Verification of applying the current gamma-ray imaging techniques for discrimination of accelerator magnet activation

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“Clearance of materials from the decommissioning of accelerator facilities”
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Outline

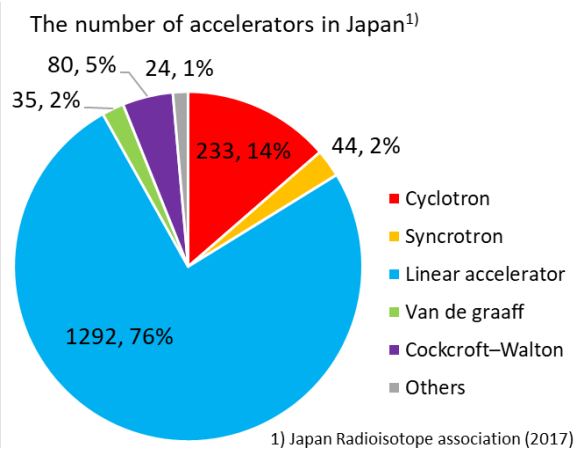
- Introduction
  - ✓ Gamma-ray imaging techniques can be applied to evaluate accelerator magnet activation?
- Experimental
  - ✓ It can detect gamma rays from ^{60}Co or not?
  - ✓ Can it be measured even in a high BG environment?
- Results and Discussion
  - ✓ Visualization of high-dose area
  - ✓ Gamma-ray spectrum (nuclides identification)
- Conclusion

Introduction

☐ Problem for decommissioning of accelerator facility

In Japan, there are over 1000 large and small accelerator facilities.

- ✓ They need updating or decommissioning.
- ✓ Guidelines were not prepared enough.



☐ About our research theme

Aim of the research — <u>establishment of more reasonable decommissioning process of accelerator facilities</u>

(1) clarification of the target facilities for assessment of activation

(2) <u>development of novel technique for assessment of activation</u>

(3) provide a guideline for decommissioning as a manual book

<u>Employed gamma-ray imaging techniques to evaluate magnet activation</u>

Introduction

How to determine the activated/not-activated material?

Where is activated?

Which nuclides are generated?

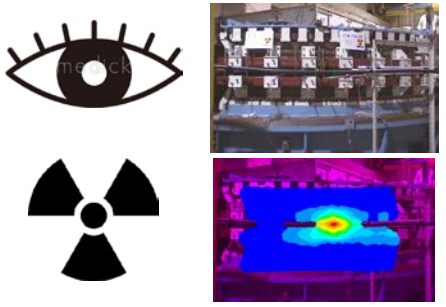
How strong the activity is?

- **Very difficult**
- **Very hard work**
- **Very long time**

Gamma-ray imaging technique

Rapidly prevailed after the FDNPP accident
Some commercially available devices

→ It can drastically improve the evaluation of activated material! … or not?

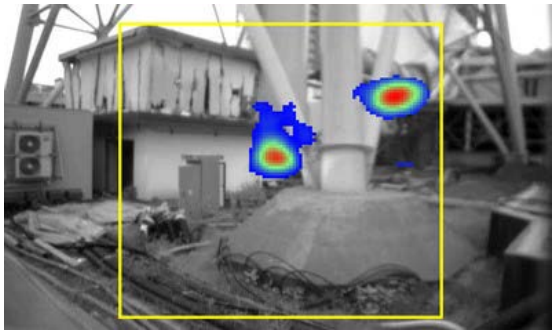


Introduction

Gamma-ray imaging technique (device)

- Device which combined a gamma-ray detector and an optical camera

  It can display the gamma-ray intensity of the part corresponding to the visible image with color contour



- A wide range of information can be obtained
- Relative high-dose area can be visualized
- (nuclide identification)
- **Optimized for ^{137}Cs (662 keV)**

  ^{60}Co is the most considerable nuclide

  Very high energy gamma-ray (over 1 MeV)

  } **Easily penetrate materials**

- **Designed for finding a radiation hotspot**

  Thermal neutrons activate any material

  Distribution of the activity is broad

  } **Source is whole direction (4π)**

Aim of our study

Gamma-ray imaging techniques can be applied to evaluate accelerator magnet activation?

We measured various activated magnets with representative commercially available devices.
Verifying the effectiveness of current imaging technique for the identification of activated areas and generated nuclides.

- ☐ It can detect gamma rays from ^{60}Co or not?
  - ✓ ^{60}Co standard calibration source
  - → Experment-1
  - ✓ Measurement an accelerator magnet alone
- ☐ Is it possible to measure even in a high BG environment?
  - ✓ Measurement of beam line magnets in the tunnel
  - → Experment-2

Experiment-1

Imaging devices employed in this study

Pin-holed type

HGD-E1500

/ Hitachi Co. Ltd.

