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The precision measurement of alpha sources is readily accomplished by means of ordinary low geometry counters when ample activity is available. When the amount of activity is small it is necessary to use a high geometry configuration in order to obtain good statistics in a reasonable counting time. The best arrangement from the standpoint of high efficiency is a 4π counter in which the source is mounted on a nearly weightless film so that essentially no alpha particles are stopped before reaching the sensitive portion of the counter chamber. This method obviously cannot be used when the source is mounted on a backing plate, which is the usual case. Under these conditions it has been customary to use a "2π" counter, and the difficulty immediately arises that a significant fraction of the alpha particles emitted into the backing plate are scattered backward and enter the counting volume. Thus a correction becomes necessary which may be from two to four percent, and the uncertainty of the magnitude of the correction reduces the precision of the measurement. To avoid the need for making such a correction, the chamber geometry can be reduced to about one π steradian. The acceptance angle is now 120° and under these conditions virtually no scattered alphas will be detected (1).

For the purpose of this paper, a high geometry counter will then be defined as one approaching π steradians in solid angle.

When a one π counter of convenient physical dimensions is examined, another difficulty appears, namely, that the geometry factor is very sensitive to the positioning of the source. For example, in a one π counter with a working distance from source to collimator of 44 mm and a collimator diameter of 154 mm, a vertical displacement of the source of only 0.1 mm will alter the geometry by 0.2%, and to reduce the uncertainty to 0.05% requires that the sample position be known to 0.025 mm, a nearly impossible requirement. Thus, some type of compensating device is required to make the goemetry less sensitive to source position. One such possibility is shown in Fig. 1. A circular stop is placed above the source. The geometry is reduced to $G_c - G_b$, where G_c = solid angle of collimator of radius c, and G_b = solid angle subtended by the stop of radius b. Since the stop is closer to the source than the collimator, G_b will be relatively more sensitive to source positions than G_c. By suitable choice of α for a given stop radius b, the change of geometry with source position can be made zero. By simple calculation it is found that the following relationship between α and b must hold for perfect compensation:

$$\alpha = \frac{b^{2/3}}{c^{2/3}} \sqrt{C^2 + h^2 - C^{4/3}\, b^{2/3}}$$

An example will illustrate the compensation obtainable with such a stop. Let h = 44 mm, C = 77 mm, and b = 11 mm. Then α = 21.5952 mm, and G = 0.19746. Curve A in Fig. 2 shows how the geometry factor varies with position of source. Curve B shows the variation which would be obtained with a chamber having no stop but with h = 58.52 and c = 77 mm as before.

And now a further complication arises. The previous curves have been drawn for point sources, but the usual source is from one millimeter to several centimeters in diameter, so the effective geometry of a point off axis becomes of importance. Figure 3 plots the variation of geometry factor versus displacement of a point source of a chamber having the same dimensions as previously given. It is evident that the non-uniformity is extremely serious from the standpoint of a precision counter. An obvious remedy is to use one or more additional stops above the first one and of such size as not to change the geometry of a point on the axis but to cast an additional shadow on the detector for an off-axis source. Figure 3 indicates that a correction resembling more or less a quadratic function will be required, whereas a single additional stop adds a nearly linear correction, hence it is concluded that an infinite number of such stops will be required, i.e., a figure of revolution continuous from the initial stop position to the plane of the collimator.

The general mathematical treatment of the problem is extremely difficult, but fortunately for practical purposes it can be simplified and solved by direct but tedious numerical methods.

It is first necessary to determine the shape of the shadow in the plane of the collimator in terms of an arbitrary shape of stop. The only figure which could be handled analytically was a conic section whose equation can be written

$$\frac{(u - k)^2}{a^2} + \frac{v^2}{m^2} = 1$$

Where v = radius of the stop measured a distance u from the bottom end, and k, a^2, and m^2 are arbitrary constants. See Fig. 4. If m^2 is positive the figure is an ellipse, if negative it is a hyperbola. Introducing two required conditions reduces the equation to

$$\frac{v^2}{b^2} = - \frac{b^2}{m^2 - b^2} \cdot \frac{u^2}{\alpha^2} + 2\frac{u}{\alpha} + 1$$

As before, α = optimum distance from stop to source, b = radius of bottom end of stop, and m^2 is the only parameter remaining to adjust for best performance.

