Monitoring Occupational Exposure to Ionizing Radiation

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SUMMARY

A brief overview is presented of methods of monitoring ocupational exposure to ionizing radiation together with reasons for such monitoring and maintaining dose histories of radiation occupationally exposed persons. The various Australian providers of external radiation monitoring services and the types of dosemeters they supply are briefly described together with some monitoring results. Brief mention is made of the Australian National Radiation Dose Register and its objectives.

1. INTRODUCTION

Mankind has always been exposed to natural background ionizing radiation from naturally occurring radioactive materials and cosmic radiation. Following their discovery X-rays and radioactive materials have been used in numerous applications in science, medicine and industry. Consequently persons engaged in such uses receive additional radiation exposure in the form of external radiation when the source of ionizing radiation is outside the person's body and as internal radiation when radioactive material is taken into the body by a mechanism such as inhalation, ingestion or absorption via intact or broken skin. External radiation exposure can be measured directly by means of various types of personal dosemeters but internal radiation exposure can only be estimated by measuring the amount of radioactive material in the body.

Early uses of ionizing radiation showed that it could cause harm to living organisms if exposures were not controlled adequately. This led to the formulation of, what are now known as, dose limits. These are recommended by the International Commission on Radiological Protection (ICRP)(1) and are adopted in national recommendations or legislation. In Australia the National Health and Medical Research Council (NHMRC) has adopted the ICRP dose limits (2).

The ICRP (1) limits the use of the term "occupational exposure" (to radiation) to exposures incurred at work, as the result of situations that can reasonably be regarded as being the responsibility of the operating management, and which arise from the intentional use of radiation source(s) in the workplace to which the ICRP system of protection for practices applies. Occupational exposure consists of both external and internal ionizing radiation received by persons during their work but does not normally include exposure from natural background radiation.

The ICRP recommmends that exposure to natural radiation sources should be regarded as part of occupational exposure in some specific cases including:

- operations where the regulatory agency has declared that radon in the workplace needs attention and has identified the relevant workplaces,
- operations with, and storage of, materials not usually regarded as radioactive, but which contain significant traces of natural radionuclides and which have been identified by the regulatory authority,
- operation of jet aircraft.

The primary justification for monitoring occupational exposure to ionizing radiation is that it helps to achieve an appropriate level of protection and to demonstrate that it is maintained. Maintaining permanent records of the doses to exposed persons, enables:

- exposed persons and management to be informed of the radiation doses received ,
- demonstration that occupational dose limits are not exceeded,
- data to be provided for analysis of dose distributions,
- identification of trends in exposure levels of various groups of occupationally exposed persons,
- production of information for optimisation purposes, i.e. to ensure that radiation exposures are as low as reasonably achievable, economic and social factors being taken into account,
- provision of radiation exposure data for epidemiological studies of occupationally exposed persons,
- provision of radiation dose histories relating to claims by occupationally exposed persons that health problems are related to their radiation exposure.

2. MONITORING EXTERNAL RADIATION EXPOSURE

In Australia the personal monitoring devices generally used to monitor external radiation exposure of occupationally exposed persons are film badge dosemeters and thermoluminescent dosemeters (TLD). (See Appendix)

Each personal radiation monitoring service providing such dosemeters requires calibration facilities which expose reference film badge dosemeters, or reference TLDs, to known doses of beta, X-, gamma or neutron radiation as appropriate. Reference film badge dosemeters are exposed to known radiation doses to produce calibration curves (optical density of the processed film badge versus radiation dose) which enable the optical density of a wearer's film badge to be interpreted in terms of radiation dose received. Reference TLDs exposed to known doses of radiation allows production of similar calibration data which relates TLD light output to radiation dose as a function of radiation type and energy.

An external radiation personal monitoring dosemeter should be worn in a position which provides a representative measurement of the maximum radiation dose to the exposed part of the body. When a single dosemeter is provided it is usually worn on the chest or at waist height. If a protective lead apron is also used, as in some medical procedures with X-rays, the dosemeter should be worn under the apron. However if the exposed person is close to the radiation source, and some parts of the body are not shielded by the lead apron it is desirable to wear a second dosemeter outside the apron to measure the radiation dose to the unshielded parts of the body.