Size : 193 × 327 × 295mm
Weight : 32 kg
Detector : CdTe
Radiation shield
equivalent to Pb 4cm
Spectrometry

Compton scattering type

Gamma-catcher

/ Chiyoda Technol Co. Ltd.

Size : 138 × 150 × 150mm
Weight : 2 kg
Detector : GAGG, t5+10mm
Very light
Spectrometry

Masked type

iPIX

/ Mirion Technologies Camberra

Size : 188 × 90 × 90mm
Weight : 2 kg
Detector : CdTe, t1mm
Very light and compact

Experiment-1

Objects : Standard source×1, Magnet×5

Standard source

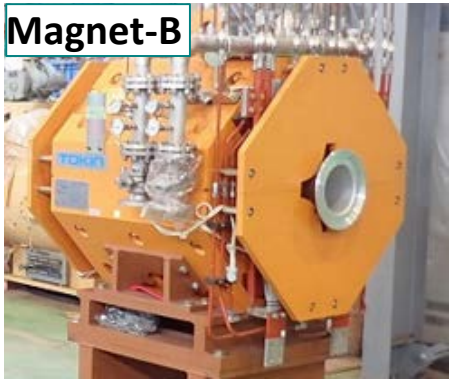
^{60}Co: 500 kBq

^{137}Cs: 500 kBq

Magnet-A

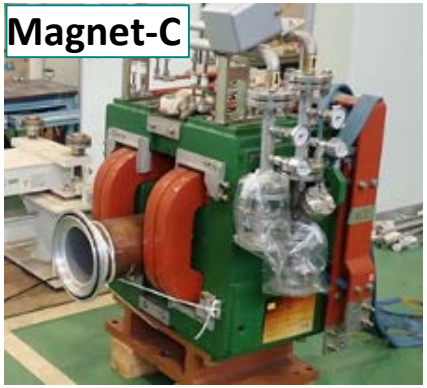
Max. dose-rate: 110 μSv/h
Identified nuclides: ^{60}Co, ^{22}Na
Installed place: 12 GeV, p^+

Magnet-B



Max. dose-rate: 15 μSv/h
Identified nuclides: ^{60}Co, ^{22}Na
Installed place: 12 GeV, p^+

Magnet-C

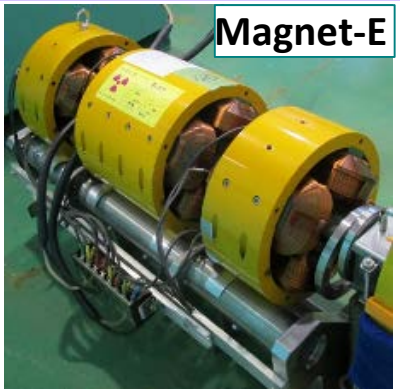


Max. dose-rate : 40 μSv/h
Identified nuclides : ^{60}Co, ^{22}Na
Installed place : 12 GeV, p^+

Magnet-D

Max. dose-rate : 20 μSv/h
Identified nuclides : ^{60}Co, ^{22}Na
Installed place : 12 GeV, p^+

Magnet-E



Max. dose-rate : 1 μSv/h
Identified nuclides : ^{60}Co, ^{54}Mn
Installed place : 6 GeV, e^-

