DIRECT INTERNAL DOSIMETRY - A NEW WAY FOR ROUTINE INCORPORATION MONITORING OF γ-EMITTING RADIONUCLIDES

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INTRUDUCTION

The conventional procedures for *in vivo* monitoring of γ-emitting radionuclides involve the determination of body or organ burdens using whole body counting techniques and the subsequent estimation of intake and committed dose equivalent, respectively. For these procedures many information are required, such as time and pathway of intake, physical and chemical form of incorporated materials, metabolism etc. At routine monitoring these information are hardly available, thus resulting in significant uncertainties for the estimation of intake and committed dose equivalent. Besides, it is extremely difficult or even impossible to define general criteria such as lower limit of detection or confidence interval for intake and committed dose equivalent, respectively. Thus it is problematic to define minimum requirements for incorporation monitoring devices or to compare different monitoring procedures with respect to the quality of their dose estimates. In order to meet these difficulties, at Karlsruhe Research Center a new method for direct internal dosimetry has recently been developed.

MEASURING PRINCIPLE

The method refers especially to those radionuclides which commonly are detected with standard whole body counters, i.e. radionuclides emitting γ-rays with relative high abundancy (>10 %) and relative high energy (>100 keV) If such a radionuclide is deposited in some organ or region of the body, there is a well defined correlation between the photon flux at particular points of the body surface and the dose equivalent rate due to the incorporated radionuclide. This correlation may be used for direct dose assessment with an adequately designed detector system according to the following general equation:

$$H'_{eff}(S) = C(S) \cdot \sum_{i=1}^{n} [\alpha_i \cdot R_i(S)] \qquad \text{with} \qquad C(S) = \frac{\sum_{T} [w_T \cdot SEE(T,S)]}{\sum_{i=1}^{n} [\alpha_i \cdot \varepsilon_i(S)]}$$

$H'_{eff}(S)$	effective dose equivalent rate due to a given radionuclide deposition in the source organ S
$C(S)$	calibration factor of the detector system consisting of n detectors at well defined measuring points for the same deposition in S
$R_i(S)$	response of the detector i for the deposition in S
α_i	weighing factor for the detector i ($\sum\alpha_i=1$)
$SEE(T,S)$	specific effective energy for the source organ S and the target organ T according to ICRP 30
w_T	weighing factor for T according to ICRP 30
$\varepsilon_i(S)$	counting efficiency of detector i for the deposition in S

In general the calibration factor C(S) defined by the above equation depends both on the radiation emitted by the radionuclide and on the pattern of the deposition in the body. This dependence, however, can be minimized by adequate optimization of the detector system, i.e. optimization of type, number, arrangement, size and lateral shielding of the detectors, material and thickness of radiation entrance windows, electronic settings of amplification and discriminator levels etc.

„INDOS" DETECTOR SYSTEM

The INDOS detector system has been developed both for routine incorporation monitoring and for special monitoring at incidents or accidents. Thus, the following practical aspects were taken into account:

- The measurement should be performed with a simple counting detector system without spectrometry.
- The measurement should be performed automatically without the need of any trained staff.
- The measuring time should be very short (≤ 20s), thus allowing for monitoring a large number of persons with a high frequency (1 measurement/week).

The detector system which meets these conditions is shown schematically in Fig. 1. The main components of the system are four plastic scintillation detectors, being positioned in front of the thyroid (detector 1: 6.5 x 6.5 x 10 cm^3), in front of the respiratory tract (detector 2: 16 x 16 x 10 cm^3), over the thighs (detector 3: 20 x 20 x 10 cm^3) and under the gastro-intestinal tract (detector 4: 20 x 20 x 10 cm^3). The detectors are operated by standard electronics consisting of a high voltage power supply. a preamplifier and a main amplifier with a single channel analyzer. The detector pulses are fed into four counting channels of a PC. The PC is connected to a chip card unit for input of personal data (i.e. personal identification, body weight, body height, chest circumference) and for output of measuring results. For individual adjustment of the measuring geometry the seat of the detector system can be moved by computer controlled stepping motors in the horizontal and vertical direction according to the subjekct's body proportions (chest circumference for horizontal movement and body height for vertical movement, respectively). The individual adjustment allows for measurement of all subjects with body heights ranging from 150 cm up to 200 cm.

