RADIATION PROTECTION

Principles of Environmental Monitoring related to the Handling of Radioactive Materials

ICRP PUBLICATION 7

A Report by Committee 4 of the International Commission on Radiological Protection

Adopted by the Commission on September 13, 1965

PUBLISHED FOR
The International Commission on Radiological Protection
BY
PERGAMON PRESS
OXFORD · LONDON · EDINBURGH · NEW YORK
TORONTO · PARIS · BRAUNSCHWEIG

Pergamon Press Ltd., Headington Hill Hall, Oxford
4 & 5 Fitzroy Square, London, W.1
Pergamon Press (Scotland) Ltd. 2 & 3 Teviot Place, Edinburgh 1
Pergamon Press Inc., 44-01 21st Street, Long Island City, New York 11101
Pergamon of Canada Ltd., 6 Adelaide Street East, Toronto, Ontario
Pergamon Press S.A.R.L., 24 rue des Écoles, Paris 5e
Friedr. Vieweg & Sohn Verlag, Postfach 185, 33 Braunschweig

Library of Congress Catalog Card No. 66-19542

PRINTED IN GREAT BRITAIN BY BELL AND BAIN LTD GLASGOW

(24/2871)

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PREFACE

In May 1962 the International Commission on Radiological Protection established a new structure of committees and decided to appoint *ad hoc* task groups to deal with specific problems. Committee 4 on the Application of Recommendations decided at its first meeting in May 1963 to set up a Task Group on Environmental Monitoring. The Commission approved the formation of this Task Group with the following terms of reference and membership:

To review the objectives of environmental monitoring both in the vicinity of installations handling radioactive materials and more generally;

To prepare a report setting out recommended policy for achieving these objectives.

Membership:

H. J. Dunster (*Chairman*)	Great Britain
D. Beninson	Argentina
A. K. Ganguly	India
C. A. Mawson	Canada
G. Michon	France
C. P. Straub	U.S.A.
E. G. Struxness	U.S.A.

R. Scott Russell (Great Britain) joined the Task Group in September 1963, as a representative of Committee 1.

This report of Committee 4 is the outcome of the work of the Task Group on Environmental Monitoring and deals with environmental monitoring in the vicinity of installations handling radioactive materials.

MEMBERSHIP OF COMMITTEE 4 (1962-1965)

H. Jammet (*Chairman*) (France)	D. Mechali (France)
D. Beninson (Argentina)	C. Polvani (Italy)
G. C. Butler (Canada)	P. Recht (Belgium)
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REPORT OF COMMITTEE 4

A. INTRODUCTION

(1) In this report, environmental *monitoring** means the measurement of radiation and radioactivity outside the boundaries of installations handling radioactive materials or radiation sources, and is restricted to measurements made necessary by the operation of these installations. Monitoring of the process and of the releases of waste are closely connected with any environmental program and, for the great majority of installations, provide sufficient information to make environmental monitoring unnecessary.

(2) The broad objectives of environmental monitoring programs can be summarized as follows:

(*a*) Assessment of the actual or potential exposure of man to radioactive materials or radiation present in his environment, or the estimation of the probable upper limits of such exposure.

(*b*) Scientific investigation, sometimes related to the assessment of exposures, sometimes to other objectives.

(*c*) Improved public relations.

Objective (*a*) is particularly important to the Commission because it is usually impracticable to assess doses to members of the public by personal monitoring methods.

(3) This report is therefore concerned primarily with those monitoring programs outside the boundaries of installations and with those investigations that are aimed at obtaining information essential to the assessment or control of the exposure of man to radiation or to radioactive materials, as described in objective (*a*) of paragraph 2. The aim of the report is to indicate general principles by which such programs can be designed and operated. Since the problems of fallout of debris from nuclear explosions have been the subject of detailed study by other bodies, notably the United Nations Scientific Committee on the Effects of Atomic Radiation,[1, 2] this report deals only with environmental surveys related to the handling of radioactive materials and radiation sources. In many cases, however, the results can be interpreted only in conjunction with surveys of fallout of debris from nuclear explosions, and some mention is therefore made of such surveys.

