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**RADIATION DOSE DUE TO ACUTE
INTAKE OF TRITIUM BY MAN**

April 1972

Health and Safety Laboratory
New York Operations Office (AEC)
New York, New York

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THE RADIATION DOSE DUE TO ACUTE INTAKE OF TRITIUM BY MAN

Burton G. Bennett

April 1972

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ABSTRACT

Small amounts of tritium acquired as water by man are incorporated into tissue compounds and retained considerably longer than the 8 to 10 day half-time associated with retention in the body water. A review of the data from the few long-term observations of human cases of exposure to tritium shows that two bound components with retention half-times of about 30 and 450 days can be identified. A two compartment estimate and three compartment model calculations are made to determine the contribution to the tissue dose from tritium in the body water and in the bound compartments. For the average retention half-times of 9, 30, and 450 days, the tissue dose is 84 mrad per mCi intake, due 84% to tritium in body water and 16% to combined tritium in tissue. Fifty percent of the total tissue dose is delivered within 11 days and 90% within 200 days following the intake. The bound tritium in tissue is not the major contributor to the tissue dose following a single intake of HTO, but its contribution is not insignificant.

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INTRODUCTION

Tritium has been considered one of the least hazardous of radioactive isotopes, primarily because of its very low β energy ($E_{avg} = 5.7$ keV) and the short initial biological half-time in man (8 - 10 days). The increasing amounts of tritium in the environment from the expanding nuclear power industry, however, and the corresponding increases in the numbers of workers at risk from high level intakes and of the general population at risk from low level chronic exposure require continual evaluation of the radiation dose to man and the biological effects of tritium.

Woodard⁽¹⁾ recently summarized the information available on the incorporation of tritium into body components and discussed the nature of the biological effects. There is an increasing body of evidence which shows that small amounts of tritium acquired as water by mammals are incorporated into tissue compounds and retained with half-times considerably longer than that associated with body water retention. There is little evidence whether such low level labeling of tissue constituents either causes or does not cause biological injury. Higher level labeling of the constituents of the cell nucleus, especially DNA, through incorporation of artificially prepared tritiated precursors can lead to mutations and/or cell death. It is possible that similar precursors could be formed in vivo, producing similar effects. It is, at any rate, important that the amounts of combined tritium in tissue be considered in evaluating the radiation dose to man.

A model calculation of the dose to tissue from a single intake of HTO by man, in which account was taken of combined tritium, was reported in HASL-229⁽¹⁾. This calculation, however, has been shown to contain errors in interpretation of the experimental data which provided the basis for the calculation. Alternate calculations of the tissue dose from a single intake of 70 mCi HTO by a 70 kg standard man are presented in this report.

HUMAN DATA FROM OCCUPATIONAL TRITIUM EXPOSURES

There have been a large number of short-term observations of human cases of acute low level exposure to tritium. These observations indicate that the initial rate of elimination of tritium from the body is exponential with a half-time ranging from 4 to 18 days. The average half-times reported were 8.5 days in one study⁽²⁾ and 9.5 days in another⁽³⁾.

Experience from observations for more than 30 or 40 days of human cases of exposure to tritium is rather limited. There have been only three cases of accidental exposures to tritium reported with intakes large enough to allow relatively long-term monitoring of the retention of tritium in the body. The 415 day observation of a case reported by Sanders and Reinig⁽⁴⁾ allowed three components of retention to be identified. The elimination half-times of these components were found to be 6.1, 23 and 344 days. The first component can be associated with free water in the body and the other two components with bound tritium in tissue.

Snyder et al.⁽⁵⁾ studied another case for 255 days and identified two retention components of half-times 8.7 and 34 days. Further analysis of the Snyder data, reported below in this study, shows that the data is not inconsistent with a fit by three components of half-times 8.7, 30 and 550 days. These elimination rates are somewhat longer than in the preceding case. In the case studied by Sanders and Reinig, however, a diuretic was administered from the 3rd to 35th day, which undoubtedly increased the turnover rate of body water.

Another case was recently reported by Lambert, Sharpe, and Dawson⁽⁶⁾. The observation period was 161 days, and elimination half-times of 9.1 and 36 days were determined. A half-time of 62 days for non-volatile tritium in blood was found, which is presumably representative of combined tritium in organic compounds in blood. The results from body water activity measurements are very similar to those reported by Snyder et al. The observation period is not quite long enough to allow a definitive fit with three retention components.

Other cases of human tritium exposures which have been reported involve occupational exposures of repeated low level intakes with observations begun some time after the exposures ended^(7,8). The following table summarizes the elimination half-times identified in these studies.

