Challenges for Enhancing Fukushima Environmental Remediation

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The great east Japan earthquake was occurred 2011 March 11 14:46.
The Fukushima Dai-ichi Nuclear Power Plant Accident

- **14:46 Mar. 11**: Earthquake and following big wave (tsunami) struck the power plant (Magnitude 9.0, max height of tsunami: over 15 m)
- **15:42**: Loss of all electric power through unit 1 to 5 (without unit 6), and data from 24 MPs around plant had been stopped.
- **19:03**: *The Prime Minister declared “Nuclear Emergency”*
- **21:23**: Residents evacuation within 3 km and shelter-in-place within 10 km, 5:44, Mar. 12; expanded evacuation within 10km.
- **23:00 Mar. 11**: 1.2mSv/h in front of the north door to reactor and turbine buildings of unit 1.
- **15:36 Mar. 12**: Hydrogen explosion occurred in the unit 1 reactor building.
- **18:25**: Evacuation zone had been expanded within 20km.
- **11:01 Mar. 14**: Hydrogen explosion occurred in the unit 3 reactor building.
- **6:14 Mar. 15**: Hydrogen explosion occurred in the unit 4 reactor building.

Increasing air dose rate around plant

Dispacted specialists to Fukushima OFC

*March 11 to 12, 2011*

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**22:46 Mar. 11**; Requested by MEXT (Ministry of Education, Culture, Sports, Science and Technology), JAEA gathered the 1st specialist team at the Operation Room of NEAT in IBARAKI pref.

**1:54 Mar. 12**;
The 1st team started from NEAT to Hyakuri Air Base, and moved to Fukushima OFC at Ookuma town by a helicopter of JSDF.

**06:00 Mar. 12**; Arrived at the monitoring center (Atomic center) next to Fukushima OFC in Ookuma town

**6:30 Mar. 12**; The 1st JAEA Team joined with emergency response meeting at Fukushima OFC
Dispatching Special Vehicles

**Monitoring vehicle installed Ge spectrometer with shielding**

- Mar.14: Monitoring vehicle installed Ge detector was dispatched from NEAT-Fukui

**Whole-body counter (WBC) vehicle for Internal Exposure survey for occupational**

- Mar.12: Dispatched from NEAT-Ibaraki
- Mar.16: Located at Fukushima Medical College.
- Mar.21: Located at TEPCO Onahama
- May.30: Another WBC vehicle was dispatched
- Internal doses were measured and evaluated for about 330 workers until April 25.

**Surface contamination monitoring vehicle and decontamination vehicle**

- Mar.15: A monitoring vehicle was dispatched from NEAT-Ibaraki (Three monitoring cars had been worked in Fukushima from JAEA)
- Mar.15: Dispatched from NEAT-Ibaraki
- Mar.16: Located at Fukushima Medical College.
## Milestone of Fukushima Environmental Remediation

By JAEA Fukushima

<table>
<thead>
<tr>
<th>Year</th>
<th>Short Term (2y)</th>
<th>Mid Term (3-5y)</th>
<th>Long Term (6-10y)</th>
</tr>
</thead>
</table>
| 2011 |                | Unix, Sahei building, Fukushima Univ., Sasakino analytical center | |}
| 2012 |                | Fukushima Pref. Centre for Environmental Creation (Minamisoma) | |}
| 2013 |                | Fukushima Pref. Centre for Environmental Creation (Miharu) | |}

### Environmental Monitoring

- Personal Dose monitoring
- Planing for Decontamination
- Designation of evacuation areas

### Decontamination and Volume Reduction

- Research and Actual Estimation for Decontamination Technique
- Effective Decontamination
- Industrialization
- Development of Volume Reduction technique (Heat treatment, Cs Absorption and Desorption)

### Environmental Dynamics

- Decontamination
- Long-term Assessment of Transport of Radioactive Contaminant in the Environment of Fukushima (F-TRACE) (Cs Prediction Model of Air Dose Rate Distribution, Migration Control and Dose Reduction)

