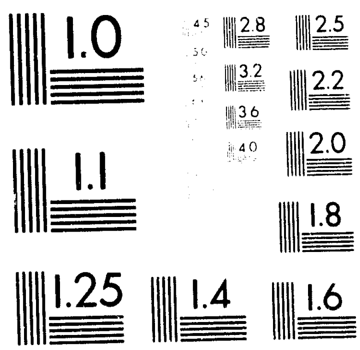
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Conf-931049--1

UCRL-JC-113252
PREPRINT

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This paper was prepared for submittal to
International Symposium
on Substance Identification Technologies
October 4-8, 1993
Innsbruck, Austria

December 1992

Lawrence Livermore National Laboratory

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ABSTRACT

We have applied the Monte Carlo radiation transport code COG[1)] to assess the utility of a proposed explosives detection scheme based on neutron transmission. In this scheme a pulsed neutron beam is generated by an approximately seven MeV deuteron beam incident on a thick Be target. A scintillation detector operating in the current mode measures the neutrons transmitted through the object as a function of time. The flight time of unscattered neutrons from the source to the detector is simply related to the neutron energy. This information along with neutron cross section excitation functions is used to infer the densities of H, C, N and O in the volume sampled.

The code we have chosen to use enables us to create very detailed and realistic models of the geometrical configuration of the system, the neutron source and of the detector response. By calculating the signals that will be observed for several configurations and compositions of interrogated objects we can investigate and begin to understand how a system that could actually be fielded will perform. Using this modeling capability many aspects of the design of a system can be optimized early on with substantial savings in time and cost and with improvements in performance.

We will present our signal predictions for simple single element test cases and for explosive compositions. From these studies it is clear that the interpretation of the signals from such an explosives identification system will pose a substantial challenge.

1. INTRODUCTION

Development of methods to accomplish the detection of hidden explosives and other contraband materials is a high priority in several branches of 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, currency and a nuclear weapon or weapon component that is hidden or being transported. 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 [2)].

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 (HE) in checked airline luggage will be considered (the HE composition used here is that of LX040). The HE detection problem will be explored by looking at signals predicted for homogeneous interrogated objects of carbon and LX040. Some of the problems and considerations in the detection of HE are archetypal of all nuclear-based detection schemes.

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 [2]. Schematic views of the set-up that has been modeled are shown in Figures 1 and 2 which is described more fully below.

Neutron energy can be inferred from the time-of-flight (TOF) from the source to the detector. The inspection rate requirements for the system preclude the use of a neutron detector in the pulse counting mode so that the TOF is the only information that is available from which to infer neutron energy. To identify the contents of the item it should be sufficient to infer the carbon, nitrogen and oxygen densities. The neutron scattering cross sections for these elements have several strong narrow structures in the few MeV energy range which can be used as signatures (the cross sections are shown in Figure 3). In a typical luggage item incident neutrons may be

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

strongly scattered, i.e. the probability that a neutron would pass through the item without scattering is quite small. Since the detector signal will be due to both directly 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. The effect of multiply scattered neutrons can be mitigated by design of the detector and its housing and by collimation of the source. These design issues are among those that can be addressed by model calculations of signals.

2. DETAILS OF THE MODEL

In addition to the actual transport, the task of modeling radiation transport breaks down naturally into three parts. The parts that the user must supply are descriptions of the radiation source, the objects and materials of the system and the detector. The transport is controlled by the set of cross-sections that are used by the code. In this work the ENDL[3)] data base was used.

The neutron source is generated by a deuteron beam of about seven MeV energy incident on a Be target that is thick enough to stop it. A forward peaked neutron beam with a wide energy range (0 to ~12 MeV) impinges on the item to be inspected. The neutron source that was used in the calculations reported here is that measured by Smith, Meadows and Guenther [4)] for seven MeV deuterons on a thick Be target. Energy spectra for the angular bins (0° - 1.25°) and (12.5° - 17.5°) are shown in Figure 4. All the spectra have qualitatively the same shape, with a sharp drop-off at about six MeV. The neutron flux is fairly strongly forward peaked. Neutron producing reactions have been extensively studied and the calculational methods described here permit the optimal target and beam to be selected without building any hardware. One of the parameters that must be optimized is the incident beam energy. If the beam energy is too low some of the structure in the cross sections will not be seen, however the higher the incoming neutron beam energy is the more neutrons there will be that arrive at the detector later than expected and thus the more the lower energy structures are contaminated by multiply scattered neutrons. For these calculations the neutron source was taken to be a one centimeter disk on the surface of the Be target. The source was treated as a delta function in time. The real time dependence of the source can be treated by convolving the signals predicted here with the appropriate source function. The angular distribution of the source was described in terms of six angle bins, each with its own energy distribution.

