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TERMINAL BALLISTICS IN ORDINARY SNOW. SMALL ARMS FIRE ATTENUATION

George K. Swinzow

Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire

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Small Arms Fire Attenuation

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13. ABSTRACT

The terminal ballistics of various types of snow were investigated experimentally and the resulting data have been researched and tabulated. The experimental procedures, especially designed for this purpose, are described and illustrated. It was concluded that snow is an effective protective material, with measurable and significant capability to attenuate small arms fire and neutralize fragment action. A brief discourse was made into the role of snow-covered terrain in combat, its geography and general properties.

14. Key Words

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PREFACE

This report was prepared by Dr. George K. Swinzow, Geologist, Construction Engineering Research Branch (Mr. E.F. Lobacz, Chief), Experimental Engineering Division (Mr. K.A. Linell, Chief), U.S. Army Cold Regions Research and Engineering Laboratory.

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TERMINAL BALLISTICS IN ORDINARY SNOW

by

G.K. Swinzow

INTRODUCTION

The purpose of this paper is to explore the possibility that ordinary snow may be a material suitable for protection against lethal fragments and small arms fire. From previous observations (Swinzow 1970) the author became convinced that snow has an unexpectedly high attenuation capability in the case of fast-moving projectiles and fragments. This paper is an attempt to systematize observations and to arrive at some data directly applicable in fortification.

Although there are ample indications (see quoted literature) that ordinary snow is a legitimate and advantageous fortification material, as far as could be ascertained, studies of terminal ballistics in ordinary snow are unavailable.

Generally, classical knowledge in ballistics is divided into three parts sequentially and causally related to each other:

a. *Internal ballistics*: acceleration, pressure, friction etc. in the barrel of the weapon, resulting in initial velocity (muzzle velocity) of the projectile.

b. *External ballistics*: the projectile's relation to the fluid (air) through which it travels. The predictions obtainable from existing empirical equations are precise, the precision increasing with caliber and range.

c. *Terminal ballistics*: the relation of projectile to target. Here the kinetic energy of the projectile is applied to penetrate, puncture, defeat by cratering, or ricochet. These terms denote all the interactions between projectile and target. Generally, in the case of a homogeneous target, most efficient penetration takes place at lower velocities while higher velocities are accompanied by progressively greater cratering which may be regarded as inefficient utilization of energy. All other conditions being equal, low velocity projectiles are the efficient ones. Finally, when the angle of projectile incidence upon the target becomes less than 90° ricocheting may take place.

With snow as the target, cratering by small projectiles could never be observed, penetration being the predominant factor. Ricocheting was observed only in very dense (0.6-0.7 g/cm^3) snow and at angles of approximately 7° or less (own observation).

Since snow does not respond to a fast-moving projectile like a solid target (absence of observable cratering, spalling and uncertain ricocheting) we may examine some equations of external ballistics for their applicability to the motion of a projectile in snow.

$$\left.\begin{aligned} m\frac{d^2x}{dt^2} &= -D\cos\theta \\ \text{and} \\ m\frac{d^2y}{dt^2} &= -D\sin\theta - mg. \end{aligned}\right\} \quad (1)$$

Here

m = mass of projectile

x = horizontal distance to impact point

y = elevation of horizontal muzzle above impact point

t = time

θ = angle of impact

g = acceleration of gravity (981 cm/sec^2)

D = force of drag

(all units metric, as appropriate).

The drag force is highly dependent upon the initial velocity of the projectile. Drag is usually expressed as a relation of the physical components of the projectile to the environment and a coefficient.

$$D = \rho d^2 V^2 K_x \quad (2)$$

where

ρ = density of air

V = projectile velocity

d = projectile diameter

K_x = drag coefficient (obtainable from experiment).

The basic difficulty in applying eq 1 and 2 to snow is that the impact angle θ at the end of the trajectory is unmeasurable, therefore y is also unmeasurable and the influence of the force of gravity is negligible. Precise solutions for these equations are unknown. External ballistics is based on empirical data which, as was mentioned, give precise results. There is also the condition under which K_x is applied. The drag force decreases with decreased Mach numbers (which cannot be readily determined for snow) while Coulomb friction begins to play an increased role in energy dissipation at low velocities. For this reason, considering snow to be a fluid, such as air, leads to theoretical difficulties.

Robertson (1941) suggests the use of general equations for the penetration of solids. His treatment is based on the so-called sectional pressure theory. A general expression of penetration as related to terminal velocity was developed:

$$D_x = W(F_{(ro)} - F_{(r)}) \quad (3)$$

where

D_x = an auxiliary penetration function

W = weight of the projectile in grams

$F_{(ro)}$ = function of initial velocity

$F_{(r)}$ = function of final velocity.

This form is claimed to be applicable for the case of penetration of two discontinuities. When the projectile comes to a complete rest after penetrating the first discontinuity, the term $F_{(r)}$ disappears. The left side of eq 3 constitutes a somewhat complex concept, apparently not readily applicable in the case of snow. A different form of eq 3 attempts to take the analysis one step further:

$$x = \frac{m}{a} y^1 (F_{(ro)} F_{(r)}) \tag{4}$$

where

x = a point along the projectile trajectory, valid *after* penetration to more than one projectile length

m = mass of projectile

a = caliber area

y^1 = dimensionless shape factor

$F_{(ro)}$, $F_{(r)}$ = same as in eq 3.

One special problem is the difficulty in investigating the factor y^1 which requires very concise penetration data from large groups of shots.

Poncelet (1835) developed an equation which, it was claimed, was accurate for predicting penetration depth in such semicohesive media as sand, certain soils etc. The introduction of a concept of sectional density brings it into the category of the "sectional density" group of theories.

Sectional density is defined as the ratio of projectile weight to its caliber area. According to Poncelet introduction of this term results in the following equation:

$$x_{(max)} = \frac{p}{2gbi} \ln \left(1 + \frac{b}{a} V_t^2\right) \tag{5}$$

where

p = sectional density (g/cm^2)

a = shatter (shear) strength of target (g/cm^2)

b = an inertial coefficient (g/cm^3)(sec^2/cm)

g = acceleration of gravity (981 cm/sec^2)

V_t = terminal velocity (cm/sec)

i = projectile shape factor (nondimensional)

$x_{(max)}$ = maximum penetration (cm).

