INVESTIGATION LEVELS OF RADIOISOTOPES IN THE BODY AND IN URINE. CONSEQUENCES OF THE RECENT RECOMMENDATIONS ON THE ANNUAL LIMITS OF INTAKE

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The recommendations of Committee 2 of the International Commission on Radiological Protection (ICRP) concerning annual limits of intake (ALI) for workers (1) have recently been published. These limits differ in many cases from the maximum permissible annual intake (MPAI) recommended previously by the same committee (2,3). The new recommendations directly influence the derived health physics parameters, such as the acceptable total body burden and concentrations of radioisotopes in the urine.

Radioactivity in the body can be monitored routinely either by whole body counting or indirectly by urine analysis. Thus the monitoring laboratories have to know the relation between the activity in the urine or the body and the committed dose for calculating the latter from their measurements.

The activity of a radioelement in the body at any time t after intake of a unit of activity is given by its retention R(t):

$$R(t) = F_1 \exp(-\lambda t)\sum_i A_i \sum_j B_{ij} \exp(-\lambda_{ij} t)$$

where F_1 is the coefficient expressing the fraction of the intake transferred to the transfer compartment; A_i are coefficients expressing the fractions transferred from the transfer compartment to the i-th organ; B_{ij} are the coefficients of the linear combination of exponentials with decay constants λ_{ij} representing the retention in the i-th organ (1,4) and λ is the physical decay constant.

The amount of activity U(t) excreted in the urine at any time t after the intake of a unit of activity, is given by the first derivative of the biological retention function, multiplied by F_u the fraction of the excretion that is excreted through the urine (3,5):

$$U(t) = F_1 F_u \exp(-\lambda t)\sum_i A_i \sum_j \lambda_{ij} B_{ij} \exp(-\lambda_{ij} t)$$

When the decay constants λ are expressed in days^{-1} then U(t) is the daily excretion. The average daily urine volume is 1.4 liters (5); thus division by 1.4 yields the concentration of the radioelement per liter.

The investigation level at any time t after intake was defined as the concentration of activity in the urine arising from an intake of 1/20 of an ALI (3). An analogous definition is used here for the total body investigation level. A computer code was written which receives as input the various coefficients $F_1, F_u, A_i, B_{ij}, \lambda_{ij}, \lambda$ and the ALI (1,4) and calculates the investigation levels. Tables 1 and 2 list the investigation levels in the body and the urine of a few commonly used radioisotopes, as a function of time after ingestion. Different tables should be used for the case of inhalation.

TABLE 1. Total body investigation levels as a function of time after ingestion.

Isotope	Organ	Chemical form	Investigation level (μCi)			
			days after ingestion			
			3	7	30	60
^{22}Na	T.B.*		14	12	4.0	0.97
^{42}K	T.B.		0.51	$2.2\cdot10^{-3}$	-	-
^{51}Cr	T.B.	Trivalent	9.1	6.5	2.0	0.73
	T.B.	Hexavalent	91	65	20	7.3
^{57}Co	T.B.	Inorganic	8.4	6.5	3.3	2.5
	T.B.	Organic	26	20	10	7.9
^{60}Co	T.B.	Inorganic	0.52	0.41	0.22	0.18
	T.B.	Organic	1.2	0.92	0.50	0.40
^{59}Fe	T.B.		3.9	3.6	2.5	1.6
^{65}Zn	T.B.		8.5	8.1	6.5	5.3
^{67}Ga	T.B.		0.17	0.056	$0.19\cdot10^{-3}$	-
^{75}Se	T.B.	Elemental	5.4	4.2	2.1	1.1
	T.B.	Inorganic	30	23	11	6.2
^{99}Mo	T.B.	Sulfide	1.1	0.39	$0.96\cdot10^{-3}$	-
	T.B.	Other	27	9.4	0.023	$9.0\cdot10^{-6}$
^{99m}Tc	T.B.		0.66	$3.5\cdot10^{-6}$	-	-
^{125}I	Thyroid		0.39	0.36	0.25	0.16
^{131}I	Thyroid		0.31	0.21	0.026	$1.7\cdot10^{-3}$
^{137}Cs	T.B.		5.0	4.7	4.0	3.3
^{144}Ce	L.L.I.*		$3.2\cdot10^{-3}$	$3.2\cdot10^{-3}$	$3.0\cdot10^{-3}$	$2.8\cdot10^{-3}$
^{226}Ra	B.S.*		$4.8\cdot10^{-3}$	$2.9\cdot10^{-3}$	$1.5\cdot10^{-3}$	$1.2\cdot10^{-3}$
^{232}Th	B.S.		$7.3\cdot10^{-6}$	$7.3\cdot10^{-6}$	$7.2\cdot10^{-6}$	$7.2\cdot10^{-6}$
^{238}U	B.S.	Hexavalent	$13\cdot10^{-3}$	$9.6\cdot10^{-3}$	$3.4\cdot10^{-3}$	$1.6\cdot10^{-3}$
	T.B.	Tetravalent	$7.2\cdot10^{-3}$	$5.4\cdot10^{-3}$	$1.9\cdot10^{-3}$	$0.9\cdot10^{-3}$
^{239}Pu	B.S.		$24\cdot10^{-6}$	$24\cdot10^{-6}$	$24\cdot10^{-6}$	$24\cdot10^{-6}$
^{241}Am	B.S.		$30\cdot10^{-6}$	$30\cdot10^{-6}$	$30\cdot10^{-6}$	$30\cdot10^{-6}$

* T.B. = total body; B.S. = bone surface; L.L.I. = lower large intestine

The following assumptions are inherent in the calculations:

a) The activity build-up time in the organs is assumed to be negligible compared to the decay time. Since the exponential approximation is in any case too crude to use for calculations for the first day no attempt was made to insert the build-up effect in the calculations. Therefore, this calculation should not be used for the first day.

b) The urinary excretion fraction F_u is taken as one constant for all organs and at any time. It will be possible to insert better approximations into the computer code when more biological information is available.