(4) The details of the design and interpretation of an environmental monitoring program can be developed only in relation to the installations with which the survey is associated; in particular in relation to the individual environments of these installations and the planned, or foreseen accidental, releases of radioactive material. The guidance in this report is intended primarily for those who are concerned with the design and operation of environmental monitoring programs. This guidance is necessarily of a general nature, but will be sufficient to provide a basis for decisions in each individual case. It will also provide an indication of the circumstances which make environmental monitoring necessary. The responsibility for carrying out the programs of monitoring and investigation will fall partly on the management of the installation and partly on public authorities. The demarcation of these responsibilities will depend on local and national arrangements, but in each situation should be clearly defined.

(5) For the purposes of this report, it is convenient to identify three types of environmental monitoring program:

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* See Explanation of Terms, Section E. Terms explained in Section E are italicized on their first appearance in the text.

(*a*) *Surveys outside installations* handling radioactive materials, including, where necessary, *preoperational* surveys.
(*b*) *Emergency* surveys.
(*c*) Surveys for fallout of debris from nuclear explosions.

In these types of program, the predominant objective should usually be that of assessment, or limitation, of exposure. In order to achieve this objective, considerable attention must be paid to carefully conducted scientific investigations.

(6) The type of information which should be provided by an environmental monitoring program will depend on the function that the program is intended to fulfil. Before a survey is to be carried out, it must be clear how the expected data are to be used. In practice, it often happens that information obtained for one purpose can validly be used for another, and the possibility of extending the information obtained in one type of environmental survey to meet the objectives of another should not be overlooked. Such extensions, however, should be applied carefully to avoid the danger of overburdening the program with the collection of valueless data.

(7) The Commission recommends maximum permissible doses to individual members of the public and gives guidance on the exposure of the population as a whole.[3] Within the framework of the recommendations of the Commission, Committee 2 gives complementary recommendations concerning the contamination of members of the public by inhalation and ingestion.[4]

(8) A number of regional, national and local legislative bodies have now applied legal restrictions to releases of radioactive material to the environment and to the presence in the environment of radioactive materials and radiation arising from installations. Such restrictions sometimes establish minimum requirements for environmental monitoring, either directly or by implication.

B. RECOMMENDATIONS OF THE COMMISSION

(9) The basic recommendations of the Commission are in terms of radiation doses to organs of the body and from these are derived maximum permissible body burdens, maximum permissible intakes and maximum permissible concentrations. In the Commission's recommendations for individual members of the public, these doses and intakes are expressed as annual values so that corresponding dose rates or concentrations relate to annual averages and not to short-term values. Details are given in other publications of the Commission.[3, 4]

(10) Those of the Commission's recommendations which bear directly on environmental monitoring are listed below. They must be read in the context of the complete recommendations of the Commission and its Committees.

Relevant Recommendations of the Commission

The recommendations are taken from ICRP Publication 9,[3] to which the paragraph numbers refer.

Basic principles
Paragraphs 34, 37, 41–51
Dose limits
Paragraph 52
Individual members of the public
Paragraphs 70–75
Whole of population
Paragraphs 86, 87, 95
Action levels for exposures from uncontrolled sources
Paragraphs 96–98, 103–106
General principles for operational radiation protection
Paragraphs 108, 109, 117, 129, 125

Interpretation of the Recommendations

(11) In applying the Commission's recommendations to environmental situations, it is necessary to consider certain problems which do not arise in the control of occupational exposure. Chief among these is the interpretation of recommendations concerning the exposure of an individual member of the public. Another is the application of the data relating to the *standard man*. These problems are discussed in succeeding paragraphs.

