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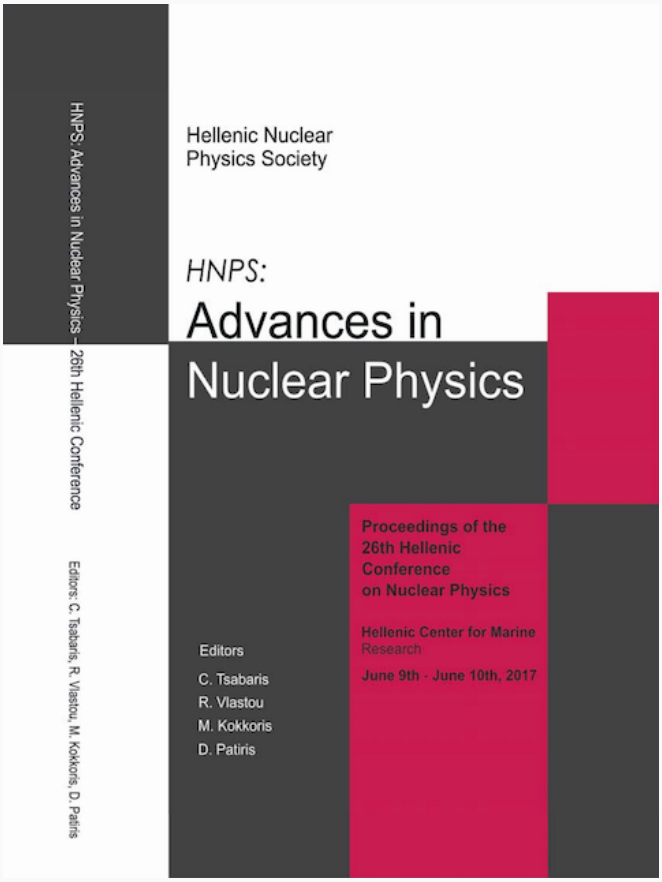

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Individual occupational radiation monitoring in Greece: where do we stand?

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Abstract The aim of this study was to assess the adequacy of the currently employed methodologies in Greece on the radiation monitoring of occupationally exposed workers, based on the experience gained by the internal and external occupational monitoring at the Ioannina University Hospital (IUH). The first aim was to compare the personal dose equivalent values at 10 mm depth, Hp(10), reported over a 16 year-long period by the Greek Atomic Energy Commission and by the University of Ioannina Medical Physics Laboratory (UIMPL). Trunk badges with thermoluminescent dosimeters were used side-by-side by thirty selected IUH workers. Comparison of about 200 Hp(10) annual values reported by the two services indicated good agreement over the entire dose region. The second aim was to test the adequacy of the currently employed policy on individual occupational monitoring for internal exposure. Twenty random direct measurements of whole body activity carried out at UIMPL in eight IUH Nuclear Medicine workers under normal operational conditions, indicated internal contamination with 99mTc and 131I, up to about 10 kBq and 130 Bq, respectively. Assuming the measured twenty values to be representative to those in daily practice, the mean and the maximum annual occupational effective doses in the studied group of workers due to intakes were 0.25 mSv and 0.65 mSv, respectively i.e. less than the 1.0 mSv threshold. Note that and their collective annual committed dose was an order of magnitude lower than their collective occupational effective dose from external irradiation during 2016.

Keywords Occupational exposure, Radiation protection, Hp(10), Whole body counting

INTRODUCTION

Exposed workers are those liable to accumulate due to their work a dose exceeding at least one of the annual dose limits for members of the public, such as 1.0 mSv in case of the effective dose [1]. Such workers can be found in medical institutions, a range of industries, nuclear cycle facilities, mines, aviation, educational and research establishments, etc. Systematic monitoring of individual occupational exposure (external or/and internal) and medical surveillance must be carried out to Category A workers, i.e. those who usually work in controlled areas and are liable to receive an occupational effective dose greater than 6 mSv/y, or an equivalent eye lens dose, or a skin/extremities dose of at least 15 and 150 mSv/y, respectively. The occupational exposure of those that regularly work in supervised areas or those who enter to control areas only occasionally and are not liable to receive doses higher doses (Category B workers), can be assessed by combining screening of the workplace

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characteristics (e.g. dose rate, energy and direction distribution and radon-daughter activity in air) and data on the employed practices (e.g. occupancy factor and worker orientation), or/and by systematic individual exposure monitoring [2].

