A novel method for estimating the 3-D distribution of radioactive isotopes in the material

Yasuhiro IWAMOTO (Waseda Univ., JPN)
J. Kataoka, A. Kishimoto, T. Nishiyama,
T. Taya, H. Okochi, H. Ogata (Waseda Univ.)
S. Yamamoto (Nagoya Univ.)

Outline

■ Background

- Images acquired by a gamma camera
- General method for obtaining distribution of isotopes in depth direction

■ Methods for obtaining depth information

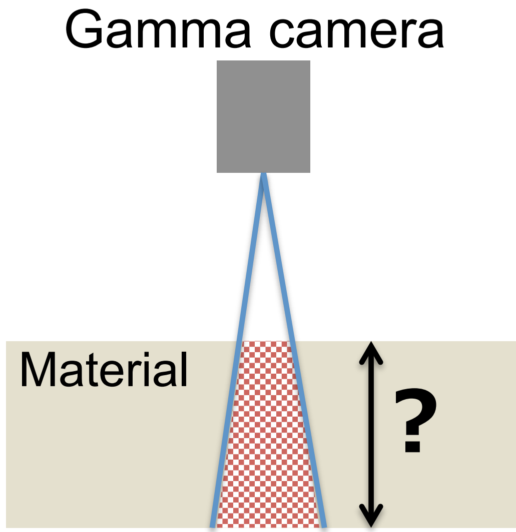
- 1st method ~Comparing spectra~

  ➡ Application in a field in Fukushima

- 2nd method ~Comparing images~

■ Summary & Future work

Images acquired by a gamma camera



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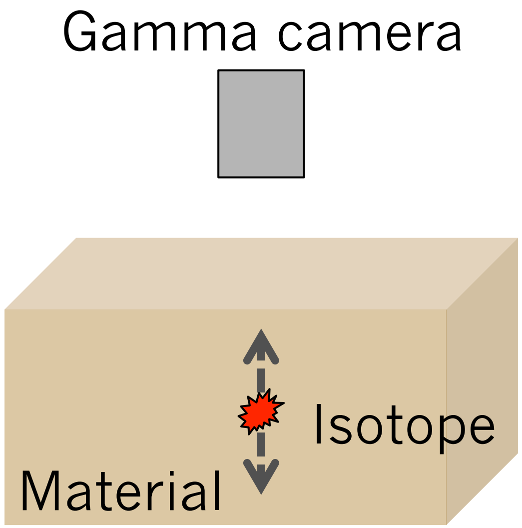
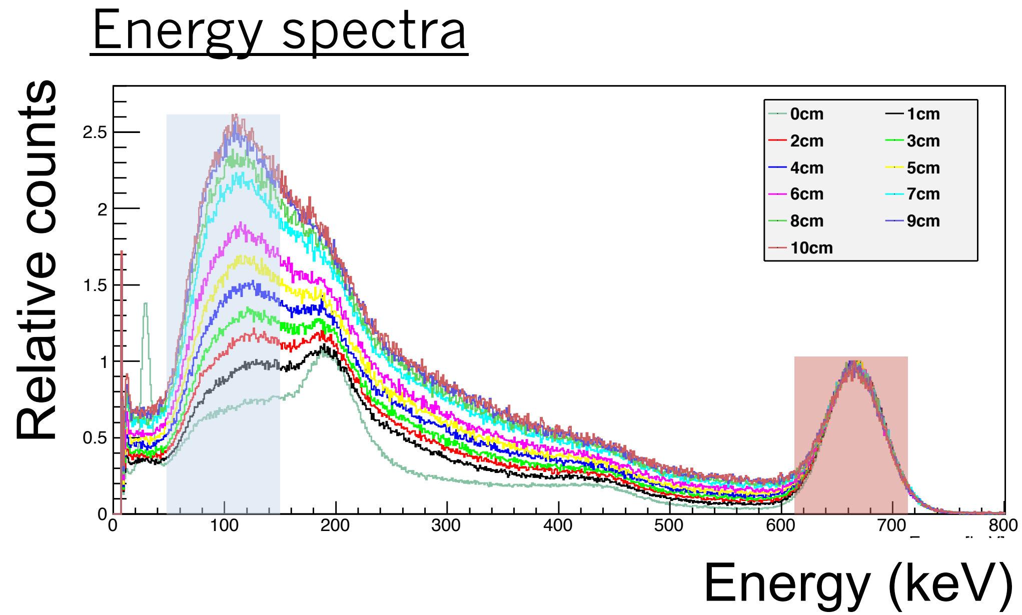
- Images do not include the distance information between radioactive isotopes and the camera

- General methods for obtaining depth information of radioactive isotopes embedded in materials is to dig a hole.

