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Evaluation of the Pb-212 Detection Limit for a Lung Count at the Y-12 Facility from 1992 -1995

Lara Hughes
Document Owner, DCAS

James W. Neton
Subject Matter Expert, NIOSH Contractor

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Approval: Signature on file
T. Taulbee, Associate Director for Science

Date: 04/27/2020

National Institute for Occupational Safety and Health (NIOSH)
Division of Compensation Analysis and Support (DCAS)
1090 Tusculum Avenue
Cincinnati, Ohio 45226

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1.0 INTRODUCTION

When evaluating lung count results for thorium at the Y-12 facility, the records were found to fit into three different categories. The first category (years available: 1958-1982) consists of thorium lung counts that list the thorium lung burden in form of milligram units. Those results cannot be used for dose reconstruction, because the associated calibration information is not available. The second category of lung counts (years available: 1979-1991) consists of records that report the activity data for gamma emitting thorium chain radionuclides Ac-228 and Pb-212. These records can be interpreted using available NIOSH methods. The third category (years available: 1992-1994) consists of lung count results that only contain the Ac-228 activity value, but not the Pb-212 value. These records are addressed in this report. It is expected that any of the two latter approaches can be used to evaluate thorium lung burden data past the 1994 cut-off for this analysis, which was precipitated by the Y-12 Special Exposure Cohort evaluation (SEC-00250).

The purpose of this report is to establish a Minimum Detectable Activity (MDA) for Pb-212 for an in vivo examination of Y-12 workers who were potentially exposed to Th-232. Th-232 does not emit photons that can be used for in vivo detection. Using the methodology prescribed in ORAUT-OTIB-0076 [ORAUT 2014], however, the MDA for Pb-212 can be used to evaluate a missed dose for Th-232 based on an in vivo examination. To establish the MDA for Pb-212, this evaluation uses a compilation of lung counting reports collected from the Y-12 site as the basis for this analysis [Y-12 1989-1995]. Other documents relevant to this subject were reviewed and incorporated into the analysis as appropriate.

Y-12 [1989-1995] is a large PDF file that contains 23,970 pages of in vivo examination reports associated with lung counts taken at the Y-12 facility between 1989 and 1995[1]. A review of this PDF file indicated that there were several types of report formats, each one associated with the specific type of lung count that was performed during the reported period. The earliest format covered the time period through 1991 (see example provided in Attachment 1). As can be seen, eight individual values were reported on the hand-written cover sheet, including values for uranium, potassium and lead. In later years, the hand-written report shown in Attachment 1 also included a computer printout of the results that included detector configuration and name (see Attachment 2). From January through June of 1992, lung counts for Y-12 personnel were made at the K-25 in vivo exam center using low-energy germanium detectors. An example report is provided in Attachment 3. In addition, the second page of the report provided a spectral plot of the count data (Attachment 4). As can be seen in Attachment 3, an MDA value is reported for Th-232, but it is not known which Th-232 progeny was used to estimate this value.

Starting around June of 1992, the Y-12 in vivo exam center began counting workers using an array of low-energy germanium detectors. An example of the report format for this type of count is provided in Attachments 5 and 6. For all the counts during this time period, measured activity values (or MDA values) were reported for U-235, U-238, and Ac-228. Additionally, a spectral plot was included. Occasionally, values were also reported for Np-237, but the number of reported Np-237 values was judged to be insufficient for use in this evaluation. None of the reports provided an activity value or MDA for Pb-212.

Because uncensored Pb-212 values were reported for any Y-12 counts performed before 1992, these values can be used directly in the estimate of an intake or the calculation of a missed dose for Th-232

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[1] As discussed later, from January to June of 1992, in vivo exams of Y-12 workers were made at the K-25 in vivo exam center. In vivo exams made at this facility were not included in this analysis.

using the methodology described in ORAU-OTIB-0076 [ORAUT 2014]. For counts performed on Y-12 workers in the 1992 time-frame at the K-25 in vivo counter (Attachments 3 and 4), there are insufficient data available at this time to estimate Pb-212 lung burdens. While spectral plots are provided on the K-25 in vivo exam reports, they did not provide any net or background count information for positively identified peaks. In theory, the background in the Pb-212 region could be approximated by examining the counts displayed in these plots. The plots, however, have many channels compressed into a small space, making it difficult to evaluate the background with any degree of accuracy. ORAU is currently working on obtaining additional information on the counts made at K-25 during this time period. The information required to estimate MDAs for Pb-212 for the K-25 counter includes raw spectral data (i.e., channel by channel printouts) and the efficiency calibration curves that were used to estimate Th-232 values. Interviews with subject matter experts and additional data captures might more clearly define the parameters associated with these measurements.

For counts made at the Y-12 facility between 1992 and 1995, peak search reports provide MDAs, measured activity results (including net counts in the peak), and background count data. If sufficient positive peak information is available, this should allow for a reasonable estimate to be made of the MDA for Pb-212. The remainder of this report provides the approach used to develop the parameters needed to estimate the MDA for counts made at Y-12 between 1992 and 1995. These parameters are the detection efficiency for the Pb-212 photopeak at 238 keV and the subject background counts in that region.

2.0 DISCUSSION OF THE Y-12 IN VIVO COUNTING METHODOLOGY 1992-1995

Starting in June of 1992, the in vivo measurement methodology at Y-12 most likely used an array of four low-energy germanium detectors positioned over the lungs. While no specific document that characterized the system could be found, the use of germanium detectors is supported by the spectral plots that are included with each lung count. As can be seen in Attachment 6, the plotted spectrum clearly exhibits the characteristics of a high-resolution germanium system. In addition, a writeup that was attached to some of the early lung counts during this period stated that the algorithm used to identify photopeaks was the “peak/singlet” routine and that two of the detectors were new (see Attachment 7)[2].

The peak/singlet routine was specifically developed for the evaluation of peaks in low-energy lung counting applications. The identification of photopeaks was accomplished using a methodology that was described by Spitz et al. [1985]. It consists of applying a variance stabilizing transformation to the raw spectral data. A background spectrum is then synthesized using a median smoothing technique. Peaks are identified whenever the gross spectral data exceeds the calculated background by a predetermined statistical confidence level. Thus, whenever a photopeak is positively identified, the number of background counts under the net photopeak area is also reported.

In addition to providing the net and background peak area, the in vivo exam report also included a value for the subject’s chest wall thickness. This indicates that the efficiency of detection (as well as the reported activity or MDA) was not only dependent on energy but on the subject’s chest wall thickness. Because of this, the detection efficiency associated with an individual subject count is represented by a three-dimensional function. An example that depicts this relationship for the Y-12 HPGe detection system in 2008 is provided in Figure 1 below [Gose and Veinot 2006, pdf page 16]

[2] A copy that can be expanded and read more clearly can be viewed at SRDB #176611, pdf page 165.

