Advantages and Limitations of Electronic Devices for Primary Occupational Dosimetry

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Introduction

In Spain occupational dosimetry is performed by approved Dosimetry Services, which use TL dosemeters as sensitive material. At NPPs, the information obtained with the passive legal dosemeters is complemented by measurements from personal electronic dosemeters (EPD) that are worn in radiologically controlled areas. Recently, electronic dosemeters have improved their performance and have added new features. They have become smaller and lighter, produce dose and dose-rate alarm, offer a wide measurement range, perform automatic electronic checks, are better shielded from external electromagnetic fields and have specific software for automatic dose-record management. The use of electronic personal dosemeters has reduced workers' dose in most industries and improved their safety, thus they are considered as important tools for ALARA practices. The benefits of the new electronic personal dosemeters (EPD) have brought about general concerns about the possibility of using them for legal dosimetry as substitutes of passive dosemeters, currently in use. In some European countries, such as Great Britain and France, EPDs have been recently accepted as legal dosemeters at some specific workplaces. On this basis, the Spanish Authorities in the field of Radiation Protection and Nuclear Safety (CSN) entrusted the Institute of Energy Technology of the Technical University of Catalonia (INTE) to undertake the present study, within the framework of the first CSN-UNESA research programme. The project is aimed at establishing a calibration protocol to verify EPD performance and reliability and at evaluating the state-of-the-art of some commercially available devices, compared with standard passive systems. It consisted of two main parts. The first included a thorough review of the literature to learn about other authors' experiences, peer intercomparison results, international Standards and new developments. The second part included an experimental study to get an overview of the performance of a set of selected dosemeters, to detect their main weaknesses and to test the proposed Protocol.

The INTE is a university research centre with proven experience in the field of radiation metrology. It has a dosimetry and calibration laboratory, accredited by the Spanish Accreditation Body, which has signed the European multilateral agreement for accreditation. The project was carried out between September 1998 and March 1999.

Material and methods

While EPDs have been used as operational dosemeters in most countries, they have not undergone accreditation programs or intercomparisons. However, if they were to become primary dosemeters, such verification would be advisable. Therefore, one of the purposes of this study was to propose a calibration and testing procedure, which would ensure EPD reliability, in case they are used for primary dosimetry. The latest International Standards were reviewed and a Protocol based on IEC publication 61526 (1998) produced (1,2). This Standard was the first to be suitable for electronic devices calibrated in units of personal dose equivalents, $H_p(10)$ and $H_p(0.07)$, or personal dose equivalent rates, which are the operational quantities for personal dosimetry nowadays in use in Europe. Nevertheless, if the critical quantity from a radiation protection point of view is $H_p(10)$, IEC publication 1283 (1995), can also be adopted (3).

The INTE Protocol included, apart from radiological tests very similar to the tests used for passive dosemeters, specific requirements about their physical characteristics, mechanical and environmental performance and software and safety setting reliability.

Since one of the most often reported limitations of EPDs was their dependence on external electromagnetic fields, measurements were undertaken to analyse electromagnetic fields at some specific places in a PWR nuclear power plant, which were taken to present especially high intensity fields. Two sites, from Vandellos II NPP, were selected; the electromagnetic filter from the steam generator blow-down system and the electric generator.

To organise the experimental part of the study, a survey was undertaken to overview the available EPDs on the European market, and to ask the manufacturers to participate in the project. As regards the choice of the dosemeters, models presently in use and connected to centralised dosimetric systems, and thus more likely to eventually become official dosemeters have been preferred. Manufacturers were invited to present their most recent developments. However, the Alnor ELD dosemeter based on the Direct Ion Storage detection system (4) and the electronic pocket dosemeters from the PDM series from Aloka, were not available for the experiment. The nine electronic personal dosemeters that, in the end, were reviewed are listed in Table 1.

Electronic Personal Dosemeter	Type of Detector	Measured Quantity
RADOS Type RAD-101S	Geiger	X - H (1 mR ≈ 10 µSv)
Eurisys Mesures Type DOSICARD	Si Diode	$H_p(10)$
MGP Type DMC-100	Si Diode	$H_p(10)$
MGP Type DMC-2000S	Si Diode	$H_p(10)$
RADOS Type RAD-50S	Si Diode	$H_p(10)$
PANASONIC Type ZP-145 M	Si Diode	X - H (1 mR ≈ 10 µSv)
DOSITEC Type L36	Si Diode	X - H (1 mR ≈ 10 µSv)
SIEMENS Type EPD-2	3 Si Diodes	$H_p(10)$ and $H_p(0.07)$
SIEMENS Type New EPD	3 Si Diodes	$H_p(10)$ and $H_p(0.07)$

Table 1: Electronic personal dosemeters that have been evaluated in the study

According to the INTE Protocol, the following verifications were performed:

Physical characteristics: size, weight, case design, battery capacity, switch operation and data display.

