG, is shown in Figure 1. The detector is a 0.5″ thick piece of BC-401 scintillator in a boron loaded epoxy resin housing. The distance from the source to the detector is four meters and the suitcase is in the middle. Neutron energy can be inferred from the time-of-flight from the source to the detector. To identify the contents of the item it should be sufficient to infer the C, N and O densities. The neutron scattering cross sections for these elements have several strong narrow structures in the relevant energy range which can be used as signatures (the cross sections are shown in Figure 3). In a typical luggage item incident neutrons will be strongly scattered. Since the detector signal will be due to both transmitted neutrons and neutrons that have undergone one or more scatterings the detector signal is not simply the neutron source intensity times the transmission factor at the appropriate energy. One conclusion from the modeling that has been done is that the signal at the detector is <u>larger</u> with the inspected item in place than without it. This interference effect of neutrons arriving at the wrong time will make the interpretation of the measured signals extremely challenging. The inspection rate requirements for the system preclude the use of a neutron detector in the pulse counting mode. A source pulse with a Gaussian shape and a FWHM of 1 nS and a detector impulse response with an exponential fall with a time constant of 1 nS have been used in calculating the predicted signals.

III. Results

The Monte-Carlo coupled neutron-photon transport code COG [2] was used to model this system As a first step toward understanding the functioning of the system very simple cases were simulated, namely a "suitcase" that was a solid block of a single material.

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The geometry description part of the code is fully capable of handling a realistic, complicated luggage model. The materials studied were carbon, nitrogen, oxygen (all at a density of 2.25 g/cc) and the high explosive LXO40 at normal density. Figure 2 shows the effect of including multiple scattering for a solid carbon block, which is to move part of the signal strength to later times. In general, the later in time a cross section feature will fall, the more badly it will be corrupted by late-arriving neutrons.

Features in the cross section are clearly reflected in the signal when multiple scattered neutrons are eliminated (center plot of Figure 2). In the full calculation the correspondence is less clear.

Figure 3 shows the neutron scattering cross sections for the elements of interest and the predicted signal for a solid block of LXO40. Even in this extremely simplified model it is very difficult to identify clearly features in the signal that indicate the presence of the component elements. The possible utility of neural network methods to recover elemental densities from the measured signals are beginning to be looked at.

IV. Conclusions

It is clear that the nuclear interrogation method considered here, or any other, presents challenging technical problems, and that careful design of the measurement system and data interpretation methods will be necessary. Detailed accurate radiation transport modeling can be used to accurately and objectively assess possible substance detection schemes. These assessments and some optimizations of designs can be accomplished without costly and time consuming prototyping experiments (and without hazard control training or paperwork).

V. References

[1] Lee Grodzins, "Nuclear techniques for finding chemical explosives in airport luggage", *Nucl. Inst. Meth.*, B57/57 (1991) 829-833

[2] Thomas P. Wilcox, Jr. and Edward M. Lent, *COG- A Particle Transport Code Designed to Solve the Boltzmann Equation for Deep-Penetration (Shielding) Problems*, LLNL Report M-221-1

