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A METHOD FOR PREDICTING SUBJECT
BACKGROUND FOR IN VIVO
PLUTONIUM MEASUREMENTS

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Robert W. Bistline

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A METHOD FOR PREDICTING SUBJECT BACKGROUND FOR IN VIVO PLUTONIUM MEASUREMENTS

Robert W. Bistline

Abstract. *In vivo* plutonium measurements in liver and chest are made in the Rocky Flats body counter using ^{241}Am as a tracer. Measurements are made using the 35- to 64-keV band which includes the 60-keV photon of ^{241}Am . Data obtained from 202 subjects show that background counts were contributed by room background, scatter radiation, and the ^{137}Cs and ^{40}K in the individual's body. The difference in counts from one person to another in this energy range was most affected by the scatter radiation. The background counting rate for a person can be predicted by an exponential function where height and weight reflect the difference in body volume and shape.

INTRODUCTION

The Rocky Flats body counter (1) has been used, for the past 3 years, to single out persons with internal plutonium contamination in the chest and liver. Counts have been conducted on employees to establish individual backgrounds for reference. The 60-keV gamma rays of ^{241}Am , the daughter of ^{241}Pu , have been used to measure plutonium in the chest and liver (2). A phantom was used to study the parameters that contribute to human background.

In the past it has been the practice to choose counting information from matching "cold" individuals (2). Discrepancies between the recorded counts on various persons with similar ^{137}Cs and ^{40}K burdens prompted this study. A question was raised whether the variability in counts was actually caused by the ^{137}Cs and ^{40}K contributions, or if it was predominantly a function of scatter radiation which is, in turn, a function of body size and shape. The work described in this paper led to a prediction equation.

PROCEDURE

The body counter used for this study has been described in previous papers (1-3). The counter had two 4-inch by 4-mm and one 9-inch by 4-inch NaI(Tl) crystal detectors (Harshaw Chemical Company,

Cleveland, Ohio). The No. 1 detector (4-inch by 4-mm) was placed over the liver region and No. 2 detector (4-inch by 4-mm) was placed over the left chest. The 9-inch diameter by 4-inch thick detector was placed under the bed near the kidney region. The data on the human subjects from the three detectors were recorded for future comparison with the phantom studies.

The following phantom measurements were used to study the contributions to the counts from liver and chest. A water-filled commercial phantom* was counted, then recounted with an average body burden of ^{137}Cs (10 nCi) and potassium (approximately 150 g) simulating a normal whole body distribution. These data were compared with the average human backgrounds to determine the contribution in the 60-keV region from room background and body scatter, and the ^{137}Cs and ^{40}K burdens.

RESULTS

In this study the data from 202 subjects were analyzed. The distribution of net counts per minute obtained over the 60-keV region is shown in Figures 1 and 2 for the liver and left chest, respectively.

The net counts per minute in the 60-keV band for the left chest were plotted versus the nanocuries of ^{137}Cs (Figure 3) and grams of potassium (Figure 4) to see if any correlation existed. No correlation was indicated by these data. A study of the relationship of ^{137}Cs and potassium to body circumference also showed no correlation by our methods for determining the burdens of these nuclides. Average gross counts were obtained from room background, phantom, and human counts. See Table I. These data show that the average contribution to chest and liver counts over the 60-keV energy band from ^{137}Cs and ^{40}K in the Rocky Flats body counter is approximately 18 c/m. The remaining 32 c/m are from scatter radiation and room background. A phantom containing water and a normal

*REMCAI, Model by Alderson Research Laboratories, Inc., Long Island City, New York.

Figure 1. Net counts per minute from left chest of 202 individuals over the 60-keV region.

body burden of ^{137}Cs and potassium has a resulting gross count in the chest and liver in the 60-keV energy region similar to that of an average-sized human being.

Table I. Gross counts per minute over the 60-keV region with 4-in. dia. by 4-mm thick NaI(Tl) detectors.

Room background without a phantom	20 $\pm$ 1.2 c/m
REMCAL phantom (H_2O -filled)	32 $\pm$ 1.5 c/m
REMCAL phantom (H_2O with ^{137}Cs and potassium)	50 $\pm$ 1.5 c/m
Average human	50 $\pm$ 3.1 c/m

The counts per minute from the energy region (Table I) were then plotted against an index number which was the individual's weight in pounds divided by 2 times his or her height in inches ($W/2H$). Figures 5 and 6 showed a good correlation.

A group of subjects was measured for chest and below-sternum thickness and circumference. These data show a positive correlation to the weight-height relationship (Figure 7) but give a very wide distribution of counts (Figure 8). The method for obtaining the mean and standard deviation lines was the same as that described later for Figures 5 and 6.

