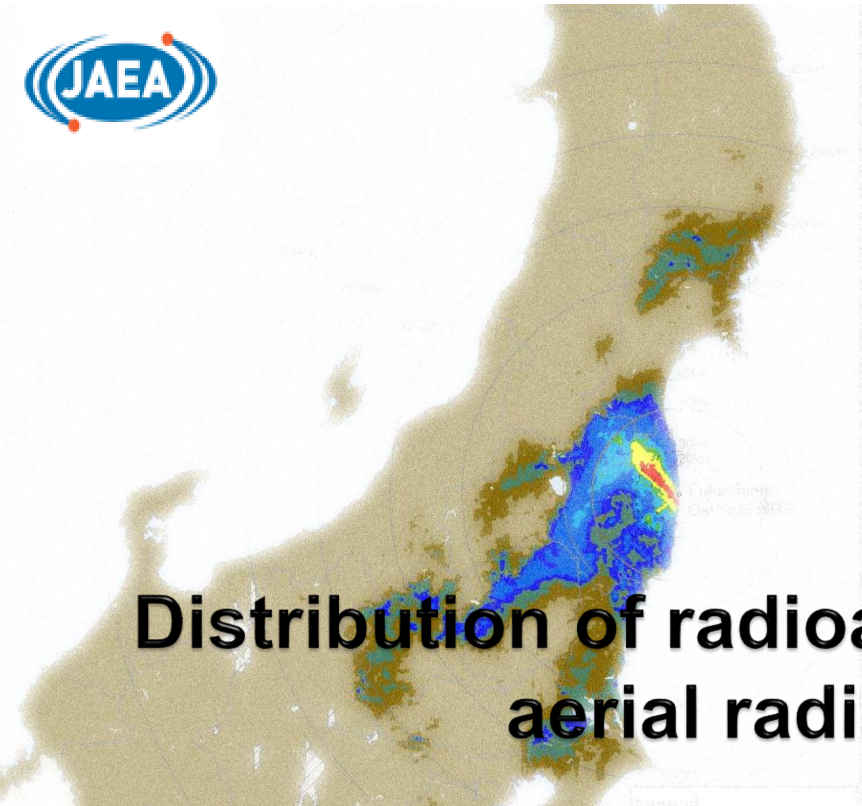


Distribution of radioactive cesium measured by aerial radiation monitoring

Yukihisa SANADA, Atsuya KONDO, Takeshi Sugita, and Tatsuo Torii

Headquarters of Fukushima Partnership Operation,
Japan Atomic Energy Agency (JAEA)

PIXEL2012

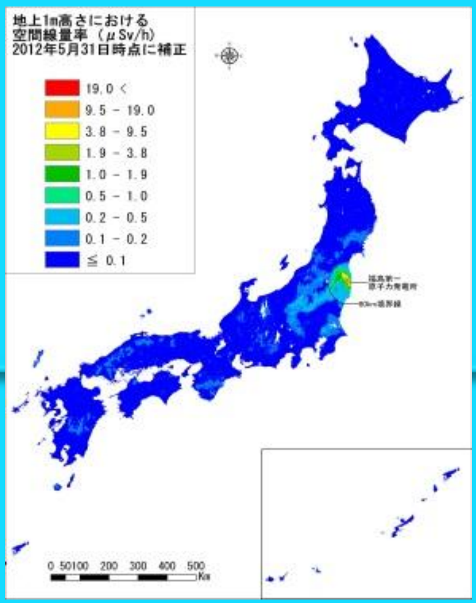
JAEA / Fukushima Environmental Safety center

Remote radiation sensing Group

Concept：Research and development about the technology which measures and visualizes radiation distantly

Approach from the sky (widely and quickly!)

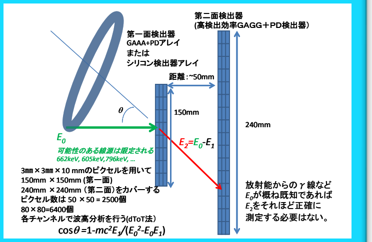
Aerial radiation monitoring



Autonomous unmanned Helicopter and Airplane

Joint of JAEA and JAXA

Compton Camera

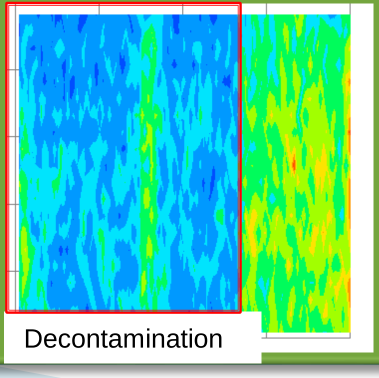


Compton Camera+AUH

JST competitive research funding
Furukawa Co.Ltd・Uni. Tokyo and Tohoku

Approach from the ground
（Effective of Decontamination）

・Plastic Scintillation Fiber (PSF)



JST competitive research funding
.JREC Co. Ltd. and JAEA

etc.

- ・Radioactivity measurement of waterbed
- ・In-situ Ge measurement

Outline

- Achievement of aerial radiation monitoring (ARM)

- ARM system (ARMS)

- Analysis method
  - Conversion to dose rate at 1 m on the ground
  - Discrimination of γ-ray from the natural nuclides

- Result and discussion
  (Map of dose rate and radiocesium deposition)

- Summary

Achievement of aerial radiation monitoring (ARM)

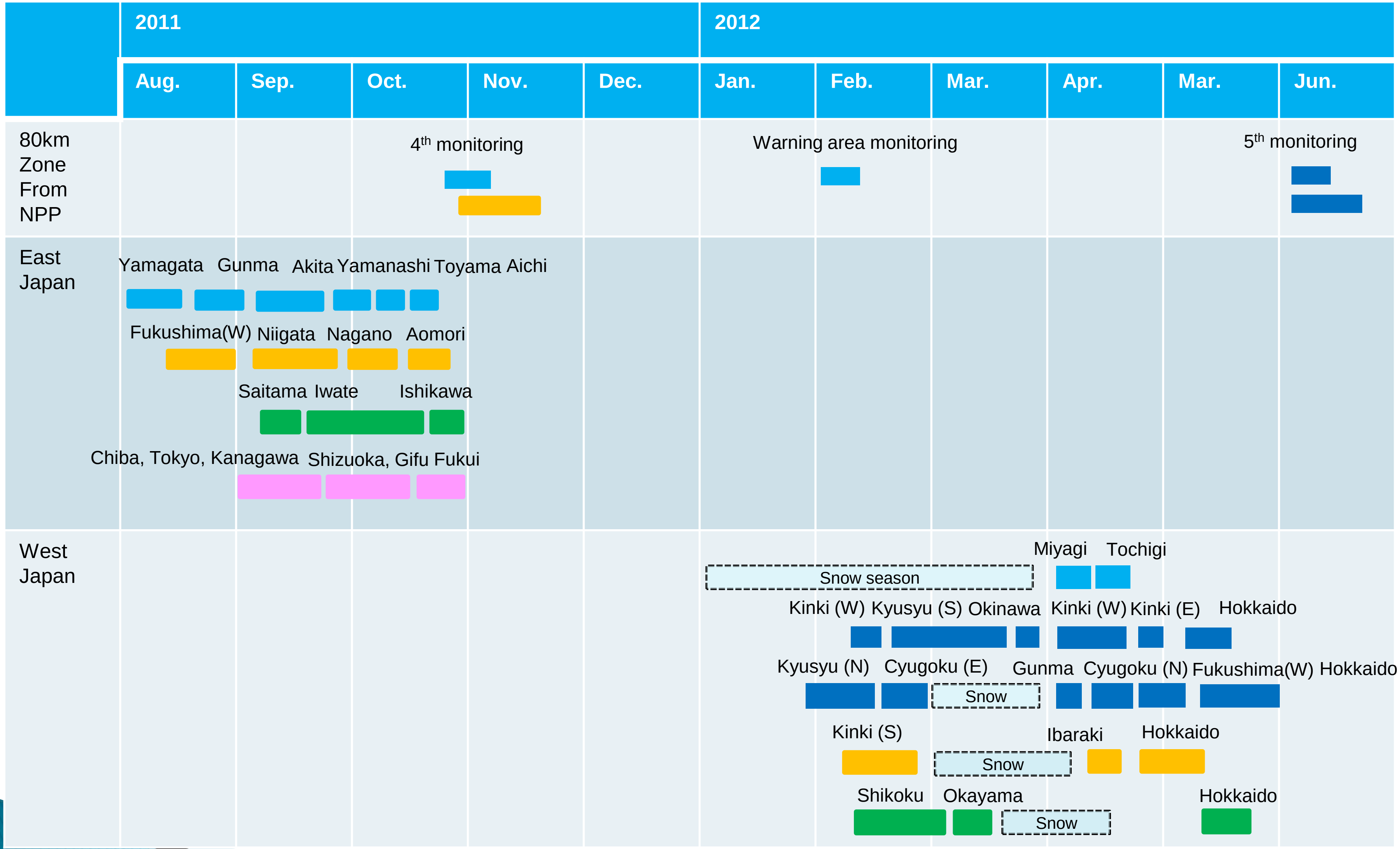
- Mar. 25, 2011 MEXT Press release of a plan for aerial radiation monitoring
- Apr. 5, 2011 **<1st monitoring>** 60km zone from the NPP (DOE) + 60-80km (NUSTEC)
- May 17, 2011 **<2nd monitoring>** 80-100km zone from the NPP (NUSTEC)
- May 30, 2011 **<3rd monitoring>**
  40km zone from the NPP(NUSTEC + JAEA) + 40-80km (NUSTEC)
- Jun. 21, 2011 Miyagi-pref., Tochigi-pref., and Ibaraki-pref. (NUSTEC + JAEA)

*2：DOE system in helicopter of the air-rescue

- Aug. 2, 2011 **<East Japan monitoring>** (JAEA, NUSTEC, …)
- Oct. 22, 2011 **<4th monitoring>**
  40km zone from the NPP(NUSTEC+JAEA) + 40-80km zone (NUSTEC)
- Jan. 30, 2012 **<West Japan monitoring>** (JAEA, NUSTEC, …)
- Feb. 6, 2012 **<monitoring above the warning area around the NPP>** (JAEA+NUSTEC)
- Jun. 6, 2012 **<5th monitoring>** (JAEA+JCAC)

JAEA：Japan Atomic Energy Agency,
NUSTEC：Nuclear Safety technology Center
JCAC: Japan Chemical Analysis Center

Monitoring Schedule

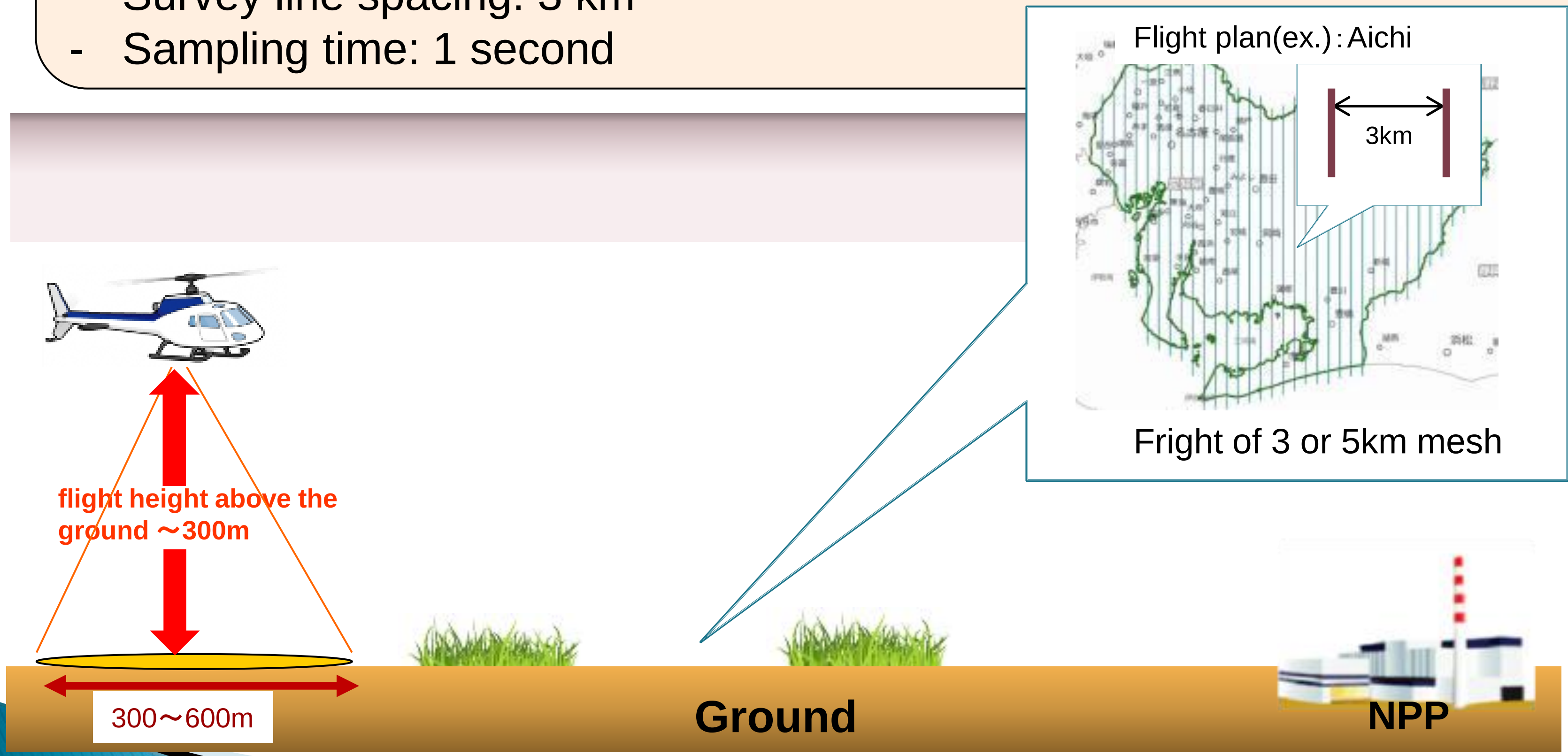


: RSI (rental from DOE) : RSI (MEXT)

: NUSTEC : OYO : FUGRO

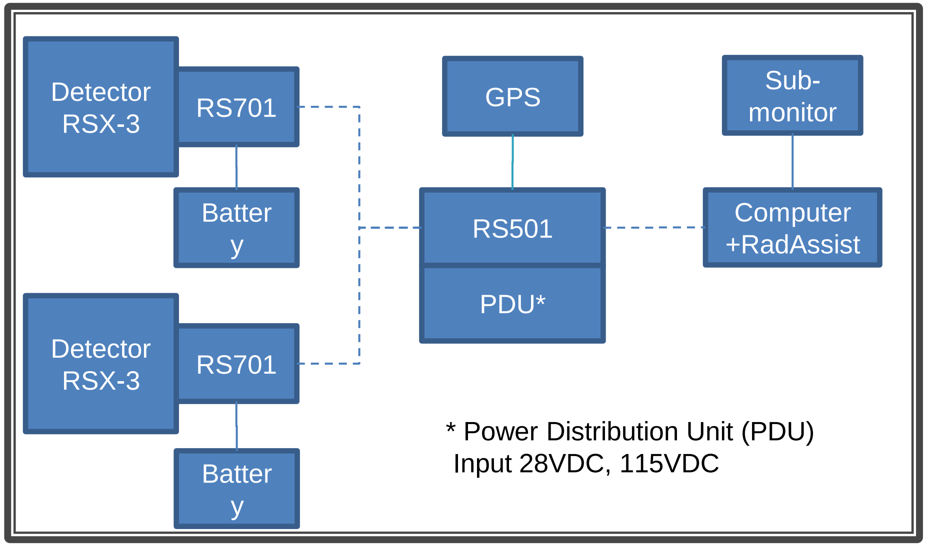
Method of Aerial radiation monitoring (Data acquisition)

- Count-rate was obtained by a large detector installed on a helicopter
- Altitude above the ground: about 300m (150 – 450m)
- Flight speed 70 – 80 knots
- Survey line spacing: 3 km
- Sampling time: 1 second



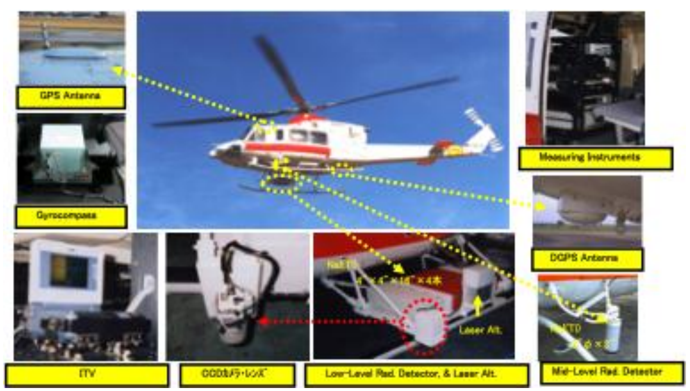
Aerial monitoring system = System "A"

