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PROCEEDINGS
Workshop
DOSIMETRY OF WORKERS IN RADIOLOGY
Brussels, April 24, 1998

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PROCEEDINGS

Workshop

Dosimetry of workers in Radiology

Reflections on new technologies and legislation on personal dosimetry in radiology.
Brussels, April 24, 1998

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Dosimetry of workers in Radiology

Reflections on new technologies and legislation on personal dosimetry in radiology.

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IMPLEMENTATION OF EUROPEAN DIRECTIVES IN SPANISH LEGISLATION

E. Vano.
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INTRODUCTION

Spain has enacted in 1996, a Royal Decree establishing the quality criteria in diagnostic radiology (1) following the European Directives. Now it is mandatory in Spain to measure on a yearly basis, patient doses in all the X-ray rooms (using samples of a minimum of 10 patients) and to evaluate simultaneously the image quality, using clinical criteria or test objects. The yearly evaluation of the film rejection rate is also compulsory and a progressive implementation of Quality Assurance programmes is required.

PATIENT DOSIMETRY

Concerning patient doses, if mean values are higher than the reference level (in more than 25%), corrective action in the equipment or in the clinical or technical protocol, is imperative within two months. European reference doses values have been adopted by the Spanish standard. Acceptance tests for all the new X-ray systems are also mandatory and must be performed by the supplier with the presence of a qualified delegate of the purchaser.

OCCUPATIONAL DOSIMETRY

For occupational dosimetry (OD), only one personal dosemeter is required for workers who could receive more than 15 mSv/year (classified as "A" workers). In other cases, doses could be estimated by area dosimetry. In practice, all the workers in diagnostic radiology installations wear a personal dosemeter.

We recommend, as other authors (2, 3), the use of 2 or 3 dosemeters for workers in interventional radiology (IR) theatres: under and over apron, and on the hands, if convenient, due to the very high dose gradients near the patient and because dose rate is highly dependent on the procedure (beam orientation, field size, kV, patient dimensions, image quality required, etc).

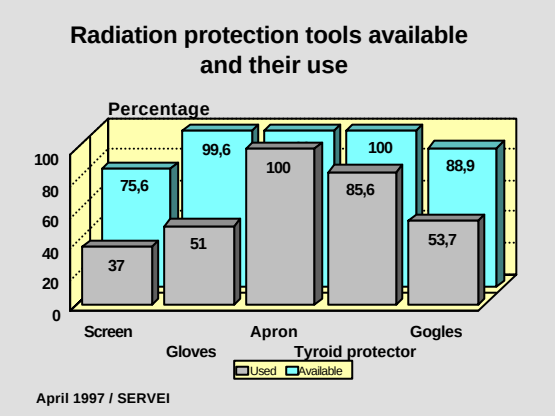
If only one dosemeter is used under the apron, the stochastic risk is underestimated and it is not possible to estimate the risk of deterministic effects.

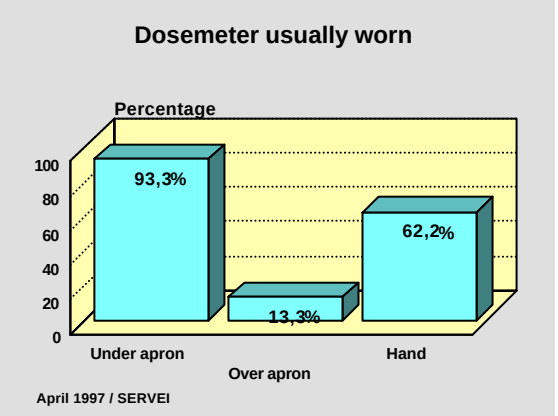
Mateya *et al* have recently published results demonstrating that at 80 kV and with undercouch tube configuration, the effective dose may be 10-26 higher than the value registered by the dosemeter worn under the apron (4).

One of the additional problems in occupational dosimetry for interventional radiology is that radiation protection tools are not always used (screen, glasses, gloves, etc) and dosemeters are not always worn by the specialists.

Since legal dose limits may be exceeded in IR, some radiologists could tend to avoid the regular use of radiation dosemeters, in order to elude possible problems with the regulatory authority, as suggested in a previous work by Niklason et al (3). This fact may explain that personal dosimetry files from regulatory bodies may show occasional lack of reliability and stresses the need for a research on OD ranges in IR.

In April 1997, a national trial concerning aspects of radiation protection (RP) has been performed between the Spanish Society of Vascular and Interventional Radiology (SERVEI) and the Medical Physics Group of the Complutense University. Some of the obtained results are shown in the figures. They are representative of the commented problems.





The Spanish Regulatory Authority is supporting a research project on occupational risk evaluation in interventional radiology with the collaboration of the Spanish Society of Vascular and Interventional Radiology. The project is conducted by the Medical Physics Group of the Complutense University and some recommendations concerning occupational dosimetry will be presented to the Regulatory Authority at the end of the project concerning the following aspects:

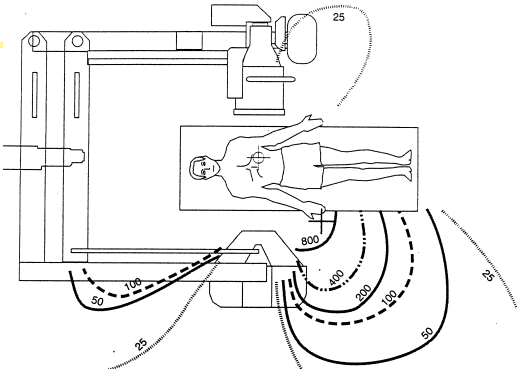
- A second level of training in radiation protection specific for IR should be required, as recommended by the World Health Organization (5).
- A new analysis of the occupational dose data bank considering mistakes in the reported results.
- Two personal dosemeters, under and over apron, should be worn.
- Suspended screens should be mandatory in all IR X-ray rooms.
- X-ray systems should be specifically designed for IR.
- Over couch tube geometry should not be permitted.

Finally, and as example of the consequences of non optimised installations and procedures, some occupational radiation injuries produced in interventional radiology specialists are presented and analysed (6). Several cases of lens injuries, ophthalmologically confirmed, caused by occupational radiation exposure have been produced in two x-ray rooms devoted to vascular and visceral interventional radiology procedures. Both laboratories were equipped with overcouch x-ray systems not designed for interventional radiology, without specific tools for radiation protection of the eyes. Dose rates in these conditions could be as high as 8 mGy/h (7). Typical workloads ranged from between 2 to 5 procedures/day. For the two radiologists affected, estimates for the dose to eye lens ranged from between 450 and 900 mSv/year, over several years. Since these lens injuries were only detected accidentally, measures to avoid similar occurrences in the future should be implemented.

Continuously increasing workloads and lack of a good radiation protection training in these substandard facilities will produce an increase of overirradiation incidents unless urgent action is taken.

Dose rate near the patient can be as high as 8 mSv/h

Marx and Balter 1995



These incidents will reinforce the recommendations that will be presented to the Spanish Regulatory Authority.

OCCUPATIONAL RADIATION RISK. CONCLUSIONS.

As conclusions of the research work on occupational dosimetry undertaken by the Medical Physics Group of the Complutense University, the following aspects could be highlighted:

- Additional dosimetry outside the lead apron to estimate lens doses should be routinely performed on IR staff. Otherwise, realistic estimates of the dose to the lens become difficult because of the high dose gradients close to the patient.
- Planned replacement of old x-ray systems, that have the x-ray tube above the patient, and are used for a significant workload of IR procedures, is urgent.
- An ophthalmological examination should be a part of the routine periodical medical occupational control for these specialists.
- Regulatory boards should encourage procedure optimization, but avoiding the application of immediate sanctions, aiming to overcome the possible tendency to “neglect” the use of the dosemeter.

- RP training should be strengthened to guarantee IR staff have the ability to ascertain the extent to which a given measure improves or worsens RP

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THE EXPERIENCE OF BELGIAN RADIOLOGISTS WITH PERSONAL DOSIMETRY IN DAILY PRACTICE

E. Ponette, H. Bosmans, V. Celis, J. Van Dam, P. Schonken

with the co-operation of the staff members of Department of Radiology

and Department of Radioprotection,

University Hospitals Leuven

Abstract

In most radiological departments the personal dosimeter is worn under the lead apron, giving a good idea on the total body dose but no information about the dose on the unprotected body parts (hands, face with eyes, neck with thyroid gland, feet).
The kinds of radiological acts, necessitating the radiologists to work next to the patient is increasing in the last years; moreover the frequency of these acts with sometimes long fluoroscopic times is increasing too, so that earlier complications such as radiodermitis of the hands and cataract could appear again in the future.
For these reasons in most radiological departments several extra measures for the protection of the radiologists have already been taken. But simultaneously there is a need to take extra dosimetrical measures, so that each radiologist could follow up his own risk and could organize an adapted protection and eventually a lower frequency of some examinations. Obligatory wearing of (an) extra-dosimeter(s) outside the lead apron (e.g. on the breast, the head, the wrist or/and a finger) has to be considered, either systematically or only in some circumstances.

The experience with personal dosimetry, about which I will inform you, is a result of personal experience and of many discussions with the members of our radiological staff, with other radiologists and naturally with colleagues of the department of radioprotection.
Concerning these problems I will make three appointments, followed by some recommendations.

My **first appointment** is, that the personal dosimeter, generally worn under the lead apron, may give a good idea on the so-called total body dose, but no or very poor information about the dose on the unprotected body parts.
This thesis is confirmed by the two following dosimetrical experiments, the first one during a phlebography with thrombectomy of the arm (Table 1), and the second one during a transjugular intrahepatic porto-systemic stent (TIPSS)-placing (Table 2).

In the first interventional radiological act the eye-dose outside glasses was 4 times higher than the breast dose under the lead apron and the right finger dose was 15 times higher (Table 1).
In the second interventional act, the discordance between the dose on the same non-protected parts of the examiner and the under-apron dose was still greater: 9 times higher on the eyes and 18 times higher on the right finger (Table 2).