The second component of the model is the geometric description of the system. Cross-section views and a perspective view of the model of the system are shown in Figures 1 and 2. The luggage item rests on a low mass aluminum table midway between the source and the front face of the detector. Here only results using solid blocks of single materials are presented. These results are difficult enough to interpret that results from more realistic luggage items are not presented at this time. The detector is on the end of an aluminum support column and is encased in a borated resin shield to reduce signals from objects other than the item being interrogated. Calculations were performed for three different detector shielding configurations. In the first case there was no shielding around the detector at all. In the second the detector was housed in a block of borated resin (BR). The final variation has the detector further shielded and collimated by a long BR snout added to the housing. There is a four inch thick concrete floor under the set-up and air surrounds the whole system. One important lesson that has been learned in conducting underground nuclear tests at LLNL is that it is important to use quite detailed and complete geometric models in order to accurately simulate radiation transport. The compositions of the materials used in these calculations are given in Table 1 and the cross section excitation functions for the HE, carbon, nitrogen and oxygen are shown in Figure 3.

The third component of the model is the detector. The detector is taken to have a delta function response in time so that the results of the calculations can be convolved with any real detector temporal impulse response. The detector neutron energy response function is taken from Koehler *et al.*[5)] and is shown in Figure 5. The detector is a 0.5" thick piece of BC-401 scintillator in a boron loaded resin housing. Calculations have been completed for two different housing configurations and for a bare detector. The detector signal is calculated for every neutron that enters or interacts in the volume of the detector. For each event in the detector the signal strength for that neutron is calculated and added to the appropriate time bin.

3. RESULTS

Calculated detector signals are shown in Figures 6 and 7. For comparison cross-section excitation functions, converted into the time domain, are overlaid on the signal predictions. The first case to be discussed, the results of which are displayed in Figure 6, is a very simple experiment, namely the object being interrogated is a solid block of carbon. The first observation that can be made regarding these results is that the material around the detector has an important impact on the performance of the system as expected. In the case of no shield at all the multiply scattered neutrons almost entirely wash out the characteristic features of carbon. The relative contributions to the time integrated signal due to neutrons that have experienced different numbers of scatters are shown in Table 2 for the system without the long snout.

The second case is that in which a solid block of HE is the interrogated item. The result of this calculation along with the cross sections for the HE and some elemental components of the HE are shown in Figure 7. Just looking at the elemental and HE cross sections one can see that the distinctive features characteristic of each of the elements are much less pronounced in the HE cross section. This is because the HE cross section is a combination of the carbon, nitrogen and oxygen cross sections along with substantial contributions from other elements, mainly hydrogen. The hydrogen cross section is fairly large and very smooth so that the elemental features of interest are made less distinct. The predicted signal for this case does not obviously reflect the presence of any of the elements in HE.

4. CONCLUSIONS

From an examination of the predicted signals presented here it is clear that elemental compositions of even solid blocks of single materials can not be easily extracted from the data when the material composition is non-trivial. One conclusion from the modeling that has been done is that the signal at the detector can be larger 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. Even though elemental signatures are readily apparent when the object is a single element the complexity of the signal due to a slightly complex mixture of elements makes the extraction of the composition difficult. A realistic luggage item would yield signals even more refractory to analysis. One possible strategy for extracting elemental compositions from measured signals, which we are beginning to pursue, is to apply neural network methods.

The sort of modeling for signal predictions shown here can be used to develop and evaluate detector systems and signal processing and analysis methods. This evaluation can include false alarm and false negative rate assessments. The predicted signals shown here for a realistic interrogation system looking at rather simple targets clearly show that the processing of the data will require substantial investigation and development.

5. ACKNOWLEDGMENTS

The author would like to acknowledge the help of Rich Buck and Ed Lent, two members of the COG development group, and Jim Hall, Jim Morgan and Wini Parker.

