

# An Evaluation of Deviation from the International Atomic Energy Agency-International Commission on Radiological Protection Proposed Equation for Calculation of Radiation Dose Rate Emanating from the Patients with Differentiated Thyroid Cancer Undergoing Radioiodine ( $I-131$ ) Therapy

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## Abstract

The main purpose of this study was to investigate dose rate emanating from patients treated with  $^{131}I$  to evaluate which of the theoretical formulas, inverse-square law (ISL) and International Atomic Energy Agency-International Commission on Radiological Protection (IAEA-ICRP) suggested equation, can provide a sufficiently close approximation of the measured dose rate. Measurements were performed based on the IAEA safety report No. 63 method at 0, 12, 24, and 48 h after administration of radioiodine at a distance of 1 m for 69 patients and for the rest of 67 patients, dose rate was measured at 2, 4, 24, and 48 h at a distance of 2 m. Results revealed that the ISL formula gained better approximation of measured dose rates than the IAEA-ICRP equation with the lesser error. The ISL formula is still more reliable than the novel method of dose calculation in the vicinity of patients. This finding reminded us the prime importance of distance as a radiation protection principle.

**Keywords:** Differentiated thyroid cancer, inverse square law, iodine therapy, radiation protection

## Introduction

Differentiated thyroid cancer (DTC) is a common and slow-growing malignancy of the endocrine system that includes papillary and follicular histology and generally represents as a bulky mass in the front of the patient's neck.<sup>[1]</sup> The common therapeutic procedure

administered for patients with this type of pathology is radioiodine ( $^{131}I$ ), which is known as one of the most successful applications of ionizing radiation in the therapeutic radiology.<sup>[2]</sup> The promising result of this treatment option is mainly due to the physical properties of radioactive iodine that could deliver a major radiation dose to the thyroid tumor. The primary emissions of  $^{131}I$  decay are beta particles with a maximal energy of 606 keV (89% abundance, others 248–807 keV) and 364

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keV gamma-rays (81% abundance, others 723 keV). However, energetic gamma photons can escape from the body and leads to the unwanted exposure of people around the treated patients.

Thus these patients can be considered as a potential sources of relatively high dose of exposure that may have radiation hazard for those who are in close contact with them.<sup>[3]</sup> Therefore, to mitigate potential risk of radiation exposure from treated patients to the surrounding people, besides benefiting from significant therapeutic advantage of radioiodine, radiation protection regulations must be implemented in practice.

A variety of studies has been conducted to ensure radiation exposure to family members of treated patients with <sup>131</sup>I, associated caregivers, hospital staffs and the general public who may be in close contact of these patients are well restricted to the minimum acceptable level.<sup>[4-10]</sup> In addition, international protocols that are mainly based on the amount of radioiodine residual activity and the radiation dose rate at a distance of 1 m from the standing patient, determine when treated patients with radioiodine could be discharged from the hospital and return to their daily activity.<sup>[11-15]</sup>

While such regulations are not fixed and may vary between countries, but they all are based on the classic principles of radiation protection.<sup>[9]</sup> There are well-established connections among radiation dose rate emanating from the treated patient with several parameters such as retained activity in the body of patients, time of dose rate measurement and distance from the patient. As the administered radioiodine in the body of patients gradually washes out from the body due to physiological function of kidneys as well as physical decay of <sup>131</sup>I, external radiation dose rate and its related hazardous decreases over the time. There is also an inverse relation between dose and the distance in which dose is measured, so for a fixed value of radioiodine in the body of a patient, radiation exposure decreases as distance from the patient increases. This inverse correlation between radiation dose rate and separation distance from the source of radiation provides the simplest way to reduce unwanted exposure from patients administered with <sup>131</sup>I. For a point source, the inverse-square law (ISL) is generally used to calculate the dose rate at different distances from the source, but it is noteworthy that in the case of a source distributed in the body volume, the ISL may not be reliable at distances <3 m from the patient.<sup>[11]</sup> With respect to the International Atomic Energy Agency-International Commission on Radiological Protection (IAEA-ICRP) suggestion, a good approximation is that the dose rate falls according to (distance)<sup>-1.5</sup>, reflecting the fact that radiation exposure

from treated patients is probably underestimated in proximity of patients if ISL formula is applied.<sup>[12,13]</sup>

As in a routine radioiodine therapy procedure, high amount of activity is administered to patients, calculation of radiation dose around the patient can impose a significant amount of uncertainty if the inappropriate method is used. Therefore, the main purpose of this study was to measure dose rate from the body of patients treated with <sup>131</sup>I at two close distances of 1 and 2 m so as to do a quantitative comparison of calculated dose rate obtained from the classic ISL formula with the IAEA-ICRP suggested equation and evaluate which can provide a sufficiently close approximation of measured dose rate. Clearance of <sup>131</sup>I from the body of a patient over the time and at three different activities was also studied.