### Research and Actual Estimation for Decontamination Technique

- Effective Decontamination
- Industrialization
- Development of Volume Reduction technique (Heat treatment, Cs Absorption and Desorption)

### Decontamination Long-term Assessment of Transport of Radioactive Contaminant in the Environment of Fukushima (F-TRACE) (Cs Prediction Model of Air Dose Rate Distribution, Migration Control and Dose Reduction)

- Apply for Post Accident Rapid and Remort Monitoring
Environmental Monitoring

Aerial monitoring

Dose rate $\mu$Sv/h at 1m

<table>
<thead>
<tr>
<th>Det. size (inch), quantity</th>
<th>Energy range</th>
<th>Channel</th>
<th>Altimeter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$16'' \times 4'' \times 2''$, 6 detector</td>
<td>0.02 - 3 MeV</td>
<td>1,024 ch</td>
<td>GPS</td>
</tr>
</tbody>
</table>

$^{134}$Cs + $^{137}$Cs

flight height above the ground $\sim 300$ m

http://radioactivity.nsr.go.jp/en/list/270/list-1.html
Environmental Monitoring
Dose Rate Distribution as a Passing Time
- by aircraft monitoring -

After 7 months
(2011.11.05)

After 11 months
(2011.02.10)

After 15 months
(2012.06.28)

After 20 months
(2012.11.16)

After 24 months
(2013.03.11)

After 30 months
(2013.09.28)

Air dose rate at 1m height above the ground (μSv/h)
- 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

※ White parts surrounded by solid line are snow covered zones
Environmental Monitoring

Dose rate variation with time based on airborne monitoring

<table>
<thead>
<tr>
<th>FY</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4-6</td>
<td>7-9</td>
<td>10-12</td>
</tr>
<tr>
<td>&lt;80 km</td>
<td>1st</td>
<td>3rd</td>
<td>4th</td>
</tr>
<tr>
<td>&gt;80 km</td>
<td>2nd</td>
<td>East Japan 1st</td>
<td></td>
</tr>
</tbody>
</table>

* Covering of a part of 100 - 120 km

- AMS monitoring
- Half life

Normalized of 4th monitoring vs. Elapsed days after the accident

9th monitoring after 42 months (2014.09.20)
Protective Actions

**Evacuation Order Areas**
Designation of evacuation areas is completed just after the accident (Apr. 22, 2011)

Switched from distance to a threshold radiation dose of 20 mSv/y on Apr. 22

Rapidly expanded (3-km, 10-km, 20-km radius by Mar. 12)

Specific Spots Recommended for Evacuation

**Food and water restrictions**

- Regulatory limits for contaminated food and water based on
  - <5 mSv/y (March 20, 2011)
  - <1 mSv/y (April 1, 2012)

<table>
<thead>
<tr>
<th>Category</th>
<th>Limit (Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drinking water</td>
<td>10</td>
</tr>
<tr>
<td>Milk</td>
<td>50</td>
</tr>
<tr>
<td>General Foods</td>
<td>100</td>
</tr>
<tr>
<td>Infant Foods</td>
<td>50</td>
</tr>
</tbody>
</table>
Environmental Monitoring

**Result of Estimation (External Exposure)**

<table>
<thead>
<tr>
<th>Target</th>
<th>Reply</th>
<th>Estimate</th>
<th>Notice</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,055,305</td>
<td>565,904</td>
<td>551,510</td>
<td>551,110</td>
</tr>
<tr>
<td>(27.5%)</td>
<td>(97.5%)</td>
<td>(97.4%)</td>
<td></td>
</tr>
</tbody>
</table>

For 4 months after accident  
Excluding occupationally exposed person

<table>
<thead>
<tr>
<th>Effective Dose</th>
<th>Less than 1mSv</th>
<th>1~2 mSv</th>
<th>• •</th>
<th>Over 15mSv</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>288,401</td>
<td>146,701</td>
<td>• •</td>
<td>15</td>
<td>463,659</td>
</tr>
</tbody>
</table>

Max.: 25mSv  
2016.12.27, Fukushima pref.

