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MEMORANDUM REPORT NO. 1242
January 1960

THE APPLICATION OF RADIOACTIVE TRACERS TO SHAPED CHARGE LINERS

M. K. Gainer

Department of the Army Project No. 5B03-04-009
Ordnance Management Structure Code - 5010.11.588

BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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ABSTRACT

Radioactive tracers have been used to study the contribution of different segments of a shaped charge liner to the penetration of steel targets by the jet for confined and unconfined rounds.

It was found that in a confined round, only the base region of the liner contributed significantly to penetration, whereas the base region contributes little to penetration when the round is unconfined. Penetration time measurements showed that the jet velocities at the maximum depth of penetration were the same for both confined and unconfined rounds.

These observations indicated that the jet from the upper part of the confined round lacked a high enough velocity gradient to produce penetration, whereas the jet velocity gradient from same region of an unconfined round was much higher. Consequently, the jet from the base region of the unconfined round reached a velocity which was too low to produce penetration.

It was concluded that the effect of confinement is to produce a steady state collapse over all but the base region of the liner, and that non-steady state collapse takes place over nearly the entire liner when unconfined.

INTRODUCTION

One type of shaped charge consists of a cylinder of high explosive with a metal-lined conical cavity at one end. When the charge is detonated the metal liner collapses, forming a high-velocity metallic jet, and a slower moving slug. During collapse of the cone, a velocity gradient is produced in the jet, causing it to lengthen as it moves through space. Pressures close to a million atmospheres are produced when the jet strikes a target, thus forcing the target material to flow.[1,2,3]

Accurate determinations of the velocity of an element of the jet as a function of its position in the liner before collapse would be invaluable for experimentally investigating the jet forming process. In the past, such measurements were made by an indirect method which involved the collection and weighing of a portion of the jet for which the velocity has been measured.[1] For precise qualitative results a more direct and less elaborate method is required.

Early experiments with narrow bands of Fe^{59} electroplated on the inside surfaces of M9A1 conical steel liners yielded promising but somewhat inconclusive results.[4,5] Therefore, a new series of experiments using Ag^{110} as a tracer on conical copper liners was begun.

It is the purpose of this paper to describe the "radioactive tracer method" and report the results of its application to the determination of the effects of confinement on shaped charge liners.

PROCEDURE

Ag^{110} was used as a tracer because it possesses many desirable properties for this type of work. It is a good indicator, giving off both strong gamma and high-energy beta radiation; it has a sufficiently long half-life (270 days); and its physical properties are similar to those of copper.

Radioactive silver was plated on the inside surfaces of 105 mm copper liners in the form of narrow bands. The width and position of these bands were accurately controlled by machining similar liners to serve as masks during the electroplating process as seen in Fig. 1. An activity level of 200 microcuries per band was used. This was low enough to permit convenient handling of liners and target material, but high enough to provide excellent resolution of the distribution of the radioactive material in the target.

Liners plated with only one radioactive band were used initially for studying the phenomenon. Later, multiple banded liners were used in an attempt to obtain a large amount of data from a minimum number of firings. All electroplating was done by Dr. V. A. Lamb and Mr. H. I. Salmon of the National Bureau of Standards.[6] Table I gives dimensions, positions, and activities for a typical lot of cones.

105 mm liners were used in the experiments since they produce large diameter holes in the target plates, and thereby minimize the carrying of tracer material from one section of the target to another by succeeding sections of the jet. The target hole is small enough, however, so that the target size is not too large for convenient handling.

The liners were fired into stacked 6" x 6" x 1" mild-steel target plates at an 8-1/4" standoff (Figure 2). In order to determine the effect of lateral confinement of the charge on the liner collapse process, the charges were cased in either a 3/8" steel body or a 3/8" plastic body, the plastic offering essentially no confinement to the round.

The radioactivity of the target plate was measured with a Geiger-Mueller tube and scaler unit. The tube was placed at the fixed distance of ten inches from the surface of each plate to minimize errors introduced by the differences in distribution of the isotope in the different target plates. Both sides of each plate were measured. The value of the activity at an interface between plates was taken as the average of the activities of the two adjacent surfaces.

To determine the effect of initial band activity on the ability to resolve intensity distribution in the target, a liner having a single band of Ag^{110} with an initial activity of 170 microcuries was stored for 270 days, the half life of the Ag^{110}. The activity of the band after this

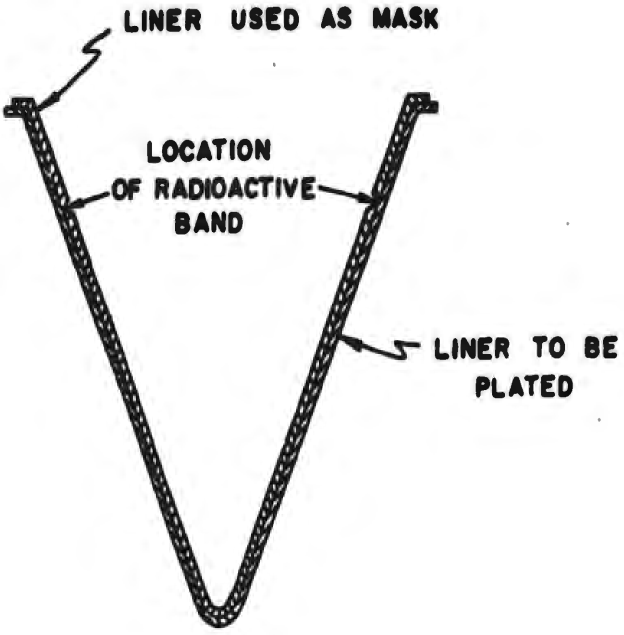

FIG. 1 - MASKING ARRANGEMENT FOR ELECTROPLATING Ag^{110} ON 105 MM LINERS.

TABLE I

Data for Group of Cones Received from the National Bureau of Standards

Identification Symbol	Location of* Band (inches)	Thickness of Ag^{110} (inches)	Activity of Ag^{110} (micro-curies)
2A-1	0.50	0.00004	155
2A-2	0.50	0.00004	150
2B-1	1.00	0.00001	170
2B-2	1.00	0.00010	220
2C-1	1.50	0.00010	190
2C-2	1.50	0.00011	215
2D-1	2.00	0.00006	180
2D-2	2.00	0.00006	175
2E-1	2.50	0.00014	310
2E-2	2.50	0.00009	195

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*Location of the band is measured parallel to the cone axis from the underside of the base flange to the near side of the band. The band width is 1/16" in all cases.

