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LETTERS

Israeli Ballistic Missile Capabilities

The letter by Alexeff and response by Fetter in the January 1991 issue reflect a small but significant educational problem. In discussing nuclear warheads, Alexeff writes of shells "weighing 43 kg", while Fetter uses the kilogram both as a unit of weight and a unit of mass.

Mass and weight are completely different quantities and so they have very different units. Mass is measured in kilograms. Weight is a force and hence should be expressed in newtons. The international documents which are the basis of the SI units go out of their way to be absolutely clear that the kilogram is not a unit of weight (force).

Students have struggled for decades with the problem. "Is the pound a unit of mass or of force?" The confusing answer is that it is both. When pound is the unit of mass, the corresponding force unit is the poundal. When the pound is the unit of force, the corresponding unit of mass is the slug. We don't want this unnecessary confusion to carry over into our usage of the metric system.

Let me request that the editor correct cases of incorrect usage of SI that may appear in manuscripts so that the educational value of our journal is increased.

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A Lunar-Energy SDI Conversion Proposal

My article (January 1991) contains a number of printing errors in its published form. To correct these, replace "a" by "α" in Eq.(2); "S" by "$\equiv$" in Eq.(4); "=" by "+" on the second line below Eq.(8); "v" by "V" and "$v= v_t$" by "$V= V_t$" for the integration limits in Eq.(8); "e" by "e" in Eqs.(2) and (5), and just above Eq.(10); "e_m" by "e_M" on the third line above Eq.(4); "R_m" by "R_M" just above Eq.(4); "v_m" by "v_M" in and just above Eq.(4) and on the third line below Eq.(8); "v^2_m" by "v_M^2" in Eq.(10); and "received" by "receiver" on the fifth line of the last column.

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A Radiation Unit for the Public

The public has an exaggerated fear of even small amounts of ionizing radiation, such as x-rays and radioactivity. The fear of radiation is made worse by not understanding the scientific words used to describe it. This article describes a radiation unit based on natural radiation that is easily understood by the public.

I propose a simple way to explain radiation. The quantity is called *ionizing radiation*, which will often be shortened to *radiation*. The new unit for ionizing radiation is time—"Background Equivalent Radiation Time" (BERT). BERT is the number of days, weeks, months or years that would give an adult the same "effective dose equivalent" from natural or background radiation. In calculating the BERT I suggest using an average background rate of 3 mSv (300 mrem) per year even though the background varies somewhat over the earth. (I thank my colleague Professor H.T. Richards for suggesting the name for the unit.)

In describing radiation to the public BERT would not be mentioned. The amount of ionizing radiation would be expressed simply in terms of days, weeks, or months of natural radiation. For example, compare the information in the following statements: "Your x-ray study gave you about 100 millirems or 1 mSv of effective dose equivalent;" or "Your x-ray study gave you radiation equivalent to about four months of natural radiation."

It is easy to use the new unit. You have to remember that natural radiation to the public is about 300 millirem or 3 mSv per year. Once you know the effective dose equivalent in mSv or mrem you can figure the days, weeks, months or years of natural radiation. For example, the BERT for 1 mrem is roughly one day of natural radiation and the BERT for 1 mSv is about four months. Radiation that strikes only part of the body, such as medical x-rays, is not as hazardous as the same amount of radiation to the whole body. For example, 100 mrem to your lungs is equivalent to only 12 mrem of effective does equivalent to the whole body. Other organs have similar factors to convert the dose equivalent to effective does equivalent.

Typical BERTs of ionizing radiation from medical x-rays with this new unit are: for a dental bitewing, about one week; for a chest x-ray, about ten days; for a mammogram, about three months; and for a barium enema x-ray study, about one year. The values vary greatly from one medical center to another. The BERT for the average amount of radiation to the public each year from diagnostic x-rays is about seven weeks. Of course, some people receive much more than others. The BERT for the average amount of radiation we receive each year from nuclear power plants is less than one day of additional natural radiation even for people who live in the vicinity of a nuclear power plant. The BERT for a trans-Atlantic jet flight is about five days.

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ARTICLES

Stability Through a Comprehensive Ballistic Missile Flight-Test Ban

Robert Sherman

U.S.-Soviet tension has virtually disappeared, and the danger of global nuclear war appears to have gone with it. But leaders and policies can change rapidly. Should psychologically insecure militaristic leaders come to power on either or both sides, they would have at hand the same destabilizing and massively destructive strategic nuclear power as their Cold War predecessors. The risk of nuclear annihilation would return.

