Feasibility Study of Gamma CT Based on Compton Kinematics

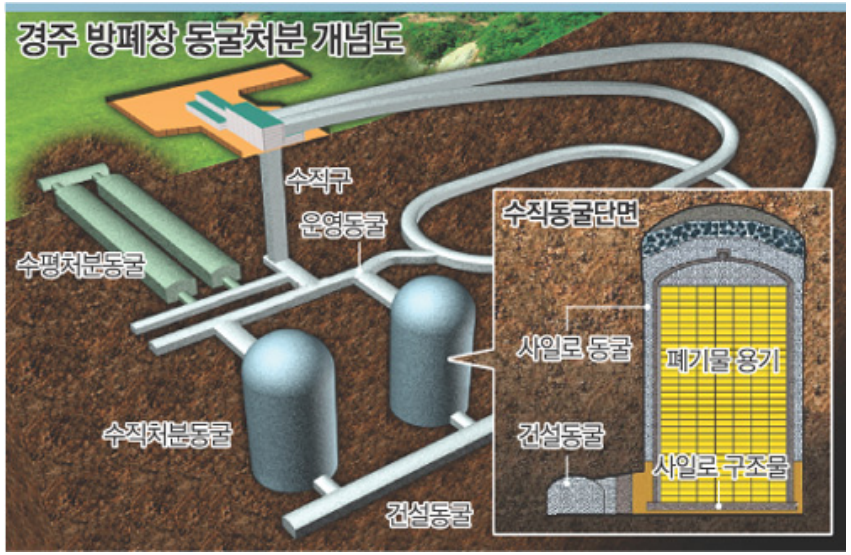
2017. 05. 18

김 재 현 · 김 영 수 · 김 찬 형*

한양대학교 원자력공학과

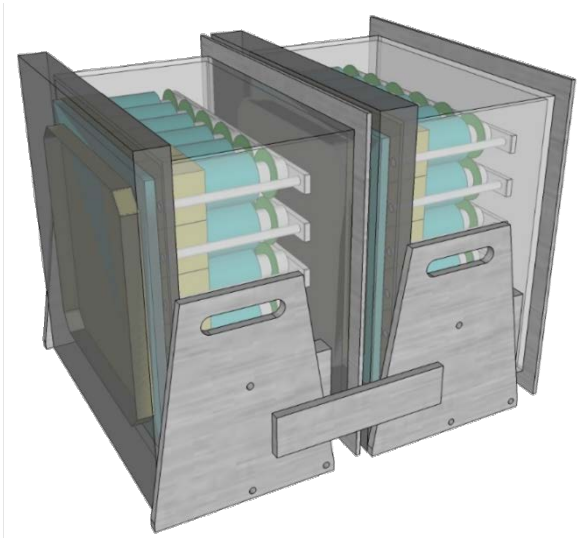
Introduction

Radioactive waste disposal

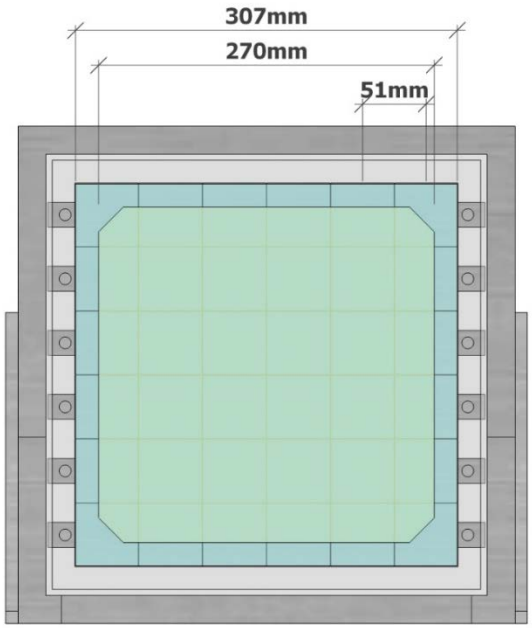


- **Considerable radioactive waste** occur in the decommissioning process.
- There is a need to **estimate the location and activity of the hot spots** in the waste drum to **reduce the expenses of the decommissioning.**

Hot spot imaging system: Compton camera



Large-area Compton camera

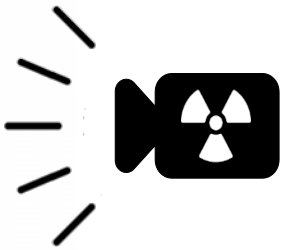


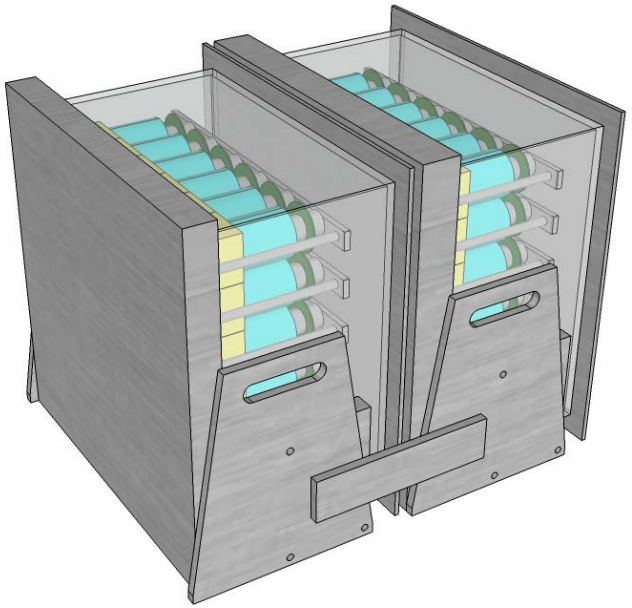
Large-area Compton camera

- High efficiency
- Able to get 3-D hot spots images by single measurement

Necessity of attenuation map information

Hot spots imaging



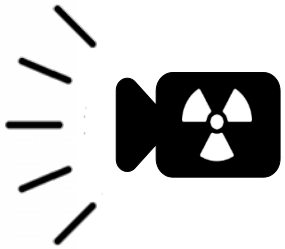


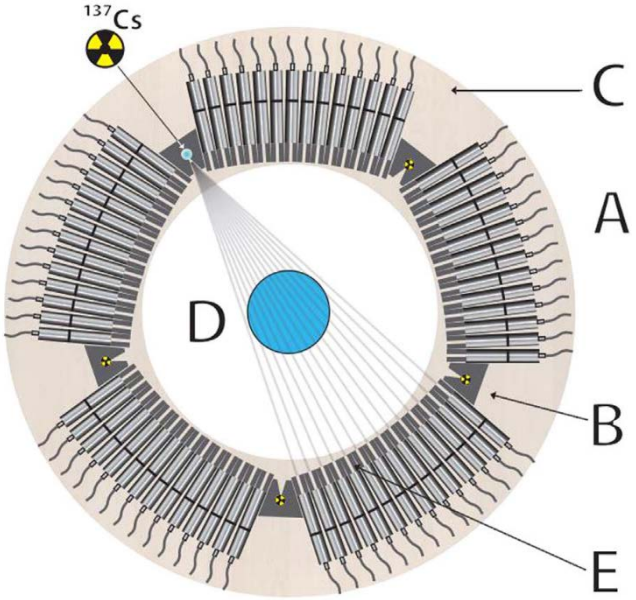
Compton camera

- For the image reconstruction and activity estimation of the hot spots, it is necessary to get the **attenuation map in the waste drum**.

Industrial gamma CT system for attenuation map

Attenuation map information



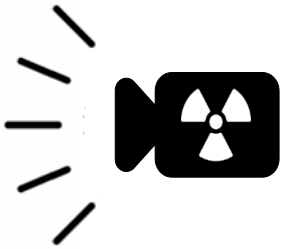


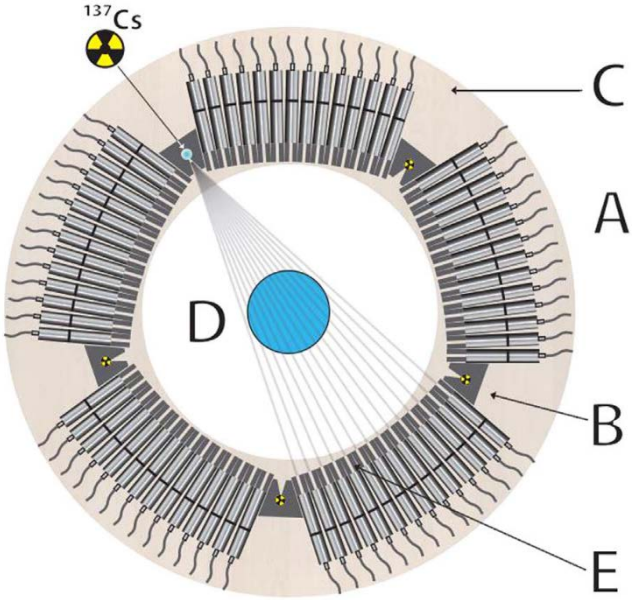
Gamma CT

- Inner attenuation map information can be obtained by **an additional industrial gamma CT system**.
- In using gamma CT system, the scattered events and other gamma rays events may deteriorate the image quality.

