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EVALUATION OF INTERNAL EXPOSURE OF NUCLEAR MEDICINE STAFF WORKING WITH RADIOIODINE IN POLAND

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Abstract
The iodine-131 (I-131) content in the thyroid of staff members working with this radionuclides has been measured with about 500 employees in about 25 hospital's departments of nuclear medicine performing therapy and diagnosis of thyroid disease in Poland. The measurements were performed with portable detection unit for *in situ* measurements of radioiodine. This is consist with scintillation detector sodium iodine activated by thallium (NaI(Tl)) – battery-powered and portable tube base Multichannel Analyzer Canberra UniSPEC. Based on direct measurements of the iodine content, the effective dose equivalent for workers due to inhalation of I-131 was estimated. All individuals actively working with iodine show measurable amounts of this isotopes in their thyroids. The average measured activity in the thyroid of the nuclear medicine staff was found to be equal at average 550 Bq within the range 70 Bq–2.5 kBq. There is no apparent correlation between the measured I-131 levels and risk categories. Nevertheless the technical and nuclear medicine staff show higher I-131 thyroid level comparing to hospital services staff. Calculated maximum committed effective dose for particular exposed person is <10% of 20 mSv/year. Int J Occup Med Environ Health. 2023;36(5):587–95

Key words:
nursing, medical imaging, radionuclide imaging, radiation effects, radioisotope therapy, radioisotope scanning

INTRODUCTION

Human thyroid gland has the unique ability to take up iodine – an essential component of its hormones and one of the elements that are essential for normal functioning of the human organism. The phenomenon of specific and natural accumulation of iodine in the thyroid gland allowed for the use of iodine isotopes in nuclear medicine. Iodine has about 35 known unstable isotopes, but the most frequently applied is radioiodine.

Iodine-131 (I-131) is an important radioisotope which has been widely applied both in diagnosis and therapy of thyroid-related illnesses. It is also used in others function medical tests and procedures. Main radioiodine data on I-131 are as fallow: radioactive half-life – 8.04 days; effective half-life in the thyroid – 7.3 days; time to maximum thyroid burden after acute exposure – 1.2 days; main photon energy – 364.5 keV.

Medical personnel who administer substantial doses of radioiodine to patients may accidentally inhale or ingest some of the radioiodine, leading to significant thyroid burdens. The purpose of each thyroid screening program or research is to monitor the intake of volatile radioiodines. Current information produced by the above steps used to assess any intake of volatile radioiodines, provide assurance that the radiation protection program of medical personnel is working, and demonstrate compliance with regulatory dose limits.

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Polish legal acts require that the staff of facilities using open sources of I-131 for the treatment of thyroid cancer should be subject to internal control of the content of radioactive iodine in the thyroid gland [1,2]. In particular, many specific documents, e.g., the American National Standards Institute (ANSI) [3], constitute that workers and other persons who have been occupationally exposed due to radioiodine in nuclear medicine should be screened for the relevant radioiodine:

– exposed to a volatile I-131 spill greater than around 2 MBq;
– externally contaminated by I-131;
– worked within 2 m of a person whose screening measurement results are ≥1 kBq, if they were working within 1 h after the time of the suspected exposure.

METHODS

Measurements of radioactive iodine I-131 content in the thyroid gland of professionally exposed employees were carried out in 25 hospital units in Poland, mainly in departments of endocrinology or nuclear medicine, deals with the diagnosis and treatment of diseases affecting the endocrine glands (including the pituitary and thyroid glands). The clinical activity of the departments includes imaging diagnostics (*in vivo*), radioisotope therapy and *in vitro* diagnostics. Radioiodine is administrated to patients to perform all types of scintigraphic examinations and tests or diagnostics and treatment of patients with thyroid cancer. Measurements were made for approx. 500 workers and other persons who have been occupationally exposed due to radioiodine occurs in nuclear medicine.

