Comparison of the Performance of a Set of nine Electronic Personal Dosemeters

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INTRODUCTION

Most countries use passive dosemeters, such as TL dosemeters or films, to evaluate occupational dosimetry. In Spain, for instance, personal dosimetry is performed by approved dosimetric services, which are based on TL systems. However, electronic direct-reading devices, are also often used as secondary dosemeters, mainly by nuclear power plant workers and by industrial gammagraphy operators. The recent improvements in the performance and reliability of such detectors, together with their interesting technical features in comparison with passive systems, have brought about general concerns about the possibility of accepting them as legal primary dosemeters (1).

The European Directive 96/29/Euratom (2), which lays down basic safety standards for health protection of workers and the general public against the dangers arising from ionising radiation was to be implemented in the European Union Member States regulations and laws before the 13th May 2000. This Directive, based on the ICRP-60 recommendations (3), reduces the former maximum permissible doses and introduces the concept of dose constraints within the context of optimisation of radiological protection. Such features, as well as the need of harmonization in dosimetry among the European Member States led the Spanish Nuclear Safety Council, the Spanish Authority in Nuclear Safety and Radiation Protection, to ask the Institute of Energy Technology (INTE) of the Technical University of Catalonia in Barcelona (Spain) to undertake the present study. 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 also supported by the Spanish Electric Utilities Association (UNESA), which, as the main users of electronic personal dosemeters (EPD), was very interested in knowing the performance of recent developments.

The project, carried out between September 1998 and March 1999, aimed at establishing a calibration and testing Protocol for electronic personal dosemeters in order to ensure its reliability both for secondary and legal personal dosimetry. Subsequently, the Protocol was to be applied to a set of selected commercial electronic personal dosemeters to evaluate the state-of-the-art of the available devices and thus the suitability of the proposed testing methods.

MATERIAL AND METHODS

In 1998, the International Electrotechnical Commission (IEC) issued IEC publication 61526 (4), this was the first international standard to be applied to dosemeters which are worn on the trunk of the body and are used for the measurement of personal dose equivalents, $H_p(10)$ and $H_p(0.07)$, or personal dose equivalent rates received by the wearer. The Standard adopts the operational quantities and the calibration phantom recommended by the International Organization for Standardization (ISO) in its new Standard ISO 4037-part 3 (5). Moreover, IEC 61526 states that some countries may establish the use of dosemeters that fulfil this Standard as the basis of a personal monitoring service approved for dose record-keeping purposes for radiation workers.

Since the scope and object of IEC 61526 was compatible with the aim of our study, a Protocol based on this Standard was established to verify EPD performance. This document (6) specified technical requirements for the dosemeters, classified into six parts: physical characteristics, radiological, mechanical and environmental performance, safety settings and reliability of associated readout system, if supplied. Table 1 summarises the proposed main technical requirements.

A survey was undertaken to overview the available EPDs, on the European market and to ask the manufacturers to participate in the present study, aimed at analysing their performance according to the above-mentioned Protocol requirements. 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 (7) and the electronic pocket dosimeters from the PDM series from Aloka, were not available for the experiment. The set of nine electronic personal dosemeters that, in the end, were reviewed are listed in Table 2.

