HOW TO INTERPRET MEASUREMENTS OF INTERNAL CONTAMINATION

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SCOPE OF THIS PAPER

To judge measurements of internal contamination has been so far reserved to some scientifically oriented specialists. However, this must not remain necessarily so. Some basic understanding and some simple formulas should allow it to the non expert, to compare the measurements with the regulations. To provide this basic understanding and the very simple formulas needed for some important cases is the scope of this paper.

This paper must limit itself to some interesting simple cases. Nuclides with long effective half-life are not treated here. We deal only with cases, where the measured activity after a single intake becomes insignificant after one year.

CONCEPT FOR THE CALCULATIONS

The basis of the calculations are the dose limitation of ICRP-26 and the data given in ICRP-30. Data on urinary excretion from ICRP-10 are also used [1].
The scope of the calculations is to determine the probable committed dose equivalent or uptake and to compare it to the annual limit given by ICRP-30. We propose to abandon the idea of calculating the worst case, i.e. the assumption that any discovered contamination took place on the day after collection of the immediately preceeding bioassay sample (ICRP-10).

If we drop the assumption or information on the time of intake the calculations gain unexpectedly simplicity because we can drop some other assumptions derived from metabolic models! Of course, for a single intake, the uncertainty due to the lack of knoweldege about the time of intake is considerable, however, for recurrent intakes our calculation converges to the correct result. The remaining error depends mainly on the length of the intervals between the measurements, relative to the effective half-life of the nuclide.

SOME SIMPLE EXAMPLES

Simple cases are characterized by the possibility to measure the activity in the most important source organ. The isotopes of iodine are good examples. If we track the iodine in the thyroid with a calibrated NaI-crystal at reasonably short intervals, we can easily calculate the number of nuclear transformations in the thyroid (nnt_m) from these measurements:

$$nnt_m = \bar{A} \times T_e \qquad (1)$$

$\bar{A}$ is the mean of the measured activities (Bq), T_e the period (s) for which we would like to calculate the dose from the measurements. Fig. 1 shows, how the area representing the real number of nuclear transformations is approximated by the area under the measured activities.

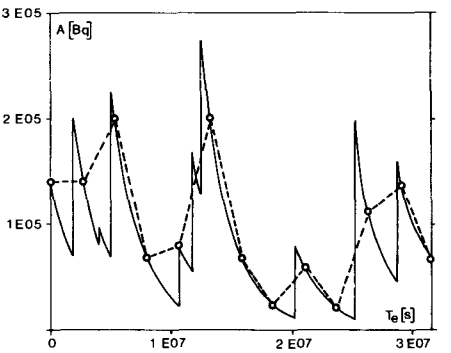

Fig. 1: Approximation of the number of nuclear transformations by the area under the measured activities

Now we have to add some dosimetry from ICRP-30. We would like to compare a measured value nnt_m to a value nnt_a corresponding to the annual limit. From there we calculate the result $I_{\%}$, the percentage intake to the annual limit of intake ALI.

$$I_{\%} = 100\% \times nnt_m / nnt_a \qquad (2)$$

The value of nnt_a results from the multiplication of the ALI by the number of nuclear transformations in the thyroid per unit intake (nnt). From the supplement to part 1 of ICRP-30 we calculate for nnt_a 2.3E12 and 3.0E11 for I-125 and I-131 respectively. Hence we obtain for a period T_e of one year the following simple formulas ($\bar{A}$ in Bq):

$$\underline{\text{I-125}} \quad I_{\%} = \frac{100\% \ \bar{A} \times 3600 \times 24 \times 365}{2.3E12} = \bar{A} \times 1.4E\text{-}03 \ \% \qquad (3)$$

$$\underline{\text{I-131}} \quad I_{\%} = \frac{100\% \ \bar{A} \times 3600 \times 24 \times 365}{3.0E11} = \bar{A} \times 1.0E\text{-}02 \ \% \qquad (4)$$

The results for ingestion (oral) or inhalation are identical in this case (except for rounding errors). The dosimetric calculation involves only one assumption for the weight of the thyroid. E.g. the assumed effective half-life cancels out in the multiplication of nnt by ALI.

A similar and important case is tritiated water. The concentration of tritium in urine (C_u) is an excellent measure of the internal irradiation. From the models used in ICRP-30 we obtain for 42 L in the body.

$$nnt_m = 42 \times \bar{C}_u \times T_e \qquad (5)$$

For nnt_a we find from nnt and ALI 3.5E15. Again for a period T_e of one year we obtain (C_u in Bq/L).

$$\underline{\text{HTO}} \quad I_{\%} = \frac{100\% \times \bar{C}_u \times 42 \times 3600 \times 24 \times 365}{3.5E15} = \bar{C}_u \times 3.8E\text{-}05\ \% \qquad (6)$$

Recently, Johnson [2] proposed a similar formula with 10% higher figures in order to include the irradiation from non-exchangeable tritium. He also pointed out, that the dose is estimated accurately and independently of individual differences in body water retention, if urine samples are obtained frequently enough.

