Muography at Kyushu University

~ Investigation of Infrastructure Degradation ~

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Summary and Future Plans
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Background

History of cosmic-ray muon and Muography

1912
Cosmic ray discovered (Hess)

1937
Cosmic-ray muon discovered (Anderson)

1955
Overburden thickness of tunnel by cosmic-ray flux attenuation (George)

1970
The first cosmic-ray muon radiography at Giza pyramid (Álvarez)

1987
Subway station depths and cosmic-ray intensity (Minato)

2008
Critical Assembly Reactor (Morris)

2008
Pyramid of Khufu (Morishima)

University Building (our data)

Underground Cavities at Mt. Echia (Saracino)
## Background

### Infrastructure Degradation

<table>
<thead>
<tr>
<th>Target Object</th>
<th>Degradation size</th>
<th>Existing Survey Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road &amp; Bridge</td>
<td>0.1~10cm in ~200cm</td>
<td>Ground Penetrating Radar, Visual check</td>
</tr>
<tr>
<td>Fire brick</td>
<td>5<del>20cm in 30</del>35cm</td>
<td>Visual check, Heat leakage monitoring</td>
</tr>
<tr>
<td>Rock fill dam</td>
<td>1<del>10m in 20</del>300m</td>
<td>Visual check, Underground water gauge</td>
</tr>
</tbody>
</table>

Muography has potential to explore the degradation.
Background: Aims of our study

Development of Muography Detector for Infrastructure Degradation Investigation

Demonstration of a building muography have successfully done.

Feasibility study on fire brick wall muography
- Imaging of fire bricks installed in gas duct of a furnace
- Their thickness estimation to inspect its degradation

Collaboration study with JFE Engineering Co. Ltd.

Measurement of Terrestrial Muon Energy Spectrum

Lower energy muons have possibility to investigate small sized structures.

No data available

We have been conducting measurements of muon energy spectrum from 10 to 350 MeV.
(Not by muography detector)
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Requisites for the Muography Detector

◆ **Portability**
  → Easy detection position arrangement
  → Multi-point measurements for 3D tomography

◆ **Stability / Maintenance-free**
  → a few weeks ~ a few months

◆ **Online Data Acquisition**
  → e.g. water level deviation for dam, levee
Prototype Muography Detector

Mu-PSD (Muon position sensitive detector)

Light shielding and Heat insulating Box with Peltier heating-cooling unit

Prototype Muography Detector

- Attenuation type
- Portable
- ~8msr resolution
- Long term stability
- ~200 Watts
All we need for a measurement are …

**NIM modules**
They will be removed after update of EASIROC firmware.

**Oscilloscope**
Required only for starting-up.

**Muography detector**

**Temperature controller**

**Data storage HDD**

**Front-end PC**
It will be replaced to Raspberry Pi, a card sized PC.
Infrastructure Muography Test of Fire Brick Wall of Duct of Demonstration Plant of Stoker Furnace

- Gas duct
- Spraying refractory (10~15cm thick)
- Almina brick (20cm thick)

Furnace

Collaboration study with JFE engineering Co. Ltd.
Open-air & Duct Imaging Measurement

Fire brick wall of duct of stoker furnace of JFE Eng. Co. Ltd.

Measurement Time: 2 weeks
Detector Temperature: 17 degrees
Location: Nearby the following measurement

Measurement Time: 3 weeks
Detector Temperature: 17 degrees
Location: Just beside the duct

Cross section view

by K. Chaiwongkhot, R. Sasaki, Y. Nagata, T. Komori
Results and Discussion: Muography

Open-air Measurement

Muon Intensity Low High

Gas Duct Measurement

Attenuation rate map

$1 - \left( \frac{I_m}{I_0} \right)$
Results and Discussion: Muography

Conversion Function: Attenuation Rate $\rightarrow$ Fire Brick Thickness

Function of minimum muon energy ($E_{\text{min}}$) required to penetrate target material having thickness $L$ was obtained by PHITS code.

Ratio $R$ of muon having higher energy than $E_{\text{min}}$ to total was calculated by EXPACS (PARMA model).

Inversion Function of “$R(E_{\text{min}}(L))$” is the conversion function.
Results and Discussion: Muography

Our detector has enough performance for fire brick muography.
# Muography at Kyushu University

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**Detector: Low Energy Muon Spectrum**

- **Center PS**: Main detector of energy spectrum measurement
- **Top + Center PS**: $\Delta E$-$E$ detection to suppress cosmic-ray electrons
- **Under PS**: Reject penetrating high energy muon events
- **Lead between Top and Center PSs**: Energy degrader

<table>
<thead>
<tr>
<th>Detector ID</th>
<th>Size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top PS</td>
<td>20x20x1$^t$</td>
</tr>
<tr>
<td>Center PS</td>
<td>19x19x20$^t$</td>
</tr>
<tr>
<td>Under PS</td>
<td>60x60x2$^t$</td>
</tr>
</tbody>
</table>
By $\Delta E-E$ detection, Muon events are clearly identified from Electron events.

Count rate function respect to muon energy is obtained.
Cosmic-ray muon spectrum

from 20 to 140 MeV
at Top PS position
in 40 degrees of zenith angle
was obtained
Results: Low Energy Muon Spectrum

*Present values are divided by 0.78 for the comparison with vertical fluxes.
(The normalized factor “0.78” was calculated by well-known cos2 distribution.)

Consistent value with Allkofer spectrum

Discrepancy between theoretical model and present data

Flux (/cm$^2$/s/sr/MeV)

Energy (MeV)

0 (A), 1 (B), and 5 (C) cm lead degrader
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Summary and Future plans

Demonstration of Infrastructure Muography

- Collaboration study with JFE Eng. Co. Ltd.
- The muography result of the gas duct of the furnace was in reasonably good agreement with the fire brick wall thickness obtained by drawing.
- Muography is a feasible technique for the investigation of fire brick degradation.

Measurement of Low Energy Muon Spectrum

- The cosmic-ray muon energy spectrum in low energy region has measured.
- Inconsistency with theoretical model in lower energy region.
Investigation of Degradation of Bridge

- Collaboration study with JFE Eng. Co. Ltd.
- Construction of test samples of bridge which include artificial degradation such as cavities or concrete gravel
- Development of screening method
- Probing the limit size of investigation
- Simulation approach by PHITS

Muon Energy Spectrum

- Obtain higher energy region to know the consistency with Allkofer spectrum
- Measurement of zenith angular differential flux with other detector setup
- Improve the muon event identification process
One More Thing…
Another Muography at Kyushu University

“Volcano Monitoring with Scintillators with SiPM Readout”
by Faculty of Science and Institute of Seismology and Volcanology

Prof. Kawagoe and Prof. Shimizu organize the project and has started this year.

1st candidate of the monitoring

- Plastic scintillator + MPPC
- 1.2m x 1.2m x 3 layers

Detector Fabrication and 1st Engineering test has finished.

Monitoring of Mt. Unzen will be soon started.