PROCEEDINGS SERIES

RADIATION PROTECTION MONITORING

PROCEEDINGS OF A REGIONAL SEMINAR
FOR ASIA AND THE FAR EAST
ON RADIATION PROTECTION MONITORING
JOINTLY ORGANIZED
BY THE INTERNATIONAL ATOMIC ENERGY AGENCY
AND THE WORLD HEALTH ORGANIZATION
AND HELD IN BOMBAY, 9 - 13 DECEMBER 1968

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

In view of the seriousness of the possible effects of exposure of the human body to radiation, and the long time that may elapse before these effects are noticed, it is absolutely necessary that the development of the peaceful uses of atomic energy be accompanied by the development of an effective radiation control program.

Monitoring of the working environment and individual monitoring to check the effectiveness of the radiation control measures and to assess the doses that workers may receive form essential parts of such a control program. Another essential part is the monitoring of the environment accessible to the public — this involves the biosphere — to assess the dose that individuals and the public as a whole may receive.

As the basic aim of such monitoring is to ensure continuing protection of the health of radiation workers as well as the public, it is clearly of great interest to both the World Health Organization and the International Atomic Energy Agency. The two organizations, in co-operation with the Department of Atomic Energy of India, held a Regional Seminar for Asia and the Far East on Radiation Protection Monitoring in Bombay, 9 - 13 December 1968.

Eighty-three participants from 12 countries in the region attended the meeting, and in addition eight radiation protection experts from countries outside the region presented review papers.

In all, 47 papers were presented, covering such topics as methods of radiation measurement, interpretation of results, sources of inaccuracy; special attention was given to the basic recommendations of the International Commission on Radiological Protection (ICRP), and to the calibration and maintenance of instruments and the effects of climatic and other local conditions on their performance.

In his inaugural address to the Seminar, Dr. A. Chandrasekar, Union Minister of State for Health, Family Planning and Urban Development, said that radiation hazard is one of the problems arising in the rapid expansion of the uses of radiation in various scientific and technological fields. He summarized the work done in India to counteract the rise in environmental radiation to which radiation workers and the general population may be exposed.

The discussions at the meeting revealed clearly that there is a need to undertake the intercomparison of measurement techniques, especially for neutron dosimetry, and to standardize the calibration of instruments and procedures. It would be of great benefit to establish centralized calibration facilities in the region, and joint action by WHO and the IAEA in this matter would be welcome.

The book contains the papers and discussions in full.

The IAEA and WHO gratefully acknowledge the co-operation of the Government of India and, in particular, of the Department of Atomic Energy of India in the organization of the Seminar.

CONTENTS

C. MONITORING OF THE WORKING ENVIRONMENT
(Sessions III and IV)

D. INDIVIDUAL MONITORING (Sessions V and VI)

A

PURPOSE OF RADIATION PROTECTION MONITORING

(Session I)

Chairman: P. N. KRISHNAMOORTHY

INDIA

BASIS OF THE ICRP MAXIMUM PERMISSIBLE DOSES AND APPLICATION OF BASIC SAFETY STANDARDS

H.J. DUNSTER
Radiological Protection Division,
UKAEA Health and Safety Branch,
Harwell, Didcot, Berks,
United Kingdom

Abstract

BASIS OF THE ICRP MAXIMUM PERMISSIBLE DOSES AND APPLICATION OF BASIC SAFETY STANDARDS. Some of the effects on man of ionizing radiation have a long latent period (many years) and are severe, sometimes irreversible, by the time they can be detected. It is thus not sufficient to assess the adequacy of a radiation protection program by direct checks on the health of the exposed workers. A more effective criterion is needed and is provided reasonably well by radiation dose. Since there is some correlation between dose and injury it is possible, at least in principle, to define a maximum permissible dose by assessing an acceptable level of injury. In practice, the choice is complicated by uncertainties in the dose-effect relationship and by uncertainties in the meaning of words, such as 'acceptable' and 'permissible'. Nevertheless, numerical values widely accepted have been selected and recommended by the International Commission on Radiological Protection.

