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ACTIVE ELECTRONIC PERSONAL DOSEMETER IN INTERVENTIONAL RADIOLOGY

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A recently developed active electronic personal dosemeter (AEPD) was utilised in order to measure the levels and the structure of occupational exposure to scattered X-ray radiation of medical staff who performed percutaneous revascularisation therapy that involves interventional radiology (IR) on the pelvis and upper leg arteries. The AEPDs, placed on the operators' and assistants' chests, that is, above the protective apron, continuously measured and recorded the received doses and, as a novelty, dose rates as a function of time, thus yielding a unique record of occupational doses and dose rates pattern at the working place. This paper presents and discusses one typical daily pattern in which seven percutaneous interventions were performed.

INTRODUCTION

In recent decades, passive dosemeters (film badge and thermoluminescent) have been extensively used for occupational exposure monitoring. Their physical properties and technical characteristics are well understood and they have successfully fulfilled measurement demands for many years[(1)].

However, modern technology progress and newly developed techniques and procedures, used in industry and medicine (medical imaging and therapy), are more demanding and require customised and upgraded occupational dosimetry. Occupational doses in diagnostic and interventional procedures in medicine range from very low to low doses (up to 50 mSv y^{-1}—a little above the recommended limit)[(2)]. These doses are related predominantly to scattered X-ray radiation. In such procedures, professionals are occasionally arbitrarily exposed to radiation with dose rates that vary from background (BG) (80–130 nSv h^{-1}) to 100 times higher[(3–6)].

Passive dosemeters, film badges and TLDs, have some limitations, inabilities such as immediate dose-reading, dose absorption time resolution and re-reading after being read out.

Electronic personal dosemeters (EPDs) are designed to remove these limitations. Those that are sensitive enough in the very low dose region of professional exposures might be used to supplement passive dosemeters. Electronic dosemeters have been in use for many years, but only recently have been considered as regular occupational monitoring dosemeters. New technologies have enabled electronic dosemeters to become small, low power consumption devices with high data acquisition performances and real-time measurement capabilities.

As explicitly stated by Luszig-Bhadra and Perle[(1)], EPD can record doses that are almost up to three orders of magnitude lower (smaller) than those detected by passive dosemeters. Their sensitivity is of the order of 100 counts per μSv and can reliably detect doses as low as ~ 0.015 μSv[(1,7)] within an hour, which is within the BG radiation range.

The EPD is very comfortable to wear, can be easily manipulated, provides an immediate readout option, and allows for real-time measurements with an early warning alarm in possible accidental exposure situations. All of these characteristics allow the worker and the radiation protection officer to optimise and minimise the radiation exposure for special types of jobs, especially in medicine. This is a direct contribution to the ALARA principle.

In this paper, the characteristics of the new active electronic personal dosemeter (AEPD), ALARA OD, are demonstrated (see www.alara.hr). It was utilised together with a film badge dosemeter to measure accumulated dose and dose rate time dependence during an exposure of the professional medical staff to scattered X-ray radiation while performing interventional radiology (IR) procedures. IR was chosen due to the fact that interventional

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radiologists are the most exposed sub-group among sub-specialties in diagnostic radiology[8]. While performing an IR procedure, the operator (OP), leading radiologist, or other individuals occasionally expose unprotected parts of her/his body (extremities) to the primary X-ray beam. Furthermore, at the same time, his/her whole body is exposed to indirect, scattered radiation. The IR occupational dose rate pattern or the time-dependent dose rate is not accessible with passive dosemeters. AEPDs ALARA OD were used to continuously measure and record dose and dose rate as a function of time. The results yielded a unique record of occupational dose and dose rates patterns in the working place during a typical workday in which seven different percutaneous interventions were performed. (The percutaneous approach is commonly used in vascular procedures. This involves a needle catheter getting access to a blood vessel, followed by the introduction of a wire through the lumen of the needle.)

