POSSIBLE SOURCES OF ERROR IN THE MEASUREMENT OF GAMMA RAY SPECTRA

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This presentation is intended to discuss certain possible sources of error associated with the counting of samples for the purpose of N.A.A. In addition to a simple tabulation of errors, solutions will be offered where known, and examples of the magnitude of the errors involved will be given wherever possible.

1. THE SAMPLE

1.1 Sample Homogeneity.

This is an ever present problem that is not always recognised in reactor N.A.A. as compared to fast N.A.A. because of the isotopic neutron fluxes involved in reactor N.A.A. However, if the sample itself is inhomogenious, considerable errors are possible. The solution is to rotate the sample during counting, thus obtaining an average value.

For example, analysis of a diamond crystal containing an inclusion.
Repeated counts, 1.3cm from the face of the detector

Random positioning	48 %	(cov)
Rotated during counting	0.6 %	(cov)

1.2 Sample Shape.

The sample shape should be such as to minimise gamma attenuation during counting, i.e. there should be a small dimension of the sample which should be placed axially in line with the detector during counting. (See TABLE 1)

TABLE 1.

Attenuation of Gamma Rays.

Element	Energy / Thickness	100 KeV	800 KeV	2000 KeV
Carbon	1.0 mm	0.967	0.984	0.990
	10.0 mm	0.914	0.852	0.905
Silicon	1.0 mm	0.961	0.984	0.980
	10.0 mm	0.670	0.848	0.901
Lead	1.0 mm	0.0025	0.910	0.950
	10.0 mm	1.E-27	0.388	0.596

Two Geometries are in general use:

(1) Disc source.

This is a convenient geometry for counting chemical precipitates or other small samples. It may be advisable to cover the sample with mylar film to reduce the possiblity of comtamination during counting. A disc source is most easily counted using a vertically mounted detector.

(2) Cylindrical source.

In this case the diameter of the cylinder is best kept as small as possible, and the height not much larger than the diameter of the crystal for maximum detector efficiency. A horizontally mounted detector may be more convenient for this sample shape.

The smallest dimension of the sample should be kept constant, (i.e. the diameter of a cylinder of variable height) and should be placed along the axis of the detector to minimise geometry errors.

2. GAMMA SCATTERING

The scattering of the gamma rays should be kept to a minimum so as to maximise the full energy peak, and to minimise the activity levels at lower energies which contribute significantly to the peak error.

When investigating backscattering, it should be noted that a backscatter peak is inherited in any Ge(Li) detector spectrum. (See Fig.1)

The energy of the scattering electron is given as a function of the incident energy in Fig. 2.

When counting highly active samples, scattering from air can be of considerable importance. This is generally in the form of multiple low energy scattering and is therefore, predominantly in the low energy region of the spectrum. The severity of this effect is demonstrated in Fig 3.

The solution to this problem of 'air glow' is to collimate either or both the detector and or the source.

It may also be of importance to shield the detector from natural (background) radiation when counting very low activity samples. A simple 2" lead shield should give a 20 times reduction in the level. However, counting systems are generally used for both low and high level activity samples. This involves a compromise between containing the low activity sample within the shield, and the high activity sample outside the shield, which can then be used to collimate the detector. The crossover between these two extremes appears to be at about 20cm. (Sample to detector counting distance). It is interesting to note that the dimensions of the lead shield need not be as large as is generally believed (20*20cm is adequate).