## **Materials and Methods**

A total of 136 DTC patients who had referred to the three chosen <sup>131</sup>I therapy centers across Iran to receive radioiodine therapy have been selected for this study. All patients had a history of thyroidectomy before the initiation of treatment. Based on the orally administered activities of radioiodine, patients were divided into three groups; 3.7 GBq (100 mCi) (55%), 5.6 GBq (150 mCi) (36%), and 7.4 GBq (200 mCi) (9%). All patients were hospitalized for the following days after administration so that their exposure was reduced to the acceptable level to discharge (70 μSv/h). All the measurements were taken after emptying the bladder, and each patient was informed about the procedure and given their consent.

### **Dose rate measurement and analysis method**

In this work, dosimetry approach was adopted according to the IAEA Safety Report Series No. 63.<sup>[12]</sup> The dosimetry method is schematically shown in Figure 1.

For 69 of patients, dose rate measurement was performed at 0, 12, 24, and 48 h after administration of radioiodine at a distance of 1 m, and for the rest of 67 patients dose rate was measured at 2, 4, 24, and 48 h after administration at a distance of 2 m. A calibrated ion chamber counter (Geiger-Muller GM X5C plus, Germany) was used for dose rate measurements from the standing patients at the upper trunk level. To reduce measurement error, an approach was employed to have fixed marks for both the standing patient and the measurement positions on the floor of the room. Measurement of the radiation dose rate was repeated 3 times to reduce the likelihood of errors or anomalous results. All statistical analysis was done in SPSS version 16 software (IBM Corporation, United States).

## Dose rates calculations obtained from the inverse-square law and International Atomic Energy Agency-International Commission on Radiological Protection formulas

Based on the ISL formula, which is applied for a point source of radiation, the dose rate has an inverse proportion with the square of distance from the radiation source ( $D \propto X^{-2}$ ). However, when a source is distributed in the body of a patient, in order for ISL to be reliable and applicable, dose rates should be measured at large distances, namely  $>3$  m, to meet the criterion of point source. For short distances (below 3 m), the relationship is approximated as Eq. 1:

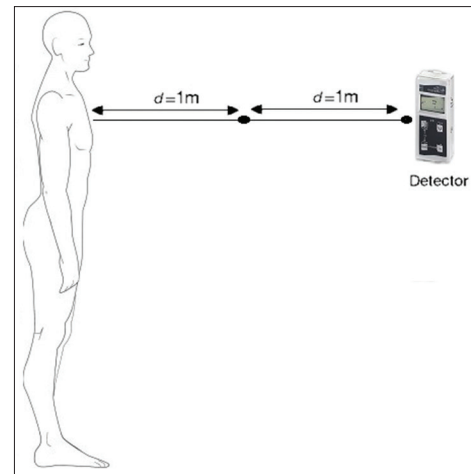
$$D = D_1 X^{-1.5} \quad (1)$$

where  $D$  is the dose rate in Gy at point  $X$ ,  $X$  is the distance in meter and  $D_1$  is the reference dose rate at distance of 1 m. Comparing both methods, it is evident that the dose rate calculate with new formula is higher than that of obtained from ISL. Applying the setup of the experiment, measured dose rate at the distance of 1 m is considered as the reference, then dose rates at the distance of 2 m were calculated according to the both classic ISL formula and the IAEA-ICRP proposed equation (Eq. 1), then obtained results were compared with the practically measured dose rate by the dosimeter.

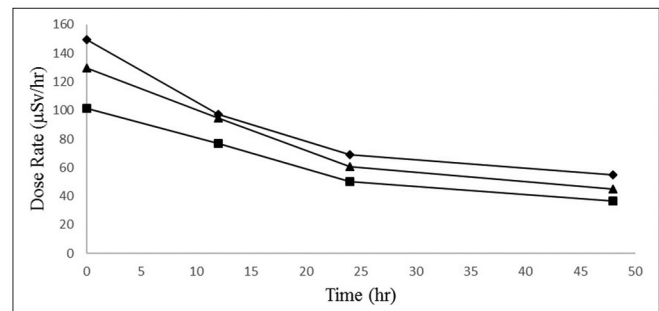
## Results

We studied dose rate exciting from the body of DTC patients treated with radioiodine, at different postadministration times and distances of 1 and 2 m. Figures 2 and 3 illustrate how dose rate of patients was reduced over the time. It is clear from the figures that the significant portion of the activities cleared from the body in the 1<sup>st</sup> h after administration of radioiodine.

