RADIOLOGICAL PROTECTION

TECHNICAL RECOMMENDATIONS FOR MONITORING THE EXPOSURE OF INDIVIDUALS TO EXTERNAL RADIATION

1975 EUR 5287 e

COMMISSION OF THE EUROPEAN COMMUNITIES

radiological protection

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Directorate-General Social Affairs
Luxembourg

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PREFACE

In the Directive on Basic Safety Standards for protection against ionizing radiations [1] the main principles for the health protection of workers and populations adopted by the Council on 2.2.1959 (O.J. No 11 of 20.2.1959) and partly revised on 5th March 1962 (O.J. No. 57 of 9.7.1962) and 27.10.1966 (O.J. No. 216 of 26.11.1966) are laid down.

Taking into account the radiological hazards, it is necessary to carry out measurements in order to assess the personal doses received by each worker. The assessment should be based on individual measurements and the results should be recorded. In order to provide advice to those people who are responsible for the monitoring of individuals, the group of technical experts in personal dosimetry convened from the Member States of the European Community and the Directorate of Health Protection decided to set up a working party to elaborate a Report on the "Technical Recommendations for Monitoring the Exposure of Individuals to External Radiation".

This Report will be reviewed one or two years after publication. In carrying out this review the Commission in collaboration with the above mentioned group of experts will take into account all comments and suggestions made in the intervening period.

These comments are to be sent to the following address :

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NOTE

shall : signifies an essential requirement

should: signifies a strong recommendation

may : signifies an acceptable method or an example of a good practice

1. Introduction

During the last 20 years, a very considerable effort has been made to provide individual monitoring for workers who are exposed to ionising radiation from sources external to the body, during the course of their work. Substantial advances have been made both in technique and in the establishment of regulatory codes. Already in many countries there are well established monitoring programmes at the service of those who are responsible for the radiological protection of workers, the equivalent of which exists for practically no other type of risk.

The aim of this document is to provide advice, based on this experience, to those people in member countries of the EEC who are responsible for the monitoring of individuals for exposure to external radiation. Advice is given on the objectives of individual monitoring programmes and on the requirements which personal dosemeters should satisfy. The recommandations are also intended to provide general advice to those who are responsible for the drafting of legislation in this field.

In preparing this document, guidance has been sought from a number of relevant publications. Indications of this are made at appropriate positions in the text and full details are given in the list of references. Guidance has been obtained particularly from Publications 12 and 22 of the International Commission on Radiological Protection (ICRP)[2, 15] and most of Section 2 of the recommandations is firmly based on these publications.

The terminology used in these recommendations is identical to that defined and used in the Commission of European Communities (CEC) Directive on Basic Safety Standards for the health protection of the population and workers against Ionizing Radiations (BSS)[1]. A glossary of technical terms used in this document is contained in Appendix II, and a more detailed description of the terms penetrating and non-penetrating radiation is given in Appendix III.

This document is mainly concerned with the assessment of doses due to photon and electron radiations (X, β, γ, e^-). The measurement of neutron doses will be the subject of separate papers, which will be published later.

Where the expression "dose" is used alone, it should normally be interpreted as meaning dose equivalent unless it is obvious from the context that some other meaning is intented.

2. Objectives and Principles

"The primary objective of individual monitoring for external radiation is to assess, and thus to limit, radiation doses to individual workers" (2, Paragraph 72). In particular the results of individual monitoring can be used to demonstrate compliance with BSS (1). In general the aim should be to ensure that the appropriate Maximum Permissible Doses (MPD) as laid down in the BSS (1), are not exceeded and in each case to minimise the exposure of personnel. "Supplementary objectives are to provide information about the trends of these doses and about the conditions in workplaces, and to give information in the event of accidental exposures" (2, paragraph 72). It also serves to improve the attitudes of individuals.

Those responsible for the radiological protection of persons shall assess each situation and ensure that any dosemeters worn are suitable for the measurement of existing and potential exposures to radiation.

2.1. The Measurement of Dose at the Surface of the Body

There is a highly complex relationship between the sources of radiation in the working environment and the radiation doses to the organs and tissues of the worker's body. Within the workplace, the radiation dose rate varies as a function of position and time, while within the worker's body the dose delivered to an organ or tissue depends on factors such as the type and energy of the radiation, the orientation of the worker relative to the radiation field, and the position, size and composition of the organs within the body (2, paragraph 89). Consequently, if one wished to calculate, during each exposure period, the dose to each organ or part of the body, it would be necessary to provide each worker with highly sophisticated individual dosemeters. Even then the calculation of the doses to specific organs or parts of the body would be difficult, especially in situations where the worker comes into close proximity to discrete radiation sources.

However, the primary objective of individual monitoring can be achieved in a very high proportion of cases by simply measuring the dose at or near the surface of the body by the regular use of a single dosemeter worn at an appropriate place on the trunk of the body. It will sometimes be necessary to distinguish between body dose and skin dose; some

radiation is sufficiently penetrating to irradiate tissues lying well below the surface of the body, while other more easily absorbed radiation could only irradiate the skin (see Appendix III). It is shown in Appendix III that the dose at the depth of 5–10 mg/cm^2 below the surface of the body due to both the penetrating and non-penetrating components of the radiation field can be regarded as a measure of skin dose, while the dose at a depth of 400–1000 mg/cm^2 below the surface, most of which is due to the penetrating component, can be regarded as a measure of the dose to the underlying organs (except the eye – see Appendix III). Estimates of doses at these depths, obtained from suitable dosemeters worn on the surface of the body, should be compared with the appropriate MPD limits contained in Articles 7 and 8 of the BSS [1] relating to exposure of the skin and of the whole body respectively, and used as a basis for administrative control to ensure that these limits are not exceeded.

