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LOS ALAMOS SCIENTIFIC LABORATORY
OF THE UNIVERSITY OF CALIFORNIA o LOS ALAMOS NEW MEXICO

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ESTIMATION OF WHOLE BODY DOSE (REM) FROM TRITIUM IN BODY WATER

by

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ABSTRACT

The most reasonable method of detecting tritium in the body is by urinalysis. A detailed procedure, in use at LASL since 1953, is given for estimating the whole body exposure from a known concentration of tritium in the body water. As presented it is based on 1956 accepted standards of a permissible body burden of 3.7 mc, a 43.4 kg critical organ (total body water), and a 1.7 RBE for tritium in the body.

I. Purpose

It has been found at the Los Alamos Scientific Laboratory (LASL) that persons working with tritium inevitably take small quantities of tritium into their bodies sooner or later. This intake is the result of inhalation, skin absorption, and ingestion. Although considerable research has been done on the effects of tritium in the body, no methods have been published for computing the whole body exposure resulting from the intake of this material. In this paper, the method in use at LASL for computing the whole body exposure resulting from the intake of tritium is presented.

Tritium is usually taken into the body in the form of tritium water. It acts as normal water and follows the same biological processes as normal water. It has been reported by Pinson and Langham[1] that the tritium activity in sweat, insensible perspiration, expired water vapor, sputum, urine, and blood was found to be the same. Therefore, the most reasonable method of detecting tritium in the body is urinalysis.

II. Basic Premises and Method of Calculation

Over the past several years there has been considerable discussion as to the appropriate composition of the 70 kg standard man and also as to the RBE (relative biological effectiveness) of tritium. Until some agreement on these numbers could be reached, an acceptable figure for the maximum permissible body burden could not be established.

Such a compromise was reached in 1956, and the results are discussed fully in the paper "Physiology and Toxicology of Tritium in Man" by Pinson and Langham.[1]

In the 1953 edition, the NBS Handbook 52 value[2] of the maximum permissible body burden of tritium was 10 mc; this was based on an RBE for the tritium beta particles of 1.0 and the critical organ being the whole body (70 kg). The 1956 compromise set the total body water (43.4 kg) as the critical organ and the RBE for tritium as 1.7. These figures result in a maximum permissible constant body burden of 3.7 mc to give a 0.3 rem/wk dose to the whole body. The elimination half life, based on the 43.4 kg critical organ, is 12.0 days. The 3.7 mc body burden, 43.4 kg critical organ, and 1.7 RBE for tritium are included in a prepublication copy of the revised NBS Handbook 52.

At this Laboratory tritium urinalyses are expressed in microcuries per liter (μc/l). The constant body concentration $(MPC)_{body}$ which will deliver 0.3 rem/wk is

$$\frac{3700\ \mu c}{43.4\ kg} = \frac{3700\ \mu c}{43.4\ l} = 85\ \mu c/l$$

The problem in most cases is not that of constantly maintained body concentrations of tritium. Rather it is that of occasional acute body concentration which is exponentially eliminated, and which exposes the body in an exponentially decreasing manner. The

dose (D_t) at any time t after an acute intake of tritium may be expressed as

$$D_t = \frac{(\text{rem/wk})/(\text{MPC})_{\text{body}}}{(\text{MPC})_{\text{body}}} B_b \int_0^t e^{-0.693y/t_{1/2}}\, dy$$

where $(\text{rem/wk})/(\text{MPC})_{\text{body}} = 0.3$ rem/wk

$(\text{MPC})_{\text{body}} = 85$ μc/l

B_b = actual measured acute body concentration (μc/l) in water of urine or other body water

$t_{1/2}$ = elimination half life (std. man) in weeks

= 12/7 = 1.714 weeks

Integrating we have

$$D_t = 0.00873B_b \left(1 - e^{-0.693t/1.714}\right) \quad (1)$$

At $t = \infty$ (i.e., after all significant tritium is eliminated)

$$D_\infty = 0.00873B_b \text{ rem} \quad (2)$$

In some cases it is practical to measure the actual elimination half life exhibited by the person receiving the exposure. In this case the exposure received is

$$D_\infty = 0.00873B_b \times t_{1/2}/1.714 = 0.00509B_b t_{1/2} \quad (3)$$

where $t_{1/2}$ is the observed elimination half life expressed in weeks.

