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INTERCALIBRATION FOR LOW-ENERGY
PHOTON MEASUREMENTS (a)

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INTERCALIBRATION FOR LOW-ENERGY
PHOTON MEASUREMENTS^(a)

K. L. Swinth and P. N. Dean

ABSTRACT

In 1970 an informal group of scientists working on the in vivo measurement of low-energy photon emitters (plutonium) convened to consider an intercalibration program for plutonium whole body counters. It was decided that an intercalibration program should be undertaken in three phases. First, pertinent data on the photon emissions from the transuranic materials should be compiled; and second, the counters should be inter-compared with a source and, finally, the same subjects with a body burden of plutonium should be counted at the participating laboratories. The purpose of this paper is to summarize preliminary results from the source intercalibration of participating facilities.

Three sources each of ^{241}Am and of ^{238}Pu , representing three decades of activity, were routed to participating laboratories along with instructions, a counting jig and absorbers. The laboratories were to count the various sources in a fixed geometry with and without the absorbers and to determine the source activity with their own standard. The first reports for the high level ^{241}Am source (50-70 keV energy band) had a mean of 589 nCi and a standard deviation of 34 nCi. The range was 90 nCi. For the high level ^{238}Pu source, the mean was 385 nCi with a standard deviation of 35 nCi. The range was 102 nCi. Results with the other sources are similar with variations greater than expected from statistics.

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INTRODUCTION

In 1970, with the help of C. R. Richmond (then AEC), an informal group of scientists were brought together under the title "Intercalibration Committee for Low-Energy Photon Measurements." The purpose of this group, which still meets under an informal arrangement, was to find a relative basis for discussion and comparison of plutonium whole body counting data and techniques - not to make an absolute calibration of the counters. The purpose of this paper is to summarize the efforts of this group and to present source intercalibration results from the first group of laboratories participating in this phase of the effort.

At the first meeting of the intercalibration committee which was held during the 1970 Health Physics Society Meeting, it was decided to undertake a general program of three phases. First, basic data on photon intensities from the isotopes of interest was to be accumulated followed by system calibration using a standard consisting of either a source or a phantom. At the initial meeting a phantom was favored over sources. The third phase of the intercalibration program was to involve counting of a subject or subjects who had been accidentally exposed to plutonium. At the second meeting of the committee (July 1971), the routing of a phantom was rejected and it was decided to route calibration standards between the various laboratories. This would aid in pointing out instrumental and possible calibration difficulties. At this meeting a compilation of low energy photon intensities from plutonium and other transuranic isotopes was distributed, thus completing phase 1.⁽¹⁾

Figure 1 outlines the three phases of the effort undertaken by the intercalibration committee and adds a documentation phase which is really a portion of each of the other three phases.

Photon Intensity Compilation

The first phase of the intercalibration involved compilation of photon intensities⁽¹⁾ for a number of transuranic nuclides of interest. The intensities collected were limited since the decay schemes of the transuranics are complex (90 transitions identified in ^{239}Pu ,⁽²⁾) and a lot of the data was not necessary for the committee's purposes. In general, photons above 150 keV and with intensities less than one per 10^5 decay were not tabulated. The K X-rays are often more intense than neighboring gamma rays, but they are not of interest in assigning decay schemes and are not widely tabulated; therefore, only a few of these intensities were listed.

Table 1 is a summary of the data collected for some transuranic materials.⁽¹⁾ The actual compilation was much more extensive and included many gamma transitions for the various isotopes.

Source Intercalibration

The purpose of the source intercalibration portion of the program was to show how the individual laboratory was performing relative to other laboratories.

Specific objectives were:

- 1) Indicate count rate problems or other instrument problems
- 2) Compare calibration standards
- 3) Provide a common basis for calibration and comparison.

To accomplish these objectives it was decided that isotopically pure sources would be counted in a standard geometry. Three sources of ^{238}Pu and three of ^{241}Am with nominal activities of 5, 50 and 500 nCi were prepared at Los Alamos for the intercalibration. The ^{238}Pu was to cover the L X-ray region (12-24 keV) and the ^{241}Am was to cover the 59.6 keV gamma (50-70 keV) of ^{241}Am which is often used as a tracer.