Where specific parts of the body are likely to receive higher doses of radiation then additional dosemeters may need to be worn e.g. on fingers, wrist, or head.

A decision to be made relating to occupational exposure is the selection of those workers who should be monitored individually for external radiation. Factors influencing this decision include the level of radiation dose which may be expected in relation to dose limits and probable variations in the dose. In some cases there may be reasons relating to industrial relations. Individual monitoring for external radiation is relatively simple and does not require major commitment of resources. The ICRP (1)(3) recommends that:

- groups of workers in which the annual effective dose to some individuals is liable to exceed a selected value between 5 and 10 mSv should be monitored for external radiation, unless their doses can be assessed more conveniently in some other way e.g. air crew.
- groups of workers in which all the members are likely to receive an annual effective dose less than 1 mSv need not be monitored,
- monitoring of the intermediate group is desirable but can be less formal for than the more highly exposed group.

In principle individual monitoring should be carried out for all persons working in controlled areas where normal working conditions require them to follow well-established procedures and practices aimed specifically at controlling radiation exposures. In supervised areas, in which the working conditions are kept under review but special procedures are not normally needed, monitoring of workers should be considered unless it is known that their doses will be consistently low.

In Australia the requirement for occupationally exposed persons to wear personal monitoring dosemeters to measure external radiation is prescribed by the radiation control legislation of the State where the persons work. This requirement varies from State to State as shown in Table 1. Any other persons, or category of persons, who are not included in the requirement, are not precluded from being issued with personal monitoring dosemeters if their employers so desire.

The external radiation exposure of every person working with ionizing radiation and/or radioactive materials in Australia is not monitored and recorded. In cases where individual personal dosemeters are not issued the radiation doses received may be estimated from a knowledge of the dose rate in the working area and the time spent there. In some cases a single integrating type dosemeter may be used to estimate the exposure of persons who are not monitored individually. Thus in Western Australia individual monitoring of persons in dental practices has been replaced by a single "environmental" monitor attached close to the exposure button on the X-ray machine exposure cable.

3. BIOLOGICAL DETERMINATION OF HIGH RADIATION DOSES

If it is suspected that a person has received a high dose of ionizing radiation then cytogenic studies of a blood sample may be undertaken to determine dicentric chromosome aberrations caused by ionizing radiation (4). The dicentric aberration is used because it is easily identified and is produced by few other agents which cause chromosome breaks so that unirradiated controls have a low background incidence. Reliable *in vitro* dose response curves can be prepared.

As indicated by Lloyd (5) this method of dose estimation can be useful in circumstances, when:

- it is necessary to confirm that a high radiation dose, as indicated by a personal monitoring device, was actually received by the person to whom the device was issued,
- it is suspected that a large radiation dose may have been received by a person who is known not to have worn a monitoring device,
- a large radiation dose is known to have been received and it is required to make a direct comparison of physical and biological methods of estimating the dose,
- a person has been chronically exposed to internal and/or external ionizing radiation.

The approximate lower limits of dose estimation by chromosome aberration analysis are:

gamma radiation	100 mGy
250 kVp X-rays	50 mGy
fission spectrum neutrons	10 - 20 mGy

These lower limit doses are much smaller than the dose at which any irradiated person would be given medical treatment. The upper limit of detection extends to a few gray.

4. MONITORING INTERNAL RADATION EXPOSURE

The chemical and physical forms of a particular radionuclide determine how it is distributed within the human body. Some radionuclides, e.g. tritium, are distributed fairly uniformly within the body causing irradiation of the whole body. Other radionuclides concentrate in specific body organs causing exposure of those organs e.g. radioiodines concentrate in the thyroid gland and plutonium concentrates in the lung or bone. A radionuclide in the body will decay at a rate determined by its radioactive half life and there will also be be some biological elimination. The total internal radiation dose will depend on the amount of radionuclide taken into the body and the types and energies of the radiations it emits. When a radionuclide is first incorporated in the body there is an initial internal radiation dose rate which subsequently decreases as radioactive decay and excretion of the radionuclide occurs. A given intake of a radionuclide therefore commits the organ(s) at risk to a certain dose, known as the dose committment, which depends on the initial dose rate and the excretion rate of the radionuclide. The dose, over a period of 50 years, accumulated from the intake is known as the committed effective dose.

