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In-Vivo Measurements of Pb-210 To Determine Cumulative Exposure to Radon Daughters: A Pilot Study

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SUMMARY

The objective of this study is to demonstrate the feasibility of estimating cumulative exposure of individuals to low concentrations of radon by measuring the amount of Pb-210 in their skeletons. This report presents progress to date establishing the validity of an *in-vivo* technique to measure skeletal burdens of Pb-210, accumulated from exposure to radon and radon progeny.

With the skeletal content of Pb-210 and a model for Pb metabolism, cumulative exposure to radon and its short-lived daughters (radon/daughters) may be calculated for use in deriving a dose-response relationship between lung cancer and exposure to radon/daughters.

Data are presented for 29 subjects exposed to "above-average" Rn concentrations in their homes, showing the correlation between measured Pb-210 burdens, and measured pCi/l and WLM exposure estimates. Their results are compared to measurements of a population of 24 subjects presumed exposed to average concentrations, i.e., <1pCi/l.

Measurements of a Pennsylvania family exposed for a year in a home with an extremely high radon content are also presented. This family was not part of the NYS subject selection but was included in the study when the opportunity to measure them arose.

Results of an ongoing study of the biological half-time of Pb-210 in man are also presented. These measurements, of a retired radiation worker with a 40 year old skeletal burden of Pb-210, have been in progress for about 10yrs. Although not planned as part of this contract, they are presented because of their relevance to the problem of establishing a meaningful correlation between lung cancer incidence and radon/daughter radiation dose to the lungs. It is the first report of a measurement, in man, of the half-time of this isotope.

Finally, progress on the determination of Pb-210 in samples of food, tobacco and mine air obtained from the Yunnan Tin Corporation in

Gejiu City, PRC, is reported.

Introduction

It is now universally accepted that a relationship exists between pulmonary deposition of alpha-emitting radionuclide particulates and lung cancer. Thus epidemiologists, radiation health specialists and radiation biologists agree that a technique which yields estimates of cumulative exposure to Rn and its alpha-emitting decay products would be an essential tool to the establishment of this relationship - especially one in which the exposed individual acts as his own sampler/dosimeter, thereby insuring the accuracy of the estimate on a "person-specific" basis.

The EPA radon concentration "action" limit of 4pCi/l in air has been promulgated using in part, data obtained from the uranium mining, occupational experience, involving men laboring in extremely high concentrations of radon/daughters. Exposures, even in "higher than average" homes, are not only much lower in general, but also may involve large differences in the amount of radon/daughters inhaled because of far less strenuous home-oriented activities. The cumulative amount of radon/daughters inhaled is of course what is responsible for the radiation dose to lung tissue, and the Pb-210 measurement technique can yield an estimate of this amount.

Thus far, Pb-210 measurements have been performed on 29 subjects living in homes along the "Southern Tier" section of New York State with above-average levels of Rn, and 24 control subjects working at A.J. Lanza Laboratory, NYUMC. Four members of a family from Pennsylvania who lived one year in a home with extremely high radon levels - on the order of 2000pCi/l - were also measured. The control subjects live in an area known to have home levels averaging about 1pCi/l, whereas subjects' homes range from 30pCi/l to 70pCi/l. The difference in measured Pb-210 skull burdens between controls and subjects is distinct. Of the 29 subjects, 14 show levels from 78pCi to 301pCi and 15 were below a detection limit of about 70pCi, whereas 23 of the 24 controls are below the detection limit. Three of the four members of the Pennsylvania family have measurable burdens of Pb-210, with the highest found in the youngest son(6yrs old) who spent the first year of his life there.

Methodology

Subject Selection: Using the Radon Exposure Registry of the New York State Health Department , co-investigators in the Bureau of Environmental and Occupational Epidemiology select homes in which radon exposure levels of more than 100 WLM had been reported. A letter (Figure 1) requesting their participation in the NYU/NYS Pb-210 study is mailed to each of the selected home owners . If the response is positive, NYUMC/IEM investigators are notified and follow up with a phone call to arrange a measurement date. Thus far the percentage of positive responses has been about 50%. To extend the number of subjects in the current study, the identification level will be lowered to 50WLM.

Pb-210 Measurement: Pb-210, a bone-seeker and the longest-lived daughter product of radon, may be measured externally by detection of its 47keV gamma-ray (abundance = 4%) with NaI(Tl)/CsI(Tl), "phoswich" detectors, placed around the subject's head. These detectors were specially designed and developed at NYUMC/IEM(1) for the detection and measurement of low-energy (<200keV) photon emitters such as Pb-210. The skull is the selected measurement site because it is a large bone mass with relatively little overlying tissue, thus minimizing absorption of the 47keV photon. Also, the relatively small variation in skull size over a wide range of body sizes and weights yields a Pb-210 calibration factor (cpm/unit Pb-210 in skull) which has a minimum associated geometry error.

For the measurement, six, 15min. counts are accumulated - 90min. total. The subjects are placed in a comfortable, semi-reclining position on a padded, variable-position chair, in the NYUMC/IEM whole-body counter, and can watch television or listen to music during the measurement. The six periods are divided into groups of two, 15min. periods. After 30min., the subjects are given the opportunity to walk about before resuming the measurement. During the measurement, three phoswich detectors are placed in reproducible positions around the subject's head; i.e., on each side and at the top (Figure 2). At the same time, a measurement is made with the 8x4in. NaI(Tl) detector in the whole-body counting position to account for possible contribution to the Pb-210 skull count from other nuclides which may be present, due for example, to a medical procedure involving radioisotopes that the subject may have been exposed to recently.

Measurement Results

Phoswich detector spectra for each of the six, 15min. counting periods are acquired and stored in a PC-based, multi-channel analyzer system. The spectra are converted to ASCII and ported to a program, written in the LOTUS 123 macro language, which analyzes the counting data and presents the final result of the measurement - pCi of Pb-210 in the subject's skull. Figure 3 shows the program's output of an NYU control subject measurement; Figure 4, the output of one of the NYS subjects.

The first line of the output lists the subject's name, age, height and weight. "Head Measurements" lists the tape measurements (CIRCumference Front to Back and Chin to Crown) and caliper measurements (DIAMeter Front to Back, Chin to Crown and Side to Side) of their head size. The latter are taken for possible future refinement of the skull calibration factor. The central portion of the output, "Pb-210 MEASUREMENT RESULTS", lists the total counts for each 15min. period, summed over three separate regions of the subject's spectra; (1) the Pb-210 peak region, "Pb cnt" = the sum of 72 channels (approx. 30-60keV), (2) a Low-Energy region, "LE cnt" = sum of 24 channels immediately below the Pb-210 peak channels, and (3) a High Energy region, "HE cnt" = the sum of 24 channels immediately above the Pb-210 peak channels. The standard deviation (SD, 1 sigma) for each count in each region is also calculated. The LE and HE regions are used to obtain the subject's Pb-210 peak region background correction, discussed in detail below.

Counts in the three regions are summed in the next line as "MEAN(cpm)" - the mean, and standard error of the mean, of the counts for the N periods. Conversion to cpm allows for the possibility that N may not always be 6 for each subject. For example, the children, 6 and 9yrs. old ,of the Pennsylvania family were in the WBC for four, 15min. periods. "BKGD(cpm)" is the mean and standard error of 50, 14hr. measurements of a head phantom, summed over the LE, HE and Pb-210 regions. The "CORrected BKGD" is the product of the "CORrection FACTor" and the mean and standard error of the head phantom BKGD(cpm) in the Pb-210 region. The CORrection FACTor is the average of the "LE CORrection" and "HE CORrection" factors, obtained by taking the ratio of the MEAN(cpm) and BKGD(cpm) in the LE and HE regions, respectively. The errors shown are the propagation of the counting errors in each region.

Background, an important component in any measurement of radioactivity, is especially important in measurements which are at or near the limits of detection since these limits are functionally related to the background. For measurements of human subjects, it is often possible to measure a control subject of the same age and size as the subject as background. In the case of Pb-210 however, it is impossible to find anyone who has not been exposed to radon/daughters - everyone must have a Pb-210 burden - and thus another method must be found to obtain the "subject" background.

Inside the whole-body counter, the subject's background counts in the Pb-210 region are due to (1) "room" background, i.e., external sources such as cosmic-ray interactions and radioactivity in the detectors, building materials, soil, etc., and (2) low-energy, Compton-scattered photons and bremsstrahlung photons from K-40 in the subject's body. The former is reasonably constant and statistically predictable; the latter - subject K-40 contribution - is much more variable. "Subject" background is thus the sum of predictable "room" background counts, and a variable contribution due to the subject's K-40 content - which is a function of size and age. A reliable method for prediction of this variable contribution has been derived with the use of a head phantom containing potassium and calcium dissolved in water, as described below.