6. REFERENCES

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[4] D. L. Smith, J. W. Meadows and P. T. Guenther, "Fast-Neutron-Spectrum Measurements for the Thick-Target $^{9}Be(d,n)^{10}B$ Reaction at E_d= 7 MeV", Argonne National Laboratory/Nuclear Data Measurement report ANL/NDM--90, M85010481, (1985)

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6. TABLES AND FIGURES

Table 1. compositions of materials used in model.

Material	element	density (g/cc)
air	nitrogen	9.74×10^{-4}
	oxygen	2.99×10^{-4}
	argon	1.68×10^{-5}
BC-401	carbon	0.8563
	hydrogen	0.1371
LX040	hydrogen	0.00491
	carbon	0.336
	nitrogen	0.643
	oxygen	0.735
	fluorine	0.127
concrete	hydrogen	0.0124
	oxygen	1.09
	sodium	0.0578
	magnesium	0.0338
	aluminum	0.0965
	silicon	0.745
	calcium	0.135
	iron	0.0767

Table 2. Relative contribution (in per cent) to time integrated detector signal versus number of scatters (results for the system without the long snout are shown) for a solid block of carbon.

# of scatters	% contribution
0 to 0	83.6863
1 to 1	11.0672
2 to 2	3.0673
3 to 3	1.2368
4 to 4	.5254
5 to 5	.2248
6 to 6	.1011
7 to 7	.0465
8 to 8	.0248
9 to 9	.0107
10 to 10	.0057
11 to 11	.0026
12 to 12	.0010
13 to 13	.0007
14 to 14	.0002
15 to 15	.0001

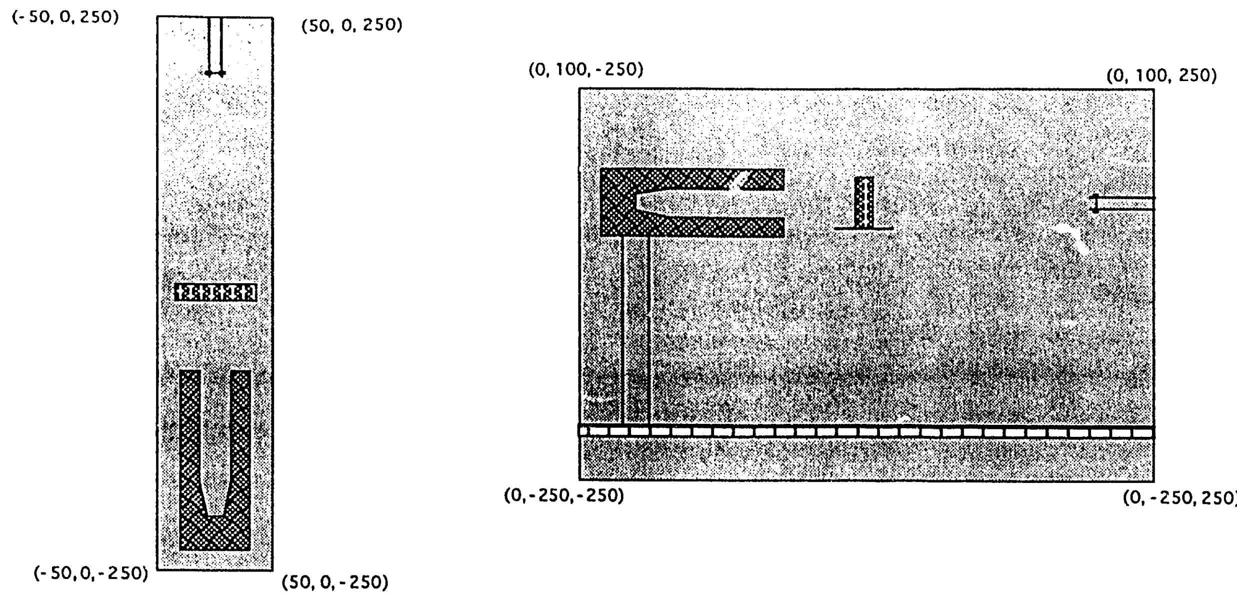

Figure1. Two cross section views of the system modeled here. The coordinates (in cm) of the corners of the slices are shown. Cross section and perspective pictures are generated by COG as an aid in confirming the correctness of the geometry description. These pictures show the system with the long snout on the detector shield.

