Use of Air Dose Rates to Estimate Whole Body Dose and Guide Remediation Efforts in Areas around the Fukushima Evacuation Zone
Bio

• BS Physics – Clemson
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• AECOM – Greenville, SC
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• Lead AECOM’s Global Radiological Services Practice
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• Technical Focus Areas
  • Site Assessment and Remediation
  • Decontamination and Decommissioning
  • Environmental Impact Assessment for nuclear projects
  • Shielding Design
Outline

• Summarize of IAEA Mission to Fukushima – October, 2013
• Framework of decontamination in Japan
• Air dose rate
• Assessment of decontamination efforts
• Summarize and discuss findings provided in IAEA report

Date City (~ 50 km)  Kawauchi Village (< 20 km)  Okuma Town (~ 2 km)
Summary of IAEA Mission - October 2013

- Multiple meetings with national and location officials
- Visited two temporary waste storage sites
- Toured rice warehouse with assay process
- Toured sewage sludge incinerator
- Visited forest remediation site
- Visited potential interim waste storage site (~2km from NPP)
- Drafted and presented Highlights and Advices to MOE
Remediation Techniques

- 73 demonstration projects
- Low-tech/high production
  - Pressure Washing
  - Surface soil removal
  - Pruning
  - Shot/grit blasting
  - Forest debris removal
  - Deep plowing/soil enhancements

Before Plowing

After Plowing
Waste Management

- On-site storage (3 yrs)
- 365+ Temporary Waste Storage Sites (3 yrs)
- Interim waste site(s) (30 yrs)
- Permanent waste disposal
- Incineration
Summary IAEA Mission
October 2013

News - 24 January 2014
IAEA Delivers Final Report on Remediation in Fukushima to Japan:

Report:
Framework of Decontamination

Special Decontamination Area

- Former restricted or evacuation zone
- 11 municipalities
- Implementation controlled by the national government
  - Areas where evacuation order have or are ready to be lifted (<5 mSv/y)
  - Areas where residents are not permitted to live (< 20 mSv/y)
  - Areas where it is expected that residents will not return for a long time (>20 mSv/y)

Intensive Contamination Survey Area

- 100 municipalities in 8 prefectures
- Implementation controlled by the local governments
- Dose rate > 0.23 µSv/hr; equivalent to over 1 mSv/yr of additional dose
Basic Principles of Decontamination

ICRP Recommendations

100 mSv/yr

Special Decon Areas

Emergency actions required
Significant decontamination efforts

Goal to reduce annual dose to 20 mSv or less

20 mSv/yr

ICRP Target Range

Long-term exposure following emergency

Long-term goal to reduce annual dose to 1 mSv or less

1 mSv/yr

National Government is responsible for decontamination

Higher Dose – Large-scale surface decontamination

Lower Dose – Hot-spot decontamination

Local Governments area responsible for decontamination

Goal to reduce annual dose to 20 mSv or less

Long-term goal to reduce annual dose to 1 mSv or less
Relation Between Air Dose Rate and Annual Radiation Exposure

- Air dose rate = air absorbed dose rate ($\mu$Sv/hr)
- Based on the following assumptions:
  - Staying inside for 16 hours and outside for 8 hours
  - Shielding effect of a wooden house is 60% reduction

$$\left(0.23 \, \mu\text{Sv/hr} - 0.04 \, \mu\text{Sv/hr}\right) \times (8 + (0.4)16) \text{hr} \times 365 \text{ days} / 1000 = 1 \, \text{mSv/yr}$$
  - 0.04 $\mu$Sv/hr: background (national average – Japan)

- Equation applied in most (if not all) cases regardless of population demographics
Assessment of Decontamination Results

• Air Dose Rate in Living Spaces
  – Inside and outside
  – Serves as the target for decontamination
  – NaI or CsI scintillation detectors
  – Taken at 1 m above the ground (50 cm for children)

