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**CASUALTIES AND DAMAGE FROM SCUD ATTACKS
IN THE 1991 GULF WAR**

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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Working Paper

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THE 1991 GULF WAR

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CASUALTIES AND DAMAGE FROM SCUD ATTACKS IN THE 1991 GULF WAR¹

INTRODUCTION

The proliferation of ballistic missiles has in recent years become a major international security concern. This increased concern is in part due to the highly visible role played by Iraqi Scud missiles during the 1991 Persian Gulf War. However, it is also due to the widespread -- but incorrect -- perception that even conventionally-armed ballistic missiles are tremendously destructive.²

This perception that ballistic missiles are inherently weapons of great destructive capability may have played a key role in the politics of the Gulf War. Iraq fired more than 80 modified Scud missiles at Israel and Saudi Arabia during the 1991 Persian Gulf War, causing 31 deaths, numerous injuries, and substantial property damage. However, with the exception of the Scud that hit a barracks in Dhahran, Saudi Arabia, and killed 28 U.S. soldiers, the number of casualties caused by these Scuds was much lower than was generally anticipated. During the war,

¹ A short version of this paper was published as Steve Fetter, George N. Lewis, and Lisbeth Gronlund, "Why Were Scud Casualties So Low?" *Nature*, 28 January 1993, pp. 293-296.

Some of the numbers in this paper are different from the those in the *Nature* paper due to additional information we have received since the short version was completed. In the *Nature* paper, we estimated, based on news media reports, that 10 to 11 Scud warheads detonated in Israeli metropolitan areas. Based on recent interviews conducted in Israel by Reuven Pedatzur, we have now been able to identify a total of 13 Scud warheads that detonated in Israeli metropolitan areas; in addition, we are now able to produce a map of the impact points. We also now have some additional information about dud Scud warheads and Patriots that dove into the ground in Israel. Finally, the figure for the number of Scuds fired at Israel was 38 in the *Nature* paper; since the U.S. Army now appears to use a figure of 39, that is used here (with the additional Scud falling on January 18).

² Ballistic missiles are often referred to as "weapons of mass destruction," without regard to the nature of their warheads. While missiles armed with nuclear, biological, and, under some circumstances, chemical warheads deserve that designation, a high-explosive warhead delivered by a missile is not significantly more destructive than the same amount of explosive delivered by other means, and should not be termed a weapon of mass destruction. For a discussion of the destructive capabilities of ballistic missiles armed with different types of warheads, see Steve Fetter, "Ballistic Missiles and Weapons of Mass Destruction: What Is the Threat? What Should Be Done?," *International Security*, Summer 1991, pp. 5-42. For an assessment of the military effectiveness of ballistic missiles relative to attack aircraft, see John R. Harvey, "Regional Ballistic Missiles and Advanced Strike Aircraft: Comparing Military Effectiveness," *International Security*, Fall 1992, pp. 41-83.

the Patriot missile system was credited with almost complete success in intercepting the Iraqi Scud missiles, and the low casualty rate (relative to the public's expectations) seemed to confirm Patriot's success. The belief on the part of the Israeli population that they were being successfully defended by Patriot was crucial in keeping Israel out of the war.

Since the end of war, the casualties caused by the Scuds have become part of the debate over the effectiveness of the Patriot missile defense system. Several analysts have cited the relatively low casualty rate as evidence of the success of Patriot³, while others have argued that