Employees employed in the controlled units were divided, according to the activities (professions) performed, into the following groups:

1) electro-radiologist, technician,
2) medical physicist or a radiological protection inspector,
3) medical doctor,
4) nurse,
5) cleaner or orderly,
6) radio-immunologist, radiochemist, conservator engineer.

Units where measurements of employees were taken, can be divided into 3 groups, depending on the type of procedures used and tests performed:

I. Oncological centers (with departments of endocrinology and nuclear medicine), where diagnostic tests of thyroid diseases are performed and advanced cancers of this gland are treated in a hospital stay in a closed ward, under the strict dosimetry control regime.
II. Hospital nuclear medicine departments, where diagnostics and therapy of diseases (thyroid and other) are carried out, however, treatment is carried out on an outpatient basis. After administering a therapeutic dose of, e.g., iodine or technetium, the patients are not subjected to a strict isolation regime, they are sent to his home.
III. Nuclear medicine departments/laboratories, conducting diagnostic tests with the use of isotopes (iodine, technetium and others), in particular performing thyroid scintigraphy.

Usually, in each of the above-mentioned units there is a radiochemical laboratory in which radiopharmaceuticals are prepared for therapy or diagnosis tests.

Method of I-131 activity measurements

The scintillation detector is currently the most common type of instrument used for measuring radioiodine in the thyroid. It typically consists of a probe (usually a sodium iodide [NaI] crystal) operated in conjunction with a channel analyzer systems that should be as simple as a portable unit, that produces results in counts [4,5].

The measurements of iodine content of occupationally exposed personnel were performed by Central Laboratory for Radiological Protection with portable detection unit (Canberra-Packard, Schwadorf, Austria) (Figure 1), which is consist with scintillation detector sodium iodine thallium activated (NaI(Tl)) (size 76 × 76 mm, the energy

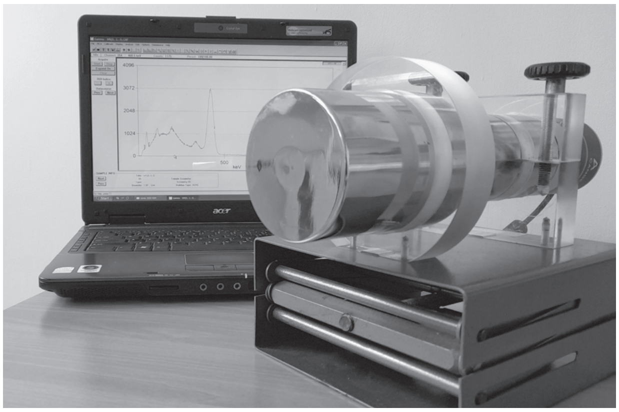


Figure 1. The portable unit with scintillation detector sodium iodine activated by thallium (NaI(Tl)) for measurement of I-131 carried out in 25 hospital units in Poland

resolution, i.e., full width at half of maximum (FWHM) of the Cs-137 photopeak at 662 keV is 9%) – battery-powered, portable tube base Multichannel Analyzer Canberra UniSPEC, paired with the notebook computer and Genie-2000 Basic Spectroscopy Software [6]. Measurements were carried out in the last 10 years, i.e., in 2011–2021.

The counting configuration for monitoring personnel was identical to that used in the calibration procedure of equipment. Typically, detector set at a neck-to-detector distance of 10 cm, using a 300 s counting time. The background was measured with detector placed 10 cm away from the availably RSD neck phantom (Radiology Support Devices, Inc., Long Beach, USA) (Figure 2), prior to or just following the count performed on the person. The measurements were performed in selected as low as possible background places. The minimum detectable activity, detection limit (LD), the smallest amount of radioactivity that can be detected with a 95% confidence limit (CL), for portable measuring kit being used ranges from 50–70 Bq at the time measurement of 300 s and depends on background condition in individual hospital units where the measurements were performed [7].

The scintillation detector was calibrated with an RSD neck phantom using an I-131 calibration source of known activity (POLATOM). The radioactive iodine solution was

Figure 2. Radiology Support Devices (RSD) neck phantom with thyroid gland

placed in the thyroid phantom, measurements were made in the geometry as for measurements in occupationally exposed thyroid. The measurement time was 300 s, the calibration coefficient was 6.8×10^{-3} count per second (cps)/Bq, and the LD (limit of detection) was 70.0 Bq.