1st concept: Comparing energy spectra





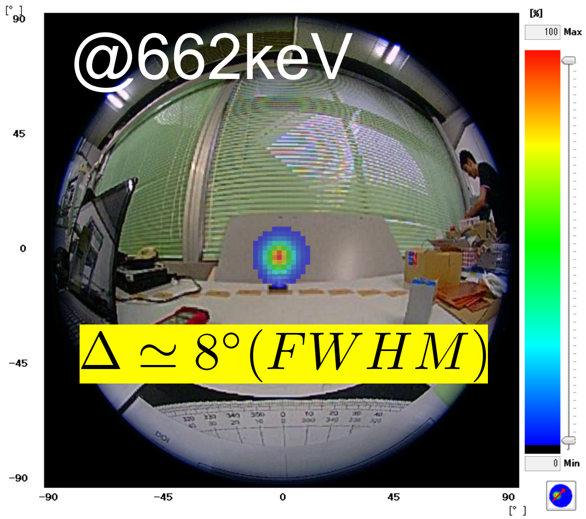
- We defined energy ranges as
  Scattered gamma ray : 50 – 150 keV
  Direct gamma ray : 612 − 712 keV
- If the isotope exist near the surface of the material, direct gamma rays are superior to scattered gamma rays and vice versa
- Ratio of scattered to direct gamma rays includes depth information of the isotope

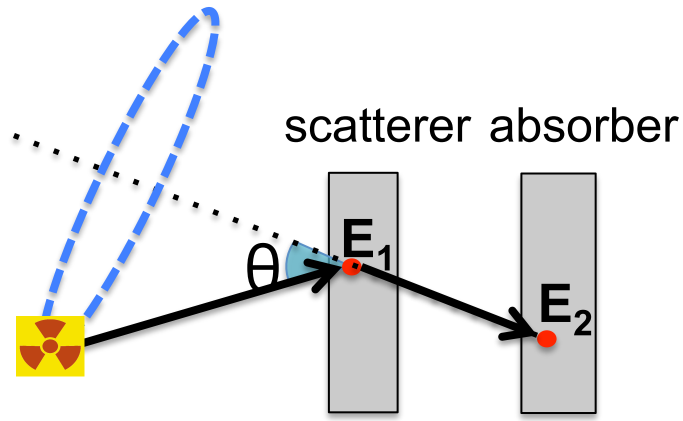
Experimental setup

Kataoka et al. 2014, NIM-A

■ Compton Camera (C.C.)

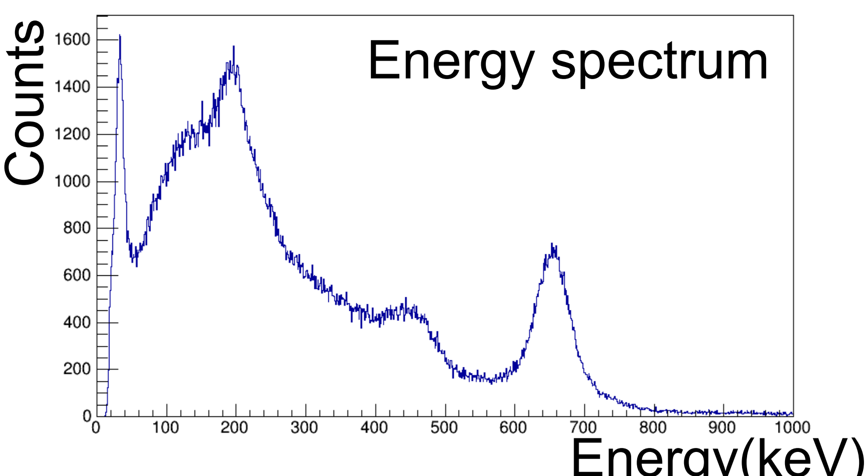
- C.C. uses for measuring **images** and **energy spectrum**





