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The BIDAS Program : Bioassay Data Analysis Software for Evaluating Radionuclide Intake and Dose

BIDAS 프로그램 : 방사성핵종의 섭취량과 선량 평가용 생물학적분석 자료 해석 소프트웨어 프로그램

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Abstract

A computer software program, called BIDAS (BIoassay Data Analysis Software) is developed to interpret the bioassay measurement data in terms of intakes and the committed effective dose using the human respiratory tract model (HRTM), gastrointestinal tract (GI-tract) model and biokinetic models currently recommended by the International Commission on Radiological Protection (ICRP) to describe the behavior of the radioactive materials within the body. The program consists of three modules; first, a database module to manage the bioassay data, second, another databasee module to store the predicted bioassay quantities of each radionuclide and finally, a computational module to estimate the intake and committed effective dose calculated with the bioassay quantity measurement values from either an acute or chronic exposure of the radionuclies within the body. This paper describes the features of the program as well as the quality assurance check results of the BIDAS software program.

Key Words : Bioassay data, Biokinetic models, Intake, Committed effective dose, Acute exposure, Chronic exposure

요약

본 연구에서는 인체내에서 방사성핵종의 거동에 관하여 국제방사선방호위원회에서 권고한 최

근 호흡기 모델, 소화기 모델 및 생체동역학 모델을 사용하여 생물학적분석 자료로부터 섭취량과 예탁유효선량을 평가하기 위한 BIDAS 프로그램을 개발하였다. 프로그램은 생물학적분석 자료를 관리하는 데이터베이스 모듈, 각 방사성핵종에 대한 예측 생물학적분석 양을 내장하고 있는 모듈, 측정된 생물학적분석 양에 근거하여 급성 및 만성 피폭으로부터 섭취량과 선량을 평가하는 계산모듈 등으로 구성되어 있다. 본 논문은 프로그램의 특성과 검증결과에 대해 기술한다.

중심단어 : 생물학적분석 자료, 생체동역학 모델, 섭취, 예탁유효선량, 급성피폭, 만성피폭

I. Introduction

Determination of a committed effective dose is an essential component of the individual monitoring programmes for the radiation workers. It may also be required for the members of the public, who may have intakes of radionuclides from the treatment practices in nuclear medicine and also in normal life followed by the accidental releases of radionuclides into the environment. Estimation of the committed effective doses can be divided into two steps such as follows:

- First, determine the amount of radioactive materials in the human body, other specific body organs or wounds by a direct measurement method and/or in urine or feces by an indirect measurement method, and
- Second, interpret the value of the bioassay quantity in terms of an intake and committed effective dose by taking into account the factors that can create a significant influence on the dose calculations, such as the physical and chemical characteristics of the radioactive substances, time of intake, the mode of intake, the biokinetic model and etc.

Since 1990 the International Commission on Radiological Protection (ICRP) has revised various biokinetic models, dose coefficients and its parameter values used for internal dosimetry. They include 1) various tissue weighting factors and the average annual dose limit of 20 mSv or maximum 50 mSv per any year of practice recommended in the ICRP Publication 60[1]; 2) a new human respiratory tract model (HRTM) for the use in radiological protection as recommended in ICRP Publication 66[2]; and 3) variety of new biokinetic models developed for the selected radionuclides, which were recommended in ICRP Publication 30[3]. These include recommendations on the treatment of the decay products given in ICRP Publications 56[4], 67[5], 69[6], 71[7], and 72[8].

In order to estimate the intakes and calculate the resulting committed effective doses using the recent models, dose coefficients and parameter values for the internal dosimetry recommended by the ICRP, we develop a computer software program, called BIDAS (Bioassay Data Analysis Software). This software is a user-friendly and menu-driven program. The program enables us to estimate the raionuclide intakes and calculate the resulting committed effective dose to be yielded by the internal exposure from the radiation with the measurements of the activities of the radionuclides in the body. These radionuclides are either 1) retained in the whole body, lungs, or any other specific organ, and/or 2) excreted in urine or feces. The software program can be run on a series of Microsoft Windows (MS Windows^{R}) operating systems such as MS Windows 98^{R}, MS Windows 2000^{R}, MS Windows XP^{R}. It consists of a database

module to manage the bioassay data, another database module to store the predicted bioassay quantities of all radionuclides implemented in the program, and computational module that incorporates an algorithms to estimate a radionuclide intake and the corresponding committed effective dose from either an acute or chronic exposure based on the measured bioassay quantities.

