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COMMENTS ON BOOST-PHASE INTERCEPT

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This piece summarizes the comments I made at the National Defense University "Defense Horizons" session of 08/14/03. What is new and helpful is the very impressive report of the American Physical Society study of boost-phase intercept (BPI), ably summarized here by Fred Lamb.[1] The technical analysis is first-rate; it shows not only the influence of experts but also the merit of a study group which critically evaluates the individual contributions.

I agree with the technical analyses, which go far beyond those I was able to make in past years, when I introduced the option of BPI in the context of protection against threats from North Korea, Iran, or Iraq.[2] However, I do not agree with many of the strategic judgments, which have been made on the basis of these technical assessments. Some of these judgments are found in the Report, others in the American Physical Society Press Release, and still more simplistic judgments in the Press commentary on the Report.

In particular, I believe that the Report's technical analyses bear out the effectiveness of surface-based BPI against liquid-fueled missiles launched from North Korea against the United States. They also support the effectiveness of surface-based BPI against liquid-fueled ICBMs launched from Iraq against the United States-- a non-problem from 2003 on. And they allow also substantial effectiveness of surface-based BPI against liquid-fueled ICBMs launched from Iran. None of this could be inferred from Press reports or from the APS Press Release.

In particular I will discuss here the implications of the APS BPI Study Group results in the following categories:

1. Short timeline for tactical decision.

2. Interceptor launch might be mistaken for offensive ICBM.

3. Successful BPI does not destroy BW bomblets or possibly disable a nuclear warhead. In any case, plutonium may be dispersed. The payload may fall short on the Aleutians or in Europe.

4. BPI is ultimately ineffective against 100-s fast-burn booster, or even against a 150-s solid-fuel ICBM from Iran.

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[1] "Report of the APS Study Group on Boost-Phase Intercept Systems For National Missile Defense," http://www.aps.org/public_affairs/popa/reports/nmd03.html

[2] "Cooperative Ballistic Missile Defense," by R.L. Garwin, presented at the State Department Secretary's Open Forum on National Missile Defense Against Biological and Nuclear Weapons, November 18, 1999.

5. Space-based interceptors are inferior to surface basing for North Korea and probably for Iran.

SHORT TIMELINE FOR TACTICAL DECISION.

The Study states, "A system with 6.5-km/s interceptors based in either of these locations could provide a decision time of about 30 seconds." I believe and have always written that there should be no tactical human decision. Therefore there is no time needed for this. None. Zero.

It is very important to define the system and the rules of engagement. All of this review and design should be done in the most responsible and coherent fashion. But once done, it needs to be incorporated into the system and not second-guessed at the moment of use.

This is particularly feasible in that there are very limited regrets to a wrong decision to engage in BPI. In contrast, in case of nuclear response to a nuclear attack on U.S. ICBM silos, the regrets could have been the destruction of Soviet society and the resultant destruction of U.S. society and much of the rest of the world.

In the case of BPI, the interceptors are physically incapable of destroying anything except a boosting missile outside the atmosphere. And the system should be arranged so that those relatively few states with a capability of detecting the launch of an interceptor will understand in advance that this is evidently not an attack on their territory.

So remove any time for tactical launch decision and any criticism of BPI because it does not allow “sufficient time for decision.”

INTERCEPTOR LAUNCH MIGHT BE MISTAKEN FOR OFFENSIVE ICBM LAUNCH.

It should be arranged well in advance of system operability that the launch of interceptors be reported within seconds to an appropriate body of the United Nations, to NATO, to Russia and China.

Any state (particularly those without worldwide launch detection capabilities—such as China) could at any moment assume that some real nuclear-armed ICBM has been fired at them. Why would they have more concern when a sea-based interceptor off North Korea was announced by the United States to have been fired against a North Korean missile launch?

Such an announcement would help China interpret what might be visible to them within some minutes-- such as the reentry of debris into the atmosphere over their territory. And, in fact, it would be helpful to communicate as well the estimated impact area of first and second stage boosters.

SUCCESSFUL BPI DOES NOT DESTROY BW BOMBLETS OR POSSIBLY DISABLE A NUCLEAR WARHEAD.

Indeed, the most successful BPI would disable a nuclear warhead, but the plutonium might very well be dispersed on reentry. Or the high explosive might detonate at the time of intercept either with a resultant nuclear explosion (for weapons which are not one-point safe) or with the conversion of the plutonium to fragments or dust with subsequent reentry.