Industrial gamma CT system for attenuation map

Attenuation map information



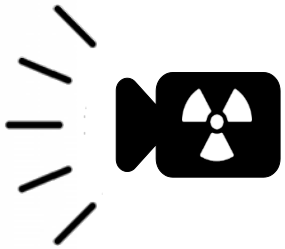


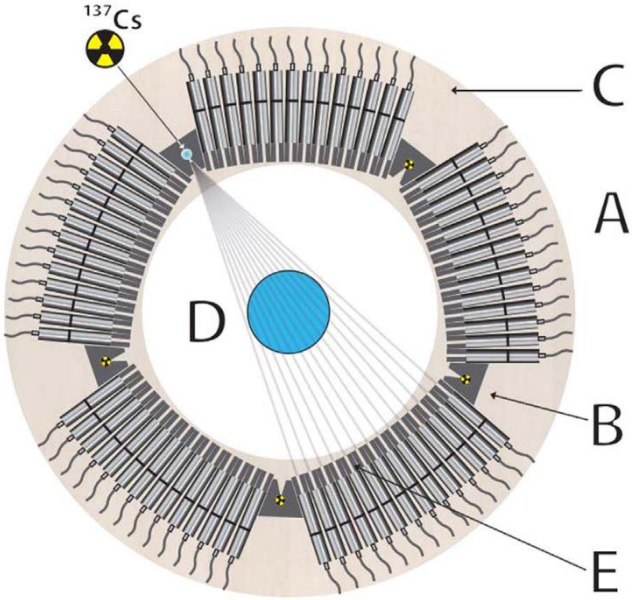
Gamma CT

- For this reason, in order to get sufficient image quality, **it is important to record the unscattered events, and to block the scattered events.**
- Existing industrial gamma CT systems generally use **mechanical collimation method** or **electronic collimation method**.

Industrial gamma CT system – mechanical based

Attenuation map information



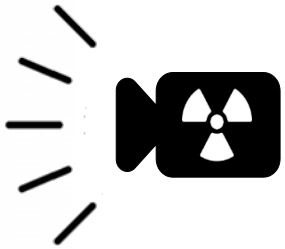


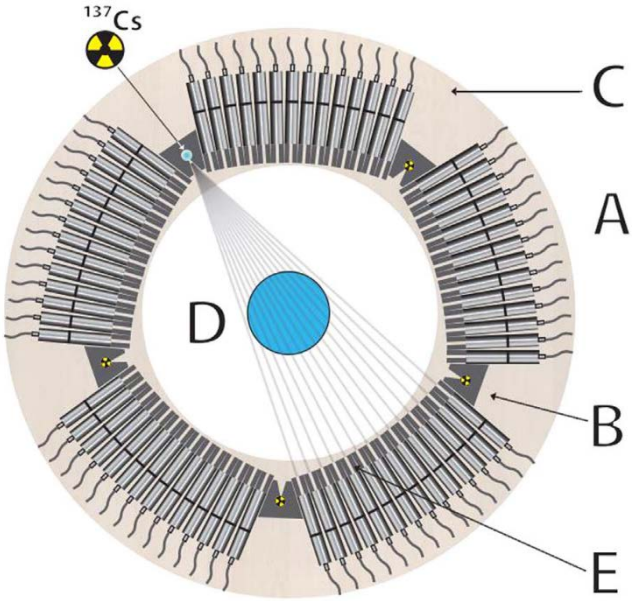
Gamma CT

- Mechanical-collimation-based Gamma CT system uses a **mechanical collimator to record the unscattered gamma rays events, and to block the scattered events and other gamma rays events.**

Industrial gamma CT system – mechanical based

Attenuation map information



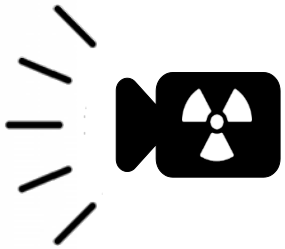


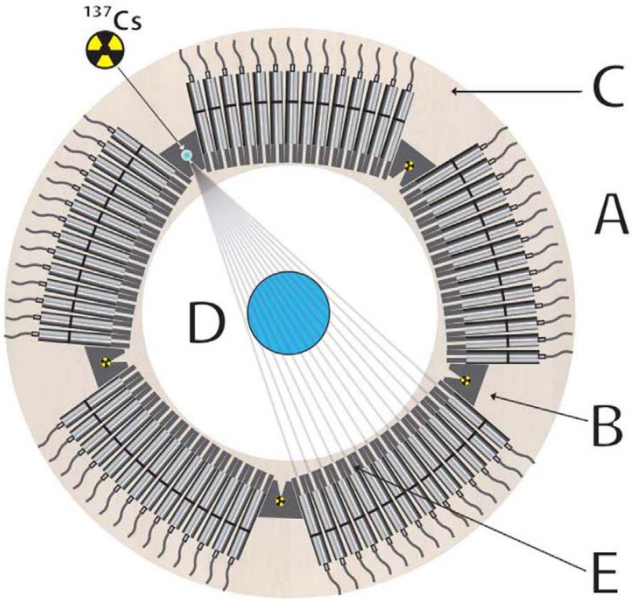
Gamma CT

- Mechanical-collimation-based Gamma CT system is generally **bulky** due to their mechanical collimator, and it should be changed depending on the structure.
- The collimator also has a limitation **that cannot block the high-energy scattered gamma rays**.

Industrial gamma CT system – electronic based

Attenuation map information



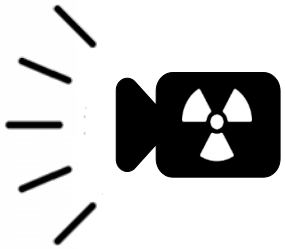


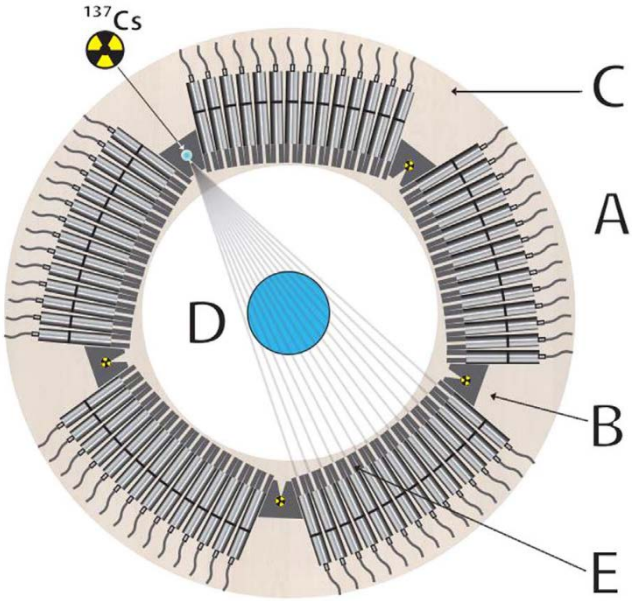
Gamma CT

- Electronic-collimation-based Gamma CT system can select the unscattered events and block the scattered events **using the energy window**.

Industrial gamma CT system – electronic based

Attenuation map information

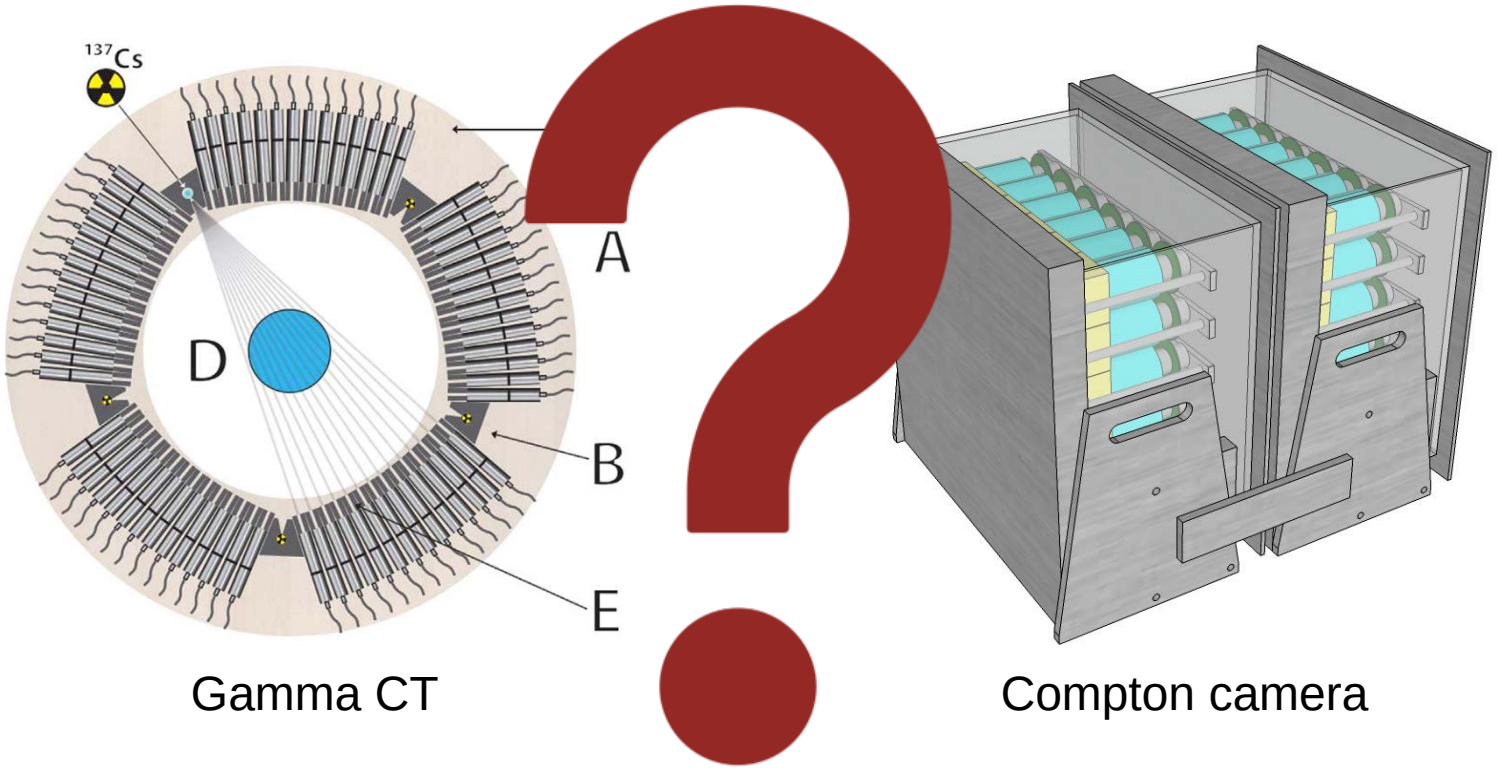




Gamma CT

- It is necessary to use radiation detectors which has **excellent energy resolution**.
- It also has a limitation that cannot discriminate other gamma rays events which have **same energy with the outer gamma ray source**.

