On the scenario of passive dosimeters in personnel monitoring: Relevance to diagnostic radiology and fluoroscopy-based interventional cardiology

World Scenario of Personnel Monitoring Passive Dosimeters

In the recent times, with the ongoing revisions of radiation protection requirements and the developments of newer devices, the scenario of personnel monitoring service (PMS) is changing fast. Personnel monitoring (also called personal monitoring or individual monitoring or personal dosimetry) is intended to provide information on radiation exposure of occupational workers during normal and accident situations and to assist in planning and control of workplaces. For this, a badge containing suitable passive dosimeter/s (held under appropriate filters in a cassette) is worn by individuals on their body during the course of work in radiation fields. PMS is obligatory for the users of radiation sources and radiation generating equipment to ensure the compliance of the radiation protection rules. To begin with, routine PMS appears to have started with the use of film badge during the late 1940s and early1950s,[1] which became a standard practice during 1950s (in India, it started in 1952) and remained so until the advent of thermoluminescence dosimeters (TLDs) and the availability of the commercial TLD systems in the late 1960s. TLD provided a tool for overcoming the problems associated with the use of films (mainly, the loss of dose information during use and storage for long durations in hot and humid climates, and also to some extent the limitations of the dose range, the dark room processing, and the variations in film sensitivity affecting the accuracy). This resulted in the beginning of the process of replacing film badge by TLD badge, which peaked between the late 1970s and 1990s[2] and the process continues even to date. The continuation of the use of film badge by some users may be attributed to the inertia in introducing a change (or may be by the economic aspect of the change in some cases) by those facing no serious problem in countries with cold climates. In the late 1990s, the findings of intense optically stimulated luminescence (OSL) in irradiated Al_2O_3:C TLD[3-5] brought another turning point in the large scale use of passive personal dosimeters. Recognizing the potential of OSL of Al_2O_3:C, Landauer Inc., USA (www.landauerinc.com), one of the leading radiation dosimetry service providers, adopted Al_2O_3:C as a dosimeter of choice, designed personal monitoring badges and developed compatible reader systems.[4,5] In the last 10 years, Al_2O_3:C-based OSL dosimeters have attracted the large attention of the professionals and radiation protection community all over the world. The other OSL material which has made some impact is BeO (better in tissue equivalence and cost-effectiveness than Al_2O_3:C) which has been recently adopted for personnel monitoring by some institutions in Germany and Belgium. It may be noted that in many countries, different types of accredited systems based on different dosimeters and several accredited service providers are available, and the user institutions have option to choose any of them. The recent growth of OSL systems may be assigned mainly to the superiority of OSL in terms of its capability of repeated readout without losing the dose information, fast readout (about 280 badges/h can be readout in Landauer's system), and the simplicity of operation due to all-optical process (no limitations of heating and thickness of dosimeter). It is estimated that by now, OSL dosimeters are in use for monitoring of more than one-third of the radiation workers (~1.7 million[6] users of OSL system out of estimated more than 5 million users of personal dosimetry badges[7]) the world over. Although the impact is evident in all the countries, its prevalence is more conspicuous in the USA, UK, France, China, Japan, Sweden, Ireland, Chile, Peru, Germany, and Belgium.[6] In fact, Landauer (accredited in the USA by National Voluntary Accreditation Program and Department of Energy Voluntary Accreditation Program) not only provides OSL dosimeters, dosimeter badges, and reader systems but also appears to prefer offering turn-key service of the entire service from handling of dosimeter preparation, centralized readout of dosimeters, and overexposure notification, to maintaining dose records, and providing online access to the institutions. The same appears to have become the case with some other service providers also. In the actual practice,[6] the feature of repeated OSL readouts without affecting the subsequent main readout after the prescribed monitoring period for the official dose records has enabled to make additional onsite intermittent measurement of doses accumulated during shorter durations in suspected incidences. This provides an instant dose information of the workplace and a comparison with the doses measured by other active or passive dosimeters such as pocket/electronic dosimeters.[6]