³ Robert M. Stein, Manager of Advanced Air Defense Systems for the Raytheon Company, has argued that "the one or two civilian deaths directly related to TBMs [tactical ballistic missiles] in Israel and no civilian deaths in Saudi Arabia contrasted sharply with the effects of Scuds against other countries without anti-TBM (ATBM) defense, such as the "War of the Cities" between Iraq and Iran, in which TBMs killed or injured more than 5000 Iranian citizens, and in Afghanistan when three Scuds killed 300 people on a single day . . . the casualty rates per TBM in Israel and Saudi Arabia differed from those in the comparison examples by orders of magnitude. Such differences transcend the possible variations in circumstances. . . ." (Robert Stein, "Correspondence: Patriot Experience in the Gulf War," *International Security*, Vol. 17, No. 1 (Summer 1992), p. 200.) Stein acknowledges in a footnote the 28 U.S. military personnel killed when a Scud, which Patriot failed to engage, struck a barracks in Dhahran on 25 February 1991. Similar statistics were cited by Charles Zraket, a Scholar in Residence at Harvard University's Center for Science and International Affairs and past CEO of the MITRE Corporation, as evidence of Patriot effectiveness in his *Defense News* article "Patriot Gave Stellar Gulf Performance," 9 December 1991, p. 31.

Both Zraket and Peter Zimmerman, a physicist and Senior fellow for Arms Control and Verification at the Center for Strategic and International Studies, gave testimony to the Subcommittee on Legislation and National Security of the House Committee on Government Operations during hearings on the performance of the Patriot missile in the Gulf War on 7 April 1992, in which they asserted that there was a "common sense" argument that Patriot was successful because no catastrophic damage occurred. In his testimony, Zraket stated "...if you don't have a lot of catastrophic damage in an area and say in Israel or in eastern Saudi Arabia, when something like over 30 Scuds fell in each of the inhabited areas and almost 50 were fired into each area, then common sense tells you that something is going on that's preventing that catastrophic damage." During later questioning by Representative Steven Neal, Zimmerman stated, ". . . the common-sense argument that Dr. Zraket has made indicates to me very clearly that large numbers--reasonable fractions--of the incoming al-Hussein missiles were interdicted, were neutralized, and were prevented from causing damage on the ground." (*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. 179, 209.) More recently, Zimmerman again stated that a common-sense case could be made that Patriot was modestly successful in defending Israel because the Scuds did not cause as much damage as might have been expected (Max Boot, "New US House Committee Report Will Say Patriot Missile Failed," *Christian Science Monitor*, 23 September 1992, p. 9.).

These arguments have been repeated in several editorials and opinion pieces, including "An Unjustly Criticized Patriot" by Robert L. Pfaltzgraff Jr. (*Wall Street Journal*, 8 April 1992, p. A20), and "Conyers vs. the Patriots" (*Detroit News*, 13 April 1992, p. 8), which states that "Saddam Hussein lobbed 40 Scuds at Israeli cities, and no significant damage occurred in the areas defended by Patriot batteries....compare that with the 1988 Iran-Iraq "War of the Cities" when Iraq launched 125 Scuds at Teheran and other populated areas, killing 1,000 to 2,000 Iranians." Former U.S. Congressman Frank Horton similarly argues that ". . . the historical evidence that when tactical ballistic missiles are shot at defenseless civilians, casualties are high, but that in Desert Storm, the only situation where civilian populations were defended--by Patriot--casualties were exceedingly low." (Frank Horton, "The Patriot Debate: Part 2," *Arms Control Today*, January/February 1993, pp. 26-27.)

the same casualty data suggests that the Patriot may not have been very successful.⁴

In the nearly two years since the end of the Gulf War, however, it has become apparent that Patriot was far less effective in intercepting Scuds than was believed during the war.⁵ How then can the apparently low casualties caused by the Scud attacks be explained?

In this paper, we review the casualty rate from previous ballistic missile attacks, compare this to the experience in the Gulf War by taking into account differences in population density and warhead size, and examine a variety of other factors that may account for the casualty rate in the Scud attacks on Israel. We primarily focus on Israel because relatively little data is available from Saudi Arabia. We conclude that there were a number of factors that, taken together, appear to be able to account for the number of deaths and serious injuries in Israel. The most important of these factors were the inaccuracy of the modified Scud missile; its small warhead and breakup upon atmospheric reentry; the availability of attack warning, which allowed citizens to take shelter; and Israeli construction practices, which prevented buildings from collapsing and burying their occupants. Finally, simple good fortune may have played a role. The available data do not support claims that Patriot played a significant role in reducing casualties. We conclude with some observations on lessons learned that may be relevant to future ballistic missile attacks.

