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Remote radiation sensing Group

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

Approach from the ground (Effective of Decontamination)
- Plastic Scintillation Fiber (PSF)

Approach from the sky (widely and quickly!)
- Aerial radiation monitoring
  - Autonomous unmanned Helicopter and Airplane
  - Compton Camera

Joint of JAEA and JAXA

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

etc.
- Radioactivity measurement of waterbed
- In-situ Ge measurement

Decontamination

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

- Achievement of aerial radiation monitoring (ARM)
- ARM system (ARMS)
- Analysis method
  - Conversion to dose rate at 1 m on the ground
  - Discrimination of $\gamma$-ray from the natural nuclides
- Result and discussion
  (Map of dose rate and radiocesium deposition)
- Summary

PIXEL 2012 in Inawashiro, Sep. 3–7
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

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>80km Zone From NPP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East Japan</td>
<td>Yamagata</td>
<td>Gunma</td>
<td>Akita</td>
</tr>
<tr>
<td></td>
<td>Fukushima(W)</td>
<td>Niigata</td>
<td>Nagano</td>
</tr>
<tr>
<td></td>
<td>Chiba, Tokyo, Kanagawa</td>
<td>Shizuoka, Gifu</td>
<td>Fukui</td>
</tr>
<tr>
<td>West Japan</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **80km Zone From NPP**: 4th monitoring
- **East Japan**: Warning area monitoring
- **West Japan**: 5th monitoring

### 80km Zone From NPP

- **Aug.**: RSI (rental from DOE)
- **Sep.**: RSI (MEXT)
- **Oct.**: NUSTEC
- **Nov.**: OYO
- **Dec.**: FUGRO

### Snow Season

- **Miyagi**: Kinki (W)
- **Tochigi**: Kyusyu (S), Okinawa
- **Kinki (W)**: Kinki (E), Hokkaido
- **Kyusyu (N)**: Cyugoku (E)
- **Gunma**: Cyugoku (N), Fukushima (W)
- **Hokkaido**: Shikoku
- **Ibaraki**: Okayama
- **Hokkaido**: Snow

**Legend**:
- : 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

Flight plan (ex.): Aichi

Flight of 3 or 5km mesh

Ground

NPP

300 – 600m

flight height above the ground ~300m

3km
## Aerial monitoring system

### Spec

<table>
<thead>
<tr>
<th>Manufacture</th>
<th>RSI Co., Ltd (Canada)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The date of manufacture</td>
<td>2009</td>
</tr>
</tbody>
</table>
| 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        | 1 second              |
| Note                 | The same specification as DOE |

### Diagram

- **Detector RSX-3**
- **RS701**
- **Battery**
- **GPS**
- **RS501**
- **PDU**
- **Sub-monitor**
- **Computer + RadAssist**

* Power Distribution Unit (PDU) Input 28VDC, 115VDC

Note: The same specification as DOE

**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.
## Aerial monitoring system

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>Install</th>
<th>Det.size(inch), quantity</th>
<th>Energy range</th>
<th>Channel</th>
<th>Altimeter</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Inside</td>
<td>16&quot; × 4&quot; × 2&quot;, 6 detector</td>
<td>0.02 - 3 MeV</td>
<td>1,024 ch</td>
<td>GPS</td>
</tr>
<tr>
<td>B</td>
<td>Outside</td>
<td>16&quot; × 4&quot; × 4&quot;, 4 detector</td>
<td>0.05 - 3 MeV</td>
<td>256 ch</td>
<td>Laser</td>
</tr>
<tr>
<td>C</td>
<td>Outside</td>
<td>16&quot; × 4&quot; × 4&quot;, 8 detector</td>
<td>0.2 - 3 MeV</td>
<td>256 ch</td>
<td>Radio wave</td>
</tr>
<tr>
<td>D</td>
<td>Inside</td>
<td>16&quot; × 4&quot; × 4&quot;, 4 detector</td>
<td>0.05 - 3 MeV</td>
<td>256 ch</td>
<td>GPS</td>
</tr>
</tbody>
</table>

**Images:**
- System “B”
- System “C”
- System “D”

*PIXEL 2012 in Inawashiro, Sep. 3-7*
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)

<table>
<thead>
<tr>
<th>System</th>
<th>cps/μSv/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.93x10⁴</td>
</tr>
<tr>
<td>B</td>
<td>1.06x10⁴</td>
</tr>
<tr>
<td>C</td>
<td>1.12x10⁴</td>
</tr>
<tr>
<td>D</td>
<td>1.22x10⁴</td>
</tr>
</tbody>
</table>
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 (Nal survey-Meter)

![Graph showing gamma energy distribution and system comparison]
Where is measured?

- Simulation for detector response (EGS5)

Angular response \times \text{the area of each circle}

80 knots \equiv 40 \text{ 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)

Measurement above test line
Attenuation factor ($\mu$) was measured at altitude from 500 to 2000ft each 500ft

Coefficient from dose-rate to radioactivity ($CF$) by ICRU rep53 table

Coefficient of dose-rate on the reference altitude ($CD$)

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

The reliability of parameters

Altitude (ft)

BG

Count rate (cps)

Dose-rate at 1m above the ground

Measurement above sea or lake

PIXEL 2012 in Inawashiro, Sep. 3-7
Analysis method (test line data)

Conversion factor (CD)

\[ y = 126000 \times R^2 = 0.999 \]

Attenuation factor (\( \mu \))

\[ y = 201000 e^{-0.0025x} \]

\[ R^2 = 0.995 \]
Methods of analysis (Conversion formula)

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

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

- $C_{all}$: 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 ($V_{Cs-134+137}$) at the ground

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

- $C_{all}$: 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)

- $CF$: Coefficient from dose-rate to radioactivity
  (ICRU 53 table; $\beta=1$)
- $D_{nat}$: 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)

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 \( I_{BG} \) = \( \frac{(a+b+c)}{b} \)
CR index \( I_{CR} \) = \( \frac{(a+b+c)}{c} \)

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.

<table>
<thead>
<tr>
<th>System</th>
<th>Detection limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dose rate at 1m above the ground (μSv/h)</td>
</tr>
<tr>
<td>A</td>
<td>0.0095</td>
</tr>
<tr>
<td>B</td>
<td>0.015</td>
</tr>
<tr>
<td>C</td>
<td>0.014</td>
</tr>
</tbody>
</table>

* 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 method 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
$^{134}\text{Cs} + ^{137}\text{Cs}$

Dose rate

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PIXEL 2012 in Inawashiro, Sep. 3-7
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

Ground measurement by in-situ Ge
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
Summary

- We carried out aerial radiation monitoring in the whole area of Japan.
- The attenuation factor ($\mu$) 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.
(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

Ave. : 31.67
S.D. : 8.78

RSI–2

Ave. : 25.60
S.D. : 8.20

NUSTEC

Ave. : 12.97
S.D. : 3.42

OYO

Ave. : 15.52
S.D. : 4.92
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

![Graph showing energy spectrum and spectral index]

\[
SI = \frac{\text{Count-rate more than 450keV}}{\text{Count-rate more than 900keV}}
\]
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/μSv/h

Maximum: 0.04 μSv/h over estimation
Geographical features

The place which receives radiation from a transverse direction

Over estimate

GPS Altitude (above sea level)

DEM (Digital elevation model)
Geographical features

\[ h = EH - GL \]

- **h**: 海拔高度
- **EH**: 椎円体高 (GPS)
- **GL**: 標高 (DEM)

(\(X, Y, \) 標高)

图 USGS 90m DEM（例）
Prediction of dose rate

After 1 year

After 5 years