

RADIATION PROTECTION

*Recommendations of
the International Commission on
Radiological Protection*

ICRP PUBLICATION 10

Report of Committee IV
on
Evaluation of Radiation Doses
to Body Tissues from Internal
Contamination due to Occupational
Exposure

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FOREWORD

IN January of 1964 the International Commission on Radiological Protection (ICRP) appointed a Task Group consisting of

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to study and report on the Evaluation of Internal Contamination of Workers. When it began its work, the Task Group made its objective an amplification of paragraph 86 of ICRP Publication 6⁽¹⁾. The paragraph was:

“Tests should be performed to estimate the total body-burden for workers who deal with unsealed radioactive isotopes that may give rise to levels of ingestion or inhalation in excess of the maximum permissible concentrations. Such tests should also be performed where radioisotopes may enter the body through the skin or through skin punctures and open wounds. These tests may require the monitoring of breath and excreta, and the direct determination of the body-burden by means of a total body monitor, according to circumstances. The radiation doses delivered to the appropriate organs or tissues should be calculated and noted on the personal record, and the permitted doses of external radiation should be adjusted to allow for the ‘internal’ doses.”

The Task Group wishes to acknowledge its gratitude for valuable information and profitable discussion provided by

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MEMBERSHIP OF COMMITTEE 4 (1966)

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REPORT OF COMMITTEE 4

1. INTRODUCTION

(1) Estimates of the total radiation dose to the critical organ(s) of an internally contaminated worker require a knowledge of the time course of organ contamination and in particular its time integral expressed, for example, in $\mu\text{Ci-days}$. Publication 2 of ICRP⁽²⁾ provides a metabolic model and some dimensions of a Standard Man which may be used in calculating this quantity from measurements of radionuclides in the body or its excreta. The body content of radionuclides or the radiation dose estimated from the properties of Standard Man can only be an approximation of the actual values resulting from a particular intake, but such rough estimates are needed in:

- (i) planning the safety and containment of operations;
- (ii) assessing the safety of an environment for public use;
- (iii) indicating exposures too low to be of further concern, or high enough to warrant more accurate estimates.

In all such cases, allowances must be made for the differences between individuals and Standard Man. In using the model, one must not forget that it was developed to calculate maximum permissible daily intakes and maximum permissible concentrations for chronic low-level exposures of an average worker during 50 years. Consequently the model needs considerable modification and supplementation if it is to be used for calculating excretion from acute single intakes or for individuals differing from Standard Man.

(2) Two theoretical models may be used to formulate the calculation of radiation dose to a worker resulting from entry of a radionuclide into his body. One of these has to do with daily exposure to a constant level for which Publications 2 and 6 of ICRP give guidance by listing values of MPC_a and MPC_w . In contrast to this is the model based on a single short-term intake of a radionuclide, which forms the subject of this report of Committee 4. In many practical situations repeated short-term exposures occur and to deal with these the idealized approach of this report will need some modification.

(3) This publication deals with current knowledge of the metabolism of radionuclides and mathematical descriptions of this metabolism, with methods and programs of monitoring and with quantitative guides for assessing internal exposures. The report has Appendix C containing detailed information about the metabolism of approximately thirty radionuclides that are most frequently encountered as internal contaminants of workers. New (since ICRP Publication 2) data derived from studies of human beings are presented for all these radionuclides except Te-132 , Ce-144 , and Np-239 for which the new data pertain to animal experiments. Appendix C also presents the information and procedures for calculating the Investigation Levels (see Chapter 5) used in assessing the importance of internal contamination.

2. METABOLISM OF RADIONUCLIDES

(4) An understanding of the metabolism of radionuclides and their compounds is necessary for estimating radiation doses received by the body and its component parts from radionuclides taken into the body. This is especially important for interpretation of measurements of body radioactivity and the results of analyses of excreta. The purpose of this chapter is to summarize pertinent metabolic information available at present.

(5) The so-called “soluble” and “insoluble” compounds of radionuclides are metabolized so differently that the two types of behaviour must be recognized and defined at the outset. The usual chemical and physical definitions of solubility in aqueous solutions are not adequate in many cases to predict the translocation of a radionuclide from one site (gut, lung, wound) into extracellular fluid and thence to another organ or tissue within the body. Examples are:

inhalation of insoluble uranium oxide is followed within 24 hr by the excretion of uranium in urine;⁽⁴⁾

inhalation of insoluble AgI containing I-131 leads to the rapid appearance of I-131 in the thyroid (p. 35 of Ref. 5);

ingestion of the readily soluble CeCl_3 containing Ce-144 is followed by practically no absorption of Ce-144 from the gut ($f_1 < 10^{-4}$).⁽²⁾

