Coded-aperture Gamma Imager for the Measurement of Ambient Dose Equivalent Rate

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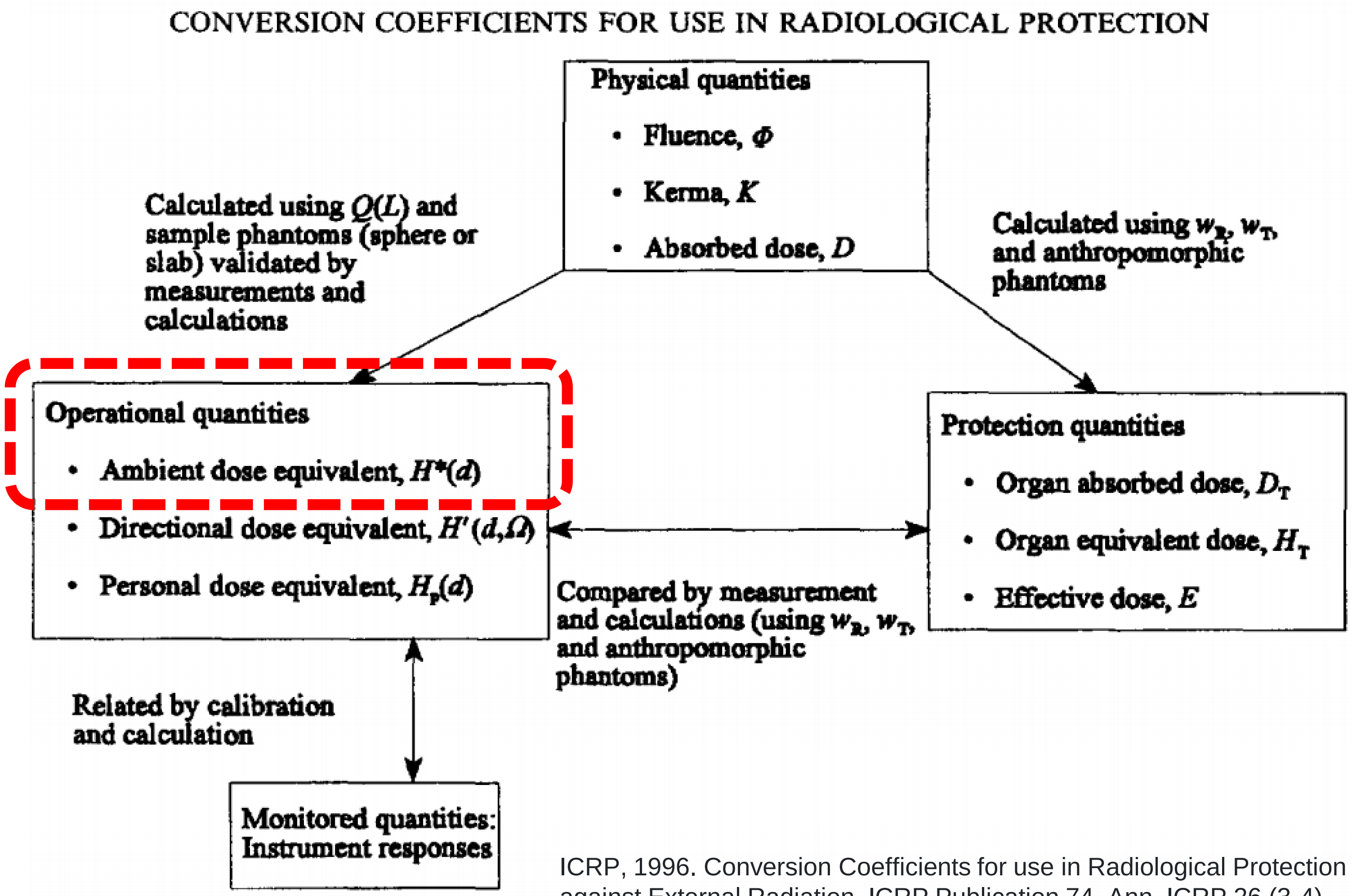
Introduction

Operational quantities for assessing effective dose in area monitoring

- For area monitoring, the appropriate operational quantities are the $H^*(10)$



ICRP, 1996. Conversion Coefficients for use in Radiological Protection against External Radiation. ICRP Publication 74. Ann. ICRP 26 (3-4).

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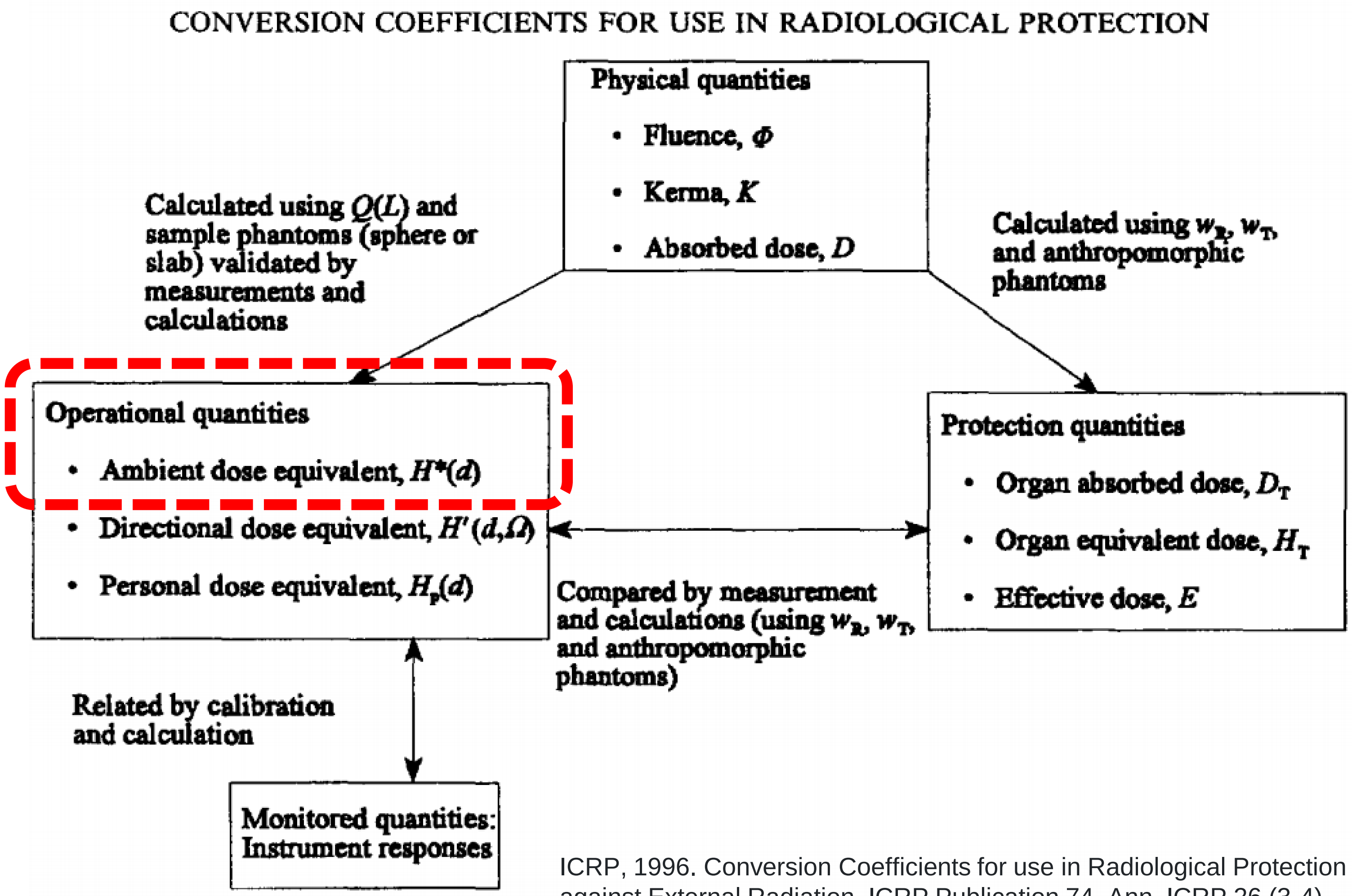

CONVERSION COEFFICIENTS FOR USE IN RADIOLOGICAL PROTECTION

Physical quantities
- Fluence, Φ
- Kerma, K
- Absorbed dose, D

Calculated using $Q(L)$ and sample phantoms (sphere or slab) validated by measurements and calculations

Calculated using w_R, w_T, and anthropomorphic phantoms

Operational quantities
- Ambient dose equivalent, $H^{*}(d)$
- Directional dose equivalent, $H'(d,\Omega)$
- Personal dose equivalent, $H_p(d)$

Protection quantities
- Organ absorbed dose, D_T
- Organ equivalent dose, H_T
- Effective dose, E

Compared by measurement and calculations (using w_R, w_T, and anthropomorphic phantoms)

Related by calibration and calculation

Monitored quantities:
Instrument responses

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Operational quantities for assessing effective dose in area monitoring