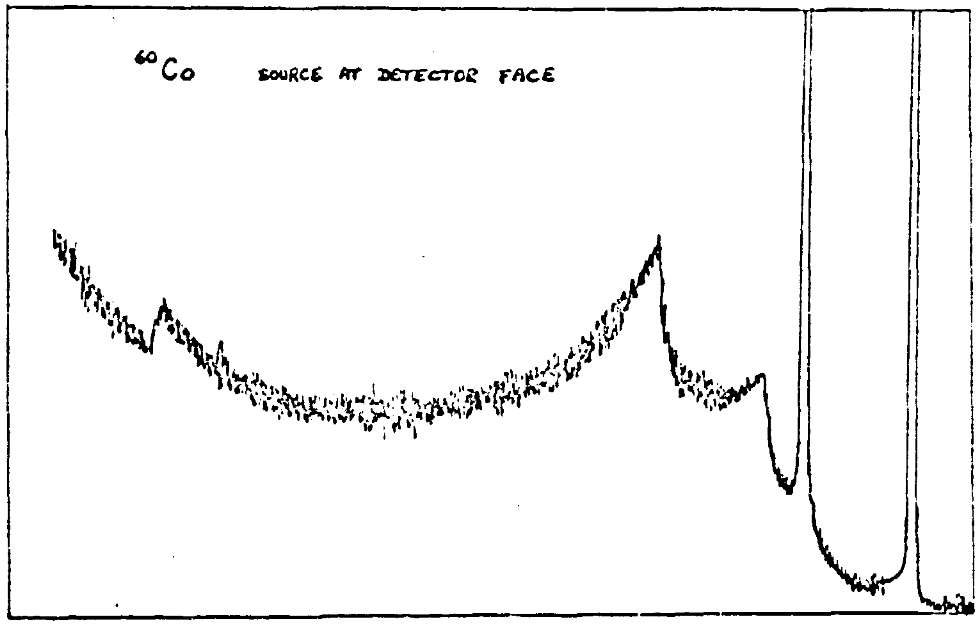

FIG 1 CO-60 SPECTRUM SHOWING BACKSCATTER OFF CRYSTAL MOUNT

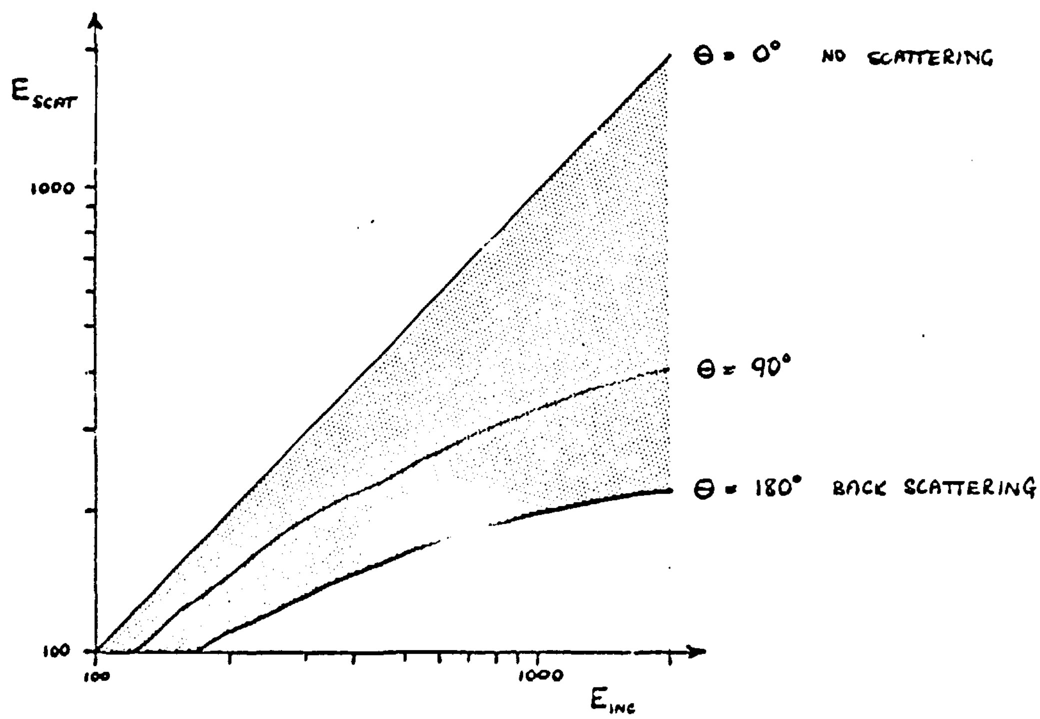

FIG 2 ENERGY OF COMPTON SCATTER ELECTRON

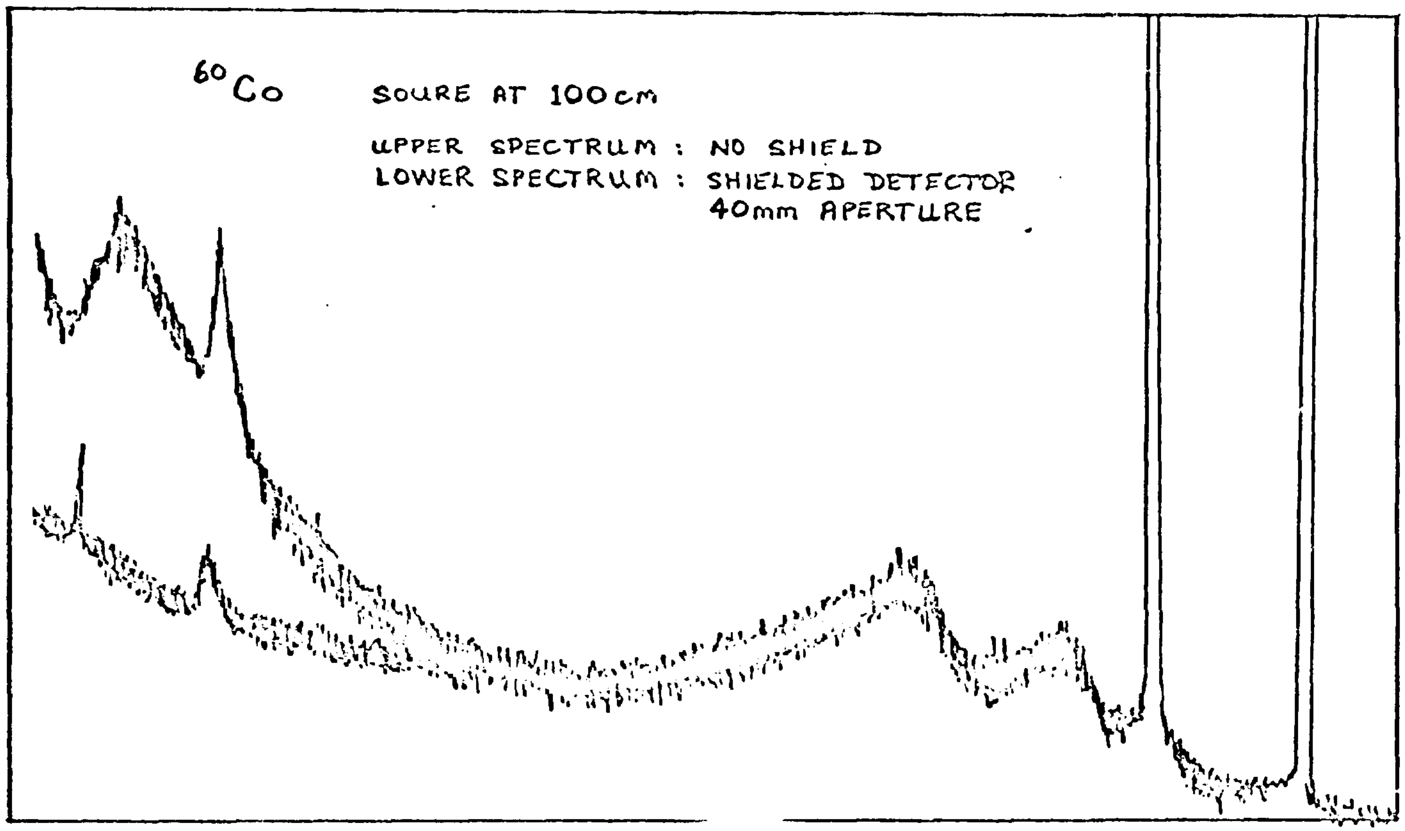

FIG 3 CO-60 SPECTRUM SHOWING AIR SCATTER

3. COUNTING DISTANCE NORMALISATION

It is common practice to standardise on say one to five different counting geometries and to obtain detailed normalisation factors between these different positions. This can be an unnecessary constraint. It is perfectly feasible to calibrate any given geometry for a range of detector to sample counting distances. In practise it is found that a simple modification to the 1/R law offers a form of the calibration curve which is readily computable. This involves the introduction of an interaction depth, ΔR, which is of course a function of energy. This $1/(R+\Delta R(E))$ law is found to give errors of 1% or less down to distances of 1-2 cm. The greatest problem is the accurate determination of $\Delta R(E)$.

