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and Nuclear Safety Agency

TECHNICAL REPORT

# Personal Radiation Monitoring Service and Assessment of Doses Received by Radiation Workers (2004)

*Neil D Morris, Peter D Thomas  
and Kevin P Rafferty*

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**Australian Government**

**Australian Radiation Protection and Nuclear Safety Agency**

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**by**

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## **Preface**

This report is an update of ARL/TR121 (Morris 1996) which included data for the year 1996. Since 1996, the Personal Radiation Monitoring Service operated by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) has increased the number of workers monitored by about 6%. It now covers approximately 35,000 occupationally exposed workers throughout Australia and Papua New Guinea.

## **Introduction**

Exposure to radiation can cause genetic effects or cancer. People who use sources of radiation as part of their employment are potentially at a greater risk than others owing to their being continually exposed to small radiation doses over a long period of time.

In Australia, the ARPANSA and the National Occupational Health and Safety Commission (NOHSC) establish radiation protection standards and set annual effective dose limits for radiation workers in order to minimise the chance of adverse effects occurring (Radiation Protection Series No. 1). These standards are based on the recommendations of the International Commission on Radiological Protection Publication 60 (ICRP 1990).

In order to ensure that the prescribed limits are not exceeded and to ensure that doses are kept to a minimum, some sort of monitoring is necessary. For exposure to external radiation, personal monitoring is recommended.

# 1. The ARPANSA Personal Radiation Monitoring Service

The Personal Radiation Monitoring Service (PRMS) has been in continuous operation since 1932. The Service enables people working with radiation to determine the radiation doses that they receive due to their occupation.

Since 1986, all persons regularly monitored by the Service have been registered on a database that maintains records of the doses received by each individual wearer. At present, the Service regularly monitors approximately 35,000 persons and maintains dose histories of over 115,000 people.

## 1.1 Monitors Available

The radiation doses received by occupationally exposed workers can be measured by using one of the five types of monitor issued by the Service:



The **Thermoluminescent dosimeter (TLD monitor)** is the most commonly used with about 175,000 issued annually. The badge is comprised of a thermoluminescent dosimeter (TLD) card, which is placed in a holder that incorporates a filter system. This allows the radiation type and energy to be determined. It is used to determine the whole body exposure of people who may be exposed to beta, gamma or X-rays. It can be worn for a 4, 8 or 12 weekly wearing period, depending on the work carried out and any restrictions placed on the wearing period by the Regulatory Authority in each State or Territory.

The **Extremity (or Finger) TLD** is used by persons who may be exposed to significant doses to the fingers or other extremities. The monitor consists of a small plastic sachet containing a TLD. It can be chemically disinfected. It measures exposure to beta, gamma or x-rays and is worn for a 4 weekly wearing period.



The **Neutron monitor** is used to measure the doses received by people exposed to a combined field of fast neutrons, beta and gamma rays. It is worn for a 4, 8 or 12 weekly wearing period. The badge consists of a neutron sensitive plastic (CR39) and a TLD card loaded inside a plastic holder prior to issue. It is used by persons potentially exposed to fast neutrons produced from certain radioactive sources such as americium/beryllium or californium-252 or those emitted from certain high-energy particle accelerators, neutron generators or moisture density gauges.

The **Special TLD** is a monitor constructed within the Service prior to issue. It is comprised of a TLD Badge that is sealed in a plastic envelope. The badge is used in special situations such as in uranium and mineral sand mining operations where conditions may be dusty and in laboratories where there is a significant risk of radioactive contamination. In uranium or mineral sands mining areas, the monitors may be stored in areas that have elevated background radiation levels. These monitors require a special assessment procedure. The monitor is normally worn for periods of between 1 and 3 months and may also be used as an **Environmental** area monitor.



## 1.2 Wearing periods

The choice of wearing period depends on a number of factors. As radiation has the potential to cause adverse health effects, it is necessary to try to minimise the doses received. An investigation of the causes of radiation doses may be hampered if the wearing period is too long. The Licensing Authority may also restrict the length of the wearing period.

Wearing monitors longer than the recommended wearing period can also affect the accuracy of the reported doses. This is due to the build-up of background radiation on the monitors and the fading of the radiation doses with time. The annual background radiation dose is approximately 1 to 2 millisieverts (mSv) each year.

An extra monitor is always issued to each establishment to act as a control. This monitor is always labelled Control A. The control is used in the assessment of doses received by the other monitors and serves as a means of determining the background radiation level or transit dose to which the batch as a whole is exposed. It will also assist in determining if the batch is accidentally exposed to radiation at any time. Any reading from a worn monitor that is statistically different from the control is assumed to be due to occupational exposure provided that certain consistency checks are also satisfied.

The integrity of the doses reported is of the highest importance. The PRMS is accredited by the National Association of Testing Authorities (NATA Accredited Laboratory Number 14442). All measurements are performed in accordance with the NATA requirements which include the requirements of the Standard "General requirements for the competence of testing and calibration laboratories" (ISO/IEC 17025). All doses are traceable to Australian Primary Standards. A comprehensive quality assurance program is also maintained in order to ensure the reliability of the Service.



## 2. How the Monitors Work – A Technical Description of the Monitors

When certain crystals are exposed to radiation, some of the radiation energy is trapped within the crystal structure. If the crystals are subsequently heated, the trapped energy is released from the crystal structure in the form of light. The amount of light emitted is dependent on the radiation exposure that the crystal has received. If the amount of light emitted is measured it will be proportional to the radiation dose received. This method of radiation detection is called thermo-luminescent dosimetry (TLD)

