First demonstration of portable Compton camera to visualize 223-Ra concentration for radionuclide therapy

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Abstract

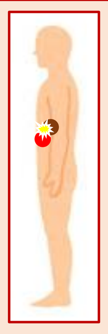
Radionuclide therapy (RNT) is an internal radiation therapy that can selectively damage cancer cells. Recently, the use of alpha-emitting radionuclides was initiated in RNT owing to its dose concentration and short range. In particular, 223-Ra is widely used for bone metastasis cancer. Despite its potential for clinical applications, it is difficult to know whether the drug has been properly delivered to the target lesion. As such, we propose a new method of monitoring nuclear gamma rays promptly/simultaneously emitted from 223-Ra in alpha-decay by using a high-sensitivity Compton camera. We first observed a small bottle of 223-Ra solution that had a total radio-activity of 0.56 MBq. The reconstructed image converged at the correct position with a position resolution of ~20 mm at a plane 10 cm ahead of the camera. Next, we observed a phantom consisting of three spheres, with diameters ranging from 13 to 37 mm, filled with 223-Ra solution (9 kBq/ml) and then surrounded by a ~20-cm layer of water. A 3D image was constructed by rotating the Compton camera around the phantom. Then, images were taken from eight directions at 30-min intervals, respectively. Although the image resolution remains limited at 351 keV, three spheres were resolved at the correct position in the 3D image with their relative intensities. As a next step, we imaged 223-Ra in the body of a patient and succeeded in reconstructing accumulation in the large intestine. Finally, we discuss current problems and plans for improving the sensitivity and angular resolution for future clinical applications.

1. Introduction

External radiation therapies

- Irradiating from the outside of the body
- Damage to not only cancer cells but also normal cells

Radionuclide therapy (RNT)

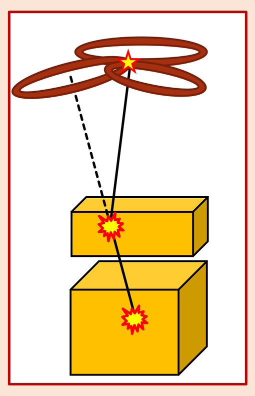


- Placing the drug in or near the tumor
- Selectively damage cancer cells with alpha particles
  - Large linear energy transfer
  - Shorter range (~10 μm)

SPECT

- Identify the direction of arrival of gamma rays by passive collimators
- Burdens to patients
  - The relatively long exposure
  - Planar geometry

A Compton camera

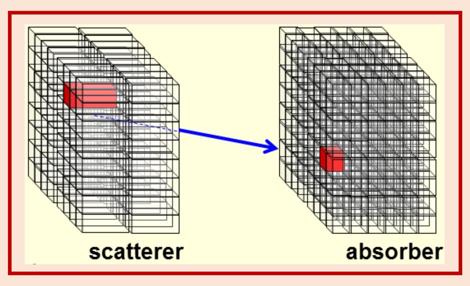


- Identify the direction of arrival of gamma rays with Compton-scattering kinematics
- Advantages to patients
  - Wider field of view
  - Less burdens in imaging
  - Easiness of 3D imaging

➡ **Achieve less burden with a Compton camera in RNT**

2. Method

- DOI-CC
  - A portable Compton camera (16 cm × 15 cm × 15 cm, 2.5 kg)
  - Developed for an environmental survey in Fukushima
  - Obtain the depth of interaction (DOI-CC)
  - The angular resolution: ~8° (FWHM at the center of FOV @ 662 keV)
  - The energy resolution: 7.8 % (FWHM @ 662 keV)

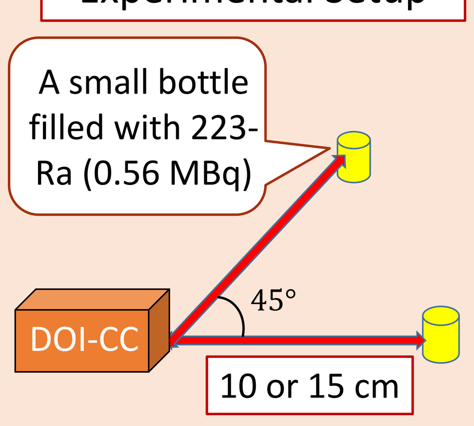


- Constitution of DOI-CC
  - Scintillator: Ce:GAGG arrays (Ce-doped $Gd_3Al_2Ga_3O_{12}$)
  - Photon detector: 8 × 8 MPPC arrays
  - Two couples of Ce:GAGG and MPPC @ scatterer
  - One Ce:GAGG sandwiched with two MPPC @ absorber