A dosemeter carried on the surface of the worker's body is best regarded as a sampling device. It provides a sample of the dose received at the surface of the body during the movement of the worker through his environment. It does not provide a direct measurement of the radiation dose to organs or tissues [2, paragraph 90]. Nevertheless, over a long period it is unlikely that the dose to any organ or tissue (other than the skin and possibly the eye) will exceed the doses due to penetrating radiation indicated by individual dosemeters worn on the surface of the body; in fact, the organ dose will generally be less than the dose indicated by the dosemeter. Therefore it is justifiable to base administrative control on the readings of such dosemeters, i.e. to behave as though the surface dosemeter provides a true measure of the dose to the body as a whole.

2.2. Use of Dosemters to Provide Environmental Information

In the event of accidental over-exposure, it is important that one should be able to identify the source of the exposure, so that steps can be taken to prevent a recurrence. In many situations the source of the exposure will be obvious, but in others, where a person may be exposed to more than one source, this may not be the case.

When there is a substantial risk of over-exposure, and the source of such exposure cannot be determined unambiguously by a study of the environmental situation, the personal dosemeter should be capable of providing information about the type and energy of the radiation, as well as the surface dose.

2.3. Estimation of Organ Doses

As pointed out in Section 2.1, it is administratively convenient in routine dosimetry to act as though the reading of a dosemeter worn on the surface of the body provides a true measure of the dose to the whole of the body. Although this is not true, the discrepancy between the reading of the dosemeter and the dose to individual organs is biologically insignificant in most routine dosimetry where small doses are involved; moreover the dosemeter generally over-estimates the dose, so that any discrepancies are on the side of safety. However, it must not be forgotten that the reading of a surface dosemeter does not provide a true measure of the dose to the organs or parts of the body, and the difference may be highly significant where large doses are involved. Consequently in the event that there is a substantial over-exposure, it may be necessary to compute the doses to particular organs, from the reading of the surface dosemeter, together with other information about the nature and direction of the irradiation.

It must be recognised that even if a dosemeter of the type referred to in Section 2.2 is used, it will not provide all of the information required to enable one to calculate organ doses with any degree of precision, since in general the direction of irradiation will not be known. In situations where the risk of over-exposure is high, it is often more desirable to wear several simple dosemeters on different parts of the body than to reply upon a more sophisticated dosemeter, worn at a single point of the body. However, the risk of over-exposure will rarely be such as to justify this.

In accidents in which persons are irradiated to such an extent that there is a strong probability of acute biological effect, a reasonably precise indication of organ doses may be required from a medical standpoint. It may be necessary to reconstruct the radiation field causing the exposure;

the personal dosemeter will then provide an important point of reference (2, paragraph 103). Additional information (e.g. biological dosimetry based on chromosome aberration analysis) other than that provided by the dosemeter may be required.

2.4. Extremity dosemeters

In some operations the doses to the extremities, especially to the hands, may be greatly in excess of the dose to the trunk of the body. It may then be necessary to wear an additional dosemeter at the point of highest exposure or to assess extremity doses by other means.

2.5. Exposure to Neutrons

Very few of the exposed persons are exposed to neutrons. Those few persons who are exposed to neutrons (mainly in Atomic Energy Centres) are exposed to gamma radiation at the same time, and it has been found that the exposure to neutrons is usually small compared with the exposure to gamma rays (and hence even smaller compared with the limiting BSS doses). As a result, individual neutron monitoring has until now rarely been necessary. The detailed discussion of the requirements for neutron dosemeters is beyond the scope of these recommendations, and will be considered in detail in a separate report.

2.6. Situations in which the Use of Dosemeters is Impossible or Inadequate

There are some situations where people work with materials which emit radiation which is incapable of penetrating the dead layer of skin on the surface of the body. Clearly in such cases personal dosimetry for assessing external radiation exposure is unnecessary.

There are other situations, particularly those involving exposure to beta radiation of low energy, where the radiation is sufficiently penetrating to irradiate the skin, but where methods for direct measurement of absorbed dose by the use of personal dosemeters is inadequate. In such cases it is necessary to base radiological protection procedures on assessments made by other methods.

3. Categories of Workers and Dosemeters

3.1. Workers

In the BSS [1], a distinction is made between the following categories of workers :

(a) Exposed worker category A : a worker who is liable to receive more than 3/10 of the Maximum Permissible Doses (MPD)

(b) Exposed worker category B : a worker who is liable to receive more than 1/10 of the MPD, but not more than 3/10 of these doses.

3.2. Dosemeters

Basic Dosemeter

A basic dosemeter is one which is worn for a relatively long period to monitor exposure of the trunk of the body; i.e. to estimate body dose and often also skin dose (see Appendices II and III).

If it is worn for the sole purpose of providing a measure of dose (body and possibly also skin dose) it is called a non-discriminating basic dosemeter.