My **second appointment** is that the types of radiological acts, necessitating the radiologists to work next to the patient, increase during the last years, that these acts need sometimes relatively long fluoroscopic times and that there is an increasing demand for these acts (Table 3).
It is not needless to remember that for performing a good examination of the GI-tract including correct compression, working next to the patient is necessary.
But especially several interventional radiological acts contribute now to a higher radiation load for the examiner.
In the interventional angiography I mention especially the balloon dilation of arterial stenoses, eventually followed by an arterial stent, the arterial embolisation for acute bleeding of the digestive system, the arterial embolisation and chemotherapy for malignant hepatic tumors, the already mentioned transjugular intrahepatic porto-systemic stent placing, the embolisation of bleeding oesophageal varices and the also already mentioned venous thrombectomy.
There are the uro-radiological interventions such as nephrostomy, ablation of stones and urological stenting, some of these interventions being executed in the radiological room, others in the operation room.
Further there are the interventional radiological acts for the digestive system with the percutaneous drainage or antegrade stenting of the bile ducts especially in tumoral pathology, the percutaneous drainage of the gallbladder in acute cholecystitis, the percutaneous drainage of abdominal abscesses, ...
There is the interventional Endoscopic Retrograde Cholangio-Pancreatography (ERCP) with papillotomy, stone ablation, retrograde stenting; there is also the combined PTC-ERCP stenting of the bile ducts.
The radiological acts in cardiology will be discussed by another colleague.
We have to mention finally in this incomplete list the increasing radiological acts in the operation rooms.

The result of these facts is that nearly forgotten complications such as RADIODERMITIS OF THE HANDS and CATARACT could appear again in radiological workers.
Indeed, from the already mentioned figures, it is possible to deduce that, without protection of the eyes, a maximum of 3,8 phlebographies with thrombectomy pro day are allowed (Table 4), or a maximum of 1,9 TIPSS pro day in the given careful radioprotectional circumstances (Table 5), supposed moreover that no additional radiological acts are performed by this examiner.

Concerning the finger doses, the number of allowed examinations pro day is respectively 3,8 (Table 4) and 3,2 (Table 5) in the given circumstances.

My **third appointment** is that fortunately in most radiological departments several extra measures for the protection of radiologists have already been taken (Table 6a and 6b). The old rule, never to put the unprotected hands in the primary X-ray beam, remains mandatory.
For decreasing secondary radiation it is important to decrease primary radiation, especially fluoroscopy:

- the recommendation to use only short fluoroscopic flashes is facilitated by the "last image hold" system,
- the fluoroscopic dose is further decreased when the fluoroscopic pedal is handled by the examiner himself, when automatic dose adaptation is used, and when different fluoroscopic dose levels can be chosen,
- other measures leading to a decrease of secondary radiation are: pulsed and half dose fluoroscopy, regular quality control of image intensifier and TV-chain and correct direction of the axis X-tube-image intensifier.

In pulsed fluoroscopy the X-ray beam is not continuous but rhythmically interrupted: the lower the pulse frequency, the lower the dose.
In primary pulsing this interruption happens in the generator, in grid pulsation it happens at the exit of the X-ray tube by means of a grid.
Another technique leading to a decrease of dose is the image-integration system: while in continuous fluoroscopy the TV-signal is read out during one image-period and transmitted to the monitor, in the image-integration system the dose is halved and the TV-signal is integrated over two image periods so that the image-frequency is halved but the light intensity on the monitor remains unchanged.
Finally it is possible to decrease fluoroscopic dose by combining pulsed fluoroscopy with digitally stored images, filling in the non-fluoro periods and creating the illusion of a continuous image.
Regular quality control of image intensifier and TV-chain prohibits gradually increase of fluoroscopic dose after a lapse of several years.
The amount of secondary radiation to the eyes and hands of the operator can be lowered by correct use of a C-arch. The best position is the tube under and the image intensifier above the patient. Indeed, the amount of secondary radiation is greatest at the side of the patient first contacted by the primary X-ray beam. When the tube is above the table, this is the side of the patient near the face and hands of the operator. When the tube is under the table, this is the side of the patient more distant from the face and hands of the operator. The so realized dose reduction may reach a factor of more than the figure 10.

Finally radioprotection of the operator is completed by adequate shielding including supplementary lead-glass screen, covering the patient with lead, covering the examiner with lead and by keeping distance (Table 6b).

We use actually movable lead-glass screens with a great surface, allowing an excellent view on the patient as well as a good protection of the operator's head and neck.
Lead flaps hanging around the image intensifier absorb a considerable amount of secondary radiation leaving the patient, and protect in this way the operator.
For the C-arch apparatus we ordered to construct lead-flaps hanging down from the table top, in order to protect our lower legs and feet.
When we work with our hands near the patient, e.g. for abdominal compression in prone position of the patient with a Picker compressor, we use classic lead gloves.
Remark moreover that we bring the image intensifier as close as possible to the patient before fluoroscopy, reducing the weak components of the X-ray beam to the patient, as well as the secondary radiation to the operator.
We use lead aprons enveloping all sides of the operator and we wear lead thyroid protectors.
For some examinations, we use moreover lead glasses for the protection of the eyes and supple surgical gloves.
Finally it is important to keep distance from the patient whenever it is possible during scopy or graphy, since the dose of radiation decreases with the square of this distance.

Conclusion

On the base of the preceding appointments I conclude that OBLIGATORY EXTRA DOSIMETRICAL MEASURES ARE NECESSARY, so that each radiologist could follow-up his own risk and could organize an adapted protection and eventually a lower frequency of some examinations.
In my opinion obligatory wearing of one or more extra-dosimeters outside the lead apron has to be considered and we have to discuss the modalities.

Table 1:
Dose radiologist during phlebography + thrombectomy of the arm (under circumstances B)

Organ	Dose (m Sv)
- breast (under Pb apron)	0.036
- breast (above Pb apron)	0.255
- right finger	0.521
- left finger	0.412
- right arm	0.231
- left arm	0.206
- thyroid gland	0.233
- outside of glasses (eyes)	0.159

Table 2:
Dose radiologist during TIPPS (under circumstances A)

Organ	Dose (m Sv)
- breast (under Pb apron)	0.036
- breast (above Pb apron)	0.255
- right finger	0.633
- left finger	0.581
- right arm	0.315
- left arm	0.281
- thyroid gland	0.364
- front (eyes)	0.314

Table 3:
Radiological acts next the patient

- Conventional RX of G.I.-tract
- Interventional RX
  - angiological
  - urological
  - digestive system (bile ducts, abscess drainage, ...)
- ERCP
- RX in operation room
- RX in cardiology

Table 4:
Legal number of examinations
phlebography + thrombectomy of the arm
(under circumstances B)

Unprotected	Number/year	Number/day
- for eye dose	943	3.8
- for finger dose	959	3.8
- for thyroid dose	2145	8.6

Table 5:
Legal number of examinations
TIPPS
(under circumstances A)

Unprotected	Number/year	Number/day
- for eye dose	477	1.9
- for finger dose	789	3.2
- for thyroid dose	1373	5.5

Table 6a:
Extra protection measures for the radiologist

- NEVER PUT UNPROTECTED HANDS IN PRIMARY X-BEAM
- DECREASE OF AMOUNT OF SECONDARY X
  - decrease of amount of primary X : fluoroscopy
    - * time as short as possible
    - * fluoroscopic command by examiner
    - * automatic dose adaptation
    - * different dose levels
    - * "last image hold"
    - * pulsed fluoroscopy
    - * half dose fluoroscopy
    - * control of image intensifier and TV-chain
  - direction of axis X-tube-image intensifier

Table 6b:
Extra protection measures for the radiologist
(continued)

- SHIELDING
  - supplementary Pb glass-screen
  - cover the patient:
    - * Pb-flaps along image intensifier and table top
    - * image intensifier above and as close as possible to the patient
  - cover the examiner:
    - * Pb gloves (classic, surgical)
    - * Pb apron
    - * Pb thyroid protector
    - * Pb glasses
  - keep distance

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THE EXPERIENCES OF BELGIAN HOSPITAL PHYSICISTS WITH PERSONAL DOSIMETRY AT RADIOLOGICAL DEPARTMENTS

R. Van Loon

Vrije Universiteit Brussel

Traditionally almost no medical physicists were active in radiological departments till the 90's. Even at present less than a dozen are present in this area in Belgium, and although only a few are directly involved in personal dosimetry they will play a major role in the future.

How is the situation of staff exposure in Radiology Departments?

Most of the radiation dose to staff in radiology originates in stray radiation, often from the patient and the doses radiographers and radiologists receive are very low, well below occupational exposure limits. But nowadays, interventional radiology is more and more practised: they require long exposures to fluoroscopy, and will involve significant higher levels of exposure. Frequently hands will end up in the primary beam.

From recent official data from Spain and France, we can see that a rather high number of workers in radiology experience doses that exceed the 20 or 50 mSv/y level and this needs attention.

Occupation	**# workers (+-)**	**IndDose> 20mSv/y**	**IndDose> 50mSv/y**
Radiology	87000	104	31
Radiotherapy	8500	11	1
Nuclear Med	4000	3	1
Dental Radiol	20000	6	3

Table 1. Individual doses over 20 and 50 mSv by activity sectors in medical field in France, 1995. (From OPRI Annual Report 1995)

Occupation	**# workers (+-)**	**IndDose> 20mSv/y**
DiagnRadiol	42000	15
Radiotherapy	1600	1
Nucl Med	1500	1
Dental Radiol	4600	2

Table 2. Individual doses over 20 mSv/y in Spain in 1995 (Source: Nuclear Safety Council CSN)

Personnel dosimeters indicate only the exposure at the position at which it is worn. Often the device is worn under the apron, and will not provide a reliable indication of the exposure outside the protected region. Since the read-outs are corrected for background, the results can be zero, and the radiographer or radiologist *feels* safe.

A radioprotection officer is seen as the man who wants to reduce the dose...and his optimisation strategy tries to reduce it to almost zero: this is valid for energy production sites and industry using ionising radiation. But this does not hold for diagnostic radiology: reduction of levels of exposure may reduce or annihilate the level of benefit.

The presence of a physicist will allow a better estimation of personnel doses, and lead to reduction is staff doses: by observation he can recommend change in position or procedure of the operating doctor, or suggest the places to wear extra dosimeters, since when occupational

What lessons can we learn from other countries and our own experience?

