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IMAGES THAT SPEAK ABOUT ERRORS IN PERSONAL DOSIMETER HANDLING AND PARTICULAR SOLUTIONS

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Abstract. This work presents the errors induced by the wrong handling of personal dosimeter and their effect on the halide film image quality and radiation dose measurement accuracy. Errors such us the use of damaged dosimeter film or old films with high background optical density; deliberate exposure to radiation; dosimeters left carelessly near radiation sources and the increase of the background optical density during the chemical developing process are highlight in this work. The measurement accuracy improvements by optical density corrections on a large range of doses (0.1 ÷ 1000) mSv are here presented. For a conventional true value of 1.0 mSv dose, the calculated erroneous dose is 1.28 mSv ± 6.7% and decreases at 1.06 mSv ± 10% after correction. Particular methods, strategies for resolving cases of personal dosimeter wrong handling introduced by the monitored personnel are fully presented. The errors are highlighted by 2D images recorded with dosimetric halide film used in occupational radiation exposure monitoring.

Key words: radiation dosimetry, dose imaging, handling errors, occupational exposure monitoring.

1. INTRODUCTION

The personal radiological monitoring is performed with different individual dosimeters, such as halide film dosimeter, thermoluminescence dosimeter, optically stimulated luminescence dosimeter and electronic dosimeter that are used depending of their performances and the costumer option.

The radiological monitoring ensures the radiological tracking of each person or the group of persons occupationally exposed and gives information on the radiation doses recorded in some areas of nuclear activity. Generally, the achieved data are used in studies of improvement of the occupational exposed workers, population and environmental radiation protection safety. The individual dosimetry utilized efficiently involves a number of technical and organizational factors that have to be evaluated and is applied properly in order to mitigate the introduction of errors in radiation dose assessment.

The workers exposed to radiation are trained on the radiation sources and also, on the proper use of personal dosimeters [1–4]. Nevertheless, the radiological monitoring services report many errors introduced by the monitored personnel due to the wrong handling conditions of dosimeters, such as damaging by water or light contact, radioactive contamination, film exposure without dosimetric badge and / or no filters in dosimetric badge, dosimetric film is not properly inserted into the badge, the personal dosimeter is returned to the dosimetry service [5].

The errors are made either by the occupationally exposed workers or by the technical personnel from dosimetry services. In certain circumstances, the wrong handling of the dosimeters involves the radiation protection investigations to establish the causes of the errors and it is necessary to apply special technical procedures in order to assess the personal doses as close as possibly to reality.

Out of all the types of personal dosimeters, the descriptive and complete information on the dosimeter handling are provided by the film dosimeter that has the ability to show in 2D images the radiation and working condition influence on the photographic emulsion. Since 1960, the Photodosimetric Unit – USF from "Horia Hulubei" National Institute for R&D in Physics and Nuclear Engineering, IFIN-HH, has been performing the monitoring of the personnel exposed to ionizing radiation by work tasks and holds many records that highlight by images the wrong handling conditions of the dosimeters.

Although some dosimeter handling errors have a low frequency, they can have serious consequences on the person or group of persons in question. So, without making a statistic on the frequency of incidence of the dosimeter handling errors, this work presents the most common errors due to the wrong handling of the personal dosimeters recorded by the USF along the time, and some solutions for addressing the induced shortcomings. The work highlights the following errors: i) damaged dosimeter film by tearing or puncturing of the protective covering; ii) metallic filters failure or removed from the dosimetric badge; iii) film entered incorrectly in the dosimetric badge; iv) deliberate exposure to radiation; v) dosimeters left carelessly near radiation sources; vi) use of old films in personal monitoring with veil density (background optical density) higher than those from batch of films in use; vii) increase of the background optical density during the chemical developing process. The main methods of correction applicable in special circumstances and suggested by this paper are: the subtraction of the optical density growing and the reporting of the optical density difference recorded on the film under badge filters to the dose.