This paper describes the features of the BIDAS software program as well as the results of the estimations in the intake values with the uncertainties involved. The calculations were performed as a part of the quality assurance check of the program, with the intake scenario cases provided by the 3rd European Inter-comparison Exercise on Internal Dose[9].

II. Materials and Methods

The BIDAS software program is developed as a tool to aid a user in the evaluation of the internal exposures to radiation workers. It enables the user to estimate the acute or chronic intakes of various radionuclides, and calculate the resulting committed effective dose from the measurements of the activity in the body and/or excreta. The brief features of the BIDAS program are summarized as follows:

1. Coding Language and Computer

Visual C++, MS Windows 98R, MS Windows 2000R, MS Windows XPR

2. Nature of Problem Solved

The BIDAS program estimates the intakes of radionuclides by way of inhalation, ingestion or injection pathway and calculates the resulting committed effective doses with the measured bioassay quantities. Implemented quantities are activities in whole body, lungs, urine, feces, or thyroid for the iodine case.

3. Method of Solution

The BIDAS program considers two types of intake pathways. For an acute intake case, the best estimate of the amount of the intake is calculated with a basic formula for the weighted least-square regression of a linear relationship with a zero intercept as follows:

$$I = \frac{\sum_{i=1}^{i=n} \frac{M_i f(t_i)}{\sigma_i^2}}{\sum_{i=1}^{i=n} \frac{f^2(t_i)}{\sigma_i^2}} \qquad \cdots\cdots\cdots(1)$$

Where I is the best estimate of the intake amounts, M_i is the i^{th} bioassay measurement value, $f(t_i)$ is the predicted bioassay quantity at time t_i in the body and/or excreta following an acute intake, σ_i is the error for the i^{th} bioassay measurement value, and n is the number of bioassay points. If each measurement value has a known error associated with it, then eqn (1) is used directly applied. If, however, the errors are not known, then few assumptions are made. The assumptions made for unknown error values are as follow:

- Uniform absolute error ($\sigma_i = k$),
- Uniform relative error ($\sigma_i = k M_i$), and
- Square root error ($\sigma_i = k\sqrt{M_i}$).

where k is a constant of the proportionality. For a chronic intake, the total amount of an intake is calculated as follows[10]:

$$I = \frac{M(t) \times T}{\int_0^t f(u)\,du} \qquad \text{for} \quad t < T \qquad \cdots\cdots\cdots(2)$$

$$I = \frac{M(t) \times T}{\int_{t-T}^t f(u)\,du} \qquad \text{for} \quad t \geq T \qquad \cdots\cdots\cdots(3)$$

Where I is the total amount of an intake during a period of a chronic exposure T, $M(t)$ is the amount

of an activity in the body and/or excreta at time t following the onset of an intake, T is the period of a chronic exposure, t is the time from the onset of an intake to the time of a measurement, $f(u)$ is the predicted bioassay quantity at time in the body and/or excreta following an acute intake, and u is a variable time between the integration limits. The integrations of eqns (2) and (3) are obtained by a numerical integration method.

The calculations of the predicted bioassay quantities following an acute intake either by inhalation, ingestion or injection pathway are based on the parameter values and dose coefficients used in the HRTM, GI-tract model and various biokinetic models for Reference Man, currently recommended by the ICRP. The general system of the models is designed by using a commercial software package, called MathCad^R by Mathsoft Engineering and Education and a method is applied to solve the systems of the first-order linear differential equations that uses the eigenvectors and eigenvalues derived from the system of the equations.

The committed effective dose from an intake is calculated by multiplying the amount of an intake by the corresponding dose coefficient for a radionuclide, which was previously generated from ICRP CD-ROM[11] and stored in the BIDAS_DOS module in the program.

4. Modes of Bioassay Data Analysis

Three modes of the analysis are available in the BIDAS program as follows:

- ICRP 78 mode,
- Semi-automated mode, and
- Smart mode.

The ICRP 78 mode is based on a classical interpretation scheme for the individual monitoring, which was recommended in ICRP Publication 78[12]. Provided that the times of the intakes are known, this mode uses the real time of an intake. If, however, the real time of an intake is not known, it is assumed that an intake took place in the middle of monitoring interval. The ICRP 78 mode can be used for the analysis of all intake cases of the radionuclides. In many cases, we can estimate a reasonably accurate amount of the total intake with an acceptable uncertainty involved with a particular mode, but the mode has some substantial limitations in connection with the approaches in the estimation of an intake.