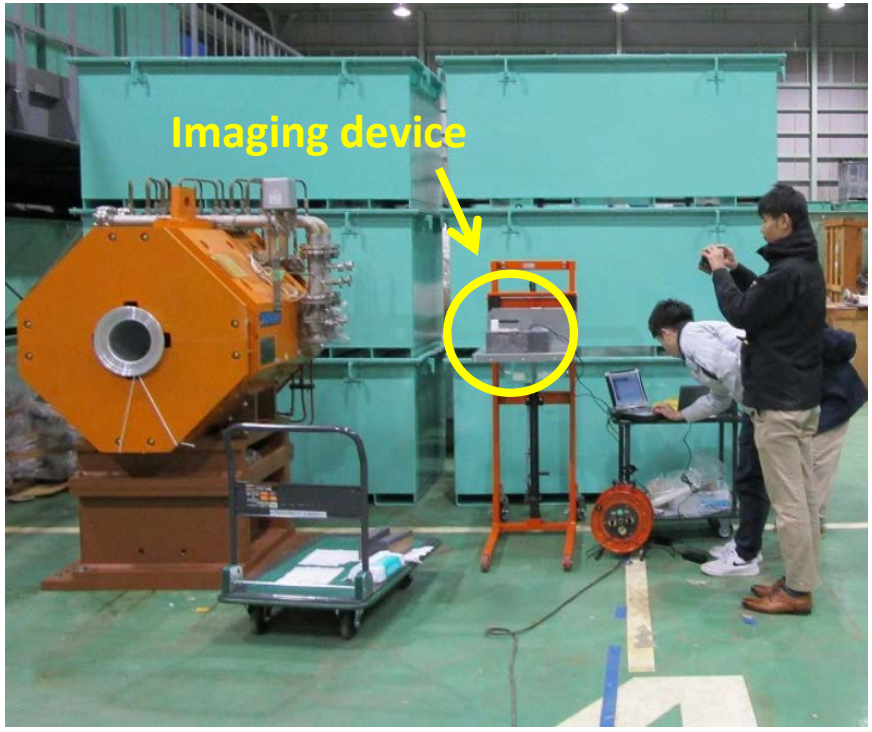
Experiment-1

Measurements were conducted at low BG condition

Storage hall of activated materials

Ambient dose-rate：0.1 ~ 0.5 μSv/h

Measurement with an imaging device

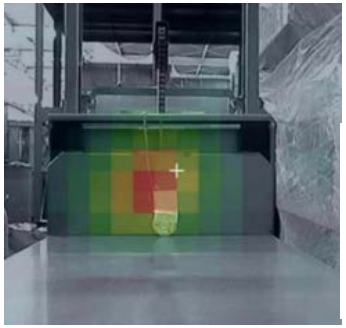
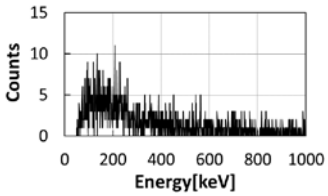
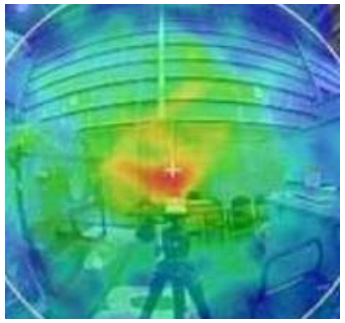
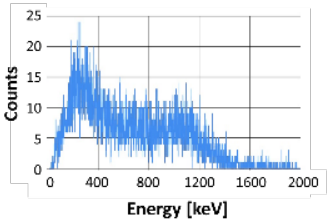
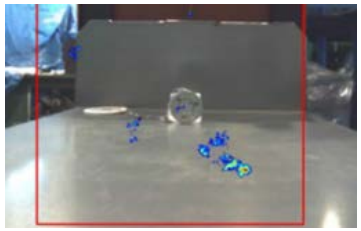
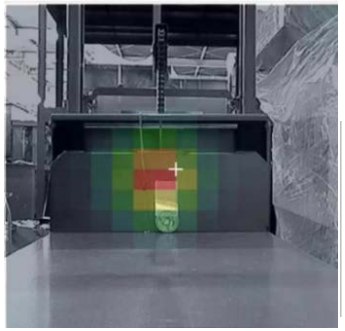
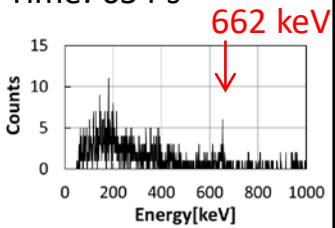
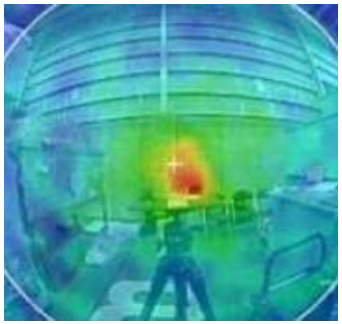
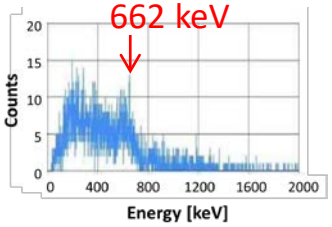
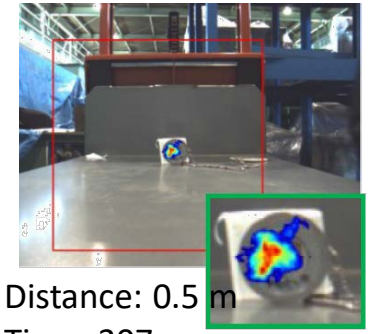