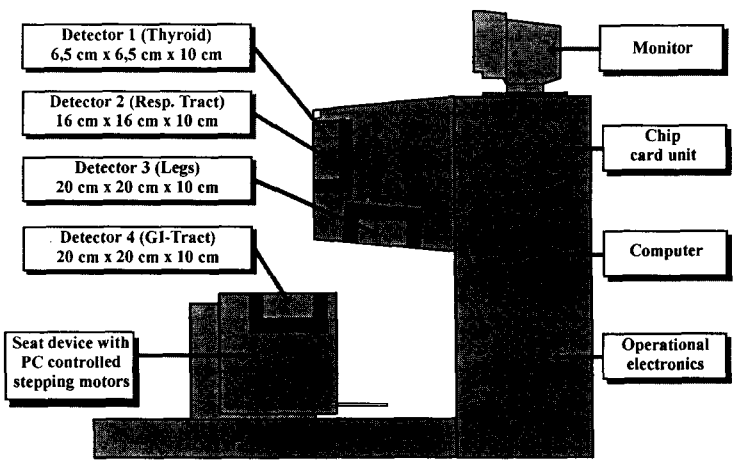

Fig. 1:
The INDOS
detector system

In order to use the detector system for dose estimations in any meausuring geometry, a mathematical calibration procedure was applied. This procedure is based on a set of semi-emprical formulas for the calculation of the detector response as a function of the photon energy of the source, the coordinates of the source position and of the thickness of the tissue between the source and the detectors. The measurements in general are performed using calibration factors for the reference man having a body weight of 70 kg and a body height of 170 cm. Since the SEE values of ICRP Puplication 30 also refer to the reference man, this procedure will yield realistic results for all persons having simaler body propertions. Moreover, this procedure will also yield very good results for persons with different body proportions, because the calibration factors and the SEE values show a very simaler dependence on the body size. Thus, this method of internal dosimetry to some extend has a built-in correction of the body size effects. This is an important advantage of the direct method.

The background counting rate is governed by radiation emitted from the natural radionuclides, i.e. K-40 contained in the materials of the environment of the detector system. The contribution of the natural airborne activity is relatively small and so the background of the detector system is very stable when counting is done susequently without subject in the same environment. When counting with a subject, however, the background of all detectors is reduced significantly due to the absorption of the environmental radiation in the

body. The absorption effect has been studied on the basis of more than 300 measurements with about 40 male and 20 female subjects with different body proportions. These measurements show the backgrount counting rate to be in very good approximation a linear function of the body weight (detector 1 and 4), the chest circumference (detector 2) and the body height (detector 3), respectively. The mean deviation of the measured background counting rates from the respective fit values are ±26 cts/20s (detector 1), ±115 cts/20s (detector 2), ±142 cts/20s (detector 3) and ±140 cts/20s (detector 4), these values being less than twice the standard deviation due to counting statistics.

EVALUATION

For evaluation of the measurement, first the individual background counting rates of the four detectors are calculated on the basis of the biometric parameters of the subject. These hypothetical background values are subtracted from the measured counting rates. If the resulting net counting rate of any detector is significant larger than the respective standard deviation (>3.29σ), the net counting rates of all four detectors are analyzed with a special logic algorithm in order to select one of the four deposition cases listed in the first column of Tab. 1. As can be seen from Tab. 1, the measured dose qanatities are the effective dose equivalent in the first two deposition cases, the lung dose equivalent in the third deposition case and the thyroid dose equivalent in the fourth deposition case, respectively. The calibration factors and the values for the lower limit of detection refer to Co-60 in the first three cases and I-131 in the last case. For unknown mixtures of radionuclides the choice of these standard calibration factors result in a mean calibration error of about 50 %. Otherwise the calibration error amounts to about 20 %.

Tab. 1:
Parameters for evaluation of the measurement and corresponding values of the lower limit of detection for one 20 s measurement (95 % confidence level)

Deposition case	Measured dose quantity	Weighing factors ($/\alpha_1/\alpha_2/\alpha_3/\alpha_4$)	Calibration factor (μSv/d per cps)	Lower limit of det. (μSv/week)
Homogenious whole body deposition	Effective dose equivalent	0/0.34/0.33/0.33	0.018	1.6
Inhomogenious trunk deposition	Effective dose equivalent	0/0.14/0.36/.50	0.062	6.3
Dose relevant lung deposition	Lung dose equivalent	0/1/0/0	0.72	9.6
Dose relevant thyroid deposition	Thyroid dose equivalent	1/0/0/0	4.7	140

CONCLUSIONS

The INDOS detector system offers the following advantages with respect to routine incorporation monitoring:

- The measurement is performed automatically and there is no need for trained staff.
- The measuring time is short und thus a relative large number of persons may be monitored with a relative high measuring frequency.
- First estimates of the individual effective dose equivalent rate are available immediately after the measuremt.
- The direct determination of the dose equivalent in principle is more precise than the conventional procedures for internal dosimetry, because (i) the retention of radionuclides in the body may be measured explicitely and (ii) the dependence of the dose equivalent on the body proportions is corrected implecitely.
- The measuring procedure is comparable to the external dosimetry with respect to accuracy and lower limit of detection. Thus, the results of internal and external dosimetry can be summed up in an easy and reasonable manner.
- The detector system can be installed in any building; it also can be installed as a mobile unit in a car or a container for long distance transportation by aircraft or train.
- Last but not least, the cost for monitoring with INDOS is much lower than for the conventional monitoring procedures using whole body counters.