The shadow cast by this stop from an off-axis point is a semicircle of radius $\frac{bh}{\alpha}$ joined by half an ellipse, with semi diameters of $\frac{bh}{\alpha}$ and $\frac{bh}{\alpha}\sqrt{1 + r^2\left(\frac{2}{b^2} - \frac{1}{m^2}\right)}$, where r = distance of source from the axis.

On the basis of numerical integrations carried out on the shadow a stop was made with $m^2 = 2\,\alpha^2$. To avoid scattering off the surface and to simplify the fabrication it is made with a number of steps, as shown in Fig. 5. These steps introduce a slight error, which varies approximately as the cube of the horizontal displacement of the source, and inversely as the square of the number of steps. With a source 20 mm off axis the error is less than 0.02% if the steps are about 2.5 mm as in the present case.

Figures 6 and 7 show a cross section drawing and photograph of the counter as finally constructed. The collimator diameter is 152.405 mm, stop diameter 21.77 mm at bottom end, the distance from source to stop, α = 21.37 mm, and from collimator to bottom of stop is 22.17 mm. The calculated geometry factor is 0.19748. A zinc sulfide-Ag screen is deposited on the glass plate and scintillations from the alpha particles are detected by a photomultiplier tube above the glass plate (2).

The glass plate is 12.6 mm thick and under vacuum deflects 0.012 mm. This was allowed for in making the stop.

The performance of the counter was tested using an Am^{241} source about 2 mm diameter on platinum, and the count rate plotted as a function of source displacement both vertically and horizontally.

In Fig. 8 the straight line is the theoretical variation for an uncompensated chamber having the same geometry factor and collimator diameter. The curve is the theoretical performance of a chamber having a single plane circular stop. A solid stop will cause the curve to fall off more rapidly on the "down" side, but will not alter the "up" half.

Figure 9 presents the preliminary data taken with this counter showing performance as a function of horizontal displacement of source at several values of h, indicated by values of Δh above or below the design value Also shown are calculated values for an uncompensated one π chamber, and a chamber having the same geometry as at present but with only a single plane stop compensator.

Each point in both figures represents from two to ten million counts (2 to 10×10^6), so that the standard deviation of each point is about 0.05% on the average.

On the basis of the results obtained so far it is concluded that the design is sound and the counter is successfully operating. It may be possible to remove the dip in the curves of Fig. 9 by slightly altering the shape of the elliptical stop, probably in the upper half. It should be noted that ordinarily the error in locating the vertical position of the source will not be more than 0.1 mm, so that there need be no concern about the divergence of the curves plotted in Fig. 9. The two closer curves represent a relative displacement of 0.33 mm.

A single cross check of the geometry of this chamber with a precision medium geometry counter gave agreement within 0.03%.

In the future the effect of making α smaller will be investigated. It may be possible by this means to extend the flat portion of the curves shown in Fig. 9, although for present purposes the performance is entirely satisfactory.

This paper describes one means of compensating a counter to make its effective solid angle independent of source position, within limits.

A second method could utilize a series of collimators above or below the primary one, and a combination of both methods could probably be used to obtain horizontal compensation to appreciably greater distances than at present.

REFERENCES

(1) JAFFEY, A. H., Private communication.

(2) CALDWELL, D. O. and ARMSTRONG, J. R.: "Uniform, Nonhydrogenous Screens of ZnS-Type Phosphors". Review of Scientific Instruments 9, 508 (1952).

CAPTIONS FOR FIGURES

Fig. 1 Counter with compensating stop.

Fig. 2 Variation of geometry with vertical displacement.

Fig. 3 Variation of geometry with horizontal displacement.

Fig. 4 Counter with solid stop.

