First precision spectroscopy of cesium-137 from the ground to 150m above in Fukushima

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Outline

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- Result: height dependence
  - Gamma-ray dose as measured in 30-2000 keV
  - Comparison of different energy ranges
  - Monochromatic 662-keV gamma rays
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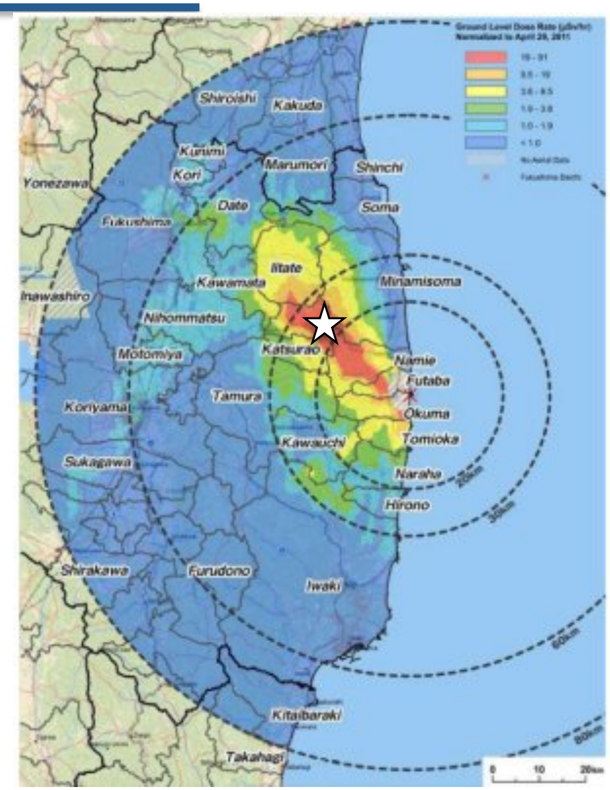
Introduction

Current status

After the Fukushima nuclear disaster in 2011, large amounts of radioisotopes were released

- mainly 137-Cs and 134-Cs

→ The distribution of the radiation sources was monitored in the contamination field in Fukushima



However

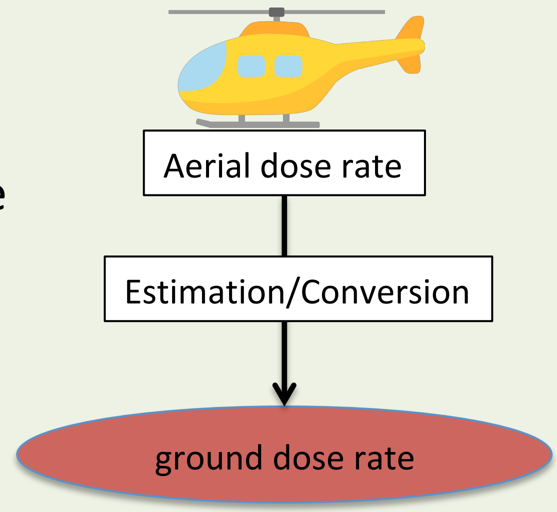
Only few estimations on the height dependence of the air dose rate

- The variation of gross count rates measured in a wide energy range, e.g., 30 – 2000 keV

Introduction

Conventional measurement

1. Compare an aerial and ground dose rate for a calibration purpose
2. Convert aerial dose rate to ground dose rate



However

- Physical meaning of correction is **unknown**
- Large uncertainties owing to different ground conditions

Necessity of detailed measurement

We performed detailed spectral measurement from 0-m to 150-m above for the first time!