Equation 5 is empirical. The coefficient *b* is expressed here in a way to make the equation dimensionally correct. It appears also that shear strength of the target material (factor *a*) may not be the only factor governing penetration. Besides the applicability limits for various factors in equation 5, an analytical expression for snow penetration would have to take into account density which seems to be the most important one as it will be shown below; there is also compression, melting, drag, and friction. Data obtained for this report indicate that snow does not satisfy the predictions of external ballistics (penetration of gas or fluid), nor does snow respond as a solid yet density seems to relate closely to penetration of a fast projectile into ordinary snow.

EXPERIMENTS IN SNOW PENETRATION

Since the main objective of the experiments was to determine projectile motion in ordinary snow, i.e. to find the degree of protection snow can give against small arms fire, the experimental work was conceived in a way to be directly applicable. The main variables were projectile and target. The mass and velocity of the projectile (energy) were varied from the lowest possible to reasonably high values, mainly by changing the amount of propellant used in the rounds.

Ordinary snow varies in density, hardness, grain size and degree of metamorphism. Density varies from very low, 0.1 g/cm^3, to very high, 0.75 g/cm^3 (solid ice is approximately 0.9 g/cm^3). The density of deposited snow depends upon the conditions under which the snow cover formed. Slow precipitation in calm air results in light snow, and uniform flake size is also a factor in producing a light, "soft" snow cover. Drifting and decomposition in wind (redeposition) generally result in heavier snow masses. Undisturbed snow gradually hardens with time (age hardening). Reworking, compacting, ploughing, etc. result in densification and accelerated hardening (work hardening). In both cases, the process consists in fusing of individual grains at their points of contact. The process and the resulting properties are described in detail by Bader and Kuroiwa (1962).

The author's observations indicate that at a constant density, hardness influences penetration only at very low velocities (such as free fall from 1 m). With increased velocities, uncertainties in hardness measurements are larger than variations in penetration depth. At velocities above 40 m/sec hardness, grain size and degree of metamorphism (change of grain shape) did not influence penetration. It appears that the transitional velocity above which density becomes the predominant factor affecting penetration may be a property of the target material (see for example Vieser 1936). Since penetration at very low terminal velocities is outside the realm of terminal ballistics it was not studied. And since among all the properties of snow only density affects penetration to a *measurable* degree, only data in relation to density are reported.

The weapon selected was a stationary device modified from a standard .30 caliber (7.7 mm) rifle. Since it was found that a bullet-shaped projectile does have an intrinsic instability in snow, it was found necessary to use, in addition to standard ammunition, a sphere launched at various velocities from a smoothbore barrel. Properties of the projectiles are listed in Table I.

The snow penetration experiments were conducted by placing snow block targets in the line of fire 5 meters away from the weapon to eliminate muzzle blast effects. A series of chronograph screens* were placed within each target, with one screen placed in front so that the terminal velocity of the projectile was registered before it entered the target. All screens were electrified and were connected to an oscilloscope. The arrival times of each projectile were registered so that velocities within the target could be calculated. Figure 1 shows the experimental set-up and Figure 2 shows a typical oscilloscope plot.

*A chronograph screen consists of a semi-metal cloth made from a continuous conductor interwoven with a non-conductor. A bullet hole interrupts an electric circuit.

Table 1. Projectile properties.

a. *.30 calibers*	Radius: 0.385 cm	Caliber area: 0.465 cm^2
Mass = 10.5 g	Sectional density = 22.58 g/cm^2	
Mass = 11.2 g	Sectional density = 24.09 g/cm^2	
Mass = 12.5 g	Sectional density = 26.88 g/cm^2	
b. *Steel spheres*	Radius: 0.644 cm	Caliber area: 1.258 cm^2
Mass = 8.3 g	Sectional density = 6.58 g/cm^2	

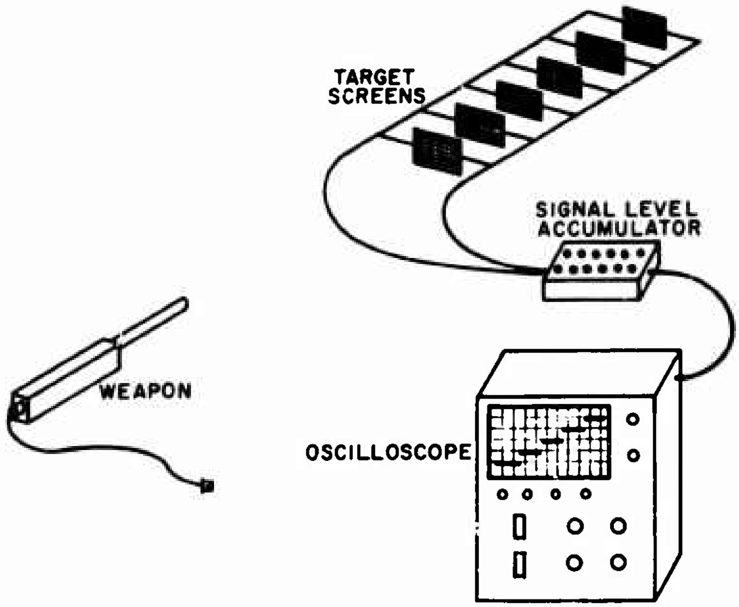

Figure 1. Experiment set-up. All screens are an equal distance apart. The first screen is in air, the second is in contact with the target, the rest are inside the target.

In most cases the targets were 40 × 40 × 150-cm blocks of snow. Where deep penetration was anticipated, as in the case of very light snow, the length of the target blocks was extended to 200 cm. Various techniques were used for target preparation, depending upon the available or desired density. Very low density targets were produced by allowing naturally falling snow to fill molds. Average density targets were cut from slightly reworked fresh, low temperature snow. Since at the prevailing relatively high temperatures (-3° to -20°C) age hardening proceeds at a relatively fast rate, it was used to ensure that target blocks were manageable. High density snow targets were often produced by screening snow through a series of sieves, eliminating intermediate grains so that densities up to 0.65 g/cm^3 could be achieved.