• Surface Contamination Density
  – GM surveys (Bq/cm²)
  – “Reduction Rate” or “Decontamination Factor” used to determine effectiveness of the method(s)
  – Not used for “release” of areas
Assessment Tools

Figure 1-7. Examples of Scintillation Survey Meters
(NaI scintillation survey meters)

Figure 1-8. Examples of GM Survey Meters
Assessment of Decontamination Results

• Tamura City (edge of the 20 km evacuation zone; south west of the reactor site)
• Work Period: July 5, 2012 – June 28, 2013
• Number of Workers: 1,300/day
  – 120,000 man hours
• Volume of Work:
  – Buildings: 228,249 m² (121 family homes)
  – Roads: 95.6 km
  – Farmland: 1,274,021 m²
  – Forests: 1,921,543 m²
Effect of Reducing Radiation Dose by Decontamination Work (Surface Concentration of contamination*)

*Surface concentration of contamination is the number of radiation per minute counted by a detector. As it is detected at the level above 1cm from decontaminated surface, changes due to the figures can be clearly evaluated.

※The measurement was taken before and after the decontamination work so that natural attenuation effect after the work was not included.

- Measurement period before the decontamination work : July 25, 2012 ～ May 23, 2013
Effect of Radiation Dose Reduction by the Decontamination Work
- Surface Concentration of Contamination -

<table>
<thead>
<tr>
<th>Area</th>
<th>Surface Concentration of Contamination (cpm)</th>
<th>Measurement Points</th>
<th>Average Value before the Decontamination Work (cpm)</th>
<th>Average Value after the Decontamination Work (cpm)</th>
<th>Reduction Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Area</td>
<td>more than 900</td>
<td>2,370</td>
<td>1,784</td>
<td>398</td>
<td>78%</td>
</tr>
<tr>
<td></td>
<td>600〜900</td>
<td>1,706</td>
<td>753</td>
<td>338</td>
<td>55%</td>
</tr>
<tr>
<td></td>
<td>300〜600</td>
<td>4,271</td>
<td>453</td>
<td>274</td>
<td>40%</td>
</tr>
<tr>
<td></td>
<td>less than 299</td>
<td>3,190</td>
<td>243</td>
<td>193</td>
<td>20%</td>
</tr>
<tr>
<td>Farmland</td>
<td>more than 900</td>
<td>95</td>
<td>1,230</td>
<td>432</td>
<td>65%</td>
</tr>
<tr>
<td></td>
<td>600〜900</td>
<td>323</td>
<td>722</td>
<td>359</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>300〜600</td>
<td>1,961</td>
<td>436</td>
<td>286</td>
<td>34%</td>
</tr>
<tr>
<td></td>
<td>less than 299</td>
<td>801</td>
<td>263</td>
<td>218</td>
<td>17%</td>
</tr>
<tr>
<td>Forest</td>
<td>more than 900</td>
<td>527</td>
<td>1,229</td>
<td>520</td>
<td>58%</td>
</tr>
<tr>
<td></td>
<td>600〜900</td>
<td>1,201</td>
<td>742</td>
<td>475</td>
<td>36%</td>
</tr>
<tr>
<td></td>
<td>300〜600</td>
<td>2,097</td>
<td>475</td>
<td>383</td>
<td>19%</td>
</tr>
<tr>
<td></td>
<td>less than 299</td>
<td>155</td>
<td>280</td>
<td>276</td>
<td>1%</td>
</tr>
<tr>
<td>Roads</td>
<td>more than 900</td>
<td>1,019</td>
<td>1,206</td>
<td>352</td>
<td>71%</td>
</tr>
<tr>
<td></td>
<td>600〜900</td>
<td>1,314</td>
<td>758</td>
<td>331</td>
<td>56%</td>
</tr>
<tr>
<td></td>
<td>300〜600</td>
<td>2,342</td>
<td>456</td>
<td>270</td>
<td>41%</td>
</tr>
<tr>
<td></td>
<td>less than 299</td>
<td>730</td>
<td>260</td>
<td>214</td>
<td>18%</td>
</tr>
</tbody>
</table>
Effect of Radiation Dose Reduction by Decontamination Work
(Air Dose Rate at the height of 1m above ground)

※ The measurement was taken before and after the decontamination work so that natural attenuation effect after the work was not included.

