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Physics and Calculus of Countercity and Counterforce Nuclear Attacks

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The performance characteristics of nuclear warheads and the ballistic missiles that transport them to their targets are rarely discussed in any detail in public. This is often attributed either to the secrecy that of necessity surrounds these weapons, or to the technical complexity of the subject. There is, however, enough relatively straightforward and publicly available information to be used as a basis for a public debate concerning nuclear weapons. Simple concepts like the numbers and sizes of the missiles various countries possess do appear in public statements of defense officials, but such intangible yet important parameters as accuracy or reliability are rarely mentioned. These performance parameters are more important in a debate of nuclear strategy than the numbers of launchers or their sizes.

The debate in Congress, the academic community, and the press has contained very little analysis of the performance parameters of existing and proposed weapons. This ignores the fact that the new strategy of counterforce advocated by Schlesinger (*1*) is based on a set of nuclear weapons properties that are different from the properties of the countercity (countervalue) weapons that implement the strategy of deterrence. Arguments and counterarguments concerning the future capabilities of U.S. and Soviet strategic arsenals are based on the aggregate number and physical size of weapons, parameters that may be relevant in a comparison of deterrent value, but have limited relevance in an analysis of counterforce capabilities. As a result, the entire public debate on future U.S. nuclear policy is based on physical properties and performance parameters of nuclear missiles that are largely orthogonal to the task of destroying missiles in their silos. Thus, there is a very good chance that the conclusions of the public debate will be at best irrelevant and at worst erroneous and misleading.

This article is a discussion of the physical properties of nuclear weapons that are revelant in countervalue and counterforce strategies and the mathematical tools necessary for an evaluation of the performance of present and proposed weapons (*2*). Its intention is to introduce a new analytical tool and not to advocate in favor of either a counterforce or a countervalue strategy.

Physics of Countervalue and Counterforce Attacks

A land-based intercontinental ballistic missile (ICBM) consists of a rocket divided in several stages, propelled by a solid fuel, and guided by an inertial guidance system (*3*). It carries either a single reentry vehicle containing the nuclear explosive or multiple independently targeted reentry vehicles (MIRV's), each carrying a nuclear warhead. Each such warhead may weigh as little as a few tens of kilograms, since the nuclear charge itself may weigh as little as 10 to 20 kilograms.

Although the same nuclear warhead can be used against a city or industrial complex (countervalue attack) or against a reinforced concrete silo housing a missile (counterforce attack), the performance characteristics of the warhead and the missile that are relevant to each type of attack are very different.

The destructive effect of nuclear weapons arises from the almost instantaneous release of enormous amounts of energy at the point of explosion. The detonation of a 1-megaton warhead generates energy equivalent to that released by the explosion of 1 million tons of TNT, that is, about 10^{15} calories. This energy is released within a few nanoseconds (10^{-9} second), causing in the immediate vicinity of the explosion temperatures of millions of degrees centigrade. This rapid heating causes sudden expansion of the air around the point of explosion, which in turn gives rise to a shock wave in which pressures reach 10^5 pounds per square inch (psi) (about 7000 atmospheres) and then decay rapidly in time as the shock wave propagates outward from the point of explosion.

An overpressure of only 20 psi will usually kill an unprotected human being, while one of 5 psi will demolish an ordinary brick house. Since overpressure is proportional to the energy released by a nuclear charge and inversely proportional to the cube of the distance from the point of explosion, the larger the energy yield of the weapon the further from its point of impact will be the perimeter of total destruction. A 1-megaton nuclear weapon, for example, will cause a 5-psi overpressure about 4 kilometers from the point of explosion, and will thus destroy all houses in an area of 50 square kilometers around its point of impact. Therefore a missile aimed against a city does not have to be very accurate, since the destruction of property and life caused by the weapon will be immense no matter where in the city it lands.