From these considerations a method may be devised for routine calculations of personnel exposures from urinalysis results. The routine method in use at LASL normally estimates the dose received until elimination (D_∞) for an assumed 12 day elimination half life.

III. Routine Method of Dose Estimation

For simplicity of calculation two tables are provided. These appear here as Table I, "Fraction Expected in Urine Based on 12 Day Half Life," and Table II, "Total Whole Body Exposure After All Tritium is Eliminated." A work sheet was devised to provide a systematic and orderly presentation of data to be calculated (see Exhibit 1).

The report on tritium urinalysis contains the name and identification of the person submitting the sample, the date the sample was submitted, and the closest integral number of $\mu c/l$ found in the urine. On occasions when a high exposure is expected, several samples are submitted in a single day. The highest level encountered in the urine each day is used for computational purposes. The accuracy of the analysis for tritium varies from 1 to 2 $\mu c/l$ at a reported 1 $\mu c/l$, from 9.5 to 10.5 for a reported 10 $\mu c/l$, and from 99 to 101 for a reported 100 $\mu c/l$.[3]

The stepwise procedure for evaluating tritium exposures, using the work sheet shown in Exhibit 1, follows:

1. Prepare a work sheet for each newly encountered person.
2. Should there be reported several analyses within 24 hours, record the maximum value in $\mu c/l$ as the acute exposure for an individual for the date indicated. Do not enter the other lower values on the work sheet.

TABLE I

FRACTION EXPECTED IN URINE BASED ON 12 DAY HALF LIFE

Time in Days	Fraction of Immediately Preceding Sample	Time in Days	Fraction of Immediately Preceding Sample
1	0.94	26	0.22
2	0.89	27	0.21
3	0.84	28	0.20
4	0.79	29	0.19
5	0.75	30	0.18
6	0.71	31	0.17
7	0.67	32	0.16
8	0.63	33	0.15
9	0.59	34	0.14
10	0.56	35	0.13
11	0.53	36-37	0.12
12	0.50	38	0.11
13	0.47	39-40	0.10
14	0.44	41-42	0.09
15	0.42	43-44	0.08
16	0.40	45-47	0.07
17	0.37	48-50	0.06
18	0.35	51-55	0.05
19	0.33	56-58	0.04
20	0.31	59-63	0.03
21	0.30	64-72	0.02
22	0.28	73-91	0.01
23	0.26	92 on	0.00
24	0.25		
25	0.24		

TABLE II

TOTAL WHOLE BODY EXPOSURE AFTER ALL TRITIUM IS ELIMINATED
Based on constant body burden of
3.7 mc or 85 μc/l to give constant
0.3 rem/wk dose and a 12 day half life

μc/l in Urine	Body Exposure (rem) from Acute Dose until Eliminated	μc/l in Urine	Body Exposure (rem) from Acute Dose until Eliminated
0	0.000	150	1.31
1	0.009	160	1.40
2	0.017	170	1.48
3	0.026	180	1.57
4	0.035	190	1.66
5	0.044	200	1.75
6	0.052	210	1.83
7	0.061	220	1.92
8	0.070	230	2.01
9	0.079	240	2.10
10	0.087	250	2.18
20	0.175	260	2.27
30	0.262	270	2.36
40	0.349	280	2.44
50	0.436	290	2.53
60	0.524	300	2.62
70	0.611	400	3.49
80	0.698	500	4.36
90	0.786	600	5.24
100	0.873	700	6.11
110	0.960	800	6.98
120	1.05	900	7.86
130	1.13	1000	8.73
140	1.22		