(12) The exposure of an individual is a function not only of the levels of radiation and radioactivity in his environment, but also of the individual's use of that environment and of his personal habits. The Commission recognized this difficulty in paragraph 39 of ICRP Publication 6,[5] and suggested a procedure for assessing and controlling individual exposures. This procedure involves studying a sample of the exposed group and setting the environmental level so that no individual in the sample receives any excessive exposure. This method has sometimes been used satisfactorily, but has proved somewhat arbitrary, especially when the exposed group contains individuals with a wide range of habits.

(13) Most installations which handle radioactive materials are designed and operated to contain the radiation and radioactive materials, and to concentrate their by-product wastes. Nevertheless, some release of radioactivity to man's environment occurs, due either to the disposal of low activity wastes or to accidents. The releases are made to many different sectors of the environment and the amounts and compositions of the releases will vary from installation to installation (even between installations of the same general type) and from time to time.

(14) Thus, in most situations in which radioactive materials are introduced to man's environment, there will be numerous and complex pathways by which each of the released nuclides may ultimately cause radiation exposure of man. An example of such a pathway is the deposition of strontium-90 on grazing land, its direct retention on grass or its uptake into the grass from the soil, its ingestion by cows and the subsequent ingestion of cow's milk by people, especially children. Further examples are given in Appendix A. A comprehensive and detailed study of all such pathways will not be needed, even for installations which involve potential radiation hazards of the greatest magnitude, e.g. reactors, reactor fuel reprocessing plants and stores of fuel reprocessing wastes. Experience has shown that a study of the situation will indicate that certain nuclides and certain exposure pathways are much more important than others. These nuclides and pathways are designated " *critical* ".

(15) The presence of a critical nuclide in some critical pathway will not cause the same exposure of each member of the population outside an installation, and preoperational investigations (see paragraphs 25 and 26) will usually establish the existence of one or two groups of people whose characteristics, e.g. habits, location, or age, cause them to receive doses higher than those received by the rest of the population outside the installation and thus require them to be considered separately, i.e. to be designated as critical. Great judgment is necessary in defining such a group in practice and the following aspects will have to be considered. Some of these are the same as the factors influencing the design of routine surveys (see paragraph 25) and only those concerned with the critical group itself are listed below:

(*a*) The location and age distribution of the potentially exposed group.
(*b*) Dietary habits, e.g. special foodstuffs and amounts consumed.
(*c*) Special occupational habits, e.g. the handling of fishing gear.
(*d*) The type of dwelling, e.g. shielding characteristics.
(*e*) Domestic habits, e.g. time spent indoors, frequency of personal washing and laundering of clothes.
(*f*) Hobbies, e.g. sport, fishing or sunbathing.

Such groups in the population may be in the vicinity of the installation or at some distant location; they may include adult males, adult females, pregnant women, and children; they may be individuals who eat foodstuffs prepared in a special way or produced in a particular location; or they may be people who work in a particular industry. Only general guidance can be given on the considerations needed to define the critical group and the associated critical nuclides and pathways, for the situation will be specific for each installation and its environment, but the importance of such a definition is considerable. The concept of the critical group provides a sound and practical way of complying with the Commission's recommendations concerning members of the public. It also allows economies in the conduct of environmental monitoring.

(16) The critical group should be identified in such a way that it is representative of the more highly exposed individuals in the population and is as homogeneous as practicable with respect to radiation dose, that is, with respect to those factors in paragraph 15 which affect the dose in the specific case considered.

(17) Once a critical group has been identified in this way, a suitably representative sample of the group should be selected and studied so as to assess their actual or potential exposure. The average exposure of such a sample should then be regarded as typical of that of the highly exposed individuals and the Commission's recommendations for the maximum permissible doses for individual members of the public applied to that average. The spread of values in the sample will give some measure of its homogeneity with respect to the characteristics which have been studied. It must be recognized that there are many characteristics of the individual (such as metabolic rates) which may influence the dose received and which are not measured. These individual differences may tend to increase the spread of the individual doses received within the critical group. It must also be recognized that, outside the critical group, there may be a few individuals whose habits and characteristics are dramatically unconventional. Such peculiarities may sometimes mean that these individuals receive doses somewhat higher than those to the critical group. It is expected that methods of waste management will be determined not by the possible exposure of these individuals but rather by the dose to the critical group.