Industrial gamma CT system – limitation



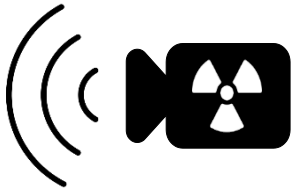
Gamma CT

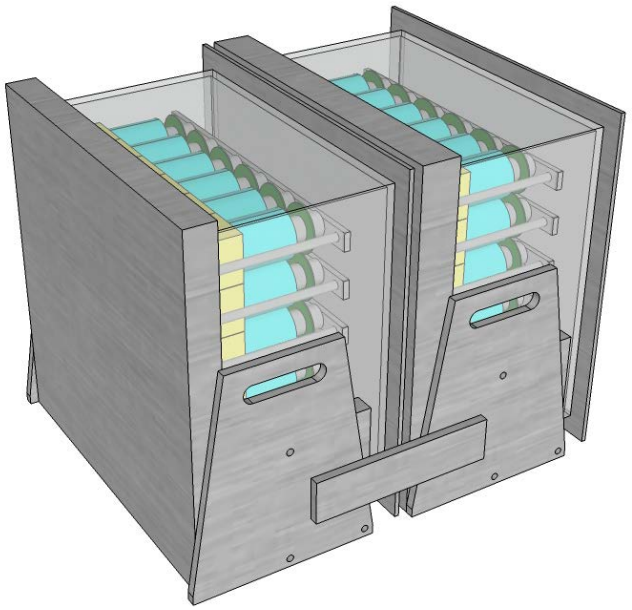
Compton camera

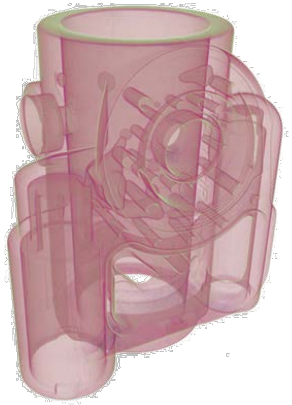
- It is inefficient to have an additional gamma CT system with Compton camera to get the **attenuation map in the waste drum**.

Gamma CT method based on Compton kinematics

Hot spots imaging





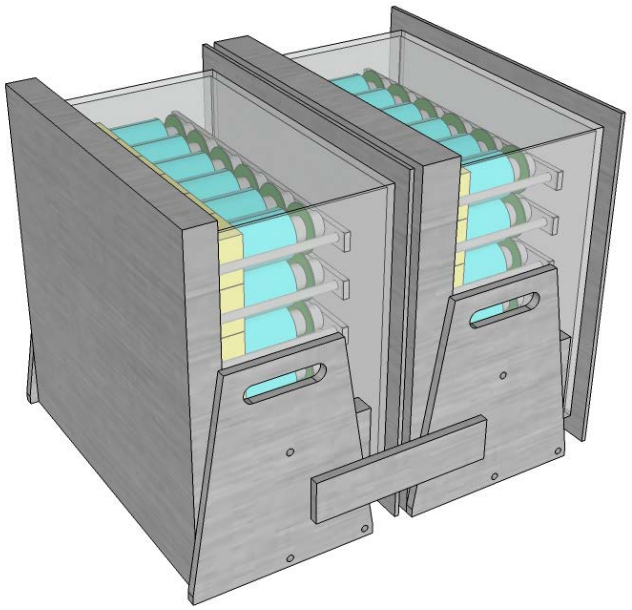


Attenuation map information

- **<u>Compton CT</u>**: gamma CT method based on Compton kinematics.
- **We can record the unscattered events, and block the scattered events using Compton CT** without any additional systems.