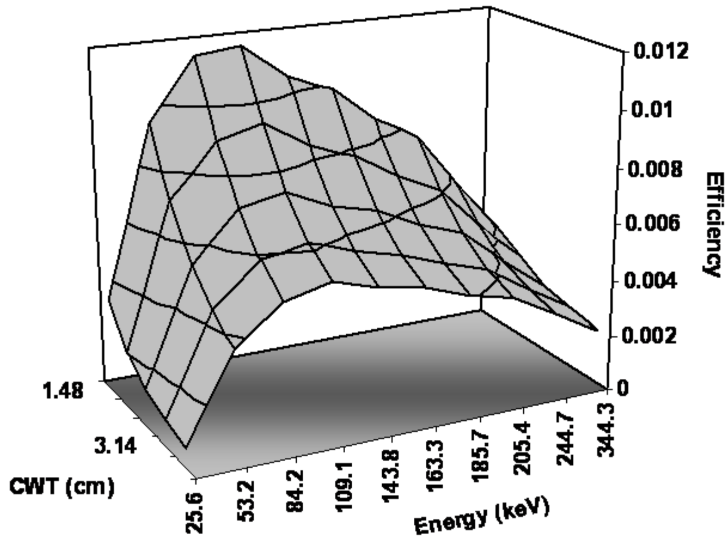


Figure 1. Detection Efficiency for a Lung Count at Y-12 in 2008 for a 4 detector Array

3.0 EVALUATION OF DETECTION EFFICIENCY FOR LUNG COUNTS 1992-1995

If the detection efficiencies for the nuclides that were reported (i.e., U-235, U-238, and Ac-228) can be determined, it would be possible to interpolate a detection efficiency for Pb-212. Table 1 provides the energies and abundances of the photon emissions that were used by the in vivo software to quantify activity. All values are from Kocher [1981].

Table 1. Energies and Abundances of Photons Evaluated

Nuclide	Energy (keV)	Abundance (%)[3]
U-238 (Th-234)	63.29	3.8
U-238 (Th-234)	92.38	2.72
U-238 (Th-234)	92.80	2.69
U-235	185.71	54.0
Pb-212	238.65	44.6
Ac-228	338.32	11.4

3.1 EFFICIENCY FOR U-238 USING THE TH-234 63.29 AND 92.38 KEV EMISSIONS

As shown in Table 1, there are three useful energies associated with the decay of Th-234, the daughter of U-238. The first at 63.3 keV has an abundance of 3.8%, while there are two higher energy emissions at 92.38 and 92.80 keV, each with an abundance of 2.72% and 2.69%, respectively. The attachment that was placed with the initial lung counts in 1992, stated that the 92.38 keV photopeak

[3] Abundance in this context refers to the fractional photon yield that is emitted during the radioactive decay process.

was used for the quantification of U-238 (see Attachment 7). Thus, the 2.72% abundance will be used in this analysis.

It should be noted that the discussion provided in Attachment 7 indicates that the positive peaks in the 63 and 92 keV regions were most likely due to contamination in two newly installed detectors. The positive peak search results and reported activities, however, can still be used to evaluate the detection efficiency at these energies. This is because the software assumes that any positive Th-234 peaks identified in the spectrum are due to internal contamination.

To identify reports that had positive Th-234 peaks, Y-12 [1989-1995] was searched for all reports that contained the character strings “63.” And “92.”[4]. To facilitate this search, a version of Y-12 [1989-1995] was created that enabled Optical Character Recognition (OCR). This new version resulted in the original file being split into 24 files, with files 1-23 containing 1,000 pages and the last file containing 970 pages. After reviewing the results of this search, there were six lung count reports in the 1992 – 1995 time period that had a positively identified photopeak at 63 keV and a reported activity for U-238. In addition, there were eight in vivo exam reports that had a positively identified photopeak at 92 keV and a reported activity for U-238. These reports also provided net counts, background counts, and chest wall thickness (CWT). Using these data, it was possible to calculate the detection efficiency for each reported count using the following equation:

$$\mathrm{Eff}\left(\frac{\mathrm{c}}{\gamma}\right) = \frac{net\ counts}{Activity\ (nCi) * 2200\ \left(\frac{dpm}{nCi}\right) * 30\ minutes * Y\ \left(\frac{gamma}{dis.}\right)}$$

Where: Y = the photon yield in gammas per disintegration.

Tables 2 and 3 provide a summary of the values extracted from the reports, as well as the calculated efficiency, using these reported values.

Table 2. Summary of Data Extracted from Y-12 [1989-1995] for 63 keV photopeak

Report page	Net Counts	CWT (cm)	Activity (nCi)	Efficiency[5] (counts/gamma)
691	24	5.83	5.1	0.00188
1255	12	4.37	1.4	0.00342
1475	30	3.13	2.2	0.00544
1988	15	5.44	2.7	0.00222
2899	43	2.64	2.6	0.00659
3450	17	2.53	0.95	0.00714

[4] While this search included in vivo exam reports made at K-25, none of these counts were included in this analysis. This is because, no quantitative peak information (i.e., net and background counts) was provided in these reports. This is true for all subsequent character searches described in this report.

[5] The values reported in this column were calculated using the net counts and activity in this table and the equation provided in this section.

Table 3. Summary of Data Extracted from Y-12 [1989-1995] for 92.8 keV photopeak

Report page	Net Counts	CWT (cm)	Activity (nCi)	Efficiency[5] (counts/gamma)
160	23	2.03	0.8	0.01601
11767	20	1.97	0.67	0.01663
12240	30	1.38	0.81	0.02063
13286	15	4.00	1.1	0.00760
14260	7	2.58	0.29	0.01345
15104	60	4.19	4.6	0.00727
15901	28	5.92	4.1	0.00380
17573	3	3.61	0.18	0.00928

As previously shown in Figure 1, the detection efficiency for a low-energy lung count is a function of both energy and chest wall thickness (CWT). Thus, the detection efficiencies at the 63 and 92 keV regions of interest were evaluated as a function of CWT using the CWT values contained in Tables 2 and 3. As shown in Figures 2 and 3, the data fit an exponential function with R^2 values of 0.9981 for the 62.38 keV peak and 0.9991 for the 92.8 keV peak.