(6) It was therefore considered desirable to use a word other than “soluble” to describe the property of a radionuclide-containing compound which results in its ready transfer across body membranes. The word “transportable” is used in this report to convey this meaning. The degree of transportability from one site to another (but not necessarily in the reverse direction) depends on the physical and chemical properties of the compound involved, on its reactions with body cells and fluids and upon biological processes such as phagocytosis. There is a continuous spectrum of transportability ranging from compounds which pass rapidly and completely through the first membrane separating the exterior from the interior of the body, to those which do so very slowly and to a small extent. Thus, the use of the word “transportable” and its opposite “non-transportable”, should not be taken to mean that there is any simple division of radioactive compounds into two sharply defined classes. The word “transportable” as used in this report corresponds to the word “clearable” used in a similar way by the ICRP Task Group on Lung Dynamics.⁽⁶⁾

(7) Figure 1 summarizes diagrammatically the most important metabolic routes that must be considered in internal contamination. Before proceeding to discuss these, it should be pointed out that radionuclides in the lumen of the gut, in the bladder, in the air passages of the lung, or in the outer layer of skin, are not yet involved in the metabolic processes of the body. Once they have been absorbed from these sites into extracellular fluid or into lymph nodes, they are said to constitute *systemic* contamination.

ENTRY OF RADIONUCLIDES INTO THE BODY

(8) In discussing this subject it is necessary to have a regular terminology. As far as possible the following words will be used with the meanings given:

Intake, the amount entering the nose or mouth.

Uptake, the amount absorbed into extracellular fluid.

Deposition, the amount present in the organ of reference (see para. 17).

(9) Radionuclides may enter the body by inhalation, ingestion, or through intact or wounded skin.

INHALATION

(10) Radioactive gases, liquids or solids may enter the body by inhalation. Water-soluble gases, e.g. those containing tritium oxide or radioiodine, are rapidly absorbed from inhaled air and thus appear in extracellular fluid within a few seconds. Liquid or solid radioactive compounds inhaled in the form of aerosols have a number of possible fates depending on their physicochemical properties. A part of that inhaled will be deposited in the respiratory tree and the remainder exhaled. The portion deposited in the upper respiratory passages may be expelled by ciliary action into the gastrointestinal tract, and the portion deposited in deeper portions of the lungs may be completely and rapidly absorbed if it is transportable. If it is non-transportable, it will be partially eliminated and partially absorbed at a slow rate. The clearance of non-transportable particles from the deep parts of the lungs is not fully understood, but is known to vary a great deal from case to case. This is due in part to the fact that the transportability of inhaled material is related to particle size and perhaps shape, to the individual's dimensions and physiology and to the chemical nature and reactions of the radioactive compound. The influence of these factors is discussed at length in References 5, 6, 7, 8, and 9. For practical purposes, ICRP Committee 2 (Table 10 of Ref. 2) adopted the following model:

PARTICULATES IN RESPIRATORY TRACT OF THE STANDARD MAN

Retention of particulate matter in the lungs depends on many factors, such as the size, shape and density of the particles, the chemical form and whether or not the person is a mouth breather; however, when specific data are lacking it is assumed the distribution is as shown below

	Readily soluble compounds (%)	Other compounds (%)
Exhaled	25	25
Deposited in upper respiratory passages and subsequently swallowed	50	50
Deposited in the lungs (lower respiratory passages)	25 (this is taken up into the body)	25*

*Of this, half is eliminated from the lungs and swallowed in the first 24 hr, making a total of 62½% swallowed. The remaining 12½% is retained in the lungs with a half-life of 120 days, it being assumed that this portion is taken up into the body fluids.

Possible revisions of this model have been considered by a Task Group of ICRP Committee 2.⁽⁶⁾

(11) The table indicates that transportable compounds, after inhalation, pass into extracellular fluids either directly from the lungs or from the gut after they have been eliminated from the tracheo-bronchial tree and swallowed. Non-transportable compounds, on the other hand, do not pass readily into extracellular fluids; in the model above, 62½% of them pass over into the gastrointestinal tract.

to be partially absorbed or excreted, while 12½% remains in the lung alveoli for long periods of time. A portion of these alveolar deposits may be transferred to pulmonary lymph nodes⁽⁶⁾ and retained there for long periods. It should be noted that very few compounds have been found to be completely non-transportable in body fluids, and some excretion in the urine may be expected in most cases following inhalation of a non-transportable compound, although it is frequently quite small and cannot be related quantitatively to the body content.