PREVIOUS BALLISTIC-MISSILE ATTACKS

In order to put the casualties and damage in Israel into perspective, it is useful to review the effects of previous ballistic missile attacks. Before the 1991 Gulf War, ballistic missiles had been used extensively in war only three times: the Germans launched over 3,000 V-2 missiles against urban British and European targets during World War II; Iraq and Iran together launched nearly 1,000 missiles against each other's cities during the 1980-88 Persian Gulf War; and the Kabul government fired over 2,000 Soviet-made Scud missiles against Mujahideen guerrillas in

⁴ Theodore A. Postol, "Lessons of the Gulf War Patriot Experience," *International Security*, Vol. 16, No. 3 (Winter 1991/92), pp. 119-171. This paper notes that the deployment of Patriot in Israel did not appear to have reduced the damage per Scud missile relative to that before Patriot was deployed.

⁵ After the war, the U.S. Army claimed a 96% success rate. The Army's currently claims a 40% success rate in Israel and a 70% success rate in Saudi Arabia. However, only 40% of the Army's claimed successful intercepts are in the Army's "highest confidence" category. See John Conyers, Jr., "The Patriot Myth: Caveat Emptor," *Arms Control Today*, November 1992, pp. 3-10.

the Afghanistan civil war. In all cases the missiles were armed with conventional high-explosive warheads. Detailed information on casualties and physical damage is, however, available only for the V-2 attacks on London.

The V-2 Attacks on London

From September 1944 until March 1945, Germany launched over 3,000 V-2 ballistic missiles at targets in Britain and continental Europe.⁶ Of the approximately 1,400 V-2s fired against Britain, 518 fell in the London Civil Defense District. In addition, nearly 10,000 V-1 cruise missiles were fired against London, and although most of them malfunctioned or were destroyed by British defenses, roughly 2,420 V-1s fell in London.

Casualties

Table 1 gives the number of deaths and injuries that resulted from V-1 and V-2 impacts in the London area.⁷ Although the V-2 and the V-1 missiles produced roughly equal areas of physical destruction (see below), the number of casualties (deaths and injuries) per V-2 impact in London was about twice that caused by the V-1. The U.S. Strategic Bombing Survey concluded that the lower casualty rate for the V-1 was due to the fact that people in the target area could hear the V-1 approach and could take cover before its warhead exploded,⁸ while the V-2 gave no warning of its approach.⁹

⁶ The primary sources of the V-2 statistics cited in this paper are: U.S. Strategic Bombing Survey, Physical Damage Division, *V-Weapons in London*, Report No. 152, January 1947; Air Chief Marshall Sir Roderic Hill, "Air Operations by Air Defence of Great Britain And Fighter Command in Connection with the German Flying Bomb and Rocket Offensives, 1944-45," *London Gazette*, 20 October 1948, pp. 5585-5617; C.L. Dunn, *The Emergency Medical Services, vol. 1: England and Wales* (London: Her Majesty's Stationery Office, 1952), pp. 170-180; M.C. Helfers, *The Employment of V-Weapons by the Germans During World War II* (Washington, DC: U.S. Army, Office of the Chief of Military History, 31 May 1954); Terrence H. O'Brien, *Civil Defence* (London: Her Majesty's Stationery Office, 1955); and Norman Longmate, *The Doodlebugs: The Story of the Flying Bombs* (London: Hutchinson, 1981).

⁷ The London area is defined by the boundaries of the wartime London Civil Defense District.

⁸ V-1s flew at a constant altitude until a timing device caused the missile to go into a steep dive, which cut off the flow of fuel to the engine. People in the target area knew that when the sound of the engine stopped, an explosion would soon follow, typically in 8 to 12 seconds.

