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Simulation of a High Pressure Xe-^{3}He Detector

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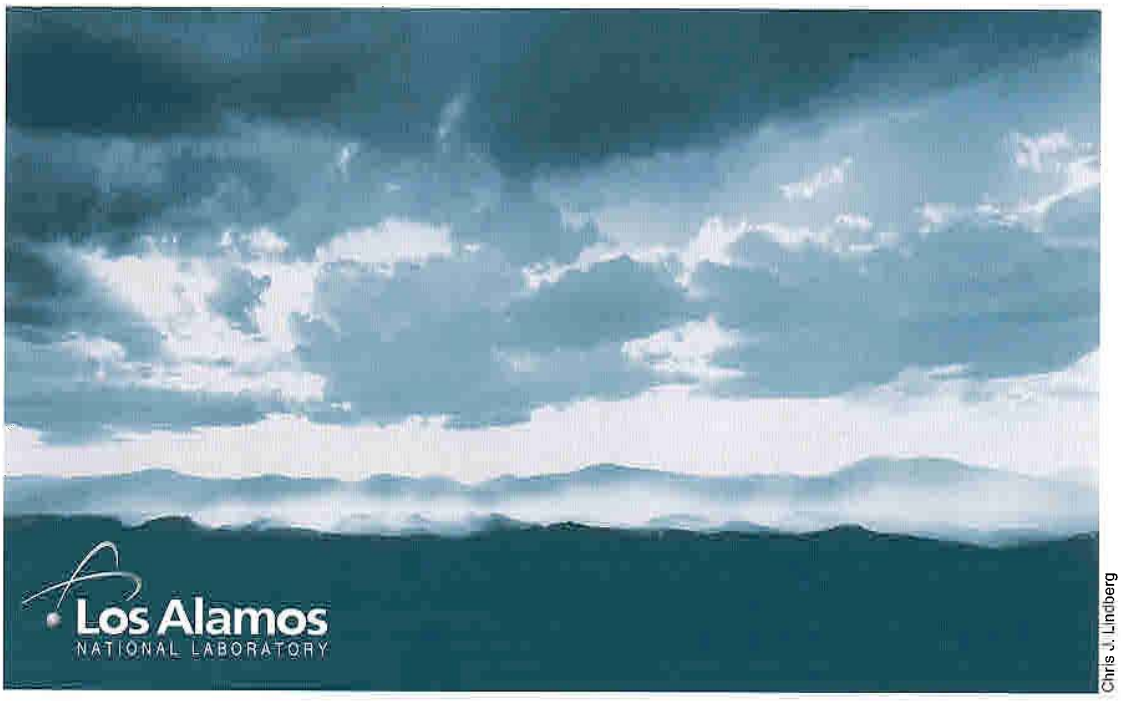

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Abstract

New designs of high-pressure xenon detectors are being developed and show promise as robust, intermediate-resolution gamma detectors. In order to better understand the potential of these detectors as neutron sensitive systems, a computational model of a high-pressure Xenon-^{3}He detector has been made. The model uses the Geant4 toolkit with a simple model for charge transport. This work was sponsored by the DOE Office of Security, Office of Materials Inventory and Technology Development (SO-20.3). LAUR 04-4359

1 Introduction

High Pressure Xenon detectors offer a promising direction for photon spectroscopy. These detectors are insensitive to temperature and radiation damage, have good long term stability and an energy resolution of 14.4 keV has been demonstrated at 662 keV [1]. This performance makes these detectors interesting for Nuclear Safeguards applications [2]. Extending this class of detectors by adding ^{3}He in order to make them sensitive to neutrons could further increase their potential value.

This paper presents results of a simulation of such a detector, using the Geant4 [3] toolkit to model the primary particle interaction in the detector and using a simple expression to model the pulse response from the detector. Geant provides a C++ library which allows detector geometry definition,

particle transport and simulation of particle interaction in materials. The low energy EM package [4] was used for this work. Because of the object oriented nature of the library, the results of the interactions can be seamlessly coupled to custom algorithms that simulate the detailed detector response.