Name: John Doe Film Badge No.: None

Z-Number: XX1X0 Group: H-10

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Date	No. of Intervening Days	μc/l Stated in Report	μc/l for Last Date	Fraction Present of Concentration for Last Date	μc/l Present of Concentration for Last Date	μc/l for Current Date	Body Dose Due to T for Current Date, rem
12/28	--	35	0	--	--	35	0.306
1/14	17	31	35	0.37	12	19	0.166
1/26	12	38	31	0.50	15	24	0.210
2/2	7	17	38	0.67	25	0	0
2/14	12	8	17	0.50	8	0	0
2/25	13	3	8	0.47	3	0	0
3/10	13	2	3	0.47	1	1	0.009
3/17	7	1	2	0.67	1	0	0
3/24	7	1	1	0.67	0	1	0.009
3/31	7	0	1	0.67	0	0	0
						Total for quarter	0.700 rem

Exhibit 1. Example of a Routine Tritium Exposure Evaluation

3. In column 1 enter the date the urine sample was submitted, as stated on report of tritium urinalyses. Be sure the dates of samples are listed chronologically.

4. In column 3 enter the number of $\mu c/l$ for the corresponding date. For analyses indicated as "less than" one (<1), record a zero (0). (Note: In practice, these four steps are completed whenever a report of tritium urinalyses is received, and the remaining steps are completed after the report of final urine assay each quarter year is received. See next section for nonroutine high acute exposures.)

5. a) For the first recorded sample for a person, draw a dash (-) in column 2 (No. of Intervening Days).

   b) For the second and successive samples for a person, indicate the number of days between the current and the immediately preceding exposure in the same column.

6. a) For the first sample indicate a zero (0) in column 4 ($\mu c/l$ for Last Date).

   b) For the second and successive samples, copy in column 4 the figure entered in the immediately preceding line in column 3 ($\mu c/l$ as Stated in Report).

7. a) For the first sample, draw a dash (-) in column 5 (Fraction Present of Concentration for Last Date).

   b) For second and successive samples, look up on Table I the

"Fraction Expected in Urine" corresponding to the "No. of Intervening Days," and enter this figure in column 5.

8. a) For the first sample, draw a dash in column 6 (μc/l Present of Concentration for Last Date).

   b) For the second and successive samples, form the product of columns 4 and 5 (μc/l for Last Date X Fraction Present of Concentration for Last Date). Then enter the smallest whole number of this product in column 6 (μc/l Present of Concentration for Last Date); e.g., if product comes out 17.99, enter 17.

   (Note: This technique of recording the smallest whole number, while appearing mathematically unsound, is used to prevent the underestimation of low exposures. It, in reality, overestimates the actual dose received.)

9. a) For the first sample, enter the figure in column 7 (μc/l for Current Date) which has previously been entered in column 3.

   b) For the second and successive samples, subtract the figure in column 6 (μc/l Present of Concentration for Last Date) from the figure entered in column 3, and enter this difference in column 7. If this difference is negative, enter zero (0) in place of the negative figure.

10. Look up on Table II the "Body Exposure (rem) From Acute Dose Until Eliminated" corresponding to the figure entered in column 7 and enter this in column 8 (Body Dose Due to T for Current

Date, rem). The values in Table II are additive; i.e., to find the exposure corresponding to 323 $\mu c/l$ add the exposures of 300 $\mu c/l$, 20 $\mu c/l$, and 3 $\mu c/l$.

11. For the total exposures resulting from tritium intake during the quarter, sum the exposures in column 8.

IV. Special Procedures for High Acute Exposures

In order to control tritium exposures in a similar manner to that of external whole body exposures, some permissible intake level had to be established. When this limit is exceeded, it is the current practice at this Laboratory to remove the person exceeding it from all work involving the risk of tritium intake.

It was decided to use that body concentration which, if not increased, would result in an exposure of 0.6 rem in the first two week period following the intake. Using Eq. 1, this is 124 $\mu c/l$. In actual practice when a person maintains a level about 85 $\mu c/l$ for several days, it is suggested that he leave the area. However, no special corrections are made in the exposure evaluation.