Figure 3 is a plot of the data taken from the chronographic record in Figure 2 together with the position of the recovered projectile. The zero position on the graph indicates the point where the projectile interrupted the current in the first screen. The second point is the point of entry into the target. The two points give the terminal velocity. All data except those for projectiles fired into natural snow cover were collected in the described way.

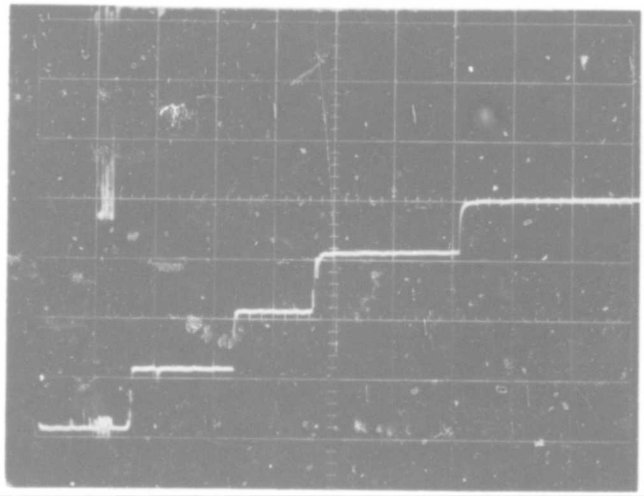

Figure 2. Example of an oscilloscope record obtained by the set-up shown in Figure 1. Snow density 0.37 g/cm^3, terminal velocity 19,677 cm/sec, maximum penetration 91 cm, projectile mass 12.5 grams.

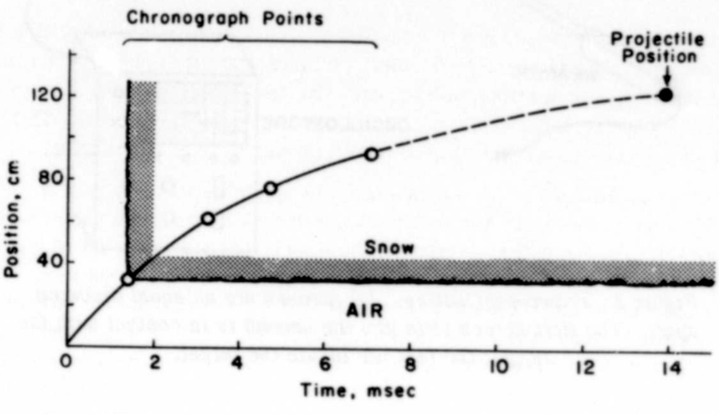

Figure 3. Projectile penetration into snow. Data from Figure 2.

THE TRAVEL OF THE PROJECTILE IN SNOW

As already mentioned, cratering of natural or artificial snow targets was not observable under the given conditions. The canal left behind as the projectile penetrated the snow was surrounded by a cone of disturbed snow which expanded perceptibly in the direction of motion. The canal was filled with a fine, powderlike snow which aged rapidly, becoming harder than the snow target itself. In an ideal case, the velocity of the projectile decreased exponentially until maximum penetration was achieved (Fig. 3).

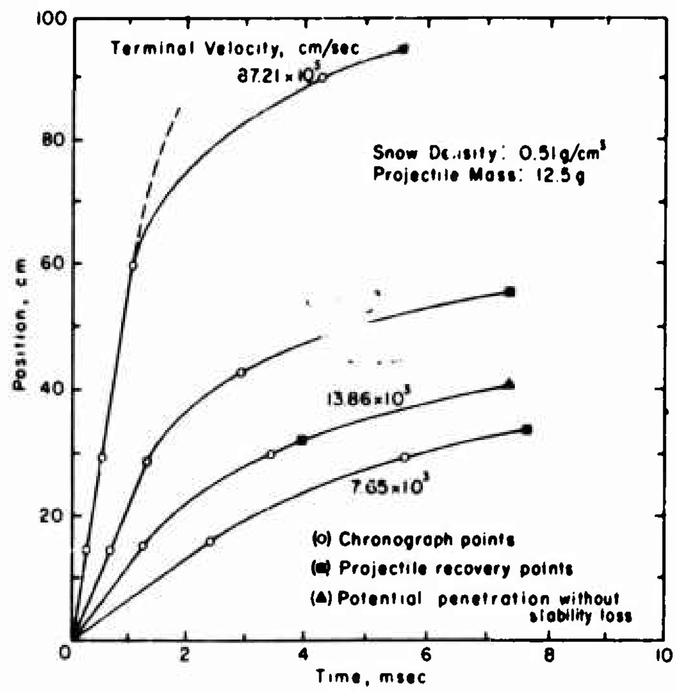

Figure 4. Loss of projectile stability in snow.

By dissecting the snow target, it was established that at some distance within the snow the projectile became unstable and began to tumble. To investigate this phenomenon further, projectiles were marked on one side with a strong soluble dye. By dissecting the path of such a marked projectile it was found that its spinning decreased at a lower rate than its velocity. This evidently may be a reason for loss of stability. Tumbling results in a decrease of penetration.

Figure 4 shows an example of penetration of snow by stable and unstable projectiles. The bottom curve (76 m/sec) represents a projectile which traveled through the snow without any tumbling whatsoever. By dissecting the target, the projectile recovery point was established (solid square). The third curve from the bottom (305 m/sec) was like the previous one. Dissecting the target of the second curve from the bottom (138 m/sec) it was found that the projectile tumbled and its trajectory shortened. Since the curve is bracketed by the other two, it might be surmised that without tumbling it would lie somewhere between the first and third curves (solid triangle). The upper curve displays a noticeable break in velocity loss rate. Again, dissection and recovery of the projectile indicated tumbling.

Observations revealed two simple modes of projectile tumbling: rotation of the projectile around the short axis perpendicular to the trajectory and rotation around the short axis parallel to the trajectory. Both types of instability apparently result from inhomogeneity in snow, take place a certain distance after penetration, and result in shortening of the total travel through the snow.

To discover whether or not the apparent shortening of the trajectory such as the fourth curve in Figure 4 shows was due to tumbling, a series of shots were made using an 8.3-g steel sphere fired from a smoothbore barrel.