The methodology for determination of the activity of radioactive iodine in thyroid gland, including the estimation of the uncertainty of measuring procedure, has been accredited by the Polish Center for Accreditation, No. AB-450 [8]. Fulfilling accreditation requirements, the uncertainty of radioiodine activity measurement in the thyroid has been evaluated taking into account errors resulting from the uncertainty of the thyroid position of the measured person in relation to the NaI(Tl) detector, uncertainty of estimation of the calibration factor, the background impact, etc. The overall single measurement uncertainty of 30% on 95% CL was estimated.

Methodology of assessing committed effective dose to medical staff due to inhalation

Although, the dose assessment base on direct measurement of I-131 in thyroid seems to be the most accurate method, however in a case of medical staff which has constant contact with airborne I-131, several assumptions regarding period of time and frequency of potential intake via inhalation of radioiodine are required. As it was indicated in the previous studies [9], the occupational limit dose equal to 20 mSv/year is resulting from I-131 yearly intake equal to 1.8×10^6 Bq. Depending on adopted scenario, i.e., 1 h/day, 5 h/day, 8 h/day spending in the room with airborne I-131, the relevant equilibrium level of I-131 in thyroid will be equal to 9 kBq, 7 kBq and 6.4 kBq respectively. The calculation has been performed base on thyroid metabolic model of Johnson [10] and committed effective dose per unit intake e(g) for 5 mm aerosol inhalation equal to 1.1×10^{-8} Sv/Bq [11]. Consequently, to adequately reflect complex radiological scenario, the proportion has been adopted, that 1 kBq of I-131 measured any time in the thyroid of medical employer which continuously operates with I-131 is equivalent of effective dose equal to 3 mSv.

RESULTS

The total number of about 500 staff members in the 25 departments of nuclear medicine in Poland, were examined. The measurement results are presented in the Table 1. The table contains the mean activities of I-131 in the thyroid and standard deviations of the set of measured values for 3 medical unit categories (I–III) vs. employment categories (1–6). The range of minimum and maximum values for each set as well as percentage of measurements in the individual categories of employment and percentage of measurements above the detection limit are also included. Uncertainties were calculated as standard deviations for each set of measurements of activities of I-131 in the thyroid.

The I-131 activity in thyroids was found to be below the detection limit (LD = 70 Bq of I-131 in the thyroid) for about 70% subjects in the study.

Among the remaining 30% of individuals, I-131 thyroid activity ranged from 70±40 Bq to 2500±500 Bq, depending on the type of work of individual employees and the place of employment, meaning, medical unit category. Figure 3 presents a typical spectrum of I-131 collected at thyroid of exposed worker.

Figure 4 shows the average levels of radioactive iodine in the thyroid gland for employees of 6 employment groups (1–6) for the discussed medical units (I–III), these levels are presented as bars together with associated standard deviations. The effective dose equivalent values for the above discussed employment categories, broken down by medical units are shown in the comments above of the bars.

The largest medical units, that is a big oncological centers (unit category I), with departments of endocrinology and nuclear medicine, where advanced diseases of thyroid cancer are treated in a hospital stay in a closed ward, under the strict dosimetric control regime, 65% of employees for the cleaning staff (employment category 5) showed higher levels of radioiodine iodine (mean activity equals 480 Bq). However, the highest activity of iodine I-131 has been measured by electroradiologist that is, radiology technicians (employment category 1) (mean activity 640 Bq).

Radioiodine I-131 was detectable in the thyroid of all of the radiology technicians, half of the cleaning staff members and one-fourth of the nurses under examination, whereas it remained undetected for all medical doctors.

This pattern of radioiodine distribution among employees can be explained by the types of duties performed with respect to exposure to I-131: electroradiologists (radiology technicians) were found to be the most exposed contaminated individuals, because they directly participate in preparing and administering radiopharmaceuticals. This group shows the highest exposure to radioactive iodine inhalation, regardless of the type of medical facility in which it is employed.