Theory

Theoretical calculation of the height dependence of the dose rate

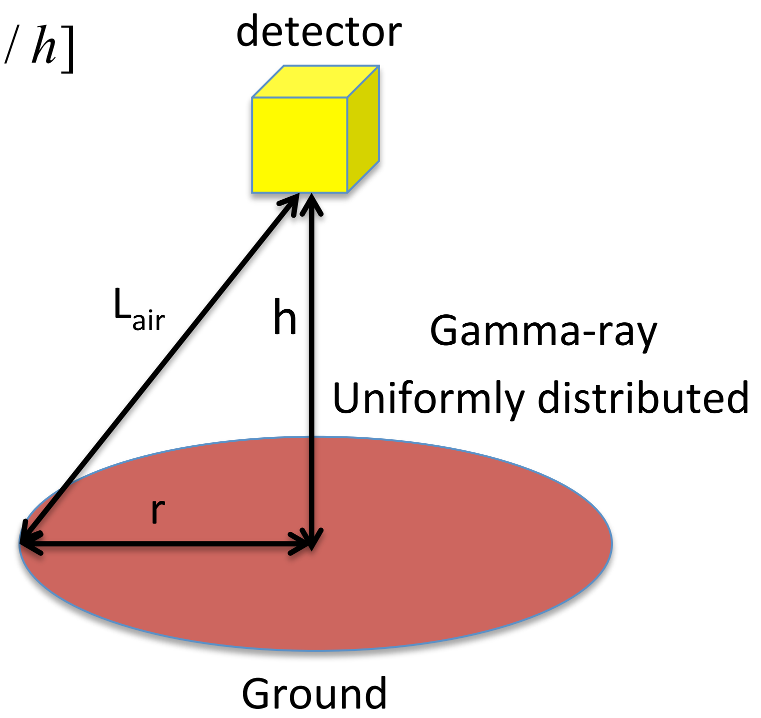
- Suppose the uniformly distributed radiation sources on the ground
- Calculate the dose rate

The absorbed dose rate : $\varepsilon_{abs} = \hbar\omega\zeta_{en} I \quad [\mu Sv / h]$

Gamma-ray flux : $I = \dfrac{e^{-\mu_{air} r}\eta P}{4\pi r^2} \quad [\mu Sv / h]$

The half-value layer of air : $L_{air} = \dfrac{\ln 2}{\mu_{air}} = 69 \quad [m]$

$$\Rightarrow \varepsilon_{abs} = \int_0^{L_{air}} \frac{\hbar\omega\zeta_{en}\eta P}{4\pi\left(r^2+h^2\right)} 2\pi r\, dr \quad [\mu Sv / h]$$



Measurement

The survey site

- A schoolyard in the Tsushima branch of Namie high school in Namie-city, Fukushima Prefecture
- The ground is ~100×100 m^2 in size
- 30km from the nuclear power plant
- Mostly designated as a difficult-to-return area

Measurement point is indicated by the red star in the left panel

Measurement

Flight system

- **Drone**
  The diagonal wheelbase : 643mm
  The weight : 3.8kg
  the maximum payload : 2.34kg

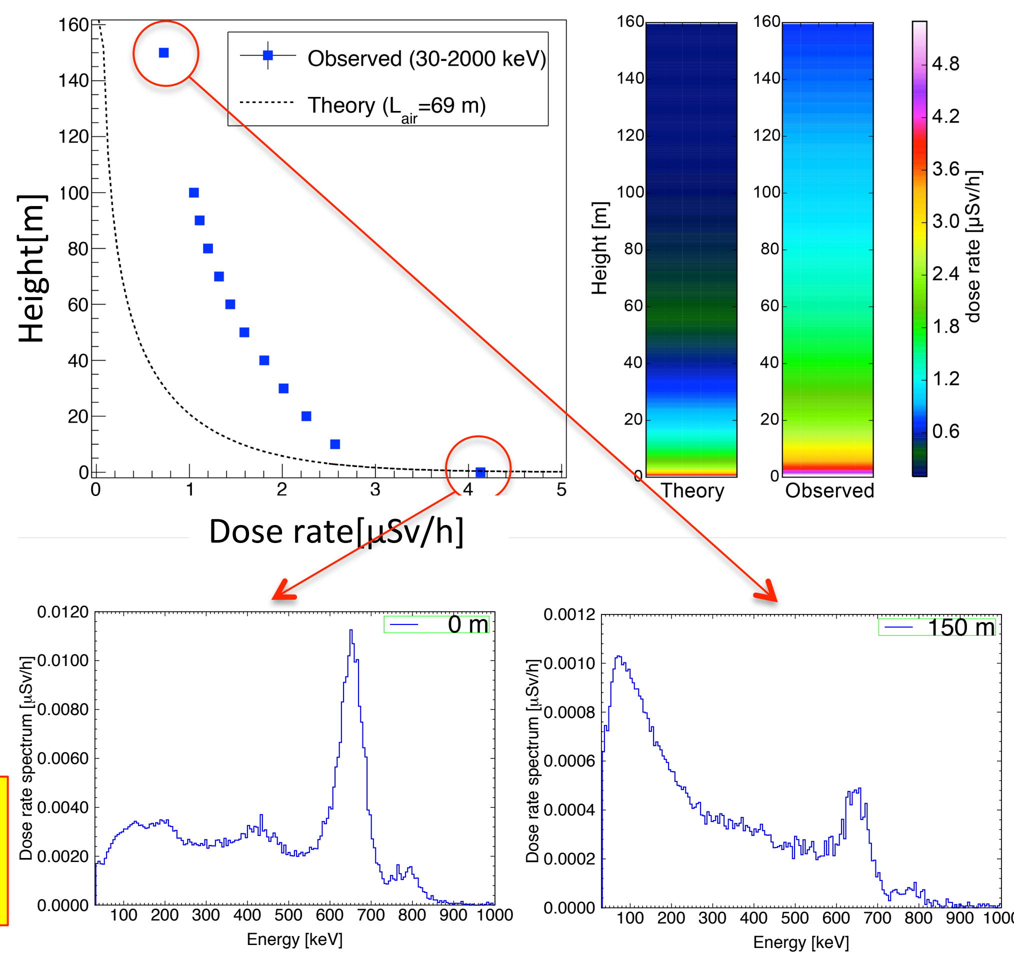
- **Gamma-ray detector module**
  Scintillator : CsI(TI) 13×13×20 mm^3
  Photo detector : MPPC
  The detector size : 110×55×27 mm^3
  The detector weight : 120g
  Energy range : 30 – 2000 keV
  Energy resolution : 8% @ 662keV