(18) In some situations, for example in preliminary planning or when the dose to the critical group will clearly be very small, it may not be necessary to make the detailed studies required for the identification of the critical group. It will then be convenient to postulate a hypothetical group of extreme characteristics, e.g. a group breathing or drinking undiluted effluent. The estimated dose to this hypothetical group will thus provide an upper limit to the dose that any real critical group could possibly receive. This procedure is equivalent to estimating the mean dose to an inhomogeneous and ill-defined group of the exposed population and then applying a safety factor to the permissible environmental conditions specified for this group.

(19) It must be recognized that the procedures of paragraphs 14 to 17 depart slightly from the idealized aim of setting an upper limit to the dose received by any single individual. This aim is unattainable in practice and the procedures recommended in these paragraphs approach it as closely as practicable. The methods of obtaining a sample of the critical group must be carefully chosen and appropriate specialists should be consulted in defining the critical group and in selecting both the individuals to be studied and the information to be obtained concerning them.

(20) Another factor influencing the assessment of radiation dose to individual members of the population is the use of the characteristics of the standard man. At present, the data on the standard man relate only to adults, although their extension to children is now in hand. Specific data for children should be used in cases where the radiation dose to children may be significantly higher than that to other members of the exposed group. Apart from age distribution there may be other reasons, such as ethnic differences, why the characteristics of the exposed group differ from those of the standard man; such differences will not often have a *significant* effect on dose

assessments. However, where data specific to a group are available, they may be selected by the competent national authority in place of those for the standard man.

(21) Not every installation that handles radioactive material or disposes of radioactive waste need necessarily have an environmental monitoring program. There should always be a pre-operational review of the environmental situation related to the foreseeable releases of radioactivity from the installation, and this review may provide sufficient information to demonstrate conclusively that the radiation doses to man from the installation will be trivial. It will then be adequate to measure and control the releases of radioactive material from the installation without making any environmental measurements. This situation will apply to the great majority of installations, since the handling of large quantities of radioactivity and the discharge of significant amounts of waste are normally confined to a small number of establishments. In some installations it may also be possible to dispense with the monitoring of waste, e.g. it is not normally necessary to monitor the exhaust air from tracer laboratories or hospitals. On the other hand, with the increased utilization of radioactive materials, there may arise concentrations of users individually handling small amounts of radioactivity, but together giving rise to a cumulative risk of significant contamination of the environment. In such cases, a carefully designed, but usually very limited, environmental monitoring program may be required, and may become the responsibility of public authorities.

C. ROUTINE SURVEYS OUTSIDE INSTALLATIONS

Objectives

(22) The primary objective of the routine surveys dealt with in this report is to test compliance with the relevant national or local requirements, at least in so far as these are based on the recommendations of the Commission. The Commission's recommendations relate to annual radiation doses and annual intakes of radioactive material, but since, in practice, the actual doses received are usually well below those recommended as maximum permissible values, it will often be sufficient to provide estimates of the upper limits rather than of actual annual doses or intakes.

(23) For the purpose of controlling, rather than assessing, exposures it will sometimes be necessary to predict trends and not merely to measure the current situation. The trends should be assessed in terms of organ doses or intakes of radioactive material, since their evaluation in terms of an arbitrary baseline, such as the natural radioactivity in the environment, cannot be related to the Commission's recommendations. For control purposes it is also desirable to identify the source of radioactivity in the environment.

(24) To achieve these objectives it may be necessary to interpret the results of operational surveys in the light of information both on the pre-existing level of radioactivity in the environment and on subsequent additions from sources other than the installation.