How can this be avoided?

Rapid disarmament is not in the cards, due to the extreme difficulty of verifying small numbers (tens) of clandestine strategic nuclear weapons, combined with the political advantage such a force would present against an opponent having no nuclear weapons. Neither is effective strategic defense probable within the next few decades, for reasons familiar to every reader of this journal.

Rapid disarmament is not in the cards.

The only solution is deterrence by threat of retaliation—that is, bilateral dominance of retaliatory capability over first-strike capability. To determine the best means of maximizing deterrence, I suggest a three-step process. The first two steps may seem so conventional and noncontroversial as to be hardly worth stating. But they lead inexorably to a third step which deviates widely from past and present arms control practice.

Identify the assets that deter attack

These are manned bombers on ground alert, ballistic missile submarines on station or in transit, ICBMs in silos, and the command, control, and communication (C^3) needed to make them work. In addition, the Soviet Union already possesses mobile ICBMs, and the United States may acquire these in the future.

Identify the threats that could disable those assets

These are the villains of the piece. The strategic nuclear weapon properties which most directly threaten to enable first strike and undermine deterrence are:

- *Accuracy* to destroy hard silos and hard C^3.
- *Surprise* (less than 7 or 8 minutes' warning) to destroy unlaunched, bombers soft C^3, and mobile ICBMs. Lesser surprise capability (about 15 minutes' warning) can, if combined with accuracy, destroy silo-based ICBMs before they can be launched under attack.
- *Warhead/silo ratio above 2:1* to enable an ICBM counterforce exchange to disarm the victim more than it disarms the aggressor. As a rough approximation, a disarming first strike requires aggressor two warheads (to compensate for inaccuracy and/or unreliability) per enemy silo or other strategic-force high-value target, plus a third warhead for research and/or lower value targets.
- *Strategic anti-submarine capability* to pre-empt against that leg of the victim's triad.
- *Weapon reliability* to give the aggressor confidence in his ability to minimize retaliation. Since the retaliator has an easier mission—his targets are fewer, softer, and not time-urgent—he needs less reliability than the aggressor. Thus, high weapon reliability shifts the balance away from deterrence and toward first-strike aggression.

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All five villains must be on line for a disarming first strike. While elimination of only one of the five would be sufficient to deter rational leadership, national leaders are not always rational leaders. Thus, the larger the number of first-strike ingredients that can be limited, reduced, or eliminated, the lower the probability of strategic nuclear war.

Seek means to control those threats

SALT I and SALT II are useful in other ways, but have negligible impact on any of the five villains. START, as it is presently formulated, does no better. The only villain it even seeks to address is warhead/silo ratio, and it does this in an ineffective way, leaving the probable ratio above 4:1.

A better solution is to move directly into negotiations for START II. This could be done by shuttling down START I, which in any case seems deadlocked over secondary issues, or by opening a START II track while continuing to seek completion of START. The latter course is probably more politically palatable, particularly on the Soviet side. But wat should START II, or any related agreement, consist of?

SALT has negligible impact on any of the villians. START does no better.

We can divide the possibilities into three categories.

Temporary palliatives may be desirable. But it is fair to ask if they are worth the immense time and effort which must go into any ratified arms control agreement.

Paul Nitze argues for abolition of the SS-18 and MX forces. This would remove the most accurate missiles now in existence and would marginally lower the warhead/silo ration. But its benefit would disappear as the accuracy of Minuteman 3, Trident

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1 and 2, SS-19, SS-24, SSN-20, and SSN-23 progressively improved.

Senate Armed Services Committee Sam Nunn recommends abolition of all land-based MIRVs. This is, in essence, the Nitze plan taken a step further. As with the Nitze plan, its excellent near-term benefit would degrade as SLBM accuracy improved. We need more enduring solutions.

Single-benefit permanent solutions are far more beneficial. Military technologies have a way of breaking out in unexpected an destabilizing ways. Any door we can close for good may prevent problems we can't even anticipate at the time; the 1972 ABM Treaty, which closed the door on SDI, is the best example of this. In the unlikely event that a prohibited technology should develop unambiguous and persuasive net stabilizing ramifications, the treaty can always be revisited.

A Comprehensive Test Ban on nuclear test explosions would permanently lower weapon reliability, and is desirable for that reason.