The main objectives of systematic individual monitoring of occupational exposure are to:
- control the exposure and ensure acceptably safe and satisfactory working conditions,
- demonstrate the effectiveness of the measures taken for protection and safety,
- demonstrate the compliance with managerial and regulatory requirements,
- provide data for analysis of dose distributions and trends amongst and within worker groups,
- contribute to the control of the employed practices and design of the facilities,
- inform workers of their occupational exposure,
- safeguard the interests of both employees and employers,
- provide valuable information for the initiation and support of any health surveillance and treatment, if appropriate, in case of an accidental exposure, and
- provide data for epidemiological studies on radiation effects.

Systematic monitoring of individual occupational exposure has to be carried out by approved dosimetry services and the monitoring results to be stored in a national dose registry [1, 2]. Currently, the Greek Atomic Energy Commission (GAEC) is the only approved service in Greece for systematic individual occupational external monitoring (measurement and interpretation of the result). However, the University of Ioannina Medical Physics Laboratory (UIMPL) provides small scale complementary dosimetry services since early 90's [3].

Talking into account that almost ¾ of the collective occupational exposure in Greece corresponds to medical radiation workers, the present small-scale study was confined to occupational exposed workers in photon and electron fields at the Ioannina University Hospital (IUH), i.e. a 756-bed tertiary hospital. The first aim was to compare the annual personal dose equivalent values at 10 mm depth, Hp(10) (i.e. the operational quantity that usually provides a reasonable estimation of the effective dose in photon fields of energy higher than about 50 keV) by the two dosimetry services using passive integrating dosimeters over a 16 year-long period. The second aim was to test the adequacy of the currently employed policy in the country on occupational monitoring of radiation exposure due intakes of radionuclides.

EXTERNAL EXPOSURE

According to the current recommendations, the standard uncertainty of Hp(10) at photon or electron workplaces should be less than 30% at doses of at least 1.0 mSv/y and not exceeding 20% at values at or near the 20 mSv/y level [2, 4, 5]. Moreover, the combined standard uncertainty at the 95% confidence interval of the effective dose values at or near the 20 mSv annual limit should not exceed 0.67 to 1.5, after all corrections have been made.

Both services use badges with thermoluminescent dosimeters (TLD) since late 2000, i.e. the time when GAEC replaced film badges with TLD badges [6]. UIMPL issues badges once to three times annually containing three TLD-elements each (two ^{n}LiF:Mg,Ti elements and CaF_2:Dy) rather one by GAEC (a ^{n}LiF:Mg,Ti element behind a 1.0 mm-thick Al filter) for Hp(10) measurements [3, 6]. Both services use an additional element for Hp(0.07) assessment.

GAEC provides annually eleven badges per worker (a badge monthly, but in July and August, when a single badge is issued) and reports 0.0 mSv Hp(10) values for badges with readings less than 0.1 mSv [2]. Therefore, a reported zero annual value by GAEC, reflects an annual photon Hp(10) value between 0.0 and 1.0 mSv. UIMPL has access to more accurate data on the natural background H*(10) doses at the IUH workplaces than GAEC (typically 0.57 mSv/y) and on the exposure conditions of each individual worker (factors that allow the use of workplace field-specific correction factors) and reports annual occupational doses higher than 0.1 mSv.

During the 16 year-long study period badges were worn (outside the protective lead clothing, if appropriate) side by side at the chest (the most common case) or at the waist level by thirty selected exposed workers at various IUH departments, allowing to compare about 200 annual Hp(10) values under field conditions (two values were excluded from the analysis, because the users did not use the badges side by side over the entire period). The data shown in Table 1 was divided in eight groups based on the UIMPL measurement results (the GAEC data was divided in two groups, those with nonreportable annual value, n_1, and those with a reportable one, n_2).