2. MATERIALS AND METHODS

The Personal and Environmental Dosimetry Laboratory (LDPM) from “Horia Hulubei” National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH) performs the occupational expose monitoring by the halide film and thermoluminescence dosimetric methods, according to radiation protection norms in force and under quality management, that involve conditions of laboratory organizing, recording and reporting of dose measurements [3, 6]. The halide film dosimeter used by USF consists of “personal monitoring” Agfa film and FD-III-B badge made by Nuclear and Vacuum, Romania. The halide film has two different sensitivity photographic films sealed in a protective folder; the dosimetric box contains five metal filters of different materials and thicknesses: Al, Cu, Pb, an acrylonitrile- butadiene- styrene plastic filter and a window for beta radiation recording. The badge filters are designed to discriminate the radiation energy but their presence provides important information about dosimeter handling conditions, because through the photodosimeter radiation exposure an image on the film is recorded. According to USF procedures, the individual dosimeter has to be worn during one month in front of the chest and the film must to be correctly introduced in the badge so as the recognition number to be printed on the film right to the Al filter. The films that served in the personal monitoring are chemically processed together with the witness films and then visually analyzed. The optical densities are measured with the densitometer device and the dose values are calculated with the mathematic relationship which fits the dependence between optical density and dose.

3. RESULTS AND DISCUSSIONS

Errors in the individual dosimetry monitoring introduced by the persons occupationally exposed to radiation are analyzed.

The most common errors recorded and reported by USF regarding the wrong handling of the dosimeters by personnel occupationally exposed to ionizing radiation are shown in the following:

3.1. MECHANICAL AGGRESSION – THE FILM PROTECTIVE COVERING IS BROKEN OR PUNCTURED

The films with protective covering unstuck, broken or punctured are blackened in the place where they suffered the aggression. The problems arise when beyond the blacking phenomenon, there is an image on the film that indicates that the photodosimeter was exposed to radiation and the monitored person in question received a dose.

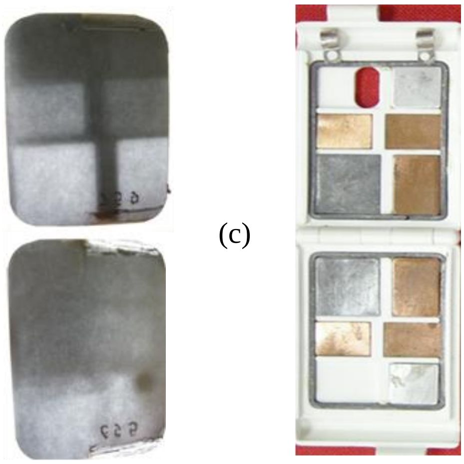


Fig. 1 – Occupational exposure: a) film wrongly inserted into the dosimetric badge;
b) the film, mechanically aggressed, introduced wrongly into a damaged dosimetric badge;
c) FD-III-B dosimeter badge.

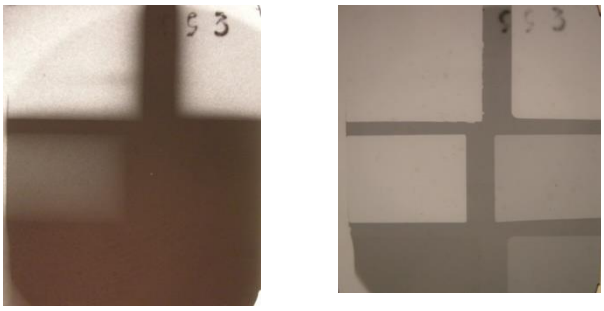
In Fig. 1a and b the films were wrongly inserted in the dosimetric badges so, the identification numbers were stamped at the bottom of the films; in Fig. 1b, the film was also mechanically aggressed by puncture in the bottom right and introduced in a damaged dosimetric badge with the Cu 0.5 mm filter fallen and partially caught between the Pb 0.4 mm filters; Regarding (b) film, the dose can be assessed on the plastic or Al filters and on the Cu 1mm filter, bottom right position, avoiding the damaged area. Although, the aggressed area is blackened, there are places on the film under some badge filters where the dose can be assessed (Fig. 1). The image recorded gives the possibility to select clearly the areas on the film for the optical density measurements.

3.2. METALLIC FILTERS MISSED FROM THE BADGE

The image recorded on the film shows missed or fallen metallic filters, Fig. 1b, fact often reported by the film dosimetry service units. The dose is assessed on the sensitometric curves characteristic of the filters fixed in dosimetric badge.