In contrary, because the main duty of medical doctors is to perform medical surveys, order examinations and provide specialist advice, so their contact with I-131 is limited or small, they show a rather low level of iodine activity in the thyroid glands.

The data of measured I-131 thyroid activity for different employment category in the 3 considered units were analyzed regarding possible correlations between the catego-

Table 1. Measured I-131 thyroid activity in exposed worker during measurement carried out in 25 hospital units in Poland

Variable	Employment category					
	electro-radiologist	medical physicist/radiological protection inspector	doctor	nurse	cleaner/orderly	radio-immunologist, radiochemist, conservator engineer
Medical unit category I (246 measurements)						
measurements [%]						
in the employment category	18	15	22	28	8	9
above the detection limit (LD = 70 Bq)	32	28	24	29	65	9
activity of I-131 in the thyroid for measurements above LD [Bq]						
M±SD	640±540	380±250	300±240	490±450	480±350	240±20
range	70–2500	70–1000	70–1010	70–1700	70–1150	70–220
effective dose [mSv]						
M±SD	1.92±1.60	1.10±0.70	0.9±0.7	1.5±1.3	1.5±1.0	0.7±0.1
range	0.38–7.50	0.38–3.00	0.38–3.03	0.38–5.10	0.38–3.45	0.38–0.66
Medical unit category II (227 measurements)						
measurements [%]						
in the employment category	19	13	31	19	6	12
above the detection limit (LD = 70 Bq)	10	10	1	21	0	0
activity of I-131 in the thyroid for measurements above LD [Bq]						
M±SD	280±140	270±25	250*	510±470	LD	LD
range	70–500	70–300	70–250	70–1500		
effective dose [mSv]						
M±SD	0.8±0.4	0.8±0.1	0.8*	1.5±1.4	0.38	0.38
range	0.38–1.50	0.38–0.90	0.38–0.75	0.38–4.50		
Medical unit category III (42 measurements)						
measurements [%]						
in the employment category	24	36	16	0	12	12
above the detection limit (LD = 70 Bq)	10	10	28	0	40	0
activity of I-131 in the thyroid for measurements above LD [Bq]						
M±SD	500*	350*	330±105	–	310±210	LD
range	70–500	70–350	70–400	–	70–760	

Table 1. Measured I-131 thyroid activity – cont.

Variable	Employment category					
	electro-radiologist	medical physicist/ radiological protection inspector	doctor	nurse	cleaner/orderly	radio-immunologist, radiochemist, conservator engineer
Medical unit category III (42 measurements)– cont.						
effective dose [mSv]						
M±SD	1.5*	1.0*	0.9±0.3	–	0.8±0.6	0.38
range	0.38–1.50	0.38–1.0	0.38–1.35	–	0.38–2.28	

Medical unit category: I. Oncological centers (with departments of endocrinology and nuclear medicine), where diagnostic tests of thyroid diseases are performed and advanced cancers of this gland are treated in a hospital stay in a closed ward, under the strict dosimetry control regime; II. Hospital nuclear medicine departments, where diagnostics and therapy of diseases (thyroid and other) are carried out, however, treatment is carried out on an outpatient basis. After administering a therapeutic dose of, e.g., iodine or technetium, the patients are not subjected to a strict isolation regime, they are sent to his home; III. Nuclear medicine departments/laboratories, conducting diagnostic tests with the use of isotopes (iodine, technetium and others), in particular performing thyroid scintigraphy.
* Single measurement.

ries and units. The Microsoft Excel Microsoft 365 MSO, function TEST.T was used, which provided STUDENT test p-value (2 tiled, heterogeneity of variance) as both samples sizes and variances are not equal [12,13].

The statistical significance of 0.05 was chosen, to test null hypothesis that 2 population have equal mean and alternate hypothesis that the means of 2 populations are not equal.