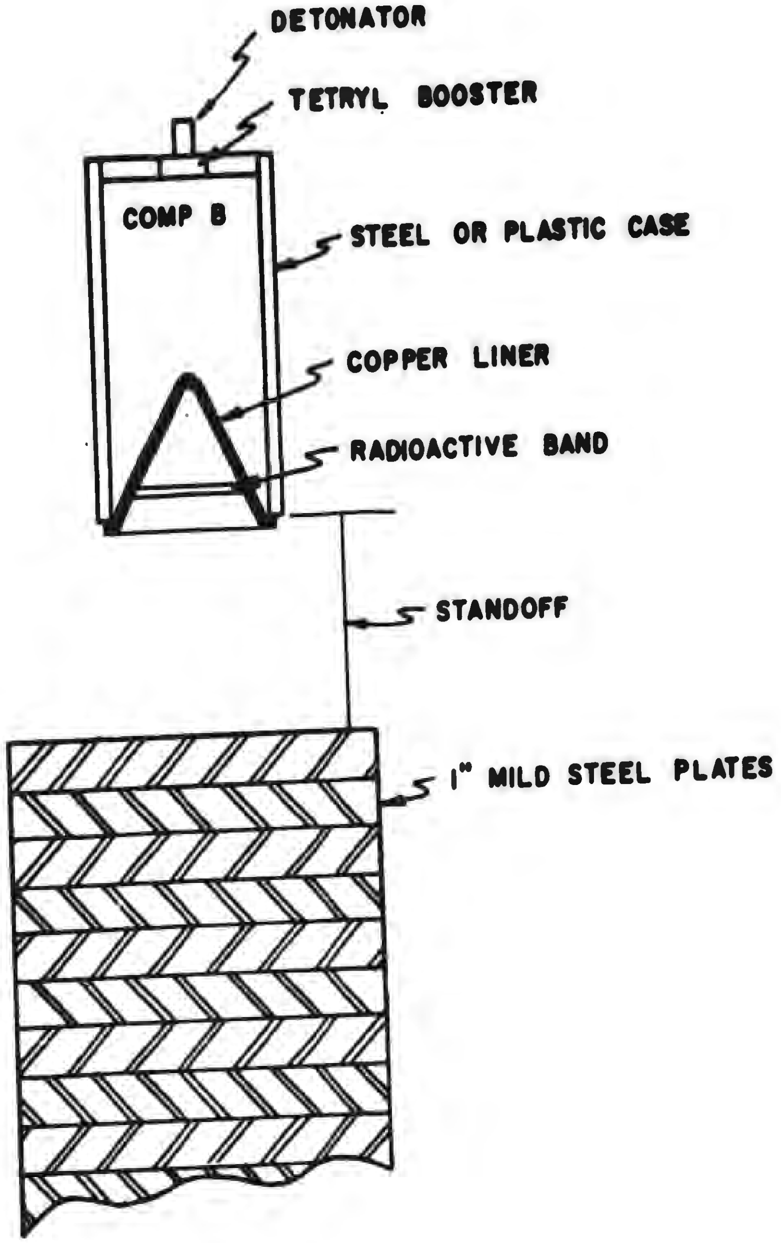

FIG. 2 - ARRANGEMENT FOR FIRING.

time was approximately 85 microcuries. Figure 3 shows the target penetration versus activity curve for this liner, compared to that of a similar liner that has a band activity of approximately 190 microcuries. The detection of intensity distribution in the targets is made easier by the increased initial activity.

Penetration velocities were measured by Mr. A. Merendino using the penetration-time method described in earlier literature.[3] The jet velocity was obtained by the equation,

$$\frac{V}{U} = 1+\sqrt{\frac{\rho_j}{\lambda\rho}}$$

where

V = jet velocity

U = penetration velocity

ρ_j = jet density

ρ = target density

λ = jet break-up factor
(unity for a continuous jet)

The calculation of the jet velocity was simplified by assuming that the jet was continuous over its measured length. Therefore, the jet break-up factor λ was taken as unity. However, for regions near the bottom of the target, λ may be as low as 0.5. Therefore, the reported velocities are lower than the actual velocities in those regions. If we let $U = 0.83$ mm/μs, $\rho = 8.9$ $\lambda = 0.5$ then

$$V = (0.83) \quad 1 + \frac{(7.8)}{(0.5)\ (8.9)}$$

$$= 1.9 \text{ mm/μs}.$$

The value of V shown in Figure 11 for $\lambda = 1$ and $U = 0.83$ mm/μs. is 1mm/μs.