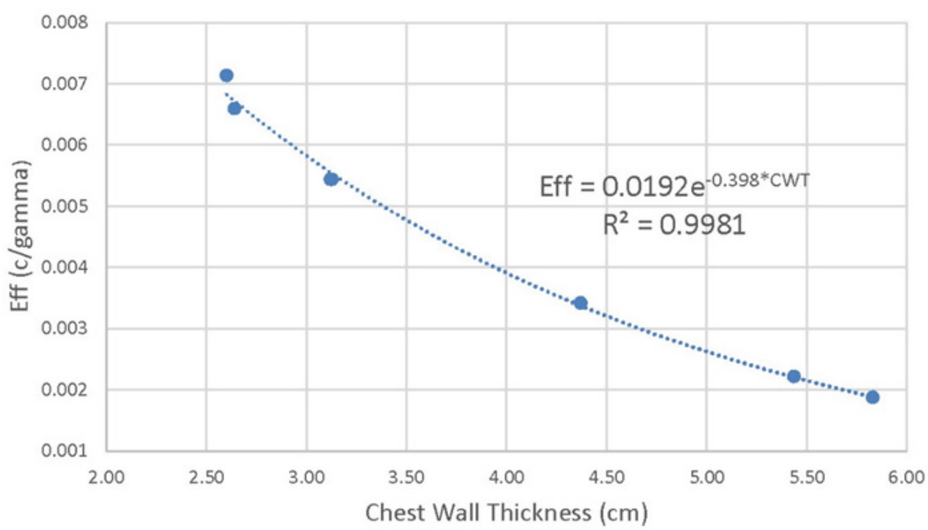


Figure 2. Detection Efficiency at 63.29 keV

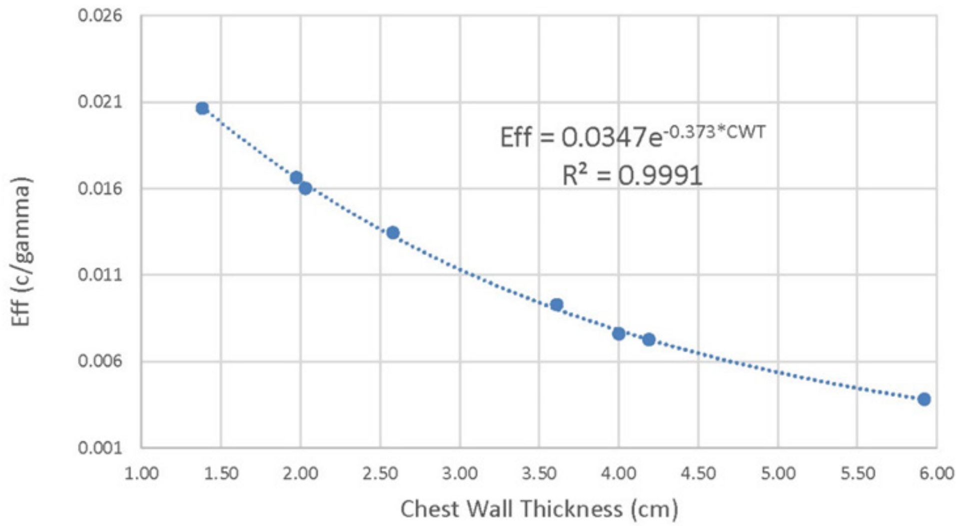


Figure 3. Detection Efficiency at 92.8 keV

3.2 EFFICIENCY FOR U-235 USING THE 185.71 KEV EMISSION

For a Y-12 lung count, U-235 was quantified using the 185.71 keV emission which has an abundance of 54%. In a similar manner to that used for the U-238 analysis, the 24 OCR files that were created from Y-12 [1989-1995] were searched for the character string “185.” and “186.”. This search resulted in the identification of 8 in vivo exam reports that had a positive 185 or 186 keV photopeak and also a reported U-235 activity. Table 4 provides the data that were extracted. As with the U-238 analysis, the efficiency value in the table was calculated using equation provided in Section 3.1.

Table 4. Summary of Data Extracted from Y-12 [1989-1995] for 185.7 keV photopeak

Report page	Net Counts	CWT (cm)	Activity (nCi)	Efficiency[6] (counts/gamma)
2511	29	3.75	0.21	0.003875
5078	17	4.43	0.14	0.003407
5280	40	2.64	0.19	0.005907
5851	40	2.70	0.20	0.005612
5854	33	2.70	0.16	0.005787
10020	335	1.48	1.1	0.008545
11331	31	4.51	0.27	0.003222
18059	3	3.30	0.0193	0.004361

As with the U-238 analysis, the CWT and efficiency data in Table 4 were fit to an exponential function with an R^2 of 0.9863. The results of this fit are provided in Figure 4.

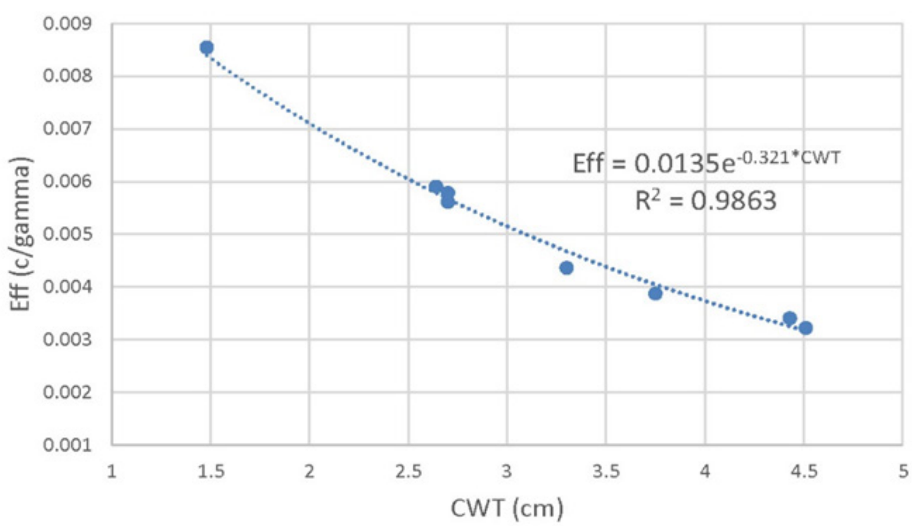


Figure 4. Detection Efficiency at 185.7 keV

3.3 EFFICIENCY FOR AC-228 USING THE 338.32 KEV EMISSION

For a Y-12 lung count, Ac-228 was quantified using the 338.32 keV emission which has an abundance of 11.4%. In a similar manner to that used for the U-238 and U-235 analysis, the 24 OCR files that were created from Y-12 [1989-1995] were searched for the character string “338.”. This search resulted in the identification of 5 in vivo exam reports that had a positive 338 keV photopeak

[6] The values reported in this column were calculated using the net counts and activity in this table and the equation provided in this section.

and also reported an Ac-228 activity. Table 5 provides the data that were extracted. As with the U-238 and U-235 analyses, the efficiency value in the table was calculated using the equation provided in Section 3.1.

Table 5. Summary of Data Extracted from Y-12 [1989-1995] for the 338.32 keV photopeak

Report page	Net Counts	CWT (cm)	Activity (nCi)	Efficiency[7] (counts/gamma)
1531	9	3.37	0.42	0.002848
11503	6	4.54	0.44	0.0018124
13618	16	3.16	0.79	0.0026918
17715	16	3.72	0.93	0.0022866
18678	11	3.67	0.63	0.0023206

As with the U-238 and U-235 analyses, the CWT and efficiency data in Table 5 were fit to an exponential function with an R^2 value of 0.9204. The results of this fit are provided in Figure 5.