Plutonium -238 was used in preference to ^{239}Pu to avoid uncertainties in the isotopic composition of the source.

7. Figure 2 shows the calibration stand used for the counting. It is a simple stand made of plexiglas and allows accurate control of the geometry. Besides the permanent 1/16th inch of absorber at the top of the stand, three absorbers 0.59, 1.02 and 1.89 cm thick were provided for absorption measurements. These absorbers fit inside the bottom of the stand over the source.

With the sources and stand were a set of instructions which are summarized below:

- 1) Measure background counting rate with stand (>1 hr).
- 2) Count each source without absorbers (1% statistics)
- 3) Count each source with absorbers

- a) 0.59 cm, 2.46 cm, 3.45 cm combinations
 - b) 1% counting statistics
 - c) May skip low activity sources
- 4) Determine activity of standards
 - 5) Use 12 to 24 keV and 50 to 70 keV for analysis
 - 6) Send in data, calculations and a diagram of the detector.

Source Intercalibration Results

The intercalibration procedure turned out to be a lengthy chore requiring about 5 days of counting and about 3 days to transport the sources between laboratories. Only one-half the participating laboratories provided all the information requested. Some had valid reasons for not participating in a portion of the measurements while others neglected to show calculations or to include a description of their detector. In other cases extra information was documented including multiple detector calibrations. In the case of multiple calibrations, the first listed calibration was used unless a preference was stated.

Figure 3 shows a plot of the ratio of the measured Pu-238 activity to the average measured value for the various laboratories. The measurements without added absorbers were used for this plot and the standard deviation from the average is listed on the figure. Figure 4 shows similar data for the Am-241 sources. A gross disagreement from the average is indicative of an erroneous detector calibration and is probably due to the calibration source employed.

It is apparent that most deviations are consistent within a laboratory. Figures 5 and 6 shows plots of the ratios of source activities along with standard deviations. The consistency of these plots indicates that count rate problems are not serious for the various investigators and that most of the variation in Figures 3 and 4 is probably due to the calibration sources.

Figure 7 shows a plot for each laboratory of the count rate for the 500 nCi ^{238}Pu source with various absorbers.

The slope of the curves are practically identical indicating that count rate problems are not significant at the various laboratories.

Table 2 shows background count rates and counting sensitivities with ~2.5 cm of added absorber. This shows the range of backgrounds and sensitivities available. The data represents counts taken with proportional counters, phoswich detectors and large area sodium iodide detectors. The mean value of the source activity was used to calculate the sensitivity in order to remove bias from the laboratories calibration source. Figure 8 shows a plot of the normalized sensitivity. The two points not included in the mean are rejected because of bias from the calibration technique. These detectors are larger than the calibration stand and because of the influence of r^2 , variable absorption lengths in the absorber and shielding of the stand, the effective area of the detector will not be the same as the physical area.

Although this will lower the apparent sensitivity with the point sources, the sensitivity may be better than the other detectors when counting a large area source such as a lung.

CONCLUSIONS

The intercalibration indicates good instrumental control between the laboratories and indicates that calibration differences are probably due to errors in calibration standards. Although, the agreement between normalized sensitivities and backgrounds is fairly good, the disagreement between practically identical detectors is unexplainable. Differences in coincidence techniques or effective area of the detector may explain the difference.

REFERENCES

- 1) K. L. Swinth, "Photon Intensities and Their Importance In Counting Transuranic Materials." BNWL-1648, (May, 1972).
- 2) J. E. Cline, "Level Structure of ^{235}U Observed by a Study of the Alpha Decay of ^{239}Pu ." Nuclear Physics, A106, p.481 (1968).