3.3. DOSIMETER DELIBERATELY EXPOSURE TO RADIATION

The dosimetric film allows to appreciate if the image printed was acquired through the work tasks, negligent work or deliberate radiation exposure. If the dosimetric badge with film was purposely exposed to radiation the filter image is clear. In Fig. 2 a and b are presented the images recorded on the D10 and D2 films that were used in occupationally exposure monitoring. Analyzing the image printed results that the photodosimeter was stationary exposed in front of the x-ray source, fact confirmed subsequently by the radiation protection investigation realized on the work place. Also, the film was inadequately introduced in the dosimetric badge, so the identification number appears on the 1.00 mm Cu filter image instead of being printed on the 0.1 mm Al filter image. The dose assessment is made on the characteristic sensitometric curves for D10 or D2 films. It is necessary to establish if the person in question was sitting close to the radiation source during the deliberate photodosimeter exposure and in function of the report obtained by radiation protection investigation, the dose is attributed or not to the person concerned.



(a) (b)

Fig. 2 – Deliberate exposure of the photodosimeter with D10 film (a) and D2 film (b).

3.4. DOSIMETER LEFT NEAR THE RADIOACTIVE SOURCES

The dosimeters are left negligently close to the radiation source. Generally, the films irradiated negligently show overlapped images. A workplace investigation by announcing of the radiation protection controller in order to establishing the exact error cause is required. In Fig. 3 is presented the case of the films exposed negligently to an x-ray generator and were used in personnel monitoring by a nuclear unit. The images are obtained only on the D2 less sensible films because the D10 films were fully blackened. This case and, also, dosimeter deliberate exposure case, have to be recognized early because the blackening given by the error handling and the blackening due to the dose recorded by work duty cannot be separated. The optical densities measured on the films right handled by the rest of the personnel monitored give information about the doses at work place.

This type of handling error must be followed by a radiation protection investigation in order to determine doses for persons in question and working conditions.

Beside of radiation protection investigation, a web camera at the workplace could elucidate the cause of exposure of the film dosimeter to the radiation source.

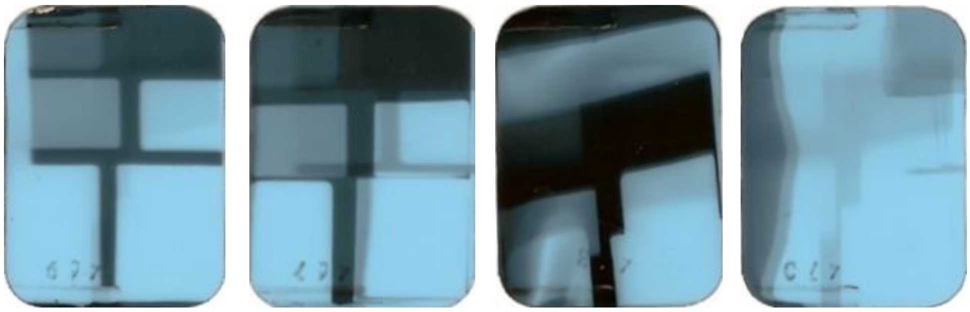


Fig. 3 – Film negligently exposed to an x-ray generator.

3.5. FILM INTRODUCED INCORRECTLY INTO THE DOSIMETRIC BADGE

Usually, the films are introduced incorrectly in the dosimetric badge at their monthly changing that occurs in the nuclear laboratory – the most common error of film handling and often reported not only by the USF dosimetry but also by other photodosimetry services [5]. This type of error does not affect the dose assessment; the printed image allows the establishment of filter position. The case becomes complicated when some filters are missing from the badge, the small doses are given by high energy radiation sources and there is no image. However, an optical density higher than those measured on the witness films indicates a dose recording.