1) Diagnostic radiology intentionally and directly exposes persons to ionising radiation, but expecting a medical benefit. This naturally leads to a symbiosis between radioprotection and quality assurance: the quality of the outcome must be an integral part of the radiation protection strategy. Recent EC Directives and Belgian Royal Decrees include quality assurance and actions to lower patient exposure: most measures reducing patient dose will also reduce dose to staff. Our experience shows that their is a lack of knowledge in this field. The role of a medical physicist will be first a fight against ignorance, and by training and on-site demonstrations reduce patient and thus staff doses.
2) We observed that radiologists in Belgium are a “radiation protected” species: either some dosimeter readings are lower than background ... or they have an “unexplained” overdose! Double dosimetry will have only a future in Belgium if a radiation expert has information -in a direct or indirect way- on the habits and working patterns of the staff members, radiologists and technicians. Reducing the number of zero’s in the reporting will be of great help.
3) Radiology is often a business in an environment of power and authority, conservatism and sometimes suspicion. A “stranger” from outside the department will be experienced as an enemy.

So, the conditions of use of the personal dosimeter in radiology have to be improved; adjusting regulations only, even introducing double dosimetry, will not reduce risk but increase confusion. We need a positive radiation protection and quality assurance philosophy, and medical physicists will contribute to this by observation, by providing guidance, advice, training programmes and continuing education ... and some further research

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THE EXPERIENCES OF BELGIAN ACKNOWLEDGED BODIES WITH PERSONAL AT RADIOLOGICAL DEPARTMENTS

D. Godechal
AV Controlatom

Introduction.

Determining individual doses is one of the major tasks of the physical control department. Monitoring and analysing doses is a vital procedure used by the physical control department for optimising doses. Below we give two examples, the first in the coronarography room and the other in nuclear medicine, where doses are monitored and analysed in order to optimise the doses received by medical staff.

1. Doses received by medical staff in coronarography.

Doses are measured using film-badge dosimeters in a coronarography department. Four doctors were monitored over a period of three years. Each of them carried a dosimeter at chest height under a leaded apron and a second dosimeter on the left shoulder. The results from these dosimeters are given in table 1 below.

Table I

	chest doses under the leaded apron (mSv.)			**Shoulder doses (mSv.)**		
	1995	**1996**	**1997**	**1995**	**1996**	**1997**
Cardiologist 1	8.9	4.3	2.0	124	159.7	87
Cardiologist 2	7.7	1.3	1.8	122	56.1	93.6
Cardiologist 3	3.4	3.6	1.0	48	99.4	-
Cardiologist 4	5.9	3.1	1.2	7.4	26.6	-

In 1995, a leaded apron was the only form of protection available for medical staff. In 1996, image intensifiers were replaced by more advanced intensifiers giving a reduction in the doses measured under the leaded apron estimated at 50% for cardiologist 1. However, an increased dose at shoulder level was observed due to the higher number of examinations. In 1997, the use of a mobile leaded screen placed between the patient and the medical worker resulted in a reduction in the doses measured under the leaded apron and at shoulder level. However, carrying two dosimeters required special attention. It was necessary to take great care to ensure that the dosimeters were worn in the correct position. Table II shows the doses measured during 10 periods on two cardiologists.

Table II

(dosimeter A under the leaded apron and dosimeter B on the shoulder)

Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Cardiologist 1										
A :	900	520	450	570	420	260	370	370	190	250
B :	21000	20500	12000	14500	20700	10500	23500	11550	9400	16000
Cardiologist 2										
A :	0	0	23480	20	70	0	0	30	30	2520
B :	0	2800	440	20	8000	2120	0	4620	100	450

Analysis of the dosimeter readings for cardiologist 2 shows that the dosimeters are not worn regularly and are also not worn in the correct position.

2. Doses for medical staff in nuclear medicine.

An analysis of 12 annual doses of more than 10 millisieverts was carried out on five male and seven female technicians working in nuclear medicine departments.
Radioprotection measures were proposed in order of priority. (1-3)

Table III

Suggested radioprotection measures

Technician	**Avoid remaining near the patient**	**Use syringe protectors**	**Establish a turning point during preparation**
A	1		
B	3	1	2
C	1		
D	3	1	2
E	1		
F	1		
G	1		
H	1	2	
I	1	2	
J	1	2	
K	2	1	
L	2	1	

A comparison of equivalent doses is used to optimise the doses.

Table IV

Technician	Equivalent dose 1996 (mSv)	Equivalent dose 1997 (mSv)
A	12.3	10.7
B	28.1	19.0
C	20.7	10.8
D	10.7	7.1
E	10.9	9.8
F	11.8	8.5
G	11.8	9.3
H	10.2	4.2
I	11.0	11.6

A more detailed analysis shows that a large majority of the doses of more than 10 mSv measured in nuclear medicine is higher for smaller technicians on whom the dosimeter is closer to the patient than on average sized technicians.

3. Conclusions

Monitoring and analysing dosimeter readings provides an important tool for the physical control department for optimising doses. The positioning of the dosimeter which supplements the chest dosimeter is defined in collaboration with the physical control department.

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THE PRESENT SITUATION IN PERSONAL DOSIMETRY : TYPES OF DOSEMETERS, QUANTITIES, PRECISION AND SPECTRAL RESPONSE.

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The main quantities and units are defined. A short description of the operating principle of the film and thermoluninescent dosemeters is given together with a general overview of the characteristics such as detection limits, energy response, angular dependence and linearity. Still some miscellaneous aspects of the two types of dosemeters are discussed.

1 Quantities and Units

The International Commission on Radiation Units and Measurements (ICRU) gives recommendations regarding the definitions and use of quantities in radiation protection.
The absorbed dose, D is defined as the mean energy imparted by ionizing radiation to matter in a given point. The unit is J/kg and the special name is Gray (Gy).
The dose equivalent, H is defined as the product of a quality factor Q and the absorbed dose D (H=QD). Where the quality factor takes into account the relative effectiveness of different types of ionizing radiation. The unit is J/kg and the special name is Sievert (Sv). In order to obtain the Effective Dose Equivalent, the weighted sum of dose equivalents in certain organs has to be made : $H_E = \Sigma w_T H_T$. Given this definition it is very difficult to use this quantity in radiological protection to verify whether dose limits are respected since D_T cannot be evaluated experimentally.
To solve this problem, ICRU has defined an operational quantity which can be used in this context namely the Personal Dose Equivalent $H_p(d)$. This quantity reflects the dose equivalent in soft tissue at a depth d below a specified point on the body. This quantity can be measured with a detector worn at the surface of the body and covered with a thickness d of tissue-equivalent material.
A commonly used depth is 10 mm, giving the dose equivalent appropriate for strongly penetrating radiation.
Calibration of the dosemeter can be performed on an appropriate phantom (eg. PMMA slab) in simplified conditions (eg. monoenergetic beam).

2 Types of Dosemeters

2.1 Film Dosemeter

A photografic film consists of an emulsion of silver halide grains (silver bromide) suspended in a gelatin matrix which is supported by a polyester film.The ionizing radiation acts in a similar way as visible light, in that some of the grains will be 'sensitized' through the interaction of radiation with the electrons of the silver halide molecules. The 'sensitised' grains remain in this state and store an 'image' of the ionizing particle track. During the development the sensitized grains are converted to metallic silver in such a way that the number of affected molecules reach a size where they become visible. During the fixation process the undeveloped silver halide grains are dissolved away and a washing step removes the processing solutions.

The 'film badge' itself consists of a small packet of film with a light-tight wrapping mounted within a film holder of 'badge'. The evaluation of the dose accumulated over the course of exposure is carried out by comparing the optical density of the developed film with that of an identical film exposed to a calibrated dose.

The sensitivity of the film is greatest for photons of low energy, so the unfiltered film will tend to overestimate the dose of soft X-rays compared with those of an higher energy (fig. 1). However, using a set of small filters confined to local regions of the film the response can be made flatter over a wide photon energy range. These filters and more precisely the differences in optical density they produce can be used to sort out various components of the radiation exposure (betas and different components of the gamma ray spectrum).

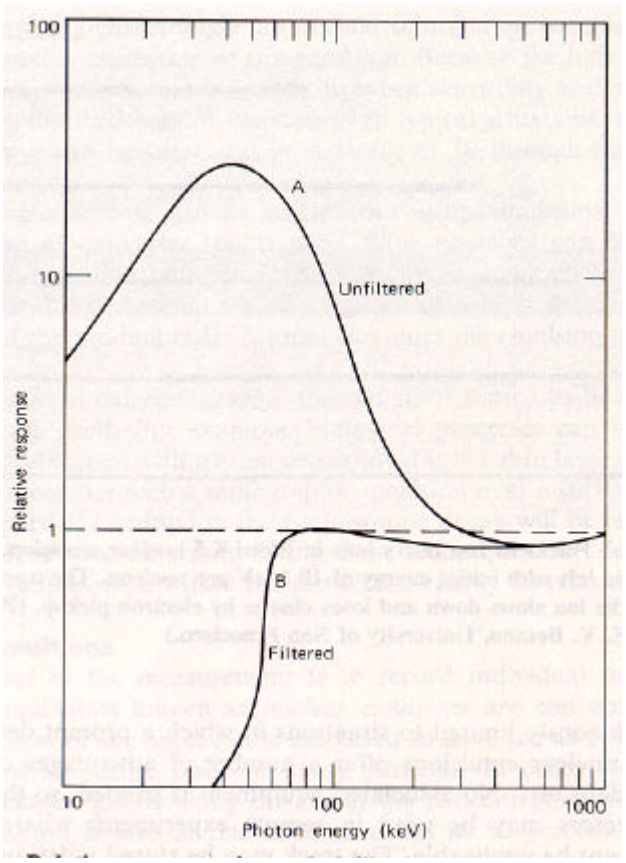

Fig. 1 Energy dependance of film dosemeter

2.2 Thermoluminescent Dosemeter (TLD)

Inorganic scintillation material (NaI, BaF2,....) emits light in the form of prompt fluorescence when exposed to ionizing radiation. This scintillation light is formed during the recombination of electron-hole pairs initially created by the incident ionizing radiation.

