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# The Influence of Surface Coatings on the Performance of Strategic Earth Penetrators (U)

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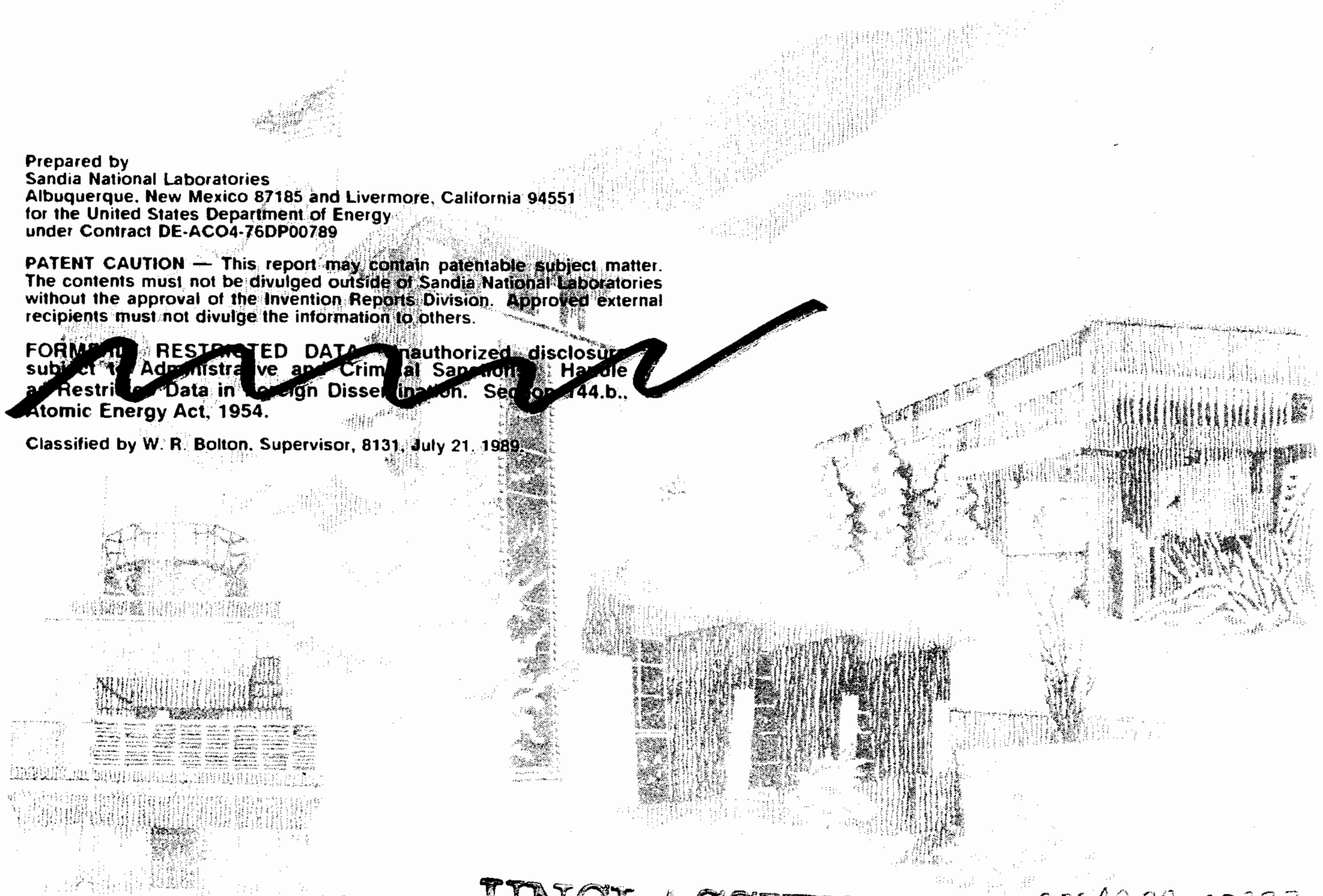
A. R. Ortega, J. Lipkin, H. R. Johnson, J. P. Lucas, J. C. Farmer



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**Albuquerque, New Mexico 87185 and Livermore, California 94551**
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# The Influence of Surface Coatings on the Performance of Strategic Earth Penetrators (U)

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## Abstract

The effect of surface coatings on the performance of 1/10-scale model earth penetrators has been investigated. Test units were accelerated using a 4 inch diameter light gas gun and, after a short free flight, impacted a simulated rock target. [redacted]

**DOE b(3)**

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*Currently at Lawrence Livermore National Laboratory, Livermore, CA.