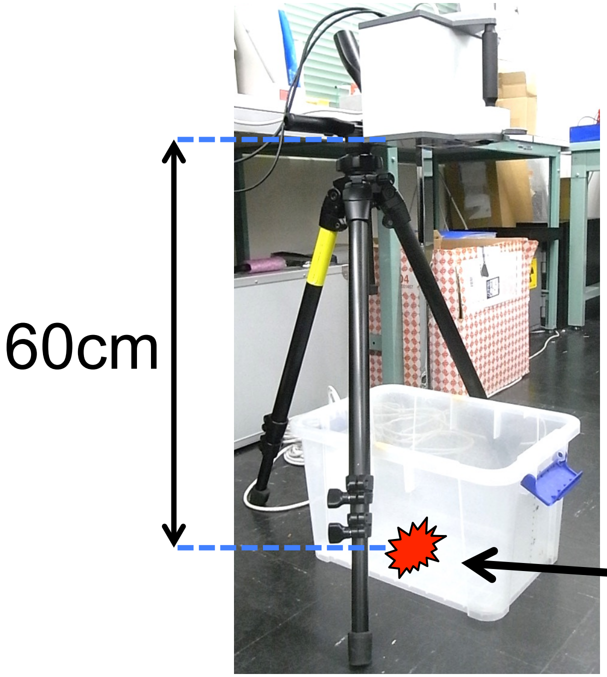
➢ Compton kinematics

$$\cos\theta = 1 - \frac{m_e c^2}{E_2} + \frac{m_e c^2}{E_1 + E_2}$$



■ Our C.C. is suited to survey environmental radiation because of **high angular resolution**

Experimental setup



■ Measurement condition

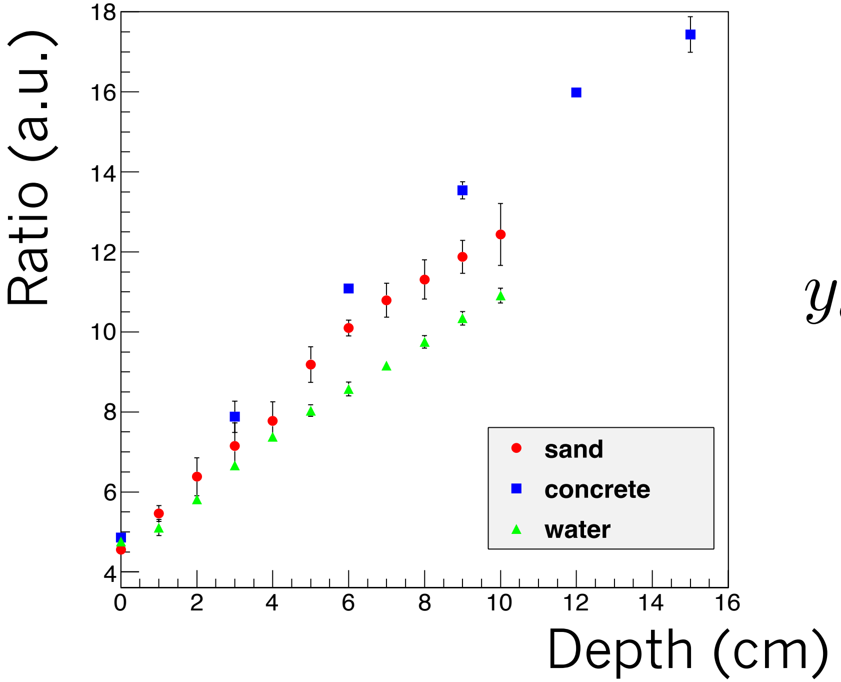
Distance from C.C. to source: **60 cm**
Measuring time: **1 hour**

■ Material

1. Sand (per 1cm, from 0cm to 10cm)
2. Concrete (per 3cm, from 0cm to 15cm)
3. Water (per 1cm, from 0cm to 10cm)

- The size of the receptacle is 26cm × 38cm × 23cm

Depth vs. Ratio



$$y_{sand} = 0.87x + 4.57$$
$$y_{concrete} = 0.94x + 4.96$$
$$y_{water} = 0.64x + 4.69$$

- There are positive correlations between depth and ratio in each material

→ The plots were fitted with linear function

Next,
we attempt estimating depth of isotope using the fitting functions

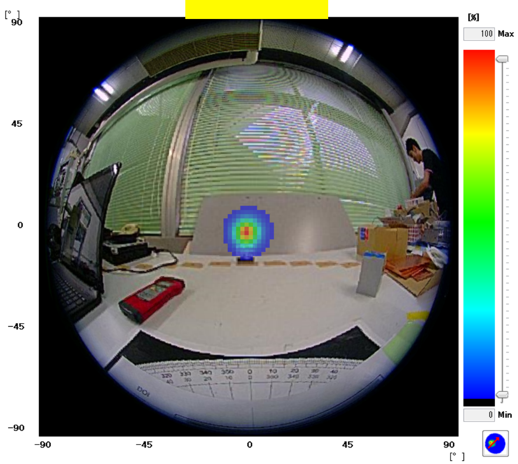
Results of depth estimation

	Sand	Concrete	Water
Observed ratio [a.u.]	11.5	16.1	9.4
Estimated depth[cm]	**7.9±0.2**	**11.9±0.1**	**7.4±0.2**
Actual depth[cm]	**8.0**	**12.0**	**7.0**