### 2.1 Thermoluminescent dosimeter (TLD monitor)

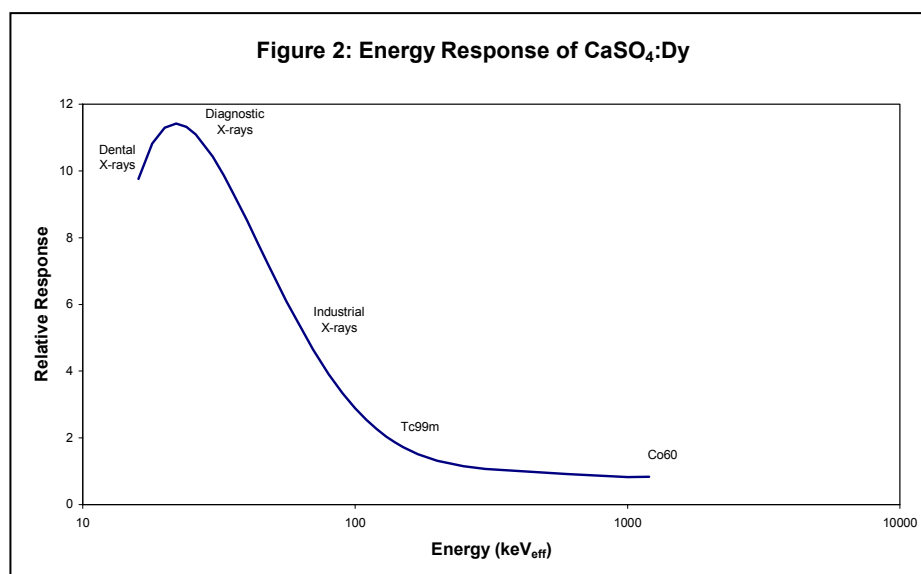
The TLD monitor consists of a TLD card sealed into a Tyvek® (DuPont) envelope, which is then placed inside a plastic TLD holder. The doses are determined by the measurement of the light output from the TLD card when it is heated through a specific temperature cycle.



**Figure 1**

The TLD card comprises 8 elements of  $\text{CaSO}_4:\text{Dy}$  in a PTFE matrix mounted in an aluminium frame and has a uniquely numbered barcode that can be read automatically. The radiation dose can be measured in four discrete primary areas of the card with another four areas acting as a backup. The card is shown in Figure 1. After readout, the card can be annealed to get rid of any residual reading and then re-issued. A TLD card can go through this readout/anneal cycle more than 500 times.

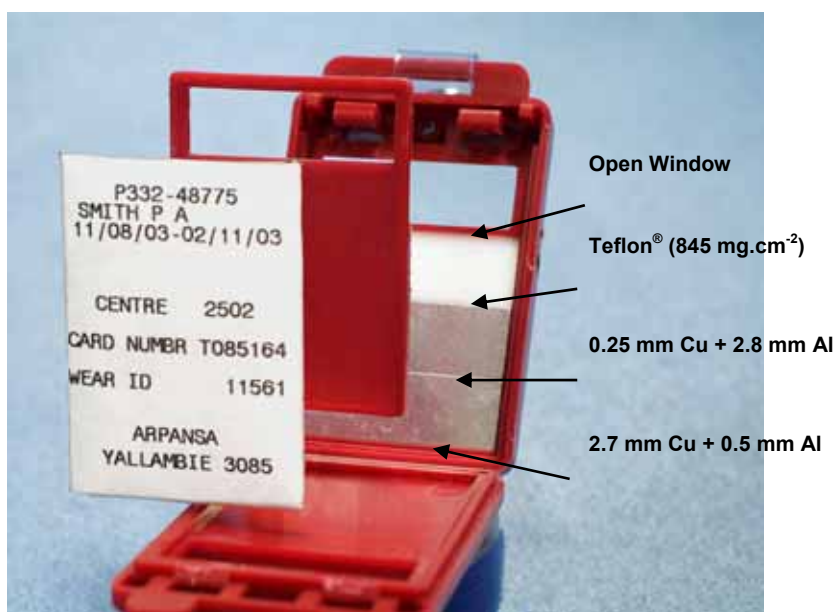
$\text{CaSO}_4:\text{Dy}$  is a sensitive TLD material and this allows for a low minimum detectable dose but has the disadvantage that its response is extremely energy dependent. A graph of the energy response of TLD cards that were exposed to the same dose of radiation is given in Figure 2. The peak of the graph coincides with diagnostic X-ray energies and is approximately ten times the response that would result from the same dose of high-energy gamma rays.



It is also possible to use the TLD cards to assess beta ray doses provided that the beta ray energy is greater than 70 keV. Beta rays below this energy will not penetrate the Tyvek® envelope and reach the TLD card.

In order to determine the actual dose that the monitor received, it is necessary to take into account the difference in response of the TLD to different types of radiation and different radiation energies. Knowledge of the type of radiation and radiation energy to which the TLD card was exposed is therefore important and the user is always asked to specify the radiation sources used.

An estimate of the type and energy of the radiation to which the TLD card was exposed can be made if the card is placed in a holder that contains filters of different materials to attenuate the radiation beam to differing extents. The holder used in the Service is illustrated in Figure 3.



**Figure 3**

## **2.2 Extremity (or Finger) TLD**

The extremity monitor consists of either a disc of LiF:Mg,Ti in a PTFE matrix or a small square chip of LiF:Mg,Ti mounted on a kapton strip, known as a chipstrate, which is inserted into a flexible plastic sachet. The sachet can be wrapped around a finger and taped together to make a ring. The LiF:Mg,Ti disc and chipstrate that are used in the extremity monitors are shown in Figure 4.

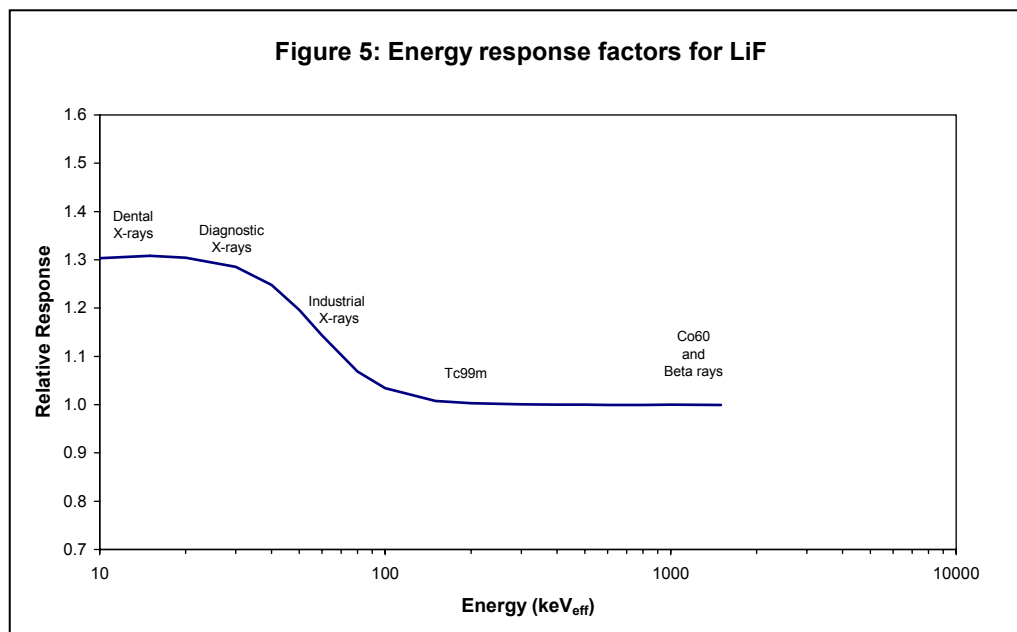
Extremity monitors are generally worn by people handling high activity radioactive sources, such as those used in the treatment of patients, or by people using X-ray diffraction units, where there is the possibility that the wearer may get a high dose to the fingers.