Research goal

Hot spots imaging



Attenuation map information

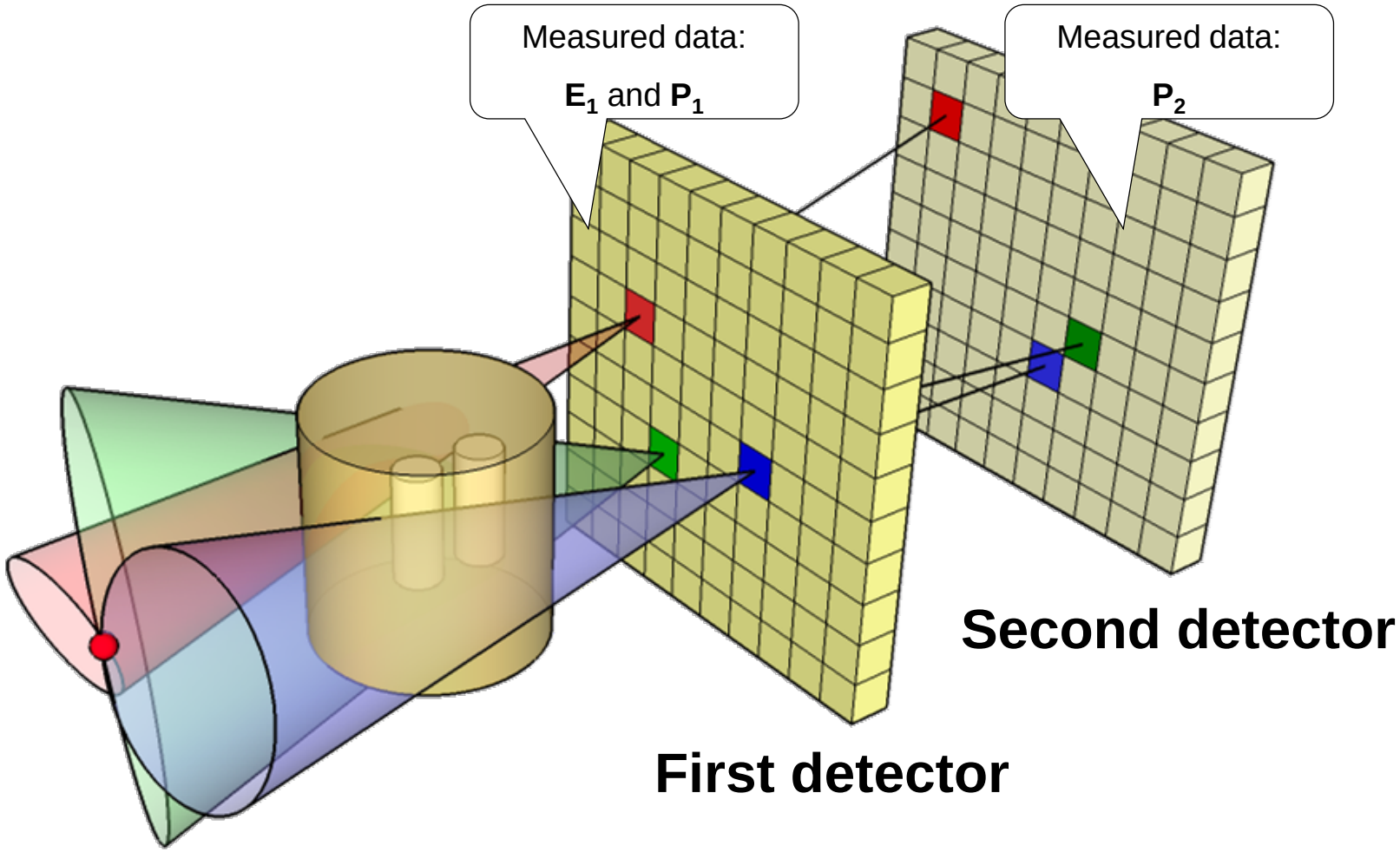
Feasibility of Compton CT

by

Monte Carlo simulation

Principle of Compton CT

Principle of Compton CT

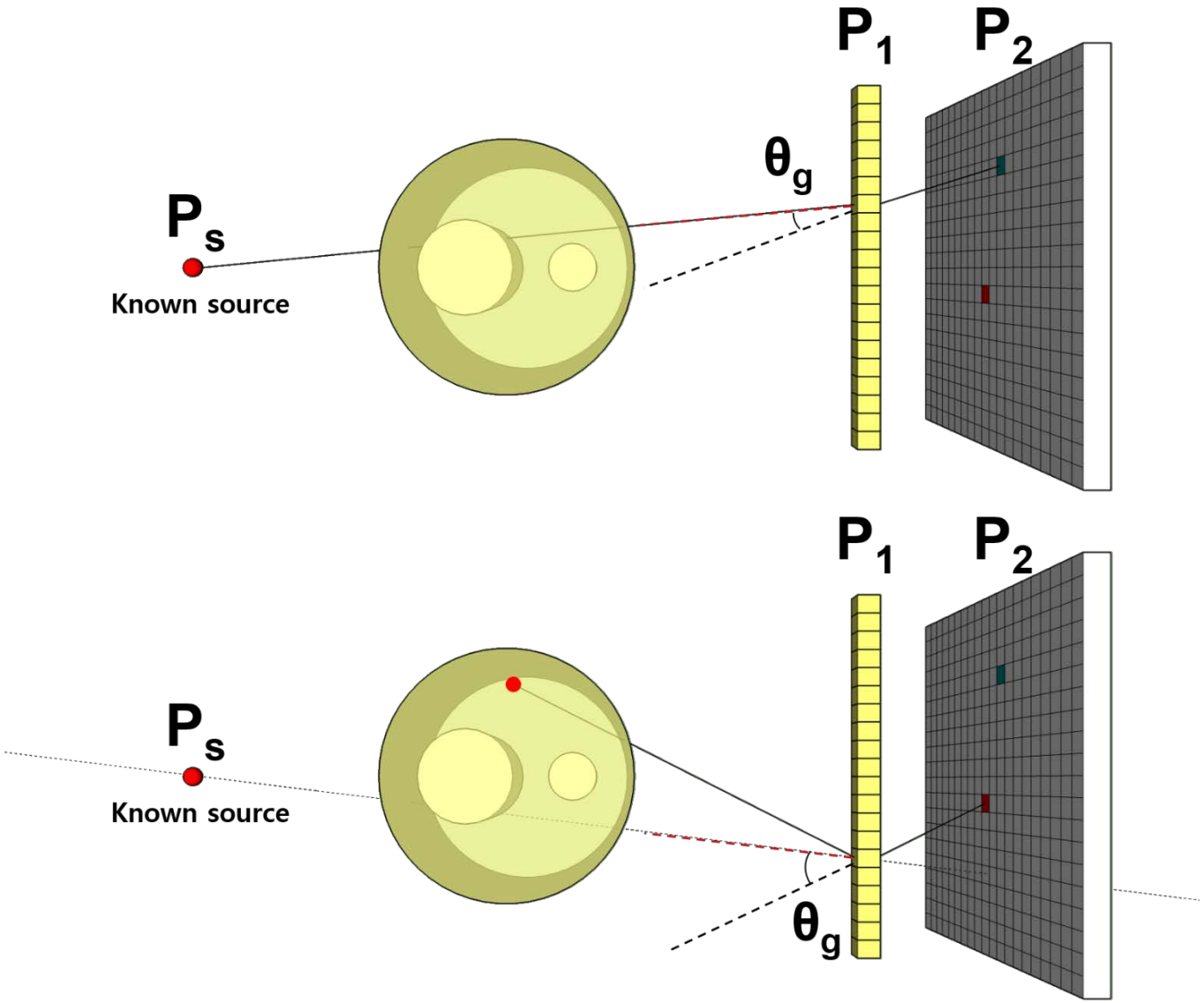


θ_g: Geometrical angle (by interaction position)

θ_c: Compton cone angle (by deposited energy)

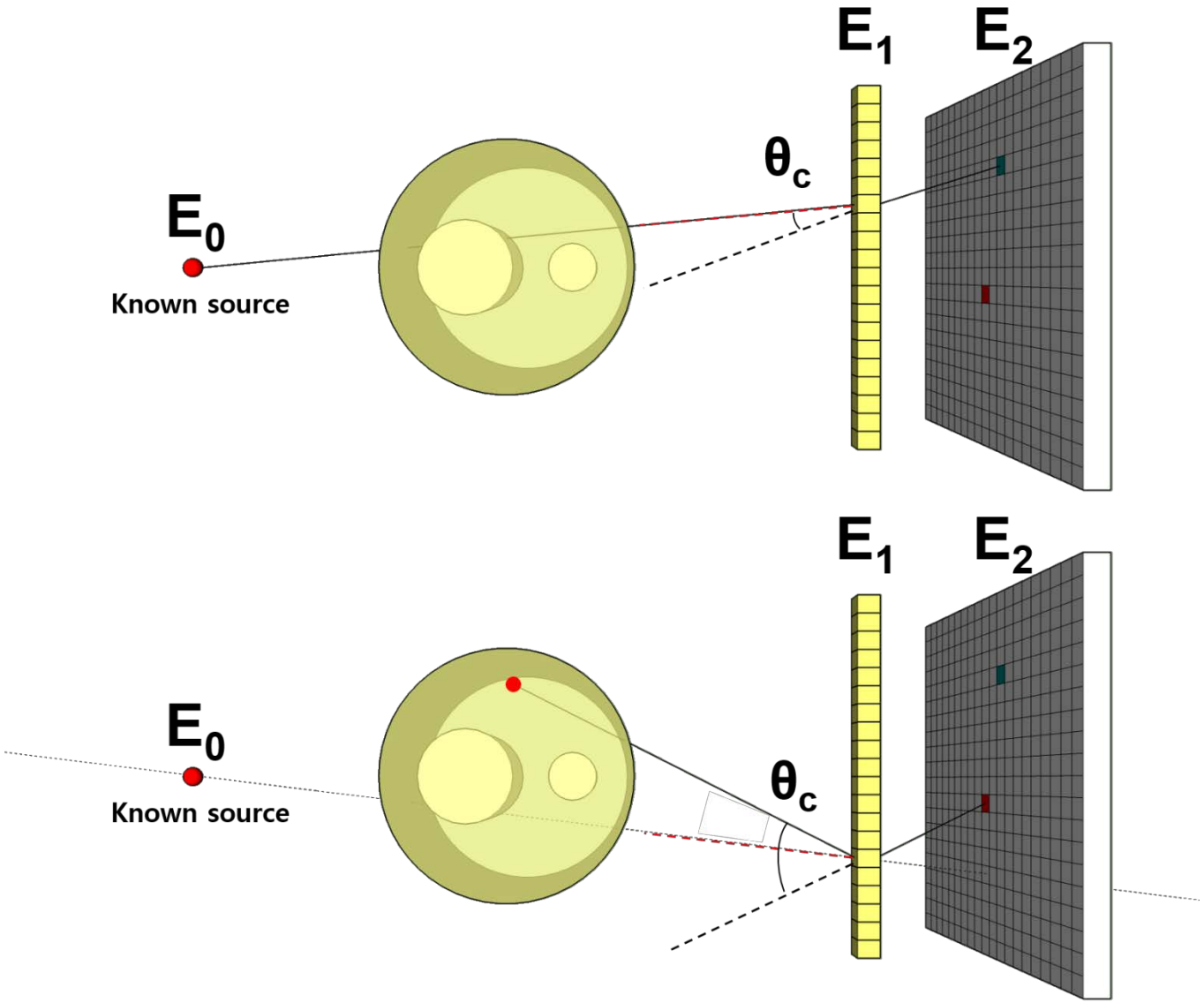
Principle of Compton CT – continued

θ_g: Geometrical angle (calculated by position information)



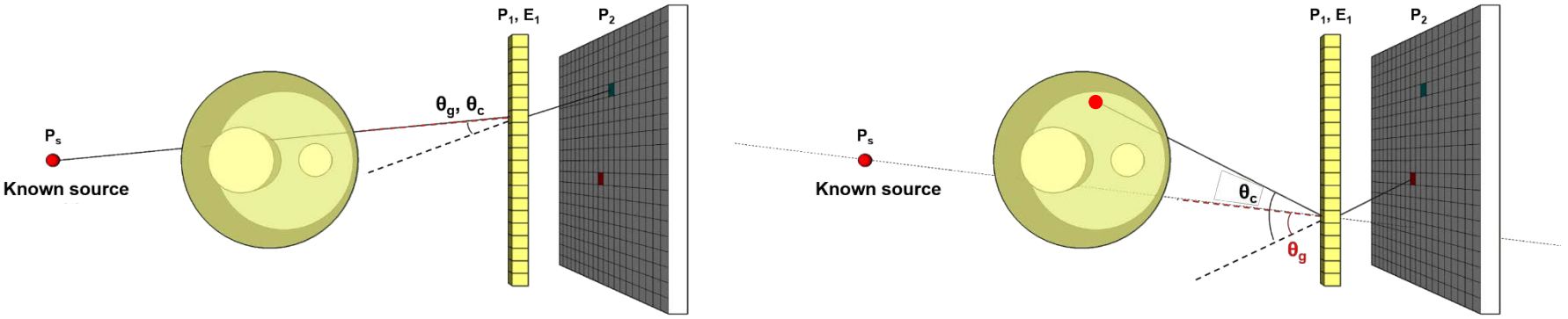
Principle of Compton CT – continued

θ_c: Compton cone angle (calculated by energy information)



Principle of Compton CT – continued

Scattering Angle Difference (SAD)

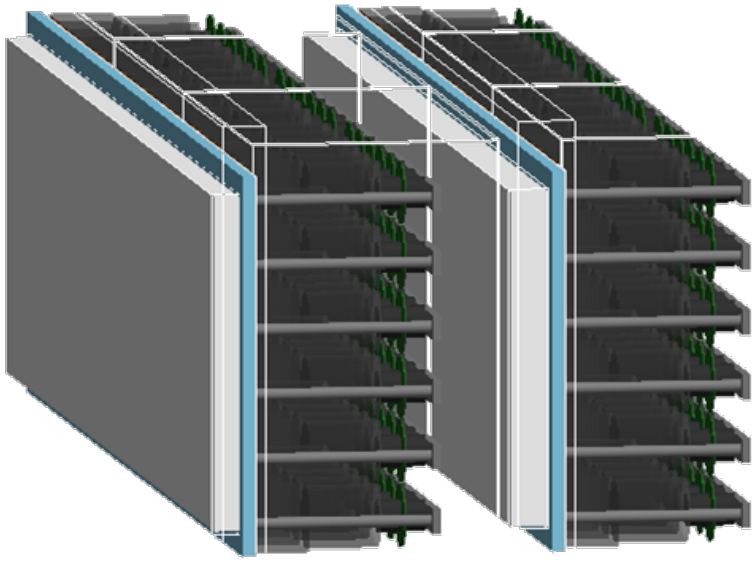


$$SAD = \theta_g - \theta_c$$

- Thus, **SAD will be almost zero for the unscattered events**, not for the scattered or other gamma-rays events.
- **Using the SAD window**, we can discriminate the unscattered events among the unwished events such as the scattered or other gamma rays events.