It was found that non-spinning spheres also have an intrinsic instability but it is dissimilar to the direct tumbling of spin-stabilized projectiles. A sphere traveling at high speed through snow accumulates by compaction an ogive-shaped densified body of about 0.8 g/cm^3 density, very close

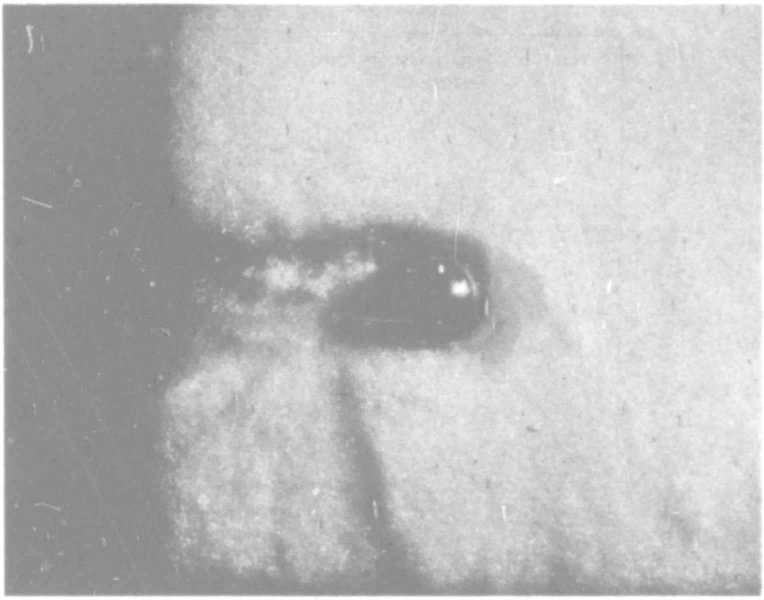

Figure 5. Terminal position of spherical projectile in snow (part of a target). In front of the projectile is an ogive-shaped compacted mass approximately one-half the thickness of the projectile.

to that of ice. The streamlined ice ogive is itself unstable and slips off, thus deflecting the trajectory by one or two degrees. Dissecting the projectile canal revealed that such ogives formed every 10 to 15 cm. Since the type of instability thus imposed is not accompanied by such drastic changes of resistance and mode of travel as is the case with spin-stabilized projectiles, all time-distance records for spheres were similar to those in Figure 4 (curves 1 and 3 from bottom).

By dissecting a target with a projectile in its terminal position the formation of such ogives could be observed in place (Fig. 5). It appears, then, that instability of a projectile traveling in snow is a systematic phenomenon and is unavoidable with existing types of small arms.

RELATION OF ENERGY TO TOTAL PENETRATION

Since caliber, mass and velocity of the projectile all affected its total penetration into a given type of snow, the comparison was based on kinetic energy normalized against caliber area. Thus:

$$En = \frac{E}{A} = \frac{1}{2}\frac{MV^2}{A} \qquad (6)$$

where

A = caliber area, cm^2

M = mass of projectile, g

V = velocity, cm/sec

En = normalized kinetic energy.

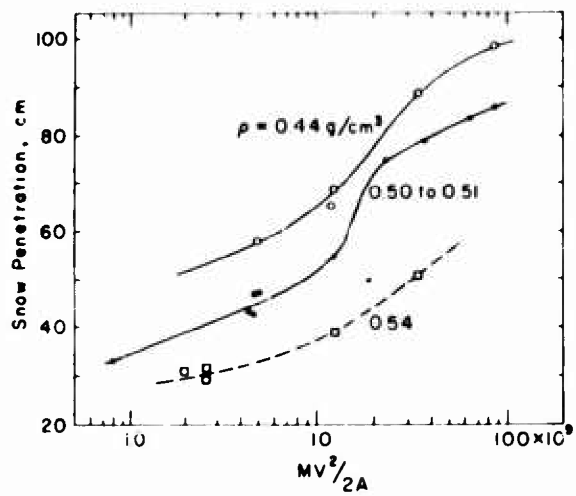

Figure 6. Snow penetration as a function of energy, .30-caliber projectile.

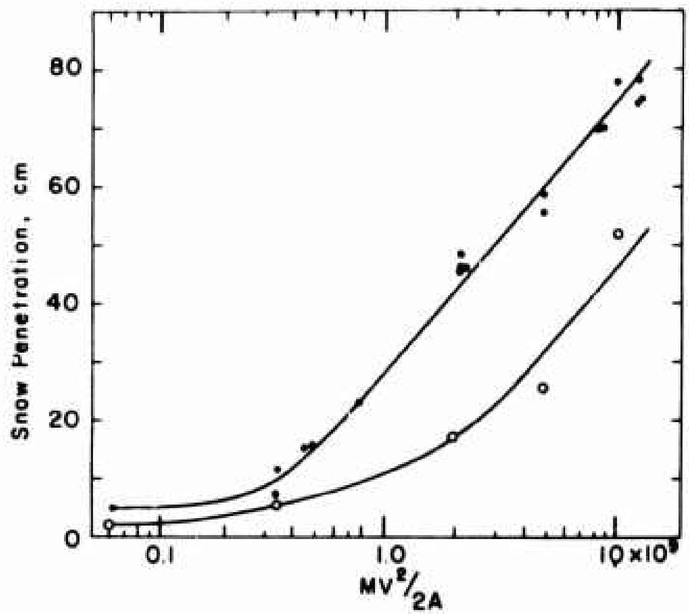

Figure 7. Snow penetration as a function of energy, 8.3 g spherical projectile. Dots: snow density 0.4 g/cm³. Circles: snow density 0.6 g/cm³.

Expression 6 was used to normalize all snow penetration data. The expression, called *energy intensity*, justifies the sectional density principle in ballistics, and has the dimensions of g $\overline{cm}^2$/sec^2 $\overline{cm}^2$, which is kinetic energy per unit area.

Comparing low energy penetration with the performance of a high energy projectile disclosed a decrease in energy effectiveness with increased velocity (Fig. 6). The role of projectile shape is apparent from comparing the performance of ogive-shaped projectiles with that of spheres (Fig. 7). It appears that at low energy (velocity) the spherical shape is a disadvantage, while at high velocities the phenomenon of tumbling becomes a more significant factor affecting total penetration.