The semi-automated and smart mode are the extensions of the ICRP 78 mode. The main difference between these two modes is the level of automation. The smart mode has a higher level of automation, while the user would have a lower influence by the program in the analysis process. Four flow charts of a semi-automated and smart mode calculation to estimate the amounts of activity either from an acute or chronic intake are shown in Fig. 1, Fig. 2, Fig. 3, and Fig. 4, respectively.

5. List of Available Radionuclides

The radionuclides implemented in the BIDAS program are as follow:

hydrogen	^{3}H
iron	^{59}Fe
cobalt	^{57}Co, ^{58}Co, ^{60}Co
strontium	^{85}Sr, ^{89}Sr, ^{90}Sr
ruthenium	^{106}Ru
iodine	^{125}I, ^{129}I, ^{131}I
caesium	^{134}Cs, ^{137}Cs
radium	^{226}Ra, ^{228}Ra
thorium	^{228}Th, ^{232}Th
uranium	^{234}U, ^{235}U, ^{238}U
neptunium	^{237}Np

plutonium	^{238}Pu, ^{239}Pu, ^{240}Pu
americium	^{241}Am
curium	^{242}Cm, ^{244}Cm
californium	^{252}Cf

III. Results and Discussion

The BIDAS program has been tested extensively to calculate the uncertainties in the estimated values

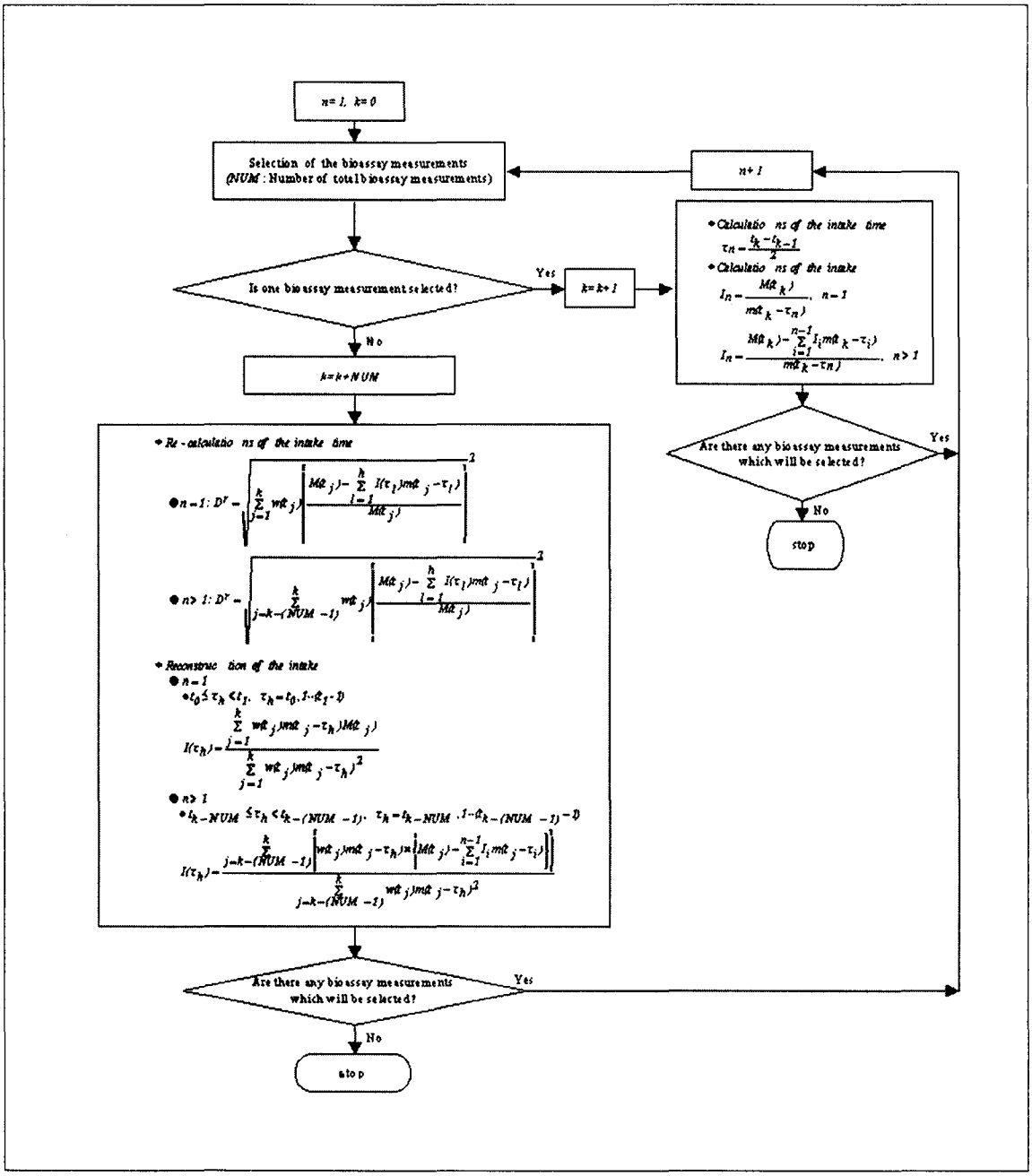

Figure 1. A flow chart of the semi-automated mode calculation to estimate the amount of activity from an acute intake.