⁹ An additional factor is that the V-2 produced more intense destruction than the V-1 (i.e., walls were not only

Table 1. Deaths and injuries from V-1 and V-2 impacts in the London area.¹⁰

Number of Missiles	Casualties			Casualties per Missile			
	Deaths	Serious Injuries	Slight Injuries	Deaths	Serious Injuries	Slight Injuries	
V-1	2420	5,370	15,250	19,900	2.2	6.3	8.2
V-2	518	2,510	6,050	13,200	4.8	11.7	25.5

Source: Dunn, *The Emergency Medical Services*, pp. 174, 179.

Table 2. The number of houses destroyed or seriously damaged by V-1 or V-2 impacts in the London area.

Number of Missiles	Number of Houses		Houses per Missile	
	Destroyed	Seriously Damaged	Destroyed	Seriously Damaged
2938	29,400	170,000+	10	58+

blown over, but blasted into small pieces), which may have resulted in the suffocation of victims buried under the debris who might otherwise have survived. However, if this was a significant factor, we would expect the death rate for the V-2 relative to that of the V-1 to increase more than the injury rate. Since both deaths and injuries per missile are greater for the V-2 by roughly a factor of two, the more intense disintegration of debris produced by the V-2 does not appear to be a decisive factor in increasing the death rate.

¹⁰ Some sources give figures for deaths which are slightly (up to about 10%) higher. In addition, these figures are for civilians only and do not include casualties among military personnel, which were about 5% of the total for the V-1 attacks (Kenneth P. Werrell, *Archie, Flak, AAA, and SAM: A Short Operational History of Ground-Based Air Defense* (Washington, D.C.: U.S. Government Printing Office, 1998), p. 19). Thus the figures in Table 1 likely represent lower limits.

Property Damage

More than a million homes were damaged by the nearly 3,000 V-1 and V-2 missiles that fell in the London area, although most of these suffered only light damage. It is difficult to sort out damage caused by the V-2s from that caused by the V-1s; the available data suggests that, on a per missile basis, they caused roughly equal amounts of damage. These data, which are summarized in Table 2, indicate that about ten houses were destroyed and sixty seriously damaged per missile impact.

The effects of a number of V-1 and V-2 impacts were investigated in detail by the British, and the results of these investigations were published in the U.S. Strategic Bombing Survey.¹¹ The British compared the effects of the V-1 and V-2 missile warheads with those of the German SC bomb on brick row houses, which were a common building type in London. All three weapons contained roughly equal amounts of high-explosive (HE); Table 3 gives the total mass and the mass of HE for each weapon, and the mass of TNT that would result in an equivalent explosive yield.

In calculating the total explosive energy released on impact, the kinetic energy of the warhead must be taken into account. This contribution is quite small for the SC bomb and the V-1 cruise missile, since their velocities at impact were relatively small.¹² The V-2, on the other hand, reached a terminal velocity of about 800 meters per second;¹³ in this case

¹¹ Strategic Bombing Survey, *V-Weapons in London*.

¹² A 1-tonne (1,000-kilogram) mass traveling at the speed of sound (330 meters per second) would have a kinetic energy of $\frac{1}{2}mv^2 = \frac{1}{2}(1000 \text{ kg})(330 \text{ m/s})^2 = 54 \text{ megajoules (MJ)}$; since 1 kilogram of TNT releases 4.6 MJ, this is equivalent to 12 kilograms of TNT per tonne of mass, or only about 1% of the energy released by an equal mass of TNT. Since the impact velocities of the bomb and the V-1 were substantially less than the speed of sound, the contribution of their kinetic energy to the explosive yield will be less than 1% of the total and can therefore be neglected.