Two aspects of the application of the maximum permissible doses are important in relation to monitoring. First, the limits must be used prospectively with a choice of operating procedures, so that the doses are held below the maximum permissible values. Secondly, they must be used retrospectively as a criterion against which to decide whether the operational procedures have been satisfactory. The interpretation of monitoring results in terms of the basic maximum permissible doses should form an integral part of the design of monitoring programs, both for the prospective control of exposures and for their retrospective confirmation.

INTRODUCTION

Ionising radiation was recognised as a hazard within 6 months of the discovery of X-rays by Roentgen and again a few years later after the isolation of radium by the Curies. These early effects were confined to superficial damage to the skin and it was some years before the link between radiation and cancer was suspected. It was not until the 1930s that the toxicity of radioactive materials, such as radium, taken into the body was fully appreciated. From these early experiences and from subsequent studies, the early effects of large doses of radiation can now be described as a function of dose with a considerable degree of confidence. However, as the experience with radium showed, some of the effects of exposure to radiation have a long latent period and, even after large doses, occur in only a small proportion of the exposed individuals. Quantitative information on these aspects has become available only in the last decade or so. Considerable doubt still exists about the relationship between low doses, or moderate doses spread over a whole lifetime, and the possible incidence of late effects.

Over the years, improved techniques and increasing attention to radiological protection have tended to decrease the doses received by individuals, and early clinical effects of exposure are now almost unheard of. The only risk which may be significant now is that of late effects and, in particular, the late effects of prolonged low-dose exposure. It is just in this field that our information is least satisfactory.

Although the risks of present-day exposure are small, a substantial fraction of the delayed effects that do occur take the form of malignancies. The severity of these conditions and the long delay in their appearance makes it impossible to use medical surveillance as the primary method of controlling radiation exposures. This difficulty leads to the need to establish a less direct basic standard, and the one selected has been that of radiation dose. This correlates fairly well with a range of biological effects, although it requires correction for certain types of radiation. The dose corrected for this effect of different types of radiation and for other effects where necessary has become known as the Dose Equivalent although in practice the term "dose" is still used without undue ambiguity.

THE MAXIMUM PERMISSIBLE DOSE

The International Commission on Radiological Protection uses the term Maximum Permissible Dose "to describe the doses that are regarded as being the maximum that should be permitted under particular circumstances".[1] In discussing the choice of values for maximum permissible doses, the Commission also says, "In conditions where the source of exposure is subject to control, it is desirable and reasonable to set specific dose limitations so that the associated risk is judged to be appropriately small in relation to the benefits resulting from the practice." The Commission obviously recognises the difficulty of quantifying this comparison of risk and benefit and provides a more easily applied criterion by saying, "In the case of occupational exposure, the hazards should not exceed those that are accepted in most other industrial or scientific occupations with a high standard of safety."

To apply any of these criteria quantitatively in the selection of a value for the maximum permissible dose, it is essential to provide two pieces of information. The first is the relationship between the dose, or more strictly the dose equivalent, and the subsequent risk of clinical effects, in particular the subsequent risk of malignancy. Secondly, having established this dose-risk relationship, it is necessary to select a point on the risk axis at which it can be said that the risk is acceptable. This selection of an acceptable risk is at present, and probably will always be, somewhat arbitrary and contains an element of intuition. By contrast, the establishment of a dose-risk relationship is, at least in principle, a straightforward scientific task in radiobiology.

Animal experiments are extremely valuable in elucidating radiobiological mechanisms, and to some extent in making com-

parisons between the effects of different levels of dose or between different types of radiation. Nevertheless, the likelihood of inter-species differences makes it extremely desirable to use human data for establishing dose-risk relationships. The present information about the effects of external radiation come from three principal sources: the survivors of the atomic bomb explosions at Hiroshima and Nagasaki; patients suffering from ankylosing spondylitis who have been treated by radiation therapy; and children who were treated for enlarged thymus by X-irradiation. For a group to provide useful information, they must meet certain fairly stringent requirements. The risk of radiation-induced malignancy is small, so the number in the group must be large and the radiation doses fairly high; the doses must be reasonably well established; and the period of follow-up must be long enough for a substantial fraction of the cases to have appeared. These three groups meet all these requirements fairly well, although the information is becoming more valuable as the duration of the study increases. Thus, the study of the spondylitics involved a total dose (to bone marrow) of about 10^7 man-rads and 1.7×10^5 man-years of observation. The corresponding figures for the Japanese survivors are about 2×10^6 man-rads (air dose) and 6×10^4 man-years, and for the children treated for enlarged thymus, about 10^6 man-rads (thyroid dose) and 5×10^4 man-years of observation.