Measurement time：10 min ~ 6 h

Distance：0.5 m ~ 3 m

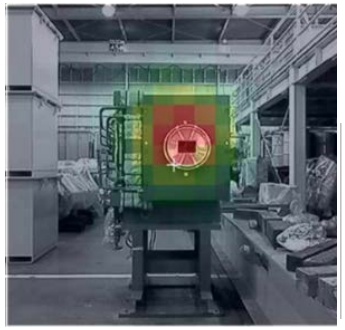
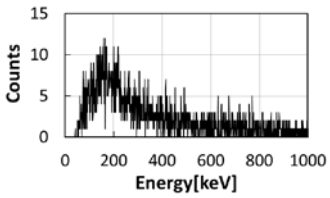
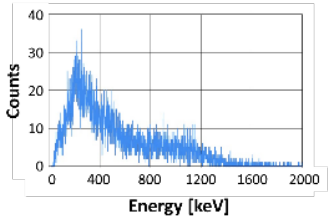
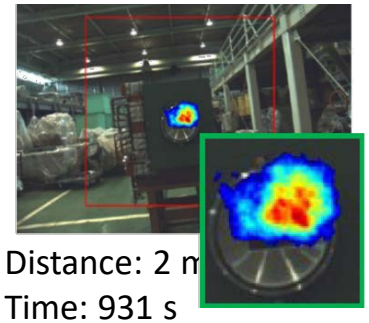
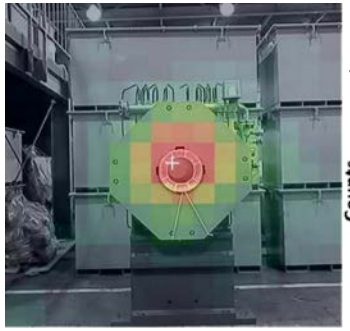
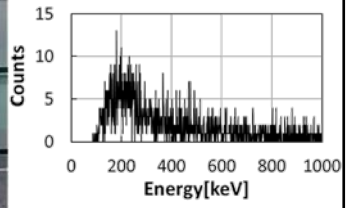
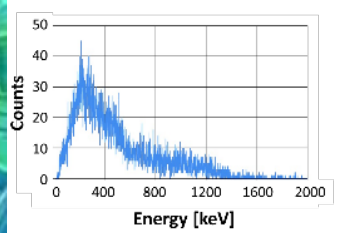
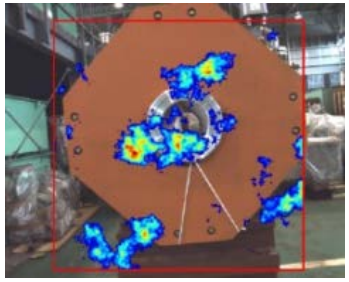
Results1

Standard source (Top: ^{60}Co, Bottom: ^{137}Cs)

HGD-E1500 (pin-holed)	Gamma-catcher (Compton scattering)	iPIX (Masked)
 Distance: 1 m Time: 950 s  · Identified the source location · No peaks	 Distance: 0.5 m Time: 1055 s  · Identified the source location · No peaks	 Distance: 0.5 m Time: 594 s Cannot identify the source location
 Distance: 1 m Time: 654 s  · Identified the source location · peak at 662 keV was found	 Distance: 0.5 m Time: 321 s  · Identified the source location · peak at 662 keV was found	 Distance: 0.5 m Time: 307 s Identified the source location

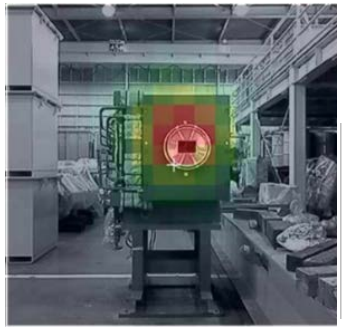
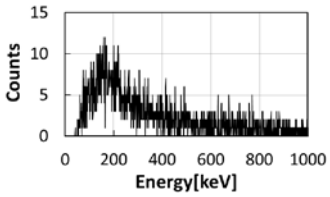
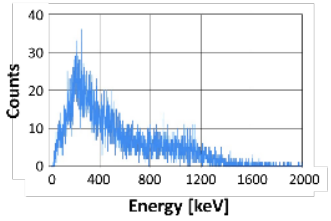
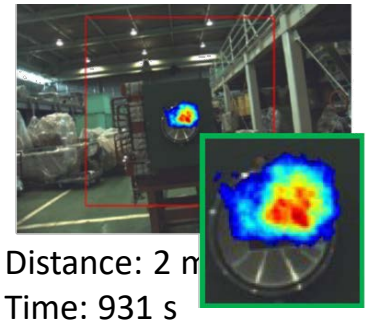
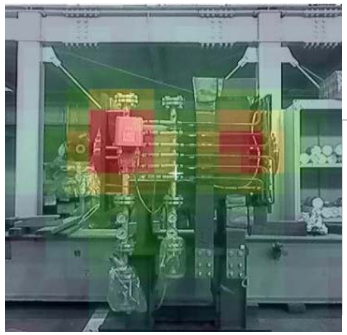
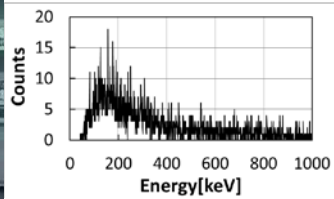
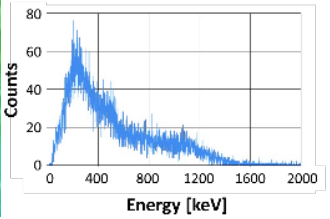
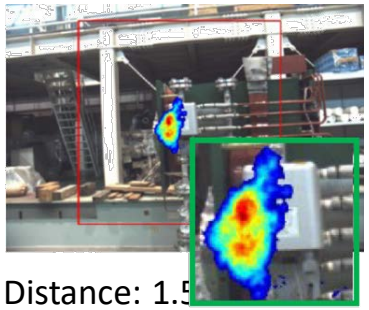
Results1