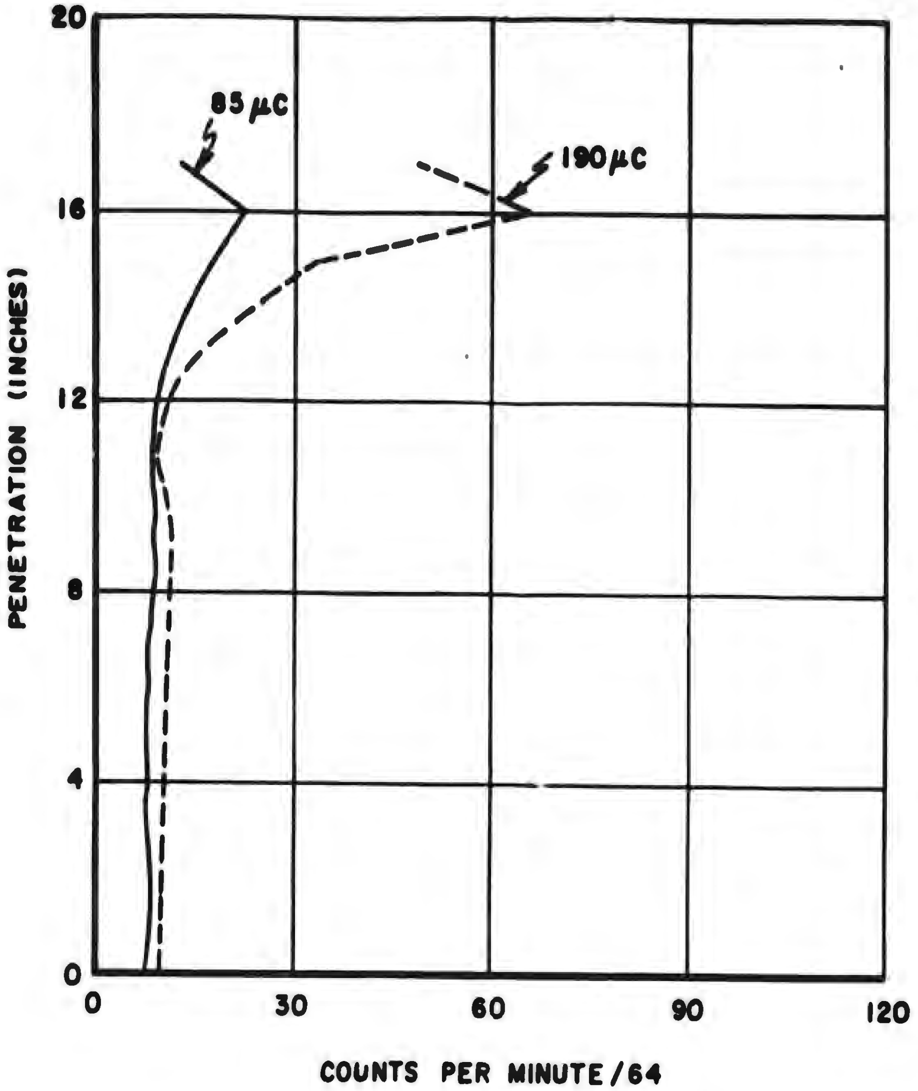

FIG. 3 - COMPARISON OF PEAKS FROM LOW AND HIGH ACTIVITY BANDS.

Penetration time measurements were made with radioactive liners, but, in some cases, it was found that the maximum activity peak was located at or near the foil detectors used to measure velocities. Since the detectors were usually destroyed during firing and could not be recovered, their use seriously affected the resolution of the distribution of the tracer in the target. Therefore the remaining penetration time measurements were made with similar liners that were not plated.

RESULTS

Figures 4 through 9 show the target penetration versus activity curves for a large number of firings of confined and unconfined liners, plated at different positions, for both single and multiple bands. When the standoff and position of the band on the liner were kept constant, the location of the peak in the target was reproducible to within the thickness of a target plate. The multiple-banded liners gave the same degree of resolution as the single-banded liners when the bands were plated on the sections of the liner that gave the most penetration; multiple banding at other locations made it difficult to resolve individual peaks.

The resolution of the distribution of activity in the target was found to be considerably better than that obtained in earlier experiments.[4,5] This may be attributed to the fact that the activity per band in the liner was much higher, making it easy to detect the differences between the peaks and the "smeared" activity in the target plates. It is probable that the smearing of the isotope in the target hole is caused by the jet picking up active material deposited during the early stages of penetration. Also, there is some indication that the target may become contaminated by ablation along the entire jet. However, at the present time there is not sufficient evidence to draw any conclusion on this point.

By comparing the results recently obtained with those from earlier work, and by reference to Figure 3 one can see that the degree of resolution depends only on the width and activity of the band. An increase in resolution can be obtained either by increasing the activity per band or by narrowing the band.

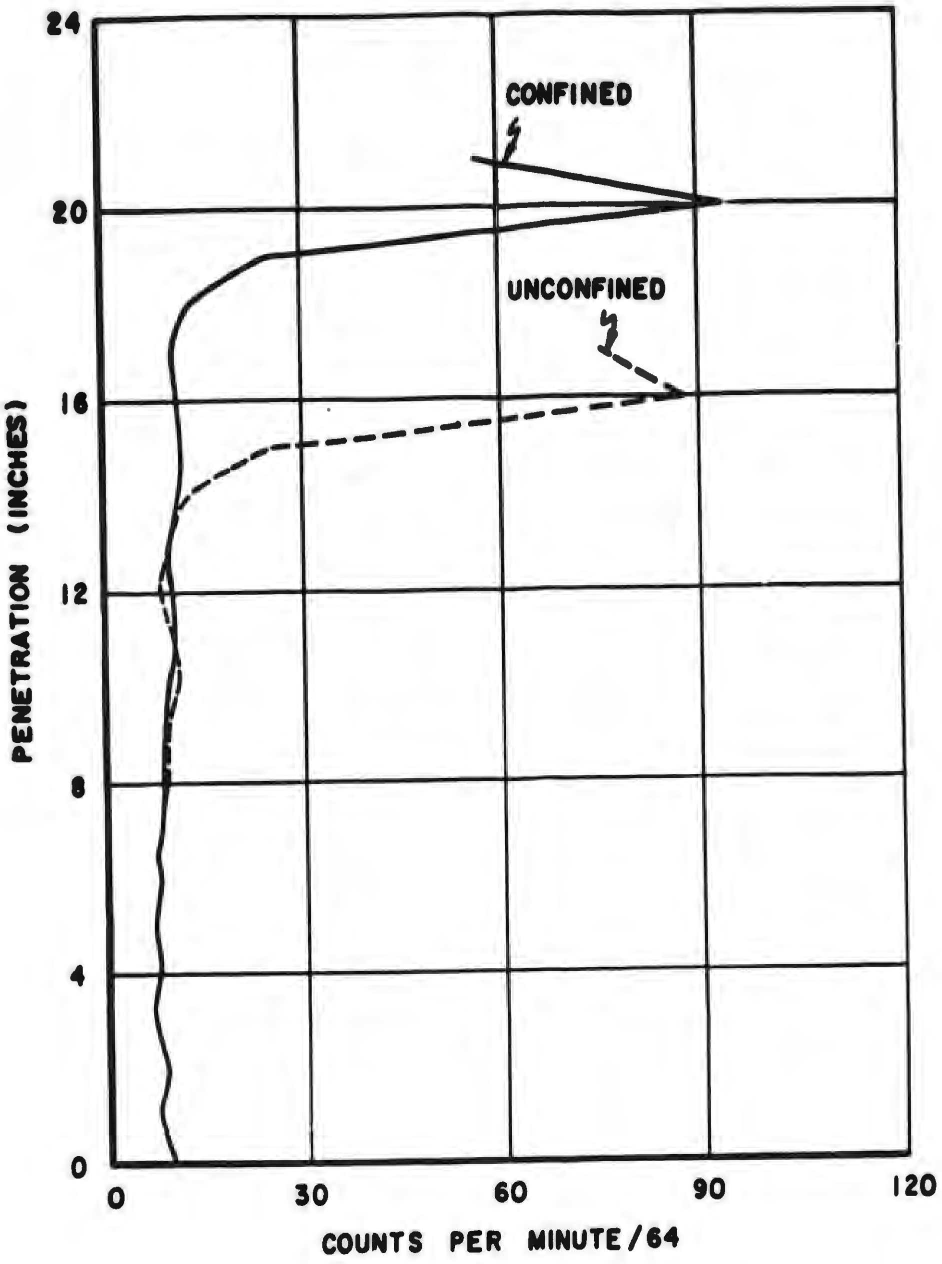

FIG. 4 – PENETRATION vs. ACTIVITY FOR CONFINED AND UNCONFINED LINERS PLATED WITH 1/16" BANDS AT 0.25" FROM THE. BASE.