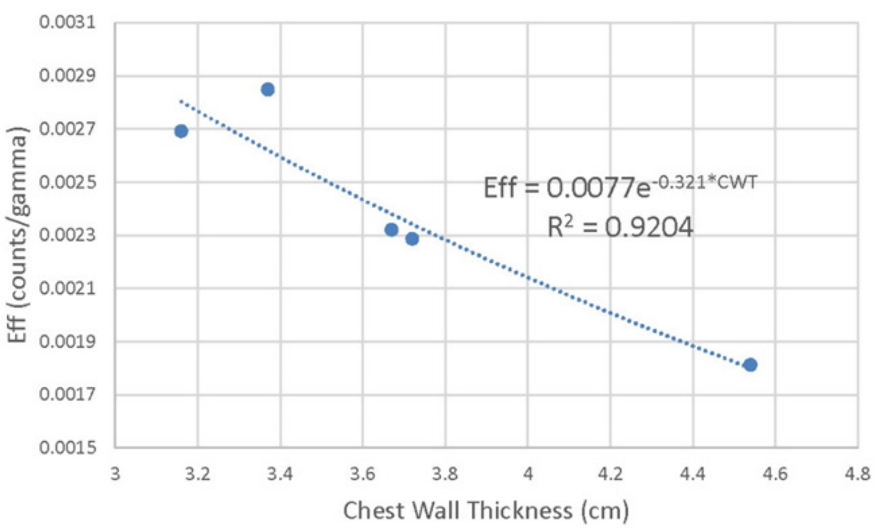


Figure 5. Detection Efficiency at 338.32 keV

[7] The values reported in this column were calculated using the net counts and activity in this table and the equation provided in this section.

3.4 EVALUATION OF DETECTION EFFICIENCY FOR PB-212 AT 238.65 KEV

Using the exponential functions generated for the 63.29, 92.80, 185.7, and 338.32 keV peaks, the detection efficiency at a CWT of 1.5 cm was calculated[8]. The results of these calculations are provided in Figure 6.

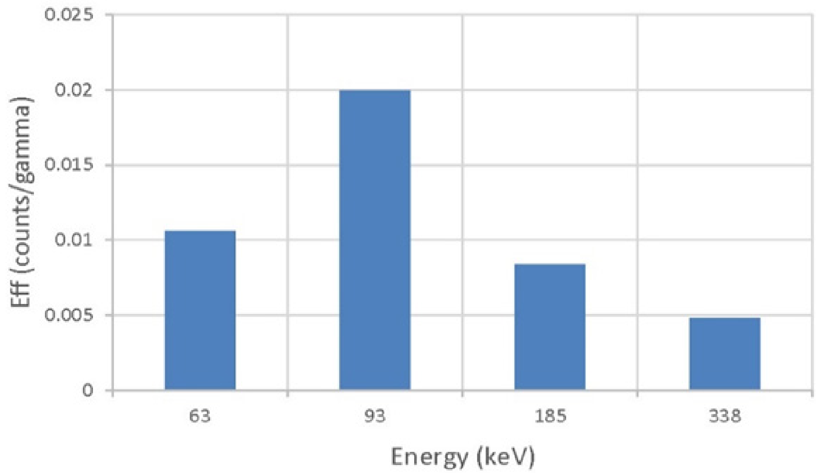


Figure 6. Detection Efficiency at a CWT of 1.5 cm at the Y-12 Lung Counter 1992-1995

Although the shape of the actual efficiency curve is represented by a smooth function, there are insufficient data points in this example to flesh out the details of the actual shape. It can be seen, however, that the efficiency increases from 63 keV up to a peak at 93 keV[9] and then declines in a roughly exponential fashion down to 338 keV. This is characteristic of low-energy photon measurements, including those made with intrinsic germanium detectors [ICRU 2003]. To interpolate the detection efficiency at 238 keV, an exponential function was fit between the efficiencies at 185 and 338 keV. The results of this fit are provided in Figure 7.

[8] It was decided to calculate the efficiency at 1.5 cm, because that was the thickness (CWT) of the thinnest chest overlay provided by the Y-12 calibration phantom.

[9] The peak (or knee) of this efficiency curve is probably somewhat higher than 93 keV.

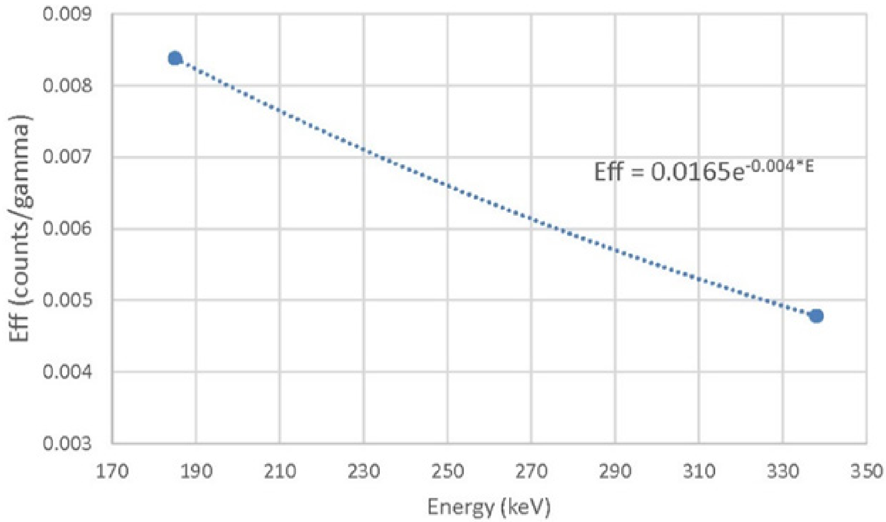


Figure 7. Exponential fit between 185 and 338 keV, 1.5 cm CWT

Using the relationship shown in Figure 7, the detection efficiency at the Pb-212 photopeak energy of 238 keV at a CWT of 1.5 cm was calculated to be 0.006368 counts/gamma. The detection efficiency at 238 keV is a function of CWT. The reduction in detection efficiency at higher energies, however, is less dependent on photon scattering than it is at lower energies like 63 and 93 keV. This is because the attenuation coefficient for photon scattering at higher energies is reduced. Thus, at higher energies, the reduction in efficiency due to the change in geometry (i.e., the increased distance from the deposited activity) contributes more to the overall reduction than it does at lower energies. In fact, examination of the attenuation coefficient for the efficiency functions reveals that the reduction in efficiency due to chest wall thickness is the same at both 185 and 338 keV. That is, the exponential reduction coefficients are both 0.321 per cm, whereas the reduction coefficients at 63 and 93 are 0.398 and 0.373 per cm, respectively. Thus, it is reasonable to infer that the reduction in efficiency as a function of chest wall thickness at 238 keV can be assumed to be 0.321 per cm as well. Using this reduction coefficient and the calculated efficiency of 0.006368 counts / gamma at 1.5 cm CWT[10], the relationship for efficiency as a function of chest wall thickness can be calculated as follows:

$$0.006368\left(\frac{c}{\gamma}\right) = E_0 * \exp(-0.321 * 1.5\, cm)$$

$$E_0 = 0.010307\ \left(\frac{c}{\gamma}\right)$$

$$Eff_{238} = 0.010307 * \exp(-0.321 * CWT)$$

[10] Although a 1.5 cm chest wall thickness (CWT) was used for this calculation, any thickness could be used to derive this relationship. For example, using a 3.5 cm CWT in the calculation (which is the average CWT for all the positive lung counts) produces the same MDA function that appears in Figure 10.

As can be calculated, the efficiency at 238 keV can vary by a factor of 2.6, going from 0.006368 at 1.5 cm CWT to 0.002431 at 4.5 cm. As will be discussed in Section 5, this change in efficiency will directly affect the MDA calculation for a lung count.