Factors Affecting the Design of the Survey

(25) There are many factors which may affect the design of a routine survey for radioactivity or radiation outside the boundaries of an installation. The more important of these factors are indicated in the following list:

(*a*) The type of installation and the potential hazard associated with it.
(*b*) The nuclides to be released, their activity, their physical and chemical form, and the method and route of release.
(*c*) The existing or expected presence of these nuclides from other sources.
(*d*) The behaviour of the released nuclides in the environment.
(*e*) Natural features of the environment which affect the behaviour of released nuclides, e.g. climate, topography, pedology, geology, hydrology and hydrography, and vegetative cover.

(*f*) Man-made features of the environment which affect the behaviour of released nuclides, e.g. reservoirs, regulated streams or rivers, and harbour installations.

(*g*) The utilization of the environment for agriculture, fisheries, water and food supplies, industry and recreation.

(*h*) The population distribution and habits. (See also paragraph 15.)

Information on these factors should be gathered with the aim of identifying the critical nuclides, the critical pathways and the critical groups, and evaluating the existing or expected radiation dose to the critical groups. Such information should then form the principal basis upon which to design environmental surveys and may also be relevant to other aspects such as the choice of a site, the methods of waste management and the appropriate degree of containment. These problems should be examined in a program of preoperational investigations. Information on most of the listed factors will usually be readily available, but it may also be necessary to undertake specific studies of particular aspects which are insufficiently understood.

Preoperational Investigations

(26) Preoperational investigations thus have a number of objectives. In relation to monitoring programs, this number reduces to three:

(*a*) Obtaining information on the critical nuclides, pathways and groups, thus leading to the design of the operational survey and to the provision of the quantitative basis for interpreting the results in terms of the actual or potential exposure of man.

(*b*) Providing information on the preoperational level of radiation and radioactivity in the environment, in cases where this information is helpful in interpreting operational surveys.

(*c*) Testing and exercising operational survey methods and procedures.

(27) Man's environment always contains some radioactive materials, partly of natural and partly of artificial origin. Radioactivity resulting from the operations of the installation can usually be distinguished from natural activity by appropriate chemical and physical identification of the radionuclides. More difficulty sometimes exists in distinguishing locally-produced activity from that due to fallout of debris from nuclear explosions. These difficulties are much increased if reliance is placed on non-specific determinations, such as those of gross beta or gross alpha activity. Such measurements can rarely be used for assessing radiation exposure resulting from the operations of an installation, and then only in conjunction with other information. They may, however, have their place in estimating upper limits of exposure (see paragraph 22), and in emergency surveys (see paragraph 41).

(28) The inclusion of measurements of radioactivity in the program of preoperational investigations has a number of advantages, but will seldom provide the best way of distinguishing between activity from the installation and that from other sources. The natural activity of most environmental samples will vary seasonally and, to a lesser extent, from year to year. Preoperational results can be extrapolated to later years only approximately. It is therefore better, wherever possible, to distinguish between the activity from the installation and the natural activity by specific analytical techniques. If fallout makes a significant contribution to the results of the operational survey, quantitative information on its magnitude may be necessary. In these circumstances, the best interpretation of the local survey data will be obtained by linking this survey, and any preoperational survey, with larger-scale fallout programs. It is important that comparable methods of sample collection and analysis be employed in all these survey programs.

Operational Surveys

(29) The types of measurements to be made in operational surveys and the area over which the survey is to extend should be determined by the principles discussed in paragraphs 9–28. The

manner in which the measurements are made should be guided by the three main aspects of these principles:

(*a*) The information is needed to assess the actual or potential exposure of the critical groups averaged over extended periods, e.g. a year.
(*b*) Only the exposure via the critical pathways needs routine examination.
(*c*) In addition to estimating exposures it may sometimes be necessary to follow trends.

The application of these principles can simplify the choice of suitable samples and measurements and can achieve substantial economies in the operation of surveys.