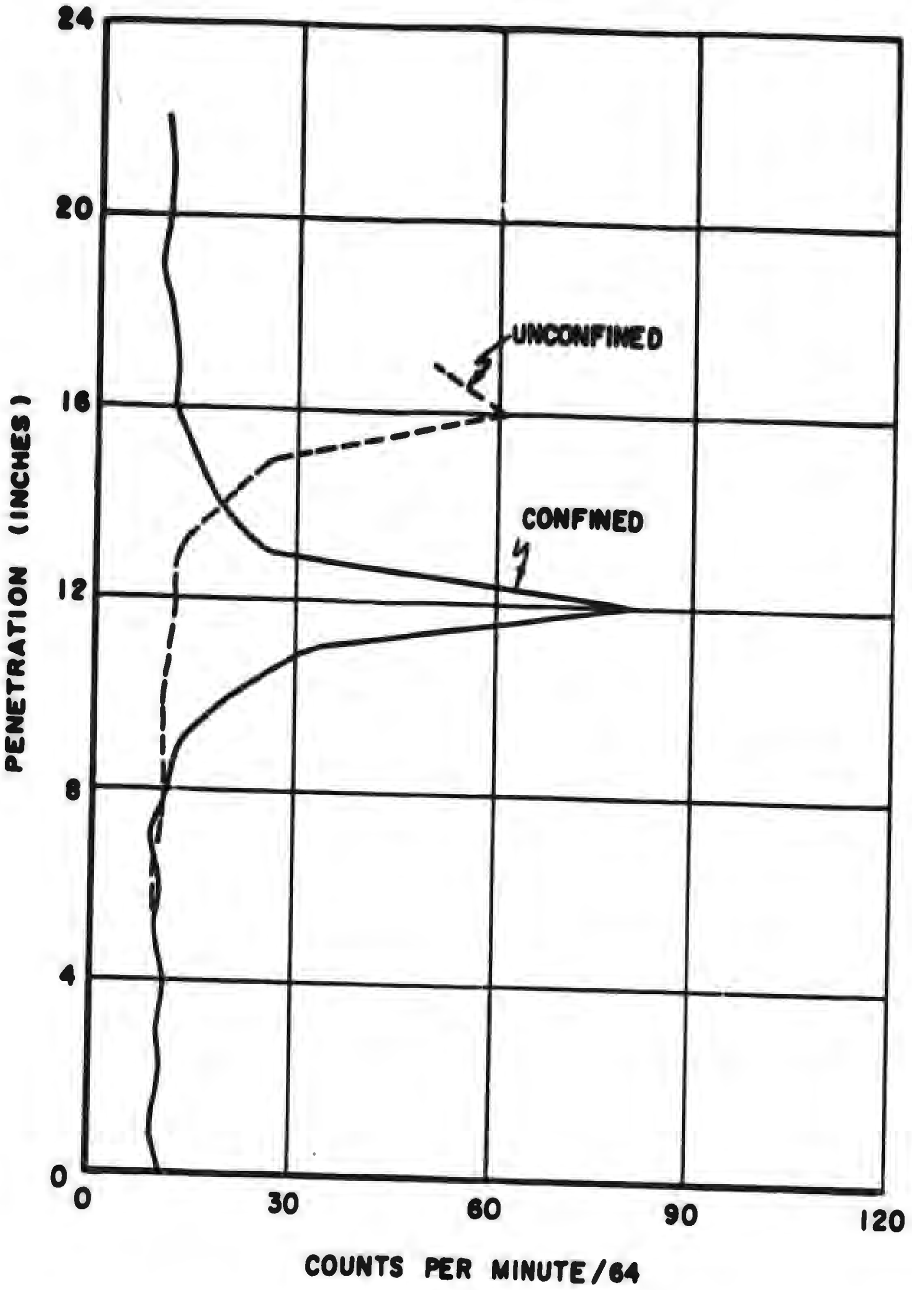

FIG. 5- PENETRATION vs. ACTIVITY FOR CONFINED AND UNCONFINED LINERS PLATED WITH 1/16" BANDS AT 0.50" FROM THE BASE.