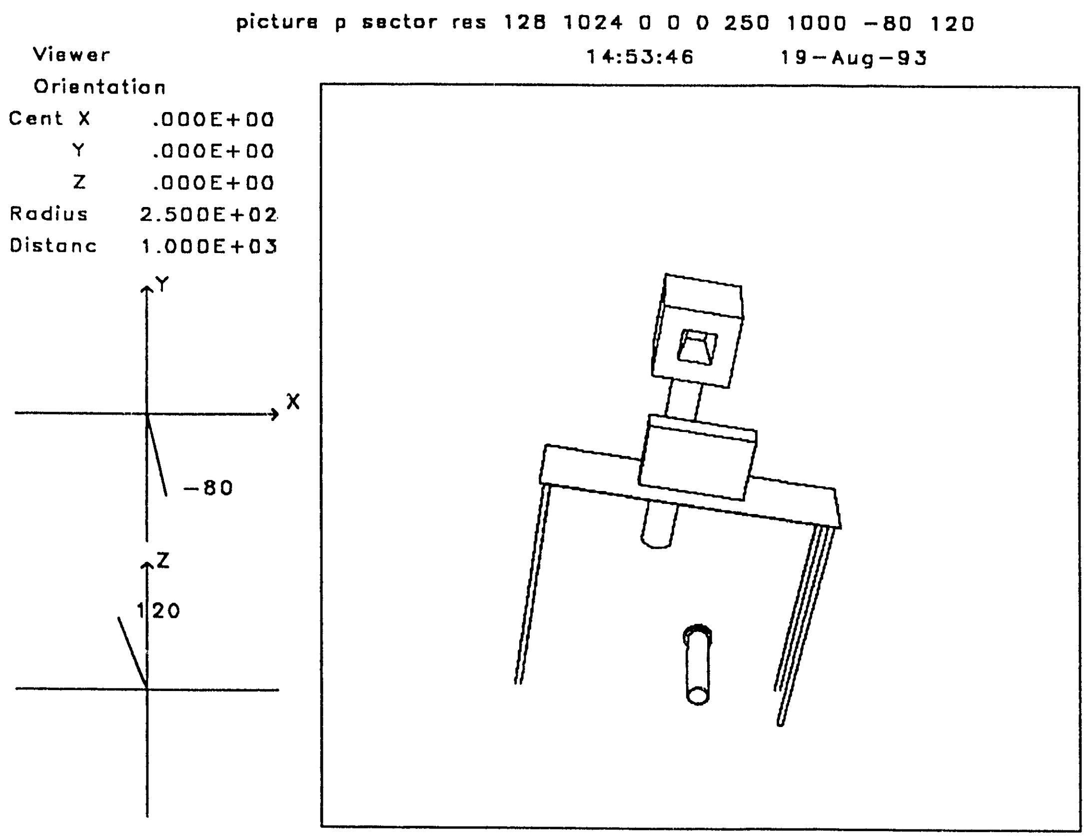

Figure 2. A perspective picture of the system generated by COG. The variation of the system with no snout on the detector shield is shown here. The neutron source is at the end of the beam pipe at the bottom of the picture and the detector is at the top.