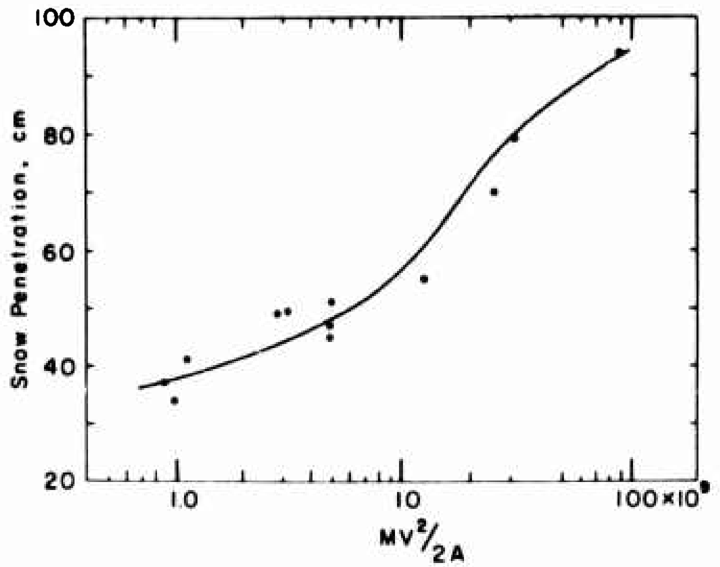

Figure 8. Penetration of sifted and hardened snow by .30-caliber projectile. Snow density 0.52 g/cm^3.

As already mentioned snow hardness and age do not measurably affect penetration. Figure 8 is the result of a series of shots into sifted, reworked snow, hardened at -3°C and used for targets between -5 and -10°C. Comparison with Figure 6 reveals no difference. The results which Figures 3 and 8 summarize were obtained using homogeneous snow targets either selected from natural snowdrifts or prepared artificially by sifting and aging for 24 to 48 hours.

A natural snow cover, especially one developed in the second half of the winter season in moderate to subarctic climates, is often stratified, with varying density and composition. Wind crusts and ice crusts are often found at the surface as well as within the snow mass. For obvious reasons, there was an interest in seeing how far a typical projectile would travel within such a natural snow cover. Figure 9 is a summary of a representative part of the data, collected using targets of undisturbed natural snow. As before, the mass and velocity of the projectile constitute the energy parameter which was plotted against the depth of penetration (distance to projectile recovery point). The data scatter in Figure 9 is explained by density gradation, especially density differences along the projectile path, as well as by the inevitable tumbling. (All density observations were performed by field methods. Similar observations with standard ammunition were made in the field. It appears that penetrations of more than about 140 cm are unlikely to be observed.

The foregoing experiments were conducted at temperatures below freezing. It is known that snow and ice can exist in above-freezing surroundings as a transient phenomenon. Depending upon temperature above freezing and duration, snow under these conditions contains an ever-increasing amount of water until it melts completely. Common descriptive terms for such snow are melting snow, soggy snow and slush. The density of such a "warm" snow begins to increase at a certain stage of melting and it becomes waterlogged.

The results of a few trials disclosed that the attenuation of projectile motion in such snow is unreliable and cannot be predicted with great accuracy. Its density appears to be abnormally high. Table II gives examples of such trials. It must be remembered that the 0.63-g/cm^3 snow was undisturbed, but its density was increased from the original 0.4 g/cm^3 by percolating water. Snow artificially compacted to similar densities and kept at temperatures below freezing presents significantly more penetration resistance (Fig. 6 and 7).

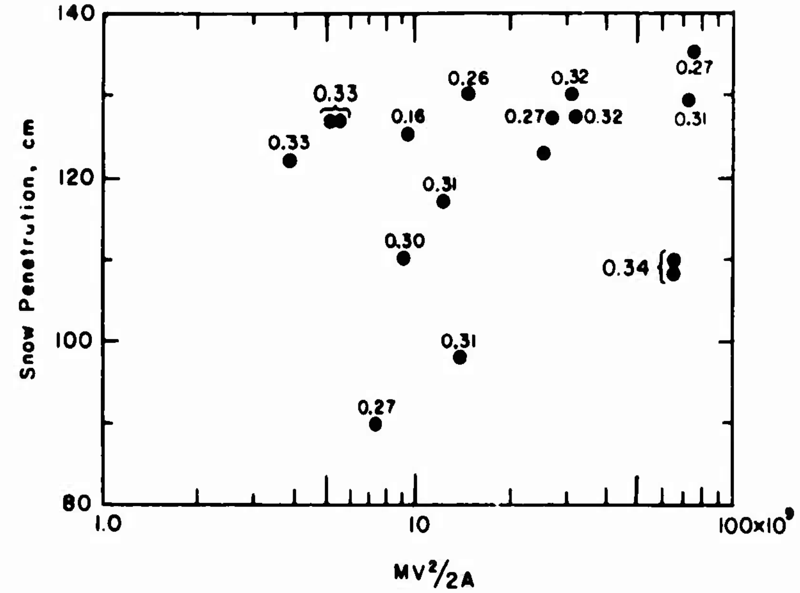

Figure 9. Penetration of natural snow cover by .30-caliber projectile. Numbers beside data points indicate snow densities.

Table II. Attenuation of .30-caliber projectile by melting snow.
All shots at +5°C, snow density 0.63 g/cm³.

Penetration (cm)	*En ($MV^2/2A \times 10^9$)*	*Projectile mass (g)*	*Velocity (10^3 cm/sec)*
71.7	4.38	11.2	19.060
(145)	81.0	10.5	84.700*
71.0	4.96	12.7	19.063

*Projectile not recovered.

SOME INTERPRETATIONS

The preceding experiments demonstrated that snow is indeed suitable for protecting a soldier against small arms fire. The exact mechanism of dissipation of the projectile's energy was not investigated sufficiently and a rigorous theoretical treatment of the subject is still missing. However, it is now clear that trajectory instability plays a role and tumbling is one of the mechanisms by which the projectile loses its lethal energy.

As we see from Figure 9, combat over natural snow cover will require more fire at closer range if the adversary is not exposed in an upright position. It might be assumed that the point was made that snow is a legitimate material for hasty fortifications. Besides its impact attenuation abilities, snow is routinely used to build tank obstacles (M.K. 1938), to provide camouflage and protection (Karatun 1940).

