

Technical Debate over Patriot Performance in the Gulf War: American Physical Society Panel Correctly Rejects Criticisms of Analysis Showing Patriot Failed to Destroy Scud Warheads

George N. Lewis^a and Theodore A. Postol^b

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INTRODUCTION

From 1991 through 1993, we carried out a detailed study of the performance of the Patriot system in attempting to destroy Iraqi Scud (Al-Hussein) missiles during the 1991 Gulf War. This work was based in large part on analyses of news media videos of Patriot-Scud engagements. We found that the actual success rate for Patriot against the Iraqi missiles was very low, and most likely was zero.¹

a Dr. George N. Lewis is Associate Director of the Security Studies Program at the Massachusetts Institute of Technology, Cambridge, Massachusetts.

b Theodore A. Postol is Professor of Science Technology and National Security Policy at the Massachusetts Institute of Technology, Cambridge, Massachusetts.

For comparison, the U.S. Army initially assessed Patriot to be 96% effective, and this claim was subsequently reduced in several stages to about 61%, which is the currently claimed success rate. Today the U.S. Army continues to claim that Patriot “did what it was designed to do in terms of knocking down most of the SCUD missiles which were fired at it.”²

Our analysis was immediately attacked by persons associated with the U.S. Army, the Raytheon Company (the prime contractor for Patriot) and others. These criticisms were based on arguments that were either irrelevant or incorrect (or both) but nevertheless succeeded at least to some extent in obscuring public and congressional awareness of the failure of the Patriot system to destroy the Iraqi missiles. Given the importance of this issue, and the fact that the debate revolved around technical and scientific issues, we asked the American Physical Society (APS) to examine our analysis and the objections raised by our critics. In effect, we asked the APS to provide a scientific and technical “peer review” of our work and of the claims of our critics.

In the spring of 1993, the Panel on Public Affairs (POPA) of the APS appointed an ad-hoc panel (hereafter referred to as the “POPA Panel”) to look into the technical questions surrounding the debate over Patriot performance. This Panel held a meeting in Washington, DC in May 1993 at which we, some of our critics, and others made presentations. In November, 1993, the Panel submitted its report to POPA.³ One of the recommendations of that report was that “APS/POPA appoint a small team to prepare a short article about the current status of the debate over the performance of the Patriot system in the Persian Gulf War, suitable for publication in *Physics Today*, *Science*, or an equivalent technical journal.” POPA subsequently asked the six members of the Panel to write just such an article. The result was the report, “Technical Debate over Patriot Performance in the Gulf War,” by Jeremiah D. Sullivan, et.al., published in *Science & Global Security* in 1998. This report (hereafter referred to as the “POPA Panel report”) rejected all of the arguments made by our critics and concluded that our work produced “a physically consistent interpretation of all the phenomena observable in the videos together with all the other pertinent data available in the public domain.”⁴ It further found that our analyses showing that the Patriot success rate was zero or near zero were “insensitive to minor changes in their analysis and are demonstrably inconsistent with success rates reported by the Army for the performance of the Patriot system in the Gulf War.”⁵

We are disturbed by the fact that the POPA Panel took five years to produce an article that we believe could have been written in a few months. This long delay reduces the value of their report. Nevertheless, the major findings of the POPA Panel Report are both clearly laid out and correct.

In contrast, we find that Robert M. Stein, John P. Kantelis, and Peter D. Zimmerman in “Response to *Science & Global Security* Article ‘Technical Debate over Patriot Performance in the Gulf War’ by Jeremiah Sullivan et al.,” (hereafter referred to as “SKZ”) make many incorrect and misleading arguments in an apparent attempt to discredit the findings of the POPA Panel.⁶

As we will show, SKZ make no valid arguments that call into question any of the POPA Panel’s major findings. We focus on the main points that SKZ attempt to make (for clarity we discuss them in a different order than SKZ). Below, we first summarize our major points; the rest of this article then discusses each point in much greater detail.

(1) SKZ argue that our analysis showing that an intercept attempt that appears to be a clear miss on the videos must in actuality be a miss (an analysis confirmed by the POPA Panel) is incorrect. They construct a scenario which they claim shows how an intercept attempt that appears to be a miss on the videos could actually be a successful intercept. We will show that this argument by SKZ is completely wrong. SKZ construct their argument about what is seen on the videos using a “true” Patriot fireball size that is much smaller than the fireballs actually seen in the videos. With the use of the correct fireball diameter, SKZ’s argument fails completely. It is difficult to understand how SKZ could make such an obvious and egregious error, given the intense scrutiny that has been focused on this issue, and that a member of SKZ conceded before the POPA Panel that the Patriot fireballs were indeed large. SKZ then go on to argue that their small “true” fireball size could be consistent with the much larger Patriot fireballs actually seen in the videos. We show that this argument is both logically and mathematically incorrect. Finally, quite aside from the above errors, we note that SKZ’s scenario is invalidated by the use of a critical parameter value that is far outside the range of values that actually occurred in the Gulf War videos.

(2) SKZ claim that classified “hard evidence” was found in recovered debris that showed that Patriots had killed the Scud warheads in two engagements in which the videos clearly showed that all the intercept attempts were clear misses.⁷ Together with their (incorrect) scenario discussed in (1) above, they argue that this classified data shows that there are engagements in which the videos show only clear misses but in which the Scud warhead was actually hit. We will show, using SKZ’s own description of the recovered debris, that this classified evidence in fact provides no evidence whatsoever for Patriot success, and indeed is fully consistent with the Patriot interceptors missing the warhead by a large distance, as the videos prove. More generally, the U.S. Army, Raytheon, and others have repeatedly argued that the Army has classified physical evidence that proves Patriot’s success. We will show

that such claims cannot be taken seriously, given the inability of the Army to produce this claimed “hard data” for congressional investigators and given the history of incorrect claims regarding classified data that have occurred throughout the Patriot debate.

(3) SKZ raise questions regarding our identification of the falling object seen in the videos as the Scud warhead, a finding that was confirmed by calculations carried out by the POPA Panel. SKZ present calculations that they ambiguously portray as calling into question the POPA Panel’s conclusions. We will show that the calculations presented by SKZ in no way challenge the POPA Panel’s calculations and findings confirming that the falling object seen in the videos is in fact the Scud warhead. In fact, SKZ’s calculations simply confirm part of the POPA Panel’s calculations, but do so over a much wider range of initial conditions than those assumed by the POPA Panel.

(4) SKZ dispute our analysis that proved that the bright flashes of light seen in the videos when the warhead reaches ground are the explosions of the Scud warheads, an analysis that was confirmed by the POPA Panel. Specifically, SKZ argue that the POPA Panel’s assessment of the ground light flashes is flawed because they misunderstand the U.S. Army’s definition of a “dud” Scud warhead, and thus undercount the number of non-exploding warheads. We will show that this claim is incorrect, that the POPA Panel does not undercount the number of non-exploding warheads, and that the POPA Panel’s definition of a “dud” warhead is exactly the same as the Army’s definition. SKZ also incorrectly argue that the POPA Panel only considers whether the flashes seen in the videos are consistent with warheads exploding on the ground, but ignores other possible causes. In fact, the Panel did consider other possibilities, including both of those raised by SKZ, and *rejected* them.

(5) SKZ argue we have established criteria for assessing Patriot performance that “all but guarantee” that Patriot could not be assessed as achieving a successful intercept. SKZ further argue that a successful intercept would not be recognized on the videos, because the detonation of the Scud warhead would not “vaporize” the rest of the Scud, and so objects would be seen emerging from even a successful Patriot intercept. Both of these arguments are incorrect. We will show that all of our criteria for assessing the failure of an engagement are valid and reasonable. We will also show that a successful intercept would have an outcome that would be quite evident on the videos. The fact that such outcomes are never seen on the videos is not due to our criteria for assessing success or failure, but due to the failure of Patriot to destroy Scud warheads.

(6) SKZ argue that one of us (Postol) “eventually backed away from his earlier claims” that ground damage data in Israel demonstrated that Patriot

did not work as claimed. We will show that, in fact, Postol's "earlier claim" is now known beyond doubt to be correct. Indeed, Postol did later change his assessment on what the ground data damage can reveal about the U.S. Army's claims of Patriot success, but only because the Army changed its claimed Patriot failure rate by a factor of ten (a fact not noted by SKZ).

(7) Although SKZ do not discuss this issue, nevertheless, the reader may wonder how the U.S. Army could have assessed Patriot as having a 61% success rate (an assessment endorsed by Raytheon), when the publicly available videos clearly prove the Patriot was a complete or near complete failure. We urged the POPA Panel to also review in detail the U.S. Army's assessment of Patriot's effectiveness. Because the Army's data was classified, the Panel chose not to do so, simply noting that the Army's approach could have introduced an "upward bias" in their claimed success rate.⁸ We will show that the U.S. Army's methodology (which is unclassified) for assessing Patriot success is clearly and deeply flawed, and show how such a flawed methodology can be used to obtain the Army's claimed success rate even when absolutely no success was actually achieved.

(8) Finally, SKZ argue that there is now "virtually no significance" left in the debate over Patriot effectiveness in the Gulf War. They argue that the Patriot system has changed significantly since 1991, and thus analysis of its performance in the War has little relevance today. However, the true significance of the Patriot experience lies not in such narrow technical issues, but instead centers on questions of accountability and credibility. It is unacceptable that the U.S. Army, supported by a major defense contractor, should be able to present the U.S. Congress and the American people with a completely invalid assessment of the performance of a major weapons system, and subsequently obtain a multi-billion dollar upgrade of that system.

In addition, in the near future, the United States will be facing many crucial decisions about ballistic missile defenses, decisions that will inevitably be colored by the false perception that the only time the United States has used a missile defense, the defense worked. The central issue confronting these defenses will be their ability to defeat efforts by missile attackers to defeat the defenses (countermeasures), a problem missile defense supporters say they can solve, but can't say how because of classification. The Patriot experience emphasizes not only that missile defenses must be able to deal effectively with countermeasures, but also that the assessment of these defenses' ability to defeat such countermeasures cannot be left in the hands of those with vested organizational and financial interests in the systems.

Background

One of the major problems in assessing Patriot's performance during the Gulf War was the quality of the available data collected by the U.S. Army. In general, Patriot batteries collected only limited types of target and interceptor track data, and even this was not routinely collected (it required the operator to push a button to print out just the current data). Towards the end of the War, video cameras were installed in some batteries to record what was displayed on the radar and control screens. Portable data recorders that would have recorded far more detailed radar data were only installed in Israel towards the end of the war (at Israeli insistence) and recorded only three engagements. Although the Israelis performed systematic searches for and analyses of ground impact sites, this did not happen in Saudi Arabia.

In the course of our work, we found that the news media videos of Patriot-Scud engagements in fact appear to provide the best single source of information about the outcomes of these engagements. These nighttime videos from the Gulf War typically show the cameras picking up the Scud as an incandescent falling object. As the Scud falls, it is generally seen to break up, producing a series of flashes and a cloud of debris. This break-up took place whether or not the Scud was engaged by Patriot. One object, and only one object, is seen to emerge from this break-up and continues to the ground at a high rate of speed, typically reaching the ground in 9 to 15 seconds.⁹ Using simple physics, it is straightforward to show that the warhead of the Scud can reach the ground in the time observed *and* that no other part of the Scud can do so. Thus the observed falling object must be the Scud warhead. With the exception of one Scud warhead that is known to be a dud, when this falling warhead reaches the ground a bright flash of light is seen. We have shown that this flash must be due to the Scud warhead exploding.

Patriot missiles are often seen in the videos attempting to intercept the Scud, both before and after the observed Scud breakup. When the Patriot warhead detonates, it produces a large fireball on the video screen. If the Scud is well outside of the Patriot fireball at the moment of detonation, we label this a "clear miss," and have presented analysis proving that the Patriot detonation could not have damaged the Scud warhead. If the fireball covers the Scud as seen on the videos (a "fireball overlap") then one cannot tell just from the location of the Scud and Patriot at the moment of detonation whether or not the Patriot intercept attempt was successful. This uncertainty results from both the large size of the fireball as seen in the videos (100 meters or more, much larger than the Patriot warhead's kill radius) and an uncertainty of up to about 70 meters in the actual position of the Scud at the time of the

Patriot detonation due to video frame time effects. However, the videos often provide additional information that allows a determination of success or failure. For example, if the Scud warhead is seen emerging unchanged from the intercept attempt and continuing on to the ground and/or the Scud warhead is seen exploding on the ground, then it is clear that the intercept attempt did not succeed in detonating the Scud warhead.