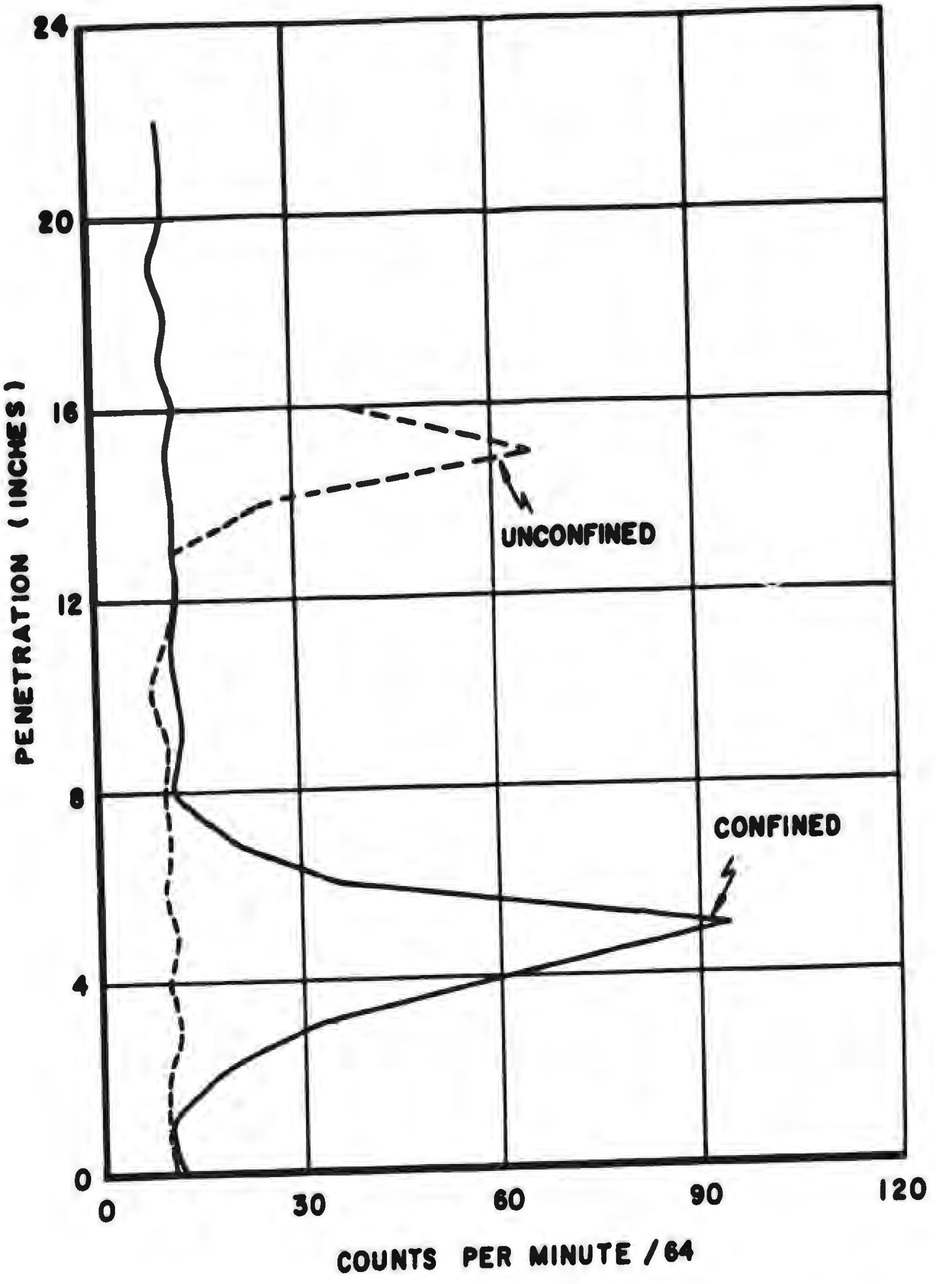

FIG. 6-PENETRATION vs. ACTIVITY FOR CONFINED AND UNCONFINED LINERS PLATED WITH 1/16" BANDS AT 1.00" FROM THE BASE.