EXPERIMENTAL METHOD

AEPDs ALARA OD, based on GM tube, are used. An AEPD records accumulated dose, starting time and the duration of each deliberately performed fluoroscopic X-ray exposure during the IR procedure, and it operates in two modes. In the normal or BG mode, it accumulates doses over a certain preset time interval (from 1 h to 256 h, usually 8 h) and records the dose (number of impulses) at the end of the interval. The second is the 'event' (E) mode where 'event' refers to any actual dose rate higher than the threshold that is set to 2 impulse per second i.e. 200–500 times the local BG (the average local BG dose rate reads from 80 to 130 nSv h^{-1} i.e. about 30 impulse per hour (0.011 impulse per second)). The device is in the BG mode for as long as the dose rate, tested every second, is below the preset threshold value (2 impulse per second). As soon as it exceeds the preset value, the AEPD switches to the E mode in which it records the time duration in seconds and the accumulated dose of the time interval. In other words, AEPD can record in detail the time sequence of the received accumulated dose. All the readout data: doses, exposure fractions, fraction time sequences, dates, cumulative doses, total number of impulses of GM tube, total time duration of measurements and calibration factors are continuously recorded. Moreover, the AEPD by ALARA OD has no-'turn-off'-option; it is active for as long as batteries live (~3 y).

The recordings were downloaded to a PC and processed using the ALARA OD software. BG was measured using the RS 131 Reuter Stokes high-pressure ionising radiation monitoring chamber. The quality factor $Q = 1$ for X rays was used. The AEPDs were tuned and calibrated for BG energies and checked for X-ray energies at ~70 keV, which is a standard calibration of common X-ray angiography units used in IR[9,10]. Quality control measurements were done on the conventional X-ray radiography unit prior to IR treatment of patients. In this study, the equipment and patients were regarded as secondary radiation sources emitting scattered X rays. Data were collected while performing percutaneous revascularisation therapy procedures on the pelvis and upper leg arteries.

RESULTS AND DISCUSSION

This article presents data recorded by ALARA OD—type of AEPDs[10–12] worn as additional personal dosemeters[4,5,9] by four medical specialists as shown in Figure 1. AEPDs were strapped on the protective apron, on the left side at the chest level[9,10]. In one working day, the four IR specialists performed or took part in seven IR procedures each lasting more than 30 min (Table 1).

During the working day, their roles changed from leading radiologist (OP1) to first-line assistant radiologist (A1). As OP1s, they received from 4.0 to 7.5 μSv per procedure while as A1s the received dose ranged from 0.3 to 1.4 μSv per procedure. In the rest of IR procedures, they were observers (A2), still near the patient table, but behind the OP1 and A1s. As A2s, they received from 0.1 to 0.3 μSv per procedure.

One additional AEPD was placed in the X-ray remote control room, properly shielded[2] from scattered radiation behind the protective wall and windows. That room was not considered as a controlled area[2] where the expected annual equivalent dose is >1 mSv[2,11,12].

All AEPDs, strapped on the protective aprons hanging in the IR wardrobe room, were started at

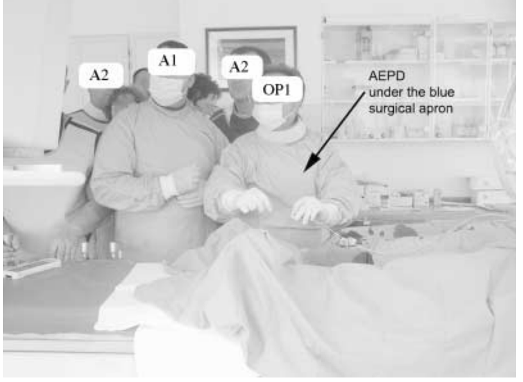

Figure 1. Arrangement of specialists performing IR procedure no. 1.

Table 1. Timetable of IR procedures of a single specialist wearing ALARA OD no. 00204 and his role in a particular procedure.

IR procedure	IR time table	IR specialist's role	AEPD time operating in E mode (in s)	AEPD location
	0:54–9:00			Wa[a]
I	9:15–9:55	OP1	245	Ap[b]
II	10:20–11:10	A1	62	Ap
III	11:20–12:55	A1	15	Ap
IV	13:10–13:45	A2	4	Ap
	13:55–16:00	Lunch break		Wa
V	16:05–16:55	OP1	313	Ap
VI	17:20–18:57	A1	15	Ap
VII	19:10–19:55	OP1	198	Ap
	20:00–00:26			Wa

[a]Wa, wardrobe.
[b]Ap, strapped on the apron/front.

