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Neutral Particle Beam Discrimination and Lethality

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CONTENTS

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ABSTRACT

Using, or possibly just developing, neutral particle beams (NPBs) to both discriminate decoys and kill weapons could induce 10-fold reductions in each. The conventional "factor of two" increase in the time required to do both does not capture particle beams' impact. They could reduce the threat to ≈ 1 reentry vehicle (RV) plus ≈ 10 decoys per heavy missile, which could be defeated at a 10-100:1 cost effectiveness ratio by current interceptors.

I. INTRODUCTION

This note assesses NPBs' relative value in kill and discrimination. It concludes that there is distinctly greater benefit if they do both, which could force significant reductions in the number of both decoys and weapons. Using, or perhaps just developing, particle beams to both discriminate decoys and kill weapons could induce greater than 10-fold reductions of each. The beams needed to do both are essentially the next stage beyond current programs.

II. DISCRIMINATION AND LETHALITY

Particle beams, like other directed energy weapons, are primarily characterized by their brightness (Appendix A). Reentry vehicles at typical ranges would absorb a lethal fluence in ≈ 0.1 s. Such beams could also deliver the 100-fold lower fluence needed to discriminate a decoy in ≈ 1 ms. There are, however, up to 100 decoys per weapon, so the total time to discriminate them would again be ≈ 0.1 s. Thus, the time to discriminate a weapon's decoys is comparable to the time required to kill it once it is identified. If a particle beam is used to both discriminate and kill, that roughly halves the total number of unshielded reentry vehicles that it can address.

In midcourse a few platforms could discriminate roughly the whole unattenuated threat. Discrimination could cost ≈ $ 200 per decoy, as compared to $ 2 M per object for ground-based interceptors. Popup platforms can only access the latter part of the objects' trajectories, but with proper energies and detector placement, popups can achieve performance within a factor of 1.5-2 of these estimates. Particle beams that were predeployed in space would have a factor of ≈ 10 absenteeism, but that would only increase their costs to ≈ $ 2 K per discrimination.[1]

Figure 1 shows the number of popup beams needed to meet the full threat as a function of the particle type and energy.[2] The top curve is for hydrogen beams, for which the number of platforms is roughly inversely proportional to their energy. The bottom curve is for deuterium, which produces a larger discrimination signal, particularly at lower energies, which could produce much lower overall costs. Platforms operating at 50-100 MeV could be launched with existing boosters. Those energies are within factors of 2-4 of those now being tested.

Alternatively, a beam could kill ≈ 10,000 weapons, most of the threat, for ≈ $ 20K per kill for popups or $ 200 K for space-deployed beams, as opposed to ground-based interceptors' ≈ $ 2 M. Thus, the beams' leverage in killing weapons would be about as large as for discrimination. Against unshielded reentry vehicles, the number of platforms required for kill would again be roughly those shown in Fig 1. There are, however, a number of other ways to kill bare weapons. While ground-based interceptors might be 10 times more expensive than particle beams, they would still be ≈ 10 times cheaper than \$ 20 M bare reentry vehicles.[3] Neutral particle beams have been advocated primarily for discrimination, for which there are no good alternatives. They do, however, have leverage for kill--much more than generally thought. That leverage is increased when shielding is considered.

III. SHIELDING TRADEOFFS

Weapons could be shielded against particle beams, but for 100-MeV beams, shielding would require ≈ 10 g/cm^2 of external material, and shielding against 200 MeV would require ≈ 40 g/cm^2 of additional material.[4] Thus, reentry vehicles with ≈ 10^4 cm^2 area to shield would face a 0.1-1 ton penalty. Current Soviet SS-18 reentry vehicles weigh ≈ 300 kg, so for each one shielded against 200-MeV beams, ≈ 3 others would have to be offloaded. For 100-kg reentry vehicles, ≈ 10 would have to be offloaded. Either would essentially de-MIRV the threat, forcing a return to earlier, manifestly more stable configurations.

The fewer, shielded weapons then faced could be addressed by increasing the beam energies, because the shielding penalty increases roughly as the square of the energy. Ground-based interceptors could also be used. Their lethality would not be impaired by the particle beam shielding, and their cost-effectiveness would be improved by it. Against current \$ 20 M reentry vehicles, \$ 2 M ground-based interceptors would have an advantage of ≈ 10:1. If shielding reduced the number of reentry vehicles per missile ≈ 10-fold to 1 or 2, ground-based interceptors would have cost-effectiveness ratios of 50-100:1.

Figure 2 shows the results of more detailed calculations (Appendix B), which confirm that increasing beam energy forces the attacker to use more of his mass as shielding, which essentially transmutes his fission and fusion mass into inert lead. The two upper curves show the effect of variations due to reentry vehicle construction. The number of reentry vehicles falls roughly as the inverse square of the beam energy, in accord with the scaling arguments above.