TABLE 1
OBSERVED TRITIUM ELIMINATION HALF-TIMES FOR MAN

	Elimination Half-Times (days)		
	T ₁	T ₂	T ₃
Wylie et al. (7 cases)	6-12		
Average:	8.5		
Butler and Leroy (310 cases)	4-18		
Average:	9.5		
Lambert et al. (1 case)	9.1	36	
Snyder et al. (1 case)	8.7	34	
This study - Snyder data	8.7	30	550
Sanders and Reinig (1 case)	6.1	23	344
Minder (1 case)		10-30	139-230
Moghissi et al. (2 cases)		21-33	280-2020
Reasonable range:	8-10	20-36	200-550

TISSUE DOSE FOLLOWING ACUTE INTAKE

Two Compartment Analysis

The dose to tissue following an intake of tritium arises from tritium in body water, the tissue free water tritium

(TFWT), and from tritium combined in tissue (TCT). A first estimate of the tissue dose can be obtained assuming the combined tritium to be represented by a single compartment.

The integral exposures from TFWT 2000 days following an intake of 70 mCi HTO is calculated by the formula

$$\frac{70 \text{ mCi}}{42 \text{ kg H}_2\text{O}} \times \frac{0.75 \text{ kg H}_2\text{O}}{1 \text{ kg wet tissue}} \times \int_0^{2000} f_A dt \left(\frac{\text{mCi days}}{\text{kg}} \right)$$

where f_A is the fractional concentration of tritium remaining in the body free water. A 70 kg man contains on average 42 kg water⁽¹⁾. Wet tissue is assumed to consist of 75% water. Conversion to dose units is given by the relation 1 mCi day/kg = 0.29 rad. Using the data of Snyder et al. to indicate the declining concentration of tritium in body water (the concentration is urine given in Table 1 of their paper), the dose to tissue from TFWT is 16.5 mCi days/kg or 4.8 rads.

The tissue dose from TCT depends on the amount of the tritium intake which becomes combined and the retention time. Based on data from animal experiments, Woodard⁽¹⁾ assumed that 1.4% of the intake becomes combined. A rough indication of the average retention time of hydrogen in tissue can be obtained using this assumption. Incorporation of 1.4% of the intake amounts to combining about 0.12% of the body free water tritium per day, based on the Snyder et al. data of the decline of body free water tritium. Due to the rapidly declining concentration of tritium in the body water, the incorporation of tritium into tissue is negligible after 30 days. Incorporation of 0.12% of the hydrogen in the body free water,

$$\left(42 \text{ kg H}_2\text{O} \times \frac{1 \text{ kg H}}{9 \text{ kg H}_2\text{O}} \right),$$

amounts to ~5.6 g hydrogen per day. The 10 kg of active tissue solids⁽¹⁾ containing ~7% hydrogen is 700 g hydrogen. The average retention time is

$$\frac{\text{total amount of hydrogen in tissue}}{\text{incorporation rate of hydrogen into tissue}} = \frac{700 \text{ g}}{5.6 \text{ g/day}} = 125 \text{ days}$$

The corresponding retention half-time is 87 days. Assuming that 1.4% of the tritium intake becomes combined in tissue and the retention half-time is 87 days, the integral exposure from TCT 2000 days following the intake is 3.1 mCi days/kg or 0.9 rads.

Similar estimates of the tissue dose could be made using the data of Sanders and Reinig to indicate the decline of body free water tritium. However, if the diuretic accelerated the decline in concentration of tritium in the body water, the retention half-time of TCT and thus the integral exposure would be underestimated. The relatively rapid first component elimination half-time (6.1 days) and the high excretion rate ($.105 \text{ day}^{-1} \times 42 \text{ kg} = 4.4 \text{ l/d}$), estimated from the reported transfer coefficient, indicate that the diuretic was effective in accelerating the turnover of body water.

The dose to tissue from a 70 mCi intake is thus estimated to be about 4.8 rads from tritium in body water and 0.9 rads from tritium combined in tissue. The total dose, 5.7 rads, is 1.2 times that due to tritium in body water. The tissue dose can be compared to the dose usually calculated for the body water, which is

$$\frac{70 \text{ mCi}}{42 \text{ kg H}_2\text{O}} \times \int_0^{2000} f_A dt = 22.1 \frac{\text{mCi days}}{\text{kg}} = 6.4 \text{ rads}$$

The dose to body water is, of course, less significant than the tissue dose from the standpoint of potential hazard.