Although blast effects of a nuclear detonation can prove fatal to people, by far the most lethal effect of a nuclear weapon is the thermal radiation it releases. The fireball created by a

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Table 1. Countersilo kill capacity (*KN*) values of currently deployed U.S. and Soviet missiles. Abbreviations: *Y*, yield; *CEP*, circular error probable; *K*, lethality; *n*, reentry vehicles per missile; *m*, number of missiles; and $N = mn$.

Missile	*Y* (megatons)	*CEP* (nautical miles)	*K*	*n*	*m*	*KN*
		United States				
MM III	0.160	0.2	5	3	550	8,250
MM II	1	0.3	11	1	450	4,950
Titan	5	0.5	12	1	54	648
Poseidon	0.05	0.3	1.5	10	496	7,440
Polaris	0.200	0.5	1	3	160	480
Totals					1,710	21,768
		Soviet Union				
SS-9	20	*1	7	1	288	2,016
S-11, 13	1	*1	1	1	970	970
SS-N-6	1	*1–2	1	1	528	528
SS-N-8	1	*1–2	1	1	80	80
SS-7, 8	5	*1.5	1.3	1	209	270
Totals					2,075	3,864

* Estimate.

nuclear blast attains temperatures of tens of millions of degrees and therefore radiates very much like the sun. So nuclear weapons, unlike conventional weapons, destroy both structures and human beings by direct thermal effects and by the fires and fire storms induced by the heat released in the explosion. Both the direct and induced thermal effects, whose magnitudes are proportional to the size of the warhead, extend to great distances from the point of its explosion: the heat released by a 1-megaton nuclear explosion, for example, will cause paper to ignite 14 km away from its center. As an example of the lethality of these thermal effects, about 50 percent of the fatalities caused by the Hiroshima bomb, whose yield was about 15 kilotons, were due to the primary or induced thermal effects, 30 percent to nuclear radiation, and 20 percent to blast. The thermal radiation effects of a nuclear explosion, like the blast effects, spread over very large areas Consequently, a nuclear weapon can cause extensive damage to a city by fire even if it is not delivered accurately against it.

An attack against urban or industrial centers, therefore, requires the delivery of large amounts of thermal energy and the creation of modest overpressures (5 to 10 psi) over very large areas. This can be achieved either by delivering a high-yield nuclear weapon somewhere in the area of the target or, more efficiently, by scattering several small weapons even at random over the area. These are the performance requirements of a countervalue nuclear weapons system.

The performance requirements of a weapon destined for counterforce use, that is to destroy a missile inside a reinforced concrete silo, are quite different. Since a silo is designed to withstand overpressures of hundreds of pounds per square inch and is immune to thermal effects, it will remain intact unless the weapon lands in its immediate vicinity. The weapon must therefore generate large overpressures very near essentially a point target, since overpressure decreases rapidly with distance from the point of impact. Consequently, the ability of a warhead to destroy a silo depends strongly on the accuracy with which it is delivered to its target. The lethality of a warhead against a silo rises much more rapidly with improvements in accuracy of delivery than with yield. For example, a weapon with ten times the yield of a Minuteman III (MM III) warhead but with the same accuracy is only four times more effective in destroying a silo; but a weapon that has the same yield as a MM III but is ten times more accurate is 100 times more lethal to a silo. So it is the accuracy of the reentry vehicle that delivers the warhead on target which is relevant in a counterforce nuclear arsenal and not the size of the

Table 2. Numbers of missiles and reentry vehicles and total *KN* values for the United States and the Soviet Union for 1961 to 1975 and 1964 to 1974, respectively.