The value of ΔR is obviously different for different detectors since it takes into account such variables as the distance between the front face of the detector and the actual crystal. Typical values for open ended coaxial detectors are from 1.5 to 3.0 cm. [illegible] ry of the sample has an effect on the value of ΔR which can be as high as 10% when comparing volumes of say, 0.5 to 120 ml.

It should be noted that the calibration values so obtained are experimental and include therefore, any small effects peculiar to a given system.

4. Geometry Errors.

4.1 Axial displacement: The errors associated with a displacement along the axis of a cylindrical detector are very easily calculated from the $1/(R+\Delta R(E))$ law. The error is displayed in fig 4 for an average value of ΔR of 2.0 CM.

The minimisation of the axial displacement error is not very easy, and it is suggested that a value of 0.2 mm. is the best that might be expected. This gives rise to an error of 1% at a counting distance of 2.0 cm. Thus, if the experimental error is required to be below 1%. the counting distance should not be made smaller than 2.0 cm.

These results have not been verified for Na(I) detectors, but from a simple geometric arguement, the errors involved should be smaller. Calculations for a 3"*3" Na(I) suggest that for a given 0.2 cm displacement error of a point source, the error is below 1% for any counting distance.

4.2 Transaxial displacement errors: the error associated with a displacement error at right angles to the axis of a coaxial detector is considerably smaller than for the corresponding axial displacement. This is because the transaxial efficiency is fairly constant and a transaxial displacement does not cause a large axial displacement.

To a first approximation at a counting distance of 2.0 cm, the axial displacement error is 20 times larger than the corresponding transaxial error. An example of experimentally determined errors is given in Fig. 5.

