Acta Physica Academiae Scientiarum Hungaricae, 52 (3—4), pp. 303—310 (1982)

QUANTITATIVE PROFILE SCANNING, A MEANS FOR INTERNAL DOSE ASSESSMENT

A. ANDRÁSI and É. BELEZNAY

HEALTH PHYSICS DEPARTMENT, CENTRAL RESEARCH INSTITUTE FOR PHYSICS
1525 BUDAPEST, HUNGARY

A combined measuring and computing method is given by means of which the Committed Effective Dose Equivalent can be estimated. A sensitive detector equipped with a suitable collimator moving along the length of a person being investigated, enables the count rate profile to be obtained from which organ activities can be deduced. With repeated measurements the activity time variations and their time integrals can be derived, the latter being proportional to the organ doses. The general description of the methods and its implementation in the radiation protection practice of the Central Research Institute for Physics is given. Test experiments show the method to be suitable for internal dose assessment when the activity exceeds 0.5 kBq per organ.

Introduction

The dose received from internal sources is characterized by the Committed Effective Dose Equivalent, the weighted sum of the Committed Dose Equivalent values concerning the individual tissues specified by the ICRP. The Committed Dose Equivalent $H_{50,T}$ for a given target tissue T, and a given radionuclide can be obtained as follows:

$$H_{50,T} = \sum_S U_S \times SEE\,(T \leftarrow S),$$

where $SEE\ (T \leftarrow S)$ is the specific effective energy absorbed in T per radioactive disintegration in the source organ S, U_s is the number of disintegrations of the radionuclide in each source organ.

In the radiation protection practice the number of disintegrations U_s, or, in other words, the time integral of activity for the source organs over 50 yr, has to be determined in each case when individual dose assessment is needed. The calculated SEE values for Reference Man are tabulated in a couple of reports [1, 2]. The influence of individual differences on these values can be considerable, but this is beyond the scope of the present paper. The activity variation in time in different source organs, i.e. the retention functions, can be determined by the method of quantitative profile scanning.

Method

In the last few years an increasing number of whole body counters are being used not only for the activity determination in the human body as a whole, but also for obtaining information about the activity distribution.

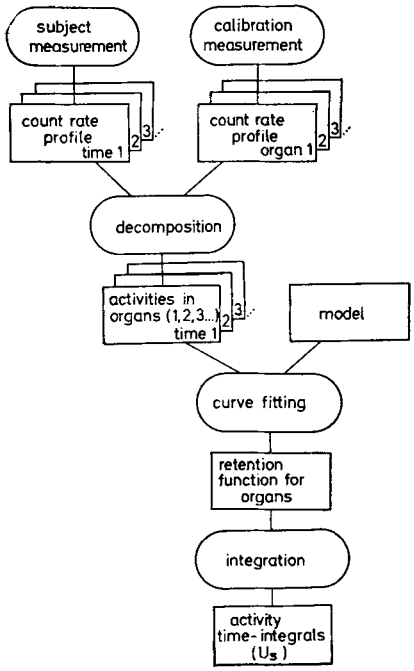

Fig. 1. Scheme of activity time integral determination by quantitative profile scanning.

If a large NaI(Tl) detector equipped with proper collimator is moving along the length of the person to be investigated, the count rate profile in a given energy range can be obtained. After a sophisticated calibration procedure using an anthropomorphic phantom containing the organs in question, the activities in the different organs of the investigated person can be computed from the count rate profile. With repeated measurements the activities at discrete points of time are obtained from which the required time integral can be derived. The best fit can be expected if the function describes the real transport of radionuclides in the body. As a good approximation these functions can advantageously be obtained for instance by means of multi-compartment modelling of the radionuclide transport. If there is no possibility to carry out such sophisticated calculations, a simpler curve fitting procedure can also be satisfactory for obtaining retention functions to be integrated. The different steps for determining the activity time integral can be followed in Fig. 1.