(30) The frequency of sampling and measurement in routine surveys is dictated partly by the fact that the relevant recommendations of the Commission relate to periods of a year, and partly by the probable rate of change of the conditions in the environment. For nuclides of long half-life, sampling may be infrequent, e.g. quarterly or annual, unless there are large fluctuations in the rate of discharge of waste or marked changes in environmental conditions. If such fluctuations require more frequent or even continuous sampling, it is still probable that quarterly analyses of composite samples will be adequate. If monitoring is necessary for short half-life nuclides, both sampling and analysis will be required at intervals of no more than about two to three half-lives. In either case, additional supplementary samples should be taken if results show any significant and unexpected increase.

(31) With respect to dietary contamination, it will usually be found that the critical mode of exposure will be due to the presence of only one or two nuclides in one or two foodstuffs consumed by a small group of people. If the existence of these critical nuclides, foodstuffs and groups is established, the dietary aspects of the operational survey may ultimately be limited to the assessment of the doses due to these critical nuclides and foodstuffs. In addition, a similar approach should be used to determine whether pathways involving inhalation or external exposure are critical.

(32) Although the preoperational studies will usually provide sufficient information to identify unequivocally the critical pathways and groups, this may not always be so. The initial design of the operational survey should then aim not only at assessing the doses incurred but also at providing further data on the critical pathways, so that experience can ultimately lead to a more appropriate design of survey. If large amounts of activity are to be discharged, it may also be desirable to design the initial operational survey so as to assess the doses incurred by some non-critical groups, since these doses, while smaller than those to the critical groups, may not be trivial, and the trend of variation of these doses may sometimes be important.

(33) It sometimes happens that the aim of assessing the dose via the critical pathways is satisfactorily achieved by monitoring materials not directly causing exposure of man. This procedure may have advantages when a material can be identified, the radioactivity of which is consistently related to that of the critical foodstuff, but is appreciably higher. Another indirect monitoring method is the sampling and measurement of the discharged waste itself. Whenever the monitored material is not itself critical, the probable relationship between the measured indicator and the corresponding dose to man must be assessed from the preoperational studies or early environmental monitoring results.

(34) It is important that the design of the monitoring program should be reconsidered from time to time. The initial design may have been based on inadequate information, and the results should be reviewed periodically to revise the design and to determine whether the program continues to achieve its objectives. Such reviews often lead to substantial reductions in the scale of monitoring programs without loss of relevant information. Changes in the method of operation of the installation, e.g. in the characteristics or quantity of the wastes discharged, or in the characteristics or utilization of the environment, may require modification of the survey program.

Adequate monitoring of the discharged waste may also provide sufficient information to allow simplification of the original design of survey.

D. EMERGENCY SURVEYS

(35) Emergency surveys may be needed round any installation handling sufficiently large amounts of radioactive material to constitute a potential hazard to people outside the installation. With the increasing transportation of radioactive materials and the development of nuclear power for transport, there arises the possibility of the need for emergency surveys in other areas. This section deals principally with surveys in the vicinity of installations, but the objectives and principles of design are equally applicable to surveys in other areas.

Objectives

(36) The primary objective of an emergency survey is to obtain rapid information on the magnitude and location of the immediate hazard to man, so as to define the type and extent of any necessary emergency procedures and counter-measures. The most urgent problem, though not the most likely, will be the assessment of the hazard from inhalation or external radiation. A further specific objective is the rapid determination of the contamination of foodstuffs, including drinking water, as a basis for rejection or continued use.

(37) A secondary objective is the assessment of radiation doses actually incurred by the public, taking into account any counter-measures which have been applied. This assessment should be made even when the doses are below the level considered to require emergency action, and will usually need more sensitive and more widespread measurements than those used for determining immediate emergency action.

(38) The theoretical assessment of the effects of accidental releases of radioactive material to the environment is often based on scanty information, and a third objective of emergency surveys is therefore to obtain scientific information on the results of the emergency and on the behaviour of the released radioactive material.

(39) It is almost always more satisfactory to make provision for detecting the emergency at the source rather than in the environment. However, in exceptional circumstances, part of an emergency monitoring program may be operated continuously in such a way as to detect the occurrence of an emergency situation.