TABLE 1. *Data for Some Heavy Isotopes*

Isotope	Specific Activity Curies/g	Maximum Permissible Body Burden		X-rays per Alpha	
		μCi	μg	Measured ^(a)	Average ^(b)
^{238}Pu	16.8	0.04	0.0023	0.114 (0.112)	0.115
^{239}Pu	6.16×10^{-2}	0.04	0.65	0.0460 (0.0476)	0.0465
^{240}Pu	0.227	0.04	0.18	0.115 (0.106)	0.108
^{241}Pu	113	0.90	0.0082	- - -	- - -
^{242}Pu	3.91×10^{-3}	0.05	0.13	- - -	0.100
^{241}Am	3.22	0.05	0.016	- - -	0.376
^{237}U	8.2×10^4	- - -	- - -	- - -	0.63
^{242}Cm	3.21×10^3	0.05	1.55×10^{-5}	0.117 (0.113)	0.106
^{244}Cm	81.1	0.1	0.00123	0.0918 (0.0937)	0.0923
^{237}Np	7.06×10^{-4}	0.06	85	0.597 (0.543)	0.57

a. Values in parenthesis refer to data taken with the proportional scintillation system (Ref 1) while the other values were taken with the solid-state system (Ref 2).

b. The averages include the measured values and recent values from the literature (see Appendix).

DETECTOR CHARACTERISTICS FOR THE PARTICIPATING LABORATORIES

LABORATORY IDENTIFICATION	DETECTOR AREA (cm ²)	²³⁸ Pu (12-24 keV)	
		BACKGROUND (cpm/cm ²)	SENSITIVITY WITH 2.5 cm ABSORBER (cpm/nCi)
1	81	0.0183	0.491
2	103	0.0157	0.692
3	202	0.0487	0.727
4	254	0.272	0.631
5	130	0.0468	0.884
6	103	0.347	0.997
6	127	0.191	0.726
7	103	0.0489	0.826
8	81	1.12	0.662

TABLE 2a

DETECTOR CHARACTERISTICS FOR THE PARTICIPATING LABORATORIES

LABORATORY IDENTIFICATION	DETECTOR AREA (cm ²)	²⁴¹ Am (50-70 keV)	
		BACKGROUND (cpm/cm ²)	SENSITIVITY WITH 2.5 cm ABSORBER (cpm/nCi)
1	81		
2	103	0.0268	19.7
3	202	0.0995	16.8
4	254	0.089	65.1
5	130	0.0362	25.1
6	103	0.105	24.5
6	127	0.218	17.9
7	103	0.0565	25.8
8	81	0.475	16.6

TABLE 2b

Figure Captions

- Figure 1: Intercalibration committee goals
- Figure 2: Intercalibration source stand
- Figure 3: Ratio of Individual Laboratory Determined Activity to Mean Activity of Laboratories for Pu-238 Calibration Sources.
- Figure 4: Ratio of Individual Laboratory Determined Activity to Mean Activity of Laboratories for Am-241 Calibration Sources.
- Figure 5: Ratio between source count rates for the various laboratories with the Pu-238 sources.
- Figure 6: Ratio between source count rates for the various laboratories with the Am-241 sources.
- Figure 7: Absorber measurements for the participating laboratories.
- Figure 8: Normalized sensitivities for the participating laboratories.

"INTERCALIBRATION COMMITTEE
FOR LOW-ENERGY PHOTON MEASUREMENTS"

1. PHOTON INTENSITY DATA
2. SOURCE COMPARISON OF COUNTERS
 - a) COMMITTEE LABORATORIES
 - b) OTHER INTERESTED LABORATORIES
 - c) FOREIGN PARTICIPANTS?
3. INTERCALIBRATION WITH EXPOSED SUBJECTS
4. DOCUMENTATION OF RESULTS

CALIBRATION STAND

²³⁸Pu INTERCOMPARISON
RATIO OF INDIVIDUAL LAB ACTIVITY TO
MEAN OF ALL LABS

²⁴¹Am INTERCALIBRATION (50-70 keV)
 RATIO OF INDIVIDUAL LAB ACTIVITY TO
 MEAN OF ALL REPORTED VALUES

^{238}Pu SOURCE RATIOS
RATIO OF SOURCE COUNT RATES FOR ^{238}Pu

^{241}Am SOURCE RATIOS
RATIO OF SOURCE COUNT RATES FOR ^{241}Am

Normalized Sensitivity (cpm/nCi-cm²)

Pu-238

Am-241

241Am

238Pu

NORMALIZED SENSITIVITY (cpm/nCi-cm²)

* SOLID CIRCLES NOT INCLUDED IN MEAN OR STANDARD DEVIATION

* Solid circles not LABORATORY IDENTIFICATION