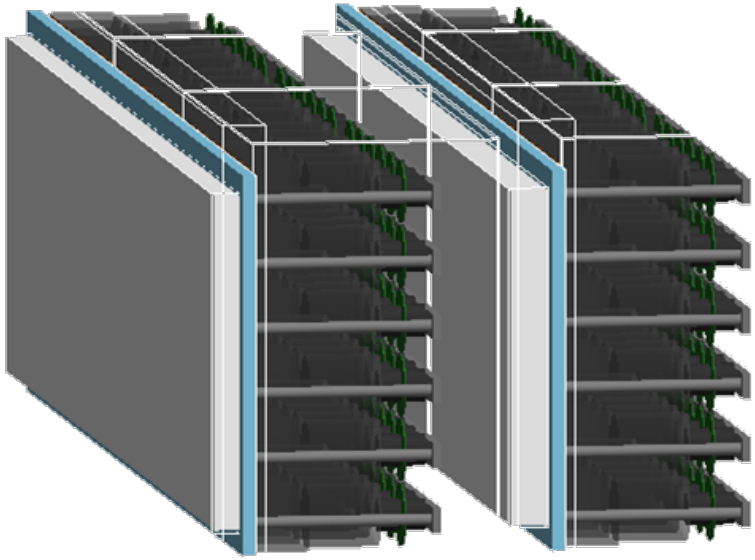
Feasibility study of Compton CT

Geant4 simulation: detector modeling



- **Geant4 (version 10.03)**
- Scintillation detector: monolithic NaI(Tl) scintillator (Scintititech, MA, USA) + square-type PMTs array
- Scintillator dimension: 105 cm (W) × 27 cm (H)
  - Thickness: 2 cm for first detector, 3 cm for second detector
- Distance between the first detector and the second detector: 25 cm

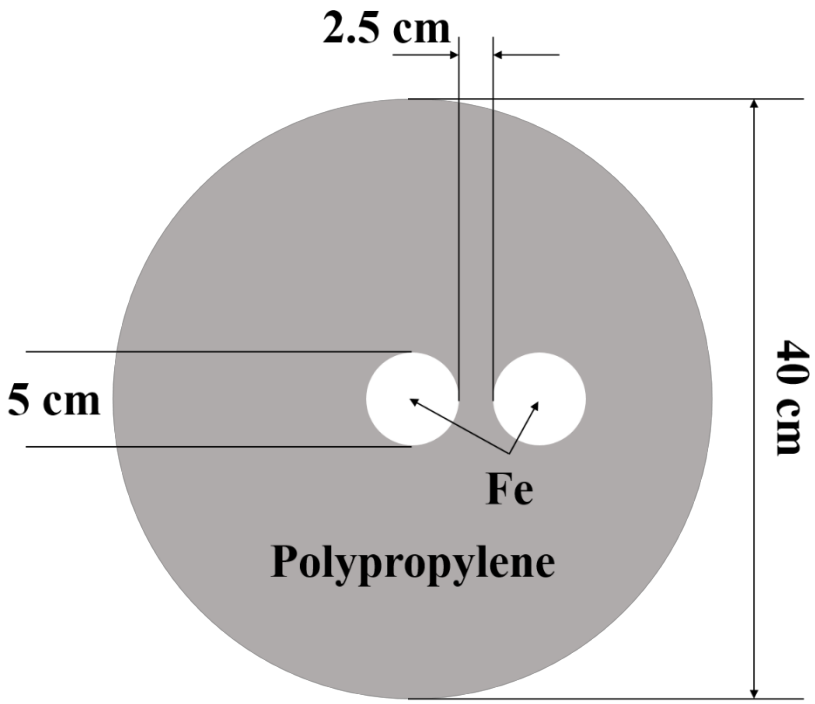
Geant4 simulation: detector modeling



- **Energy resolution and spatial resolution** were applied in Geant4.
  - Energy resolution: 7.62% (@662 keV)
  - Spatial resolution: 5 mm FWHM

- **G4EMLivermorePhyisics** was used for physics library.

Geant4 simulation: phantom modeling

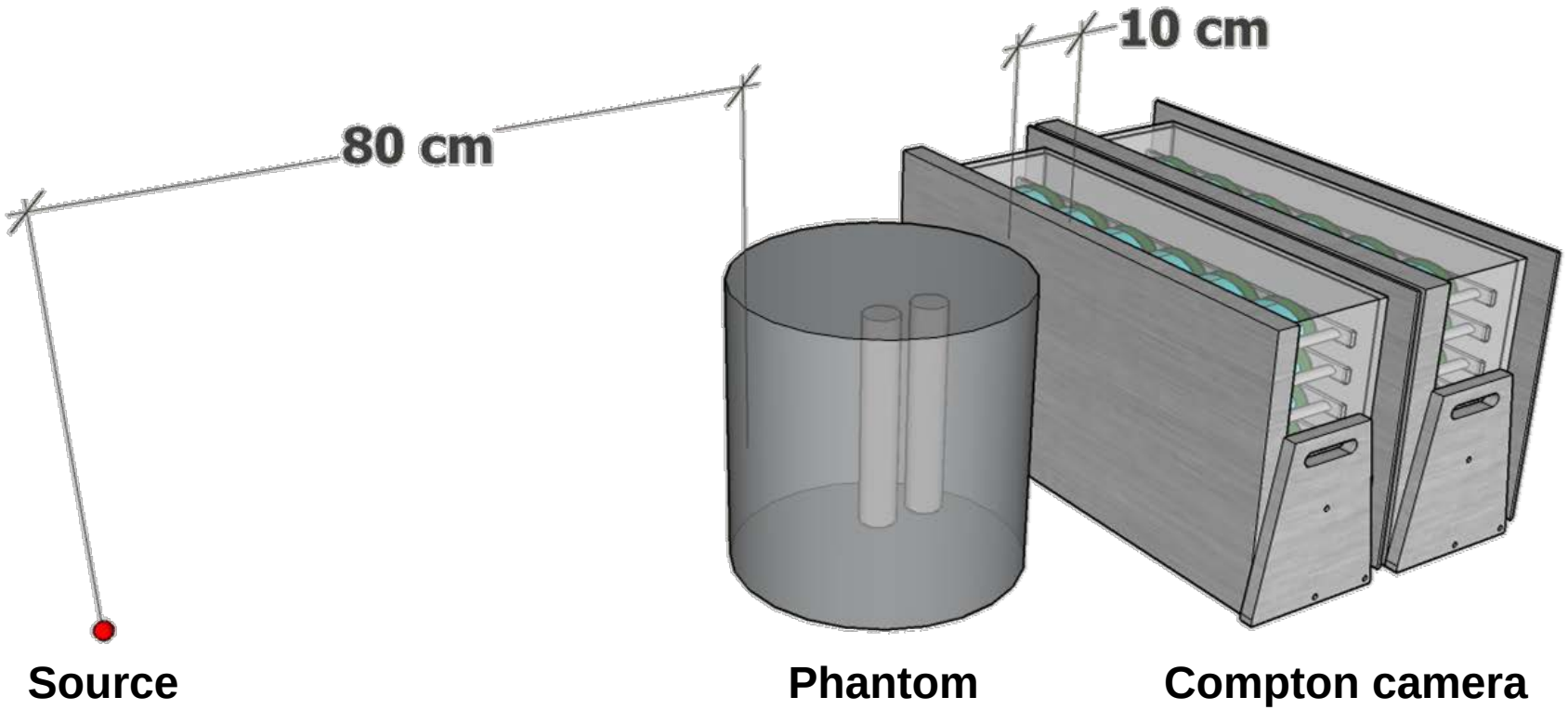


- ***IAEA standard phantom for industrial gamma CT system**

- Dimension: 40 cm (D) × 80 cm (H)
- Density: 0.93 g/cm^3 for polypropylene and 7.8 g/cm^3 for Fe

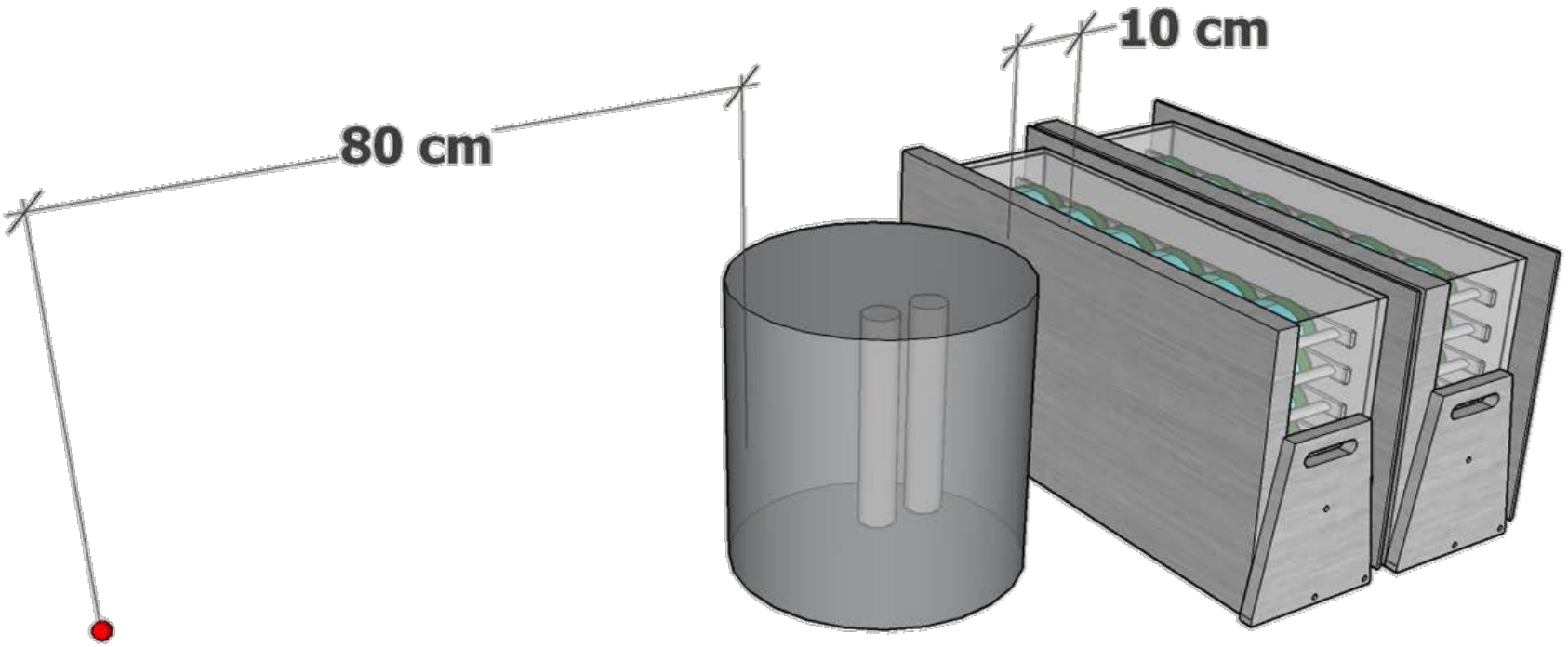
***Ref**: TECDOC, IAEA. "1589, Industrial Process Gamma Tomography, Final Report of a Coordinated Research Project 2003–2007." *International Atomic Energy Agency, Austria* (2008).

