Manual on radiation protection in hospitals and general practice

Volume 5

Personnel Monitoring Services

W. MINDER & S.B. OSBORN

Jointly sponsored by ILO, IAEA, and WHO

WORLD HEALTH ORGANIZATION GENEVA

MANUAL ON RADIATION PROTECTION IN HOSPITALS AND GENERAL PRACTICE

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Personnel Monitoring Services

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CONTENTS

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Preface

Much technical material has been published at the national and international levels on radiation protection in the nuclear power industry, nuclear research, and conventional industries. On the other hand, the subject of radiation protection in hospitals and general practice, where a large proportion of public and occupational radiation exposure occurs, has not yet received much attention in the international literature.

The International Labour Organisation, the International Atomic Energy Agency, and the World Health Organization all have a long-standing interest in these problems from various points of view. They therefore decided to collaborate in the preparation of a Manual on Radiation Protection in Hospitals and General Practice *in several volumes, with each agency taking special responsibility for the volumes that concern it most. However, to simplify distribution and to make it easier for readers to purchase the various volumes, the entire work is being published by WHO.*

The manual as a whole deals with the radiation protection of patients, occupationally exposed persons, and the public and is written for the reader having a basic general knowledge of radiation and biology. It is hoped that it will be found helpful not only to those who are directly engaged in radiation protection in hospitals and general practice but also to national authorities, hospital administrators, supervisors, hospital workers, teachers in training centres, and all those who have some responsibility in the subject.

The present volume, the fifth in the series, deals with services for monitoring the radiation doses received by individuals working in places where they are (or may be) subjected to radiation exposure. Such personnel monitoring is specified in international recommendations and is compulsory in many countries. Within the field of medicine, the places of work where individual monitoring devices would be called for are typically departments of radiotherapy, X-ray diagnosis, and nuclear medicine.

IAEA and WHO have frequently been asked by Member States for technical advice on the establishment of personnel monitoring services, and it is therefore appropriate to devote one volume of the manual to this subject, especially since much of the standard literature is hard to obtain in developing countries. The approach adopted is essentially practical and enables the reader to choose those methods that are most suitable in his particular circumstances.

The first draft of the volume was prepared by Professor Walter Minder and circulated to a number of experts (see list of reviewers on page 7). The manuscript was then revised by Professor Minder and Dr S. B. Osborn in the light of the comments received, all of which are gratefully acknowledged. Special thanks are due to Dr J. Moroni, Central Service for Protection against Ionizing Radiation, France, and to Mr E. Smith, formerly Deputy Director of the Radiological Protection Service, United Kingdom, for their contributions on the monitoring systems used in their countries.

1. Personnel Monitoring Services

This volume attemps to review in an objective manner the problems involved in establishing personnel monitoring services for health care workers, with particular reference to developing countries. It describes the various methods that can be used, and compares their advantages and disadvantages. No attempt has been made to discuss other aspects of radiation monitoring, such as monitoring the workplace for radiation or monitoring for radioactive contamination, since these are covered elsewhere—e. g., in textbooks and the publications of various authorities (*1–14*).

The fact that ionizing radiations can cause harm to living organisms was discovered in the early days of work with X-rays and radium, when many of the pioneers in this field suffered severely from overexposure. Two kinds of monitoring are necessary to protect people against such exposure — monitoring of the workplace and monitoring of the personnel who work there. This book deals solely with the latter kind and in doing so draws on the authoritative publications of the International Commission on Radiological Protection (ICRP) (*1–4*).

Objectives of personnel monitoring

The growing use of ionizing radiations in medicine, industry, and research has brought a large number of people into contact with them. In countries with advanced technology, as many as 0.25% of the population may be involved with radiation work in one way or another and require protection against this modern occupational hazard. Individual radiation measurement is necessary for radiation workers because, even if the radiation in the workplace is standardized, methods of working differ from one person to another.

The primary objective of individual monitoring for external radiation must be to assess, and thereby to be able to limit, the radiation received by individual workers. It is important to ensure that the dose-equivalent limits recommended by ICRP (*1*) are not exceeded, and the radiation actually received by any individual should be kept as far below these limits as is readily achievable, economic and social factors being taken into account.

Personnel monitoring is also useful in other ways. For example, it provides an excellent check on working discipline, on which the amount of radiation received in daily work largely depends. This is particularly important in places where routine work may involve short exposures at high dose-rates, where complicated installations must be used, or where new procedures are being carried out for the first time.

Monitoring of the workplace will usually be carried out before a new installation is put into normal operation, using operating conditions similar to those to be expected in practice. Such monitoring will furnish valuable information about the potential risk to which a worker may be exposed, but it can in no way replace the individual monitoring of the worker because it cannot take into account all the special circumstances in which the work will be done.