The computer code and Tables 1 and 2 give the levels in the urine and the body arising from an intake that corresponds to a particular committed dose. In the future we shall use the same tables and routines to reverse the procedure and calculate the committed dose from a measured activity.

TABLE 2. Investigation level in urine as a function of time after ingestion.

Isotope	Organ	Chemical form	Investigation level (μCi) days after ingestion 3	7	30	60
^{3}H	T.B.	Water	81	62	12	1.6
^{22}Na	T.B.		0.46	0.39	0.13	0.032
^{32}P	T.B.		0.49	0.18	0.017	$1.3 \cdot 10^{-3}$
^{35}S	L.L.I.	Elemental	0.37	0.068	0.025	$7.2 \cdot 10^{-3}$
	T.B.	Other	9.3	1.7	0.63	0.18
^{36}Cl	T.B.		3.3	2.5	0.50	0.063
^{42}K	T.B.		$7.1 \cdot 10^{-3}$	$31 \cdot 10^{-6}$	-	-
^{45}Ca	T.B.		0.32	0.12	0.024	$8.1 \cdot 10^{-3}$
^{51}Cr	T.B.	Trivalent	0.21	0.11	$8.2 \cdot 10^{-3}$	$1.7 \cdot 10^{-3}$
	T.B.	Hexavalent	2.1	1.1	0.082	0.017
^{57}Co	T.B.	Inorganic	0.37	0.17	0.019	$6.0 \cdot 10^{-3}$
	T.B.	Organic	1.1	0.52	0.058	0.019
^{60}Co	T.B.	Inorganic	0.023	0.01	$1.2 \cdot 10^{-3}$	$0.42 \cdot 10^{-3}$
	T.B.	Organic	0.052	0.024	$2.8 \cdot 10^{-3}$	$0.96 \cdot 10^{-3}$
^{65}Zn	T.B.		0.014	0.012	$6.0 \cdot 10^{-3}$	$2.9 \cdot 10^{-3}$
^{67}Ga	T.B.		$2.2 \cdot 10^{-3}$	$0.6 \cdot 10^{-3}$	$0.8 \cdot 10^{-6}$	-
^{75}Se	T.B.	Elemental	0.12	0.039	$9.3 \cdot 10^{-3}$	$3.2 \cdot 10^{-3}$
	T.B.	Inorganic	0.67	0.21	0.05	0.017
^{85}Sr	T.B.	Titanate	0.021	$5.6 \cdot 10^{-3}$	$0.32 \cdot 10^{-3}$	$0.11 \cdot 10^{-3}$
	T.B.	Other	0.42	0.11	$6.4 \cdot 10^{-3}$	$2.2 \cdot 10^{-3}$
^{90}Sr	T.B.	Titanate	$2.7 \cdot 10^{-3}$	$0.76 \cdot 10^{-3}$	$55 \cdot 10^{-6}$	$27 \cdot 10^{-6}$
	B.S.	Other	$4.8 \cdot 10^{-3}$	$1.3 \cdot 10^{-3}$	$0.1 \cdot 10^{-3}$	$47 \cdot 10^{-6}$
^{99}Mo	T.B.	Sulfide	0.010	$2.1 \cdot 10^{-3}$	$5.0 \cdot 10^{-6}$	-
	T.B.	Other	0.24	0.051	$0.12 \cdot 10^{-3}$	-
^{99m}Tc	T.B.		0.074	-	-	-
^{125}I	Thyroid		$3.2 \cdot 10^{-3}$	$0.8 \cdot 10^{-3}$	$0.54 \cdot 10^{-3}$	$0.34 \cdot 10^{-3}$
^{131}I	Thyroid		$2.6 \cdot 10^{-3}$	$0.46 \cdot 10^{-3}$	$57 \cdot 10^{-6}$	$3.7 \cdot 10^{-6}$
^{137}Cs	T.B.		0.055	0.026	0.014	0.012
^{204}Tl	T.B.		0.87	0.58	0.059	$3.0 \cdot 10^{-3}$
^{226}Ra	B.S.		$32 \cdot 10^{-6}$	$8.6 \cdot 10^{-6}$	$0.6 \cdot 10^{-6}$	$0.3 \cdot 10^{-6}$
^{238}U	B.S.	Hexavalent	$0.18 \cdot 10^{-3}$	$86 \cdot 10^{-6}$	$16 \cdot 10^{-6}$	$4.3 \cdot 10^{-6}$
	T.B.	Tetravalent	$0.1 \cdot 10^{-3}$	$48 \cdot 10^{-6}$	$8.9 \cdot 10^{-6}$	$2.4 \cdot 10^{-6}$

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