The report remarks (as I did in Ref. 2) "the payload may fall short on the Aleutians (for a launch from North Korea against the United States) or in Europe (for a launch from Iran against the United States)." Indeed it may.

But nations go to great length to achieve the capability to disseminate BW agents in the proper place and in the proper form, or to detonate nuclear explosives where the target is, and not at a random point. If the shortfall should occur elsewhere in the United States other than the intended city target, or at an average point in Europe other than the intended U.S. city target, the density of population is typically one percent that of the target area, and detailed studies have shown that for a nuclear explosion in Europe, on the average some 1300 people would die.

Given the objective of Iran or North Korea in launching an ICBM against the United States, the likelihood that it will instead kill 1300 people in Europe in a non-target area[3] would strongly inhibit the desire to launch. So instead of 99% protection, this could well be 100% protection.

It is argued that Europeans would oppose a U.S. missile defense deployment if were likely that a missile, once launched, would have a shortfall in Europe. This would be shortsighted from the point of view of the international community, and would have to be counted as a great failure of diplomacy on the part of the United States, given the arguments I have sketched above.

If there were some benefit to Iran or North Korea in launching a weapon that would detonate in Europe, or in Japan or in some other country rather than in the United States, it would be far simpler for those countries to do that. They would not need missiles of ICBM range, and the possibility of boost-phase intercept would be much reduced. They could even target a city in Europe or Japan, rather than accept only a possibility of successful explosion possibly at a random point in these countries.

BPI IS ULTIMATELY INEFFECTIVE AGAINST A 100-S FAST-BURN BOOSTER, OR EVEN AGAINST A 150-S SOLID-FUEL ICBM FROM IRAN.

This was one of my principal arguments against the deployment of the so-called Star Wars system (more formally, the Strategic Defense Initiative) against the Soviet Union in the mid-1980s. Edward Teller and colleagues at Livermore National Laboratory were advocating that we build a nuclear-weapon-pumped x-ray laser to counter Soviet missiles in their boost phase; because these U.S.

[3] A participant at the NDU session quoted the result of a government study to the effect that the explosion of a nuclear warhead at a random point in Europe would kill an average of 1300 people.

interceptors bearing the nuclear explosives would be ground-based, presumably on U.S. soil, it would be necessary for them to be fired on warning of Soviet ICBM launch.

The x-ray laser warheads would then need to be propelled sufficiently high during the ICBM boost time so that the x-ray beam would clear the rim of the Earth on their way to the ICBM booster. But the nominal ICBM burn time could be shortened from 250 s to, say, 100 s with about a 5% increase in overall system cost with the technology then available to the Soviet Union. As a result the x-ray laser interceptor would need not only to shorten its burn time, but also to increase its ultimate speed, so that it would get to pretty much the same altitude (or higher, actually) in this shorter time. Indeed, it would need to achieve a speed some 2.5 times as great as the nominal speed it had.

Given the laws of rocket propulsion, by which a doubling of final speed SQUARES the ratio of launch mass to payload, an interceptor which had a launch mass 100 times the 1-ton payload and so weighed in at 100 tons gross launch overall weight, would now weigh in at 30,000 tons. This would be totally inconceivable.

So I am not skeptical of the possibility to reduce the ICBM burn time to 100 s, if necessary. But that was for the Soviet Union (or the United States) with highly mature technology in the 1980s and it is not about to happen for North Korea or Iran. If they stop working on liquid-fuel ICBM or normal solid-fuel ICBM with 170-250-s burn time, to build instead a 100-s (or 150-s) burn-time solid, we will have gained several years of protection without ever having built a BPI system.

The point is that nothing is forever-- offensive or defensive. And regimes are not forever, either. There are real prospects that Iran will rejoin the community of nations in five years or ten years.

SPACE-BASED INTERCEPTORS ARE INFERIOR TO SURFACE-BASING FOR NORTH KOREA AND PROBABLY FOR IRAN.