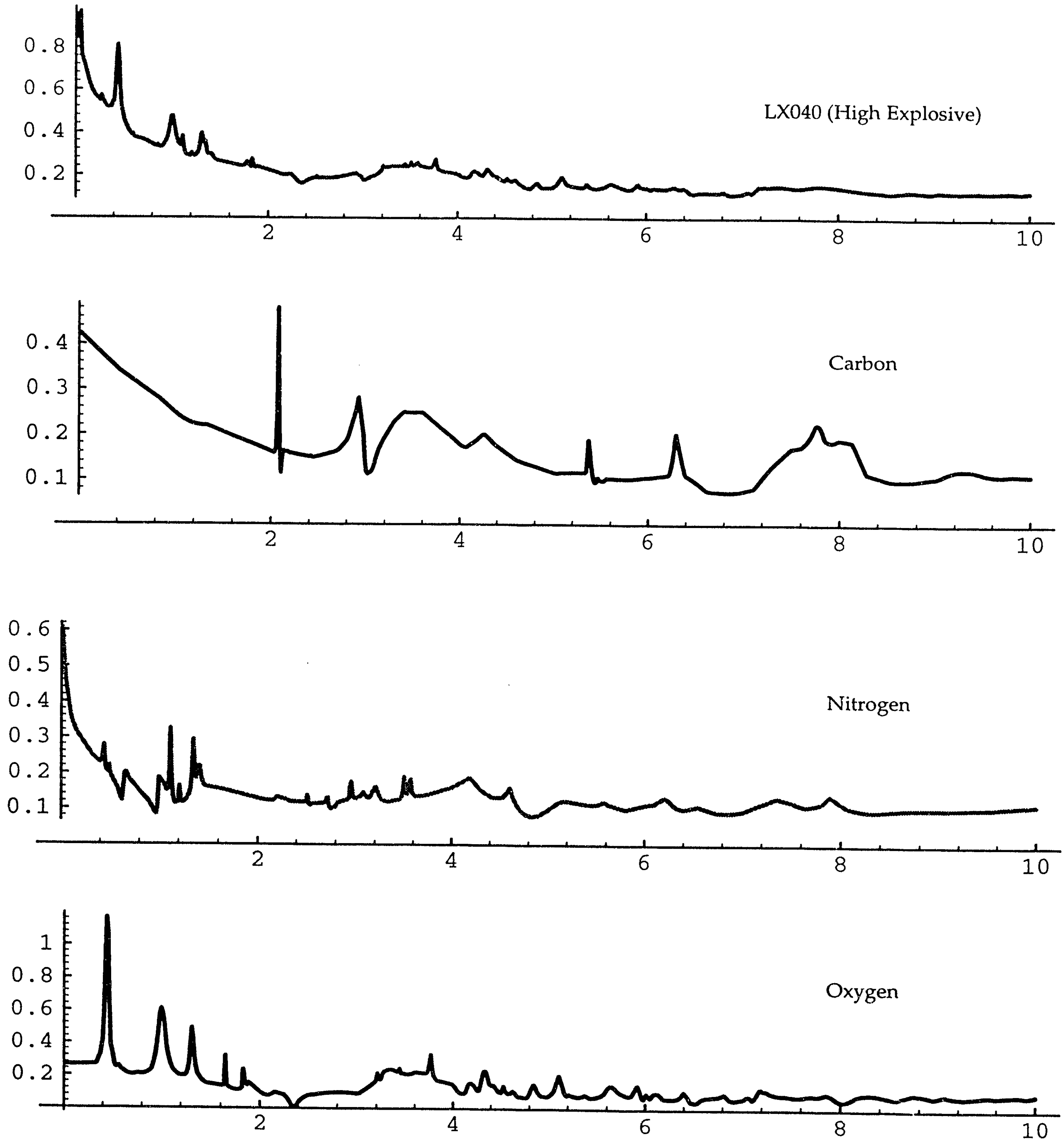

Figure 3. Neutron total cross sections (in cm^{-1}) for LX040, carbon, nitrogen and oxygen versus energy (in MeV).

