Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 89 (2016) 389 – 394
Energy Procedia

CoE on Sustainable Energy System (Thai-Japan), Faculty of Engineering, Rajamangala University of Technology Thanyaburi (RMUTT), Thailand

Simulation Study on Computer Tomography Imaging of Nuclear Distribution by Quasi Monoenergetic Gamma Rays with Nuclear Resonance Fluorescence: case study for ELI-NP application

I. Daito[a]*, H. Ohgaki[a], G. Suliman[b], V. Iancu[b], C. A. Ur[b], M. Iovea[c]

[a] *Institute of Advanced Energy, Kyoto University Goka-sho, Uji, kyoto 6110011, JAPAN*
[b] *Extreme Light Infrastructure – Nuclear Physics (ELI-NP)/Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), 30 Reactorului Street, P.O.B. MG-6, Bucharest-Magurele, Judet Ilfov, RO-077125, Romania*
[c] *Accent Pro2000, s.r.l., Nerva Traian 1, K6, Apt 26, Bucharest, S3, RO-031041, Romania*

Abstract

Non-destructive inspection carried out by using nuclear resonances excited by an MeV energy region gamma ray is a promising method. The high penetrability of MeV gamma ray of nuclear resonant energy makes possible the detection of nuclides surrounded by massive materials. As an application of this method, computed tomography imaging of nuclear distribution inside objects can be reconstructed from transmission factor of gamma rays. We have studied the image reconstruction of the nuclear distribution using Monte-Carlo simulations to estimate the gamma-ray transmission factor assuming the ELI-NP facility where about 3 order higher intensity of quasi-monoenergetic gamma rays will be available.

Peer-review under responsibility of the organizing committee of the 12th EMSES 2015
Keywords: Laser Compton Scattering; Nuclear Resonance Fluorescence; non-destructive inspection; Computed Tomography

1. Introduction

An MeV energy region gamma-ray is a good probe for non-destructive inspection of high density and massive objects because of its high penetrability. Because of the weak element dependence of attenuation coefficient in this energy regime, it is possible to know the mass distribution. Moreover, it is possible to detect the presence of a

* Corresponding author. Tel.: +81-774-71-3485; fax: +81-774-71-3316.
E-mail address: daito.izuru@gmail.com

Peer-review under responsibility of the organizing committee of the 12th EMSES 2015
doi:10.1016/j.egypro.2016.05.051

specific nuclide by the process of nuclear excitation, provided that the energy of the incident gamma ray is equal to the excitation energy of the nuclear resonance state (Nuclear Resonance Fluorescence: NRF) of the target nucleus. A non-destructive inspection of Special Nuclear Materials (SNMs) hidden in a container cargo using NRF is proposed by Bertozzi [1] for the nuclear non-proliferation and prevention of the nuclear terrorism. Several developments have been carried out at many institutes for SNM detection systems [2-4] and non-destructive detection of Plutonium and other nuclear products inside of a spent nuclear fuel rod [5,6]. For NRF experiments, a Laser Compton Scattering (LCS) gamma-ray beam, which can generate energy tunable and quasi-mono energetic gamma rays, is an ideal gamma-ray source. Quasi-mono energetic gamma-rays suppress a number of off-resonant energy gamma-rays which make the huge background events at the foot of NRF gamma-rays caused by atomic processes i.e. Compton- and Rayleigh-scattering and so on.

Images of the density and nuclear distributions inside objects can be reconstructed from one-dimensional distribution of the off-resonance transmission factor by Computed Tomography (CT) [7] and on-resonance (NRF) scattering technique [8]. However, the intensity of existing LCS gamma-ray beams [9-11] is not high enough to obtain a nuclear distribution image reconstruction from the NRF method. Currently, a new LCS gamma-ray facility is being built as part of the Extreme Light Infrastructure-Nuclear Physics (ELI-NP) [12] in Romania and will deliver one of the brightest and highest quality LCS gamma-ray source. The designed flux of the collimated gamma-ray beam is in the range of 10^8 ph/s with the energy spread of 0.5 % in standard deviation. The non-destructive imaging of density and nuclear distribution is part of a proposal for industrial application research at ELI-NP [13].

In this work, we made a feasibility study of reconstruction of a CT image of density and nuclear distribution of ^{238}U surrounded by high density materials in ELI-NP. The gamma-ray beam parameter and the detection system are taken from Ref. [13]. A modified version of GEANT4, which takes into account all NRF processes, developed by our group [14] was employed for this work, because the NRF process was not included in an original GEANT4 code [15].

2. Nuclear Resonance Fluorescence

NRF is a process in which a nucleus absorbs energy from gamma rays and is excited to a nuclear state of higher energy. Subsequently, the excited nucleus emits one or more gamma rays to de-excite to the ground state (Fig. 1). The excitation energy of the resonant state is specific to each nuclide. By irradiating nuclei with gamma rays of energy Existence of the NRF gamma rays or decrease of gamma-ray intensity at the resonant energy which pass through a measured object show the presence of the nuclide in the object. The natural width of the NRF resonances is usually equal to the nuclear excitation energy, a resonant absorption of the gamma ray occurs only in the nuclide of interest. Existence of the NRF gamma rays or decrease of gamma-ray intensity at the resonant energy which pass through a measured object show the presence of the nuclide in the object. The natural width of the NRF resonances is usually quite narrow, being less than 100 meV. However, because of thermal motion of the nucleus, the width of the resonance is typically of the order of eV. Therefore a mono energetic gamma-ray beam with high spectral density is desired for realistic applications of the NRF. In this work, we performed Monte Carlo simulations to

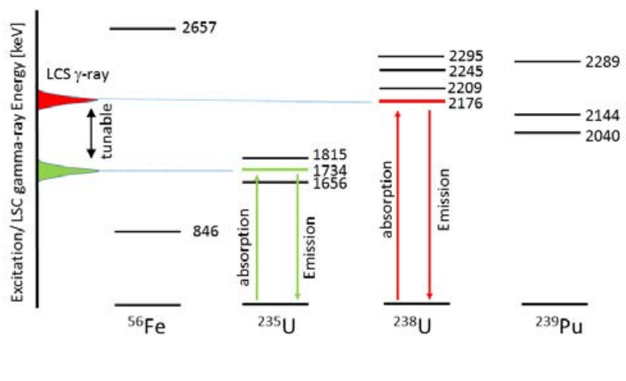

Fig. 1. A schematic drawing of the NRF process excited by LCS gamma-ray beam.