4.0 EVALUATION OF BACKGROUND IN THE 238 keV REGION

The other value needed to estimate an MDA for Pb-212 is the number of background counts in the 238 keV region of interest. Originally, it was thought that this could be estimated by examining the spectral printout that was included with each in vivo exam report. An example of the spectral printout is provided in Figure 8 below.

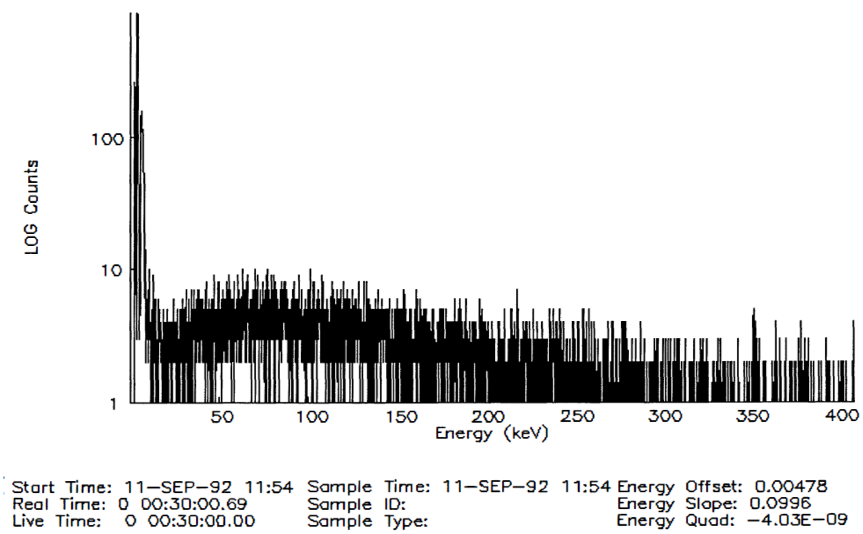


Figure 8. Example Spectral Printout

If the full-width-at- half-maximum (FWHM) were known, one could estimate the number of counts in the 238 keV region by adding up the counts displayed in the printout. As can be seen in Figure 8, the printout covers the region of 0-400 keV with an energy calibration of slightly less than 0.1 keV per channel. Thus, the spectrum constitutes a printout of approximately 4,000 (actually 4096) data channels. Given that the compressed nature of the spectrum made it difficult to estimate background accurately, it was decided to investigate other methods of establishing background in the 238 keV region. As previously discussed, the peak search algorithm provides the calculated background counts under each peak that is positively identified. An examination of the in vivo reports contained in Y-12 [1989-1995] for a character string of "238." indicated that were at least 24 reports that contained a positive peak for the 238 keV emission of Pb-212. A summary of the peak search results extracted from these reports is provided in Table 6. The average background in the Pb-212 region was calculated to be 34.4 counts with a standard deviation of 9.7 counts.

Table 6. Summary of Peak Search Results for Peaks Identified at 238 keV

Pdf Page[11] [ORAUT 2014]	Net Counts	Background Counts
571	15	38
617	55	46
1034	21	33
1122	21	39
1536	23	30
2777	13	45
3758	13	36
6071	2	34
6692	26	27
6871	15	21
7404	13	38
7549	14	30
8629	18	22
10477	27	23
10822	13	29
10874	12	49
12191	29	20
12206	10	29
14682	22	37
15922	13	48
17605	30	25
17955	19	52
18809	20	50
20636	19	25
Mean	**NA**	**34.42**
Std. Deviation	**NA**	**9.70**

For comparison purposes, the background counting statistics at other energies associated with radon daughter activity was also evaluated. For this comparison, Y-12 [1989-1995] was searched for the character strings “295.” and “352.”, which are peak energies associated with the decay of Pb-214. Twenty-nine peaks were identified at 295 keV and twenty-four peaks were identified at 352 keV. The average background areas under these peaks were 32.7 and 29.7 for the 295 and 353 keV peaks, respectively. Figure 9 provides a chart of the background areas in each region that was evaluated.

[11] These were independent measurements of 24 different workers.

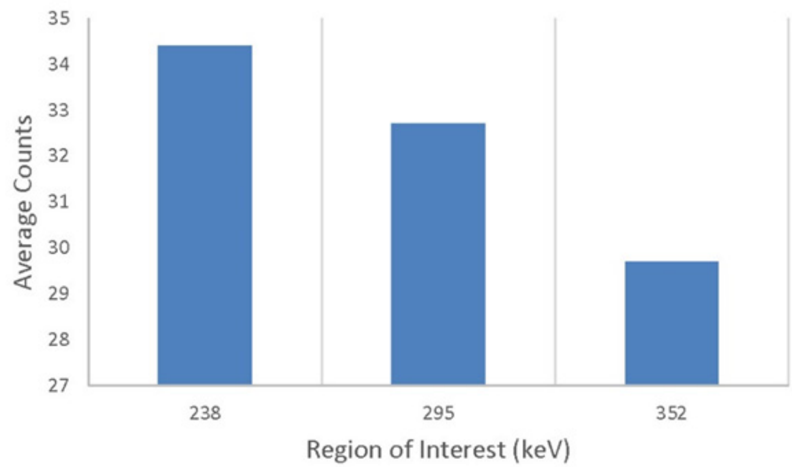


Figure 9. Background Counts Collected During a 30 Minute Measurement

As can be seen, the decrease in the average background counts as the energy increases is consistent with the trend that can be seen in the example spectrum provided in Figure 8.

5.0 EVALUATION OF MINIMUM DETECTABLE ACTIVITY

The formula for calculation of an MDA is based on the statistical concept derived by Currie [1968]. For an in vivo exam this is expressed as:

$$MDA\ (nCi) = \frac{4.66 * \ \sigma_b}{e * y * t * 2200}$$

Where:
σ_b = the standard deviation of a background count;
e = the detection efficiency in counts/gamma;
y = the photon yield in gamma/disintegration = 0.446 for Pb-212;
t = the count-time in minutes = 30; and,
2200 = the number of disintegrations per minute per nCi of activity.

Normally, the standard deviation of the background count is approximated by taking the square root of the number of counts in the background region. In this case the square root of the mean background count of 34.42 is 5.87. The background for a lung count, however, is subject to more variability than what would be expected by the Poisson distribution. This is because other parameters, such as subject size and K-40 content, can have significant effects on the background. Because of this, the standard deviation of the background calculated from the subject population of 9.70 will be used in the MDA calculation.

As discussed in Section 3.4, the detection efficiency is a function of CWT. Thus, the complete MDA formula for a 30-minute lung count at 238 keV is:

$$MDA\ (nCi) = \frac{4.66 * \ \sigma_b}{(0.010307 * \exp(-0.321 * CWT)) * 0.446 * 30 * 2200}$$

Using the above formula, the MDA was calculated for CTWs of 1.5., 2.5, 3.5, 4.5, and 5.5 cm. The results of these calculations are provided in Figure 10.