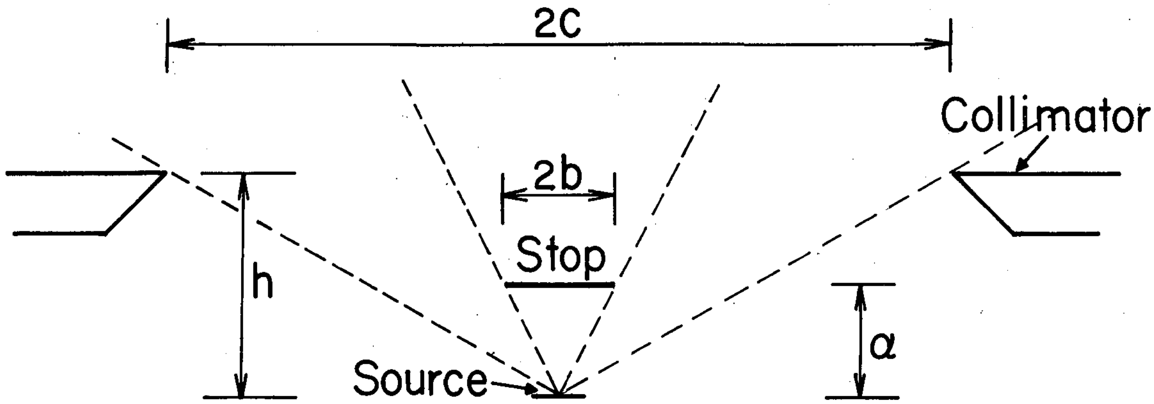
Fig. 5 Elliptical stop.

Fig. 6 Cross section of counter.

Fig. 7 Photograph of counter.

Fig. 8 Observed counting rate versus vertical displacement.

Fig. 9 Observed counting rate versus horizontal displacement.