Implementation

The whole body counter of the Central Research Institute for Physics [3] has proved to be suitable for profile scanning measurements. The one or two 150×100 mm NaI(Tl) cylindrical scintillation detectors move along the

subject to be investigated with controllable speed in the range of 0.6—20 mm/s, and with adjustable length up to 1330 mm. The distance between the bed and the detectors can also be varied in a reasonably wide range. The detectors are equipped with changeable collimators like 2 and 8 cm thick simple slit and focusing slit collimators. The spatial resolutions and relative efficiencies of different collimators are shown in Fig. 2 [4]. The pulses coming from the detectors are processed by a multi-channel analyser in externally controlled multi-scaling mode, making it possible to obtain the count-profile in a preselected gamma energy range. The measured data are punched on paper tape for further computer evaluation. The bed-detector arrangement is surrounded by a 200 mm thick iron shielded room covered by 4 mm lead and 1 mm copper with inside dimensions of $1600 \times 2000 \times 2200$ mm. A REMCAL type anthropomorphic phantom containing ten different organs is at our disposal for calibration. By filling the organs of the phantom with a water solution containing the radionuclide in question with known activity the count rate profile due to unit activity in the individual organs can be obtained.

A computer code DECOMP (DAS2) was developed by means of which the most probable activities in the individual organs can be calculated from the measured count profile [5]. This calculation consists of the numerical solution of a linear equation system, where the most probable values of the

No.	collimator	FWHM [cm]	total relative efficiency [%]
1	—	—	100
2	15 cm ø hole	37.5	53.2
3	8 cm slit	20	25.7
4	2 cm slit	7.0	2.66
5	focusing	4.6	4.80

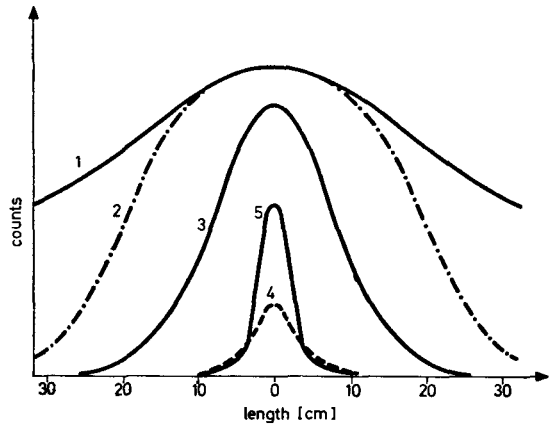

Fig. 2. Spatial resolution and total relative efficiency of different collimators.

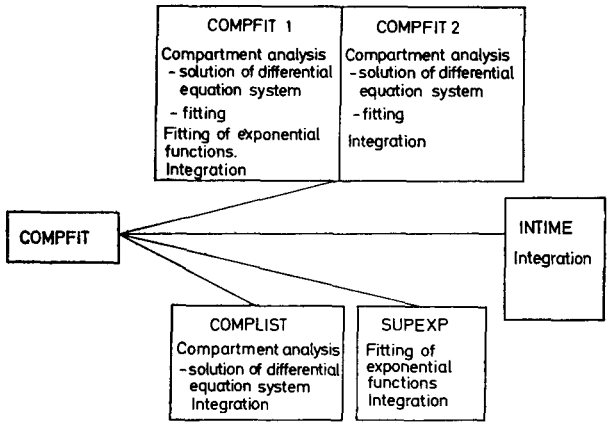

Fig. 3. Functions of the different subprograms of COMPFIT.

organ activities can be determined using the method of weighted least squares by minimizing the expression

$$\sum_i W_i (N_i - \sum_j A_j X_{i,j})^2,$$

where W_i is a weighting factor calculated for the i-th channel, N_i is the number of counts in the i-th channel, A_j is the activity of the j-th organ, $X_{i,j}$ is the number of counts due to unit activity of the j-th organ in the i-th channel.

The DECOMP program can be run on ES 1020 and 1040 as well as on IBM/360 and 370 machines. A computer program with similar capability was also developed for a PDP 11/34 under RT-11 operating system.