Missiles, reentry vehicles, and *KN* values	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
							United States								
Missiles															
MM I	60	240	370	780	800	800	800	750	650	550	490	400	300	140	0
MM II	0	0	0	0	0	50	200	250	350	450	500	500	500	500	450
MM III	0	0	0	0	0	0	0	0	0	0	10	100	200	360	550
A_1 (Polaris)	80	80	80	80											
A_2 (Polaris)	16	64	176	208	208	208	208	208	208	208	160	128	64		
A_3 (Polaris)				176	336	448	448	448	448	448	432	368	272	240	160
B_3 (Poseidon)											64	160	320	416	496
Titan			54	54	54	54	54	54	54	54	54	54	54	54	54
Total missiles	156	388	680	1,298	1,398	1,544	1,710	1,710	1,710	1,710	1,710	1,710	1,710	1,710	1,710
Reentry vehicles	156	388	680	1,298	1,398	1,544	1,710	1,710	1,710	1,710	2,300	3,250	4,990	6,154	7,594
KN	150	398	1,346	2,332	2,768	3,550	4,200	5,700	6,700	7,700	9,172	11,654	15,128	18,648	21,768
							Soviet Union								
Missiles															
SS-7, 8				200	220	220	220	220	220	220	220	210	209	209	
SS-9					42	108	162	192	228	288	288	283	288	288	
SS-11						31	340	500	730	960	960	970	970	970	
SS-13									30	40	60	60	30		
SS-N-6								32	96	224	336	432	528	528	
SS-N-8												12	36	80	
Total missiles				200	262	359	722	942	1,304	1,732	1,864	1,972	2,061	2,075	
Reentry vehicles				200	262	359	722	942	1,304	1,732	1,864	1,972	2,061	2,075	
KN				286	580	1,073	1,760	2,162	2,738	3,526	3,638	3,746	3,852	3,864	

missile that boosts it into its ballistic trajectory.

Another phenomenon associated with counterforce weapons is the so-called electromagnetic pulse (EMP). A nuclear explosion ionizes the atoms of the atmosphere in its immediate vicinity, giving rise to space distributions of negative and positive charges. These distributions are not symmetrical in space and therefore create oscillating electric and magnetic fields near the point of detonation that can reach strengths of tens of kilovolts per meter and several hundred gauss, respectively. Such fields can penetrate an electrically unshielded silo and destroy the complex and delicate electronic equipment of a missile and its launching facilities, even if the silo has withstood the mechanical loading due to the overpressure created by the blast.

The EMP, the violent movement of the air near the explosion, the large amounts of debris that rise rapidly into the upper atmosphere after the explosion, and the persistently high level of radioactivity emanating from the expanding fireball combine to create another effect, known as interference, screening, or fratricide (the latter term coined by the Pentagon). Interference refers to the fact that the results of a nuclear explosion near the ground make it difficult, if not impossible, to deliver a second reentry vehicle to the same point soon after the first one has arrived and detonated, and therefore constitutes a limitation of counterforce use of nuclear weapons. As the second reentry vehicle enters the atmosphere near the point where the first exploded, it encounters high densities of dust that can cause its ablative shield to burn prematurely, or it can be deflected off target by the violent winds that persist in the area for considerable lengths of time, or if it arrives a few seconds after the first weapon, it can even be destroyed by the EMP or the nuclear radiation emanating from the rising fireball of that weapon. Thus, the interference effect does not physically forbid the use of several reentry vehicles against the same silo, but renders such a targeting schedule inefficient and uncertain. An attacker can, of course, attempt to avoid the interference effect by timing the arrival of reentry vehicles so that the first will not affect the second, and so on.

Some of the physical effects of a nuclear explosion that interfere with the arrival of reentry vehicles in rapid succession at a missile silo also interfere with the launching of the missile housed in the silo. This so-called pin-down effect moderates the limitations that the interference effect imposes on a counterforce attack, since it does not allow the missile in the silo to be launched during almost the same period of time when the interference effect does not allow the next reentry vehicle to arrive accurately at the silo. Also, the pin-down effect, in conjunction with possible damage to the missile caused by the EMP, can facilitate the use of bombers against silos. Bombers can penetrate into the vicinity of the silos and launch standoff missiles armed with nuclear weapons with an accuracy of a few tens of meters while the missiles in the silos are kept pinned down by the carefully timed arrival and detonation of reentry vehicles overhead.