$$\alpha = \frac{b^{2/3}}{c^{2/3}} \sqrt{c^2 + h^2 - c^{4/3} b^{2/3}}$$

MU-18467

Fig. 1

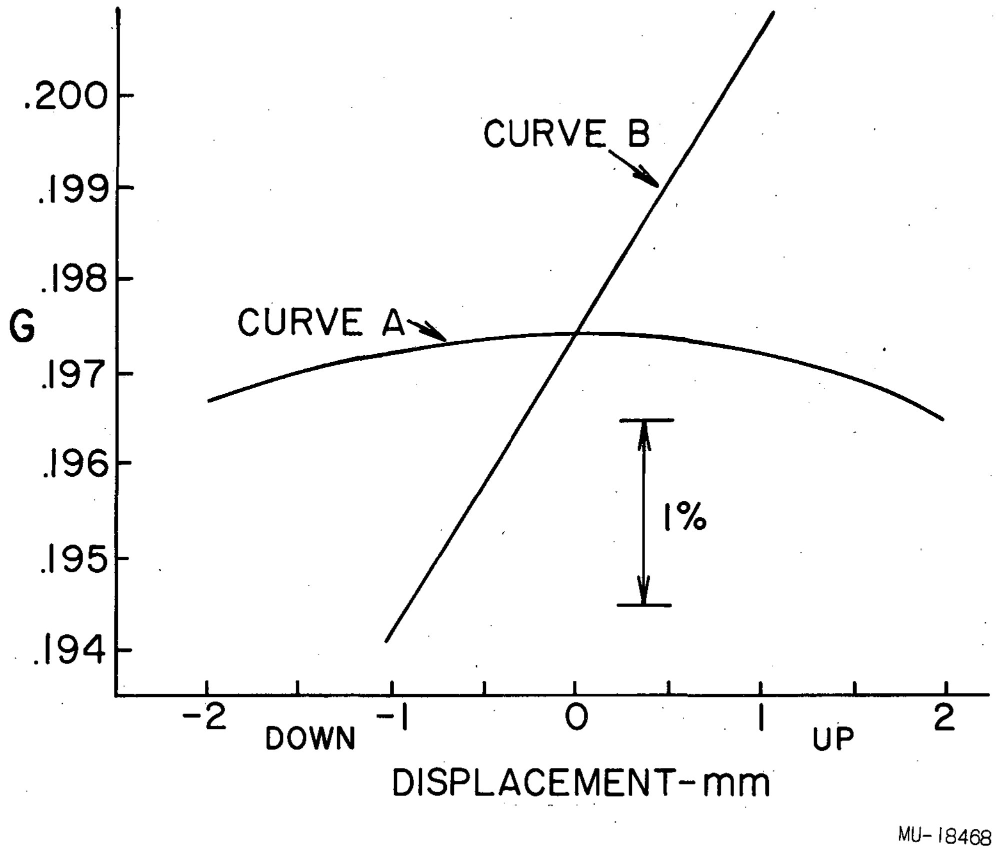
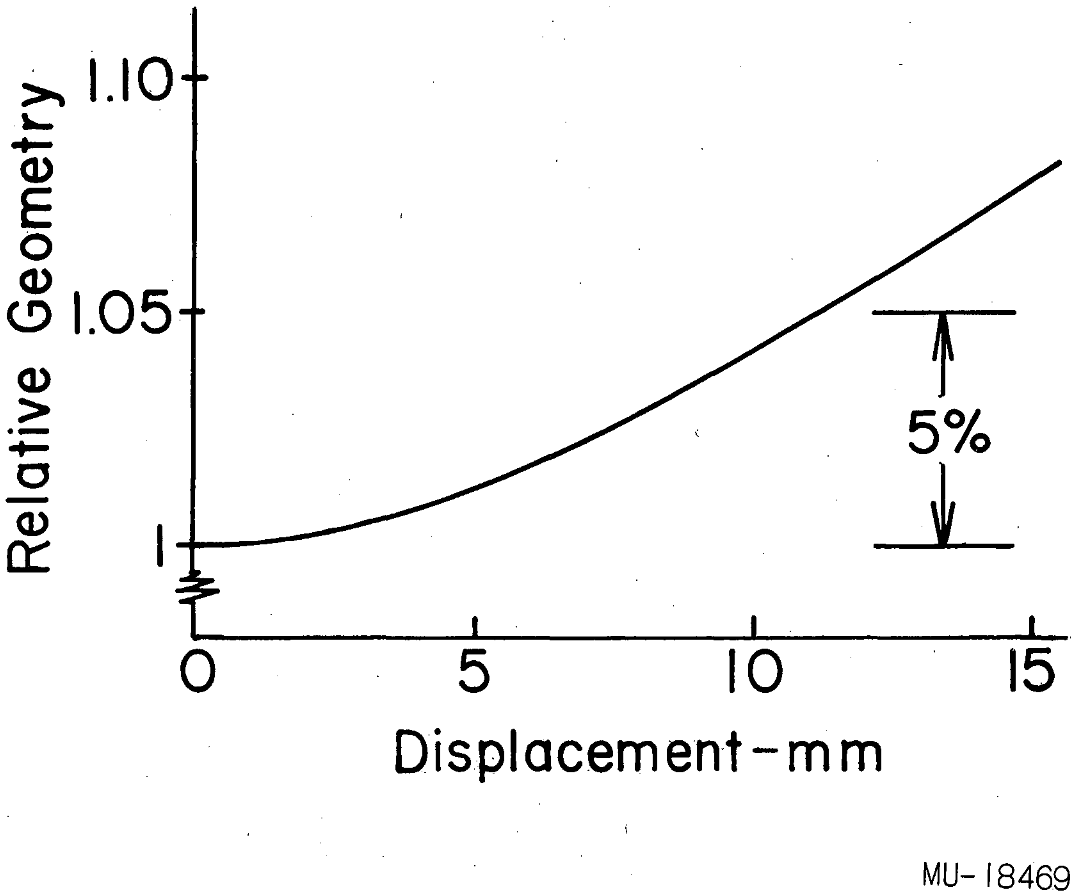
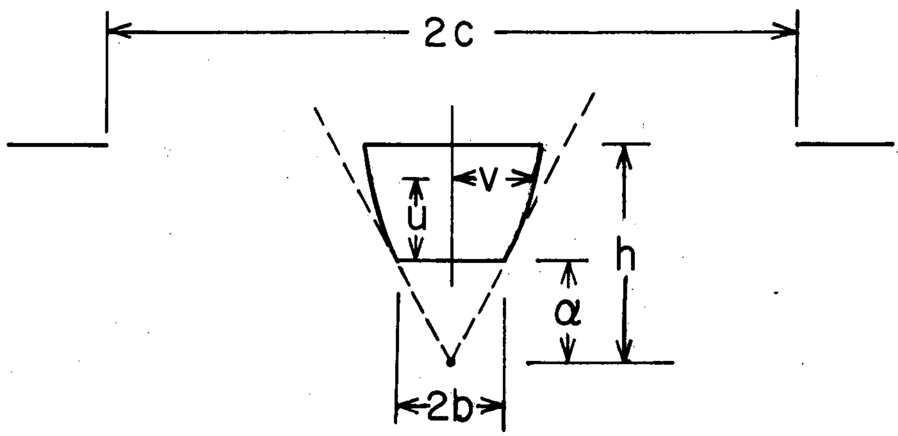

