INTRODUCTION

The primary limits of radiation protection standards are expressed in terms of an annual limit on dose equivalent to certain organs or tissues. For example, in recent guidance of the ICRP it is recommended that, as a primary limit, the effective committed dose equivalent from intakes in any year should not exceed 0.05 Sv.¹ Secondary and higher order limits, such as limits on intake or potential exposure, are developed to facilitate application of the standard in the workplace. The primary limit on dose equivalent is the overriding limit and the secondary limits should be used circumspectly. Thus, the practicing health physicist is often called upon not only to estimate annual intakes for comparison with secondary limits, but also to estimate dose equivalent for comparison with primary limits.

The information upon which the health physicist must base his estimates is often scanty and uncertain and sometimes must be supplemented with rather broad assumptions. This situation exists for exposures to external radiation as well as to internally deposited radionuclides. The basic difficulty is that most data obtained through monitoring programs are not direct measures of those parameters used in the dosimetric formulations.

The complexity in estimation of dose arises from two principal sources:

[1] Imperfect knowledge of the exposure situation.
Information as basic as the date of the intake or the physical and chemical characteristics of the


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suspected contaminants may not be known.

[2] Imperfect knowledge of the behavior of the contaminant in the individual. Most estimates of dose to body tissues are based on a hypothetical Reference Man.² Large variability in the distribution of material within the body and its rate of elimination (excretion rate) is found among individuals. Moreover, there is still a great deal of uncertainty concerning the "typical" behavior of many radionuclides, that is, their behavior in Reference Man.

In this paper, the problem of estimating the dose from internal emitters will be discussed.

Objectives of a Routine Monitoring Program

Establishment and maintenance of a routine monitoring program is required to ensure that safe work practices are being followed. Such programs address radiation exposure (external and internal) as well as aspects of industrial hygiene and basic work safety. The objectives of a routine monitoring program are

1. the establishment of uniform and sound work practices among those working with radioactive material;

2. the promotion of effective communication between the workers and those responsible for radiation safety programs;

3. the establishment of information which can be used to determine compliance with authorized limits; and

4. the development of the capability to provide timely and accurate information into the decision process following an event which might result in exposures in excess of authorized limits.
These programs provide information for evaluating the general exposure conditions throughout an operating facility. Careful analysis of serial results can indicate trends toward greater or lesser exposures or intakes within the work force. These trends, in turn, may be correlated with new or altered work procedures. The determination of whether individuals have been exposed to radioactive material in a manner which resulted in internal deposition is evaluated through measurement of activity present in the body or in excreta, generally referred to as bioassay. Although work procedures are established to minimize or eliminate the intake of radionuclides by workers, it is recognized that accidental depositions do occur. Information obtained through a bioassay program serves to quantify any internal deposition and is also invaluable in the development of metabolic models. It is, therefore, strongly recommended that results for individuals be collected, analyzed, and published in the open literature. Such information is invaluable in relating bioassay results to intake and internal dose.

Inhalation Intakes

Inhalation is the principal route of intake for workers, and such intakes are often acute rather than chronic in duration. The model of the respiratory tract of the ICRP is shown in Fig. 1.\textsuperscript{1,4} The fractional deposition in each region of the tract ($D_{NP}$, $D_{TB}$, or $D_p$) is a function of the activity median aerodynamic diameter (AMAD) of the aerosol. The deposition fractions shown in Fig. 1 are for AMAD = 1 μm. Regional deposition fractions for aerosols of other AMAD values between 0.2 and 10 μm can be obtained from Fig. 5.1 of Publication 30.\textsuperscript{3}

Clearance of material deposited in the lung reflects both the mechanical removal of the deposited material to the gastrointestinal tract and transfer of material directly from the lung to body fluids. The fraction of the deposition in a region of the lung model assigned to these clearance compartments depends on the solubility of the material and is assumed to be independent of AMAD. For classification purposes, clearance classes are defined in terms of the clearance rate of the chemical compounds from the pulmonary region of the lung. Clearance classes D (days), W (weeks), and Y (years) correspond to clearance
halftimes of less than 10 days, 10-100 days, and greater than 100 days, respectively. Guidance on the classification of inorganic compounds has been given by the ICRP. This guidance is recommended for use only when specific information is not available.

Functions describing the fraction of inhaled activity expected to be present in the lung at time $t$ following a unit intake at time zero are displayed graphically in Fig. 2 for AMAD values between 0.2 and 10 μm. Note that the function $I_L(t)$ reflects only biological clearance; for application to a particular radionuclide one multiplies $I_L(t)$ by $e^{-λt}$, where $λ$ is the radiological decay-rate constant for the nuclide of interest. An estimate of intake can be made by applying these functions to in vivo measurement of the lung burden at time $t$. Note that in applying these functions at times (up to several days) soon after an acute intake, it is more important to know the AMAD than the solubility class. For example, deposition may vary by a factor of 6 for particle size range of 0.2 to 10 μm.

Nasal swabs are commonly used to evaluate deposition in the NP region, although this method is fraught with uncertainty. Positive swabs usually indicate inhalation of a contaminant, but the converse may not hold. Nasal swabs are useful only when obtained immediately after suspected inhalation. Furthermore, mouth breathing can lead to a significant lung deposition with little or no deposition in the nasal region. In vivo measurement of lung burden or analysis of excreta are the preferred methods for estimating the quantity inhaled. However, nasal swabs can be readily obtained and thus can provide early information regarding the identification of the radionuclides which may have been airborne during the event.

