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Luminescence imaging of water during alpha particle irradiation

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ABSTRACT

The luminescence imaging of water using the alpha particle irradiation of several MeV energy range is thought to be impossible because this alpha particle energy is far below the Cerenkov-light threshold and the secondary electrons produced in this energy range do not emit Cerenkov-light. Contrary to this consensus, we found that the luminescence imaging of water was possible with 5.5 MeV alpha particle irradiation. We placed a 2 MBq of ^{241}Am alpha source in water, and luminescence images of the source were conducted with a high-sensitivity, cooled charge-coupled device (CCD) camera. We also carried out such imaging of the alpha source in three different conditions to compare the photon productions with that of water, in air, with a plastic scintillator, and an acrylic plate. The luminescence imaging of water was observed from 10 to 20 s acquisition, and the intensity was linearly increased with time. The intensity of the luminescence with the alpha irradiation of water was 0.05% of that with the plastic scintillator, 4% with air, and 15% with the acrylic plate. The resolution of the luminescence image of water was better than 0.25 mm FWHM. Alpha particles of 5.5 MeV energy emit luminescence in water. Although the intensity of the luminescence was smaller than that in air, it was clearly observable. The luminescence of water with alpha particles would be a new method for alpha particle detection and distribution measurements in water.

1. Introduction

Alpha imaging detectors employing high-sensitivity charge-coupled device (CCD) cameras are used for autoradiography for targeted alpha particle therapy [1–2]. Alpha particle detection is also important for mixed oxide fuel (MOX) fuel fabrication facilities where plutonium contamination must be detected to prevent exposure to workers. For this purpose, alpha imaging detectors have been developed using an image intensifier [3], position sensitive photomultiplier tubes (PSPMT) [4], or a silicon photomultiplier (Si–PM) [5]. Although these alpha particle imaging detectors have high resolution and high sensitivity, they need to use a scintillator that is optically coupled with a photodetector surface [3–5] or placed on the subjects [1–2]. Imaging alpha particles in such materials as water without a scintillator would be an innovative advance in radiation detection research.

Alpha particle imaging without scintillators in air has been conducted using a CCD camera [6–8]. The imaging of alpha particles in air, which used nitrogen gas (N_2) in air as a scintillator, has been successful. In these imaging of alpha particles in air, high sensitivity CCD cameras were used, and the scintillation photons generated by alpha particles from N_2 gas in air were imaged. Imaging of high energy X-rays and electron beams for therapy has also been reported [9]. However, the imaging of alpha particles in water is generally not possible because scintillation or luminescence mechanism in water is not produced although there was a report on detection of luminescence of water with alpha particles irradiation more than 50 years ago [10].

Cerenkov-light, which is a possible imaging method without a scintillator for charged particles, has been employed for dose estimation in water phantoms using X-ray photons produced by a high-energy linear accelerator [11–12]. In these works of Cerenkov-light imaging, X-ray photons exceeding several MeV were irradiated to the phantoms, and high-sensitivity CCD cameras were used for the imaging. However, for the energy of alpha particles of several MeV, no Cerenkov-light will be produced because the energy is far below the Cerenkov-light threshold for alpha particles ($\sim$2 GeV).

Recently, we successfully imaged proton-beam distribution in water during proton irradiation using a CCD camera [13]. The luminescence was not thought to be from the Cerenkov-light emitted by the produced electrons but from the radicals produced in water by the irradiation of the proton beam. These results suggest the possibility of imaging the distribution of alpha particles at energy around several MeV, which is an energy range at which Cerenkov-light is not produced. For this purpose, we placed

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a ^{241}Am alpha source in water, and luminescence images of the source were conducted with a high-sensitivity CCD camera. We also carried out such imaging of the alpha source in air, with a plastic scintillator, and an acrylic plate to compare the photon productions with that of water.

2. Materials and methods

2.1. Experimental setup for luminescence imaging

Fig. 1(A) shows schematic drawing of our experimental setup for luminescence imaging during alpha particle irradiation to pure water (de-ionized type, TRUSCO, W-20, Japan). We placed an alpha source (^{241}Am, 2-MBq) in a container filled with water. The source's active area was 10 mm × 10 mm, and its periphery was covered by black tape (Saint Gobain, BC638) to use the uniform central 5 mm × 5 mm area for the imaging. A cooled electron multiplied CCD (EM-CCD) camera operating at −65 °C (ImagEM, Hamamatsu, Japan) with a C-mount F-0.95 lens (Schneider) was set ~8 cm from the source surface.