Usually, when the level of 124 $\mu c/l$ is exceeded, it is grossly exceeded. In addition to removing the person from the area of potential re-exposure, a special evaluation procedure is followed at the end of the quarter year. This consists of computing the actual elimination half life and making the appropriate correction to the routinely computed exposure (Exhibit 2). In practice, the

Name: John Doe, II Film Badge No.: None

Z-Number: XX1X1 Group: H-10

Date	No. of Intervening Days	μc/l Stated in Report	μc/l for Last Date	Fraction Present of Concentration for Last Date	μc/l Present of Concentration for Last Date	μc/l for Current Date	Body Dose Due to T for Current Date, rem
1/26	--	17	0	--	--	17	0.148
2/5	10	13	17	0.56	9	4	0.035
2/12	7	540	13	0.67	8	532	4.639
2/14	2	430	540	0.89	480	0	0
2/17	3	305	430	0.84	360	0	0
2/19	2	240	305	0.89	271	0	0
2/21	2	198	240	0.89	213	0	0
2/24	3	160	198	0.84	166	0	0
2/26	2	139	160	0.89	142	0	0
2/28	2	120	139	0.89	123	0	0
3/3	3	97	120	0.84	100	0	0
3/10	7	66	97	0.67	64	2	0.017
3/17	7	48	66	0.67	44	4	0.035
3/24	7	35	48	0.67	32	3	0.026
3/31	7	25	35	0.67	23	2	0.017
						Total	4.917

Exhibit 2. Routine Uncorrected Evaluation Work Sheet as Basis for a Special Evaluation for High Acute Tritium Exposure

method may become complicated by the observation of two or more elimination rates. The following stepwise procedure allows for the simple case of high acute exposure when there is a single elimination rate (a), and for the more complicated case where there are two or more elimination rates (b). Exhibits 3 and 4 demonstrate the instructions for situation (b).

1. a) and b) From the occurrence of the high exposure, plot the $\mu c/l$ and number of days elapsed since occurrence of the "high" sample on a sheet of semi-log paper (Exhibit 3). Plot the $\mu c/l$ on the log scale and the number of days since the high sample on the linear scale.

2. a) For the simple case, where a single straight line reasonably fits the points plotted, draw this line and compute the elimination half life in days.

   (Note: The elimination half life is the number of days required for the body concentration, as plotted on the graph, to fall to one-half of the original level.)

   b) For the more complicated case, where two or more straight lines are required to fit the points plotted, draw these lines and compute the elimination half lives (in days) corresponding to each.

3. a) Not applicable.

   b) Mark on the graph the point(s) at which the slope changes.