A dosemeter which is intended to provide information about the type and energy of the penetrating component of the radiation causing the exposure, in addition to the information provided by the non-discriminating basic dosemeter, is called a discriminating basic dosemeter.

Extremety Dosemeter

An extremity dosemeter is a dosemeter which is worn on an extremity in situations where the dose to the extremity may be singificantly greater than the dose to the trunk of the body. Such dosemeters are worn in

addition to the basic dosemeter.

Dosemeters for high dose rate conditions

Dosemeters for rapid assessment can be used in operations when exposure for a short period to a high dose-rate may be required and when it may be necessary to check the dose received in order to make decisions about the conduct of the operation. These are worn in addition to the basic dosemeter.

Audible warning dosemeters or dose-ratemeters are often useful in operations and in areas where accidents or malfunctions could result in dose-rates such that maximum permissible doses could be rapidly exceeded if people stayed in the area.

In areas where nuclear (criticality) accidents could occur it may be necessary to wear dosemeters which are designed with the objective of providing, in an accident situation, more information of value from a medical standpoint than could normally be obtained from a basic dosemeter.

4. Requirements for the Use of Personal Dosemeters

As explained in Section 2.1, a single dosemeter worn on the trunk of the body normally provides an adequate measure of the body dose and the skin dose.

In situations where exposure is grossly non-uniform, it may be necessary to wear an additional dosemeter on the most highly exposed part of the body; and in particular, where the nature of the work is such that the hands are exposed to much more radiation than the trunk, then as explained in Section 2.4 it may be necessary to wear an extremity dosemeter on the most highly exposed part of the hands.

When there is exposure to neutrons, it may be necessary to wear an additional neutron dosemeter (but see paragraph 2.5).

4.1. Measurement of Doses to the Trunk due to Penetrating Radiation

As required by Article 25 of BSS, except in those cases where it can be shown that the resulting measurements would be inadequate (see Section 2.6), Category A Workers shall wear a basic dosemeter at all times when they are in controlled areas and if considered necessary in supervised areas (see BSS [1] Article 17).

A more sophisticated discriminating type of basic dosemeter need only be worn in situations where additional information might be required about the type and energy of the radiation to which a person has been exposed. In situations where there can be little or no doubt about the source of exposure, the non-discriminating basic dosemeter will provide all of the information which is required.

Category B Workers and non-exposed workers need not be issued with individual dosemeters, if sufficient is known from monitoring of the working environment to indicate unambiguously that they fall into one of these categories. However, in many work situations it is not possible to estimate with adequate precision the doses which people will receive simply by studying their working habits and their working environment. In such situations persons working in these areas shall be issued with personal dosemeters, at least for an experimental period, in order to establish that they are not in Category A. If it is shown during such an experimental

period that the doses being received are less than 3/10 of the MPD, the wearing of dosemeters can be discontinued at the discretion of the competent radiological authorities.

When personal dosemeters are issued to such workers, the principles which determine the choice of dosemeter type are the same as they are for Category A Workers.

4.2 Measurement of Doses to the Skin

If there is exposure to both penetrating and non-penetrating radiation, the basic dosemeter should normally be capable of measuring the total skin dose due to both the penetrating and non-penetrating components.

However, where low energy radiation (particularly beta radiation) is involved, it may not be possible to provide a personal dosemeter which conveniently and reliably measures the dose. In such cases protection measures should be based on dose estimates made by other means (see Section 2.6).

4.3 Measurement of Extremity Doses

If the dose to any part of the extremities of a worker is likely to exceed 3/10 of the relevant maximum permissible quarterly or annual dose, that worker should normally wear an extremity dosemeter as well as the dosemeter worn to monitor dose to the trunk of the body, during any work period in which the exposure of the extremity in question is likely to be significantly greater than the exposure of the trunk. If the use of extremity dosemeters is inadequate, indirect methods of assessment must be used (see Section 2.6).

4.4 Monitoring of Neutron Doses

If a worker is exposed to neutrons to such an extent that the resulting exposure is likely to exceed 1/10 of the MPD to the body, he shall wear a neutron dosemeter as well as any other dosemeters required under sections 4.1, 4.2, 4.3 etc., unless adequate or more accurate information can be obtained from the results of area monitoring.

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4.5 Use of Direct Reading Dosemeters

When a worker is temporarily engaged in work of such a nature that he is being or is likely to be exposed to radiation at a rate greatly in excess of 2.5 mrem in one hour, (i.e. the maximum rate to which he can be continuously exposed, 40 hrs/week, 50 weeks/year), it may be desirable to issue him with a direct reading dosemeter such as a quartz fibre electrometer in addition to other dosemeters which he normally wears. If the dosemeter is read by the worker or by supervisory staff at appropriate intervals, the information so obtained will be of value in determining whether the operation can be safely continued, or whether it should be terminated or modified. The readings from the direct reading dosemeter should be used only for control purposes, while the readings of the basic dosemeter should be used in assessing whether there has been compliance with BSS [1].

A rather similar need for issuing special dosemeters which can be directly or easily read can arise if people are required to enter areas where there are very high dose rates as a result of an accident (see also last part of Section 4.6 below).

