METABOLIC BALANCES OF ^{210}PB AND ^{210}PO IN UNEXPOSED MEN*

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Abstract

The metabolic balances of ^{210}Pb and ^{210}Po were measured in each of 12 men maintained on a metabolic ward. These nuclides were determined in urine and feces from each subject collected for one month or more from each. Representative diets, drinking water and atmospheric levels in the ward were also sampled. The mean levels (±S.E.) were for ^{210}Pb and ^{210}Po, respectively, in diets over a period of five months (1.25 ± 0.04) and (1.63 ± 0.05) pCi/day, in urine (0.275 ± 0.026) and (0.269 ± 0.033) pCi/day, and in feces (1.333 ± 0.062) and (1.89 ± 0.10) pCi/day.

The mean overall balances (the difference between diet and excreta) of (-0.235 ± 0.075) pCi ^{210}Pb/day and (-0.337 ± 0.100) pCi ^{210}Po/day show that over the collection period, larger amounts were excreted than taken in the diet. Atmospheric intake accounts for an additional ^{210}Pb intake of 0.07 pCi/day, but it contributes a ^{210}Po intake of only about 0.02 pCi/day. The contribution of cigarette smoke and dietary levels of calcium to the balances is discussed.

Introduction

The metabolic properties of ^{210}Pb and its decay product, ^{210}Po, in people exposed only to normal environmental levels of these nuclides are important because they contribute a large fraction of the dose from internally deposited nuclides.[1,2] The ^{210}Pb produces essentially no dose, but with its 22-year physical half life, it can accumulate in the body. On the other hand, the ^{210}Po with its 5.3-Mev alpha particle contributes 90 to 95% of the dose from this series (^{210}Pb-^{210}Bi-^{210}Po), but its 138-day half life allows only a limited accumulation from sources other than the ^{210}Pb in the body.

Metabolic balance studies may indicate other routes of intake and excretion. Thus, if the balance is negative (based on diet and excreta), one may look for other sources of intake which may be difficult to measure directly, such as atmospheric aerosols and cigarette smoke.

Some dietary and excretion data have been reported in unexposed populations, but the studies were generally of a limited nature. Glöbel et al.[3] studied the metabolic balances of these nuclides on one person over a one-month period. Magno et al.[4] measured the ^{210}Pb in "typical" diets from several cities, and Morse and Welford[5] determined these levels in a composite New York diet. Some urinary excretion rates have been measured in people with potentially high exposures.[6-9]

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We report here on a study of the metabolic balances of ^{210}Pb and ^{210}Po in men maintained on a metabolic ward for four weeks or more.

Experimental Methods and Materials

Twelve fully ambulatory patients in good physical condition were studied under strictly controlled conditions on the Metabolic Research Ward.[10,11] Their ages were from 42 to 64 years with an average age (±S.E.) of (52.0 ± 1.7) years, and their weights were from 62.6 to 87.0 kg with a mean of (76.0 ± 2.0) kg. Each consumed a constant diet daily which weighed about 2 kg and contained 2200 calories, about 200 mg of calcium and 800 mg of phosphorus. Each subject chose his own daily consumption of water intake (average 2.8 liters/day) which was then maintained constant over the period of study. In some of the studies the calcium intake was increased to 800 or 2400 mg/day by addition of either milk, calcium lactate or calcium gluconate tablets to the above low calcium diet. Most of the patients had been maintained on the ward on the same diet for many months prior to these studies.

Complete urine and stool collections obtained for the study were usually pooled on a six-day basis, although some were combined into four-, eight-, or ten-day pools. Aliquots of representative diets were taken for analysis once a week over a period of 27 weeks. Two sets of drinking water samples of 1 liter each were measured. The atmospheric concentration of these nuclides in the ward was estimated from collections made at several periods during the study.

The ^{210}Pb and ^{210}Po in the samples were determined by the previously described procedure[1] of wet ashing and plating the ^{210}Po onto a silver disk which was then alpha counted. Calcium was determined by atomic absorption analysis on a Perkin Elmer Model 303 Atomic Absorption Spectrophotometer.[12] The accuracy of the analytical results was generally ±5% or better, except that those of the ^{210}Po were about 10%.