Estimates of Internal Deposition

Measurement of radionuclides present in excreta or in vivo detection of radionuclides within the body are the primary bases for establishing the existence of internal deposition. Background measurements prior to assignment of a worker should be performed if an individual's work history indicates that the potential existed for internal deposition. Routinely scheduled measurements, performed after the individual is on the
job assignment, are important in evaluating the extent of protection and the observance of safe work practices by the individual. Bioassay results obtained when an individual terminates a job assignment document the estimated body burden or intake associated with that assignment.

In the usual operational situation, the earliest information available following an exposure will consist of preliminary reports of the circumstances surrounding the exposure, probable identification of the radionuclides, and preliminary surveys of air and surface contamination. Measurements of surface contamination and nasal swabs may give evidence of potential inhalation exposure, but negative findings do not eliminate the possibility of internal deposition.

Detailed dosimetric assessments of internal contamination, including estimates of the intake, of the burden of material in body organs, and of the dose equivalent to organs must be based on sequential in vivo measurements and assays of activity in excreta. Early estimates, of course, will rely heavily upon reference values for the relevant parameters governing the deposition and translocation of the material in the body. However, as further measurements are obtained, these estimates may be improved.

In Vivo Counting

In vivo detection of photon-emitting radionuclides, when possible, provides the most informative data for defining the extent of internal deposition. Proper interpretation of the measurements includes consideration of external contamination, calibration of the detection systems, and other factors typical of radionuclide assay. As noted above, an initial estimate of intake can be obtained from measurements of activity present in the lung. Estimation of dose requires information on the spatial and temporal distribution of activity among the organs of the body. Some information on the distribution of activity among organs may be obtainable from measurements made with detectors placed over the organs. However, at later times the activity may become sufficiently dispersed that assignment of relative fractions to organs is difficult.

Analysis of Excretion
Measurements of activity in excreta can be performed with considerable analytical sensitivity. For radionuclides not emitting photon radiations, the assay of excretion is the only means of estimating internal deposition. The collection of excreta requires the cooperation of the worker in providing the samples and avoiding the possibility of contamination. Routine monitoring generally involves urine sampling; fecal sampling is used in the event of possible substantial intake of an insoluble form. The activity present in a urine sample reflects the activity present in body fluids, having arrived there as the result of clearance from the lung, the GI-tract, the site of a wound, or from other tissues in which it had been deposited earlier. Using a metabolic model for the radionuclide, one attempts to characterize the intake that would best support the observed excretion rate.

**Metabolic Models**

The information on the metabolism of radionuclides presented in Publication 30 generally is not suitable for application to bioassay needs. Committee 2 provided no information on the routes of excretion in the metabolic data sheets. In Publication 30, no attempt has been made to estimate doses along the routes of excretion, except in the case of gold. The formulation of the metabolic models includes consideration of a transfer compartment, which on the initial entrance of the material represents body fluids; however, feedback of material released from organs to this compartment was not considered in Publication 30. Thus, estimates of activity present in this compartment are not applicable to considerations of excretion. Because of these problems, the continued use of the bioassay information from ICRP Publication 10 and 10A is suggested unless better information is available from the literature. Updates of these publications can be expected in the near future.

**Estimation of Dose Equivalent**

Doses from internal deposition of radionuclides are routinely estimated on the basis of Reference Man, which cannot be expected to be highly accurate in an individual case. In some cases, adjustments can be made to standard values. For example, the committed dose equivalent
per unit intake given in the supplements\textsuperscript{7,10} to Publication 30 can be adjusted for inhalation of different particle sizes. Dose estimates for material entering body fluids through puncture wounds can be estimated by scaling the inhalation values by the appropriate fraction of material reaching body fluids (some error, although generally quite small, may be expected due to difference in photon cross-fire between the lung and organ of interest). Adjustments to account for the characteristics of the exposed individual when different from Reference Man, however, may be of greater importance. The individual's weight and the weight of his organs are the most obvious characteristics requiring adjustment. A variety of techniques are available for estimating some characteristics, e.g., total body water or lean body mass, but for many others, such as masses of organs and tissues, such procedures are not available. As noted above, the rates of elimination of the radionuclide from various tissues also vary greatly from one individual to another and these differences may produce substantial differences in dose estimates. Most estimates of dose equivalent are based on an assumed uniform distribution of the activity within organs of the body. If information is available to the contrary, as in the case of wounds, it should be used. In evaluating the committed dose equivalent for a given individual, some consideration of the length of the commitment period may be required.

Summary

Data obtained by routine personnel monitoring is usually not a sufficient basis for estimation of dose. Collected data must be interpreted carefully and supplemented with appropriate information before reasonably accurate estimates of dose (i.e., accurate enough to indicate whether or not personnel are exposed in excess of recommended limits) can be developed. When the exposure is of sufficient magnitude that a rather precise estimate of dose is needed, the health physicist will bring to bear on the problem other, more refined, methods of dosimetry. These might include a reconstruction of the incident and, for internal emitters, an extensive series of in vivo measurements or analyses of excreta. Thus, cases of special significance must often be evaluated using techniques and resources beyond those routinely employed. This is
not a criticism of most routine monitoring programs. These programs are usually carefully designed in a manner commensurate with the degree of exposure routinely encountered and the requirement of a practical program of radiation protection.
REFERENCES


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