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SPECIAL-GEOMETRY PROPORTIONAL COUNTERS AND TECHNIQUES FOR DETECTION OF LOW-LEVELS OF X-RAYS AND β-PARTICLES

by

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SUMMARY

Part of the program of development of a planetary x-ray diffractometer at UAH has involved the devising of arrays of detectors of special geometries to increase the counting efficiency of a Martian instrument for signal photons.

The multiwire, multiplane proportional counter described here was designed and built to test various modes of increasing efficiency by using coincidence and anticoincidence techniques. Another application of these techniques was developed during the work and is described here. The β-detection application and the Martian x-ray application involve pulling low level signals out of gamma- and singly charged particle background and are conveniently tackled by proportional counter methods as described here.

The use of the inert radioactive gas Kr-85 for tracer studies, leak detection, etc., will become more widespread as the sensitivity of available detectors increases. A multiwire multiplane proportional counter system for beta detection has been developed with a measured minimum detectable concentration for a 3-minute count of 3×10^{-3} pCi cm^{-3} of Kr-85 in a semi-infinite cloud. Larger proportional counters operated for counting times of several hours can reduce this limit to below 1×10^{-4} pCi cm^{-3}. These detectors should be useful in monitoring low levels of the radioactive inert gases and of x-ray emitting nuclides.

INTRODUCTION

In the last ten years, a number of applications of krypton-85 as a fluid-flow detection medium have been developed. Some examples in the literature[1-4] describing applications and advantages of the radioactive gas tracer techniques and a rather complete bibliography[5] of krypton-85 uses are referenced. The technique has been used to detect leaks in hermetic seals, for oil field porosity studies, blood flow studies, and detecting stress cracks in turbine blades. The use of the krypton-85 tracer has been considered for general leak detection[1,6] in much the same way that helium detection is now applied. Acceptance by industry and other users has suffered from a lack of detectors of sufficient sensitivity to detect levels of radio-krypton low enough to satisfy concern about statutory limits[7] for practical applications.

Recently we have used the technology of construction of large area proportional counter hodoscopes, originally developed for accelerator experiments, to build a number of detectors with optimum sensitivity for low concentrations of krypton-85 in ambient air. In addition to laboratory applications where krypton-85 and other beta emitting gases are used, the counters have application in monitoring beta and x-ray emitting radio nuclides at low activity levels in the environment.

A comprehensive discussion of the calibration and testing of a variety of different krypton-85 detectors commercially available in 1970 in the U.S. was given by Smith, Cochran and Shleien[8], and in 1972 in Germany by Maushart[9].

DETECTOR SENSITIVITY TO KRYPTON-85

The sensitivity of a detector to a particular radiation may be expressed in terms of the statistical error in the signal, S, in counts, obtained when the detector of area A is exposed for time t seconds to a concentration of radioactivity of activity C (in this case in picoCuries per cm^3).

$S = F_s ACt$ where F_s is the efficiency of calibration factor for the particular radiation and detector combination in counts $cm^{-2}s^{-1}$ pCi^{-1} cm^3.

Similarly, the sensitivity to background radiatiors given by:

$B = F_B ARt$ where F_B is a composite calibration factor for the background radiation and R is the background activity.

The limit of detection of the radioactivity is set at some number, N, of standard deviations of the background counting rate $\sigma(B) \sim \sqrt{B}$.

$$S_L = N\sigma(B) = N\sqrt{B}.$$

This limit corresponds to a minimum detectable concentration, C_L, where

$$C = N\frac{\sqrt{F_B ARt}}{F_s At} = \frac{N}{F_s}\sqrt{\frac{F_B \cdot R}{A \cdot t}} \quad .$$

Thus to increase the sensitivity of any measurement to the lowest activities, we maximize the exposure, A · t, and design our detector for optimum F_s. Usually this also increases F_B; but, since the sensitivity increases as $F_S/\sqrt{F_B}$, the net result is beneficial. Design features may be incorporated deliberately to reduce F_B.