Three Compartment Analysis

The dose to tissue from combined tritium can also be estimated from the calculated retention in each of the bound tritium compartments. Sanders and Reinig selected combinations of exchange and elimination rates for each compartment which resulted in close agreement with the measured fractional

assimilated tritium in the body water compartment. The model used for the calculation is represented by the following diagram:

A is the body water compartment, and B and C are bound compartments. E represents elimination from the body. The transfer coefficients represent constant fractional exchange of the compartment contents.

To fit the data of Snyder et al. by the above model with three exponential components, transfer coefficients were tested which covered a range of retention half-times and various estimates of the B and C compartment sizes, consistent with the assumed total size of B plus C of around 700 g hydrogen. The best fit to the data was obtained using half-times of 8.7, 30 and 550 days with 720 g hydrogen combined in tissue and the ratio of B to C of 1 to 5. The transfer coefficients (fractional exchange per day) used for this fit and a listing of calculated results are given in Table 2.

The results for tritium assimilated in the body water compartment, A, are quite consistent with the observed results, as shown in Figure 1.

The compartment sizes and the B to C ratio from this fit are in general agreement with what can be inferred from the transfer coefficients used by Sanders and Reinig. Assuming the elimination from each compartment to be exponential, the following half-times are computed from the transfer coefficients given by Sanders and Reinig (the "out" transfer coefficient = $1 - e^{-\lambda}$).

$$A_{\text{out}} = E + B_{\text{in}} + C_{\text{in}} = .1063 \quad T_{\frac{1}{2}}(A) = 6.17 \text{ days}$$

$$B_{\text{out}} = .04 \quad T_{\frac{1}{2}}(B) = 17 \text{ days}$$

$$C_{\text{out}} = .002 \quad T_{\frac{1}{2}}(C) = 346 \text{ days}$$

The mean residence time in a compartment is equal to the compartment size divided by the transfer rate into or out of the compartment. The transfer rate into the bound compartments is the fractional exchange per day (transfer coefficient) times the size of the body water compartment ($42000 \text{ g H}_2\text{O} \times 1 \text{ g H}/9 \text{ g H}_2\text{O}$). The size of the B and C compartments can be inferred from these relations and the transfer coefficients given by Sanders and Reinig.

$$B_{in} = .001: \quad (.001) \left(\frac{42000}{9} \right) (1.44 \times 17) = 114 \text{ g H in B}$$

$$C_{in} = .0003: \quad (.0003) \left(\frac{42000}{9} \right) (1.44 \times 346) = 698 \text{ g H in C}$$

Total 812 g H bound

The B to C ratio is about 1 to 6.

In Figure 1, the dashed line shows the Sanders-Reinig results, from application of the three compartment model, of the fit to the measured tritium levels in the body water compartment. The fit is quite good, except for slight over-estimation of observations made after 200 days following the intake. Also shown in Figure 1 is an alternate fit to these observations using transfer coefficients corresponding to compartment elimination half-times of 6.1, 20, and 345 days and B and C compartment sizes of 120 and 600 gH. The B to C ratio of 1 to 5 is then consistent with that used to fit the Snyder et al. data. This fit is just as good, perhaps somewhat better at long times after intake. The dose estimates are little changed from the results reported by Sanders and Reinig⁽⁹⁾. Detailed results from this calculation are given in Table 3.

The physiological significance of the B to C ratio is unknown. The compartments B and C are thought, however, to be chemical in nature rather than being identifiable with specific organs or tissues.

The integral exposure to tissue 2000 days following a 70 mCi intake of HTO is computed for the three compartment model fits to observed data as follows:

TFWT

$$\frac{70 \text{ mCi}}{42 \text{ kg H}_2\text{O}} \times \frac{0.75 \text{ kg H}_2\text{O}}{1 \text{ kg wet tissue}} \times \int_0^{2000} f_A \, dt$$

TCT

$$\frac{70 \text{ mCi}}{10 \text{ kg tissue solids}} \times \frac{0.25 \text{ kg tissue solids}}{1 \text{ kg wet tissue}} \int_0^{2000} f_{B+C} \, dt$$

<u>Elimination Half-times (days)</u>	<u>Tissue Dose (70 mCi intake)</u>		
	<u>TFWT</u>	<u>TCT</u>	<u>Total</u>
6.1 - 20 - 345	11.7	2.4	14.1 (mCi days/kg)
8.7 - 30 - 550	16.4	3.1	19.5 (mCi days/kg)

In terms of approximate average elimination half-times for these two cases, the results may be summarized as follows:

<u>Elimination Half-times (days)</u>	<u>Tissue Dose (70 mCi intake)</u>		
	<u>TFWT</u>	<u>TCT</u>	<u>Total</u>
8 - 25 - 450	15.2	3.0	18.2 (mCi days/kg)
	4.4	0.9	5.3 (rads)

These dose results are in good agreement with those estimated from the two compartment analysis.