Result

The height dependence of the gamma-ray dose in 30-2000 keV

◆ Observed vs Theory

Observed dose rate was generally much higher than the theoretical prediction



The scattered component increases as the altitude increases

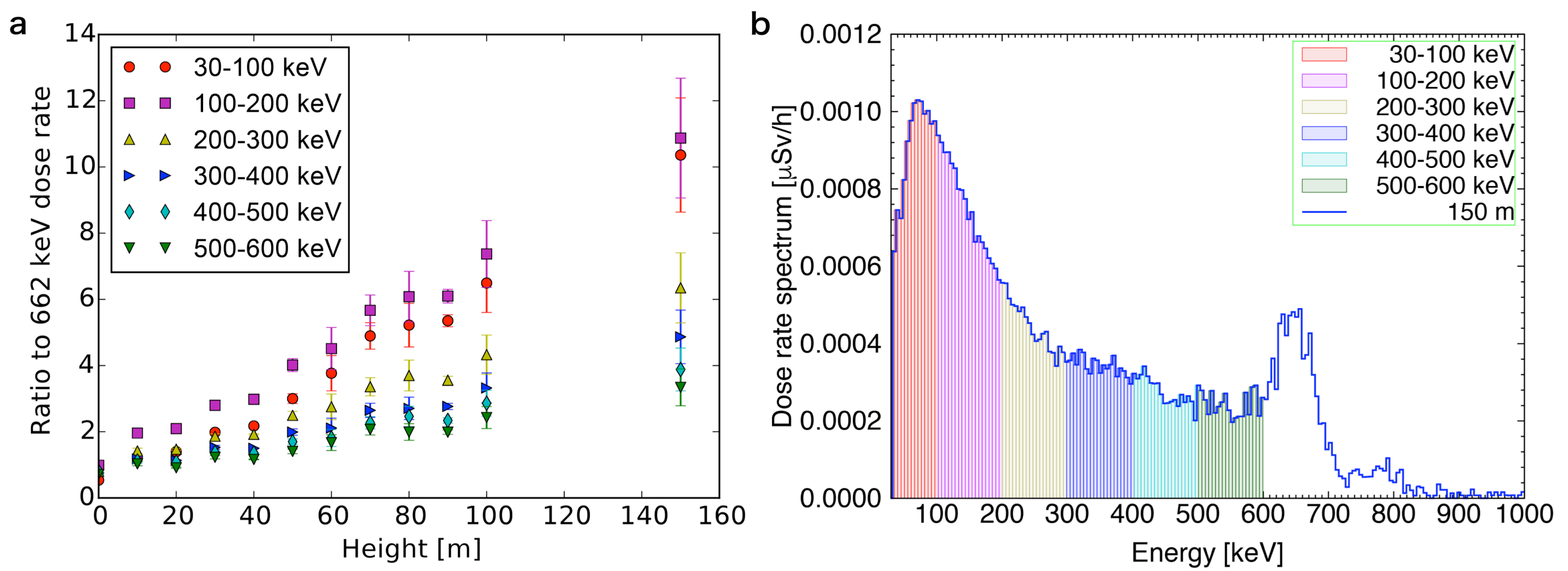
Evaluation of the air dose rate within a fixed, wide E-range is not valid