3.6. USE OF THE FILMS WITH HIGH BACKGROUND OPTICAL DENSITY

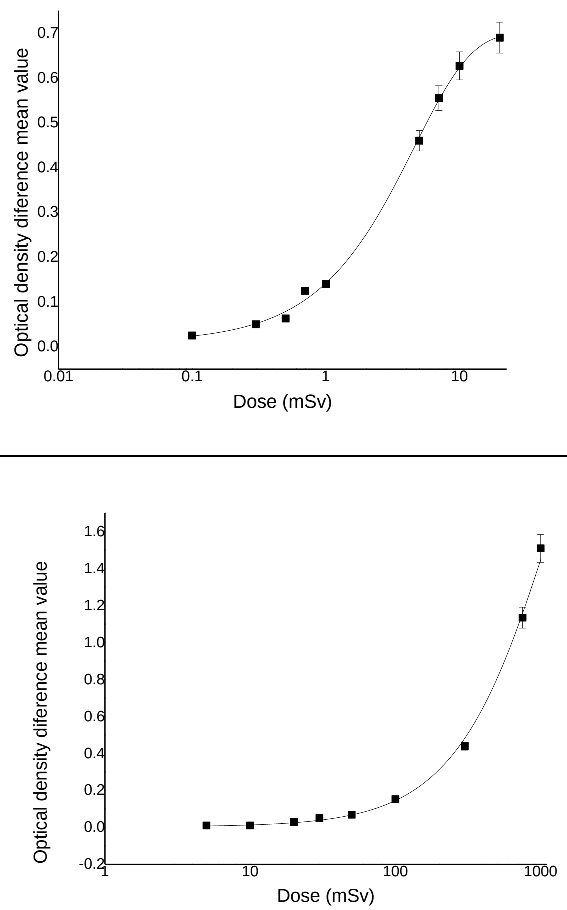
The films that were used in monitoring have a high background optical density comparing with witness films used by dosimetry laboratory; the optical density is uniform on the film surface and the standard deviation is the same with that calculated on the witness films. The film storage in environment wrong conditions leads to the background optical density increase. Some nuclear laboratories use films with higher background optical density either due to local procurement policy, when they take from dosimetry service all the contracted films for personnel monitoring, ensuring the properly climatic conditions for their storage or, more fervent case, when they use old films that remained in the laboratory from a month to another. The climatic work conditions, high temperature, humidity and the film wearing without dosimetric box and their exposing to radiation may be other reasons. Almost every time, the dosimetric and radiation protection investigations showed that the films were older than current batch of films used by dosimetry laboratory. Generally each nuclear laboratory makes properly deal with dosimetry laboratory regarding the “coming and going” of the films in order to ensure dosimetry service. Unfortunately, some economic and legislation policies slow the smooth running of the dosimetry rules.

To avoid such inconveniences, the monitored nuclear laboratory has to: i) renounce to the inappropriate acquisition policy and eventually to issue for contracted films a custody document with the dosimetry laboratory; ii) assure that monthly all the films have to come back into the dosimetry laboratory even if all or only a part from the monitored persons worked in that month although, from economic point of view, this is hardly accepted on the ground that the service was paid but the service itself does not make sense; iii) acquire monthly witness films.

Whatever would be the reason of the dosimetry errors, the witness film sent by nuclear laboratory has an important role in dosimetric or radiation protection investigation and dose assessment. Even if the film that served in personal monitoring has a background optical density higher than witness film from dosimetry laboratory, the dose assessment can be made with good accuracy. In this respect, either the optical density function dose sensitometric curve characterized by the same background optical density as witness film from nuclear laboratory, or the normal sensitometric curve of the dosimetry laboratory after the optical density increasing extracting could be used.

What happens if the optical density is increased on the entire surface of the film and there not exist a witness film. In this case the differences between the optical densities measured on the film under the badge filters can give information about the film blackening due to on one hand the fogging degree, the aging effect, the wrong chemical processing of the film, and on the other hand, the dose of radiation. In Figure 4 are presented the mean values of optical density differences between Pb 0.4 mm and Cu 1.00 mm filters, in function of doses, at different background optical density values. The increase of the background optical density was achieved either by the aging effect or by the wrong chemical processing of films. So, lots of D10 films with following background optical density units (odu): 0.40, 0.43, 0.51, 0.53 and a special case of increase of odu during chemical processing from 0.37 up to 0.69 odu for a D10 film were taken in study. The background optical densities for D2 films were 0.13; 0.14; 0.15; 0.16 odu. The optical density standard deviations for batches of films were under 3.5 %. The data are collected from different batches of films that were exposed to the ^{137}Cs standard source at different values of dose from the 0.1 mSv–1.0 Sv range, not every time in the same points of doses, but the same irradiation and chemical processing procedures was followed [7, 8]. The data fitting was performed with the mathematic equation tested and used in USF laboratory [9].

Between three and seven data of optical densities were averaged for a certain dose. From all obtained data the most relevant were the optical density differences calculated by subtraction of the optical density measured on the film under Cu 1.00 mm filter from the Pb 0.4 mm filter optical density. A low difference indicates a low dose exposure even if the optical densities measured on the film are higher. In the case of the D10, more sensitive film, Fig. 4a, for a given radiation dose the optical density differences obtained on the films with different background optical density are less accurate. The standard deviation of the optical density difference mean value is almost 46% in the point of 0.3 mSv dose and the plotting curve is stopped at 10.00 mSv because the dependence of the optical density difference in function of dose, becomes incoherent from one to other batch. For example, at the dose value of 1.00 mSv conventional true value for the batch of film characterized by the background optical density of 0.53 ± 3.00% odu the optical density recorded on the film under Cu 1 mm filter is 0.9 ± 2.3% odu and the optical density difference between Pb 0.4 mm and Cu 1.0 mm is 0.15 ± 2.8% odu.