Factors Affecting the Design of the Survey

(40) The general form of emergency surveys should be settled during the preoperational studies and should be reviewed periodically. The design must be flexible to take account of unexpected features of the emergency and of the changing situation as the emergency develops. The factors affecting the original design will be basically similar to those for routine surveys, but will be modified by the higher activity levels expected under emergency conditions and by the need for rapid evaluation. This need for speed is particularly important in assessing the inhalation hazard. No precise assessment of this hazard will be possible and decisions may have to be taken on the basis of very simple measurements, combined with an appraisal of the magnitude of the accident.

(41) The need for speed may necessitate the use of non-specific measurements of contamination, such as the determination of gross beta activity in selected foodstuffs or of gamma-radiation levels in the environment. The high activity levels occurring transiently during an emergency will often make background measurements unnecessary—this will almost always be true of specific measurements—but the interpretation of some measurements will be greatly assisted if background values taken by precisely the same methods have been provided as part of a preoperational or routine survey program. The design of the emergency survey should therefore establish whether non-

specific measurements are likely to be needed and, if so, what background measurements should be included in earlier surveys.

(42) In order to estimate in advance the extent of the emergency survey likely to be required, and thus of any background measurements, some assessment will be needed of the scale and consequences of the largest accident for which it is considered reasonable to make advance plans. In making this assessment, it may be expected that some degree of improvisation can be used to extend surveys beyond the range for which they were originally planned. This aspect of improvisation becomes more important for surveys following accidents to radioactive materials remote from installations.

(43) In making final decisions at the time of the emergency on the form, scope and interpretation of emergency surveys, it will be helpful to have current information on a number of relevant environmental factors, such as meteorological conditions, river flows, tidal conditions and harvesting and animal feeding conditions.

Emergency Exposures

(44) The Commission distinguishes between controllable exposures, for which dose limits can be specified, and uncontrollable exposures where different considerations apply. Even in severe emergencies some measure of control can be achieved, either within the establishment or by counter-measures outside, and it is not always easy to draw a clear line between minor mishaps, in which the doses are at least in part controllable, and emergencies which require special treatment. The Commission's recommendations for normal conditions should be applied to minor accidents whenever practicable. In deciding on counter-measures, however, it is necessary to justify the hazard and social inconvenience of such measures by the reduction in dose which they achieve. Because of the great variability in the circumstances in which counter-measures might be required, it is not possible to make generally applicable recommendations on action levels at which counter-measures become a matter of considerable importance. Guidance on such action levels is necessary, however, both for estimating the scope of an emergency survey and for interpreting the results in terms of remedial action. The Commission has drawn attention to the work of the United Kingdom Medical Research Council [6, 7, 8] and of the Federal Radiation Council [9, 10] in the United States.

(45) A clear policy on counter-measures should be established during the preoperational studies so that emergency surveys can be designed to provide the data needed for deciding on the initiation and scope of any necessary counter-measures.

E. EXPLANATION OF TERMS

(46) A number of terms used in this report have come to have specialized meanings or implications which are defined or clarified below.

Critical. The word " critical " has been used by the Commission to describe the organ of the body whose damage by radiation results in the greatest injury to the individual (or his descendants). The injury may result from inherent radiosensitivity or indispensability of the organ, or from high dose, or from a combination of all three. The use of the term " critical " has here been extended to describe nuclides, articles of diet, and pathways of exposure which deserve primary consideration as being the mechanisms of principal exposure of individuals. By a further extension, the term has been used to describe groups of the population whose exposure is homogeneous and typical of that of the most highly exposed individuals in the exposed population.

Emergency (adj.). Associated with an accident giving rise, or potentially giving rise, to radiation doses or intakes in excess of those recommended by the Commission for normal operations.

Monitoring. The measurement of radiation or radioactivity for reasons related to the assessment or control of exposure to radiation or radioactive material.

Outside an installation. Here used with an implied limitation to the region in which the installation may significantly affect the radiation dose to members of the public. This region could include areas geographically remote from the installation.