Next we consider in detail the main points summarized in the introduction.

(1) "Clear misses" are actually misses

We first consider the argument made by SKZ that intercept attempts that we label as "clear misses" could in fact be hits. SKZ devote over a quarter of their paper -- ten full pages (including three figures) -- to this argument. SKZ construct a scenario which they argue shows that an intercept attempt that appeared to be a clear miss could actually have been a hit. Based on this scenario, they then argue that our analysis "...has the potential, on occasion, to classify a successful intercept incorrectly as a clear miss."¹⁰ Their argument is completely wrong, for several reasons:

(a) Their argument relies on a profound conceptual error. Specifically, their argument requires the use of a relatively small Patriot fireball diameter. They use a value for this Patriot fireball diameter which is far too small and which is completely unrelated to anything seen on the nighttime Gulf War videos. Such an error is highly surprising, since the size of the Patriot fireball has been perhaps the most intensely debated aspect of the video analysis, and at the May 1993 meeting organized by the POPA Panel one of SKZ conceded that the Patriot fireballs seen on the videos were indeed quite large.

(b) SKZ construct a mathematically incorrect argument to claim that the so-called "true" fireball they use in their analysis could be consistent with the much larger Patriot fireballs actually seen in the videos. This argument relies on varying two parameters while holding a third parameter constant. But this third parameter is inversely proportional to both of the first two parameters! When this error is corrected, it is clear that SKZ's small "true" fireball cannot be consistent with the much larger fireballs seen in the videos.

(c) Their argument relies on using a crucial parameter value (for the camera viewing angle) that is far outside the range of values that were actually seen on the videos.

(1a) SKZ's scenario is invalidated by its use of an incorrect Patriot fireball diameter

SKZ's scenario depends crucially on the use of a Patriot fireball diameter that is far too small.

First, some additional background information is needed.

Because the video only has a frame rate of 30 frames per second, the Scud moves a distance $V_{\text{SCUD}}/30$ between each video frame, where V_{SCUD} is the speed of the Scud.

When a Patriot warhead detonates, it produces a fireball that persists for many video frames. This fireball is essentially stationary in space, and thus provides a reference point that can be used to measure the motion of the Scud as seen on the video. If the Patriot fireball, on the first frame it is seen, covers the location of the Scud, we refer to this event as a "fireball overlap." In such a case one cannot determine whether the Patriot has hit or missed the Scud based only on the location of the Scud and the Patriot detonation as seen on the video.

However, in the large majority of the intercept attempts seen on the videos, the fireball and Scud are clearly separated, with the Patriot fireball in almost all cases located behind the Scud. Note that because of the large closing speeds involved, the Patriot must explode ahead of the Scud if fragments from its warhead are to strike the Scud warhead.

In principle, however, even if the Patriot detonation appears on the video to be behind the Scud, it may still be possible for the Patriot detonation to have occurred ahead of the Scud, so that its warhead fragments could actually hit the Scud warhead. This is because the actual position of the Scud at the moment of the Patriot detonation is uncertain by a distance of $V_{\text{SCUD}}/30$ due to the frame rate of the videos. This distance can be as large as about 70 meters.¹¹

However, we have shown unambiguously that such an occurrence could not have happened on any of the "clear misses" seen on the videos. Thus any intercept attempt that appears to be a miss on the videos is in fact an actual miss.

A key parameter in our analysis is the size of the Patriot fireball as seen on the videos. If the Patriot fireball as seen in the videos is extremely small, say five to ten meters, than indeed it would be possible for an apparent miss to actually be a hit. If a somewhat larger fireball diameter is used, for example the 25 meter diameter used by SKZ in their scenario, then while it is still theoretically possible for an apparent miss to be a hit, such an outcome requires the use of a set of parameters (such as the camera viewing angle) that are well outside those that actually occurred in the intercept attempts seen in the vid-

eos.

However, we have shown that the Patriot fireball diameters seen on the videos are in fact much larger than the 25 meters used by SKZ, with diameters of order 100 meters or larger. In this situation, it is *impossible* for an apparent miss to actually be a hit. The POPA Panel confirmed our analysis demonstrating this, and SKZ raise no valid challenge to either our original analysis or the POPA Panel's confirmation of this analysis.

The previous debate over the Patriot fireball diameter

Given the central importance of the large size of the Patriot fireballs as seen on the videos to the debate on Patriot effectiveness, the reader might wonder why the POPA Panel did not devote considerable space to discussing this issue. The reason is simple: the main critics of our analysis, Peter Zimmerman and Robert Stein (respectively the "Z" and "S" of SKZ), had already conceded this point at the 1993 meeting with the POPA Panel.

A simple calculation of the size of the fireball, based on the distance that the combustion products from the detonation would travel before being stopped by atmospheric drag, gives a fireball diameter of about 10 meters. However, the apparent sizes of the fireballs seen on videos are considerably larger than such a calculation would indicate.

We had shown, prior to the 1993 POPA Panel meeting, using test range video footage, that *daytime* Patriot fireballs appear to be about 25 meters in diameter. However, in the *nighttime* Gulf War videos, the fireballs appear to be much larger. It hardly seems surprising that fireballs appear larger at night than during the day, and the POPA Panel suggests a number of possible explanations, including "atmospheric effects, internal scattering within the camera optical system, focal plane saturation, or a combination of such effects."¹² We have published detailed analysis, based on cases in which the location of both the video camera and the Scud impact point were known, that conclusively demonstrated that the fireballs seen in the videos were very large, with diameters of 100 meters or more.¹³ The APS Panel reviewed our analysis, and agreed with it. No one has ever raised any valid objections to these analyses, and SKZ do not even attempt to do so. In fact, as we discuss next, they have already conceded that the nighttime fireballs do appear much larger.

Prior to the May 1993 POPA Panel meeting, Peter Zimmerman had submitted to Congress a paper arguing that the fireball diameters seen on the videos would be about 8 to 10 meters (based on a calculation of the stopping distance for the explosion's combustion products) and thus that what appeared to be a clear miss could be a hit.¹⁴ However, as noted above, we had

unambiguously demonstrated -- based on data from the videos -- that the fireballs seen in the video were much larger, of order 100 meters or more. Moreover, we also showed that Zimmerman's assumed small fireball diameter led to fatal inconsistencies, such as requiring that all the Scuds must have impacted much closer to the camera locations than was known to have happened.

At the May, 1993 POPA Panel meeting, Peter Zimmerman, in a presentation coordinated with one by Robert Stein, conceded that the nighttime fireballs were indeed much larger than those seen in daytime (or than would have been expected based on the stopping range of combustion products). According to the first report issued by the POPA Panel (the report which led to the Panel being asked to prepare the paper that was published in *Science & Global Security*): "By the time of the ad hoc panel's meeting, Zimmerman had concluded that the large fireball size seen in the videos could be due to blooming, other camera artifacts, atmospheric effects, or perhaps some combination of these effects."¹⁵ The POPA Panel report thus only briefly discusses this history, concluding that this 25 meter daytime Patriot fireball is "far smaller" than the fireballs that actually appear in the videos.¹⁶ It does not analyze this issue in detail, presumably because the POPA Panel believed that this issue was now completely resolved.¹⁷

The fireball size in SKZ's scenario

In order to be able to construct a scenario in which an apparent miss could be a hit, SKZ needed to use a Patriot fireball diameter as seen on the videos that is not much more than about 25 meters in diameter. But as discussed above, it has already been established that the Patriot fireballs seen on the videos have diameters of order 100 meters or larger. How do SKZ justify using this 25 meter fireball diameter rather than the much larger fireball diameter actually seen on the videos? They don't. SKZ do not challenge the fact that the Patriot fireballs seen in the nighttime videos are very large -- a fact which has been supported by detailed analysis, which was noted by the POPA Panel in their Report, and which, as noted above, had already been conceded by Zimmerman at the POPA Panel meeting.

Instead, they simply construct their scenario using what they call a "true" fireball diameter that is much smaller than the Patriot fireball seen in the videos. Here is how they justify using this fireball size:

"The [POPA] Panel reports a value in note 38 where they say 'An unclassified daytime photo of an interception at White Sands Missile Range of a Lance missile by Patriot PAC-2 shows a fireball diameter of about 25m.' How much of the 25m diameter is an artifact of the camera, even in daytime, is not

known. Here, to be conservative, we have selected the larger 25 meter true diameter for our example scenario.”¹⁸

Thus although they cite the POPA Panel Report as the source for the 25 meter fireball diameter they use, SKZ do not mention that the POPA Panel Report says this 25 meter fireball was “far smaller” than the fireballs seen in the videos. Thus SKZ simply use a 25 meter fireball saying that this diameter has been seen in a daytime intercept. They then use this so called “true diameter” in a discussion of what would be seen on the video screens, even though this “true diameter” has nothing at all to do with what is seen on the video screens, where what is seen is the much larger nighttime fireball diameter. SKZ’s “true diameter” simply has no relevance to what is seen in the videos.

If SKZ had used Patriot fireballs of the size actually seen in the videos in their scenario, their argument would fail completely. Instead, they simply choose a diameter for the Patriot fireball that allows them to make the argument they want, in complete disregard of the absolutely clear evidence and data on the size of the Patriot fireballs seen in the videos.

(1b) SKZ’s argument that their 25 m fireball diameter is consistent with what is seen on the videos is logically and mathematically incorrect.

SKZ make a mathematically and logically incorrect argument that their 25 meter “true” fireball, if observed over the range of Scud velocities and viewing angles seen in the videos, could actually appear to be very large and is thus consistent with the large fireballs seen in the videos. SKZ construct this argument by varying two parameters, while holding a third parameter constant, even though this third parameter is inversely proportional to both of the other parameters!

SKZ correctly state that the fireball size seen on the videos can be calculated using the equation:

$$\text{Fireball Diameter} = \#JDV * V_{\text{SCUD}} * \sin(\theta) / 30$$

In this equation, V_{SCUD} is the velocity of the Scud and θ is the angle between the Scud’s velocity vector and the camera viewing direction. Thus the camera sees a Scud speed of $V_{\text{SCUD}} * \sin(\theta)$. Since the camera has a frame rate 30 frames per second, the camera sees a Scud motion per frame of $V_{\text{SCUD}} * \sin(\theta) / 30$. Equivalently, this quantity is the distance the Scud is seen to “jump” between successive video frames, and is known as the video jump distance, referred to as JDV by the POPA Panel. If we then measure the ratio of the Patriot fireball diameter to this video jump distance, and call this ratio #JDV (again using the POPA Panel’s terminology), we get the above equation, which gives the Patriot fireball diameter as seen on the videos.

In the scenario SKZ constructed to argue (incorrectly) that clear misses

could be hits, for example, they use $\theta = 7$ degrees and $V_{\text{SCUD}} = 1$ km/second and a fireball size of 25 meters. This gives an apparent Scud motion per video frame of $1,000/30 * \sin(7^\circ) = 4.06$ meters and thus a #JDV of $25/4.06 = 6.2$.

SKZ then claim that assessing this equation using the limits of the values we cite for the Scud's velocity and viewing angle (from 6 to 37 degrees) and a constant value of 6.2 for the #JDV taken from the scenario they constructed, shows that their 25 meter fireball is consistent with the much larger fireballs seen in the videos. Plugging in these numbers, they get fireball diameters ranging from 43 to 274 m, which they claim demonstrates that their assumed 25 m fireball is consistent with the 100 meter and larger fireball sizes seen in the videos.

This argument is clearly absurd. Not only does their calculation mix actual data (for V_{SCUD} and θ) with a value for #JDV that is derived from a number – the 25 m “true” fireball diameter –that has nothing to do with what is seen on the videos, but their use of a constant value of #JDV in this argument ignores the fact that for the fixed 25 meter value of the fireball diameter they are assuming, #JDV is inversely related to both V_{SCUD} and $\sin(\theta)$.