The method used to measure the amount of radioactive material in the body depends upon the type of radionuclide(s) in the body. Biological monitoring methods, generally known as radiobioassay, are used to determine internal radiation dose.

Direct radiobioassay requires measurements of radioactive material in the body using instruments which detect the ionizing radiation emitted from this radioactive material. The radionuclides may be distributed throughout the whole body or localised in individual organs such as the lungs or the thyroid. In the former case a whole body monitor is used and in the latter case an organ monitor is used.

Indirect radiobioassay requires measurements to estimate the amount of radioactive material in body excreta or other biological materials from the body. Samples collected for such measurement may include urine, faeces, breath, nasal fluid, blood, hair clippings or finger nail clippings. Routine indirect bioassay programs may normally be instituted when workers are using significant quantities of unsealed radioactive substances such as tritium or uranium. ANSTO maintains a urinalysis program for members of its staff who work with tritium. Examples of the use of radiobioassay methods for specific radionuclide intakes are given in Table 2.

There are no routine biological monitoring service providers in Australia. Whole body monitors are available at ARL, ANSTO and a few hospitals. Thyroid monitoring facilities are generally available in nuclear medicine departments of large hospitals.

5. AUSTRALIAN PERSONAL RADIATION MONITORING SERVICES

Australian personal radiation monitoring sevices for external radiation have been in existence for many years. The Australian Radiation Laboratory (ARL), previously the Commonwealth X-Ray Laboratory (CXRL), has operated a service for about sixty years and the Australian Nuclear Science and Technology Organisation, previously the Australian Atomic Energy Commission (AAEC), has operated its service for about forty years.

In Australia there are currently five providers of personal radiation monitoring services (PRMS) for external ionizing radiation. The New South Wales Health Department previously provided a film badge service free of charge until it was discontinued in mid-1991. Some details of the current services and the types and numbers of dosemeters which they issue are given in Tables 3 and 4. Table 3 also indicates the minimum detectable radiation levels quoted by the various PRMS providers.

The issue frequency of personal external radiation dosemeters to occupationally exposed persons is determined by a number of factors including the type of radiation work performed and the environmental conditions encountered. Table 5 shows the issue frequencies used by each PRMS and Table 6 shows fees charged.

A PRMS provides a control dosemeter which is used to assess the exposure of the dosemeters to natural background radiation dose in the work area and during their transport to and from the PRMS provider. Normally one control dosemeter is supplied with each batch of dosemeters. However more than one control dosemeter may be supplied to larger users where background levels may vary from one place to another in the user's organisation. Fees are not charged for the supply of control dosemeters.

Table 7.1, derived from an ARL Technical Report (6), shows some average doses and maximum doses measured for various occupational classifications for the year 1996. One surprising fact is that pathology receptionists have a higher average dose than any other group of persons listed in this table.

In any given group of occupationally exposed persons the majority will record doses in the lower part of the measured range with a smaller number recording some doses in the higher part of the range. This is clearly illustrated in the distribution of annual doses in Western Australia (7), for the year 1995, and for ANSTO (8) employees, for the financial year 1996-97, shown in Tables 7.2 and 7.3. The effective annual whole body doses for ANSTO include external radiation doses and internal radiation doses: the average effective dose being 1 mSv and the maximum effective dose being 15 mSv.

As may be expected, Tables 7.1 and 7.2 show that the majority of persons in these groups received an annual dose less than one tenth of the occupational annual dose limit of 20 mSv.