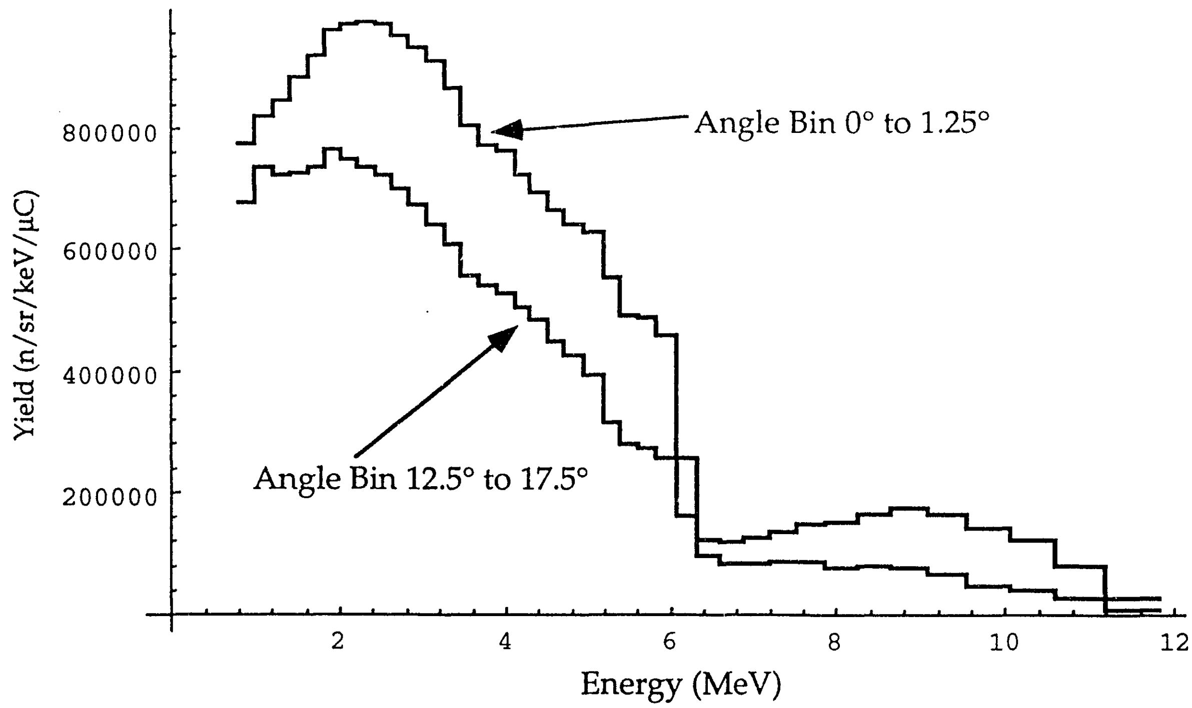

Figure 4. Two of the neutron spectra that were used in the description of the neutron source for these calculations.

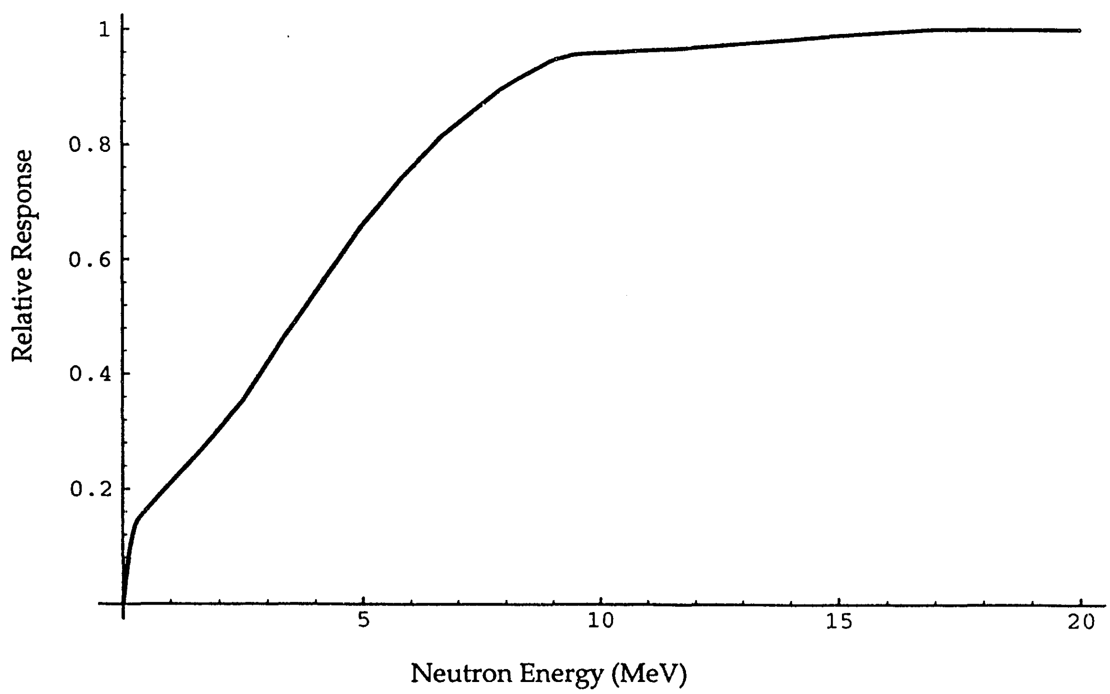

Figure 5. Detector relative response versus neutron energy.