The horizontal band shows the range in the number of shielded weapons that could be killed by a beam of that energy. The lower bound is the ≈ 100 J/g threshold for component melting or detonation; the upper bound is for killing hardened firing electronics at ≈ 10 J/g. For the latter, above 200 MeV the beams could kill more weapons than the attacker could launch with his current payload, and increasing payload would favor the defense.

The curve is for 10 nominal popup beams of the energy shown, i.e., beams with the brightness set by foil neutralization of the beams. Advanced neutralizers would have significant impact. A 3- to 5-fold decrease in angular divergence with laser neutralization could increase the number of weapons killed by about an order of magnitude or reduce the number of platforms for the number of weapon kills shown.

IV. DECOY REDUCTION

Decoys should be reduced accordingly. In the absence of discrimination, heavy missiles could provide each reentry vehicle ≈ 100 decoys. For example, SS-18 buses weigh ≈ 8 tons in ≈ 10 reentry vehicles weighing a total of ≈ 3 tons, ≈ 2 tons of structure, and ≈ 3 tons of fuel, apparently for cross-targeting. If the last was halved, the 1.5 tons of payload released could provide ≈ (1,500 kg/missile)/(1-3 kg/decoy x 10 reentry vehicle/missile) ≈ 50-150 decoys per reentry vehicle.[5] With partial discrimination the offense-optimal number of decoys drops to ≈ 20-30 per weapon. For good discrimination decoys are essentially a drag on the offense, and would be foregone to provide shielding, which would give simpler intercepts.[6]

V. CONCLUSIONS

Using, or perhaps just developing, particle beams to both discriminate decoys and kill weapons could induce greater than 10-fold reductions of each. Nominal beams could discriminate a weapon's decoys or kill it in a tenth of a second. The conventional "factor of two" increase in the time required to perform both missions does not capture particle beams' impact in combined applications. For shielding penalties estimated above, the threat could be reduced to ≈ 1 reentry vehicle plus ≈ 10 decoys per heavy missile. At that point strategic defenses would have won, because that threat could be defeated at a 10-100:1 cost-effectiveness ratio by current interceptors. The beams needed to do both are essentially the next stage beyond current programs.

APPENDIX A. NPB SCALING

Particle beams, like other directed energy weapons, are primarily characterized by their brightness, i.e., power divided by the angle into which it is directed. A typical near-term beam brightness is $B \approx 10^{19}$ W/sr. A beam of brightness B produces an energy flux of B/r^2 at range r. Thus, a reentry vehicle at a range of $r \approx 1{,}000$ km would absorb a lethal fluence $J_L \approx 10^6$ J/m^2 in a time $t \approx J_L/(B/r^2) \approx 0.1$ s.[7]

Such a beam could deliver the $J_D \approx 10^4$ J/m^2 fluence needed to discriminate in a time $J_D/(B/r^2) = 1$ ms, which is less than that to kill by the ratio of the discrimination and lethal fluences, which is $J_D/J_L \approx 0.01$. There are, however, up to 100 decoys per weapon, so the total time to discriminate them would be $\approx 100 \cdot 1$ ms $= 0.1$ s.

In the $\approx 1{,}000$ s of midcourse, a beam could discriminate $\approx 1{,}000$ s/0.001 s $\approx 10^6$ objects, roughly the whole threat. If popup platforms cost ≈ \$ 200 M apiece, discrimination would cost ≈ \$ 200 M/10^6 objects ≈ \$ 200 per decoy, as compared to \$ 2 M per object for ground-based interceptors. Particle beams that were predeployed in space would have a factor of ≈ 10 absenteeism, but that would only increase their cost to ≈ \$ 2,000 per discrimination.[8]

Alternatively, a beam could kill ≈ 1,000 s/0.1 s ≈ 10,000 weapons, most of the threat, for ≈ \$ 200M/10,000 ≈ \$ 20K per kill for popups or \$ 200K per kill for space-deployed beams, as opposed to ≈ \$ 2M for ground-based interceptors.

APPENDIX B. SHIELDING PENALTIES

The lethal fluence, $J(J/cm^2)$, is roughly the product of the specific energy $j(J/g)$ to kill the weakest component in the weapon and the range $L(g/cm^2)$ particles must penetrate to reach it. The range increases with beam energy E(MeV) as

$$L \approx kE^{7/4}, \quad (1)$$

where for proton beams $k \approx 3.3 \cdot 10^{-3}$ g/cm^2-$MeV^{7/4}$. If the thickness of the reentry vehicles' aeroshell is σ, $J = j(L + \sigma)$, where $j(J/g)$ is the specific energy deposition required to kill the weakest component. The mass of shielding for a reentry vehicle of area $\Phi \approx 10,000$ cm^2 is $(L+\sigma) \cdot \Phi$, of which $L \cdot \Phi$ must be subtracted from the weapon payload. If the initial number of weapons is R_0, and the mass of an unshielded weapon is M, then after hardening the number is

$$R = R_0 M/[M + (L+\sigma)\Phi] = R_0/[1 + (L+\sigma)\Phi/M], \quad (2)$$

which is shown in Fig. 2.