For the Queensland PRMS the largest number of persons wearing monitoring devices are those concerned with diagnostic radiology and the next highest number is for persons in industry. The majority of persons monitored by this service receive an annual dose less than 200 μSv.

6. ACCREDITATION OF PERSONAL RADIATION MONITORING SERVICES

Clause 15 of the NSW Radiation Control Regulation 1993 requires that an employer must issue approved personal monitoring devices to persons involved in the use of ionizing radiation for a number of defined purposes (see Table 1) and Clause 18 of that Regulation requires that all monitoring devices issued by an employer are maintained and calibrated in accordance with the Guideline "Monitoring Devices" adopted by the NSW Radiation Advisory Council. That Guideline refers to personal monitoring devices, which must be approved by the Environment Protection Authority and provided by approved organisations which offer personal monitoring services.

Each PRMS should be able to demonstrate traceability of to its measurements to the appropriate Australian national standard for ionizing radiation quantities. Recent discussions on NATA accreditation of calibration facilities for radiation monitoring instruments have given rise to the concept of NATA accreditation of PRMS.

7. THE AUSTRALIAN NATIONAL RADIATION DOSE REGISTRY

The Australian National Radiation Dose Registry, which commenced operation on 1 July 1996, is managed by the Australian Radiation Laboratory and was established to provide a permanent national register of personal dose records for persons who are occupationally exposed to ionizing radiation. The objective is to obtain copies of such personal dose histories from the various Australian Personal Radiation Monitoring Services (PRMS) for inclusion in a secure central register. It is anticipated that the National Radiation Dose Registry will issue an annual report containing relevant dose history statistics. An occupationally exposed worker will be able to request a printout of his/her exposure record from the Registry.

To date, dose records of occupational external radiation exposure have been supplied to the Registry by the personal radiation monitoring services provided by the Australian Radiation Laboratory, Western Australia and Cumberland College, NSW. The input from the Australian Radiation Laboratory records consist of computerised records for approximately the past ten years. The records from the ANSTO and Queensland personal radiation monitoring services are expected to be provided to the National Radiation Dose Registry after privacy questions have been resolved.

In the past personal radiation monitoring services did not maintain computerised records of personal dose histories and incorporation of these older records in the Registry would present an almost impossible task.

It may be anticipated that the records of occupational exposure to ionizing radiation held by the National Radiation Dose Registry will eventually be used for statistical analyses to identify radiation dose trends and anomalies within various groups of occupationally exposed persons, for epidemiological studies and examination of possible connections between occupational ionizing radiation exposure and health problems.

REFERENCES

(1) ICRP Publication 60 "1990 Recommendations of the International Commission on Radiological Protection" (Pergamon Press 1991)

(2) National Health and Medical Research Council (1995) Radiation Health Series No.39. Recommendations for limiting exposure to ionizing radiation (1995) (Guidance note [NOHSC;3022(1995)]) and national standard for limiting occupational exposure to ionizing radiation [NOHSC:1013(1995)]

(3) ICRP Publication 75 "General Principles for the Radiation Protection of Workers" (Pergamon Press 1997)

(4) Lloyd, D.C. and Purrott, R.J., Chromosome Aberration Analysis in Radiological Protection Dosimetry. Radiation Protection Dosimetry Vol.1, No.1, 1981

(5) Lloyd, D.C. (1984) An Overview of Radiation Dosimetry by Conventional Cytogenic Methods, in *Biological Dosimetry - Cytometric Approaches to Mammalian Systems (Eds.Eisert and Mendelsohn) (Springer-Verlag)*

(6) Morris, N.D. (1996) Personal Radiation Monitoring and Assessment of Doses Received by Radiation Workers (1996), Australian Radiation Laboratory, ARL/TR121

(7) Radiological Council of Western Australia, Report of the Council for the Year ended 31 December 1996.

(8) Hacker, Celia (1997), Private communication.