.200
.199
.198
G
.197
.196
.195
.194
CURVE B
CURVE A
1%
-2
DOWN
-1
0
1
UP
2
DISPLACEMENT-mm
MU-18468

Fig. 2



1.10
1.05
1
Relative Geometry
5%
0
5
10
15
Displacement-mm
MU-18469

Fig. 3

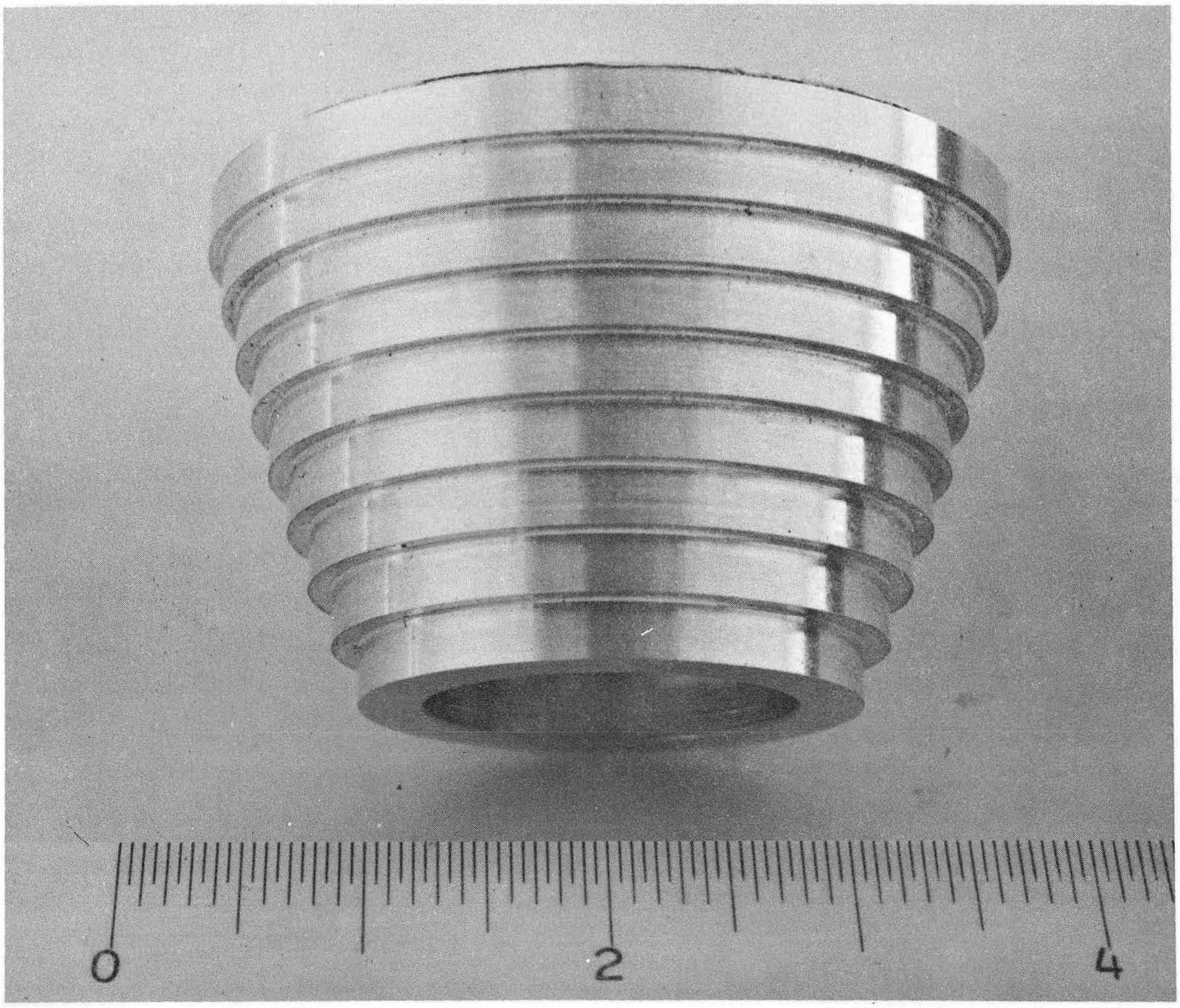


$$\frac{(u-k)^2}{a^2} + \frac{v^2}{m^2} = 1$$

$$\frac{v^2}{b^2} = -\frac{b^2}{m^2-b^2} \cdot \frac{u^2}{\alpha^2} + 2\frac{u}{\alpha} + 1$$

