A reliable and robust method for monitoring large populations to assess thyroid internal exposure from radioiodine in a nuclear accident: A proposal based on experiences of Fukushima

The 4th ARADOS Annual Meeting
October 17th-19th 2018
Best Western Arirang Hill Dongdaemun Hotel, Seoul, Korea

Kazuaki Yajima, Kim Eunjoo, Kotaro Tani, Hideo Tatsuzaki, and Osamu Kurihara
National Institutes for Quantum and Radiological Science and Technology, National Institute of Radiological Sciences (QST-NIRS)

This work is partly supported by the Nuclear Regulation Authority (NRA) of Japan.
Outline

• Background
• Proposed method for monitoring large population “three-phase monitoring system”
• Progress on 3 activities regarding the technical aspects of the proposed method
  – Practical screening survey exercise
  – Age-specific conversion coefficients of a NaI(Tl) survey meter
  – Developing a new spectrometric device for use in the detailed survey
• Summary
Much effort has been made to estimate doses for the affected populations.

- A common view is that the radiation exposure to the population due to the accident is low in general.
- The uncertainty associated with the dose estimation remains unsolved, particularly for thyroid internal dose mainly from iodine-131.

### Background

Seven years have passed since the 2011 Fukushima nuclear disaster in Japan.

**Early phase (< 1 year after the accident)**
- Basic survey as a part of Fukushima Health Management Survey.
- The individual external doses for the first 4 months were $< 3 \text{ mSv}$ for 99.4% of 421,394 residents.

**Late phase (≥ 1 year)**
- The estimated annual external doses were generally $< 1 \text{ mSv y}^{-1}$ in the non-evacuation areas, and $<$ the projected annual external dose in the other areas.

<table>
<thead>
<tr>
<th></th>
<th>Early phase (&lt; 1 year after the accident)</th>
<th>Late phase (≥ 1 year)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External dose</strong></td>
<td>Basic survey as a part of Fukushima Health Management Survey. The individual external doses for the first 4 months were $&lt; 3 \text{ mSv}$ for 99.4% of 421,394 residents.</td>
<td>The estimated annual external doses were generally $&lt; 1 \text{ mSv y}^{-1}$ in the non-evacuation areas, and $&lt;$ the projected annual external dose in the other areas.</td>
</tr>
<tr>
<td><strong>Internal Dose</strong></td>
<td>Thyroid survey.</td>
<td>Fukushima Health Management Survey (WBC measurement) committed effective doses for only 26 subjects $\geq 1 \text{ mSv}$ ($1 \text{ mSv} \sim 14$, $2 \text{ mSv} \sim 10$, $3 \text{ mSv} \sim 2$). The number of the subjects: 334,795 as of August, 2018.</td>
</tr>
</tbody>
</table>

- The Nuclear Emergency Response Local Headquarters of the Japanese Government. Subjects totaled 1,080 $< 15.9 \text{ mSv}$ (90th percentile value).
- Tokonami S, et al. Subjects totaled 62. children 23 mSv(max), adult 33 mSv (max).
- Matsuda N, et al. (WBC measurement) Subjects totaled 173. 20 mSv(max).
Fukushima experience

- The number of direct measurements for $^{131}$I in human thyroids totaled only $\sim 1,300$.
- A screening survey using a handheld device (a NaI(Tl) survey meter) was performed on 1,080 children in late March 2011, about two weeks after the accident.
  - No subject was found to exceed a thyroid equivalent dose of 100 mSv.
  - The measurements were considered inadequate for accurately estimating individual internal doses due to the delay of the survey as well as the use of a non-spectrometric device.
- It was difficult to find places suitable for direct thyroid measurements in areas with elevated radiation levels.
  - The net signal was registered as zero for more than a half of the subjects.
  - The actual individual dose estimates based on such measurements may be missing trivial signal.
The most important lesson learnt from the Fukushima nuclear disaster is that monitoring of individuals in the affected populations should be performed as promptly as possible and on as many subjects as possible so as not to miss their internal exposure mainly from short-lived radioiodine.