A DIFFICULT EXAMPLE

To analyze samples of urine at intervals of e.g. 1 month is a popular method of routine survey. If urinary excretion follows an exponential law with only one time constant then the concentration C_u or daily excretion A_u must be proportional to the activity in some important source organ and we can assess $I_{\%}$ as outlined in the previous chapter. If the excretion function is more complicated, we have to use another way of calculation. Let us take P-32 as an example.

Exept for inhalation class W, which will not be treated here, the irradiation of the red marrow is the dominating factor. On the other hand we do not get any measurable signal in the urine from the P-32 in trabecular bone, the source organ for this irradiation. Therefore we have to rely very much on the metabolic model. The best we can do is to estimate the total activity in urine (tau_m) excreted during the period T_e on the basis of regular samples of the daily excretion (A_u). From the mean $\bar{A}_u$ we obtain

$$tau_m = \bar{A}_u \times T_e. \qquad (7)$$

Again we have to compare this to a value tau_a corresponding to the annual limit. We calculate this from ICRP-30 and ICRP-10 for oral ingestion:

$$tau_a = 0.8 \times 2.4E07 \times 0.9 \int_0^{\infty} (0.2e^{-t/0.7} + 0.05e^{-t/2.5} + 0.013e^{-t/11.7})\,dt \qquad (8)$$

Unfortunately the first term with a half-life of half a day would disturb the measurements. But we can eliminate most of this fast decaying component by the prescription that urine samples for dosimetric purposes should be taken regularly at Sunday evening or Monday morning before work. In this case we systematically loose the first two days, therefore the lower boundary of the integral in (8) should start at 2 days. If we evaluate the integral and if we put T_e in (7) equal to one year, we obtain ($\bar{A}_u$ in Bq/day).

$$\underline{\text{P-32}} \quad I_{\%} = \frac{100\% \times \bar{A}_u \times 365}{1.7E07 \times 0.19} = \bar{A}_u \times 1.1E\text{-}02\ \% \qquad (9)$$

For inhalation (class D) of P-32 the first two terms in (8) change: Instead of 0.8x2.4E07 Bq we derive from the lung model (47.6 % + 0.8x15.4%) x 3.4E07 Bq and obtain practically the same result (9). Inhalation class W is more complicated and not so important for P-32. With formula (9) one would underestimate the dose by about a factor of 2.

CALCULATION FOR KNOWN TIME OF INCORPORATION

If the time t elapsed between the intake and the time of measurement is known, this information can be used to increase the precision of the evaluation of the committed dose. We suggest to use this procedure only for serious cases and not for routine evaluation of small doses.

As soon as a measurement A(t), $C_u(t)$ or $A_u(t)$ is available, we would like to compare it to what we expect from the models. E.g. for P-32 the latter would be the non integrated form of (8). Given the urinary excretion $A_u(t)$ in Bq/day for the day t after intake, we calculate

$$\underline{\text{P-32}} \qquad I_{\%} = \frac{100\% \times A_u(t)}{1.7E07 \times (0.2e^{-t/0.7} + 0.05e^{-t/2.5} + 0.013e^{-t/11.7})} \qquad (10)$$

In the simple case of iodine and HTO we propose to work out the daily number of nuclear transformations measured versus expected (from the intake of 1 ALI). The integral of the expected number must be nnt_a, for the rest the function looks like the retention function. We obtain for $C_u(t)$ in Bq/L and A(t) in Bq

$$\underline{\text{HTO}} \qquad I_{\%} = \frac{100\% \times C_u(t) \times 42 \times 3600 \times 24}{3.5E15 \times e^{-t/14.4} / 14.4} \qquad (11)$$

$$\underline{\text{I-125}} \qquad I_{\%} = \frac{100\% \times A(t) \times 3600 \times 24}{2.3E12 \times e^{-t/57.7} / 57.7} \qquad (12)$$

$$\underline{\text{I-131}} \qquad I_{\%} = \frac{100\% \times A(t) \times 3600 \times 24}{3.0E11 \times e^{-t/10.9} / 10.9} \qquad (13)$$

If several measurements in the period from t_1 to t_2 are available we suggest to insert in the nominator of the equations (10) to (13) a graphical or numerical solution of the area $A_u(t)$, $C_u(t)$ or A(t) times $(t_2 - t_1)$ and in the denominator the corresponding integration from t_1 to t_2. The equations (3), (4), (6) and (9) are nothing else than such an integration for one year.

REFERENCES

[1] Annals of the ICRP, Pergamon Press
[2] Johnson J.R. (1982),The Estimation of the Effective Dose Equivalent from Tritiated Water Exposures Using Tritium Concentrations in Urine. Rad. Prot. Dosimetry 2, 245-247.