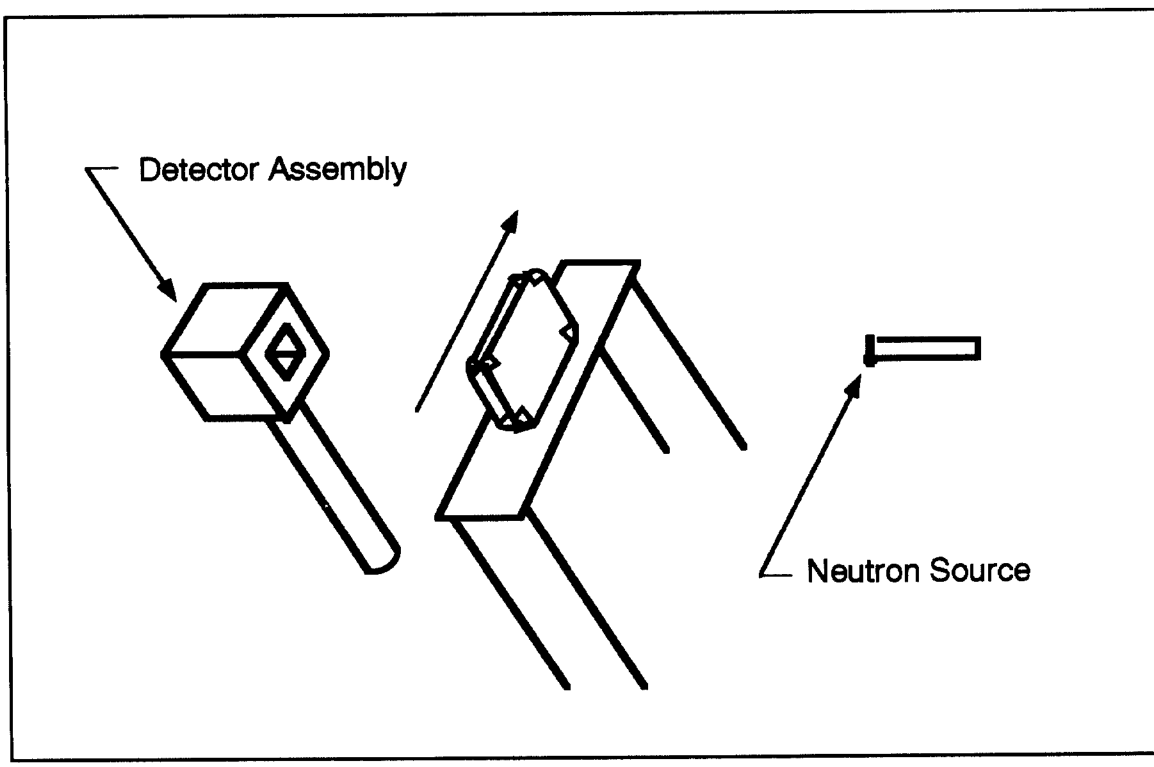

Figure 1. Perspective picture output of the the set-up modeled from the code COG.