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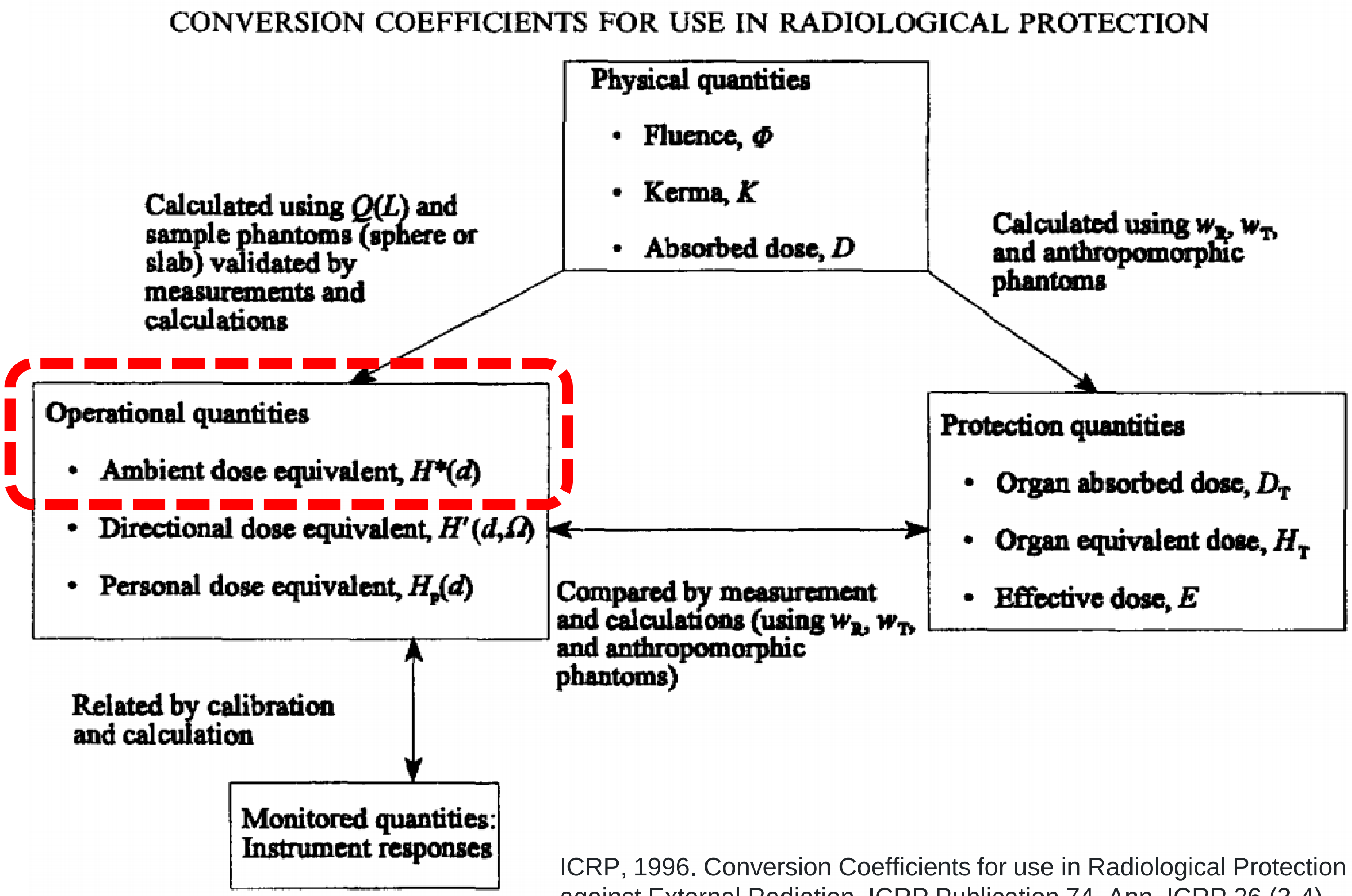
- These quantities were designed to estimate the protection quantities in existence at that time
- H*(10) can be measured by the ICRU sphere at a depth of 10 mm



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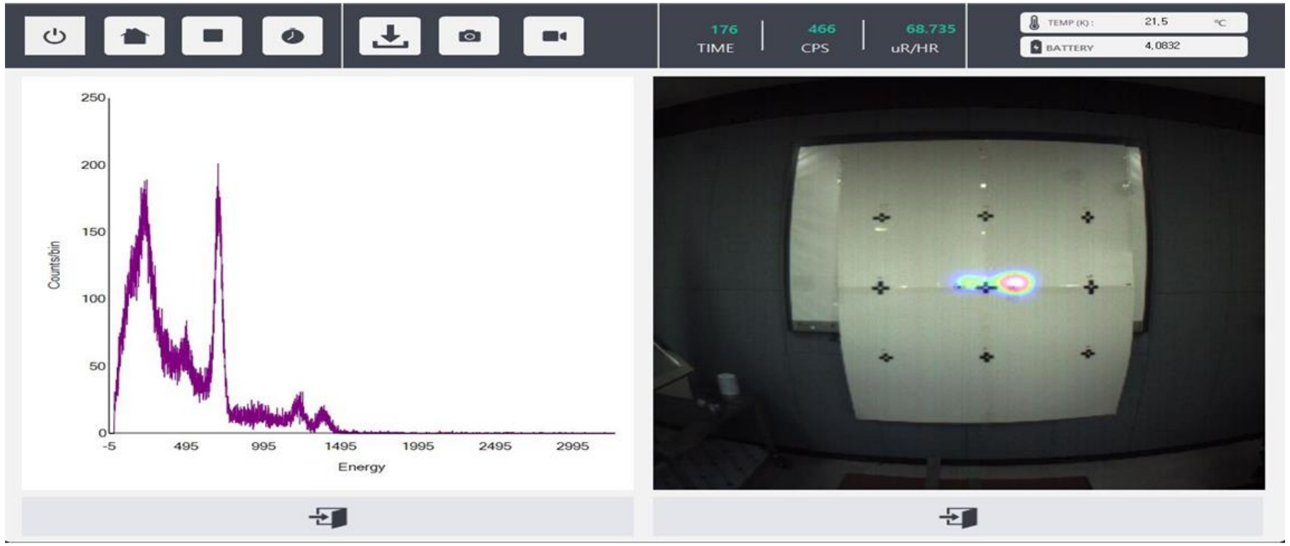
Introduction

EPSILON-G

(Energetic Particle Sensor for the Identification and Localization of Originating Nuclei)

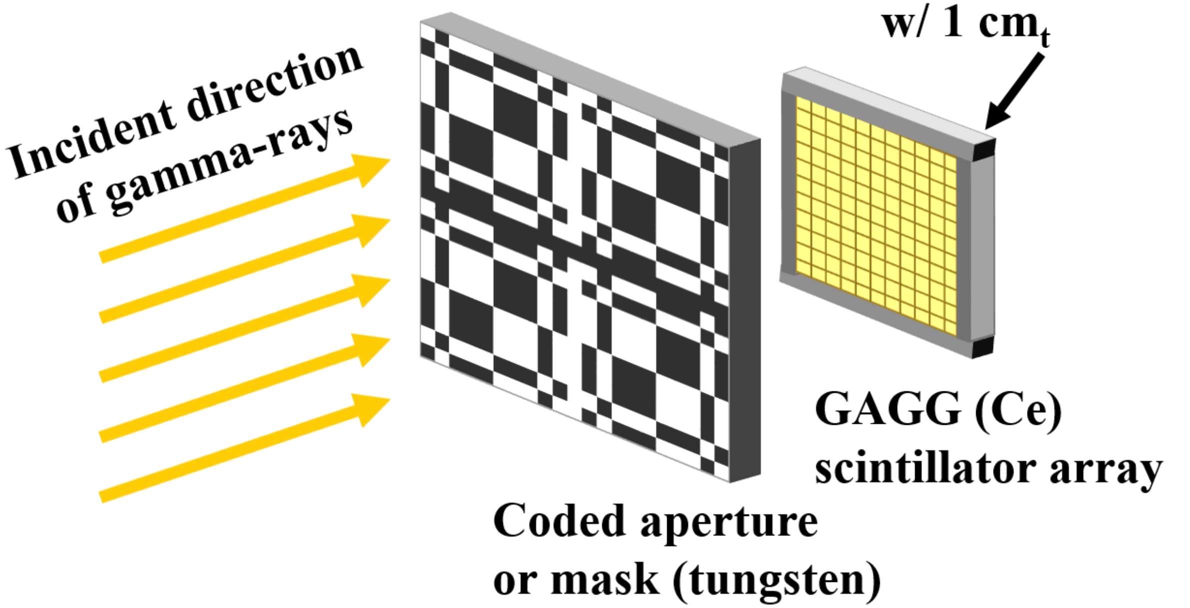


Specification

Technology	Coded-aperture
Field-of-view	45°
Energy Range	30 keV – 3 MeV
Energy Resolution	8% @ 662keV
Sensitivity	<2 sec. for 0.3 µSv/hr of ^{137}Cs
Operational temperature range	-20°C to 60°C
Size (weight)	104 x 144 x 197 mm (5.1 kg)
Sensor (intercept area)	GAGG:Ce & SiPM array (50.2 mm x 50.2 mm)

Methods

Conversion factors (MCNPX simulation) – (1) derivation of the response matrix



$$S_i = f\, M_{ij}\, \phi_j \quad \Rightarrow \quad M_{ij} = f^{-1} S_i\, \phi_j^{-1}$$

S_i : the measured spectrum or counts in the i-th energy in the energy spectrum

M_{ij} : the response matrix

ϕ_j : the gamma-ray fluence at an energy corresponding to the j-th channel

f : the open fraction that has 50% in the mask's pattern

Methods

Conversion factors (MCNPX simulation) – (2) converting the measured spectrum to the H*(10)

$$H^*(10) = \sum_{E_0=j} \left(\frac{H^*(10)}{\phi}\right)_j \phi_j$$

$$= \sum_{E_0=j} \left(\frac{H^*(10)}{\phi}\right)_j M_{ij}^{-1} f^{-1} \mathrm{S_i}$$

$$= \sum_{E_0=j} G_H S_i\,,$$

$$where\ G_H = \left(\frac{H^*(10)}{\phi}\right)_j M_{ij}^{-1} f^{-1}$$

- $\mathrm{H}^*(10)$: Ambient dose equivalent
- $\mathrm{H}^*(10)/\phi$: The conversion coefficient of the gamma-ray fluence to an ambient equivalent for gamma rays with an energy corresponding to the j-th channel
- $\mathrm{G_H}$: The conversion factor for the $\mathrm{H}^*(10)$