Although information about acute effects can be obtained from the heavy local exposure used in cancer therapy, this experience is not so useful for evaluating the long delayed effects, partly because the dose to healthy tissue is extremely non-uniform and partly because the doses are high enough to produce early effects, such as fibrosis, which may alter the probability of the development of malignancy at a later stage. The late effects of the small doses produced by modern diagnostic X-ray examinations have given positive results only in the case of the effects on the unborn child of X-irradiation of the mother in pregnancy. These studies show that the foetus is more sensitive than the adult, but do not provide any information of direct value in establishing maximum permissible doses.

The combined effect of all this work is to establish that radiation doses in the region of 100 rads or more delivered over a fairly short period produce a measurable increase in the risk of subsequent malignancy. There is a marked tendency for this risk to increase as the dose rises from 100 to perhaps 1000 rads but the data are not good enough to establish unequivocally the nature of this relationship. The data are broadly consistent with a linear relationship passing through the origin, and it is this relationship which is conventionally used in interpreting the data for the purposes of establishing maximum permissible doses. It is on the assumption of this linear relationship that the risk rates can be expressed as a probability of malignancy per rad of exposure. Risk rates expressed in this way may grossly overestimate the risk of small doses. Some typical figures for these risk rates are shown in Table I. A comparison of the risks derived from these figures for some of the maximum permissible doses currently recommended by ICRP and other natural risks is shown in Table II.

TABLE I. SOME CURRENT ESTIMATES OF THE RISK OF CANCER FOLLOWING RADIATION EXPOSURE IF A LINEAR DOSE-RISK RELATIONSHIP IS ASSUMED

Type of malignancy	Probability per rad
Leukaemia [2]	2×10^{-5}
Other fatal neoplasms [2]	2×10^{-5}
Thyroid carcinoma [3]	1×10^{-4}

NOTE: The figure for other fatal neoplasms is probably too low compared with that for leukaemia because of the generally longer latent period for the other neoplasms. See also Dolphin [4].

TABLE II. COMPARISON OF THE RISK OF FATAL MALIGNANCY FOLLOWING RADIATION EXPOSURE AND OTHER CAUSES OF DEATH IN UK MALES [5]

Exposure or other risk	Probability of death
Accumulated exposure of 30 rems whole body in 10 years	1.5×10^{-3}
Natural death from malignancy in 10 years following the age of:	
30	3×10^{-3}
40	1×10^{-2}
50	3×10^{-2}
60	1×10^{-1}
Natural death from all causes in 10 years following the age of:	
30	1.4×10^{-2}
40	4×10^{-2}
50	1.2×10^{-1}
60	3×10^{-1}

NOTE: The radiation risk is assumed to be 5×10^{-5} per rad, independent of dose rate or distribution.

Another field of study which has had a marked effect on the choice of maximum permissible doses has been that of genetics. No significant genetic detriment has been demonstrated following human exposure to radiation, and the genetic doses to whole populations from occupational exposure have been, and are expected to remain, trivial by comparison with the dose from natural background radiation. Nevertheless, it is clear from animal experiments that there must be some genetic risk to the offspring of exposed people and that there is some risk of severe detriment in the first generation offspring, caused by dominant mutations.

A further human group studied in detail has been the people containing radium in their bodies, mainly following ingestion at a period when this was thought to have therapeutic properties. These data bear mainly on the choice of values for maximum permissible body burdens, but also provide information on the maximum permissible dose to bone.

Although in principle the maximum permissible dose should be established by first choosing an acceptable level of risk, then using the dose-risk relationship, in practice the concept of the maximum permissible dose has developed over the years before the information about risks began to become available. With a few exceptions, the maximum permissible doses have decreased over the years as biological knowledge has improved. The present figures have thus been arrived at by a process of successive approximation rather than by the formal application of decisions about an acceptable level of risk.