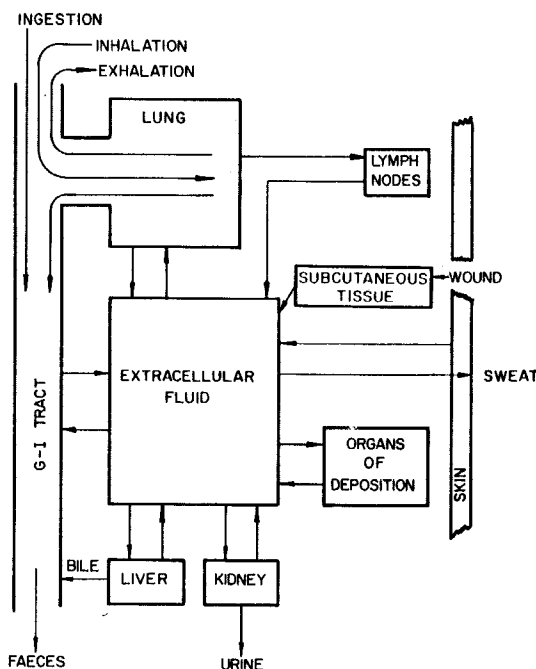


FIG. 1. Principal metabolic pathways of radionuclides in the body.

INGESTION

(12) When a worker ingests a radioactive substance, he will usually do so over a short time, and this constitutes a single intake to gut. Although he may have a series of such intakes, it is best, in order to keep the discussion simple, to consider the consequences of one intake only.

(13) If the material is non-transportable, most of it will traverse the gastrointestinal tract and emerge in the faeces. In the absence of detailed metabolic information on the contaminated individual, Table 11 of ICRP Publication 2 may be used to estimate the concentrations and residence times in the various portions of the gastrointestinal tract. There are, however, indications that this concept may need modification. ^(10, 11, 41)

(14) If the material is transportable, a significant fraction will be absorbed into extracellular fluid, mainly during its passage through the small intestine (lasting 4 hr in Standard Man). Table 12 of ICRP Publication 2 lists values of f_1 , the fraction of radionuclide absorbed from the gastrointestinal tract into extracellular fluid. These are also presented in Table 1 of Appendix A (p. 25) for compounds containing

the twenty-four elements included therein. It should be borne in mind that the single value of f_1 indicates only the extent of transportability assumed in the calculation of the maximum permissible concentration in drinking water (MPC_w). Thus the values used in ICRP Publication 2 merely define the extent of transfer across the intestinal mucosa implied by the term “soluble”. The actual magnitude of f_1 in a particular case will depend on the metabolism and nutrition of the individual as well as the chemical compound in which the radionuclide is ingested. Other aspects of the behaviour of the gastrointestinal tract will be discussed in that part of Chapter 3 dealing with excretion of faeces (paras. 39–41).

ABSORPTION THROUGH SKIN

(15) Intact skin provides an effective barrier against the entry of most radioactive materials into the body. Exceptions of practical importance are the absorption through intact skin of:

- tritium oxide either as liquid or vapour,
- iodine as vapour or in solution and iodide in solution.⁽¹³⁾

ENTRY BY A WOUND

(16) When skin is broken, punctured or abraded, radioactive substances can penetrate to subcutaneous tissues and thence to extracellular fluid, rapidly in the case of transportable compounds, and slowly in the case of non-transportable compounds. In the latter case, if the wound is not decontaminated, the time course of systemic contamination may resemble that resulting from chronic exposure.

TRANSLOCATION AND DEPOSITION

(17) Extracellular fluid is the chief vehicle by which transportable materials are transferred from one part of the body to another. Two examples of other methods of transportation are the movement of insoluble plutonium oxide from lungs to lymph nodes and the attachment of radionuclides or their compounds to red blood cells. A portion of the radionuclide in extracellular fluid will be excreted by kidney, liver, intestine, skin, or lung, and the remainder will be deposited in any organs or tissues for which it has a special affinity. Soon after systemic contamination by a transportable radionuclide, there will be a net transfer of it into the organ(s) of deposition. This will continue until the concentration in extracellular fluid falls (due to excretion and deposition) to a level which results in a net transfer of radionuclide from the organs of deposition back into extracellular fluid. At this point in time the amount in the critical organ has reached a maximum the value of which is the “deposition” used to calculate the radiation dose (see para. 62). A model of this behaviour in a two-compartment system has been described by Zilversmit *et al.*^(14, 15) There are a few radioactive substances of practical importance such as tritium oxide, chlorides and polonium compounds which are not appreciably concentrated in any tissue, and their concentrations in extracellular fluid exhibit a simple exponential decline for rather long periods of time (see sections on these nuclides in Appendix C).

(18) In Table 12 of Reference 2 (and Table 1 of Appendix A) are values for f'_2 , the fraction of radionuclide going from blood (or extracellular fluid) to organs of reference (deposition). These values for f'_2 may not be applicable to short intervals after single exposures nor to very short-lived radionuclides which undergo appreciable decay during deposition. One such example is the uptake of I-132, I-133, I-134, and I-135 by the thyroid gland.