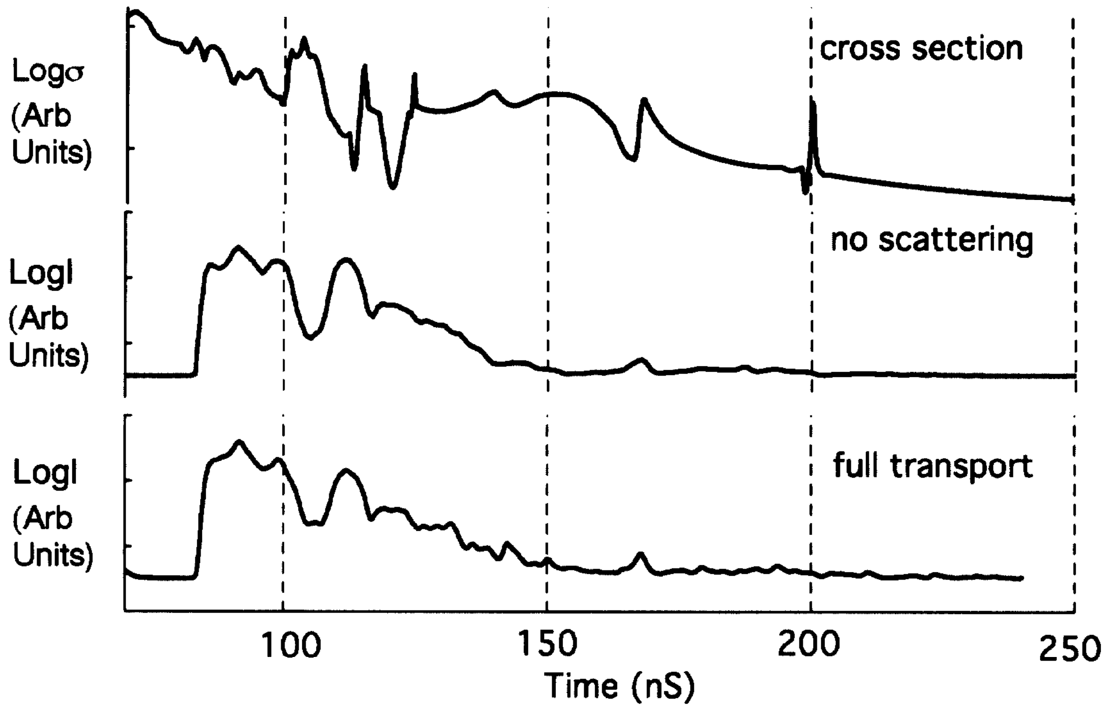

Figure 2. The top plot shows the log of the cross section for neutron scattering on C^{12} converted into a function of time. The center plot shows the calculated detector signal with multiple scattering suppressed. The third plot is of the total predicted signal. The signal predictions are convolved with a source pulse shape and a detector impulse response.

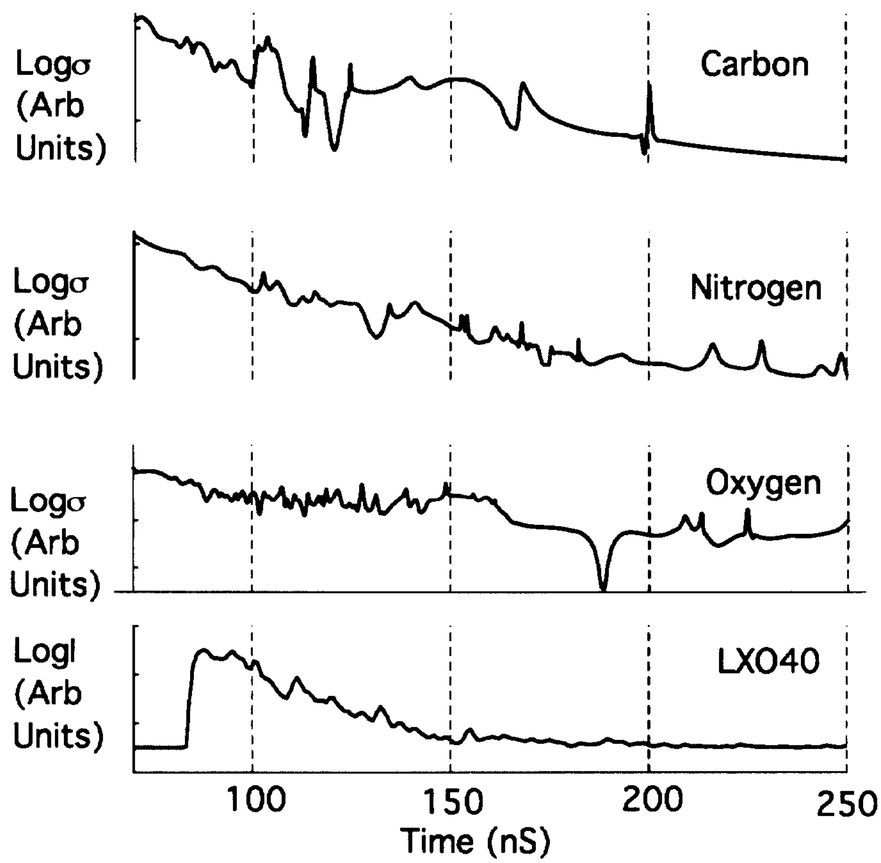

Figure 3. Logs of cross sections (converted from energy as the abcissa to time) for C^{12}, N^{14} and O^{16} are shown in the top three plots and the log of the predicted signal for a block of LXO40 in the bottom plot.