In some inorganic crystals (LiF, CaSO4,CaF2,...) high concentrations of 'trapping centers' are found and no prompt fluorescence is observed. The energy imparted by the ionizing radiation to the crystal is thus stored in these trapping centers in the band-gap. If the energy distance of the trapping center to the conduction band (electron) or the valence band (hole) is sufficiently large the probability of recombination at room temperature is very small. The 'shallow' traps however will give rise to a loss of electron-hole pairs even at room temperature and thus the material will show some 'fading'.

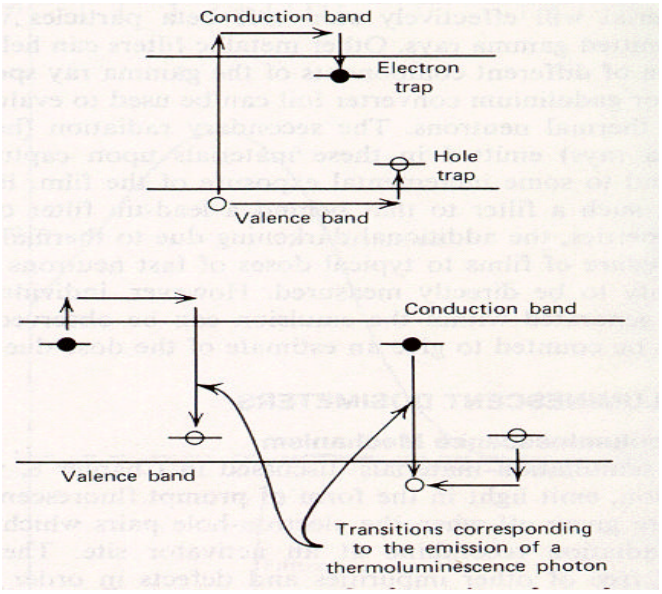

Fig.2 Recombination of electron-hole in TLD

If, however some additional energy is given to the deeper traps in the form of a temperature rise, the electron-hole pairs can migrate and recombine. During this recombination, the energy difference is emitted in the form of visible light (fig. 2). In principle the amount of emitted light is proportional to the number of electron-hole pairs created by the ionizing radiation.

Different TLD materials have, due to their different atomic numbers a different energy response (fig. 3). This principle can be used to sort out components of the incident spectrum by using different material in one dosemeter. When it gives rise to an unwanted energy response this can be flattened by using filters(see film dosemeter).

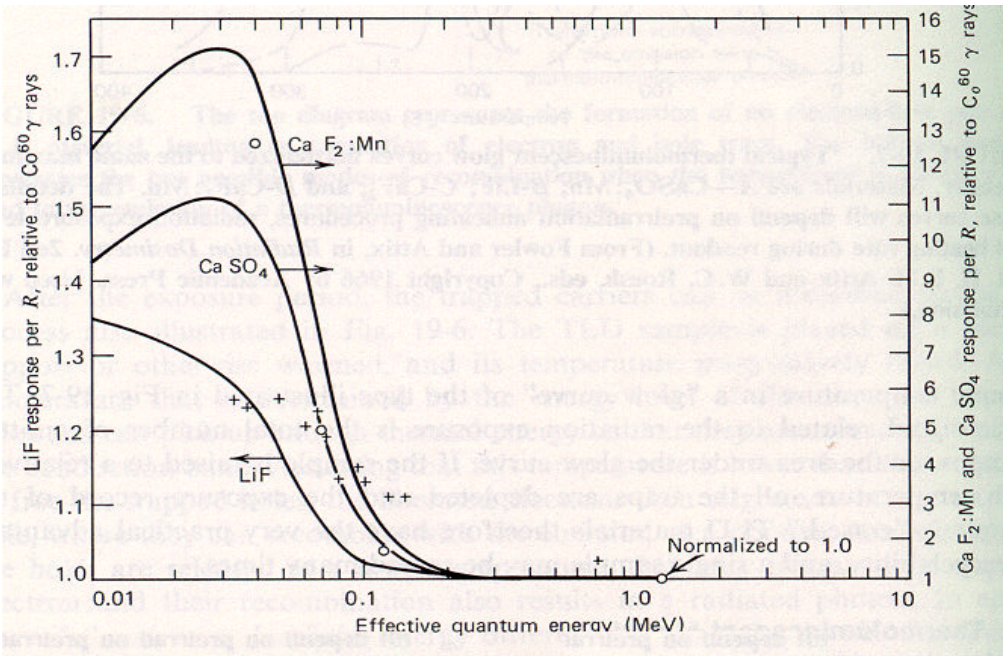

Fig. 3 Energy dependence of some TL- materials

3 Comparison

The two most frequently used dosemeters for 'offical' dose registration can be compared on some of their features : eg. linearity, angular response, detection limit,... .

3.1 Linearity

In the case of high doses the film dosemeter presents a problem of a saturating optical density this limits the usefull range to 30 mSv. By using a second (slow) emulsion one can extend the range to 300 mSv.

The linearity of the TLD dosemeter extends over 6 decades (10 µSv to 1 Sv). Beyond this range a certain 'supra-linearity' can be observed.

3.2 Angular response

The angular response is influenced by filters used to compensate for the energy dependence of the dosemeter. The effect is similar for the film and TLD dosemeter. In fact the increase in effective thickness of the filter in terms of angle of incidence of the radiation causes a decrease in sensitivity. This can be upto 20% for angles of incidence of 60°.

3.3 Detection limit

The detection limit is function of the energy of the radiation. For film a detection limit of 70 µSv can be used in the case of a gamma spectrum (>100 keV) and 20 µSv in the case of an X-ray spectrum.
In general, the energy dependence for TLD is less pronounced so that a detection limit of 20 µSv can be assumed.
The detection limit of dosemeters used in the field will also depend on local variations in natural background as compared with the background used by the dosimetry service.

3.4 Miscellaneous

Film :

- An hardcopy archive of the result can be kept
- Artefacts can be easily detected (direct exposure, shielding objects, ...)
- Contaminations can be observed and a readout correction can be made

- Low cost, but limited automatisation
- Slightly dependent on climatological conditions (humidity, temperature)

TLD :

- A copy of the glowcurves can be kept as an archive
- Artefacts, such as shielding objects in front of sensitive elements are more difficult to detect
- High cost, but easy to automise.

4 Conclusion

Both film and TLD dosemeters exhibit good caracteristics to be used as agreed dosemeter for occupationally exposed persons. In radiology the performance caracteristics of both types of dosemeters are similar except perhaps the limited dose range of the film dosemeter.

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NEW DEVELOPMENTS IN PERSONAL DOSIMETRY

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Introduction

At present thermoluminescent, film and electronic dosemeters are in use for gamma- and beta-radiation. The intention of this paper is to give an overview of some new developments in personal dosimetry. The topics will only be discussed very briefly, for further information we refer to more detailed papers.

New developments in thermoluminescence dosimetry include the introduction of new TLD-materials, for instance LiF:Mg,Cu,P. A new technique that is getting a lot of attention is optically stimulated luminescence (OSL). For electronic dosemeters, the further development of the DIS-dosemeter (Direct Ion Storage) is promising.

In this paper we will also discuss a new development in detecting beta-radiation. At the SCK/CEN we have tested a new kind of TLD-chip (Harshaw TLD-720) consisting of an inert chip with a thin layer of sensitive material on top. The laboratory tests show an improved response for low energy beta's. These new badges were tested at the VUB in parallel with normal ones, but no significant differences were found.

Hypersensitive TLD-material

The last ten years there have been extensive studies on the new TLD material LiF:Mg,Cu,P. It is now established that the sensitivity of this material is 10 to 30 times better than that of normal LiF:Mg,Ti. The exact value of the sensitivity depends upon the origin of the detector and on the detector handling procedures[(1)]. These new materials are commercially available from three different manufacturers: GR-200 (Solid Dosimetric Detection and Method Laboratory, China), MCP-N (TLD Niewiadomski and Co, Poland) and TLD-100H (Harshaw/Bicron, USA). Different thermal handling procedures have been described[(2)] and discussed. A loss of sensitivity and reproducibility have been reported when a maximum temperature of 270°C is surpassed during read-out and/or annealing. Even for temperatures beyond 240°C a loss of sensitivity can be observed, although this is generally negligible[(3)]. The cause or causes of this phenomenon are unclear at the moment. Several studies are being undertaken to provide a better understanding of these materials (e.g. determining the characteristics when varying the concentration of dopants[(4)], determining the kinetic trap parameters[(5)]).

Photon energy response is another peculiar property of LiF:Mg,Cu,P. The under-response for low energy photons is quite different from the behaviour observed in LiF:Mg,Ti. As a consequence, a relative flat photon energy response can be more easily achieved with simple design dosemeters. For high energy photons (>1 MeV) on the other hand, the response is a little less than that of normal TLD-100. These small differences in energy response can cause discontinuities when a dosimetry system is switching from one detector type to another.

Because of the high sensitivity of LiF:Mg,Cu,P it is possible to obtain a very low detection limit and to provide a significant improvement in total uncertainty. The lowest level of detection can go down to about 1µSv. It has also been shown that the fading of the main peak of LiF:Mg,Cu,P is negligible, so that no corrections have to be made for this[6]. Thanks to all these advantages, this material is particularly useful in the environmental dosimetry, e.g. the monitoring around nuclear facilities or the measurement of natural radiation. At the SCK/CEN, environmental dosimetry is already done using LiF:Mg,Cu,P detectors.

Optically Stimulated Luminescence

In thermoluminescence dosimetry the radiation-induced signal is released from the detector material by heating. The resulting light pulses are counted and this gives a measure of the dose imparted on the detector. In optically stimulated luminescence (OSL) the release of the trapped charges is stimulated not by heat, but by light. OSL measurements can be performed in two basic configurations: continuous or pulsed. In continuous measurements the luminescence is continually monitored during optical stimulation and the stimulating light is separated from the emitted light by the use of filters. In pulsed OSL measurements, the luminescence is only detected after the end of the stimulating pulse, and discrimination is accomplished using shutters[7].

The detector material best suited for OSL is ι-Al_2O_3:C. Such a dosimetry system has quite some advantages. First of all the sensitivity is higher than that of a normal LiF:Mg,Ti TL system. Because only a small part of the induced signal is released during OSL it is possible to re-evaluate the result. In other words, the problem with TL that the signal is destroyed after read-out is solved here. Because there is no need to heat the sample, the reading instrument has a simpler design. The measurements can be done completely automatic in a shorter time than a TL measurement (reading time=1 second). A disadvantage is that the detector has to be shielded from UV light that can induce false signals.