4.6 Other Dosemeters for High Dose Rate Conditions

In situations where a malfunction could lead to a sudden increase in the doserate to which people are exposed to such an extent that the permitted quarterly dose could be exceeded in a short time, steps should be taken to ensure that an audible warning is given to warn people working in the area if such an event occurs. In the part, such warning has often been given by the use of appropriate fixed installed instruments, but it is also possible to use personal dosemeters or dose-rate meters to give the alarm. It may also be necessary for people working in such areas to wear special dosemeters, several such dosemeters being worn so that if necessary a reasonably accurate assessment of absorbed dose can be obtained irrespective of the orientation of the individual.

If people are required to work in a place where dose rates are not only extremely high but may fluctuate significantly, alarm dosemeters or dose-rate meters should be worn in addition to dosemeters worn to satisfy the requirements of Sections 4.1, 4.2, etc.

4.7 Monitoring Period

The choice of monitoring period should be related to the exposure situation; except in situations where people are being exposed at a very non-uniform rate, a monitoring period of between a week and a month is likely to be convenient for basic, extremity and neutron dosemeters. Unless exposures are particularly low or uniform, an issue period of more than 1 month is undesirable, since the longer the time which has elapsed, the more difficult it becomes to establish the reason for the exposure. In any case, the issue period should not exceed 3 months, since it may be necessary to assess the quarterly dose to demonstrate compliance with Articles 7 and 8 of the Euratom Directive on BSS.[1]

Direct reading dosemeters and audible warning dosemeters should normally be issued only for short periods, to cover the duration of one particular task. The issue period shall not exceed one working day or one shift.

Nuclear accident dosemeters can normally be issued for long periods, and it will not be necessary to change them or read them out unless and until an accident occurs, unless they contain elements which deteriorate in time.

4.8 Action levels for the Recording and Reporting of Results

It is usually easy to record and report all radiation doses above the threshold of detection of the dosemeter, and this procedure is recommended in most cases. In some cases, however, this detailed attention to low doses may focus unrealistic attention on insignificant exposures. In ICRP Publication 12 [2], paragraph 96, it is suggested that information below a selected investigation level can be disregarded. This investigation level must be chosen sufficiently low that the neglect of the data at low levels has no significant effect either on the value of the personal dose records or on the control of the situation in workplaces.

Many competent authorities would consider that the numerical values suggested for the investigation level in ICRP Publication 12, paragraph 98 are excessively high, on the grounds that information about changes in doses below such an investigation level may be of value to managements who

properly wish to ensure that doses are kept to a minimum, and may in some circumstances indicate a deterioration in an environmental situation whic should be investigated. Difficulties can also arise if such doses are disregarded in situations where radiation exposure occurs at a grossly non-uniform rate throughout the quarter or the year.

In deciding whether or not to adopt the relevant recommendations in ICRP Publication 12, therefore, it will be necessary to consider the nature of the work, the exact administrative arrangements of the dosimetr service, and possibly other factors.

4.9 Other Action Levels

If the dose recorded during a particular issue period unexpectedly corresponds to an exposure rate which, if it persisted for a whole year, would lead to the annual MPD in question being exceeded the working environment and the working methods and attitudes of the person should be examined. This need not be done if the observed result had been anticipated.

If the dose indicated by the basic dosemeters is in excess of the M but acute biological effects are unlikely, it will be convenient to assum that the whole body or the whole skin of the body has been exposed to the same dose as that indicated by the dosemeters, when discussing administra tive measures such as a change in the nature of the person's duties in the immediately ensuing period. However, if the dose is such that acute biological effects are possible or likely, it will be necessary to recognise that the doses to different organs or parts of the body will in general be different from the dose indicated by the surface dosemeter in such cases steps should be taken to obtain the best estimate possible of the dose to the critical organ or organs. The estimates so obtained should form the basis for any advice to the person responsible for the medical care of the irradiated person.

4.10 Accuracy Required from Basic Dosemeters

Recommandations concerning the accuracy acceptable in routine individual monitoring are contained in paragraph 101 of ICRP Publication 12 [2]; this states that "the uncertainty in assessing the

upper limits to the annual dose equivalent to the whole body or to the organs of the body should not exceed 50%". In the context of the discussion in that publication, however, it is apparent that what was meant was that the apparent annual dose as indicated by practical basic dosemeters worn on the surface of the body should not differ from the annual dose indicated by ideal or perfect dosemeters worn at the same points by more than 50 %.

For the purpose of the present document it is more useful to specify the acceptable uncertainty for a single dosemeter. There may be systematic errors arising from the fact that the exposure conditions differ in a systematic way from those adopted in the calibration, in regard to the energy of the radiation, the direction of incidence etc., and there may be random errors arising from variations in those and other parameters. In order to satisfy the requirements of ICRP Publication 12, for doses approaching the maximum permissible it is suggested that the combined effects of the systematic uncertainties should not exceed 40%, while the uncertainty arising from random errors on a single dosemeter should not exceed 20% (with 95% confidence). In practice the random error on the total annual dose estimate will then probably not exceed 10%.

It will neither be feasible nor necessary to achieve this accuracy for very small doses, and consequently the following overall specification for accuracy is suggested.

(a) Systematic uncertainties should not exceed 40% of the dose being measured, or 10% of the average permissible dose for the monitoring period, whichever is the greater.

(b) Random errors on a single dosemeter should not exceed 20% of the dose being measured, or 10% of the average permissible dose for the monitoring periods, whichever is the greater (at 95% confidence).