**Figure 4**

LiF:Mg,Ti is used as the TLD material as it is relatively energy independent compared to the response of CaSO<sub>4</sub>:Dy; the sensitivity at 20 keV is only about 30% higher than it is for high energy photons. The minimum detectable dose is greater than that of CaSO<sub>4</sub>:Dy, particularly for X-rays, however this is not a significant disadvantage as the dose limit for the extremities is 25 times greater than for the

whole body. A graph of the energy response of LiF:Mg,Ti dosimeters that were exposed to the same dose of radiation is given in Figure 5.

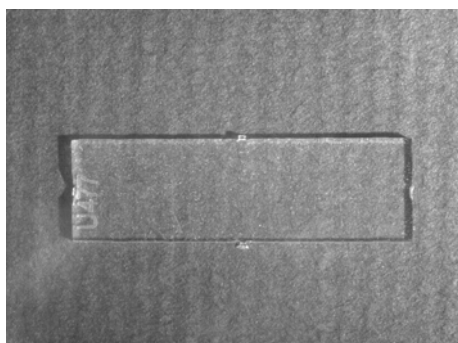


The Extremity (or Finger) TLD is also sensitive to beta rays that have an energy greater than 70 keV and to gamma and X-rays, but as it has no filtration system the accuracy of the assessment depends on the user correctly identifying the radiation sources used.

### 2.3 Neutron monitor

The neutron monitor consists of a TLD card for the detection of photon and beta radiation and a plaque of CR-39 plastic, which is sensitive to fast neutrons. The card and the plaque are placed in a specially modified holder similar to that used with the TLD monitor.

The neutron monitor is constructed prior to issue. Each CR-39 plaque is uniquely numbered for identification purposes. A CR-39 plaque is shown in Figure 6.

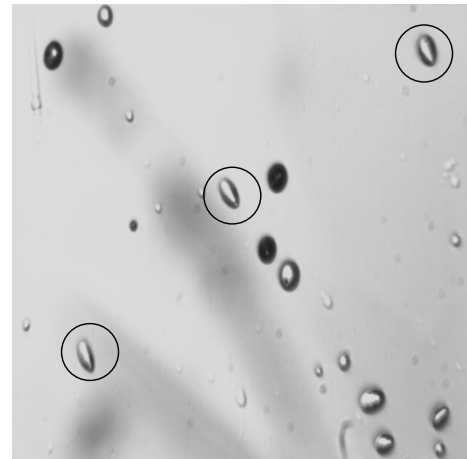


**Figure 6**

The photon and beta ray doses are measured in the same manner as described previously for the TLD monitor.

The neutron monitor is routinely calibrated using an Americium/Beryllium source and is sensitive to neutrons of energies ranging from 150 keV to 15 MeV.

The fast neutron dose is measured using the CR-39 plastic plaque. When neutrons interact with CR-39, proton recoil produces events in the plastic that are visible through a microscope after the plastic has been etched overnight by a concentrated potassium hydroxide solution. The events can be recognised by their shape, which may be elliptical or conical. The number of events per unit area is proportional to the neutron dose received by the plastic. A magnified view of an etched CR-39 plaque is shown in Figure 7. The neutron events are circled. The other events are not positively identifiable as being due to neutrons and are, therefore, not measured.



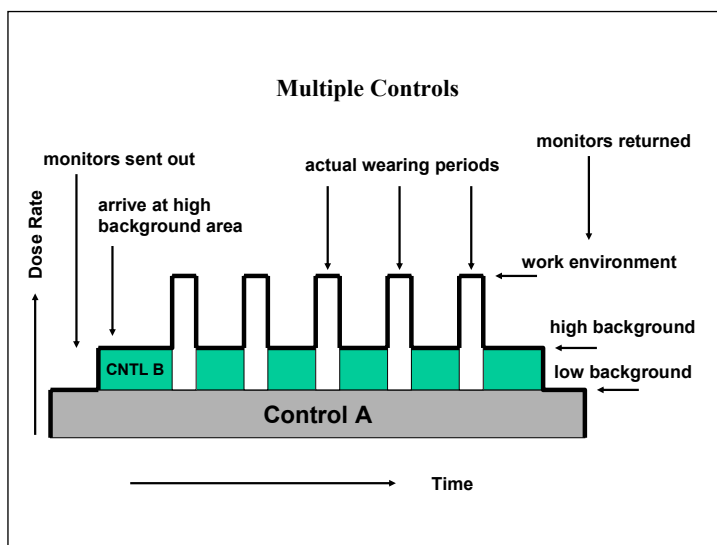
**Figure 7**

## 2.4 Special TLD

The Special TLD monitor consists of an assembly of a TLD card and a TLD holder. The monitor is assembled prior to issue. It is sealed into a plastic envelope so that, when the monitor is used in a dirty or dusty environment, the monitor itself cannot become contaminated.

The monitor is often issued to uranium or mineral sand mining establishments, which have the added difficulty that the monitors could be stored in a high background area when not being worn. Consequently, more than one control monitor may be issued. The extra controls are labelled “B”, “C”, etc.

The Control A is used to measure the normal background radiation level or doses received in transit and must be stored in a low background area. The Control B measures the high background area where the worn monitors are stored. It helps to separate the dose that the wearer actually received from that which their monitor received while it was stored in the high background area.



**Figure 8**

Figure 8 demonstrates the problem. The grey shaded area is the exposure received by Control A, the green area is the extra exposure received by Control B above the Control A exposure, due to the higher background area in which it is stored. The white area is the occupational dose that the wearer received. The total number of hours worked in the wearing period by the wearer is also required.