Many people believe that OSL is the next step in personal dosimetry after TLD. At present the largest dosimetry service in the USA, Landauer, has introduced an OSL dosimetry system (Luxel) in some places. Their key features include: complete reanalysis to confirm the radiation dose measurement, imaging of a filter pattern that provides qualitative information about conditions during radiation exposure, large dynamic range, increased sensitivity and excellent long-term stability. Although it is possible, they do not reuse the detectors, simply because the detector material is very cheap. Landauer has plans to change all of his TLD systems into OSL systems.

Direct Ion Storage

In the search for new and better dosimetry systems the performance demands are high. The ideal technology would have good radiological performance (energy dependence, sensitivity,...) combined with a simple and durable structure, low initial and operating cost and most importantly, the possibility for direct and non-destructive read-out. The present active electronic dosemeters have, next to operational problems (e.g. e-m disturbances) a very high initial cost.

A new development that is very promising is the Direct Ion Storage dosemeter (DIS), invented by J. Kahilainen and commercially developed by RADOS Technology[8,9]. A schematic picture of the DIS can be seen in figure 1.

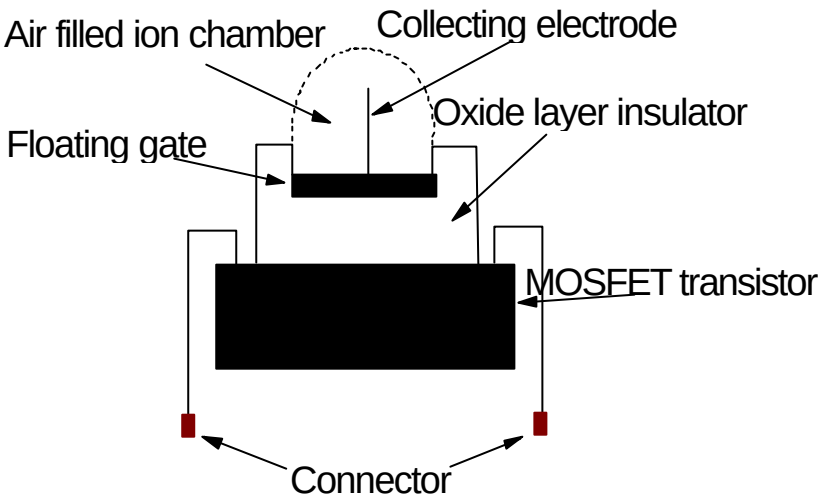

Figure 1: Schematic view of the Direct Ion Storage dosemeter

The DIS consists of a small air filled ion chamber where an electrode collects the charge that is being formed by the ionising radiation. The charge is stored on the floating gate of a MOSFET-transistor, a similar principle as used for an analog-EEPROM memory. In modern facilities memory cells capable of retaining the stored charge for hundreds of years can be manufactured. The reading of the stored information is done without disturbing the stored charge by measuring the channel conductivity of the transistor. The DIS can be used in the same way as the present TL dosemeters, with a possibility to check the dose at any given time using a small and simple reader. Or it can be integrated into a direct reading and alarming electronic dosemeter. By constructing the inner surface of the ion chamber from a suitable layer of conductive plastic, the energy response of the dosemeter can be made to correspond closely to either $H_p(10)$ or $H_p(0.07)$. To cover the required range of integrated doses, an assembly with multiple DIS elements has to be constructed, each with different sensitivities. The angular dependence of this dosemeter can be made very good due to the fact that there are no dense materials in the entire structure (no battery). And the immunity to external interference is very good due to the fact that the DIS dosemeter does not count pulses.

At present the DIS dosemeter is already commercially available, but several studies are running to test the different characteristics. The first results show that the qualities of this dosemeter (both radiological as mechanical) are very good, nevertheless some effort has still to be done to get a better control of the fabrication process (uniformity and reliability).

The implementation of a new beta-dosemeter

For beta-radiation, the quantity to measure is $H_p(0.07)$, the dose equivalent at a depth of 0.07 mm in the body. To measure this with a TLD-badge, one not only needs a very thin filter but also a thin detector. The present SCK/CEN dosemeter consists of three TLD-700 detectors, positioned behind three filters with different thicknesses (700, 330 and 44 mg/cm²). If there is a substantial skin-dose the value of the detector behind the thinnest filter is taken as $H_p(0.07)$. The present filter is actually too thick so that doses coming from beta's and X-rays with low energies are underestimated. This can be seen in figure 2, where the results of some laboratory tests are shown.

To solve this problem a new configuration has been tested. It consists of a thinner filter (7 mg/cm²) and a new type of detector (TLD-720). This new detector has a thin sensitive layer of LiF:Mg,Ti upon an inert part of LiF. This detector has less total sensitivity, but must be relatively more sensitive to low energy radiation. This is confirmed by laboratory irradiations, as also can be seen in figure 2.

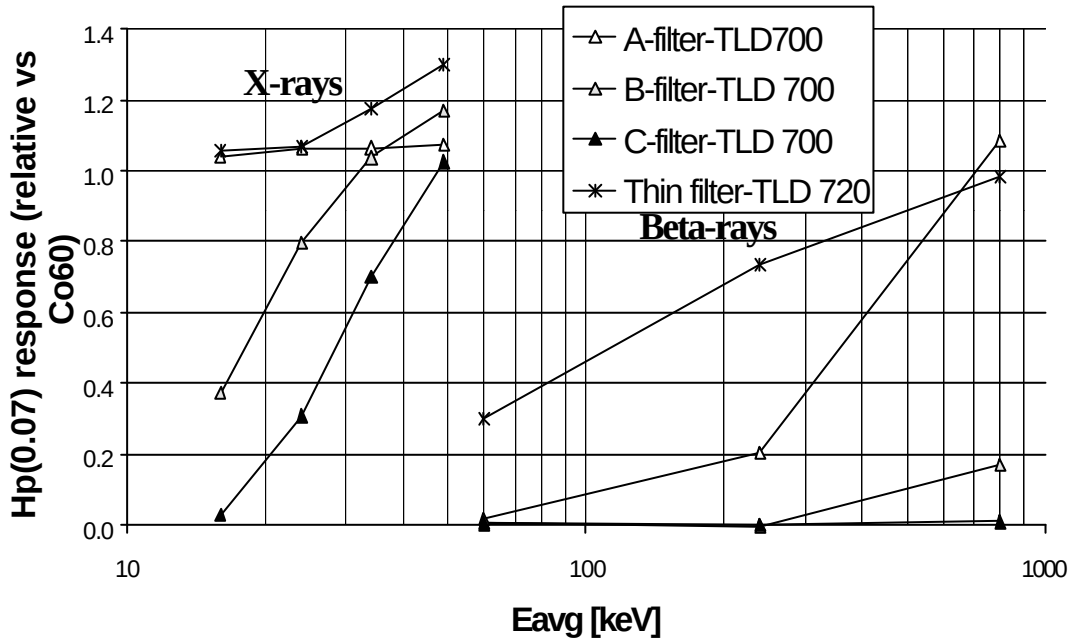

Figure 2: $H_p(0.07)$ response of different filter/detector combinations for low energy X-rays and beta-rays (relative to Co^{60})

To test this new dosemeter configuration a program was set up in collaboration with the VUB. For nine months several persons have worn two dosemeters simultaneously: one with the old, thick beta-filter, and one with the new configuration. The people chosen for the experiment were working with beta-radiation, and in lesser extent also with X-rays.

The results were that only in very few cases a small extra dose was measured with the thin filter and detector, compared to the normal ones. This can be seen in figure 3, where all the measured doses (after background subtraction) are shown. The major part of the doses are centered around zero, with a small ending towards positive doses. The absolute number of counts is lower in the new configuration, because the detector is thinner. This results in a larger uncertainty and therefor a larger spread in the results. If there would have been a considerable beta-dose burden, the results of the new configuration should be shifted compared to the normal dosemeter results. The fact that this is not the case proves that the personnel working with beta-emitters receive only very small doses from these emitters. Nevertheless it was decided to routinely provide a limited number of people with this type of dosemeter.

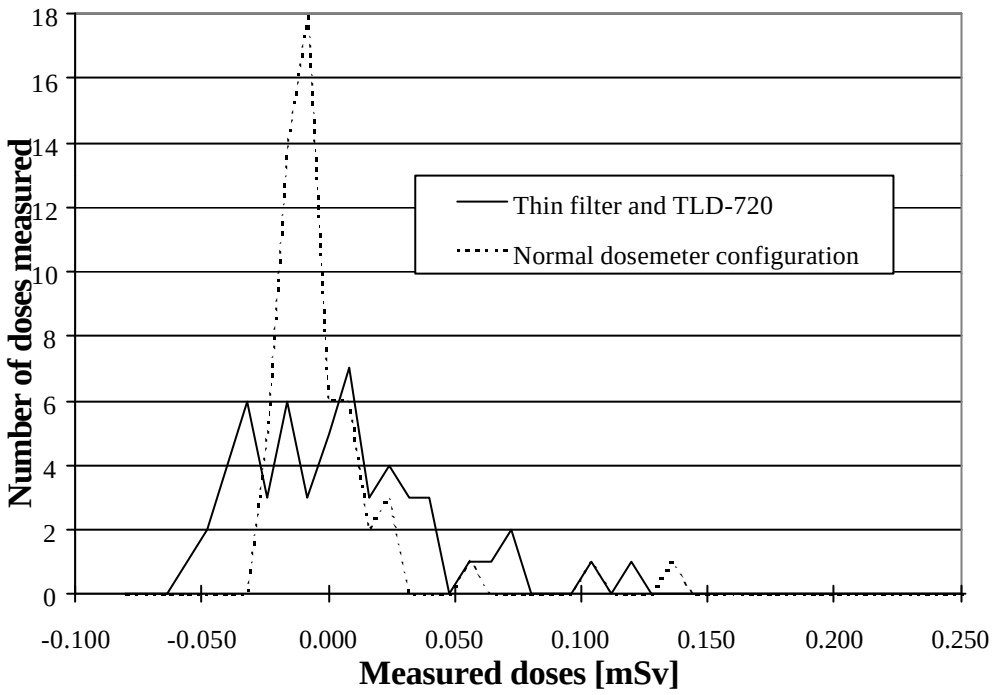

Figure 3: The results from a nine months test period of the new dosemeter configuration at the VUB

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CONDITIONS D'UTILISATION DU DOSIMETRE PERSONNEL ET INTERPRETATION DES RESULTATS : PREMIERE INTEPRETATION EN BELGIQUE

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Résumé

L'exposé se réfère à la publication du Dr A. Wambersie et J. Delhove sur « Radioprotection en Radiologie, une pratique controversée : Comment porter les dosimètre individuels » (Journal Belge de Radiologie, 1993-76).