Table 1. Comparison of 200 annual Hp(10) values (in mSv) reported by the two services.

UIMPL:	n	range	mean	GAEC:	n_1	n_2	UIMPL / GAEC *
	125	0.01-0.19	-		125	0	-
	17	0.20-0.49	0.31		13	4	1.94+1.19 (0.8 - 3.0)
	17	0.50-0.99	0.71		10	7	1.26+0.61 (0.6 - 2.5)
	8	1.00-1.35	1.21		0	8	0.91+0.15 (0.73-1.15)
	9	1.35-2.99	1.90		0	9	1.18+0.33 (0.75-1.62)
	8	3.00-9.99	4.69		0	8	1.15+0.25 (0.89-1.59)
	9	10.0-19.9	15.4		0	9	0.92+0.20 (0.62-1.27)
	7	>= 20	25.8		0	7	0.96+0.25 (0.68-1.37)

n: number of annual Hp(10) values per dose group by UIMPL,
n_1 and n_2: number of annual Hp(10) values below and above the reportable limit, respectively
* ratio of the annual Hp(10) values reported by the University of Ioannina Medical Physics Laboratory and the Greek Atomic Commission; mean value ± standard deviation (range of values)

Most of the annual Hp(10) doses reported by UIMPL (62%) were less than 0.2 mSv; GAEC assessed non-reportable doses in all these cases. Reportable doses were given by GAEC in 11 out of the 34 cases that UIMPL reported values in the region 0.20 to 1.0 mSv. At higher doses (up to 41 mSv) the mean UIMPL to GAEC dose ratio was 1.02 and the range among the 41 values from 0.62 to 1.62. Note that all 24 annual values that exceeded 4.0 mSv were registered by badges worn outside 0.5 mm thick aprons by interventionists (5 cardiologists and 2 radiologists). Therefore, among the studied exposed workers none got an annual effective dose higher than 4.0 mSv (20% of the corresponding limit). However, all workers with typical effective doses above 1.0 mSv, were encouraged to participate to the IUH occupational health surveillance program. In conclusion, a good agreement was found between the annual Hp(10) values reported by the two dosimetry services using passive dosimeters under real field conditions.

INTERNAL EXPOSURE

In case of internal exposure, there are no operational quantities, such as Hp(10) and Hp(0.07). The quantities committed equivalent dose in a tissue or an organ and committed effective dose (CED) are derived indirectly combining activity measurements and models. Therefore, the intake (i.e. the activity of each radionuclide taken into the human body) is the quantity of primary interest [7]. Retrospective assessment is often carried out at some time, *t,* after the intake, by measurements of the activity of radionuclides present in the worker's body by whole body- or organ-counting in case of nuclides that emit photons of sufficient energy (direct bioassay), or in biological samples (indirect bioassay), such as in urine, or/and by measurements of the activity concentration of radionuclides in ambient air at workplaces. The intake of a radionuclide j by a worker (e.g. assessed as the measured activity in his body at time *t* divided by the fraction of the intake retained) is multiplied by the appropriate dose coefficient, $e(g)_j$, to estimate the CED. Thus, the various intakes are coupled with radionuclide-dependent biokinetic and dosimetric models, its physicochemical form the route and the conditions of each intake (inhalation, ingestion, entrance through woods or intact skin).

In case of anticipated CEDs that exceed 6.0 mSv/year, individual metabolic and dosimetric data are to be used. At lower levels, the "reference worker" models proposed by the International Commission on Radiological Protection (ICRP) are often used [8, 9], that combine data on biodistribution and retention of the incorporated radionuclides with data on radiation transport in the human bod are often used. However, according to the recommended practice, as long as the result of a dose assessment that is based on experience gives an annual CED value from the intake from all radionuclides at the workplace that does not exceed 1.0 mSv, monitoring and documentation of the characteristics of the workplace fields and the employed practices are usually considered adequate [7]. Such assessments depend on factors such as the type and the amount of the radioactive materials present at the workplace, their physical and chemical form, the type of the containment used, the operations performed and the general working conditions.

