Research progress on double-photon-emission coincidence imaging with cascade gamma-ray-emitting nuclide

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Positron emission tomography (PET) and single-photon-emission computed tomography (SPECT) are important nuclear medicine modalities that have been widely used for clinical diagnosis. PET detects the coincidence of annihilation gamma-rays from a positron-emitting nuclide. SPECT uses a collimator to restrict the incident direction of gamma-rays. Therefore, nuclides for PET imaging are limited to positron-emitting nuclides and there is a theoretical spatial resolution limit derived from the positron range. The sensitivity of SPECT is relatively low because of its use of a collimator, and it is difficult to image multiple nuclides simultaneously. To realize highly sensitive multi-nuclide imaging, we proposed a double-photon -emission coincidence imaging method.[1)]

For SPECT imaging, single-photon-emitting nuclides are preferable. Among them, there are nuclides that emit two photons in cascade decay. For example, ^{111}In, which is widely used in SPECT imaging, emits two gamma-rays at 171 keV and 245 keV. Using two gamma-rays, the position of nuclides can be determined with higher sensitivity. One of the methods using two gamma-rays is double-photon-emission computed tomography (DPECT).[1,2)] This method can drastically increase the signal-to-noise (SN) ratio of Compton imaging[3)] by coincidence detection for cascade gamma-rays with multiple Compton cameras, which is based on Compton scattering kinetics. Conventional Compton imaging can obtain only the angle information of incident gamma-rays, and drawing many Compton cones results in a low SN ratio. However, DPECT can limit the nuclide position from a Compton cone to an overlap of two Compton cones. We previously demonstrated DPECT using ^{134}Cs and ^{60}Co for application to fuel debris imaging[2)] with GAGG-SiPM Compton cameras.[4)] In the present research, we developed small GAGG-SiPM Compton cameras for application to nuclear medicine and demonstrated double-photon-emission coincidence methods using ^{43}K, which is one of the promising double-photon-emitting nuclides because of its short decay time and suitable gamma-ray energies.

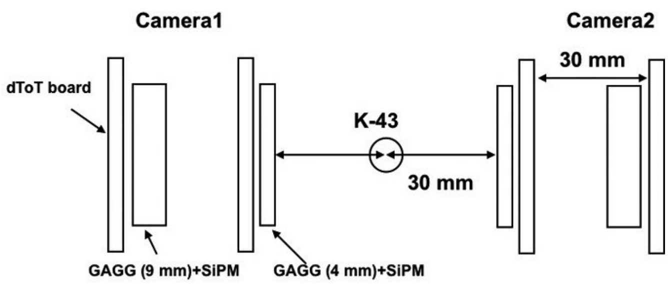

Fig. 1. Experimental setup of DPECT for ^{43}K.

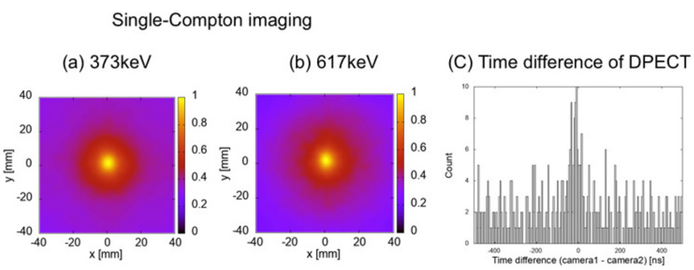

Fig. 2. Single-photon Compton imaging at (a) 373 keV and (b) 617 keV. (c) Time difference of DPECT (camera1-camera2).

^{43}K was produced in the ^{43}Ca$(d, 2p)^{43}$K reaction at the RIKEN AVF cyclotron. After chemical separation, 2 (6) MBq of ^{43}K in 6 (18) μL H_2O was placed in a vial as a gamma-ray source. Figure 1 shows the experimental setup of DPECT for ^{43}K. ^{43}K mainly emits cascade gamma-rays at 617 keV and 373 keV. A Compton camera consists of a scatter layer and an absorber layer. Each layer consists of an 8×8 GAGG array coupled to an 8×8 SiPM array. The thicknesses of the GAGG arrays is 4 mm and 9 mm for scatterers and absorbers, respectively. The pixel size of the GAGG arrays is 2.5 mm $\times$ 2.5 mm, and each crystal is separated by $BaSO_4$ reflectors. The signal from SiPM is processed by the dynamic time over threshold (dToT) method[5)] to extract the energy. The distance from the ^{43}K source to a scatterer was 30 mm, and two Compton cameras were placed in opposite directions.

Figures 2(a) and 2(b) show images reconstructed through back projection. Figure 2(a) shows a single-photon Compton image at 373 keV and (b) shows an image at 617 keV. We succeeded in obtaining images of single-photon Compton imaging with our small Compton cameras. Figure 2(c) shows a histogram of time difference of double Compton coincidence events at 373 keV and 617 keV. However, the number of coincidence events that can be used for DPECT with Compton scattering energy windows was only 12. After this experiment, we increased the number of Compton cameras to detect double Compton coincident events efficiently and repeated the experiment with eight modules. The result is under analysis.

References
1) Y. Yoshihara *et al.*, Nucl. Instrum. Methods Phys. Res. A **873**, 51 (2017).
2) M. Uenomachi *et al.*, Nucl. Instrum. Methods Phys. Res. A **954**, 161682 (2020).
3) R. W. Todd *et al.*, Nature **251**, 132 (1974).
4) J. Jiang *et al.*, J. Nucl. Sci. Technol. **53**, 1067 (2015).
5) K. Shimazoe *et al.*, IEEE Trans. Nucl. Sci. **59**, 3213 (2012).

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