	Spec
Manufacture	RSI Co., Ltd (Canada)
The date of manufacture	2009
Detector size	2"x 4"x 16" NaI 3 det.=1unit x 2 (1unit:6.3L x 2)
MCA ch	1024 ch
Energy band	0.02 ～ 3 MeV
Helicopter	・Due to shipping type inside the plane, the body is not chosen. ・The body which does not have a fuel tank in a bottom must be selected.
Sampling time	1second
Note	The same specification as DOE



Aerial monitoring system

SYSTEM	Install	Det.size(inch), quantity	Energy range	Channel	Altimeter
A	Inside	16" × 4" × 2", 6 detector	0.02 - 3 MeV	1,024 ch	GPS
B	Outside	16" × 4" × 4", 4 detector	0.05 - 3 MeV	256 ch	Laser
C	Outside	16" × 4" × 4", 8 detector	0.2 - 3 MeV	256 ch	Radio wave
D	Inside	16" × 4" × 4", 4 detector	0.05 - 3 MeV	256 ch	GPS



System "B"

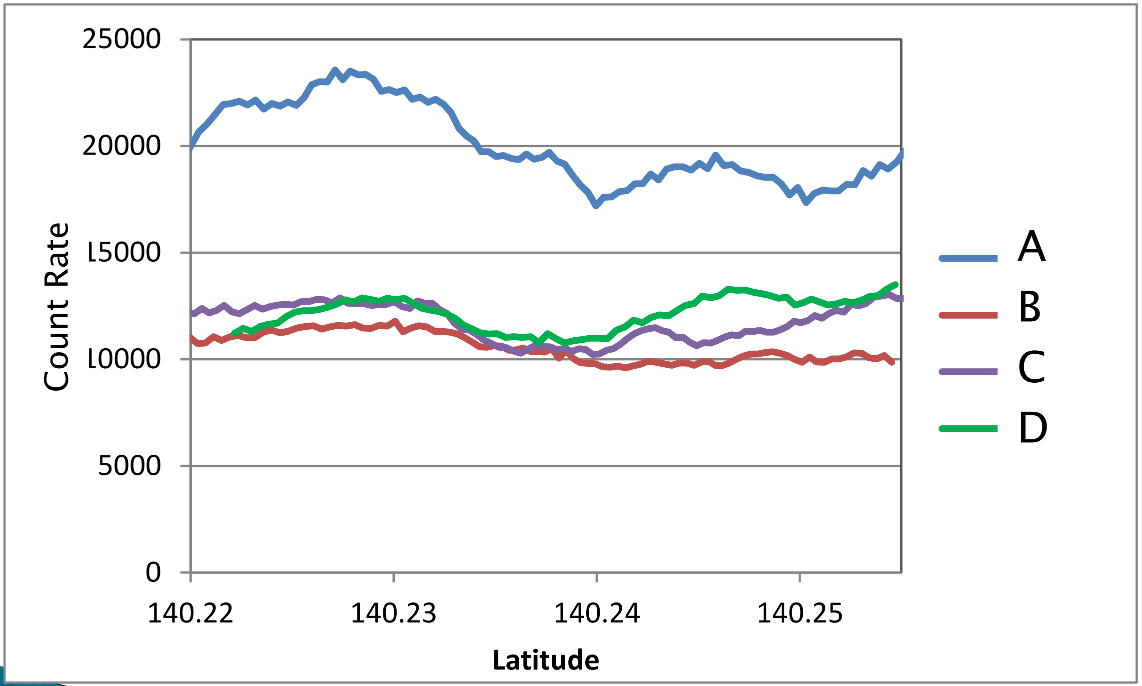
System "C"

System "D"

Detector Responses at the Test Line

The flight altitude of 1000 feet in four systems on the test line(*), we compared the count−rate of each systems.

* Test-Line: on the R18 (Sukagawa City, Fukushima Pref.), ~1.5μSv/h（NaI survey-Meter）

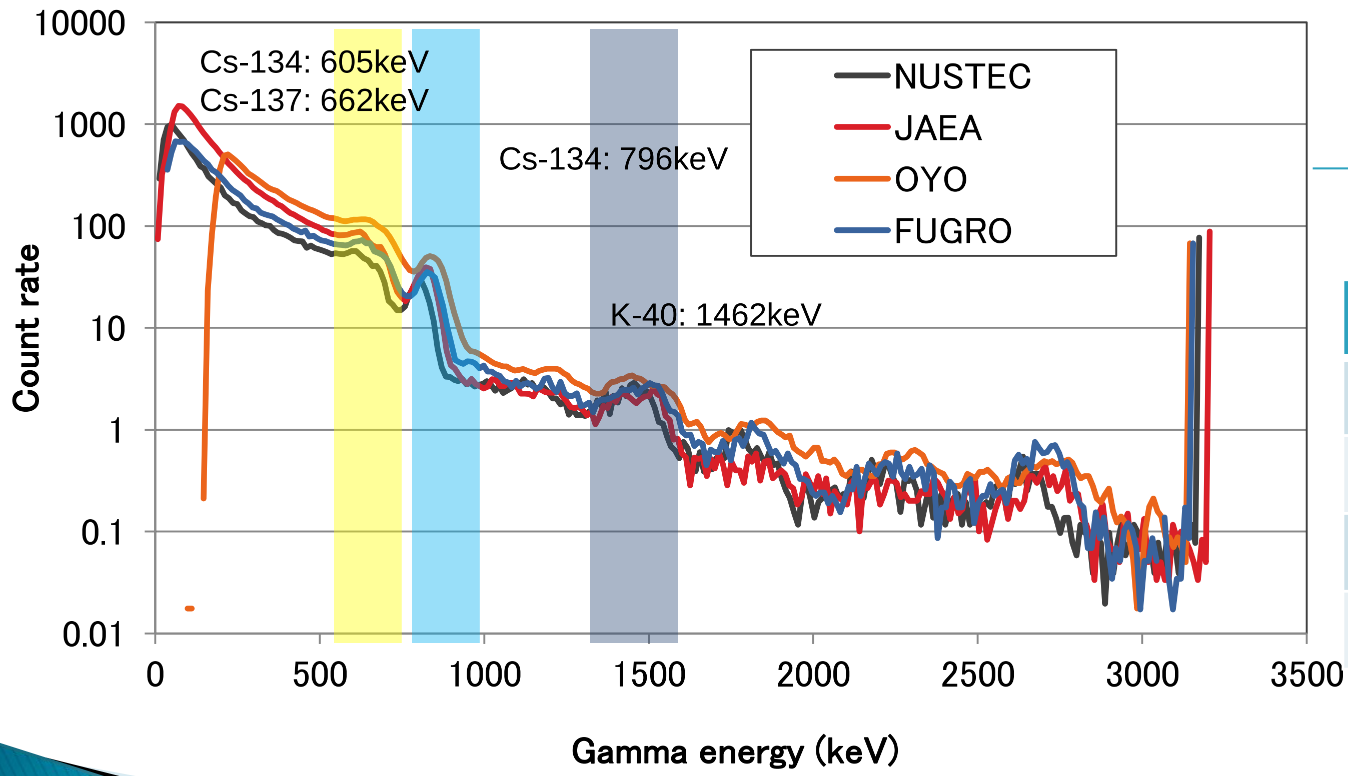


System	cps/μSv/h
A	$1.93x10^4$
B	$1.06x10^4$
C	$1.12x10^4$
D	$1.22x10^4$

Comparison of the pulse height distribution

The flight altitude of 1000 feet in four systems on the test line(*), we compared the count—rate of each systems.

* Test-Line: on the R18 (Sukagawa City, Fukushima Pref.), ~1.5μSv/h（NaI survey-Meter）



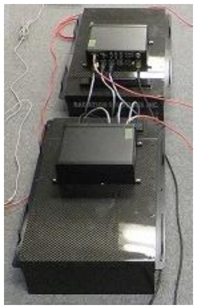
Peak-Compton Ratio=

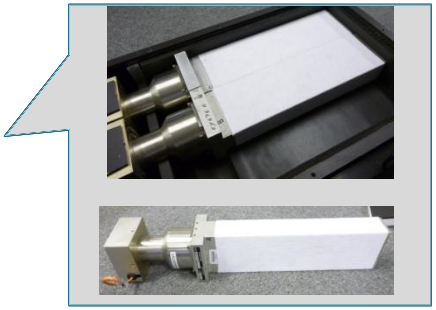
$$\frac{\text{Peak (510-750keV)}}{\text{Compton (200-510keV)}}$$

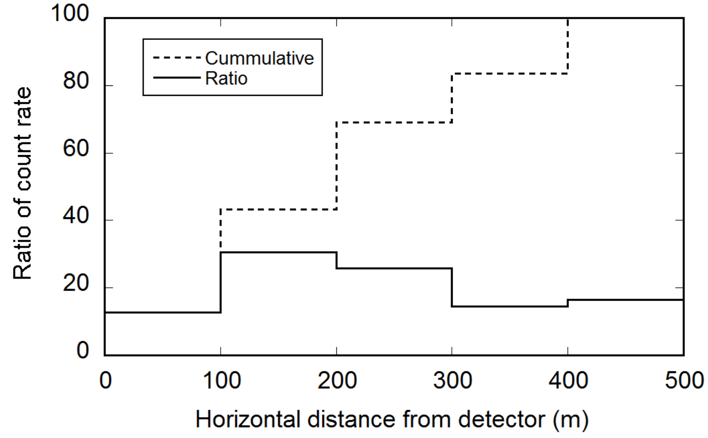
System	P/C
A: RSI	0.25
B: NUSTEC	0.31
C: OYO	0.31
D: FUGRO	0.33

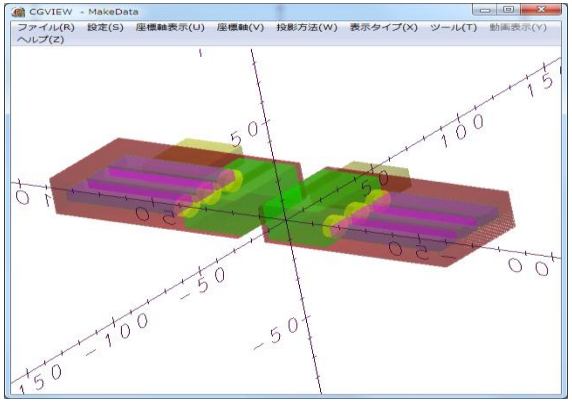
Where is measured?

▪Simulation for detector response (EGS5)



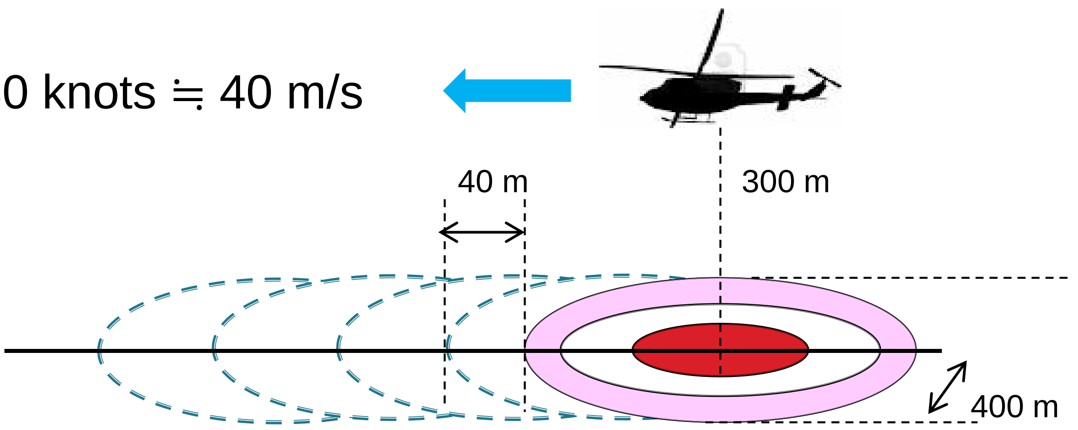






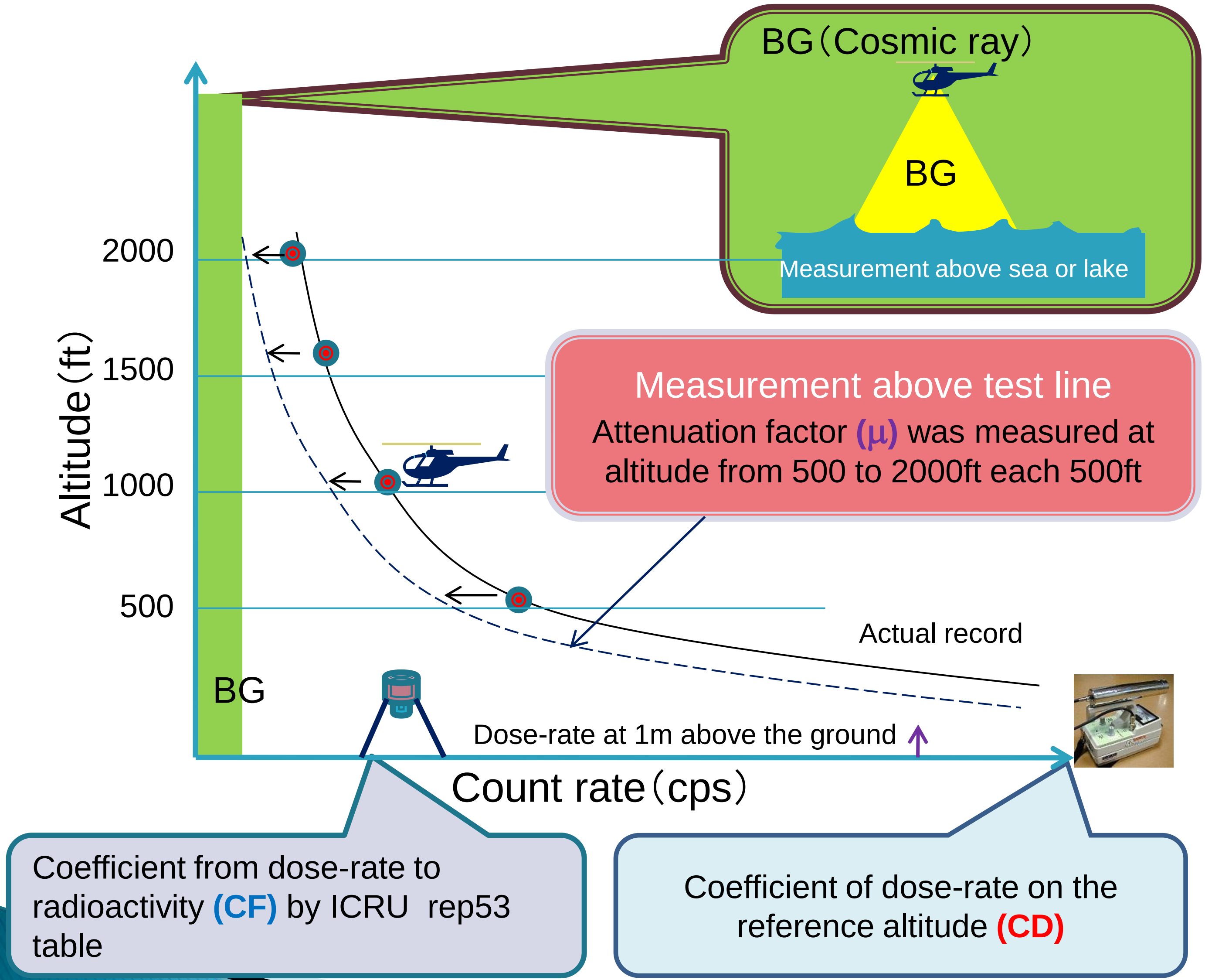
Angular response
×the area of each circle

80 knots ≒ 40 m/s



The average value of 400 m in radius a circle is measured from an altitude of 300 m.