Magnet-A and B (Top: A, Bottom: B, Both images are taken from beam direction)

HGD-E1500 (pin-holed)	Gamma-catcher (Compton scattering)	iPIX (Masked)
 Distance: 3 m Time: 351 s  · Identified the source location · No peaks	 Distance: 1 m Time: 400 s  · Identified the source location · No peaks	 Distance: 2 m Time: 931 s Identified the source location
 Distance: 3 m Time: 1442 s  · Identified the source location · No peaks	 Distance: 1 m Time: 602 s  · Identified the source location · No peaks	 Distance: 1.2 m Time: 3004 s Couldn't identify the source location

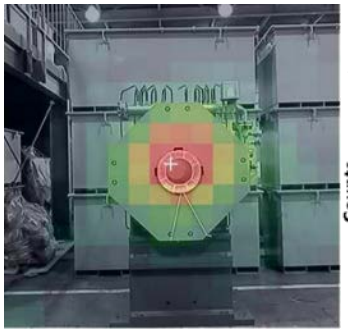
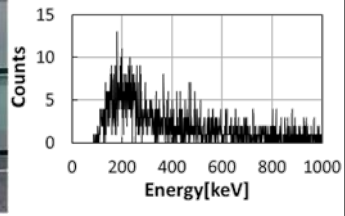
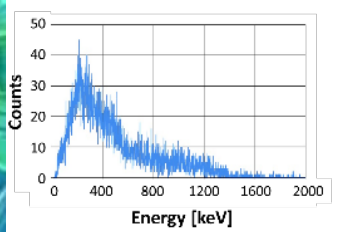
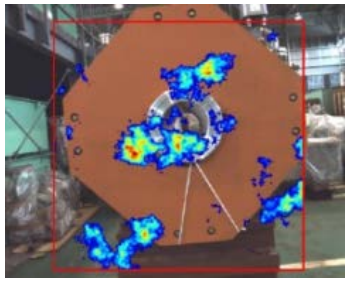
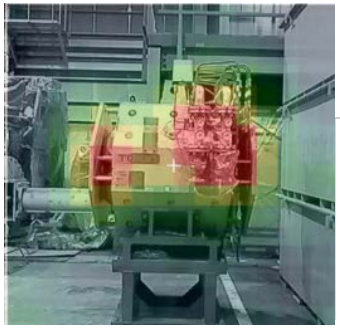
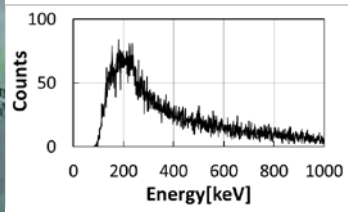
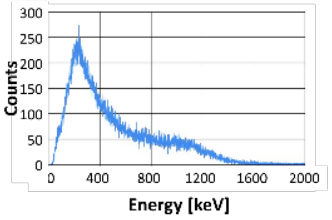
Results1

Magnet-A (Top: Horizontal to beam, Bottom: Perpendicular to beam)

HGD-E1500 (pin-holed)	Gamma-catcher (Compton scattering)	iPIX (Masked)
 Distance: 3 m Time: 351 s  · Identified the source location · No peaks	 Distance: 1 m Time: 400 s  · Identified the source location · No peaks	 Distance: 2 m Time: 931 s Identified the source location
 Distance: 2.5 m Time: 376 s  · Identified the source location · No peaks	 Distance: 1 m Time: 705 s  · Identified the source location · No peaks	 Distance: 1.5 Time: 2151 s Identified the source location