- The estimated depths agree very well with the actual depths

Next Attempt to estimate 3-D distribution of isotope

2-D



\+

1-D

Ratio

$$\frac{scattered\ gamma\ rays}{direct\ gamma\ rays}$$

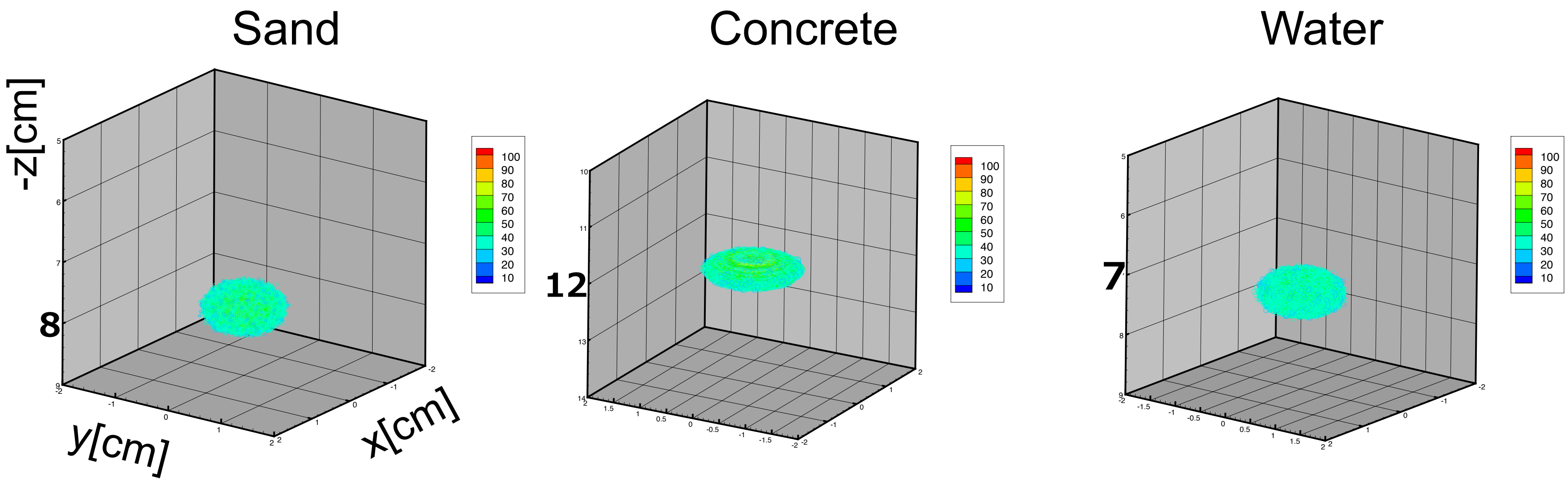
↓

Depth information

=

3-D information

Combining depth information with 2-D image



■ We obtain 3-D distribution of isotope in each material by uniting the 2-D image of direct gamma-rays with depth information of isotopes