Analysis method (Test line for calibration)



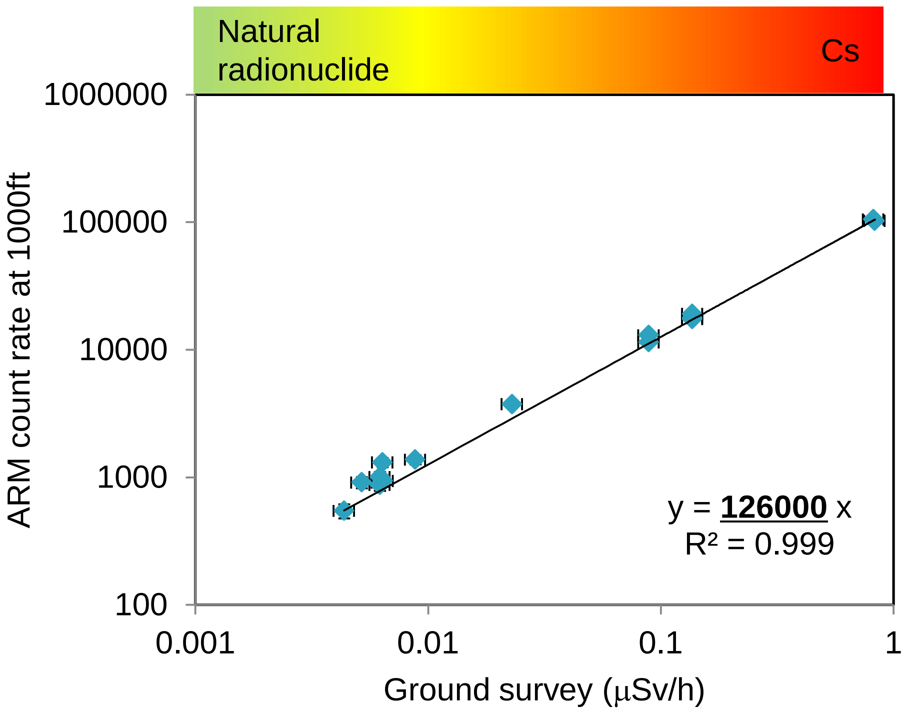
Test-line

- Distribution of a dose rate is constant
- Flat ground altitude

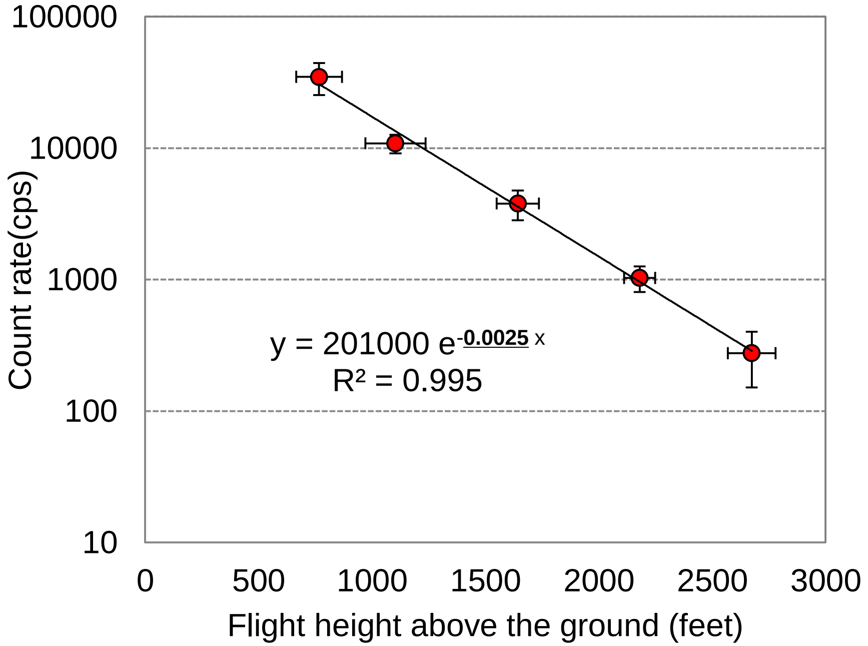
The reliability of parameters

Analysis method (test line data)

Conversion factor (CD)



Attenuation factor (μ)



Methods of analysis (Conversion foumula)

Dose rate at 1m on the ground (D_{1m})

$$D_{1m} = \frac{\left(C_{all} - C_{BG}\right) \times \exp\left\{-\mu\left(H_{std} - H_m\right)\right\}}{CD}$$

C_{all} : AMS all count (cps)
C_{BG} : BG count (cosmic ray+self contamination)
H_{std} : Standard altitude (1000 ft)
H_m : Actual altitude *
* : GPS altitude – 90m mesh DEM
DEM (Digital Elevation Model)

Radioactivity of Cs-134+137 ($V_{Cs\text{-}134+137}$) at the ground

$$V_{Cs134+137} = CF \times \left(D_{1m} - D_{nat}\right)$$

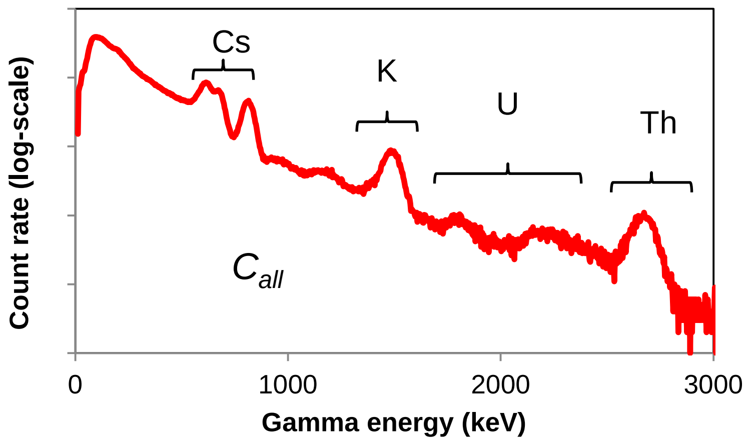
CF : Coefficient from dose-rate to radioactivity (ICRU 53 table; β=1)
D_{nat} : Dose rate of natural radionuclide

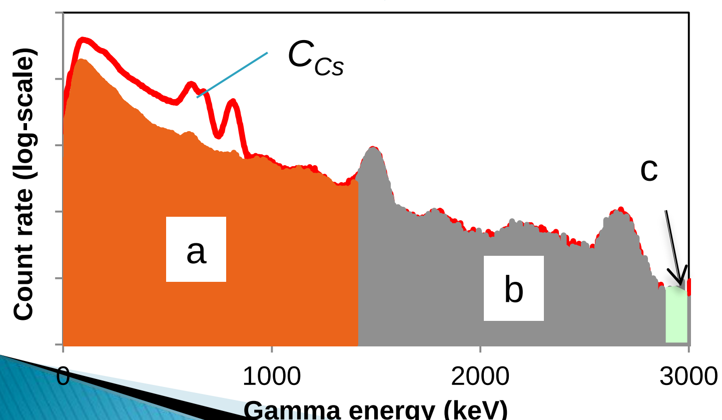
Next…

Distribution of dose-rate and radioactivity

MMGC methods (Man Made Gross Count): Discrimination of natural radiation using spectrum index (devised by DOE)

T. J. Hendricks, S. R. Riedhauser, An Aerial Radiological Survey of the Nevada Test Site, DOE/NV/11718-324 (1999)





Background

1. Gamma-ray of natural nuclides from the ground
2. Cosmic-ray
3. Gamma-ray of Rn-progeny in the air (Under consideration)

\# Spectrum index : Spectrum index was set up by flight data of a place without radioactive cesium

BG index (I_{BG}) = (a+b+c)/(b)

CR index (I_{CR}) = (a+b+c)/(c)

Count rate of radioactive Cs (C_{Cs})

$$C_{Cs} = C_{all} - \left(C_{>1400keV} \times I_{BG}\right) - \left(C_{>2800keV} \times I_{CR}\right)$$

C_{Cs}	: Count rate of radioactive Cs
C_{all}	: All count rate
$C_{>1400keV}$	: Count rate of 1400 – 2800 keV
$C_{>2800keV}$	: Count rate of above 2800 keV

Detection limit of ARM

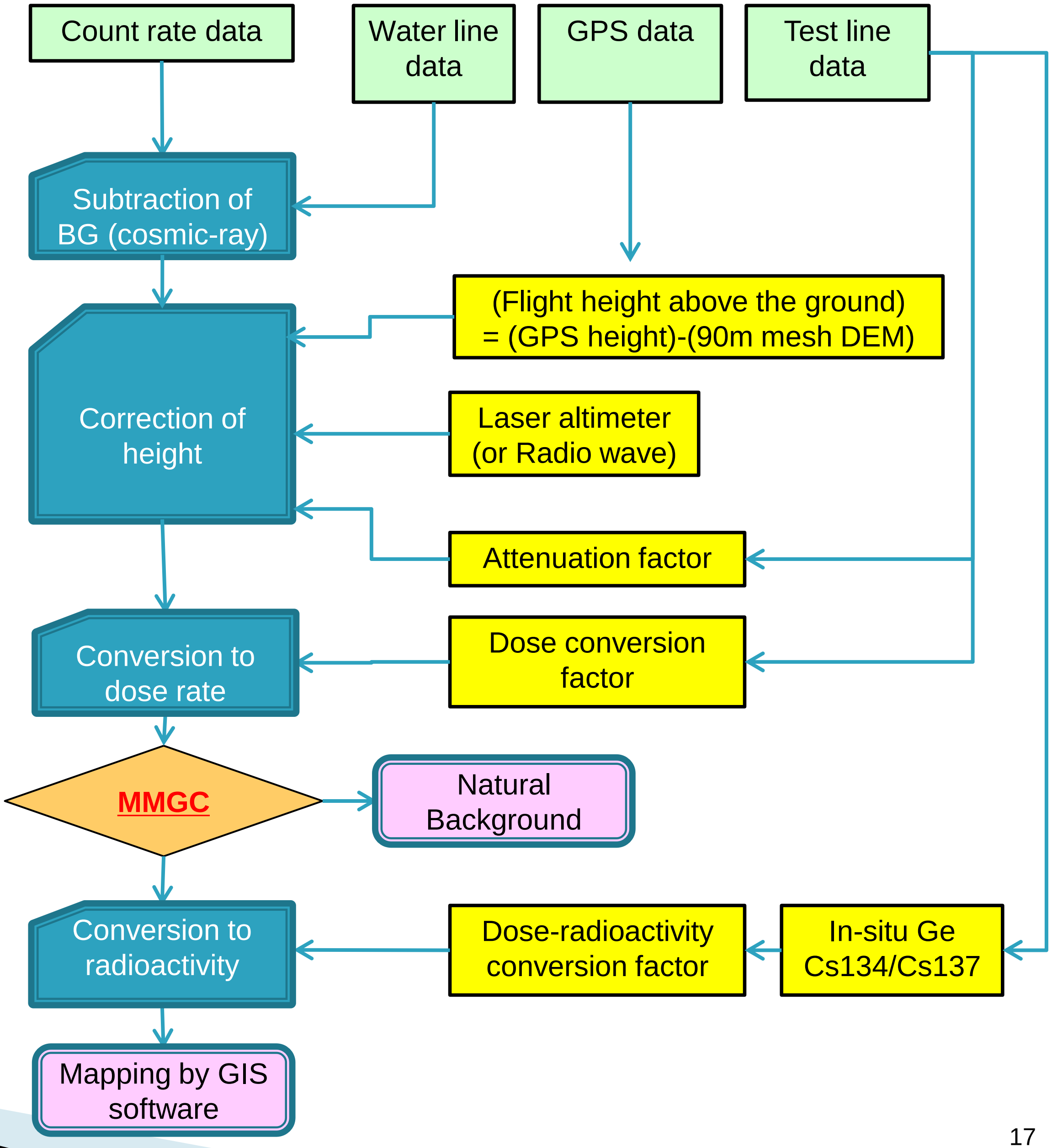
The detection limit of ARMS was calculated in condition of a typical background. Furthermore, parameters (AF, CD) can be estimated accurately, it is important to reduce the uncertainty.

System	Detection limit	
	Dose rate at 1m above the ground (μSv/h)	Radioactivity of deposition radiocesium (kBq/m^2) *
A	0.0095	16
B	0.015	26
C	0.014	24

* Typically BG count: 3000 cps

Summary of analysis method

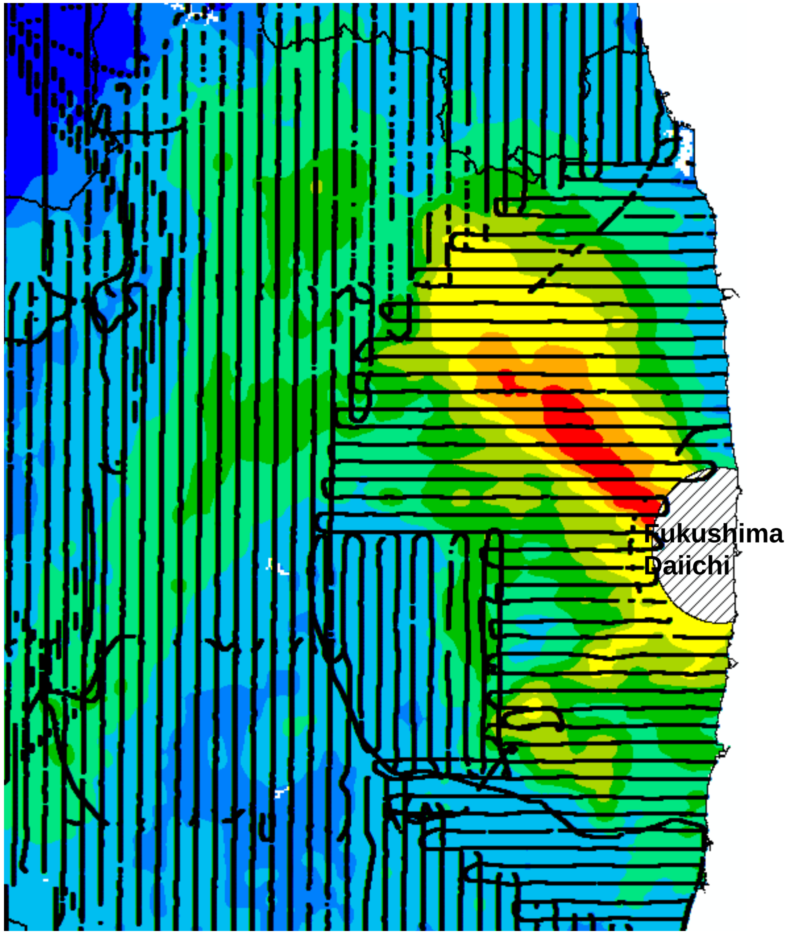
1) Conversion to dose-rate
2) MMGC method
3) Conversion to radioactivity
4) Mapping



Methods of mapping（IDW method）

IDW：Inverse Distance Weighted

This methods is presumed the cell value by averaging the value of the point near the cell to process
The dignity in IDW is in inverse proportion to distance (it will assume, if it becomes small as the distance from a point becomes far).



Evaluated cell value

- smaller than measured maximum value
- bigger than measured minimum value

→An exact value cannot be expressed when the extremism is not sampled.