APPENDIX

Film Badge Dosemeter

The film badge dosemeter can be used to measure exposure from beta, X- and gamma radiations. A piece of X-ray film in a light-tight paper envelope is enclosed in a small cassette containing a number of radiation filters of different metals, which are used to make the film response energy independent and to permit assessment of doses of different types of ionizing radiation, which after impinging on the film produce a latent image on it. After development the film shows a degree of blackening which is a measure of the dose of ionizing radiation received. The film pack often contains two emulsions of differing sensitivities. A high sensitivity emulsion is used to monitor normal radiation doses in the range of approximately 0.1 mSv to 100 mSv and a low sensitivity emulsion is used to monitor high doses in the range of approximately 100 mSv to 10 Sv.

Use of a nuclear emulsion film, placed in a holder containing various filters allows exposure to fast neutron radiation to be measured. Fast neutrons cause protons to be ejected from the base material of the film creating ionization tracks which are visible after development of the film. A microscope is needed to count these tracks; the number of tracks per unit area is a measure of the fast neutron dose. These fast neutron films have a dose range of about 1 mSv to 1 Sv and an energy threshold of about 0.5 MeV. They are sensitive to gamma radiation and track counting is not possible if a fast neutron film is exposed to about 100 mSv of gamma radiation. Track counting is time consuming and is therefore costly.

The film badge is not a direct reading personal dosemeter as the dose is obtained only after the film has been developed. It can be affected by heat and various chemicals and can be used once only.

Thermoluminescent Dosemeter

The thermoluminescent dosemeter (TLD) consist of a material which when heated, after being exposed to ionizing radiation, emits a quantity of light which is proportional to the amount of radiation received . TLDs of suitable materials may be used to measure beta, X- and gamma radiations. Two TLD materials are calcium fluoride and lithium fluoride. Calcium fluoride has a high sensitivity and a poor energy response. Lithium fluoride has a lower sensitivity and a good energy response. In practice such TLD materials are used in the form of powder or a thin disc. The TLD can measure doses over the range approximately 0.1 mSv to 1000 Sv and can be reused after being measured and re-annealed. It is not a direct reading personal dosemeter.

Table 1

(see next page)

Table 2
Biological Monitoring

Method	Radionuclide intake
whole body monitoring	gamma-emitting radionuclide e.g. Cs-137
organ monitoring (thyroid counting)	I-131
organ monitoring (lung counting)	U-235, Pu-238, Pu-239
urine analysis	tritium
faecal analysis	plutonium
breath analysis	radon, thoron

Table 1
Australian State Requirements for External Radiation Personal Monitoring Devices

State	Requirement
ACT	Occ. exp. persons (Not dental practices)
New South Wales	To be worn by persons involved in the use of ionizing radiation for: . radiotherapy, . industrial radiography, . nuclear medicine, . scientific research in medium or high level laboratories (defined in AS 2243.4)
Northern Territory	Occ.exp. persons
Queensland	All persons working in controlled areas. (Exemptions from wearing dosemeters in dental, veterinary, radiation gauging practices.
South Australia	Specified employers required to issue to each radiation worker employed.
Tasmania	Persons for whom there is a hazard of exposure.
Victoria	Occ. exp. persons unless exempt,e.g.dentists
Western Australia	Selected occupationally exposed persons.

Table 5
Issue Frequency for External Radiation Personal Dosemeters

PRMS Service	Issue Frequency
ARL	4, 8 or 12 weeks
ANSTO	3 months (designated workers) 1 month (extremity dosemeters)
Queensland	1 to 3 months
WA	8 weeks
Cumberland College, NSW	3 months

Table 7.2
Distribution of Annual Doses (Western Australia 1995)

Dose Range (mSv)	0-1	1-5	5-20	20-50	>50
All Rad. Workers	4335	118	6	2	0
Ind. Radiog.	1451	48	4	2	0

Mean dose - all rad.workers 0.11 mSv

Mean dose - ind. radiographers 1.07 mSv

Table 7.3
Distribution of Annual Whole Body Doses (ANSTO 1996-97)

Dose range (mSv)	<2	2 - 5	5 - 10
No	657	66	28
Dose range (mSv)	10 - 15	15 - 20	>20
No	3	0	0

