# EXAMINATION OF THE EFFECT OF COUNTING GEOMETRY ON $^{125}I$ MONITORING USING MCNP.

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## INTRODUCTION

Since the publication of the five-part series (Kramer et al. 1993, Kramer and Meyerhof 1994a, 1994b, 1994c, 1994d) dealing with various aspects of occupational thyroid monitoring, the Canadian National Calibration Reference Centre for *In Vivo* Monitoring has received many enquiries concerning choice of detector. As a result of these enquiries, the Human Monitoring Laboratory, which operates the Reference Centre, has theoretically determined the effect of the counting geometry on the counting efficiency of three selected detectors (NaI) that are representative of the equipment currently in use in thyroid monitoring facilities.

The counting geometry may be affected by a variety of factors. Some of these factors have been experimentally evaluated by Likhtarev et al (Likhtarev et al 1995) for $^{131}I$ ; however, a similar study for $^{125}I$ has not been performed. Other techniques have been developed to overcome the problems due to varying organ size and depth (Burns and Peggie 1980) providing the activity is sufficiently high; for example this technique can measure a thyroid burden of 5.5 kBq with an uncertainty of 6% (1σ) but at lower activities, 300 Bq, the uncertainty rises to 20% (1σ). These low values are more typical of the small intakes of $^{125}I$ for occupationally exposed personnel in Canada.

This presentation considers the following: neck-detector distance, misplacement of the detector at a given neck-detector distance, thickness of overlaying tissue, and size of the thyroid gland. The detector sizes selected for this study were: small, 2.54 cm diameter and 0.2 cm crystal thickness; medium, 7.62 cm diameter and 0.2 cm crystal thickness; large 30.48 cm diameter and 0.2 cm crystal thickness. The evaluations were determined using a Monte Carlo technique. This technique offers the advantage of being able to assess systems without having to purchase the hardware.

## MONTE CARLO METHODS

The Monte Carlo method is a mathematical technique for solving a problem that is dependent upon probability in some manner. The technique is useful when exact formulation describing a process may be too difficult, or even impossible, to derive and solve by direct methods.

MCNP (Monte Carlo N-Particle transport code system) is a general purpose radiationtransport code that is the result of 50 years of developmental efforts. The release[1] version used in the calculations described below is MCNP4.2A. This code is robust and over the period 1991-1993 it was in use by thousands of users.

A sodium iodide detector cannot resolve the x rays emitted by $^{125}$I; therefore, they have been combined by a weighted average to a single x-ray of 28.4 keV. The number of photons used in the MCNP simulations was 600,000 which resulted in tally errors between 0.0025 to 0.1 for the $^{125}$I composite photopeak, 28.4 keV. The number of simulations performed in this analysis was 792 which represents approximately 1,500 hours of computer time using a combination of microcomputers that had either a 486-66 or a 586-90 processor.

## GEOMETRY CONSIDERATIONS

The virtual neck and thyroid gland were modeled on Reference Man's neck and thyroid as described elsewhere (ICRP 1975); unless otherwise stated a simulations have been performed for a 20 g thyroid. The tissue compositions for the thyroid gland were obtained from an ICRU report (ICRU 1989).

The virtual thyroid gland was filled with material of the same elemental composition as a real thyroid gland (ICRU 1989), the neck surrounding the thyroid and trachea was filled with material of the same composition as muscle (ICRU 1989), the trachea was filled with air (O 23.29%, N 76.71%), the detector crystal was sodium iodide (Na 15.34%, I 84.66%), the detector shield was aluminum, the back of the detector touched a quartz plate (Si 46.74%, O 53.26%), which simulated the photomultiplier tube, and the window material was Be 0.05 cm, which is typical for commercially available detectors used for this application[2]. The window was 0.178 cm from the crystal and this gap was filled with air (O 23.3%, N 76.7%).