Because of the uncertainties which these two effects and their interaction create about the efficacy of a multiwarhead attack against a silo, a missile force cannot be considered to have unmistakable countersilo capabilities unless it includes weapons with a high enough yield and accuracy to destroy a silo with a single reentry vehicle. Even if a "MIRVed" missile has this capability in principle, it is doubtful that it has it in fact. A prudent strategist would not use such a weapon in a first strike against the opponent's silos: the interference effect makes doubtful the efficacy of all but the first reentry vehicle that reaches the silo; its effects would probably destroy or divert all subsequent incoming warheads. Therefore, if a country does not possess missiles accurate enough to destroy a silo with a single warhead, the interference effect must always be considered in calculating its ability to launch a successful countersilo attack.

Table 3. Total *KS* needed to destroy all U.S. or Soviet silos with $P_k = .97$ and .90. Abbreviations: *H*, hardness; *S*, number of silos; and *K*, lethality.

H (psi)	*S*	*K* per silo $P = .97$	*K* per silo $P = .90$	Total *KS* $P = .97$	Total *KS* $P = .90$
		U.S. silos			
1000	550	108	71	59,400	39,050
300	450	45	30	20,250	13,500
300	54	45	30	2,430	1,620
Totals				82,080	54,170
		Soviet silos			
100	1,100	20	13	22,000	14,300
300	400	45	30	18,000	12,000
Totals				40,000	26,300

Calculus of Destruction

A nuclear warhead with an explosive yield equivalent to Y megatons of TNT will create an overpressure of Δp pounds per square inch R kilofeet away from the point of detonation (1 kilofoot $\approx$ 300 km) according to the formula (*4*)

$$\Delta p = 3.3 \times 10^3 \frac{Y}{R^3} + 192\left(\frac{Y}{R^3}\right)^{1/2} \quad (1)$$

Converting from kilofeet to nautical miles, a unit of distance conventionally used in discussions of nuclear weapons performance, and using r for distance in nautical miles, we have

$$\frac{\Delta p}{12.8} = 1.15 \frac{Y}{r^3} + \left(\frac{Y}{r^3}\right)^{1/2} \quad (2)$$

which is solved for $(Y/r^3)^{1/2}$

$$\left(\frac{Y}{r^3}\right)^{1/2} = \frac{-1 \pm (1 + 0.36\Delta p)^{1/2}}{2.3} \quad (3)$$

For values of interest, $\Delta p \geq 300$, omitting the 1 under the square root for simplification introduces an error of less than 1 percent, so

$$\left(\frac{Y}{r^3}\right)^{1/2} = -0.435 \pm 0.26(\Delta p)^{1/2} \quad (4)$$

Squaring both sides gives

$$\frac{Y}{r^3} = 0.19 - 0.23(\Delta p)^{1/2} + 0.068\Delta p \quad (5)$$

where the positive solution of Eq. 4 is retained because the negative one is aphysical and was introduced artificially.

From Eq. 5 we can derive an expression for r in terms of Y and Δp

$$r^3 = \frac{Y}{\Delta p\,[0.19(\Delta p)^{-1} - 0.23(\Delta p)^{-1/2} + 0.068]} = \frac{Y}{\Delta p[f(\Delta p)]} \quad (6)$$

where $f(\Delta p)$ is the correction factor $0.19(\Delta p)^{-1} - 0.23(\Delta p)^{-1/2} + 0.068$. From Eq. 6 we have

$$r = \frac{Y^{1/3}}{\Delta p^{1/3}[f(\Delta p)]^{1/3}} \quad (7)$$

The hardness H of a missile silo, measured in pounds per square inch, expresses the upper limit of overpressure that the silo is able to withstand without being damaged. Therefore, if a nuclear warhead explodes at a distance r_s from the silo such that it creates an overpressure $\Delta p \leq H$ at the silo, the silo is expected to survive; but if it explodes nearer to the silo than r_s such that it creates an overpressure $\Delta p > H$, then the silo will be destroyed. The probability that a silo will survive a reentry vehicle launched against it with a given accuracy, which is expressed as a circular error probable (CEP) and measured in nautical miles, is