## Acknowledgements

The authors wish to express their gratitude to D. B. Sparger and J. E. Collins who assisted in all aspects of this study. The authors also acknowledge contributions from the following: M. L. Chiesa (numerical earth penetration simulations), M. L. Tootle and J. S. Korellis (gas gun facility), B. R. Pelletier and D. M. Abrahams (high speed photography), and C. J. DeCarli (statistical analyses).

# Contents

## List of Figures

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# List of Tables

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# 1 Introduction

In the last 30 years a number of issues bearing on earth penetrator performance have been examined both experimentally and analytically (e.g., nose shape, weight/area ratio, impact velocity, etc.). However, one issue which has not been studied is the role of friction in penetration events and, in particular, how frictional loading between the penetrator and target might be affected by modifications of the penetrator surface. The present study was undertaken to examine this complex issue.

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[redacted] These friction forces resist penetration and can contribute substantially to loads that the penetrator case and internal components must withstand.

Numerical simulations of earth penetration events give a clear indication of the importance of friction [1]. [redacted] In the present study, we use an experimental approach to investigate this same question. Namely, can we modify the surface of a penetrator to reduce the axial acceleration to the same degree predicted by these numerical simulations?

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A simple method of changing the properties of the penetrator surface is through the use of a surface coating. Since the characteristics of an effective coating were initially unknown, we experimentally evaluated various coatings having a wide range of physical, thermal and mechanical properties. This study was accomplished using a laboratory-scale test technique developed to compare the performance of 1/10-scale model coated and uncoated Sandia, Livermore, strategic earth penetrators. The models were accelerated to steady velocities using a gas gun and, after a short free flight, impacted a foundry stone target. The foundry stone targets used in the present study are a simulated rock which was developed to resemble a natural rock geology at the Sandia Tonopah Test Range (TTR), Nevada, where full-scale field tests are conducted. The effectiveness of a coating was judged primarily on the measured penetration depth into the target compared to that obtained for uncoated penetrators.

## 2 Experimental Procedure

A 4 inch diameter light gas gun, operated and maintained by Division 8243, was used in this study. The test facility, depicted schematically in Figure 1, consists of a gas gun, a sabot stripper mounted at the end of the gun barrel, and a target chamber. Prior to launching, a 1/10-scale model penetrator is assembled into an aluminum/polyurethane foam sabot with a preset 0° angle of attack (Figure 2). Since the weight of the sabot is approximately the same as the test unit, it was necessary to strip the sabot prior to target impact. The stripper was designed to separate the model from the sabot and capture most of the debris associated with the stripping process at the muzzle of the gun. A schematic of the stripper is shown in Figure 3. Projectile velocity and attitude in free flight were recorded with two image motion or streaking cameras (focused at 3 and 20 inches from the gun barrel). By using mirrors, both side and bottom views were captured with a single camera (Figure 4). These two views are needed to determine the pitch and yaw angles of attack prior to impact.[1] After travelling a total of 30 inches in free flight, the penetrator impacted the target. The impact angle was 90° (normal impact) for all tests.

The target consisted of foundry stone, a man-made rock resembling cemented sandstone. This material is primarily silica sand with chemical binders and a catalyst (see Appendix A). Targets were fabricated at the Sandia Foundry, Division 7473, using the same process as that used to make molds for metal castings. Physical and mechanical properties measured periodically during this program [2,3] indicated that foundry stone was slightly weaker than Antelope Tuff, a low strength rock at TTR used for large-scale earth penetration tests.[2] The strength of foundry stone can be varied by adjusting the binder content. Targets containing 7% binder (by weight) were chosen after investigating 1% and 3% targets.[3]

Early development tests revealed severe cracking and fragmentation of the target. This damage was influenced by (1) a low tensile strength target, and (2) edge effects due to a finite radius target. Analyses [4] showed that the addition of a 1/2 inch thick mild steel sleeve around a target approximately 3 feet in diameter would considerably reduce the hoop tensile stresses and thus minimize target cracking during penetration. In addition, these analyses indicated that using a constrained target of this size would result in 1/10-scale model penetration depths similar to that expected for a semi-infinite medium. Satisfactory results were achieved when a hexagonal target was used with a matching sleeve. This sleeve, which was fabricated in two parts, was

---

[1] The measured angle of attack in both pitch and yaw planes was nominally less than 1/4°.