## RESULTS AND DISCUSSION

### Effect of Neck Detector Distance and Detector Size on Counting Efficiency

Optimizing the neck-detector distance when measuring occupationally exposed workers is important. A high counting efficiency, which is obtained at a short neck-detector distance or by using a large diameter detector, will result in a short counting time; however, geometry errors will potentially be much larger (Kramer and Meyerhof 1994a) if a high counting efficiency is obtained by reducing the neck-detector distance. Conversely, geometry errors are minimised at large neck-detector distances, but this will result in low counting efficiencies that in turn will raise the Minimum Detectable Activity (MDA).

The effect of neck to detector distance was studied using the small, medium and large

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1 MCNP is available from the Radiation Shielding Centre, Oak Ridge National Laboratory, PO Box 2008, Oak Ridge TN 37831-6362

2 Private communication. Bicron, 12345 Kinsman Rd., Newbery, Ohio 44065

detectors defined above. The detectors were placed at 0, 3, 6, 9, 12, 15, 18, and 30 cm from the neck. As expected, the large detector is more efficient at all distances, the medium is second, and the small detector is the least efficient. The ratio of the counting efficiency on contact to that of the counting efficiency at the furthest distance gives an indication of the effect of neck-detector distance. The ratio is 62.0 for the small detector, 47.8 for the medium detector, and 6.7 for the large detector.

It is clear that the large detector has a higher efficiency than the small detector, and that its counting efficiency varies considerably less as the neck-detector distance is increased.

**Effect of Detector Offset**

Detector offset is defined as the positioning error of a detector on the x-y plane, which is defined as that plane normal to the neck-detector axis. The vertical offset is given by ±y and the horizontal offset is given by ±x. A detector offset can occur in a variety of ways: a poorly positioned detector; the thyroid in the subject is not centered; the subject readjusts his/her position for comfort after the detector has been placed.

The misplacement error decreases as either the size of the detector increases or as the neck-distance increases. The large detector is relatively insensitive to misplacement compared to the other two detectors. The maximum value is about 3% for the large detector, whereas the small and medium detectors can reach values greater than 45%.

**Effect of Neck Thickness**

This effect was investigated by enlarging the neck so that the amount of tissue between the detector and the thyroid gland was increased from 1 cm to 5 cm in steps of 1 cm. This was achieved by enlarging the neck diameter. As the practical measurement in thyroid monitoring facilities is the neck-detector distance, the detector was moved so that all the z-values were the same as above. Therefore, the counting efficiency was affected in two ways: the attenuation was increased by adding more tissue; the thyroid-detector distance was increased as the neck-detector distance was kept constant.

Examination of the data shows that there are large differences moving from contact counting (0.01 cm) to a neck-detector distance of 30 cm. For example, if a small detector is used on a subject with 5 cm of overlaying tissue and the counting efficiency has been determined for a subject that has only 1 cm of overlaying tissue. Table 1 shows the final result will be underestimated by a factor of approximately 12. In other words, the final result obtained with this detector should be multiplied by 12 to obtain the true result.

For small and medium detectors the error due to overlaying tissue decreases with neck-detector distance becoming approximately constant when this exceeds 15 cm; however, the large detector shows little change as the neck-detector distance increases. This is due to the geometry independence of the large detector.

**Effect of thyroid size on the counting efficiency.**
As the size of the thyroid changes from the standard value of 20 g (ICRP 1975) two factors will change: the solid angle between it and the detector; and the attenuation of photons as the thickness of the gland changes. These effects have been simulated using 10 g, 30 g, and 40 g thyroids. The sizes of all the virtual glands are shown in Table 2.

At small neck-detector distance the effect of thyroid gland size is pronounced, but decreasing as the detector size increases. The effect diminishes as the neck-detector distance increases. The ratio of the photon efficiency for the 10 g to the 20 g thyroid, and the ratio of the photon efficiency for the 40 g to the 20 g thyroid are shown in the Table 3. Table 3 shows that the largest error in the photon efficiency is at the shortest neck-detector distance; however, if the neck-detector distance is increased, this error decreases. The data clearly show that small detectors should not be placed on contact with the neck. A good compromise distance appears to be between 6 cm and 18 cm.