DISCUSSION

The results obtained above for the tissue dose following an acute intake of tritium could be adjusted slightly, based on all the information available from human tritium exposures. An average half-time of 9 days for the first retention component and about 30 days for the second component might be considered most representative. There is very little information yet to judge the half-time of the third component or to indicate whether even longer retention components might be present.

A half-time of less than 9 days for the first component results in a fairly high estimate of daily water excretion. Three compartment analysis with half-times of 9, 30, and 450 days with the B to C ratio of 1 to 5 results in an estimated excretion of 3.08 l/day. This is probably as high as can be assumed for standard man calculations. Results of a calculation using these assumptions are given in Table 4 and are summarized below. These are considered the best estimate of the tissue dose following a single intake of 70 mCi HTO by a 70 kg standard man.

<u>Elimination Half-times (days)</u>	<u>Tissue Dose (70 mCi intake)</u>		
	<u>TFWT</u>	<u>TCT</u>	<u>Total</u>
9 - 30 - 450	17.0	3.3	20.3 (mCi days/kg)
	4.9	1.0	5.9 (rads)

Figure 2 shows the fractional total retention in the body and also the retention in the body water and bound compartments for these average elimination half-times.

The tissue dose is due 84% to tritium in body water; 16% is from combined tritium in tissue. A maximum of 0.7% of the tritium intake becomes combined, this maximum being reached in about 20 days. Fifty percent of the total tissue dose is

delivered within 11 days, and 90% of the dose is delivered within 200 days. The tissue dose can also be expressed as 84 mrad per mCi intake.

In the model calculation reported by Woodard⁽¹⁾, the proper method of considering the dose due to combined tritium was pointed out, however in using the data of Sanders and Reinig, the estimated tritium concentration in the total body was misinterpreted to be the tritium concentration in body water. There is little difference in the two curves for the first 30 days following the intake, during which time a major portion of the total dose is delivered, so the dose from TFWT is little over-estimated. The dose from TCT is more seriously in error. Assuming 1.4% of the intake becomes combined was not unreasonable, though the model calculations indicate an amount slightly less than 1%, but misinterpretation of the excretion curves resulted in only small amounts of combined tritium being slowly removed from the originally combined amount. This led to the over-estimation of dose from TCT. The calculations given in this report should correct this misunderstanding.

CONCLUSION

This analysis has indicated the approximate tissue dose due to acute acquisition of HTO by man, based on the rather limited experience of observation of actual human exposures. The differences in retention times in the cases reported allude to the variability which might be anticipated due to differences in metabolism. There are also known to be effects due to age, ambient temperature, water intake, and treatment procedures following exposure.

Although long-term retention components of tritium combined in tissue have been identified, the rapidly declining concentration of tritium in the body free water allows only relatively small amounts of the intake to become combined. The bound tritium in tissue is thus not the major contributor to the total dose to tissue following a single intake of HTO,

but its contribution is not insignificant. Chronic intakes would result in greater labeling of tissue compounds, in which case contribution of bound tritium to the total dose to tissue would be increased.

Acute intake of tritium other than in the form HTO may require special consideration. The bound tritium contribution to the tissue dose is expected to be more significant for intakes of tritium in food, since any bound tritium in food may be more directly assimilated into bound compounds in tissue. Further study will be required to establish the combined amounts, the retention half-times, and the distribution in the various compartments for various possible forms of tritium intake.

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TABLE 2

TRITIUM RETENTION AND CUMULATIVE DOSE (1 MCI/KG INTAKE)

RETENTION HALF-TIMES: 8.7, 30, 550, DAYS PLUS RADIOACTIVE DECAY (12.26 YR HALF-LIFE)