In case of anticipated annual doses higher than 1.0 mSv, individual monitoring of internal exposure on a fixed schedule (such as an interval of 1 and 3 months in case of *in vivo* monitoring of ^{131}I and ^{137}Cs, respectively) is required to improve the reliability of the dose estimates. In that case the potential maximum underestimate of intake shall be less than a factor of 3 within the monitoring interval [7]. However, when radionuclides with short effective half-live are present in workplaces, such as in poorly ventilated radon-prone workplaces and in Nuclear Medicine Departments (NMDs), the application of such a policy by a central dosimetry service is often unrealistic [10-12].

Taking into account the current activities in Greece, monitoring due intakes of radionuclides is carried out by GAEC and UIMPL either as task-related or as special monitoring, such as in case of a known or a suspected radiological incidence. Most of the collective occupational exposure in the country due intakes of radionuclides is attributed to about 800 Nuclear Medicine exposed workers. Note that even though they number only ~1/14 of the occupationally exposed workers in Greece, they receive almost ¼ of the collective occupational effective dose from external sources. Their intake is related to the nature of the implemented practices that require the handling of substantial amounts of radioactive sources. The most commonly administered radionuclides in NMDs for scitigraphic and PET studies, ^{99m}Tc and ^{18}F, respectively, have physical half-lives of only 6.015 and 1.83, h, a factor that makes impractical a country-wide systematic individual monitoring program by a single dosimetry service [10].

The close proximity between IUH and UIMPL provided a rare opportunity to study Nuclear Medicine workers under normal working conditions. Ten radionuclides are currently in use at IUH/NMD. For example, about 8 TBq of the short-lived ^{99m}Tc were milked from ^{99}Mo generators during 2016; 2.5 TBq of ^{99m}Tc-containing radiopharmaceuticals were synthesized locally, out of which 1.9 TBq were administered intravenously (i.v.) to patients for diagnostic purposes. During that year, 0.23 TBq of ^{131}I were administered in form of capsules for either therapeutic or diagnostic purposes. In addition, 35 GBq of ^{123}I or ^{177}Lu containing radio-pharmaceuticals were administered i.v., as well as ^{67}Ga, ^{153}Sm, ^{201}Tl and ^{223}Ra preparations of lower activities. Twenty whole body activity measurements were carried out using the mutli-detector shadow-shield UIMPL whole body counter [11,12] in nine out of the twenty IUH/NMD radiation workers at a time less than 4 h after the termination of their daily shift (these workers receive ~50% of the collective Hp(10)).

Besides the detected naturally occurring ^{40}K and the radon products ^{214}Pb and ^{214}Bi at levels that did not differ from those in the general population at Ioannina [13], ^{99m}Tc activity above the corresponding minimum detection limit was found in the body of six workers (range 140 to 9500 Bq) and ^{131}I in four (range 55 to 265 Bq). Based on the knowledge of their working patterns and assuming that these random measurements were typical, it was found that their annual committed effective dose due to ^{99m}Tc intakes did not exceed 30 μSv. The corresponding doses to those contaminated with ^{131}I were between 55 and 230 μSv. Note that the latter workers (two nurses and two medical physicists) offered services to the IUH/NMD Radioiodine Treatment Unit and their contamination was mainly attribution to inhalation of the volatile ^{131}I, despite the frequent forced exchange of air in the Unit [14]. None of the studied workers received an annual CED from intake of radionuclides higher than 250 μSv (¼ of the proposed 1.0 mSv threshold for systematic individual monitoring for internal exposure) and their annual collective committed effective dose, about 0.75 man mSv, was an order of magnitude lower than their collective effective dose from external radiation sources, 8 man mSv, during 2016.

The limited number of direct activity measurements carried out in this study indicated that systematic individual monitoring for internal exposure of the IUH/NMD personnel that is not related with the therapeutic uses of ^{131}I is not required. Such a statement may not hold to other NMDs that may not apply state-of-art practices with regards to radiation protection. Further studies are required to reach to a general conclusion on the adequacy of the currently employed monitoring policy on the occupational intakes of radionuclides in Greece.

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