Après un bref rappel sur la calibration des dosimètres et l'interprétation de résultats, il reprend les conclusions principales de la publication, à savoir que la mesure de la dose individuelle pose dans le domaine de la radiologie, et de la radiologie interventionnelle en particulier, un certain nombre de difficultés pratiques en cas d'utilisation d'un seul dosimètre : en particulier, lorsque le dosimètre est porté sous le tablier, la mesure faite sur le dosimètre peut conduire à une sous-estimation importante de la dose. L'utilisation de deux dosimètres s'impose dans ce cas et une formule d'interprétation de la dose avait été proposée.

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CONDITIONS FOR THE USE AND INTERPRETATION OF PERSONAL DOSEMETERS

Re-examining the problem in Belgium

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Introduction

In radiology departments a lead apron is regularly worn during examinations in angiography, cardiology, urology, gastro-intestinal examinations and pediatrics. In Belgium, when using a lead apron in radiology, the legally required dosemeter for workers is worn under the apron. It is known that the reading of a standard personal dosemeter worn under the apron gives an *under*estimation of the effective dose. However, when the dosemeter is worn on the apron, the reading will give an *over*estimation of the dose. Seventeen workers of the radiology department at the academic hospital of the Free University of Brussels (VUB), wore a second dosemeter above the lead apron in 1996 and 1997. The effective dose for these workers was derived from the readings of both dosemeters using three methods previously described in published literature. The aim of the study was to derive an accurate, feasable way to estimate the workers' exposure to ionising radiation.

The project[1]

Seventeen workers of the department of radiology and medical imaging of the academic hospital of the Free University of Brussels (VUB) who frequently wear a lead apron received a second personal dosemeter. This dosemeter was positioned on the apron at chest level, while the first dosemeter is worn at the same position under the apron. Both dosemeters were supplied by the SCK-Mol. They were handeled as standard personal dosemeters.

Three methods described in puvblished literature were used to calculate the effective dose from the dosemeter readings. The results were compared with the reading of the dosemeter under the apron, this being the value currently reported to the Belgium officials. The methods used were those of Wambersie and Delhove[2], Rosenstein and Webster[3] and Huyskens, Franken and Hummel[4].

Wambersie and Delhove defined the formula:

$$E = H_0 + \tfrac{1}{10} H_B \qquad (1)$$

Where: E = the effective dose

H_O= H(10) measured under the apron

H_B= H(10) measured on the apron

In their article Wambersie and Delhove state that the factor $\frac{1}{10}$ leads to a conservative estimation of the increased risk due to the unshielded tissues and organs.

Rosenstein and Webster derived a formula for the calculation of the effective dose from a fit on theoretical data of Faulkner[5]:

$$E = 0.5H_O + 0.025H_B \qquad (2)$$

In this formula H_O is measured under the apron at waist level

H_B is measured on the apron at the collar

The formula was corrected, using Hummel's[6] data, for dose values measured at the chest. This leads to the formula:

$$E = 0.57H_O + 0.017H_B \qquad (3)$$

Huyskens et al. presented in their article a method based on simulations. They published tables with *Divider* and *Multiplier*values. The effective dose is derived by multiplying the reading of the dosemeter under the apron by the Multiplier or by dividing the reading of the dosemeter on the apron by the Divider. The correct value of the Multiplier or Divider is chosen from tables, taking into account the energy of the beam, the type of apron (wrap around or frontal type), the lead-equivalent of the apron and the general position of the worker towards the radiation source (frontal, lateral, rear).

Pilot studies leading to this project showed that is was nescessary that each participant had his own apron. When aprons are shared by several workers in a room, errors can easily occur.

Results and discussion

Tabel 1 gives, for the 17 workers, the type of examinations they perform, the H_O, the H_B and the ratio between the two. The results show that H_B/H_O is roughly related to the type of work

Nr	Type	Ho	Hb	Ho/Hb
1	peadiatry	0	10.8	-
2	peadiatry	0.25	5.85	23
3	digestive	3.87	107	28
4	digestive	3.15	112	36
5	digestive	1.97	73.5	37
6	angiography	1.99	83.5	42
7	angiography	0.21	11.1	53
8	cardiology	1.70	8.95	5
9	cardiology	2.44	10.8	4
10	mobile x-ray	0.40	10.5	26
11	gastrology	0	2.15	-
12	gastrology	0	0.45	-
13	gastrology	1.16	24.1	21
14	gastrology	1.14	0	0
15	gastrology	0	0.60	-
16	gastrology	0	2.70	-
17	CT	0.48	4.80	10

Table 1: the type of examinations peformed by the workers, the dose under the apron (H_O) and the dose measured on the apron (H_B) in mSv and the ratio H_O/ H_B.

that is done and/or the type of apron that is worn. The table also shows that dose can be received on the apron without any indication by the dosemeter under the apron (Nr. 1, 11 and 16). It is abvious from the results that there has been a mistake in positioning the dosemeters of worker nr. 14. The dose measured under the apron is higher than that on the apron.

Nr	Wambersie	Rosenstein	Huyskens (divider)	Huyskens (multipl)
1	1.08	0.18	0.98	0
2	0.84	0.24	0.53	0.75
3	14.5	3.97	14.2	15.4
4	14.3	3.65	14.9	12.6
5	9.32	2.34	9.80	7.88
6	10.3	2.52	7.26	11.9
7	1.32	0.30	2.22	0.63
8	2.60	1.11	1.19	6.80
9	3.52	1.56	0.94	14.6
10	1.45	0.40	0.95	1.20
11	0.22	0.04	0.29	0
12	0.05	0.01	0.06	0
13	3.57	1.06	3.21	4.64
14	1.14	0.64	0	4.56
15	0.06	0.01	0.08	0
16	0.27	0.05	0.36	0
17	0.96	0.35	0.44	1.44

Table 2: Effective dose in mSv, calculated using three methods.

Tabel 2 gives the results of the calculations using the formulas of Wambersie, Rosenstein and the values for the Divider and Multiplier of Huyskens. There is a relatively good correlation between the results obtained with the formula of Wambersie and the Divider values of Huyskens. This is especially true for higher doses. The values of Rosenstein are in general only 1/3 of those of Wambersie. Table 2 shows also that the differences in results become more apparent for lower effective doses. This can be explained by the low H_O values resulting in relatively large uncertainties. The method of Huyskens using the Multiplier values is clearly not appropriate for these cases.

Nr	Deff	Ho	Deff/Ho
1	1.08	0	-
3	14.5	3.87	3.7
4	14.3	3.15	4.5
5	9.32	1.97	4.7
6	10.3	1.99	5.2
7	1.32	0.21	6.3
8	2.60	1.70	1.5
9	3.52	2.44	1.4
10	1.45	0.40	3.6
13	3.57	1.16	3.1

Table 3: Relation between the effective dose and the dose measured under the apron (in mSv).

Table 3 displays the effective dose and the dose measured under the apron for all participating workers who receive an effective dose over 1 mSv. The effective dose here is obtained using formula (1). The last column of table 3 shows the ratio of Deff to Ho. Deff/Ho is the smallest for the workers at the cardiology department (Nrs 9 and 10): ±1.5. This means that for these workers the underestimation of the dose is smallest when the dose is measured under the lead apron. Deff/Ho is largest for worker nr 7 (6.3). This worker works at the angiography department and wears a frontal apron. The large underestimation is mainly due to the dose he receives from the back.

Nr	Ho	H-cristalline	Ho [when H-crist=150]
1	0	5.1	-
3	3.87	49.9	12
4	3.15	52.2	9
5	1.97	34.3	9
6	1.99	39.0	8
7	0.21	5.2	6
8	1.70	4.2	60
9	2.44	5.1	70
10	0.40	4.9	12
13	1.16	11.3	15

Tabel 4: Dose under the apron (H_B), the dose to the cristalline and the dose under the apron if the dose to the cristallinen would be 150 mSv (in mSv).

Another parameter we can derive from doses measured on the apron is the dose to the cristalline. Hummel reported that the dose to the cristalline is roughly half of the dose measured on the chest. The relevant doses to the cristalline, calculated from the H_B, are given in tabel 4. The values in the last column of table 4 is the calculated dose under the apron if the critalline would receive a

dose limit of 150 mSv. These results indicate that the dose limit to the cristalline is not guaranteed by a general dose limit of 50 mSv if this value is measured under the apron.

Conclusions

Measurement of the dose with a single dosemeter under the apron leads to an underestimation of the dose up to a factor of 5.

Measurement of the dose under the apron leads to the loss of information on the dose to the cristalline. This information is important because the limiting factor in radiation protection seems to be dose limit to the cristalline and not the general dose limit of 50 mSv.

Correction of the dose measured is not always possible due to the detection limit.

The procedures for dose correction of Wambersie and of Huyskens lead to consistent results.

The formula of Wambersie seems the most feasable to use in daily practice.

Dosimetry performed with a single unshielded dosemeter has the disadvantage that errors are difficult to detect.

Recommendations

When a lead apron is worn in daily routine, the use of two dosemeters is recommended.

The exact interpretation of the results of dosimetry using two dosemeters should be performed by a local expert (i.e. the medical physicist of the department).

An evaluation of the dose to the cristalline is essential when fluoroscopy is performed regulary.

Detailed information on the received dose is valuable in the process of improving the attitude towards radiation protection.

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POINT OF VIEW OF A FRENCH EXPERT

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In France, radiation protection is supervised by a competent person (in radiation protection) appointed by the director. This nomination is mandatory in each hospital and since the decree of October 86 the roll of this competent person has been precisely defined [1].
He must : - analyse periodically the working conditions in order to apply the ALARA principle, - ascertain that the regulation in radiation protection is repected, - identify the situations where accidental exposures can occur, - and train the workers.