In this contention I agree with the analysis of the APS Committee on Boost-Phase Intercept, and provide some of my own simple calculations presented at a workshop at Stanford University, October 2002, in which the APS BPI team were active participants. To begin, note that a KKV in its orbit is no more useful than a KKV stationary on the ground. Given the launch of an ICBM, a given KKV closest to that site at the time of potential intercept might be alerted to the launch, but unless it had "divert capability" it could do nothing. And if it has only a small divert capability, it could reach out only a small distance from its orbital path. More quantitatively, the time required to command and initiate burn of a KKV orbital divert rocket may be assumed to be the same as that to initiate launch of a surface-based interceptor. Call T_D the time required to detect and assess an ICBM launch.

In the time remaining before burnout of the ICBM, a KKV must reach the trajectory of the ICBM and collide with it. This is somewhat more difficult than for the surface-based interceptor, because in addition to the divert velocity the SBI has its orbital velocity, so there is less time for the engagement and more acceleration required to achieve a successful intercept.

To counter a single launch, the number of KKVs in the constellation varies inversely as the square of the divert distance in the available time, and thus inversely as the square of the divert velocity. Although the number goes down as the divert velocity increases, the mass of propellant for a particular interceptor to achieve higher divert velocity grows exponentially, as indicated in the previous analyses.

The SBI can have a larger divert acceleration than the launch acceleration of a surface-based interceptor, since there is neither air resistance nor heating from the atmosphere. So it is reasonable to take accelerations of 20 or 30 g--0.2 to 0.3 km/second-squared.

A very substantial element of the cost of an SBI constellation is the cost of launch. This is much reduced for KKVs of small mass, and to move toward the sublime from the ridiculous (or perhaps vice-versa) I assume in some calculations a KKV mass of 4 kg, as proposed at times by the Livermore group. Alternatively, I take a bare KKV mass of 22 kg, which is more in line with the APS Study.

In order to reduce the number of parameters, I take a launch cost to LEO of $22,000 per kg of mass entering orbit.

Finally, I standardize on what has been established to be a near optimum (reach-out speed + divert speed) for SBIs of 6 km/s.[4]

If the entire surface of the Earth needed to be covered with equal effectiveness, the constellation would need to be uniform over 500 million sq km of surface. On the other hand, if the threat is concentrated near the latitude of North Korea, for instance, the orbits can be so arranged as to have their northern turning points at similar latitude, thus saving about a factor 3.1 (more generally, "f") in area required to be covered.[5]

The results are shown in the appended Table with the following parameters: ICBM burn time TB = 250 s; delay time (time to launch) TD = 65 s; reach-out speed V = 6 km/s; interceptor acceleration A = 0.2 km/s; cost of the KKV, CKV $0.4 million; launch cost, CL $0.022 million/kg; equivalent Isp (specific impulse) for the rocket (including compensation for structure and staging, C = 2.85 km/s or 285 s; radius of the Earth, R = 6 Mm; mass of the kill vehicle, MKV = 4 or 22 kg; orbital numbers required (inverse concentration factor), f = 1/3.1

The results are tabulated for ICBM burn times of 250 or 170 s; for time–to-launch of 65 or 100 s; for on-orbit accelerations of 0.1, 0.2, and 0.3 km/s2; and for kill-vehicle masses of 4 and 22 kg.

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[4]Two-stage SBIs optimize near 4 km/s according to Roger Speed.
[5] "How many Orbiting Lasers For Boost-Phase Intercept," by R.L. Garwin, *Nature*, Vol. 315, pp. 286-290, May 23, 1985.

Interceptor numbers then range from 44 to 807, the numbers being larger for the lower acceleration interceptor and the shorter ICBM boost time. And the cost for a constellation, which would allow a single interceptor to be fired at a single launch, is shown in the third column, ranging from $50 million to $3.40 billion.

The mass on orbit of the constellation is shown in the fourth column and ranges from 1.5 tons to 145 tons for these assumptions. However, no defense would fire a single interceptor at a threatening ICBM.

Furthermore, the mass on orbit must include not only the ultimate kill vehicle and its rocket, but also a "life jacket" to provide the solar energy, radio receiving system, and housekeeping for years on orbit. This is assumed to multiply the on-orbit mass by a factor two. And finally, such a system would have to handle simultaneous launches of several ICBMs in a given area. We assume here five ICBMs, with four interceptors dispatched per ICBM launch detected. The product of these three factors (interceptors per launch; simultaneous cluster launches; and a factor two for a life jacket) result in the factor 40 shown in Column 5, and system costs ranging from $2 billion to $136 billion.