¹³ Gregory P. Kennedy, *Vengeance Weapon 2: The V-2 Guided Missile* (Washington, DC: Smithsonian Institution Press, 1983), p. 18. To achieve this velocity, the empty missile must have had a ballistic coefficient (" \hat{a} ") of about 8500 kg/m^2 (1700 lb/ft^2), assuming a burnout velocity of 1600 meters per second, a burnout altitude of 28 kilometers, and a reentry angle of 45 degrees; since $\hat{a} = M/C_dA$, where M is the mass (4000 kilograms) and A is the area (2.14 m^2), this corresponds to a drag coefficient C_d of about 0.22. This value is in agreement with German measurements, which found that C_d was 0.22 at a velocity of 800 meters per second. Hermann H. Kurzweg, "The Aerodynamic Development of the V-2," in T.H. Benecke and A.W. Quick, *History of German Guided Missiles Development* (Brunswick, Germany: Verlag E. Appelhans & Co., 1957), p. 59.

Table 3. Characteristics of the German SC bomb and the V-1 and V-2 warheads.

Weapon	Type of HE	Mass (kg) of		Energy (kg TNT equiv.) ^a		
		Device	HE	HE	Kinetic	Total
SC Bomb	Amatol	1089	620	520	--- ^b	520
V-1	52A	900	849	800	--- ^b	800
V-2	Amatol	978	736	620	280	900

Source: U.S. Strategic Bombing Survey, *V-Weapons in London*.

^aAmatol (60% TNT, 40% ammonium nitrate) releases about 84% as much energy as an equal mass of TNT; 52A (a mixture of RDX, ammonium nitrate, dinitro benzene, and calcium nitrate) is about 94% as energetic as TNT. Explosive energy releases estimated from data in Gilbert Ford Kinney, *Explosive Shocks in Air* (New York: Macmillan, 1963).

^bBoth the SC bomb and the V-1 had relatively low impact velocities, and their kinetic energies were therefore negligible. See footnote 12.

Table 4. Average damage radii (meters) and corresponding peak overpressures (psi) for three types of weapons against brick-row houses for three levels of damage: completely destroyed ("A"), damaged beyond repair ("B"), and seriously damaged but habitable with repairs ("C").

Weapon	Number of Explosions	Damage Radius (m)			Overpressure (psi)		
		A	B	C	A	B	C
SC Bomb	5	16	26	48	32.6	10.2	3.5
V-1	19	22	31	52	19.7	9.7	3.9
V-2	22	23	31	57	18.9	10.6	3.6

Source: U.S. Strategic Bombing Survey, Physical Damage Division, *V-Weapons in London*.

the kinetic energy of the missile is a significant fraction of the energy released by the HE.¹⁴ Table 3 gives the kinetic energy and the total energy released by the impact and detonation of each weapon.¹⁵ The average damage radii of each of these weapons against a brick row-houses are given in Table 4. Radii are given for three levels of damage: completely destroyed ("A"), damaged beyond repair ("B"), and seriously damaged but habitable with repairs ("C"). Note that the damage radii for the V-1 and V-2 are quite similar for each level of damage, with the V-2 being slightly more destructive (which is consistent with its slightly greater energy release on impact). The SC bomb, which released significantly less energy on impact, had smaller damage radii.

Since in each case the damage to the structures was due almost exclusively to blast, we should expect that for each given level of damage ("A," "B," or "C") the radii for the three different weapons would correspond to about the same peak overpressure. Table 4 lists the peak overpressures from each weapon at the radii for "A," "B," and "C" damage.¹⁶ Note that, with the exception of the "A" level damage for the SC bomb, there is excellent agreement in every case.¹⁷ In general, brick row houses were completely destroyed at overpressures greater than roughly 20 pounds per square inch (psi), damaged beyond repair at about 10 psi, and severely damaged but repairable at overpressures of about 3 to 4 psi.¹⁸ The excellent agreement in the overpressures at

¹⁴ A 4-tonne missile traveling at a speed of 800 meters per second would have a kinetic energy of $\frac{1}{2}(4,000)(800)^2 = 1300$ MJ, which is equivalent to 280 kilograms of TNT.

