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High-altitude nuclear burst "Starfish Prime" as seen from Honolulu through thin clouds in 1962.

MISSILE DEFENSE

Sorting Out Collateral Damage

BY JAY WILLIS

The successful intercept of a threat ballistic missile or cruise missile does not completely negate all hazards to friendly personnel or assets. Prediction of the effects resulting from the various debris that result from the intercept is a science that is still growing more than 37 years after the first anti-ballistic missile system was deployed, with many remaining knowledge gaps and many people unaware of the issue of post-intercept collateral effects. The hazards can be particularly significant if the threat missile contains a Weapon of Mass Destruction payload. A very brief overview history of the issue is presented.

Early Strategic Missile Defense

The first deployment of a ballistic missile defense capability for the United States was the Safeguard Program. It protected only some of our offensive ballistic missile fields, and the emphasis was on engaging Soviet strategic intercontinental ballistic missiles (ICBM) carrying large-yield nuclear warheads. The interceptor missiles (Sprint and Spartan) themselves carried nuclear warheads to inflict catastrophic damage on the threat nuclear payloads. The nuclear warheads on the interceptors were necessary because the technology of the era prevented reliably getting the interceptor close enough to the threat to insure destruction by means of a conventional explosive (blast/fragmentation) warhead.

Even with a nuclear warhead detonation, or possibly two (both the interceptor and the threat), there would have remained debris from both the threat and the interceptor (including booster components) that ultimately would have come to earth. That debris could have ranged from a severely damaged and inoperable but largely intact threat warhead landing near the intended ground target to very small particles of radioactive fission products and nuclear material (including uranium and plutonium) spread around the globe. There also could have been significant collateral effects from the electromagnetic pulse caused by the nuclear detonations.

But concerns about collateral effects of the engagements were generally judged far less important than preventing the horrendous consequences of a nuclear strike conducted as intended by our enemy. Such a strike against our missile fields might have crippled our nuclear retaliatory capability, killed large numbers of civilians and military personnel in the target area, and caused millions of deaths among the general population due to nuclear fallout hundreds of miles downwind.

The advent of the Strategic Defense Initiative Organization in 1983 again stimulated serious interest in ballistic missile defense. The objective became a defense of the entire United States and our allies against a massive nuclear strike by the Soviet Union. The means of engaging these thousands of threat missiles also changed from nuclear-tipped interceptors launched near the ground target to a wide variety of interceptors relying on conventional warheads or simple direct impact kinetic energy ("hit-to-kill") or on more than a half dozen directed energy weapon concepts from lasers to particle beams.

Under SDIO, the paradigm regarding concern over collateral effects changed very little. The non-nuclear interceptors or directed energy weapons still resulted in debris from the threat nuclear weapons, interceptors, and possibly detonation of the threat nuclear warhead. There would have been no EMP from the interceptor, since none were nuclear-tipped, but there may have been EMP from a threat warhead detonation, and it may have occurred anywhere between the Soviet Union and the United States, depending on the missile defense weapon used. There also would have been the inevitable release of nuclear materials from the threat warhead. But any of this would have been far preferable to a successful massive nuclear strike on our homeland or allies.

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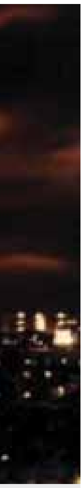
Investigation of the various collateral effects was largely limited to consideration of whether the effects would hamper the operation of the missile defense system, itself. The various debris and their effects could interfere with radar, optical seekers, electronics, or structures of satellites or interceptor missiles. These concerns were rarely in the public eye, and they usually took a back seat to the fundamental problems of developing an interceptor or directed energy weapon that could reliably "destroy" a threat nuclear warhead.



Theater Ballistic Missile Defense

The 1990-1991 Gulf War, followed closely by the demise of the Soviet Union and the reduced perceived risk of a massive nuclear strike against the United States, changed the ballistic missile defense business. The Strategic Defense Initiative Organization became the Ballistic Missile Defense Organization.