Methods

- **Conversion factors (MCNPX simulation) – (2) converting the measured spectrum to the $H^*(10)$**

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$$= \sum_{E_0=j} \left(\frac{H^*(10)}{\phi}\right)_j M_{ij}^{-1} f^{-1} \mathrm{S_i}$$

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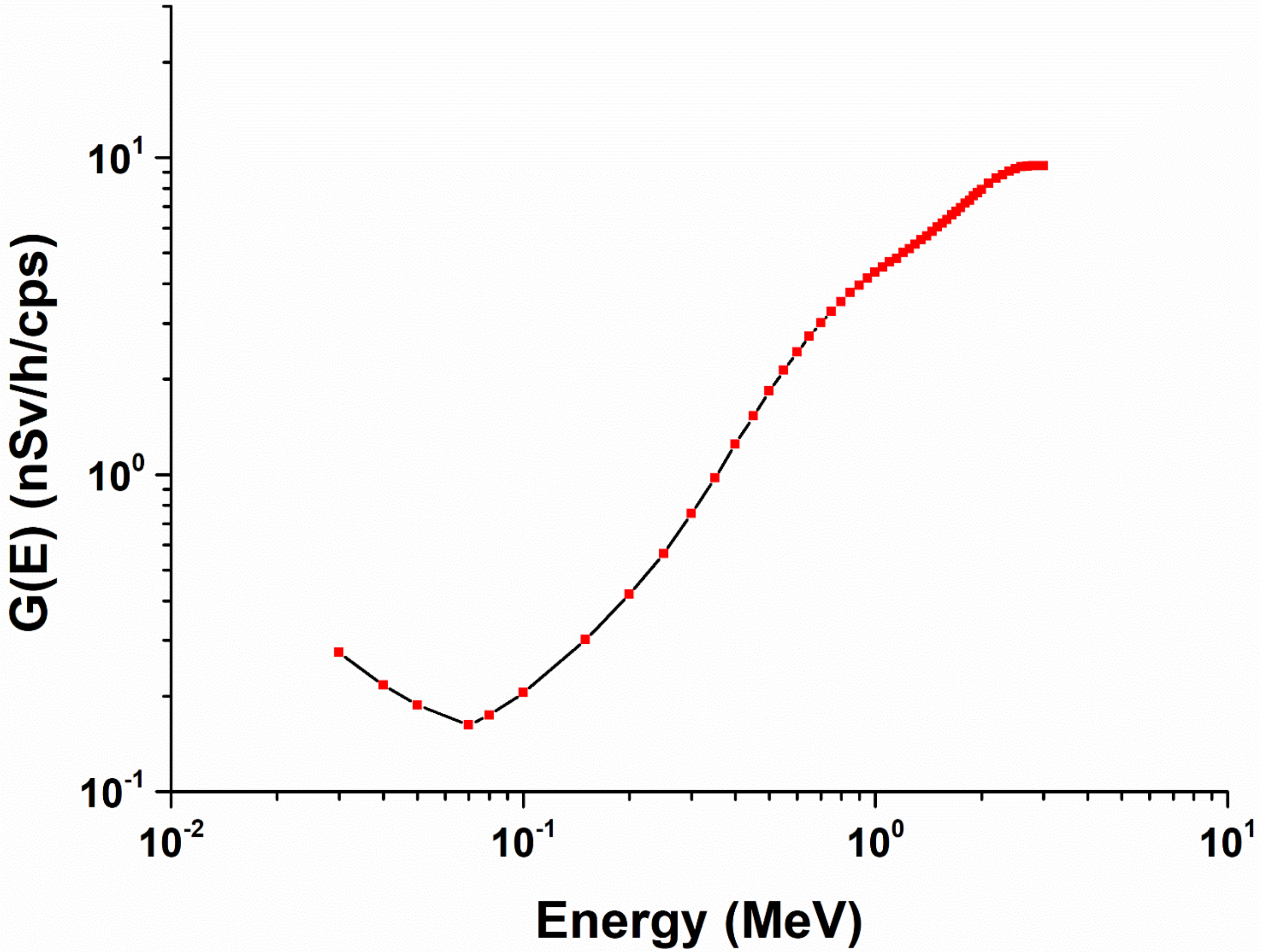

Methods

Conversion factors (MCNPX simulation) – (3) converting the measured spectrum to an air kerma (K_a)

$$K_a = \sum_{E_0=j} \left(\frac{K_a}{\phi}\right)_j \phi_j$$

$$= \sum_{E_0=j} \left(\frac{K_a}{\phi}\right)_j M_{ij}^{-1} f^{-1} \mathrm{S_i}$$

$$= \sum_{E_0=j} G_K S_i \,,$$

$$where\ G_K = \left(\frac{K_a}{\phi}\right)_j M_{ij}^{-1} f^{-1}$$

- $\mathrm{K_a}$: Air kerma
- $\mathrm{K_a}/\phi$: the conversion coefficient of the gamma-ray fluence to an air kerma for gamma rays with an energy corresponding to the j-th channel
- $\mathrm{G_k}$: the conversion factor for an air kerma

Methods

- **Conversion factors (MCNPX simulation) – (3) converting the measured spectrum to an air kerma (K_a)**

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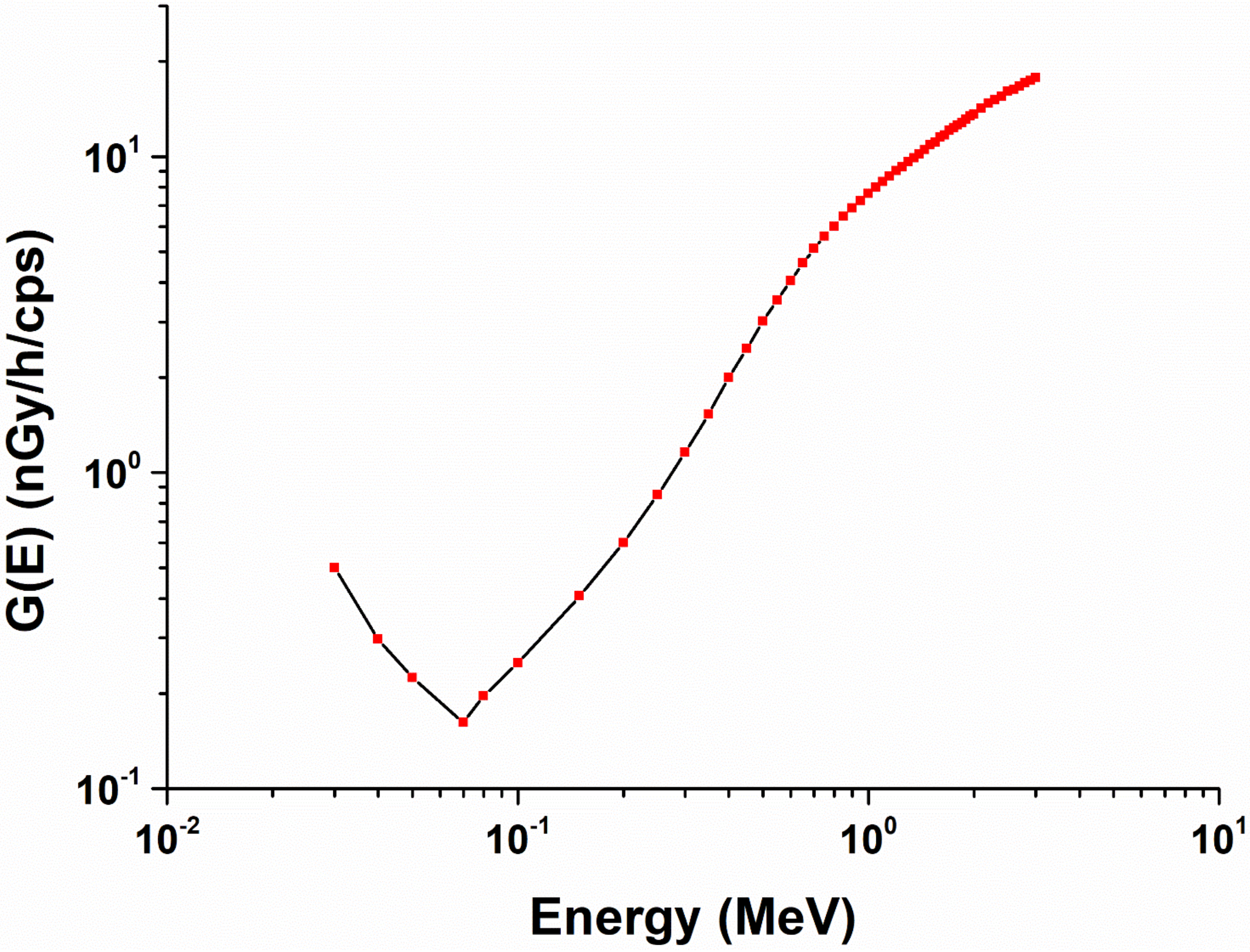
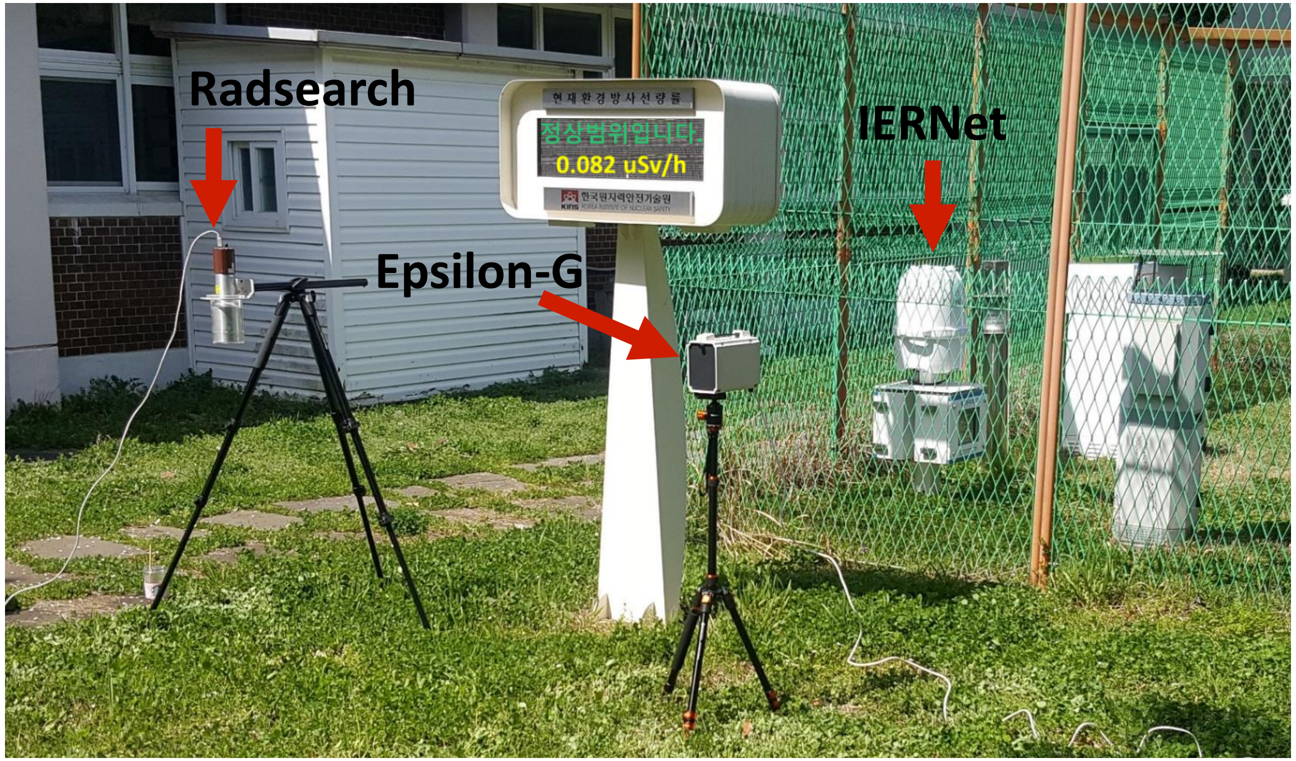