The wearer dose is calculated in the following manner:

$$DOSE = (R - C_A) - (C_B - C_A) \times \frac{(WP \times 168 - TSH)}{WP \times 168}$$

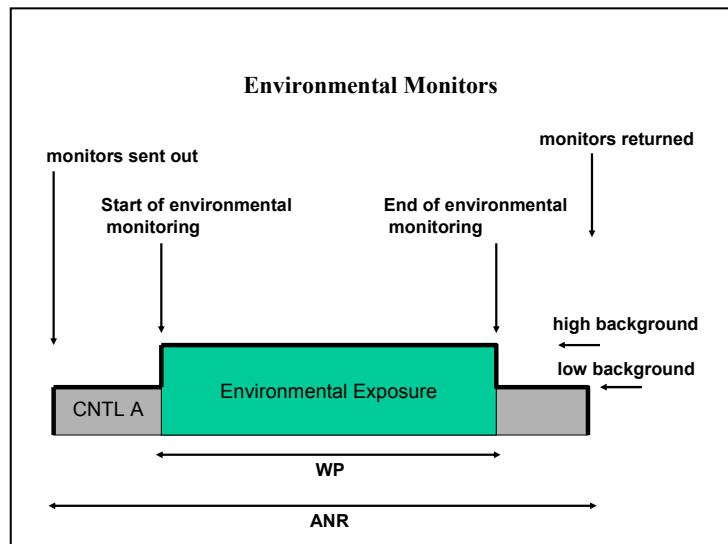
where: R is the total dose recorded by the worn monitor  
 $C_B$  is the dose recorded by the Control B monitor  
 $C_A$  is the dose recorded by the Control A monitor  
 WP is the wearing period in weeks (168 hours per week)  
 TSH is the total number of hours worked during the wearing period

## 2.5 Environmental Monitor

The Special TLD monitor can also be used to measure the environmental dose at a site. The environmental dose is the total photon dose recorded at the site for the period that the monitor is in place and includes the normal background radiation.

The Control A is used to measure the dose received by the environmental monitor during transit.

Figure 9 demonstrates the calculation of the environmental dose, where the green shaded area is the total environmental exposure measured and the grey area is the exposure received by the Control A during transit.



**Figure 9**

The environmental dose is calculated in the following manner:

$$DOSE = R - C_A \times \frac{(ANR - WP)}{ANR}$$

where: R is the total dose recorded by the environmental monitor  
 $C_A$  is the dose recorded by the Control A monitor  
 WP is the wearing period in weeks  
 ANR is the period, in weeks, between the date of preparation of the monitor and the date that it is read out.

## 2.6 Estimation of the Radiation Energy

Measurements are made on the TLD card in the four areas that correspond to the filtered areas in the TLD holder.

All radiation will interact with the part of the TLD card behind the open window area. The thick plastic area will effectively stop any beta rays getting to the TLD card and will attenuate gamma and X-rays to a small extent. The filter that is predominantly aluminium will reduce the photon radiation reaching the TLD card for energies of less than 60 keV and the predominantly copper filter will significantly reduce the photon radiation reaching the TLD card for energies of less than 150 keV. Consequently, by taking ratios of measurements made on the TLD card which correspond to these four areas, the type of radiation can be distinguished and an effective energy estimated.

When the radiation listed by the user differs from the estimated radiation energy as determined from the TLD measurements, a comment to that effect can be included on the dose report. This may help the wearer to determine the cause of the dose received.

## 2.7 Method of Calculating a Radiation Dose

For the TLD monitor, Special TLD monitor and Neutron monitor, the TLD measurements are made on a Teledyne 300 TLD reader. As each TLD card passes through the machine, the four sensors on each card which correspond to the four filtered areas in the holder are individually heated producing four readings which are related to the dose received by the monitor and the amount of filtering.

The readings on a worn monitor will be reported as a radiation dose if they are statistically different from the readings on the control and if the readings from the different filtered areas of the holder also obey a specific relationship.

In order to convert the readings on the worn monitor to a dose, the effective radiation energy must be estimated. The energy is determined from the relationship between the four readings and checked against the information about the type of radiation used which is provided by the wearer on the forms returned with the monitors. The estimated energy of the radiation used also has to be consistent with that expected for the particular occupational classification for that wearer.

Once the effective radiation energy has been estimated, the appropriate response factor taken from Figure 2 can be determined. This response factor converts the readings on the monitor to the operational quantity personal dose equivalent at a depth of 0.07 mm ( $H_p(0.07)$ ), also referred to as a skin dose.

The dose to the monitor is then:

$$Dose (\mu Sv) = \frac{\text{Monitor Reading} - \text{Control Reading}}{\text{Response Factor}}$$

A similar procedure is used for the Extremity (or Finger) monitor, although only one measurement is made on the TLD disc or chip. The energy of the radiation is taken from the information supplied by the user and the response factor determined from Figure 5. As the response to radiations of different energies does not vary by more than 30%, errors in the estimation of the energy do not alter the assessed dose to any great extent.

## 2.8 Accuracy of Measurements

All measurements are made using standard operating procedures that are performed in accordance to the NATA requirements which include the requirements of the Standard “General requirements for the competence of testing and calibration laboratories” (ISO/IEC 17025). All doses are traceable to Australian Primary Standards. A comprehensive quality assurance program is also maintained in order to ensure the reliability of the Service.

The minimum detectable dose level (MDL) and the uncertainties for each monitor type are given in Table 1 for TLD, Special TLD and Neutron Badges. Table 2 gives the data for Extremity monitors. The overall uncertainty is whichever of the two numbers (Maximum Error at MDL or Expanded Uncertainty) is larger.