Preoperational. Occurring prior to the operation of an installation or prior to a major extension of such operations.

Significant. Here used not in its statistical sense but rather to indicate a situation noteworthy either because of its unexpectedness or because it might result in doses approaching a figure recommended by the Commission as a maximum permissible value.

Standard man. A notional adult designed to represent a typical or average adult who is exposed occupationally. The characteristics of the standard man are defined by Committee 2 in Tables 6–12 of their 1959 Report.[4] A new report on the standard man is in preparation. See also paragraph 17 of this report.

Survey. A systematic program of measurement of radioactivity or radiation.

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APPENDIX A

Pathways by which Man may be Exposed to Radiation and Radioactivity following the Release of Radioactive Materials to the Environment

When radioactive materials are released to man's environment, there are numerous and complex pathways by which radionuclides will ultimately cause radiation exposure of man. Simplified examples of some of the more important pathways are shown in Figs. 1 and 2. The diagrams are

not exhaustive, but illustrate the principal types of pathway which usually occur. In practice, however, one, or at most a few, pathways are the major sources of exposure in any given situation, and it will be appropriate to confine attention to these critical pathways.

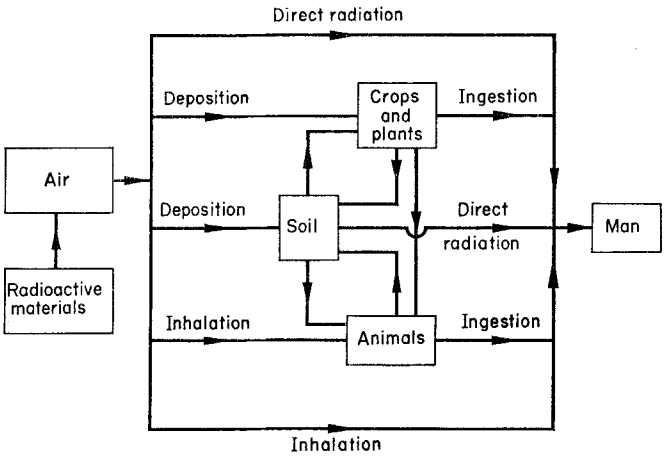

FIGURE 1
Simplified pathways between radioactive materials released to atmosphere and man

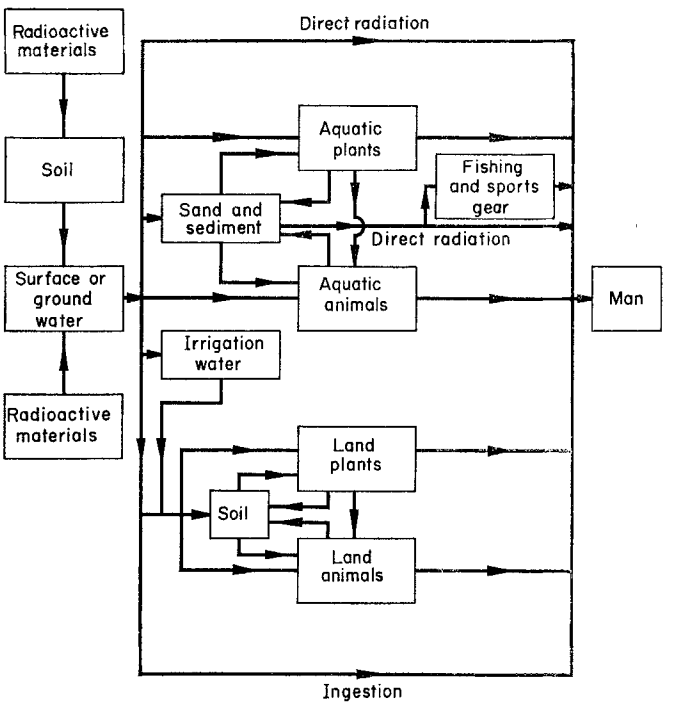

FIGURE 2
Simplified pathways between radioactive materials released to ground or surface waters (including oceans) and man