¹⁵ The table does not include the energy released by unburned fuel that may have remained in the tanks of the missiles; the Strategic Bombing Survey makes no mention of this or of its possible contribution to the initial explosion or subsequent fires. If one percent of the gasoline remained in the V-1s tanks at impact, the additional energy released would have been equivalent to 50 kilograms of TNT; in the case of the V-2, one percent of the alcohol fuel would have been equivalent to 250 kilograms of TNT.

¹⁶ The overpressures given here are calculated assuming that the weapons are ground-burst. Data for the overpressure as a function of distance from the explosion were taken from Kinney, *Explosive Shocks in Air*, p. 188, for a free air burst of a 1-ton spherical charge of TNT at sea level. If the ground was an ideal reflector, the overpressures from a ground burst would be twice that of a free air burst of the same yield. Because some of the explosive energy is expended in ground shock and cratering, however, the actual yield for a ground burst is only about 1.6 times greater. The factor of 1.6 can be derived from data in Samuel Glasstone and Philip J. Dolan, eds., *The Effects of Nuclear Weapons* (Washington, DC: U.S. Department of Defense, 1977), figs. 3.72 and 3.73.

¹⁷ The exception of the level "A" damage from the SC bomb may be due to the relatively small number of observations in this case (five), combined with the fact that small variations in the height of burst or the immediate surroundings of the blast would result in much larger variations in the radius of level "A" damage.

¹⁸ It is interesting to compare the results in Table 4 with the results of U.S. studies on the effects of nuclear

which a given degree of damage occurs from these three very different types of weapons should give us a measure of confidence in using these results to predict damage from missile attacks in similar circumstances.¹⁹

It is informative to compare the average radii for deaths and injuries with those for damage to brick row houses. This can be done by dividing the average number of casualties per missile impact by the average population density of London to find the area per missile, and then calculating the radius of that area. The average population density of London during the missile attacks is difficult to estimate because of widespread evacuation. The V-1 attacks began in June 1944; by August, 1.45 million people (about 20 percent of the population) were estimated to have left London.²⁰ In July, the nighttime population was estimated at 6.75 million.²¹ Assuming that these population estimates correspond to the London Civil Defense Region, the population density during the V-weapon attacks was about 3,600 per square km.²² Thus, in the case of the V-2 attacks, the average radii for deaths, serious injuries, and slight injuries were 21, 32, and 48 meters, which are comparable to the radii for the "A" (destroyed), "B" (damaged beyond repair),

explosions on buildings. In nuclear tests in Nevada, unreinforced, two-story brick houses were exposed to peak overpressures of 5 and 1.7 psi. At 5 psi, the houses were completely destroyed; at 1.7 psi the damage was considerable but the houses were repairable. Thus, the peak overpressure required to damage this type of structure to a given extent is two to four times higher for a 1-ton conventional explosive than for a 30-kt nuclear explosive. This is because the blast wave from the nuclear explosion lasts much longer. For example, the duration of the blast wave is nearly 1 second for a 30-kt nuclear explosion and a peak overpressure of 5 psi; for one ton of TNT and an overpressure of 20 psi it is only about 0.01 s. Because the duration of the chemical blast is short compared to the natural period of the structure (which is roughly 0.2 s), increases in the duration (which is proportional to the cube root of the yield for a given overpressure) result in increased displacement and damage. When the duration of the blast is longer than the natural period of the structure (as is the case with most nuclear explosions), damage becomes insensitive to duration and depends only on peak overpressure. The observed ratio of 2-4:1 for the peak overpressures required to destroy these structures with chemical and nuclear explosives, respectively, is in accord with theoretical predictions. See Kinney, *Explosive Shocks in Air*, pp. 142-144.