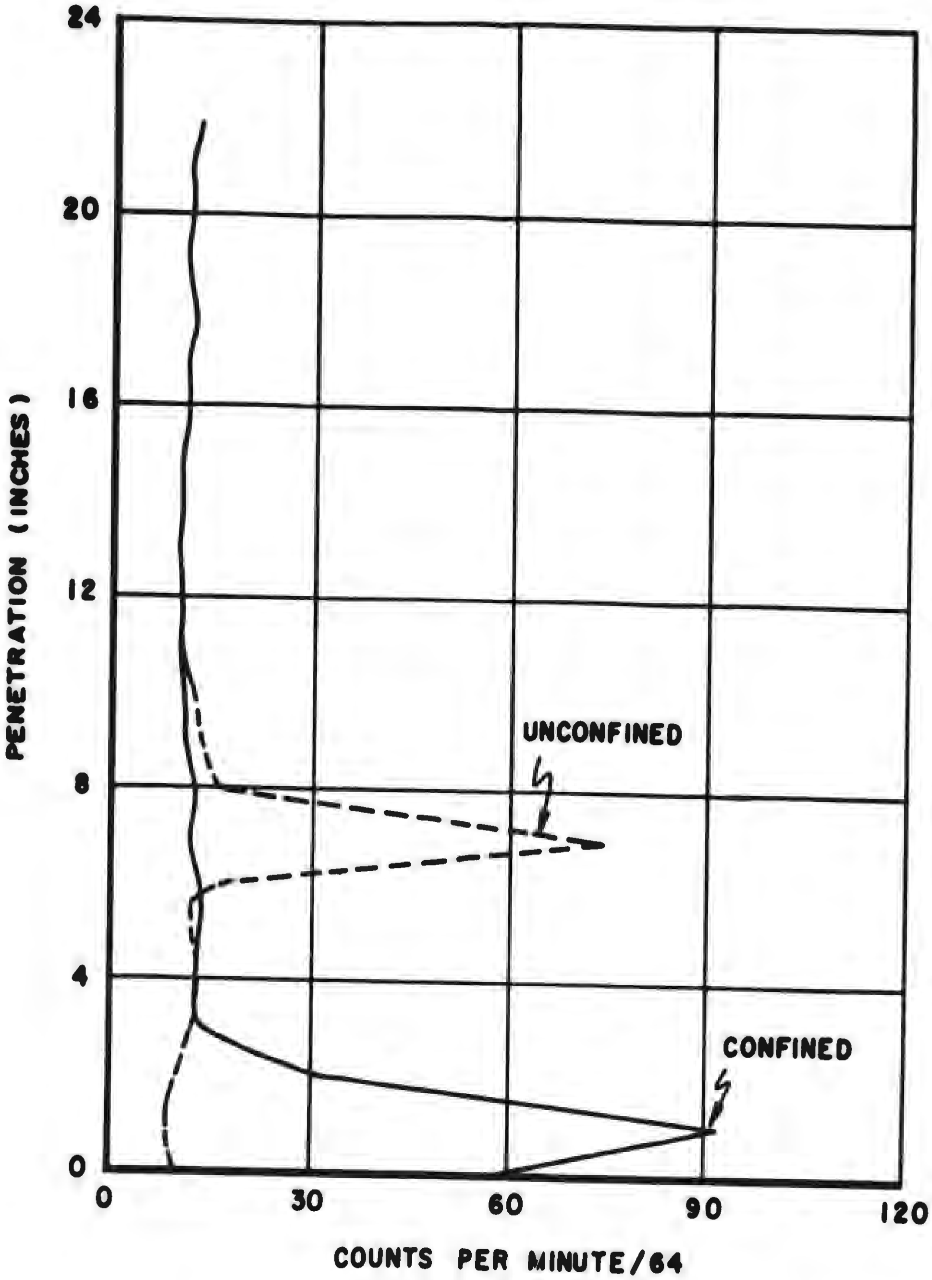

FIG. 7 – PENETRATION vs. ACTIVITY FOR CONFINED AND UNCONFINED LINERS PLATED WITH 1/16" BANDS AT 1.50" FROM THE BASE

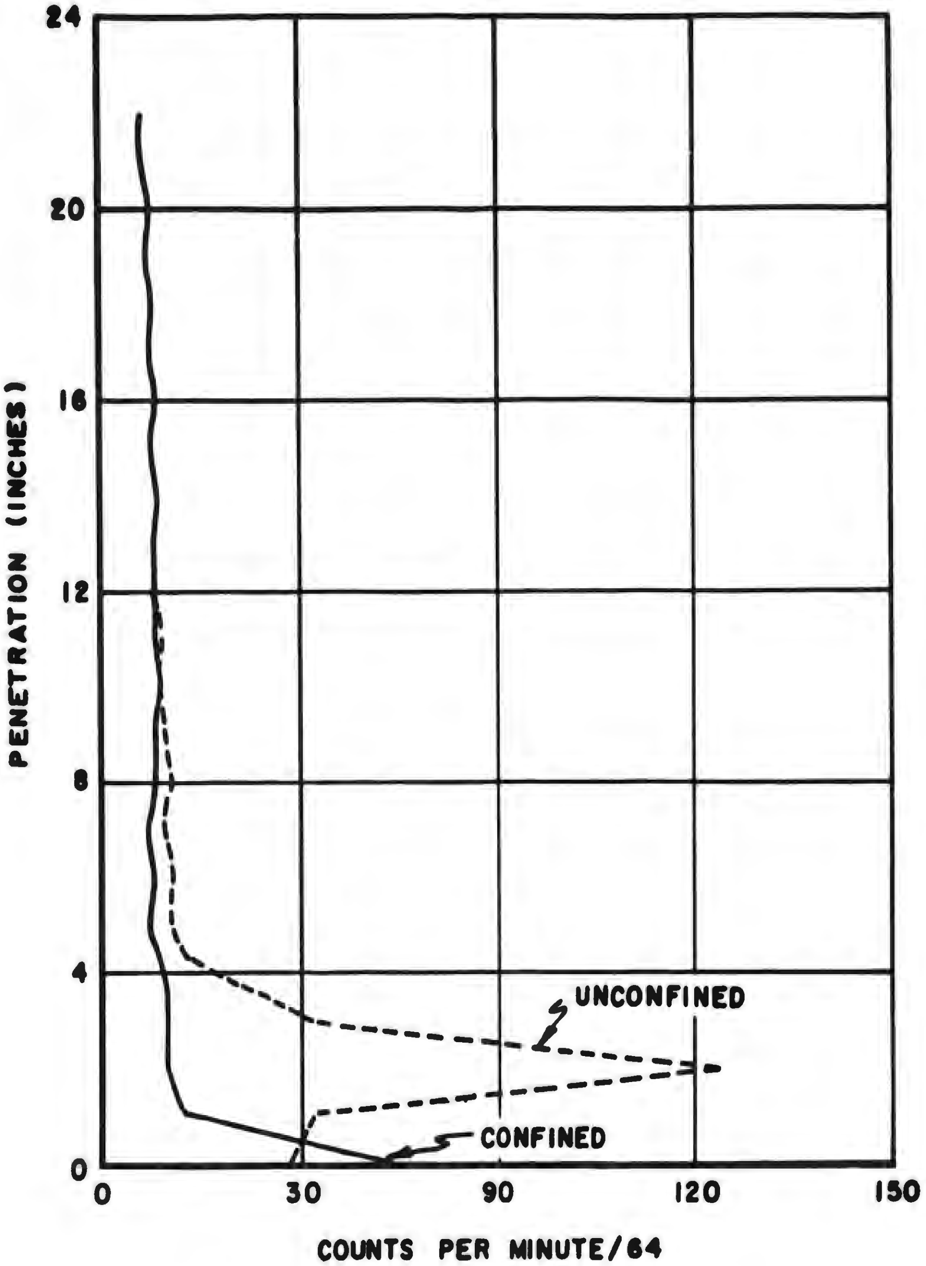

FIG. 8 - PENETRATION vs. ACTIVITY FOR CONFINED AND UNCONFINED 105 MM LINERS PLATED WITH 1/16" BANDS AT 2.00" FROM THE BASE.

