A Novel Concept and Technique for Individual Monitoring for Photon, Beta and Neutron Radiation

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Abstract
Advanced dosemeter designs and modern IT technology offer new solutions for individual monitoring. For photon radiation, the most important component of external exposure of radiation workers, several types of high quality dosemeters are in use. In recent years special electronic dosemeter systems improved significantly and today, some of them fulfil the dosimetric requirements of international standards, and even those of national regulations. The development of electronic dosemeters for neutron radiation was quite remarkable in the last few years, but legal electronic neutron dosemeters have not yet emerged. Limitations of such instruments include unsatisfactory neutron energy response and photon/neutron discrimination, small dynamic range, large size and weight, as well as high cost.

Taking into account the increased demands for fast and site specific availability of dosimetric data and the options of modern technology, a novel system for individual monitoring for photon, beta and neutron radiation has been developed and made operational for use at the accelerator centres of PSI and CERN.

1. Introduction

The classical procedure of individual monitoring for external exposure is based on passive dosemeters issued and, after exposure, processed by a central laboratory to determine legal dose. A crucial aspect is the optimal duration of the exposure period. From an organisational, financial and sometimes also technical view it would be advantageous to have long exposure periods, e.g. up to one year. On the other hand, managerial aspects of an efficient radiation protection programme favour very short exposure periods. Only then, unusual exposures would be noticed on time and countermeasures could be taken quickly, dose allocated to specific types of work (job dosimetry) could be registered, and formal registration procedures for workers leaving the organisation could be completed efficiently, just to mention some arguments. Today it is often necessary to wear two types of detectors, a passive legal dosemeter and an active, electronic operational system to fulfil all requirements. In nuclear industries this cumbersome procedure is widely used, and such requests come up in other fields also.

It can be assumed that the actual situation is a consequence of the lack of adequate instrumentation covering the needs of operational radiation protection and not the result of a dedicated development. Therefore, evaluation of the fundamental needs is necessary before a new dosimetry system is developed and installed.

2. Discussion of the operational needs for individual monitoring

Individual monitoring is just one aspect of operational radiation protection. In an efficient radiation protection programme workplace monitoring is a key issue. The radiation fields should be well known before workers spend extended times in a given area. Dose rate measurements or indications are elements of workplace monitoring and should not be confused with personal dosimetry. A personal dosemeter has to be personally allocated to and properly worn by the worker for all the time he spends in a radiation area and this unit should never be used to indicate radiation levels, to search for sources, or for other duties of workplace monitoring. In cases where extremely inhomogeneous radiation fields occur or accidental exposures are feared dose rate warning units may be needed and in fact be very efficient to keep exposures low. Such units need to be available for all workers in a critical area, but do not need to be personal. They may be seen as allocated to specific areas or types of work but not to persons. The design of many types of so called “electronic dosemeters” is driven by almost unlimited options of modern technology ending up with highly sophisticated instruments not adjusted to the real
needs of the user, and mixing up functions of individual and workplace monitoring. In the following, only aspects of individual monitoring will be discussed.

Individual and collective dose of workers are generally dominated by external photon radiation. The quality of various dosimetric techniques to determine the operational quantities $H_p(10)$ and $H_p(0.07)$ for photon radiation has significantly improved over the last few years. Today, the operational requirements can first be formulated and the techniques and procedures to be used can then be selected accordingly. This advantageous situation did not yet exist when most of the actually used dosimetry systems were installed years ago, and even today it exists only partly for beta radiation and not yet at all for neutron radiation. To begin with, the needs for photon and partly beta dosimetry are discussed. The situation of neutron dosimetry will be handled separately.

In operational radiation protection the immediate availability of photon and eventually beta dose information is of increasing importance. Especially job dosimetry has become a useful tool for radiation protection programmes and this type of dose information is often requested by legal authorities. Quick availability of dosimetric results is also advantageous for a continuous follow up of ongoing activities and special investigations in case of unexpected high dose readings. The technological approach with direct dose display on the dosemeter unit may be convenient for the worker, but more relevant is the option for frequent readout and centralised registration of the accumulated dose. Only the registered dose values can be used for analysis and evaluation. Therefore, an ideal dosimetry system should allow for easy, frequent and local readout with automatic central registration of dosemeter identification, dose, location and time.