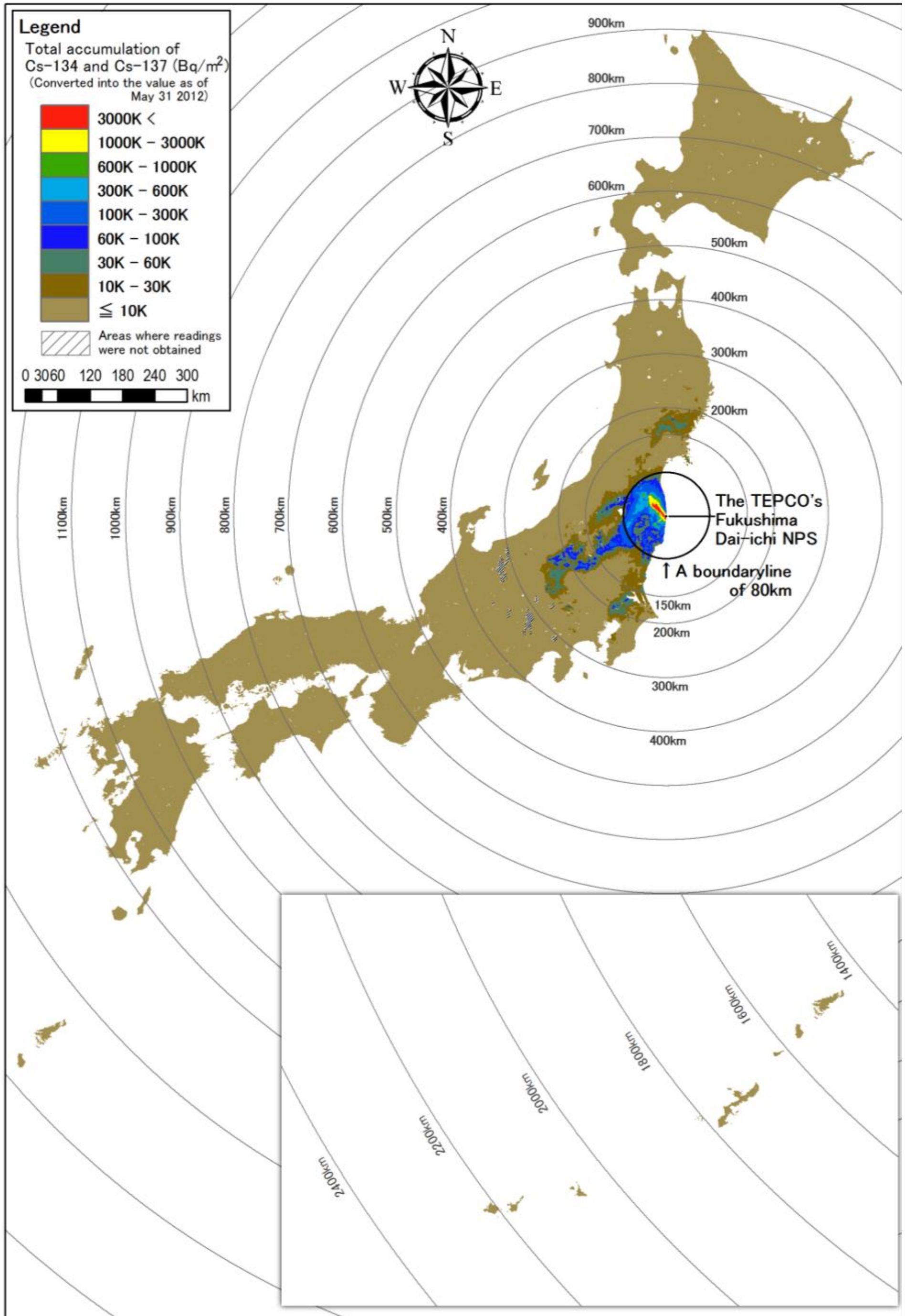
Parameter

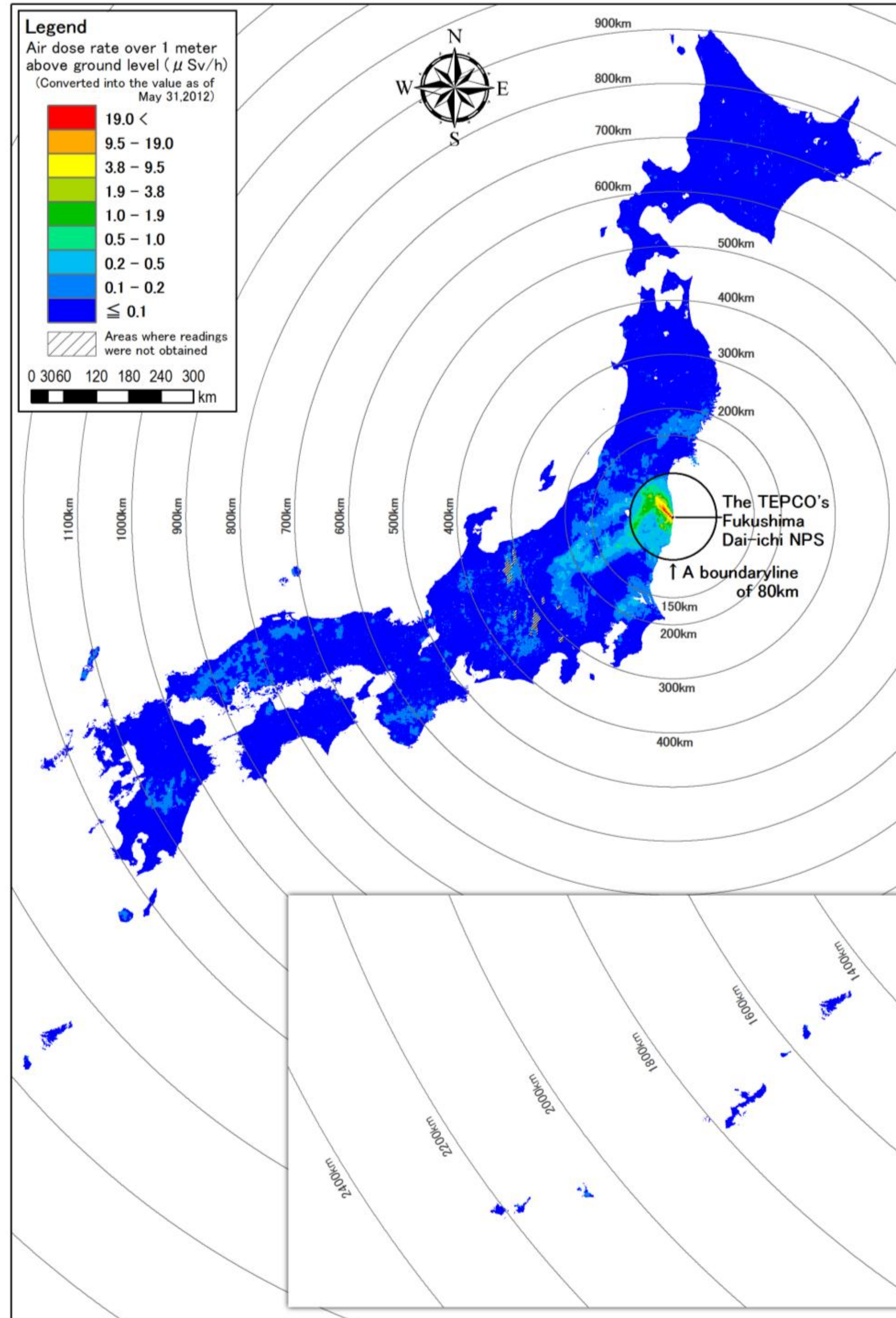
・Multiplier parameter：The reciprocal of the involved distance

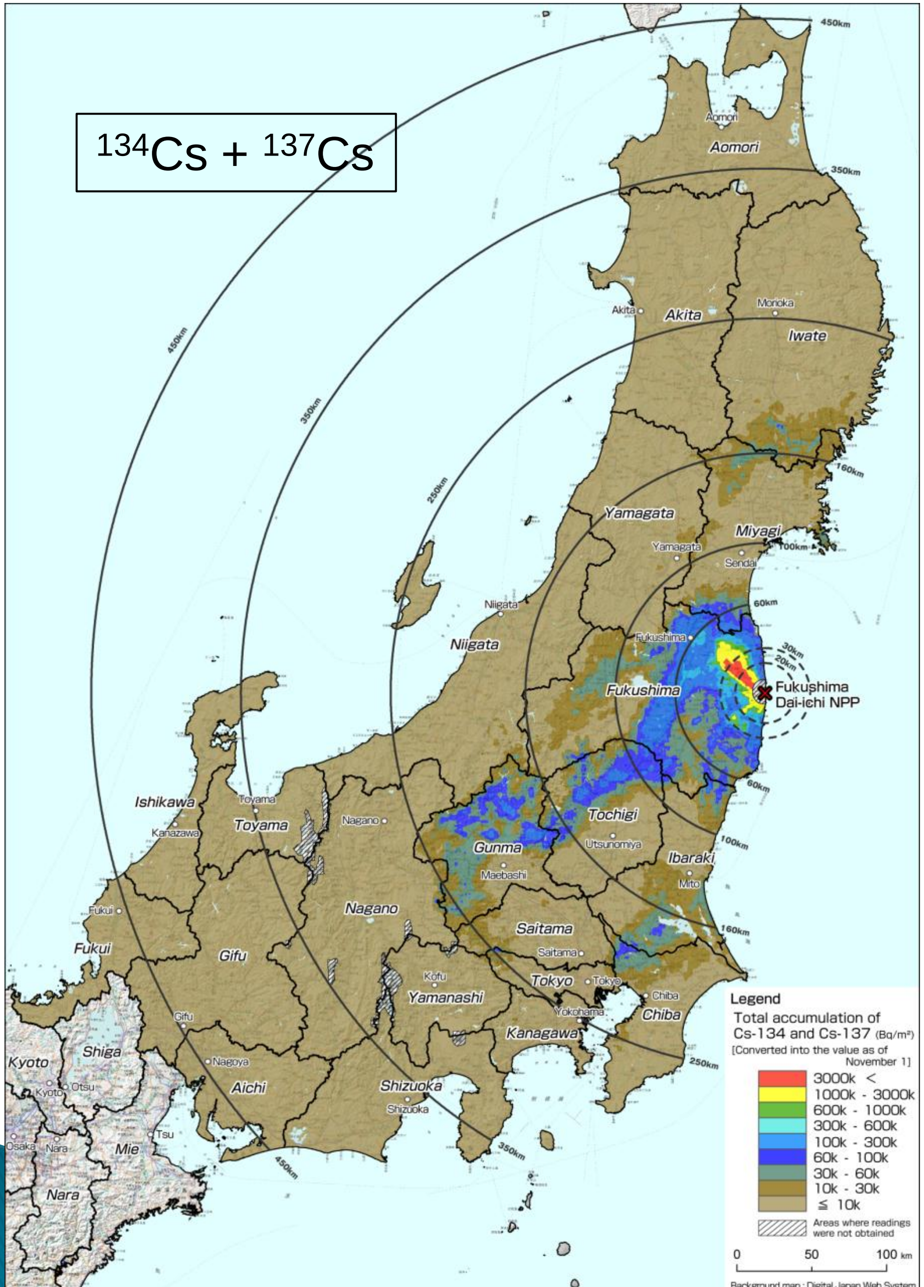
Big value：（neighbor data）
Small value：（far data）

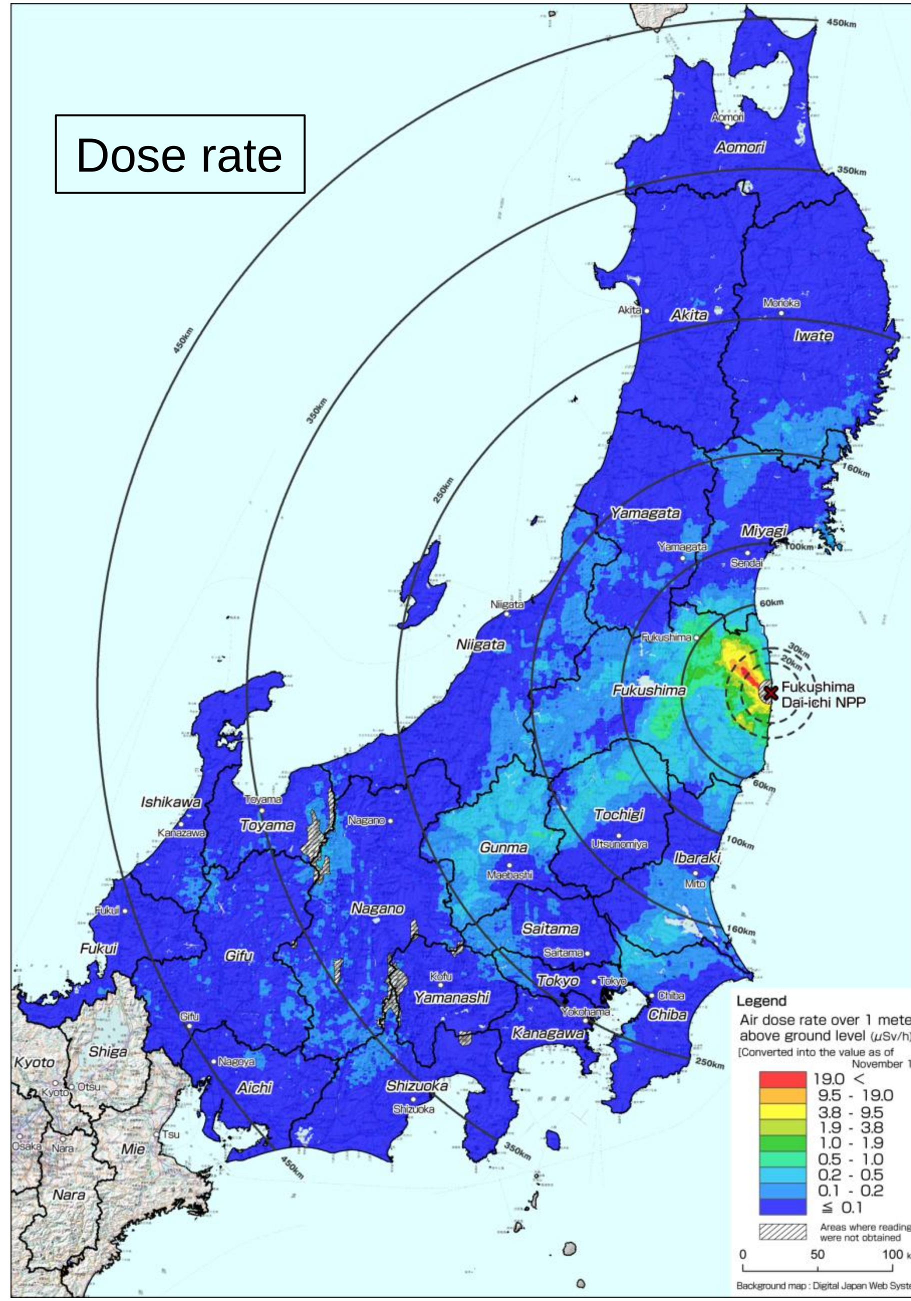
・Search of a neighboring point: The selection of the point to interpolate
A variable search radius / fixed search radius

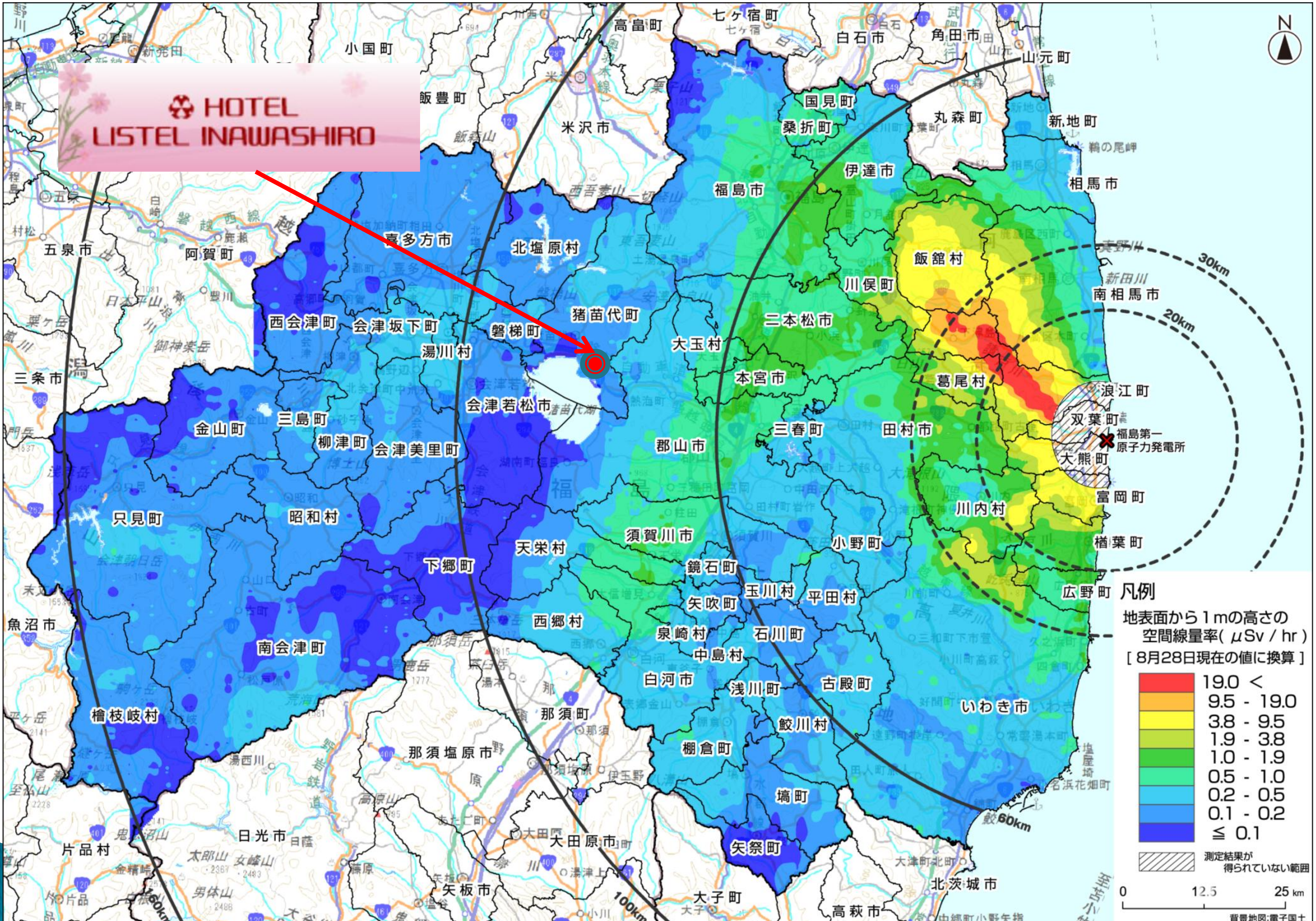
→ Complicated parameter setup is unnecessary