TRANSFER COEFFICIENTS: B(IN)=0.00060 B(OUT)=0.02284 C(IN)=0.00016 C(OUT)=0.00126 F=0.07581

DAY	PERCENTAGE OF INTAKE RETAINED				TOTAL	CUMULATIVE DOSE (MCI DAYS/KG)			TOTAL
	A	B	C	B+C		A	B	C	
0	100.000000	0.0	0.0	0.0	100.000000	1.250000	0.0	0.0	1.250000
1	92.328705	0.059991	0.015998	0.075988	92.404678	2.404108	0.001050	0.000280	2.405437
2	85.247269	0.114000	0.030745	0.144745	85.391998	3.469698	0.003045	0.000818	3.473558
3	78.710312	0.162519	0.044339	0.206858	78.917145	4.453576	0.005889	0.001594	4.461058
4	72.675964	0.206002	0.056868	0.262870	72.938812	5.362025	0.009494	0.002589	5.374107
5	67.105530	0.244864	0.068414	0.313278	67.418793	6.200844	0.013779	0.003786	6.218409
6	61.963303	0.279491	0.079052	0.358544	62.321823	6.975385	0.018670	0.005170	6.999224
7	57.216370	0.310238	0.088853	0.399091	57.615448	7.690589	0.024099	0.006725	7.721412
8	52.834305	0.337429	0.097881	0.435310	53.269592	8.351017	0.030004	0.008438	8.389458
9	48.789047	0.361367	0.106194	0.467561	49.256592	8.960879	0.036328	0.010296	9.007503
10	45.054642	0.382327	0.113849	0.496176	45.550812	9.524062	0.043019	0.012288	9.579369
11	41.607224	0.400566	0.120895	0.521461	42.128677	10.044152	0.050029	0.014404	10.108584
12	38.424667	0.416317	0.127380	0.543697	38.968353	10.524460	0.057314	0.016633	10.598407
13	35.486649	0.429796	0.133347	0.563143	36.049789	10.968042	0.064836	0.018967	11.051845
14	32.774323	0.441203	0.138835	0.580038	33.354340	11.377721	0.072557	0.021396	11.471673
15	30.270340	0.450721	0.143882	0.594603	30.864929	11.756100	0.080444	0.023914	11.860457
16	27.958649	0.458517	0.148521	0.607038	28.565674	12.105582	0.088468	0.026513	12.220563
17	25.824493	0.464748	0.152783	0.617531	26.442001	12.428388	0.096601	0.029187	12.554175
18	23.854187	0.469555	0.156698	0.626253	24.480423	12.726564	0.104819	0.031929	12.863312
19	22.035141	0.473069	0.160293	0.633362	22.668488	13.002003	0.113097	0.034734	13.149834
20	20.355743	0.475412	0.163591	0.639003	20.994736	13.256449	0.121417	0.037597	13.415462
30	9.241831	0.454791	0.184526	0.639317	9.881147	14.946359	0.203559	0.068509	15.218426
40	4.231725	0.395949	0.192512	0.588461	4.820185	15.716476	0.277736	0.101691	16.095901
50	1.965937	0.330138	0.194674	0.524812	2.490747	16.071350	0.340675	0.135642	16.547653
60	0.935531	0.269292	0.194218	0.463510	1.399041	16.237930	0.392481	0.169690	16.800079
70	0.462435	0.217107	0.192587	0.409695	0.872130	16.318527	0.434451	0.203532	16.956497
80	0.241673	0.173920	0.190435	0.364355	0.606028	16.359375	0.468163	0.237032	17.064560
90	0.135904	0.138832	0.188055	0.326887	0.462792	16.381470	0.495113	0.270131	17.146698
100	0.083122	0.110606	0.185584	0.296191	0.379313	16.394424	0.516602	0.302803	17.213821
200	0.007438	0.011193	0.161453	0.172646	0.180084	16.424973	0.591704	0.605886	17.622543
300	0.002837	0.001180	0.140198	0.141378	0.144215	16.429626	0.599348	0.869213	17.898163
400	0.002101	0.000169	0.121718	0.121887	0.123988	16.431717	0.600207	1.097825	18.129745
500	0.001788	0.000061	0.105672	0.105733	0.107521	16.433243	0.600373	1.296270	18.329880
600	0.001548	0.000044	0.091740	0.091784	0.093333	16.434769	0.600459	1.468548	18.503754
700	0.001344	0.000037	0.079643	0.079681	0.081024	16.436295	0.600527	1.618104	18.654922
800	0.001167	0.000032	0.069141	0.069174	0.070340	16.437317	0.600584	1.747929	18.785812
900	0.001013	0.000028	0.060025	0.060053	0.061066	16.437317	0.600634	1.860633	18.898575
1000	0.000879	0.000024	0.052115	0.052140	0.053019	16.437317	0.600677	1.958474	18.996445
1100	0.000763	0.000021	0.045248	0.045269	0.046032	16.437317	0.600714	2.043417	19.081436
1200	0.000663	0.000018	0.039285	0.039303	0.039966	16.437317	0.600746	2.117161	19.155212
1300	0.000575	0.000016	0.034108	0.034124	0.034700	16.437317	0.600773	2.181173	19.219254
1400	0.000500	0.000014	0.029613	0.029627	0.030127	16.437317	0.600797	2.236752	19.274841
1500	0.000434	0.000012	0.025711	0.025723	0.026157	16.437317	0.600815	2.285000	19.323120
1600	0.000377	0.000010	0.022322	0.022333	0.022709	16.437317	0.600833	2.326880	19.365021
1700	0.000327	0.000009	0.019381	0.019390	0.019717	16.437317	0.600846	2.363236	19.401398
1800	0.000284	0.000008	0.016826	0.016834	0.017118	16.437317	0.600858	2.394795	19.432953
1900	0.000246	0.000007	0.014609	0.014615	0.014862	16.437317	0.600870	2.422190	19.460358
2000	0.000214	0.000006	0.012683	0.012689	0.012903	16.437317	0.600876	2.445968	19.484146