Source modeling & simulation condition



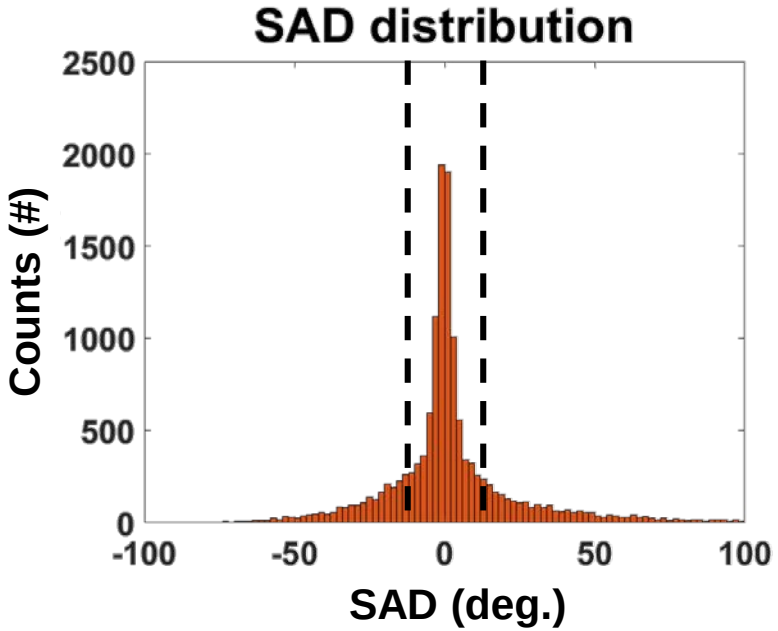
- Source: fan-shaped **1.33 MeV** gamma rays (Co-60, 20 mCi)
- The projection data was acquired at the **360 angular positions over 360º.**
- The acquisition time was assumed to be **1 second** for each projection.

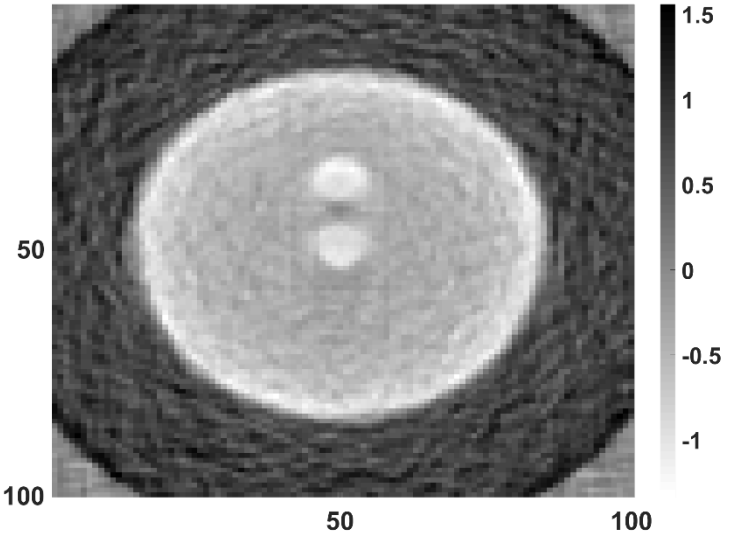
Image reconstruction algorithm



- **Filtered back projection (FBP)** was used to reconstruct CT image.
- **Ram-Lak filter** was applied in the FBP.
- Image reconstruction was carried out using MATLAB®.

Feasibility study of Compton CT – results



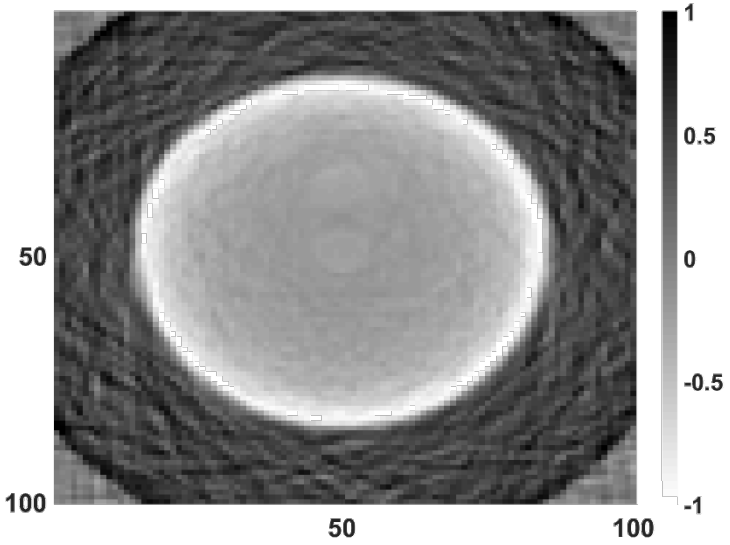


SAD window: [-5^{o}, 5^{o}]

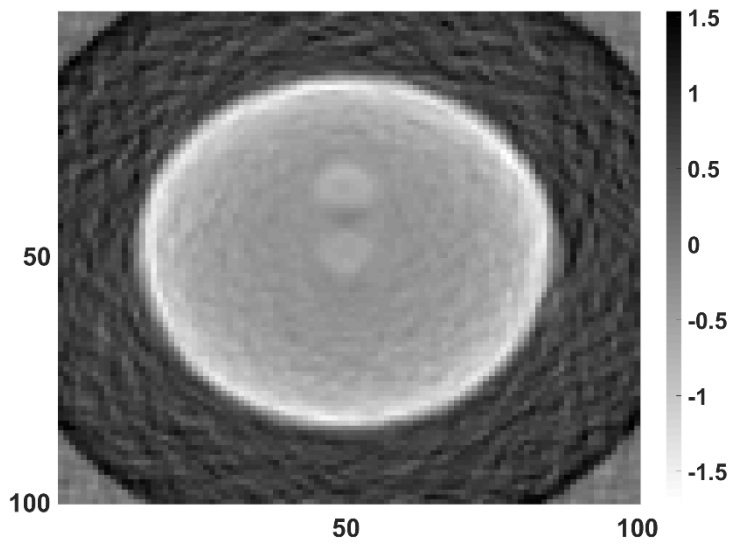
- For the unscattered gamma events, it was confirmed that SAD distribution converges on 0^{o}.
- **The result shows that Compton CT can give us an attenuation map in the waste drum.**

Feasibility study of Compton CT – results

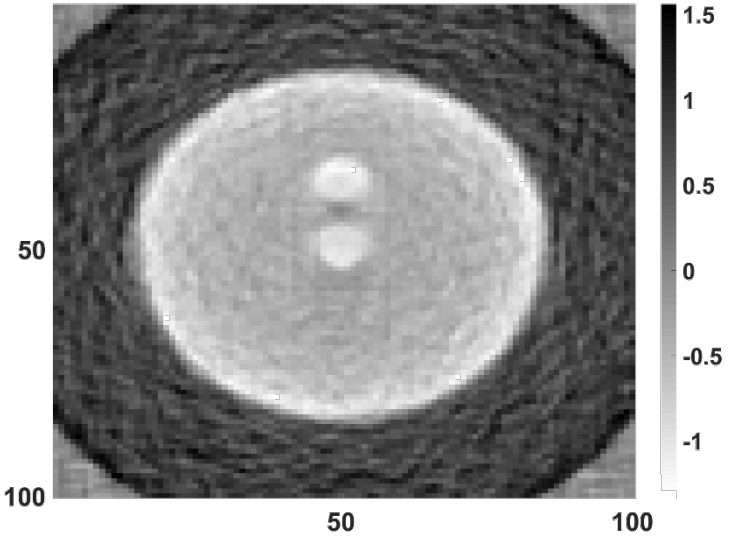
CT images for gamma rays of various energy