**Table 1: Uncertainties for TLD Badges, Special TLD Badges and Neutron Badges**

Radiation Type	Minimum Detectable Dose ( $\mu\text{Sv}$ )	Maximum Error at MDL ( $\mu\text{Sv}$ )	Expanded Uncertainty ( $k=2$ )
30 - 50 kV X-rays	10	$\pm 20$	$\pm 20 \%$
50 - 120 kV X-rays	10	$\pm 20$	$\pm 15 \%$
120 - 250 kV X-rays (medium filtration)	10	$\pm 20$	$\pm 20 \%$
200 - 300 kV X-rays (heavy filtration)	20	$\pm 50$	$\pm 15 \%$
$\gamma$ rays from single specified radioactive sources	70	$\pm 100$	$\pm 15 \%$
$\gamma$ rays from single unspecified radioactive sources	70	$\pm 100$	$\pm 25 \%$
$\beta$ rays from single specified source (above 70 keV)	100	$\pm 100$	$\pm 30 \%$
mixtures of radioactive sources (excluding $\beta$ rays and neutrons)	70	$\pm 150$	$\pm 50 \%$
fast neutrons	60	$\pm 100$	$\pm 30 \%$



**Table 2: Uncertainties for other types of Monitor**

Monitor Type	Radiation Type	Minimum Detectable Dose	Maximum Error at MDL	Expanded Uncertainty (k=2)
Extremity (or Finger) TLD	All (excluding neutrons)	100 $\mu$ Sv	$\pm$ 100 $\mu$ Sv	$\pm$ 30 %

### 3. How do your Doses Compare? - Occupational Exposure Levels

All persons monitored by the Personal Radiation Monitoring Service are classified into the various occupational categories listed in Table 3. The establishments in which they work are also classified into the establishment types listed in Table 4. These classifications have been derived from the type of work performed and workload involved rather than from strict occupational categories.

The comparison of the doses received by a particular worker with those received by the same type of worker at the same type of establishment can be used to check the adequacy of radiation protection measures at the worker's establishment. Such comparisons can show whether these are as effective as those used at similar establishments.

Table 5 gives data on annual photon doses to monitors worn by occupationally exposed personnel. The data have been derived for each occupational category according to the establishment type. The Table lists the quartile doses together with the maximum measured dose, the average dose and the number of workers in each occupational category. Categories with less than 5 workers have been omitted.

One quarter of the doses to workers in each occupational category are below the value listed for the first quartile (Q<sub>1</sub>) for that category, half are below the median value and three quarters are below the third quartile (Q<sub>3</sub>).

Workers can compare the annual doses that they receive with the data in Table 5 to see how they compare with workers undertaking the same type of work. If a particular occupational category is not listed, the category that best fits the type of work undertaken should be used.

As good radiation practice suggests that the radiation doses received by workers should be kept as low as reasonably achievable (ALARA), radiation workers should aim to reduce their annual dose to below the median value. If the annual dose is between the median value and the third quartile value, an investigation may be conducted to examine the procedures which caused the dose so that future doses can be reduced to below the median if at all possible. If the annual dose is above the third quartile, an immediate and thorough investigation should be made to determine the causes as this is well above the dose levels that workers undertaking similar work receive.

For particular occupational groups, the average annual doses to the extremities are given in Table 6 and the annual average photon and neutron doses are given in Table 7. These tables can also be used for comparing the doses of workers



undertaking similar work. Radiation workers should aim to make the doses as low as possible, bearing in mind that the average value should be indicative of what is generally achievable in normal practice. Any doses significantly above this value should be investigated in an attempt to reduce the dose levels.

If all workers were to reduce their doses below the current median values for their occupational categories reported here, the chances of adverse effects occurring would also be reduced.

For adult workers, the health risks arising from low doses of ionizing radiation as listed in the International Commission on Radiological Protection, Publication 60 ICRP(1990) are as follows:

Risk of cancer from 1 microsievert (1 $\mu$ Sv) of radiation:	1 in 21,000,000
Risk of severe hereditary effects from 1 $\mu$ Sv of radiation	1 in 125,000,000
Total risk from 1 $\mu$ Sv of radiation	1 in 18,000,000

**Table 3: Classification of Wearer Occupations**

Code	Classification of Wearer Occupations
	<b>Diagnostic Radiology</b>
01	Radiation Safety Officers, Hospital Physicists
02	Radiologists
03	Medical Practitioners (other than 07 below)
04	Radiographers and others X-raying patients (including trainees)
05	Assistants to the above
06	Receptionists, office workers, etc
07	Medical Specialists (eg cardiologists, urologists, surgeons)
	<b>Radiotherapy</b>
11	Radiotherapists, dermatologists, gynaecologists
12	Radiation Safety Officers, Hospital Physicists, Therapy Radiographers (including trainees)
13	Those nursing patients with radioactive sources in situ
14	Assistants to the above
15	Receptionists, office workers
	<b>Nuclear Medicine or Pathology</b>
21	Radiation Safety Officers, Hospital or Medical Physicists
22	Nuclear Medicine Specialists or Pathologists
23	Nuclear Medicine Technologists or Medical Lab. Technologists (including trainees)
24	Assistants to above
25	Receptionists, office workers
	<b>Dentistry</b>
31	Dentists
32	Assistants to above
33	Receptionists, office workers

**Table 3: Classification of Wearer Occupations (continued)**

<b>Code</b>	<b>Classification of Wearer Occupations</b>
	<b>Chiropractic</b>
41	Chiropractors, osteopaths, etc
42	Assistants to above
43	Receptionists, office workers, etc
	<b>Veterinary</b>
51	Veterinary surgeons
52	Assistants to above
53	Receptionists, office workers, etc
	<b>Industry, Research and Education</b>
61	Those using X-ray diffraction units and/or electron microscopes, etc
62	Those working outside totally enclosed installations
63	Those using non or partially enclosed radiation sources (other than 64)
64	Those using radioactive isotopes in tracer techniques
66	Teachers/Demonstrators
67	Students (other than post-graduate research included in above classifications)
68	Radiation Safety Officers
	<b>Uranium Mining</b>
71	Mine workers
72	Mill workers
73	Miscellaneous
74	Radiation Safety Officers
	<b>Mineral Sand Mining</b>
81	Miner
82	Wet Plant Operator
83	Dry Plant Operator
84	Miscellaneous
85	Radiation Safety Officers
	<b>Other</b>
90	Installation and Maintenance Personnel
91	Inspectors

**Table 4: Classification of Establishment Types**

Code	Classification of Establishment Types
	<b>Diagnostic Radiology</b>
01	Small hospital department with one or two radiographers
02	Large hospital department with more than two radiographers
03	Private radiological practice
04	Other medical practices
05	Other hospital and nursing establishments
	<b>Radiotherapy</b>
11	Dermatology
12	Radiotherapy department
13	Private radiotherapy practice
	<b>Nuclear medicine/pathology</b>
20	Nuclear medicine department
21	Private nuclear medicine practice
25	Pathology departments or practices
	<b>Dental</b>
30	Hospital
31	Private practice
32	Government service
33	School dental service
	<b>Chiropractic</b>
40	Chiropractic practice
	<b>Veterinary</b>
50	Veterinary practice
	<b>Industry</b>
60	Manufacturer utilising quality control or quality assurance devices
61	Industrial radiography
	<b>Mining</b>
70	Uranium mining
80	Mineral sand mining
	<b>Research</b>
90	Government
91	Medical and veterinary
92	Industry
	<b>Education</b>
93	Tertiary
94	Secondary