Legend
Total accumulation of Cs-134 and Cs-137 (Bq/m2)
(Converted into the value as of May 31 2012)
3000K <
1000K - 3000K
600K - 1000K
300K - 600K
100K - 300K
60K - 100K
30K - 60K
10K - 30K
≦ 10K
Areas where readings were not obtained
0 30 60 120 180 240 300
km
N
E
S
W
The TEPCO's Fukushima Dai-ichi NPS
A boundaryline of 80km
150km
200km
300km
400km
500km
600km
700km
800km
900km
1000km
1100km
1400km
1600km
1800km
2000km
2200km
2400km

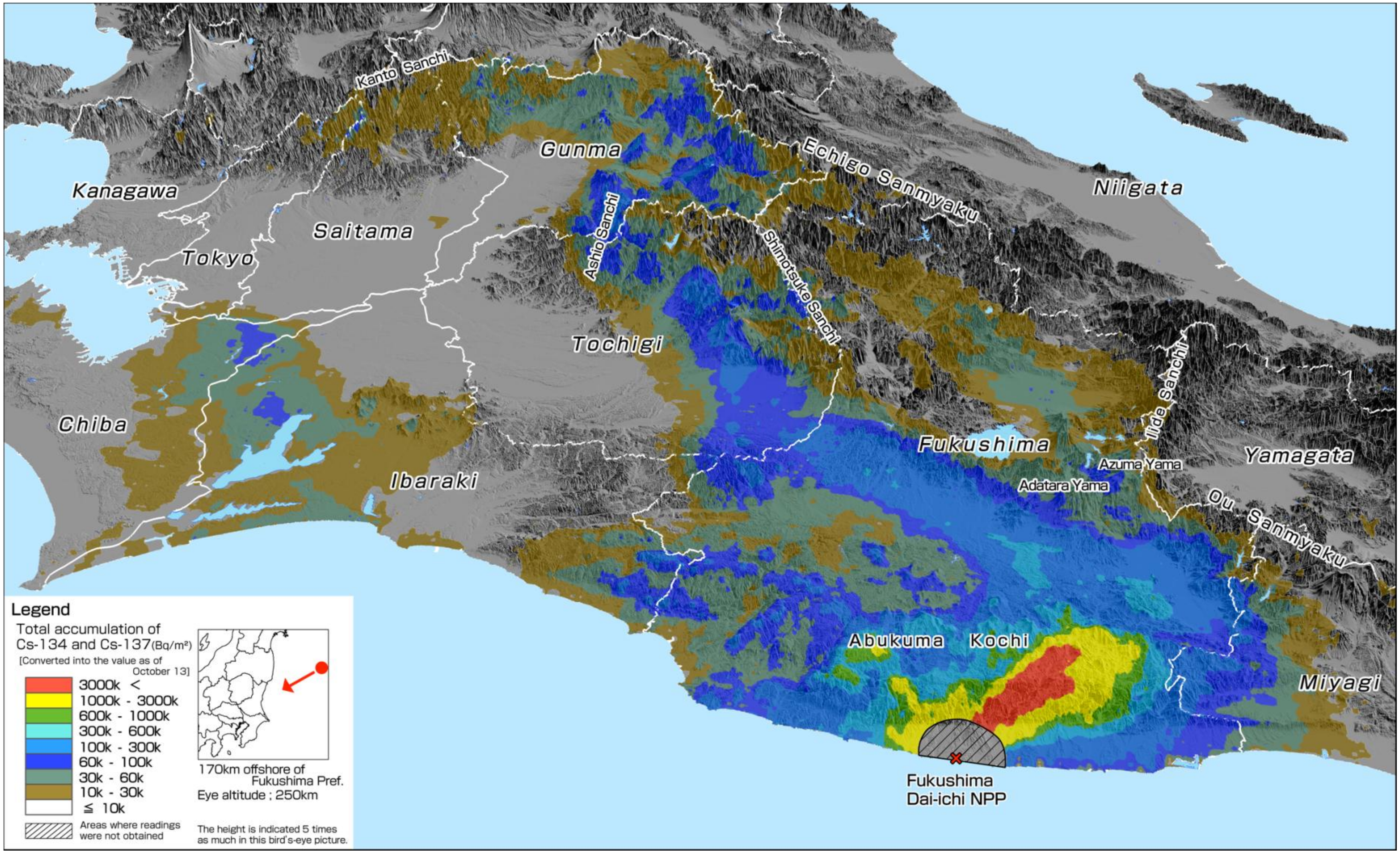

Legend
Air dose rate over 1 meter above ground level (μ Sv/h)
(Converted into the value as of May 31,2012)
19.0 <
9.5 - 19.0
3.8 - 9.5
1.9 - 3.8
1.0 - 1.9
0.5 - 1.0
0.2 - 0.5
0.1 - 0.2
≦ 0.1
Areas where readings were not obtained
0 30 60 120 180 240 300
km
N
E
S
W
The TEPCO's Fukushima Dai-ichi NPS
A boundaryline of 80km
150km
200km
300km
400km
500km
600km
700km
800km
900km
1000km
1100km
1400km
1600km
1800km
2000km
2200km
2400km


$^{134}Cs + ^{137}Cs$
Aomori
Akita
Iwate
Yamagata
Miyagi
Niigata
Fukushima
Fukushima Dai-ichi NPP
Ishikawa
Toyama
Tochigi
Gunma
Ibaraki
Nagano
Saitama
Fukui
Gifu
Tokyo
Yamanashi
Chiba
Kanagawa
Shiga
Kyoto
Aichi
Shizuoka
Mie
Nara
Legend
Total accumulation of Cs-134 and Cs-137 (Bq/m²)
[Converted into the value as of November 1]
3000k <
1000k - 3000k
600k - 1000k
300k - 600k
100k - 300k
60k - 100k
30k - 60k
10k - 30k
≦ 10k
Areas where readings were not obtained
0 50 100 km
Background map : Digital Japan Web System


Dose rate
Aomori
Akita
Iwate
Yamagata
Miyagi
Niigata
Fukushima
Fukushima Dai-ichi NPP
Ishikawa
Toyama
Tochigi
Gunma
Ibaraki
Nagano
Saitama
Fukui
Gifu
Tokyo
Yamanashi
Chiba
Kanagawa
Shiga
Kyoto
Aichi
Shizuoka
Mie
Nara
Legend
Air dose rate over 1 meter above ground level (μSv/h)
[Converted into the value as of November 1]
19.0 <
9.5 - 19.0
3.8 - 9.5
1.9 - 3.8
1.0 - 1.9
0.5 - 1.0
0.2 - 0.5
0.1 - 0.2
≦ 0.1
Areas where readings were not obtained
0 50 100 km
Background map : Digital Japan Web System


HOTEL LISTEL INAWASHIRO
N
30km
20km
60km
100km
160km
福島第一原子力発電所
凡例
地表面から１mの高さの空間線量率(μSv / hr)
[8月28日現在の値に換算]
19.0 <
9.5 - 19.0
3.8 - 9.5
1.9 - 3.8
1.0 - 1.9
0.5 - 1.0
0.2 - 0.5
0.1 - 0.2
≦ 0.1
測定結果が得られていない範囲
0
12.5
25 km
背景地図:電子国土
喜多方市
北塩原村
猪苗代町
磐梯町
会津坂下町
西会津町
湯川村
会津若松市
三島町
金山町
柳津町
会津美里町
只見町
昭和村
下郷町
天栄村
南会津町
檜枝岐村
西郷村
福島市
伊達市
国見町
桑折町
川俣町
飯舘村
二本松市
大玉村
本宮市
葛尾村
三春町
田村市
郡山市
須賀川市
鏡石町
小野町
川内村
玉川村
平田村
矢吹町
泉崎村
石川町
中島村
白河市
浅川町
古殿町
鮫川村
棚倉町
塙町
矢祭町
いわき市
浪江町
双葉町
大熊町
富岡町
楢葉町
広野町
南相馬市
相馬市
新地町
丸森町
山元町
角田市
白石市
七ヶ宿町
高畠町
米沢市
小国町
飯豊町
五泉市
阿賀町
三条市
魚沼市
那須町
那須塩原市
日光市
大田原市
矢板市
片品村
大子町
高萩市
北茨城市

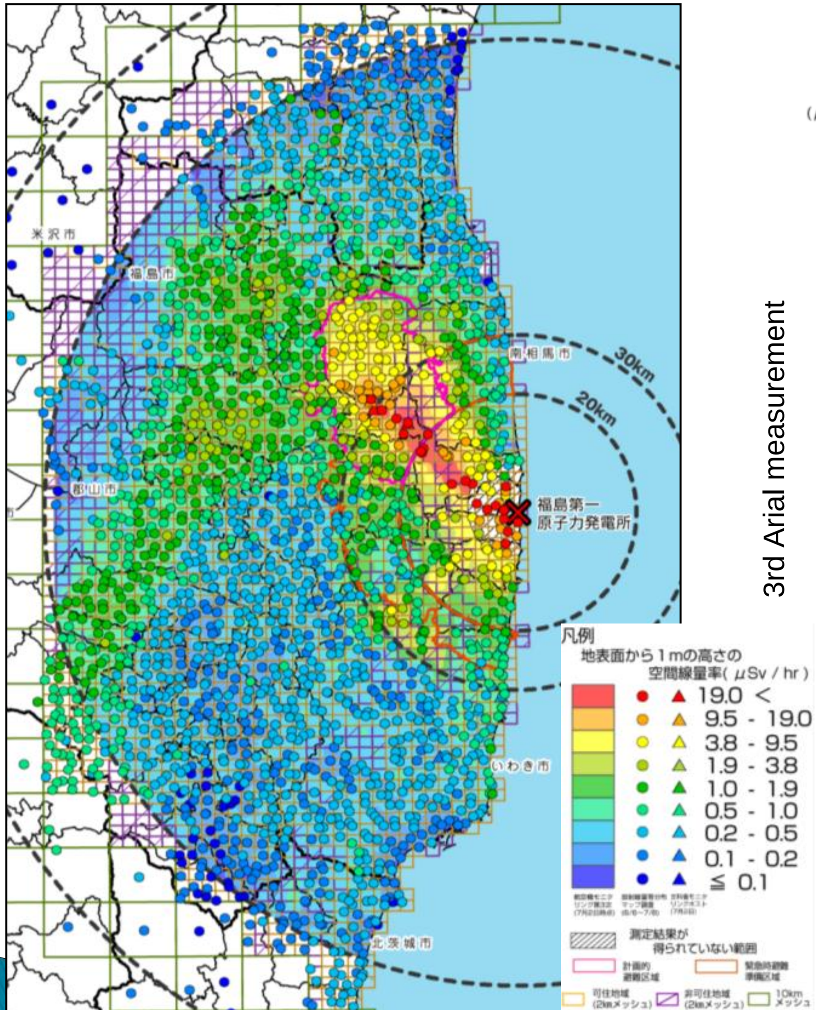
3D map of radiocesium distribution



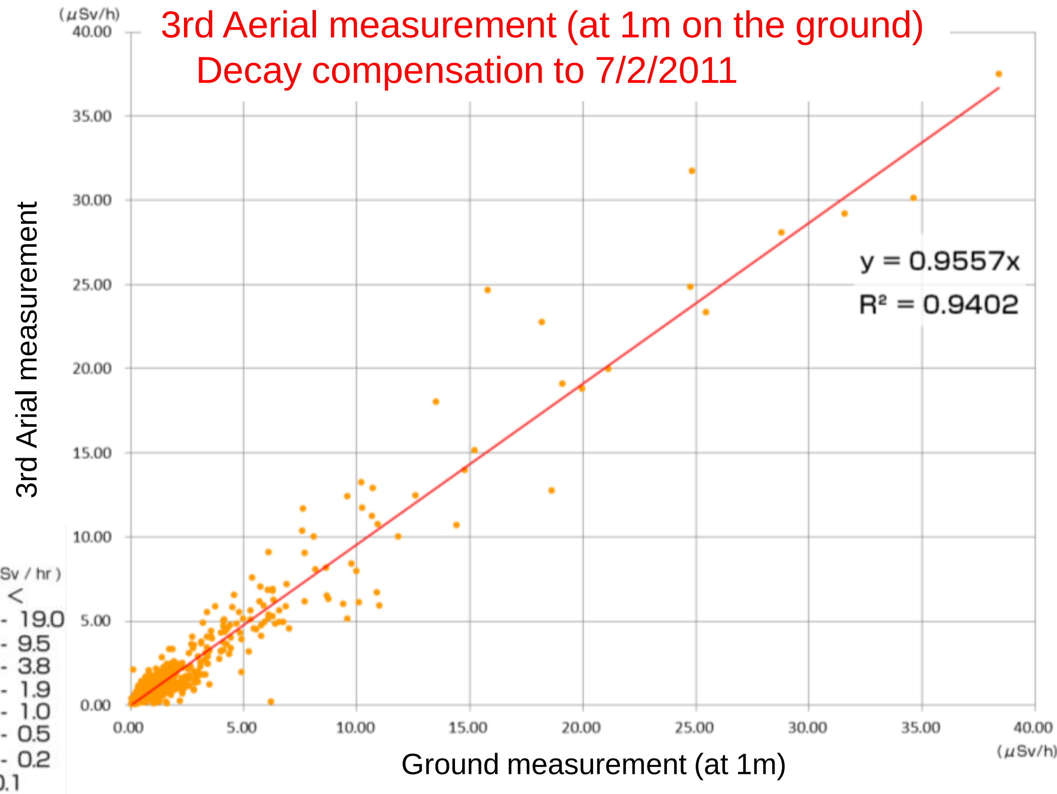
Comparison with the ground measurement

Ground measurement (NaI survey meter)

(http://radioactivity.mext.go.jp/ja/distribution_map_around_FukushimaNPP/0002/11555_0830.pdf)