5. Calibration : Type Tests and Routine Calibration

In the case of an ideal dosemeter, there should be a unique relationship between some relevant signal (or combination of such signals) being measured, and the dose to which the dosemeter has been subjected. In the case of practical dosemeters this ideal situation cannot be achieved, and consequently it is not possible to carry out a once-for-all calibration which will apply in all conditions of use. Instead, it is usual for personal dosemeters except those based on ionization chambers to do routine calibrations under well defined test conditions for each monitoring period (see Section 5.2), and then separately to examine the effect of those influence quantities which may vary during use. The latter part of the investigation is called a type test (see Section 5.1). Usually, it is not necessary to repeat the type test each time a new batch of dosemeters is calibrated, but only if changes in the quality of the dosemeters are to be suspected.

The conditions of the tests should always be stated clearly in records or certificates. A detailed description of calibration facilities for radiation protection monitoring instruments is given in an IAEA report [9]; methods for calibrating in units of absorbed dose from ionization measurements are dealt with in several ICRU-reports [10], German Stardards [11], and other publications [12].

5.1 Type Tests

Before a new type of dosemeter is used, an investigation shall be made of the characteristics of this type in order to establish that such a dosemeter is capable of satisfying the necessary requirements. A type test has to be performed with respect to those influence quantities which could change the response of dosemeters of that type, namely the type and energy of the radiation, direction of incidence, temperature, humidity, etc.

General requirements for personal dosemeters are specified in Section 6. Up to now specific requirements including test procedures have been worked out only for dosemeters based on photographic films (ISO 1971 [7]) and on ionization chambers (German DIN, 1974 [8]). A document [17] which is in course of preparation gives specific requirements for thermoluminescence dosemeters. Beam qualities to be used for type

testing and calibrations are recommended by ISO, 1973 [3].

5.2 Routine Calibration of Dosemeters

The reading obtained from dosemeters is transformed into units of absorbed dose in soft tissue either by direct calibration of each single dosemeter (which is not always possible or convenient) or by the aid of reference dosemeters out of each batch which are used to calibrate dosemeters of the same batch. This is done under conditions which ensure that dose significant influence quantities which affect the calibration (whose effects have been examined in the type test) have fixed and known values. The dosemeters are irradiated in a field whose properties are either defined through use of a standard source, or which have been fully explored with a reference instrument. The calibration of the reference instrument must be determined by comparison with an institutional or national standard. The details of the calibration procedure and the assessment of which influence quantities have to be investigated with the type test or routinely checked together with the calibration, depends upon the dosemeter type and cannot be described here.

6. Requirements for Basic Dosemeters

6.1 General

Dosemeters must be convenient to wear, mechanically strong and inexpensive, and must not be affected by the kinds of mechanical shocks to which they are likely to be subjected during use.

Where skin or extremity doses are concerned, the primary objective is to assess the dose to the basal layer of the epidermis of the most exposed part of the body. The basal layer may be taken to be at a depth of 5 to 10 mg/cm^2 (see Appendix III).

Where penetrating radiation is to be recorded and no neutrons are involved, the objective should be to measure the dose at a depth of 400 to 1000 mg/cm^2 below the surface of the body. The response of the dosemeter should be substantially independent of the energy of the radiation. This objective can most easily be met if the material with which the radiation interacts in the dosemeter is roughly tissue-equivalent. However, it is also possible to get an energy-independent response by the use of other detectors combined with appropriate filters.

The dosemeter assembly must give the person responsible for radiological protection the possibility to assess the dose equivalent independent of the type of radiation of the energy and of the direction of incidence with an accuracy specified in ICRP Publication 12 and ICRU Publication 20 (see Section 4.10). The systematic and random uncertainties should not exceed the values specified in Section 4.10.

Such uncertainties can arise from a number of causes, some of the more important of which are discussed in the following paragraphs; limits are suggested in those paragraphs for the uncertainties arising from such factors. These recommendations need not be rigidly adhered to, provided that the general requirement of uncertainty stated above is satisfied.

6.2 Dose Range and Response

Dosemeters must be capable of measuring doses in the range from 10% of the average permissible dose for the monitoring period up to at least 100 rads, and in many cases up to 1000 rads. There shall be a monotonic (preferably linear) relationship between dose and response over this entire dose range, and the accuracy achieved throughout that range shall be as stated in the previous paragraph.

6.3. Energy Dependence

The uncertainty in dose determination, due to the fact that the dosemeter may be exposed to radiation whose energy is different from that used in the calibration, should not exceed - 20% or + 40% over the entire range of energy which the dosemeter is intended to measure, e.g. 10 keV to 10 MeV for photons, or for all energies $\geq$ 0.5 MeV for beta radiation.

6.4 Directional Dependence

If the dosemeter assembly is rotated in free air around any axis during exposure to photons with energy about 40 keV, the dosemeter response should not vary by more than $\pm$ 30% from its response to the same radiation under static conditions at the angle of incidence used in the calibration[7].

6.5 Dependence on Other Influence Quantities

6.5.1 The response should be independent of dose rate, within $\pm$ 5%, for all dose rates up to at least 10^3 rads per second, and in particular cases involving pulsed radiation sources, up to 10^{10} rads per second.

6.5.2 The uncertainty arising from aging or fading of the signal or response, or arising from environmental influences such as temperature, humidity or light, should not exceed 10% at 95% confidence level.