For example, SKZ argue that if one uses another set of Scud parameters, $\theta = 21.5$ degrees and $V = 2.1$ km/second, and holds #JDV constant, then their 25 meter fireball would appear to be 159 meters in diameter. But one cannot simply hold #JDV constant, since as noted above it is inversely proportional to both $\sin(\theta)$ and V . If they had done this example correctly, they would have noted that for a 25 meter fireball, the parameters they have chosen for θ (21.5 degrees) and V (2.1 km/second), give a value for #JDV of 0.97. Not surprisingly, when this error is corrected, one finds that their 25 meter fireball will remain a 25 meter fireball as other parameters are varied, and their argument that their 25 meter fireball is consistent with what is seen on the videos is clearly wrong.

(1c) SKZ's scenario depends on an incorrect parameter value

In fact, even with their arbitrarily selected and incorrect Patriot fireball diameter, SKZ's scenario still fails, since their scenario requires the use of a value for a key parameter which is far outside the range of values that actually occurred in the intercept attempts on the videos.

Aside from their incorrect fireball diameter, SKZ need two other key assumptions in order to make their scenario work: a relatively low intercept altitude (so the Scud velocity would be relatively low), and a Scud approaching nearly directly at the camera (7 degrees off).¹⁹ This combination of low altitude and small viewing angle does not correspond to any of the clear misses

observed on the videos.²⁰

While the most intercept attempts occurred at higher altitudes (7 to 12 km), some did occur at lower altitudes. Thus the altitude of 5 km used by SKZ, while far from typical, is possible.

However, SKZ use a figure for the viewing angle of 7 degrees, which is far too small. SKZ give the reader the impression that the 7° viewing angle they use in their calculation is consistent with the values of observed in the videos, since they note that we report a minimum value of 6°. However, what they neglect to tell the reader is that our angles are calculated using the distance between Scud impact points and the camera location, and that the resulting viewing angle is a function of the altitude of intercept attempt. As is clearly explained in Appendix B of our *Video Evidence* paper, the extreme minimum value for of 6 degrees is calculated assuming an intercept altitude of 10 km.²¹ If one wishes to use a different altitude, one must scale accordingly: for the 5 km altitude they use, one gets an extreme minimum value of 13°. Had SKZ used a valid value of in their scenario, it would have failed. Even with their wrong fireball size, in order to construct their engagement scenario, SKZ need to use a parameter value that falls well outside those seen in the videos.

(2) “Hard Evidence” of Patriot Success

SKZ claim that in two engagements in which the videos show that all the Patriots fired at the Scud warhead were clear misses, there exists classified “hard evidence” that proves these engagements were successful. They go on to argue that combined with their scenario that shows how clear misses could actually be hits, this “hard evidence” demonstrates that there were cases in which there were only clear misses on the videos, yet the Patriot hit the Scud warhead.

But we have already shown that SKZ’s argument that clear misses could in fact be hits is wrong. Intercept attempts that appear on the videos to be clear misses are in fact misses.

So how can SKZ claim there is hard physical evidence of Patriot success in two cases in which all the Patriots clearly missed the Scud? First we will show, based on SKZ’s own description, that this “hard evidence” actually provides no evidence at all for Patriot success, and that, in fact, it is entirely consistent with all the Patriots missing the Scud warhead, as the videos show they did. Then we will more generally show that claims that there is classified evidence supporting Patriot success cannot be regarded as credible.

(2a) The two cases of "hard evidence" cited by SKZ

First consider the two cases cited by SKZ for which they say there were only clear misses on the videos, but for which they say there is "hard evidence" showing Patriot succeeded. Their description of this "hard evidence" is as follows: "in one case, recovered Scud debris with Patriot fragment holes and in the other, recovered debris imbedded with Patriot warhead and guidance parts."²² These descriptions are very similar to the official descriptions of these two cases taken from the U.S. Army's ground damage assessment database:

- Small crater (and recovered debris with fragment holes) not indicative of high order ground detonation
- Recovered debris with possible warhead parts (with serial numbers) and guidance implies no explosion at impact.²³

However, note neither SKZ nor the Army database description say that the recovered Scud debris are from the Scuds' *warheads*. This is certainly not the case for the second Scud described above, where they say parts from the Patriot warhead were found in the debris, since it is known that no Patriot fragments were recovered from any Scud warhead.²⁴ Thus it appears clear that the Scud debris referred to by SKZ is not Scud warhead debris, but debris from some other parts of the Scud.

Finding Patriot damage to a part of a Scud other than the warhead provides absolutely no evidence at all of Patriot success. In fact, it would not be surprising to find evidence of a Patriot warhead detonation in Scud debris, because in both of these engagements, the Patriot detonations occurred well behind the warhead where, following the Scud breakup, so was the rest of the Scud. Thus in these engagements, the Patriot may well have fused on the body of a Scud or other Scud parts that were trailing well behind the warhead. Moreover, it is now known that 30% of all the Patriots fired in the Gulf War were not even fired at Scud warheads, but at Scud debris (and another 15% were fired at non-existent targets).²⁵

However, such evidence provides absolutely no evidence that Patriot in any way damaged the Scud *warhead*. Moreover, as we discuss in (2b) below, in general any claims about classified evidence of Patriot's success need to be viewed with considerable skepticism.

So there is no conflict at all between the videos and the ground data. The videos clearly show the engagements failed, and the classified evidence cited by SKZ provides no evidence for Patriot success.

(2b) General claims that classified data shows that Patriot succeeded.

More generally, claims that there is classified physical evidence that clearly

supports claims of Patriot success have been made before. But when Congressional investigators, with security clearances allowing them access to the classified data, looked into such claims, they found that the claimed evidence did not exist:

“The Army did not have evidence of any scientific analysis performed on a Scud warhead to determine whether, in fact, the marks found on the Scud warheads were caused by Patriot fragments or by ground impact or detonation. These assertions are based in each case on the opinion of a single individual, sometimes recorded months after the event. In one case they are based on the opinion of a Patriot Program Office Official who told the GAO he had seen a classified photo of a warhead and in his opinion the damage could only have been caused by a Patriot. He refused to show the photo to the GAO on the grounds that it was too highly classified, a claim later proved to be incorrect.”²⁶

Moreover, recovered Scud warheads that were not even fired at by Patriot were found to have suffered damage similar to that claimed as being evidence of Patriot’s success. Responding to a claim similar to that made by SKZ, that there was “clear physical evidence” that Patriot caused Scuds to be duds, Representative John Conyers, then chairman of the House Committee on Government Operations that conducted the Congressional investigation into Patriot’s performance stated that:

“The duds were often burned and broken from impact, but this was hardly ‘clear physical evidence of Patriot intercept damage,’ although in one case an Army officer thought a Patriot fragment caused a hole. This opinion was not supported by any chemical or metallurgic analysis or recovery of a fragment. Duds not engaged by Patriot showed similar damage.”²⁷

The questionable validity of claims of Patriot damage to Scud warheads is well illustrated by a discovery made by the Congressional investigators reviewing classified data that supposedly supported claims of Patriot success. They found that “a photograph purportedly depicting a Scud warhead disabled by Patriot actually pictured a Scud fuel tank.”²⁸

Other claims that there was classified evidence proving Patriot success have also not held up under closer examination.

In 1992, Robert Stein wrote: “Overall, the success rate of Patriot against TBMS fired into Saudi Arabia was very high. A group of U.S. ordnance experts from the Army’s Ballistic Research Laboratory (BRL) performed an independent assessment and published their findings in a classified report.” “Given the circumstances of a wartime environment, the investigation was as thorough as humanly possible.” “The Army’s publicly released figure of greater than 80 percent TBM warhead kills in Saudi Arabia is based on this investiga-

tion.”²⁹

However, when Congressional investigators looked into these claims, they found that this report had not been performed by a team, was not independent, and certainly was not “as thorough as humanly possible.” In fact the report was found to be based on one engineer from BRL whose investigation was limited to interviewing several Army warrant officers and visiting several Scud impact sites “days or weeks after an impact” when “craters had often been filled and missile debris removed.”³⁰ Moreover, even though this report was cited as the basis for assessing all engagements in Saudi Arabia, it only contained information on one-third of the engagements.³¹

In summary, the U.S. Army has claimed that it has clear physical evidence of Patriot success. However, when challenged by Congressional investigators to produce this evidence, it was unable to do so. Now we have SKZ claiming that such classified proof of Patriot success actually applies to two Scuds in which we have clearly and unambiguously demonstrated that no Patriot could have in any way damaged either Scud warhead. However, as we have shown above, even without access to the classified data, the description of the evidence by SKZ makes it clear that it in no way shows that Patriot was successful in either of these engagements. This example simply makes it even clearer that Army claims of classified physical evidence proving Patriot’s success cannot be taken seriously.

(3) Identification of the Scud warhead and intercept altitudes

SKZ raise questions regarding the nature of the falling object seen in the videos and about the calculations performed by the POPA Panel which confirmed our analysis proving that the falling object must be the warhead. They devote two full pages plus three figures to this discussion.³² There appear to be two separate issues mixed together here, which for clarity we will separate out.

(a) First, SKZ appear to be challenging our conclusion, confirmed by the POPA Panel, that the falling object seen in the videos must be the Scud warhead. Clearly the identification of the falling object as the warhead is central to the analysis of the video tapes. Resolving the question of whether or not the falling object was the warhead was in fact the *only* reason the POPA Panel carried out the falling object calculations that SKZ discuss. SKZ carry out their own calculations on falling objects seen in the videos, and come to the conclusion that -- “*the fall times are consistent with nearly any situation one might choose to analyze*”(italics in original). This ambiguously stated conclusion is clearly meant to imply that our analysis and its confirmation by the

Panel is flawed. However, we will show that SKZ actually do not raise any questions that call into question our finding, confirmed by the POPA Panel, that the falling object seen in the videos must be the warhead. In fact, we will show that SKZ's calculations simply support part of the POPA's Panel analysis, but over a wider range of initial conditions.

(b) SKZ use their calculations to argue that Scud breakups could have occurred over a wide range of altitudes and still be consistent with what is seen on the videos, and thus that intercept attempts could have involved much lower altitudes and Scud speeds than the typical values cited by us and the POPA Panel. They then use such a lower intercept altitude and Scud speed in their incorrect scenario, discussed above in (1a), that attempts to argue that a clear miss could actually be a miss. However, the fact that some engagements occurred at lower altitudes and involved lower Scud speeds has never been in dispute, and raises no problems for our analysis or conclusions. In fact, in our original *Video Evidence* paper we analyzed in detail two engagements that occurred at altitudes *lower* than the 5 km altitude SKZ consider in their scenario.³³

(3a) Is the falling object the Scud warhead?

We proved that the falling object seen in the videos must be the Scud warhead with a simple two part argument:

-First, it can be shown that the Scud warhead could reach the ground in the times observed in the videos. So the falling object seen in the videos *could* be the Scud warhead.

Second, no other part of the Scud other than the warhead could possibly reach the ground in the times observed. Thus the falling object *must* be the Scud warhead.

The first part was demonstrated by our analysis showing that for a reasonable range of altitudes for the intercept attempts (roughly 7 to 12 km), an object with the characteristics of the Scud warhead can reach the ground in the times observed (9 to 15 seconds). While this shows that the object could be the Scud warhead, it does not prove that it must be. For this we need the second part of the argument.

The second part of this argument is that it is easily shown that no other part of the Scud could possibly reach the ground in the times observed. This is true for a Scud that is intact except for the warhead section as well as for any other component part of the Scud, such as the fuel tanks, rocket motor, turbo pumps, etc. All such parts would take roughly one minute to reach ground, not the ten seconds seen in the videos. Thus we demonstrated that all such objects take much longer than the observed time to reach the ground.

Taken together, these two observations demonstrate that the object seen falling in the videos both can and must be the Scud warhead section. The POPA Panel independently confirmed our calculations. These are not difficult calculations to perform or understand – in fact, they have also been used as a problem set for freshmen engineers at Cornell University.