If the activities of the radionuclides in the different organs or tissues have already been obtained at discrete points of time the retention function and the activity time integral can be calculated by the COMPFIT computer program developed in our laboratory [6]. The program consists of the five subprograms seen in Fig. 3, these make it possible to solve the task in a large variety of cases, i.e. the program can handle the task of multicompartment analysis, can fit the sum of exponential functions and can calculate the time integral, separately or simultaneously in various reasonable combinations.

The subprogram COMPFIT1 and its variant COMPFIT2 perform the numerical solution of the differential equation system defined by an arbitrarily chosen compartment model which describes the radionuclide transport in the living organism and estimates the transport coefficients and the values of the time integral by fitting the solution to the organ activity data calculated by the DECOMP code. COMPFIT1 and COMPFIT2 have a number of very useful features, e.g. they can handle measured activities relating not only to one compartment but to some of their combinations (in the case of poor spatial

resolution or overlapping organs), they can also calculate activity data for those compartments that take part in the process without any measured data, they can extend the validity of the calculated data beyond the time range of observations, etc.

The subprogram COMPLIST in turn, computes the activities at discrete points of time of the individual compartments and the time integrals for the arbitrarily chosen values of transport coefficients. In this way, the most different models and the values of their transport coefficients can be tested. It can also help in the selection of the most appropriate model describing the real kinetic situation in the case investigated.

When insufficient information is available to carry out compartment analysis, it is expedient to fit a sum of exponential functions to the measured activity data and calculate the exponential parameters together with the values of the time integral. These calculations can be performed by the subprogram SUPEXP.

The simple subprogram INTIME is suitable for the calculation of the time integral in a given period of time from an arbitrary series of data. This subprogram is generally used as a part of other subprograms but it can also be applied separately.

Testing

The suitability of the applied method has been tested by phantom measurements and by in vivo experiments as well.

Known activities of ^{131}I nuclide were put into different organs of the REMCAL phantom and the count profiles were measured separately and together with different combinations. Then the profiles measured on the phantom having a radioactive source in two organs were decomposed by the DECOMP program. The results can be seen in Table I, where the calculated activities

Table I

Comparison of calculated phantom organ activities with actual values

Organs	Relative differences from actual values [%]	
	(1)	(2)
Bladder (1) + liver (2)	−5.8	−1.5
Liver (1) + stomach (2)	−14.0	+5.0
Stomach (1) + thyroid (2)	− 2.5	0
Thyroid (1) "whole body" (2)	− 2.6	0

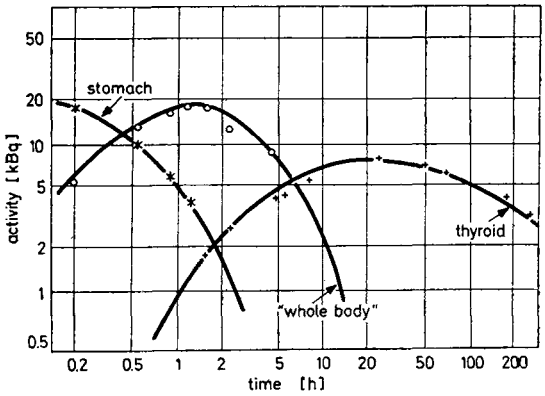

Fig. 4. Time variation of measured and calculated activities after a single ingestion of ^{131}I.

of the single organs are compared with the actual values. The measurements were carried out using an 8 cm wide slit collimator and 45 cm bed-detector distance. The decomposition can be considered as successful especially in cases where the count profiles belonging to the organs in question are quite different but it is even acceptable for the liver and stomach combination where the organs have a partly overlapping position in the phantom and consequently the count profiles are very similar.