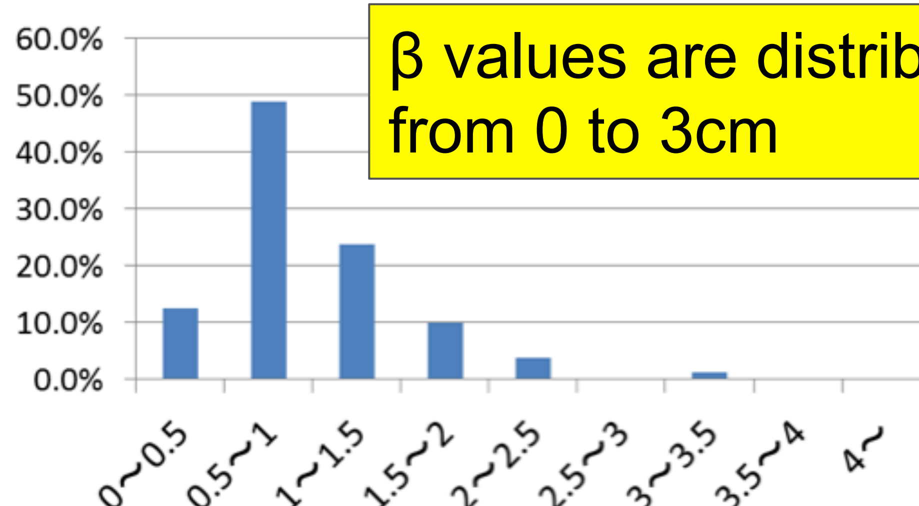
Distribution of isotopes in Fukushima

- Distribution of ^{137}Cs in soil
  - β[cm]: buffer depth

$$A(z) = A_0 \cdot \exp\left(-\frac{z}{\beta}\right)$$

A: Radioactivity
z: Depth

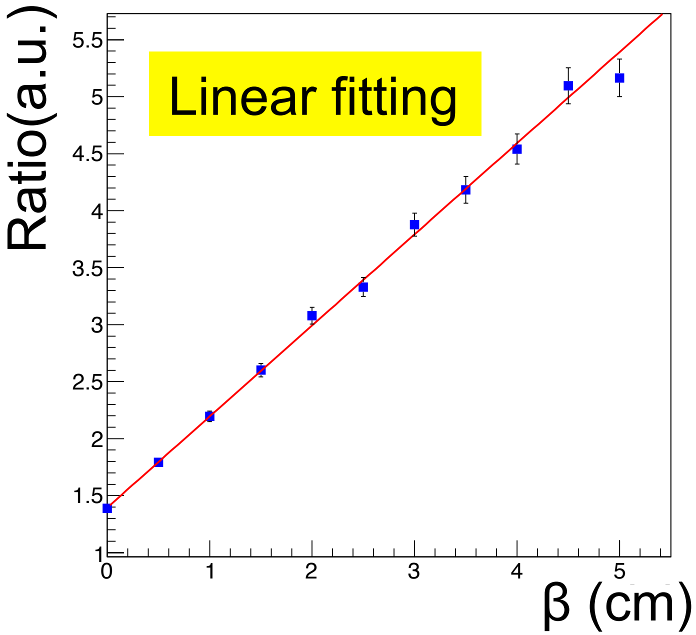
- Histogram of buffer depth in Fukushima
  It surveyed with scraper plate

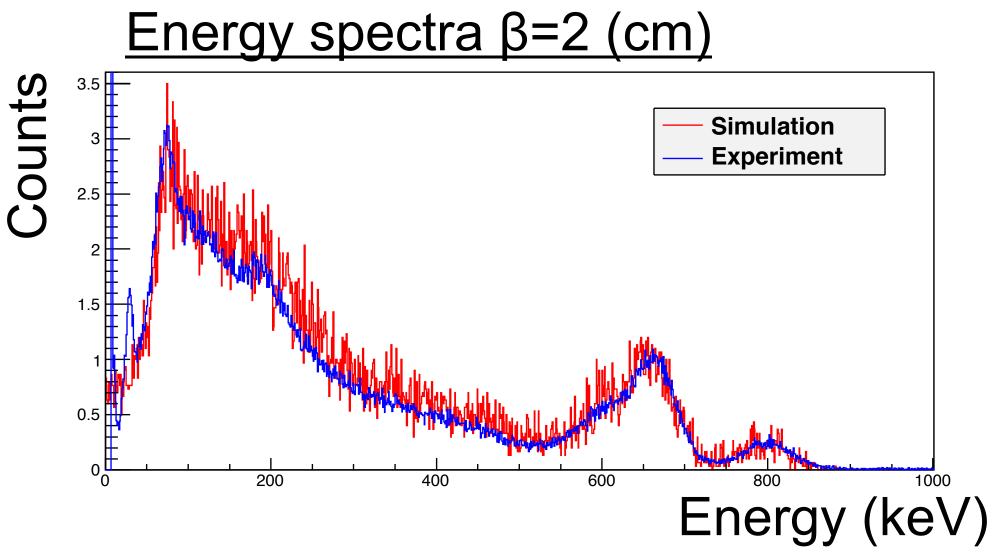


β values are distributed from 0 to 3cm

β[cm]

Result of estimating β value





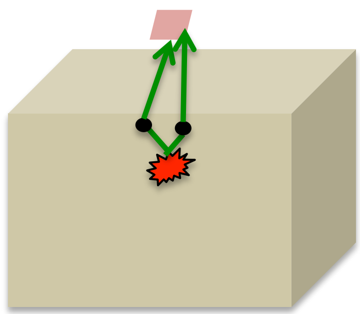
- The estimated β value is led from the fitting function
  Observed ratio: **3.16 (a.u.)** ➡ β value: **2.22±0.05 (cm)**

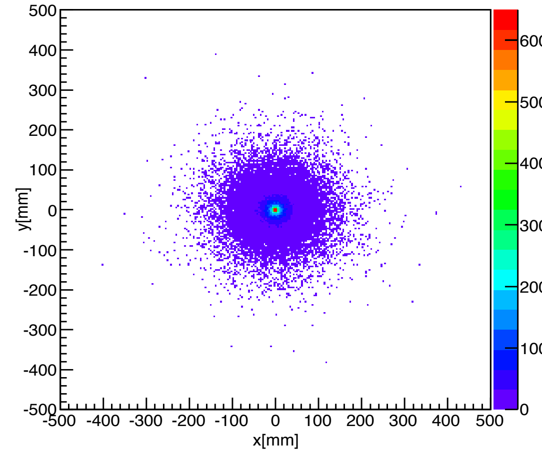
- The estimated β value is in the range of observed β distribution in Fukushima.