Fortunately, radiation accidents are extremely rare. If, however, a person has been exposed to high radiation levels, an individual monitoring device can give information of great value in deciding on any treatment that might be necessary or on the future work schedule of that person. It can also help greatly in any measures to be taken to modify the installation giving rise to the radiation.

Note. In this volume the terms "dose" and "dose rate" must be taken to include "dose-equivalent" and "dose-equivalent rate" unless the context indicates otherwise.

Limitations of personnel monitoring

A person will normally wear only one monitoring device and it can indicate only the radiation received at the place on the body where it is worn. Other parts of the body could be irradiated with different doses. Additional dosimeters may therefore be of great value in certain circumstances. For instance, where highly radioactive material is to be manipulated a ring device may be worn to record the finger dose, and, where short exposures at high dose rates may occur, an early estimate of the radiation received may be obtained from a pocket ionization chamber suitable for that dose and dose rate. Normally, however, only one device is worn by each person.

Radiation workers frequently have to deal with radiations of different energies and different types, and most individual monitoring devices do not respond equally to all radiations of all energies. X-rays, beta rays, and neutrons usually have a fairly broad spectrum. Gamma rays have specific energies determined by the emitting nuclide, but scattered gamma rays will have a broader spectrum.

There is no single device that can accurately measure radiation of all types and of all energies from all directions. In practice, therefore, personnel monitoring devices involve a compromise. The accuracy possible is always limited, but high accuracy is not usually necessary.

According to the International Commission on Radiation Units and Measurements (*15*), where the radiation received approximates to the annual occupational dose limit, it should be known to within 30%, but where it is less than one-tenth of this level an error of a factor 2 is acceptable. Where the radiation received is 10 or 100 times the annual dose limit, it should be known as accurately as possible, because this knowledge may influence medical treatment. Where the dose received is 1000 or more times the annual dose limit, accuracy is irrelevant because it will not affect treatment.

Some measurement errors are inherent in the nature of the measuring process, and these limitations must always be borne in mind. For instance, a dosimeter may give different values for the same dose when it is delivered from different directions, and this is especially true for beta rays and low-energy X- and gamma rays.

Persons to be monitored

In circumstances in which exposures might exceed three-tenths of the dose-equivalent limits, all workers should be individually monitored (*1*). Those working in conditions where it is most unlikely that the annual exposure will exceed three-tenths of the dose-equivalent limit do not require individual monitoring, although it may be wise for many of them to wear dosimeters occasionally to check that they do not in fact receive sufficient radiation to warrant constant monitoring. It is usually a matter for local judgement which individuals might, and which might not, be exposed to sufficient radiation to justify recording the doses received. For example, the staff of a diagnostic X-ray department will normally be required to wear dosimeters even though, on the basis of past records, they are most unlikely to receive as much as three-tenths of the ICRP dose-equivalent limits, because the nature of their work is such that a single careless error could result in a high exposure. Similarly, people working in a department with radioactive sources usually need individual monitoring, especially of the hands, even though in practice they receive quite small amounts of radiation. The hazard of radioactive contamination is another matter, and for further information on that aspect of radiation work the reader is referred to Volume 2 of this manual.

It is recommended by the ICRP (*1*) that radiation workers who might receive annual exposures exceeding three-tenths of the dose-equivalent limits should not only be monitored but also receive a pre-employment medical examination. Those who are unlikely to receive exposures as great as this, even if required to be monitored like workers in X-ray diagnostic departments, need not be medically examined.

Area monitoring in relation to personnel monitoring

Many radiation sources used in medical radiology, such as most X-ray machines and cobalt-60 or caesium-137 therapy units, are installed in a fixed position. When in operation, they produce a radiation field of known size, shape, and intensity, although the beam direction and duration may vary. It is therefore possible to determine the areas where substantial irradiation of individuals could occur. Measurements made at these places will give a quantitative indication of the radiation to which a worker would be exposed at each place and hence the time he could stay there without exceeding the recommended limit of dose equivalent. Such area monitoring should be conducted in the neighbourhood of all fixed installations, preferably before the machines are put into routine operation. A further result will be to show whether the protective walls or barriers are sufficient or not, and this is particularly important for the protection of people in adjacent rooms. Area monitoring can also indicate very clearly those places in or around a department where there is no risk from radiation and where, therefore, no protective measures are necessary. Nevertheless, area monitoring may be based on false assumptions and therefore cannot replace individual monitoring, which is the only way of measuring the radiation actually received by a particular person.