**Result of Estimation (Internal Exposure)**

<table>
<thead>
<tr>
<th>Committed Effective Dose</th>
<th>Less than 1mSv</th>
<th>1mSv</th>
<th>2mSv</th>
<th>3mSv</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>316,496</td>
<td>14</td>
<td>10</td>
<td>2</td>
<td>316,522</td>
</tr>
</tbody>
</table>

2017.1.30, Fukushima pref.
## Decontamination and Volume Reduction
### Recommended Clean-up Technologies

<table>
<thead>
<tr>
<th>Land use classification</th>
<th>Comprehensive evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>◎ Removal of leaf litter and humus layers (on flat ground and slopes), ○ Removal of leaf litter, humus layers and topsoil (on flat ground), ▲ Trunk washing, ○ Branch trimming in the lower part (evergreen tree)</td>
</tr>
<tr>
<td>Farmland</td>
<td>◎ Machine that strips off surface of soils, ○ Backhoe (stripping off depth of 5 cm of the soil), ◎ Reversal tillage (by tractor and plough), ○ Ploughing to replace surface soil with subsoil (by backhoe)</td>
</tr>
<tr>
<td>Residential area</td>
<td></td>
</tr>
<tr>
<td>Roof</td>
<td>▲ High pressure water, ○ Brushing, ○ Wiping, ▲ Apply a remover</td>
</tr>
<tr>
<td>Gutter</td>
<td>△ High pressure water, ○ Wiping</td>
</tr>
<tr>
<td>Wall</td>
<td>○ Brushing</td>
</tr>
<tr>
<td>Topsoil</td>
<td>○ Removal of topsoil</td>
</tr>
<tr>
<td>Rubble</td>
<td>○ Washing of the rubble, ○ Removal of the rubble</td>
</tr>
<tr>
<td>Turf</td>
<td>○ Removal of the Turf</td>
</tr>
<tr>
<td>Garden tree</td>
<td>▲ Clipping a garden tree</td>
</tr>
<tr>
<td>Interlocking block</td>
<td>△ High pressure water</td>
</tr>
<tr>
<td>Large structure</td>
<td></td>
</tr>
<tr>
<td>Concrete and Mortar</td>
<td>△ Sanding machine with the dust-collection (Plane which scrapes concrete), ○ Ultrahigh pressure water (Over 150MPa), ○ High pressure water (10-20MPa), ○ Iron shot blasting</td>
</tr>
<tr>
<td>Concrete surface</td>
<td>○ High pressure water (including brushing)</td>
</tr>
<tr>
<td>Waterproof coating</td>
<td>○ High pressure water (including brushing)</td>
</tr>
<tr>
<td>Downpipe</td>
<td>○ High pressure water (Maximum 50MPa)</td>
</tr>
<tr>
<td>Playing field</td>
<td>○ Strips off surface of soils (Large mower+Sweeper), ○ Strips off surface of soils (Road planers), ○ Strips off surface of soils (Motor grader), ○ Ploughing to replace surface soil with subsoil</td>
</tr>
<tr>
<td>Swimming pool</td>
<td>○ High pressure water</td>
</tr>
<tr>
<td>Turf</td>
<td>○ Turf stripper</td>
</tr>
<tr>
<td>Paved road</td>
<td>▲ Road cleaners + Riding style road sweepers, △ High pressure water (About 15MPa)+Brushing, △ Car of a functional recovery drainage pavement, ○ Ultrahigh pressure water (120～240MPa), ○ Iron shot blasting, ○ TS Road planers</td>
</tr>
</tbody>
</table>

◎ : highly effective, ○ : effective, △ : moderately effective, ▲ : limited effect

[http://dx.doi.org/10.11484/jaea-review-2014-051](http://dx.doi.org/10.11484/jaea-review-2014-051)
Hot spot monitoring

Places of hotspots around housing

- Dirt of the roof
- Wind gathers
- Part of crack
- Place of raindrop
- Drainage of rain gutter
- Rain gutter
- Puddle
- The place of the tree root
- Border of a concrete tile and the soil

Hot spots in evacuation area /Geographical features

- e.g. Way of the wind in valley line and weather condition

Decontamination and Volume Reduction

Hot spot monitoring (continue)