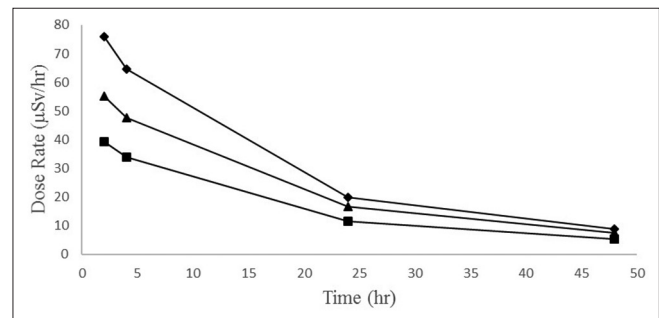
Results of dose rate measurement at 0, 12, 24, and 48 h after administration of radioiodine at a distance of 1 m were respectively as  $101.59 \pm 14.07$ ,  $77.12 \pm 10.62$ ,  $50.04 \pm 10.6$ , and  $36.69 \pm 10$   $\mu\text{Sv/h}$  for 3.7 GBq,  $129.40 \pm 21.61$ ,  $94.45 \pm 14.56$ ,  $60.45 \pm 12.9$ , and  $45.10 \pm 9.9$   $\mu\text{Sv/h}$  for 5.6 GBq and  $149.75 \pm 23.32$ ,  $97.50 \pm 16.78$ ,  $69.00 \pm 6.4$ , and  $55.13 \pm 6.8$   $\mu\text{Sv/h}$  for 7.4 GBq of activity. Furthermore, dose rates measurement at 2, 4, 24, and 48 h after administration at distance of 2 m were respectively as  $39.33 \pm 6.52$ ,  $33.97 \pm 6.17$ ,  $11.56 \pm 4.3$  and  $5.44 \pm 2.7$   $\mu\text{Sv/h}$  for 3.7 GBq,  $55.14 \pm 9.89$ ,  $47.65 \pm 9.54$ ,  $16.59 \pm 6.8$ , and  $7.58 \pm 3.6$   $\mu\text{Sv/h}$  for 5.6 GBq and  $76.00 \pm 14.75$ ,  $64.60 \pm 10.99$ ,  $19.80 \pm 7.6$ , and  $8.80 \pm 1.30$   $\mu\text{Sv/h}$  for 7.4 GBq of activity.



**Figure 1:** Schematic diagram of patient dosimetry method at the distances of 1 and 2 m in specific postadministration times



**Figure 2:** Dose rate measurements at the distance of 1 m after administration of 3.7 GBq (■), 5.6 GBq (▲), and 7.4 GBq (◆) of radioiodine



**Figure 3:** Dose rate measurements at the distance of 2 m after administration of 3.7 GBq (■), 5.6 GBq (▲), and 7.4 GBq (◆) of radioiodine

As represented in Table 1, to semi-quantitatively assessment of the effect of distance-from-patient on the absorbed dose received by people around the treated patients, ratio of the measured dose rate at the distance of 2 m to the measured dose rate at the distance of 1 m was calculated at 24 and 48 h after administration of radioiodine. From Table 1, for all three administered activities, dose rate value at the distance of 2 m is

considerably less than the amount in the distance of 1 m, and this ratio 48 h after the administration are less than the amount of the 24 h post administration.

Likewise, in order to have a sensible evaluation of dose rate drop over the time, ratio of the dose rates measured at 24 and 48 h after the administration of activity to the initial dose rate were calculated and presented in Table 2. The amount of this ratio at 24 and 48 h after the administration of radioiodine, was reported about half and one-third, respectively.

Table 3 shows the findings of the second part of this study. As it can be seen, comparison was made between measured and calculated dose rates at the distances of one and 2 m at 24 and 48 h after administration. Comparing the two calculation methods revealed that although during the dose measurement,  $^{131}\text{I}$  had been distributed in the body, ISL gained better approximation of measured dose rates than the IAEA-ICRP formula with lesser percentage error. We also observed that percentage errors for the both calculated dose rates were increased as postadministration time increased.