MAIN TECHNICAL REQUIREMENTS FOR ELECTRONIC PERSONAL DOSE EQUIVALENT AND/OR PERSONAL DOSE EQUIVALENT RATE DOSEMETERS FOR X, GAMMA AND BETA RADIATION
PHYSICAL CHARACTERISTICS
Mass: Cannot exceed 200 g.
Maximum Dimensions (length x depth x width): 15x3x8 cm^3 excluding clip or other fixing arrangement.
Case design: The case should be smooth, rigid, shock resistant, dust and shower proof. External switches shall be protected from accidental or unauthorised operation. The display shall be clearly visible, even in the dark, and clearly indicate the quantity being measured.
Battery: Under standard test conditions, the capacity of primary batteries shall stand 100 h of continuous operation and the capacity of secondary batteries 24 h. After 24 h from the loss of the principal voltage supply, the integrated dose reading shall not change by more than ± 5 %.
RADIOLOGICAL PERFORMANCE
Range: Dose equivalent: 1 µSv to 1 Sv Dose equivalent rate: 1 µSv/h to 1 Sv/h
Relative intrinsic error: Dose equivalent: ±15% Dose equivalent rate: ±20% (±30% for the lowest decade or scale)
Energy response (normal incidence)**:** The dosemeter response shall be within ± 30 % ^{137}Cs response for photon radiation in the range 50 keV-1.5 MeV and within ± 50 % $^{90}Sr/^{90}Y$ response for beta radiation in the range 2 MeV< Emax < 3.5 MeV.
Angular response: The ratio of the dosemeter readings at an angle α relative to the reading at α= 0º, for angles from –60º to 60º, shall be within ± 20 % for ^{137}Cs, ± 50% for ^{241}Am and ± 30 % for $^{90}Sr/^{90}Y$.
Influence of dose equivalent rate: The response of the dosemeter shall be such that its dose equivalent relative intrinsic error remains within ± 20% for all dose equivalent rates up to 1 Sv/h.
Alarm accuracy: When the dosemeter is exposed for 10 min to a dose equivalent rate of 20 % less than the alarm set point, the alarm shall not be activated. When it is exposed to a dose equivalent rate 20 % greater than the alarm set point, the alarm shall actuate within 5 s.
Response time: When the dosemeter is subjected to an increase or decrease in dose equivalent rate, the readout shall indicate the new value, within ± 10 % in less than 5 s for an increase and less than 10s for a decrease.
MECHANICAL PERFORMANCE
Drop test: The dosemeter shall withstand drops from heights of 1.5 m onto a hard-tiled surface, without affecting its response to radiation, within ±10%.
Vibration test: The dosemeter response shall not vary more than ± 10% following harmonic loading of 2 g applied for 15 min in the frequency range 10 Hz – 33 Hz.
ENVIRONMENTAL PERFORMANCE
Temperature: The dosemeter response shall not vary more than ± 20% relative to 20 ºC in the range -10 ºC to 40 ºC and than ± 50% in the range -20 ºC to 50 ºC.
Relative humidity: The dosemeter response shall not vary more than ± 10% in the range 40% to 90% at 35 ºC.
External electromagnetic fields: The dosemeter response shall not vary more than ±10% in a constant waveform electromagnetic field strength of 100 V/m at frequencies between 100 kHz and 500 MHz and of 1 V/m at frequencies between 500 MHz and 1 GHz.
Electrostatic discharge: The dosemeter response shall not vary more than ± 10% when it is exposed to an electrostatic discharge across the case of 8 kV with energy of 2 mJ on earthed chassis .
SAFETY SETTINGS AND RELIABILITY OF READOUT SYSTEM
Safety indications: The dosemeter shall provide an indication when the remaining operation life of the batteries is at least 8 h, at dose rates of about 0.1 $mSvh^{-1}$, and when battery condition is no longer adequate. An overload indication must appear when the effective measurement range is exceeded. The dosemeter shall provide a self-check test to verify the detector and display operation.
Readout reliability: Transfer data from the detector to the readout system, and vice-versa, shall have an accuracy of 1 digit in the less significant decade.

Table 1: Main technical requirements for electronic personal dose equivalent and/or personal dose equivalent rate dosemeters for X, gamma and beta radiation

Electronic personal dosemeter Manufacturer and type	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 2: Electronic personal dosemeters that have been evaluated in the study

The following features have been evaluated and compared with the established requirements:
- Physical characteristics (size, weight, case design, switches, data accessibility, batteries).
- Radiological performance (measured quantity and type of radiation, range of measurement, accuracy, alarm output, energy response, angular response, response time, dose rate response dependence).
- Mechanical performance (drop and vibration test).
- Influence of several environmental parameters (temperature, relative humidity and external electromagnetic fields, magnetic fields and electrostatic discharges).
- Safety settings (self check, warning indications).
- Reliability of associated readout system (data transfer).