1:00 a.m. ($\pm$5 min). They were started early enough in order to properly measure the BG radiation. AEPDs have measured BG from starting time to the beginning of IR procedures and the results were in agreement with the RS131 ionising chamber's BG. At 8:00 a.m., IR specialists put on protective aprons and wore them throughout the working day, except for the lunch break ($\sim$2 h), while the aprons were left hanging in the X-ray wardrobe room. The leading radiologist (OP1) performed four percutaneous revascularisation therapy interventions of various durations. He also took part in three other interventions, either as A_1 or A_2 assistant. He spent the rest of his working time outside the operating room. The timetable of performed IR procedures and the position of the particular radiologist (OP1 in first procedure) and the dosemeter assigned to him are given in Table 1.

There were four IR procedures in the morning shift, from 9:15 to 13:45, and three in the afternoon shift, from 16:05 to 19:55. Lunch break time was from 13:55 to 16:00. From 1:00 a.m. to 00:30 a.m. of the next day, the AEPDs were continuously measuring local BG (total measuring time was 23.5 h).

The total number of impulses recorded by different AEPDs during that day, varied from 1467 for the radiographer to the relatively wide range of recorded impulses, ranging from 3017 to 11 332 impulses, for other medical staff members involved in the procedures. The corresponding total equivalent doses were 4.4, 10.9 and 33.2 μSv, respectively. The readout intervals and IR procedure events are shown in Figure 2 and Tables 1 and 2. Figure 2 shows two types of records. The lowest, the radiographer's AEPD record (r), shows increasing linear time dependence of accumulated dose in agreement to being exposed to BG radiation solely (4.4 μSv). During the IR procedures, this AEPD operated exclusively in the BG mode, which demonstrates that

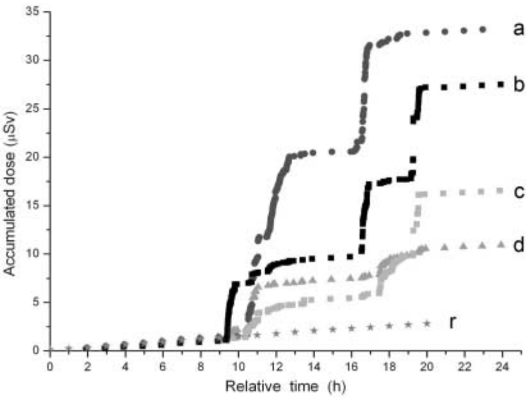

Figure 2. Accumulated dose readout of five AEPDs (ALARA OD type) continuously measuring either in BG mode or in E mode—four IR radiologists (a, b, c and d) and one radiographer (r). Recordings refer to one working day, including seven vascular IR procedures. Preset time interval was 1 h. Preset threshold value for switching into E mode was 2 imp s^{-1}. Curve r shows the dose accumulated in the control room.

the remote control room was properly shielded from radiation. The other type of records was done by AEPDs worn by the operators. The dose accumulation curves (a, b, c and d) exhibit a step-like behaviour. Each step, representing a steep increase in the accumulated dose, is related to a particular IR procedure involving an intensified fluoroscopy regime. Figure 3 shows equivalent dose rates for the first morning intervention starting at 9:15 a.m. (*I*) as a function of time. Presented sequence of dose rate values were obtained by dividing the dose accumulated during each of E mode intervals by the time duration of corresponding interval. Each single dose rate is the average of recordings obtained for each interval in which AEPDs were operating in E mode.

Table 2. Data readout for the AEPD strapped on the apron of the leading IR operator (b) during all seven IR procedures.