DISCUSSION

In past operations it has been routine practice to subtract a room background from the count of human subjects. Such a background was obtained by suspending the detectors over the examination bed in a position approximating that for a normal human counting procedure. This study showed that at least a portion of

Figure 2. Net counts per minute from livers of 202 individuals over the 60-keV region.

the recorded counts from uncontaminated humans was from scatter radiation and that the contribution from the ^{137}Cs and ^{40}K in the body was but a portion of the difference between human counts and room background. Major emphasis in the selection of "match" individuals was placed on the same ^{137}Cs and potassium burdens. Therefore, it became apparent that a more accurate account of the contribution of ^{137}Cs and ^{40}K be known in the 60-keV energy region. Because no correlation was found between net counts per minute in the chest or liver and the ^{137}Cs and potassium; height, weight, and other basic anatomical characteristics were considered.

Since the easiest measured of the afore mentioned parameters are height and weight and these two combined reflect in a very general way the body structure, an attempt was made to correlate between these two

values and the net chest and liver counts in the 60-keV band. The positive correlation of these parameters to the net chest-count values is supported by newly published work by Ramsden and Speight (4). A comparison of the values of the weight-height relationship and the obtained net counts from chest and liver, in the 60-keV region, are shown in Figures 5 and 6. An arbitrary relationship of the weight (in pounds) divided by 2 times the height (in inches) was selected. This relationship gave a convenient number with which to work and proved to be a reliable index of various individual body types. Thus, a graph of the net counts in the 60-keV region versus the index number ($W/2H$) was plotted for all values (Figures 5 and 6). Analysis of the collected net count data with respect to this weight-height relationship results in a positive correlation. The mean line in these graphs goes through the means of the net counts for each recorded

Figure 3. Net counts per minute from left chest in 60-keV region versus the nanocuries of ^{137}Cs in each individual's body.

Figure 4. Net counts per minute from left chest in 60-keV region versus the grams of potassium in each individual's body.

Figure 5. Net counts per minute from left chest of 202 individuals over the 60-keV region versus each individual's index number. Weight in pounds divided by 2 times their height in inches ($W/2H$). Points shown as Φ are the mean of all the counts taken on individuals having same index number.

Figure 6. Net counts per minute from liver area of 202 individuals over the 60-keV region versus each individual's index number. Weight in pounds divided by their height in inches ($W/2H$). Points shown as Φ are the mean of all the counts taken on individuals having same index number.

Figure 7. Correlation of the weight-height relationship (W/2H) versus chest circumference.

Figure 8. Net counts per minute from left chest in 60-keV region versus the circumference of each individual's chest.

index value. A line drawn through the means of the net counts per minute measurements in the chest and liver is described by the following general equation:

$$f(x) = k(1 - a^{-x^2}) + c$$

where k = constant of 34 for the chest and liver at the Rocky Flats counter

c = constant. Its value is 0 for the chest and +4 for the liver at the Rocky Flats counter, where $f(x)$ is the subject's net background.

x = variable which is related to torso volume.

In testing the fit of the equation it was found the constant "a" approximated the value of "e" so "e" was chosen for convenience.

The equation as applied at the Rocky Flats counter is

$$x(c/m) = 34(1 - e^{-(W/2H)^2}) + c$$

where $x(c/m)$ = the predicted net counts per minute in

60-keV region

$W/2H$ = subject's weight (pounds) divided by
2 times his height (inches)

c = constant which takes into consideration the characteristics of the counter (electronics, detectors, etc.) and the region of the body being counted.

This equation is best suited for predicting individual net background counts with present information available in the Rocky Flats files and with the variables most easily obtained when making routine counts. A slightly different equation obtained from a purely statistical least squares analysis of the data also gives a line approximately the same as the above equation over the normal range of the individuals' heights and weights.

Using the deviations of the individual data points relative to the mean line (Figures 5 and 6), a standard deviation for the line was determined and shown by the $+1\sigma$ and -1σ lines. The 0.96 error is shown by the $+2\sigma$ and -2σ lines.

In order to decide if a person is contaminated, a system was adopted where a count between two and three standard deviations (2σ and 3σ) from the mean line required a second count. If the second count is above the 2σ line, the individual is considered a probable positive contamination case.

With this equation one can determine the approximate net count a subject of any height and weight will probably count when not contaminated. This information can be extremely useful in (a) possible internal

contamination cases where a person does not have a previous count; (b) for detection during routine counting of persons who may have become unknowingly contaminated internally sometime in the past; and (c) as a guidepost in determining if a person is contaminated in an accident and quantifying the amount if the counts are above 2σ .

This equation has been used for comparison with actual routine counts on more than 900 individuals. Greater than 80 percent of these net counts has fallen within the 1σ bands.

CONCLUSIONS

The data show that the counts obtained in the energy region of 60 keV by crystal detectors on the chest and liver are contributed by room background, scatter radiation, and the ^{137}Cs and ^{40}K in the body. The difference in the net counts from one person to another in this energy range is not a function of the ^{137}Cs and ^{40}K , but rather the background and scatter radiation and it is, therefore, predictable by an equation where height and weight reflect the difference in body volume and structural body form.

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