2 Simulation Method

The simulation is broken into two parts. The first part defines the detector material, geometry and gas mixture using Geant. Incident thermal neutrons and 662 keV photons were simulated as a collimated beam through the center of the detector. This flux configuration was chosen to allow a determination of the intrinsic efficiency for the different particles. For each particle interacting in the detector, the radial charge distribution was stored in a histogram. A simple expression for the pulse shape was derived in order to estimate the observed signal.

Charge transport in the gas was modeled based on the measurements of S. Kobayashi, et. al. [6] and the detector dimensions are also approximately those used in those measurements. The measurements indicate that the electron drift velocity saturates at about 3.0×10^6 mm/s when $E/N > 2.0 \times 10^{-18}$ Vcm^2, where E is the electric field strength and N is the atomic number density. For this simulation, the mass density of the gas mixture was chosen to be 0.55 g/cm^3, corresponding to a gas pressure [5] of about 50 atmospheres. The gas mixture modeled is 15% ^{3}He and 85% Xe by abundance and is the same as that used in [6], scaled up to give the required mass density. Using the geometry listed in Table 1, an applied voltage of about 35 kV allows the detector to be operated with saturated drift velocity. Based on the assumption of saturated drift velocity, a simple expression for the current induced on the anode as a function of time can be obtained;

$$I(t) = \frac{e^{-V_d t/l_t}}{\ln(R_F/R_A)} \int_{R_A}^{R_F} \ln(r) q(v_d t + r) dr \tag{1}$$

where I is the current induced on the anode, q(r) is the radial charge distribution in the detector from an interaction, l_t is the characteristic charge trapping length in the gas, v_d is the saturated drift velocity which is defined in Table 1 and the other variables are defined in Table 1. In this simulation, the trapping length was made very large, so that there was no trapping in

the gas. This was done for simplicity and the correct trapping length needs to be determined and used in future work.

The modeled 662 keV photo-peak FWHM detector resolution was compared to the same quantity quoted in Dmitrenko [1] and found to be slightly smaller, at about 11.2 keV compared to 14.4 keV. This was considered to be good agreement, given that no readout electronics were modeled.

Detector Material	Fe
Cathode Outer Radius	50.0 mm
Cathode Inner Radius	47.8 mm
Frisch Grid Radius (R_F)	19.0 mm
Anode Outer Radius (R_A)	14.0 mm
Anode Inner Radius	1.0 mm
Applied High Voltage	
Drift Velocity (V_d)	3×10^6 mm/sec

Table 1: Simulated Detector Parameters

3 Simulation Results

3.1 Detection Efficiency

The intrinsic detector efficiency was measured as the ratio of the number of generated particles sent through the detector to the number of particles observed in the detector. This number was chosen as being indicative of the performance of the system without going into the details of how neutron moderation might be done using this type of detector. The efficiency was about 34% for 662 keV photons and 87% for thermal neutrons. Most of the observed neutrons are in the full energy peak, as shown in Figure 3.

3.2 Energy Resolution

The energy resolution for 662 keV gamma rays was slightly better in simulation than has been observed in data. A fit to the photo-electric peak is shown in Figure 1. The full energy neutron peak had an FWHM of about 10.8 keV.