"BKGD(cpm)" are the counts in the Pb-210 region from a head phantom in the same position between the detectors as a subject's head. The head phantom used for background contains 8gm of potassium - obtained from values given in "Reference Man"(2) - as the approximate amount of K in an adult head. The phantom also contains 100gm of Ca, to match the photon scattering and absorption conditions of an actual head. Repeated, long term measurements of this phantom yields a statistically "well-known" count of "room" background, plus a contribution from the K-40 contained in the 8gm of K - and will differ (+/-), from the variable "subject" background only by the unknown increment due to the subject's actual skull K content, which may be different than that of the phantom. This incremental difference is accounted for by using the LE and HE region corrections discussed above. As shown in the output (Figure 3 or 4), the ratio of the counts in these regions, taken from the subject and phantom counts, yields the CORrrection FACTor used to add or subtract the counts necessary to match the phantom spectrum to the subject's spectrum. In this manner a statistically well-known "subject" background - the COErected BKGD - is obtained for the subject in the Pb-210 region. (see NOTE below)

An example of the fit obtained from this procedure is shown in Figure 5, a phoswich spectrum of the head measurement of a control subject with the corrected background spectrum overlapped. The overlap was obtained by multiplying the head phantom spectrum by the CORrection FACTor obtained from the LE/HE correction routine. Note the much smaller deviation in the corrected background spectrum (the average of 50, 14hr. backgrounds) compared to the subject spectrum (the average of six, 15min. spectra). It is the CORrected BKGD. that is subtracted from the mean of the subject's gross counts to obtain the "NET CNT" in the Pb-210 peak region.

NOTE: "Background as defined here are all the counts in the Pb-210 region of interest that are not due to Pb-210, specifically. This definition of background should not be confused with that background due to the presence of Pb-210 from sources other than radon/daughter decay, e.g., food and tobacco. These latter sources of background must be accounted for in the model relating concentration to exposure.

Two criteria are of importance when measurements of radioactivity are made(NCRP,1985;NCRP,1988). One criterion, the "critical level" or L_c, is important to decide whether or not activity is distinguishable as being above background. The second, the LLD or "lower limit of detection, indicates the smallest sample count rate necessary to state that activity is present with a preselected degree of certainty, i.e., that the net count obtained is greater than the critical level. The critical level is the sample count rate which must be present in order to state - when the sample is counted over and over - that only 1-alpha times will the Type I error be made, i.e., saying activity is present when in fact it is not.

$$L_c = k_{alpha} * S_o$$

k_{alpha} = the value of the upper percentile of the standardized normal variate corresponding to the preselected risk (alpha) for concluding falsely that activity is present. For our counting, alpha is taken to be 0.1, for which k_{alpha} = 1.28.

S_o = the estimated standard error for the net sample count rate when the sample activity is actually zero.

$$S_o = (R_b/T_s + S_b/n)^{1/2}$$

T_s = sample count time.
R_b = background(corrected) count rate.
S_b/n = standard error of n background measurements

Thus a corrected subject background, typically of the order of 50cpm, and the background standard error of 0.2144, yields a critical level of 1.12cpm or 1.12/13.8 = approximately 80pCi for the current detection system. The critical level varies however, being dependant on age and weight of the subject, and ranges between 60pCi and 90pCi. This value is also often called MDA or minimum detectable activity.

The other criterion, sometimes preferred, is the LLD.

$$LLD = (kalpha + k_{beta}) * S_o$$

k_{beta} = the value of the standardized normal variate for a predetermined degree of confidence(1-beta) for detecting the presence of activity. Usually kbeta is selected to equal kalpha.

This value, when used, indicates the count-rate necessary in a sample in order to detect its presence above the critical level. That is, when the sample is counted over and over, only beta times will the Type II error be made, i.e., saying no activity is present in the sample when in fact activity is present.

Results below the "critical level" count-rate (C.L. on the print-out) will be reported by the program as no detected activity, i.e., "less than C.L.". Since the CORrected BKGD is different for each subject, the critical level will also be different. The C.L., in pCi, is the ratio of C.L. in cpm and the "CALibration FACtor" in cpm/nCi*1000. The final result, "SKull Pb-210" in pCi, is shown with its 1 sigma S.D., above the dotted line.

Summary of Results To Date

A summary of the Pb-210 results thus far for the NYS subjects, the NYU control subjects, and the Pennsylvania family (OTHER), are shown in Table 1. As stated earlier, the difference between the two populations is apparent. Twenty three of the 24 NYU control subjects are below the critical level. It should be noted that the one control subject with a measurable Pb-210 burden is an inveterate smoker, and tobacco is a known source of Pb-210 intake. Of the subjects, 14 of the 29 measured thus far are below the critical level; the others have skull burdens ranging from 78 to 301pCi. As shown, the highest burden was measured in C.W., the youngest in the family from Pennsylvania. He lived the first year of his life in a house which had a measured radon concentration of about 2000pCi/l. After that year, the house was "remediated" to a value well below the EPA's 4pCi/l suggested action level.

No data are currently available for radon concentrations in the

NYU control subjects homes. However, in a report of extensive measurements of home exposure levels taken throughout New York State for the NYSERDA(3), it is shown that homes in the area surrounding the location of NYUMC/IEM in Tuxedo, NY, have low, average radon concentration values (1pCi/l) relative to the homes along the Southern Tier (40-50pCi/l), where all of the NYS subjects reside. Of course, this does not account for variability among individual homes, which may be be high. Measurement of the NYU control subject homes is proposed for the coming year.

Table 2 lists the Pb-210 results of the 29 NYS subjects along with the measurements of radon concentrations in their homes, as obtained from the New York State Department of Health, Bureau of Environmental and Occupational Epidemiology. Shown are the measured values of radon concentrations in pCi/l in the basement (B-pCi/l), the 1st floor (1-pCi/l), and 2nd floor (2-pCi/l). The concentration data was obtained from charcoal canisters and track-etch detectors mailed to home owners who had been screened previously and were interested in participating in the Radon Registry study. The canisters were returned for readout after exposing them in the basements of their homes for a short period. The track-etch detectors were kept and exposed in the living area of the home for a period of one year, as per Health Department instructions. For the data obtained thus far, only one 2nd floor exposure was actually measured. The other 2nd floor concentrations were assumed to be the same as those measured on the 1st floor.

Table 3 lists the WLM exposure estimates for each of the NYS subjects. WLM estimates were calculated from the measured concentration values - assuming 50% radioactive equilibrium between radon and daughters - and estimates of the percentage of time spent in the house and in the locations listed, as obtained during the Health Department's interview of the subjects.

Note that the entries in Table 1, listed as less than C.L., have been changed to values of the order of 30+pCi in Table 2. As stated above, since radon is ubiquitous, it is not possible for anyone to have zero exposure and a zero burden of Pb-210. Thus, for a correlation analysis of the data in Table 2, a linear extrapolation was assumed between zero and the critical level for each subject, and a value is assumed for those with a measurement result below the critical level which is half their critical level.

The correlation analysis of the data in Tables 2 and 3 is shown below the tables. Figures 6 is a plot of Pb-210 vs. total radon concentration. The fit, as indicated by the "R" value in Table 2, is not strong. Given the nature of the radon concentration measurements it would be perhaps unduly optimistic to expect a better fit. Any of the following conditions that might account for the lack of a very strong fit:

1) Knowledge or correction for variability in the Rn/daughter concentration due to ventilation changes, building changes, e.g., construction additions and/or subtractions, etc., which may have occurred before the measurments of radon concentrations took place.

2) Accounting for changes in residency for significant periods during the total exposure period, e.g., vacations, retirement, visits, etc.

3) The wide variability of individual lung function parameters and changes in these parameters over the exposure period. For example, development of emphysema, bronchitis, colds, etc.

4) Changes in the composition of the indoor air particulate. For example, starting or giving up smoking, smoke from others in the house who smoke - permanent residents or guests, dust loads in the house from cleaning. The kind of home-heating system used, e.g., baseboard vs blown hot-air.

5) Changes in radon concentrations over the seasons. Even though an average concentration is obtained by leaving a track-etch detector in place for a year, this measures the average at that position only.

6) Pb-210 acquired from living in another home which had a high radon concentration before moving to the present one, in which the concentration has been measured.

7) The burdens shown still contain a contribution due to other sources of Pb-210, diet and smoking, which have not as yet been taken into account. This contribution will be calculated from the known levels of Pb-210 in foodstuffs, tobacco, etc., in the literature, and subject histories obtained during interview at NYUMC/IEM. Calculations indicate these contributions to be of the order of 40pCi-60pCi, depending on age, smoking/dietary history, etc. In some cases, these contributions will be a significant fraction of the total burden. It is thus very important to obtain the best possible estimate of them to arrive at a net burden of Pb-210 due only to radon/daughters measured in the home environment.

The correlation however between Pb-210 and total radon concentration - i.e., the "trend" of the data - is shown in the analysis to be strongly positive with an excellent "p" statistic. Thus it can be stated that there is a strong and definate correlation between the radon concentrations measured in the NYS subjects' homes and the burdens of Pb-210 as measured with the in-vivo technique. Coincident with this analysis, Tables 4 and 5 and Figures 7 and 8 show the same analysis performed on separated male and female subjects. The female data shows an even stronger correlation than the grouped data, while the males show a much poorer correlation. This may indicate the fact that subjects in this group are for the most part in their 60's who were raised in an era in which woman may have spent much more of their time at home and - at the risk of sounding sexist - may have spent more time in the basement doing laundry, etc. In any event it is further evidence of the power of the in-vivo methodology in that it is possible to distinguish so clearly a difference in the actual exposure of the two populations, otherwise indistinguishable from observation of the radon concentration and/or WLM estimates.