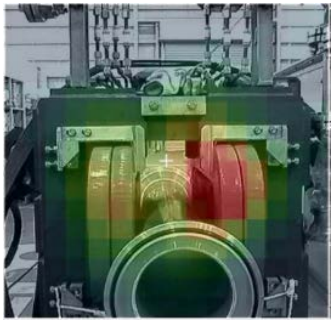
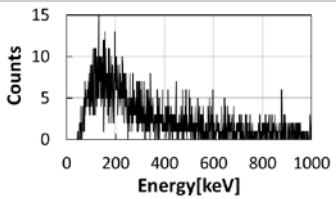
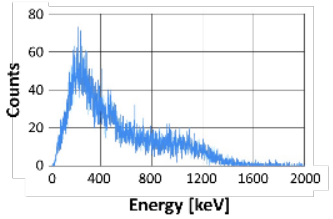
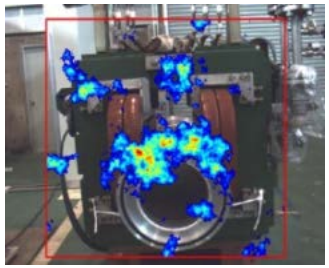
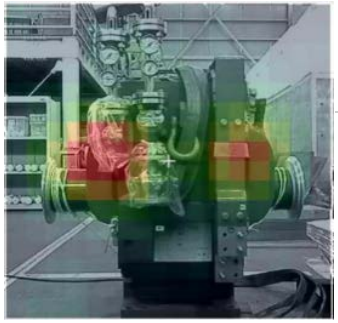
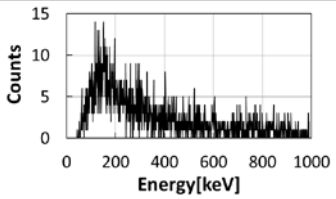
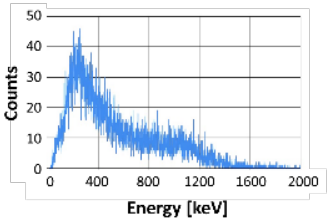
Results1

Magnet-B (Top: Horizontal to beam, Bottom: Perpendicular to beam)

HGD-E1500 (pin-holed)	Gamma-catcher (Compton scattering)	iPIX (Masked)
 Distance: 3 m Time: 1442 s  · Identified the source location · No peaks	 Distance: 1 m Time: 602 s  · Identified the source location · No peaks	 Distance: 1.2 m Time: 3004 s Cannot identify the source location
 Distance: 3 m Time: 21472 s  · Identified the source location · No peaks	 Distance: 1 m Time: 10800 s  · Identified the source location · No peaks	**Not measured**

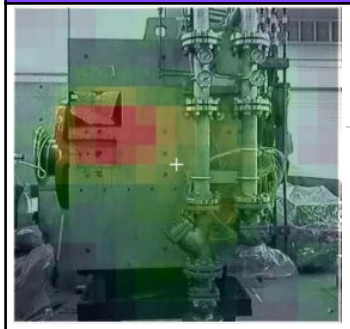
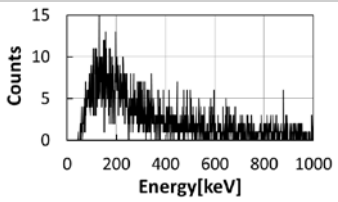
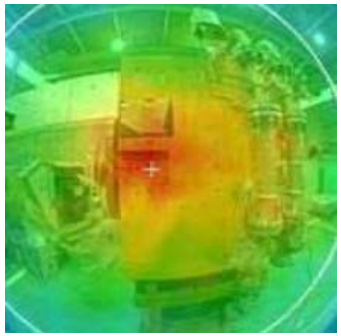
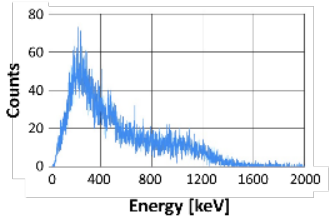
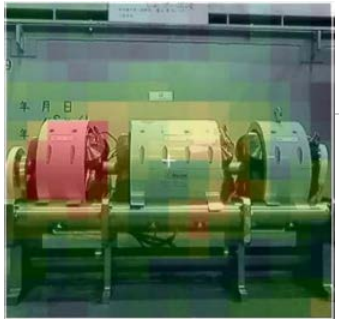
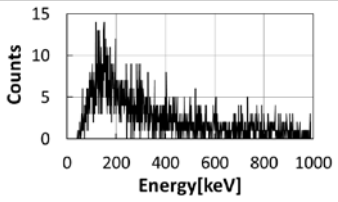
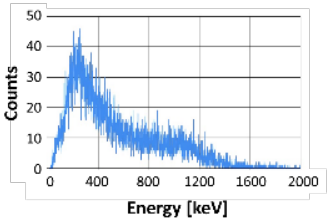
Results1

Magnet-C (Top: Horizontal to beam, Bottom: Perpendicular to beam)

HGD-E1500 (pin-holed)	Gamma-catcher (Compton scattering)	iPIX (Masked)
 Distance: 1 m Time: 243 s  · Identified the source location · No peaks	 Distance: 1 m Time: 601 s  · Identified the source location · No peaks	 Distance: 1 m Time: 4271 s Cannot identify the source location
 Distance: 1.5 m Time: 548 s  · Identified the source location · No peaks	 Distance: 1 m Time: 600 s  · Identified the source location · No peaks	**Not measured**

Results1

Magnet-D and E (Top: D, Bottom: E, Both images are perpendicular to beam)

HGD-E1500 (pin-holed)	Gamma-catcher (Compton scattering)	iPIX (Masked)
 Distance: 2 m Time: 456 s  · Identified the source location · No peaks	 Distance: 0.7 m Time: 1000 s  · Identified the source location · No peaks	**Not measured**
 Distance: 1 m Time: 5872 s  · Identified the source location · No peaks	 Distance: 0.5 m Time: 7200 s  · Identified the source location · No peaks	**Not measured**

Results1

Summary -Measurement with activated magnet alone-

- HGD-E1500 (pin-holed) and gamma catcher (Compton-scattering) could visualized the high-dose area of magnet regardless of the strength of activation.