A total MIRV deployment ban, on SLBMs as well as ICBMs, would eliminate the warhead/silo ratio villain—assuming numerical parity.

A flight test ban on depressed trajectory and other short time of flight (STOF) ballistic missiles would permanently eliminate a major component of surprise attack. A flight test ban on anti-satellite weapons would eliminate another component of surprise attack. The former has been proposed by the United States; the latter has been proposed by the Soviet Union. Each side should accept the other's offer, but has not.

Multi-benefit permanent solutions, in which one agreement would cure several problems, would be still better. But there appears to be only one arms control concept that would, at one stroke, attack more than one villain. This is a Comprehensive Ballistic Missile Flight Test Ban (BMFTB).

> *There appears to be only one concept that would attack more than one villian: a Comprehensive Ballistic Missile Flight Test Ban.*

Since new guidance or re-entry technologies could not be certified in the absence of flight testing, the BMFTB would cap accuracy near its present level. By including a STOF flight test ban, the BMFTB would prevent the most dangerous potential increase in the threat of surprise attack. And in the absence of flight testing, missile reliability would progressively decline.

Commonly-raised objections to a BMFTB

Let us now briefly examine two commonly-raised objections to a BMFTB.

Isn't ballistic missile accuracy already so good that there's no stability benefit to be gained form capping it? No, although the benefit is less than it used to be. Against an SS-18 Mod 4 attack, it is possible to get excellent ICBM survivability by modest-cost silo hardening. Against an SS-18 Mod 5 or a Trident 2 attack, survivability by hardening would be considerably more costly; against an MX attack in which the accuracy is comparable to the crater radius, survivability through hardening would be very expensive or impossible. Five years ago, the BMFTB accuracy cap could have stood alone; now it would work significantly better if combined with a low numerical limit or total prohibition on the most accurate existing MIRV ballistic missiles.

A BMFTB combined with the Nitze MX/SS-18 ban or the Nunn MIRV ICBM would be highly synergistic, with the type ban solving the problem of existing missiles and the BMFTB solving the problem of future missiles. If, as seems probable, the Soviets were to insist on a ban or low limit on Trident 2, the U.S. could insist on reciprocal constraints on SSN-20 and SSN-23. The only remaining MIRV missiles—Minuteman 3, Trident 1, SS-17, SS-19, SS-24, and SSN-18—would be well short of silo-killing lethality, and would be unable to get it without further flight testing.

Can't an aggressor deploy and use accuracy upgrades without testing them? Yes, but at the sacrifice of reliability. Net first-strike damage expectancy would be more likely to fall than to rise under such a strategy.

In a world of zero-benefit and single-benefit strategic arms control proposals the triple-benefit BMFTB stands alone. But improvements in ICBM and SLBM accuracy are gradually eroding its potential. And while STOF development does not appear to be under way on either side, there is no guarantee that this will not change. Stability would best be served by a BMFTB sooner rather than later.

REVIEW

Conventional Force Reductions: A Dynamic Assessment, by Joshua M. Epstein.
The Brookings Institution, Washington, D.C., 1990, 275 pages

Physicists were present at the creation of nuclear war, and so it is not surprising that intricate mathematical analysis (based upon real data) had evolved as part of the lore of nuclear warfighting. Critics may doubt the significance of this work should war actually come, but there is no doubt that analysis has played a role in policy studies and, to some extent, in policy. In contrast, conventional warfare antecedes physics, and analysis of conventional warfare is far more rudimentary.

While scientists, at least since Archimedes, have been builders of weapons, the first influential analysis of the prosecution of conventional warfare—more precisely, the prosecution of battle—was that of Frederick William Lanchester, an English engineer who wrote around the time of World War I. Lanchester's equations state that in an exchange of fire between two sides ("red" and "blue"), the rate of loss of reds is proportional to the number of blues, and vice versa:

$$-dR/dt = bB$$

$$-dB/dt = rR$$

Scientists, at least since Archimedes, have been builders of weapons.

The constants r and b represent the effectiveness of the firepower of R and B, respectively. Historically Lanchester's equations express the emergence of weapons accurate enough so that each soldier firing a gun may be assigned a fixed probability (per shot or per unit time) of hitting his target. The solution of these equations have some interesting consequences, notably the fact that the appropriate measure of the "strength" of a fighting force is rR^2; numbers are more important than technical capabilities. (It is easy to see that the quantity $rR^2 - bB^2$ is a constant of the motion. Thus R "wins" if $rR^2 > bB^2$ at $t = 0$, where winning means that R(t) is still positive at a time when B reaches 0.) The equations imply also that a weaker force can overcome a stronger force by dividing the enemy, and defeating portions of it in separate battles.