Beyond the name change, the new organization concerned itself far more with Theater Ballistic Missile Defense than with strategic ICBM defense, and with engaging a few missiles rather than a massive strike with thousands of inbound warheads. Rather than protecting a significant fraction of the surface of the globe, relatively small geographic areas were to be defended. Directed energy weapons were largely abandoned, with emphasis ultimately shifted to ground-based kinetic interceptors such as what we now know as Patriot, Theater High Altitude Air Defense and Aegis. Improved interceptor performance permitted reliance on hit-to-kill kinetic energy impact, which also tended to yield greater damage to the threat warhead than blast/fragmentation warheads. The threat missiles of most interest were slower, shorter-range, and less sophisticated than emphasized under SDIO (e.g., the SCUD rather than the SS-18). The altitudes of intercept generally became lower.

While threat nuclear warheads remained of great concern, attention was suddenly turned to conventional explosive threat warheads and to payloads of other weapons of mass destruction, such as chemical and biological warfare agents. The latter trend was particularly significant because so much expertise in chemical and biological warfare had been lost from our defense community over the preceding decades as the United States dismantled its offensive chemical and biological warfare capabilities.

An intercept of a chemical or a biological agent payload does not "destroy" all the agent outright. The WMD material, like all other missile defense intercept debris, generally comes down somewhere. With theater ballistic missiles, that somewhere is usually in the theater of interest, and it may be inside the defended ground area. Furthermore, it became possible that under unusual circumstances an intercept-induced release of chemical or biological agent or warhead components might create a potential for ground personnel casualty collateral effects that rival or exceed that from the non-intercepted warhead.

Thus, under BMDO, greater attention was paid to the personnel casualty-producing collateral effects that might arise from a TBMD engagement, comparing those to the casualty effects that might occur from a non-intercepted ballistic missile.

A "Hit" Is Not (Necessarily) a "Kill"

Lethality of the interceptor (whether kinetic energy or directed energy) against the threat warhead naturally had always been an active program component in SDIO, and it remained an even more important program in BMDO. The ability to negate or "kill" the threat missile is, naturally, a key measure of the missile defense system effectiveness. The things that changed were a clearer recognition that greater interceptor lethality usually did result in lower ground effects consequences, but even very heavy mechanical destruction of the threat warhead might not completely negate the ground effects.

There are six different basic threat warhead designs of primary interest

- Nuclear (including multiple warheads on a bus)
- Unitary conventional High Explosive
- High Explosive Submunitions
- Unitary Chemical
- Chemical Submunitions
- Biological Submunitions

The damage inflicted on any of these by an interceptor missile can vary widely, depending on the characteristics of the threat warhead, the characteristics of the interceptor and the intercept geometry (including angles, speeds, and precise hit point).

A nuclear warhead contains high explosive to initiate the nuclear detonation. If that explosive is initiated by the intercept event without a full nuclear detonation resulting, then the nuclear material fragments and rains to the ground. The fragments can vary greatly in size, including extremely small particles that may be distributed on a global scale. The nuclear material is usually considered to represent a long-term but relatively minor radiation hazard. The results of a nuclear detonation are explained above, and unless the intercept is at an extremely low altitude, the only prompt effects on the ground will be EMP. If the warhead is not intercepted, or if the intercept fails to inflict sufficient damage, the full nuclear yield at the threat's design burst altitude can result in huge damage to ground structures and many thousands of personnel casualties.

The fragments of non-nuclear warhead component materials that fall to ground after a non-nuclear detonation may represent a personnel hazard just due to the kinetic energy of impact, but the chance of someone being hit is quite small. This low hazard of personnel casualties resulting from the various fragments of warhead structure that impact the ground is a common feature of all the threat warhead types, and this hazard likely is less than if the threat warhead itself simply hit the ground intact but without detonation.

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A unitary high explosive warhead contains a single, relatively massive high explosive charge. If it is detonated by the intercept event (usually considered a very likely result), then only fragments of warhead component materials will remain to fall to earth. If the unitary high explosive warhead is not engaged, or the damage inflicted at intercept is insignificant, then damage on the ground can affect a good portion of a city block and the dozens of people in it.

High explosive submunition warheads contain multiple weapons that separate from the reentry vehicle at some distance above the ground, depending on the submunition and warhead design. There may be as few as two submunitions or as many as hundreds. An intercept may destroy all of them, some of them, or none, depending on the details of the engagement. The surviving submunitions may or may not be capable of detonating when they reach the ground. Any detonating high explosive submunition will affect only the area immediately around it, depending on the size of the submunition. But the surviving submunitions may be scattered over a relatively large ground area, depending on the details of the engagement. A non-intercepted warhead will usually scatter the submunitions over a relatively small ground area by design so that the effects from adjacent impacting submunitions approximately overlap. The potential for personnel casualties can be greater or less than for a unitary high explosive warhead, depending on a variety of factors, but is still small compared to WMD warheads.