THE PRACTICAL APPLICATION OF MAXIMUM PERMISSIBLE DOSES

In practice, the maximum permissible doses mentioned in the previous section are not sufficient to allow adequate control of radiation hazards. The ICRP themselves take the problem a stage further by deriving from their recommended maximum permissible doses a number of maximum permissible concentrations of radioactive materials in air and water for human consumption.[6] The aim of the calculations is to provide concentrations, exposure to which over a long period of time will ultimately result in radiation doses to the so-called critical organ equal to the recommended maximum permissible doses for those organs. The figures are derived principally for radiation workers and conversion factors for application to other groups are recommended. Even with these extensions, there are many circumstances in which the measurements made as part of a health physics control programme cannot be directly related to ICRP recommendations. Perhaps the simplest example is the measurement of radiation dose rate in a working environment. ICRP make no recommendations about such dose rates; their recommendations relate to the actual dose incurred by people. To relate a dose rate measurement to an ICRP recommendation requires additional information concerning the time which individual workers spend in the area, the doses they receive in other operations and, since cumulative dose is one of the limitations in ICRP, the dose already incurred to date. An even more complex situation arises where measurements are made of surface contamination, since the mechanism by which

surface contamination contributes to radiation dose to man is extremely involved.

Derived working limits

In these and many other cases, it is convenient to derive an intermediate control figure to be used as a standardised way of interpreting a routine measurement in terms of ICRP recommendations. Such an intermediate standard has sometimes been called a Derived Working Limit or DWL. All derived working limits have one feature in common: they are derived from ICRP recommendations with the aid of a standardised set of assumptions. These assumptions in some cases may apply only in very specialised circumstances and the DWL is then correspondingly applicable only in these narrow circumstances. Within these limits, however, it may then be very closely related to the ICRP recommendation. Alternatively, very broad assumptions may be made so that a DWL can be applied over a wide range of circumstances. In this case, however, its quantitative relationship to ICRP recommendations will be very much less precise and it will probably be true to say only that operating at the DWL will result in doses below the ICRP recommended limit, but by an amount which cannot be forecast.

An example of a derived working limit is the figure of 2.5 mrem/h as the DWL for external radiation dose rate at the shield or barrier round a radiation source. This figure is directly related to ICRP recommendations only if the point of highest dose rate is occupied for 2000 hours per year by a worker from the age of 18 years onwards. In practice, however, it is a useful guide to defining areas in which workers can be allowed unrestricted access provided that they are subject to personnel monitoring. In practice, a limit of this type means that radiation workers get substantially less than their permissible dose, since they are not at the point of highest dose rate for 2000 hours per year. On the other hand, if the radiation field is produced by a large remote source, so that there is little change of radiation dose rate with position, the figure of 2.5 mrem/h might be embarrassing in a control centre where people might spend much of their working period but from which they might move to areas of higher dose rate for specific operations. In this, as in all other cases, the value of a DWL cannot be divorced from the circumstances for which the value was derived and the limitations implied by that derivation must be borne in mind at all times.

Another example is given by the derived working limits of surface contamination. Most of the figures used for this purpose have deliberately been oversimplified so that they apply to a wide range of conditions. As a result, all that can be said is that working below these derived working limits is unlikely to give rise to airborne activity or external radiation rates sufficient to cause ICRP recommendations to be infringed. Nevertheless, it is not difficult to envisage circumstances where this statement would be untrue and the DWL for surface contamination must consequently be applied with judgment.

Investigation levels

Much of the information obtained from a monitoring programme merely confirms that the situation is satisfactory and that no action is required. It is convenient to use a method of discarding this information with the minimum of effort and the concept of an Investigation Level is of value in achieving this. An investigation level is a numerical value set for a particular type of measurement, above which the result is sufficiently important to justify further investigation. This may range from the mere recognition that circumstances made a significant result likely, up to a full enquiry into the causes and consequences of the result. Below the investigation level, the information does not need further study or investigation. The concept is also useful in some types of monitoring of the workplace, where changes in measured level, even when these are well below the DWL, may be of importance in identifying both control failures and deteriorating operating procedures.