Radiological performance*:* measured quantities, dose equivalent and dose equivalent rate range, measurement accuracy, alarm accuracy to set value, energy response, angular response, response time and dose equivalent rate dependence for dose measurements.

Mechanical performance*:* drop and vibration tests.

Environmental performance*:* response dependence on temperature, humidity, electromagnetic and magnetic fields and electrostatic discharges.

Safety settings*:* electronic self-check, overload signals.

Readout reliability: accuracy of data transfer from the dosemeter to the reader and vice-versa.

Electromagnetic tests were performed at the Catalonia Regional Calibration Laboratory (Spain), which is equipped with an anecoic chamber and several antennae and field generators. The rest of the features were tested at the Technical University of Catalonia. In particular, the radiological experiments were carried out at the INTE secondary laboratory, which has a gamma irradiation unit, an X-ray dosimetry system and a secondary beta standard. Photon reference measurements were traced to the German National Laboratory

(PTB) and beta measurements to the United States National Laboratory (NIST). Unfortunately, due to technical limitations, electromagnetic field influence during gamma irradiation could not be tested.

Repeatability and reproducibility were checked in three units of each model and the electromagnetic compatibility tests were performed simultaneously to two units of each EPD. The other tests were performed on a single unit, except when results were different to manufacturer's specification, in which case another unit of the same model was tested.

Results

"In situ" electromagnetic field measurement

By means of adequate antennae, the presence of electromagnetic fields within a wide frequency range between 0 to 22 GHz was checked at the two selected areas from Vandellós II NPP.

Measurements around the electromagnetic filter showed magnetic fields of the order of 1.2 A/m at 0.5 m, and electromagnetic fields lower than 0.1 V/m at 1.5 m, at frequencies between 10 kHz and 1 GHz.

The electromagnetic field around the electric generator was also found to be very weak, lower than 0.01 V/m at frequencies between 20 MHz and 350 MHz. However, the magnetic field strength at 50 Hz was much higher than the standard testing values specified in the Protocol and IEC standards (60 A/m at 50 Hz). Table 2 summarises the results of magnetic field measurements.

Distance (m)	**Magnetic field (A/m)**	
	Maximum	**Minimum**
0.5	4621	82.2
2.0	4432	38.4

Table 2: Magnetic field strength around the electric generator

Dosemeter performance

Advantages of electronic personal dosemeters

One of the main advantages of EPDs is their capacity to supply a direct reading of the dose and the dose rate received by the user as well as alarm signals when a preset value is exceeded. The survey undertaken has confirmed that the nine analysed dosemeters presented an accurate response for ^{137}Cs, within ± 15 % of the conventional true value, for a wide effective range of measurement from 1 μSv to 1 Sv or 10 Sv, depending on the device. It was also checked that the dose measurement accuracy was independent of dose rate within the range 0.02 mSv/h to 150 mSv/h, and that the dose equivalent alarm was activated when the dosemeter was subjected to a dose of ± 15 % of the alarm set point. All dosemeters presented an angular response within criteria for ^{137}Cs, within ±20 % for two rotation planes for angles from –60º to 60º, and seven out of nine for 60-keV filtered X-rays, within ±50 % for the same angular rotation.

Improvements were also found as regards physical characteristics and environmental performance. Weight and size of all the studied dosemeters were within established criteria. It was verified that those parameters tended to become smaller and closer to passive dosemeter characteristics. Some recent models weighed 60 g and had the size of a credit card. Moreover, it was proven that most dosemeters (7/9) withstood drops from heights of 1.5 m onto a hard-tiled surface and vibration corresponding to harmonic loadings of 2 g at a frequency of 30 Hz. As regards environmental influence, it was verified that dosemeter response did not vary when radiation exposure was performed at a temperature of 40 ºC or a humidity of 80 % at 30 ºC. Good inmmunity to an external magnetic field of 60 A/m was also proven.

Finally it was checked that the selected dosemeters had safety systems to ensure that only authorised personnel could stop or reset readings and modify alarm settings.

Weaknesses of electronic personal dosemeters

Despite the above considerations some limitations must be pointed out. Four dosemeters kept on measuring whilst the dose equivalent rate range was exceeded thus resulting in a dose underestimate. Two of these dosemeters also failed when the dose equivalent range was overcome. Furthermore, some irregularities were found when testing the dose equivalent rate alarm, four dosemeters gave frequent alarm indications for values 20 % lower than the preset level.

In general, except for two dosemeters, a poor energy response at low photon energies and beta radiation was found. Three dosemeters even had a bad energy response, variation greater than ± 30 %, in the energy range of major concern at NPPs from 100 keV to 1250 keV. As an example, figure 1 shows the relative energy response of one of the two devices that performed according to IEC 61526, one of the four EPDs that agreed with IEC 1283 criteria and one of the three detectors that did not comply with any of the two selected standards.