- iPIX (masked) could hardly be visualized high-dose area.

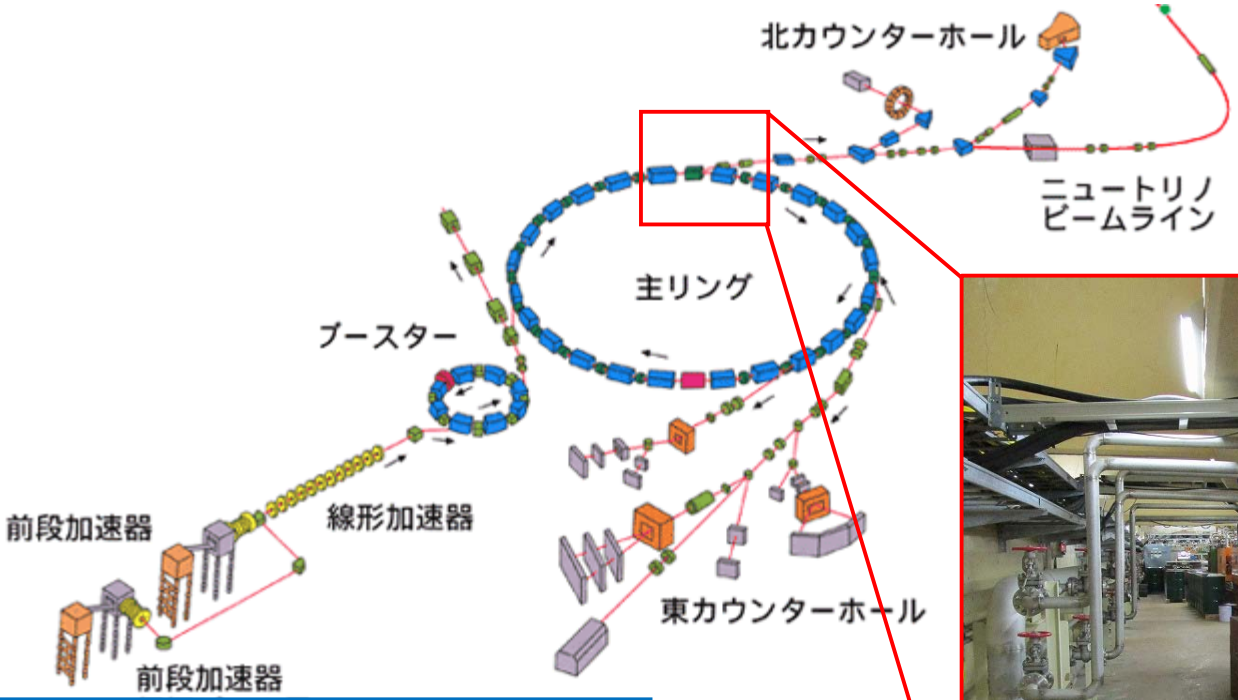
  → Insufficient crystal thickness (detection efficiency),

- peaks of ^{60}Co could not be confirmed in the spectrum, in all conditions.

  → The crystal thickness is insufficient to detect gamma rays of ^{60}Co.

Experiment-2

Measurements were conducted at KEK-PS (Shut down in 2006)



w/ , w/o radiation shield

Contact dose-rate：10～500 μSv/h
Ambient dose-rate：3～10 μSv/h

Results2

Summary -Measurement in beamline tunnel-

- Both HGD-E1500 and Gamma Catcher could visualize strongly activated area of even in high BG condition.
- BG radiation was considerably suppressed by lead shielding, but almost no effect was found on the visualization result.
- peaks of ^{60}Co could not be confirmed in the spectrum, in all conditions (insufficient detection efficiency).
- As long as using these devices, we can only find relative high dose area of the magnet, **we cannot find what kind of nuclides and their activity**.