The objective in setting an investigation level should be to ensure that doses or intakes resulting from conditions below the investigation level will certainly be below 3/10 of the annual limits recommended by ICRP. There is no simple relationship between a DWL and an investigation level, partly because of the different objectives and partly because almost all DWLs apply to average conditions over periods of up to a year, while investigation levels are applied to single results or, more rarely, to short-term averages.

It is not yet conventional to use a formal investigation level in the monitoring of individuals for external radiation. Nevertheless, personal dosemeters do have a threshold below which the results are not distinguishable from zero, and many installations establish levels of dose indicated on a film badge or other dosemeter above which they undertake specific investigations. In many types of operations during which film badges are worn, the great majority of the doses are very low and some simplification of record keeping could be achieved if these doses could be omitted from the record. For a large proportion of workers their records could merely state that none of the doses exceeded the agreed investigation level. As radiation sources become more widely used, and as radiation workers move from one employer to another, there will develop a very considerable complexity of personal records unless some move of this type is introduced. In 1965, the International Commission on Radiological Protection made a step in this direction by recommending that individual monitoring was not needed if the exposure conditions were such that the resulting doses were most unlikely to exceed 3/10 of the annual maximum permissible doses. In practice, this recommendation has had less impact than was hoped, because individual dosemeters often provide the most satisfactory way of checking on the general state of a working environment. Withdrawing the dosemeters would necessitate increased attention to environmental monitoring and this might well be more expensive than the individual monitoring it is designed to replace. More recently, therefore, the Commission have extended their advice in the hope that dosemeters used predominantly in this way will not generate

unnecessary complexity in the personal record-keeping system. In a report on monitoring, now in press, they recommend the adoption of an investigation level to be applied to individual dosemeter results and suggest that the choice of this level should be such that the accumulation of doses at or below the investigation level cannot provide a total annual dose in excess of 3/10 of the annual maximum permissible dose. The figures suggested are 50 mrem for a dosemeter issued for 2 weeks, 100 mrem for 1 month or 300 mrem for 3 months. [7]

If this system were adopted throughout the United Kingdom, it is likely that well over 90% of the individuals occupationally exposed to radiation would have radiation dose records which contained nothing more than the necessary identifying particulars and a statement that they had never received doses in excess of the investigation level. Occasional entries would be required if they ceased for some period to be subject to monitoring and on the rare occasions when a dosemeter was lost or failed to provide an answer. In the long run, this decision might also simplify the design of dosemeters, since the required sensitivity could be related to the investigation level.

THE REGULATORY USE OF MAXIMUM PERMISSIBLE DOSES

It is clear from the way in which maximum permissible doses are derived that they cannot represent a sudden transition from a condition of safety on one side to a position of danger on the other. This is even more true of the derived working limits. On the other hand, regulations ranging from local management instructions to statutory instruments are usually unsatisfactory if couched solely in qualitative terms. This is particularly true of radiation where injury cannot be demonstrated until it is severe. In practice, therefore, it has become necessary to convert maximum permissible doses and derived working limits into rules of more or less formality. When this is done the values achieve a quite different status. To incur a dose 10% above the maximum permissible dose is biologically insignificant as compared with incurring a dose 10% below the maximum permissible. But when the maximum permissible dose has been converted into a regulation, then the former becomes an offence against the regulations. The sanctions applied are then administrative or legislative and not biological, and this distinction is of importance in the management of cases of exposure somewhat in excess of the maximum permissible.

When maximum permissible doses and derived working limits are incorporated into rules, it is useful to distinguish clearly between them. The maximum permissible doses change infrequently and there is little difficulty in amending the rules on these occasions. A change in a derived working limit, however, may be required as a result of a small change in the way in which the limit is to be applied rather than as a result of any change in the fundamental recommendations, and clearly it should be possible to amend the rules relating to these without difficulty. Even in DWLs, however, some degree of stability is desirable, because frequent changes may give the impression that the figures are not soundly based.