2nd concept: Comparing images

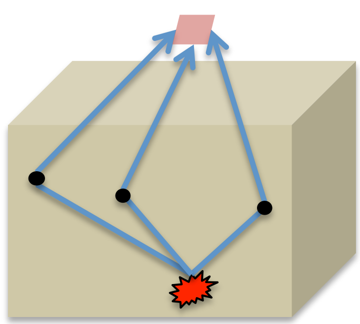
Scattered gamma rays(0keV ≦ E ≦ 400keV)

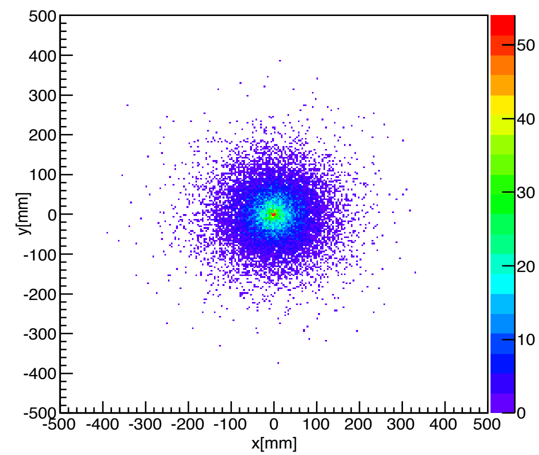
Near the surface





Deep in the material

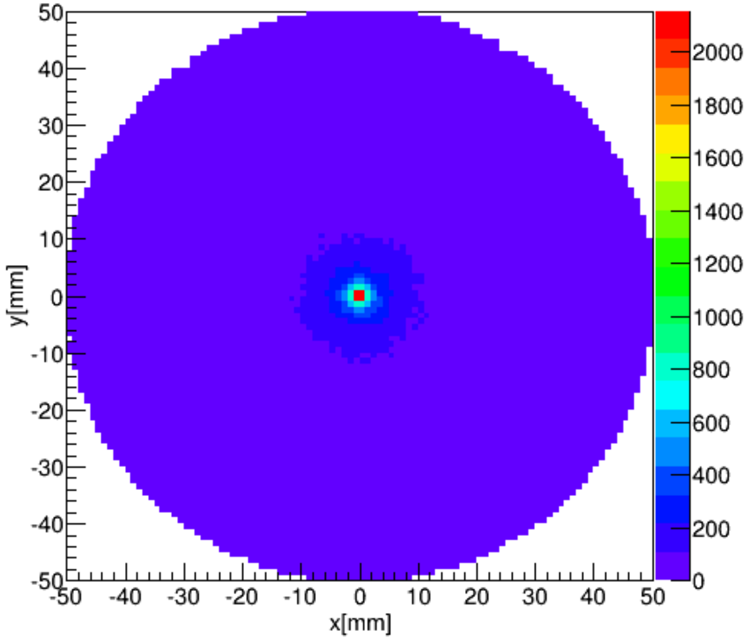


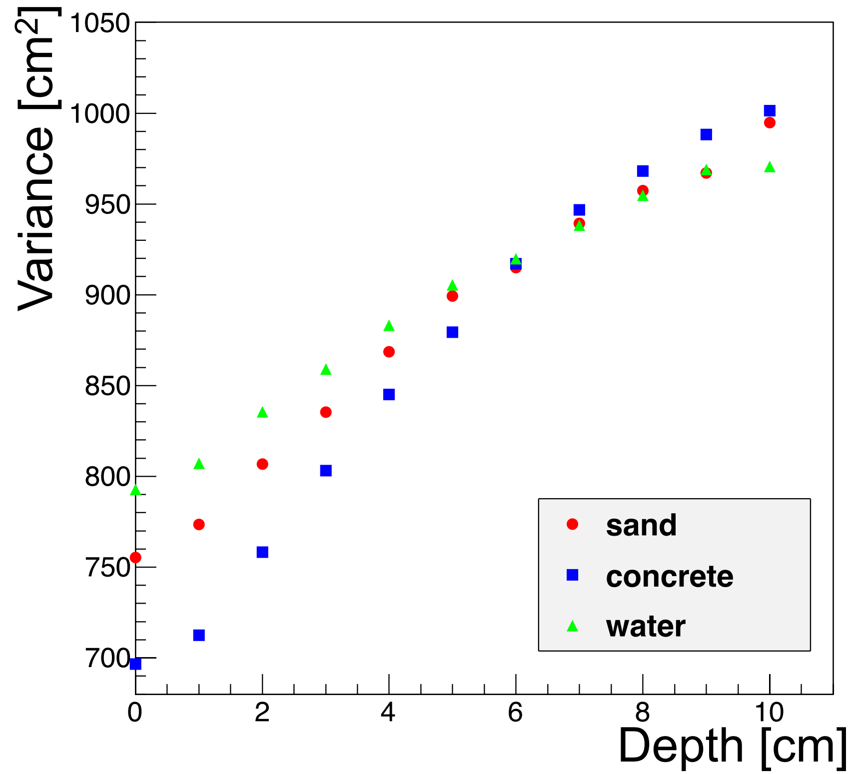


