

## INTERPRETATION OF BIOASSAY MEASUREMENTS

### 1. INTRODUCTION

#### 1.1 Problems Associated with Internal Dose Assessment

The estimation of internal radiation doses from radionuclides taken into the body, either by workers or by members of the public, often depends on the proper interpretation of bioassay measurements. Measurements of radioactivity in body organs or in the whole body (in vivo), or measurements in samples of excretion (in vitro), must be interpreted first in terms of the quantity of radioactive material taken into the body by using dynamic mathematical models that describe the translocation, distribution and elimination of specific radionuclides in specified physical and chemical forms. Although area air sampling results can provide estimates of intake for demonstrating compliance with regulatory limits, they are unreliable and inaccurate if exposure to concentrations vary in space and in time. In such cases, personnel monitoring procedures such as breathing zone air sampling and bioassay should be used for the estimation of intakes by workers (Ca 72). After known or suspected exposures have occurred or when the potential for such exposures is sufficiently great, bioassay has been required as a final quality control procedure under the provisions of 10CFR Part 20 (FR86) in order to assure adequate functioning of the air monitoring program and other elements of the internal radiation protection program.

Dose conversion factors have been calculated from ICRP Publication 30 and other models by various authors, and these factors are available to convert estimated or assumed intakes into 50 year committed doses to various body organs or into the so called committed effective dose equivalent to the whole body. However, the models of ICRP Publication 30 used in these calculations do not provide for excretion compartments. Thus, they do not provide a direct way to calculate intakes from excreta bioassay measurements. Intake calculations from bioassay measurements were found to be in demand after the Three Mile Island accident as well as after other significant cases of human intake of radioactive material by workers. Such calculations are made not only to determine compliance with applicable regulations on intake of radioactive material but also to provide continued refinement of estimates of internal dose. Such dose estimates may be needed for both early emergency medical decisions and long-term medical follow up of significantly exposed workers.

To date, the interpretations of bioassay data in terms of intakes have been made using various empirical models that have often produced inconsistent estimates, particularly in the early emergency phases after an accidental intake. The guide we have developed provides a consistent approach to calculating intakes of all important radionuclides from bioassay measurements. In this guide we describe these calculations and present tables of values for intake retention functions, thus providing a practical and consistent way of computing intakes from both in vivo and in vitro bioassay measurements.

For each radionuclide included in Appendix B, intake retention fractions (IRFs) for the inhalation of ICRP Publication 30 Classes D, W, and Y materials are provided. Similar IRF values are given for ingestion intakes. The

tabulated values in Appendix B include the decay factor. The IRF values are applicable to whole-body and lung measurement results as well as the results from urine and fecal analyses. A table of IRF values for the thyroid is provided for converting the results of thyroid measurements into estimates of intake of iodine isotopes. Methods for extending the use of the tables to include conditions of multiple and continuous intakes and for aerosols having a particle size distribution other than 1 micrometer Activity Median Aerodynamic Diameter (AMAD), as used in ICRP Publication 30, are given.

## 1.2 Criteria for Selecting this Approach, Literature Reviewed, Validation and Verification Methods

The computational method used here was selected because it was recently documented and illustrated in publications by Skrable (Sk80, Sk81, Sk83). Methods for solving for quantities associated with compartmental models, using microcomputers and algorithms, have also been described by Birchall (Bi86), and he indicates a specific algorithm, using BASIC, which executes in seconds. Skrable (Sk81), on the other hand, has written programs using Hewlett Packard language on the HP41CV for solving the retention and excretion of inhaled or ingested materials. The serial-transformation kinetics equation used by both these authors requires that all pathways leading to a compartment of interest be defined. Thus, many applications of the equation are needed to follow a nuclide through the body. Without computers these computations would be tedious. In addition, recent compilations have become available (ICRP74, ICRP77, ICRP83), which are specific for radiation protection, for standard radiological and physiological parameters that describe a radionuclide's fate in the body of a reference adult male. Thus, the computational approach for IRFs was selected based on the availability of current models and parameters, plus the availability of computers.

The ease of computing intakes, on the other hand, can be improved from the availability of tabulated values of the IRFs for both in vivo and in vitro bioassay compartments. The data in these tables are obtained by repetitive application of algorithms similar to those supplied by Birchall and Skrable. In addition, tabular data giving the intake retention fractions, expected to be present in various bioassay compartments are helpful in choosing a bioassay procedure.

In ICRP Publication 30 (ICRP79), the whole-body systemic uptake retention functions in many instances are expressed as a sum of exponential terms. Because of this and because this suited our approach, the criteria used to select an excretion or systemic uptake retention expression was that it be expressed as an exponential or sum of exponentials. Exponential functions are suitable for models which incorporate feedback and recycling of an element such as those for iodine and those used in this manual for the alkaline earth elements. In this study, we use a pseudo-retention function for plutonium based upon an excretion function recently reported by Jones (Jo85). Exponential models were fitted to the alkaline earth metabolism described in ICRP Publication 20 (ICRP72) based upon a model reported by Johnson and Myers (in Sk83), and we used these fitted functions for Ca, Sr, Ba and Ra. These models duplicate the ICRP Task Group's retention function (ICRP72) over the period 0.1 day to 20,000 days post intake but they are used here since they are appropriate functions for the computational method developed by Skrable (Sk83). For all other elements the whole-body systemic uptake retention functions in

ICRP Publication 30 were used. We note that the iodine metabolism suggested by Riggs (Ri52) was used here, and we caution users of ICRP Publication 30 (ICRP74) that the correct description of the Rigg's whole-body systemic uptake retention function for iodine appears in an Addendum to ICRP Publication 30 (ICRP81).