Table 3
External Personal Radiation Monitors Issued by PRMS

PRMS	No. Monitors Issued Annually	No. Persons Monitored	No. Persons For Whom Exposure Records Maintained	Minimum Reportable Dose
ANSTO	5,000 beta/gamma 450 neutron 1,200 extremity 5 finger ring	730 (in 1996-97)	~900	10 μSv whole body 10 μSv skin dose/ shallow dose 100 μSv extremity
ARL	~ 180,000	~ 30,000 (~ 90% of persons monitored in Australia)	75,000	10 μSv X-rays 70 μSv high energy gamma rays 100 μSv finger dose
Queensland	~40,000	5,000	9,000	100 μSv (per month)
Western Australia	24,500 (others) 4,130 (dental practices)	3,390 625		50 μSv (X-radiaition) 200 μSv (γ-radiation)
Cumberland College	1,200	~460		1000μSv

Table 4
Personal Radiation Monitoring Services - External Radiation

PRMS	Types of Dosemeter	Radiation Measured	Provision of Service
Australian Radiation Laboratory.	TLD badge. Special TLD badge Special TLD badge. Finger sachets. Neutron badges (TLD card + CR39 film).	beta, X, gamma. beta, X, gamma. beta, X, gamma. beta, X, gamma. beta, gamma, fast neutron	Australian States without own services Commonwealth authorities.
ANSTO	TLD badge. TLD finger ring TLD wrist badge TLD head badge.	beta, X, gamma, neutron.	ANSTO staff, contractors etc. on ANSTO sites.
Queensland Radiation Monitoring Service (QRMS)	TLD badge TLD badge CR39 film	gamma gamma, neutron neutron	Various.
Western Australia Radiation Monitoring Service (WARMS)	Film badge.	beta, X, gamma.	Various.
Cumberland College, Sydney University (CCSRMS)	TLD badge	beta, X, gamma.	Cumberland College staff and students.

Table 6
Fees Charged by Australian Personal Radiation Monitoring Services (July 1997)

PRMS	Fees ($)	
ARL	TLD badge	9.0
	Special TLD badge	11.00
	Finger sachet	10.00
	Neutron monitor	18.00
	TLD card holder	11.00
	TLD holder key	5.50
	TLD holder clip	0.75
	Non-returned or irreparably damaged items:	
	TLD cards	20.00
	Special TLD monitors	31.00
	Neutron monitors	36.00
Queensland	Gamma dosemeter	7.00
	Dosemeter late return (Not returned within 30 days of end of wearing period)	10.00
	Gamma dosemeter lost, not returned or returned damaged	64.00
WA	Film	6.00
	Holder	8.00

Table 7.1
Some Doses for Various Occupational Classifications (ARLPRMS 1996)
Diagnostic Radiology and Therapy

Occupational Classification	Max Dose (μSv)	Average Dose (μSv)	No. Wearers
Radiologists (Large hospitals)	6410	255	344
Radiologists (PP)	10450	159	196
Radiographers (Large hospitals)	2800	96	1841
Radiographers (Private practices)	8930	132	1498
Therapy radiographers (Large hospital	1710	143	547
Therapy radiographers (PP)	10630	243	59
Nuclear medicinetechnologist (Hospital)	6470	1241	339
Nuclear medicine technologist (PP)	9540	1678	160
Dentists (Dental hospital)	2380	33	149
Dentists (PP)	900	17	919
Pathology (Receptionist)	10760	2178	5
Chiropractor/Osteopath	2060	28	184
Veterinary Surgeons	7830	34	1318
Industrial radiography (Open installations)	9140	978	297
Uranium mining (Mine workers)	4920	833	247
Uranium mining (Mill workers)	2310	907	79
Mineral sands mining (Wet plant operator)	3260	739	15
Mineral sands mining (Dry plant operator)	6870	554	188
Users of radioactive tracers (Research)	2050	36	2185
Users of radioactive tracers (Industry)	5730	47	111

NOTE: PP = Private practice