The uncertainty introduced by the thyroid size largely disappears as the detector becomes large, this detector would also have the advantage of a very high relative counting efficiency; however, these detectors are expensive. The medium sized detector is a significant improvement over the small detector, but it also could introduce large uncertainties into the final result if placed in contact with the neck.

## CONCLUSION
Errors due to depth and size are of greater influence than geometrical errors (i.e. detector placement) and that thyroid monitoring using small diameter detectors is prone to the largest error. The detector of choice from the three presented here is the large diameter detector; however, it is recognised that large detectors are expensive. When cost is a consideration, the detector of choice should be the largest diameter that funding can obtain. The optimum neck detector distance appears to be between 10 - 18 cm for all detectors.

It has also been shown that the amount of overlaying tissue will introduce an error into the final result if it is greater than the assumed value (1 cm). This error can be as large as a factor of 12; however, it can be reduced, but not eliminated, by judicious choice of monitoring equipment and counting geometry.

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**Table 1:** Ratio of counting efficiency at 1 cm to 5 cm of overlaying tissue (i.e. each entry is the counting efficiency with 5 cm overlaying tissue divided by counting efficiency with 1 cm overlaying tissue).

| | Neck-Detector Distance (cm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.01 | 3 | 6 | 9 | 12 | 15 | 18 | 30 |
| Small | 11.74 | 8.86 | 7.68 | 6.37 | 5.77 | 5.27 | 5.12 | 4.18 |
| Medium | 10.62 | 8.21 | 6.70 | 6.01 | 5.50 | 5.36 | 4.98 | 4.46 |
| Large | 4.81 | 5.21 | 5.30 | 5.23 | 5.03 | 4.91 | 4.76 | 4.35 |

**Table 2:** Dimensions of the virtual thyroid glands

| | 10 g | | | 20 g | | |
|---|---|---|---|---|---|---|
| | Area ($cm^2$) | Height (cm) | Volume ($cm^3$) | Area ($cm^2$) | Height (cm) | Volume ($cm^3$) |
| Left Lobe | 1.45 | 3.00 | 4.35 | 1.81 | 5.00 | 9.05 |
| Right Lobe | 1.45 | 3.00 | 4.35 | 1.81 | 5.00 | 9.05 |
| Isthmus | 0.51 | 1.60 | 0.83 | 0.56 | 1.69 | 0.96 |
| Total | 3.41 | 7.60 | 9.52 | 4.18 | 11.69 | 19.05 |

| | 30 g | | | 40 g | | |
|---|---|---|---|---|---|---|
| | Area ($cm^2$) | Height (cm) | Volume ($cm^3$) | Area ($cm^2$) | Height (cm) | Volume ($cm^3$) |
| Left Lobe | 1.81 | 7.60 | 13.75 | 2.33 | 8.00 | 18.68 |
| Right Lobe | 1.81 | 7.60 | 13.75 | 2.33 | 8.00 | 18.68 |
| Isthmus | 0.56 | 1.89 | 1.07 | 0.56 | 1.30 | 0.73 |
| Total | 4.18 | 17.09 | 28.57 | 5.23 | 17.30 | 38.09 |

**Table 3:** Error when measuring a small or large thyroid gland relative to the standard size at 0 cm and 12 cm neck-detector distance.

| Neck-Detector Distance (cm) | 10 g | 40 g | Detector Size |
|---|---|---|---|
| 0 | 0.53 | -38% | Small |
| 0 | 20% | -25% | Medium |
| 0 | 2% | -4% | Large |
| 6 | 8% | -17% | Small |
| 6 | 9% | -15% | Medium |
| 6 | 3% | -6% | Large |
| 12 | 8% | -14% | Small |
| 12 | 7% | -11% | Medium |
| 12 | 3% | -7% | Large |
| 18 | 7% | -3% | Small |
| 18 | 3% | -13% | Medium |
| 18 | 1% | -8% | Large |
| 30 | 20% | 7% | Small |
| 30 | -1% | -8% | Medium |
| 30 | 2% | -6% | Large |