Our published analysis focused on the times to ground for a detached Scud warhead, not on a complete Scud, for two reasons. First, as far as is known, most or all of the Scuds broke up. Second, an intact Scud would reach the ground from a given altitude somewhat more rapidly than a detached warhead, so if the warhead could reach the ground in the times observed, so could the intact Scud. So the possibility that some of the Scuds may not have broken up in no way affects our argument.

Although SKZ repeatedly raise questions about the identification of the falling object seen on the videos and although they directly discuss the calculations the POPA Panel carried out to confirm our proof, they limit their discussion to only the first part of the argument, which shows that the falling object *could* be the warhead.

SKZ carry out calculations which they summarize with an ambiguous statement, cited above, that is clearly meant to imply that our analysis is flawed. However, what they actually show is that over a broad range of assumptions on the altitude of the Scud breakup –varying from 5 to 50 km – and also including the possibility that the Scud does not break up, the Scud warhead could reach the ground in the times observed.³⁴ What they are in fact demonstrating is that our first point – that the Scud warhead *could* reach the ground in the times observed -- is correct over a much wider range of assumptions on Scud breakup altitude than we used.

Thus SKZ present an argument that supports our first point -- that the falling object can be the warhead (although through the use of ambiguous wording, it is portrayed as a criticism of our analysis). However, they do not even mention the second part of our argument that demonstrates that the falling object could not be any other part of the Scud and thus *must* be the Scud warhead.

SKZ argue that “In its commentary and analysis, the Panel limits its attention to merely verifying that the P&L analysis and conclusion are consistent with the facts. Once again, however, they do not consider the existence of *otherequally* consistent scenarios.”³⁵ This is obviously incorrect. The calculations done by the POPA Panel, which were carried out for the sole purpose of establishing the identity of the falling object seen in the videos, not only established that it was the warhead, but also ruled out the possibility that it could be due to other parts of the Scud.³⁶

The bottom line is that we presented a proof that the falling object seen in the videos must be the warhead, and this proof was confirmed by the POPA Panel. No valid argument challenging this proof has ever been raised, nor do SKZ even attempt to do so. There can be no doubt that the falling object seen in the videos is indeed the Scud warhead.

It is also worth noting and expanding on an observation briefly made by the Panel. There is no dispute that following the breakup of the Scud, the warhead continued on with a much higher speed than the rest of the Scud, as has been noted by Stein and others.³⁷ Indeed this was how Patriot operators determined which part of the Scud to fire at following the breakup of the Scud – the leading object was the warhead. The Panel noted that if the object seen in the videos actually was not the warhead but was some other part of the Scud, then the warhead must be *ahead* of the observed object. However, almost all of the Patriot intercepts in the videos were at or *behind* the object seen in the videos. Thus if the object seen in the videos is not the warhead, then it is clear that Patriot's performance is even worse than we would argue – it would not even be getting close to the actual target. This is only one example of the kind of contradictions that arise if one looks more than superficially at the arguments SKZ make.

(3b) Typical and non-typical intercept altitudes and Scud speeds

SKZ argue that we (and the POPA Panel) only considered "typical" engagements, and that our analysis is not necessarily correct for non-typical engagements. This is simply wrong.

First, SKZ question our and the POPA Panel's use of a typical Scud velocity of 2.2 km per second at the intercept attempts and a typical intercept altitude of 10 to 12 km.

In fact, the typical Scud velocity at the intercept has been widely acknowledged to be about 2.2 km per second (or even higher) by many, including the U.S. Army, Raytheon, and Peter Zimmerman.³⁸ These high Scud speeds clearly indicate that typical intercept attempts took place at about 10 km or higher, since otherwise the speeds would be lower. So it is clear that our and the Panel's use of these figures as "typical" is fully justified.

However, the primary point of SKZ's argument appears to be that there could have been intercepts that took place at much lower altitudes and closing speeds than the typical values. They then argue that we failed to consider the possibility of low-altitude, slower-Scud speed intercept attempts, stating "Failure to consider these 'non-nominal' situations is one of the many oversimplifications limiting the applicability of P&L's work."³⁹ This argument by SKZ is transparently false. There is no dispute that such lower altitude and closing

speed intercept attempts took place. (The Israelis apparently deliberately attempted at least one such intercept in an unsuccessful effort to get around problems with Patriot's fuze.) In fact, we identify and analyze in considerable detail two such engagements in our *Video Evidence* paper, both of which occurred at *lower* altitudes than the 5 km altitude SKZ use in their scenario, and which have much shorter times to ground after the intercept attempt (4.2 and 5.6 seconds) than occur in more typical intercept attempts.⁴⁰

Such cases of lower intercept altitudes present no problems for our analysis. As we saw in 1(a) above, SKZ's claim that such low intercept altitudes could be used to construct an example in which a Patriot clear miss could actually be a hit is simply wrong.

(4) Ground flashes and Scud warhead explosions

Having established both that the falling object is indeed the Scud warhead and that the misses seen on the videos are indeed misses, we next turn to the question of the flash seen when the falling warhead reaches the ground. We have shown that this flash must be exactly what it appears to be -- the explosion of the Scud warhead. The POPA Panel reviewed our analysis and agreed with our assessment.

SKZ incorrectly argue that the POPA Panel only considers whether the flashes seen in the videos are consistent with being due to the warhead exploding, but ignore other possible causes. In fact, the panel did consider a range of other possibilities, including both those once again raised by SKZ, and *rejected* by them. The Panel concludes: "No interpretation of the ground flashes other than detonations has been put forth that is consistent with all the data contained in the commercial videos and public record."⁴¹

There is no doubt about what an exploding Scud warhead looks like on the videos. In at least five cases in which Scud warheads are known to have exploded on the ground causing extensive ground damage and/or casualties, the videos show the Scud falling to the ground followed by the flash from the warhead explosion. These Scuds include the one that hit the U.S. barracks in Dhahran killing 28 U.S. soldiers, as well as the only Scud in Saudi Arabia to cause a civilian death.⁴²

The videos show 18 Scuds that were engaged (or should have been engaged) by Patriot falling and impacting the ground. In 17 of these 18 cases, the flash from the warhead explosion is seen when the Scud reaches ground.⁴³ In the only case in which a flash is not seen (Tel Aviv, February 19), the Scud is known to be a dud, which according to Israeli sources had nothing to do with

Patriot.⁴⁴

We have already proven that the falling object seen in the videos is the warhead. When this object reaches the ground, the warhead will explode, and thus the flash seen when the falling object reaches the ground must be the warhead exploding. The only possible exception is if the Scud warhead fails to explode. However, we have shown that the number of Scuds that did not explode on impact is very small (and some of these are known not to have produced a flash on the videos), and thus could not be responsible for the flashes consistently seen on the videos. Moreover, we have shown that all other explanations for the flashes fail. This analysis was confirmed by the POPA Panel. SKZ make two primary arguments here:

(a) They argue that there may be many more warheads that did not explode than the POPA Panel acknowledges, because the POPA Panel has an incorrect understanding of the Army's definition of a dud. This argument is clearly wrong.

(b) They once again raise the incorrect argument that the flashes seen in the videos could be due to something other than a warhead explosion, specifically kinetic energy impacts or detonation of remaining fuel in the Scud's tank, arguments the POPA Panel has already assessed and rejected.

We discuss both of these arguments in more detail below:

(4a) How many duds?

The POPA Panel notes that when the Scud warhead reaches ground it must either explode or be a dud and notes that the Army states that only three Scuds engaged by Patriot were duds (and that two others exploded with reduced yield), and that two of these three duds are already known not to have produced one of the flashes seen in the videos. Thus the flashes *consistently* seen when the warhead reaches ground must be the warhead exploding.

SKZ challenge this assessment, arguing that the POPA Panel's key error is that their definition of a dud is different than the Army's. SKZ states that: "The central error in all of this is that the word 'dud,' which is the key to the Panel's logic, means something different to them than it does as used by the Army."⁴⁵ SKZ also argue that the Panel does not consider the fact that there were other warheads that did not explode but were not classified as duds by the Army.

First, the POPA Panel defined a "dud" as a warhead that failed to explode on impact. SKZ get this much correct, stating "The panel defines a dud as any Scud that does not explode when it hits the ground." The official U.S. Army definition is that a dud warhead is one that is "damaged to the point that no explosion takes place when the TBM [tactical ballistic missile] impacts the

ground (called a duded warhead).⁴⁶ Thus, contrary to what SKZ state, a “dud” means the same thing to both the Army and POPA Panel -- a warhead that does not explode on impact.

Second, SKZ argue that the Panel failed to take into account the fact that there were other Scud warheads that did not explode, but were not classified by the Army as duds. SKZ state that “Indeed other non-exploding warheads did occur as evidenced by the existence of very small craters at the impact point – craters not at all consistent in either diameter or depth with those created by high-order explosions– and by the lack of other high-order detonation damage to the surrounding area.”⁴⁷ Note that, in fact, SKZ’s description of these warheads as “non-exploding” is somewhat confusing, since these are not warheads that did not explode at all (which by definition would be classified as duds). Rather as the second half of their sentence makes clear, these are warheads that the Army claims did not produce full yield explosions (high-order explosions in SKZ’s terminology).⁴⁸

The Army does indeed claim that this happened in Scuds engaged by Patriots, and describes them as “low-yield kills.”⁴⁹ However, the Army also states only two Scud warheads fall into this category.⁵⁰ This fact was fully understood and accounted for by the POPA Panel, which states that “A greatly reduced yield is also a possibility, but the Army reports only two cases of this during the Gulf War” and that their “low yield is inconsistent with extensive ground damage or a significant ground flash.”⁵¹

Thus SKZ’s argument that the Panel’s analysis is flawed because it does not understand the Army’s definition of duds is clearly wrong. SKZ attempt to cast doubt on the Panel’s analysis by implying that there were significant numbers of warheads that did not explode with full yield but that were not classified by the Army as duds. However, there were only two such Scuds (a fact noted by the Panel but not by SKZ), and the POPA Panel’s assessment was in fact based on a correct understanding of the number of duds and warheads that exploded with less than full yield.

So let us summarize the situation with regard to duds and “low-yield” events. According to the Army’s assessment, only three of the 44 Scud warheads engaged by Patriot were duds and another two were scored as “low yield detonation” successes.⁵² Prior to SKZ’s paper, it was already known that two of the Scuds classified as duds did not produce ground flashes on the videos – in one case because no ground flash was seen and in the other because the Scud was not followed all the way to ground by the camera. But now SKZ add the additional information that “on only one of these three do P&L have videos all the way to the ground.”⁵³ Since we know that the one that was followed to ground did not produce a flash (Tel Aviv, February 19), it is now clear that

none of three duds reported by the Army caused a flash on the videos, since the other two are not followed to the ground on the videos. Thus dud warheads cannot be responsible for any of the flashes seen in the videos.

What about the two “low-yield” warheads classified by the Army as successful “mission kills?” It is known that one of these two claimed mission kills did not produce a ground flash on the videos.⁵⁴ This leaves only one possible non-high-yield exploding warhead left to account for.

Thus it is absolutely clear that at least 16 of the 17 ground flashes must be due to Scud warhead explosions. As we will see, it is also essentially certain the other ground flash was as well, since as the POPA Panel noted, all other alternative explanations for the ground flashes fail.⁵⁵

This brings us to a simple and powerful, albeit non-technical, argument not made by the POPA Panel (or by us previously). SKZ have access to the classified Army data, and have clearly performed detailed correlations of it with the video data. They know which Scuds were duds and which two were assessed by the Army as low yield mission kills. They also know which Scuds produced the 17 ground flashes we assess as warhead explosions. If any of these 17 flashes was associated with a dud (or a low yield mission kill), then SKZ could make an extremely powerful argument simply by stating that this was the case. However, even though they make several other assertions about the videos based on data in the classified record, they do not make this simple, powerful and obvious argument. It is difficult to draw any conclusion from this other than that they cannot.

(4b) Alternative causes of ground flashes

SKZ argue that the flash seen when the warhead reaches the ground could be caused by something other than the warhead exploding, specifically that it could be due to the fuel in the Scud’s fuel tank or due to the kinetic energy involved in a high speed impact. They imply that the panel simply dismisses these possibilities without considering them.