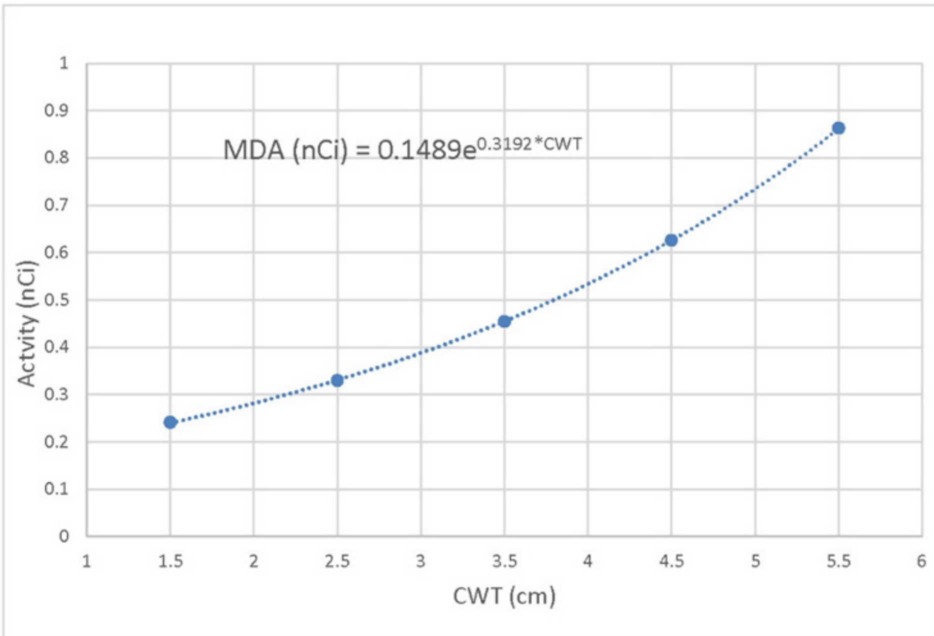


Figure 10. MDA at various CWTs for a 30 minute count.

As can be seen in Figure 10, the MDA ranges from 0.24 nCi at 1.5 cm to 0.86 nCi at 5.5 cm CWT. This is the *a priori* minimum detectable activity. That is, this is the *a priori* amount of activity that needs to be present for the lung count to positively detect a critical level of activity with 95% certainty. Once a lung count is performed, however, one can use the critical level to determine if a lung count has detected positive activity after the count has been made (i.e., *a posteriori*). In this case, the critical level, as discussed by Currie [1968] is expressed as:

$$L_c\ (nCi) = \frac{2.33 * \ \sqrt{B}}{e * y * t * 2200}$$

Where:
B = the number of background counts in the 238 keV region.

To evaluate the critical level on a count-by-count basis would require the exact background counts in the 238 keV region of interest. As discussed above, the resolution of the spectral plots was judged to be insufficient to develop this estimate on a case-by-case basis. In lieu of calculating the critical level for each count, it is recommended that the MDA be used as the upper end of a triangular distribution with a lower bound of zero and a central estimate of one-half the MDA. This is consistent with the current NIOSH practice for estimating missed dose from bioassay data with non-detectable results.

6.0 SUMMARY AND CONCLUSIONS

This report provides an evaluation of the MDA for a lung count at the Y-12 facility between 1989 and 1995. Based on a review of data contained in Y-12 [1985-1995], it was decided to limit the evaluation to the time period 1992 – 1995 when germanium detectors were used to perform lung counts at Y-12. The time period prior to 1992 provided values and MDA's for Pb-212, so no evaluation was necessary. There is a period of time from January to June of 1992, when the K-25 facility was used to perform lung counts on Y-12 personnel. Additional information is needed to evaluate the MDA for Pb-212 for these counts.

Examination of the Y-12 in vivo exam reports for the 1992-1995 time period revealed that they contained sufficient data to estimate the MDA for Pb-212. Using the positive peak search results in Y-12 [1989-1995] (which included background counts) and the reported activities for U-238, U-235, and Ac-228, efficiency curves were generated as a function of chest wall thickness at 62.39, 92.38, 185.71, and 338.32 keV. An interpolation was then done to estimate the detection efficiency for Pb-212 at 238.65 keV.

To establish background for Pb-212, 24 positive peak search results for 238 keV were extracted from Y-12 [1989-1995]. These results had a mean count of 34.4 with a standard deviation of 9.7. Comparison of these counts with those in other energy regions were consistent with the pattern observed in the spectral plots. That is, there were a diminishing number of counts in the spectrum as energy increased.

Using the efficiency and background data developed above, an equation for the Pb-212 MDA as a function of chest wall thickness was established. Given that it was not possible to estimate the background levels on a count per count basis, the critical level for an individual count was not made. In light of this, it is recommended that the MDA be used in the calculation of missed dose for a Th-232 intake. This calculation should use the MDA as the upper bound of a triangular distribution, with a lower bound of zero and a central estimate of one-half the MDA. This is consistent with the current NIOSH practice for estimating missed dose from bioassay data with non-detectable results.

REFERENCES

Currie, L.A., 1968, *Limits for Quantitative Detection Quantitative Determination Application to Radiochemistry,*

Gose, B. T., Veinot, K. G., 2006, *Verification and Validation of the Y-12 Lung Counting System, Y-12 National Security Complex*, Oak Ridge, TN. [SRDB Ref. ID: 048609]

ICRU (International Commission on Radiation Units and Measurements), 2003, *Direct Determination of Body Contents of Radionuclides*, Report 69, Volume 3, No. 1, Bethesda, Ashford England, pp. 76-77.

Kocher, D.C., 1981, *Radioactive Decay Tables*, DOE/TIC-11026, Oak Ridge National Laboratory, Oak Ridge, Tennessee. [SRDB Ref ID: 032563]

ORAUT (Oak Ridge Associated Universities Team), 2014, *Guiding Reconstruction of Intakes of Thorium Resulting from Nuclear Weapons Programs*, ORAUT-OTIB-0076, Rev. 00, Oak Ridge, Tennessee, July 10.

Spitz, H.B., Buschbom, R.L., Rieksts, G.A. and Palmer, H.E., 1985, *A New Method for Analyzing High-Resolution Spectra from Whole-Body Counter In Vivo Measurements*, Health Phys. 49, pp.1085-1096. [SRDB Ref ID 178690]

Y-12, 1989-1995, no title, compilation of Whole Body Count Data Scans from Y-12 National Security Complex, collected in May 2019. [SRDB Ref. ID: 176611]

Attachment 1

[redacted] [redacted]

Y-12 IN-VIVO RADIATION MONITORING REPORT

13:52

NAME	DATE
[redacted]	10-16-91

INPUT – SUBJECT INFORMATION

	Analysis Sequence	7
	Constant Set	—
1.	Run Number	12312
2.	Tag Word	– ROUTINE
3.	Badge	[redacted]
4.	Name	[redacted] M / F
5.	Department	[redacted]
6.	Background Number	—
7.	Weight	[redacted] Pounds
8.	Height	[redacted] Inches
9.	Chest Thickness	9.5
10.**	Surface Contamination	1
*	History — Med. Isotope	NO
	Date of Birth	
	Smoke?	No ( ) Cigarette ( ) Cigar ( ) Pipe ( )
	How Much?	