The Lanchester equations can be generalized to describe encounters involving several types of weapons (tanks, artillery, aircraft), albeit with an increasing number of uncertain parameters. And these generalized equations have played a part in military and civilian analysis of potential conventional warfare for many years. There is, however, little in the way of experimental corroboration of the theory, in the form of fits to attrition rates in historical battles.

Lanchester theory makes no distinction between offense and defense, only superficially takes account of tactics, and recognizes no diminishing marginal utility in crowding more and more forces within firing range of the enemy. This last points up the fundamental flaw in the theory, the lack of space dimensions as variables (dependent or independent) in the dynamical description of warfare. In response, Joshua Epstein, an analyst at the Brookings Institution, had developed a new model for a conventional battle, which allows for movement of forces.

Epstein focuses on a defending commander's option, in the face of heavy casualties, to withdrawal from the front. In his model, the defender's withdrawal rate, W(t) (in km/day), is determined by his casualty rate, $\alpha_d(t)$, (fractional losses per day), a threshold casualty rate, α_{dT}, and the maximum possible withdrawal rate, W_{max}. When $\alpha_d(t) > \alpha_{dT}$, W can increase according to

$$dW/dt = (W_{max} - W)(\alpha_d - \alpha_{dT}) / (1 - \alpha_{dT})$$

But when $\alpha_d(t) < \alpha_{dT}$, W is set equal to zero. An increasing value of W feeds back to reduce the casualty rates, α_d and α_a, of defender and attacker respectively. In a third feedback loop, the casualty rate suffered by the attacker determines the rate at which he prosecutes the battle, and thus affects the casualties of both sides. (It is intended that the attacker's prosecution rate increase or decrease according to whether his casualty rate is below or above a threshold, α_{aT}, although the equations will not act this way in all cases.) The model is thus characterized by *adaptive* behavior on both sides.

Other important time-dependent variables introduced in these equations are the ground casualties inflicted by close air support (treated differently from ground-to-ground casualties), and the rate at which reinforcements are introduced. In an earlier book (*Strategy and Force Planning: The Case of the Persian Gulf*, Brookings 1987) Epstein employed his model to analyze hypothetical battles between US and Soviet forces in Iran, finding authorities in the US to be, characteristically, unduly pessimistic about US conventional capability. The significance of such estimates, however unreliable they may be, goes beyond the outcome of the battle. For the nation that cannot count on its conventional force is likely to plan for and lean toward escalation—including the threat or use of nuclear weapons.

The nation that cannot count on its conventional force is likely to lean toward escalation — including the use of nuclear weapons.

This same tension between a presumedly weak conventional defense and the threat of nuclear escalation held center stage in the NATO-Warsaw Pact confrontation that dominated foreign affairs for 40 years. This confrontation, despite its being perhaps of only historical interest, is the subject of the present book. The Warsaw Pact barely exists, and the invasion from the East seems fanciful. Nonetheless, NATO will maintain 20,000 tanks and close to 200,000 troops in Europe under the (about-to-be-signed) CFE treaty, and behind the formulation of reductions to these levels lies some model of potential warfare. This book endeavors to provide a more realistic model.

A variety of calculations are shown using as input, (a) the current (late 1980s) forces, (b) the forces following unilateral cuts in the East, (c) forces expected under the CFE Treaty, and (d) forces 50% below CFE. NATO wins in all cases. Interestingly, Epstein also poses a "worst case scenario," to test the robustness of NATO defense when the attack is concentrated: the Warsaw pact shifts 60% of its force to the southern sector. In this scenario, NATO loses with the present force, but wins with the CFE force.

The drastic misallocation of defensive forces on the battlefield represent a failure in intelligence and/or "dexterity," the ability to move forces rapidly from the south to the north, i.e., in a direction parallel to the front. Thus these "60/40" calculations point to a key feature of conventional battle, which Epstein has recognized, but not modelled dynamically. One might say that while Epstein improves on the Lanchester equations by modelling the space dimension perpendicular to the front, a fuller treatment of battle awaits a dynamical model in two dimensions, those parallel and perpendicular to the front.

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