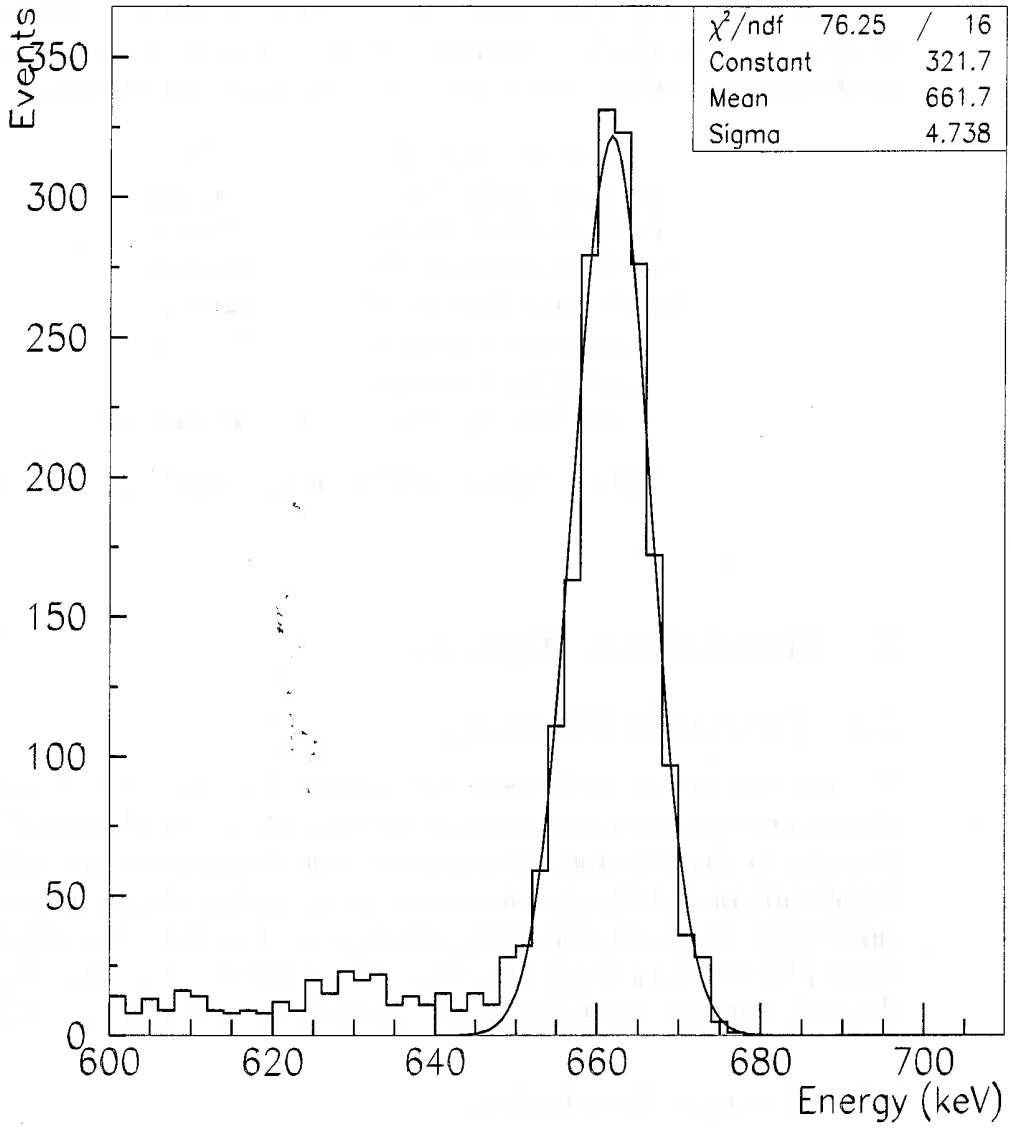

Figure 1: Simulated Photo-electric Peak for ^{137}Cs. Note the slight enhancement at 632 keV, which is the position of the Xe x-ray escape peak.

3.3 Photon and Neutron Discrimination

The possibility of using pulse shape discrimination to separate photons and neutrons was examined. The results shown in Figure 2 indicate that pulse shape discrimination is not likely to be helpful. The distribution of 10%-90% rise times peaks in the same position for both types of signal. An examination of a number of pulses indicates, in addition, that the typical pulses from each type of signal appear identical in shape.

Without pulse shape discrimination, the obvious method for separating neutrons from photons is to set a region of interest around the neutron pulse. If the neutron pulse is sufficiently narrow, so that it does not interfere with other important photon peaks, this method should be adequate. Figure 3 shows the distribution of photon and neutron energies. There is clear separation between the neutron and photon peaks which should allow windows to be set in a real system.