Survey for horizontal distribution of dose rate

Measurement at 1m high

Measurement at 1cm high

Dose rate (μSv/h)

Hotspot shows large difference

Measured position of horizon (m)

Collimator

Shielding the radiation from far side

Surface soil sampling

Measurement using the Collimator to eliminate scatter radiation from far area

**Decontamination and Volume Reduction**

**Waste Management Challenges**

- Clean-up efforts are generating huge volumes of contaminated soil and waste, which must be managed in a safe and cost-effective manner, wherever possible implementing waste volume reduction.
- Future reuse of soil for construction purposes is an important option, if constraints in terms of allowable organic and clay content can be managed.

### Volume (Mm³)

<table>
<thead>
<tr>
<th>Category</th>
<th>Volume (Mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contaminated soil and wastes</td>
<td>10.06 Mm³</td>
</tr>
<tr>
<td>Over 8kBq/kg</td>
<td>0.01 Mm³</td>
</tr>
<tr>
<td>Over 8kBq/kg, below 100kBq/kg</td>
<td></td>
</tr>
<tr>
<td>Over 100kBq/kg</td>
<td>0.02 Mm³</td>
</tr>
<tr>
<td>Incinerated ash over 100kBq/kg</td>
<td>1.55 Mm³</td>
</tr>
<tr>
<td>Waste in countermeasure area over 100kBq/kg</td>
<td>10.35 Mm³</td>
</tr>
<tr>
<td>Over 100kBq/kg</td>
<td>1.55 Mm³</td>
</tr>
<tr>
<td>Below 8kBq/kg</td>
<td>10.06 Mm³</td>
</tr>
<tr>
<td>Total</td>
<td>16-22 Mm³</td>
</tr>
</tbody>
</table>

**Notes:**
- Incinerated ash over 100kBq/kg
- Waste in countermeasure area over 100kBq/kg
Transport and accumulation in a river basin

Individual exposure in living areas
Currently, most of Cs deposited on tree has transported to forest floor.

Evolution of cumulative Cs due to transport from tree crowns to forest floor

Evolution of Cs concentration in stemflow (Bq/L)
Environmental Dynamics

Transport and accumulation in a river basin

Recovery of a river system

① Dec. 11, 2012
② Jan. 16, 2014
③ Oct. 16, 2014

Air dose rate (relative)

Elapsed time after the accident (d)

Measured
Calculated

① ② ③
Other Projects
Human Resources Development and Communications

【Nagaoka University of Technology】
2016.9.16～
lecture and Practice

【Koriyama Women’s University】
2016.9.28～
lecture and Practice

【National Institute of Technology, Fukushima College,】
2016.11.5～
lecture and Practice
Other Projects

Knowledge and experience gained for Enhancing Fukushima Environmental Remediation

● Cleanup Navi


The Cleanup-navi Communication Platform provides an overview of regional contamination due to the accident and approaches to remediation. It also includes background information on the nature of ionising radiation and its health effects to allow the user to make informed judgements as to the value of the remediation actions that are being undertaken.

● DPP reports

http://fukushima.jaea.go.jp/english/outline/20150327.html

Part 1 summarises the Decontamination Pilot Project, providing the background required to put this work in context for an international audience. In Part 2, the subsequent application of output from this project to regional remediation is discussed, along with a status update on such work (including radioactivity monitoring), an overview of JAEA's associated R&D and international input to / review of regional environmental decontamination in Fukushima.

● Lessons learned report

http://fukushima.jaea.go.jp/english/outline/20150327.html

This report provides a concise overview of knowledge and experience gained from the activities for environmental remediation after the Fukushima Daiiichi accident. It is specifically tailored for international use, to establish or refine the technical basis for strategic, off-site response to nuclear incidents.
Summary

✓ JAEA had been acted many projects (Environmental monitoring, Decontamination, etc.) in Fukushima as a first response

✓ Environmental Dynamics of Cs is studying as a long term basic research

✓ Harmonization between science and communications (Public Acceptance) were very important