As shown in Table 3, the correlation between Pb-210 and WLM estimates is poor. This is as expected since the actual value of WL is unknown - a value of 50% equilibrium is assumed - and the amount of time used in the estimate of WLM is obtained from the subjects' recollection of the the time spent in various areas of their home, for most, periods of 30 or 40 years, at the time of interview. Although necessary to make the WLM estimate, this undoubtedly represents the weakest area in the evaluation of exposure.

It is at this point that the value of the Pb-210 measurements becomes evident. From the Pb-210 measurements, it will now be possible to calculate the amount of radon and radon progeny in pCi/day which each subject inhaled to result in the observed body burden of Pb-210 at the time of the measurement, and from this, to calculate the resulting radiation dose to the lungs from the estimated exposure. The model for the exposure estimate and the assumptions necessary for its use are now under active study.

Discussion of the Pb-210 Results

From the results obtained thus far, it can be stated with certainty that the phoswich detector system currently in place at NYUMC/IEM is capable of measuring Pb-210 burdens in persons who have been exposed for long periods in homes with radon concentrations near "average" levels. This is made possible with the use of the new technique discussed above to obtain subject backgrounds with small errors by taking advantage of the stability of phantom backgrounds measured repeatedly with long counting times. As shown in the Pb-210 measurement results, there is a distinct difference between the subjects exposed in homes with "higher-than-average" concentrations of radon and those exposed in homes with "normal" levels. Many of the NYS subjects in fact had measured burdens greater than 136pCi, i.e., twice the critical level. This amount (2xC.L.) is generally accepted as statistically "detectable". These results are taken as confirmation of the technique; validation however, will have to await the acquisition of more data and additional correlation of measured Pb-210 burdens and the other measures of exposure.

Prototype Detector: As was pointed out, there is no one who has zero exposure to radon and a zero burden of Pb-210. Thus, while the critical level of 68pCi for the current system is apparently capable of detecting and measuring the Pb-210 burdens of people living in homes with average concentration levels of 40pCi/l to 50pCi/l, it would be advantageous for future measurements utilizing the <u>in-vivo</u> technique, to lower it to the order of 10pCi/l to 20pCi/l. To work toward accomplishing this, another task was undertaken for the current year. This is to test a new design of the phoswich detector which should increase the sensitivity of the measurement by about a factor of 4 which, with the concurrent increase in background, should decrease the C.L. to the order of 25pCi. This is important since, as was pointed out above, Pb-210 burdens of people living in homes with "normal" concentrations are expected to have skull Pb-210 burdens in this range. This task is currently underway, and a prototype of one section of the new detector is now under construction. Figure 8 shows the design of the prototype section. The square face adds about 25% more active detection area over that of a comparably dimensioned cylindrical phoswich. As indicated in the drawing at the top of Figure 9, the individual sections can be arranged in various positions relative to each other. For measuring Pb-210 in the skull, the detector, consisting of eight of the sections, would be arranged around the head as shown in the bottom drawing. A cylindrical phoswich placed at the top of the head would complete the system.

<u>Measurement of Pb-210 Biological Half-life</u>

One of the most important parameters in any model relating the skeletal content of Pb-210 to an estimate of the cumulative exposure to radon/daughters is the biological half-time of Pb-210 in bone. To date, values for this parameter have been derived from various animal studies, each of which has had some significant drawback leading to related uncertanties in the result. For example, two of the most prevalent limitations noted in a majority of these studies are an insufficient time-period over which the measurements have been carried out, and an inappropriate animal species in which to perform biokinetic studies of a "bone-seeking" element such as lead.

For the present study, we are fortunate to have the cooperation of an individual who not only has a skeletal burden of over 200nCi of Pb-210 but who has been available to us for measurement over the last 10 years. He is 65 years old and obtained his Pb-210 burden approximately 40yrs ago - probably by direct inhalation while he was packaging the isotope for commercial sale. The first measurement of his skull burden was performed by Pomroy on 9/26/80(4). Since then, we have performed an additional 4 measurements. Referencing Pomroy's measurement as time 0, we have a measurement at t=137 days, two on day 2629 and another on day 3585. In addition, urine collections were made on days 2629 and 3585. Thus we can now obtain a preliminary estimate of the biological retention and effective halftime of Pb-210 in man at long times after an acute exposure.

Figure 11 shows the phoswich spectrum of Pb-210 in this subject's skull, measured on 7/13/90. His skull burden as of that date was 22.5nCi. A plot of his body burden versus time is shown in Figure 12. As shown, the estimate of effective half-time from the curve is calculated as 18.1+/-4.8yrs. The urine samples obtained during two of the measurement dates - day 2629 and day 3585 - were chemically analyzed and indicate an average excretion rate of 5.51+/-0.32pCi/day. Using the formula

$$A = A_o - R_e t$$

where A = activity at some time t days
A_o = activity at time = 0
R_e = rate of excretion = 5.51+/-0.32pCi/day
t = time in days

the value obtained for biological half-time, for a body burden of 226.6+\-28.8pCi at time 0, is 56.3+/-8.3yrs. This is compared to a value of 27 years given in ICRP II. From this and a value of 22.2yrs for the physical half-time, the effective half-time is calculated to be 15.9+/-4.2yrs, in good agreement with the effective halflife obtained from the <u>in-vivo</u> measurements. From the physical halflife of 22.2yrs. the loss by decay of the isotope at day 3585 is calculated to be 59.8+\-20pCi. The loss using an effective halflife of 18.1+/-4.8yrs is calculated to be 71.1+/-20pCi at the same point in time. The loss due to urinary excretion is calculated from the above excretion rate(5.51+/-0.32pCi/day) as 19.8+/-1.1. The difference between the loss due to physical and effective halftimes of 71.1 - 59.8 = 21.3nCi is accounted for with the urinary excretion. Thus at this point in time, i.e., approximately 40yrs. after the intake, it appears that Pb-210 excretion is occurring by the urinary route only.

This will be checked in the near future with the analysis of a 24hr fecal sample.

<u>Chemical Analysis of Food, Tobacco, and Mine Air Filters from Yunnan Province, PRC</u>

Fifty-one samples have been obtained from the Institute of Labor Protection, Yunnan Tin Corporation, Gejiu City, Peoples Republic of China, for determination of their Pb-210 content. Of these 51 samples, 14 are regional foods, 7 are regional tobaccos, and 32 are mine air filters taken at various levels of the largest tin mine in the area. Data from these samples will be used to ascertain whether it will be necessary to get additional samples of these materials to obtain a correction factor for secondary sources of Pb-210 intake in a study of the Pb-210 skeletal burdens in a large population of retired tin miners of the Yunnan Tin Corporation, in Gejiu City.

The tin miner Pb-210 measurements are a part of a lung cancer/case-control study of this population which can provide valuable information on the correlation of Pb-210 skeletal burden and radon/daughter exposure to lung-cancer incidence. The tin-miners are representative of a population mid-way between the very high uranium miner occupational exposures and the current "higher-than-average" environmental exposures in this country. Because of the importance of establishing a dose-response relationship for the tin-miner population, additional funding to our current DOE contract was supplied for the above sample determinations.

The Pb-210 content of these samples are being determined by scintillation detection of their beta-particle emission. The method is based on the solvent extraction of a lead bromide complex into Aliquat-336. Pb-210 is isolated from most interferences. Its daughter, Bi-210, is separated from Pb-210 and the beta activity is measured radiometrically after ingrowth.

<u>Sample Preparation</u>

The samples are prepared for beta counting as follows:

1. Wet ash with concentrated HNO_3, add lead carrier, reduce to dryness and add 3M HBr.

2. Determination - strip the lead from the sample by combining with Aliquat-336 in a separatory funnel, separating the organic and aqueous phases. The organic phase is washed with 0.1M HBr. The lead is stripped by shaking with concentrated HCl. The strip solution is then oxidized in a beaker with concentrated HNO3.

3. Ingrowth of Bi-210 - The Bi-210 is separated from the parent Pb-210 by precipitating Bismuth Oxychloride (BiOCl), and centrifuging. The final Pb-210 solution is stored for 2-3 weeks to allow the ingrowth of Bi-210. After the 2-3 week ingrowth of Bi-210 the solution is again precipitated as BiOCl on a Whatman #42 filter paper. the filter is then mounted on a 1 inch plastic ring and disc, covered with Aluminum foil, (7.2 mg/cm2), and Mylar film. The precipitate is then counted in a beta scintillaiton counter.

Calculation

The Pb-210 disintegration rate is calculated using the following formula:

$$\text{dpm of Pb-210} = (R_n Y_1 Y_2)/(GD)$$

where R_n = net counting rate of sample

Y_1 = recovery factor for lead carrier (to be determined by Atomic Absorption)

Y_2 = recovery factor for bismuth carrier (to be determined by weight of filter)

E = counter efficiency

G = growth factor (growth of Bi-210 from first milking to final milk)

D = decay factor (decay of Bi-210 from final milking to time of counting)

Analysis of these samples has not as yet been completed.