Emissions from krypton-85 are:

β, E_{max} = 0.67 MeV, $\bar{E}$ = 0.49 MeV, frequency 99.6%

γ, E = 0.514 MeV, branching ratio 0.4%

Some detectors (e.g., scintillators) make use of the γ, but are intrinsically inefficient because of the low branching ratio. They may also have higher sensitivity to background γ's. Gas-filled β-detectors may either inhale the radioactive gas or incorporate thin windows to admit the β's. The mean range of krypton-85 β's is 20 cm of ambient air or 25 mg cm^{-2} of plastic material.

Multiwire proportional counters compare favorably with Geiger counters for this application for several reasons. They are readily fabricated in large area arrays, they may be readily stacked in layers to provide coincidence and anticoincidence for improvement in the ratio $F_S/\sqrt{F_B}$, and they posses energy resolution which may also be used to improve background rejection.

EXPERIMENTAL

The multiwire proportional counter with which the measurements described below were made is shown in Figures 1 and 2. Anode wires are 50 μm gold-plated tungsten; anode spacing and gap-width is 0.5 cm.

Three anode planes are shown, with four cathode planes. The upper two cathode planes were formed from a single continuously wound 150 μm dia. stainless steel wire. Wire separation was 0.1 cm. The cathode plane separating the second and third anode planes was a 0.125 cm- thick aluminum plate, the thickness of which exceeds the maximum range of krypton-85 β's.

Three signal outputs were brought out of the counter, one for each anode plane. All the anodes in each plane were connected. The outermost wires of the upper two planes were connected to the bottom plane to form an anticoincidence shield. The active area (central portion) was $7.5 \times 15 = 112.5\ \text{cm}^2$.

Electronics consisted of three preamplifiers, post amplifiers, and discriminators[10], plus coincidence and anticoincidence logic. The following logic requirements could be set: 1) a particle must trigger both upper plane discriminators, and it must not trigger the bottom plane (U + M - L); or 2) anticoincidence between upper and lower planes (U - L).

Calibrations with krypton-85 were performed by placing the counter in a large hermetically sealed steel box 68 cm x 68 cm x 24 cm. Known volumes of a standard 24 pCi cm^{-3} mixture of krypton-85 in N_2 were titrated into the box and mixed with the air inside with a pump. The physical arrangement used here to represent an 'infinite cloud' of krypton-85 in air will clearly give conservative estimates of the minimum detectable limit, but no corrections were made for this factor.

TEST RESULTS

The background counting rates in the laboratory are shown in Table I for each plane separately and with the counter in two logic modes.

Table I

Laboratory Background Measurement

Signal	Count Rate $(200\ s)^{-1}$
Upper plane, U	933
Middle plane, M	870
Lower plane, L	1,924
U and L in anti-coincidence (U -L)	334
U and L in anti-, plus U and M in coincidence (U + M - L)	206

It may be seen that the simple anticoincidence mode (U - L) reduces the background to one-third of its normal value, while the added requirement of coincidence with M reduces it to one-fifth.

The performance of the counter in two logic modes to an 'infinite cloud' of krypton-85 is shown in Table II.

Table II

Counts Per 200 s (Mean of 8 Readings)

Logic Mode	U + M - L	U - L
0.07 pCi cm^{-3}	689	1,102
Background	185	284

Although the ratio of source counts to background counts is only slightly improved by dropping the middle plane coincidence requirement, the ratio $F_s/\sqrt{F_B}$ increases considerably.

The results of several series of measurements of count rate at different concentrations of krypton-85 are shown in Figure 3. The count rate, S, is the number of counts in 200 s attributable to the radioactive source and is obtained by subtracting the mean background from the total count rate.

Our laboratory background in the mode (U - L) used to collect the data in Figure 3 was typically measured at 1.5 counts s^{-1} or 0.013 cts cm^{-2} s^{-1}. This is lower than the background rate with the most sensitive 4 π Geiger detector measured by Smith, et al., viz 0.021 cts cm^{-2} s^{-1}. Further improvement would be expected with passive shielding or a double window (4π) proportional detector.

From the curve in Figure 3, the calibration factor, F_s, was determined to be 0.49 counts cm^{-2} s^{-1} pCi^{-1} cm^3. C_L may also be derived from Figure 3 for a 200 s count with this detector for any desired level confidence. At the 2σ level for a 200 s count, $C_L = 3.1 \times 10^{-3}$ pCi cm^{-3}. Minimum detectable concentrations for other times and confidence levels are given in Table III.