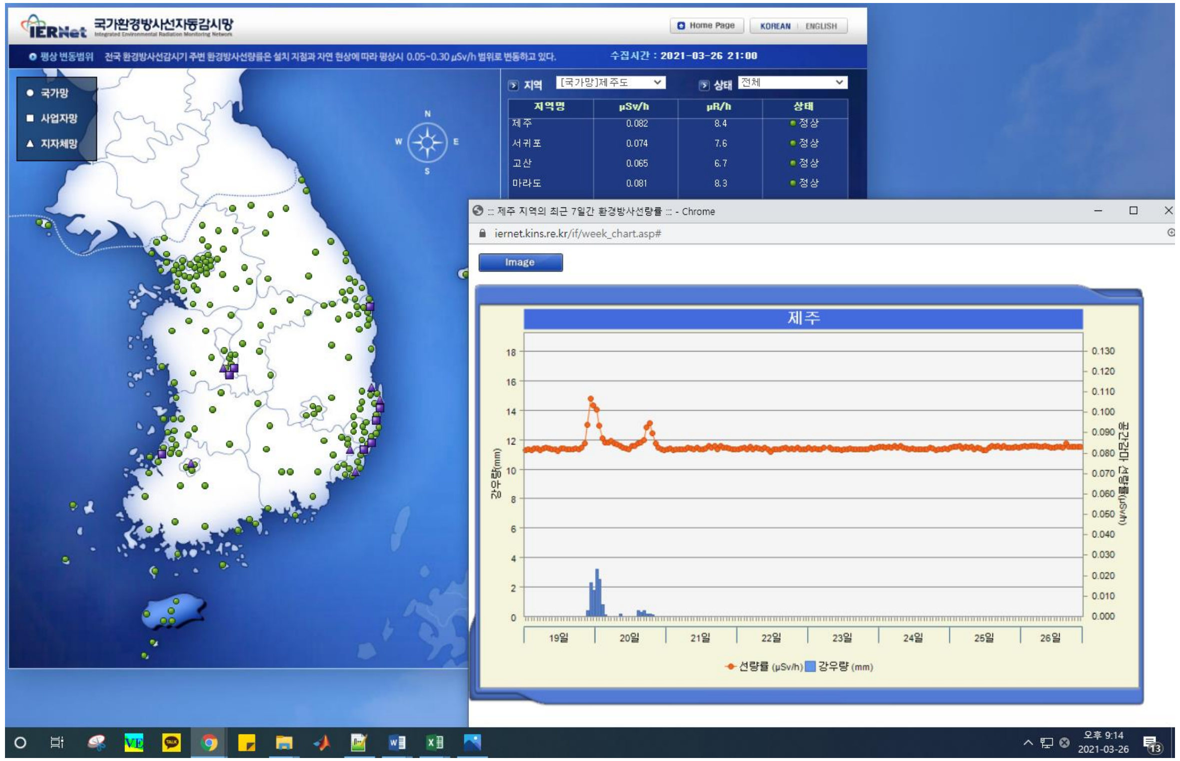
Results and discussion

- **Comparison of K evaluated from the EPSILON-G with K theoretically calculated, including the corresponding $H^*(10)$**

Isotope	Air kerma rate (nGy/h)		Relative difference (%)	Ambient dose equivalent rate (nSv/h)
	$K_{\text{theoratically calculated}}$	$K_{\text{Epsilon−G}}$		$H^*(10)_{\text{Epsilon-G}}$
Ba-133 (5.67 µCi)	119.21	112.34 ± 4.98	-7.40%	148.30 ± 5.48
Cs-137 (20.08 µCi)	226.60	237.96 ± 5.85	4.77%	292.91 ± 6.38
Na-22 (0.93 µCi)	107.28	112.27 ± 6.02	4.44%	134.27 ± 6.48

Results and discussion





평상 변동범위 전국 환경방사선감시기 주변 환경방사선량률은 설치 지점과 자연 현상에 따라 평상시 0.05~0.30 μSv/h 범위로 변동하고 있다.

수집시간 : 2021-03-26 21:00

지역 [국가망]제주도

상태 전체

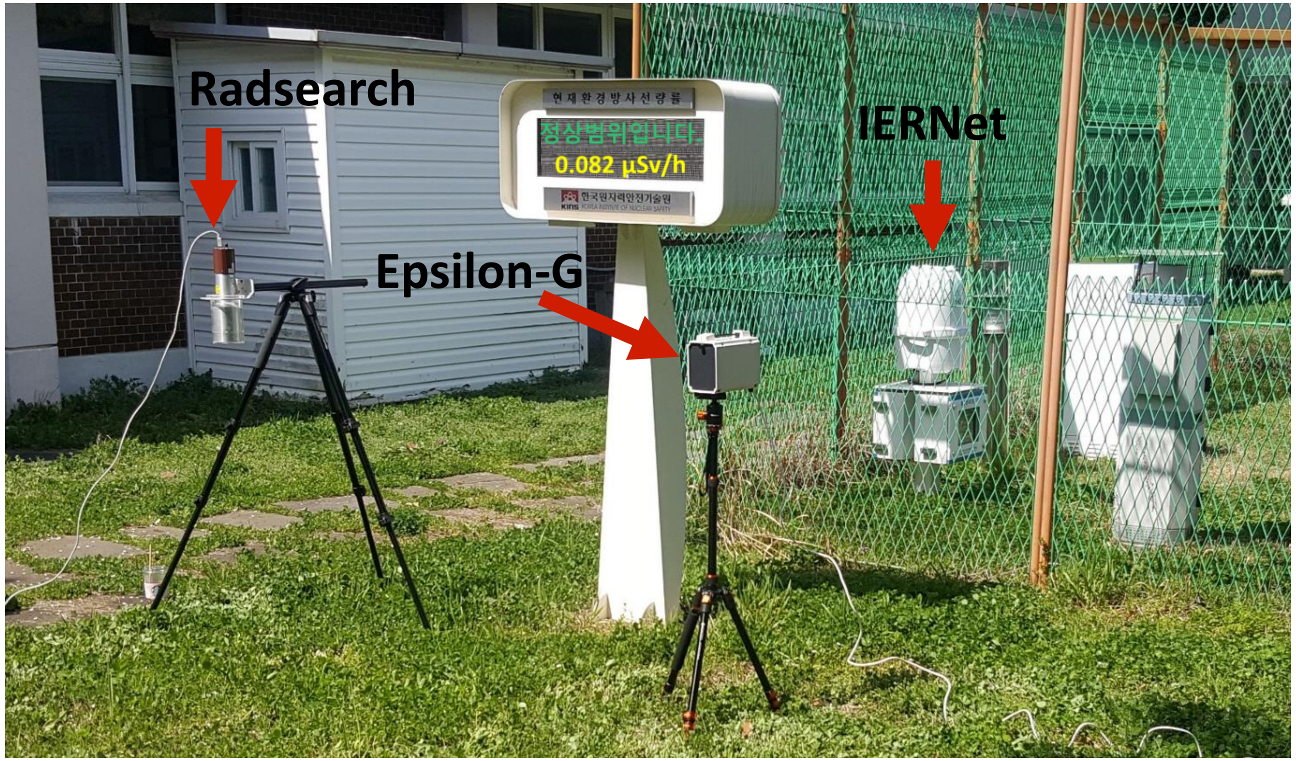
지역명	μSv/h	μR/h	상태
제주	0.082	8.4	● 정상
서귀포	0.074	7.6	● 정상
고산	0.065	6.7	● 정상
마라도	0.081	8.3	● 정상