Results and Discussion

The metabolic pathways of ^{210}Pb and ^{210}Po are illustrated in Fig. 1. Intake is from food, water, air and cigarette smoke, while output is through excretion and other pathways, such as loss of hair and desquamation of skin.[13] Both nuclides may enter the circulation from the gut and be excreted into the gut. One large contribution (and probably the major one) to the ^{210}Po pool is that from the decay of ^{210}Pb present in the body.

The largest source of intake is diet. The levels from the representative 6-day samples are shown in Fig. 2; the overall mean values (±S.E.) are 1.248 ± 0.029 and 1.630 ± 0.048 pCi/day for ^{210}Pb and ^{210}Po, respectively. The coefficient of correlation between the ^{210}Pb and ^{210}Po data is essentially zero ($R = -0.20$, $P \gg 0.05$). However, the mean ratio of ^{210}Po activity to that of ^{210}Pb, 1.33 ± 0.06 is more important, since correlations may be neither evident nor important in data which vary little about their means.

These data show some systematic variations of the ^{210}Pb, such as minima at the 3rd and 8th 6-day periods and maxima at the 5th and 17th periods. The variations are about 20% of the mean. The ^{210}Po shows similar structure but it lags 3 to 5 periods behind the ^{210}Pb. Some compensation for these variations is made in the balances by using dietary levels extant at the collection times. However, the means of the 27 measured diets and of the diets of the individuals were essentially identical.

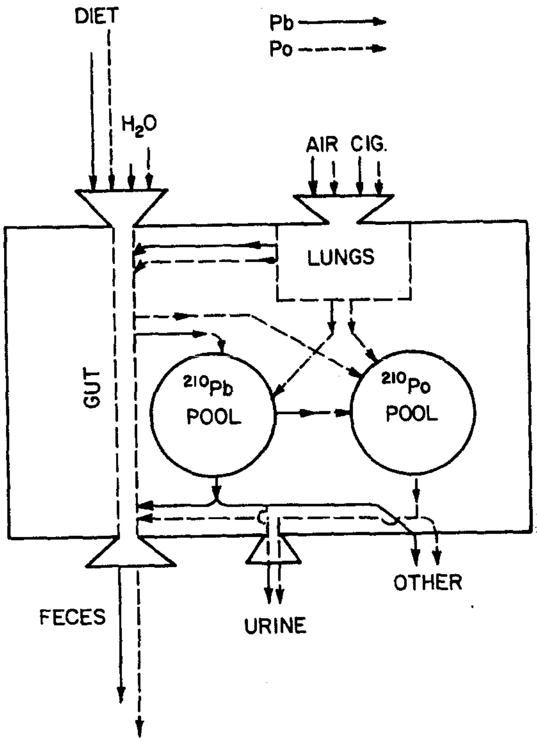

Figure 1. A model of the metabolic patterns of ^{210}Pb and ^{210}Po.