TABLE 3

TRITIUM RETENTION AND CUMULATIVE DOSE (1 MCI/KG INTAKE)

RETENTION HALF-TIMES: 6-1, 20, 345, DAYS PLUS RADIOACTIVE DECAY (12.26 YR HALF-LIFE)

TRANSFER COEFFICIENTS: B(IN)=0.00089 B(OUT)=0.03406 C(IN)=0.00026 C(OUT)=0.00201 E=0.10624

DAY	PERCENTAGE OF INTAKE RETAINED				TOTAL	CUMULATIVE DOSE (MCI DAYS/KG)			
	A	B	C	B+C		A	B	C	TOTAL
0	100.000000	0.0	0.0	0.0	100.000000	1.250000	0.0	0.0	1.250000
1	89.247177	0.088986	0.025996	0.114982	89.362137	2.365589	0.001557	0.000455	2.367600
2	79.653656	0.165360	0.049140	0.214500	79.868149	3.361259	0.004451	0.001315	3.367024
3	71.094345	0.230583	0.069741	0.300324	71.394653	4.249938	0.008486	0.002535	4.260959
4	63.457672	0.285959	0.088071	0.374030	63.831680	5.043159	0.013491	0.004077	5.060724
5	56.644089	0.332645	0.104377	0.437022	57.081100	5.751209	0.019312	0.005903	5.776423
6	50.564758	0.371671	0.118876	0.490547	51.055283	6.383268	0.025816	0.007984	6.417068
7	45.140488	0.403952	0.131764	0.535715	45.676193	6.947524	0.032885	0.010289	6.990698
8	40.300598	0.430301	0.143213	0.573514	40.874100	7.451281	0.040415	0.012796	7.504491
9	35.982071	0.451443	0.153379	0.604822	36.586868	7.901056	0.048316	0.015480	7.964850
10	32.128632	0.468018	0.162401	0.630419	32.759048	8.302664	0.056506	0.018322	8.377490
11	28.690125	0.480598	0.170402	0.650999	29.341110	8.661290	0.064916	0.021304	8.747509
12	25.621796	0.489687	0.177491	0.667178	26.288971	8.981563	0.073486	0.024410	9.079457
13	22.883728	0.495735	0.183767	0.679502	23.563217	9.267609	0.082161	0.027626	9.377395
14	20.440308	0.499139	0.189318	0.688457	21.128754	9.523112	0.090896	0.030939	9.644966
15	18.259735	0.500253	0.194222	0.694475	18.954193	9.751358	0.099651	0.034338	9.885345
16	16.313690	0.499388	0.198548	0.697936	17.011612	9.955278	0.108390	0.037812	10.101480
17	14.576907	0.496821	0.202359	0.699180	15.276087	10.137489	0.117084	0.041354	10.295926
18	13.026803	0.492796	0.205711	0.698507	13.725309	10.300323	0.125708	0.044954	10.470984
19	11.643249	0.487530	0.208652	0.696182	12.339430	10.445864	0.134240	0.048605	10.628708
20	10.408292	0.481212	0.211227	0.692439	11.100730	10.575967	0.142661	0.052301	10.770928
30	3.432887	0.388887	0.223737	0.612624	4.045510	11.317670	0.218460	0.090745	11.626874
40	1.175395	0.290978	0.224625	0.515603	1.690997	11.566007	0.276903	0.130072	11.972980
50	0.432576	0.211202	0.221801	0.433003	0.865579	11.653620	0.319845	0.169138	12.142601
60	0.179594	0.151332	0.217809	0.369142	0.548735	11.687609	0.350776	0.207577	12.245961
70	0.087540	0.107827	0.213477	0.321303	0.408844	11.702827	0.372866	0.245278	12.320971
80	0.050118	0.076642	0.209075	0.285717	0.335835	11.710877	0.388582	0.282213	12.381671
90	0.032455	0.054423	0.204698	0.259122	0.291576	11.715803	0.399747	0.318378	12.433927
100	0.022745	0.038634	0.200381	0.239015	0.261760	11.719136	0.407673	0.353784	12.480592
200	0.003680	0.001324	0.161531	0.162855	0.166536	11.729689	0.426498	0.668948	12.825133
300	0.002523	0.000109	0.130123	0.130232	0.132755	11.733331	0.427230	0.922879	13.083439
400	0.002018	0.000057	0.104817	0.104874	0.106892	11.736098	0.427355	1.127401	13.290854
500	0.001625	0.000045	0.084431	0.084476	0.086101	11.738316	0.427441	1.292126	13.457882
600	0.001309	0.000036	0.068008	0.068044	0.069353	11.740093	0.427509	1.424798	13.592400
700	0.001054	0.000029	0.054783	0.054812	0.055867	11.741515	0.427563	1.531657	13.700734
800	0.000849	0.000024	0.044132	0.044156	0.045005	11.742653	0.427606	1.617735	13.787993
900	0.000684	0.000019	0.035552	0.035571	0.036255	11.743561	0.427640	1.687065	13.858265
1000	0.000551	0.000015	0.028639	0.028655	0.029206	11.744278	0.427667	1.742908	13.914851
1100	0.000444	0.000012	0.023071	0.023083	0.023527	11.744849	0.427688	1.787878	13.960414
1200	0.000358	0.000010	0.018585	0.018595	0.018953	11.745297	0.427705	1.824098	13.997099
1300	0.000288	0.000008	0.014971	0.014979	0.015267	11.745653	0.427717	1.853268	14.026637
1400	0.000232	0.000006	0.012060	0.012067	0.012299	11.745939	0.427727	1.876759	14.050425
1500	0.000187	0.000005	0.009715	0.009720	0.009907	11.746136	0.427733	1.895668	14.069536
1600	0.000151	0.000004	0.007826	0.007830	0.007981	11.746320	0.427739	1.910890	14.084948
1700	0.000121	0.000003	0.006304	0.006307	0.006428	11.746415	0.427744	1.923144	14.097303
1800	0.000098	0.000003	0.005078	0.005080	0.005178	11.746511	0.427744	1.933006	14.107261
1900	0.000079	0.000002	0.004090	0.004092	0.004171	11.746606	0.427744	1.940942	14.115292
2000	0.000063	0.000002	0.003295	0.003297	0.003360	11.746619	0.427744	1.947322	14.121685