However, to assess radiation exposure doses of the affected population is a very challenging task in Japan due to hundreds of thousands of people may live within the Urgent Protective action planning Zone (UPZ). On the other hand, in compliance with the IAEA generic criteria (GC), the Basic Plan for Emergency Preparedness of Japan has stated that assessment of internal exposure by inhalation of radioiodine should be performed within one week.
Proposed method for monitoring large population

Three-phase monitoring system consists of three surveys: a screening survey, a detailed survey and an additional survey

- This method is robust because it utilizes different techniques suited for each phase.
- From the viewpoint of availability and practicability, the balance with the existing and newly developed instrument is important.
- This method effectively uses all human data obtained for assessing thyroid internal doses of the affected population.
- The most important objective is to coordinate monitoring of large populations during their evacuation by administrative bodies.
Three-phase monitoring system

Nuclear accident

Evacuation
Contamination survey

- 1 week

Detailed survey

- More than 10000 people

Additional survey

- More than 30000 people

Relocation

time

Screening survey

- Simple handheld device (NaI(Tl) survey meter)
- First responder
- Significant exposure, Medical triage

Detailed survey

- Spectrometric device
- Performed by Radiation measurement experts at shelter after evacuation is completed

Additional survey

- Measurement of $^{134}\text{Cs}$ and $^{137}\text{Cs}$ with WBC after $^{131}\text{I}$ cannot be detected anymore

overlap

to ensure the measurement accuracy
Within first week

overlap

Highest accuracy
Within following 3 weeks

overlap

to ensure accurately estimate the intake ratio of $^{131}\text{I}$ to $^{134}\text{Cs}/^{137}\text{Cs}$ in individuals
Within following 3 weeks
Progress on 3 activities regarding the technical aspects of the three-phase system

– Practical screening survey exercise
– Age-specific conversion coefficients of a NaI(Tl) survey meter
– Developing a new spectrometric device for use in the detailed survey
Practical screening survey exercise

Objective: To develop the skills of participants who might be potentially engaged in a screening survey of the affected populations in case of a nuclear accident, and to get feedback about the reliability and practicability of the screening survey with the NaI(Tl) survey meter.

Participants: 20 participants: administrative staff, educational staff, medical staff (radiological technologists)

Device: NaI(Tl) scintillation survey meter (TCS-171/172, Hitachi, Ltd., Japan)
Correction constant ($\alpha$) $0.86-1.32$ ($^{137}$Cs)
Same type as those used in the screening survey of the 1080 children in 2011

Provisional OIL (screening level): 0.5 $\mu$Sv h$^{-1}$
Thyroid equivalent dose of 100 mSv; acute intake via inhalation, within one week after the intake, reasonably applied to 5-year and older age group
–IAEA report: OIL8 is 0.5 $\mu$Sv h$^{-1}$ ($\leq$ 7-years) and 2 $\mu$Sv h$^{-1}$ ($>$ 7-years)
Subject: Manikin heads made of polystyrene foam

probe is placed on (or near) the front surface of the bottom of the neck

Measurement at around the center height of the stand was intended to obtain the individual’s background on the subject’s thigh

Two measurements

reading: $M_A$

reading: $M_B$
Measurements:

Net signal $[\mu \text{Sv h}^{-1}] = (M_A - M_B) \times \alpha$

Two runs – a normal background level (~0.05 $\mu \text{Sv h}^{-1}$)
– an elevated background level (~0.5 $\mu \text{Sv h}^{-1}$)

A sealed $^{137}\text{Cs}$ source was placed about 1m behind each manikin head.

Scenes from the screening survey exercise
Measurement results:

The scattering of the net signals was large for below ~0.2 μSv h^{-1} (due to statistics), but mostly lay within the range of 10–20% for above ~0.2 μSv h^{-1} (due to variation in the measurement geometry among the participants).