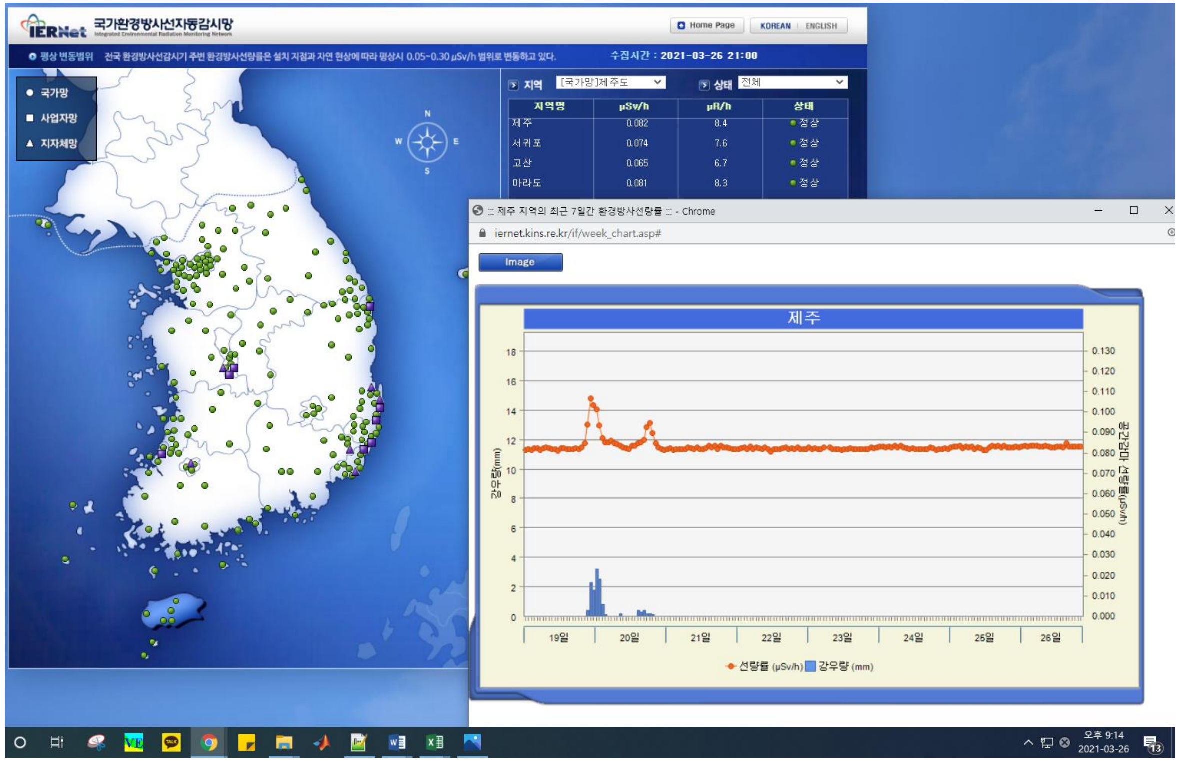
::: 제주 지역의 최근 7일간 환경방사선량률 ::: - Chrome

iernet.kins.re.kr/if/week_chart.asp#

Measurement time (30 min)	Epsilon-G facing an user	Epsilon-G facing the ground	3” x 3” NaI(Tl) (Backpack survey, Radsearch)	High pressurized ion chamber (IERNet)
$H^{*}(10)$ (μSv/h)	0.073 ± 0.003	0.076 ± 0.004	0.076	0.082

Results and discussion





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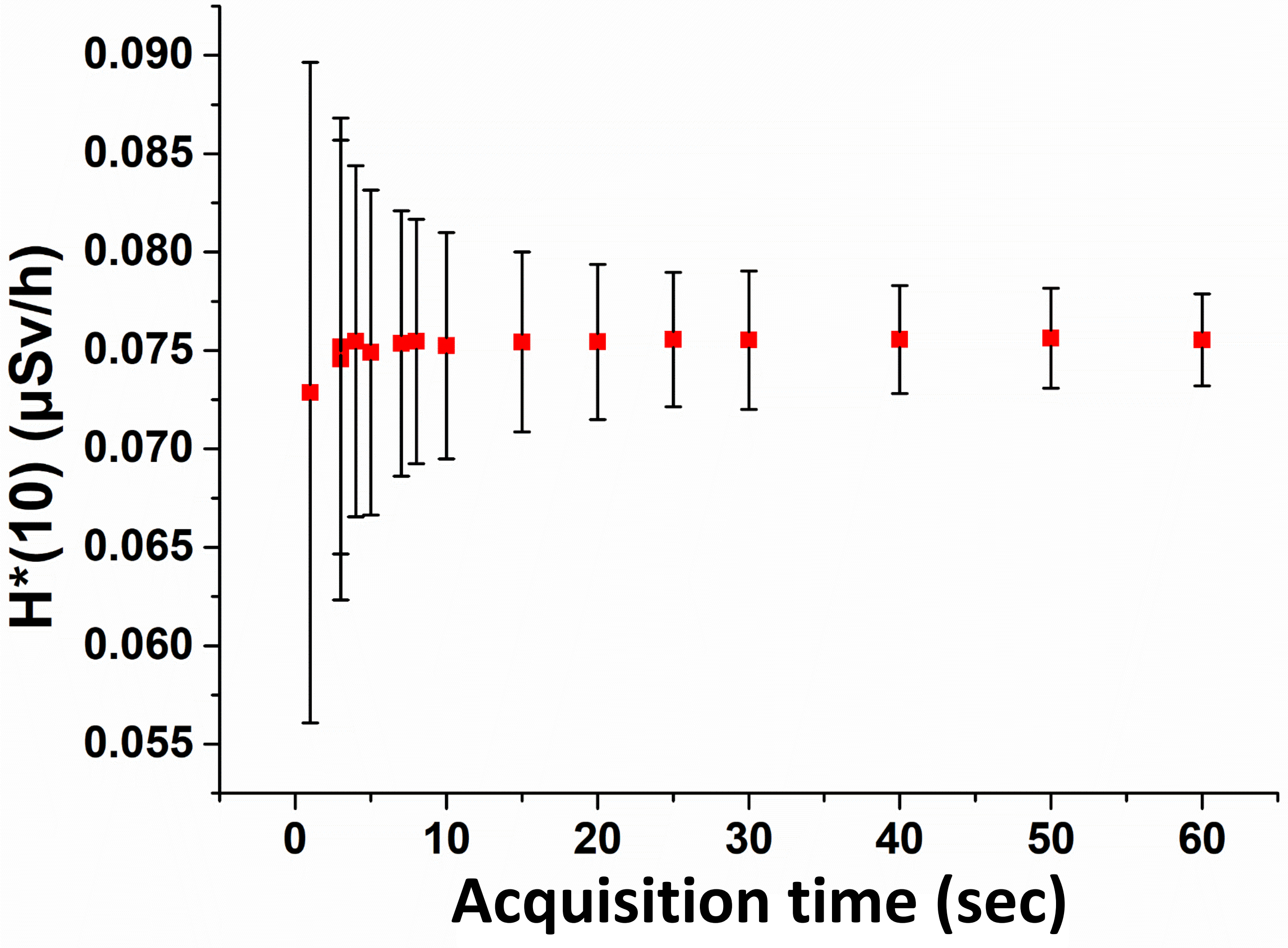
✓The relative difference is 7.9% in the case of Epsilon-G facing the ground

Results and discussion

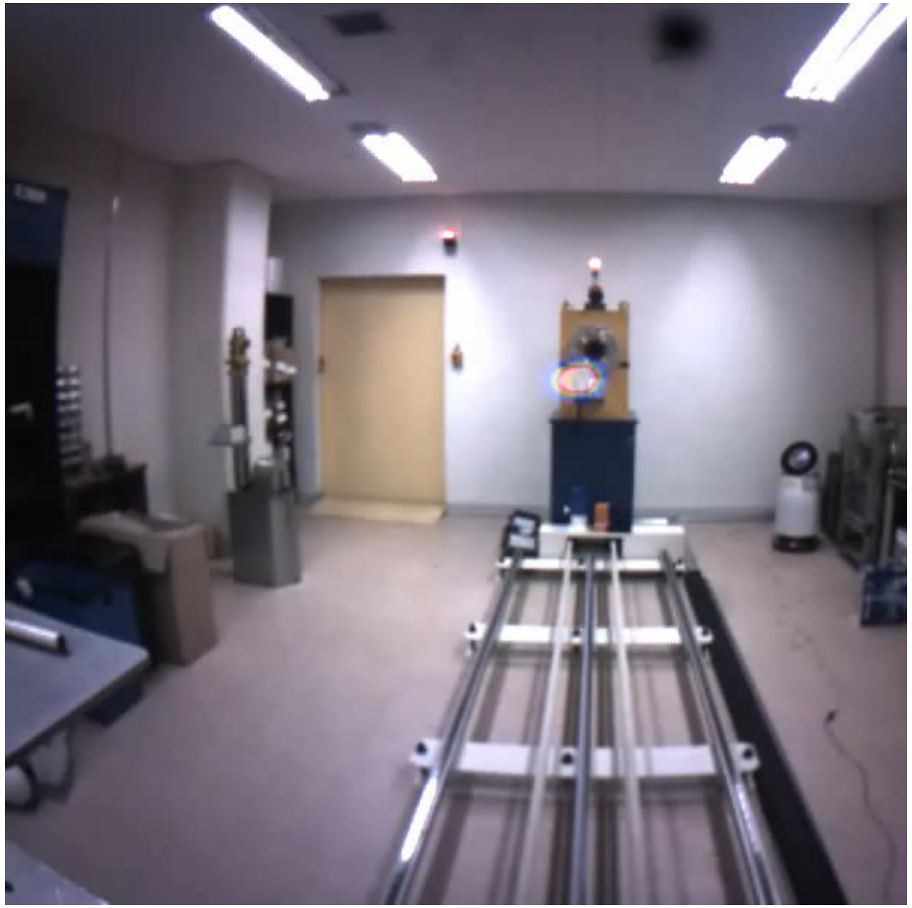
- **Comparison of the $H^{*}(10)$ obtained by EPSILON-G, which is evaluated depending on the acquisition time**