TABLE 4

TRITIUM RETENTION AND CUMULATIVE DOSE (1 MCI/KG INTAKE)

RETENTION HALF-TIMES: 9, 30, 450, DAYS PLUS RADIOACTIVE DECAY (12.26 YR HALF-LIFE)

TRANSFER COEFFICIENTS: B(IN)=0.00060 B(OUT)=0.02284 C(IN)=0.00020 C(OUT)=0.00154 E=0.07331

DAY	PERCENTAGE OF INTAKE RETAINED				TOTAL	CUMULATIVE DOSE (MCI DAYS/KG)			TOTAL
	A	B	C	B+C		A	B	C	
0	100.000000	0.0	0.0	0.0	100.000000	1.250000	0.0	0.0	1.250000
1	92.574661	0.059991	0.019997	0.079988	92.654633	2.407183	0.001050	0.000350	2.408581
2	85.702057	0.114148	0.038475	0.152623	85.854660	3.478457	0.003047	0.001023	3.482527
3	79.341019	0.162936	0.055548	0.218484	79.559494	4.470220	0.005899	0.001995	4.478113
4	73.453445	0.206787	0.071319	0.278107	73.731537	5.388387	0.009518	0.003243	5.401146
5	68.004089	0.246098	0.085887	0.331985	68.336060	6.238438	0.013824	0.004746	6.257008
6	62.960281	0.281236	0.099340	0.380576	63.340851	7.025440	0.018746	0.006485	7.050670
7	58.291824	0.312540	0.111761	0.424302	58.716110	7.754087	0.024215	0.008441	7.786742
8	53.970749	0.340324	0.123228	0.463553	54.434280	8.428721	0.030171	0.010597	8.469489
9	49.971176	0.364877	0.133812	0.498689	50.469849	9.053361	0.036556	0.012939	9.102856
10	46.269165	0.386466	0.143578	0.530044	46.759194	9.631725	0.043320	0.015452	9.690495
11	42.842545	0.405338	0.152587	0.557925	43.400452	10.167256	0.050413	0.018122	10.235790
12	39.670807	0.421720	0.160895	0.582615	40.253403	10.663141	0.057793	0.020937	10.741871
13	36.734985	0.435823	0.168555	0.604378	37.339355	11.122328	0.065420	0.023887	11.211634
14	34.017487	0.447840	0.175616	0.623456	34.640930	11.547545	0.073257	0.026960	11.647762
15	31.502045	0.457951	0.182120	0.640072	32.142105	11.941320	0.081271	0.030148	12.052738
16	29.173630	0.466320	0.188111	0.654432	29.828049	12.305990	0.089432	0.033439	12.428861
17	27.018280	0.473100	0.193626	0.666727	27.684998	12.643713	0.097711	0.036828	12.778255
18	25.023163	0.478432	0.198701	0.677132	25.700287	12.956507	0.106084	0.040305	13.102895
19	23.176331	0.482443	0.203368	0.685811	23.862122	13.246210	0.114526	0.043864	13.404599
20	21.466721	0.485255	0.207658	0.692912	22.159622	13.514544	0.123018	0.047498	13.685059
30	10.006137	0.467735	0.235065	0.702800	10.708937	15.319709	0.207222	0.086823	15.613752
40	4.701174	0.409554	0.245554	0.655108	5.356281	16.164093	0.283756	0.129129	16.576965
50	2.238156	0.342919	0.248241	0.591160	2.829316	16.563095	0.349012	0.172433	17.084518