Results of the net signals for the first and second runs. Source No. 11 and 12 in the figure are blank.

- The net signals obtained for normal BG and elevated BG are quite close to each other.
- In the 2011 screening survey, all subjects were below 0.1 μSv h^{-1}. The uncertainty in this range would reach a factor of 2, as a rough prediction of the results. This is typical value of the non-spectrometric device.
• Dose rates could be reliably measured at the provisional OIL (0.5 \( \mu \text{Sv h}^{-1} \)) with NaI(Tl) survey meter

• The measurement uncertainty would be acceptable for screening purposes
  (factor of 2 in dose rate below 0.1 \( \mu \text{Sv h}^{-1} \))

“A SCREENING SURVEY EXERCISE FOR THYROID INTERNAL EXPOSURE FROM RADIOIODINE AFTER A NUCLEAR ACCIDENT”
Age-specific conversion coefficients of a NaI(Tl) survey meter

Objective:
To prepare age-specific conversion coefficients of dose rates to thyroid content activity for a NaI(Tl) survey meter (TCS-172) using IRSN realistic age-specific thyroid phantoms
IRSN age-specific thyroid phantoms

Features
– Realistic thyroid shape
– Simulating attenuation of biological tissue
– Thyroid insert is exchangeable


Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
Measurement

Nal survey meter
TCS-172

Probe position No. 1 is on the center of the isthmus

---

Preparation of the Ba-133 source

<table>
<thead>
<tr>
<th>Activity of the Ba-133 solution [Bq]</th>
<th>Weight of the Ba-133 solution [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult</td>
<td>18.9</td>
</tr>
<tr>
<td>15 y</td>
<td>11.3</td>
</tr>
<tr>
<td>10 y</td>
<td>7.4</td>
</tr>
<tr>
<td>5 y</td>
<td>3.0</td>
</tr>
</tbody>
</table>
## Results

### Adult (IRSN Phantom)

<table>
<thead>
<tr>
<th>D cm</th>
<th>g-1</th>
<th>g-2</th>
<th>g-3</th>
<th>g-4</th>
<th>g-5</th>
<th>g-6</th>
<th>g-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20</td>
<td>20</td>
<td>23</td>
<td>21</td>
<td>22</td>
<td>26</td>
<td>31</td>
</tr>
<tr>
<td>0.5</td>
<td>26</td>
<td>26</td>
<td>29</td>
<td>26</td>
<td>27</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>1</td>
<td>32</td>
<td>30</td>
<td>32</td>
<td>32</td>
<td>35</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>59</td>
<td>60</td>
<td>61</td>
<td>59</td>
<td>66</td>
<td>72</td>
<td>66</td>
</tr>
<tr>
<td>5</td>
<td>91</td>
<td>102</td>
<td>91</td>
<td>98</td>
<td>107</td>
<td>102</td>
<td>91</td>
</tr>
</tbody>
</table>

### 10-y (IRSN Phantom)

<table>
<thead>
<tr>
<th>D cm</th>
<th>g-1</th>
<th>g-2</th>
<th>g-3</th>
<th>g-4</th>
<th>g-5</th>
<th>g-6</th>
<th>g-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>16</td>
<td>18</td>
<td>25</td>
</tr>
<tr>
<td>0.5</td>
<td>20</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>21</td>
<td>23</td>
<td>29</td>
</tr>
<tr>
<td>1</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>28</td>
<td>28</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>3</td>
<td>59</td>
<td>58</td>
<td>55</td>
<td>64</td>
<td>54</td>
<td>58</td>
<td>62</td>
</tr>
<tr>
<td>5</td>
<td>95</td>
<td>99</td>
<td>92</td>
<td>99</td>
<td>103</td>
<td>103</td>
<td>99</td>
</tr>
</tbody>
</table>

