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Calculation of HPGe Detector Response for NRF Photons Scattered from Threat Materials

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1. Introduction

Nuclear Resonance Fluorescence (NRF) is a process of resonant nuclear absorption of photons, followed by de-excitation with emission of fluorescence photons. The cross section of NRF photons process is given by [1]

$$\sigma_i^{\max} \equiv 2\pi\left(\frac{\lambda}{2\pi}\right)^2 \frac{2J+1}{2J_0+1}\frac{\Gamma_0\Gamma_i}{\Gamma_{tot}^2}, \qquad (1)$$

where λ is the wavelength of the photon, J_0 and J are the nuclear spins of the ground state and excited state, respectively, Γ_0, Γ_i and Γ_{tot} are decay width for de-excitation to the ground state, to the i-th mode state and total decay width, respectively.

NRF based security inspection technique uses the signatures of resonance energies of the fluorescence photon scattered from nuclides of the illicit materials in cargo container. NRF can be used to identify the material type, quantity and location. It is performed by measuring the fluorescence photon and the transmitted photon spectrum while irradiating Bremsstrahlung photon beam to the sample [2]. This process is demonstrated schematically in Fig. 1.

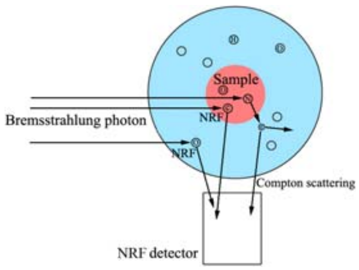

Fig. 1. Schematic drawing of the NRF measurement.

In the previous study [3], the NRF cross sections for the key elements (C,N,O,F,Cl) and the scattering rate of Bremsstrahlung radiation scattered from the threat materials were calculated. In this study, the detector response function for NRF photons scattered from threat materials was calculated by using Monte Carlo simulation, and detection sensitivity was determined by analyzing the spectrum data.

2. NRF cargo inspection system

NRF cargo inspection system contains electron accelerator, collimator, cargo container and detector. The electron accelerator is placed at a distance of 10.57 m from the center of the cargo container. The Bremsstrahlung photon beam is emitted from electron accelerator, with a maximum energy 9 MeV. And this collimated beam of Bremsstrahlung photons is scanned through the cargo. Threat material samples are placed in the center of the cargo. The material is one of the following explosives: C4, PETN, TNT, AN, Dynamite, or of the narcotics: Cocaine, Heroin, Methamphetamine, LSD, or of the chemical agents: Sarin, VX, CA, HD, Phosgene. Fluorescence photon spectra are simulated for detection by using a HPGe of relative efficiency 100% placed 200 cm from the sample at an angle of 120° relative to the beam direction. Figure 2 shows the schematic drawing of the NRF cargo inspection system and location of the collimated HPGe detector.

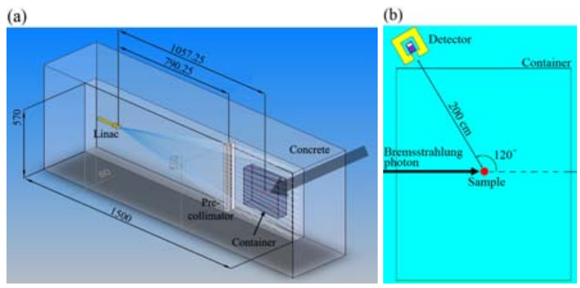

Fig. 2. Schematic drawing of the NRF cargo inspection system(a), and HPGe detector(b).

3. HPGe detector response function

The HPGe detector response function for fluorescence photons from the sample was calculated by using the pulse height distribution tally(F8) in MCNPX code [4]. The responses of the MCNPX simulation were broadened with the GEB option to better simulate a HPGe detector in which energy peaks exhibit Gaussian energy broadening.

The response function was calculated for two cases: 1 kg of threat material surrounded by water, iron and lead (packed container) and 1 kg of bare threat material (bare container). The irradiation time was assumed 10 hr for each calculation to obtain reliable detection sensitivities. The calculated NRF scattering rate for each interested materials was used as the source term of MCNPX simulation.

Examples of calculated NRF spectrum are shown in Fig. 3. The x-axis is the energy of the fluorescence photon and the y-axis is the count per channel (log scale). The key nuclides and its fluorescence photons energy are shown. The single escape(SE) and double escape(DE) peaks are also identified in the figure. Gray and black lines are the obtained spectra for the case of bare and iron packed container, respectively. Iron has NRF states in the 1 ~ 10 MeV energy range, so there are observed peaks of fluorescence photons scattered from iron at the black line (2272, 2759, 3448 and 3830 keV). Table 1 shows the calculated detection sensitivity of key nuclides(^{12}C, ^{14}N and ^{16}O) composed of two materials.

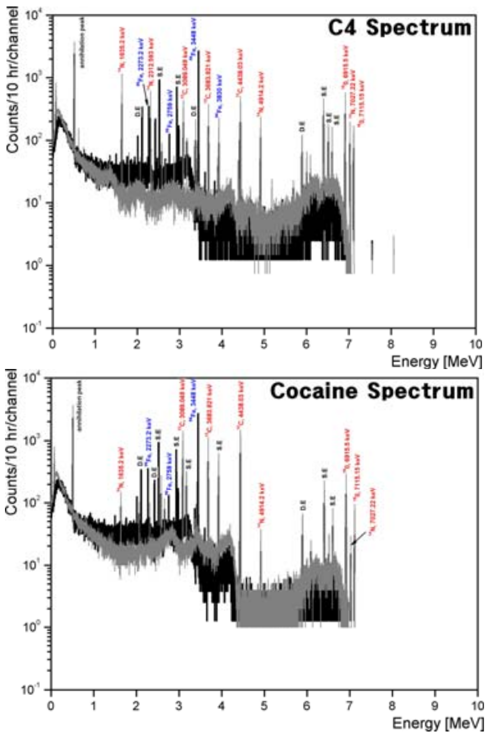

Fig. 3. NRF spectrum from C4(top) and Cocaine(bottom) in iron packed container(black line) and bare container(gray line).

Table 1. Calculated detection sensitivity of C4 and Cocaine in bare container and iron packed container.

Material	Isotope	Energy [keV]	Detection sensitivity [$\times 10^{-5}$ cps/g]	
			bare	iron packed
C4	^{14}N	1635.2	8.60±0.30	2.56±0.09
	^{12}C	4438	5.30±0.10	2.06±0.11
	^{16}O	6915.5	4.20±0.10	3.08±0.09
Cocaine	^{14}N	1635.2	2.55±0.10	0.43±0.07
	^{12}C	4438	16.56±0.18	6.61±0.17
	^{16}O	6915.5	2.06±0.09	1.61±0.07

4. Conclusion

The NRF cargo inspection system was designed and the response function of the HPGe detector was calculated for explosives, narcotics and chemical agent samples which are irradiated by using 9 MeV Bremsstrahlung photon beams. The detection sensitivity of nuclides ^{12}C, ^{14}N and ^{16}O in composition of C4 and Cocaine was calculated. The difference in the detection sensitivity at 1635.2 keV(^{14}N) and 4438 keV(^{12}C) indicates the specific content of nitrogen and carbon in the C4 and Cocaine. In the case of the iron packed container, the detection sensitivity of C4 and Cocaine decreased compared to the case of bare container. It is due to that the Bremsstrahlung photon beam and fluorescence photons scattered from the sample materials are both attenuated by the iron.

Acknowledgement

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