In defensive combat a distinction is made between deliberate and hasty position fortification. While a deliberate fortification may be expected to exist and be functional for more than one season, a snow fortification will in almost any case be considered a hasty fortification. At the proper time and place fortifying a position in snow is advantageous.

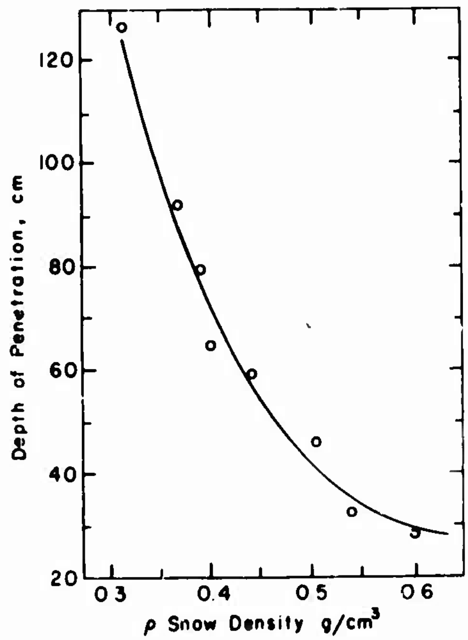

Figure 10. Dependence of snow penetration by .30-caliber projectile upon snow density at impact energy $E_n = 5 \times 10^9$ *g cm²/sec² cm².*

A defense position in snow can be constructed faster and with less effort than a similarly protective position in earth material (Karatun 1940). Any work with naturally deposited snow, milling, shoveling, compacting, etc., results most importantly in its densification and as a secondary useful effect in its hardening (Mellor 1964). It is emphasized that age hardening does not affect projectile attenuation, but is useful in other respects: structures stand up and resist wind and shock loadings; traffic over reworked snow improves. The roof of a well prepared snow shelter (igloo) will support the weight of two men.

Under realistic combat conditions small arms fire engagements often start at distances great enough to reduce the terminal velocity of a projectile to about one-half its muzzle velocity. Maximum penetration of light natural snow under these conditions may still be large (Fig. 10). However, as the data indicate, it also decreases significantly with increased density.

CONCLUDING REMARKS

The research reported here was mainly limited to ordinary spin-stabilized projectiles. For this reason the conclusions given are valid only for this case. Experiments were made with steel spheres to see whether or not trajectory instability plays a substantial role in energy dissipation. It is obvious that there is a vital need to study the motion of a fast, irregular metal fragment in snow as well as the effect of small charges of high explosives upon a surrounding snow mass. In view of the importance of such information it is planned to suggest and perform such a study. Since there have been substantial changes in small arms and anti-personnel ordnance during the last decade (higher terminal velocities, controlled fragmentation ammunition, smaller calibers), a brief updating study may be needed to find the magnitude of the changes, if any, that must be taken into account.

Otherwise, it is in the very nature of snow as a material (Bader 1962) that it provides substantial protection against small arms fire. As in certain foreign countries, our infantry must be trained to trust the snow-covered terrain, and to use its advantages in fortification, sheltering and camouflage (Shamshurov 1969, Chekotillo 1943).

It is important to note that trenches, shelters and combat positions are standard measures in foreign army manuals (ibid), but hard data on the degree of protection have never before been published. Based on our own findings 2 meters of very light natural snow are sufficient to give full protection against small arms fire. Simple compaction, shoveling or other type of reworking doubles the protection rendered.

It may be ventured that with the current trend toward smaller calibers and increased muzzle velocities the total energy of future projectiles will hardly increase. Therefore, our findings are likely to be applicable in the future. Army units trained for cold-weather operations must be able to use snow for hasty fortifications. The type of training given to foreign troops (Fig. 11) is useful. Its advantages must be properly recognized. A brief applied research program on hasty fortification in snow must be conducted in this country.

The data gathered in this investigation are sufficient for the conclusions stated. Additional studies may be made to interpret the material from a theoretical viewpoint. The specific shape of