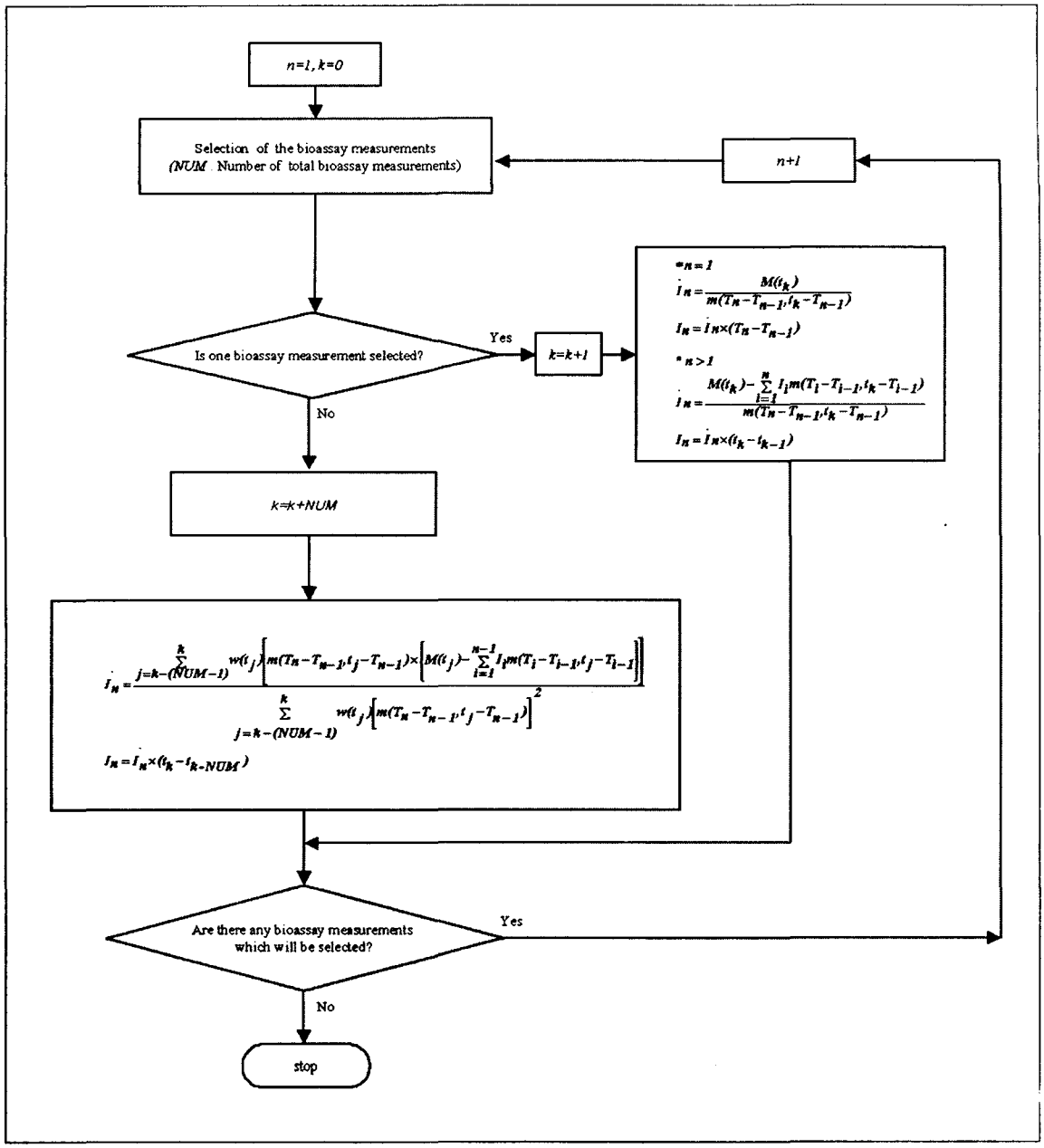

Figure 2. A flow chart of the semi-automated mode calculation to estimate the amount of activity from a chronic intake.

of intakes for a quality assurance check on its results.