**Table 1: Ratio of measured dose rates at the distance of 2 m to the distance of 1 m, 24 and 48 h after administration of 3.7, 5.6, and 7.4 GBq of radioiodine**

Ratio of dose rates at the distance of 2 m to the distance of 1 m	Administered activity (GBq)		
	3.7	5.6	7.4
24 h postadministrative	0.23	0.27	0.29
48 h postadministrative	0.15	0.17	0.16

**Table 2: Ratio of radiation dose rate at the end of 1<sup>st</sup> and 2<sup>nd</sup> days after administration of 3.7, 5.6, and 7.4 GBq of radioiodine to the initial dose rate, at the distance of 1 m**

Ratio of dose rates	Administered activity (GBq)		
	3.7	5.6	7.4
1 <sup>st</sup> day to immediately after administration	0.49	0.47	0.46
2 <sup>nd</sup> day to immediately after administration	0.36	0.35	0.37

**Table 3: Comparison of measured and calculated dose rates ( $\mu\text{Gy/h}$ ) at the distances of 1 and 2 m, 24 and 48 h after administration and percentage errors**

Activity (GBq)	Postadministration time (h)	Mean $\pm$ SD		Percentage error	
		Measured dose rate at 1 m (reference)	Measured dose rate at 2 m	ISL dose rate at 2 m	IAEA-ICRP dose rate at 2 m
100	24	50.04 $\pm$ 10.6	11.56 $\pm$ 4.3	12.51 (7.6)	17.66 (34.5)
	48	36.69 $\pm$ 10	5.44 $\pm$ 2.7	9.17 (40.6)	12.95 (58)
150	24	60.45 $\pm$ 12.9	16.59 $\pm$ 6.8	15.11 (9.8)	21.34 (22.3)
	48	45.10 $\pm$ 9.9	7.58 $\pm$ 3.6	11.28 (32.8)	15.92 (52.4)
200	24	69.00 $\pm$ 6.4	19.80 $\pm$ 7.6	17.25 (14.8)	24.36 (18.7)
	48	55.13 $\pm$ 6.8	8.80 $\pm$ 1.3	13.78 (36.1)	19.46 (54.8)

ISL: Inverse square law; ICRP: International Commission on Radiological Protection; IAEA: International Atomic Energy Agency; SD: Standard deviation

## Discussion

For DTC patients treated with radioiodine, radiation safety is an important issue for the staff, family members and those who are in close contact with these patients.<sup>[4]</sup> Measuring dose rate of these patients can be applied for estimating associated hazardous as well as establishing protection criteria. Some authorities suggest that the family members of these patients should be looked as medical exposure, allowing family members to receive absorbed doses higher than 1 mSv, although there is an exemption to the dose limit of 1 mSv for the children and pregnant women.<sup>[16]</sup> In general, there is not a solid agreement on the absorbed dose limit among the communities. Furthermore, releasing criteria from the hospital for the patient treated with radioiodine may differ from one country or region to another one.<sup>[17]</sup> Therefore, in this study, regardless of the recommended dose limits for the individuals around the patients, external dose rates of these patients were studied semi-quantitatively to have a sensible insight of how dose rate around treated patients varies with respect to the activity, time and distance. In addition, using the experimental data of the present study, comparative reliability of ISL formula as well as proposed equation by the IAEA-ICRP was assessed to see which one provides more consonant result with that of real experiment.

To assess the effect of distance on external dose rate from treated patients with radioiodine, ratio of the measured dose rates at a distance of 2 m to a distance of 1 m was calculated. Table 1 shows, this ratio is about one-fourth and one-six for measurements performed at 24 and 48 h after the administration of radioiodine, respectively. The finding presented in Table 1 shows that 1 day after the administration of  $^{131}\text{I}$ , ratio of dose rate is well agrees with the ISL, but 2 days after administration this ratio is smaller that probably reflects effects of biodistribution on measured values.