In spite of some of the attractive features of OSL, TLD continues to lead the scenario by covering more than 50% of the radiation workers the world over. This may be attributed not only to its seniority in the age of adoption but also to its features of ruggedness, insensitivity to light (unlike apprehension of light-induced fading in OSL due to light leakage, if any),[8] and unique property of exhibiting a well-defined glow peak as a clear signature of exposure to radiation for a presentable record and evidence. Although the near tissue equivalent LiF: Mg, Ti (TLD-100, TLD-600 or TLD-700) TLD continues to be used widely, of late, major shift has been to use the high sensitivity LiF: Mg, Cu, P (TLD-100H, TLD-600H or TLD-700H) TLD, which has been adopted by several organizations such as the UK Health Protection Agency/Public Health England, the US Navy, and the national personnel monitoring in Brazil. LiF: Mg, Cu, Si is another high sensitivity and near tissue equivalent TLD developed recently[9] which is also getting attention. After phasing out of the Teledyne system (based on $CaSO_4$:Dy Teflon TLD tape), India appears to be the only country still using a system based on $CaSO_4$:Dy Teflon TLD discs for the countrywide personnel monitoring. Panasonic system, which is also still prevalent in some countries, though uses $CaSO_4$:Tm, has additional dosimeter elements based on near tissue equivalent $Li_2B_4O_7$:Cu TLD. Radiophoto luminescence (RPL) dosimeter,[7] which has the feature of repeated readout (and equally sensitive and fast in readout as OSL dosimeters) is not as popular as TLD or OSL though it is used in some countries, for example, Japan, Germany, France, Taiwan, etc. The main reasons could be the need of time gap between exposure and readout (necessary for attaining equilibrium in response) and the intricacies of annealing. The other historical apprehensions associated with RPL using old readout technology, namely problem of large zero dose and surface effects, are no more valid. For the future, it is evident that both the TLD and the OSL systems are going to stay and dominate the scenario.

Placement of Badge under and over Lead Apron in Diagnostic Radiology and Fluoroscopy-based Interventional Cardiology

Personnel monitoring dosimeter badges are designed to measure the operational quantities, namely “personal dose equivalents;” $H_p(10)$ [dose equivalent in soft tissue (commonly interpreted as International Commission on Radiation Units and Measurements 'ICRU' sphere) at 10 mm depth] and $H_p(0.07)$ (dose equivalent in the soft tissue at 0.07 mm depth. $H_p(10)$ is to assess the effective dose and $H_p(0.07)$ to assess the equivalent dose to the skin (and also to hand and feet for occupational workers) for ensuring the compliances with the dose limits. There are also annual equivalent dose limits for the eye lens. The related measurable operational quantity for the lens of the eye is personal dose equivalent $H_p(3)$ (dose equivalent in the ICRU soft tissue at 3 mm depth). In general, the emphasis has always been on the measurement of $H_p(10)$, which is used for maintaining lifetime dose records of effective doses of occupational workers. In diagnostic/interventional radiology, unlike nuclear fields, etc., where apart from gamma rays, beta rays and neutrons are also of significant concern, the radiation of main concern is X-rays of varying energies.

Prior to the statement of the International Commission on Radiological Protection (ICRP) in the year 2011 and the subsequent report,[10] it was accepted that the measurements of $H_p(10)$ and $H_p(0.07)$ using passive dosimeters for the compliance of the respective dose limits was generally sufficient for ensuring the eye dose to remain within the limits and a separate dosimeter was not considered necessary for the assessment of dose to eye lens.[10] In fact, in the ICRP recommendations of 2007,[10] $H_p(0.07)$ was recommended to be used for assessing $H_p(3)$ also. Obviously, the emphasis was on the use of the dosimeter badge to be worn outside the lead apron. For the fluoroscopy based radiology and interventional cardiology, ICRP[11,12] recommended the use of two badges (double-dosimetry method), one to be worn on the trunk under the lead apron and the other at the collar/shoulder over the lead apron. In the case of a single dosimeter badge, it was recommended that the badge should be worn outside the lead apron at the collar/shoulder. For the double-dosimetry method, the algorithm for the assessment of effective dose gives weightage to the readouts of both the badges worn under the apron and outside the apron, whereas for the case of use of a single badge outside the lead apron at collar/shoulder, suitable generalized correction factors are recommended.[12,13] These recommendations appear to have become mandatory in many countries as against the use of a single personal dosimeter worn under the protective lead apron on the trunk of persons. From the recent surveys,[14,15] it has been concluded that the dosimeters worn under the lead apron in interventional cardiology and interventional radiology practices, rarely encounter a measurable signal for the estimation of dose equivalent (mostly nil). The same should be valid for the entire diagnostic radiology. The concern for the use of badge to be worn outside the lead apron is therefore needed to be raised for the cases where a single badge is used and worn under lead apron on the trunk which serves little purpose in diagnostic radiology.