Neutron radiation occurs in very limited situations only. Most prominent are specific workplaces in the nuclear industry and nuclear research, experimental areas at high energy accelerators, and applications of various neutron sources in industry and research. Exposure of air crew to cosmic radiation is excluded here, since their personal dosimetry is generally based on calculation methods by standard computer codes and not by individual measurement. The techniques available for personal neutron dosimetry are still unsatisfactory for various reasons: The energy dependence of the response is very pronounced over a wide energy range, the sensitivity is, with the exception of thermal neutrons, not as high as wished, and costs for detectors and their processing are rather high. These conditions require specific techniques and methods for given applications. Here, the situation at high energy accelerators, especially at PSI and CERN, are studied in detail. It is known from workplace monitoring, that neutron radiation fields with energies up to several hundred MeV exist in areas accessible for research workers and operational staff. On the other hand, dose statistics over the last decade show almost no significant personal neutron dose. In addition, from basic physics it can also be concluded that a high neutron dose would always be accompanied by a significant photon dose. Taking all conditions and available information together, the requirements for a neutron dosimetry system at high energy accelerators could be as follows: Monitoring for neutron radiation should be done for all workers entering the accelerator areas, since neutron irradiation can not be excluded completely. Since neutron dose is expected to be low and also to keep cost low, the exposure period for neutron dosemeters could be extended up to one year. If combined with a personal photon dosemeter read out frequently, an immediate exchange and processing of the neutron dosemeter could be initiated if an increased photon dose is registered, to minimise the risk of detection of a high neutron dose only long time after exposure.

The operational needs refer strongly to data handling also. Access to all relevant data should be easily available for all persons involved in a radiation protection programme and be adjusted to the duties and responsibilities of different groups, such as dosimetry service staff, radiation protection officers, management, and workers themselves. This requires a network solution and a modern database structure.

3. The new monitoring concept

The following individual monitoring system has been proposed for use at high energy accelerator centres, such as PSI and CERN:
- Every worker who possibly enters a radiation zone is equipped with a combined passive personnel dosemeter for the measurement of $H_p(10)$ and $H_p(0.07)$ for photon and beta radiation, as well as of $H_n(10)$ for neutron radiation.
- A number of local readout stations (e.g. ~ 40 for CERN) for the photon/beta dosemeters are distributed over the site. These stations display the accumulated dose locally and via LAN all readouts are registered automatically in a central database of the dosimetry service.
- The workers are asked to read their dosemeters periodically, e.g. at the end of each month at any station nearby. In addition, the workers are free to read their dosemeters as often as they like to do so.
- For job dosimetry a specific group of workers may be asked to read their dosemeters each time they enter or leave a given area.
- The dosemeters stay with the worker for up to one year. Every month about 10% of all dosemeters are exchanged. If the photon dose exceeds 2 mSv per month, the dosemeter is immediately exchanged.
- On return of the dosemeter to the dosimetry service, the neutron detectors are removed and processed for readout. The photon/beta dosemeters are quality controlled, the dose cleared, the badge loaded with a new neutron detector and made available for new issuing.
- Neutron dose is booked in the year of readout of the neutron dosemeter if not exceptional conditions indicate otherwise.

4. The new dosimetry system

The dosimetry system chosen to fulfil the needs identified for PSI and CERN consists of a passive electronic dosemeter for photon and beta dosimetry and a separate passive system for neutron dosimetry. The dosemeter badge is built of a Direct Ion Storage (DIS-1) detector for photon and beta radiation [1, 2, 3] and a CR-39 track etch detector for neutron radiation [4]. These detectors are mounted in one badge as shown in figure 1. The overall size without clip is 78 x 49 x 14 mm and the weight is about 60 grams.

4.1 Design of the DIS-1 dosemeter

The DIS-1 dosemeter is based on ionisation chambers with so-called Direct Ion Storage (DIS) [1]. Figure 2 illustrates the design of the DIS-1 dosemeter. The detector is the uncovered area on the surface of a floating gate of a MOSFET transistor, surrounded by an air space - the "ionisation chamber". The chamber walls are made of tissue equivalent plastic. The charge of the floating gate is set to a predetermined value and changes upon ionising radiation incidence. The read-out is performed by a digital voltage measurement, subsequently converted into $H_p(10)$ and $H_p(0.07)$ values and displayed on a dedicated DBR-1 reader. The dosemeter can measure personal dose equivalents from a few µSv up to about 30 Sv. To cover this wide dose range different ionisation chambers and two MOSFET transistors are used and described in table 1.

![FIG. 2: Design and principle of the DIS-1 dosemeter](image-url)
The photon energy dependence of dose readings $H_p(10)$ and $H_p(0.07)$ in the dose range above 1 Sv has to be taken into account. This is due to the fact that the elements for the highest dose readings (elements DH and SH) are MOSFET transistors only. An algorithm derived from the ratio of the readings of DH and SH can correct for $H_p(10)$ and $H_p(0.07)$. Those elements are used for dose measurements far above the legal dose limits and, therefore, are needed in radiological emergency situations only.