In fact, the POPA Panel Report devotes a paragraph to the possibility that the flash is due to the fuel in the Scud’s fuel tank, but rejects this argument, concluding that “the burning fuel mechanism fails as an alternative explanation.”⁵⁶ Quite aside from the conclusion in (4a) above, the Panel rejects this possibility because a Scud fuel tank cannot reach the ground in the times observed, except as part of an intact Scud, in which case the warhead would be expected to explode. SKZ’s response to this is to claim that the Panel’s conclusion is incorrect because the Panel does not understand the Army’s definition of a dud, a claim we have already shown to be false.⁵⁷

SKZ state that the POPA Panel, in its discussion of the ground flashes, “never even mentions” the possibility that the flashes could result from the kinetic energy of an intact Scud impacting the ground.⁵⁸ However, the Panel was clearly aware of this argument, since it mentions it twice in other sections of its report, and it is clear that its rejection of all explanations for the light flashes other than a warhead explosion applies to this argument as well.

SKZ argue that an intact Scud (one that did not break up during reentry) with a non-exploding warhead could impact the ground with enough kinetic energy to produce a ground flash. We have already shown above in (4a) that this possibility could account for at most one of the 17 observed ground flashes. In fact, however, their kinetic energy impact theory fails to explain even that one possible event.⁵⁹

Note that SKZ do not say that there actually were any intact Scuds with non-exploding warhead that impacted the ground – which would be an unmistakable event, and one that they would certainly be aware of.⁶⁰ In fact, according to the manager of the Patriot Project Office during the Gulf War, only one Scud did not break up – and that Scud’s warhead is known to have exploded on impact.⁶¹

SKZ then attempt to argue that a non-exploding scud warhead that “broke off late in flight” could have impacted the ground at high speed, producing the ground flash. However, Scud breakups are dramatic events that are clearly visible on the videos, and no such low altitude events are seen anywhere on the videos, much less for any of the Scuds that are seen falling and exploding on the ground. Moreover, even if such an event occurred, the energy densities involved are far too low to produce the ground light flashes seen in the videos.⁶²

(5) Criteria for success or failure

SKZ claim that our criteria for success or failure “Virtually Guarantee 100% ‘Failure.’”⁶³ This claim relies in large part on their claim that the videos cannot reveal the difference between a failed intercept and one that detonates the Scud warhead because in both cases one will see a fireball with objects emerging from it. Both of these claims are incorrect.

(5a) Do our criteria for assessing Patriot performance “Virtually Guarantee 100% ‘Failure.’”?

What are our criteria for assessing a failure? SKZ discuss four factors that would lead us to assess an engagement as being a failure. They argue that using these criteria make it virtually impossible for an engagement to be

scored as anything but a failure. This is plainly absurd, as even a casual look at these criteria shows:

First, if there is extensive ground damage or casualties due to the Scud, we classify the engagement as a failure. This criteria is self-evident and SKZ state that they agree with it.

Second, if all the Patriots that are fired at the Scud clearly miss it, we classify the engagement as a failure. Again, we believe this is self-evident.

Third (SKZ list this one fourth), if the Scud warhead is seen to explode when it reaches the ground, we classify the engagement as a failure. This one is also self-evident.⁶⁴

The fourth criterion (third, in SKZ's ordering) is the only one even needing any explanation -- that in an engagement involving a fireball overlap, if the Scud emerges from the intercept attempt with no change in either its appearance or trajectory, we assess the intercept attempt as unsuccessful. This case applies to three Scuds out of the forty-four engaged (the camera did not follow these three Scuds to the ground so there was no possibility of seeing them explode on the ground).

We have argued that, following an intercept attempt that results in a fireball overlap, if the Scud warhead is unaffected in either appearance or trajectory, then it is reasonable to conclude that the intercept attempt failed.⁶⁵ Certainly it is clear in such cases that the Patriot neither caused the Scud warhead to detonate nor pushed it significantly off its course (which the Army claims it accomplished twice). A Patriot detonation that caused the Scud warhead to burn in flight or caused such serious structural damage to the Scud warhead that it only exploded with a low yield would also be accompanied by a change in the appearance or trajectory of the Scud warhead. This leaves only the possibility that fragments produced by the Patriot warhead detonation damaged the fuzing mechanism of the Scud warhead, causing it to be a dud, and did so without changing either its appearance or trajectory.

First we note again that according to the Army, only three Scuds engaged by Patriots were duds. We do not believe that there is any basis for believing that Patriot actually caused any of the duds, particularly since, as previously noted, even though the dud warheads were recovered, the U.S. Army was unable to produce any physical evidence for Congressional investigators demonstrating that Patriot caused the duds. Moreover, the Congressional investigators also found that duds that were not engaged by Patriot showed damage similar to that claimed as evidence of Patriot success in duds that were engaged. In any event, for one of the claimed duds, the videos do not contain a fireball overlap, in another there was a fireball overlap AND a significant change in the behavior of the Scud warhead.⁶⁶ So at most one of these three

intercept attempts on the videos could possibly have led to a Scud being a dud.

We have also argued that it is very unlikely that a Patriot could have caused a Scud to become a dud without affecting its appearance or trajectory. In order for this to happen, a Patriot fragment would have to strike and destroy a critical fuzing component located adjacent to the Scud warhead without striking the warhead and detonating it or damaging it enough to change its appearance. Moreover, none of the other very large number of Patriot fragments could do so either. While it can not be ruled out with mathematical certainty that a “seeing-eye” fragment struck a fuzing component while neither it nor any of the other thousand or more fragments struck the much larger warhead, this clearly is an improbable event. Thus we believe, in the absence of any evidence for Patriot causing a dud, it is entirely justifiable to count events in which a Patriot detonation in no way affects the appearance or trajectory as failures.

Thus we would assess an engagement as a failure if it caused extensive ground damage, if all the Patriots fired clearly missed the Scud, or if the Scud warhead is actually seen exploding on the ground. These are absolutely clear and obvious demonstrations of Patriot failure, and as SKZ note, 83% of the Scuds we assess fall into one of these categories. In fact, a very large majority of the engagements we assess satisfy more than one of these criteria. In addition, we assess three engagements in which a Patriot came close enough to a Scud to produce a fireball overlap as failures based on the intercept having no effect on either the appearance or trajectory of the Scud. These are straightforward and reasonable criteria, and a Patriot intercept attempt that successfully destroyed a Scud warhead would not meet any of them.

(5b) Can a successful engagement be distinguished from a failure?

We have demonstrated that there is a great deal of evidence for failed Patriot engagements on the videos, but no evidence for successful intercepts. This is not because, as some have argued, there would be no visible evidence of a successful Patriot intercept. In fact, a successful intercept that detonated a Scud warhead would have a clear and unmistakable signature on the videos: there would be a fireball overlap, and nothing would be seen emerging from the fireball on a high-speed trajectory towards the ground.

SKZ incorrectly argue that this would not be the case. First, they spend several pages arguing that on the videos the detonation of a Patriot warhead probably could not be distinguished from detonation of both a Patriot warhead and a Scud warhead.⁶⁷ However, this point has never been in dispute – we stated that this difference might not be observable in our original *Video Evi-*

dence paper.⁶⁸

SKZ then argue that a successful intercept that detonated the Scud warhead would not be recognized on the videos, because since the Scud would be “neither annihilated nor vaporized” by the detonation of its warhead, parts of the Scud such as its fuel tanks or combustion chamber would be seen continuing onward.⁶⁹ This is simply incorrect. Neither we nor the POPA Panel have argued or believe that the detonation of the Scud warhead would “vaporize” the Scud. Rather what we have shown is that following the breakup of a Scud (a breakup caused by atmospheric forces, not by Patriot), one and only one part of the Scud is seen continuing onward, and we have proven that this object must be the Scud warhead. Other parts of the Scud, such as the fuel tanks, do continue onward, but they are rapidly slowed by atmospheric drag to much lower speeds and are not visible on the videos.⁷⁰ If a Patriot caused a Scud warhead to detonate, there would also certainly be large parts of the Scud remaining, but as in the case of a breakup caused by atmospheric forces, these other parts would slow rapidly and not be visible on the videos.

Thus a Patriot intercept attempt that succeeded in detonating a Scud's warhead would have a very clear signature. There would be a fireball overlap, indicating that the Patriot had detonated at least in the general vicinity of the Scud. Following the intercept attempt, the Scud warhead would not be seen continuing onward, nor would it be seen exploding on the ground nor would it cause extensive ground damage. This is *neverseen* to happen.

(6) Ground damage statistics

SKZ state that one of us (Postol) backed away from claims that a comparison of damage and casualties before and after Patriot was operational in Israel showed that Patriot was not working as claimed. This is simply false.

SKZ state: “The [POPA Panel] report fails to mention that Postol himself eventually backed away from his earlier claims...”⁷¹ They further approvingly cite Gregory Jones from the American Institute for Strategic Cooperation who states: “...in a more recent publication, Postol retreated from his earlier position...But rather than acknowledge his retreat, he attempts to mask it by changing his analysis in a way that lacks a methodological basis.”⁷²

These “earlier claims” were made at a April 1991 hearing before the House Armed Services Committee where Postol noted that the casualties and damage per Scud after Patriot became operational were comparable to and in some categories greater than the damage per Scud before Patriot was operational.⁷³ This finding was clearly incompatible with the official statements on Patriot effectiveness at that time, which were that it was 96% effective – or equivalently that only 4% of the Scuds got through. This level of effectiveness meant

that even if all the Patriot failures occurred in Israel (none in Saudi Arabia), only two Scuds fell in the areas defended by Patriot after it became operational. Postol noted that the damage and casualty data was inconsistent with such a low failure rate, and as more information came out, he was proven to be correct. After Postol's testimony, the official claims for the Patriot success rate in Israel were lowered in a series of steps to where they are today – over 40%.

By the time of his “more recent” publication, his article in the Winter 1991/92 issue of *International Security* Postol had indeed changed his assessment of what could be concluded from the damage and casualties in Israel – but only because it had since been admitted by the U.S. Army that its previous claims about Patriot's failure rate were more than a factor of ten too low!⁷⁴

For highly inaccurate missiles like the Scuds used in the Gulf War, large statistical fluctuations in casualties and damage per missile are unavoidable. This situation is reflected in the fact that 90% of the deaths directly caused by the Scuds were caused by one Scud – the one that struck the U.S. barracks in Dhahran.⁷⁵ If the impact point of this Scud had been moved a few tens of meters, the fatalities produced by the missile attacks would be vastly different. Conversely, moving some impact points in Israel a similar distance might have resulted in much higher fatalities there.

Given these large statistical uncertainties, while one could clearly show that the casualty and damage data was clearly inconsistent with a 4% failure rate (if for no other reason than there were known to be considerably more than two Scuds causing serious ground damage), they could be consistent with a 50-60% failure rate. However, they could also be consistent with a very wide range of possible failure rates, including a 100% failure rate. Thus after the U.S. Army lowered their claims of Patriot effectiveness, Postol correctly concluded that, from the casualty and damage statistics alone, one could not determine what Patriot's effectiveness was, nor whether the then current claims for Patriot success were valid or not. This finding was subsequently confirmed by Fetter, et. al.⁷⁶ SKZ do not seem to be claiming anything different.⁷⁷ They say their own figures “are not inconsistent with the Army's score in Israel of achieving a success rate of ‘over 40%.’”⁷⁸

Thus, contrary to what SKZ state, Postol never backed away from his “earlier claims” that the casualty and damage statistics were incompatible with the then claimed 96% success rate, and he was subsequently proven to be correct. Rather, as the official claims for Patriot success in Patriot were lowered, he correctly revised his analysis to reflect these greatly reduced claims of Patriot effectiveness.

(7) How the U.S. Army Assessed Patriot's Gulf War Performance

We have presented a clear and unambiguous case that Patriot's success rate in destroying Scud warheads was very low, and most likely was zero. Our data and evidence are public and have been subject to intense examination. Yet, as the flawed arguments raised by SKZ once again make clear, no valid criticisms that would affect our conclusions have ever been raised.