$$P_s = \exp[-\tfrac{1}{2}(r_s/CEP)^2] \quad (8)$$

where it is assumed that the precision of the reentry vehicle follows a normal distribution. Since the silo will either survive or be destroyed, the probability that the reentry vehicle will explode close enough to the silo to destroy it is

$$P_k = 1 - P_s = 1 - \exp[-\tfrac{1}{2}(r_s/CEP)^2] \quad (9)$$

The value of r_s can be found by substituting H for Δp in Eq. 7

$$r_s = \frac{Y^{1/3}}{H^{1/3}[f(H)]^{1/3}} \quad (10)$$

Substituting Eq. 10 into Eq. 9 we have

$$P_k = 1 - \exp\left\{\frac{-\tfrac{1}{2}Y^{2/3}}{H^{2/3}(CEP)^2[f(H)]^{2/3}}\right\} \quad (11)$$

If n reentry vehicles, each with probability P_k of destroying a silo once it arrives at its target and probability $P_s = 1 - P_k$ of not destroying it, are launched against the same silo, and if all reentry vehicles have the same probability of destruction (an assumption that is sometimes contradicted by the interference effect), then the probability of missing the silo altogether is $(P_s)^n$ and the probability of hitting it at least once with these n warheads and therefore destroying it is

$$P_k(n) = 1 - (P_s)^n \quad (12a)$$

$$= 1 - \exp\left\{\frac{-\tfrac{1}{2}Y^{2/3}\,n}{H^{2/3}(CEP)^2[f(H)]^{2/3}}\right\} \quad (12b)$$

Three of the four quantities involved in the expression for the kill probability in Eq. 12b—yield (Y), accuracy (CEP), and number of warheads (n)—refer to physical or performance characteristics of the missile and its warheads, while one—hardness (H)—refers to a physical property of the silo under attack. From Eq. 12b a new parameter, K, the lethality of a reentry vehicle to a silo, can be defined

$$K = \frac{Y^{2/3}}{(CEP)^2} \quad (13)$$

The better the accuracy (that is, the smaller the CEP) the larger K will be, and therefore also the probability that the warhead can destroy the silo. As seen in Eq. 13, K increases much more rapidly with improvement in accuracy than with improvement in yield. If a missile carries n warheads, each of lethality K, then Kn is the missile's cumulative destructive power against a silo. If a country possesses m such missiles, the product $Knm = KN$ is a direct measure of its ability to destroy its opponent's missiles in their silos, a measure which allows a quantitative analysis of the counterforce capabilities of a nuclear arsenal, and which is therefore more meaningful than size or total number of missiles.

To derive an expression for the Kn value necessary to destroy a silo of a particular hardness with a desired probability, we substitute Eq. 13 into Eq. 12b

$$P_k(n) = 1 - \exp\left\{-\frac{Kn}{2H^{2/3}[f(H)]^{2/3}}\right\} \quad (14)$$

and take the natural logarithm of both sides

$$\ln[1 - P_k(n)] = -Kn/2H^{2/3}[f(H)]^{2/3} \quad (15)$$

Since $\ln(1 - P_k)$ is always negative or zero, the absolute value of $\ln[1 - P_k(n)]$ can be used and the minus sign on the right hand side of Eq. 15 eliminated, so

$$Kn = 2H^{2/3}[f(H)]^{2/3}|\ln[1 - P_k(n)]| \quad (16)$$

For $n = 1$ Eq. 16 gives the degree of lethality of a warhead against a silo of a particular hardness. For example, to destroy a 300-psi silo with 97 percent probability, one needs a warhead with

$$K = 2 \times (300)^{2/3} \times 0.144 \times |\ln(1 - 0.97)| \simeq 45 \quad (17)$$

where the correction factor has been calculated from $f(H) = 0.19H^{-1} - 0.23H^{-1/2} + 0.068$ (5). To do the same with a 90 percent probability the K value needed is 30. For a silo with $H = 1000$ psi the K values necessary to destroy it with the same probabilities are 108 and 71, respectively.