**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004)**

**Diagnostic Radiology**

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
<b>Small Hospitals</b>						
Radiologists	10	80	300	2020	321	23
Medical Practitioners			20	360	21	123
Medical Specialists		10	40	710	45	78
Radiographers		10	30	760	33	372
Assistants			30	2120	35	292
Receptionists				30	3	22
<b>Large Hospitals</b>						
Hospital Physicist/RSO			10	10	4	7
Radiologists		30	110	3110	108	303
Medical Practitioners			30	600	39	42
Medical Specialists		20	90	4770	114	260
Radiographers	10	30	70	1870	56	1622
Assistants		10	60	2180	64	1048
Receptionists			20	90	12	40
Installation/Maintenance Personnel			140	17310	867	23
<b>Private Radiological Practices</b>						
Radiologists		10	60	2120	77	226
Medical Practitioners			50	330	39	19
Medical Specialists		20	150	1340	142	41
Radiographers	10	40	90	6290	81	1612
Assistants		30	110	10510	185	221
Receptionists			15	70	8	53

**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004) (continued)**

**Diagnostic Radiology**

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
<b>Other Medical Practices</b>						
Radiologists	10	40	90	490	88	25
Medical Practitioners				40	2	96
Medical Specialists		30	88	4610	158	96
Radiographers		20	63	360	42	254
Assistants			20	2900	32	252
<b>Other hospital &amp; nursing establishments</b>						
Radiologists	10	20	30	50	19	11
Medical Practitioners			20	560	32	91
Medical Specialists			30	5640	88	205
Radiographers			30	330	21	143
Assistants			10	500	20	668

**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004) (continued)**

**Radiotherapy**

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
<b>Dermatology</b>						
Radiotherapists/Dermatologists		10	155	390	84	8
Assistants		360	525	530	282	5
<b>Hospital Radiotherapy Dept</b>						
Radiotherapists/Gynaecologists		20	230	860	157	111
Therapy radiographers		120	350	3570	228	633
Those nursing patients with radioactive sources in situ		10	420	1180	208	251
Assistants		10	158	830	168	52
Installation/Maintenance Personnel			465	480	186	5
<b>Private Radiotherapy Practice</b>						
Radiotherapists/Gynaecologists		10	95	230	60	17
Therapy radiographers			158	850	94	132
Those nursing patients with radioactive sources in situ				1820	111	25

**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004) (continued)**

***Nuclear Medicine or Pathology***

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
<b>Nuclear Medicine Dept</b>						
Hospital or medical physicist		170	460	910	263	15
Nuclear medicine specialist	20	600	1270	3490	827	59
Nuclear medicine technologist	495	1530	2573	17760	1749	196
Assistant			328	6600	368	148
Receptionist		40	380	2140	242	30
<b>Private nuclear medicine practice</b>						
Nuclear medicine specialist	170	810	1360	3740	951	43
Nuclear medicine technologist	700	1840	3510	10220	2313	167
Assistant		320	1698	11560	1278	56
Receptionist	223	515	1408	9640	1094	40
<b>Pathology</b>						
Medical Lab technologist				350	9	91

**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004) (continued)**

***Dentistry***

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
<b>Dental Hospital</b>						
Dentists			20	120	13	81
Assistants			10	230	13	118
Receptionists				20	2	12
<b>Private practice</b>						
Dentists			10	490	12	984
Assistants			10	12950	14	1563
Receptionists				60	3	134
<b>Government Service</b>						
Dentists			10	110	8	228
Assistants			10	100	8	377
Receptionists			5	30	4	17
<b>School dental service</b>						
Dentists			10	90	10	47
Assistants			10	90	8	102
Installation/Maintenance Personnel		125	180	210	105	6



**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004) (continued)**

***Chiropractic practice***

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
Chiropractor/osteopath			30	3330	55	90
Assistants			20	100	17	29
Receptionists				20	2	11

***Veterinary Practice***

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
Veterinary Surgeon			10	2600	16	2164
Assistants			10	5420	13	2558
Receptionists			10	80	9	96

**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004) (continued)**

**Industry**

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
<b>Manufacturer using quality assurance or quality control devices</b>						
Users of X-ray analysis units, electron microscope, etc			10	50	6	206
Users of enclosed installations or quality assurance sources eg package monitors, thickness gauges, etc				23270	75	569
Users of open installations			10	23190	109	666
Radiation safety officers				7010	264	30
Installation & maintenance personnel			80	2300	122	372
Inspectors				220	36	12
<b>Industrial Radiography</b>						
Users of enclosed installations or quality assurance sources eg package monitors, thickness gauges, etc			180	13750	383	223
Users of open installations		100	570	54200	737	333
Radiation safety officers				540	47	15

**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004) (continued)**

***Mining***

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
<b>Uranium mining</b>						
Mine workers	260	900	1710	7770	1125	583
Mill workers		740	1780	2950	977	49
Miscellaneous		60	310	2600	302	89
<b>Mineral sands mining</b>						
Dry plant operator	338	980	1380	6970	1001	108
Miscellaneous		340	950	3380	574	51

**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004) (continued)**

**Research**

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
<b>Government</b>						
Users of X-ray analysis units, electron microscope, etc			10	1350	16	227
Users of enclosed installations or quality assurance sources eg package monitors, thickness gauges, etc		10	73	2750	107	110
Users of open installations			10	1730	41	173
Users of radioactive tracers			10	750	26	1145
Teachers/demonstrators				10	1	8
Students			8	190	21	24
Radiation safety officers				190	15	21
Installation & maintenance personnel				10	1	8
Inspectors			8	30	5	8

**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004) (continued)**

**Research**

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
<b>Medical &amp; Veterinary</b>						
Radiographer			20	270	23	19
Radiographic assistant			20	50	10	19
Users of X-ray analysis units, electron microscope, etc			10	20	4	11
Users of open installations				230	12	51
Users of radioactive tracers			10	2680	34	1757
Undergraduate students			28	80	18	10
Radiation safety officers						6