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TABLE 1 - Results of Measurements of Pb-210

TABLE I: Results of Measurements of Pb-210 (pCi in skull) in NYS Radon Register Subjects (NYS SUBJ), NYU Personnel (NYU SUBJ), and the Pennsylvania family

NYS SUBJ.	Pb-210(pCi)	NYU SUBJ.	Pb-210(pCi)	PENN. SUBJ.	Pb-210(pCi)
MEC	78+/-73	JSE	<C.L.	SJW	57+/-33
JDL	170+/-65	MTL	<C.L.	DMW	172+/-45
CFH	<C.L.	XWW	<C.L.	MW	<C.L.
KKH	301+/-59	MAM	<C.L.	CW	275+/-48
PCM	93+/-59	RSM	<C.L.		
PMM	<C.L.	RW	<C.L.		
HEB	109+/-38	DJJ	<C.L.		
TJB	216+/-45	GBC	<C.L.		
JRM	<C.L.	TAK	<C.L.		
ERM	142+/-62	JC	<C.L.		
CHT	<C.L.	BMG	<C.L.		
SET	<C.L.	GRL	<C.L.		
WHH	<C.L.	VM	81+/-68		
EEH	121+/-47	MAS	<C.L.		
JRF	<C.L.	SM	<C.L.		
MAF	<C.L.	MH	<C.L.		
CF	93+/-54	BGW	<C.L.		
PJC	92+/-59	EHC	<C.L.		
RRA	192+/-44	CMG	<C.L		
BB	184+/-70	AS	<C.L.		
VJB	92+/-70	PJ	<C.L.		
OAS	<C.L.	MDC	<C.L.		
CBS	<C.L.	RP	<C.L.		
EJR	108+/-83	HAT	<C.L.		
VJR	<C.L.	AD	<C.L.		
ADS	98+/-128	DJO	<C.L.		
HRS	<C.L.	PK	<C.L.		
MAS	<C.L.				
MJS	<C.L.				

NOTE: The Critical Level (C.L.) for both groups was calculated as the mean and standard deviation of the mean for each group and is 68.75+/-1.46 pCi and 68.13+/-2.15 pCi for the NYS and NYU groups respectively.

TABLE 2 - Regression of Skull Pb-210 on Radon Concentration
ALL SUBJECTS

REGRESSION of SKULL Pb-210 on RN. CONC.: ALL SUBJECTS

Subj	Pb210	RnConc-B	RnConc-1	RnConc-T	Sex
MEC	78	0	68	68	2
JDL	170	0	68	68	2
HEB	109	116	32	148	1
TJB	216	116	32	148	2
BB	184	70	48	118	1
VJB	92	70	48	118	2
RRA	192	100	40	140	1
JRF	36	36	24	60	1
MAF	37	36	24	60	2
CF	93	36	24	60	2
CFH	37	90	38	128	1
KKH	301	90	38	128	2
JRM	39	98	29	117	1
ERM	142	98	29	117	2
WHH	36	74	29	103	1
EEH	121	74	29	103	2
CHT	36	46	16	62	1
SET	35	46	16	62	2
PJC	92	95	40	135	2
PCM	93	29	30	59	1
PMM	33	29	30	59	2
EJR	108	0	53	53	1
VJR	37	0	53	53	2
MJS	45	35	27	62	2
HRS	38	29	19	48	1
MAS	34	29	19	48	2
OAS	38	0	30	30	1
CBS	39	0	30	30	2
ADS	98	0	24	24	1

Regression Output:

Constant		8.423587
Std Err of Y Est		57.57139
R Squared		0.310768
No. of Observations		29
Degrees of Freedom		27
X Coefficient(s)	0.981617	$t_{27}=3.49$
Std Err of Coef.	0.281336	$p<0.0008$

TABLE 3 - Regression of Skull Pb-210 on WLM
ALL SUBJECTS

REGRESSION of SKULL Pb-210 on WLM: ALL SUBJECTS

Subj	Pb210	WLM	Sex
MEC	78	261.6	2
JDL	170	261.6	2
HEB	109	277.1	1
TJB	216	288.3	2
BB	184	154.7	1
VJB	92	207.3	2
RRA	192	100.3	1
JRF	38	151.8	1
MAF	37	114.1	2
CF	93	77.9	2
CFH	37	205.4	1
KKH	301	214.9	2
JRM	39	214.7	1
ERM	142	236.4	2
WHH	38	191.1	1
EEH	121	163.8	2
CHT	36	217.8	1
SET	35	36.8	2
PJC	92	206.2	2
PCM	93	142.1	1
PMM	33	215.1	2
EJR	108	176.8	1
VJR	37	231.3	2
MJS	45	173.1	2
HRS	38	147.7	1
MAS	34	143.1	2
OAS	38	176.3	1
ADS	98	156.1	1

Regression Output:

Constant	41.03726
Std Err of Y Est	67.90838
R Squared	0.057022
No. of Observations	28
Degrees of Freedom	26

X Coefficient(s)	0.276268	$t_{26}=1.25$
Std Err of Coef.	0.220329	$p<0.1115$

TABLE 4 - Regression of Skull Pb-210 on Radon Concentration
FEMALE SUBJECTS

REGRESSION of SKULL Pb-210 on R.N. CONC.: FEMALE SUBJ.

Subj	Pb210	RnConc-B	RnConc-1	RnConc-T	Sex
MEC	78	0	68	68	2
JLL	170	0	68	68	2
TJB	216	116	32	148	2
VJB	92	70	48	118	2
MAF	37	36	24	60	2
CF	93	36	24	60	2
KKH	301	90	38	128	2
ERM	142	98	29	117	2
EEH	121	74	29	103	2
SET	35	46	16	62	2
PJC	92	95	40	135	2
PMM	33	29	30	59	2
VJR	37	0	53	53	2
MJS	45	35	27	62	2
MAS	34	29	19	48	2
CBS	39	0	30	30	2

Regression Output:

Constant	-28.8818
Std Err of Y Est	55.37934
R Squared	0.519194
No. of Observations	16
Degrees of Freedom	14

X Coefficient(s)	1.536852	t14=3.89
Std Err of Coef.	0.395265	p:0.0008

TABLE 5 - Regression of Skull Pb-210 on Radon Concentration
MALE SUBJECTS

REGRESSION of SKULL Pb-210 on RN. CONC.: MALE SUBJ.

Subj	Pb210	RnConc-B	RnConc-1	RnConc-T	Sex
HEB	109	116	32	148	1
BB	184	70	48	118	1
RRA	192	100	40	140	1
JRF	38	36	24	60	1
CFH	37	90	38	128	1
JRM	39	98	29	117	1
WHH	36	74	29	103	1
CHT	36	46	16	62	1
PCM	93	29	30	59	1
EJR	108	0	53	53	1
HRS	38	29	19	48	1
OAS	38	0	30	30	1
ADS	93	0	24	24	1

Regression Output:

Constant		64.49979	
Std Err of Y Est		57.63431	
R Squared		0.047047	
No. of Observations		13	
Degrees of Freedom		11	
X Coefficient(s)	0.298696		t11=0.74
Std Err of Coef.	0.405324		p<0.2348

FIGURE 1 - Copy of Letter Requesting Subject Participation

STATE OF NEW YORK
DEPARTMENT OF HEALTH
Corning Tower The Governor Nelson A. Rockefeller Empire State Plaza Albany, New York 12237

David Axelrod, M.D.
Commissioner

OFFICE OF PUBLIC HEALTH
Linda A. Randolph, M.D., M.P.H.
Director

William F. Leavy
Executive Deputy Director

Dear Resident:

Recently you agreed to participate in the New York State Health Department's Radon Exposure Registry. You also filled out a short questionnaire about your health and your residence that was monitored for radon. We are now inviting you to participate in another phase of our radon health studies.

As you may know, radon detectors like those used in your home can measure the amount of radon in the air, but not the amount a person actually inhales. Researchers at New York University (NYU) have developed a method to measure the radioactivity remaining in the body as a result of inhaling radon. They have also received funding to test a limited number of residents this year, and would like to provide you with more information about the testing procedure.

Briefly, you would travel, at your convenience, to the NYU facility in Tuxedo, Orange County - with time and travel expenses paid by NYU. The test involves sitting in a comfortable, reclining chair for an hour, watching television or listening to a cassette tape with the radiation detectors nearby. Also, since many other factors affect the amount of this radioactivity in your body, you would be asked about the types of food you eat and your smoking habits.

We hope that you will be interested in this opportunity to contribute to this important study and to learn more about your own personal radon exposure. We believe the study will contribute to a better understanding of the connection between radon in homes and public health.

If you want to learn more about this measurement technique, the NYU researchers, Dr. Norman Cohen and Dr. Gerald Laurer, will provide you with details and can answer any questions you may have. Please respond by completing and returning the attached form in the enclosed postage-paid envelope. One of my staff may be telephoning you within the next few weeks to discuss any questions you have. In the meantime, if you wish to contact us, please call Carole Ju or Nicholas Teresi of my staff (collect) at 518-458-6212.

Thank you for your attention.

Sincerely,

Alice Stark

Alice Stark, Dr. P.H.
Director
Bureau of Environmental and
Occupational Epidemiology

Enclosure
/kjk

NEW YORK STATE DEPARTMENT OF HEALTH
BUREAU OF ENVIRONMENTAL AND OCCUPATIONAL EPIDEMIOLOGY

RESIDENTIAL RADON EXPOSURE REGISTRY

NAME: ______________________________

ADDRESS: ______________________________

____

TELEPHONE: ______________________________

Check one box:

{ } Yes, I am interested in receiving more information about this radiation testing technique. I give my permission to have more detailed information provided directly to me by New York University.

{ } No, I am not interested in receiving more information.