(a)

(b)

Fig. 4 – Pb 0.4 mm – Cu 1.00 mm optical density difference mean value in function of dose:
a) for D10 sensitive film;
b) D2 film.

The calculated dose is 1.22 mSv ± 6.7% by the mathematic equation that fits the 0.43 ± 2.1% odu characteristic curve usually used in dosimetric laboratory and 1.06 mSv ± 10% by the optical density difference curve (Fig. 4a).

The highest standard deviation of the optical density difference mean values given by the batches of D2 films was of 30 %, recorded in point of dose 20 mSv; the average in this point of dose was calculated from five data.

Certainly, the data obtained on the film under Cu 1 mm filter is more coherent than other data recorded on the film alone. The large standard deviation is due to the film response to radiation under other dosimetric badge filters, in this case Pb filter. So, even if the optical density difference recorded with D2 film is small, 0.02 ÷ 0.04 odu, the dose calculated on the curve from Fig. 4b is 22.4 mSv ± ± 28% for 20 mSv conventional true value. The D2 film characterized by 0.15 background optical density and exposed to 20 mSv conventional true value records under Cu 1 mm filter 0.21 ± 1.2% odu and the dose calculate on the 0.14 odu Cu 1.0 mm usually sensitometric curve used in dosimetric laboratory is 20.51 mSv ± 9.7%. Regarding the higher doses, for example films characterized by 0.15 ± ± 6.7% odu background optical density and exposed to the conventional dose true value of 100 mSv record an optical density under Cu 1mm of 0.50 ± 1.1% and an optical density diference between Pb and Cu 1 mm filters of 0.15 ± 6.7%; in this case the calculated doses are: 104 ± 6.5% by graphic from Fig. 4b and 91.40 ± ± 3.6% by 0.14 odu Cu1.0 mm usually sensitometric curve. So, the veil increase of the film is less important in the case of higher doses.

3.7. TECHNICAL PROBLEMS IN HALIDE FILM DOSIMETRY. HANDLING ERRORS DURING THE CHEMICAL PROCESSING OF THE DOSIMETRIC FILM AND THEIR CORRECTION

The occupational dose monitoring is performed in standard conditions following the particularly procedures properly for each dosimetry laboratory. Beyond the physical factors such as the photodosimeter response dependence of radiation energy, the increase of the optical density by aging effect or film wrong handling during the chemical processing affects the dose assessment accuracy. The temperature increase in the developer bath leads to the blackening of the film especially in case of D10 high sensitive film. This kind of situation has been reported by USF during the chemical processing of the controlled films exposed to photon radiation. In Table 1 are presented two lots of films L1 and L2 with first optical densities (background optical density) of 0.43 ± 2.1% odu and 0.37 ± 2.0% odu respectively, that were exposed to a ^{137}Cs standard source, at different conventional true values (ctv) of doses, *D*, from the 0.1 mSv–1.0 Sv range and chemically processed in the same physico-chemical conditions, following the same procedures, but processed at different times.

The sensitometric curves obtained through the controlled radiation exposure of the films are used in dose assessment and they have to describe exactly the dependence between dose and optical density printed on the film. At each batch of purchased films, new sensitometric curves are plotted or the dosimeter response of the new films is checked on the existent curves. The difference between L1 and L2 background optical densities is under 20% so, theoretically, a correction of optical density is not necessary and, consequently, the dosimetric response of the L2 lot has to follow the dosimetric response of the existent L1 film batch. Nevertheless, wrong chemical processing changes the optical densities of the film and leads to high errors in dose assessment. The alignment of the measured density to the standard curve by subtracting or adding of the optical density difference may be a more or less efficient solution.