- Measurement period before the decontamination work: July 25, 2012 ～ May 23, 2013
<table>
<thead>
<tr>
<th>Area</th>
<th>Radiation Dose before the Decontamination Work (μSv/h)</th>
<th>Measurement Points</th>
<th>Average Value before the Decontamination Work (μSv/h)</th>
<th>Average Value after the Decontamination Work (μSv/h)</th>
<th>Reduction Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>1.0 or more</td>
<td>383</td>
<td>1.24</td>
<td>0.54</td>
<td>56%</td>
</tr>
<tr>
<td></td>
<td>0.75～1.0</td>
<td>1,107</td>
<td>0.86</td>
<td>0.50</td>
<td>42%</td>
</tr>
<tr>
<td></td>
<td>0.5～0.75</td>
<td>2,789</td>
<td>0.62</td>
<td>0.41</td>
<td>35%</td>
</tr>
<tr>
<td></td>
<td>less than 0.49</td>
<td>2,179</td>
<td>0.42</td>
<td>0.32</td>
<td>24%</td>
</tr>
<tr>
<td>Farmland</td>
<td>1.0 or more</td>
<td>93</td>
<td>1.14</td>
<td>0.76</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td>0.75～1.0</td>
<td>565</td>
<td>0.86</td>
<td>0.60</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>0.5～0.75</td>
<td>1,654</td>
<td>0.63</td>
<td>0.48</td>
<td>24%</td>
</tr>
<tr>
<td></td>
<td>less than 0.49</td>
<td>685</td>
<td>0.45</td>
<td>0.37</td>
<td>17%</td>
</tr>
<tr>
<td>Forest</td>
<td>1.0 or more</td>
<td>505</td>
<td>1.23</td>
<td>0.84</td>
<td>32%</td>
</tr>
<tr>
<td></td>
<td>0.75～1.0</td>
<td>1,176</td>
<td>0.87</td>
<td>0.67</td>
<td>23%</td>
</tr>
<tr>
<td></td>
<td>0.5～0.75</td>
<td>1,800</td>
<td>0.64</td>
<td>0.54</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>less than 0.49</td>
<td>482</td>
<td>0.45</td>
<td>0.41</td>
<td>8%</td>
</tr>
<tr>
<td>Roads</td>
<td>1.0 or more</td>
<td>189</td>
<td>1.24</td>
<td>0.89</td>
<td>28%</td>
</tr>
<tr>
<td></td>
<td>0.75～1.0</td>
<td>591</td>
<td>0.85</td>
<td>0.63</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td>0.5～0.75</td>
<td>1,871</td>
<td>0.62</td>
<td>0.46</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td>less than 0.49</td>
<td>1,526</td>
<td>0.42</td>
<td>0.33</td>
<td>21%</td>
</tr>
</tbody>
</table>
IAEA “Highlights”