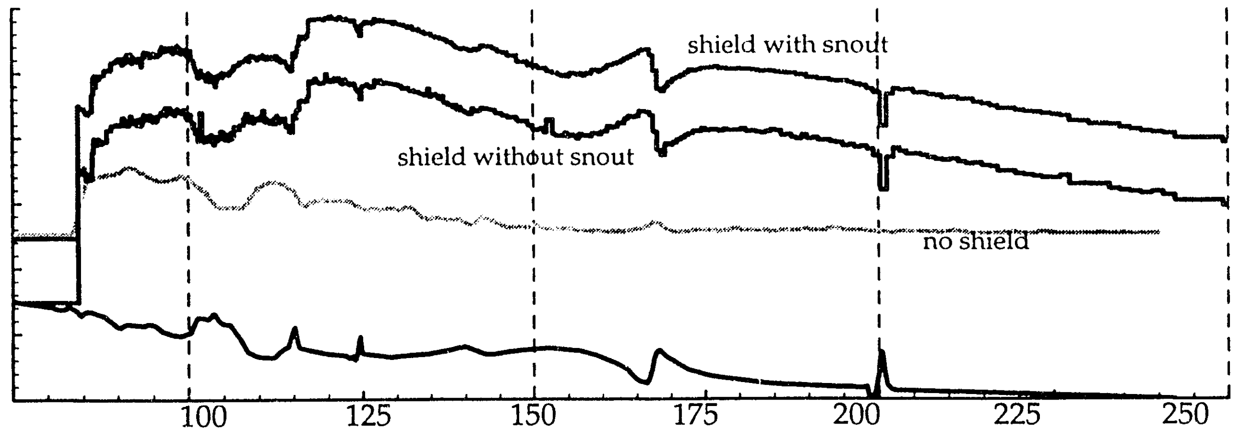

Figure 6. Semi-log plot of predicted signals from a solid block of carbon (arbitrary units) versus time (in nS) and carbon neutron total cross section. The uppermost signal is for a detector in a housing with a long shield. The second is for a shorter shield. The third is for the case of a bare detector. The carbon total scattering cross section (converted into the time domain) is the bottommost plot. The plots are offset from each other vertically to make viewing easier.

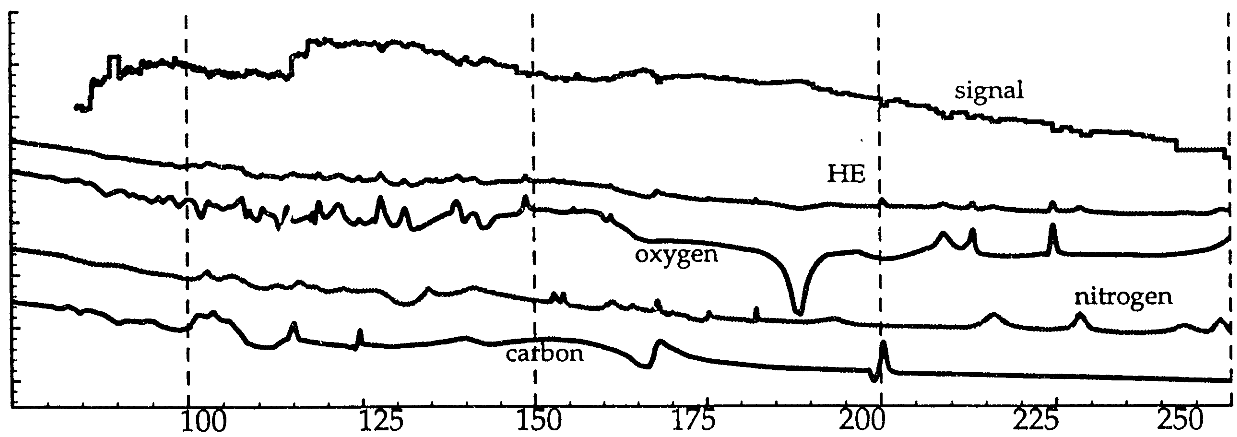

Figure 7. Semi-log plots of predicted signal for HE and component cross sections. The uppermost plot shows the signal predicted for a detector with a shield and a long snout. Below it are plots (in descending order) of the total neutron scattering cross sections in HE, oxygen, nitrogen and carbon. The plots are offset from each other vertically to make viewing easier.

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