In an experiment on a human being an amount of 20 kBq ^{131}I in iodide form was orally administered to a volunteer. The count profile was then measured at different times after the intake enabling the redistribution of the radioactive substance to be followed [7]. The activities of organs having the most important role in iodine metabolism were computed by the DECOMP code using calibration profiles obtained on the REMCAL phantom. Assuming a simple compartment model for iodine metabolism the COMPFIT program calculated the fitted values of the individual organ activities in time, the time integrals and the most probable values of transport coefficients involved in the model. The activities obtained by the DECOMP code and their time variation computed by the COMPFIT program can be seen in Fig. 4. The sum of the calculated organ activities is quite constant up to the first excretion and it

Table II

Time integrals and dose equivalents from ^{131}I for two organs

Organ	Time integral (kBq × day]	Dose equivalent [mSv]
Stomach	0.49	0.0031
Thyroid	102	14

differs by less than 10% of the activity actually present. The fitted curves, which are also determined by the model, lie quite close to the values evaluated by the DECOMP code. The computed activity time integrals to infinite time and the corresponding dose equivalents for two organs are shown in Table II. For dose equivalent calculations the *SEE* values were taken from the work of SNYDER et al [1]. The dose equivalent for thyroid per unit ingested activity, i.e. 0.7 mSv/Bq, is in the range of other published data [8].

Conclusion

The applied DECOMP program is suitable for count profile decomposition even with poor spatial resolution. This allows the use of a wider slit collimator with a higher counting efficiency which is one of the most important requirements in radiation protection practice. The method applied makes it possible to determine organ activities exceeding 0.5 kBq per organ in a reasonable measuring time. Another advantage of the method is that the whole body without the organs investigated can also be considered as a separate body region. The problem due to the differences in the shape and size of human individuals and the anthropomorphic phantom can be reduced by using two detector systems and different data handling programs.

A complete analysis of repeated profile measurements can be performed advantageously by a computer program like COMPFIT, which was specially worked out for the task discussed here and is capable of handling the problem in a large variety of cases. The special advantages of the compartment analysis by COMPFIT can be summarized as follows. The time integral of organ activity can be calculated also for organs not being measured or for organs being measured but together with others and also for times exceeding the range of observation.

Individual assessment of the committed effective dose equivalent is necessary especially in the range of the annual limit specified by the ICRP. The method of quantitative profile scanning seems to be promising in individual dose estimation due to internal contamination.

REFERENCES

1. W. S. SNYDER, MARY R. FORD, G. G. WARNER and SARAH B. WATSON, A Tabulation of Dose Equivalent per Microcurie-Day for Source and Target Organs of an Adult for Various Radionuclides, Report, Oak Ridge National Laboratory, ORNL-5000/2, 1972.
2. D. E. DUNNING, Jr. J. C. PLEASANT and G. G. KILLOUGH, SFACTOR: A Computer Code for Calculating Dose Equivalent to a Target Organ per Microcurie-Day Residence of a Radionuclide in a Source Organ, Report, Oak Ridge National Laboratory, ORNL/NUREG/TM-85, 1977.
3. Directory of Whole Body Radioactivity Monitors, IAEA, Vienna, 1970.

4. G. INGRAO, A. ANDRÁSI and G. F. CLEMENTE, The Characteristics of the Scanning System of the CSN Casaccia Whole Body Counter, Report, National Commission of Nuclear Energy, Casaccia, CNEN-RT/PROT/80/9, 1980.
5. A. ANDRÁSI and Gy. KÖTÉL, Computerized Spectrum Decomposition (in Hungarian), Report, Central Research Institute for Physics, Budapest, KFKI-71-16, 1971.
6. A. ANDRÁSI, ÉVA BELEZNAY and GY. KÖTÉL, COMPFIT: a Computer Program for Internal Tissue Dose Calculation, in Proc. Int. Symp. on Biomedical Dosimetry: Physical Aspects, Instrumentation, Calibration IAEA, Vienna, 1981.
7. A. ANDRÁSI and ÉVA BELEZNAY, Activity Distribution Measurement in the Human Body by Quantitative Profile Scanning, in Condensed Papers, Third European Congress of the International Radiation Protection Association, Amsterdam, 1975.
8. D. E. DUNNING, Jr. and G. SCHWARZ, Health Phys., **40**, 661, 1981.