Radiation quantities and units

At the time of writing, a change is taking place to the use of SI units for all radiation measurements. In accordance with WHO policy, this manual therefore uses the gray for absorbed dose (1Gy = 100 rad), the coulomb per kilogram for exposure (1 C/kg = 3876 röntgens), and the joule per kilogram for dose equivalent (1 J/kg = 100 rem).[1] Where radiation exposure is to X-rays, beta rays, or gamma rays only, a dose equivalent of 1 J/kg (100 rem) is numerically equivalent to a dose of 1 gray (100 rad). Whether this is expressed as gray in water, in soft tissue, or in air does not appreciably affect the accuracy for radiation protection purposes, but for other radiations an appropriate quality factor must be used. For X- and gamma rays, an exposure of 2.58×10^{-4} C/kg (1 R) will result in a soft-tissue dose of 0.01 gray (1 rad) with sufficient accuracy.

[1] The sievert (Sv) has been proposed as a special name for the joule per kilogram for the measurement of dose equivalent, but the matter is still under consideration by the responsible international bodies and is not yet part of the SI. Further information on SI units will be found in a WHO publication on this subject (*19*).

2. Techniques Used in Personnel Monitoring

In carrying out individual monitoring, no single technique is of universal application. The technique chosen should be one that enables the dose to be measured with an acceptable accuracy for the particular application in mind (see page 25). Thus, where the radiation doses do not vary greatly, it is possible to use techniques that would otherwise be unsuitable. Similarly, the techniques that are appropriate if radiation is received in occasional short exposures at high dose rates may be inappropriate if it is received continuously at low dose rates. The presence of different types of radiation and different radiation energies may also affect the techniques to be used. In an institution where a wide range of radiation work is carried out, it may be necessary for a range of monitoring techniques and equipment to be available.

High accuracy is unnecessary. A single measurement at one place on the body, however accurate, can only indicate the whole-body dose approximately because it is rare in medical work for anyone to receive radiation uniformly over the whole body, and the measurement is likely to be made at a place where the dose is different from the whole-body average. Again, any attempt to evaluate from a measurement by a single instrument the dose to gonads or bone marrow is likely to be subject to considerable uncertainty.

It is important that individual monitoring devices should be capable of measuring a wide range of doses and dose rates. In some situations, the dose equivalent to be measured will be less than 0.1 mJ/kg (10 mrem), but in serious accidents it may be necessary to be able to measure levels 10 000 times greater. Similarly, where the dose rate is uniform throughout the working week, it may be necessary to measure down to perhaps 1 nJ/(kg.s) (0.1 µrem/s), whereas if the dose rate is high for short periods (as in X-ray diagnosis), it may be necessary to measure a dose rate millions of times greater, if for only a fraction of a second.

In addition, measurement techniques should be simple enough to be carried out with acceptable accuracy by people who are not highly trained scientists. Equipment needs to be simple, robust, reasonably resistant to climatic effects, and capable of being worn or carried on the person while performing normal work. All these criteria restrict the choice of instrument and, in fact, no single instrument is adequate for all the situations that may be encountered. The two devices that come closest to universal application are the film badge and the thermoluminescent dosimeter, but others, such as the ionization chamber, are more appropriate in particular situations.

Film badges

Film badges can be used to monitor the exposure of staff engaged in a wide range of radiation work, and they are especially useful for monitoring hospital staff. However, it is very easy for someone with experience of photography but little knowledge of radiation monitoring to obtain results seriously in error, possibly by an order of magnitude. Careful attention must be paid to calibration and standardization. Excellent, but not recent, surveys of film badge dosimetry are to be found in the literature (*9, 16*). Details of three film badge systems are given in the Annex.

Chemistry and physics of film badges

The use of photographic films for dose determination requires some general knowledge of film chemistry and physics. The chemical reduction of silver bromide AgBr to metallic silver and elementary bromine by radiation causes blackening of the film (when developed) and therefore an absorbance A of incident light[2] according to an exponential law of the general form:

$$A = A_s (1 - e^{-\gamma D})$$

where A_s = the saturation value of the absorbance
γ = a constant that is characteristic of the particular photographic emulsion and its processing.
D = absorbed dose.

The absorbance A is the common logarithm of the ratio φ_0/φ_t where φ_0 is the radiant flux density incident on the film and φ_t is the radiant flux density transmitted through the film:

$$A = \log_{10} (\varphi_0/\varphi_t).$$

The blackening caused by the radiation gives rise to an absorbance A_r, which is evaluated by subtracting the absorbance A_n caused by normal background fogging from the total absorbance A_t:

$$A_r = A_t - A_n$$

For small amounts of radiation, which is generally the case in practice, the absorbance A_r may be considered as proportional to the radiation dose D, i.e.,

$$A_r = \gamma D$$

[2] The International Union of Pure and Applied Chemistry recommends the use of the term "absorbance" to indicate the degree of blackening of a photographic film. The older term "optical density" is deprecated.