A unitary chemical warhead contains a single, relatively large, tank of chemical warfare agent. If the damage inflicted at intercept is sufficiently great, the tank will rupture, dispersing the chemical agent near the altitude of intercept. Whether the dispersed chemical agent represents a ground hazard depends critically on properties of the fluid and other circumstances, as discussed below. If the tank is not ruptured, then there will be some sort of ground hazard as the warhead impacts the ground or releases its agent at very low altitude. A non-engaged unitary chemical warhead can spread lethal contamination over several square kilometers under certain conditions, potentially creating thousands of casualties, though the number of casualties would depend greatly on the type of agent and whether ground personnel have taken cover.

A chemical submunition warhead presents generally the same situation as a high explosive submunition warhead insofar as submunition destruction and dispersal is concerned. The chemical agent contained in submunitions destroyed at intercept will be dispersed there and may or may not represent a ground hazard. Surviving submunitions will generally disperse their agent on or near ground impact. Less chemical agent is usually carried in submunition warheads as opposed to unitary chemical warheads, simply because of the added weight and complexity of the submunition warhead design, so the total casualty-producing potential is typically correspondingly less. But the potential number of casualties can still be several hundred, and the effects can be widely scattered with the intercept-dispersed surviving submunitions.

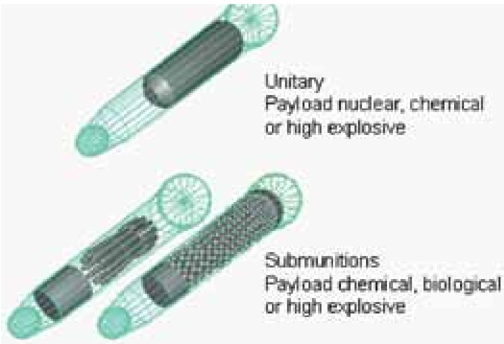
There are several critical differences between the ground effects resulting from warheads containing biological agent and chemical agent. A biological agent (e.g., anthrax) can be a thousand times more lethal to ground personnel than a similar weight or volume of chemical agent. (Some biological agents are not intended to be lethal, but rather to inflict some debilitating effect other than death.) This very high lethality makes a unitary biological warhead less likely to encounter simply because it would be a very inefficient use of the agent. A submunition warhead, on the other hand, can be designed to spread the agent effectively over a very wide ground area. The high lethality of the biological agent means that many more people can be affected, very far downwind. The casualty - creating potential might equal that of a nuclear weapon.

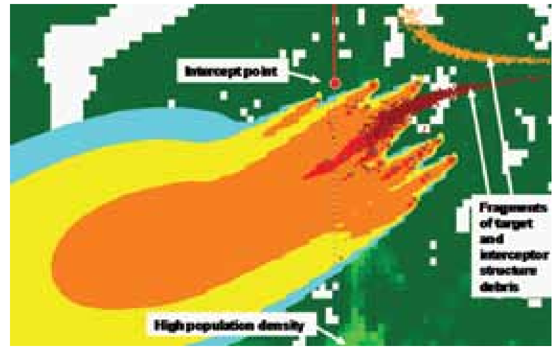
Another critical difference is that the biological agent is typically dispersed in very small particle size, on the order of a few micrometers in diameter, so that the particles may be inhaled by the ground population. (Chemical agent typically achieves its effect by drops contaminating one's skin or by the inhalation of vapors.) The small particle size means that any biological agent released at the point of intercept would not fall to ground for many hours or days. This is important because a final critical difference is that the biological agent is typically sensitive to solar ultraviolet radiation, becoming ineffective after prolonged exposure to direct sunlight. So the biological agent released at intercept altitude is unlikely to be effective when it reaches the ground. The biological agent collateral effects resulting from an intercept thus are determined first by the number of submunitions surviving to ground impact. But due to the high lethality of the agent contained in the individual submunitions, even a small fraction of the original warhead payload can affect thousands of ground personnel.

