Nuclear Instruments and Methods in Physics Research A 625 (2011) 20–28

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Spectral modeling of scintillator for the NEMO-3 and SuperNEMO detectors

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ARTICLE INFO

Article history:
Received 20 April 2010
Received in revised form
7 September 2010
Accepted 9 September 2010
Available online 20 October 2010

ABSTRACT

We have constructed a GEANT4-based detailed software model of photon transport in plastic scintillator blocks and have used it to study the NEMO-3 and SuperNEMO calorimeters employed in experiments designed to search for neutrinoless double beta decay. We compare our simulations to measurements using conversion electrons from a calibration source of ^{207}Bi and show that the agreement is improved if

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doi:10.1016/j.nima.2010.09.027

Keywords:
Scintillation
Photomultiplier
Plastic scintillators
Optical photon transport
GEANT 4
Double beta decay

wavelength-dependent properties of the calorimeter are taken into account. In this article, we briefly describe our modeling approach and results of our studies.

1. Introduction

Several dedicated efforts have recently been proposed to describe optical photon transport in scintillator detectors using various Monte Carlo packages [1–5]. Using the GEANT4 (version 4.9.1 patch 3) framework [6], we have constructed a comprehensive and detailed model of photon transport in plastic scintillator, then used the model to study the individual NEMO-3 calorimeter modules. In the model, we account for the wavelength dependence of optical properties of the scintillators, light guides, reflective wrappings, photodetectors and coupling materials. We use wavelength dependent self-absorption and re-emission in the scintillator and account for the fluorescent quantum yield of the wavelength shifter. Our results show that this detailed modeling exhibits better agreement with measurements compared to a monochromatic approach.

The NEMO-3 experiment, located at the Laboratoire Souterrain de Modane in the Fréjus tunnel, searches for neutrinoless double beta decay by employing tracking and calorimetry systems and has been taking data since 2003 [7–11]. The calorimeter modules consist of large polystyrene scintillator blocks with light guides coupled to either flat or hemispherical photomultiplier tubes (PMTs). Signals in an individual block are due to incident particles, mostly β and γ rays, and the response varies with the energy and the impact point on the entrance face. The response also depends on the size and geometry of the blocks. The energy resolution and background rejection improves if a correction for the non-uniformity due to the impact position is applied for each type of employed blocks [7]. We have reproduced the spatial dependence of response of the NEMO-3 scintillators to ^{207}Bi conversion electrons and have optimized the new scintillator block geometry for the next generation double beta decay experiment, SuperNEMO.

2. Modeling details

2.1. The detector

NEMO-3 calorimeter modules [7] were manufactured to conform to the overall cylindrical geometry of the detector. Each module faces the isotopic foil (a source of double beta transitions) and is composed of a scintillator block, a light guide, and a 3 in. or

Table 1
Types and dimensions of NEMO-3 inner and outer wall scintillator blocks.

Block type	IN	EC	EE
Thickness (mm)	98–110	99	99–123
Height (mm)	153	200	200
Width (mm)	138–154	218	218–230
Associated PMT [12]	R6091 (3 in.)	R6594 (5 in.)	R6594 (5 in.)
Total number	680	260	520

The blocks were made at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia [7].

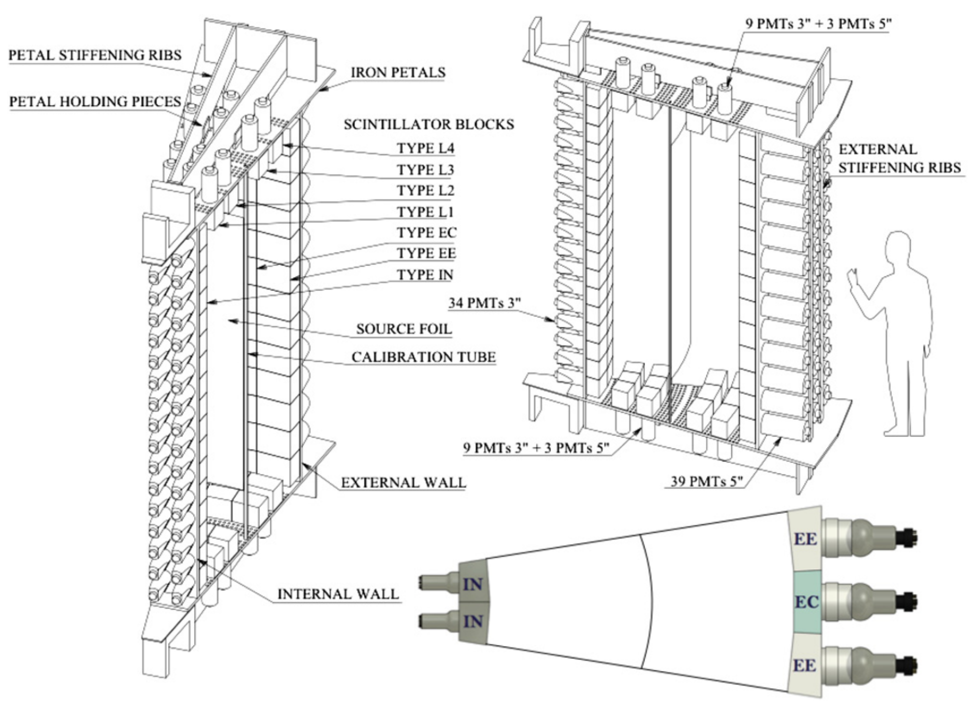

Fig. 1. One of 20 sectors of the NEMO-3 detector with details showing the source foil, scintillator blocks, and photomultipliers. EE, EC, and IN identify blocks on the exterior and interior walls. L1–L4 identify blocks on the petals (not modeled in this work). The lower figure shows a 2-D rendering of the wall blocks.