So far it has been assumed that once a missile is launched it will perform exactly as designed. This is not always true. Missiles can, and do, malfunction either at launch or during flight. The degree to which they perform as expected is expressed by a figure of merit ρ, which describes the reliability of a weapon. For example, if a certain type of missile is said to have a reliability $\rho = 0.7$, it means that on the average for every ten such missiles launched, seven will arrive on target as expected, and the other three will not because of some malfunction.

In calculating the probability P_k that a single warhead will destroy a silo against which it has been launched, the reliability of the missile that carries the warhead must therefore be taken into account. This is achieved by multiplying P_k by ρ.

$$P_k(\rho,1) = \rho P_k(1) \quad (18)$$

Then if n warheads, each carried by a missile of reliability ρ, are aimed at the same silo, the probability that the silo will survive is $(1 - P_k\rho)^n$

$$P_k(\rho,n) = 1 - [1 - \rho P_k(1)]^n \quad (19)$$

or

$$P_k(\rho,n) = 1 - \left[1 - \rho\left(1 - \exp\left\{-\frac{K}{2H^{2/3}[f(H)]^{2/3}}\right\}\right)\right]^n \quad (20)$$

For $n = 1$ Eq. 20 reduces to Eq. 18, and for $\rho = 1$ it reduces to Eq. 14. If n warheads aimed at a silo are carried by the same missile of reliability ρ, the kill probability P_k becomes

$$P_k(\rho,n) = 1 - \exp\left\{-\frac{Kn\rho}{2H^{2/3}[f(H)]^{2/3}}\right\} \quad (21)$$

These formulas indicate that the throw weight and absolute numbers of missiles, parameters which are used in the current public debate, are not directly related to the efficacy, lethality, or reliability of the missiles or of a nuclear arsenal. By far the most sensitive measure of the performance characteristic of a missile intended for counterforce use are the K value of the warhead, the ρ value of the missile, and the number of reentry vehicles n the missile carries.

Yield, and therefore K, might be thought to be related to the throw weight of a missile, because the larger the missile the heavier the warhead it can carry, and the heavier the warhead the larger its yield will be. This is not the case, however, because recent advances in nuclear technology have permitted the miniaturization of warheads while their yields have increased. While the throw weight of missiles has remained fixed for 10 years, the yields of the warheads they carry have been increased considerably. Since it is warheads that destroy silos, the size of the missile becomes largely irrelevant to any discussion regarding counterforce nuclear strategy.

Similar technological advances have tended to decouple the size of a missile from the number of independently targetable reentry vehicles it can carry. Since it is the reentry vehicle that carries the warhead to a silo, the total number N of reentry vehicles in a nuclear arsenal is more important than the number of missiles. This fact is reflected in Eq. 14, which shows that the kill probability increases with n, the number of reentry vehicles, and not with the number of missiles, a quantity that does not appear at all in the expression for P_k. The countersilo kill capacity (KN) of the U.S. missile force, for example, has risen since 1970–1971, while the number and size of the U.S. missiles has remained fixed. Consequently, comparisons of counterforce capabilities of the U.S. and Soviet strategic missile forces on the basis of numbers of missiles or the total weight they can carry are simplistic and irrelevant since they bear little relation to the actual counterforce performance parameters of a missile force.

Table 4. Number of warheads of various types necessary to destroy a silo with varying probability P_k (assuming $\rho = 1$). For each reentry vehicle the K value is given in parentheses.

P_k	H (psi)	K value needed	Existing missiles			
			MM III ($K = 5$)	Poseidon ($K = 1.5$)	SS-9 ($K = 7$)	SS-11 ($K = 1$)
.99	300	60	12	40	8	60
	500	87	17	58	12	87
	1000	142	28	95	20	142
.97	300	45	9	30	6	45
	500	66	13	44	9	66
	1000	108	22	72	15	108
.95	300	39	8	26	5	39
	500	56	11	37	8	56
	1000	93	19	62	13	93
.90	300	30	6	20	4	30
	500	43	9	29	6	43
	1000	71	14	47	10	71
.75	300	18	4	12	2	18
	500	26	5	17	4	26
	1000	43	9	29	6	43
.50	300	9	2	6	1	9
	500	13	3	9	2	13
	1000	22	4	14	3	22