Recent Concern for the Eye Lens Protection and Dosimetry

One of the most exciting developments of the recent times in the field of radiation protection is the change in the ICRP dose limits for eye lens. Based on the recent review of epidemiological studies of long-term follow-ups of larger (than ever before) number of cases of cataract formation (mainly the long-term studies on the atomic bomb survivors with acute exposures and the workers of Chernobyl clean-up operation with fractionated protracted exposures including those at doses lower than in previous studies), ICRP[10] revised the dose threshold for cataract induction down to 0.5 Gy from the earlier values of 2 Gy for single acute exposure and 5 Gy for protracted exposure, and reduced the dose limit for the occupational workers from 150 mSv/y to 20 mSv in a single year (averages over 5 years with a limit of 50 mSv in any single year), keeping the limit for public (15 mSv/y) unchanged. This resulted in wide discussions[16] among the stakeholders all over the world. In the meantime, International Atomic Energy Agency (IAEA) has incorporated the revised ICRP limits in the new Basic Safety Standards[17] and thus putting onus on its member states. It is recognized that for those working in highly nonuniform and localized radiation fields in which the eye may be preferentially exposed, if their eyes are unprotected, dose to the lens of the eye would exceed the proposed annual limit of 20 mSv. It became evident[16,18] that the largest group of such workers is the staff of fluoroscopy-based interventional radiology and interventional cardiology. This realization resulted in still wider discussions on the associated aspects of the new limits, such as concern on the radiation-sensitive part of the eye lens (the equator of the lens at the front versus whole lens for averaging the dose), review of existing practices of the use of protective equipment (lead glass spectacles, ceiling suspended shields, etc.), need of appropriate dosimeters, conversion coefficients and phantoms for calibration, procedures for type testing of dosimeters, and maintaining eye-dose records.[16] So far, from an ergonomic viewpoint, neither the newly developed "Eye-D™" dosimeter for the eye dose measurement nor the existing dosimeters have been found completely satisfactory.[19] Incidentally, from one of the recent large-scale surveys in the UK, it has been concluded that the compliance with the new ICRP limits is possible provided that the available radiation protection means are properly used.[20] For the implications of the new ICRP dose limits, some guidelines have started emerging[17] and lot more could be foreseen. IAEA Tecdoc No. 1731[18] states "if information on the workplace radiation fields is available, dosimeters type tested and calibrated in terms of $H_p(0.07)$ or $H_p(10)$ can be used to estimate a conservative value for $H_p(3)$." For the present, the following may be concluded: (1) The acceptance of protective measures in the radiation protection culture is the most important aspect for the reduction of dose to eye lens, and therefore, an emphasis has to be laid on the appropriate training and education in the field of fluoroscopy-based radiology and interventional cardiology, (2) assessment of doses to eye lens of workers in certain practices is important and until the appropriate dosimetry systems (dosimeters, phantoms, calibration procedure, etc.) become available, the measurement of $H_p(0.07)$ and $H_p(10)$ by using the double-dosimetry method or a single dosimeter at collar outside the lead apron should be continued, or adopted in cases where no dosimeter out side the lead apron is used. Evidently, with the recent concern on the eye lens protection, in diagnostic radiology and fluoroscopy-based interventional cardiology practices, the emphasis has to be on the use of personal dosimeter badge to be worn outside the lead apron (unprotected) at collar/head (as it provides a reasonable estimate of the eye lens dose)[21] for a more meaningful personal monitoring.

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Access this article online	
Quick Response Code:	**Website:** www.jmp.org.in
	DOI: 10.4103/0971-6203.181634

How to cite this article: Pradhan AS, Lee JI, Kim JL. On the scenario of passive dosimeters in personnel monitoring: Relevance to diagnostic radiology and fluoroscopy-based interventional cardiology. J Med Phys 2016;41:81-4.