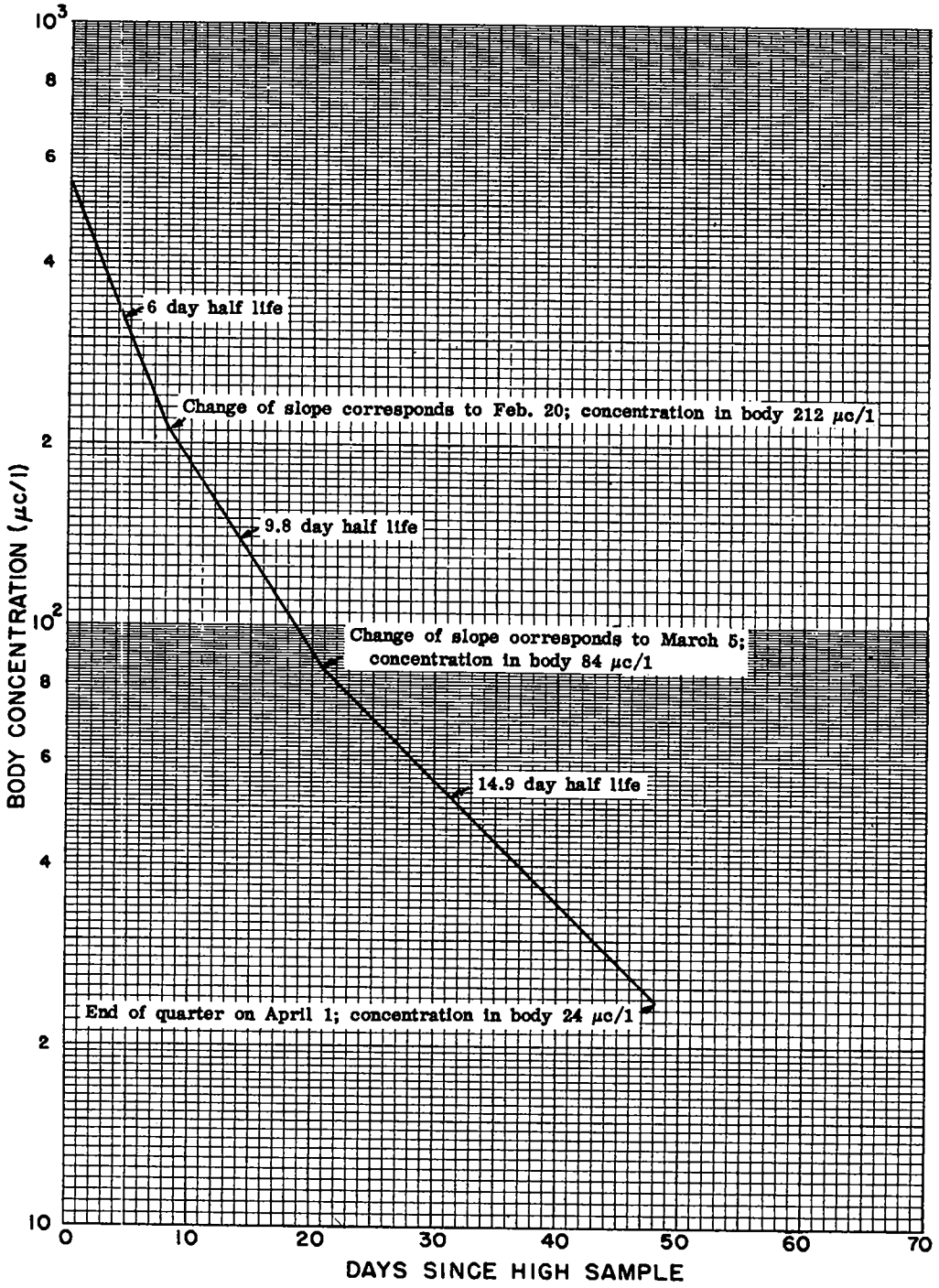

Exhibit 3. Plot of Body Concentration vs Days since High Sample for Computing Elimination Half Life. Procedural Steps 1b, 2b, 3b, 4b, 7b.

Name: John Doe, II Film Badge No.: None

Z-Number: XX1X1 Group: H-10

Step	Date	No. of Intervening Days	μc/l Stated in Report	μc/l for Last Date	Fraction Present of Concentration for Last Date	μc/l Present of Concentration for Last Date	μc/l for Current Date	Body Dose Due to T for Current Date, rem
5b	1/26	--	17	0	--	--	17	0.148
	2/5	10	13	17	0.56	9	4	0.035
								0.183 Add
6b	2/12	7	540	13	0.67	8	532	4.639
	2/14	2	430	540	0.89	480	0	0
	2/17	3	305	430	0.84	360	0	0
	2/19	2	240	305	0.89	271	0	0
8b	2/20*		212*					
9b, 10b		The elimination half life for the period 2/12 to 2/20 was 6 days. On 2/20 212 μc/l was still in the body.						4.639
11b						Dosage from 212 μc/l		-1.847
12b							6/12 X	2.792
12b								1.396 Add
13b, 14b	2/20*	--*	212*	0*	--*	--*	212*	1.847*
15b	2/21	1	198	212	0.94	199	0	0
	2/24	3	160	198	0.84	166	0	0
	2/26	2	139	160	0.89	142	0	0
	2/28	2	120	139	0.89	123	0	0
	3/3	3	97	120	0.84	100	0	0
8b	3/5*		84*					
9b, 10b		The elimination half life for the period 2/20 to 3/5 was 9.8 days. On 3/5 84 μc/l was still in the body.						1.847
11b						Dosage from 84 μc/l		-0.733
12b							9.8/12 X	1.114
12b								0.910 Add
13b, 14b	3/5*	--*	84*	0*	--*	--*	84*	0.733*
15b	3/10	5	66	84	0.75	63	3	0.026
	3/17	7	48	66	0.67	44	4	0.035
	3/24	7	35	48	0.67	32	3	0.026
	3/31	7	25	35	0.67	23	2	0.017
8b	4/1*		24*					
9b, 10b		The elimination half life for the period 3/5 to 4/1 was 14.9 days. On 4/1 24 μc/l was still in the body.						0.837
11b						Dosage from 24 μc/l		-0.210
12b							14.9/12 X	0.627
12b								0.779 Add
17b						Total Corrected Dose for 1st quarter	=	3.268
			Start of Second Quarter					
	4/1*	--*	24*	--*	--*	--*	24*	0.210*