About H3D gamma camera

H3D Gamma Camera

W: 24 cm
H: 18 cm
D: 9 cm

3.3 kg

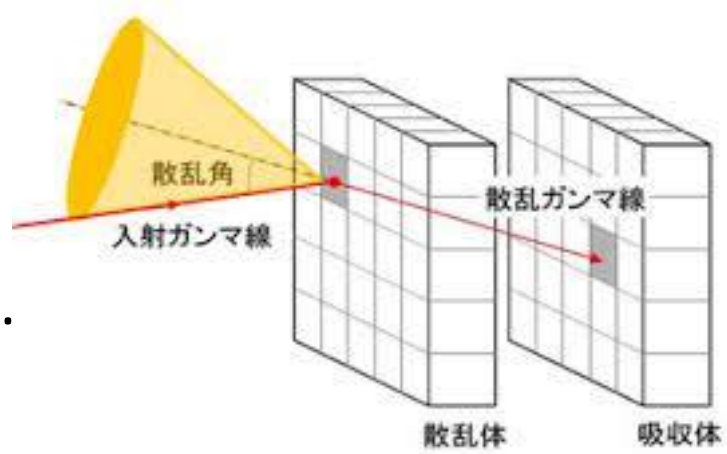
- **Compton-scattering type**
- Detector: CZT(2cm × 2cm × t1.5cm) × 4
- Good resolution (0.3% @ 1.33 MeV)
- **Very good efficiency** (equivalent to 1.5in. $LaBr_3$)

About H3D gamma camera

Why the detection efficiency is good

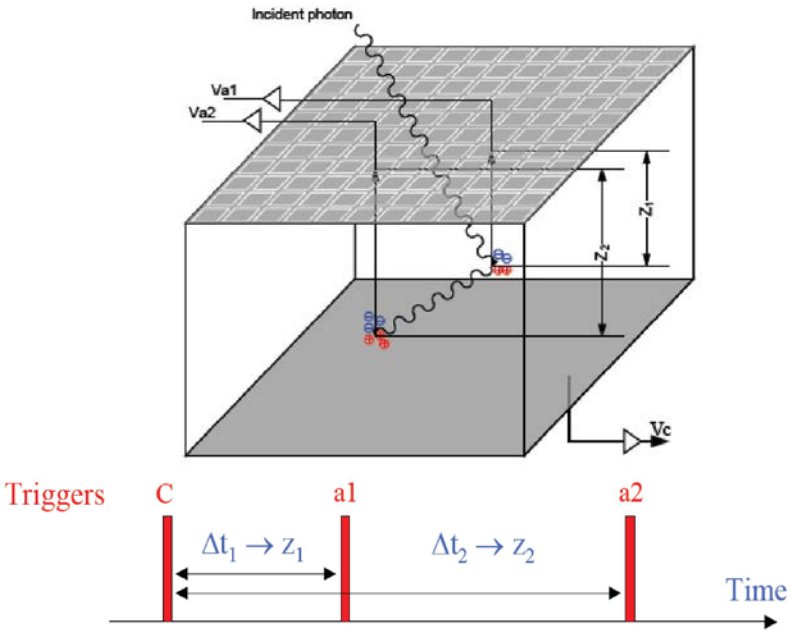
- **Ordinal Compton-scattering**
  - Multi tiny scintillator crystals
  - Only one crystal pair can absorb the photon energy in this method.

    → Detection efficiency is poor



- **H3D Gamma-camera**
  - Big semiconductor crystal
  - Electrons are attracted by external electric field applied to the crystal, and measured TOF.

    → Detection efficiency is good



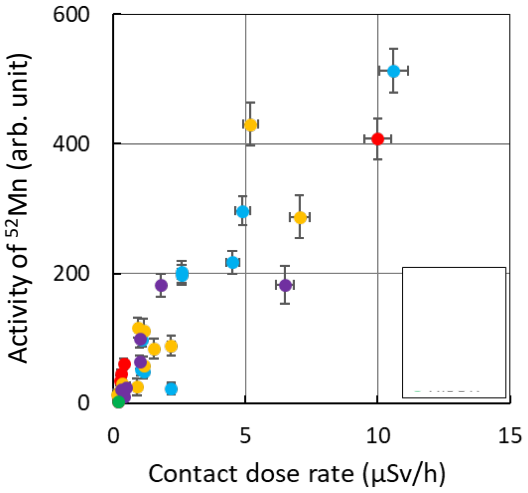
Future plans

■ Determination of the activity of beam line component

We will try to development of effective way to determine the activity of beam line component, by using H3D camera.
We plan to conduct direct sampling from activated magnets that evaluated in this study and will be compared with visualized image.

■ Beam loss estimation

Short-lived nuclides such as ^{57}Ni, ^{52}Mn supposed to be reflect the latest beam loss.
We expected that the absolute amount and range of beam loss can be clarified by applying imaging technique.



Summary · Conclusion

We experimentally evaluated activation of magnet by using commercially available gamma-ray imaging devices.

- ☐ It can detect gamma rays from ^{60}Co or not?
  - ✓ Cannot confirm full absorption peak
  - ✓ It is possible to identify high-dose areas by detecting scattered photons

- ☐ Is it possible to measure even in a high BG environment?
  - ✓ Possible and no need radiation shield.
  - ✓ Quantitative information cannot be obtained.

We conducting the evaluation by using H3D gamma-camera which has very good efficiency, and aiming at discussions for quantitative evaluation and nuclide identification.