6.5.3 The dosemeter should preferably respond only to the type or types of radiation which it is intended to measure. The response to other types of radiation which could be met in practice shall be determined so that corrections can be applied if necessary.

6.6 Reproducibility of Response of Detectors and Detector Material

The variation between the response of a single reusable detector when tested repeatedly to a given exposure, or between a number of detectors which are treated as substantially identical members of a batch, should not exceed 10% at 95% confidence.

6.7 Evaluation System

Uncertainty arising from changes in the sensitivity of readers should not exceed 10% at 95% confidence level.

The evaluation system should incorporate devices to prevent loss of information as a result of malfunctioning of the system, and shall as far as possible be "safe" in the sense that in the event of malfunctioning, it gives no answer rather than a false value.

7. Types of Dosemeter which are Acceptable for Use as Basic or Extremity Dosemeters

At the present time there are several types of dosemeter which are used on a fairly extensive scale and which satisfy the requirements for measuring doees to the body, the skin or the extremities. Almost all of these fall into one or other of the following broad categories :

(a) film-badges based on the photographic principle;
(b) devices which contain roughly tissue-equivalent thermoluminescent materials (specifically lithium fluoride or lithium borate);
(c) radiophotoluminescent glasses with appropriate filters.

Provided that the detailed requirements set out in this recommendation are satisfied, each of these types of dosemeter is considered suitable for the measurement of body, skin and extremity doses as described in paragraphs 7.1, 7.2 and 7.3 below; but it should be noted that at the present time the main usage is of film badges, and that this situation is likely to continue for some years at least. The final choice in particular circumstances will depend on many factors, and should as fas as possible be left to those who have responsibility for radiological protection of the workers.

In the rapidly developing field of personal dosimetry, it is possible that within a few years, dosemeters based on other principles will be developed, some of which may become acceptable alternatives to the above types, provided that they have first undergone extensive testing and proving trials.

7.1 Doses due to Penetrating Radiation

Doses due to X-rays and gamma rays can be satisfactorily measured using either film badges, thermoluminescence dosemeters or radiophotoluminescent glass dosemeters.

It should be noted that in their simplest forms, thermoluminescence and radiophotoluminescent glass dosemeters will be suitable only for use as non-discriminating basic dosemeters, but at the expense of increased complexity they can if necessary be used as discriminating basic dosemeters.

7.2 Skin Doses

Skin doses can be measured using either film badges or thermoluminescence dosemeters. Radiophotoluminescence dosemeters, because of their thickness, cannot satisfactorily be used for measuring skin doses due to low energy beta rays on a routine basis. Film badges cannot be used for measuring doses due to very low energy beta rays, because these are completely absorbed in the paper wrapper which has to be used to protect the film from exposure to light. In principle thermoluminescence dosemeters can be used for this purpose, but there are severe practical difficulties, because of the extent to which absorption of the radiation occurs within the thickness of practical thermoluminescence detectors.

7.3 Extremity doses

In the present state of technology, fingertip doses can only be measured satisfactorily by the use of thermoluminescence dosemeters. Because of their simplicity and small physical size these can be worn on the most exposed part of the hands, usually on the fingertip. There are practical difficulties in measuring the dose at a depth of 5-10 mg/cm^2, when part or all of the dose is due to soft non-penetrating radiation, but where the exposure of finger-tips is involved, it is neither necessary nor desirable to attempt to measure dose at this depth, since there is good evidence that the basal layer of the epidermis is at a depth of 30 to 50 mg/cm^2 below the surface of the fingertip (see Appendix III, Ref. 2). Doses to other parts of the extremities can be measured with film badges, thermoluminescence or radiophotoluminescence glass dosemeters.

7.4 Neutron Doses

Either photographic films, thermoluminescence dosemeters or glass dosemeters (as well as a number of other devices) can be used to estimate thermal neutrons. Although there are neutron dosemeters which can be used satisfactorily for measuring neutron doses in particular circumstances, no general purpose device has yet been developed which is suitable for measuring individual doses due to fast and intermediate energy neutrons. A discussion of these problems is outside the scope of this document and will be discussed at greater length in a subsequent recommendation on neutron dosimetry.

8. Administrative Requirements for Record Keeping

The data obtained from personal dosemeters are not only of value to management at the time in maintaining and improving standards of design and operation, and in demonstrating compliance with BSS [1], but may also be of use in litigation and other medico-legal matters. Consequently individual monitoring results must be recorded in a form which enables the exposure of individuals to be ascertained ~~at a later time~~ [2, paragraph 24]. The period for which such records must be retained will be prescribed in national legislation. However, it is not necessary to retain for long periods the records of dosemeters (such as direct reading dosemeters) which are worn as secondary or control dosemeters in addition to the primary dosemeter.

Care shall be taken to ensure that doses are ascribed to the correct individuals. This requires that each individual wears the dosemeter allocated to him and that the read-out and recording system is designed to maintain the relationship between dosemeter identification and dose recorded secure at all stages during processing and storing.

Those providing radiological protection services should draw the attention of those responsible for the supervision of workers of the need to wear dosemeters when working in controlled areas, and of the need to return them for processing at the appropriate time.