Nevertheless, one might wonder how this could be the case, given that the U.S. Army says that it has carried out a detailed study of Patriot performance that reaches a very different conclusion – that Patriot had an overall (combining both Israel and Saudi Arabia) 61% success rate, a conclusion that Raytheon endorses. However, this Army assessment is based on a flawed methodology that produces a greatly inflated success rate, and in fact which could produce the Army's claimed results even if Patriot did not actually destroy a single Scud warhead. This conclusion is *entirely independent* of our own assessment of Patriot's performance based on the videos.

The Army classified an engagement as a success if it could satisfy three criteria.⁷⁹ (1) An engageable Scud must be present, (2) The "PATRIOT must intercept the Scud (i.e., detect, launch, and guide to intercept)," and (3) "There must be no significant ground damage."

The first criterion -- requiring that an engageable Scud be present -- clearly is trivial.

Criterion 2 -- that Patriot must "intercept" the Scud -- might sound like a more demanding requirement. However, the term "intercept" does not imply that the Scud was hit or in any way damaged, it only means that at least one Patriot flew out to the general vicinity of the Scud. As then U.S. Army Program Executive Officer for Air Defense General Robert Drolet defined it in the April 7, 1992 House Government Operations Committee Hearing, intercept means "that a Patriot and Scud crossed paths, their paths in the sky."⁸⁰ The data that can be used to satisfy criterion 2 are extremely weak indeed; examples include statements by Patriot operators after the event (with no actual system data), "descriptions of events in general terms" by civilian eyewitnesses, and even news media videos, which by simply showing that an intercept *attempt* occurred would allow criterion 2 to be satisfied.⁸¹ While there was at least one notable exception, it appears that the Army was able to satisfy criterion 2 for the large majority of the engagements.⁸² However, this criterion provides absolutely no information about whether or not Patriot actually destroyed the Scud's warhead.

By satisfying criteria 1 and 2, the Army is in effect establishing that a Scud was present and that at least one Patriot fired against it did not grossly malfunction. All that is then needed in the Army's assessment methodology to

declare such an engagement to be a success is that it be able to satisfy criterion 3-- that no significant ground damage occurred. In actual practice, this means that there was no significant *reported* damage – as discussed in (2b) above, the ground damage assessment in Saudi Arabia was far from adequate.

The Army defines “significant damage” to mean a “high yield detonation which results in personnel casualties or significant ground damage to major structures (e.g., structural damage, walls caved in, etc.).”⁸³ In order to cause damage of this type, the Scud warhead must detonate within at least a few tens of meters of such a “major structure.”

Even in cases where Patriot radar tracking data indicates that the Scud would have impacted in a completely uninhabited area (such as the sea or desert), the resulting lack of damage is still taken as positive evidence that allows Criterion 3 to be satisfied.⁸⁴ Moreover, even if there is unambiguous evidence that a Scud warhead hit the ground and exploded, the Army’s methodology would still allow the engagement to be classified as a success. Consider a case in which criteria 1 and 2 were satisfied, but a large crater and Scud warhead fragments were found at the impact site, providing clear proof that a high-yield warhead explosion took place and that Patriot failed. However, unless this impact point was quite close to a “major structure” so that it could produce “significant ground damage to major structures (e.g., structural damage, walls caved in, etc.),” according to the U.S. Army assessment methodology, this engagement would be scored as a success.

The crucial question here is what fraction of the Scuds would have been expected to cause significant damage in the absence of Patriot. The Army’s methodology simply assumes that this figure is 100%. This is a clearly incorrect assumption, and one that completely invalidates its methodology.

The targets of the Scud attacks were either on a coast (Tel Aviv, Haifa, Dhahran port) or in the desert (Riyadh, King Khalid Military City, Dhahran airfield). These targets were protected by multiple Patriot batteries, and in every case, the coverage of Patriot extended well beyond densely populated areas into uninhabited areas. Assuming that a Patriot battery defended an area with a radius of roughly 10 km, maps of the Dhahran and Haifa areas indicate that much less than half the defended area is built up. For Tel Aviv, this figure appears to be closer to, but still less than 50%. For Riyadh, it is not possible to estimate this figure without more data on the number and location of the Patriot batteries; however, the figure is certainly nowhere near 100%. Moreover, even within the populated areas, there are many places where warheads could fall and still be nowhere near a major structure. Thus, it is clear that the fundamental assumption on which the Army’s assessment is based -- that every Scud would cause significant damage if not successfully intercepted

by Patriot -- cannot be correct. About the best defensible statement that can be made is that something like $50\% \pm 25\%$ of the missiles falling within Patriot defended areas would be expected to cause significant damage. This indicates that even if the Patriot failed completely, the U.S. Army's methodology could be expected to produce a claimed success rate of roughly $50\% \pm 25\%$.

This conclusion is strongly supported by two examples from the Gulf War. First, at least ten Patriots dove into the ground and exploded during the war. These were potentially very highly destructive events, involving very high speed impacts by missiles with high-explosive warheads and, in most or all cases, containing hundreds of pounds of unburned solid rocket fuel (as illustrated by video showing burning solid rocket fuel hurtling through the streets of Tel Aviv following a Patriot ground impact). Yet according to Raytheon, two thirds of these Patriot impacts caused no damage or only superficial damage. This gives a "significant damage" rate per missile of about 33%.

Second, there were about 12 Scuds reaching Israel before Patriot was operational. The number of these that would have been engaged by Patriot had it been operational cannot be known for certain, but is between 7 and 11.⁸⁵ Of these, it appears that at most four caused "significant damage," that would have led them to be assessed as failed engagements.⁸⁶ This indicates that the percentage of engageable Scuds causing significant damage is somewhere between 36% and 57%.

The above discussion makes it clear that it is not valid to simply assume that every Scud impacting in areas defended by Patriot will produce significant damage to major structures. In fact, it is not valid to assume that even the majority of them will. Even if Patriot had a zero success rate, the methodology established by the Army guarantees that a significant fraction of all the engagements will be assessed as successes. Using the Army's methodology, a success rate of 61% (the currently claimed figure) can be produced even if Patriot did not destroy a single Scud warhead.

(8) Significance of the debate

SKZ argue that the debate over Patriot performance no longer has any significance:

"All of the above aside, we believe there is virtually no significance to either the Patriot system or to theater missile defense as a whole left in this protracted debate. Both the Patriot system today (which has undergone two major upgrades since the war) and the evolution of other theater missile defenses are not directly related to any of P&L's analyses or issues, even according to the Panel."⁸⁷

But this argument entirely misses the point. Clearly Patriot is different today, in part due to some of the shortcomings the war revealed. And the new Patriot PAC-3 interceptor, soon to be deployed, will significantly improve Patriot's anti-missile capabilities. We have never argued that Patriot's failure in the Gulf War demonstrates that improved versions of Patriot or other theater missile defenses would not work.⁸⁸

Rather the significance of the Patriot debate today centers around questions of accountability and credibility.

It is simply unacceptable that the U.S. Army, supported by a major defense contractor, should be able to present the U.S. Congress and the American people with a completely invalid assessment of the performance of a major weapons system, and subsequently obtain a multi-billion dollar upgrade of that system. Yet our analysis clearly indicates that this is what happened, and is continuing today.

It is important to consider what can be done to prevent future misrepresentations of the performance of defense systems. Clearly, allowing the owner and operator of a weapons system, supported by its manufacturer, to be solely responsible for assessing its performance is not the way to get an unbiased assessment of performance. The Patriot case vividly illustrates the need for a mechanism for independent review of the performance of defense systems.

A related issue is the way classification has been used both to shield Patriot's Gulf War performance from scrutiny and, as SKZ's article illustrates, to argue for Patriot's success. Despite SKZ's argument that the Gulf War experience has virtually no significance for the current Patriot system, virtually all of the data collected by the Army remains classified. There is no valid reason for much of this information to remain classified. For example, even the assessed outcomes of individual engagements, which the Army freely discussed during the War, are now classified.

The United States will be facing many crucial decisions about ballistic missile defenses over the next few years. The experience with Patriot in the Gulf War, the United States' only actual experience with using ballistic missile defenses, will inevitably color perceptions about the feasibility and effectiveness of these future defenses.

In particular, this year the United States is scheduled to make a decision on whether or not to begin deployment of a national missile defense (NMD) system. Perhaps not surprisingly, both the U.S. Army and the Raytheon Company are playing central roles in the system: The Army is the lead service for the NMD system and Raytheon is the contractor for several of the NMD system's key components including the Exo-atmospheric Kill Vehicle (EKV) intended to actually destroy the target and the radar that must track and dis-

criminate the target.⁸⁹

The central factor that will determine the effectiveness of the NMD system is its ability to defeat steps an attacker might take to defeat it -- countermeasures. Patriot failed in the Gulf primarily because of an apparently inadvertent countermeasure introduced by the Iraqis -- the Iraqi-modified Scuds broke apart and maneuvered vigorously on reentry into the atmosphere. Countermeasures have always been the fundamental problem facing ballistic missile defenses, and they remain so today.

Critics of the NMD system have pointed out that states capable of building the intercontinental-range missiles the NMD system is intended to counter will also be capable of building countermeasures capable of defeating the system.⁹⁰ Supporters of NMD system claim that they know how to solve the countermeasure problem, but that they can't say how because of classification.⁹¹ In fact, even though there has not yet been a single intercept test involving a credible decoy or other countermeasure, it is claimed that the problem of countermeasures has in effect already been solved.⁹²

The experience with Patriot in the Gulf War highlights not only the need for missile defenses to be able to deal effectively with countermeasures, but perhaps most importantly demonstrates that the assessment of the ability of the planned NMD system (and other missile defense systems) to defeat such countermeasures cannot be left in the hands of those with a vested interest in the deployment of the system.

NOTES AND REFERENCES

1. The video analysis is presented in George N. Lewis and Theodore A. Postol, "Video Evidence on the Effectiveness of Patriot during the 1991 Gulf War," *Science & Global Security*, Vol. 4 (1993), 1-63. See also Theodore A. Postol, "Lessons of the Gulf War Experience with Patriot," *International Security*, Vol. 16, No. 3 (Winter 1991/92), 119-171; and Theodore A. Postol, "Correspondence: Patriot Experience in the Gulf War," *International Security* Vol. 17, No. 1 (Summer 1992), 225-240.
2. Lt. General Paul Kern, Department of Defense News Briefing, March 23, 2000.
3. Jeremiah Sullivan (chair), Dan Fenstermacher, Daniel Fisher, Ruth Howes, O'Dean Judd, and Roger Speed, *Report of the POPA Ad Hoc Panel on Patriot and Theater Missile Defenses* 6 November 1993.
4. Jeremiah D. Sullivan, Dan Fenstermacher, Daniel Fisher, Ruth Howes, O'Dean Judd, and Roger Speed, "Technical Debate over Patriot Performance in the Gulf War," *Science & Global Security*, Vol. 8 (1998), 39.
5. Sullivan, et. al., "Technical Debate," 39
6. Robert M. Stein, John P. Kantelis, and Peter D. Zimmerman, "Response to *Science & Global Security* Article 'Technical Debate over Patriot Performance in the Gulf War' by Jeremiah Sullivan et. al.," *Science & Global Security*, Vol. 8, No. 2 (1999), 217-259.