• **Highlight 5 of 13:** The Team acknowledges that the Nuclear Regulation Authority (NRA) has set up a team to conduct a study on ‘Safety and Security Measures towards Evacuees Returning Home’. It is beneficial to continue the measurement of individual external exposure doses for Fukushima Prefecture residents, to confirm the expected decreasing trend and justify the remediation decision as noted in Point 4. In addition to decontamination, other measures such as adjustment of life-styles and daily routines can also lead to reduction of individual exposures and to provide optimized protection.
• **Highlight 6 of 13**: The Team welcomes the critical evaluation of the efficiency of the removal of contaminated material compared with the reduction in dose rate offered by different methods of decontamination, recognizing that this is an important tool in the application of decontamination methods. In addition, the Team notes a welcome change from guiding remediation efforts based on surface contamination reduction, to a reduction in air dose rates. This is leading some municipalities to conclude that an additional 1 mSv per year is more applicable to long-term dose reduction goals.
• **Point 2 of 8:** Japanese institutions are encouraged to increase efforts to communicate that in remediation situations, any level of individual radiation dose in the range of 1 to 20 mSv per year is acceptable and in line with the international standards and with the recommendations from the relevant international organizations, e.g. ICRP, IAEA, UNSCEAR and WHO. The appropriate application of the optimization principle in a remediation strategy, and its practical implementation, requires a balance of all factors that influence the situation, with the aim of obtaining the maximum benefit for the health and safety of the people affected. These facts have to be considered in communication with the public, in order to achieve a more realistic perception of radiation and related risks among the population.
• **Point 4 of 8:** There needs to be a continued movement towards the use of the individual doses, as measured with personal dosimeters, to support remediation decisions. As the Nuclear Regulatory Authority (NRA) is planning to coordinate a study that focuses on individual dose, it is recommended that the dose study include a background population and also tie individual dose measurements to decontamination efforts at the homes of the monitored individuals.
The Mission Team has recognized that the values obtained from the calculation above [viewed on previous slide], resulting from external exposure to radiation cannot be considered as radiation doses specific to an individual. Individual doses will be strongly dependent on the behavior of an individual. These dose rates can only be taken as an indicator for a whole area, in which an individual person lives or is going to live. According to measurements of individual external doses using personal dosimeters, significant overestimation of individual doses may occur if such generically estimated air dose rates are taken as representative of doses to a specific individual. However, the Mission Team considers that such overestimation has the merit of providing public assurance of radiation safety.
The Mission Team was informed about the measurements of the individual external radiation doses collected from the municipalities in the Fukushima Prefecture, which were reported by the 6th Committee Meeting on Fukushima Health Management Survey, Fukushima Prefectural Government in April 2012. The summary includes the data for about 70,400 participants in 22 municipalities. Measurements were taken when short-lived iodine isotopes had already decayed away. Based on the available information, the average annual individual effective doses for all municipalities (around 0.1 to 0.2 mSv) are 3 to 7 times lower than those estimated using the equation above [viewed on previous slide].
It has recently been demonstrated that the air dose rate, registered by means of flyover methods or ground level measurements (in μSv/hour), is a conservative estimate of the annual dose. In six sample populations from different municipalities, the actual mean integrated dose was 2.6 to 7 times lower than the mean estimated dose calculated using air dose rates. Long-term dose monitoring integrates the variations in dose rates with location and time and provides useful data for indicating whether decontamination goals have been achieved. Therefore, the individual dose, measured by means of personal dosimeters, potentially provides a good tool in generating useful information for remediation, acceleration of efforts and better use of resources including labor which is currently a constraint....
Additional IAEA Discussion Points

• .... It would provide better information to guide where the highest individual doses will be received by residents. Collecting individual dose using dosimeters in an appropriate manner requires logistical and labour efforts from the community health sector in municipalities. Nevertheless, the benefits in being able to optimize where and when to perform remediation efforts using the most relevant dose rate data may be of great benefit in reducing labor requirements for remediation.
The Mission Team was informed that a whole body counting survey, involving 149,578 residents of Fukushima Prefecture, was carried out in the period between June 2011 and August 2013. The committed effective doses of internal exposure due to radiocaesium intake were below 1 mSv for 149,566 people. In ten and two cases this value was estimated to be in the order of 2 mSv and 3 mSv, respectively.
Summary

- IAEA Mission focused on remediation efforts but provided opportunities to evaluate dose monitoring and its relation to decision making.
- Air dose and contamination density measurements are important in determining remediation effectiveness in during initial remediation efforts.
- Japan has not optimized its remediation planning with population-specific exposure parameters or consideration of long-term exposures.
- IAEA’s recommendations included shifting from air dose measurements as a tool in determining “success” to using personal dosimeters and planning future actions.
Questions?