Collateral Effects Sensitivities

The severity of the ground personnel casualty collateral effects resulting from a missile defense intercept varies tremendously with the particular circumstances, ranging from negligible (structural fragments falling into the ocean) to very large (many biological submunitions falling into a highly populated area). There are many parameters that contribute in a complex and non-linear fashion. Several computer tools have been developed specifically to address these issues and predict the results of an intercept, so this discussion is only an overview of some of the most important considerations.

The threat properties are critical. Especially, what is the warhead type? Within each warhead type, what are the design characteristics of the payload? For instance, is the chemical agent highly volatile, intending to create casualties from vapor inhalation, and therefore likely to evaporate on its way to the ground when released at intercept altitude? Or is the chemical agent thickened and non-volatile, intending to create





FROM LEFT TO RIGHT (1) Ballistic missile generic warhead types. (2) Patriot (PAC-3) intercept of a ballistic missile target in 2000. (3) Sample prediction of collateral effects from an intercepted biological submunition warhead. Orange area has an incidence of biological effect on 50 percent or more of personnel. Note 10-km scale on lower right.

casualties from liquid deposition, and therefore likely to fall to the ground in a hazardous form even if released from tens of kilometers in altitude?

The interceptor properties are important. Is it a large interceptor or a small one? Does it kill with a hit-to-kill body-to-body strike or with a blast/fragmentation warhead? Coupled with this, especially with a hit-to-kill intercept, the engagement geometry makes a vital difference. What is the overlap of the two bodies? Where is the strike point: a solid hit in the payload bay of the threat warhead, or a glancing blow in a non-critical area such as an attached booster component? What are the angles? What is the closing speed between the threat and interceptor? The higher the closing speed, the higher the kinetic energy available for payload destruction.

The absolute speed of the threat might play an important role, independent of the closing speed between the threat and the interceptor. The threat speed is usually directly related to its ground range. A short-range theater missile (e.g., the original SCUD) travels more slowly than a long-range ICBM. The higher the speed, the more likely that intercept debris, including submunitions or slightly damaged warheads surviving the intercept event, will demise due to atmospheric heating. Higher speed means that dispersed chemical agent is more likely to break into very small drops or evaporate outright, thus less likely to result in casualty-producing hazardous ground contamination.

The altitude of the intercept is important. The ground scatter of all debris, both the width of the pattern and its centroid location, including surviving submunitions, depends on the altitude. The drop size of dispersed liquid chemical agent depends upon the altitude as well as the threat reentry speed, and the drop size is critically important in a determination of the potential collateral effects.

Environmental conditions are vitally important, especially the winds at all altitudes from the intercept point to the ground surface. The air turbulence and weather conditions such as cloud cover, time of day, temperature, atmospheric pressure, humidity and precipitation can all play a role. The ground surface condition can be important, including whether it is heavy forest or uninterrupted sand, as can terrain features, whether flat prairie, mountains and valleys, or tall city buildings.

Finally, the ground personnel population itself is critical. Is the affected area densely populated, or largely deserted? Are people indoors or outside? Do they have any sort of protection against WMD effects? Is it a general population including the very old, the very young and the sick, or is it solely a healthy male population of young Soldiers?

Today

Intercept-induced collateral effects remain a concern today, though the level of concern varies from year-to-year, program-to-program, and country-to-country. The concern also varies whether the collateral effects are measured in terms of personnel casualties, political impact from effects on a third-party nation, or disruptive effects on the missile defense system. The concern also varies with several closely related concepts: intercept lethality (damage inflicted on the threat warhead), hit assessment (whether/where the interceptor hit the threat missile), kill assessment, collateral effects consequence management, and warhead typing (determination of the warhead type).

The study of collateral effects remains active because there are many unresolved technical issues, and the knowledge impacts plans for missile defense deployment. It is hoped that a good understanding of the expected collateral effects can be used to minimize those effects by an intelligent choice of the intercept conditions: interceptor type, engagement location, angles and altitude.

But while being concerned about collateral effects, one must never lose sight of a fundamental tenet of missile defense: it is nearly always best to conduct an intercept rather than let the threat missile do the damage intended by our adversary, placing an extraordinarily destructive warhead in our population centers.