Results and discussion

- **Estimation of a maximum dose rate that can be obtained by EPSILON-G**

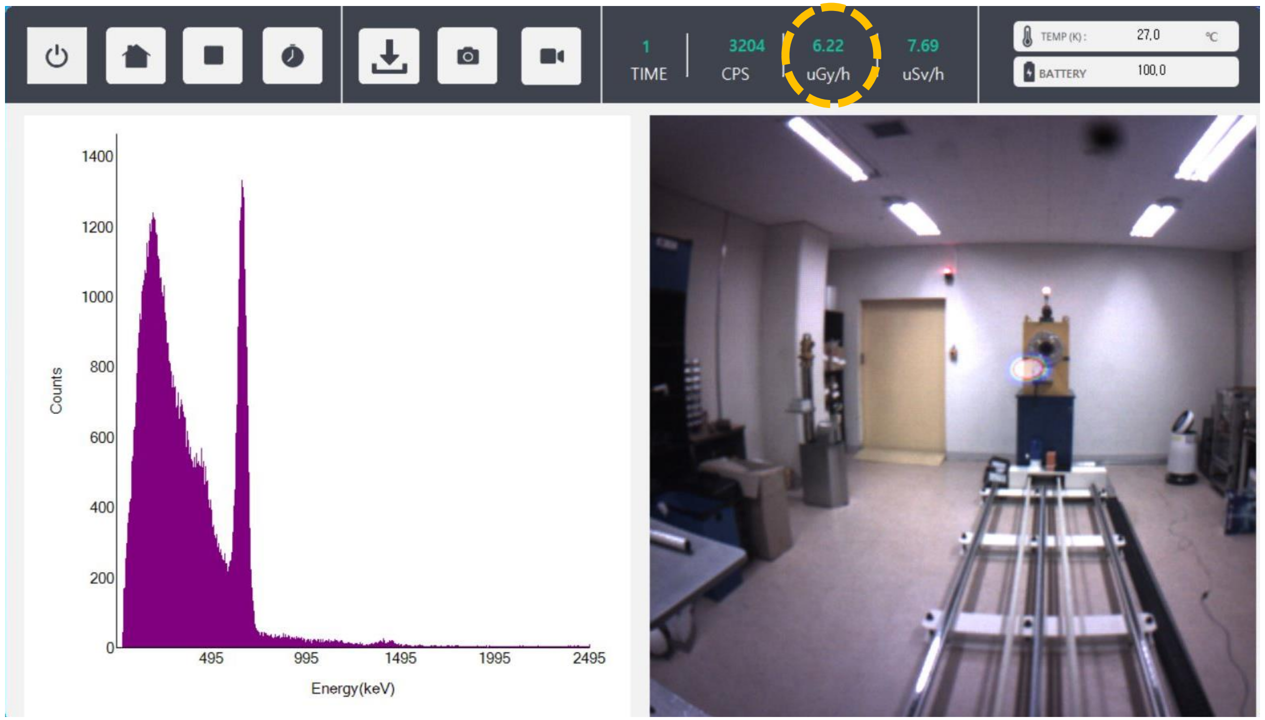
Gamma-ray imaging in rea-time
for Cs-137 (6 μGy/h)



Results and discussion

Estimation of a maximum dose rate that can be obtained by EPSILON-G

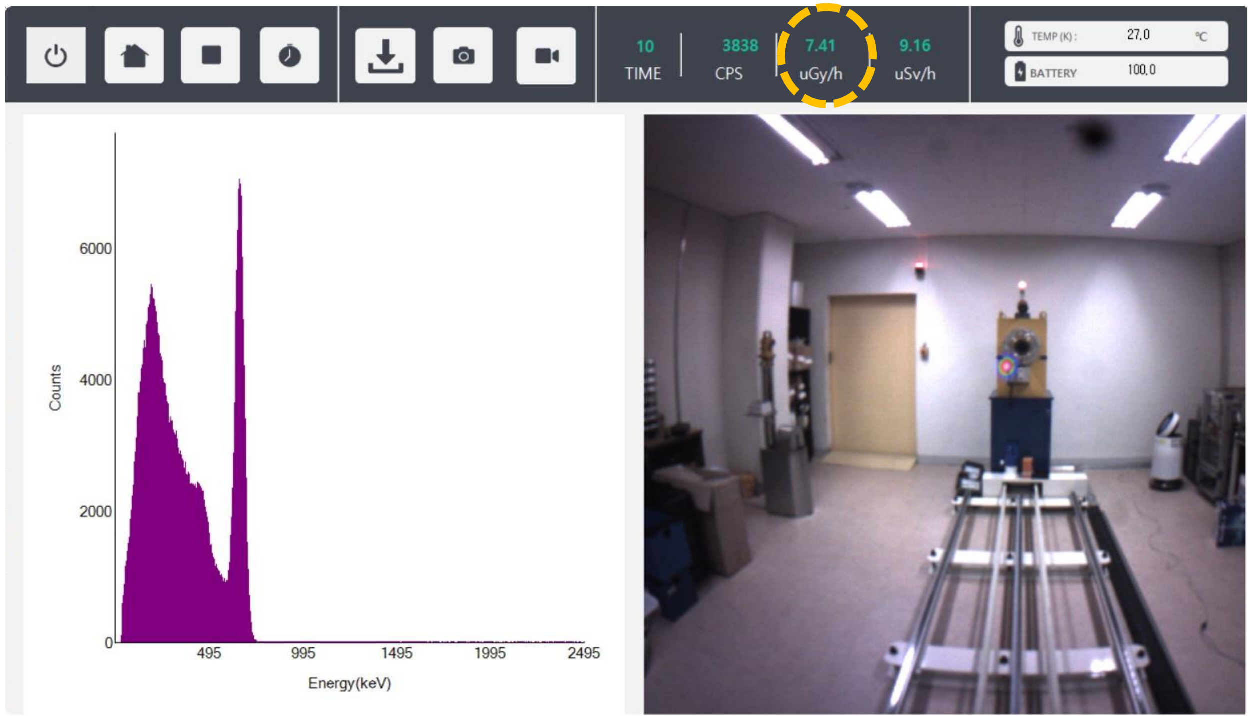
Cs-137
(K_a = 6 μGy/h)



1 TIME | 3204 CPS | 6.22 uGy/h | 7.69 uSv/h

TEMP (K) : 27.0 ℃
BATTERY 100.0

Cs-137
(K_a = 7 μGy/h)



10 TIME | 3838 CPS | 7.41 uGy/h | 9.16 uSv/h

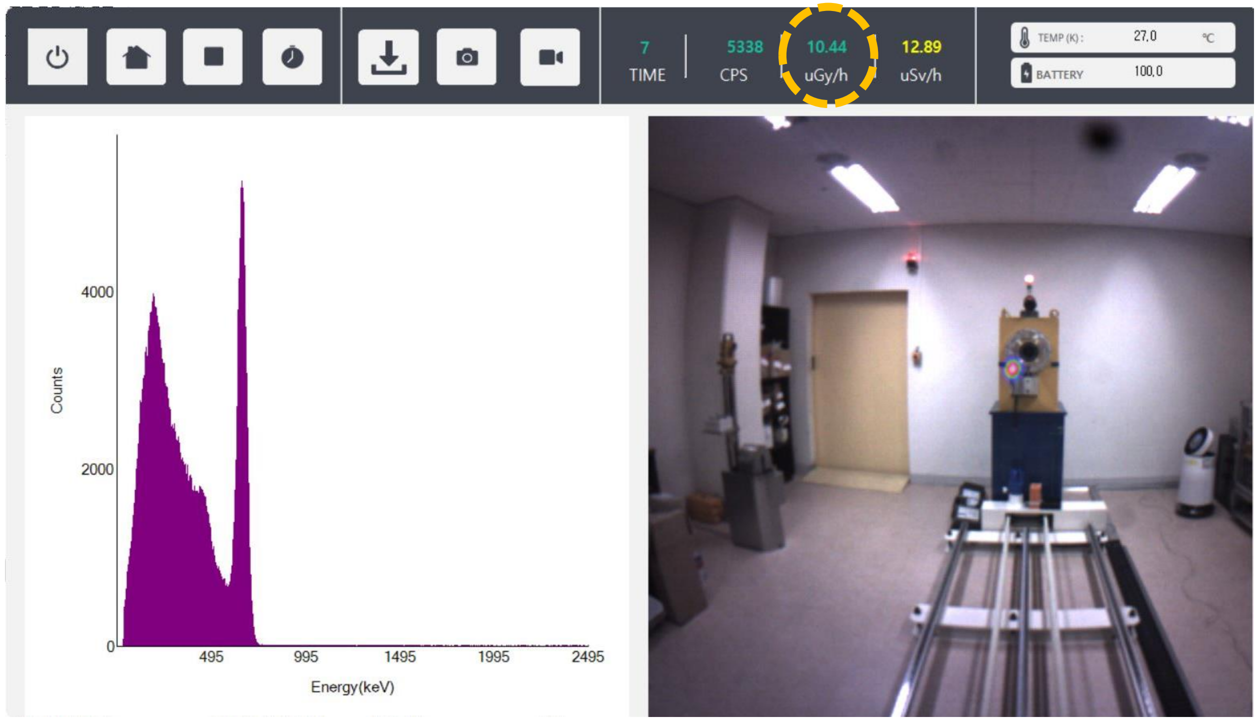
TEMP (K) : 27.0 ℃
BATTERY 100.0

※ BKG (0.08 – 0.15 μGy/h)