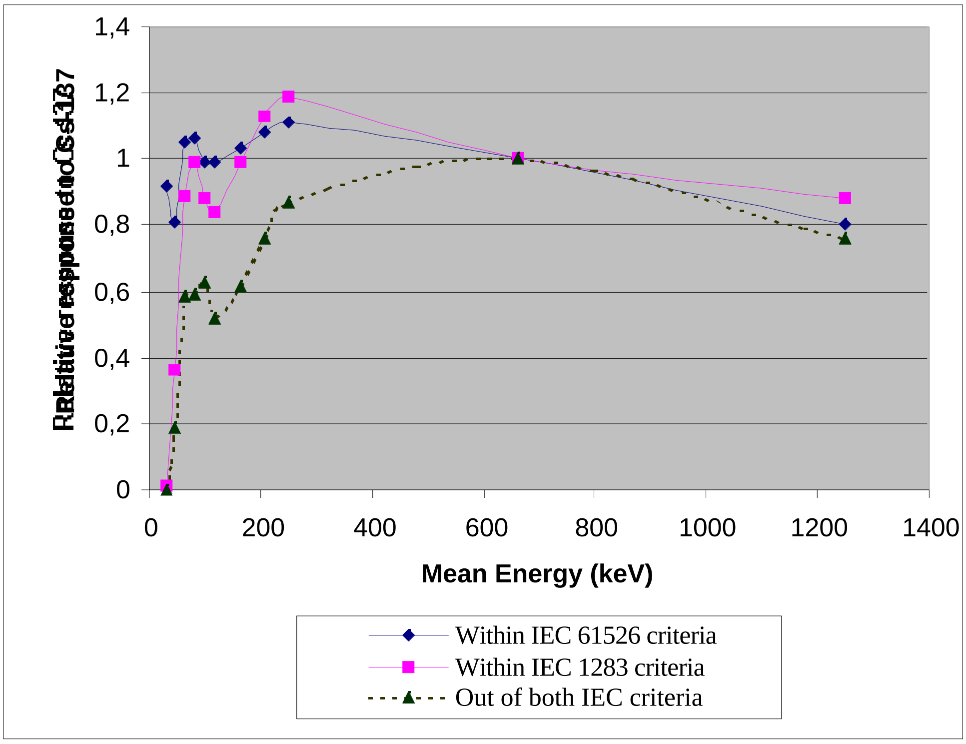

Figure 1: Example of dosemeters with different energy response

Regarding dose reading, information was retained unchanged over the following 8 h after exposure. However, 24 h after loss of power, three dosemeters lost all the stored data and three of them lost partial information, in one case the last 24 h of data and in the other two the last 15 minutes.

Several dosemeters (4/8) showed spurious signals when they were exposed to electrostatic discharges of 8 kV with an energy of 2 mJ for 10 minutes. Two of them were also affected by 100 V/m electromagnetic fields. However only one type of detector showed wrong dose readings because of the perturbation.

Work in progress

Since the end of the study, new products have appeared on the market. It is worth mentioning, for instance, a new vesion of MGP DMC 2000 which has enlarged its former effective energy range and can measure

$H_p(0.07)$. Several other approaches are in progress in order to develop active personal dosemeters for neutron dosimetry, although none of them are ready for commercialization yet (5).

Conclusion

The main objective of this paper has been to present the benefits of available electronic dosemeters and to point out some of the technical features that need further development. We have tried to outline the characteristics that future users or regulatory authorities should verify before purchase or approval of a specific dosimetric system. The results of the survey undertaken also confirmed that IEC Publication 61525 is a good tool for evaluating EPD performance, especially if they are to be used for primary dosimetry. However, additional tests should be prescribed if the dosemeters were to be worn in places, such as near the electric generator of an NPP, where the magnetic field is much higher than the Standard tested values.

The results of the experimental measurements showed that most EPDs had a good response for photon radiation above 60 keV. In this energy range, linearity to dose and to dose rate, angular response and low-level detection limit were at least as good as in TLD. Moreover, it was proven that the most recent EPDs were not influenced by environmental parameters such as temperature, humidity and electromagnetic fields. However some of the detectors presented spurious signals or false readings in some specific areas of NPPs with high electromagnetic fields. Two of the devices failed the drop test and only few very recent devices could measure low energy photon and beta exposures. Nevertheless, it must be pointed out that such radiation is, generally, a minor component of the occupational dose in NPPs. On the other hand, neutron personal dosimetry is still being developed by means of passive and active detectors, without providing a unique adequate solution at the moment.

In summary, the survey highlighted the fact that new electronic devices, which show improved radiological performance, are bound to become legal dosemeters in the near future. However, due to some of the encountered limitations we recommend using redundant dosimetry records, at least for an experimental period of time before proposing EPDs for official dosimetry. If there was agreement in measurement in both dosimetric systems, this would guarantee adequate reliability and allow the selection of the most suitable dosemeter for primary dosimetry. Furthermore, such a period of time could also give information about dosemeter long-term reliability and false-reading rate.

References

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