The Dosimetric Research Branch, Chalk River Nuclear Laboratory (CRNL), has been monitoring employees and others for internal contamination and interpreting the results in terms of dose using ICRP or other models for more than 35 years. When ICRP Publication 26 introduced the committed effective dose equivalent and annual limits on intake in 1977, they initiated a complete review of models and procedures for interpreting internal contamination monitoring. Part of this review involved the development of computer codes and data bases to carry out detailed calculations. These computer codes and data bases contain the latest ICRP recommended models and parameters as well as other models, as appropriate. For the most part, they contain the metabolic models and parameters and dosimetric data used in ICRP Publication 30. These facilities at CRNL were used to validate the tabulations of retention and excretion fractions listed in this document.

Researchers at Science Applications International Corporation (SAIC) have been involved in the development of computer programs to predict retention and excretion from ICRP 30 metabolic models for the last three years. As part of the quality control process used in the production of this document, selected tabular results were validated by comparison to results predicted by SAIC models for the same assumed set of conditions. Two SAIC programs were used in the validation tests. These programs, which are described in Section 6.1, were developed by different individuals and feature completely different computational approaches. One is a Pascal-language program which incorporates an analytic solution algorithm much like the BNL model employed to generate the tabular values. The other is a BASIC program which employs Runge-Kutta numerical integration techniques.

The SAIC validation process involved comparison of inhalation and ingestion retention results for the following radionuclides: Fe-59, Co-60, Sr-90, I-131, Cs-137, Ce-144, Th-232, U-235, Pu-239, and Am-241. This process was valuable in identifying programming or computational errors in the draft results. After correction of identified errors, very good agreement was reached between the tabulated results and those generated by the other programs.

Actual case studies were used to verify the models used in this report, and these studies were presented in Appendix A. Dr. Darrell Fisher, from Battelle Pacific Northwest Laboratories, and Dr. Joyce Landmann Lipsztein, from Brazil's National Commission for Nuclear Energy, provided most of this work based on their experiences. These case studies included: (1) inhalation of Co-60, Mn-54, Sr-90, Ce-141, Ce-144, U-233, Am-241, I-131, thorium and natural uranium and (2) ingestion of Co-60, Nb-95, Cs-137, Ce-141, Ce-144, Sr-90 and I-131. Additionally, several case studies based on the experiences of staff from Brookhaven National Laboratory were included.

### 1.3 Premise of the Manual

The estimate of intake of radioactive material depends on the proper interpretation of bioassay measurements, and often the method for interpretation is poorly documented. Because the interpretation of bioassay data involves many

physical relationships between a multitude of variables, part of the problem of interpretation involves this complexity. In some cases, refinement of the interpretation may continue for years after the initial assessment of the intake and dose equivalent. Thus, a proper approach to interpretation is to establish a clear record of the methods used throughout the assessment. We intend this manual to provide an easy to use method, yet one that incorporates the complexity of current mathematical models. This obviously leads to certain limitations that must be recognized, e.g., the use of Reference Man or other standard models for estimating the intakes by actual workers. We provide a detailed description of the approach as well as practical examples. When significant exposures occur, we encourage others to perform more detailed investigations that could provide data useful in the validation or improvement of the models and approaches used in this report.

## 2. DESCRIPTION OF CALCULATIONAL METHOD

### 2.1 Introduction

This section describes a way to obtain intake retention functions. These functions give the fraction of an intake of radioactive material expected to be present in a bioassay compartment at any time after an acute exposure or after onset of a continuous exposure. The intake is estimated from the quotient of the quantity of a radionuclide measured in a bioassay compartment by the intake retention fraction for that compartment. The intake can be compared to the NRC quarterly intake limit, the ICRP Publication 30 Annual Limit on Intake, or with other appropriate reference levels. This procedure for estimating intakes provides for a rapid assessment of the significance of measured results and thus provides a way to distinguish between exposures that require further investigation from exposures that do not. The model is based upon Reference Man models which are summarized in ICRP Publications 23 and 30 (ICRP74, ICRP79), but other metabolic models that fit the ICRP structure also can be used. The bioassay compartments may represent specific physiological entities such as the lungs or the gastrointestinal tract, total body or excreta. Intake pathways which we consider here include inhalation and ingestion. We discuss the estimation of intakes and internal radiation doses and the frequency of monitoring required for detection. Our approach to obtaining intake retention functions can be implemented into any bioassay monitoring program that employs measurements on people or measurements of excreta.

Intake retention functions that are based upon Reference Man can be used to make a rapid assessment of the committed effective dose equivalent and the committed organ or tissue dose equivalent. The quotient of the estimated intake by the stochastic Annual Limit on Intake (ALI) value, which is given in ICRP Publication 30, when multiplied by 0.05 Sv (5 rem), gives the committed effective dose equivalent of an exposed worker.

One may also obtain organ or tissue dose equivalent by computing the product of the intake and the committed dose equivalent in target organs or tissues per intake of unit activity. A weighting factor representing the ratio of the risk arising from irradiation of the organ or tissue to the total risk when the whole body is irradiated uniformly may be multiplied by the committed organ or tissue dose equivalent. The sum of the weighted committed dose equivalents in target organs or tissues is the committed effective dose equivalent. The factors for dose equivalent per unit activity intake (Sv per Bq) appear in supplements to ICRP Publication 30. Age and gender averaged