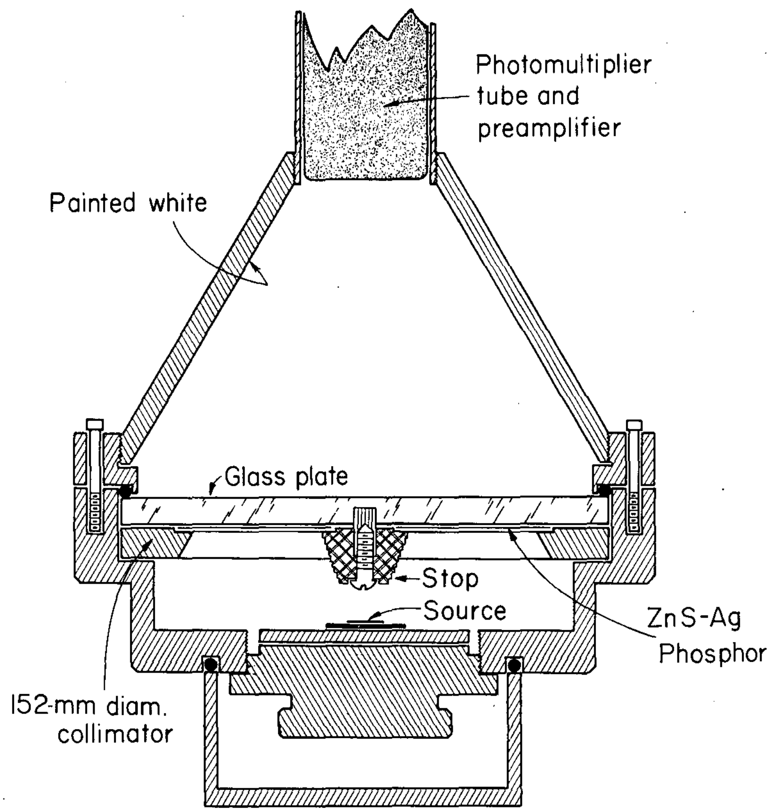
MU-18470

Fig. 4



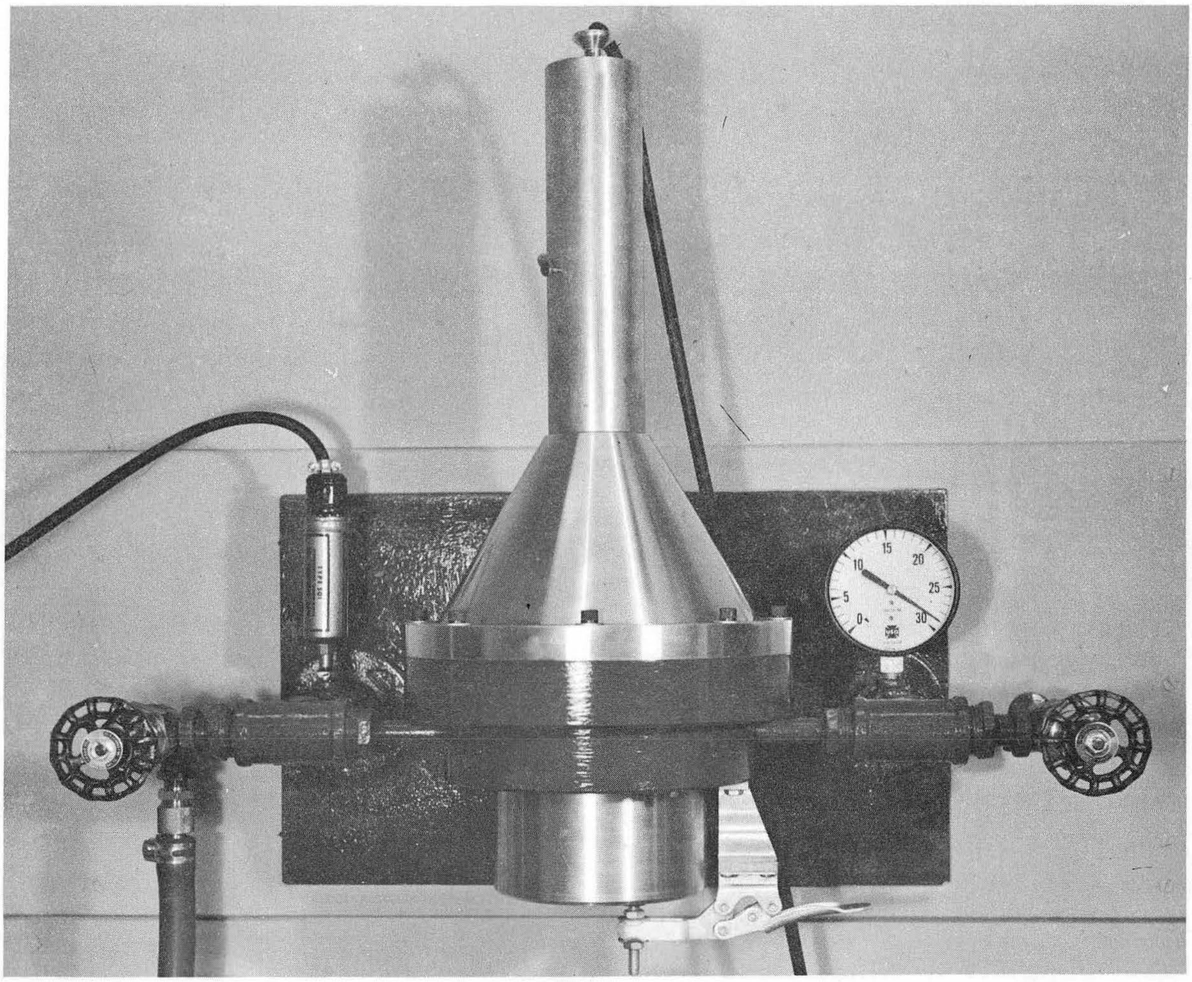
ZN-2245

Fig. 5



MU-18341

Fig. 6



ZN-2246

Fig. 7

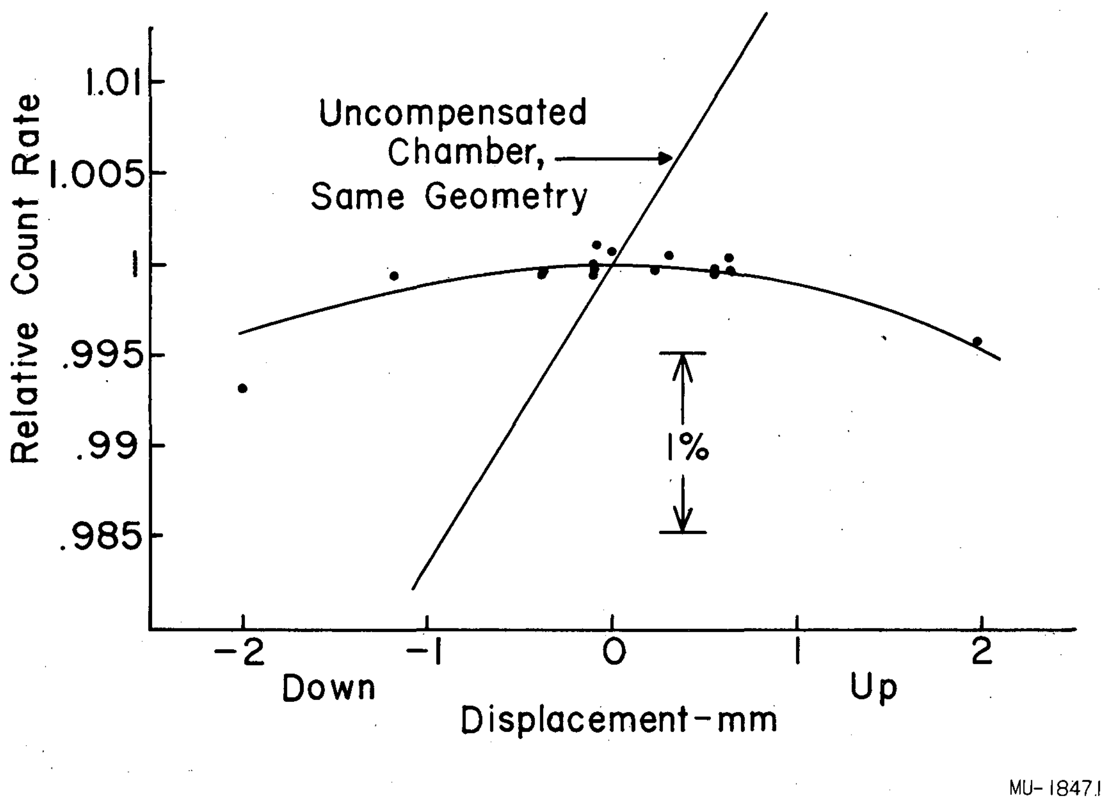