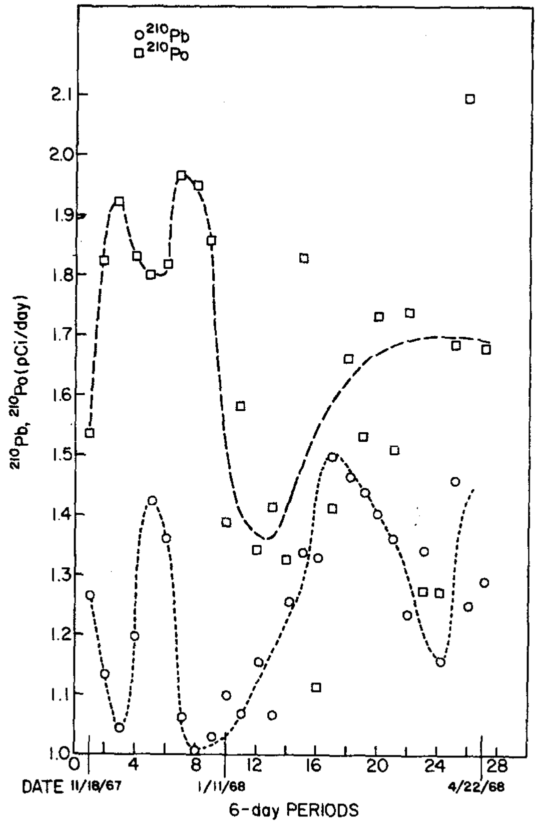

Figure 2. Contents of ^{210}Pb and ^{210}Po in the diets of the subjects measured in representative 6-day samples.

The mean ^{210}Pb content of these diets is lower than that found by Morse and Welford[5] in New York City of 1.40 ± 0.08 pCi/2 kg and than the results of Magno et al.[4] for four U. S. cities of about 1.7 pCi/2 kg. The differences may be due to the lack of some constituents high in ^{210}Pb present in the standard diet, but not present here, such as fresh vegetables and milk. The seasonal variations observed in these data suggest that these values may be at least as representative of a U. S. diet as the single and composite diets reported elsewhere. Drinking water contributes in addition about 0.11 and 0.10 pCi/day to the ^{210}Pb and ^{210}Po intakes, respectively.

The contributions of inhalation to intake are more difficult to assess because they were not measured directly, and they will be estimated only for an average subject. This is estimated from the breathing rate and the atmospheric concentration. Because of the more sedentary condition of these men relative to working men, we assumed the average man's daily breathing rate to be 15 m^3/day rather than the 20 m^3/day of the ICRP "Standard Man".[14] The atmospheric concentrations of the nuclides are shown in Fig. 3. The mean specific activities were (10.9 ± 0.9) and (1.76 ± 0.16) pCi/1000 SCM (Standard Cubic Meter) for ^{210}Pb and ^{210}Po, respectively. The total intake from the atmosphere is then 0.16 pCi ^{210}Pb and 0.026 pCi ^{210}Po per day.

The mean ^{210}Pb excretion rates for each subject, along with his respective dietary and water intake and the respective balances are shown as a function of increasing balance in Fig. 4. Because of the large uncertainties and because they were not measured directly, the contribution of inhalation are not included in these figures. The ^{210}Pb values indicate that the balances depend to a large

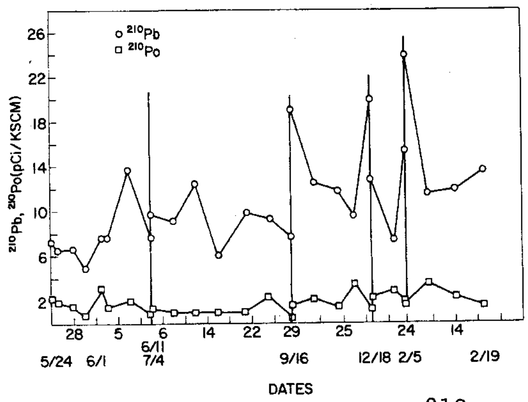

Figure 3. Concentrations of ^{210}Pb and ^{210}Po in atmospheric aerosols sampled in various periods from 5/24/68 to 2/19/69. Each date is the mean date of the sampling period.

extent on the fecal values, which in most cases are about equal to the dietary intake. The more negative balances show more fecal output than dietary input and the more positive ones less fecal output. There also appears to be a general downward trend of both fecal and urinary levels as the balance increases. The calcium balances and high calcium diets (noted by the numbers in mg/day intake next to the calcium balance points) do not appear to affect the ^{210}Pb balances.

The ^{210}Po results were similar to those of ^{210}Pb but their values scatter more and show fewer associations, such as little correlation between diet and feces. The order of the subjects by balance is different than that for ^{210}Pb.

The mean (±S.E.) excretion rates and ranges are shown in Table 1.