Table III

C_L(Kr-85) Minimum Detectable Limits (pCi cm^{-3}) for Proportional Counters of Different Areas,

Various Counting Times and Levels

of confidence

Confidence Level	2σ	3σ
Test Counter, 200 s	3.1×10^{-3}	4.9×10^{-3}
Test Counter, 4 hr.	3.8×10^{-4}	5.8×10^{-4}
0.25 m^2, 4π, Counter, 200 s	4.7×10^{-4}	7.3×10^{-4}
0.25 m^2, 4π, Counter, 4 hr.	6.0×10^{-5}	9.0×10^{-5}

Multiwire proportional counters may be made arbitrarily large. We have had several years reliable experience with such detectors of active area 50 cm x 50 cm, though we have never used them for radionuclide monitoring. Since these detectors have similar electrode dimensions and operating characteristics, we should expect them to possess similar values of F_s. Assuming this, calculated minimum detectable concentrations of krypton-85 using the 0.25 m^2 counter with windows on both sides are shown in Table III. Four hours is used as the longest counting time.

CONCLUSIONS

A multiwire multiplane proportional counter has been shown to have excellent properties for monitoring concentrations of krypton-85 in air down to 4×10^{-4} pCi cm^{-3}. Larger but still portable detectors could reduce this minimum detectable limit to $\sim 8 \times 10^{-5}$ pCi cm^{-3}. Detectable limits of this order will probably remain the practical limit, since further increases in sensitivity will require detectors of much larger area and complexity. Passive shielding could be used to increase the sensitivity somewhat by reducing the background rate. Such measurements would be practically confined to the laboratory.

Proportional counters of this type may have a wider application in the monitoring of low levels of β and x-ray emitting nuclides.

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Figure 1: Diagram of multiwire multiplane proportional counter showing configuration.

Figure 2: Photograph of test counter.

Figure 3: Calibration curve of the test counter for Kr-85 activities in the range 0.005 -1.0 pCi cm^{-3} made in the presence of normal room background.