Result

The height dependence for six independent energy ranges

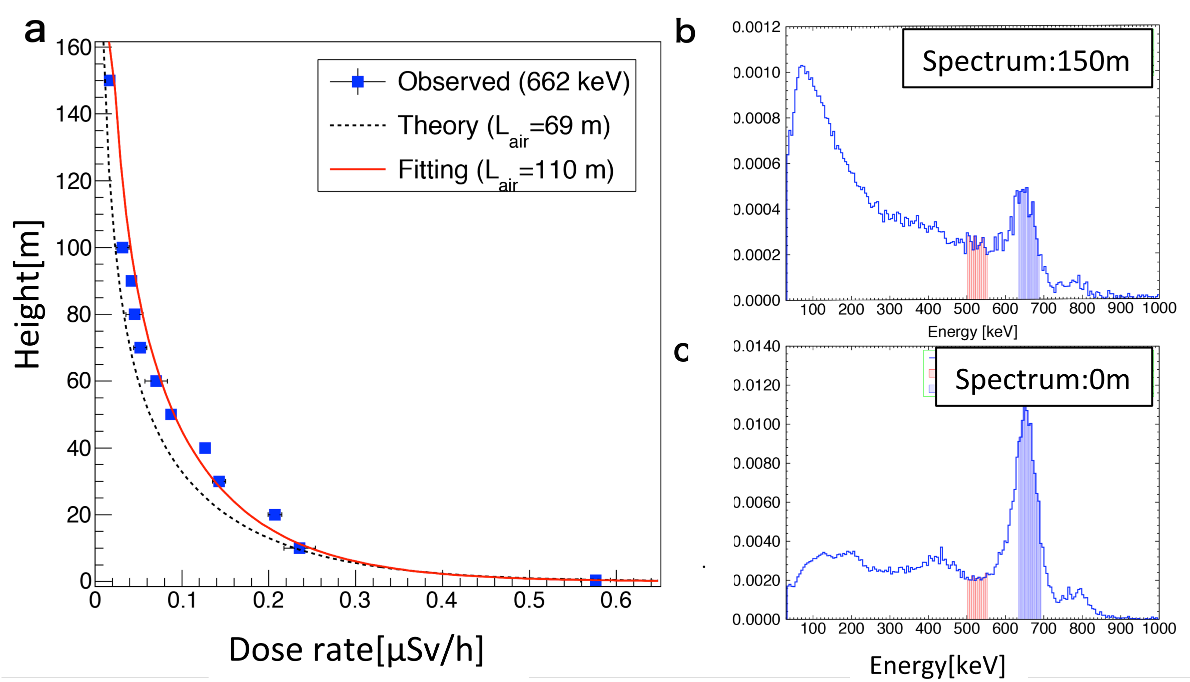
The relative dominance of each E-bands as compared with 662-keV
→ low-energy photons become more prominent as height increases

upward scattered gamma rays in the air causes a slow decay



Result

The height dependence of monochromatic 662-keV gamma rays



662 keV component
=**635-688 keV** – **500-553 keV**

Detector's FWHM 8%

multiple-scattering component

The best-fit L_{air} : 110 ± 5 m → almost twice the theoretical value

What is the cause of this discrepancy?