Activity retained in the body of patients is another factor that determines the level of external exposure. From a theoretical standpoint, as the activity of radioiodine in



the body decreases, radiation dose rate decreases, as well. Following the initiation of radioiodine therapy, activity is cleared from the body over the time as a result of physical decay as well as biological wash out.<sup>[18]</sup> In order to have a semi-quantitative evaluation to see how radiation exposure from the body of patients changes over the time, dose rates measured at the distance of 1 m, at 24 and 48 h after administration of radioiodine were normalized to the initial dose rate measured immediately after the administration of radioiodine. As represented in Table 2, at the end of the 1<sup>st</sup> day, the radiation dose rate is about half (0.46) of the initial value, and at the end of the 2<sup>nd</sup> day, this ratio is about one-third (0.36). This finding means that during the 1<sup>st</sup> day postadministration, half of the initial activity is cleared from the body and at the end of 2<sup>nd</sup> day; the total cleared activity is two-third of the initial value. In other words, in the 1<sup>st</sup> days after administration of radioiodine, because of the exponential behavior of activity washout, the clearance rate of radioiodine is higher than that of the following days, and a significant drop in the external dose rate can be seen in the 1<sup>st</sup> days. This result clearly present hospitalization policy of the patients after administration of radioiodine, by which a considerable portion of the external dose rate is reduced in the 1<sup>st</sup> days after the initiation of treatment.

Table 3 provides measured and calculated dose rates at the distances of 1 and 2 m, at 24 and 48 h after administration. A comparison between calculated values with measured values reveals that there is a contrast between these two.

The explanations for this disparity lie in some noteworthy notes. First of all, on the exiting path of the radiation, patient's body attenuates the gamma-rays. Therefore, the assumption that the activity in patients behaves as an unattenuated source is not actually correct. However, attenuation correction is not included in calculated formulas. This self-attenuation can be the main reason for large differences between the measured and calculated dose rates. In other words, both the ISL and IAEA-ICRP equations are defined to be used in air, and a major portion of the disparity between the obtained results is due to attenuation effect of the patient's body on radiation when is exiting from patient's body. Individual anatomical information such as weight and height are the other parameters that can affect the measured data, thus deviating from simplified mathematical formula.

After comparison of the calculated results from each of the formulas with measured values, we observed that ISL method shows more agreement with real measured values at close distance of 2 m. While ISL formula has been generally used to calculate relative dose of radiation at two different distances from the source, but the IAEA-ICRP has suggested a new formula for distances of <3 m.

The reasoning behind this decision is that because of distribution of radioiodine source in the body of patients, the former equation may not well reflect dose-distance pattern of radiation source at the proximity of patients. According to their report, while the ISL could be used for many purposes, but sometimes the good approximation is that the dose is related to the distance with the power of -1.5 not -2. Considering this to be the case, in the vicinity of treated patient the dose rate is higher than what was calculated by the conventional ISL formula. However, based on our findings it seems that the conventional ISL formula could still be more reliable than the new one to include effect of the distance on dose rates at proximity of patients treated with <sup>131</sup>I.

Non-uniform distribution of radioiodine is a critical factor that highly affects radiation exposure from treated patients. Based on the distribution pattern of the activity inside the body, emitted photons may have various attenuations in their paths to reach to the surface of the skin. Furthermore, distribution of activity at different parts of the body means that escaping photons travel different distances to reach to the dosimeter located outside of the body. As distribution pattern of radioiodine in the body of patient, does not match with the extensive radiation source specifications, therefore calculated values are only a good approximation and deriving accurate formula demands detailed information from the behavior of radioiodine inside the body of patients. Furthermore, the biodistribution of radioiodine includes not only the thyroid, but also kidneys, bladder, salivary glands, stomach, and breast based on medical condition of the patient. Even taking into account the possibility of metastasis in a patient's body, they are few "hot spots" and provide no real uniform distribution.<sup>[18]</sup>

As shown in Table 3, agreement of calculated data with measured data is worse in the 2<sup>nd</sup> day when compared to the 1<sup>st</sup> day after administration of radioiodine. This could confirm our assumption that as <sup>131</sup>I is more distributed inside the body, measured dose rate is more deviated from calculated values.

## **Conclusion**

In spite of difference between results of calculations and measured values, we observed that ISL gained better approximation of measured dose rates than IAEA-ICRP equation and lesser percentage error. Therefore, ISL formula is still more reliable than the novel method of dose calculation in vicinity of patients. This practical finding also reminded us that the prime importance of distance as a radiation protection measure cannot be underestimated and highlights the importance

of separation distance in the reduction of unwanted exposure from patients treated with radioiodine. This reduction factor was even more sensible when 2 days elapsed from the initiation of radioiodine therapy.

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### Conflicts of interest

There are no conflicts of interest.

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