Radiological experiments were performed at the INTE secondary calibration Laboratory, which has a gamma irradiation unit, a dosimetry X-ray 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). The influence of electromagnetic and magnetic fields and of electrostatic discharges was tested at the Regional Calibration Laboratory of Catalonia (Spain) which is equipped with an anecoic chamber and several antenna and field generators. Unfortunately, due to technical limitations, electromagnetic field influence during gamma irradiation could not be tested.

RESULTS

Although none of the nine selected EPDs completely complied with the established requirements, most dosemeters performed within the proposed criteria for the majority of the tested parameters. Table 3 highlights the tests where most problems were identified, and details how many of the verified dosemeters did not perform in accordance with the prescribed requirements.

Test		Number of EPDs that passed the test	Number of EPDs that failed the test (summary of the problem)
Physical characteristics	Display clearly visible in the dark	2	7
	Information storage after 24 h without batteries	3	3 failed 3 partial loss
Radiological Performance	Measured quantity	2 $H_p(10)$ and $H_p(0.07)$	7 (do not measure $H_p(0.07)$
	Photon energy response (± 30 %) 20 keV<E< 1.5 MeV	2	3 Failed (more than ± 30 % for 60 keV<E<1.5 MeV) 4 (Within ± 30 %, for 60 keV<E<1.5 MeV)
	Dose equivalent rate alarm	5	4 (frequent alarm indications for dose equivalent values 20 % lower than the pre-set level)
Mechanical Performance	Drop from 1.5 m hard-tiled surface	6	2 (inoperative)
Environmental Performance	Electrostatic discharge	4	4 (spurious signals)
	External electromagnetic field of 100 V/m	6	1 inoperative 1 (spurious signals)
Safety settings	Overload signal for dose equivalent	2 5 (dose>10 Sv)	2
	Overload signal for dose equivalent rate	5	2 failed 2 failed when $H_p(10)$

Table 3: Tests where most problems were identified during the survey

The main results obtained are summarised in the following paragraph. The environmental and mechanical tests were not applied to the dosemeter Rados type Rad-101S, since this device was lended by its private owner. In five dosemeters the overload signal for dose equivalent could not be checked because the upper range was greater than 10 Sv, which would require a too long irradiation time in our facility.

Physical characteristics

All dosemeters had a size, mass and case construction in accordance to the required specifications. However, the display of six devices was not clearly visible in bad light.

As regards information storage, in the event of power loss, it was seen that after 24 h without supply, three EPDs completely lost the stored information, three others lost part of the stored dose information (the last 15 minutes or 24 hours, depending on the device) and the other three retained all the stored data.

Radiological performance

Measured quantities

All the analysed dosemeters provided a dose indication in units of μSv or μSv/h, however only six of them were calibrated in units of personal dose equivalent, $H_p(10)$, whereas the other three were calibrated in units of dose equivalent, H, following the convention 10 μSv = 1 mR. Only two devices could also measure $H_p(0.07)$.

Accuracy

Under standard test conditions, all dosemeters showed accuracy in dose measurement for ^{137}Cs within ± 15 %, and within ± 20 % (30 % in the last decade) in dose rate measurement.

Dose equivalent rate and dose equivalent ranges

All the detectors had dose equivalent measurement ranges greater than the recommended values (1 μSv – 1 Sv). However in some models (4/9), the low limit range for dose equivalent rate was not ensured, where the lowest available value was 5 μSv/h or 10 μSv/h, instead of 1 μSv/h. The upper limit for dose equivalent rate was provided by all the devices.

Variation of response with radiation energy

The two dosemeters that could measure $H_p(0.07)$ were the only two that accurately measured incident beta radiation and photon radiation within the range 20 keV – 1.5 MeV.

Four other dosemeters had a response within ± 30 % ^{137}Cs response for incident photon radiation of energy between 60 keV and 1.5 MeV. This performance agreed with the manufacturer's specification, since the dosemeters were meant to measure only penetrating photon radiation. However, the last three detectors showed a bad energy response, even in this restricted energy range, in spite of the manufacturer's specification.