**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004) (continued)**

**Research**

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
<b>Industry</b>						
Users of enclosed installations or quality assurance sources eg package monitors, thickness gauges, etc						16
Users of open installations				70	4	19
Users of radioactive tracers				2870	91	55

**Table 5: Annual Photon Doses to Monitors Worn by Occupationally Exposed Personnel (2004) (continued)**

**Education**

Occupational Classification	Quartile Doses ( $\mu\text{Sv}$ )			Max Dose ( $\mu\text{Sv}$ )	Average Dose ( $\mu\text{Sv}$ )	No of Wearers
	Q1	median	Q3			
<b>Tertiary</b>						
Radiographer		10	30	550	25	766
Therapy radiographer		10	90	640	69	252
Nuclear medicine technologist or medical lab technologist		45	370	1490	207	110
Veterinary surgeon		10	30	220	26	38
Veterinary assistant	10	25	30	320	38	36
Users of X-ray analysis units, electron microscope, etc			10	140	11	274
Users of enclosed installations or quality assurance sources eg package monitors, thickness gauges, etc				280	12	29
Users of open installations				670	25	118
Users of radioactive tracers			10	670	31	1148
Teachers/demonstrators			80	6060	174	54
Undergraduate students				210	19	34
Radiation safety officers			10	220	22	39

**Table 6: Annual Extremity Doses to Occupationally Exposed Personnel (2004)**

Occupational Classification	Average Extremity Dose ( $\mu\text{Sv}$ )	No of Wearers
<b>Large Hospitals - Diagnostic Radiology</b>		
Radiographic assistants	178	9
<b>Nuclear Medicine Dept</b>		
Nuclear medicine technologist	12529	7
<b>Private Nuclear Medicine Practice</b>		
Nuclear medicine technologist	13683	6
<b>Veterinary Practice</b>		
Veterinary Surgeon	5300	6



**Table 6: Annual Extremity Doses to Occupationally Exposed Personnel (2004) (continued)**

Occupational Classification	Average Extremity Dose ( $\mu$ Sv)	No of Wearers
<b>Industry</b>		
<b>Manufacturer using quality assurance or quality control devices</b>		
Users of enclosed installations or quality assurance sources eg package monitors, thickness gauges, etc	70	10
Users of open installations	433	15
<b>Research</b>		
<b>Government</b>		
Users of X-ray analysis units, electron microscope, etc	767	6
Users of open installations	839	13
Users of radioactive tracers	488	25
<b>Medical &amp; Veterinary</b>		
Users of radioactive tracers	2576	62
<b>Industry</b>		
Users of radioactive tracers	571	7
<b>Education</b>		
<b>Tertiary</b>		
Users of X-ray analysis units, electron microscope, etc	300	19
Users of radioactive tracers	1140	48

**Table 7: Annual Doses to Monitors Worn by Personnel Exposed to Neutron Sources (2004)**

Occupational Classification	Average Photon Dose ( $\mu\text{Sv}$ )	Average Neutron Dose ( $\mu\text{Sv}$ )	No of Wearers
<b>Radiotherapy</b>			
<b>Hospital Radiotherapy Dept</b>			
Hospital Physicist/ Radiation Safety Officer or Therapy Radiographer	70	4	55
<b>Industry</b>			
<b>Manufacturer using quality assurance or quality control devices</b>			
Users of enclosed installations or quality assurance sources eg package monitors, thickness gauges, etc	115	22	59
Users of open installations	170	19	932
Radiation Safety Officer	2	13	6
Installation & maintenance personnel	274		5
Inspectors	8		19

**Table 7: Annual Doses to Monitors Worn by Personnel Exposed to Neutron Sources (2004) (continued)**

Occupational Classification	Average Photon Dose ( $\mu\text{Sv}$ )	Average Neutron Dose ( $\mu\text{Sv}$ )	No of Wearers
<b>Research</b>			
<b>Government</b>			
Users of enclosed installations or quality assurance sources eg package monitors, thickness gauges, etc	32	7	35
Users of open installations	36	12	157
Users of radioactive tracers	80	6	10
Radiation Safety Officer	70		9
Inspectors	12	5	17
<b>Medical &amp; Veterinary</b>			
Users of open installations	826	256	5
Users of radioactive tracers	62	20	11
<b>Industry</b>			
Users of open installations	62		21
<b>Education</b>			
Users of enclosed installations or quality assurance sources eg package monitors, thickness gauges, etc	29	18	9
Users of open installations	9	18	22
Radiation Safety Officer	2		5

#### 4. What do the Doses Mean? - Effective Dose and Personal Dose Equivalent

The effective dose,  $E$ , is used when describing radiation exposure from a protection point of view. It is a weighted sum of equivalent doses,  $H_T$ , to the various body tissues,  $T$ , which are themselves weighted sums of the mean absorbed doses,  $D_{T,R}$ , to those tissues from radiations of type  $R$ .

$$E = \sum_T (w_T \times H_T)$$

$$H_T = \sum_R (w_R \times D_{T,R})$$

$$E = \sum_T \left( w_T \times \sum_R (w_R \times D_{T,R}) \right)$$

The effective dose is not a measurable quantity, however it can be calculated if various parameters of the radiation field are known.

For the purposes of personal monitoring, radiation doses are often reported using the quantity personal dose equivalent,  $H_p(d)$ . This is the dose equivalent,  $H$ , in soft tissue at a depth of  $d$  mm below a point on the body. The dose equivalent,  $H$ , is the product of the absorbed dose,  $D$ , and a radiation weighting factor,  $w_R$ , which accounts for the effectiveness of different types of radiation.