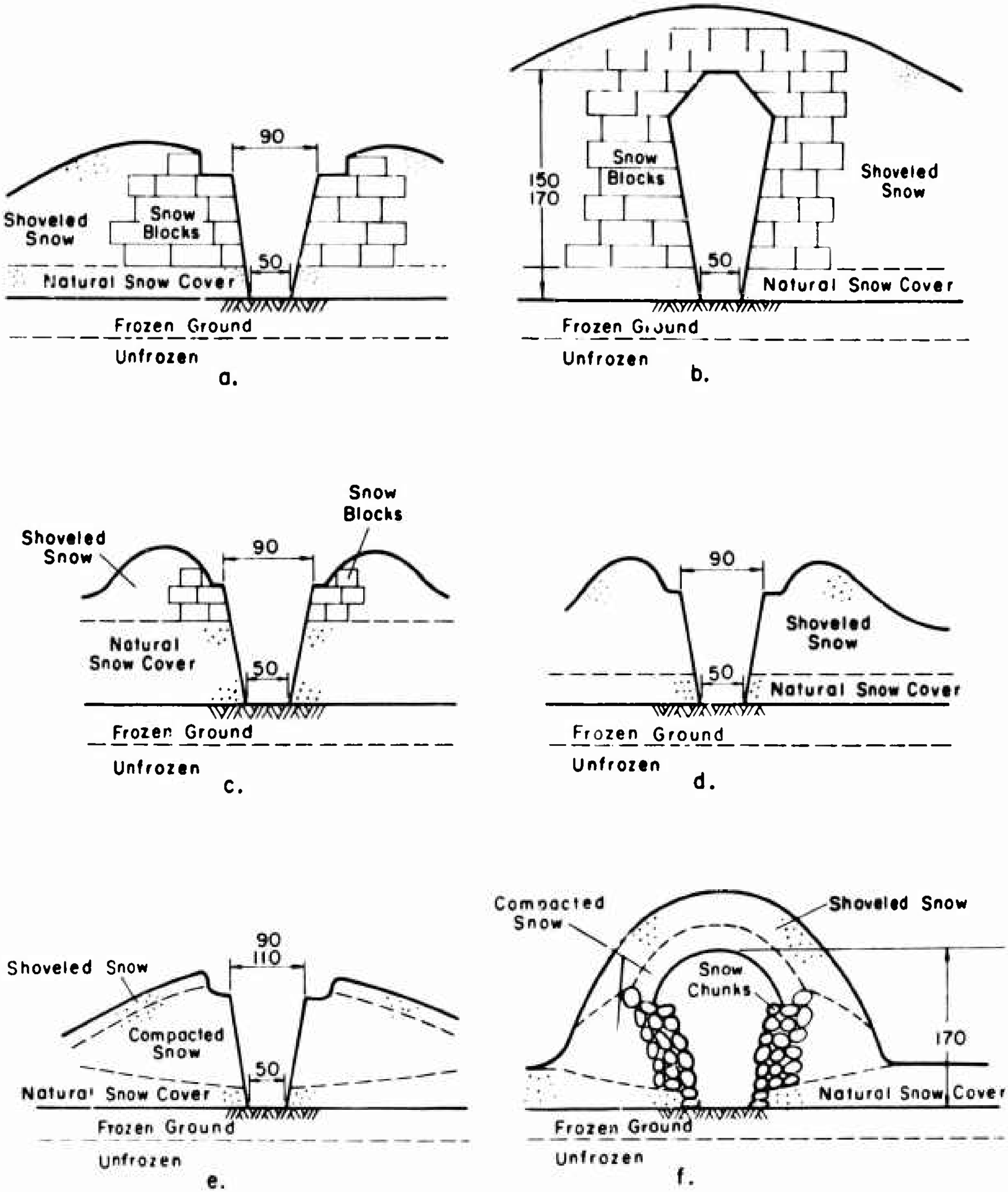

Figure 11. Types of expedient snow combat trenches. Dimension given in centimeters (not to scale). After Shamshurov (1969). a) Uncovered trench in a snowdrift using cut blocks. b) Covered trench in a deep snow drift. c) Hasty trench in medium snow. d) Hasty trench in shallow snow. e) Open trench in compacted, reworked snow. f) Covered trench in compacted snow using snowballs and chunks.

the curves in the adopted semilogarithmic system may need additional scrutiny, which is presently out of context. For the purpose of such a reexamination, data tabulations are given in the Appendix.

It is impossible to claim that the above study is complete. However, its full application is apparent. To complete the study a series of tests with projectiles of a larger caliber variation should be made. Also, the changes of energy of a projectile are brought about by changing masses or velocities. The relative role of these factors needs to be investigated. A fundamental investigation of snow targets would be incomplete without studying the processes taking place during high velocity localized loading of such types of targets. The spin of a rifle projectile introduces an unknown variable into the findings. In future studies it should be eliminated.

It is clear that the above described study has its application in cold and moderate climates and cold seasons. Its ultimate application is in warfare over snow-covered terrain. Disregarding the possibility of annoying the informed reader, we may briefly mention some fundamental sources on the value of snow in terrain modification, its properties and uses, and its treatment in military science.

The formation of snow cover on the surface creates changes in color, reflectivity and heat exchange with the atmosphere, together with effects upon man's activities such as travel, agriculture, etc. Richter (1960) discusses this in great detail in a series of papers. Snow cover, as a global phenomenon, must be regarded within the framework of frequency, duration, depth and physical properties. Bader and Kuroiwa (1962) put together a monograph on snow as a material. Being a material, and often an abundant one, snow may be used for construction purposes (Chekotillo 1945) or as an efficient shelter for man (Rowley 1938). The obstacle it presents to traffic and transportation can be overcome by thoughtful application of special engineering procedures – rigorous procedures for expedient winter roads constructed in places where summer traffic is impossible. Voitkovskii (1954) presents an overview of snow and ice construction in general and based on theory gives engineering procedures applicable for erecting permanent and temporary structures. Snow is, he concludes, a usable material. Further information on snow can be found by consulting the USA CRREL Bibliography on Cold Regions Science and Technology which is yearly updated and is one of the most comprehensive sources on the subject.

A significant part of the earth's surface may be covered by snow for periods ranging from a sporadic appearance to permanency. As it happens, 12% of dry land does have permanent ice caps and glaciers with snow on top. Generally thickness and duration of a seasonal snow cover increase with latitude, with the exception that the high arctic has less snow than subarctic regions in the Northern Hemisphere. It is clear that areas such as the southern part of North America or northern Africa experience sporadic occurrence of snow and one cannot visualize a predictable reoccurrence of snow cover. Sources of information on reoccurrence, thickness and duration of snow cover appear to be less available than one might assume. The Arctic Construction and Frost Effects Laboratory (New England Division, Corps of Engineers) produced in 1954 a compilation entitled *Depth of Snow Cover in the Northern Hemisphere*. The work gives all data available at the time, covering the North American continent together with a large part of Eurasia. Paradoxically, there is no single source of reference giving frequency, thickness and duration of snow cover over the world. The data are dispersed in regional meteorological reports. However, more than one-half of the North American continent and Eurasia have 100 or more days with freezing temperatures in a year and at least most of that time are under a snow cover.

Military doctrine may accept the phenomenon of snow cover as an obstacle or asset but must treat it as a phenomenon that recurs in time and space. The space considerations are purely geographical, e.g. in certain climates the formation of snow cover is unlikely. The time considerations are equally clear: in certain seasons snow cover is unlikely to develop over most of the earth's surface. A military power planning to operate over terrain with a heavy seasonal snow cover may be reluctant to assure preparedness for winter warfare, because of convenience, ignorance, reluctance to perform exhaustive training, etc. If such a power is aggressive, its only course of action would be to plan the beginning and end of the operation for the snow-free season. Clearly, the proper response for the attacked side is to delay decisive action until the adversary finds himself operating at a time and over a terrain he is not prepared for.

The above refers to the well known "Plan Barbarossa," the German attack of Russia in the summer of 1941. (For a detailed account of the German planning stage, refer to DA Pamphlet #20-261a.) That operational data on snow cover are vitally important is evident from a series of crash compilations produced for the German army after delays produced their effects (see Reichsamt etc. 1942).