[2] Laboratory tests of Antelope Tuff indicate that it has an average density of 112 lb/ft$^3$ and a nominal unconfined compressive strength of 2500 psi.

[3] The penetration depth for uncoated penetrators tested at identical impact velocities was approximately 33% less for 7% binder targets compared to 1% targets.

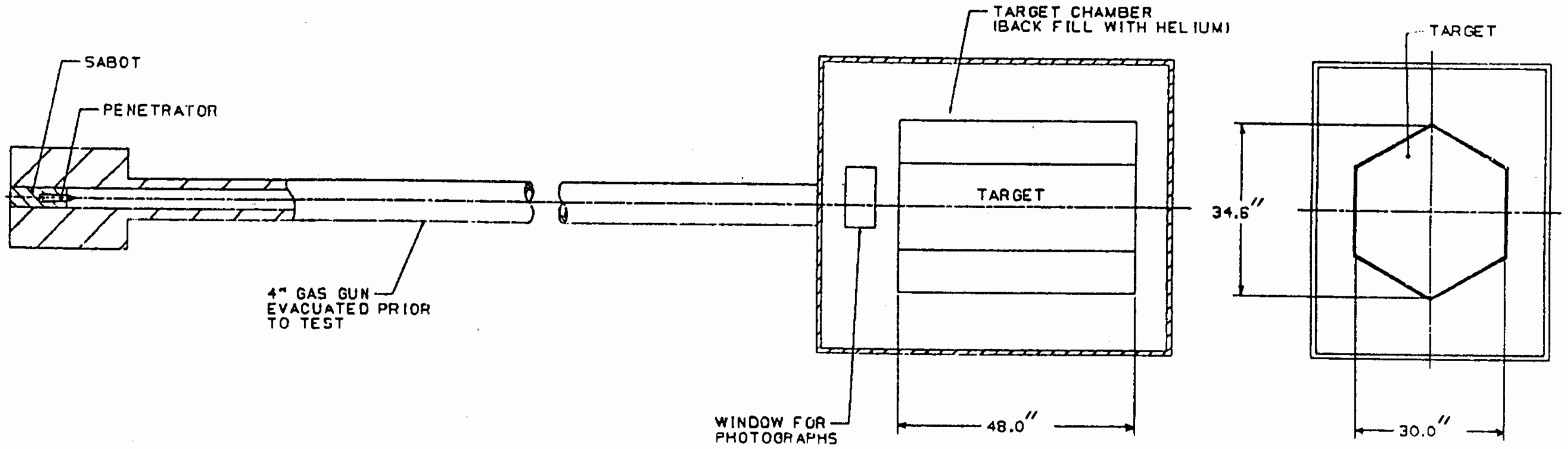

Figure 1. Gas gun facility

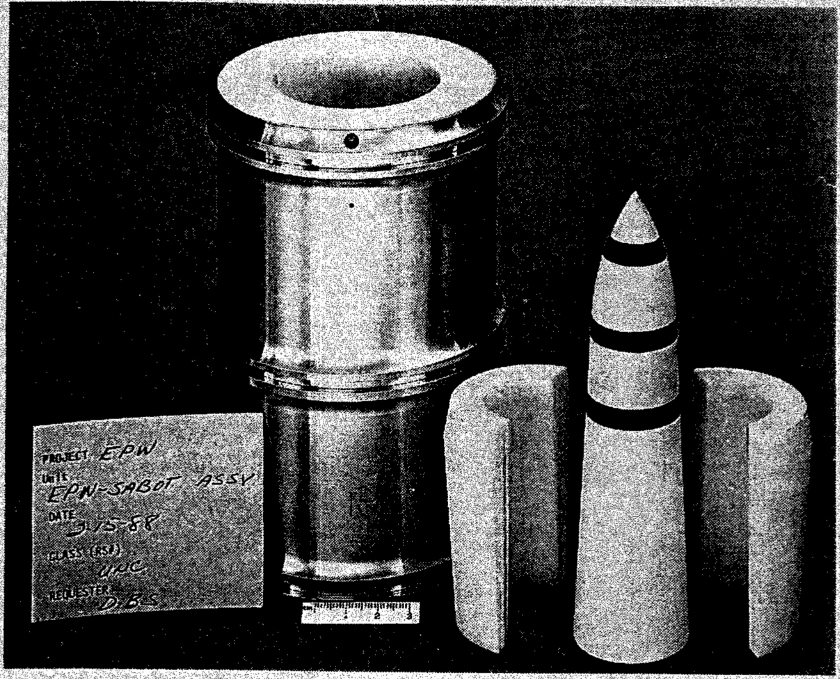

Figure 2: Penetrator/sabot assembly

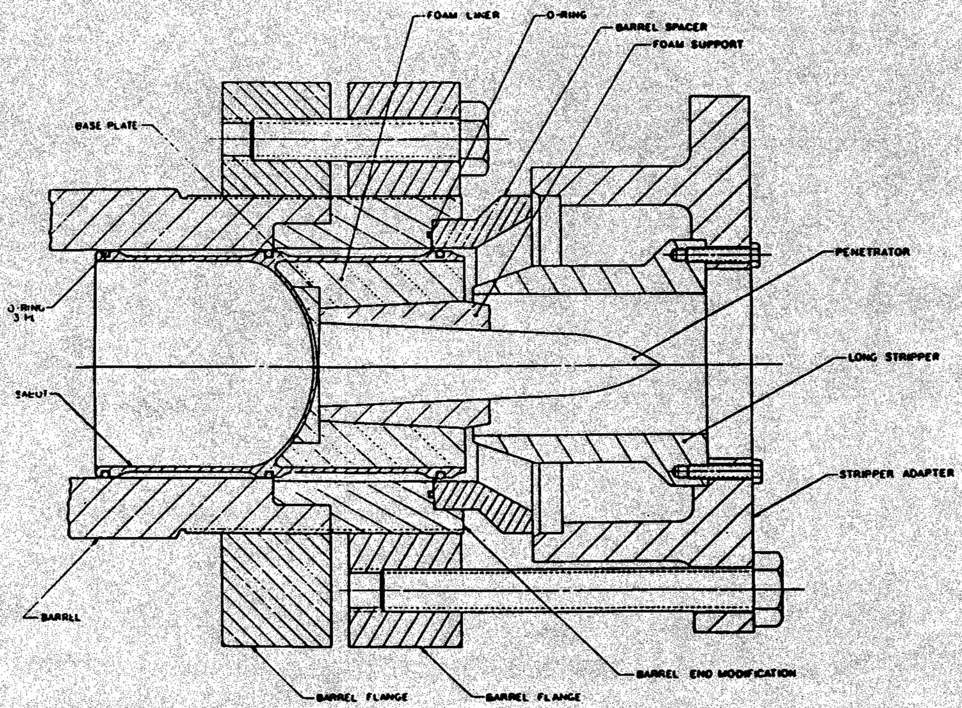