In practice only few competent persons have human and material means to perform these duties and this may explain why studies on worker dosimetry are rare in France.

Table I presents the radiological equipment in France at the end of 1996 [2]. The installations for interventional radiology (IR) are classified as heavy installations.

Table I : Type and number of radiological installation in France on 31/12/96 (data from OPRI*)

Type of installation		Number of installation (31/12/96)
Radioscopy		979
Diagnostic radiology	«light»	3 875
Diagnostic radiology	«heavy»	12 129
Mammography		2 626
Dental		36 415
CT		563

* Office de protection contre les Rayonnements ionisants

The number of exposed workers, in fact the workers classified category A and wearing a film badge, is presented in table II. These data are the official data of the national authority (OPRI) and concern the chest exposure measured with a film badge. In order to compare radiology with the other applications of ionizing radiations we have also reported the data concerning radiotherapy and nuclear medicine. One can see that more than 70 % of workers are involved in radiology and that the collective dose is mainly due to this domain. Moreover, few persons have exposure above 20 and 50 mSv.

Table II : Data concerning the worker exposure in medical field in France in 1996

Activity	Number of workers	Collective dose (man.Sv)	Number of workers	
			H > 20 mSv	H > 50 mSv
Radiology	87 733	17	107	36
Dental	20 515	1,3	7	4
Radiotherapy	8 305	2,3	12	2
Nuclear Medicine	4 264	2,4	13	0

If we classify the workers by exposure level, more than 95 % of workers are exposed to a level lower than the registration level of film badge (0.2 mSv).

The previous data were obtained from the legal dosimeter in France, the film badge worn at chest level. In practice this device has some limitations and the information obtained cannot be, especially in Radiology, a correct estimation of the effective dose. As a matter of fact, the badge must be worn under the apron and so it does not reflect the non uniform exposure of the operator. Moreover, its size is unsuited for extremities. So, it does not allow to estimate the effective dose.

The non uniform exposure is very characteristic of the working conditions in radiology where one can find very different conditions of exposure :

- for normal radiography, the shielding offers total protection,
- for some other practices when the operator is near the patient and the X-ray beam, the worker can be exposed to the scattered beam and the extremities sometimes to the primary beam. This is especially true in interventional radiology.

Some studies have been conducted in addition to the legal survey in order to analyse the working conditions of the most exposed workers. The following data concern the main results of some French groups. The majority of these studies has been performed with thermoluminescent dosimeters. A study carried out at the hospital of Orleans shows that for retrograde endoscopic cholangio-pancreatographies (RECP), the maximal of exposure is at the level of forehead or eyes, 35.2 and 26.4 mSv/year respectively [3]. Another multicenter study conducted in vascular radiology also shows that the forehead is the most exposed organ with 0.7 mSv/procedure [4]. In a study on 29 coronarography procedures at the hospital of Reims, the most exposed organ was the left wrist with 0.48 mSv/procedure [5]. At the hospital Broussais where vascular and cardiac IR are performed a maximum of 6.1 mSv has been measured with TLD in peripheral vascular radiology. Another approach with a film badge at wrist has shown for one operator practising all types of radiological procedures an exposure of 63 mSv for one month [6].

In our institute we carry out mainly urinary and biliary tract procedures and no cardiac procedures. We classified these procedures in remote procedures (RP) when the operator is far from the X ray beam and in close procedures (CP) when the operator is near the X ray beam.In these last cases, hands can be exposed to the primary beam. For RP, the maximal value was obtained for the left index finger with more than 600 µSv/procedure. For CP, hands can be exposed to the primary beam and, in these conditions, very high exposures have been measured, with a maximum of 125 mSv/procedure at left index. This data concerns procedures performed with an over couch tube.

If we draw up a balance sheet of these studies one can say that worker exposure in IR is closely depending on procedure :

- for cardiac procedures, where the operator is away from the irradiated area, eye dose is the limiting factor,
- for non cardiac procedures, where the operator can be close to the irradiated are, hand dose is often the limiting factor.

A potential of relatively high doses exists in IR, with doses varying due to the range of procedures, and depending : - on the experience of the operator, - the type of procedure and, - how close the hands are to the beam. The previous exposure data raise the following questions : - which are the risks in radiology and especially in IR ? and, - which quantity should be measured ? Taking into account the highest results obtained in some interventional procedures, there are risks of deterministic effects for hands. For radiation protection purposes we have to use the effective dose, E. To evaluate this quantity one needs to know the exposure values of the organs considered in the calculation of E and therefore exposure of organs that can be shielded or not. The legal dosimeter worn at chest level under the apron is not sufficient. The dosimetry of workers in radiology, and also in other fields such as nuclear medicine and brachytherapy, needs electronic or thermoluminescent dosimeters in addition to the film badge

In conclusion, some recommandations can be given for worker dosimetry in radiology. First of all, it is necessary to clarify the definition of category A in order to limit the number of such workers and thus increase the means and time for the survey of workers who are regularly exposed. Then, additional dosimeters must be used routinely, at shoulder level above the apron and, if necessary, at wrist or finger level. The last recommandation concerns the training and continuing education of all the workers including radiographers, radiologists and non radiologists. This training must emphasize the optimisation principle in order to move away from the limitation principle which is, unfortunately, today the principle of radiation protection mainly used in medicine in France.

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CONDITIONS FOR USE AND INTERPRETATION OF THE PERSONAL BADGE

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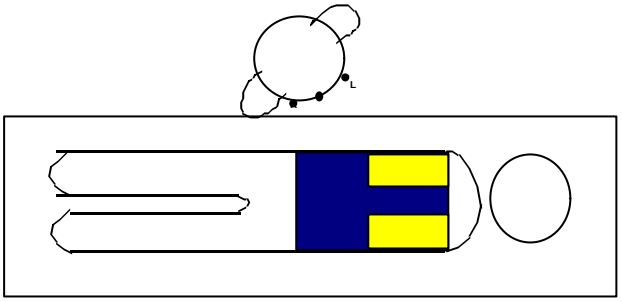
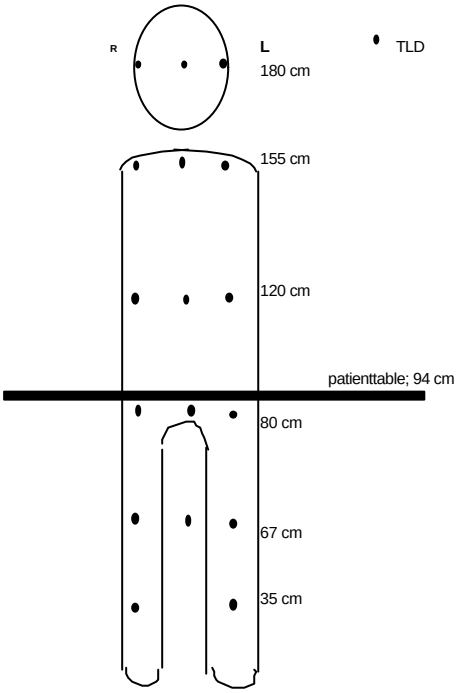
During examinations that involve a significant level of exposure, radiology staff wear protective aprons and the dose distribution in the investigation room is strongly dependent on the position. The resulting body exposure is extremly non-uniform, because of the relative short distance to the radiation source (the scattered radiation from the patient) and the attenuation of the scattered radiation by protective shielding. The conversion of the registered dose measurement on the personal badge to effective dose varies with the lead thickness of the apron and depends on body orientation in relation to X-ray projection or gantry setting. The size and fit of the protective apron is also an important factor, because that defines the actual protective effect of the apron in a particular exposure geometry.

Huyskens e.a[1] developed a computermodel to calculate equivalent organ dose as a function of the X-ray energy spectrum, shielding parameters and exposure geometry. They also defined two conversion factors (divider and multiplier) for the assesment of effective dose from single badge depth-dose measurements. Both conversion factors depend on the model, size and fit of the lead apron, the lead thickness and the exposure geometry and are based on the assumption that the badge is worn on the ventral side of the body. When the badge is positioned outside the lead apron a division factor, the divider, can be used. On the other hand, when the badge is shielded by the lead apron a multiplication factor, the multiplier, has to be used.
Additional to these conversion factors a protection factor is calculated, which describes the actual protective effect of a particular apron in a particular exposure situation.

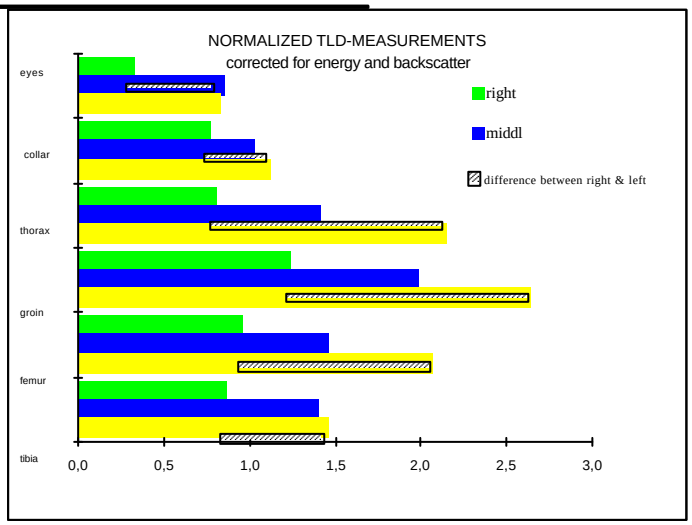
To estimate a reliable effective dose for occupational exposed persons a better insight in the exposure-distribution over the body of the investigator is neccesary.
Therefore phantom measurements were perfomed at the University Hospital Rotterdam (Thoraxcenter) in co-operation with the Eindhoven University of Technology (Radiation Protection Department)[2]. To simulate actual medical practice as closely as possible measurements were performed conform a reference protocol. Because the radiation dose for patients and for staff members are much higher in interventional radiology than in conventional general radiography, the composed reference protocol was based on detailed data from the course of 125 cardiological patient procedures[2]. During the measurements a perspex (PMMA) phantom was used to simulate the patient. A self-made phantom was designed in such a way that automatic adjusted tube settings correspond to realistic values for



Position of the dummy user in relation to the phantom



18 TLD were placed on the dummy user at 6 different levels



Measured dose values at various positions at the body

The representation of the dose values is relative to the dose measured at collar height in the middle

a standard adult. A dummy user was positioned to the right of the phantom at 75 cm of the isocenter (figure 1). To measure the occupational dose and the dose distribution 18 calibrated TLD personal dosimeters were attached to the dummy user at 6 different levels, corresponding to the eyes, collar, thorax, groin, femur and tibia (figure 2). Some important conclusions can be drawn from this study. Two of them are only mentioned here, firstly the gantry position, in casu the place of the X-ray tube, has a large influence on the dose distribution. Secondly the pattern of the dose distribution is fairly independent of the X-ray exposure parameters, (kV, mA, tube filtration), but these parameters have for sure a large influence on the absolute dose.
An other important finding was that measured dose value is depending on the position of the dosimeter (figure 3), roughly speaking there is a variation of a factor of 2 between right and left at the body and also a factor of 2 between high and low of the body. The precise variation is depending on the exposure orientation.
These findings underline why “at the collar” above the lead apron is a recommendable position for a personal dosimeter in the practice of interventional radiology. At that position minimal angular variations occur. But these findings underline also that so-called single badge personal dosimetry can be highly inaccurate for the dose assesment of the doctor in interventionel radiology, because of the variation in dose-distribution depending on the position of the X-ray tube.