The contribution of cigarette smoke to the nuclide intake is shown in Fig. 5 by balance vs. number of cigarettes smoked per week for the seven subjects on whom we measured cigarette consumption. For ^{210}Pb the linear regression of balance (B) vs. cigarettes/week (C) is

$$B = (-0.10 \pm 0.17) - (0.0015 \pm 0.00043)C$$

and the correlation coefficient is -0.59 ($P \approx 0.10$). While neither the intercept nor the slope is statistically significant, they do give an indication of the values. The intercept is equivalent to the atmospheric intake of 0.1 pCi/day and the slope is about 0.21 pCi/day, in a person smoking one pack per day. (These seven people smoked an average of 22 cigarettes per day.) For ^{210}Po the levels of significance are even poorer, although, if the intercept is forced through zero, the slope of -0.0015 pCi/day is significant ($P \approx 0.05$). Previous studies on the nuclide content of cigarette smoke[15,16] lead to an estimated total intake of 0.30 pCi ^{210}Pb and 0.72 pCi ^{210}Po per day.

Table 1. Mean excretion rates and balances of ^{210}Pb and ^{210}Po.

	^{210}Pb (pCi/day)	^{210}Po (pCi/day)
Urine	0.275 ± 0.026 (0.11 to 0.41)	0.269 ± 0.033 (0.079 to 0.52)
Feces	1.333 ± 0.062 (0.99 to 1.83)	1.89 ± 0.10 (1.54 to 2.46)
Balance*	-0.235 ± 0.075 (-0.73 to +0.25)	-0.337 ± 0.100 (-.95 to +0.25)

* diet + water - excreta

The results in Fig. 5 are compatible with the directly measured values of intake from smoke, if one assumes that retention of inhaled nuclides in the respiratory tract is 50% as indicated by various data in the literature.[14,17-19] Daily deposition would then be 0.23 pCi (0.08 from air and 0.15 from cigarettes) and that from ^{210}Po would be 0.37 pCi (0.01 from air and 0.36 from cigarettes) for persons smoking one pack/day.

The balance based on intake from diet and water only, is negative, but it becomes essentially zero, if we add to the intake the contribution from inhalation, as shown in Table 2. In this table the dietary intakes are the average of our representative 6-day samples, the inhaled values are those estimated for inhalation alone, and the excretion values are the overall averages. The different means, taken from the overall averages in Table 2 (diet + water + inhala-

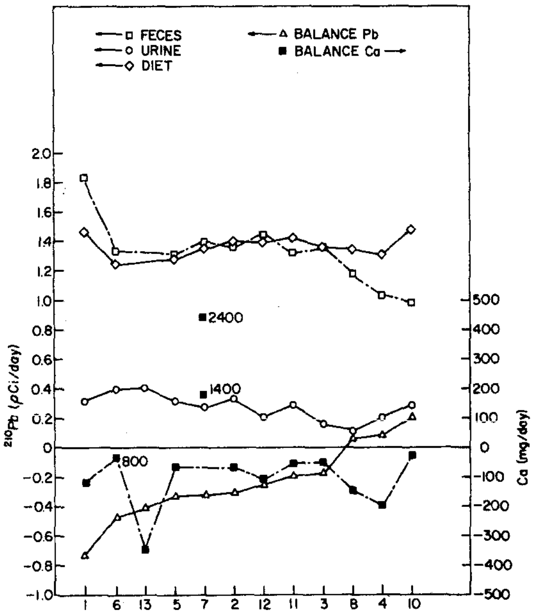

Figure 4. The mean daily levels of ^{210}Pb for each subject in diet, feces and urine and the mean daily ^{210}Pb and calcium balances. The subjects are listed in order of ^{210}Pb balance. The calcium intakes greater than the standard 200-mg per day level are given in mg/day for Subjects 6 and 7.

tion - excreta), is -0.02 pCi/day for ^{210}Pb and -0.06 pCi/day for ^{210}Po which is essentially identical to that of individual balance taken from the mean of the balances for each individual based on his diet, water and excreta (-0.275 and -0.269 pCi of ^{210}Pb and ^{210}Po, respectively) to which has been added the estimated mean daily inhalation intake of 0.23 pCi of ^{210}Pb and 0.37 pCi of ^{210}Po. Thus, the mean balances approach zero to within 3% of the intake values.