FIGURE 2 - Phoswich Positioning for Skull Count

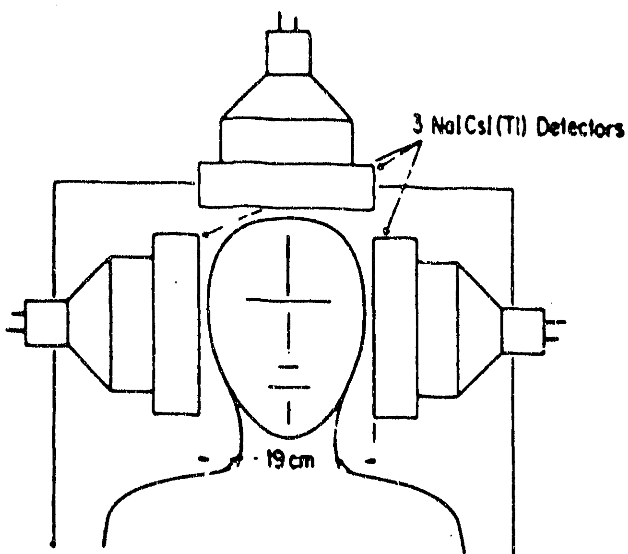


FIG. 2. Standard NYU counting geometry for *in vivo* scintillation measurement of the head (skull).

FIGURE 3 - Control Subject Program Output

SUBJECT MEASUREMENTS

NAME: Gerard Laurer AGE: 60 HGT: 2.0 m WGT: 108 kg

HEAD MEASUREMENTS:

Circ: C-C 72.0 cm
Circ: F-B 61.0 cm

Diam: C-C 24.5 cm
Diam: F-B 20.5 cm
Diam: S-B 16.0 cm

Pb-210 MEASUREMENT RESULTS

No.	LE cnt	LE SD	HE cnt	HE SD	Pb cnt	Pb SD
1	112	10.58	289	17.00	747	27.33
2	122	11.05	304	17.44	786	28.04
3	136	11.66	359	18.95	749	27.37
4	133	11.53	320	17.89	771	27.77
5	115	10.72	266	16.31	765	27.66
6	124	11.14	306	17.49	760	27.57
MEAN(cpm)	8.24	0.26	20.49	0.85	50.87	0.40
BKGD(cpm)	6.49	0.0290	15.30	0.0932	38.27	0.2144

LE COR	1.27	0.0403		COR.BKGD.	49.95	0.28 cpm
HE COR	1.34	0.0562				
COR.FACT.	1.31	0.0346		NET CNT.	0.92	0.48 cpm

C.L.(cpm) 0.97 cpm
Cal.Fact. 13.80 cpm/nCi
C.L.(pCi) 69.96 pCi

SK Pb-210 Less Than M.D.A.
....

FIGURE 4 - NYS Subject Program Output

NYS SUBJECT MEASUREMENT

Name: C.W. Age: Hgt: Wgt:

HEAD MEASUREMENTS:

Circ. C-C	60.5 cm	Diam. S-S	14.0 cm
Circ. F-B	53.5 cm	Diam. C-C	21.5 cm
		Diam. F-B	18.5 cm

Pb-210 MEASUREMENT RESULTS

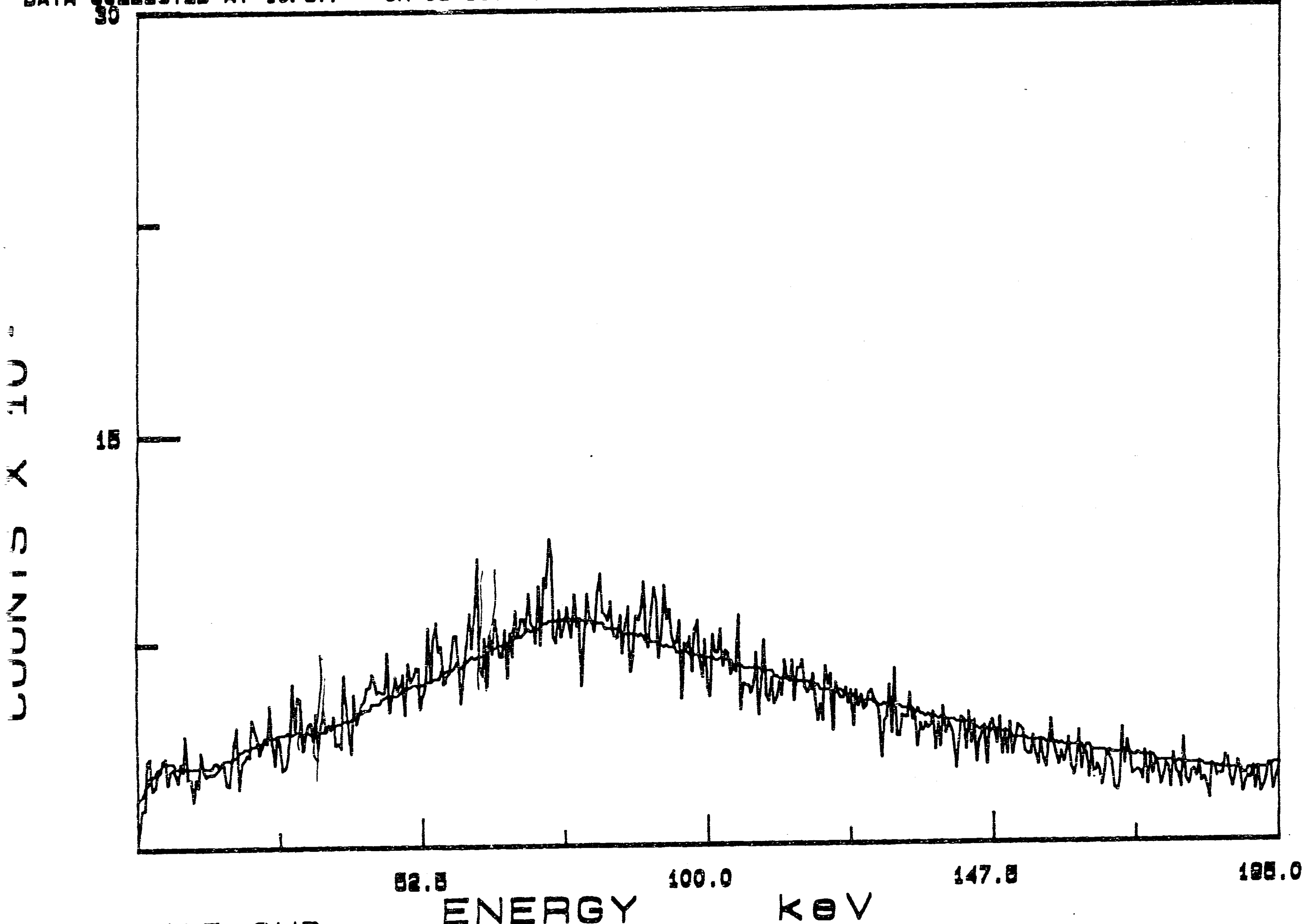
No.	LE cnt	LE SD	HE cnt	HE SD	Pb cnt	Pb SD
1	91	9.54	214	14.63	689	26.25
2	111	10.54	254	15.94	668	25.85
3	111	10.54	245	15.65	643	25.36
4	106	10.30	242	15.56	671	25.90
MEAN(cpm)	6.98	0.32	15.92	0.58	44.52	0.63
BKGD(cpm)	6.49	0.0290	15.30	0.0932	38.27	0.2144

LE COR	1.08	0.0489	COR.BKGD.	40.51	0.23 cpm
HE COR	1.04	0.0382			
COR.FACT.	1.06	0.0310	NET CNT.	4.01	0.67 cpm

M.D.Cnt.	0.78 cpm			
Cal.Fact.	13.80 cpm/nCi	SK Pb-210	291	49 pCi
M.D.A.	56.74 pCi			

FIGURE 5 - Fit of Corrected Background to Subject Spectrum

TYPE = -1 MCA # 01 SEGMENT # 03 SEQUENCE # 0
REALTIME = 50951.98 SECONDS, LIVETIME = 50900.00 SECONDS
DATA COLLECTED AT 16:32: ON 05-OCT-90