Based on the phantom measurements and the results of the computermodel the following recommendation can be made:
For single badge dosimetry, the best place to wear this badge is outside the apron “mid-front” at collar or chest. The effective dose E_{dose} can than be estimated from the registered unshielded badge depth-dose $H_p(10)$ by:

$$E_{dose} \simeq 1/5 * H_p(10) \qquad (1)$$

The divider of 5 gives a conservative approximation of the effective dose.

Dual badge dosimetry is recommended when the estimated annual effective dose may amount to a substantional fraction of the occupational dose limit.
The effective dose E_{dose} can than be estimated by:

$$E_{dose} \simeq 1/10 * H_{p,unshielded}(10) + H_{p,shielded}(10) \qquad (2)$$

The emperical formula (2) applies to aprons without neck-shielding, for lead thickness above 0.15 mm, on the condition that the type of apron suits the exposure geometry[3].

Beside the knowledge of how to convert the badge depth-dose into an approximation of the corresponding effective dose, it is also important to have some information about the level of exposure to the staff members per investigation. From the phantom measurements and from measurements in actual practice[4] some fit-functions were derived[5] to calculate the badge depth-dose at collar level. The analysis of the data of both measurements was focussed on finding correlation with the fluoroscopy time and cine-film length, using linear regression analysis. This leads to the following emperical equations which enables the assesment of the unshielded badge depth-dose, worn at the collar on 0.75 m distance from the centre of the X-ray beam:

$$H_{p,unshielded}(10) \simeq FT/100 + CL/400 \quad (3)$$

FT = fluoroscopy time in minutes

CL = cine-film length in meters (1 meter is 52 pictures)

For continuous and pulsed fluoroscopy with 25 frames per second

$$H_{p,unshielded}(10) \simeq FT/175 + CL/400 \quad (4)$$

FT = fluoroscopy time in minutes

CL = cine-film length in meters (1 meter is 52 pictures)

For pulsed fluoroscopy with 12.5 frames per second

With these equations the badge depth-dose values for almoust 3000 cardiac procedures were calculated. All cardiac procedures taken into account, the mean value is 0.16 mSv per procedure with a standard deviation of 0.11 mSv. The uncertainty in the calculated values for the badge depth-dose at reference position is approximately 30%. Due to deviations from the assumed reference conditions, the uncertainties in practical circumstances are larger, therefore a provisionally account of a factor of 2 uncertainty up and downwords should be used. Comparison with the values that are measured in pratical circumstances[4] shows that the calculated values are almost a factor of 2 higher. Comparison with the mean badge depth-dose per investigation for cardiologists in a hospital in the North of Holland shows a larger difference, the measured mean value was 0.05 mSv. The use of a lead-glass connected to the ceiling lowered the mean badge depth-dose per investigation to 0.03 mSv.

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Workshop "Dosimetry of workers in Radiology"
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Final discussion

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The final discussion is structured around four topics:
1. the quantities to measure
2. the dosimeter (energy response and sensitivity)
3. heterogeneous dose distributions
4. special topics

1. What quantity should be measured for an effective protection of workers?

The effective dose, as defined by the ICRP is the best estimation of the risk from exposure to ionising radiation, however this quantity can not be measured directly. Several parameters (energy, exposure direction, exposure size) must be known in order to calculate the effective dose. In general this information is not available from working conditions.
The participants to the discussion agree that the skin dose and the depth dose at 1 cm are valuable and applicable quantities for dosimetry of workers.
The $H_{0.1}$ and H_{10} as defined by the ICRU should be promoted as the official quantities for dosimetry of workers in Belgium.

2. Dosimetry considerations with respect to the sensitivity and energy response?

a. Sensitivity

As was presented by Mr. Vanhavere, modern dosimetry systems are available with very low threshold doses and a flat energy response over a wide energy range. A modern TLD dosimetry system can detect doses as low as 30 - 40 µSv.
The threshold value applied for the dosimetry of workers in Belgium is between 100 and 200 µSv.
Some of the participants to the discussion are in favour to decrease this threshold to 50 µSv. The main argument for a decrease is the application of the ALARA principle. The detection of doses as low as 15 µSv allows optimisation of procedures at these low doses.
Also, a lower threshold makes more workers aware of them being exposed to radiation. With a threshold of 100 µSv, workers can receive a dose up to 1.2 mSv without any dosimeter reading (the 'null-effect'). The SCK/CEN has lowered its threshold dose to 50 µSv on demand of the AZ-VUB for its workers. The reactions are positive, the confidence in dosimetry has increased. An information campaign should accompany such an action, informing the workers that e.g. they do not have to worry about a dose of 0.1 mSv.
Not all participants agree on decreasing the threshold dose. One of the arguments against it, is that very low doses give more information about fluctuations in the background than about the dose received by the workers. Mr. Vanhavere, who has experience with sensitive dosimetry systems does not agree with this point of view.

It is also stated that the cost of the dosimetry would increase with the sensitivity. However, this seems not to be the case in practice. The dosimetry system (automatic reader, TLD's) is expensive. The actual cost per reading is not necessarily more than that of reading a film dosimeter. On the contrary, a TLD can be re-used, a film not.
A practical problem of lowering the threshold dose is that the sensitivity of film dosemeters, now used for the majority of the workers in Belgium, is not high enough.

b. Energy response.

All participants agree on the fact that information is needed on the energy of the absorbed radiation. This is essential for calculating the absorption of energy in depth. All dosimeter systems used today consist of several dosimeters mounted behind windows of different materials. These give information on the dose from different energy bands. In film dosimetry 5 windows are used, TLD dosimeters use four windows.
The participants do not agree on the way this information should be presented. One option is to present to each worker the absorbed dose in three energy intervals: low, medium and high.
Another point of view is that the energy distribution is taken into account in the quantity of the depth dose (H_{10}).

3. Heterogeneity of Dose distributions

a. Lead aprons

When the body is partly shielded (e.g. by a lead apron), the dose distribution will not be homogeneous. The participants agree that it is not possible to estimate the dose to non protected organs from the dose to protected organs. In such case, A second dosimeter should be used.
The participants agree on the formula of Wambersie and Delhove to calculate the effective dose from two dosimeters readings.

$$E = H_O + \tfrac{1}{10} H_B$$

Where: E = the effective dose
H_O= the H_{10} measured under the apron
H_B= the H_{10} measured over the apron

The participants do not agree on the criteria to wear a second dosimeter. Workers that regularly wear a lead apron as in interventional radiology and cardiology are clearly defined. Less well defined groups are workers in digestive examination rooms, urology and paediatrics.
Three options were proposed during the discussion:

1. Workers with a dosimeter reading under the apron exceeding a certain level should wear second dosemeter on the apron.
2. All workers wearing regulary an apron have to wear a second dosimeter.
3. Members of certain risk groups have to wear a second dosimeter all the time. Risk groups are defined as workers in interventional radiology and cardiology.

Most participants are in favour of the first option: Workers that wear an apron frequently during examinations should wear two dosimeters. Other workers should wear their dosimeter *under* the apron.

b. Doses to hands and fingers

It is mentioned during the morning session that the dose to the hands can exceed the dose limit for the skin, especially in interventional radiology. For all kinds of reasons, finger dosimeters are hardly used. In some cases wrist dosimeters are used. However, these give a very poor indication of the dose to the fingers. Sterilisation of dosemeters is considered as a practical problem. Some participants argue for a more frequent use of finger dosimeters in interventional radiology.

c. In general:

There is a need for clear recommendations concerning the use of personal dosimeters. The participants propose that the authorities publish guidelines on the protection of workers in radiology. Attention should be given to:

- the use of protective garments: aprons, glasses, gloves, neck shielding.
- the use of dosimeters:
  - -position
  - -when and where to wear a second one
  - -finger and wrist dosimeters

4 Special topics

a. Dosimeters and low doses

A large group of workers in radiology receives a year dose below 5 mSv. Do they have to wear a dosimeter? Some participants propose that it may be interesting to place an area dosimeter in the x-ray rooms where these workers operate behind the screen.

An alternative proposal is to give these workers a dosimeter every three months instead of every month. The cost saving of such measures could compensate for the extra cost of double dosimetry in the cases mentioned above.

b. Pregnant workers.

In Belgium a woman is replaced from a controlled area once she indicates that she is pregnant. In other countries (e.g. The Netherlands) pregnant workers can continue working if they do not receive a dose higher than 1 mSv/year. This dose is measured at the waist. Dutch women can even continue working in digestive radiology, when wearing appropriate shielding. This approach is in line with the European directive. This allows pregnant radiological workers to continue work with adequate protection.

A Belgian occupational physician disagrees with this point of view. His opinion is that even if the risk for complications from radiation is very low, it will never be zero. If a child is born with malformations, who can bear the responsibility? It will never be clear that the malformations are not due to the radiation. Therefore he pleads that pregnant workers continue to be replaced from the controlled areas.

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