*Astericks indicate item should be written in red.

Exhibit 4. Corrected Evaluation Work Sheet for High Acute Exposure with More Than One Elimination Rate

4. a) Not applicable.

   b) By counting the days since the original high sample, find the actual dates in months and days (of the change of slope) corresponding to the points marked in Step 3b.

5. a) and b) Recopy the tritium evaluation work sheet to the occurrence of the high sample and sum all exposures to this point; write "Add" in the margin beside this summation (Exhibit 4).

6. a) Not applicable.

   b) Recopy the tritium evaluation work sheet from the occurrence of the high exposure up to the date of the first change of slope on the graph.

7. a) Not applicable.

   b) From the graph estimate the $\mu c/l$ concentration present in the body at this time.

8. a) Not applicable.

   b) In red (to indicate that this is not a measured body concentration), make this new entry on the evaluation sheet and date it the date of the change in slope. (For this paper, use of red is indicated by asterisks.)

9. a) Not applicable.

   b) Write a note on the work sheet stating the elimination half life for this period and the tritium concentration still in the body.

10. a) Add the rem dosage for the entire quarter.

b) Add the rem dosage computed in the usual manner for the portion of the work sheet copied in Step 6b.

11. a) Not applicable.

b) Subtract the dosage (as found on Table II) equivalent to the tritium concentration still in the body from the summed dosages of Step 10. Show this subtraction on the work sheet.

12. a) Multiply the sum found in Step 10 by 1/12th of the elimination half life as found in Step 2. This value is the "corrected rem" dose due to this tritium exposure. On the work sheet write a note stating the observed elimination half life, the correction made for this half life and the "corrected rem" dose, and an "Add" in the margin.

b) Multiply the result of Step 11b by 1/12th of the elimination half life as measured in days for the first portion of the elimination. Indicate this multiplication on the work sheet. By the answer of this multiplication, written in the "Body Dose Due to T for Current Date, rem" column of the work sheet, write an "Add" notation.

13. a) Not applicable.

b) On the next line of the work sheet write again (in red) the last date entered and the tritium concentration still in the body.

14. a) Not applicable.

b) Assume this to be an initial dose, and proceed to calculate the exposure in the routine manner.

15. a) Not applicable.

b) Copy all additional entries of tritium assays until the next change of slope, and again follow procedure from Step 7 on, until end of quarter is reached or until an approximate 12 day elimination half life is resumed.

16. a) and b) If at the end of the quarter the urine concentration is still above 124 μc/l, break off the above procedure at the end of the quarter and subtract the dosage due to the tritium still in the body. Correct the difference for the appropriate elimination half life. Record this "corrected difference" as the "corrected rem" for the quarter in which the high exposure occurred. Write "Add" by this last "corrected rem."

17. a) and b) Sum all of the figures with the "Add" notation beside them. This is the "Total corrected rem" for the quarter.

18. At the end of the quarter into which the tritium concentration was carried over in excess of 124 μc/l, complete the special evaluation procedure as per these instructions.

V. Summary

A detailed method is given for estimating the whole body exposure from a known concentration of tritium in the body water. As presented, it is based on a permissible body burden of 3.7 mc, a 43.4 kg critical

organ (total body water), and a RBE of 1.7 for tritium in the body. This method with different values for permissible body burden, critical organ, and RBE has been in use at LASL since 1953.

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