The witness films used in L1 chemical processing recorded an average optical density of 0.43 ± 2.3% odu, while the optical densities of the L2 witness films increased from 0.38 ± 2.30% odu to 0.69 ± 2.30% odu. A correction of optical density can be made either on the 0.37 ± 2.0% odu curve or on the 0.43 ± 2.1% odu curve. In this work the correction of the L2 after L1 was taken into consideration. In Table 1 are highlighted the dose errors given by the wrong handling in the chemical processing of the films and the optical density corrections that can be applied in special circumstances, trying a L2 film adjustment to the L1 films that were chemically processed in right conditions. The optical densities were measured on the D10 film under FD-III-B badge plastic filter. The optical density correction of the L2 batch was applied by

$$OD_D = OD_{mas} - (OD_M - 0.43), \quad (1)$$

where: OD_D is the optical density in point of D, dose; OD_{mas} is the optical density measured on the film exposed to D dose; OD_M is the witness film optical density used in chemical processing of the film exposed of D dose.

Table 1

Optical densities recorded on the D10 irradiated films and witness films

0	Dose ctv, mSv	0.1	0.3	0.5	0.7	1	3	5	7	10	20	30	40	50
1	OD L1, M=0.43	0.45	0.52	0.59	–	0.78	–	1.85	–	2.86	3.89	4.58	5.05	5.4
2	OD_M L2	0.38	0.38	0.4	0.4	0.4	0.43	0.43	0.57	0.57	0.57	0.7	0.7	0.69
3	OD_D L2	0.4	0.5	0.57	0.67	0.79	1.5	1.99	2.44	2.91	4.16	4.83	5.3	5.6
4	Dose L2 on L1	0.11	0.28	0.41	0.63	0.93	3.23	5.38	7.82	10.92	23.42	34.86	47.35	N/A
5	Error %	10.0	–6.7	–18.0	–10.0	–7.0	7. 7	7.6	11.7	9.2	17.1	16.2	18.4	10.0
6	OD L2 corrected to L1	0.45	0.55	0.6	0.70	0.82	1.45	1.94	2.3	2.77	4.02	4.56	5.03	5.34
7	Dose L2 corrected	0.19	0.37	0.48	0.71	1.00	3.23	5.38	7.10	9.93	21.59	29.62	39.53	48.71
8	Error % (after correction)	90	23.3	-4.0	1.4	0.0	7.7	7.6	1.4	-0.70	8.0	–1.3	–1.2	–2.6

Note. Dose ctv is conventional true value of dose; u_{ctv} = 5.0% – 6.0% and OD is optical density; OD_M – optical density of the witness from the chemical processing; N/A – not applicable; OD_M are: 0.38 ± 2.3%; 0.40 ± 1.9%; 0.43 ± 2.5%; 0.57 ± 2.4%; 0.70 ± 2.2 %; 0.69 ± 2.3%.

Discussion of Table 1. For dose values > 0.5 mSv, the dosimetric response assessment of the L2 films on the L1 curve is given with errors up to 18.4 % (row 5). After the optical density correction the dose assessment, the error goes down to 8.0% (row 8).

After applying the optical densities correction for the 0.1 mSv and 0.3 mSv doses, the error gros up to 90%, but is not relevant because the optical density difference between the L2 and L1 witness films is ± 0.05 odu and in low dose range, under 0.5 mSv is difficult to do a real correction due to the sigmoidal curve shape where the small optical density variation lead to high dose variations. On the other hand, it is much more important to measure correctly high doses than values of 0.1–0.5 mSv, and the efficiency of the correction application is demonstrated.

4. CONCLUSIONS

The images recorded on the film speak about errors introduced either by the monitored personnel or by the technical personnel from the dosimetry services. Depending on the dosimeter handling error, the dose assessment procedure is more and less complicated. The errors such as filters missed from badge, pricks that cause small points of blackening, film incorrectly introduced into the dosimetric badge can be solved by the dosimetry service through their reporting to the radiation protection officer of the nuclear laboratory in question. The personal dosimeter handling errors namely the deliberate exposure, the negligent exposure overlapped on the doses recorded by routinely monitoring of personnel can give high errors and imply special procedures of dose assessment and radiation protection investigations headed by the nationwide nuclear authority.

The proper handling of the personal dosimeter is important in assessing the radiation dose. The staff awareness on the risks to that exposed by the inappropriate use of radiation sources and the wrong handling of the individual dosimeter should be done in an organized and continuous mode. The radiation dose estimation is more accurate when the details about dosimetry method limitations, handling conditions of the personal dosimeters and radiation sources are known. The optical density correction is a good method of dose assessment and error mitigation and can be applied with good results in special circumstances; the optical density differences give information about the cases of the dose overlaid on the veil increasing of the film in question. In case of wrong personal dosimeter handling, the radiation protection investigation is essential and the surveillance of the workplaces with web camera is helpful to determining the exact events of negligent or intentional exposure.

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