60	1.088761	0.280564	0.247337	0.527900	1.616661	16.754852	0.402914	0.215822	17.373591
70	0.547771	0.226679	0.244787	0.471466	1.019237	16.849548	0.446694	0.258876	17.555099
80	0.289504	0.181862	0.241494	0.423356	0.712860	16.898270	0.481922	0.301403	17.681580
90	0.163375	0.145328	0.237879	0.383207	0.546582	16.924820	0.510120	0.343319	17.778244
100	0.099602	0.115872	0.234138	0.350010	0.449611	16.940338	0.532624	0.384589	17.857544
200	0.009431	0.011786	0.198154	0.209940	0.219371	16.976883	0.611428	0.761838	18.350128
300	0.004102	0.001272	0.167343	0.168615	0.172716	16.983475	0.619516	1.080616	18.683594
400	0.003077	0.000203	0.141294	0.141496	0.144573	16.986984	0.620468	1.349753	18.957139
500	0.002559	0.000084	0.119295	0.119379	0.121938	16.990036	0.620682	1.576934	19.187698
600	0.002157	0.000062	0.100720	0.100782	0.102939	16.991974	0.620803	1.768829	19.381592
700	0.001821	0.000051	0.085037	0.085088	0.086909	16.993500	0.620898	1.930793	19.545181
800	0.001537	0.000043	0.071794	0.071837	0.073374	16.995026	0.620978	2.067531	19.683517
900	0.001298	0.000037	0.060614	0.060650	0.061948	16.996552	0.621044	2.182970	19.800552
1000	0.001096	0.000031	0.051179	0.051210	0.052306	16.997101	0.621100	2.280429	19.898621
1100	0.000925	0.000026	0.043214	0.043240	0.044165	16.997101	0.621147	2.362709	19.980942
1200	0.000781	0.000022	0.036487	0.036509	0.037291	16.997101	0.621185	2.432174	20.050446
1300	0.000660	0.000019	0.030808	0.030827	0.031486	16.997101	0.621218	2.490814	20.109131
1400	0.000557	0.000016	0.026013	0.026029	0.026585	16.997101	0.621245	2.540325	20.158646
1500	0.000470	0.000013	0.021964	0.021977	0.022447	16.997101	0.621268	2.582123	20.200485
1600	0.000397	0.000011	0.018545	0.018556	0.018953	16.997101	0.621285	2.617405	20.235779
1700	0.000335	0.000009	0.015658	0.015668	0.016003	16.997101	0.621301	2.647189	20.265579
1800	0.000283	0.000008	0.013221	0.013229	0.013512	16.997101	0.621312	2.672328	20.290726
1900	0.000239	0.000007	0.011163	0.011169	0.011408	16.997101	0.621324	2.693545	20.311966
2000	0.000202	0.000006	0.009425	0.009430	0.009632	16.997101	0.621330	2.711457	20.329880

Figure 1. Tritium retention in body free water - two cases of long-term observation and three-component model fits.

Figure 2. Tritium retention in total body and in bound free water compartments - a three-component model with average elimination half-times.