4 Conclusions

Based on the results of our simulation, a mixed Xe-^{3}He system looks promising. The next step is to compare the simulation results with data over a wide range of energies, and also to verify that the energy response to neutron capture events is linear compared to the energy response to photon events.

5 Acknowledgments

This work was sponsored by the DOE Office of Security, Office of Materials Inventory and Technology Development (SO-20.3).

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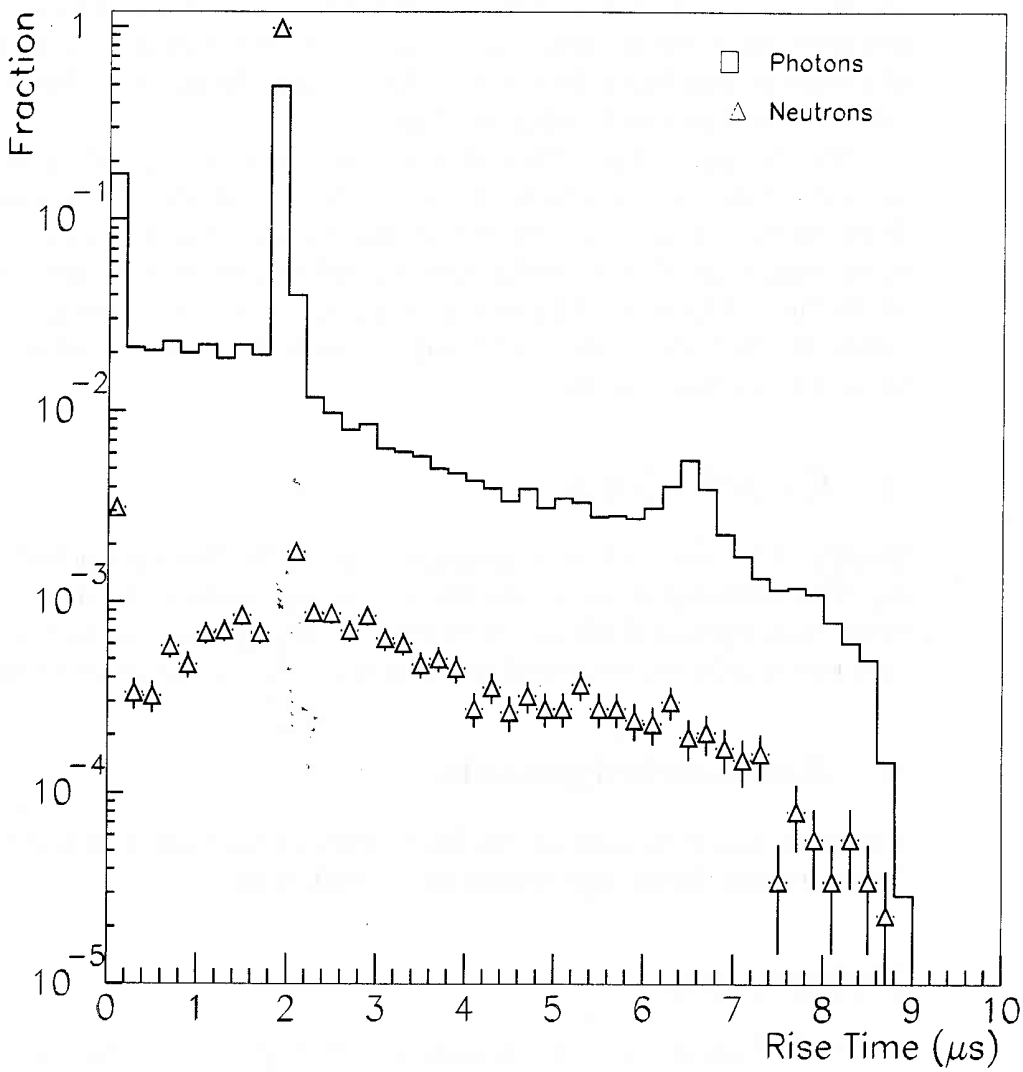