Fig. 1(B) is a schematic drawing of the experimental setup for the luminescence imaging of alpha particles in air. We placed an alpha source (^{241}Am, 2 MBq) in a container without water, and imaging was conducted by the same EM-CCD camera.

Fig. 1(C) shows a schematic drawing of the experimental setup for luminescence imaging during alpha particle irradiation to a plastic scintillator or an acrylic plate. We placed a plastic

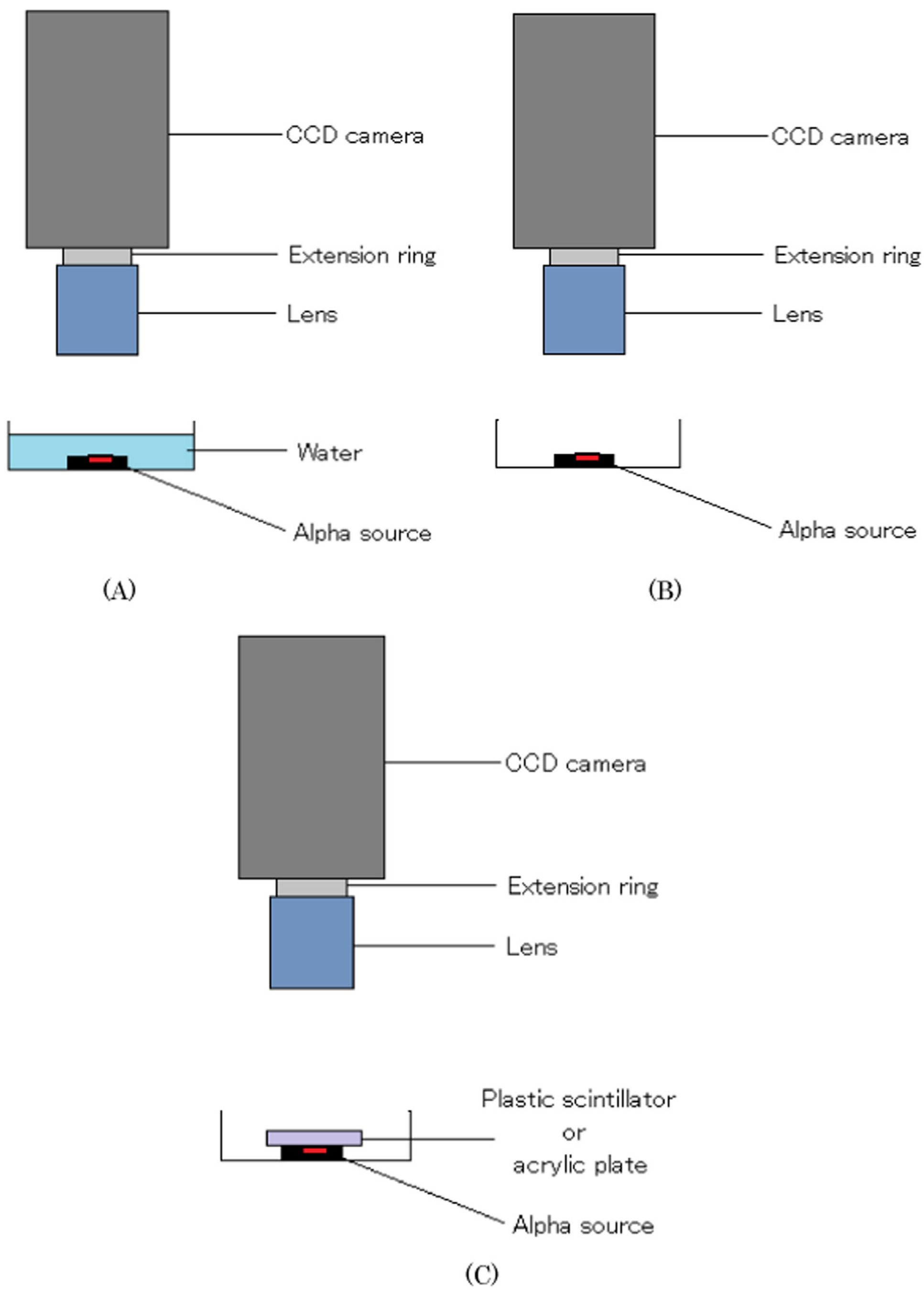

Fig. 1. Schematic drawing of experimental setup for luminescence imaging during alpha particle irradiation to water (A), imaging alpha particle in air (B), and imaging during alpha particle irradiation to plastic scintillator or acrylic plate (C). CCD camera lens was set 8 cm above source surface.