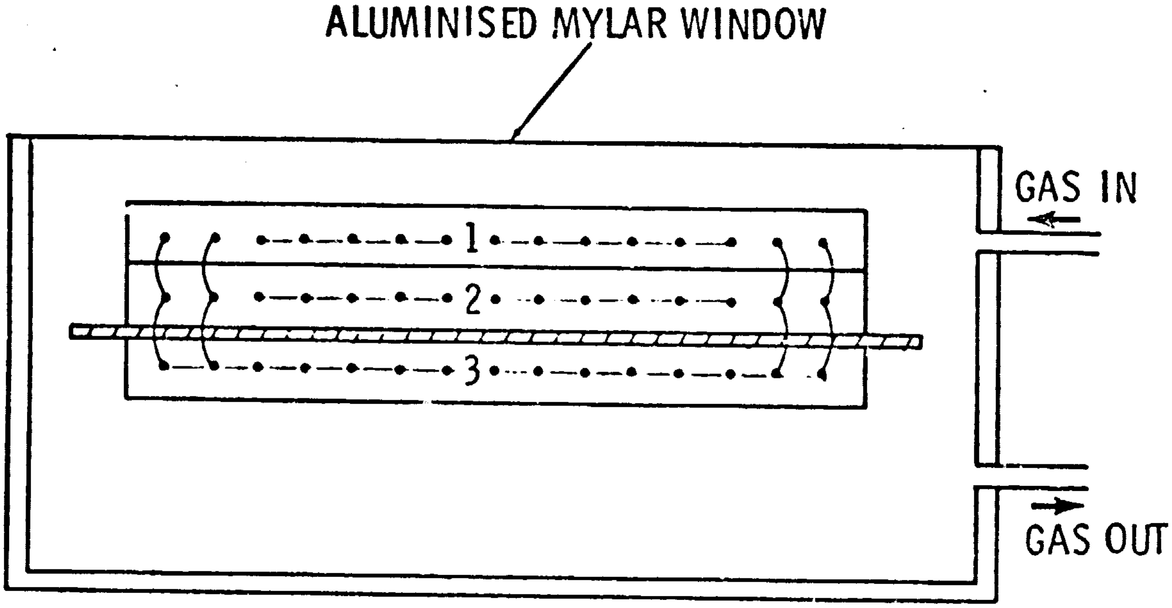


Figure 1

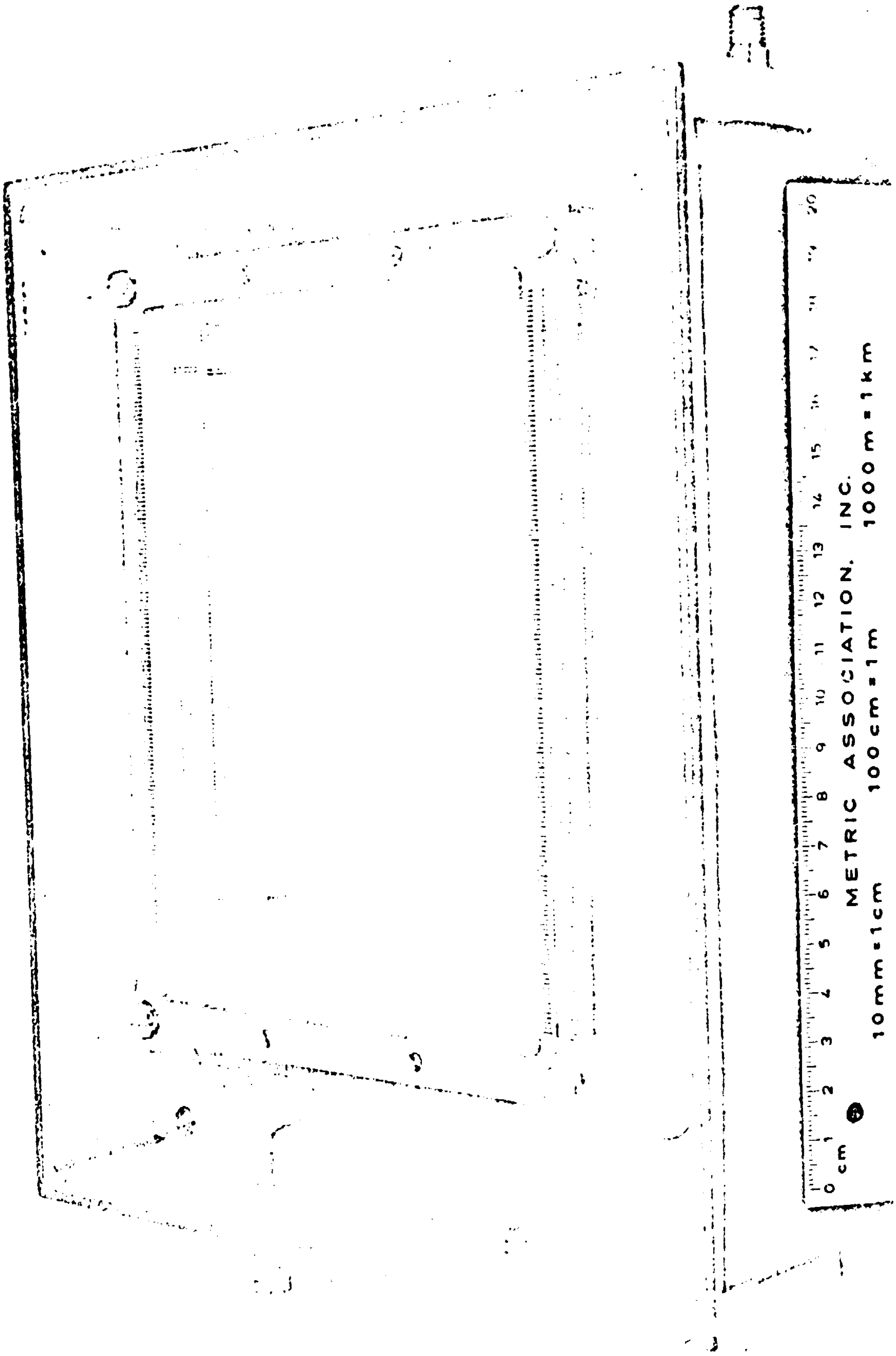
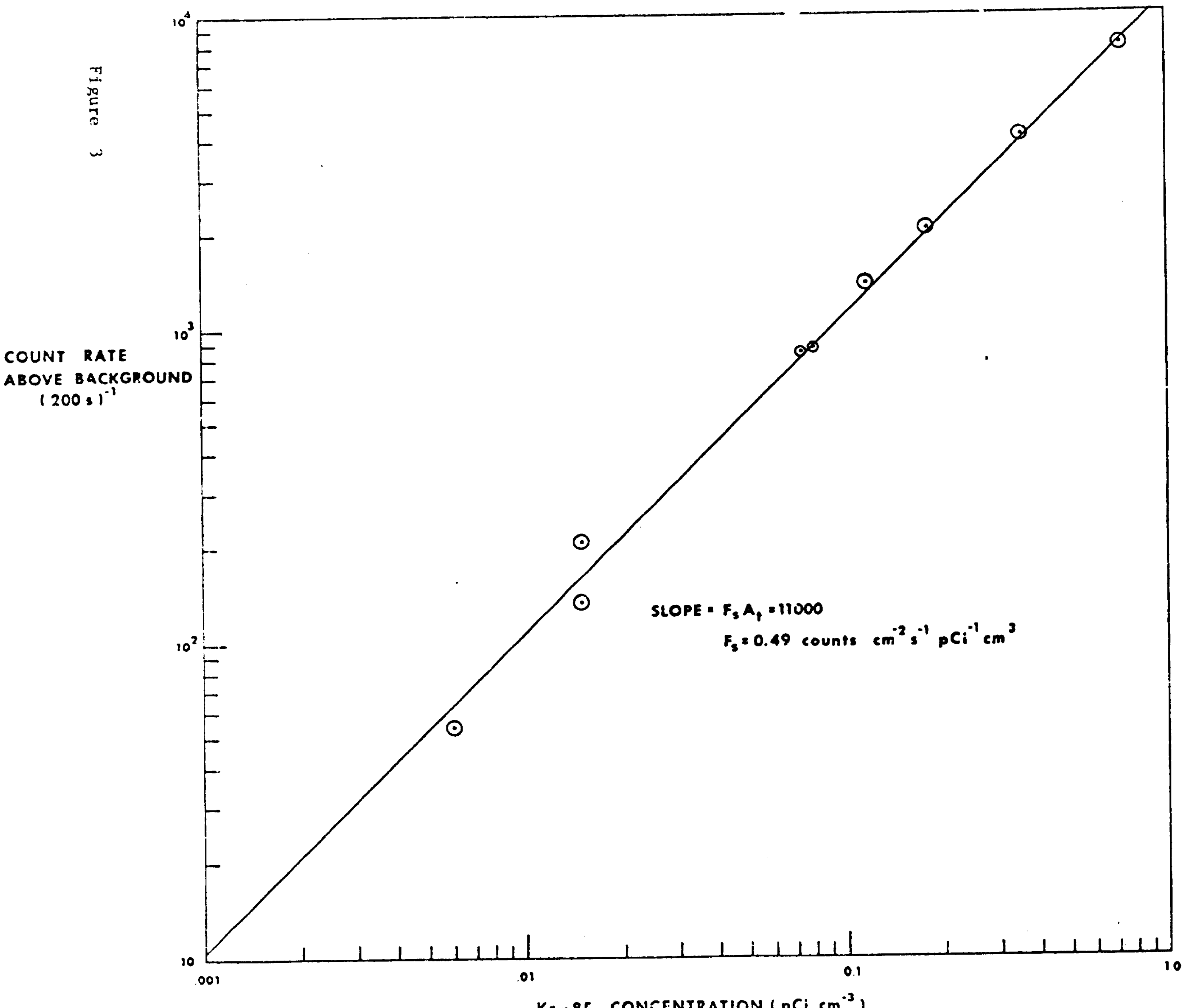

METRIC ASSOCIATION, INC.
10mm=1cm 100cm=1m 1000m=1km
cm
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Figure 2

Figure 3


COUNT RATE ABOVE BACKGROUND (200 s)$^{-1}$
10^4
10^3
10^2
10
.001
.01
0.1
10
SLOPE = $F_s A_t$ = 11000
F_s = 0.49 counts $cm^{-2} s^{-1} pCi^{-1} cm^3$
Kr-85 CONCENTRATION (pCi cm^{-3})