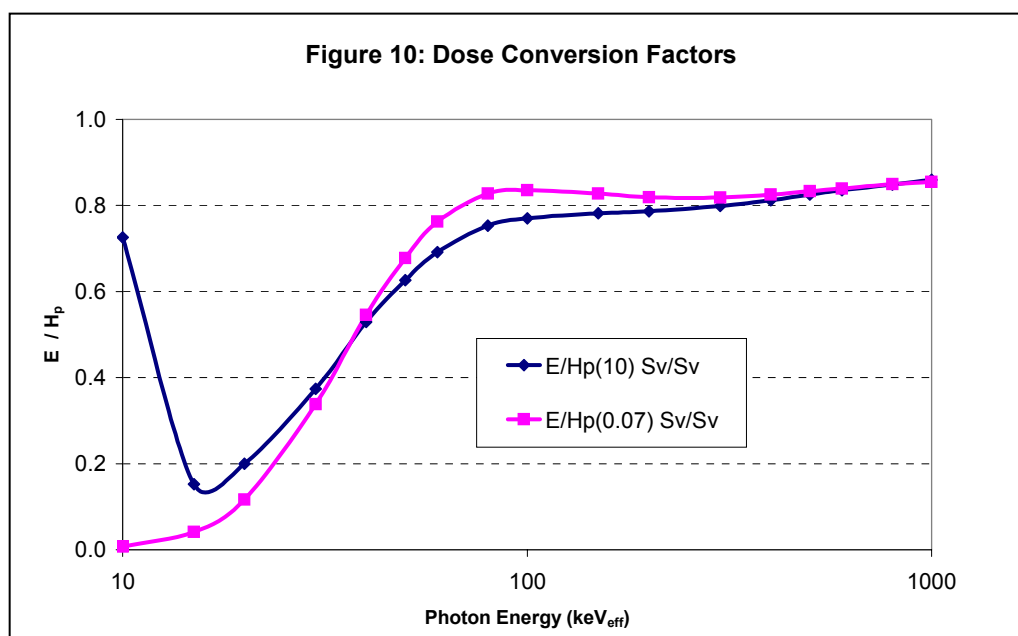
Personal dose equivalent is also not a measurable quantity, however it can be readily calculated for simplified exposures such as a beam directed at a slab of tissue-equivalent material (a phantom) and is easier to estimate than the effective dose,  $E$ . Physical measures of the radiation beam (exposure, air kerma, particle fluence, etc.) directly in front of the phantom can be related to the personal dose equivalent. Personal monitoring devices, which respond to these physical measures, are calibrated using phantoms and simplified exposures.

Personal dose equivalent is typically reported for depths,  $d$ , of 0.07 mm (the thickness of the dead layer of skin), 3 mm (the lens of the eye), and 10 mm (the main organs of the body).

$H_p(10)$  is frequently reported by personal monitoring services as an estimate of the effective dose,  $E$ . However, as can be seen in Figure 10, it is not a good estimate for energies less than 50 keV<sub>eff</sub> and is about 20 % high for higher energies.

In order to simplify matters, the Personal Radiation Monitoring Service reports photon (X/γ) and electron (β) doses in terms of  $H_p(0.07)$ , which is also termed the skin dose.

Every year the Service issues an additional report showing the cumulated effective dose,  $E$ , for each wearer in the PRMS database. All doses reported for a wearer since the inception of the computerised database in 1986 are included in this report. The reported effective dose is derived from the skin doses through the use of appropriate factors.



The factors used to convert the skin dose ( $H_p(0.07)$ ), to the effective dose,  $E$ , are given in Table 8. The factors were derived in ARL/TR124 (Wise 1998) and assume that the radiation worker has been exposed from the front in a uniform radiation field.

These factors take into account the sex of the wearer, the radiation energy and type of radiation used, the depth of the various body organs of interest and the susceptibility of the organs to harmful effects from radiation.

Table 8 also gives the conversion factors to convert the skin dose,  $H_p(0.07)$ , to  $H_p(10)$ . These factors are derived from the International Commission on Radiological Protection, Publication 74 (ICRP 1996).

The absorbed dose to the skin can be determined by the personal monitor results. Owing to the uncertainties in calculating the effective dose, it is more convenient to ensure that the absorbed dose to the skin does not exceed the effective dose limits. This assumes that the skin dose will always be greater than the effective dose. As shown in Table 8, the ratio  $E/H_p(0.07)$  is less than 1.00 for all photon energies. This indicates the assumption to be correct and that the skin dose does consistently over-estimate the effective dose. The wearer will not be exceeding the Dose Limits provided that the personal monitor results are less than the pro-rata maximum.

**Table 8: Effective Dose and  $H_p(10)$  Conversion Factors**

Radiation Type	Effective Energy (keV)	Effective Dose Conversion Factor $E/H_p(0.07)$		$H_p(10)/H_p(0.07)$ Conversion Factor
		Male	Female	
30 kV X-rays or Crystallographic X-rays	17	0.10	0.10	0.41
50 kV X-rays (Dental X-rays)	20	0.20	0.10	0.57
75 kV X-rays	23	0.30	0.20	0.69
75 - 130 kV X-rays (diagnostic X-rays)	33	0.50	0.40	0.95
130 kV X-rays (medium filtration)	43	0.60	0.60	1.06
140 - 180 kV X-rays	60	0.70	0.60	1.10
180 - 220 kV X-rays (medium filtration)	70	0.70	0.60	1.10
230 - 250 kV X-rays (medium filtration)	95	0.70	0.70	1.09
250 kV X-rays (heavy filtration)	122	0.70	0.70	1.07
$^{99m}\text{Tc}$	140	0.70	0.70	1.06
300 kV X-rays (heavy filtration)	170	0.70	0.70	1.05
$^{51}\text{Cr}$	320	0.80	0.80	1.02
$^{192}\text{Ir}$	380	0.80	0.80	1.02
$^{131}\text{I}$	385	0.80	0.80	1.02
$^{137}\text{Cs}$	662	0.80	0.80	1.00
$^{226}\text{Ra}$ , $^{60}\text{Co}$	1250	0.80	0.90	0.99

## References

- ICRP (1990) 1990 Recommendations of the International Commission on Radiological Protection. Oxford: Pergamon Press; ICRP publication 60.
- ICRP (1996) 1996 Conversion Coefficients for use in Radiological Protection against External Radiation. Oxford: Pergamon Press; ICRP publication 74.
- Morris N D (1996) Personal Radiation Monitoring and Assessment of Doses received by Radiation Workers (1996). Melbourne: Australian Radiation Laboratory; Report ARL/TR121.
- Radiation Protection Series No. 1
- Recommendations for limiting exposure to ionizing radiation (1995) (Guidance note [NOHSC:3022(1995)]) and National standard for limiting occupational exposure to ionizing radiation (1995) [NOHSC:1013(1995)].
- Wise K N (1998) The Ratios of Effective Dose to Entrance Skin Dose and to Air Kerma for some Medical Sources (1998). Melbourne: Australian Radiation Laboratory; Report ARL/TR124.