Discussion

Sources In the soil

137-Cs is distributed almost exponentially in the depth direction in soil (Kato et al. 2012)

$$A(z) = A(0) \cdot \exp\left(-\frac{z}{\beta}\right)$$

β: buffer depth

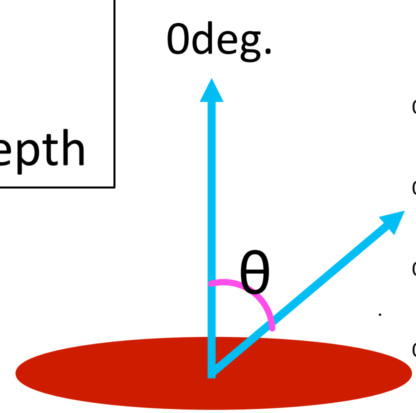
Collimate effect

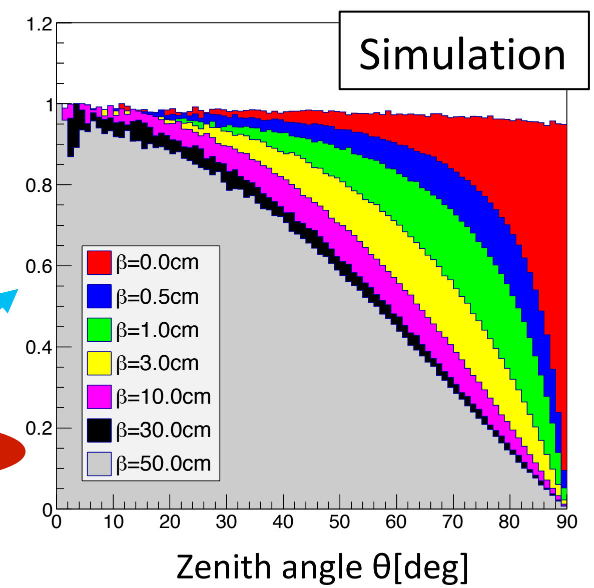
- Simulation
  Distribute 137-Cs in soil
  Measure at various buffer depth

The larger buffer depth

⇩

More collimated radiation in the vertical direction





Discussion

Estimation of the buffer depth

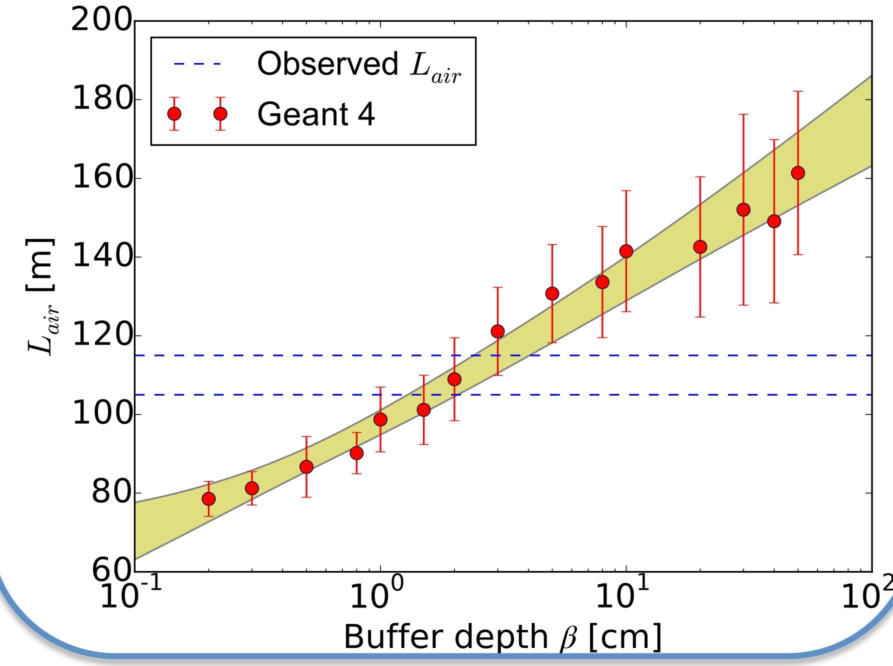
L-air increases as β increases
→ L-air increase by collimate effect

Best fit measurement data
L-air = 110 ± 5 m

estimate

Buffer depth : β = 2.5 ± 1.5cm

consistent with measured data



Conclusion

- We measured the height-dependence of the spectrum in the radiation contamination field using a drone for the first time

- We found that the aerial gamma-ray dose rate is much higher than that expected based on ground measuring

  1. the integrated dose includes contamination of upward scattered 662-keV gamma rays
  2. radiation from 137-Cs is vertically collimated because 137-Cs is buried in the soil with a buffer depth of β = 2.5±1.5 cm

- We can estimate the distribution of radioactive substances in the soil only through aerial mapping

Appendix

Appendix – Dose rate spectra at each height

0m 10m 20m

30m 40m 50m

60m 70m 80m

90m 100m 150m