For example, if one assumes that North Korea could well achieve a 170-s burn time missile and that 65 seconds are required for time to launch a KKV, then a 22 kg interceptor with 20 g (0.2 km/s^2) acceleration would dictate 40 x 159 = 6360 intercepts, at a constellation cost of some $28 billion.

In comparing such a system with surface-based interceptors against North Korea, one would need for comparability to have some 20 surface-based interceptors ready to fire. Each interceptor would cost somewhat less than one of the KKVs on orbit, since it would need to have approximately the same propulsion speed, but would not be assessed the additional $22,000/kg cost of launch to orbit.

So in an apples-to-apples comparison, the cost for the interceptor component of a surface-based system against North Korea would be smaller by a ratio of 300 than is the case for space-based interceptors.

For almost 20 years I have pointed out that the Livermore proposal for very small KKVs would be highly beneficial to ground-based and air-launched interceptors, and the decision to employ them in these roles would be much easier to make. Accompanying the reduced mass was a set of ingenious improvements, which promise much lower cost, as well. Some of these were proven in the successful moon and asteroid probe, Clementine. If a 4-kg KKV could be achieved, interceptors fitting the Navy’s vertical launch system (VLS) would indeed appear possible. But it is more straightforward in any case to allow a retrofit of surplus merchant ships to carry large vertical launch tubes for the large interceptors currently required.

Add to the handicaps of space basing that SBIs would need to plunge to make their intercepts in case of a fast-burn booster, adding to the required divert speed.

The APS Report asserts that "Single or multiple warheads or munitions could also be deployed while the final stage is still in powered flight" as if this were a complication to BPI. But so far as I can see it is irrelevant. If the booster cuts off when it has reached the desired velocity and position, and the warhead is later deployed, this provides no more nor less opportunity for intercept in powered flight than if the warhead were separated while the booster was still thrusting. This adds nothing to the analysis, and it is misleading to suggest that previous analyses, not having considered deploying warheads in powered flight, thereby are wrong or, for this reason, optimistic.

The Report assumes that it will take ten years to deploy a surface-based BPI. In fact, it may take forever to deploy one, but this need not be the case. If one rigorously eliminates portions of the system that would be nice to have but are not strictly necessary, and if one defines the interfaces early, thereby rendering the system less than optimum, but more readily achievable, one should be able to cut the time from decision to deployment to four years or less. To do this would require a hard-driving executive in the mold of BGen Leslie R. Groves, of Manhattan Project fame.

Despite my high regard for the technical analysis of the Study, I am distressed by the broad-brush disdain for previous analyses. For instance, the Report chastises earlier presentations for assuming that the rocket in boost phase is "slowly moving" and somehow an easier target. Evidently, by the time of intercept the rocket is moving almost at full speed. I, for one, never assumed that the target was "slowly moving." I have noted in other contexts that there would be an opportunity for tiny, covertly deployed boost-phase interceptors fired from a distance of a few tens of km to intercept a slowly moving rocket, but that is not what I considered in Ref. 2, for instance.

Similarly, in criticizing as impractically small the interceptors proposed for BPI by previous analysts, the APS Study Group gives the impression that the interceptor proposed by Ted Postol and myself is in this class. Indeed, we have from the beginning indicated that we could not fit our interceptor in the Vertical Launch System standard in the U.S. Navy, and that the interceptor we proposed would weigh about 14 tons-- similar to the mid-course interceptor planned for National Missile Defense. Our interceptor (Ref. 2, for instance) is assumed capable of 6.5 km/s with a gross launch weight of 14 tons (compared with a similar APS 6.5 km/s interceptor I-4 of 17 tons).

Comparable technology used for a 10 km/s interceptor would have a growth in launch mass by $e^{(\Delta V/gIsp)}$. In this case, ΔV is 3.5 km/s, and g times Isp is the exhaust velocity of the rocket or 2.8 km/s. The exponential is 3.49, so that a 17-ton interceptor at 6.5 km/s would grow to 59 tons at 10 km/s. The Study shows an interceptor of "65.6 tons[6]" for 10 km/s-- normal growth from the additional velocity and not primarily from atmospheric drag.