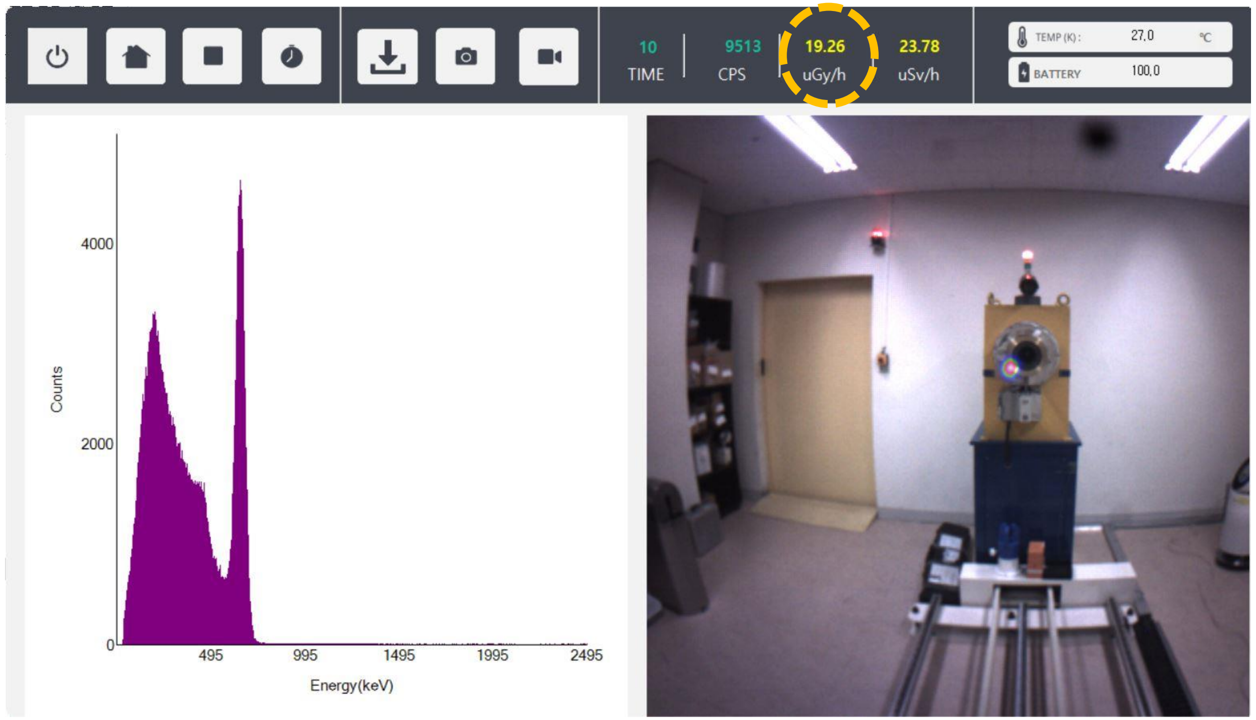
Results and discussion

Estimation of a maximum dose rate that can be obtained by EPSILON-G

Cs-137
(K_a = 10 μGy/h)


7 TIME
5338 CPS
10.44 uGy/h
12.89 uSv/h
TEMP (K): 27.0 ℃
BATTERY 100.0

Cs-137
(K_a = 20 μGy/h)

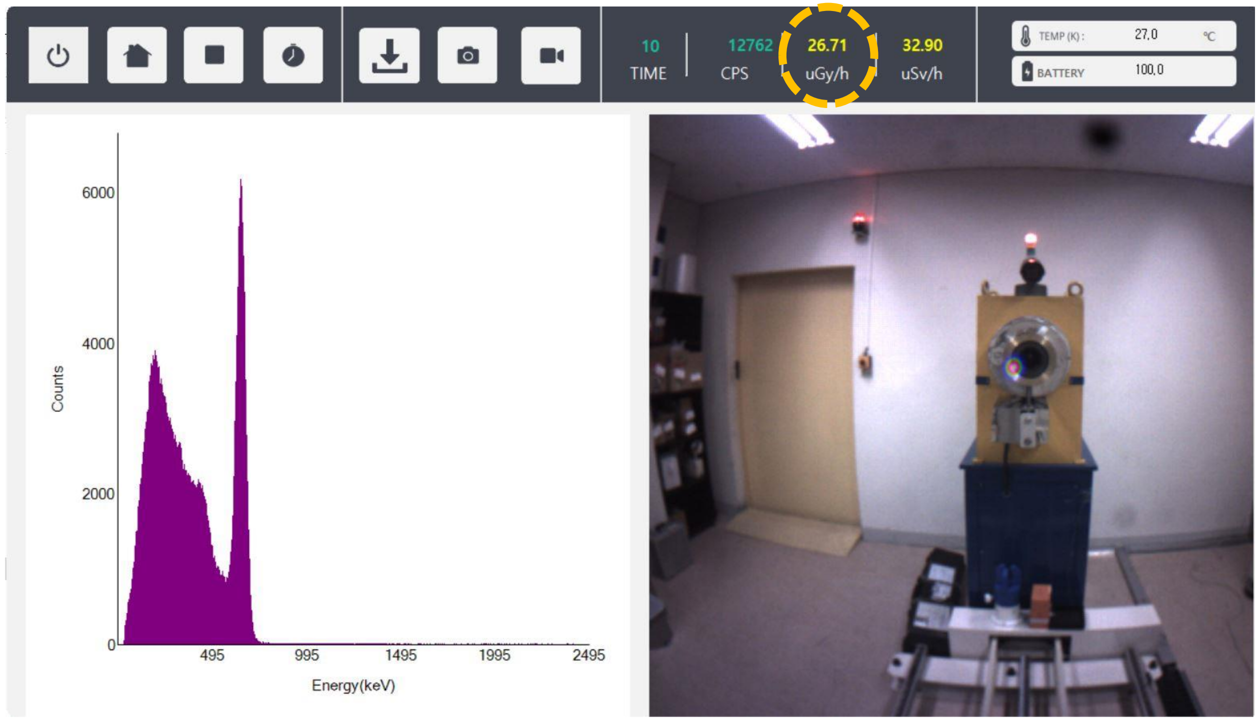

10 TIME
9513 CPS
19.26 uGy/h
23.78 uSv/h
TEMP (K): 27.0 ℃
BATTERY 100.0

※ BKG (0.08 – 0.15 μGy/h)

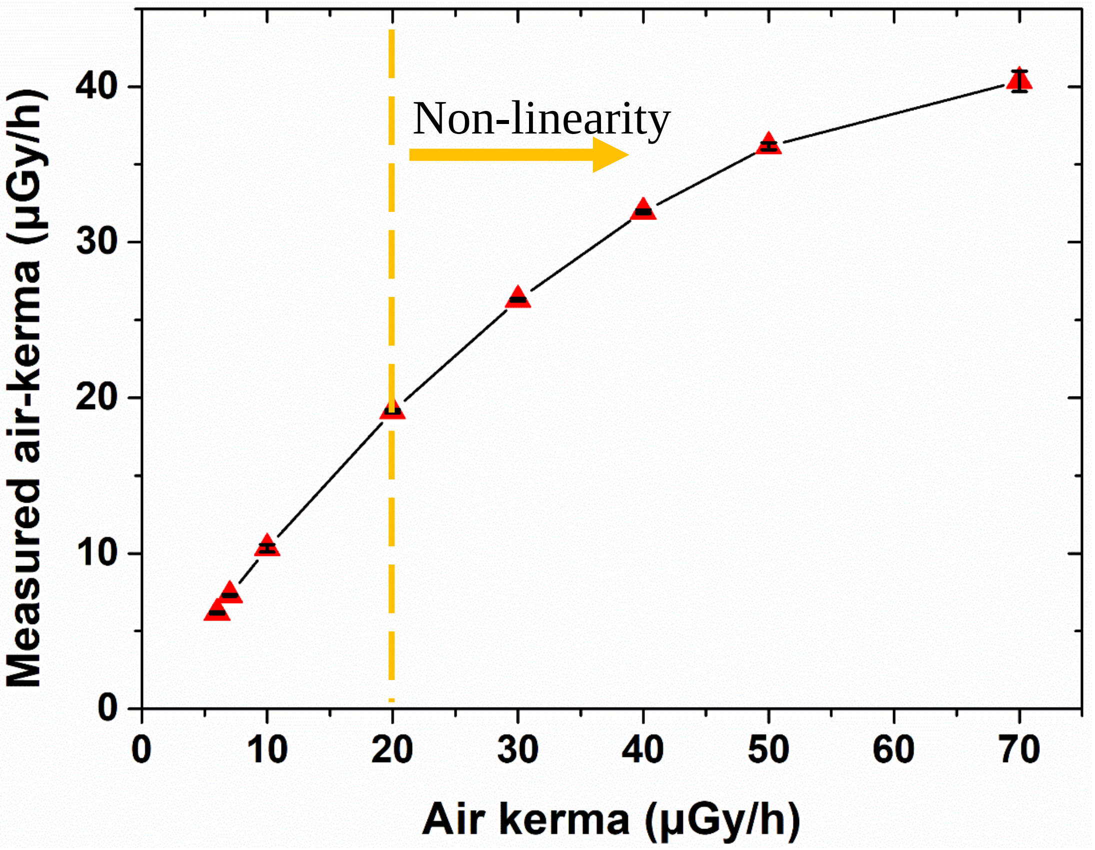
Results and discussion

Estimation of a maximum dose rate that can be obtained by EPSILON-G

Cs-137
(K_a = 30 μGy/h)