Conclusions

The physical phenomena and mathematical expressions described in the preceding two sections can now be applied to assess the performance characteristics of the currently deployed strategic forces of the United States and the Soviet Union. Table 1 shows the total KN values for each of the two arsenals; K is calculated in each case by using Eq. 13. The yields and accuracies of the warheads and their missiles are officially classified in both countries, but there was enough information in the open literature to derive the figures listed. Table 2 gives the numbers of missiles and independently targeted reentry vehicles and the total KN values for the two countries as a function of time. It must be noted that bombers are not included in this list.

In calculating the countersilo capabilities of the two forces one must consider that, as a rule, the reliability of missiles is not unity but about 0.8 or 0.9 and that not all the submarine-launched missiles are on station at all times. Furthermore, it is reasonable to assume that each country would withhold a number of its nuclear weapons from a countersilo attack to aim them at the opponent's cities, save them as bargaining power for terminating hostilities, or aim them at a third nuclear power.

With this caveat in mind, one can now use Eq. 16 to calculate the total lethality needed to destroy all the land-based missiles in their silos in each country. Setting $n = 1$ in Eq. 16 one can calculate (as illustrated in Eq. 17) the K value needed to destroy a particular silo with a desired probability. If a country has S such silos the total lethality needed to destroy them is KS. The KS values needed to destroy the U.S. and Soviet silos given in Table 3 were calculated as follows: Table 3 shows that the Soviet Union has about 1500 missile silos with varying values of hardness. Silos built before 1969 to 1970 have an H value of about 100 psi, and those built since then about 300 psi. From Table 3 one can estimate that there are about 1100 100-psi silos and about 400 300-psi silos. The United States has recently upgraded the MM III silos to $H = 1000$ psi; the MM II and Titan silos still have only $H = 300$ psi.

A comparison of the results shown in Tables 1 and 3 indicates that at the present time neither the Soviet Union nor the United States has the capability to destroy, with ballistic missiles alone, the land-based ICBM force of the other country with any reasonable probability. The total KS needed to destroy all the U.S. silos with 97 percent probability is over 82,000, while the total KN that all the Soviet missiles can deliver is about 4,000. Similarly, the total KS needed to destroy the presently deployed Soviet silos with the same probability is 40,000, while all the U.S. missiles carry a KN of about 21,000.

A similar conclusion is drawn by comparing the K values of the individual reentry vehicles available in each arsenal with the K value required to destroy a silo. The most powerful Soviet warhead, carried by the SS-9 missile, has a K value of 7; since a K value of 45 is needed to destroy a 300-psi silo with $P_k = .97$, the 288 SS-9's can destroy only 45 of the 504 U.S. 300-psi silos, or only 19 of the 550 1000-psi silos, even if perfect reliability ($\rho = 1$) is assumed and the interference effect is overlooked.

Even if it is assumed that, despite the restrictions in targeting imposed by the limited footprint of MIRV's (*6*), each of the U.S. reentry vehicles is aimed at one of the Soviet land-based ICBM's, the probability of destroying them all in their silos is 40 percent or less. Table 4 provides a more detailed demonstration of the fact that neither country's arsenal contains weapons that can destroy even a fraction of the land-based missiles of the other country. It is shown in Table 4 that, with existing weapons, the number of reentry vehicles needed to destroy a silo is so large that the interference effect precludes the possibility that these missiles and their warheads can be used successfully in a counterforce role.

References and Notes

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5. For $H = 100$, 300, 500, and 1000 psi, $[f(H)]^{2/3} =$ 0.13, 0.144, 0.15, and 0.154, respectively.
6. Warheads cannot be targeted at any arbitrary distance from each other, and the limit to the distance between any two warheads is approximately 80 km downrange and 50 km laterally. The area so defined is referred to as the footprint of the MIRV.