Figure 3: Sabot stripper design

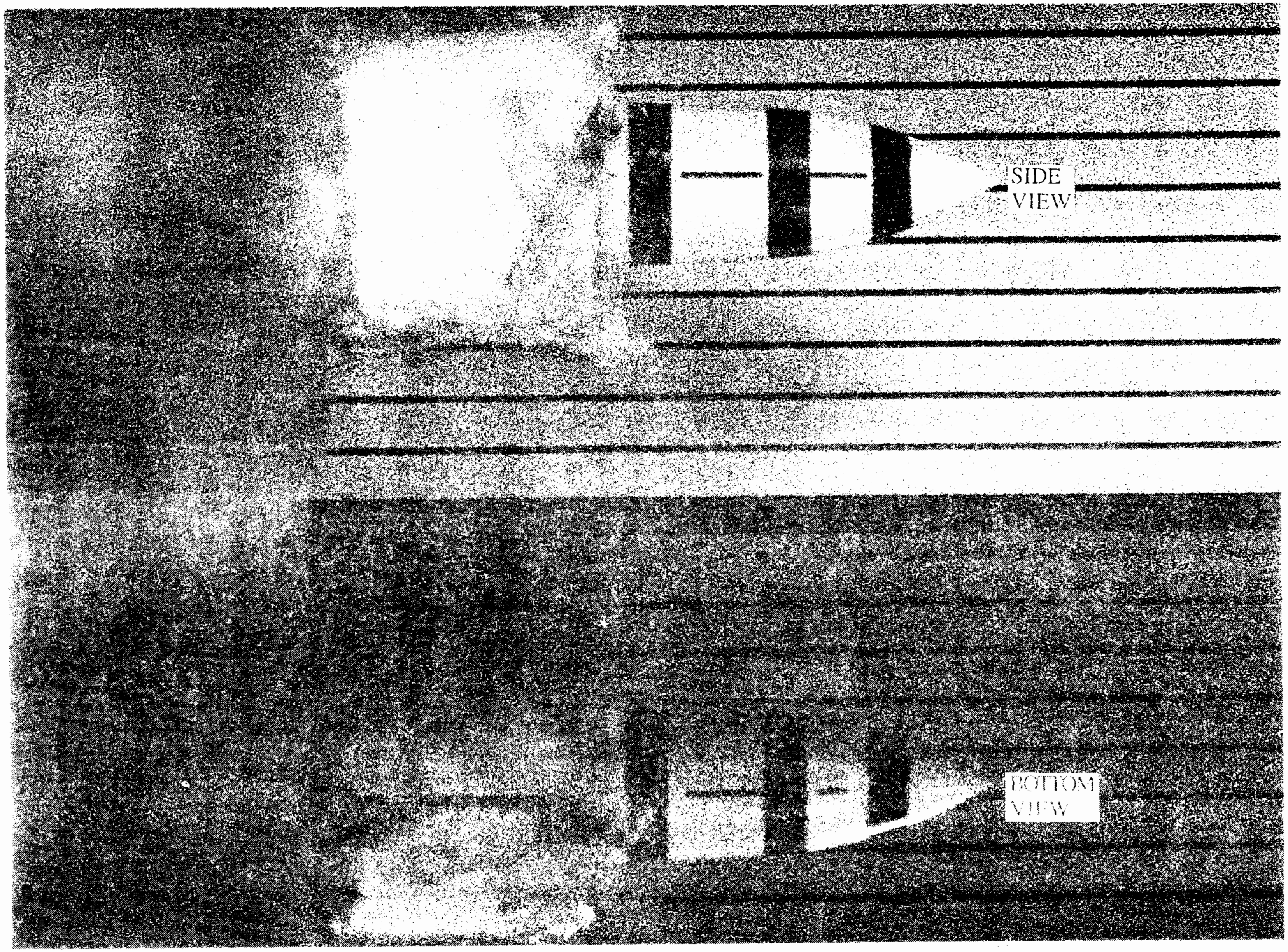

Figure 4: Penetrator in free flight prior to impacting target

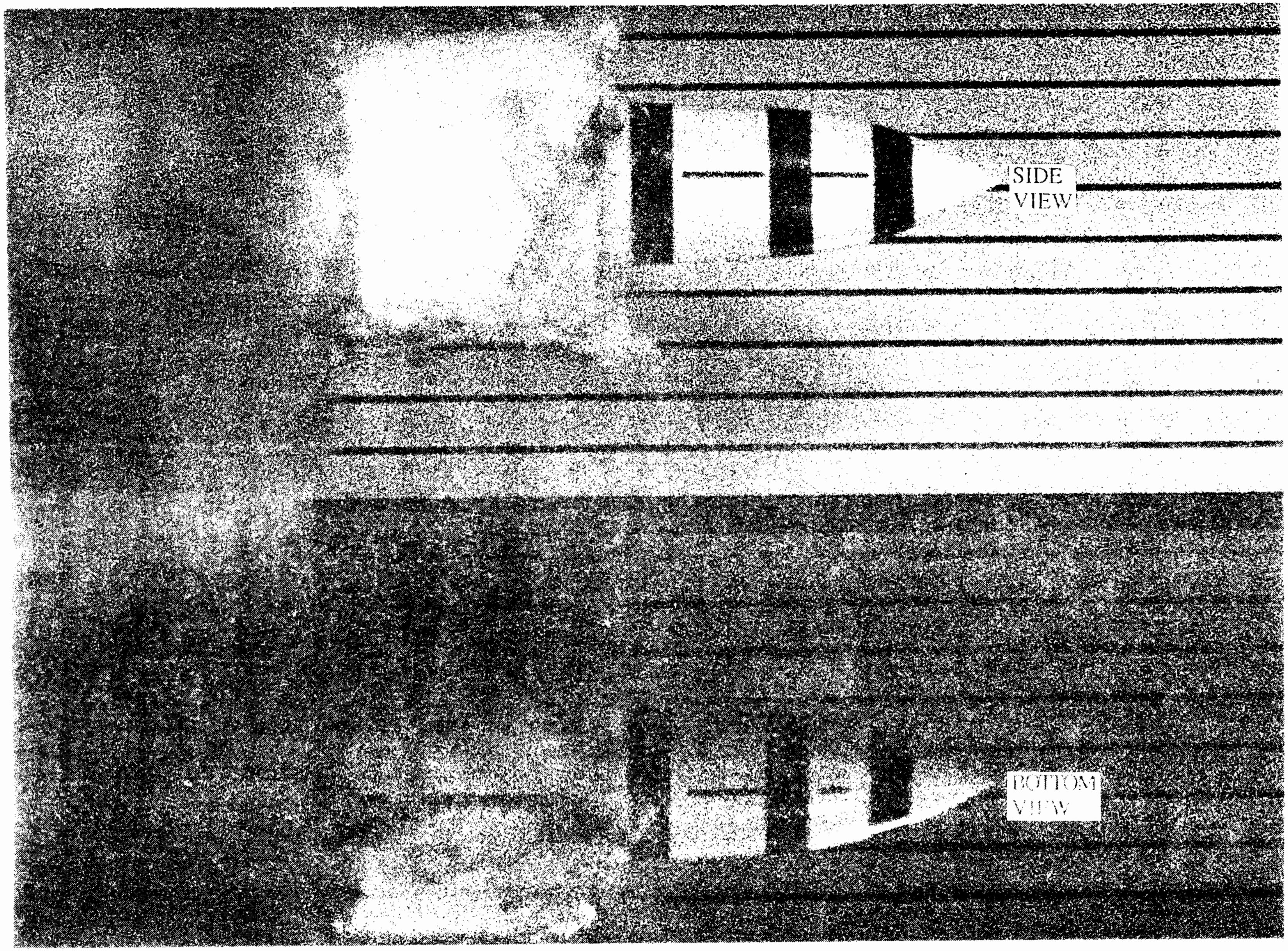

Figure 4: Penetrator in free flight prior to impacting target

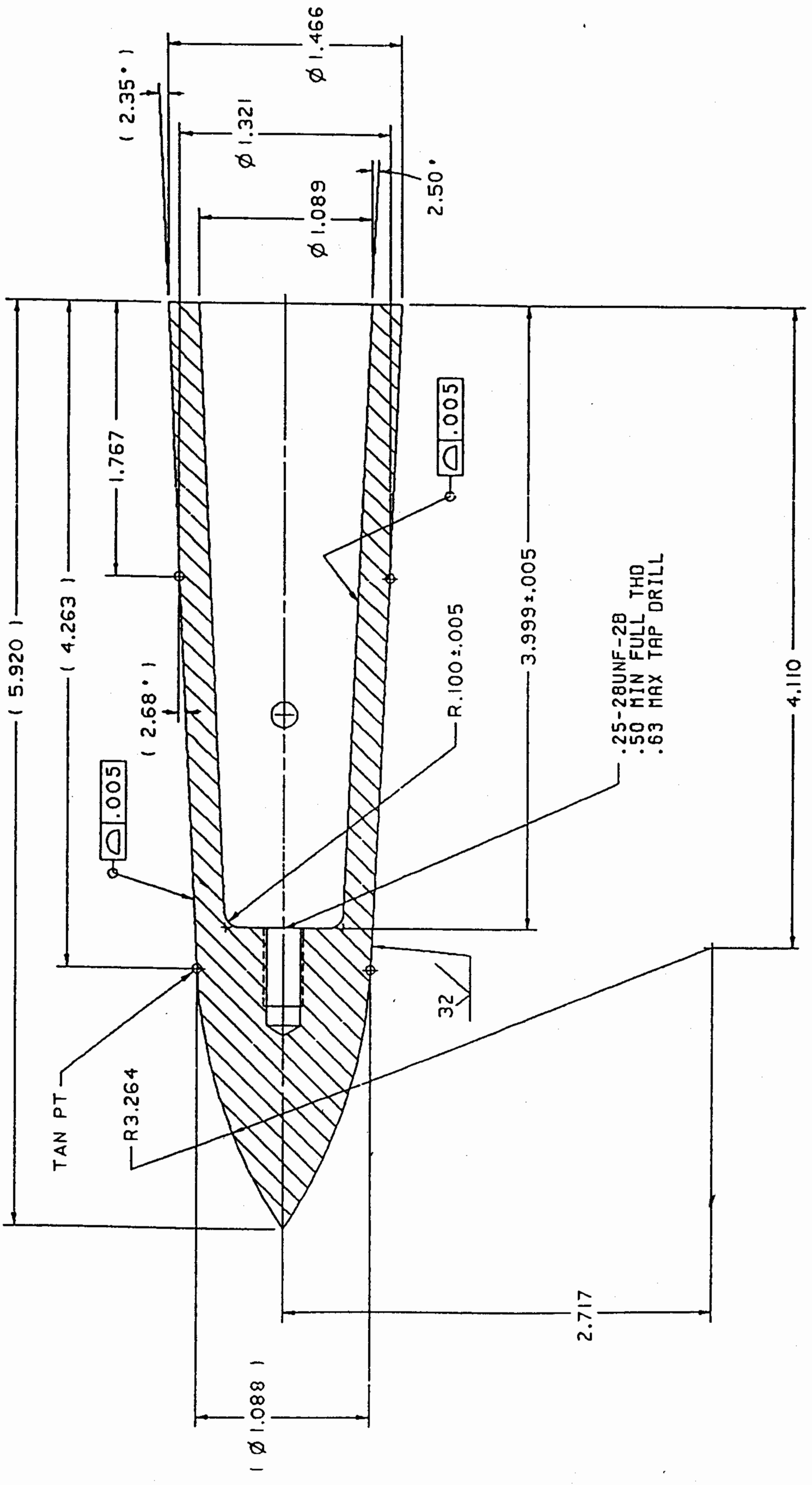

Figure 5: Drawing of 1/10-scale model earth penetrator. All dimensions are in inches.

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# 3 Test Results

## 3.1 Penetration Depth Data

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Table 2: Penetration depth test results