3rd Aerial measurement (at 1m on the ground)
Decay compensation to 7/2/2011

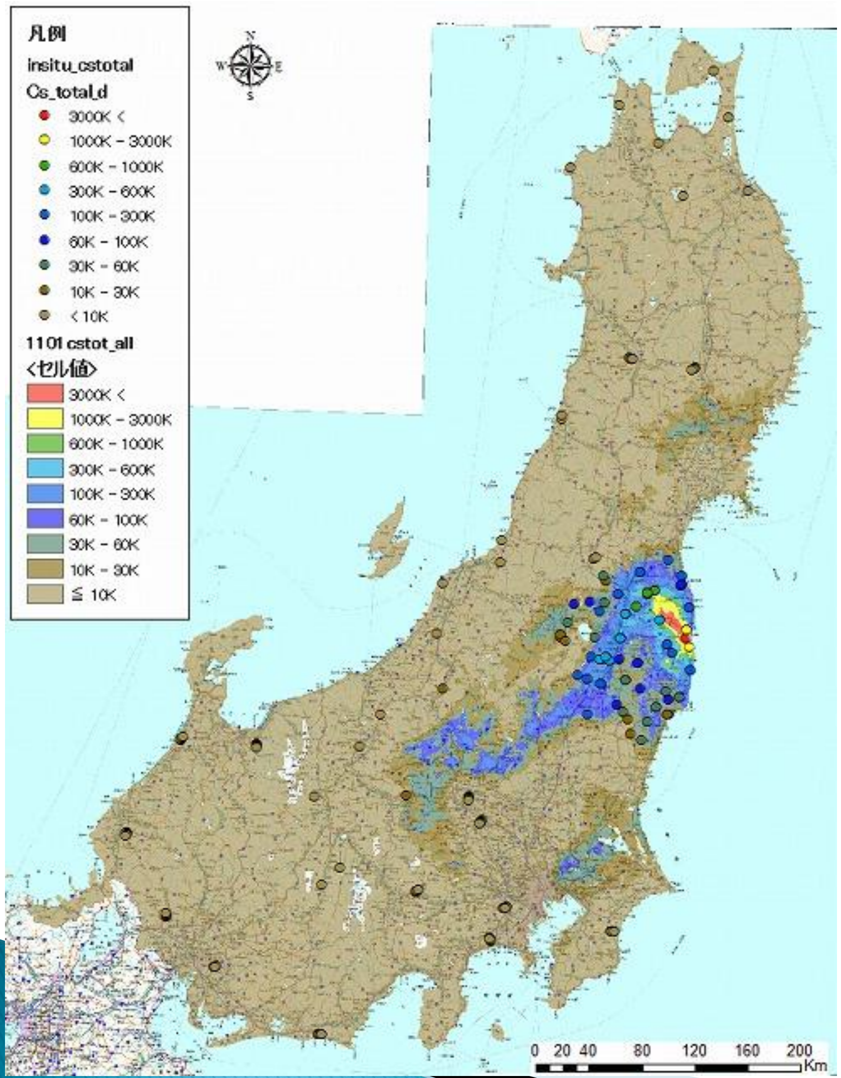


・Ground measurement (at 1m)
6/6 – 7/8/2011 : 1897 points

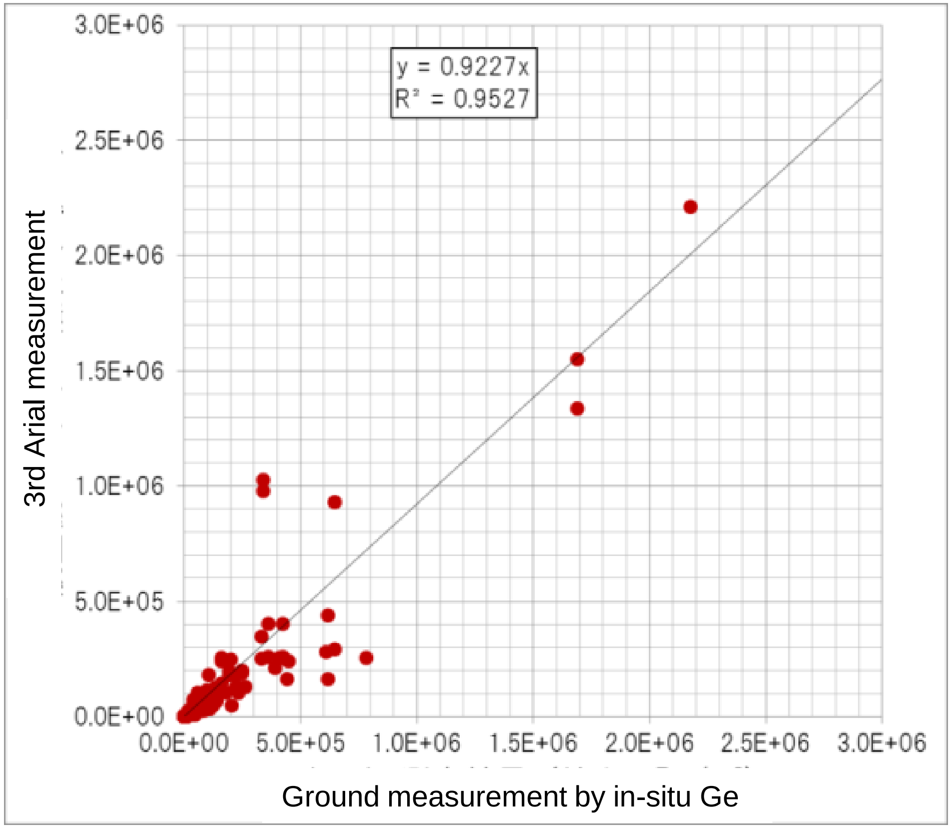
Comparison with the ground measurement

Ground measurement (In-situ Ge)

(http://radioactivity.mext.go.jp/ja/distribution_map_around_FukushimaNPP/0002/11555_0830.pdf)

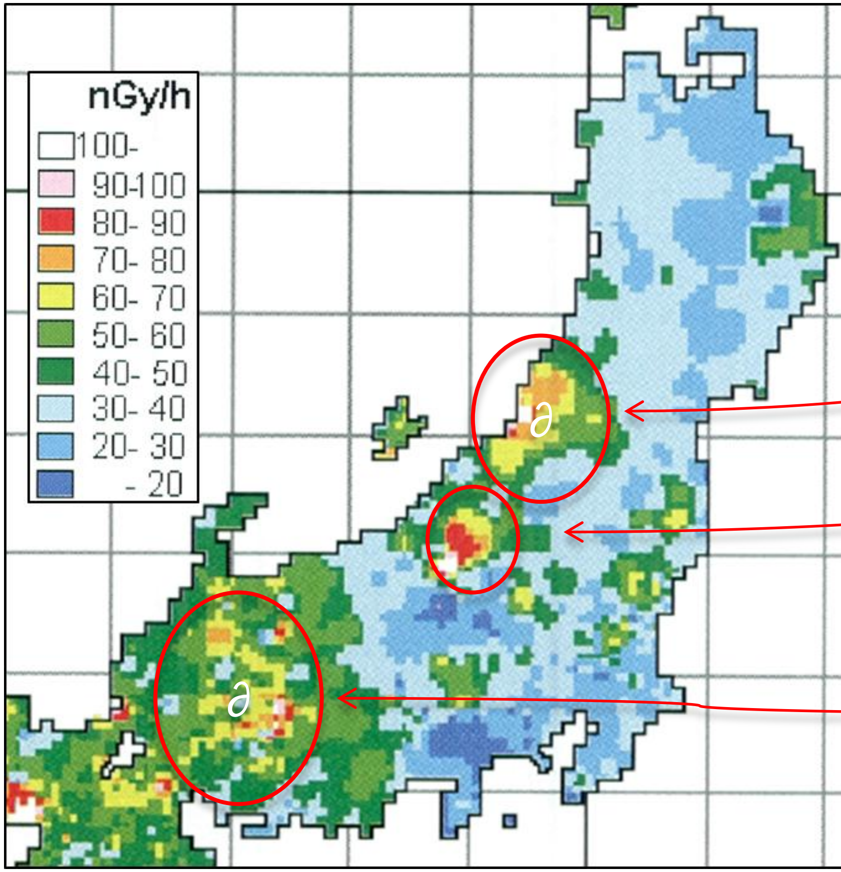


3rd Aerial measurement (at 1m on the ground)
Decay compensation to 7/2/2011

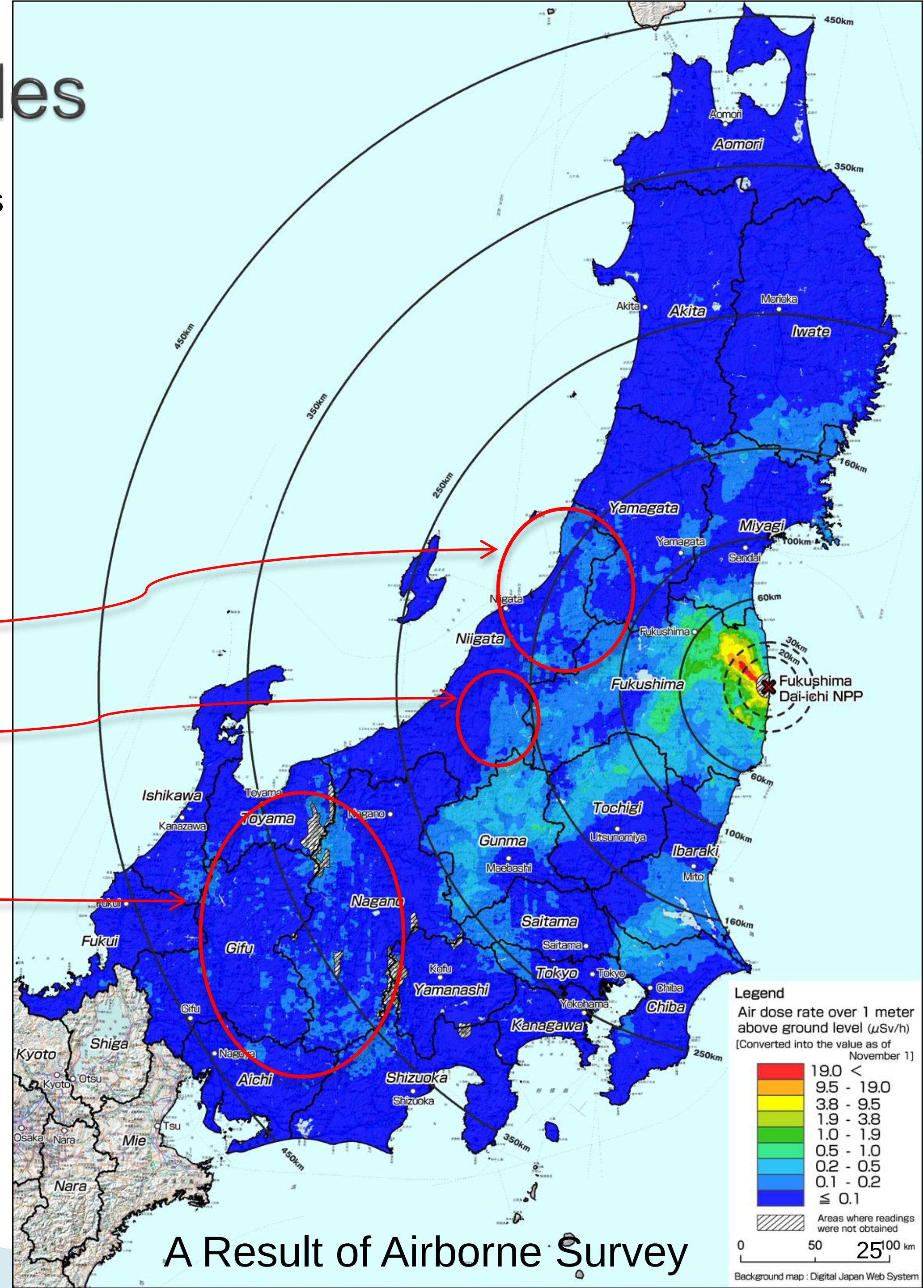


Effect of natural nuclides

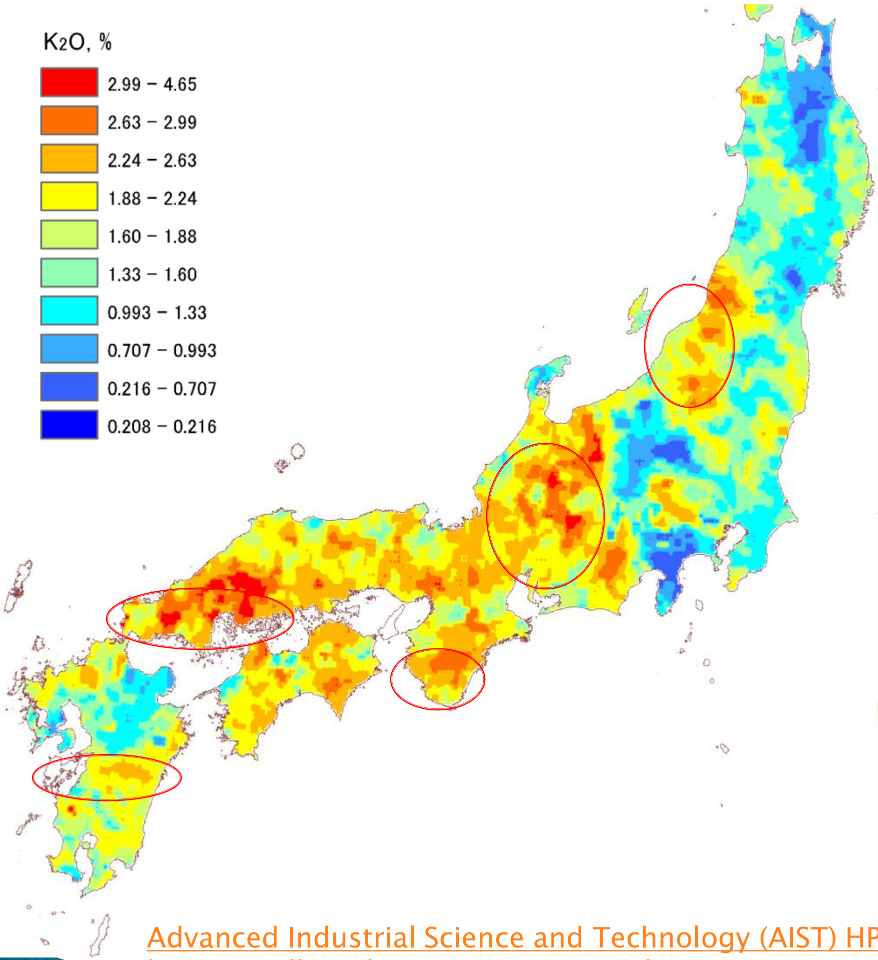
Variation of dose rate due to natural radionuclides

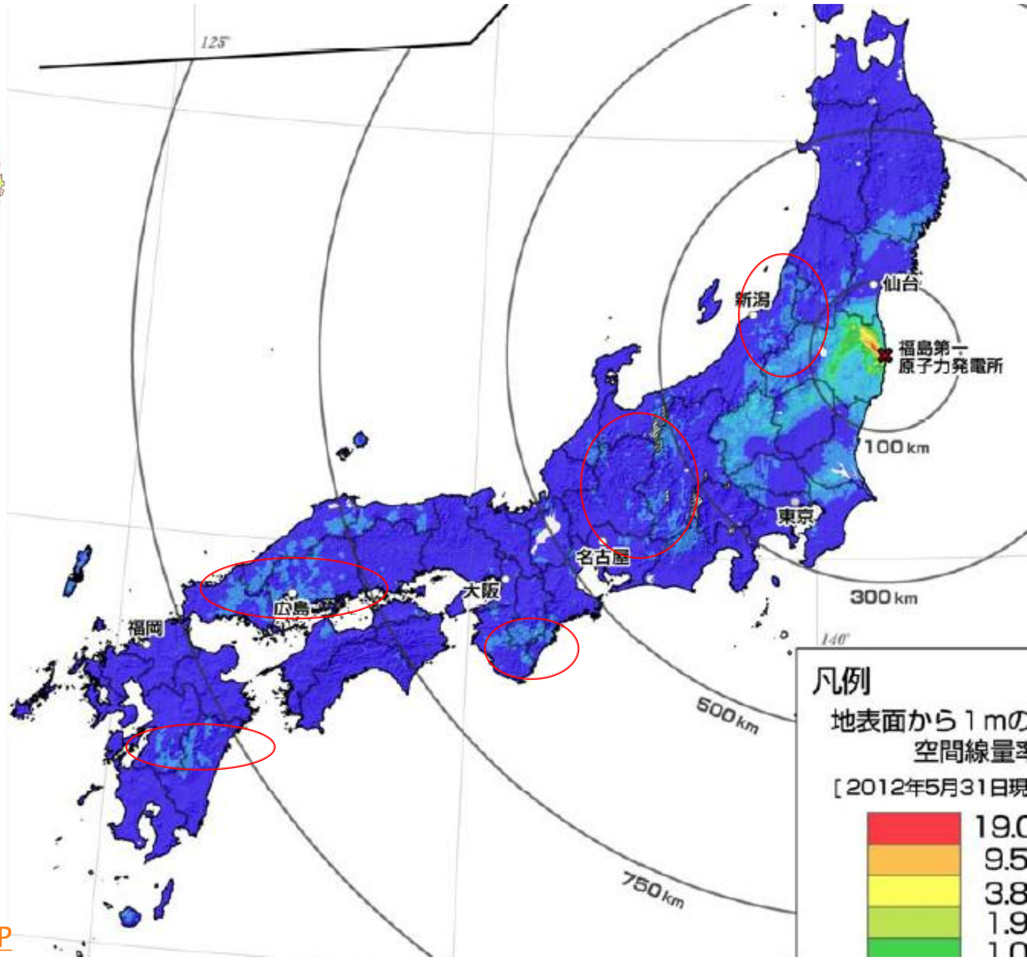


Minato et al.(2006): Chigaku zasshi, in Japanese



Effect of natural nuclides





[Advanced Industrial Science and Technology (AIST) HP](http://riodb02.ibase.aist.go.jp/geochemmap)
http://riodb02.ibase.aist.go.jp/geochemmap

Summary

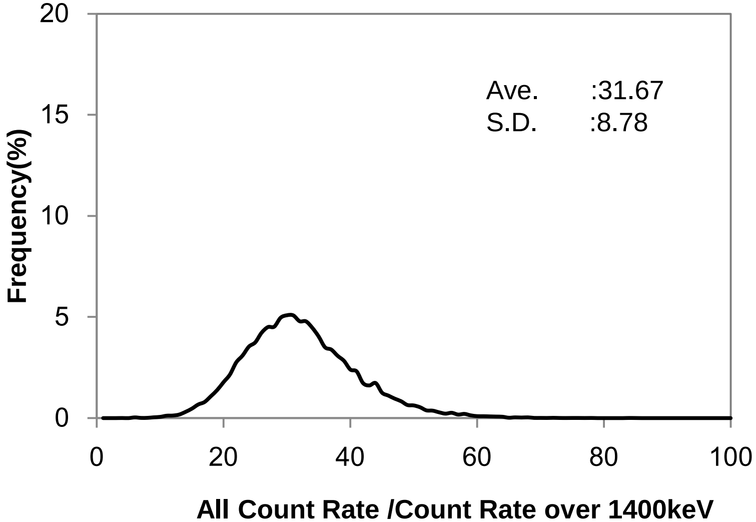
- We carried out aerial radiation monitoring in the whole area of Japan.
- The attenuation factor (μ) and dose conversion factor (CD) were obtained at each test-line.
- Both the dose-rate distribution of Japan and the deposition of radioactive cesium from Fukushima Daiichi NPP were clarified.
- As a result of measurement in the low contaminated areas, it has been understood not to be able to disregard the contribution of natural nuclides to the dose-rate.
- The spectrum of a radioactive cesium was hardly admitted in the region that was high background areas in Niigata, Nagano, Toyama and Gifu prefectures.
- The cesium concentration of a low contaminated area was evaluated by using the MMGC method.