Figure 2: Fraction of photon and neutron interactions versus rise time from 10% to 90% of maximum for neutron and photon pulses

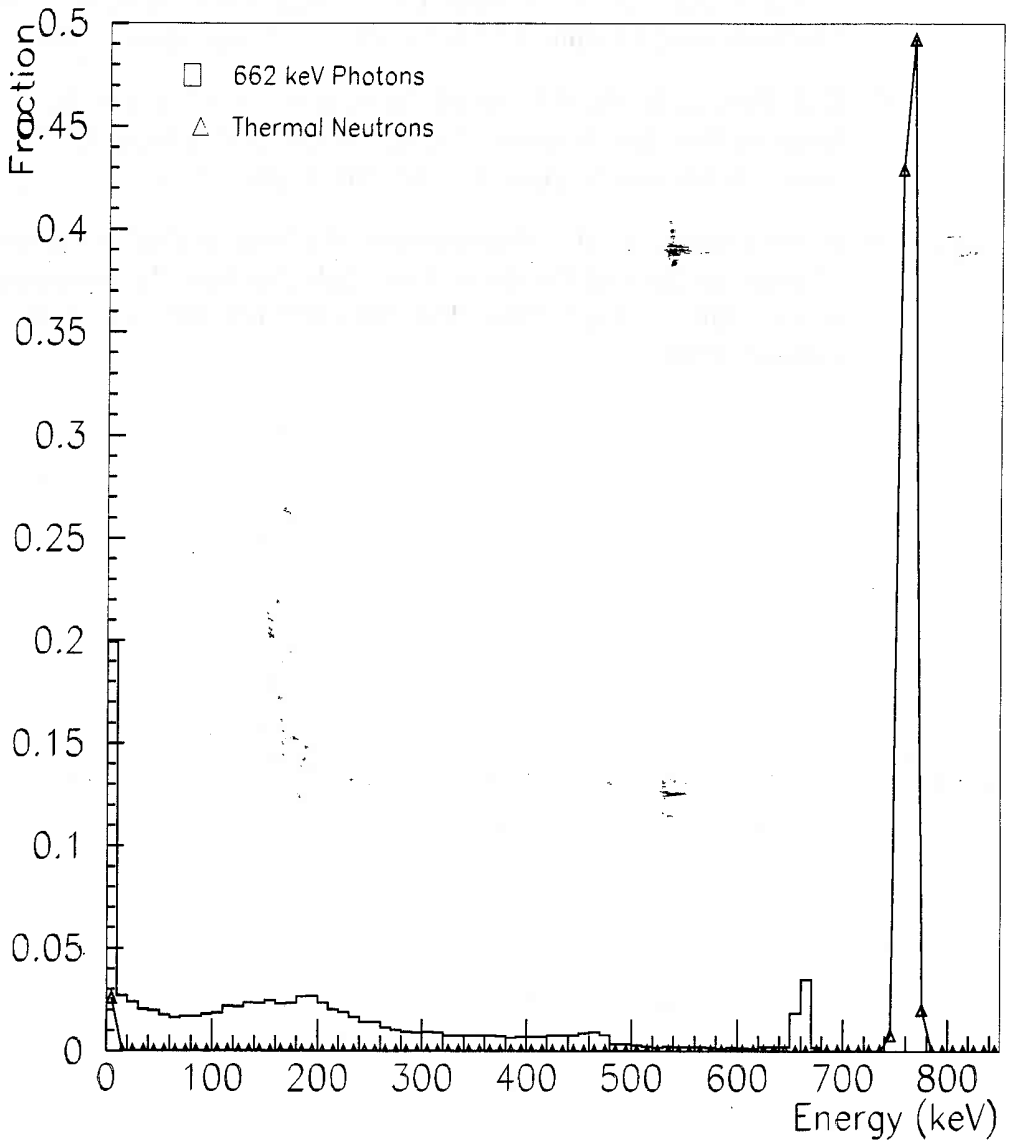

Figure 3: Simulated Response for ^{137}Cs and Thermal Neutrons.

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