If the weapons approach radially and simultaneously, N particle beams protecting an area A, could kill approximately

$$K \approx \Sigma\, dt/[J/(B/r^2)] \approx (B/JV)\, \Sigma\, dr/r^2 \approx (B/JV)\sqrt{(N/A)} \quad (3)$$

weapons, where $V \approx 8$ km/s is the weapons' velocity and $A \approx 10^4$ km^2 would correspond to a compact launch area. $B = E \cdot I/\Omega$, where $I \approx 0.1$ A is the average beam current, and $\Omega \approx \Omega'/E$, where the beam's solid angle is $\Omega \approx (2\ \mu rad)^2$ at E = 250 MeV. Thus,

$$B/J \propto E^2/E^{7/4} \propto E^{1/4}, \quad (4)$$

which only varies ≈ 30% over the range of E of interest, so that K is relatively insensitive to E and scales primarily on $\sqrt{(N/A)}$, as seen in Fig. 2. If improved neutralizers decreased Ω' by a factor of 10, K would increase proportionally, and hard component kills would be possible at all energies.

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Fig.1. Constellation size

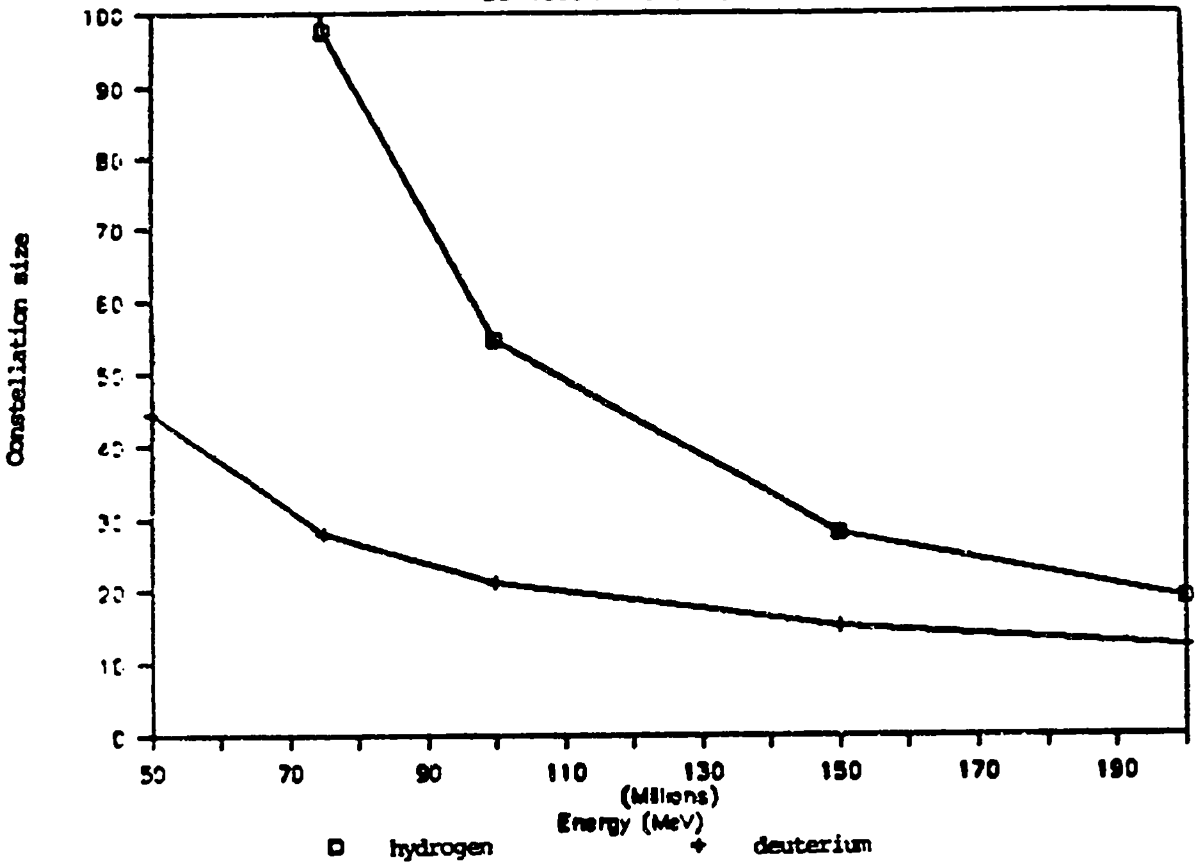

Fig. 2. Reentry vehicles vs shielding