10 TIME
12762 CPS
26.71 uGy/h
32.90 uSv/h
TEMP (K) : 27.0 ℃
BATTERY 100.0



※ BKG (0.08 – 0.15 μGy/h)

Conclusion and Future Works

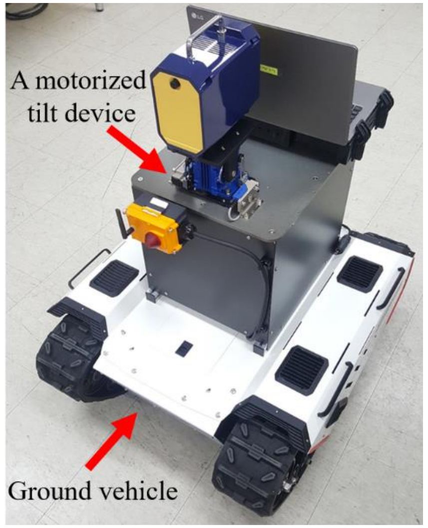
Evaluation of $H^*(10)$ using Epsilon-G

- ✓ Can provide a radionuclide distribution map
- ✓ Can provide $H^*(10)$ as the operational quantity in area monitoring

Future works

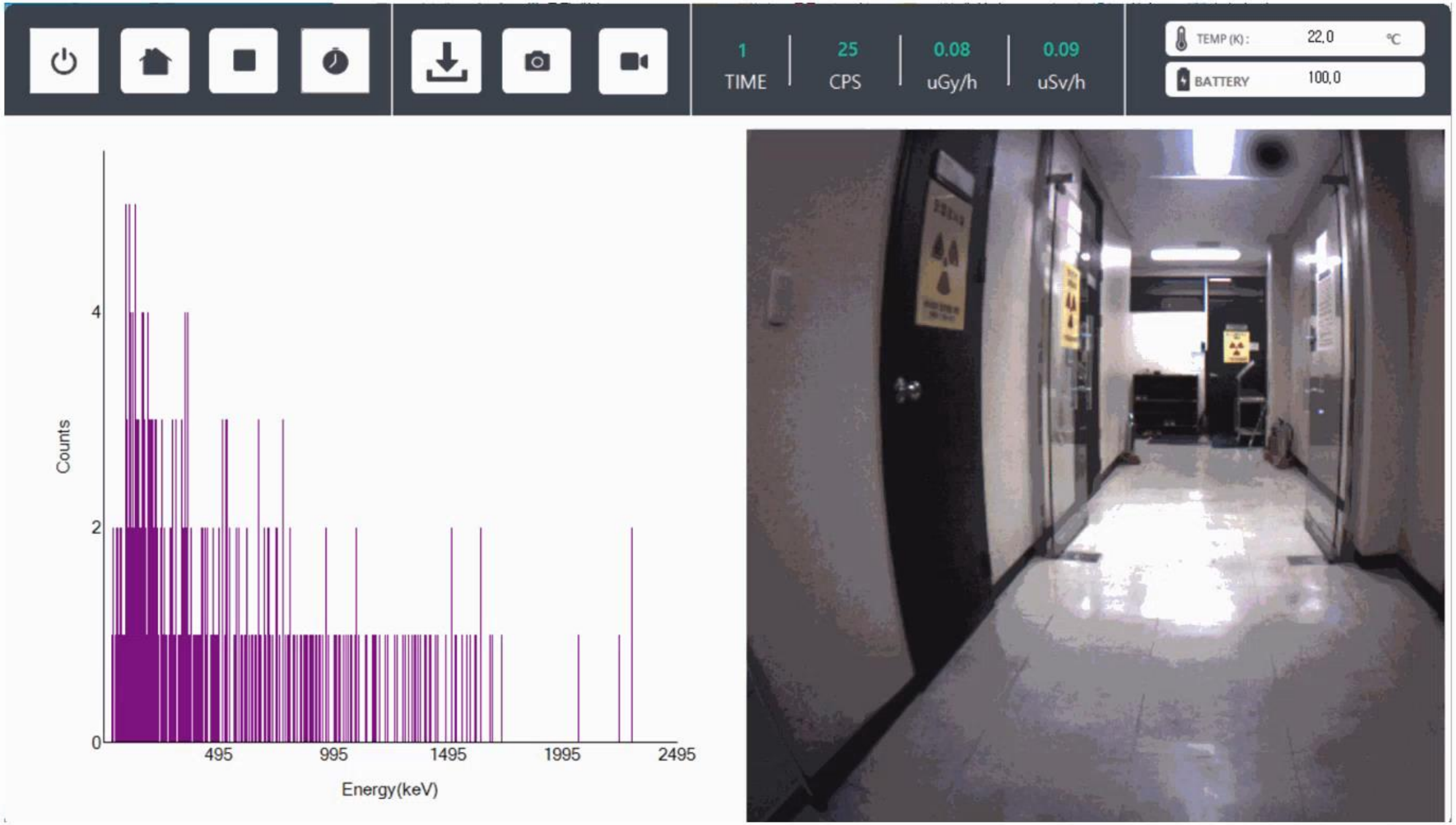
- ✓ Application of an unmanned robotic system with Epsilon-G for radiation safety diagnosis based on synchronization of digital coordinates using GPS or LIDAR

Coded-aperture Gamma Imager for the Measurement of Ambient Dose Equivalent Rate



Thank you for your attention!

Application of Epsilon-G



1 TIME

25 CPS

0.08 uGy/h

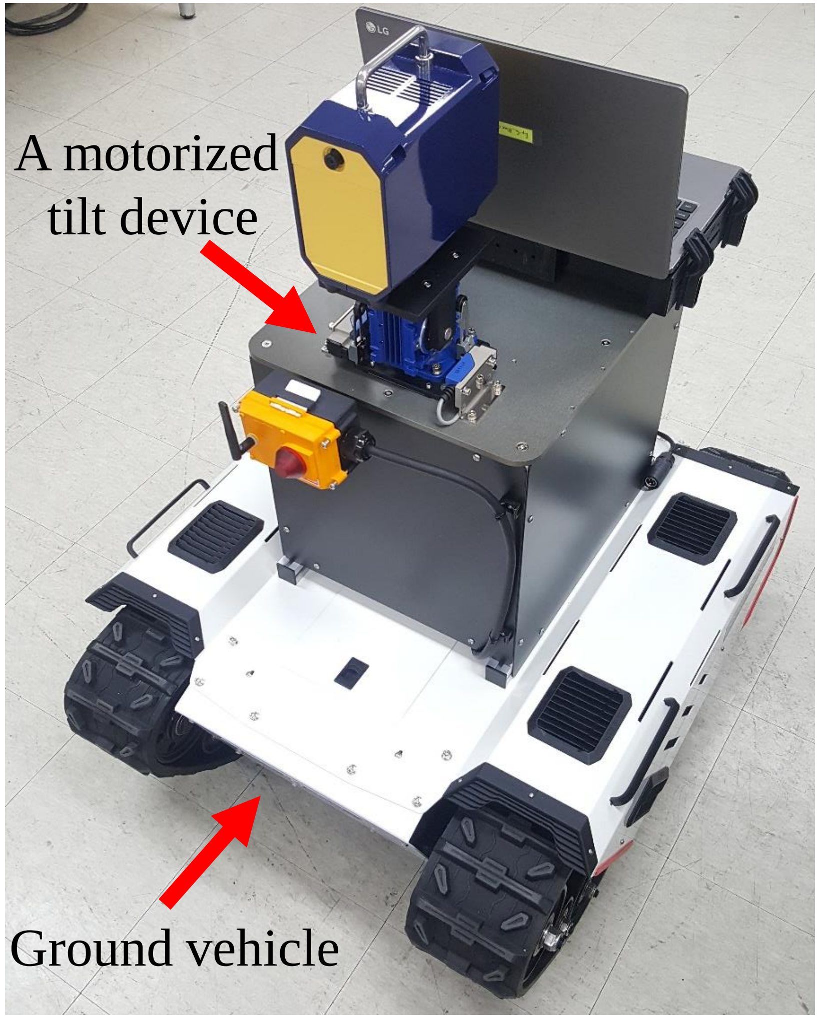
0.09 uSv/h

TEMP (K) : 22.0 ℃

BATTERY 100.0

Application of Epsilon-G

Illustration of use examples of an unmanned ground vehicle



Specification

Dimensions (W x H x D)	1023 mm × 780 mm × 900 mm
Vehicle Weight	130 kg
Battery	48V/30Ah
Max Travel (w/o loading)	10 km
Climbing Capacity	36° Can Climb Stairs
Horizontal Rotation Capacity	360°
Vertical Tilt Capacity of a Motor	± 30°