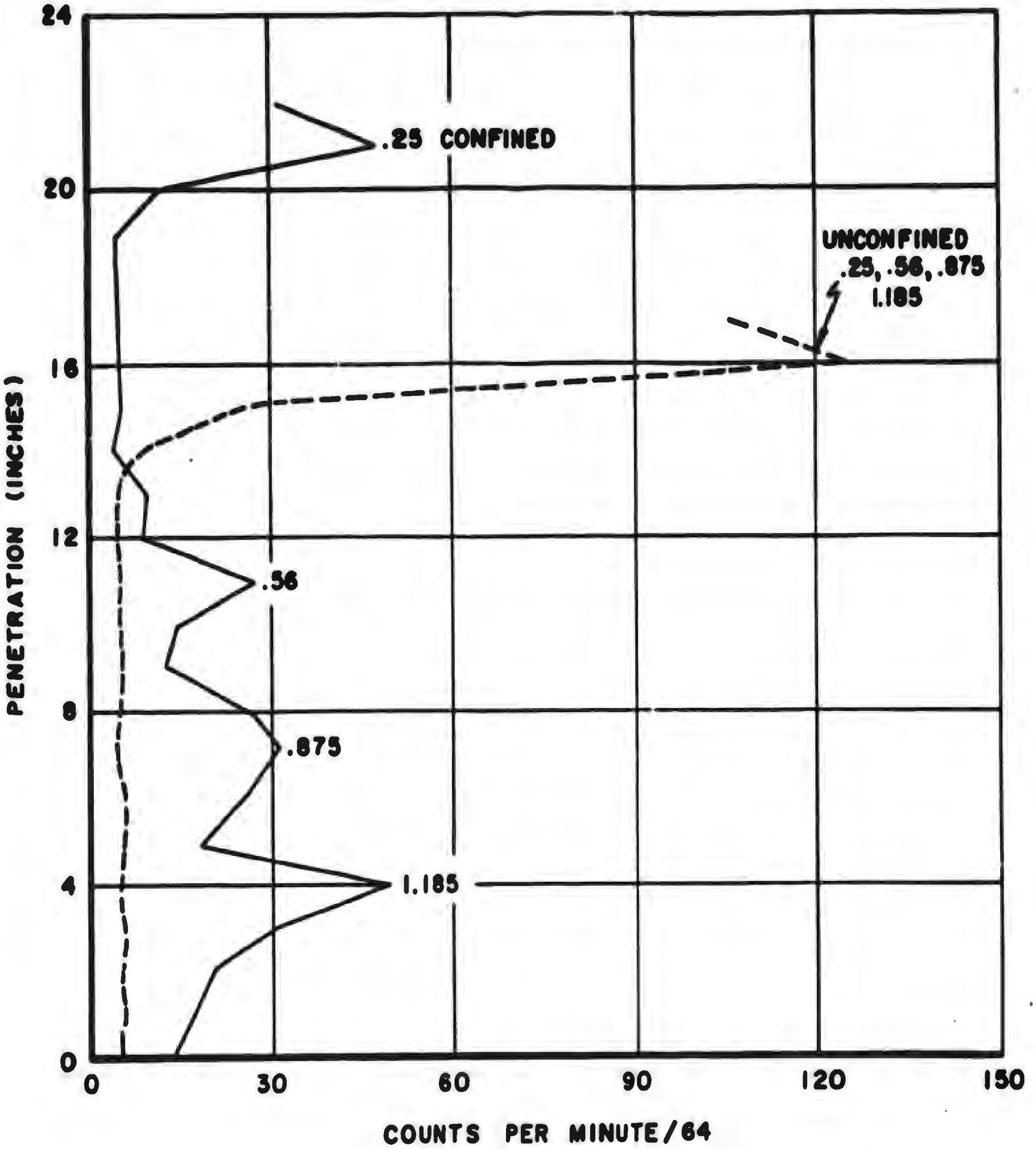

FIG. 9 – PENETRATION vs. ACTIVITY FOR CONFINED AND UNCONFINED MULTIPLE BANDED 105MM LINERS PLATED AT 0.25, 0.56, 0.875 AND 1.185 INCHES FROM THE BASE.

Data accumulated from firing of 80 rounds have been analyzed to determine the contribution to target penetration of various portions of the liner for both confined and unconfined charges. From the curves in Figure 10 it can be seen that confinement has a large effect on penetration, and, therefore, on jet formation. The jet formed by the base region of the liner accounts for almost all of the penetration by a confined charge, but provides only one inch of penetration in an unconfined charge. Although most of the penetration by a confined charge is obtained with the first 1-1/2" from the base, this does not necessarily imply that all of the jet comes from this section of the liner. In no instance was any radioactivity detected in the slug even when the isotope was plated in the apex of the liner. Figure 8 indicates that much of the activity from bands near the apex was lost in cratering from the first target plate. It can therefore be assumed that the entire inside surface of the liner contributed to the jet.

The fact that very little penetration is obtained from the upper part of a liner in a confined charge is consistent with early slug recovery measurements. They showed that the collapse angle was nearly constant in the region of the apex,[7] implying a steady-state collapse for all but the base region of a confined liner. Although such an effect is not at variance with the non-steady hydrodynamic theory for the formation of a jet by a shaped charge[1,2,3,] liner, the extent of the region of steady-state collapse is somewhat surprising. The fact that only the base region of the liner is responsible for most of the penetration should prove extremely valuable in the design of future shaped charges.

The jet velocities plottedin Figure 11 are values obtained from the average of the penetration velocities taken over 20 firings of confined and unconfined charges.

From Figures 10 and 11, a comparison of jet velocity and penetration for a given band position may be obtained. From these figures it can be seen that the jet velocity at the point of maximum penetration is the same for both confined and unconfined charges. This can be considered

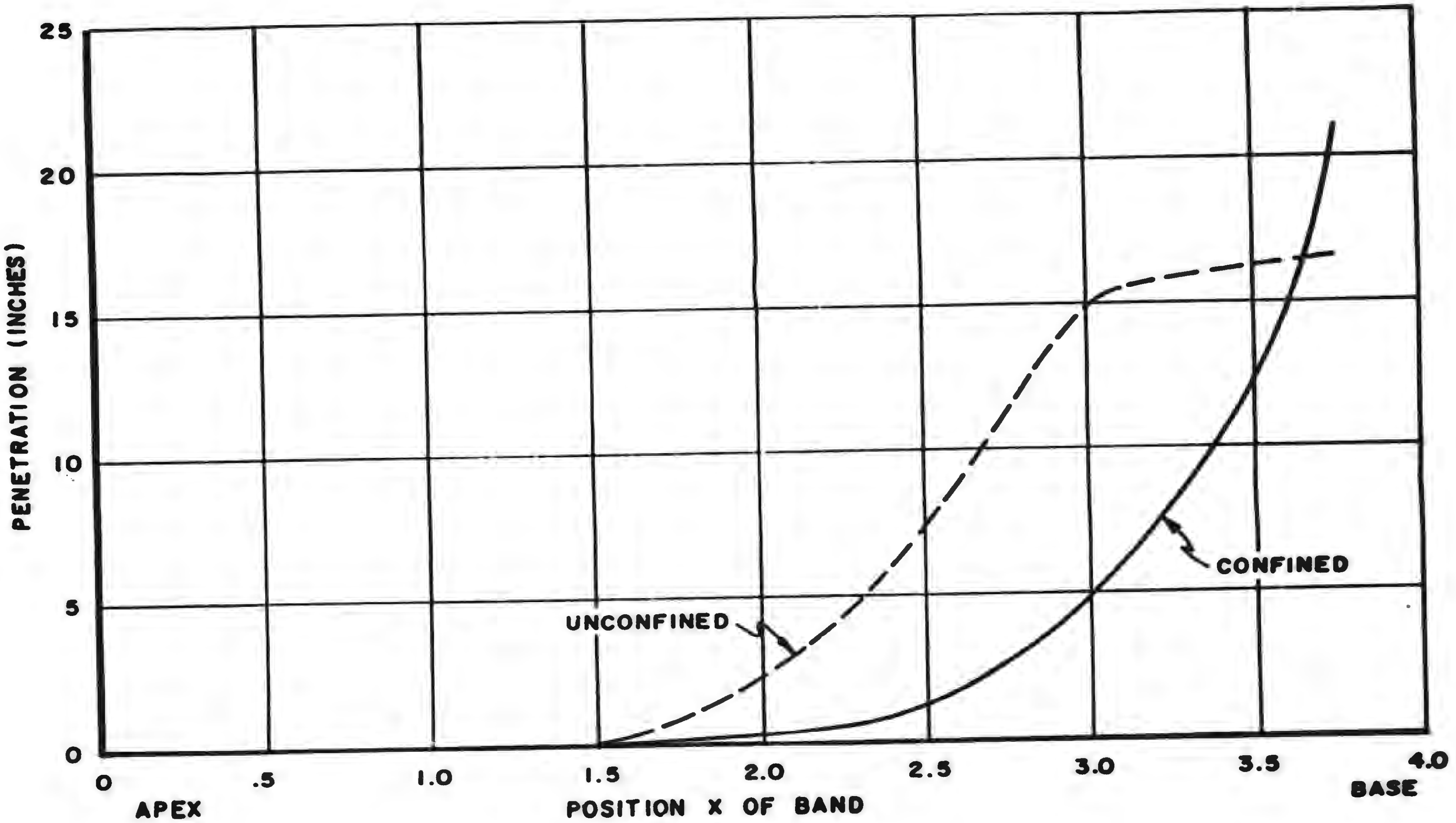

FIG. 10 – PENETRATION vs. POSITION OF BAND ON LINER BEFORE COLLAPSE, FOR CONFINED AND UNCONFINED CHARGES.