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APPENDIX I

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APPENDIX II

Terminology

This Appendix contains definitions of a number of technical terms used in the text of this Report. Wherever possible it is intended that the terms should have the same meanings as they have when used in other documents. However, the definitions given here are strictly intended to be applied in the context of this Report, and it must not necessarily be assumed that they have an identical meaning when used elsewhere.

1. Physical Quantities and Units

1.1 Absorbed Dose

The absorbed dose, D is the quotient of dW by dm, where dW is the energy imparted by ionizing radiation to the matter in a volume element and dm is the mass of the matter in that volume element.

$$D = \frac{dW}{dm}$$

The special unit of absorbed dose is the rad. (The SI (Système International) unit is the joule per kilogram (J/kg) ; 1 rad = 0.01 J/kg)

1.2 Dose equivalent

The dose equivalent, H, is the product of D, Q and N at the point of interest in tissue, where D is the absorbed dose, Q is the quality factor and N is the product of other modifying factors, both factors being dimensionless (see ICRP Publication No. 9, pp 3-4). [16]

$$H = QND$$

Note : The term dose equivalent serves only for radiation protection. Values for Q are chosen to allow for the fact that equal doses of different types of radiation do not produce similar biological effects; N = 1 for irradiations by external sources.
The special unit of dose equivalent is the rem.

$$1 \text{ rem} = 0.01 \text{ J/kg}$$

2. Radiation Protection Terms

2.1 Organ dose

The term organ dose is used to refer to the dose to a particular organ or part of the body, e.g. to the gonads, lung, bone marrow or skin. The organ which in a given irradiation situation is most likely to receive a dose of more than the maximum permissible dose (see 2.2 below) is called the critical organ. Where it is necessary to calculate doses in particular organs, it may be assumed that they are at the following depths below the front surface of the body (see Reference 13 and Appendix III).

Red bone marrow	20 mm $\simeq$ 2000 mg/cm^2
Male gonads	4-10 mm $\simeq$ 400-1000 mg/cm^2
Female gonads	70 mm $\simeq$ 7000 mg/cm^2
Eye lenses	3 mm $\simeq$ 300 mg/cm^2
Skin	0.05-0.1 mm $\simeq$ 5-10 mg/cm^2

2.2 Maximum Permissible dose (MPD)

The maximum permissible doses are the maximum dose equivalents which are not expected to cause appreciable body injury to a person during his lifetime. For the purpose of these recommendations, the values of the MPD's shall be those specified in BSS.

In the case of male exposed workers the values recommended in BSS may be summarised as follows :

Type of Exposure	Part Exposed	Permissible Dose	
		In year	In quarter
Whole body exposure	-	5 rem on average	3 rem
Partial body exposure	Bone marrow or gonads	5 rem on average	3 rem
	Hands, forearms, feet and ankles	75 rem	40 rem
	skin or bone (except of extremities)	30 rem	15 rem
	Other organs	15 rem	8 rem

2.3 Body Dose

Article 7 of BSS specifies the MPD in situations where there is approximately uniform irradiation of the whole body. In such a situation the gonads or the bone marrow will normally be the critical organ. The term body dose as used in this recommendation refers to the dose in soft tissues (strictly at an appropriate depth below the surface of the body - see Appendix III) in situations where the whole body is uniformly irradiated. It is used in the same sense that the term "whole body dose" is used in Article 7 of BSS.

2.4 Skin Dose

Skin dose means the dose to that layer of skin at an appropriate depth below the surface of the body (see Appendix III), and has the same meaning as the similar term used in Article 8 of BSS.

2.5 Extremity Dose

Extremity Dose means the dose to any part of the hands, forearms, feet or ankles, and where non-uniform irradiation of the body is concerned, is taken to mean the dose to a representative region of the most highly exposed part of the extremities.

3. Terms Used with Test and Calibration Procedures

3.1 Calibration

The act of relating the reading of a dosemeter to the value of the quantity to be measured.

3.1.1 Type Test

A qualification test which is performed on one dosemeter or on a small number of dosemeters, considered to be representative of an industrial production and which, in prinoiple, is not repeated on each dosemeter.

3.1.2 Routine Calibration

A test which is performed on each dosemeter (or on a few dosemeters of a batch,if applicable) to relate the reading to the absorbed dose. Together with the type test, it provides the overall calibration of that instrument.

3.2 Reading, indication

Synonyms for the value of a measured quantity indicated by the instrument.

3.3 Response

The relationship between the reading of an instrument and the true value of the quantity measured.

3.4 Reference Value, Reference Conditions

Reference values are certain values of influence quantities such as temperature, humidity, radiation energy, dose, etc., which have been present at the time when the calibration was performed, or to which the results of a calibration are referred to. Collectively they are referred to as reference conditions.

3.5 Test Conditions

Prescribed values or ranges of values for influence quantities, which have to be present when tests or calibrations are performed.

4. Imperfections of Measurement

4.1 Limits of Variation of Response

The maximum values of the variation in response caused by one influence quantity (e.g. temperature, angle of incidence, etc.) varying within a specified range, all other influence quantities being at their reference values (see 3.4).

4.2 Error of Indication

The difference between the indicated value of a quantity and the conventional true value of that quantity.

4.3 Conventional True Value

Since in practice the true value is unknown and unknowable, a conventional true value is used instead when calibrating or determining by the reference instrument with which the instrument under test is being compared.