These results are lower than those of Glöbel et al.[3] in Germany. Their diet (and fecal excretion) had more than twice the nuclide content of ours, 4.65 pCi of each, and the ^{210}Po/^{210}Pb ratio was about unity compared to our ratio of 1.33. The urinary excretion of ^{210}Po of 0.3 pCi/day was comparable to ours, but the ^{210}Pb excretion was twice this value, in line with the higher dietary levels. The values of Glöbel et al. are probably not typical of the U.S., either because they studied a particular person or because their foods were different.

The balance of the ^{210}Po is important to estimates of radiation dose, while the amount in the body under normal intake depends mainly on the ^{210}Pb content of the body rather than on the intake. For an internal source of ^{210}Pb of 600 pCi (the ^{210}Pb body content of an average man[20]) and with a mean balance of ^{210}Po of less than 0.1 pCi/day, the implied half life is very long and comparable to the 7-year values observed in people high in ^{226}Ra.[21] The ^{210}Po activities are then essentially in radioactive equilibrium with the ^{210}Pb (> 90% of the ^{210}Pb activity).

Thus, the low ratios of ^{210}Po to ^{210}Pb in diet and excreta confirm the previous estimates[20] that only a small fraction of the ^{210}Po in the body is supported by diet when the ratio of the activity of ^{210}Po to that of ^{210}Pb is about unity _in vivo_. Even though the residence time of ^{210}Po is much longer than the 25 days assumed earlier,[20] the limiting factor would be the 138-day physical half life. With no excess of excretion over intake, the accumulation from the diet would be only about 24 pCi, compared to 500 to 600 pCi in the body (if the ^{210}Po is nearly in radioactive equilibrium with the ^{210}Pb).

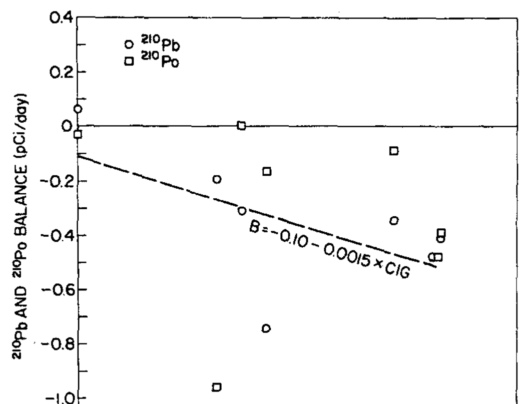

Figure 5. ^{210}Pb and ^{210}Po balances plotted against the weekly cigarette usage for each of the seven subjects for whom this quantity was determined.

Table 2. Summary of components of metabolic balances.

I. Intake				
A. Ingestion				
Diet	1.25		1.63	
Water	0.11		0.10	
		1.36		1.73
B. Inhalation (50% retention)				
Air	0.07		0.02	
Cigarette Smoke*	0.15		0.36	
		0.24		0.37
C. Total		1.60		2.10
II. Output				
Excretion				
Feces	1.33		1.89	
Urine	0.28		0.27	
		1.61		2.16
III. Balances				
A. This Table		-0.02		-0.06
B. Individual (see text)		0.00		+0.03

*1 pack/day

The values of $^{210}Po/^{210}Pb$ ratios of 1.07 in urine and 1.47 in feces make it possible to estimate the amounts of one nuclide given a measurement of the other. However, because of the large variability of these ratios, this estimate is reliable only to within a factor of 2 or so.

In summary, the ^{210}Pb-^{210}Po content of the diets appear to be representative of those in the U.S. when compared to the data of others. They exhibit seasonal variations, a phenomenon not noted in other measurements.[3-5] Both the diets and fecal excretions had a 30 to 40% excess of ^{210}Po over ^{210}Pb, while urinary excretion exhibited equal amounts of each. When account is taken of the contributions of inhalation to intake, this group is in material balance with respect to both nuclides. This result tends to justify the assumption on inhalation used in arriving at the intake values.

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