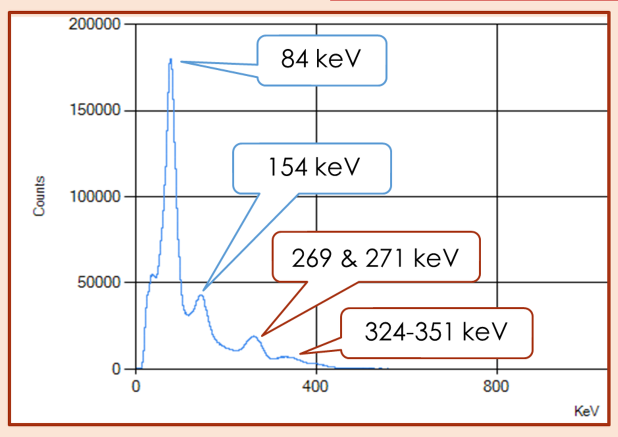
	Scatterer	Absorber
Crystal size	2.0 × 2.0 × 4.0 mm^3	2.0 × 2.0 × 2.0 mm^3
Array	11 × 11 arrays 2 × 2 set	11 × 11 arrays 2 × 2 set
Layer	2	10

3. Imaging of a small bottle with 223-Ra

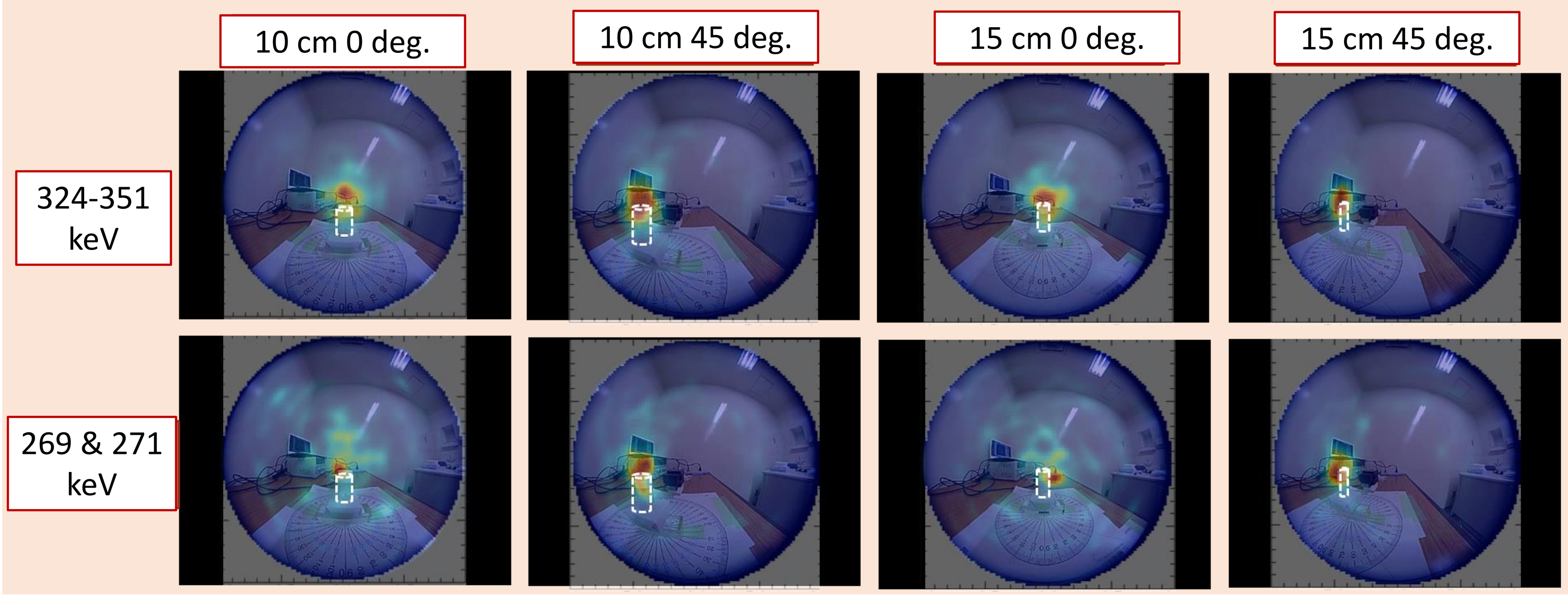
Experimental Setup



Energy spectrum (all events)