The processes of the quality assurance check are divided into two parts; 1) a quality assurance check on the database module, which stores all the information of the predicted bioassay data for the radionuclides implemented in the program, and 2) another check on the computational algorithms to estimate an intake and calculate the resulting committed effective dose as well as to check the integrity of the BIDAS program as a whole.

During the quality assurance process, the values calculated by the BIDAS program are counter

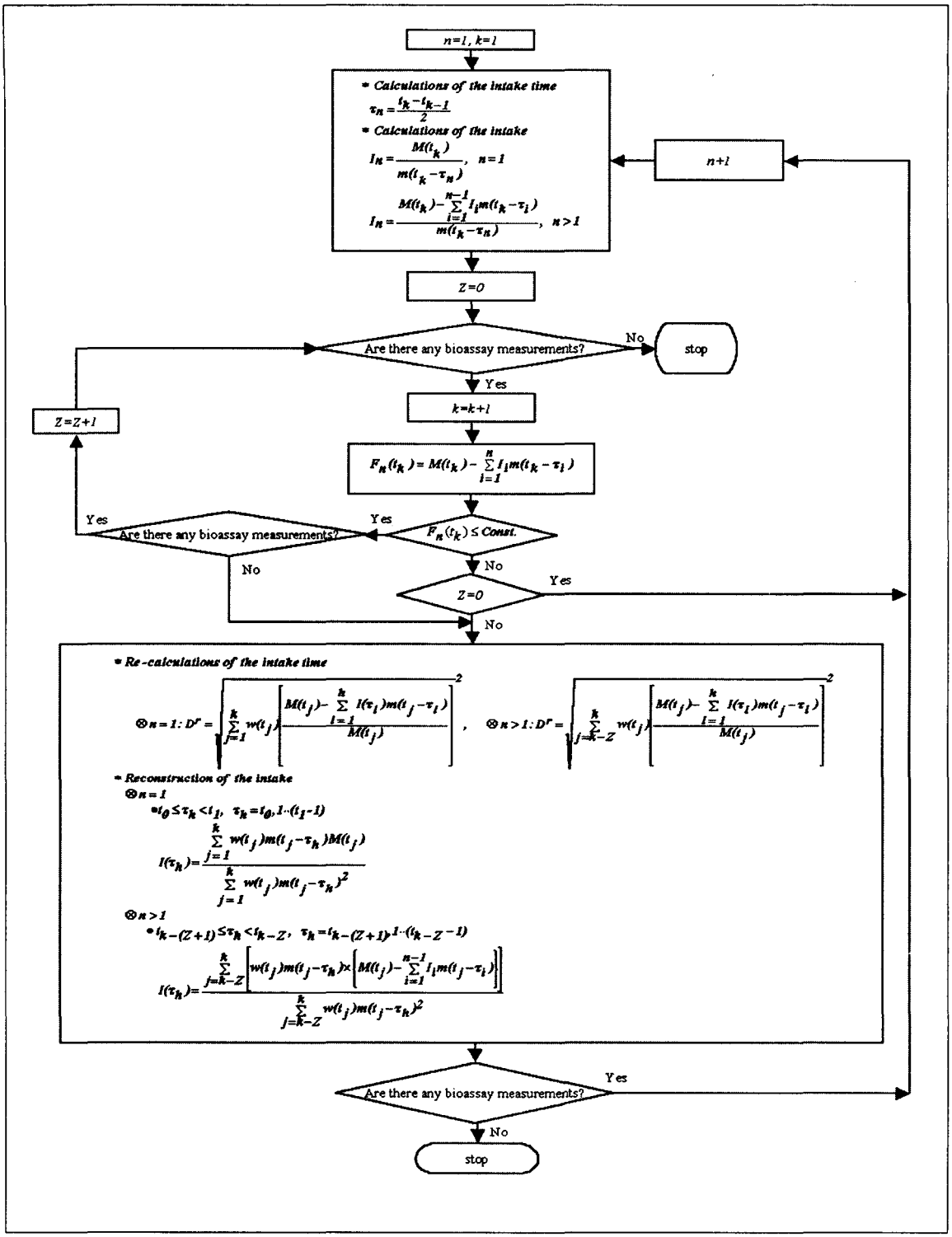

Figure 3. A flow chart of the smart mode calculation to estimate the amount of activity from an acute intake.