### 15-y (IRSN Phantom)

<table>
<thead>
<tr>
<th>D cm</th>
<th>g-1</th>
<th>g-2</th>
<th>g-3</th>
<th>g-4</th>
<th>g-5</th>
<th>g-6</th>
<th>g-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>16</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>18</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>0.5</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td>1</td>
<td>24</td>
<td>25</td>
<td>28</td>
<td>28</td>
<td>29</td>
<td>31</td>
<td>33</td>
</tr>
<tr>
<td>3</td>
<td>51</td>
<td>53</td>
<td>52</td>
<td>53</td>
<td>55</td>
<td>60</td>
<td>64</td>
</tr>
<tr>
<td>5</td>
<td>87</td>
<td>81</td>
<td>78</td>
<td>94</td>
<td>90</td>
<td>81</td>
<td>98</td>
</tr>
</tbody>
</table>

### 5-y (IRSN Phantom)

<table>
<thead>
<tr>
<th>D cm</th>
<th>g-1</th>
<th>g-2</th>
<th>g-3</th>
<th>g-4</th>
<th>g-5</th>
<th>g-6</th>
<th>g-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12</td>
<td>12</td>
<td>13</td>
<td>13</td>
<td>14</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>0.5</td>
<td>17</td>
<td>16</td>
<td>18</td>
<td>18</td>
<td>19</td>
<td>18</td>
<td>25</td>
</tr>
<tr>
<td>1</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>25</td>
<td>23</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>52</td>
<td>49</td>
<td>53</td>
<td>51</td>
<td>54</td>
<td>56</td>
<td>61</td>
</tr>
<tr>
<td>5</td>
<td>90</td>
<td>93</td>
<td>90</td>
<td>87</td>
<td>87</td>
<td>87</td>
<td>101</td>
</tr>
</tbody>
</table>
Distance affects CC more than Position

### Adult (IRSN Phantom)

<table>
<thead>
<tr>
<th>D cm</th>
<th>g-1</th>
<th>g-2</th>
<th>g-3</th>
<th>g-4</th>
<th>g-5</th>
<th>g-6</th>
<th>g-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20</td>
<td>20</td>
<td>23</td>
<td>21</td>
<td>22</td>
<td>26</td>
<td>31</td>
</tr>
<tr>
<td>0.5</td>
<td>26</td>
<td>26</td>
<td>29</td>
<td>26</td>
<td>27</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>1</td>
<td>32</td>
<td>30</td>
<td>32</td>
<td>32</td>
<td>35</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>59</td>
<td>60</td>
<td>61</td>
<td>59</td>
<td>66</td>
<td>72</td>
<td>66</td>
</tr>
<tr>
<td>5</td>
<td>91</td>
<td>102</td>
<td>91</td>
<td>98</td>
<td>107</td>
<td>102</td>
<td>91</td>
</tr>
</tbody>
</table>

### 5-y (IRSN Phantom)

<table>
<thead>
<tr>
<th>D cm</th>
<th>g-1</th>
<th>g-2</th>
<th>g-3</th>
<th>g-4</th>
<th>g-5</th>
<th>g-6</th>
<th>g-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12</td>
<td>12</td>
<td>13</td>
<td>13</td>
<td>14</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>0.5</td>
<td>17</td>
<td>16</td>
<td>18</td>
<td>18</td>
<td>19</td>
<td>18</td>
<td>25</td>
</tr>
<tr>
<td>1</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>25</td>
<td>23</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>52</td>
<td>49</td>
<td>53</td>
<td>51</td>
<td>54</td>
<td>56</td>
<td>61</td>
</tr>
<tr>
<td>5</td>
<td>90</td>
<td>93</td>
<td>90</td>
<td>87</td>
<td>87</td>
<td>87</td>
<td>101</td>
</tr>
</tbody>
</table>