OUTPUT – ANALYSIS SEQUENCE RESULTS

	F/B Ratio	1.0	
A.	Enriched Uranium	7.85	micrograms
B.	Total Uranium	4.36	milligrams
C.	Cesium	0.39	nanocuries
D.	Potassium	106.00	grams
E.	Technetium	0.39	microcuries
F.	Neptunium	0.12	nanocuries
G.	Lead	6.76 E-02	nanocuries
H.	Actinium	0.13	nanocuries

*NOT FOR INPUT. Has subject or any member of immediate family been administered a medical isotope or had a medical scan during last 12 - month period?

** – Numbers beginning with a "1" indicate no surface contamination.
– Numbers beginning with a "2" indicate presence of surfact contamination. The number following the "2" is the amount in d/m/100cm^2.

UCN-8254 (2 9-85)

[redacted]

Attachment 2

```
VAX/VMS Lung Burden [redacted]1 14:13:0[redacted]

                 ---- Subject Information ----
Employee name     : [redacted]
Badge number      : [redacted]
Plant name        : Y12                    Department       : [redacted]
Height (in)       : [redacted]             Weight (lbs)     : [redacted]
Chest Thick. (in): 9.50000                 Front/Back ratio : 1.00000E+00
                  ---- Count Information ----
Acquisition date : 16-OCT-1991 13:52:35 Elapsed live time: 0 00:20:00.00
Operator initials: [redacted]              Calib. (keV/ch)  : 2.99977E+00
---- Configuration Name ----                         ---- Detector Name ----
DKA300:[USER]012312_R.CNF;1                          Right Detector
DKA300:[USER]012312_L.CNF;1                          Left Detector
DKA300:[USER]012312_B.CNF;1                          Back Detector
DKA300:[USER]BACK_16_OCT_91_R.CNF;1                  Right Detector
DKA300:[USER]BACK_16_OCT_91_L.CNF;1                  Left Detector
DKA300:[USER]BACK_16_OCT_91_B.CNF;1                  Back Detector
```

Nuclide	Quantity	
U-235	7.85	ug
U-238	4.36	mg
Cs-137	0.388	nCi
K-40	106.	g
Tc-99	0.391	uCi
Np-237	0.124	nCi
Pb-212	6.757E-02	nCi
Ac-228	0.125	nCi

Attachment 3

ABACOS-Plus	[redacted]	Printed:13-JAN-1992 14:21:02	Page: 1

Subject name: [redacted]	Identification #: [redacted]
Dept: [redacted]	Count Started: 13-JAN-1992 14:00:20
Employee # [redacted]	Intake Date: 13-JAN-1992 14:00:20
Reason: Routine	Frequency:
Count type: Individual	Operator: [redacted]
Comment:	CWT: 31.20000

Counter:	Facility: MMES K-25
Arrangement/Geometry: LCSTD/LCSUMMED	Elapsed Live Time: 0 00:20:00.00
Detector: LUNGS	Elapsed Real Time: 0 00:20:00.31
Analysis limits: 50 to 2048	Count Rate: 2.035 2.179 0.000 0.000 0.000 0.000 0.000 0.000

Peak Search Results

----- No Peaks Found -----

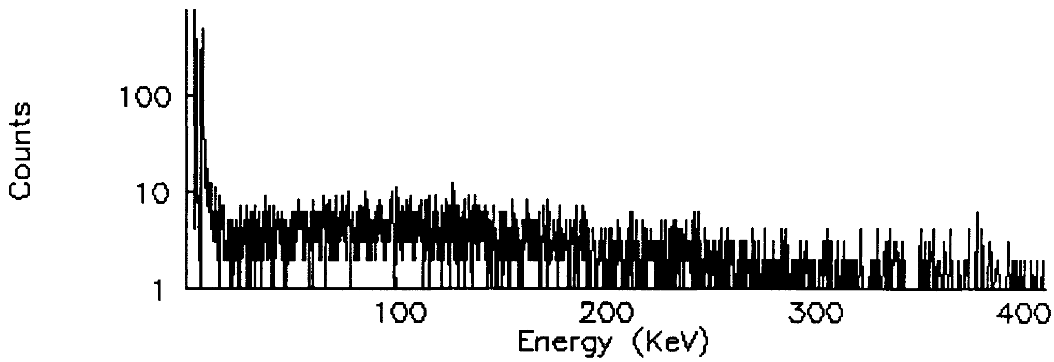
Nuclide Results

Nuclide	Activity (nCi)	%Error (2 SD)	%MPOB	Comments
TH-232	< 10.7		< 0.00	MDA activity reported
TH-234	< 3.18		< 0.00	MDA activity reported
U-234	< 121.		< 0.00	MDA activity reported
U-235	<0.275		< 0.00	MDA activity reported
U-236	< 220.		< 0.00	MDA activity reported
NP-237	< 1.13		< 0.00	MDA activity reported
PU-238	< 142.		< 0.00	MDA activity reported
U-238	< 435.		< 0.00	MDA activity reported
PU-239	< 374.		< 0.00	MDA activity reported
PU-240	< 149.		< 0.00	MDA activity reported
AM-241	<0.323		< 0.00	MDA activity reported
				----- No Nuclides Identified -----
totals:	0.000E+00		0.00	

Attachment 4

ABACOS-Plus	[redacted]	Printed:13-JAN-1992 14:00:20	Page: 2

---- LCSTD/LCSUMMED ----



Energy Calibration Performed: 5-SEP-1991 06:19:01. Efficiency Calibration Performed: 6-SEP-1991 10:28:02.
Libraries Used: ND_WBC_LIB:ROUTINE.WLB,ND_WBC_LIB:ROUTINE.WLB,ND_WBC_LIB:LENERGY.WLB
Analyses By: GAMMAM V1.0,PEAKEFF V2.2,NID V2.4,WTMEAN/KEY V1.4,MINACT V2.2

Reviewed by: [redacted] Date: 2-10-92

Attachment 5

Y-12 Lung Counting Report generated 27-DEC-1994 11:13:16

[redacted]

---- Employee Information ----

Employee name : [redacted] Department: [redacted]
Employee ID num. : [redacted] Chest Wall Thick. 3.32330

---- Count Information ----

Acquisition date : 27-DEC-1994 10:40:49 Elapsed live time: 0 00:30:00.00
Operator initials: [redacted] Detector geometry: LUNGS/TOTAL

---- Processing Parameters ----

Sensitivity : 2.57600 Secondary sens. : 1.75000
Median Win. Size: 51 Customer I.D. : [redacted]

The DOSIMETRIC information which follows is for information purposes only.
This system has been set up to provide an estimate of lung activity only.
All intake/exposure related quantities below should be ignored.