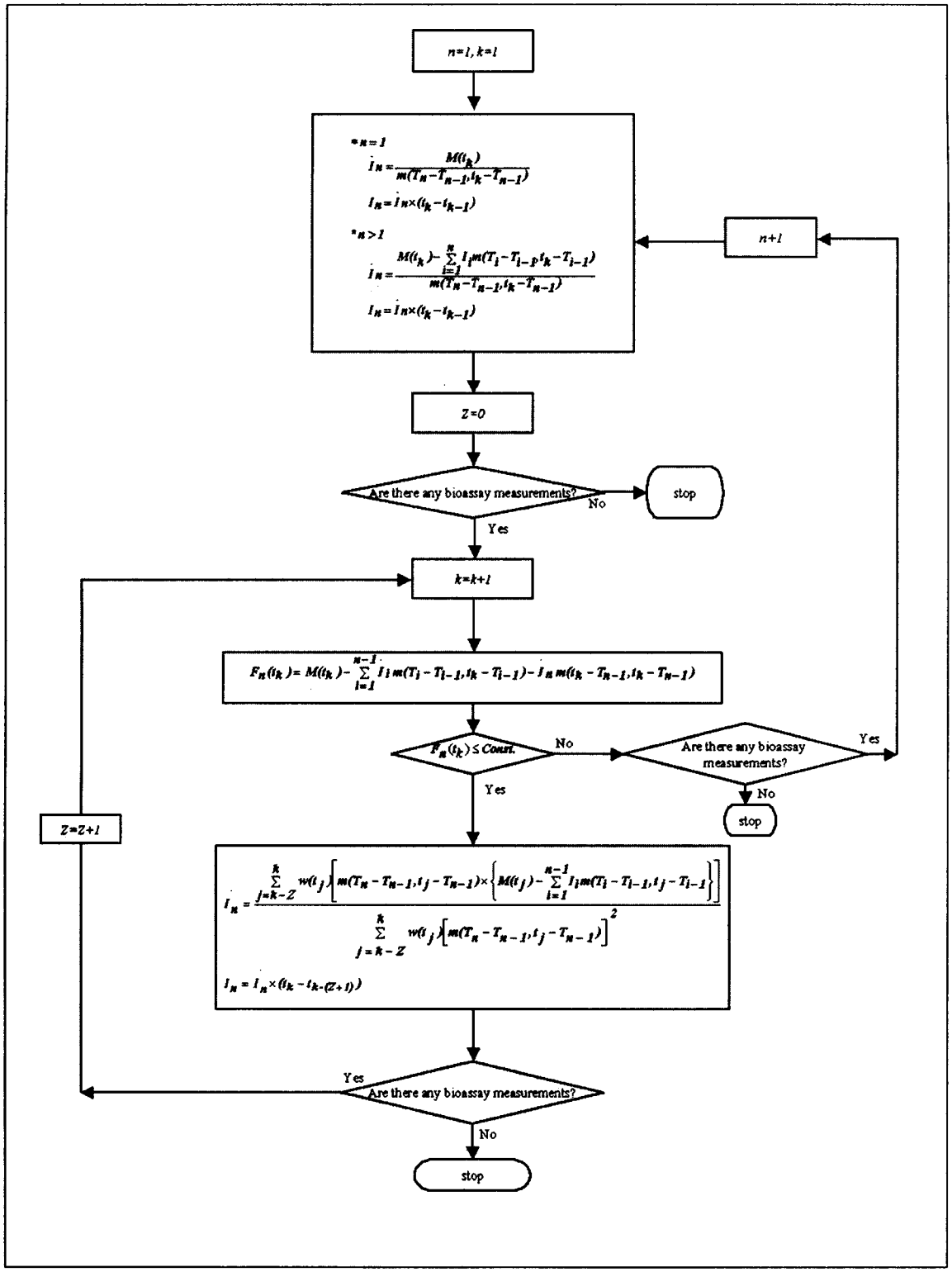

Figure 4. A flow chart of the smart mode calculation to estimate the amount of activity from a chronic intake.

checked with and referred to both those values listed in the report, NRPB-M824[13] by National Radiological Protection Board (NRPB) in the U. K. and ICRP Publication 78 as the first part of the quality assurance process. For an acute unit intake by the inhalation pathway, the values calculated for the intake of the particle-type aerosols of 5㎛Activity Median Aerodynamic Diameter (AMAD) size are compared with the values, listed both in NRPB-M824 and ICRP Publication 78 during the quality assurance process. For an acute unit intake either by an ingestion or injection pathway, the values for the intake of the same type and size aerosols are also calculated and compared with those listed in the above two references. The values are consistent and in good agreement with those values listed in the two references. The second part of the assurance check consists of estimating the intakes and calculating the resulting committed effective doses with few intake scenario cases provided by the 3rd European Inter-comparison Exercise on Internal Dose Assessment. The exercise was organized and carried out by the EULEP/EURADOS group[9] from the period of 1997 to 1999. The intake scenarios involved with the different case studies were as follows:

- Case 1 : ^{3}H(HTO), continuous intake through skin, urine measurement data,
- Case 2 : $^{90}Sr/^{90}Y$, accidental intake, pathway unknown, urine measurement data,
- Case 3 : ^{125}I, repeated intake, inhalation, thyroid measurement data,
- Case 4 : ^{125}I, repeated intake, inhalation, urine measurement data,
- Case 5 : ^{137}Cs, continuous intake, ingestion, whole body measurement data,
- Case 6 : ^{239}Pu, single intake, inhalation, urine measurement data, and
- Case 7 : ^{239}Pu, single intake, inhalation, feces measurement data.

Table 1 shows the amount of intakes estimated and the corresponding committed effective doses calculated for the described intake scenario cases by using both the BIDAS program and Individual Monitoring of the Internal Exposure (IMIE) code developed by the Radiation Protection Institute (RPI) of Ukraine[14]. The IMIE code is developed with the HRTM, GI-tract model and various biokinetic models for Reference Man, which are currently recommended by the ICRP. In addition, Fig. 5 and Fig. 6 show the results calculated by the BIDAS program for Case 2 and Case 3 provided by the EULEP/EURADOS group. All the codes gave similar results except for Case 4, where the iteration step of the IMIE code is believed to have some errors in the calculation.

Table 1. Results of the amount of an intake and committed effective dose calculated by using the BIDAS program. Values given in parentheses are the values calculated by using the IMIE code developed by the RPI of Ukraine.

Intake Scenarios	Mode	Amount of an Intake (kBq)	Committed Effective Dose (mSv)
Case 1	Semi-automated	312(313)	5.62×10^{-3}(5.74×10^{-3})
	Smart	347(347)	6.24×10^{-3}(6.36×10^{-3})
Case 2	ICRP 78	2.80(2.80)	7.85×10^{-2}(7.83×10^{-2})
	Semi-automated	1.71(1.78)	4.79×10^{-2}(4.98×10^{-2})
Case 3	ICRP 78	121(122)	6.41×19^{-1}(6.45×10^{-1})
	Smart	112(112)	5.95×10^{-1}(5.95×10^{-1})
Case 4	ICRP 78	295(356)	1.57(1.88)
	Smart	147(181)	7.79×10^{-1}(9.61×10^{-1})
Case 5	Semi-automated	14.0(14.0)	1.83×10^{-1}(1.83×10^{-1})
	Smart	15.6(15.6)	2.03×10^{-1}(2.03×10^{-1})
Case 6	Semi-automated	30.1(30.1)	250(250)
	Smart	36.0(36.7)	299(304)
Case 7	Semi-automated	31.4(31.4)	260(260)
	Smart	31.4(31.4)	260(260)