Thank you for your attention

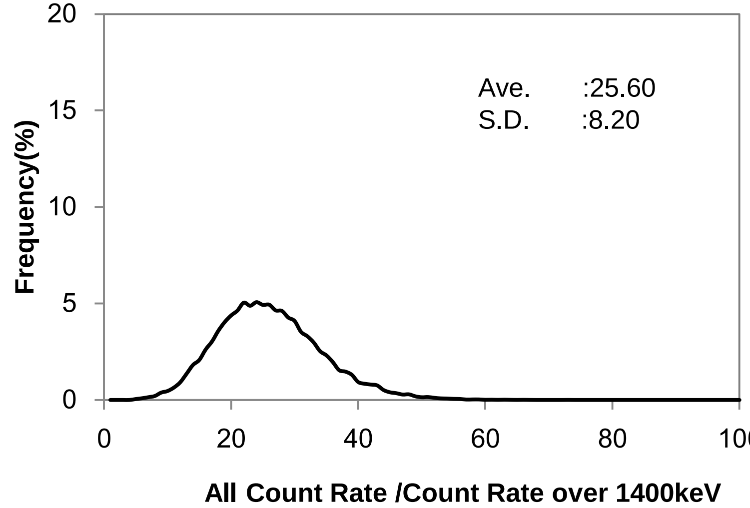
(Acknowledgement)
This work was carried out under a contract with the MEXT in the fiscal years 2011 and 2012.
More than 80 people participated from a lot of organizations and the enterprises in this monitoring project. Moreover, the cooperation of the Air Self-Defense Force, the air-rescue, and the private aircraft company was received.

Example of BG index

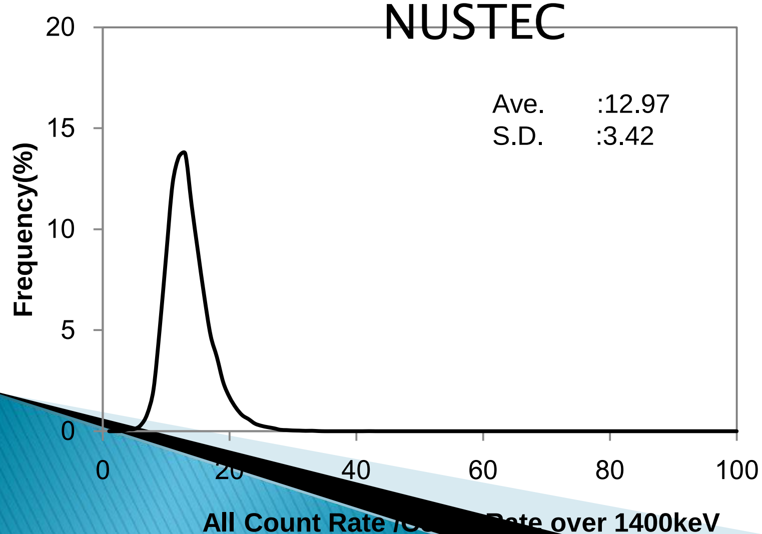
RSI-1



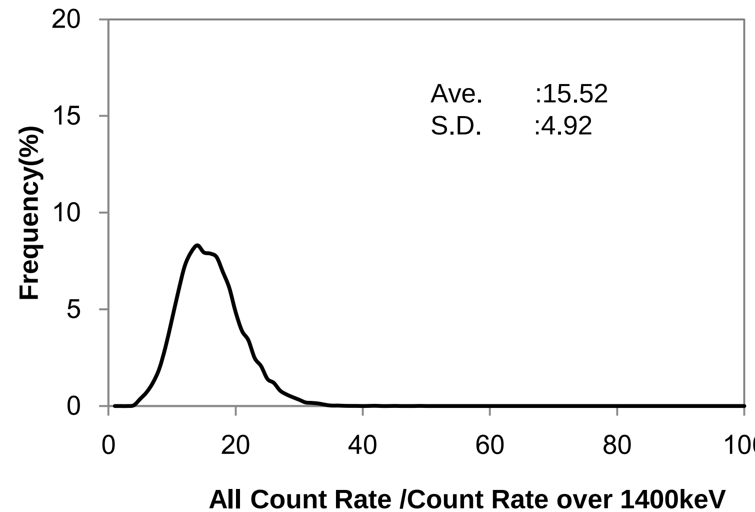
RSI-2



NUSTEC



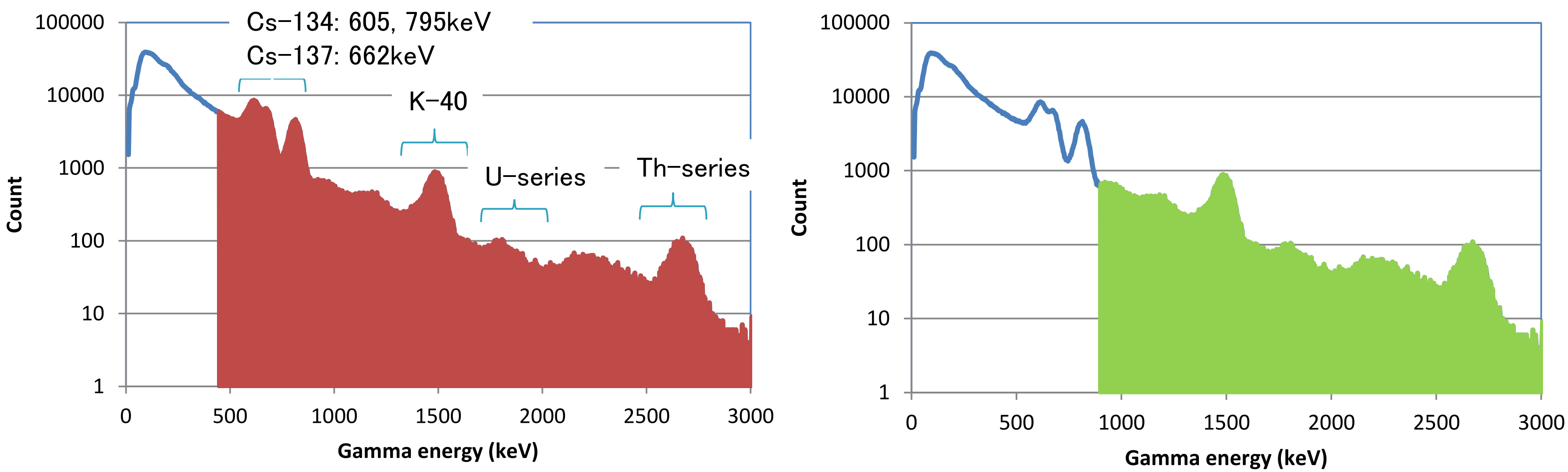
OYO



Energy spectrum and spectral index

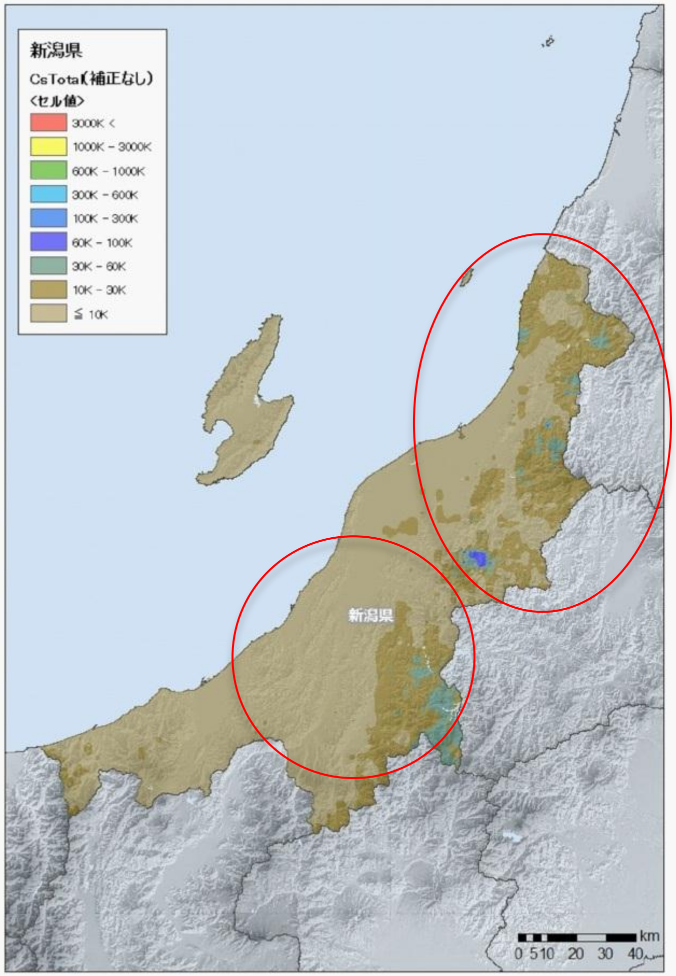
- Count rate over 450keV: Included radioactive cesium
- Count rate over 900kev: Without radioactive cesium (most natural nuclides)

→ To minimize the counting error

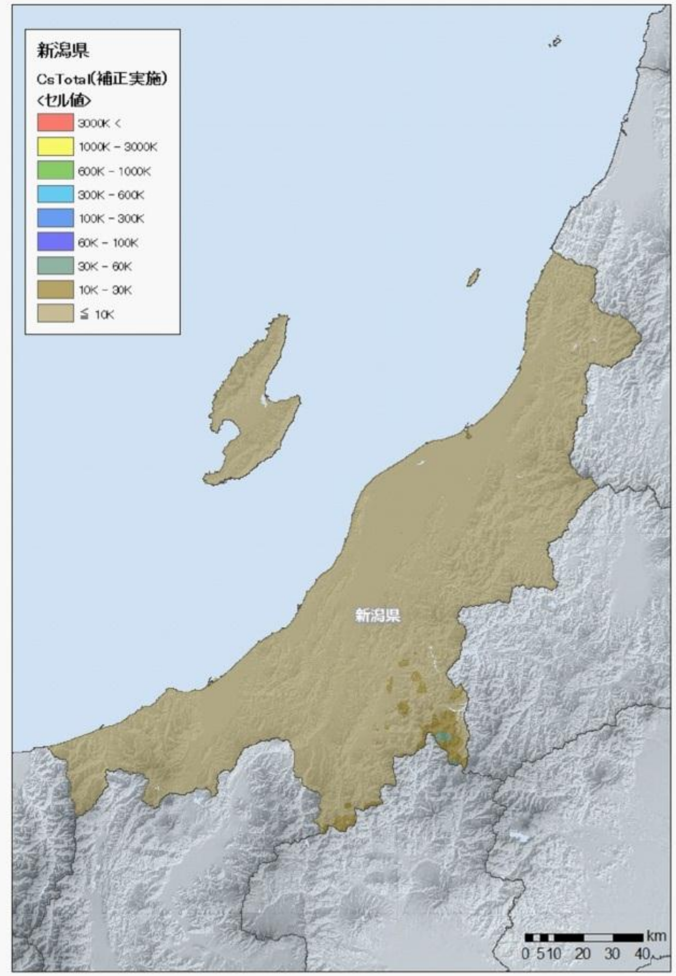


$$SI = \frac{\text{Count-rate more than 450keV}}{\text{Count-rate more than 900keV}}$$