0.364 MeV gamma

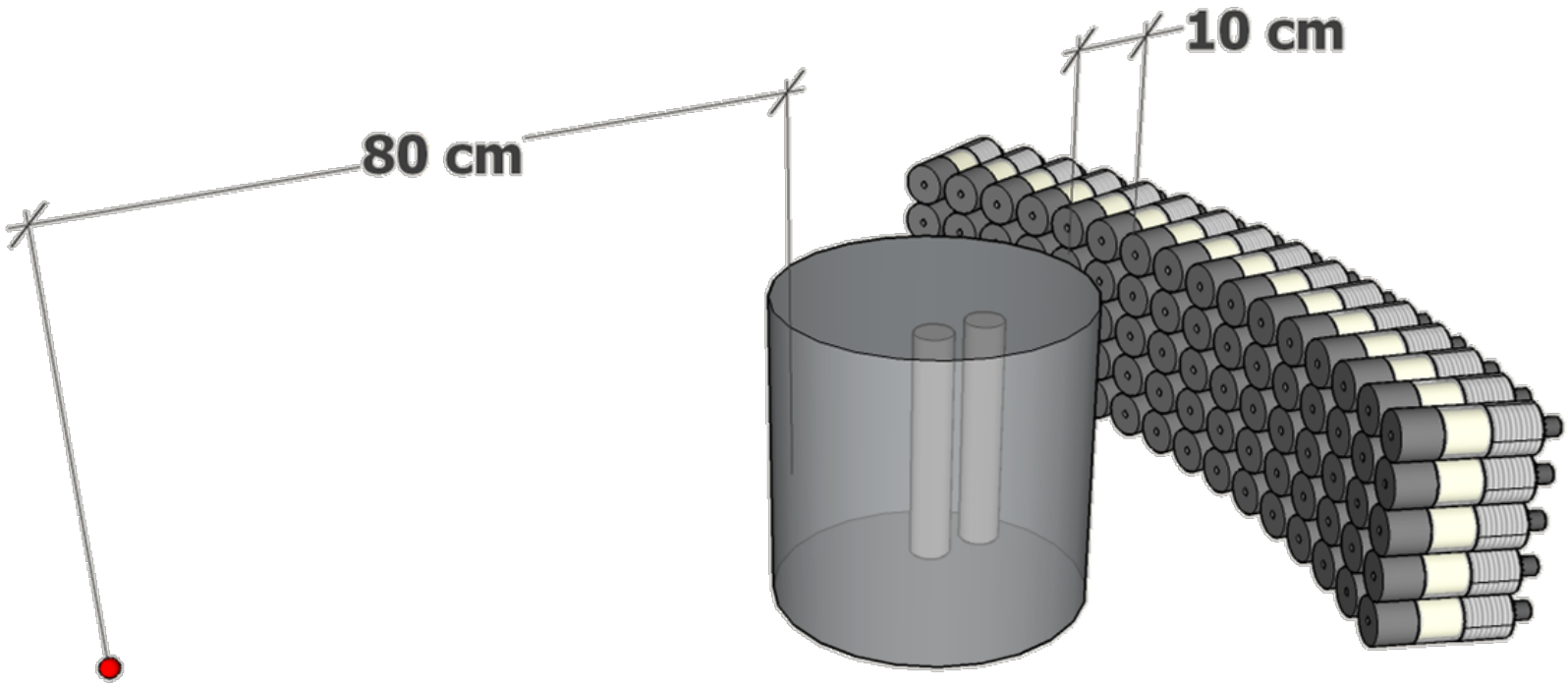


0.662 MeV gamma



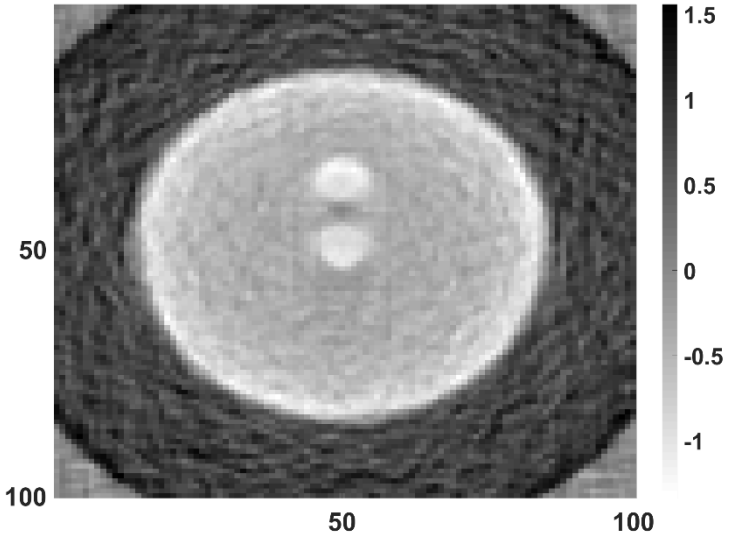
1.33 MeV gamma

Gamma CT modeling for comparison study

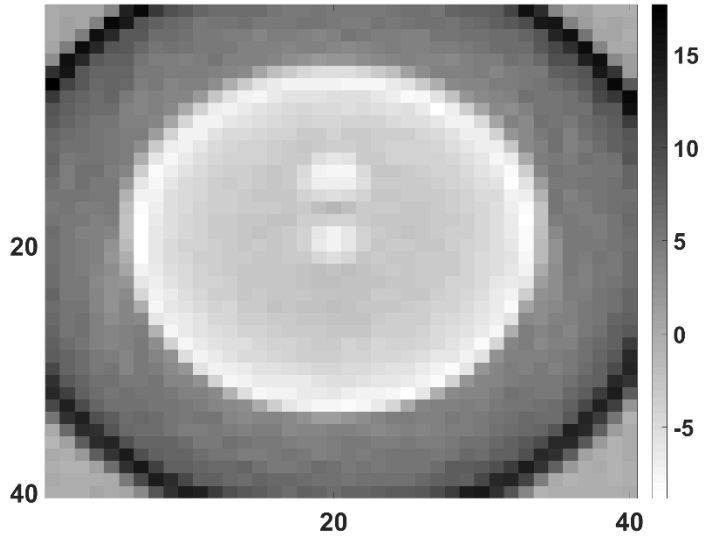


- For the comparison, **gamma CT systems** were modeled; **mechanical** and **electronic** collimation based NaI(Tl) scintillator coupled to circular PMT.
- Detector dimension: 0.5 (D) × 0.5 (T) inch, 1 (D) × 1 (T) inch
- **Collimator**: Pb collimator, 5 mm (D) hole × 50 mm (T) / **electronic**

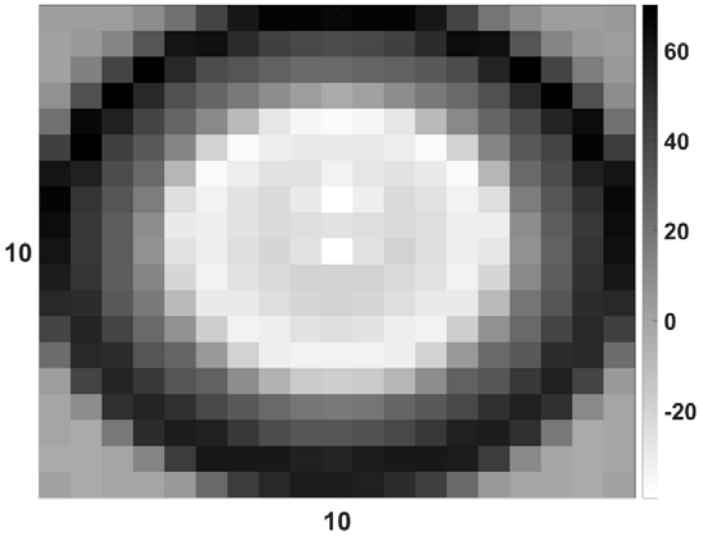
Comparison study with gamma CT – results



Compton CT

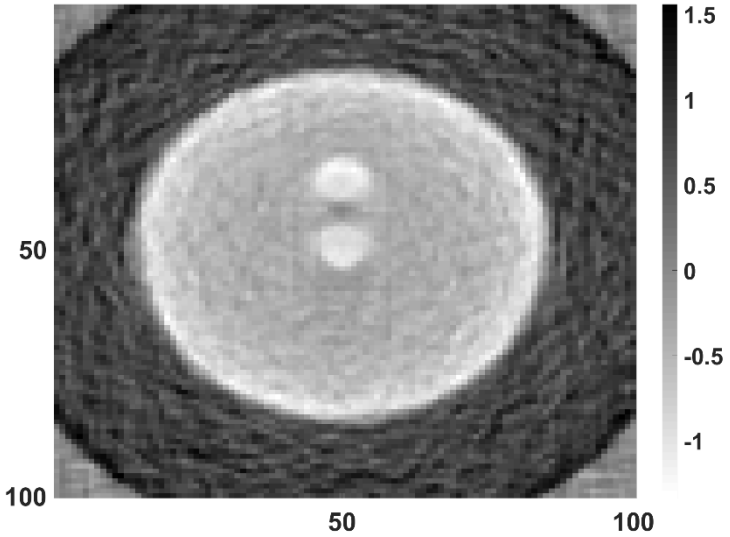


0.5 inch gamma CT (mechanical based)

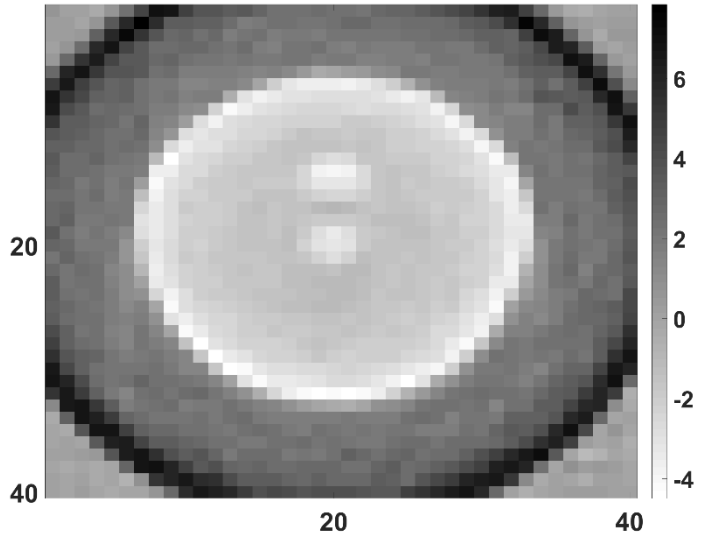


1 inch gamma CT (mechanical based)