The negative example given is an exception and presently all governments with armies in temperate and cold regions have cognizance of warfare (Degtiariev 1961) and operations in cold weather and climate. Winter warfare and operations, construction of snow airfields (Komarov 1942), antitank barriers (M.K. 1938) and fortifications (Karatun 1940) are studied and thought about in many armies. The quoted literature was selected for originality. It was found that the most prolific military literature on cold regions is Russian. As mentioned, generally most of the involved countries are instructing their soldiers to use snow as a shelter, and as an expedient individual fortification material. That snow attenuates projectile fragments and explosions is known.

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APPENDIX

The effects of fragmentation and anti-personnel fire are greatly attenuated by a snow cover (Swinzow 1970). Therefore preparation of firing positions during a defensive phase of combat is expedient in snow.

Countries in cold and polar climates provide their troops with knowledge of snow fortification (Chekotillo 1943). The art of fortifying snow-covered terrain is highly developed and standardized (Shamshurov 1969, Degtiariev 1961). An example of the instructive material developed is shown in Figure 11. As the quoted authors state, structures of this type are significantly more expedient than those providing similar protection but excavated in ground. An important point is the seasonality of a defensive structure. Almost everywhere, a snow shelter or fortified position loses its usefulness at the onset of the warm season. But a trench in the ground, excavated in winter, will also need maintenance at the beginning of the warm season, and this effort may exceed that of the original construction. This leads into the realm of deliberate fortifications in cold regions, which is an important subject but outside the scope of the present study.

Table AI. Penetration tests of various types on natural snow.

Penetration (cm)	$\frac{1}{2}(MV^2/A) \times 10^{6}$*	Mass of projectile (g)	Terminal velocity (cm/sec)	Snow density (g/cm³)
127	5.56	12.5	20333	0.33
122	3.88	11.2	17950	0.33
127	5.16	11.2	20700	0.33
108	65.73	10.5	76300	0.39 crust
110	65.73	10.5	76300	0.39 crust
130	31.20	11.2	50900	0.32
127	31.95	11.2	50883	0.32
117	12.99	11.2	32200	0.31
98	13.85	12.5	32105	0.31
129	72.80	10.5	80300	0.31
110	9.25	11.2	27720	0.30
90	7.77	11.2	25400	0.27
123	26.38	11.2	46800	0.27
127	28.31	11.2	48400	0.27
135	72.80	10.5	80300	0.27
130	15.50	11.2	35580	0.26
125	9.25	11.2	27720	0.16

*Kinetic energy normalized by caliber area. See text.

Table AII. Penetration of 0.4 g/cm^3 snow by 8.3-g steel spheres.

Penetration (cm)	$MV^2/A \times 10^9$	Terminal velocity (cm/sec)
74.2	12.28	61000
54.7	4.74	38125
45.7	2.13	25416
48.2	2.13	25417
45.7	2.13	25417
77.8	12.28	61000
74.2	12.28	61000
11.6	0.34	10167
15.2	0.45	11731
15.2	0.49	12200
22.8	0.77	15250
5.1	0.063	4357
69.9	8.51	50833
77.8	10.13	55455
58.5	4.79	38125
5.1	0.063	4360
7.6	0.33	10160
15.2	0.49	12200
45.7	2.12	25400
58.4	4.78	38100
69.9	8.49	50800
22.8	0.77	15250

Table AIII. Penetration of 0.6 g/cm^3 snow by 8.3-g steel spheres.

Penetration (cm)	$\frac{1}{2}(MV^2/A) \times 10^9$	Terminal velocity (cm/sec)
16.5	1.96	24400
(2)	0.06	4357 Entered surface
25.4	4.79	38125
5.8	0.34	10167
51.8	10.12	55425

Table AIV. Penetration of 0.52 g/cm^3 sifted and aged snow by various .30-caliber projectiles.

Penetration (cm)	$\frac{1}{2}(MV^2/A) \times 10^9$	Projectile mass (g)	Terminal velocity (cm/sec)
55	12.50	12.5	30500
69	25.52	12.5	43571
47	4.87	12.5	19043
51	4.88	12.5	19063
45	4.88	12.5	19063
34	0.98	12.7	8472
37	0.88	12.7	8026
41	1.10	12.7	8971
79	31.08	11.2	50800
48	2.80	11.2	15240
48	3.13	12.5	15250
94	85.85	10.5	87200

Table AV. Penetration of various types of snow by .30-caliber projectiles.

Penetration (cm)	$\frac{1}{2}(MV^2/A) \times 10^9$	Projectile mass (g)	Terminal velocity (cm/sec)
		Density 0.50 g/cm^3 sifted	
86	85.74	10.5	87143
47	4.98	11.2	20333
		Density 0.51 g/cm^3 sifted	
33	0.80	12.7	7650
93	4.38	11.2	19070
47	4.96	11.2	20300
55	12.50	12.5	30500
79	36.96	11.2	55900
84	65.56	10.5	76200
43	4.38	11.2	19070
75	22.89	11.2	43600
86	85.84	10.5	87200
75	25.52	12.5	43571

Table AVI. Penetration of various types of snow by .30-caliber projectiles.

Penetration (cm)	$\frac{1}{2}(MV^2/A) \times 10^9$	Projectile mass (g)	Terminal velocity (cm/sec)
		Density 0.54 g/cm^3	
51	34.69	12.5	50800
39	12.50	12.5	30500
31	1.99	12.5	12180
29	2.58	12.5	13869
32	2.58	12.5	13869
		Density 0.44 g/cm^3	
69	12.50	12.5	30500
89	34.73	12.5	50883
99	85.74	10.5	87192
66	12.44	12.5	30480
58	4.97	11.2	20330

Table AVII. Penetration of various types of snow by .30-caliber projectiles.

Penetration (cm)	*$\frac{1}{2}(MV^2/A) \times 10^9$*	*Projectile mass (g)*	*Terminal velocity (cm/sec)*
Density 0.37 g/cm^3, light soft snow			
95.0	4.66	11.2	19680
92.0	9.66	11.2	19680
92.0	5.16	11.2	20700
91.0	5.20	12.5	16677
91.0	5.56	12.5	20333
95.0	4.88	12.5	19063
Density 0.39 g/cm^3			
82.6	4.96	12.7	19062
72.4	4.40	12.7	17991
72.4	3.88	11.2	17950
82.6	3.88	11.2	19060