Dosemeter number	ALARA OD 02204
User	IR (operator b in Fig.2)
Starting time	28 September 2005—00:54:00
Readout time	29 September 2005—00:26:00
Total dose	27.6 μSv
Total number of impulses	8295
Total time	23.5 h

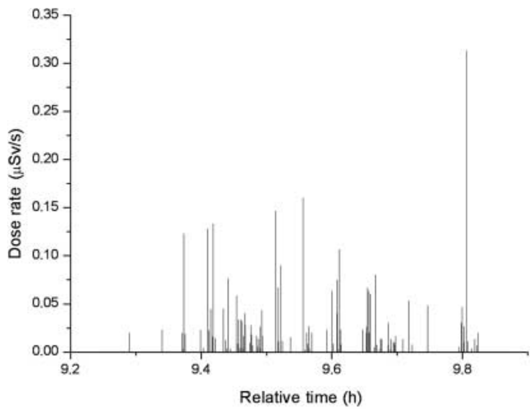

Figure 3. Dose rate recorded by the ALARA OD AEPD (average of 99 recorded E mode time intervals) over time during the first (of seven) vascular IR procedures (BG is not subtracted) performed by the leading operator (OP1). Bars denote the values of 99 during which fluoroscope was switched on. Total fluoroscopy time (AEPD in E mode) was 245 s.

Time coordinate of the particular interval is ascribed to the end of the interval.

Although occupational equivalent dose rates were very low (not exceeding 0.3 μSv s^{-1}), due to relatively numerous fluoroscopic exposures (99 of them in the first morning intervention), the accumulated dose of 5 μSv was obviously not negligible. On closer inspection, the first intervention (*I*) of the day shows that the OP1 (curve b in Figure 2) made extensive use of X-ray fluoroscopy, which reflects either his characteristic therapeutic approach or the 'fingerprint' of a specific vascular therapy procedure. The total duration of exposure (exposure burden of medical specialist, i.e. AEPD in E mode) over the 40 min of the intervention was 245 s (12% of total time). The total equivalent dose recorded by the OP1's AEPD (b) over the entire monitoring time of 23.5 h, received in 283 random fractions, was 27.6 μSv. It reveals very low X-ray exposure. The obtained equivalent doses for the leading operator (OP1) per procedure (Table 1 and Figure 2) are in the range of 4.0–7.5 μSv, which could be extrapolated to annual equivalent doses in the range of 3.2–6.0 mSv (800 IR procedures per operator per year). These values are in agreement with literature data for radiologists in vascular IR procedures[4,13] and about one-third of the value declared for the cardiologists' occupational doses[3,4,14] as generally expected[9]. During the working day followed in the study, all IR specialists were wearing additional, one-day film dosemeters, but these did not record enough radiation to be interpreted correctly. The AEPD ALARA OD is capable of measuring and recording accumulated doses as a function of time, in ranges from very low to low doses, even in time intervals that are too short for passive dosemeters to make records with acceptable statistical significance.

From the analysis presented above, it may be concluded that the AEPD ALARA OD can be utilised as an additional personal dosemeter device for performing more accurate occupational exposure measurements than is possible by using passive dosemeters, due to the fact that ALARA OD can distinguish occupational dose contributions to the BG radiation. Moreover, ALARA OD is able to record characteristic dose rates of any single IR procedure.

Health surveillance and radiation protection of medical specialists performing IR intervention have to be additionally optimised and approved. Some medical specialists performing IR procedures, outside radiological units in hospitals, are often not recognised as occupationally exposed[9,15–19].

ALARA OD dosemeter records can be utilised to improve dosimetry documentation and to optimise radiation protection facilities, education and training.

CONCLUSIONS

Occupational doses received by the medical staff performing IR procedures on the pelvis and upper legs arteries are referred to in literature in a surprisingly wide range of values (0.2–18.8 μSv per procedure)[13]. In order to improve and upgrade radiation protection of medical professionals, assuming usual IR procedure conditions, more accurate and reliable measurements of their exposure to scattered X-ray radiation (from a patient, medical equipment and air) appear to be urgently needed. Moreover, otherwise very low doses may, due to the frequent use of IR procedures (by leading medical specialists), exceed the recommended annual limits without being actually detected[6].

It is shown that the ALARA OD AEPD can continuously and precisely measure local BG and at the same time record additional gamma- and X-ray radiation. ALARA OD AEPD will automatically record all segments of occupational radiation in IR.

Besides, a new type of readouts has been obtained, not reported in the literature so far. Namely, ALARA OD AEPD can produce a detailed record of characteristic dose rate time pattern of any single IR procedure. It would be worthwhile to submit it to a Regulatory Authority for approval in special (intervention), additional (nuclear medicine), or even regular personal dosimetry in the future.

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