---- Configuration Name ---- MCA0:[LONGTW]TOTAL$1

---- Detector Name ---- LUNGS

**** LUNGS **** Post-NID Peak Search Report

It	Energy	Area	Bkgnd	FWHM	Channel	Left	Pw	%Err	Fit	Nuclides
0	9.48*	250	64	0.80	95.54	90	16	25.1		
0	373.48	14	12	0.30	3743.75	3725	36	44.0		

ICRP-30 Report [redacted]; 27-DEC-1994 10:40

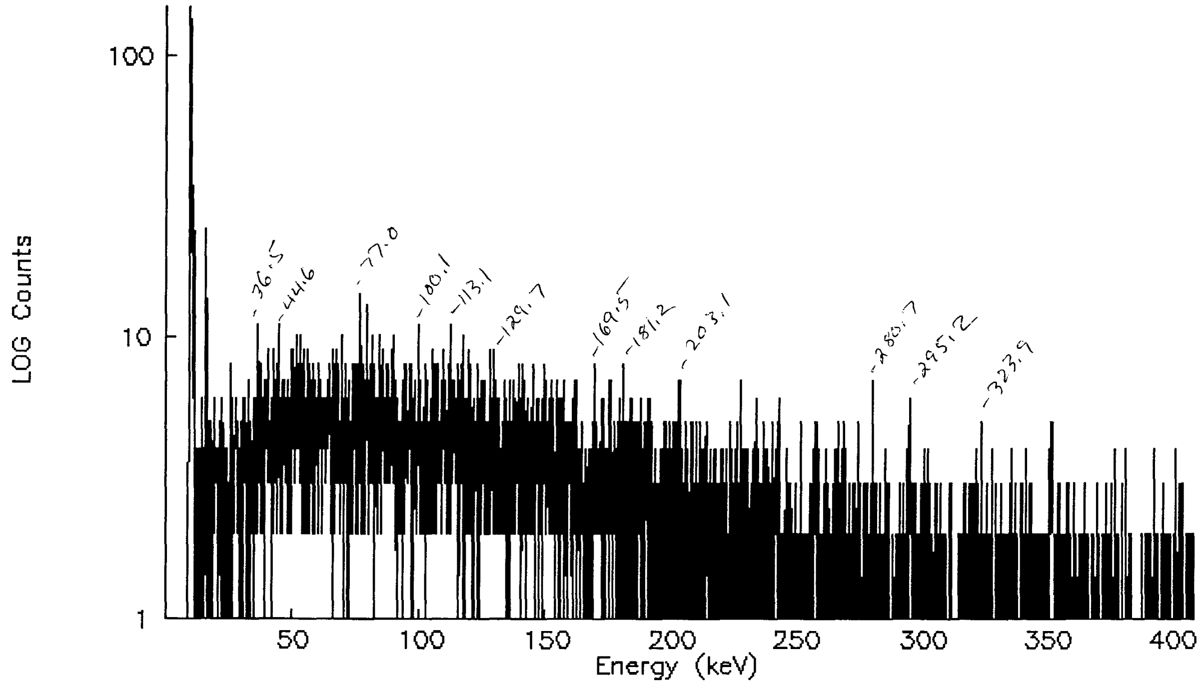
Nuclide	Activity (nCi)	1-Sigma % Error	Intake (nCi)	%ALI	DAC-Hr	H50 (mrem)	HE50 (mrem)	Flag
---- LUNGS ----								
AC-228	< 1.0	0.00	< 3.2	< 117.21	<2.34E+03	<5.85E+04	<3.65E+03	
U-235	<0.22	0.00	<0.68	< 0.10	< 2.0	<0.00E+00	< 4.9	
U-238	< 2.7	0.00	< 8.3	< 1.14	< 23.	< 57.	< 57.	
----- No Nuclides Identified -----								
Totals:	0.00E+00		0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	

Comments:

Approved by: [redacted] Date: 1/6/95

Attachment 6

Spectrum: [redacted]
Title: Lung Counting Default Configuration
Sample Title: Termination



Start Time: 27-DEC-94 10:40
Real Time: 0 00:30:00.20
Live Time: 0 00:30:00.00

Sample Time: 27-DEC-94 10:40
Sample ID:
Sample Type:

Energy Offset: -0.0868
Energy Slope: 0.100
Energy Quad: -1.03E-07

Attachment 7

Att#1

The Y-12 Lung Counter began routine operations on June 15,1992. Several baseline counts during the first week showed detectable peaks of Th-234 (63.3 and 92.4 KeV). Th-234 is a daughter of U-238 and is used to determine the presence of natural or depleted uranium. Since these were baseline counts, room contamination was concluded to be the most likely cause. After investigation, the most probable source of the contamination was determined to be two newly installed PGT detectors. Although this is an undesirable situation, personnel lung counting can be performed satisfactorily with proper statistical analysis of results showing detectable peaks of Th-234. As long as personnel results are shown to be less than the Critical Level, L_c, no further actions will be taken. L_c is defined as that net count rate or number of counts above which detectable activity is said to be present at the 95% confidence level.

A ten hour overnight background is acquired periodically, and net counts from peaks identified in this spectrum are automatically subtracted from the net counts of corresponding peaks identified in lung count spectra (after correcting for different acquisition times). However, given a lung count measurement in which a Th-234 peak is detected, there should be an equal probability of the net peak count rate observed being greater than or less than the net peak count rate observed in the background spectrum. Therefore, one would expect that one half of all counts in which the Th-234 peaks are detected will be identified as positive by the software, even after the correction based on the ten hour overnight background subtraction. It was therefore necessary to develop a method of determining L_c which takes the error introduced due to the Th-234 activity present into consideration.

The number of net counts (and hence the net peak count rate) associated with a peak is calculated by the peak search routine **Peak/Singlet**. In order to minimize any sources of error associated with the peak search, (peak search error was not included in the formulation of L_c) the method of determining L_c utilizes the sum of the Peak Area and the Peak Background (these quantities are provided on the **Peak/Singlet** report). This sum cannot be compared directly to the sum of the Peak Area and Peak Background from the ten hour empty room background acquisition. The majority of the background observed in a lung count is the background introduced by the person being counted. Therefore, the Peak Background component of the Peak Area/Peak Background sum will be much larger in the lung count of an unexposed person than in an empty room background. In order to obtain an appropriate blank for estimating the "true" Peak Area/Peak Background sum, an individual with no uranium work experience was counted for an extended period of time ($\approx$1.5 hr). The Peak Area/Peak Background sum from this count was used to determine L_c.

$$L_c = k\sigma_o$$

$$\sigma_o = \sqrt{\left(\frac{R_b}{T_t} + \frac{R_b}{T_b}\right)}$$

k	= 1.645 (95% confidence level)
R_b	= Peak Area/Peak Background sum for control individual
T_t	= standard lung count, count time
	= 30 minutes
T_b	= control individual count time
	= 87 minutes

Using these equations, the assumptions listed above were utilized to calculate the minimum Peak Area/Peak Background sum necessary before a decision that activity is present based on a Th-234 peak is made. The values used in the equations above and the minimum "sums" are given ~~below for the~~ two Th-234 peaks of concern.

Th-234 63.3 KeV Peak

R_b = 4.172 counts/min
L_c = 21.34 net counts for a 30 minute count

Therefore the expected "sum" for a 30 minute count would be 125.17 counts, and a decision that activity is present will be made when the Peak Area/Peak Background sum exceeds 147 counts.

Th-234 92.4 KeV Peak

R_b = 4.460 counts/min
L_c = 22.07 net counts for a 30 minute count

Therefore the expected "sum" for a 30 minute count would be 133.79 counts, and a decision that activity is present will be made when the Peak Area/Peak Background sum exceeds 156 counts.