Performed Student's t-tests for unit I (oncological centers) revealed some statistical differences (p = 0.049) between electroradiologists and medical physicists as well as significant statistical differences between electroradiologists and cleaners (p = 0.016) also between doctors and cleaners or nurses and cleaners (p = 0.027).

On the other hand no significant statistical differences were disclosed between the groups of electroradiologists and radiological protection inspectors (p = 0.133), electroradiologists and doctors (p = 0.404) as well as electroradiologists and nurses (p = 0.391). Similarly, it seems, that group of radiological protection inspectors and medical physicist, radiological protection inspectors and doctors and radiological protection inspectors and nurses might belong to the population of the same expected value (p = 0.458, p = 0.410, p = 0.410), respectively.

Moreover, regarding groups of medical physicists, doctors and nurses in medical unit I, the Student's test p-values remarkably exceeded critical threshold of 0.05 what indicates on lack of significant statistical differences between these groups therefore the null hypothesis that these populations have equal mean could not be rejected.

Additionally the Student's t-tests were performed between whole group of employers in the I, II and III categories of medical unit, i.e., oncological centers, hospital nuclear medicine departments and nuclear medicine departments. The Student's p-values were as follow: I–II p = 0.34; I–II p = 0.72; II–III p = 0.55, where numbers in brackets denote the pair of compared 2 medical units. The tests did not confirmed any statistical differences between total group employers in the I, II and III categories of medical unit. Moreover, there are similar value of the means and high values of SD calculated overall groups of employers in the particular medical units: (unit I: 457±401 Bq; unit II: 347±331 Bq; unit III: 429±175 Bq). It signifies

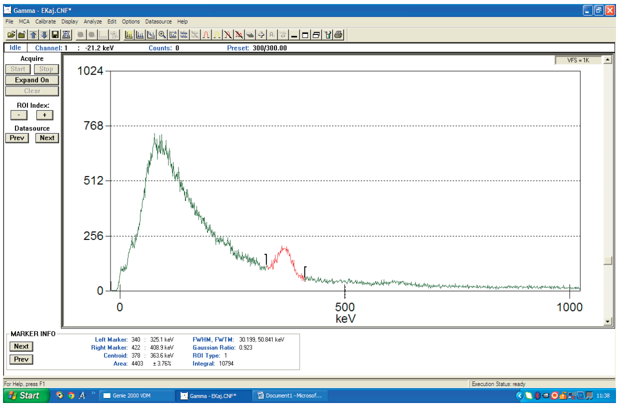
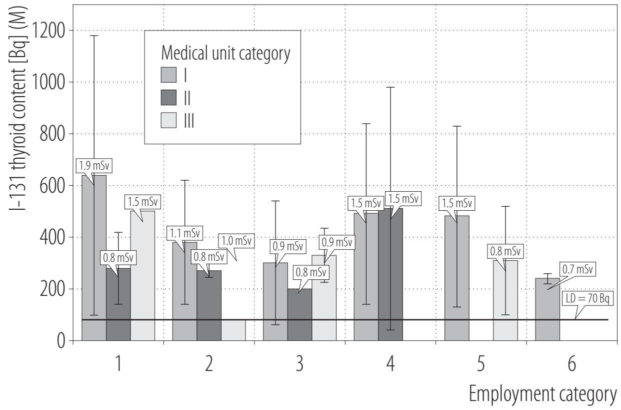


Figure 3. Spectrum of radioiodine (I-131) with photopeak of 364 keV collected at thyroid of exposed worker during measurement carried out in 25 hospital units in Poland



Employment category: 1 – electro-radiologist, technician, 2 – medical physicist or a radiological protection inspector, 3 – medical doctor, 4 – nurse, 5 – cleaner or orderly, 6 – radio-immunologist, radiochemist, conservator engineer.
For categories of medical unit explanation, please see Table 1.

Figure 4. Average thyroid content of radioiodine (I-131) and effective dose for employees in medical units during measurement carried out in 25 hospital units in Poland

that there are not apparent differences in terms of internal radiation hazard due to inhalation of radioiodine I-131 in these categories of medical units.