4.4 Error of Measurement

The residual difference between the corrected measured value of a quantity and its true value.

4.5 Uncertainty of Measurement

A quantitative estimate of the possible deviation of the measured value from the true value of the quantity being measured.

4.6 Random Error

That part of the error which varies randomly in magnitude and sign and which is brought about by fluctuating influence quantities during the measurement or its evaluation.

4.7 Systematic Error

That part of the error which either does not fluctuate or which fluctuates in a non-random manner, and which is brought about by the fact that the conditions of use differ in some non-random manner from those used during calibration.

If there are several independent sources of systematic error, the individual errors should be combined in a manner which is appropriate to the particular circumstances. Unless it is clearly inappropriate, the combined error may however normally be taken as the square root of the sum of the squares of the separate errors (as is done in the case of random errors). In any case the method of combining the errors should be stated explicitly.

4.8 Systematic Uncertainty

A quantitative estimate of that part of the uncertainty arising from systematic errors.

4.9 Overall Uncertainty

A quantitative estimate of the combined contribution of random and systematic errors to the uncertainty.

4.10 Precision

The precision of a measurement is said to be low, when the random errors are high, i.e. when there is a large scatter in a set of measurements expected to give the same answer. The term is used only in a qualitative manner.

4.11 Accuracy

The closeness with which a measurement is expected to approach the true value. This may include the effect of both systematic and random errors (the preferred use) or of systematic errors alone. The term is used only in a qualitative sence.

Appendix III

Penetrating and Non-Penetrating Radiation[1]

Broadly speaking, non-penetrating radiation consists of those very low energy photons and those beta rays which are so highly absorbed in the superficial tissues of the body that they irradiate deeper tissues to an insignificant extent. Such radiation may be regarded as irradiating only the skin. Penetrating radiation is that radiation which is sufficiently penetrating that it also irradiates the other deeper-lying organs of the body. It would be convenient if we would make a clear distinction between penetrating and non-penetrating radiation; but unfortunately some beta rays are sufficently penetrating to give significant irradiation of organs nearer the surface of the body (in particular the lens of the eye), but do not irradiate deeper-lying organs such as the bone marrow to a significant extent. It is therefore not clear whether such radiation should be regarded as penetrating or non-penetrating.

For this reason, instead of specifying that a dosemeter should be capable of measuring the doses due to penetrating and non-penetrating radiation, it is better to specify the depths below the surface of the body at which the dose should be assessed in order to determine the doses to the skin, gonads, bone marrow and other organs.

Skin

The basal layer of the epidermis is considered to be at a depth of 5-10 mg/cm^2 below the surface of the body [2](but not on the palmar surface of the hands, etc - see Section 7.3). Consequently, if we wish to measure skin dose, we should attempt to measure the dose at 5-10 mg/cm^2 below the surface.

Gonads and Bone Marrow

The effective depth of the gonads is different for male and female (see Appendix II, Section 2.1). In males, the effective depth will depend on the exposure conditions, and a variety of depths have been recommended. The German standards [5] recommend 400 mg/cm^2, although depths of 1000 mg/cm^2 or 2000 mg/cm^2 have been recommended elsewhere [3], [4]. The majority of recommendations appear to be in the range 400-1000 mg/cm^2

quoted in Appendix II, Section 2.1.

The effective depth of the bone marrow (and also of the female gonads) is greater than this. Consequently if the dosemeter is used to estimate the dose at a depth of 400-1000 mg/cm^2, this will provide a realistic measure of the dose to the male gonads; it will in general lead to a slight over-estimation of the dose to the bone marrow or the female gonads. A somewhat arbitrary choice of depth has to be made within the range 400-1000 mg/cm^2. The choice of a figure near the lower end of the range will ensure that gonad doses are never underestimated (but will in some circumstances tend to overestimate doses to the gonads and more particularly other organs). The choice of a figure nearer the upper end of the range can be considered acceptable in circumstances in which there is a strong desire to avoid unnecessary overestimation of doses.

Other Organs

It is not necessary to attempt a separate measurement or assessment of doses to most other organs. Since these are in general deeper in the body than the gonads, it can be assumed that the doses to these organs is not greater than the gonad dose. Hence if the gonad dose is controlled to within the limits specified in BSS, the doses to other organs will automatically be controlled within acceptable limits.

The only case in which this statement is not necessarily true relates to the dose to the lens of the eye, which is taken to be at a depth of 300 mg/cm^2 (i.e. closer to the surface than the gonads). If the gonads are assumed to be at 400 mg/cm^2 and skin and gonad doses are controlled to within the limits specified for skin and whole body in the BSS, the dose to the eye will automatically be less than the corresponding M.P.D. However, if the gonads are assumed to be significantly deeper than 400 mg/cm^2, it is possible to envisage situations in which the dose to the lens of the eye would not be automatically controlled in this way. In particular, this difficulty arises when the relaxation allowed in subsection (c) of Article 7, which allows the whole body dose to exceed 5 rems/year, is being invoked. These situations are those in which both the skin and gonads are exposed to near the MPD by a mixture of penetrating gamma radiation and beta rays of medium energy (3 or 4 MeV). If such conditions might be experienced, and there is a desire to take the depth

of the gonads in the upper part of the 400-1000 mg/cm^2 range, it may be necessary to make a separate measurement or assessment of the dose to the lens of the eye.

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