- Various peaks corresponded to emission lines of 223-Ra
- Set two energy bands for reconstruction due to Compton-scattering kinematics (269 & 271, 324-351 keV)



➡ **Reconstruct the true position (white dotted line) successfully**

References
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[2] J. A. Carrasquillo et al., Eur. J. Nucl. Med. Mol. Imaging, 40, (2013), 1384-1393.
[3] V. Schönfelder et al., IEEE Trans. Nucl. Sci., NS-31, (1984), 766-770.
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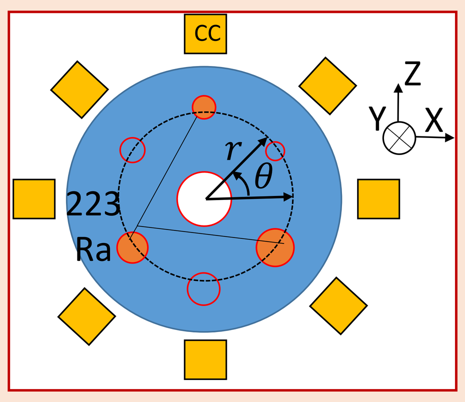
4. Imaging NEMA IEC body phantom

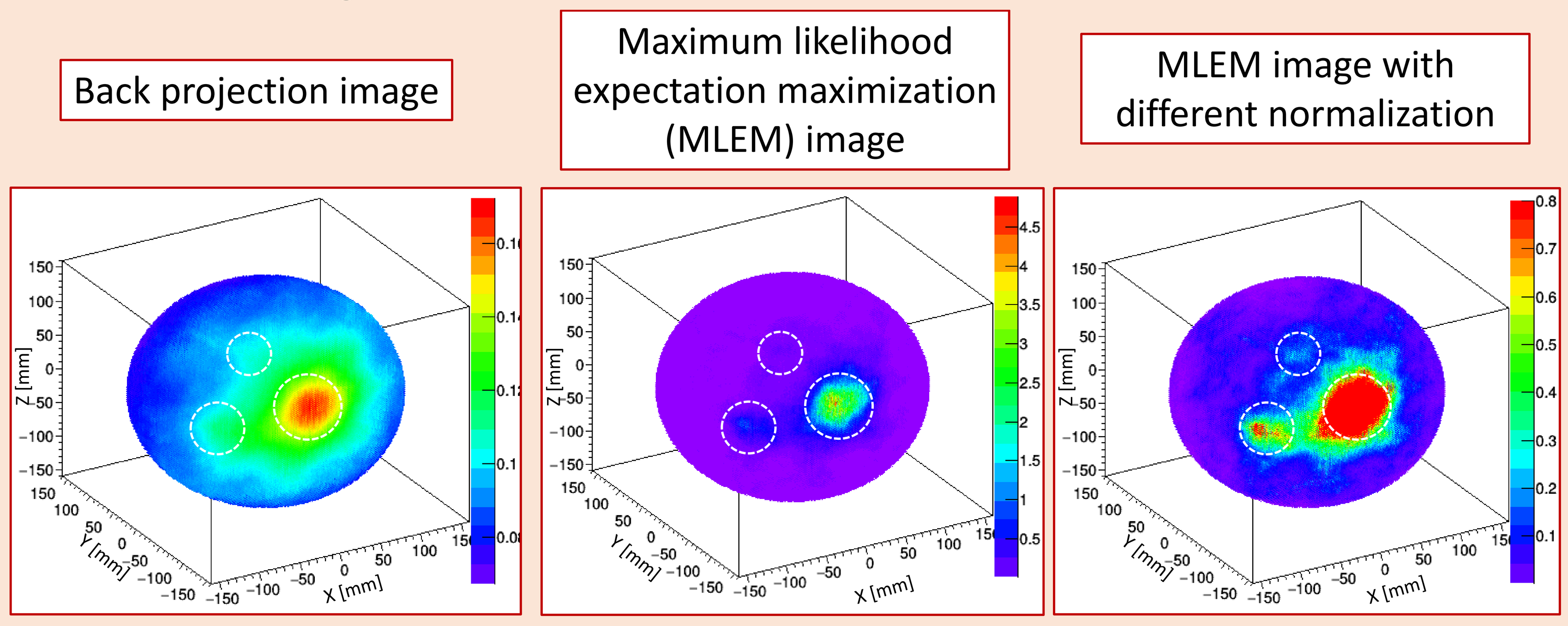
- Experimental Setup
  - Three of six spheres filled with 223-Ra (9 kBq/ml)