Testing of iodine content in thyroid workers in a Polish nuclear medical hospital was also performed by other authors [14,15]. The results indicate the occurrence of analogous ranges of measured activity in the thyroid gland. Radioiodine thyroid activity measurements in the occupationally exposed group were performed with the whole-body spectrometer. The determined I-131 activity was found to be above the detection limit, the measured activities ranged from 5±2 Bq to 217±56 Bq.

After measuring the activity, an attempt was made to estimate the corresponding annual effective doses, which the authors estimated in the thyroid gland in the range of 0.4–15.4 mSv.

The authors of foreign centers also point out the occurrence of occupational hazards from radioactive iodine for medical workers. By monitoring the thyroid I-131 in staff members of the nuclear medicine department in China [16], it was found that there are I-131 internal occupational exposure risks. The activity range was found to be 30.00±6.60 Bq to 6070.00±1335.40 Bq for the exposed personnel, and the estimated dose was 0.05–6.77 mSv. The I-131 activity was found highest in the thyroid of nuclear medicine workers involved with the manual packaging and delivery of the radioisotope, while it was not detected in staff members involved with the automatic packaging and drug delivery. There were slightly higher activities in the aforementioned group of employees, however, in the Polish healthcare system there is no combination of radioiodine production and distribution with the functions of diagnosis and therapy in hospital units.

CONCLUSIONS

The results of I-131 content in the thyroid of staff members working with radioiodine in the departments/divisions where the research was carried out, do not show any correlation between the category of a medical unit and the level of radioiodine.

Personnel employed in medical units classified as category I, where applied I-131 activities tend to be relatively high, due to longer contact with the patient or being in an isolation room, i.e., electroradiologists, nursing and cleaning staff, are exposed to higher doses of radiation (Table 1, Figure 4). Relatively low activities are administered by the diagnostic division, units classified as category II, where patients are not subjected to a rigorous isolation regime. Radioiodine levels in workers in these departments are relatively low, and elevated in nursing staff who, among other things, administer isotopes to patients.

Persons employed in category III units, where mainly scintillation tests are performed and specialist medical consultations are conducted, also show low levels of radioiodine I-131 in the thyroid gland. However, the level of I-131 of people performing scintigraphy is significantly higher. It can be clearly seen, that the highest percentage of measured values above detection limit occurred in medical unit I, particularly in the category of employment 6 (cleaners, orderly).

It should be noted that often a higher level of iodine activity in the thyroid gland does not result from the use of high activity of this isotope in a given unit, but rather from the specificity of procedures, maintaining precautionary conditions when working with isotopes, employee training and their experience, etc.

Working conditions with isotopes play a key role, efficient ventilation and air-conditioning in rooms where diagnostic tests (scintigraphy) are performed or patients treated with I-131 iodine stay. This was observed in 1 hospital (category I unit) where measurements were made twice. The second measurement, after a general renovation and reconstruction of the nuclear medicine laboratory, showed a significant decrease in the level of exposure of employees.

Performed Student's t-tests do not confirmed any statistical differences between total group employers in the I, II and III groups of medical unit, i.e., oncological centers, hospital nuclear medicine departments and nuclear medicine departments. One could note, that there is not apparent differences in terms of internal radiation hazard due to inhalation of radioiodine I-131 in these categories of medical units.

The more intensive studies on this problem would be recommended.

Base on results of measurements, the effective dose equivalent for particular person due to inhalation of I-131 was calculated with somewhat a conservative assumption that I-131 thyroid content remains constant during the whole year. For the occupational exposure limit of 20 mSv it gives the reference I-131 thyroid level is equal to 2.5 kBq. Calculated average effective dose equivalent for this particular medical staff is <10% of 20 mSv/year.

Author contributions

Research concept: Grażyna Krajewska
Research methodology: Grażyna Krajewska
Collecting material: Grażyna Krajewska
Statistical analysis: Paweł Krajewski
Interpretation of results: Grażyna Krajewska
References: Paweł Krajewski

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