A new concept thyroid monitor using multiple GAGG detectors for population monitoring in a nuclear accident

The 5th ARADOS Annual Meeting
November 6-8th, 2019
Garden Hotel, Beijing, China

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This work is partly supported by the Nuclear Regulation Authority (NRA) of Japan.
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Introduction
One of the most important missions in response to any nuclear accident is to assess radiation exposure doses of the affected population.

The internal thyroid dose due to intake of radiiodine (mainly, $^{131}\text{I}$) is a major concern in population monitoring following a nuclear accident because it may cause future thyroid diseases in small children as experienced in the Chernobyl accident.
In the 2011 Fukushima nuclear disaster, a screening campaign using conventional NaI(Tl) survey meters was performed on 1,080 children. One critical problem to be solved in the method is to place a probe of the device in contact with the neck in the case of small children. This problem is the same with other devices.

Scenes of the direct thyroid measurement of a 1-y-old boy (left) and a 4-y-old boy (right) with a conventional NaI(Tl) survey meter.
The purpose of the present work is to develop a new thyroid monitor using multiple small detectors which can be applicable to the direct thyroid measurement of small children (including infants).

We constructed a prototype model using a high energy resolution Gd$_3$(Al,Ga)$_5$O$_{12}$(Ce) (HR-GAGG) detector and carried out experiments for testing the prototype model.
Materials and Methods
The arrangement of the detector array can be optimized to increase the counting efficiency in measurements depending on the body size of a subject.

The use of HR-GAGG detectors in combination with silicon photomultipliers can realize a compact device much smaller than other existing devices available for direct thyroid measurements.
Prototype model

- Eight HR-GAGG detectors
- Multi-signal processing unit
- Laptop PC (device control and data analysis software)
- Power supply for the detectors are made by a USB connection from the laptop

- One cubic centimeter-sized high energy resolution Gd$_3$(Al,Ga)$_5$O$_{12}$(Ce) (HR-GAGG) (C&A Corporation, Japan)
- A HR-GAGG crystal mounted on a silicon photomultiplier
- Gain shift of pulses due to the change of temperature is compensated
A software package to control the HR-GAGG detectors and analyze the acquired gamma spectra is installed in the laptop.
Gamma spectra from the eight detectors for a $^{133}\text{Ba}$ point source.

The eight detectors have a uniform response.
Two arrangements of the eight HR-GAGG detectors tested in the experiments.

One was a 3-2-3 detector array to match the thyroid shape and the other was a 2 × 4 detector array which allowed to be placed in contact with the curved surface of the phantom.
IRSN age-specific thyroid phantoms


Institut de Radioprotection et de Sûreté Nucléaire (IRSN)

- Realistic thyroid shape
- Simulating attenuation of biological tissue

- These phants are modeled for the necks of an adult male and 15-y-old, 10-y-old and 5-y-old children.
- Each phantom has a thyroid-shaped container with a volume corresponding to the thyroid size for each age.
Experimental setup for the performance tests

Two set of phantoms were prepared for the experiments. One set of the thyroid-shaped containers was filled with standard $^{131}$I solution and another with standard $^{133}$Ba solution.
Results
Gamma spectra from each of the eight HR-GAGG detectors in the case of the arrangement of $2 \times 4$ detector array.

- The counting efficiency of the eight detectors changed little by little with the detector’s position.
Comparison of the (sum) gamma spectra for the $2 \times 4$ detector array, the 3-2-3 detector array and a NaI(Tl) spectrometer having a crystal with a size of 1 inch in diameter and 1 inch in thickness.

- The total counting effeminacy of the eight detectors was higher in the $2x4$ detector array arrangement than the 3-2-3 detector array arrangement.
- The difference of the counting efficiency between the 5-y-old phantom and the adult-male phantom was due to the difference in the geometrical efficiency.
Table 1 Comparison of the minimum detectable activity (MDA) values for each configuration and each phantom under a normal background radiation level in the case of a counting time of 180 sec.

<table>
<thead>
<tr>
<th></th>
<th>MDA of $^{131}$I (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adult</td>
</tr>
<tr>
<td>New monitor</td>
<td></td>
</tr>
<tr>
<td>2 x 4 detector array</td>
<td>31</td>
</tr>
<tr>
<td>New monitor</td>
<td></td>
</tr>
<tr>
<td>3-2-3 detector array</td>
<td>35</td>
</tr>
<tr>
<td>1-inch NaI(Tl)</td>
<td></td>
</tr>
<tr>
<td>spectrometer</td>
<td>45</td>
</tr>
</tbody>
</table>

- The MDA value is lower in the new thyroid monitor than in the NaI(Tl) spectrometer although the total crystal volume is smaller in the former (8.0 cm$^3$) than in the latter (12.9 cm$^3$).
Age-specific conversion factors of the NaI(Tl) survey meter (TCS-161/171/172, Hitachi) were evaluated to be 33, 29, 25 and 20 kBq (\(^{131}\text{I}\)) per \(\mu\text{Sv h}^{-1}\) for the adult male, the 15-, 10- and 5-y-old phantoms (Kim et al., Health Phys. 2019). The theoretical detectable limit of the NaI(Tl) survey meter used for the screening campaign in Fukushima is 0.01 \(\mu\text{Sv h}^{-1}\) under the normal background radiation level, which corresponds to 200–300 Bq of \(^{131}\text{I}\) in the thyroid.

The new thyroid monitor is about 10 times higher in the sensitivity than the NaI(Tl) survey meter that is intended to be used for screening.

The new thyroid monitor can be used for precise measurements after screening by the NaI(Tl) survey meter if necessary.
Summary
Summary

- We have constructed and tested the prototype model of the new thyroid monitor using eight HR-GAGG detectors.
- The 2 x 4 detector array can be preferable to the 3-2-3 detector array for the thyroid measurements.
- The MDA value is lower in the new monitor than in the NaI(Tl) spectrometer having a crystal with a size of 1 inch in diameter and 1 inch in thickness.
- The new monitor is about 10 times higher in the sensitivity than the NaI(Tl) survey meter that is currently intended to be used for screening.
- The new thyroid monitor could provide reliable direct thyroid measurements for small children.
Future plans

- We are currently testing practical thyroid monitor for adults and children (infants) which have been designed and constructed based on the present results.

Practical thyroid monitors. A 2x5 HR-GAGG detector array was applied to the adult monitor, 1x4 or 2x4 array was applied to the child monitor.

Scenes of the direct thyroid Measurement with developed practical child (infant) monitor (left) and adult monitor (right).
Thank you for your attention!
## Instruments for direct thyroid measurements

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Crystal</th>
<th>Energy resolution</th>
<th>Usability</th>
<th>Disadvantage</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaI(Tl) survey meter</td>
<td>NaI(Tl)</td>
<td>Not applicable</td>
<td>Easy to use</td>
<td>Non-spectrometric</td>
<td>Screening survey</td>
</tr>
<tr>
<td>Handheld spectrometer</td>
<td>NaI(Tl), LaBr$_3$(Ce) etc.</td>
<td>Possible</td>
<td>Need skills on spectrometry</td>
<td>Difficult to use</td>
<td>Detailed survey</td>
</tr>
<tr>
<td>HGe thyroid monitor</td>
<td>Ge</td>
<td>Good</td>
<td></td>
<td>Not movable</td>
<td>Detailed survey</td>
</tr>
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