7. Stein, et. al., 225.
8. Sullivan, et. al., "Technical Debate," p. 13.
9. In some higher-magnification views of Scud breakups, several objects are initially seen emerging from the breakup debris cloud. However, all objects other than the warhead fade from view within a few video frames.
10. Stein, et. al., "Response to," p. 225.
11. In the two cases in which the clear misses are well ahead of the Scud warhead, there can be no doubt that the Patriot missed, because in this case the video frame time effect would only cause the Patriot to appear to be closer to the Scud on the videos than it actually was.
12. Sullivan, et.al., "Technical Debate," p. 16. In an example of how SKZ has attempted to distort the work of the POPA Panel, they state that the Panel "admit that these sizes are inexplicably large" even though as cited above, the Panel offered a number of possible explanations.
13. Lewis and Postol, "Video Evidence," Appendix B.
14. Peter Zimmerman, "Patriot Effectiveness (Rev 1) and Other Subjects Concerning Patriot ATBM Performance During Operation Desert Storm," Submitted to Representative John Conyers, Jr., September 14, 1992.
15. Sullivan, et. al., "Report of the POPA Ad Hoc Panel," p. 9.
16. Sullivan, et.al., "Technical Debate," p.16 and note 38.
17. The only mention of this history in SKZ is in a footnote in a different section of their paper (Stein, et. al., "Response to," note 14), where they state that at the 1993 POPA Panel meeting, "Zimmerman changed his view on the one issue of the video-apparent fireball diameters..."
18. Stein, et. al., "Response to," note 31.
19. They also assume the Patriot is approaching the Scud at an angle well off the anti-parallel trajectory it was designed to use (30 degrees off).
20. SKZ also argue that we use a "simplified" model of the intercept geometry, and that we ignore factors such as the interceptor angle of attack or that the interceptor might not be approaching on an anti-parallel trajectory, and that when these factors are taken into account clear misses could actually be hits (Stein, et. al., "Response to," pp. 225-227). This is incorrect. In our analysis, these factors are simply irrelevant. When the correct size of the Patriot fireball is used, it is clear that the miss distance is so large that factors such as angle of attack or the angle between the Patriot and Scud trajectories simply do not matter.
21. Lewis and Postol, "Video Evidence," pp. 46-57.
22. Stein, et. al., "Response to," p. 225.
23. These descriptions are from viewgraphs distributed by Raytheon at the 1993 POPA Panel meeting, and subsequently released in slightly different form by Raytheon to *Boston Globe* reporter David Chandler.
24. According to a member of the HGOC investigative staff, "in no case was a Patriot fragment found in a Scud warhead." (private communication). That no Patriot fragments were found in Scud warheads is also indicated by SKZ: "Despite the panel's com-

ment on page 10 that 'it is not clear from the public record if actual Patriot fragments were found in recovered Scud warheads,' such evidence of Patriot fragment holes (*no fragments* as they are small and likely would have broken up or fallen out) and missile parts was specifically discussed at the ad hoc panel's May 1993 meeting." Stein, et. al., "Response to," note 17 (*italics added*).

25. Joseph Lovece, "Electronic Noise from U.S. Gear Prompted Errant Patriots," *Defense Week*, 28 September, 1992, p. 1.

26. "The Performance of the Patriot Missile System in the Gulf War," Staff Report to the Government Operations Subcommittee on Legislation and National Security, U.S. House of Representatives, October 1992, pp.27-28.

27. John Conyers, Jr., "The Patriot Debate, Part 2," *Arms Control Today*, January/February 1993, pp. 27, 29.

28. U.S. General Accounting Office, "Project Manager's Assessment of Patriot Missile's Overall Performance Is Not Supported," GAO/T-NSIAD-92-97, April 1992, p. 5.

29. Robert Stein, "Correspondence: Patriot Experience in the Gulf War," *International Security*, Summer 1992 (Vol. 17, No. 1), p. 211.

30. John Conyer, Jr., "The Patriot Myth, Caveat Emptor," *Arms Control Today* November 1992, p. 9; "The Performance of the Patriot Missile System," pp. 34-35.

31. U.S. General Accounting Office, "Project Manager's Assessment," p. 5.

32. Stein, et. al., "Response to," pp. 235-240.

33. Lewis and Postol, "Video Evidence," pp. 15, 17-26, 47-49.

34. One technical error in SKZ's analysis is worth noting. They cite our times to ground of about 9 to 15 seconds following intercept attempts, which are correct. However, they say these times apply to the *first* intercept attempt in an engagement which typically occurred at altitudes of 10 to 12 km, when in fact these times are for first, second, and in some cases third intercept attempts. Accordingly, they should have either used the range of altitudes corresponding to all the intercept attempts for which these times applied, roughly 7 to 12 km, or used only the times for the first intercept attempts, 11 to 15 seconds.

35. Stein, et. al., "Response to," page 236.

36. Sullivan, p. 34.

37. "Modified Scuds known as Al Hussein generally broke up during reentry at altitudes of 15-20 km, according to Col. Bruce Garnett, the Army's project manager for Patriot. During the raid on Riyadh on Jan. 20, involving about 10 modified Scuds, the Army realized what was happening. Patriot crews were then instructed to engage the lead track, which would be the warhead, and ignore the trailing tracks, which would be large pieces of fuel tank. The warheads continued with minimum loss of velocity and with hardly any change in direction, but they did spin and tumble, according to Robert Stein, manager of advanced air defense programs at Raytheon." (David Hughes, "Success of Patriot System Shapes Debate on Future Antimissile Weapons," *Aviation Week* April 22, 1991, pp. 90-91.) "By February 4, the Raytheon engineers say, the computer software was changed so that only the warhead would be attacked. This task was fairly easy because the warhead was cone-shaped and thus fell to earth with less drag than the other objects. Therefore, the Patriot could be programmed to attack only the most rapidly falling object." (Unidentified Raytheon engineers quoted in Fred Kaplan,

“Specialists Debate the Value of Patriot,” *Boston Globe*, May 5, 1991, pp. 1, 22. “Surprisingly, the breakup did not significantly magnify the inherent inaccuracy, because the spiraling warhead maintained a mean path more or less aligned along the original trajectory. In contrast, the broken-off pieces of tails and tank had much lower ballistic coefficients than the warhead section and tended to deviate greatly from the original trajectory, in general falling far short of the original impact position.” “In general, the highly streamlined warhead section had the highest ballistic coefficient and maintained its high velocity and relative position ahead of the other pieces or fragments that broke off of the TBM. This created a characteristic pattern, which the operators learned to recognize after a short time.” Stein, “Correspondence,” p. 213. “When the Patriot radar detects and tracks an object it assigns a track number to the target. When a missile is launched, it guides on the target with this track number. If the target then breaks up, the object with the closest velocity and trajectory to the original object maintains the original track number and the missile keeps guiding on it. Since the warhead section of the TBM remains more or less on the same trajectory with about the same velocity as the original unbroken Scud, the missile keeps guiding on it and never transfers to the other fragments which slow down very rapidly and fall behind the warhead.” Written testimony of Raytheon Vice President James W. Carter, in: *The Performance of the Patriot Missile in the Gulf War*, Hearing before the Legislation and National Security Subcommittee of the Committee on Government Operations, U.S. House of Representatives, April 7, 1992 (Washington D.C.: U.S. Government Printing Office, 1993), pp. 251-252.

38. Consider just one document, Legislation and National Security Subcommittee, House Government Operations Committee, *The Performance of the Patriot Missile in the Gulf War*: Major General Jay M. Garner: “We have an incoming Scud variant travelling at over 5,000 miles per hour. Fired up to meet it is a Patriot interceptor at over 3,000 miles an hour. We have a closing velocity somewhere around 9,000 miles an hour.” (pp. 217-218) This corresponds to a Scud velocity of over 2.24 km/sec and a Patriot velocity of over 1.34 km/sec. Peter Zimmerman (the Z of SKZ): “Since the Scud is still moving at about 5,600 miles per hour....” (p. 163). This corresponds to 2.51 km/second, which is a considerably higher speed than the Scud ever actually achieves. James W. Carter (Vice-President, Raytheon Company): “In one second, they move a combined distance of nearly 12,000 feet...” (p. 253) This corresponds to a closing speed of 3.66 km/second, which assuming a Patriot speed of 1.5 km/second, gives a Scud speed of about 2.16 km/second.

39. Stein, “Response to,” note 30. SKZ attempt to make a similar point when they state that “the majority of the intercept attempts occurred well below the P&L ‘typical’ altitude of 10 to 12 km.” However, 10 to 12 km is the typical intercept altitude for the *first* intercept attempt against a Scud. The POPA Panel report correctly notes this, as do SKZ later in their paper (Sullivan, “Technical Debate,” p. 31; Stein, “Response to,” p. 236). Since the vast majority of engagements had at least two intercept attempts, and some had three or even four, and these subsequent intercept attempts occurred at lower altitudes than the first one, it is self-evident that the majority of intercept attempts occurred below 10 to 12 km. We believe that typical engagements occurred at altitudes between 7 and 12 km, while recognizing that some occurred lower (and possibly some higher).

40. Lewis and Postol, “Video Evidence,” pp. 15-26, 47-49.

41. Sullivan, “Technical Debate,” p. 37.

42. In the POPA Panel’s categorization, these are Scuds A1, A3, A7, A9, and B12.

43. There are three relevant cases not included in this statistic. In the first (Dharan, Jan 20/21, 3rd Scud), a Scud is seen falling to ground, but the tape is cut at about the time a ground impact would have been expected. In the second, (Tel Aviv, January 25, 4th Scud) a Scud is seen falling to ground followed by a flash, however, while it is likely that this Scud is engaged by Patriot, we cannot prove that it was engaged, and thus exclude it from the cited statistic. In the third, (Tel Aviv, January 28) the Scud is seen to fall to ground followed by a flash. In this case it is known that the Scud was not engaged by Patriot, and thus it is also not included in the cited statistic.

44. There are actually six other ground flashes seen in the videos – these are due to Patriot warheads that exploded when Patriots mistakenly dove into the ground.

45. Stein, “Response to,” p. 224.

46. Unclassified pages from U.S. Army, “Patriot Performance Assessment in Desert Storm Roadmap (U),” 15 July 1992, p. 3.

47. Stein, “Response to,” p. 224.

48. The distinctions between the various types of warhead kills are clearly delineated in an earlier statement by a member of SKZ: “In the case of a successful intercept, multiple fragments will usually impact the TBM [tactical ballistic missile] over its body. When this occurs, three different events may take place. First, if some of the fragments impact the warhead region of the TBM with sufficient strike angle and energy, they will detonate the warhead. This is known as a ‘catastrophic kill.’ This is the most effective kill mechanism. Second, fragments might not actually detonate the warhead, but instead might destroy the safety, arming, or fuzing devices, or deform the warhead. In these situations, the TBM warhead will not detonate at intercept, but neither will it explode with full force when it hits the ground. Thus, ground damage will be reduced significantly. Causing the warhead to fail to explode at all is known as ‘dudding’ the warhead, and an intercept that results in burning or a very small detonation is known as a *low order* kill. In the third set of cases, the combination of fragment impact energy and the blast wave created by the Patriot warhead explosive will impart sufficient energy into the TBM to alter its trajectory significantly. As a result, a TBM that was heading into a populated area (or a military asset) may be pushed into an area where nothing is at risk (such as the sea or uninhabited desert). All three types of kills occurred in the war and all three reduced damage.” Robert Stein, “Correspondence: Patriot Experience in the Gulf War,” *International Security* Summer 1992 (Vol. 17, No. 1), p. 201.

49. We do not believe that there is any valid basis for categorizing such “low-yield” events, if any such events actually occurred, as due to Patriot. It is known that at least one non-exploding Scud warhead contained only “a very small amount” of “very poorly mixed” high explosive material (Staff Report, “The Performance of the Patriot Missile System,” p. 37). This suggests that some warheads’ failures to detonate may have been due to poorly mixed explosives. More importantly, it *almost certainly* indicates that if a warhead with such an explosive mix had exploded it would *not* have resulted in a full chemical yield. (In this situation, the oxidizer and propellant cannot interact before the passing explosive shock causes disassembly of the material. This is why explosive manufacturing carefully controls the mixing of oxidizer and propellant components to assure that the explosive will deliver its maximum chemical yield.) There are other possible causes as well of ground explosions that are or appear to be less than a full yield explosion. A warhead that detonates even one or two feet off the ground will result in a much smaller crater. Hitting a piece of structure that is a small distance above the ground could cause such a detonation. Different soil types also can produce

very different crater sizes. Furthermore, at least one of these two “low-yield” engagements occurred in Saudi Arabia, where many of the damage sites were not even surveyed until weeks or months after the event, by which time the craters had already been filled in. Furthermore, it is well known that measurements of the actual yield of an explosive munition can be difficult even under laboratory conditions. This is in part because the range at which a given overpressure occurs scales as the cube root of the yield, and the shock can be substantially modified by the “sweepup” of dust, refraction effects, and the nonuniform shape of the ground-surface. The poor quality of the Army’s ground damage data has been well documented. It would therefore be reasonable to question, or at least to want to confirm, the validity of the claim that even two Scuds detonated with substantially less than full yield.