Analytical results of discriminated natural nuclides

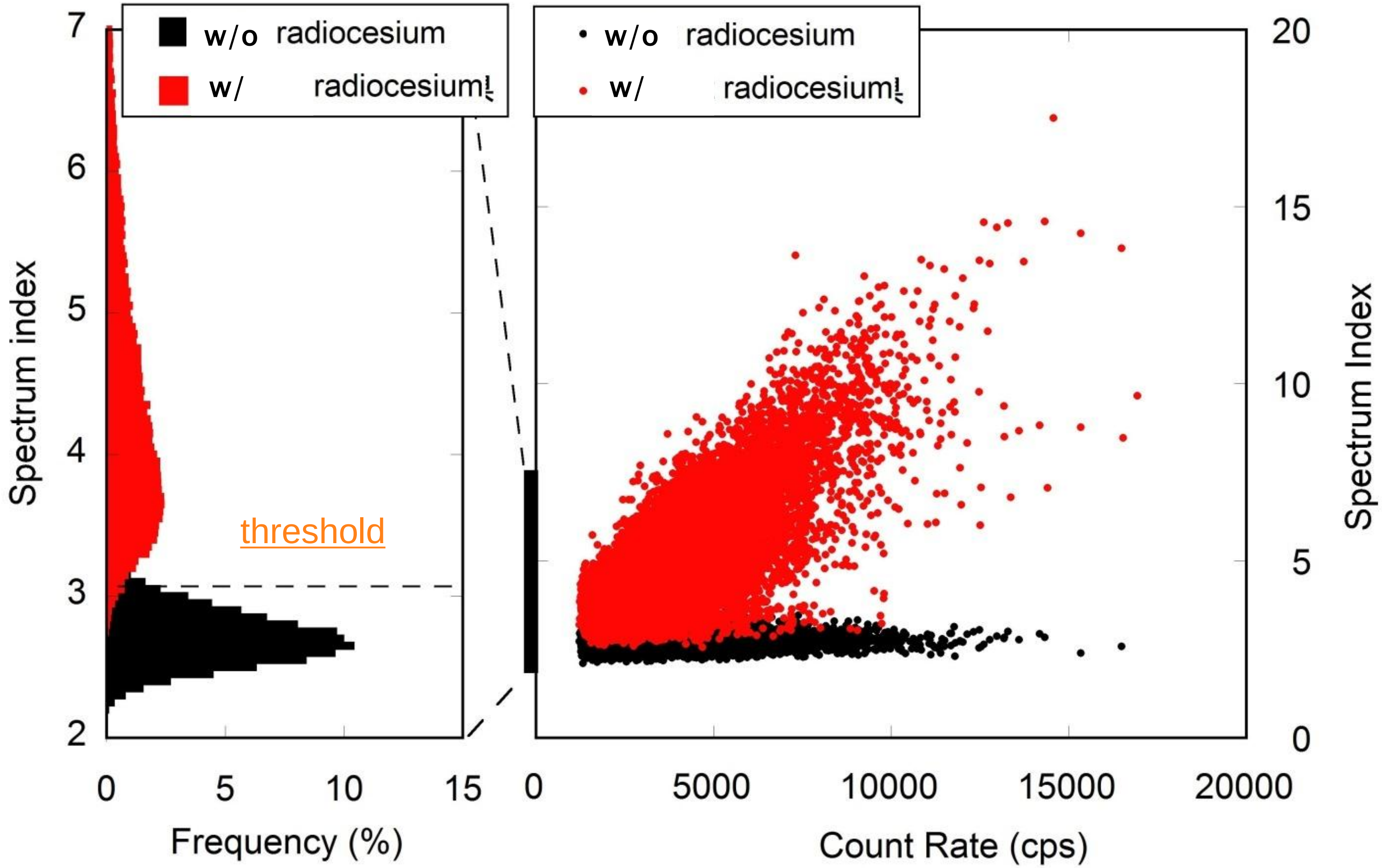


Conventional method



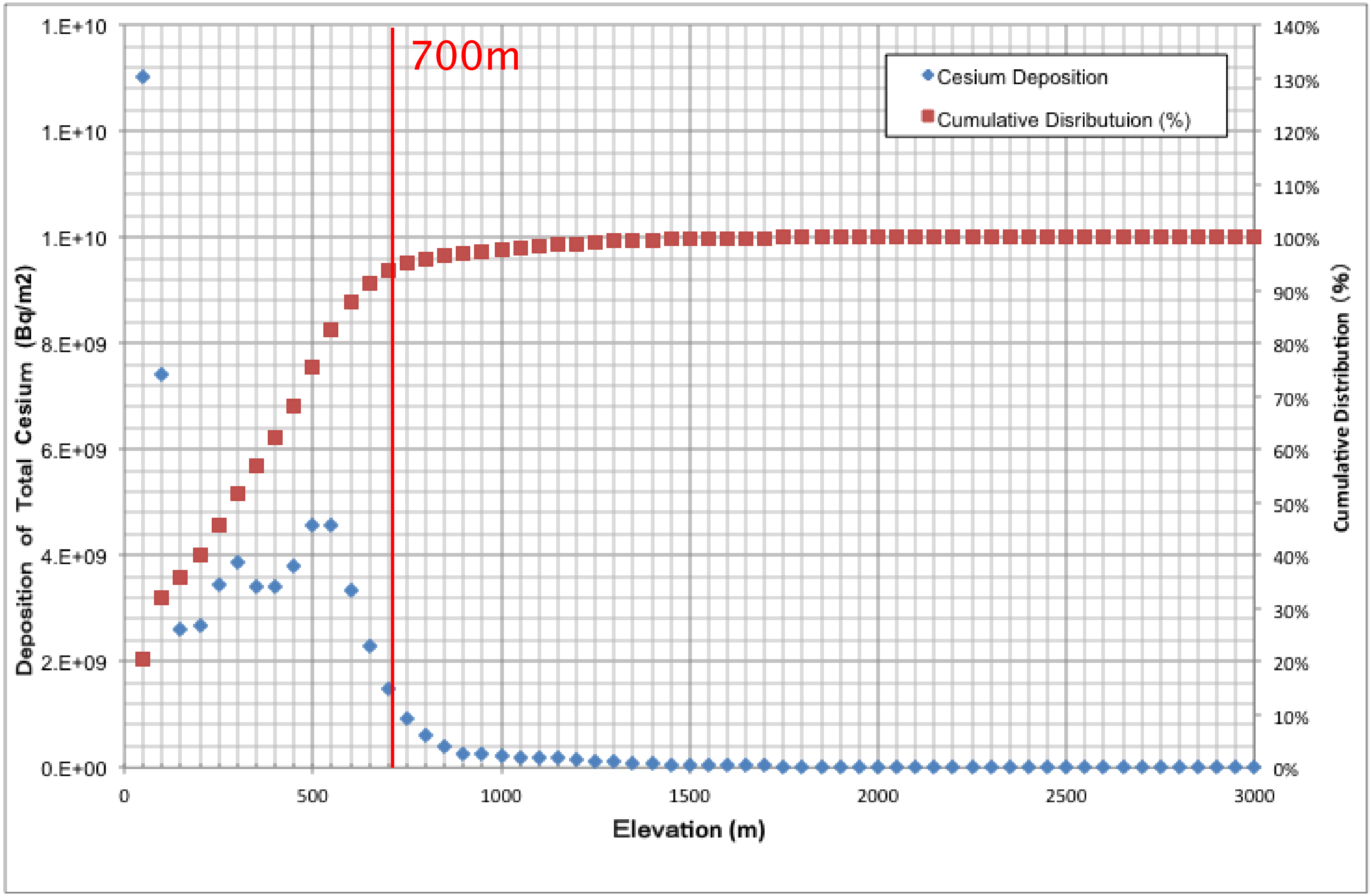
Using the SID method

Spectral Index Discrimination (SID)



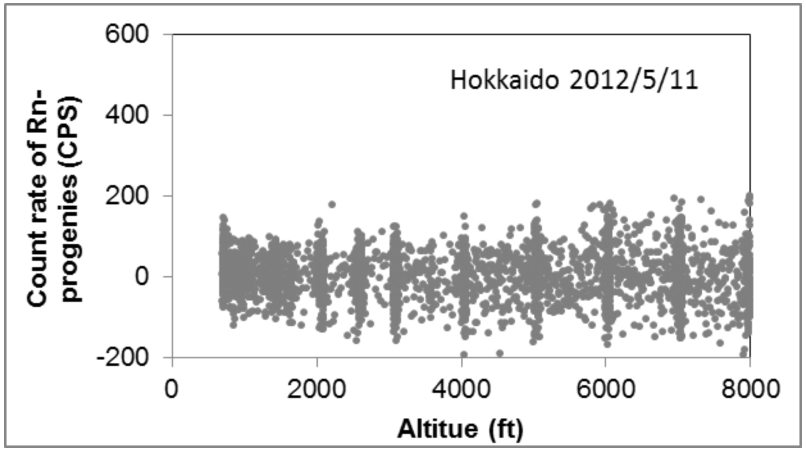
Threshold: Average+3σ of SI in the area without radioactive cesium

Altitude distribution of radioactive cesium



More than 95% of cesium is deposited in less than 700 m above sea level.

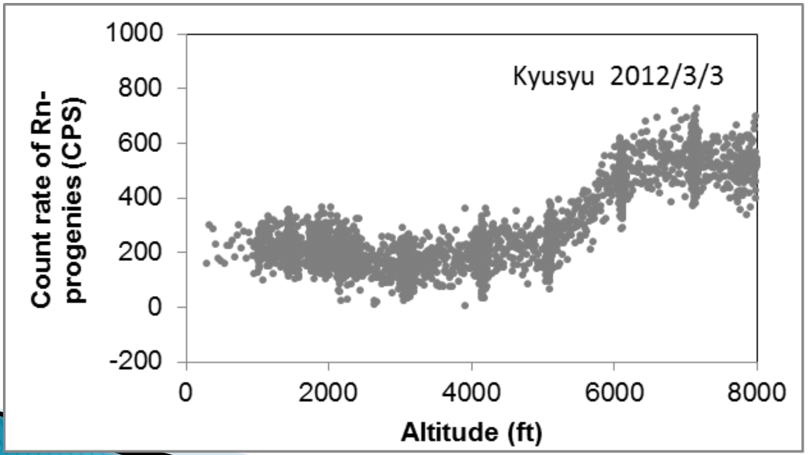
Disturbance of Rn-progeny in air

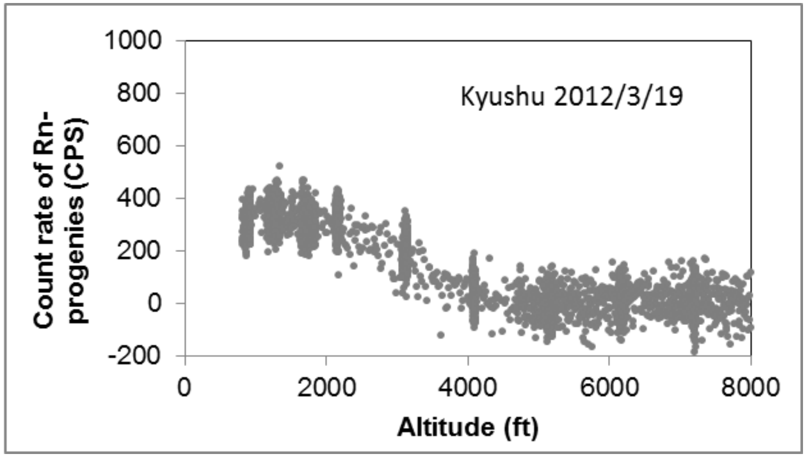


Discrimination of distribution of ground and cosmic ray

Maximum count rate：600 cps
CD: 17000 cps/uSv/h

Maximum : 0.04 uSv/h over estimation

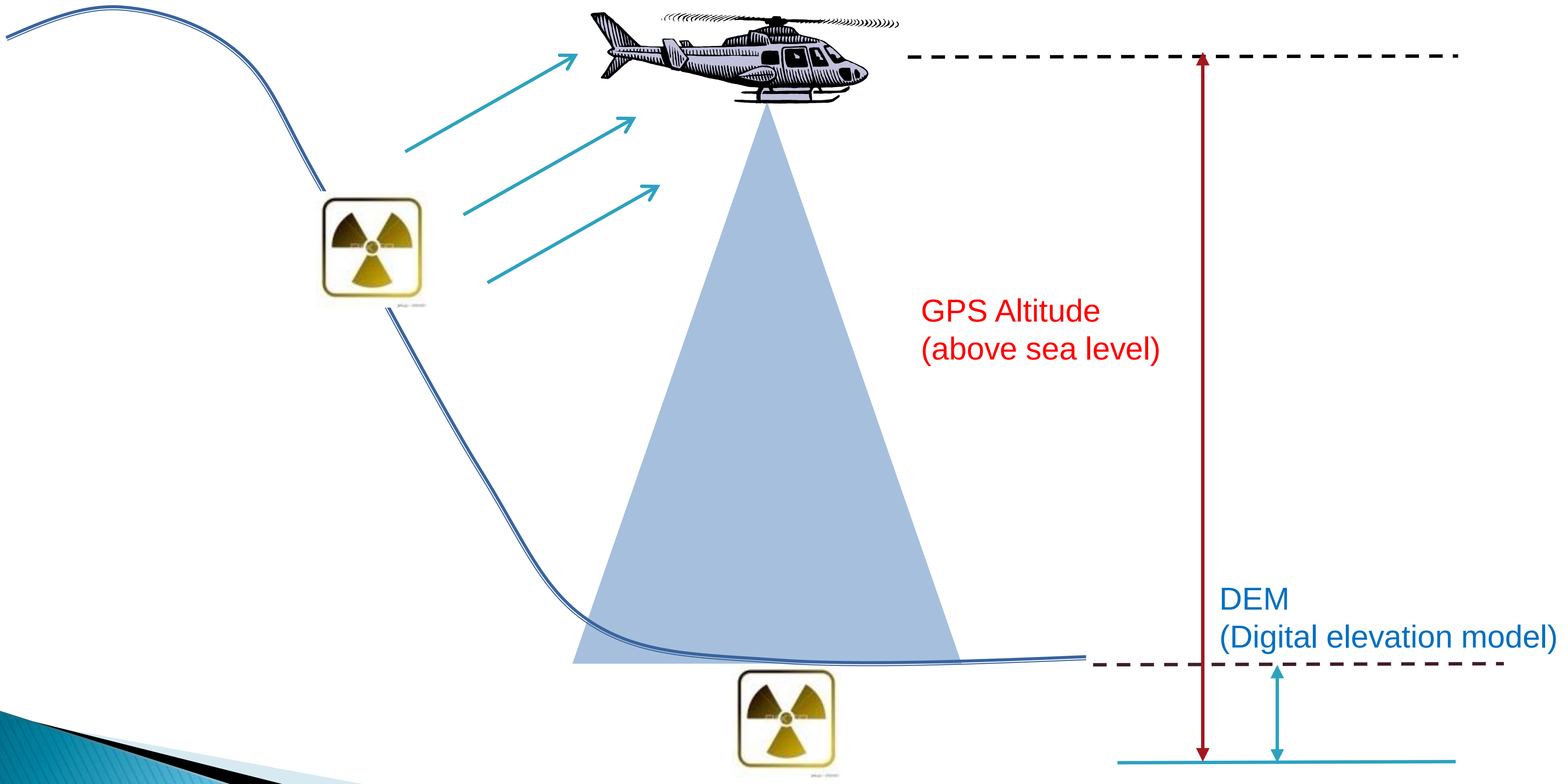




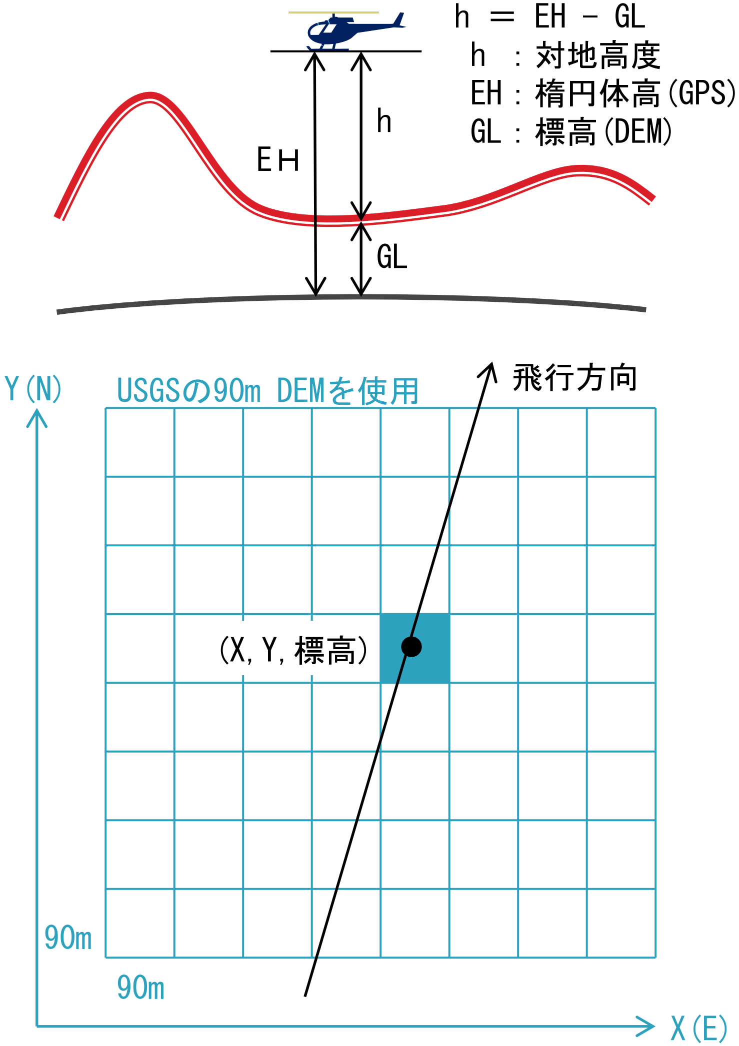
Geographical features

The place which receives radiation from a transverse direction

Over estimate



Geographical features



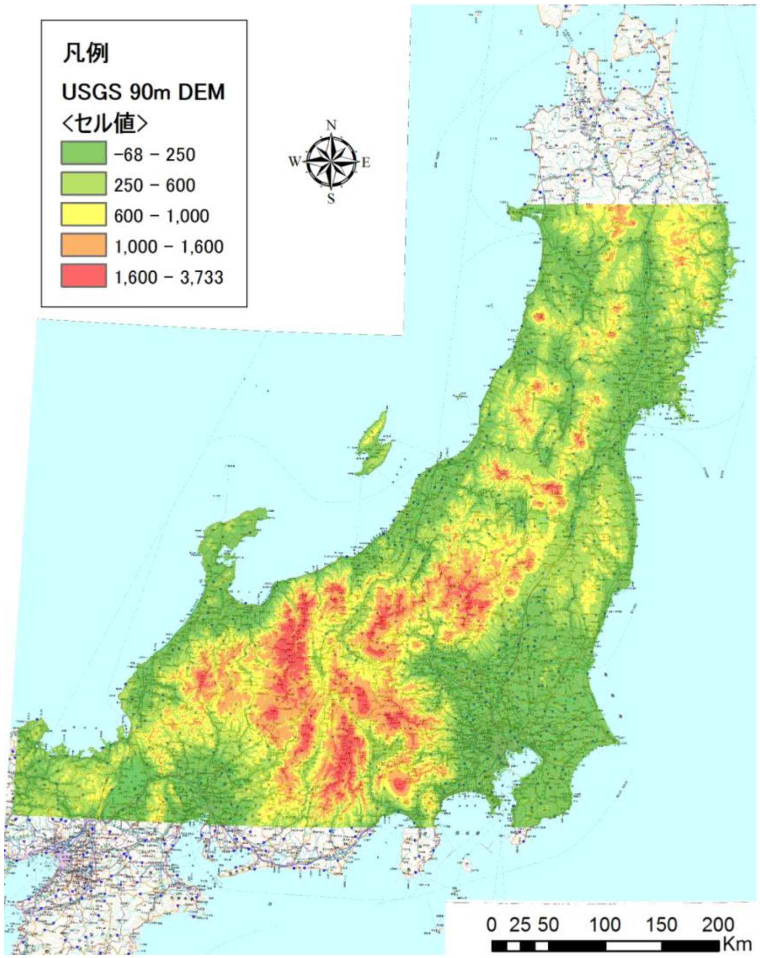


図 USGS 90m DEM (例)

Prediction of dose rate