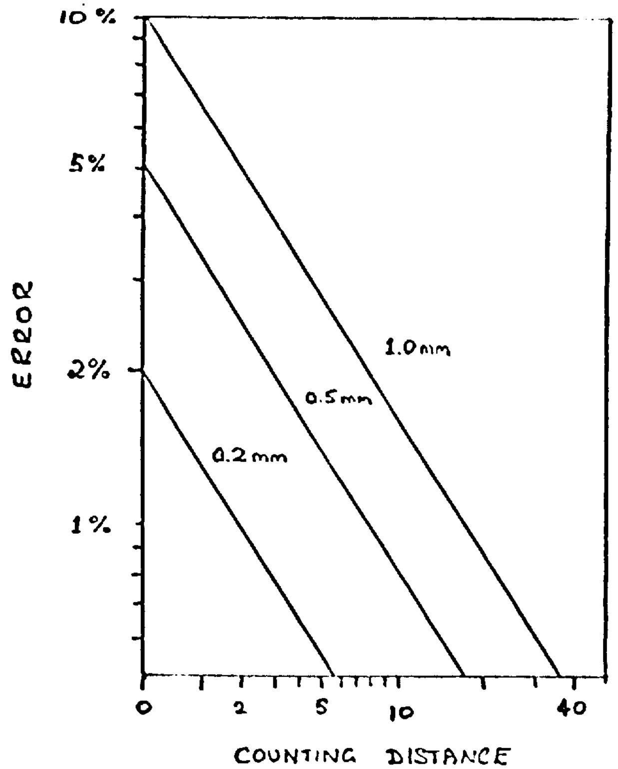

FIG 4 AXIAL DISPLACEMENT ERRORS

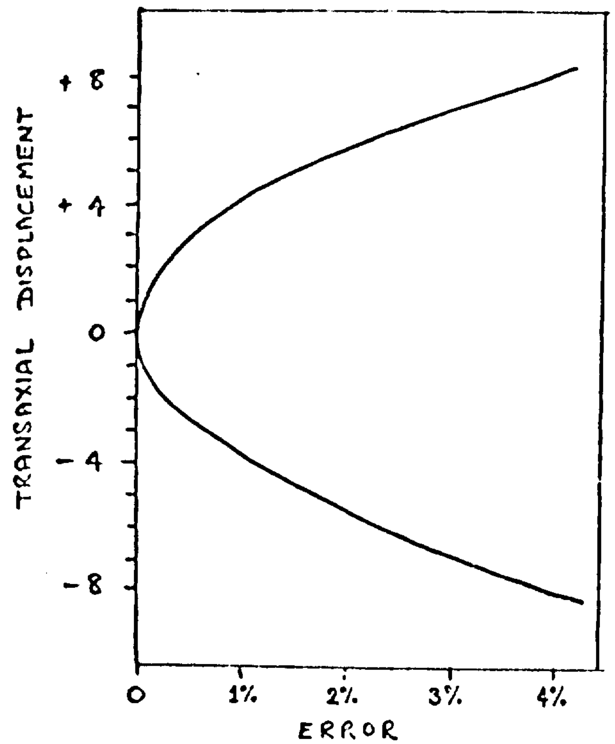

FIG 5 TRANSAXIAL DISPLACEMENT ERRORS

5. COUNT RATE LOSSES.

Sources of count rate losses are:

(1) Pulse pileup in the detector
(2) pulse pileup in the preamplifier
(3) pulse pileup in the amplifier
(4) deadtime in the A.D.C.

In general only the A.D.C. deadtime is corrected for, but in practice it is found that the amplifier pileup is equally important. Amplifier pileup can most easily be reduced by shortening the pulse width, but this unfortunately entails a consequent loss in resolution.

The criterion for choice of correction method should also take into account:

(1) possible countrate variations, i.e. a decaying isotope where the counting period is not short in comparison with the halflife.
(2) possible variations in the spectral distribution, i.e. a sample containing two or more isotopes of different halflives.

Some popular methods of correcting for count rate losses are:

(1) 'live timing' circuit in the A.D.C. which simply stops timing when the analysing circuits are busy
(2) 'fixed deadtime' circuit so that mathematical corrections can be made knowing the initial and final count rates.
(3) 'zero deadtime' circuit as proposed by J. Harms to "live time in real time".
(4) pulser method proposed by D.U. Anders which assumes a pulser of known frequency and that the pulser pulses are treated identically to those of the detector.
(5) a variable frequency pulser suggested by H.H. Bolotin which uses a pulse frequency proportional to the detector count rate, or for mixed isotopes, proportional to the count rate of that isotope of interest.
(6) the simultaneous measurement of a radioactive source, of convenient energy and strength, instead of a pulser.

The applicability of these various methods are summarised in TABLE 2.

6. CONCLUSION

Five different problems associated with the measurement of gamma spectra have been discussed. Each of these problems can give rise to considerable errors, but if due precautions are taken, the errors can in all cases be reduced to the order of 1% or less.

TABLE 2.

Applicability of Count-rate Loss Correction Methods.

Effect / Method	Detector Pileup	Preamp Pileup	Amplifier Pileup	A.D.C. D.T.	Var. Ct. Rate	Var. Spec. Distr.
Live timing	No	No	No	Yes	No	No
Fixed Dead Time	No	No	No	Yes	Yes	No
Zero Dead Time	No	No	No	Yes	Yes	Yes
Const. Freq. Pulser	No	Yes	Yes	Yes	No	No
Var. Freq. Pulser	No	Yes	Yes	Yes	Yes	No
Gated. Var. Pulser	No	Yes	Yes	Yes	Yes	Yes
Isotopic Pulser	Yes	Yes	Yes	Yes	No	No