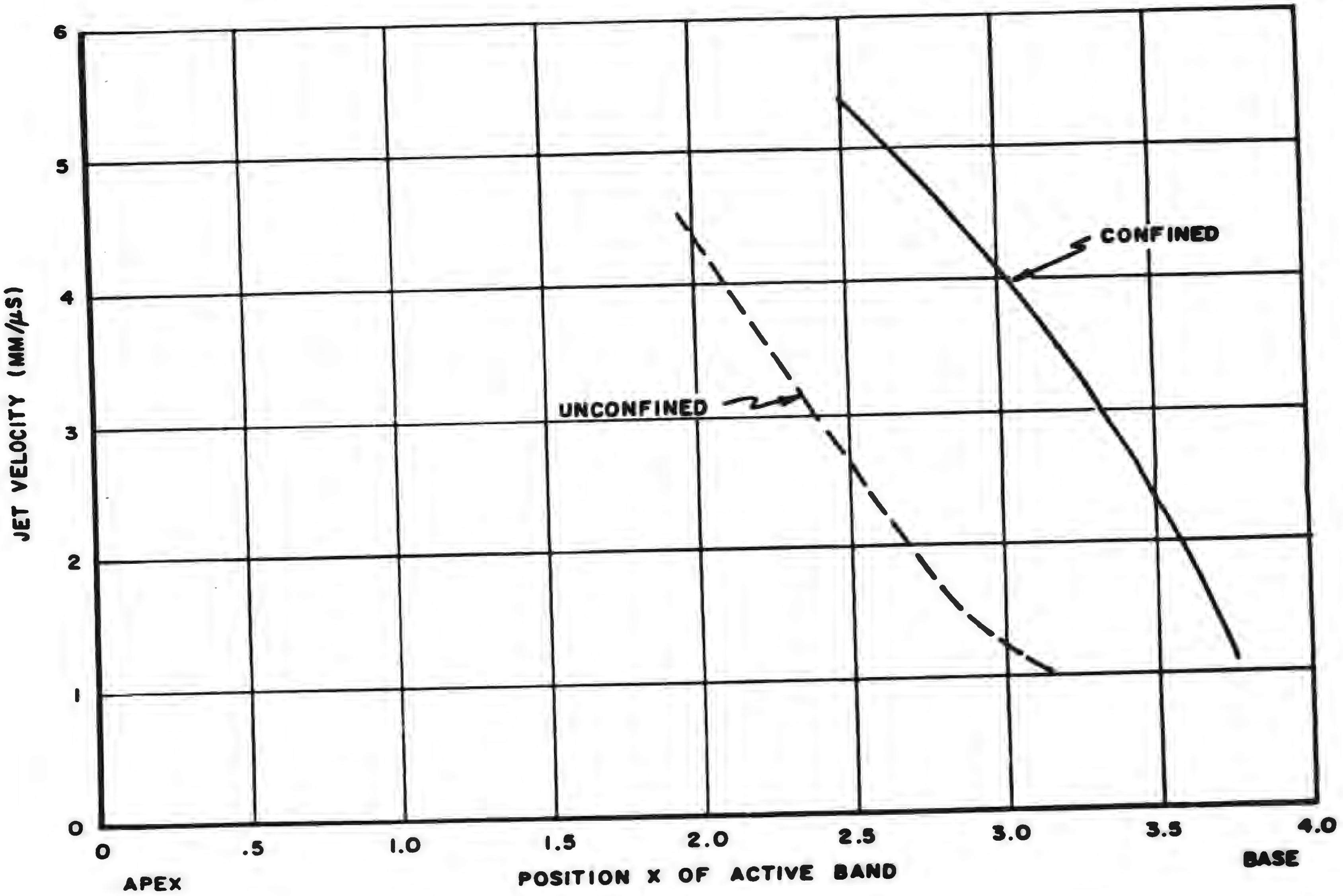

FIG. II – JET VELOCITY vs. POSITION OF PARENT LINER ELEMENT FOR CONFINED AND UNCONFINED CHARGES as being the minimum velocity for which penetration can be obtained. If p is the pressure on the target caused by the jet traveling at its minimum velocity, then

$$p = 1/2\ \rho U^2$$

If $\rho = 7.8$ and $U = 0.083$ cm/μs

then $P = 1/2\ (7.8)\ (0.083)^2 \times 10^6 = 5.3 \times 10^8$ dynes /cm^2

This value is comparable to the static yield strength of the mild steel target, plate which is about 2×10^9 dynes /cm^2.

Since the first inch from the base of an unconfined 105mm liner contributes very little to the penetration, it can be assumed that in this case, nonsteady state collapse takes place over nearly the entire liner and the minimum jet velocity for penetration is reached much earlier in the collapse process than with a confined charge. This is seen in the shape of the lower portion of the curve for the unconfined charge in Figure 11.

CONCLUSION

By the use of radioactive tracers, a direct quantitative method has been obtained for measuring the contribution to penetration by a given segment of the liner. The degree of resolution was found to depend only on the width and activity of the band. For this reason, the radioactive tracer method should work as well on any type of shaped charge liner and should prove valuable in determining the effects of variations in design parameters.

The effect of confinement is essentially to produce a steady state collapse over all but the base region of the liner. For this reason, appreciable penetration is produced only by the base region of the liner which follows a non-steady state collapse. When unconfined nearly the entire liner follows a non-steady collapse, and the penetration obtained in limited - - by the fact that near the base of the liner jet velocities are reached which are below the minimum necessary for penetration.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Dr. Robert J. Eichelberger for providing background material and many helpful suggestions pertinent to the application of radioactive tracers to shaped charge liner.

M. K. Gainer

M. K. GAINER

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