ALLENNAI.SUB

FIGURE 6 - Regression of Skull Pb-210 vs Radon Concentration
ALL SUBJECTS

SKULL Pb-210 vs RN CONC.: ALL SUBJECTS

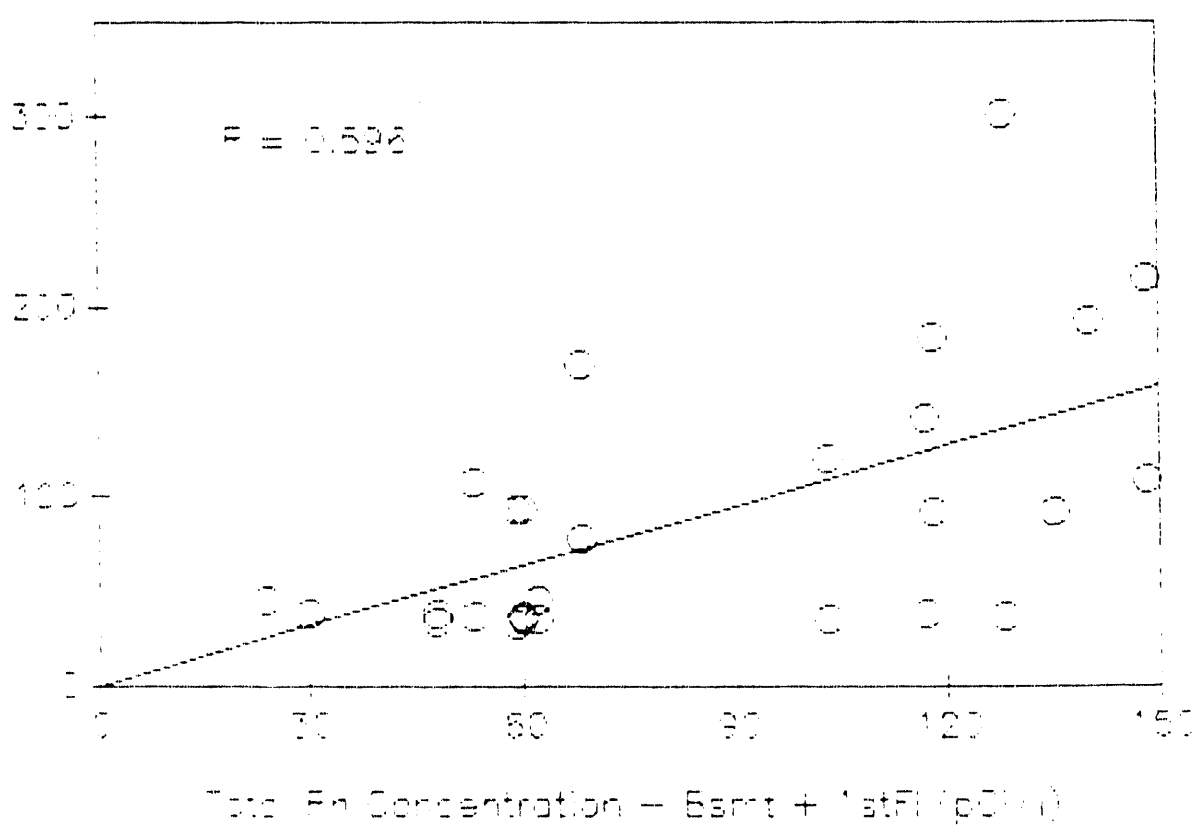


FIGURE 7 - Regression of Skull Pb-210 vs Radon Concentration
FEMALE SUBJECTS

SKULL Pb-210 vs RN CONC.: FEMALE SUBJ.

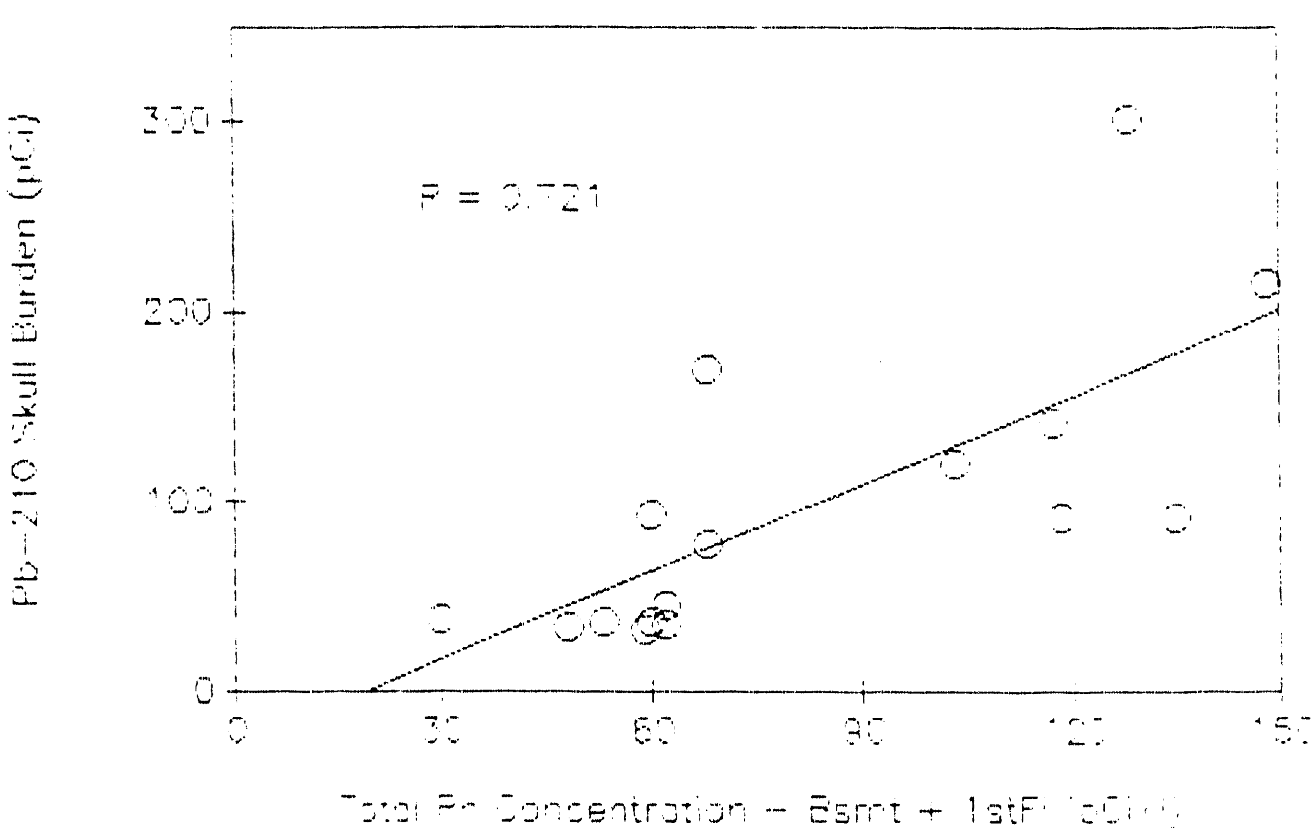
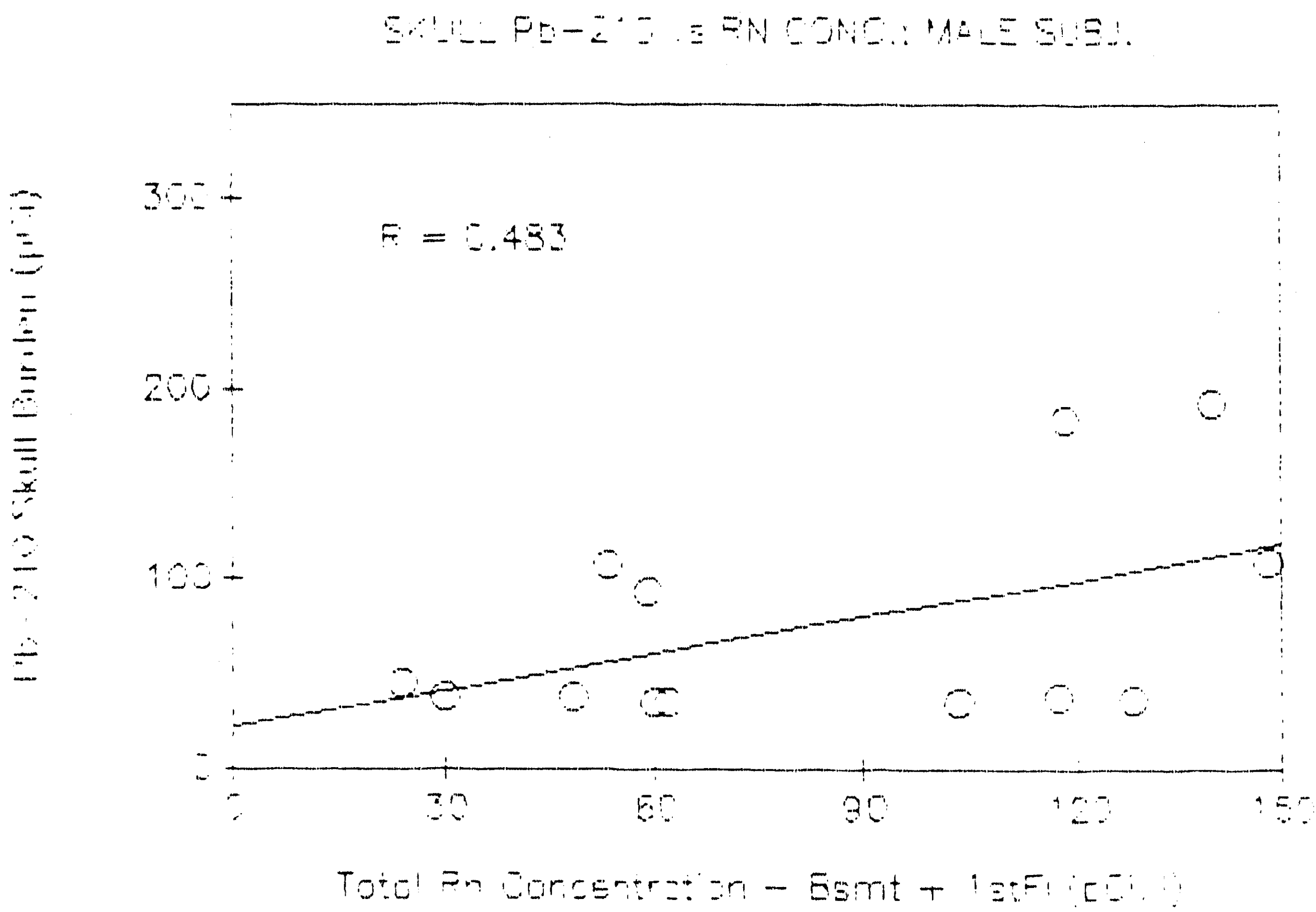