The diameters of the spheres	The radioactivity of 223-Ra	The distance from the center of the phantom
13 mm (a small sphere)	10.8 kBq	50 mm
22 mm (a middle sphere)	50.4 kBq	55 mm
37 mm (a large sphere)	238.5 kBq	60 mm

  - Rotate DOI-CC around the phantom for 3D imaging at 8 positions
  - The time for each measurement: 30 min



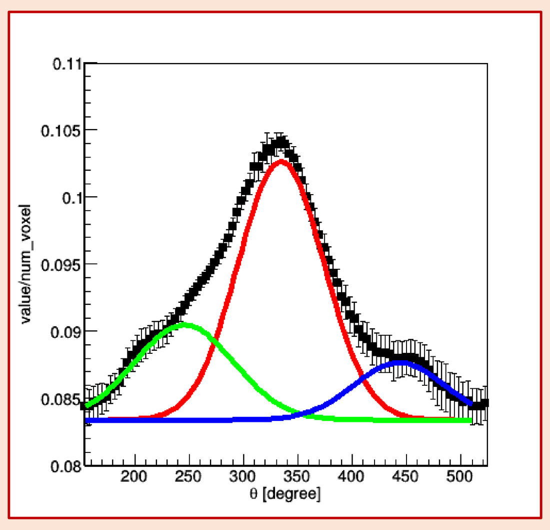
- Reconstructed images



➡ **Reconstruct the true position (white dotted line) in 3D successfully**

- Calculate the relative intensity
  - A thin slice every 15 mm in the radial direction of the phantom
  - Fitted with three Gaussian functions (red, green, blue) with a constant offset
  - Calculate the integral value and compare with the radioactivity of 223-Ra

Azimuth profile



Result of calculation

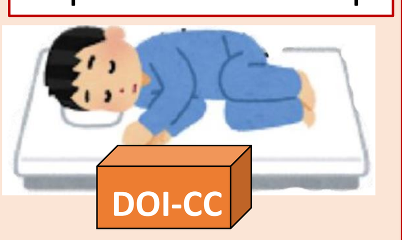
The diameter of the spheres	The normalized integral value (the value of the large sphere equal to the radioactivity of 223-Ra)	The radioactivity of 223-Ra
13 mm (blue)	13.0 +/- 3.1	10.8 kBq
22 mm (green)	48.9 +/- 8.3	50.4 kBq
37 mm (red)	238.5 +/- 18.3	238.5 kBq

➡ **Reconstruct the relative intensity of 223-Ra successfully**

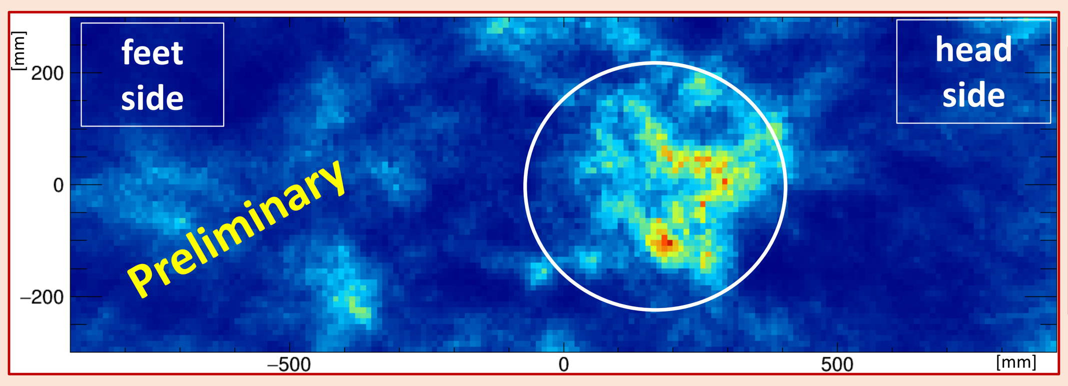
5. Conclusion and future work

- Conclusion
  - Reconstruct the correct positon and relative intensity successfully
- Future work
  - Optimize the detector configuration to improve the angular resolution
  - Imaging of the body of patient

Experimental setup



DOI-CC



SPECT

➡ **The accumulation consistent with SPECT**
Shorter time for measurement (DOI-CC: 10 min. / SPECT: 30 min.)
Wider FOV