1.01
1.005
1
.995
.99
.985
Relative Count Rate
Uncompensated
Chamber,
Same Geometry
1%
-2
-1
0
1
2
Down
Up
Displacement-mm
MU-18471

Fig. 8

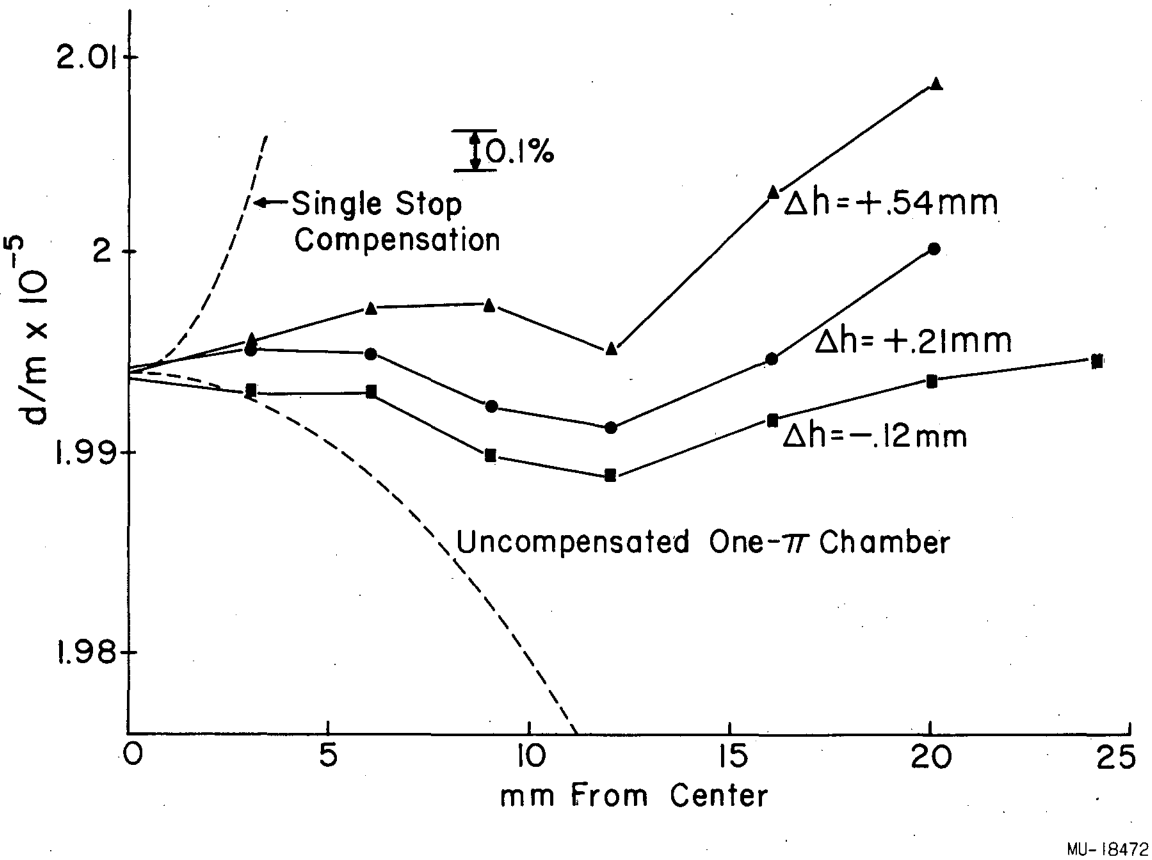

2.01
2
1.99
1.98
d/m x 10^-5
0.1%
Single Stop Compensation
Δh=+.54mm
Δh= +.21mm
Δh=-.12mm
Uncompensated One-π Chamber
0
5
10
15
20
25
mm From Center
MU-18472

Fig. 9