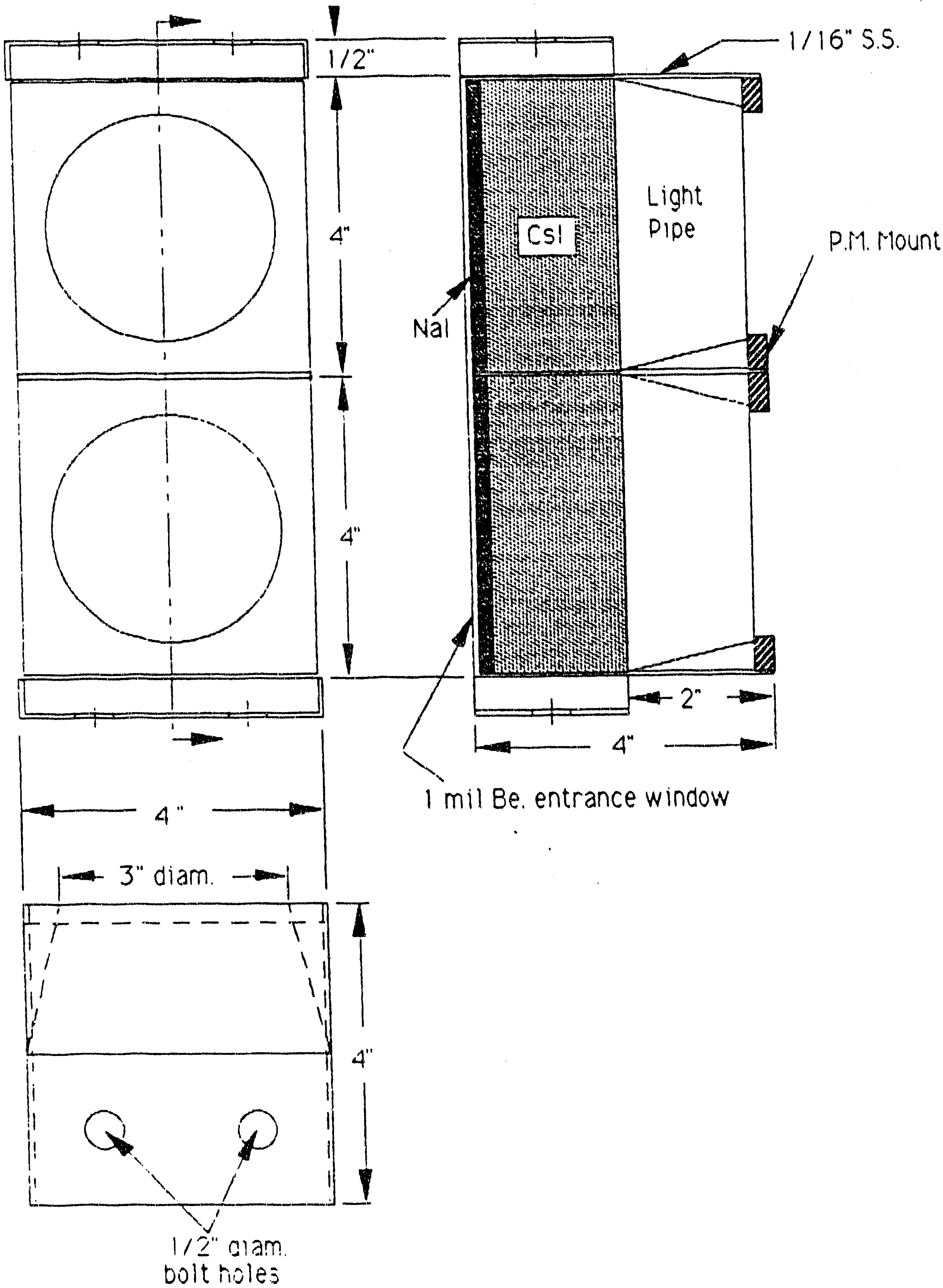
FIGURE 8 - Regression of Skull Pb-210 vs Radon Concentration
MALE SUBJECTS

FIGURE 9 - Regression of Skull Pb-210 vs Radon Concentration
MALE SUBJECTS



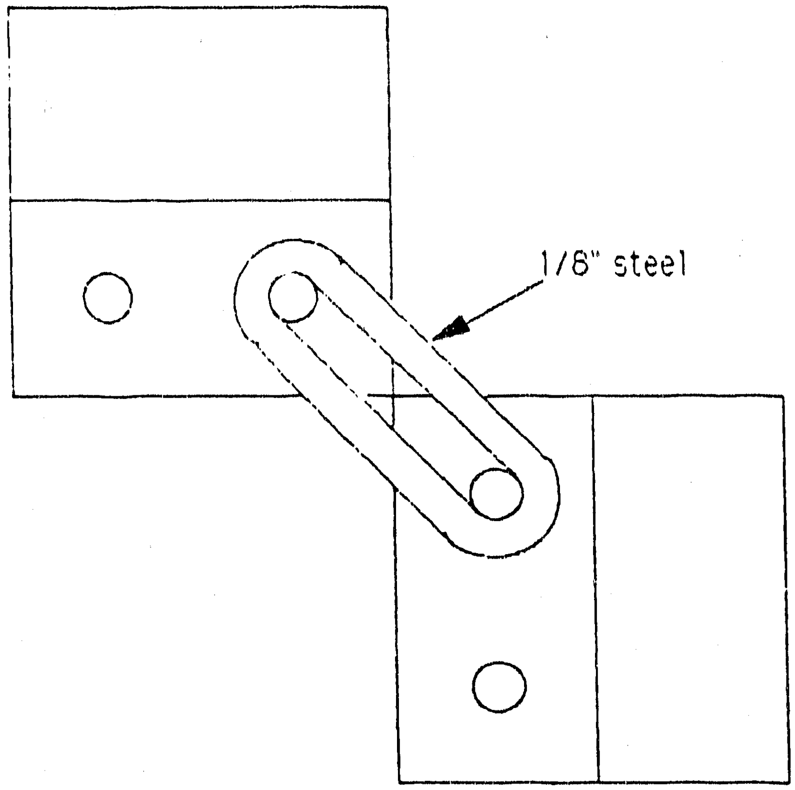
R = 0.483
300
200
100
0
30
60
90
150

FIGURE 8 - Prototype Detector Section Design



1/2"
1/16" S.S.
4"
4"
CsI
Light Pipe
P.M. Mount
NaI
2"
4"
1 mil Be. entrance window
4"
3" diam.
4"
1/2" diam. bolt holes

<u>FIGURE 10</u> - Example of Connection of 2 Detector Sections; Skull Counting Geometry with Complete 8 Section Detector