- The spatial extent of the position where gamma rays scatter increases with increasing depth

Results of the 2nd method

Source depth: 0cm

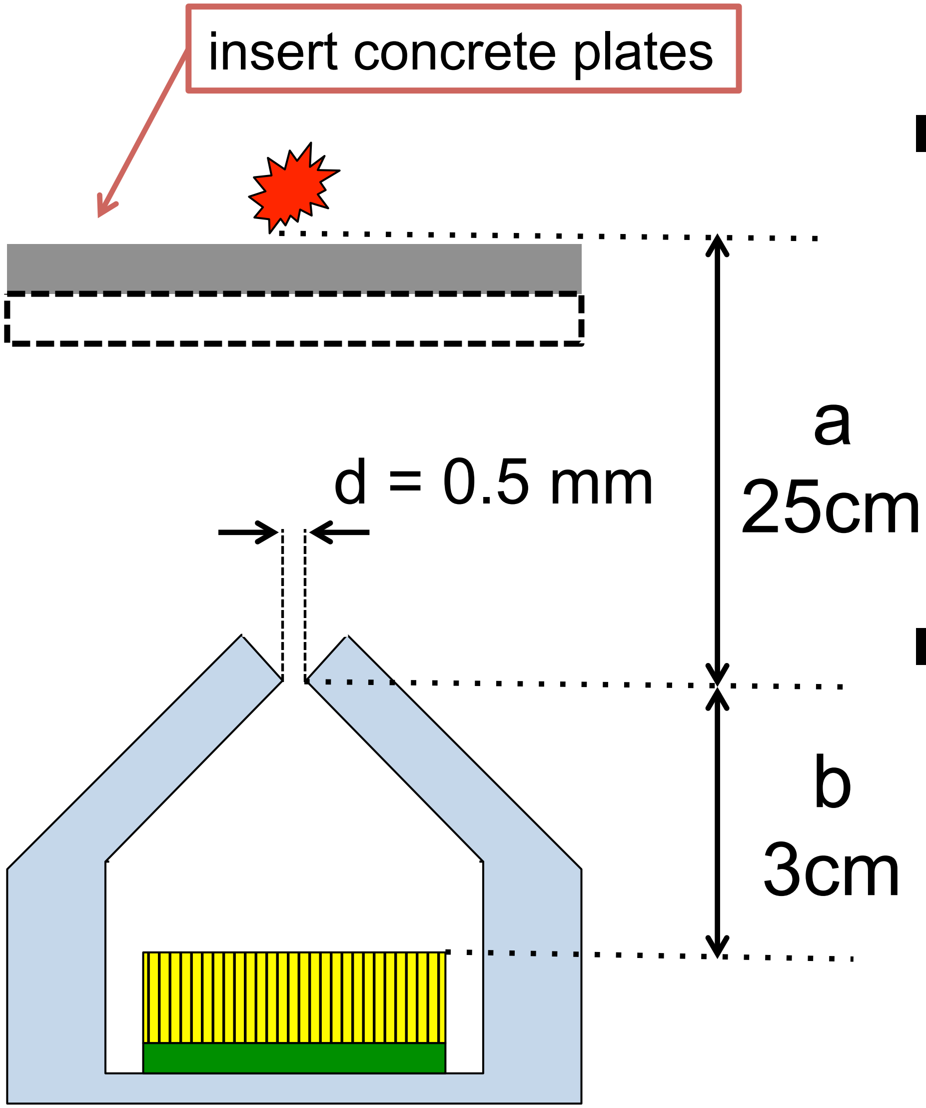




- Positive correlation between depth and spatial extent
- We are now developing various gamma cameras to visualize scattered gamma rays.