Table 1: Dose range, unit displayed on DBR-1 reader and identification of the different ion chambers or MOSFET transistors of the DIS-1 dosemeter.

<table>
<thead>
<tr>
<th>Dose range</th>
<th>Unit on DBR-1 display</th>
<th>Personal deep dose equivalent $H_p(10)$</th>
<th>Personal shallow dose equivalent $H_p(0.07)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 µSv - ~ 4000 µSv</td>
<td>µSv</td>
<td>DS (deep small dose)</td>
<td>-</td>
</tr>
<tr>
<td>~ 0.5 mSv - ~ 1000 mSv</td>
<td>mSv</td>
<td>DL (deep large dose)</td>
<td>SL (shallow large dose)</td>
</tr>
<tr>
<td>~ 0.5 Sv - ~ 30 Sv</td>
<td>Sv</td>
<td>DH (deep high dose)</td>
<td>SH (shallow high dose)</td>
</tr>
</tbody>
</table>

Two options are available to reset the dose: The “soft reset” option resets the displayed values to zero by calculating a dose offset. The charge on the “floating gate” is not affected and the information on the accumulated dose since the last “hard reset” is still accessible. The “hard reset” option resets the charge of the “floating gate” to a predetermined value. By this all information on previous exposures is lost. A comprehensive description of the system and its characteristics can be found in references [2 and 3].

4.2 The DBR-1 reader for the DIS-1 dosemeter

The DBR-1 reader (figure 3) is a wall or bench mounted unit for readout of the DIS-1 dosemeter. It displays $H_p(10)$ and $H_p(0.07)$ and transfers data via either standard RS-232 or optional LAN connection. With this unit the dose of the DIS-1 can be reset using appropriate codes. The overall size of the DBR-1 is 260 x 265 x 230 mm and the weight is 8.5 kg.

DBR-1 readers are located at the dosimetry service as well as, in a larger number, throughout the site. The distributed remote DBR-1 readers are freely accessible and configured in such a way that no dose reset is possible. Solely the readers located at the dosimetry service can be used to reset the dosemeters. The readout of a DIS-1 dosemeter takes few seconds.

4.3 The network for the DIS system

The concept of data acquisition and capture is shown in figure 4. If needed, the continuously registered reader data can be made available to the radiation protection officer for additional dose reporting related to specific tasks (e.g. job dosimetry).

FIG. 3. DBR-1 reader for DIS-1 dosemeters

FIG. 4. Schematic of the dosimetry network

The detectors used for neutron dosimetry are made of CR-39, type PN3. These detectors are 1.5 mm thick and $20 \times 25$ mm in size (figure 5).

![FIG. 5. CR-39 track etch detectors](image)

A two-step etching process is used to chemically etch the PN3 detectors. In a first step, the ‘pre-etch’, the detectors are etched for 60 minutes in a mixture of 60% methanol and 40% 6.25 M sodium hydroxide at 70°C to polish the surface and to remove alpha particle tracks and scratches. On each side of the CR-39 detector, material to a depth of 15 $\mu$m is removed during the pre-etch. Afterwards the detectors are etched for six hours at 70°C in 6.25 M sodium hydroxide. Finally the detectors are neutralized in a weak hydrochloric acid solution and washed with hot and cold distilled water.

4.5 The Autoscan 60 reading system for CR-39 detectors

The CR-39 detectors are read by the Autoscan 60 (figure 6). The detectors can be read in the same carousel used for etching. One carousel can hold up to sixty detectors which can be read within 30 minutes. For the readout, the detectors are elevated automatically into the path of strong light channelled into one edge of the detector. The light is internally reflected from the faces of the detector except at defects or tracks where it is refracted. When the detector is viewed from a position in front of its surface, the tracks are appearing as bright spots of light. The light is so intense that the camera-monitor system registers images much larger than the true pit size. Therefore the pit images can easily be counted by a simple image analysis system. For fast neutrons a dose range from $\sim 0.3$ mSv up to $\sim 100$ mSv can be covered by this readout process. In case of need, higher doses can be read by transmission spectrometric methods.

![FIG. 6. Autoscan 60 reader for CR-39 detectors](image)

5. Conclusion and outlook

A new dosimetry system has been developed and is being introduced at CERN and PSI in near future. The basic dosimetric characteristics of the single elements of the system have been described elsewhere [1 - 5]. All these elements have been further improved and the actual technical data will be published as soon as possible. Parts of the IT tools have been newly developed and adjusted the specific application. A challenge will be the direct involvement of the workers in the dosemeter readout process. Reporting on the experience with this new approach in individual monitoring will be indispensable.

References