1/8" steel

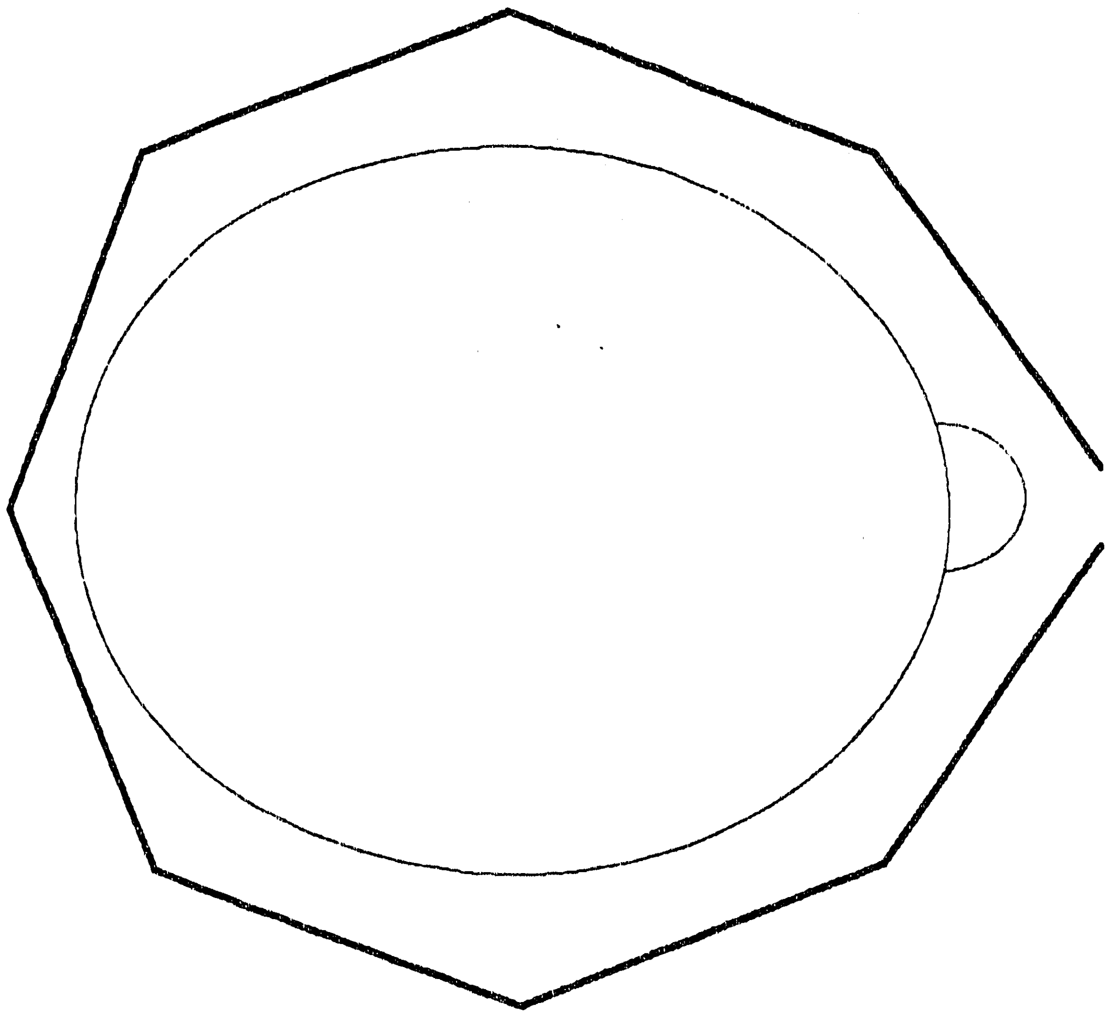


FIGURE 11 - Spectrum of 25nCi Pb-210 Skull Burden

TYPE = -1 MCA # 01 SEGMENT # 03 SEQUENCE # 0
REALTIME = 901.50 SECONDS, LIVETIME = 900.00 SECONDS
DATA COLLECTED AT 11:18: ON 23-JUL-90

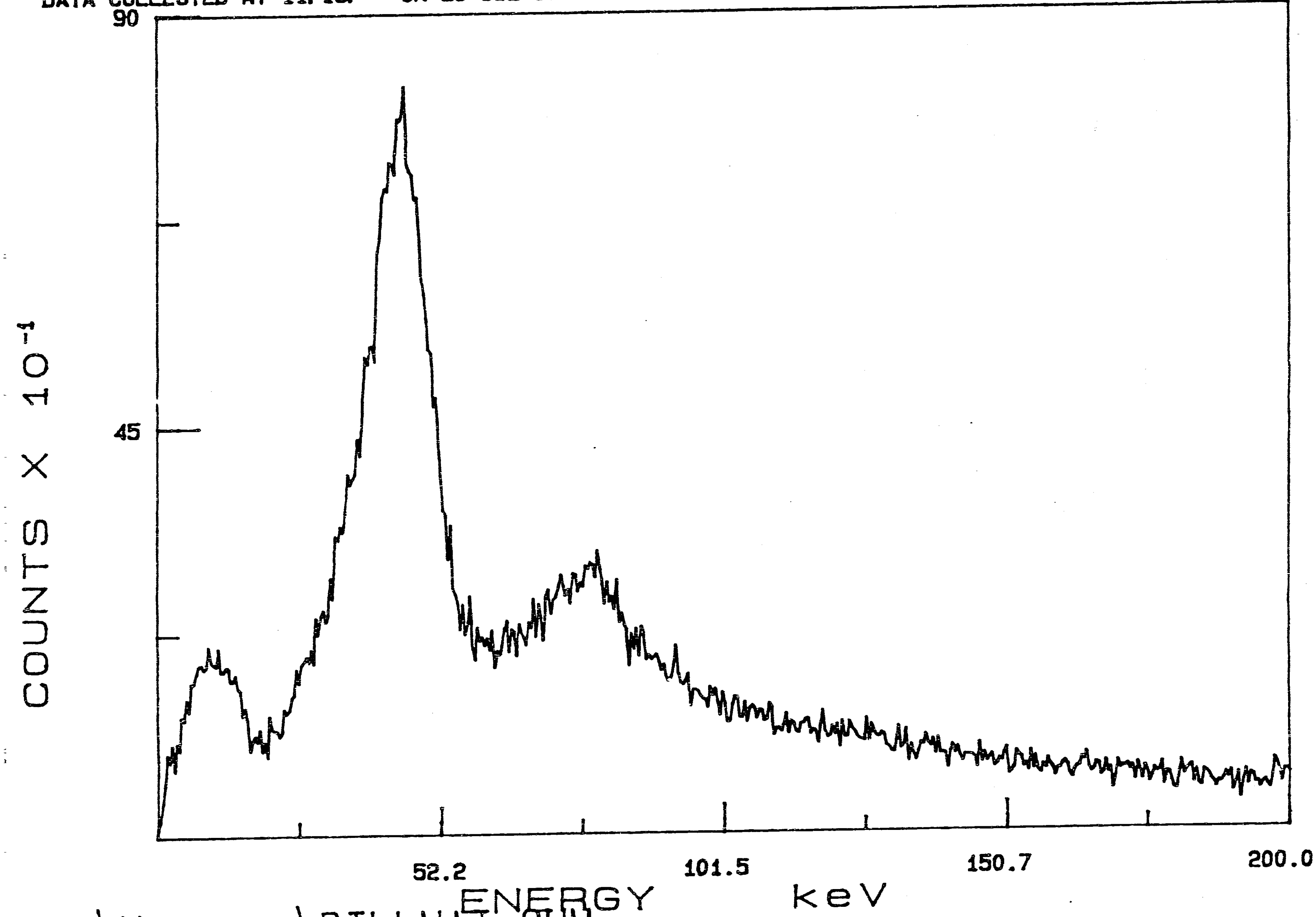


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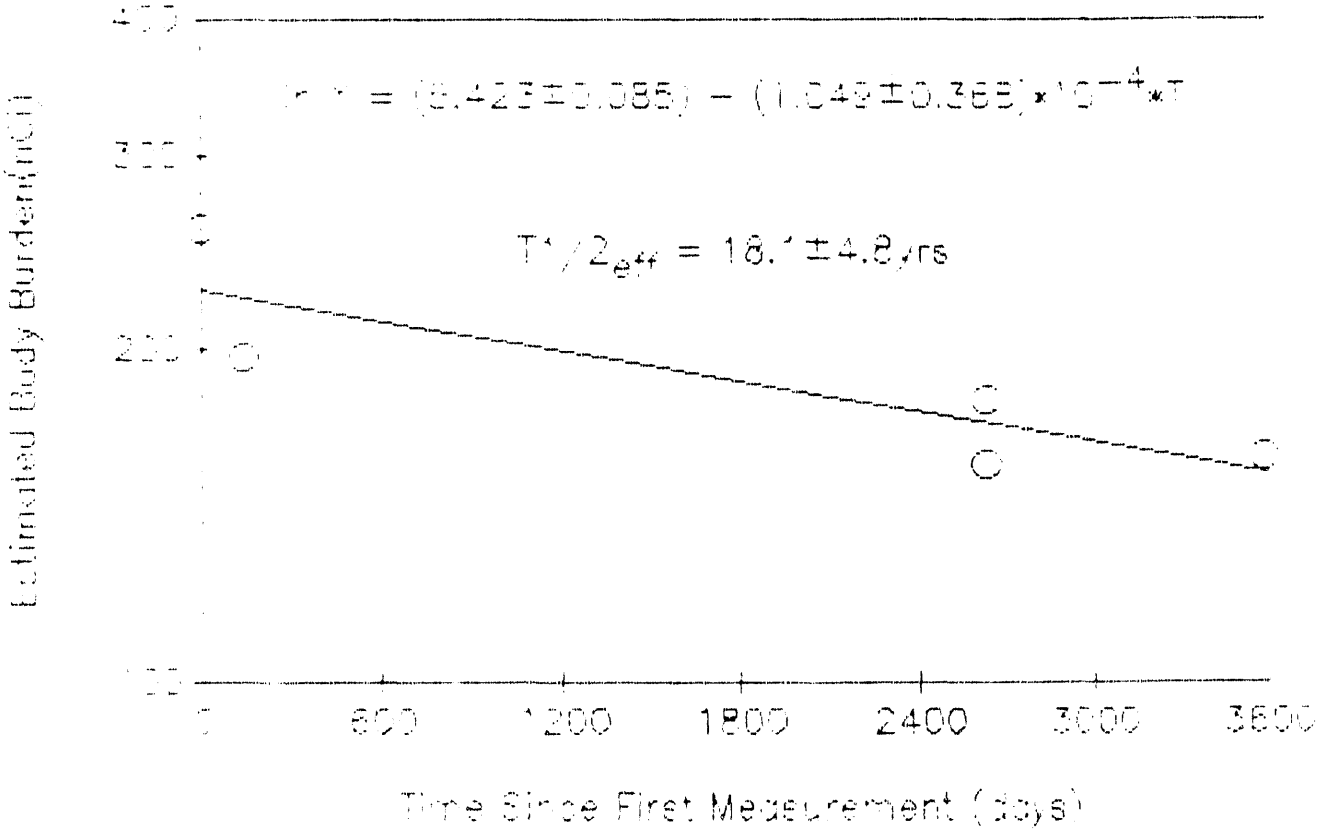
FIGURE 12 - Effective Half-time of Pb-210 in Man
- Preliminary Estimate

Pb−210 RETENTION IN MAN



END

DATE FILMED

9/15/92