Variation of response with angle of incident radiation

All dosemeters presented an appropriate angular response in a horizontal and a vertical plane of rotation, for ^{137}Cs energy, but in two dosemeters some problems were found when the test was performed with 65 keV filtered X-radiation.

Response time and influence of dose rate in dose measurement

All dosemeters presented satisfactory results to the response time test and the influence of dose rate in dose measurement tests.

Alarm signals

Several irregularities were found when performing the alarm tests. In four detectors, the dose equivalent rate alarm was activated for values 20 % lower than the alarm set point.

Mechanical performance

Drop test

Two dosemeters did not withstand drops from heights of 1.5 m onto a hard-tiled surface. The dosemeter case was damaged and in one of the dosemeters the stored information could not be recovered.

Vibration test

The physical conditions and measurement performance of all the nine dosemeters were not influenced after having been exposed to a set of harmonic loadings of 2 g applied for 15 min at a frequency of 30 Hz. The test was repeated on each orthogonal direction of the detectors.

Environment influence

Ambient temperature and relative humidity

The response of the nine dosemeters irradiated at 40 ºC was the same as when they were irradiated at 21 ºC. Their response after having been exposed to a relative humidity of 80 % at 35 ºC did not vary either.

External electromagnetic fields

One of the dosemeters presented spurious signals, not significative from a radiation protection point of view, particularly when the electromagnetic field changed its frequency. Another dosemeter became inoperative after having been exposed to an electromagnetic field of 100 V/m in a frequency range of 100 kHz to 500 MHz. The rest of the detectors were not affected by the external disturbance.

Electrostatic discharge

Four dosemeters gave spurious signals while they were exposed to electrostatic discharges of 8 kV with energy of 2 mJ across the case. After the test, the dosemeters worked correctly.

External magnetic fields

The presence of an external magnetic field with strength of 60 A/m at 50 Hz, did not produce any irregular reading in the tested dosemeters, nor did it influence its subsequent response.

Safety settings and reliability of associated readout system

Overload signal

Two dosemeters did not show an "overload" signal when the effective dose equivalent or dose equivalent rate ranges were overridden. Two other detectors did not show a dose equivalent rate overload signal, when the unit display was measuring dose equivalent. Both problems resulted in false dose estimates.

Data transfer

All the dosemeter that were supplied with an associated readout system (7/9) fulfilled the established data transfer requirements.

CONCLUSION

The present study gives a general overview of the state-of-the-art in electronic personal dosimeters, and has proven that some of the nine tested dosemeters almost satisfy all the established requirements for a reliable personal dosemeter system.

One of the limitations that were shown in the study was that, in general, the EPDs had a poor energy response for beta and low-energy photon radiation, and that very few of them were able to measure shallow dose, $H_p(0.07)$. At present, several manufacturers have already designed new systems with two or three diodes to widen the dosemeter sensitivity, thus solving this drawback. Another feature that was verified in this project is that most of the tested detectors ensured immunity to external electromagnetic fields and ambient conditions. This behaviour improves the results found in previous older systems. However, it must be born in mind that, in practice, in some particular places, one can find radio-frequency fields stronger than those tested and that, therefore, additional verifications would be needed in such situations. In general, the radiological performance from most of the dosemeters was proven to be satisfactory and comparable to that of the passive detectors.

Such results together with the advantages inherent from this type of dosimetry, namely, direct reading, alarm setting facilities for dose equivalent and dose equivalent rate, makes the introduction of such systems possible for dose-keeping record dosimetry. However, since some models presented relevant limitations such as false alarm signals, false readings due to overload conditions and loss of information because of battery failure or mechanical damage, the competent authorities should require specific tests before approving any particular dosemeter. Moreover, since it is very difficult to establish long-term reliability or failure rate of measurements in a type-test, it would be advisable to recommend, at least at some sites, redundant dosimetry records for an experimental period of time prior to official approval.

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