THE ROLE OF RADAR TRACKING IN BPI

The Report (Sec. 10.2, pp. 173 ff) does an excellent job on estimated radar cross sections and the performance of radars in detecting and tracking liquid and solid-fuel ICBMs. As shown by Table 10.3, THAAD Performance Requirements for ICBM Searches, the Theater High-Altitude Air Defense radar with its power-

[6] Report p.53, interceptor I-5

aperture product of 324 kWm2 more than meets the 53-60 kWm^2 requirement for detecting and tracking either a liquid or solid-fuel ICBM at a standoff of 800 km from the launch site. THAAD is air transportable and could also be mounted on a stabilized platform on a ship.

The consequence of assuming that the radar is based at least 800 km from the launch site is that the horizon at the radar site blocks view of the trajectory until the missile has reached altitude h= L2/2Re = 50 km. (L is the distance from the radar.) This corresponds to times of 80-100 s after launch. But the text also notes (p. 183), “All the radars discussed here could achieve detections early enough to provide the initial warning of an ICBM launch, if they could operate within about 300 km of the ICBM launch site.” For ICBM launch from any point in North Korea, a range below 300 km could be achieved by radars in South Korea and on two ships off the East Coast of North Korea. The radar and the interceptors need not be based at the same locations.

The radar horizon at 300 km distance is 7 km above sea level, corresponding to an ICBM (L) flight time of 42 s from a launcher at sea level and somewhat shorter times from launch sites at altitude. Hence the radar can be the primary sensor, providing more fly-out time for the interceptor. Note that terrain in the region of the launch site does not mask the trajectory, so long as the radar has a clear view of its own horizon.

The APS study does a good job on the performance of radar at a range of 800 or 1000 km from the launch site, but it gives no compelling reason why the radar could not be deployed at 300-400 km range.

CONCLUSION.

The American Physical Society BPI Study is an excellent analysis of the limits of BPI. By definition, a defensive system fails beyond its limit, and that has been the lesson learned by some commentators. But one doesn't need a study to teach this lesson; it is a tautology.

The Study also shows that boost phase intercept against currently projected liquid-fueled ICBMs launched from North Korea is feasible, in support of the analyses Ted Postol and I have put forth. No amount of detailed analysis as to the time for tactical decision is necessary if tactical decision has been eliminated by design. No detailed analysis of the size and capability of missiles fitting the Vertical Launch System is necessary if the commitment is to use an interceptor based in a special-purpose refitted merchant ship, or launched from the ground just outside North Korean territory. The Study is indeed extremely helpful in validating the utility of laser ranging in the intercept, and numerous other analyses. I am grateful to the authors and to the American Physical Society for this major and widely accessible contribution to our understanding.

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MASSES AND COSTS FROM WHICH TO SCALE SBI SYSTEMS

Using Greg Canavan's model of 10/29/02, with cost in $ as "C" and masses in kg as "M" we have

$$C_{int} = C_{kv} + M_{KV}e^{V/V_e} \times C_{launch}$$

(C_{launch} or C_L is the cost per kg; c = g×I_{sp}).

Nint = f × ($4\pi Re^2/\pi Ro^2$), where Ro is "reach-out"

Ro = V × (T_{boost} – T_{delay} – V/2a);

F = 1/3.1, is the concentration factor.

From 1992 Defense Acquisition Board (DAB),

C_{KV} = $0.4 million; M_{KV} = 4 kg.

Some results:	T_B	T_D	V	A	C_{KV}	C_L	C	R_E	M_{KV}	f
E.g.,	250	65	6	0.2	0.4	0.022	2.85	6E6	4	1/3.1

T_B	T_D	A	M_{KV}	N_{INT}	Cost ($B)	Mass (t)	Cost x 40
250	65	0.2	4	44	0.05	1.5	$B 2
250	65	0.2	22	44	0.20	8.1	8
170	100	0.2	4	426	0.48	14	20
170	100	0.2	22	426	1.90	77	76
170	100	0.1	22	807	3.40	145	136
170	65	0.2	22	159	0.70	29	28
170	65	0.3	22	143	0.63	26	25
170	65	0.3	55	143	1.48	65	59
170	30	0.3	55	76	0.79	34	32

Costs and masses must be multiplied by number of simultaneous launches and by KKV/launch—e.g., 20 = 2x10. And also by mass growth factor to include the life jacket—another factor 2: last column in Table.