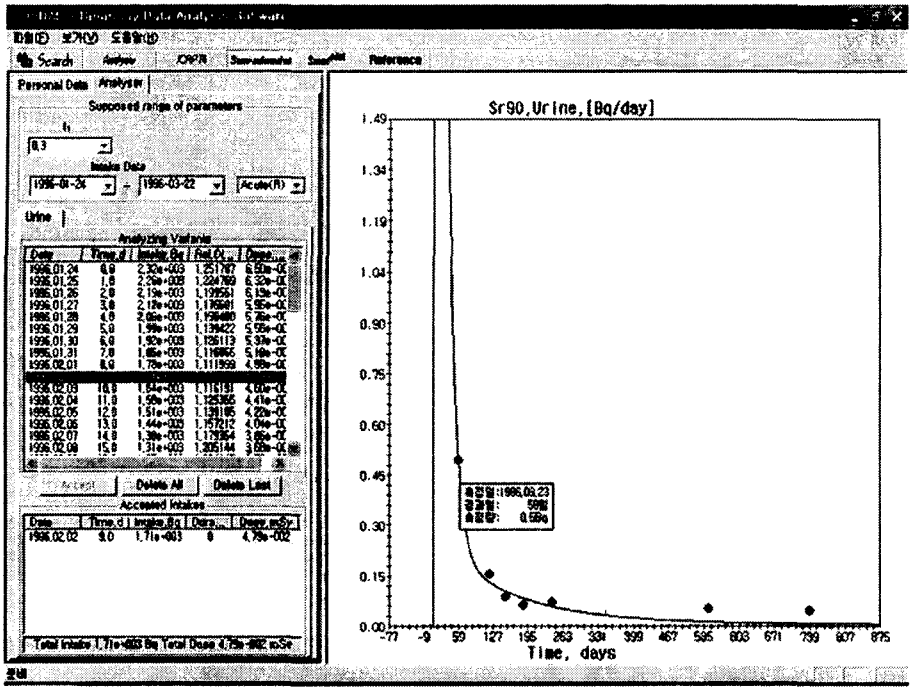

Figure 5. Displayed results of the amount of an intake and resulting committed effective dose from an *incidental intake of* ^{90}Sr/ Y (Case 2).

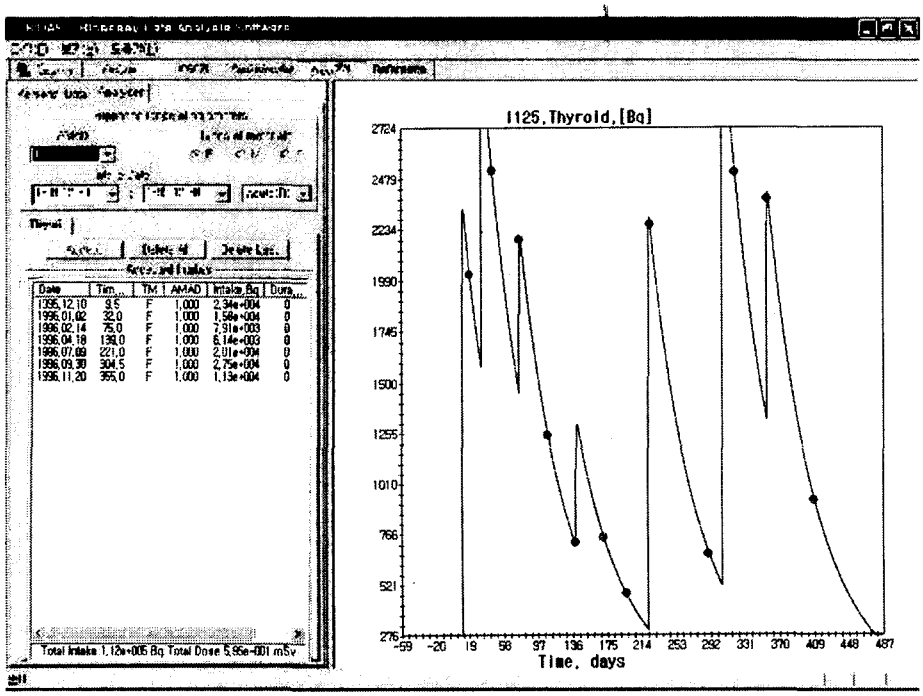

Figure 6. Displayed results of the amount of intakes and resulting committed effective doses from the repeated intakes of I (Case 3).

IV. Conclusion

The BIDAS software program is developed to estimate the intakes and resulting committed effective doses from the measurement values of the activities of the radionuclides. The program uses the human respiratory tract model, GI-tract model and biokinetic models for Reference Man, currently recommended by the ICRP. As a part of the quality assurance check of the program, calculations are made for the various intake scenario cases provided by the 3rd European Inter-comparison Exercise on Internal Dose Assessment. Then, the values calculated by the BIDAS program are compared with those values by the IMIE code of the RPI, Ukraine. As a result, it is found that they are consistent and in good agreement with those values by the IMIE code. The aim of this study is to develop a user friendly software program for the internal dose assessment available to ordinary routine users such as users at the Korean nuclear power plants or nuclear fuel cycle facility in general. The future program development will aim at improving the calculation methods to increase the reliability of the program by effectively managing the uncertainties in the intake estimation and calculation of the committed effective dose with the minimum errors involved. This would be achieved by the improvement both in the statistical and mathematical approaches for the bioassay data interpretation.

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Nomenclature

n	numerical index for the n^{th} intake of interest
k	numerical index for the k^{th} measurement at time
T_n	time of the n^{th} intake
t_k	time of k^{th} measurement
t_{k-1}	time of $(k-1)^{th}$ measurement
I_n	amount of intake of the n^{th} intake of interest
$M(t_k)$	amount of measurement at time t_k
$m(t_k - T_n)$	measured bioassay quantity at time $(t_k - T_n)$ following a single acute intake
$F_n(t_k)$	predicted bioassay quantity of n^{th} intake for $M(t_k)$ at time t_k
$w(t_j)$	weighting factor for measurement value at time t_j

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