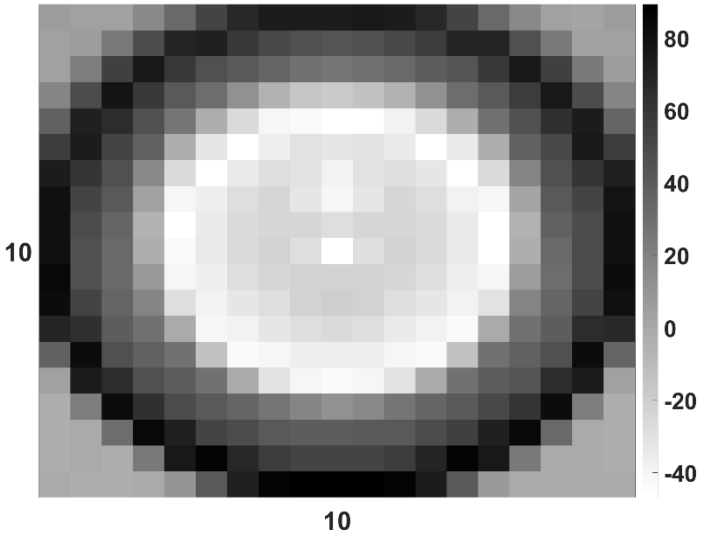
Comparison study with gamma CT – results



Compton CT



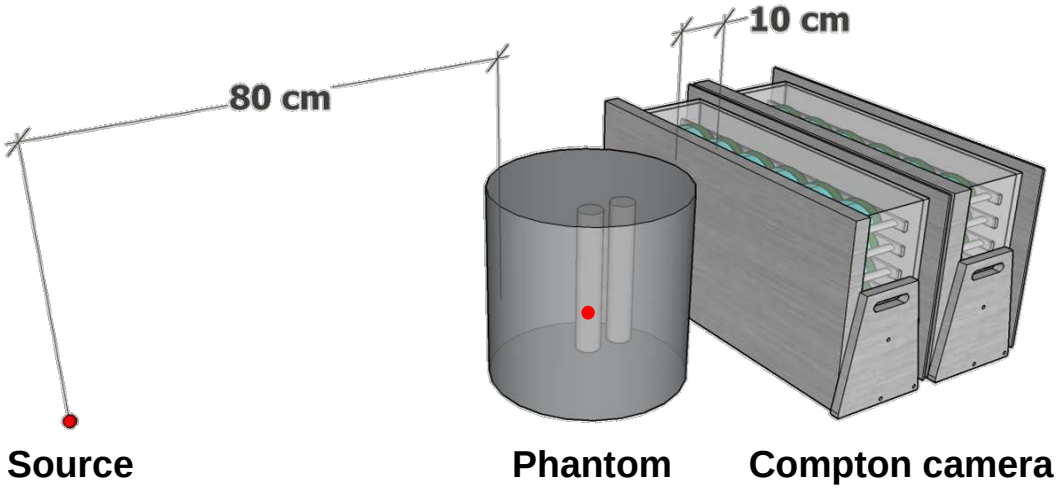
0.5 inch gamma CT (electronic based)

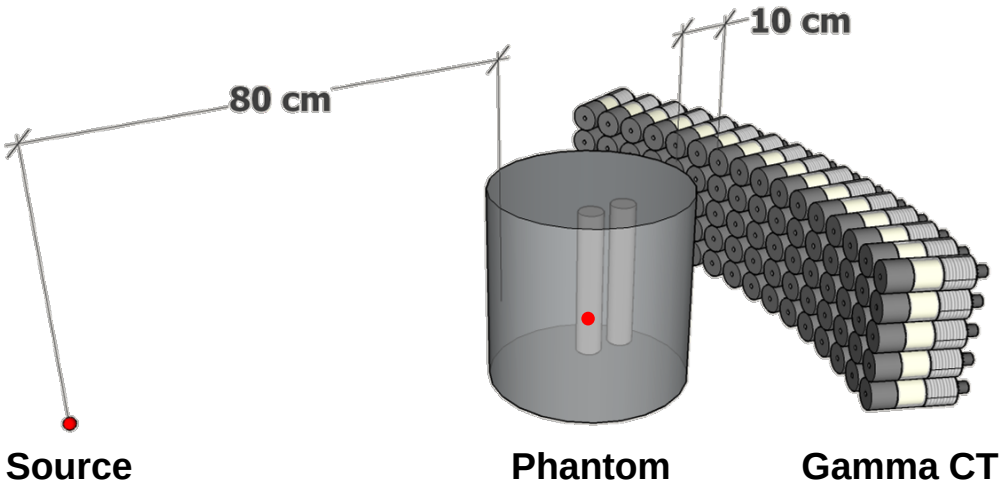


1 inch gamma CT (electronic based)

Feasibility study of Compton CT; comparison study

Existence of inner source in the phantom

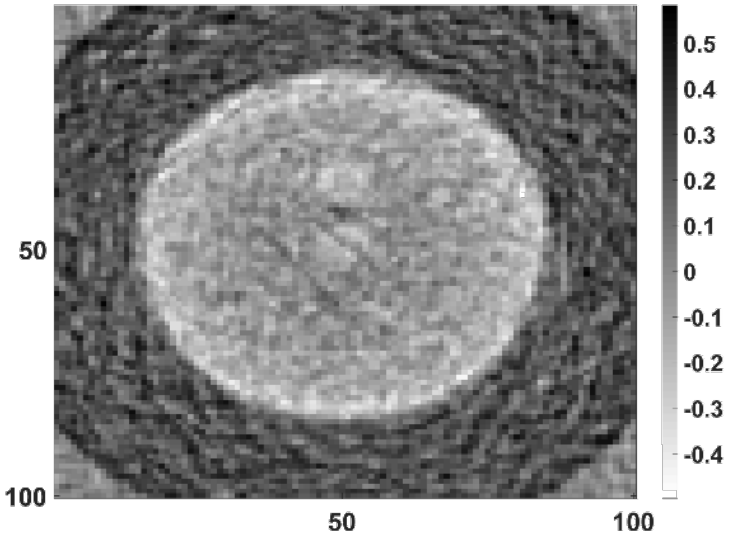




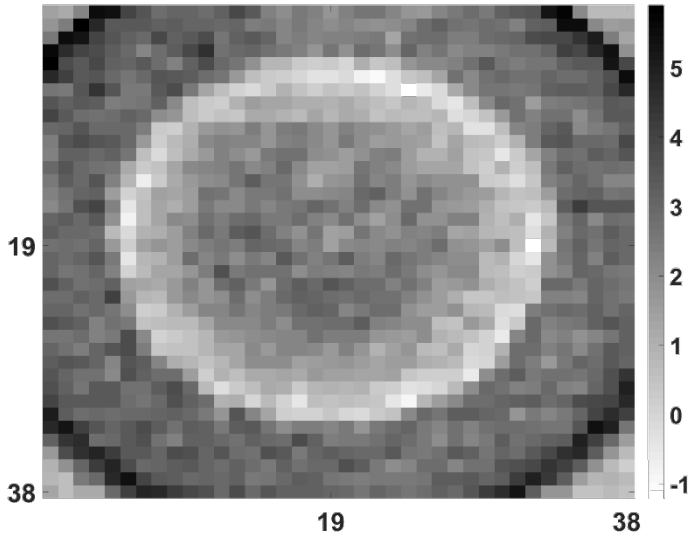
- Inner source: **Co-60**
  (1.33 MeV gamma)
- (0, -10 cm, 0) for phantom
- Activity ratio between the external source and inner source;
  10:1 (6.4 mCi: 0.64 mCi)
  1 second/1 projection
- **Gamma CT**
  Mechanical collimation
  Electronical collimation

Feasibility study of Compton CT – results

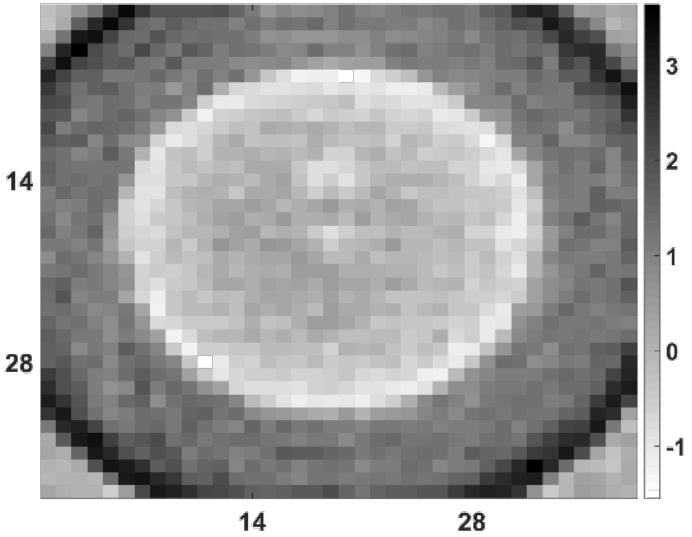
Existence of inner source in the phantom



Compton CT



Gamma CT (mechanical collimation)



Gamma CT
(electronic collimation)

Conclusion

Conclusion

- In the present research, we proposed a new gamma CT method, **Compton CT**, and estimated the feasibility of the Compton CT using Monte Carlo simulation.

- It was confirmed that **we can get the attenuation map distribution in the waste drum using Compton CT.**

- The results show that **Compton CT can effectively block the scattered events and other gamma events better than the gamma CT system**.

- Large-area Compton camera system will be able to obtain **the hot spot image as well as attenuation map distribution in the waste drum, without any additional equipment**.

Thank you