[redacted]

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## 3.2 Post-test Macroscopic Observations

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Figure 6: Typical post-test target

Table 3: Erosion of coated and uncoated penetrators

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## 4 Discussion

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## 5 Conclusion

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# 7 Appendix A

Table 4: Constituents of 7% binder foundry stone

| Weight (lbs.) | Component |
|---|---|
| 100 | silica sand (grain size 50) |
| 3.5 | Pep Set* 53-914 |
| 3.5 | Pep Set 2610 |
| 0.14 | Pep Set 3500 |

* Pep Set is a trade name of Ashland Chemical Co.

# 8 Appendix B

Summary of Cauchy Scaling Laws

Definitions:

$l$ = length

$m$ = mass

$v$ = velocity

$a$ = acceleration

$\rho$ = density

$\sigma$ = stress

$t$ = time

$\dot{\varepsilon}$ = strain rate

$\lambda$ = geometric scale factor; e.g. for $\frac{1}{10}$ - scale, $\lambda = \frac{1}{10}$

superscript * = sub-scale quantity

The following set of independent relationships forms a basis from which other quantities can be generated:

$$l^* = \lambda\, l \qquad \sigma^* = \sigma \qquad \rho^* = \rho$$

For example, one can derive the expressions shown below:

$$t^* = \lambda\, t \qquad m^* = \lambda^3 m \qquad a^* = \frac{1}{\lambda} a$$

$$v^* = v \qquad \dot{\varepsilon}^* = \frac{1}{\lambda} \dot{\varepsilon}$$

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