→ **Pinhole Camera**

Pinhole Camera



- **Collimeter**
  Heavy metal (ρ~14 g/cm^3)
- **Detector**
  - **Scintillator**
    GAGG 0.5 X 0.5 X 3.0 mm^3
    45 X 45 X 1 Array
  - **Light senor**
    MPPC (Hamamatsu)
- **Resolution**

$$R_{sys} = \sqrt{\left(\frac{a}{b} \times R_{ins}\right)^2 + \left(\frac{a+b}{b} \times d\right)^2}$$

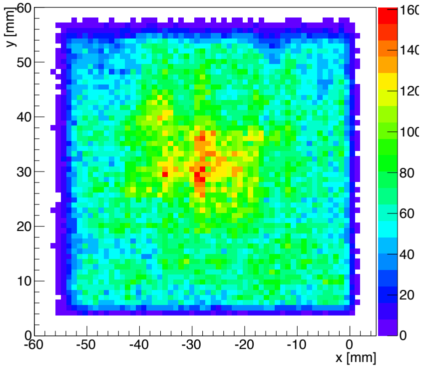
In this geometry,

$$R_{sys} \simeq 8.1 \text{ mm}$$

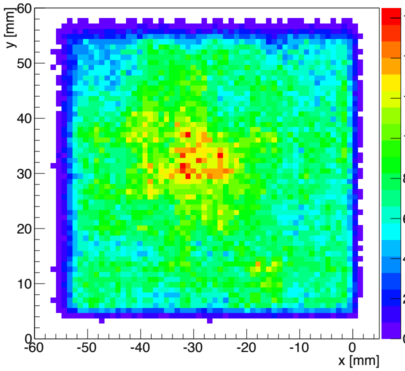
Pinhole camera's images

- Images of pinhole cameras (**Energy range: 0 – 400 keV**)

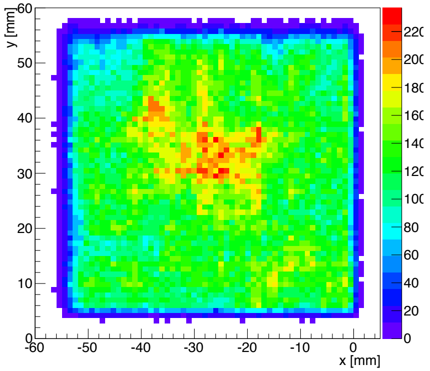
Nothing



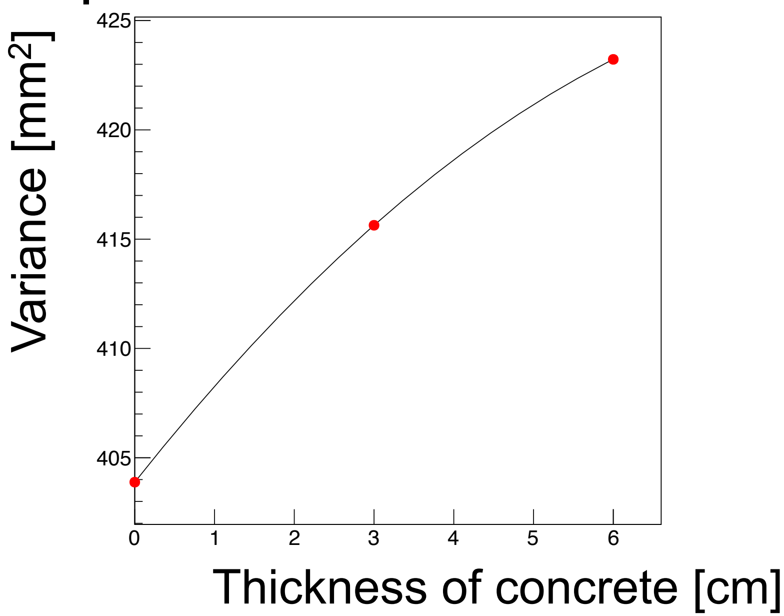
Concrete 3cm



Concrete 6cm



- No. of concrete plate vs. Variance



■Summary & □Future work

We have reported methods to obtain depth information of isotopes using scattered gamma rays.

■ **1st method:**

- Ratio of scattered to direct gamma rays has depth information of isotopes
- 3-D distribution of isotope is obtained by uniting a 2-D image and the depth information

■ **2nd method:**

- Spatial extent of scattered gamma rays increases with increasing depth

□ We will confirm that it is possible to identify depth of isotope with the 2nd method in experiment.