50. The Army assesses these two engagements as successful “mission kills,” and describes them “low yield kills, in which the TBM warhead is damaged to the point that it either only burns at ground impact or it explodes with greatly reduced force.” U.S. Army. “Roadmap,” p. 3.

51. Sullivan, pp. 34 and 38.

52. The Army has never released a precise figure for the number of Scuds engaged by Patriot, although it is clear that this number must be in the mid-forties. We have established that 44 is the only number that is consistent with the statistics the Army has released.

53. Stein, “Response to,” note 16.

54. In a viewgraph presented by Robert Stein at the 1993 POPA meeting and subsequently released to *Boston Globe* reporter David Chandler, the U.S. Army’s assessment of one warhead is described as: “Small Crater (and Recovered Debris with Fragment Holes) Not Indicative of High Order Ground Detonation,” clearly indicating that this was one of the two low-yield mission kills. This “mission kill” is one of the four engagements discussed by SKZ as containing only clear misses but without extensive ground damage. None of these four engagements (A2, A10, A12, and A13 in the POPA Panel classification) have a ground flash associated with them.

55. Sullivan, “Technical Debate,” p. 36-37.

56. Sullivan, “Technical Debate,” p. 36.

57. Stein, “Response to,” note 13.

58. Stein, “Response to,” p. 223.

59. SKZ cite as evidence a video they showed at the POPA Panel meeting which showed the impact of an Army Line of Sight Anti-Tank (LOSAT) missile on an armored vehicle. While this metal-to-metal impact (unlike the Scud impacting the ground) did produce some light, it was not even bright enough to light up the ground directly beneath the tank. Moreover, SKZ do not inform the reader that, as was noted by a member of the POPA Panel at the May 1993 meeting, the core of the LOSAT impactor is depleted uranium, a pyrophoric material. SKZ also argue that impacts of 2 km/second tungsten cubes “with kinetic energy five orders of magnitude less than non-exploding 600 km Scuds,” produce light flashes. However, it is obvious that what matters in such impacts is not total energy, but energy density, that is, the energy per unit mass, because this determines the temperature increase. In fact the energy density of these titanium cubes is greater than that of an intact Scud, not “five orders of magnitude less.” SKZ similarly argue that the total energy released in the impact of an intact Scud is considerably greater than that released by the explosion of the Scud warhead,

when in fact the energy density of the explosive material in the warhead is significantly greater.

60. Moreover, SKZ's intact Scud argument also requires that a Patriot causes the Scud warhead to fail to explode while leaving the Scud missile intact. SKZ argue that it is possible for a Patriot fragment to strike part of the Scud's fuzing mechanism without passing through or detonating the warhead. The idea that a single Scud fragment could hit a vital fuze component without the much larger Scud body being hit by multiple fragments or blast effects which would tear it apart simply defies credulity.

61. Sean Naylor, "Official Says Glitch Let Scud Bypass Patriot," *Defense News* May 6, 1991, p. 20.

62. High explosive detonations typically achieve temperatures of about 5000 K and their detonation gases typically initially expand at speeds of 6 to 8 kilometers per second. These expanding detonation gases then rapidly suddenly compress the surrounding air into a luminous high temperature (up to 10,000 K) compressed shell of gas. These high temperatures are the source of the very bright flash of light produced when the warhead explodes. Objects (blackbodies) at 5000 K radiate almost 3000 times more 0.55 micron light (the visible light spectrum extends from 0.4 to 0.7 microns) than those at 3000 K, and 150,000 times more light than those at 1,500 K. Consider a warhead that breaks off from the Scud at a low altitude of 5 km, as illustrated in SKZ's figure 5. Such a warhead would indeed be moving rapidly at the moment of breakup, roughly 1.85 km/second, but it would slow up rapidly. Using the Scud warhead ballistic coefficient shown in SKZ's figure 3, one finds that the Scud warhead would impact the ground in about 5.7 seconds (as SKZ's figure 5 also shows) and with a speed of about 670 meters/second. This impact speed corresponds to kinetic energy of about 225,000 J/kg. Much, and perhaps most, of this energy would be dissipated into the ground. However, if we assume that all of the energy is perfectly converted into heat, then it would only raise the temperature of the iron casing of the warhead by 450 K. Such a small temperature increase cannot possibly account for the light produced at impact.

63. Stein, "Responses to," p. 219.

64. SKZ exclude two engagements (A15 and A16 in the POPA Panel's notation) from the category of all clear misses because they say that there is "another intercept attempt that is hidden behind clouds" and thus cannot be considered a clear miss. This claim suggests a lack of familiarity with the videos. As the POPA Panel's summary correctly notes, in each of these two engagements there was a Patriot detonation behind a cloud. However, in both cases, the Scud itself was clearly visible at the time of the Patriot detonation, in one case on the near side of the cloud (that is, between the cloud and the camera), and in the other well ahead of the cloud. There is no doubt that both these Patriot intercept attempts were clear misses.

65. In three of the six engagements involving a fireball overlap, the ground flash from the Scud warhead exploding is seen. In one of these cases, there was extensive ground damage.

66. In the case of the warhead for which a significant change in behavior was seen, this warhead (Feb 19 in Tel Aviv) was followed to the ground and no ground flash was seen. It is known that this warhead did not explode, and we have been informed by Israeli sources that this was due to defective fuzing on the Scud and had nothing to do with Patriot. Given this, the Army's complete lack of any physical or chemical analysis supporting a dud claim (despite recovering the warhead) and the lack of any plau-

sible mechanism by which Patriot could cause a dud without detonating the warhead except as a very rare event, we conclude that this engagement is almost certainly a failure. This was one of two engagements classified by SKZ as not falling into one of the four categories discussed here. In the other case, a Scud is seen falling near Riyadh. No Patriots are seen engaging this Scud. Two Patriots are eventually launched after the Scud has disappeared from view, but far too late to attempt to intercept the Scud.

67. Stein, "Response to," pp. 245-247.

68. Lewis and Postol, "Video Evidence," note 40.

69. Stein, "Response to," p. 28

70. In a few cases where Scud breakups are viewed at a high magnification, multiple objects are indeed seen coming out of the cloud of breakup debris. However, within a few video frames, all of these disappear from sight except for the warhead.

71. Stein, "Response to," p. 234.

72. Stein, "Response to," note 44.

73. Theodore A. Postol, "Lessons for SDI from the Gulf War Experience with Patriot," Testimony delivered before the House Armed Services Committee, April 16, 1991.

74. Postol, "Lessons of the Gulf War Experience." As Postol noted in this article, Les Aspin, then the Chairman of the House Armed Services Committee, had already indicated that Patriot's failure rate in Israel was 56%. Postol, "Lessons of the Gulf War," p. 135.

75. By "directly" we mean we are excluding deaths such as those due to heart attacks or improper use of gas masks.

76. Steve Fetter, George Lewis, and Lisbeth Gronlund, "Why Were Scud Casualties So Low?," *Nature* 362 (January 26, 1993), pp. 293-296.

77. However, SKZ's claim that casualties per Scud were lower after Patriot is simply wrong. The numbers for damage and casualties used by both Postol and SKZ were taken from one or two Israeli newspaper stories published shortly after the end of the Gulf War. Postol and SKZ get different figures for damage and casualties per Scud because they use different numbers for the numbers of Scuds before and after Patriot (SKZ get their numbers from the classified database, which Postol does not have access to). However, by the time of the May 1993 POPA Panel meeting, at which the statistics cited by SKZ were presented, far more definitive statistics on casualties, published by Israeli doctors (including doctors from the Medical Corps of the Israeli Defence Force) in medical journals were available. This data shows there were 52 physical injuries before Patriot and 177 after. Even using SKZ's numbers (6 to 8 Scuds before Patriot, 18 after), one finds that there were more casualties per Scud after Patriot was operational than before. (The numbers of Scuds are for Scuds fired at Tel Aviv, while the casualty data is for both Tel Aviv and Haifa. However, there were at most two casualties in Haifa after Patriot was deployed, so that the conclusion that the number of casualties per Scud was greater after Patriot is not affected by this). Thus it is clear that both injuries and deaths (there were only two deaths, both after Patriot) per Scud were greater after Patriot, even using SKZ's numbers for Scuds. See Avi Bleich, Anat Dycian, Meni Koslowsky, Zahava Solomon, and Michael Wiener, "Psychiatric Implications of Missile Attacks on a Civilian Population," *Journal of the American Medical Association*, August, 1995, pp. 613-615.

78. Stein, "Response to," p. 234.

79. The most detailed description of the Army's assessment is contained in the unclassified pages from the Army's Roadmap (U.S. Army, "Roadmap," pp. 2-10). The Army's methodology is also very clearly laid out in other places, such as at the April 1992 House Government Operations Committee Hearing.

80. House Government Operations Committee, "Performance of the Patriot Missile in the Gulf War," p. 237:

81. See U.S. Army, "Roadmap," p. 6.

82. Clearly they could not satisfy criterion 2 for the Scud that hit the Dhahran barracks on February 25 as well as for any other engagements (if there were any) in which no Patriots were launched.

83. U.S. Army, "Roadmap," p. 5.

84. U.S. Army, "Roadmap," p. C-15.

85. SKZ's damage per missile statistics are based on there being 6-8 Scuds in "Patriot Zones" at Tel Aviv prior to Patriot being operational. In addition, there were also at least three Scuds landing in or near Haifa, one of which caused significant damage to a shopping center and would certainly have been engaged if Patriot had been operational.

86. One of the Scuds was a dud that struck a multi-story building in Tel Aviv. We do not count this Scud as producing significant damage, since under the Army's methodology, the dud would have been taken as indicative of a successful engagement.

87. Stein, "Responses to," pp. 218-219.

88. We have argued that there are two general lessons from the Patriot experience in the Gulf War. First, countermeasures, whether deliberate or inadvertent (as was the case in the Gulf War) are fundamental problem facing ballistic missile defenses. Second, a system that is perfect on the test range (as Patriot was before the Gulf War) may not work well in actual practice, because the real world can be quite different than the test range.

89. Daniel G. Dupont, "Army Named Lead Service for Land-Based NMD System," *Inside Missile Defense* December 1, 1999, 13.

90. Andrew M. Sessler (Chair), John M. Cornwall, Bob Dietz, Steve Fetter, Sherman Frankel, Richard L. Garwin, Kurt Gottfried, Lisbeth Gronlund, George N. Lewis, Theodore A. Postol, and David C. Wright, "Countermeasures: A Technical Evaluation of the Operational Effectiveness of the Planned U.S. National Missile Defense System" (Cambridge, Mass.: Union of Concerned Scientists and M.I.T. Security Studies Program, April 2000).

91. "Much of the debate about the usefulness of National Missile Defense revolves around the E.K.V.'s ability to outsmart these decoys, and the debate devolves into a ballistic form of he said, she said, with some critics saying the decoy-foiling technology does not exist and will not exist anytime soon and Raytheon engineers insisting just as strongly that it does, though the evidence is, unfortunately, classified." Peter Maass, "Get Ready, Here Comes the Exoatmospheric Kill Vehicle," *New York Times Magazine* September 26, 1999, 58. Thomas Ward (BMDO's director of threats and countermeasures): "...it [the ability to deal with countermeasures] is one of the crown jewels that is shrouded in secrecy. And that is the way it is and that is the way it has to be." "We just have to listen and keep our mouths shut." Michael C. Sirak, "DoD, Industry: NMD Countermeasures Getting Attention," *Inside Missile Defense* May 19, 1999, 1, 17-19.

92. "...both competing Exo-Atmospheric Kill Vehicles performed so well during their seeker tests that they can effectively discriminate incoming reentry vehicles from a complex range of approaching targets, according to Boeing Vice President for National Missile Defense John Peller. As a result, there exists no technology problem regarding discrimination for the initial NMD deployment, Peller said..." Michael C. Sirak, "EKV Prototypes Discriminate 'Spectacularly Well,' Boeing NMD Chief Says," *Inside Missile Defense* September 30, 1998, 14-15.