### ORINS phantom

<table>
<thead>
<tr>
<th>D cm</th>
<th>0cm</th>
<th>1cm</th>
<th>5cm</th>
<th>10cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>l-131</td>
<td>22±2</td>
<td>34±2</td>
<td>113±6</td>
<td>264±9</td>
</tr>
<tr>
<td>ba-133</td>
<td>20±2</td>
<td>33±2</td>
<td>109±4</td>
<td>257±13</td>
</tr>
<tr>
<td>cs-137</td>
<td>17±2</td>
<td>28±2</td>
<td>92±4</td>
<td>228±11</td>
</tr>
</tbody>
</table>

### ANSI phantom

<table>
<thead>
<tr>
<th>D cm</th>
<th>0cm</th>
<th>1cm</th>
<th>5cm</th>
<th>10cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>l-131</td>
<td>33±2</td>
<td>46±3</td>
<td>125±5</td>
<td>286±26</td>
</tr>
<tr>
<td>ba-133</td>
<td>31±2</td>
<td>44±2</td>
<td>122±3</td>
<td>273±12</td>
</tr>
<tr>
<td>cs-137</td>
<td>27±2</td>
<td>38±2</td>
<td>104±6</td>
<td>238±14</td>
</tr>
</tbody>
</table>

Ref. ORINS-19 Thyroid radioiodine uptake measurement (1959)
Ref. ANSI N44.3-1973 Ref. ANSI/HPS N13.44-2014

ORINS phantom
ANSI phantom

Distance affects CC more than Position.
• Distance between phantom surface and probe top was larger, the difference of the conversion coefficients for probe position was smaller. It is thought that this is because the influence of the geometry became small.

• We plan to prepare IRSN phantoms filled with iodine-131 solution and are going to carry out the measurement under same condition presented here.
Developing a new spectrometric device for use in the detailed survey

**Objective:** To develop a new compact and efficient spectrometric thyroid monitor for the detailed survey composed of small GAGG detector modules

GAGG: \((\text{Gd,Lu,Y})_3(\text{Al,Ga,Sc})_5\text{O}_{12}\)

GAGG crystal (+SiPM), and casing

GAGG monitor (assembled 8 GAGG modules)
• Problems in thyroid measurement learned from Fukushima experience
  – Existing short life-time radioactive nuclides other than I-131
  – The shape of the neck was differed by the age

It is suitable for an infant thyroid measurement.

Downsize and light-weight

The placement of the GAGG module can be optimized to the shape of the infant neck.
Trial software for GAGG thyroid monitor

Module Control software

Control and spectra analysis
Characteristic test of prototype GAGG monitor was performed using IRSN age-specific thyroid phantom.

IRSN 5-y phantom (Ba-133) → 12791 cnts/180 s → 70 Bq/cps
IRSN adult phantom (Ba-133) → 8709 cnts/180 s → 104 Bq/cps
Pulse height spectra from GAGG monitor, 1.5 inch NaI detector, and 1.5 inch CeBr detector; IRSN-adult (Ba-133) LT 180 s
• The prototype GAGG thyroid monitor is tested now. The energy resolution at 356 keV (Ba-133) was close to that of the 1.5-inch NaI detector. The efficiency of 8 module assembly was slightly lower than that of the 1.5 inch-NaI detector. However, the efficiency is expected to rise by adding modules. It has enough performance in comparison with NaI detector.

• We will perform optimization of GAGG module placement in case of the infant measurement and a characteristic test using the age-specific IRSN phantoms.
Summary

- We proposed three-phase monitoring system consists of three surveys to assess the affected population thyroid internal doses.
- The results of the practical screening survey exercise showed that the uncertainty using NaI(Tl) survey meter would be acceptable for screening purposes.
- The experiment to acquire the dose rate to activity conversion coefficients using IRSN age-specific phantoms is pushed forward.
- The new thyroid monitor using GAGG module is developed. The prototype test showed that it has enough applicability as a spectrometric thyroid monitor for use in the detailed survey.
Thank you for your attention!