¹⁹ The 6:1 ratio of houses damaged to houses destroyed in London (see Table 2) is what one would expect from the roughly 2.5:1 ratio of the radii for "A" and "C" damage given in Table 4, since the area of destruction is proportional to the square of the damage radii.

²⁰ O' Brien, *Civil Defence*, p. 655. This was apparently the peak number of evacuees, at least during the V-1 attacks. Some of the evacuees subsequently returned to London before the missile attacks ended.

²¹ Longmate, *The Doodlebugs*, p. 261.

²² The London Civil Defense Region had an area of about 730 square miles, or 1,900 square kilometers. (Strategic Bombing Survey, *V-Weapons in London*, p. 1.)

and "C" (seriously damaged but repairable) levels of structural damage, of 23, 31, and 57 meters, respectively.

The Scud Attacks on Tehran

Only limited information is available on casualties and damage from the Iraqi Scud attacks on Tehran during the so-called "War of the Cities." A total of 189 modified Scud-B missiles (dubbed the "al Hussein" by Iraq--the same missile used against Israel and Saudi Arabia) fell on six different Iranian cities from 29 February to 20 April 1988; 135 of these landed in Tehran.²³ On 4 April, after about 125 missiles had fallen, Iranian sources reported that 1,150 people had died and 4,000 had been injured from the missile attacks.²⁴ However, some foreign analysts believe that Iran underestimated casualties to minimize civilian panic, and estimate that 2,000 people died.²⁵

If 1,150 people died, and if all of the Iranian cities attacked have roughly equal population densities, then as few as nine people were killed and 32 injured per missile impact in Tehran; if 2,000 died, then about 16 people were killed per missile impact in Tehran. If the smaller cities had population densities significantly less than that of Tehran (or were small enough that a higher fraction of Scuds missed the city), the casualty rate in Tehran would be somewhat higher.

Assume for the moment that the circumstances of the Scud attacks on Tehran were similar to those of the V-2 attacks on London. Under this assumption, we need only modify the casualty and damage rates for London to account for differences in population density and warhead yield in order to estimate the expected casualty rate in Tehran.

Population density

²³ W. Seth Carus and Joseph S. Bermudez, Jr., "Iraq's *Al-Husayn* Missile Programme," *Jane's Soviet Intelligence Review*, Vol. 2, No. 6 (June 1990), pp. 242-248. During the entire war, Iraq claims to have fired 331 Scuds against Iran ("Iraqi Missile Declarations," *Arms Control Today*, November 1992, p. 28). Iraq also fired many shorter range missiles at Iranian cities closer to its borders.

²⁴ John Bierman, "A Battered City Under Siege," *Maclean's*, 18 April 1988, pp. 34-36.

²⁵ Carus and Bermudez, "Iraq's *Al-Husayn* Missile Programme," p. 244.

In 1988, the Tehran metropolitan area had a population of about 8.6 million²⁶ concentrated in a relatively small area of 290 square kilometers,²⁷ for a population density of about 30,000 per square km. As in London, large-scale evacuation resulted from the missile attacks; some diplomats estimated that as many as two million people (nearly one-quarter of the population) left the city.²⁸ If, for lack of better information, we assume the same fraction of evacuees as in London (about 20 percent), the population density of Tehran would have been about seven times greater than that of London during the missile attacks. Therefore, all else being equal, the same type of warhead would on average kill and injure about seven times as many people if targeted against Tehran rather than London.

Warhead yield

Iran claimed that the modified Scud used by the Iraqis carried a warhead containing 160 to 190 kilograms of high explosives;²⁹ in addition, the kinetic energy of the intact missile at impact would have been equivalent to about 400 kilograms of TNT.³⁰ However, reports from Iran suggested that the missiles did not remain intact, but that the Scud's warhead separated from the booster prior to impact.³¹ Based on the Gulf War experience, it seems clear that these reports were actually referring to the breakup of the booster during reentry due to the instability of the modified missile.³² In this case, the total energy released on impact would have been less than the

²⁶ The population of the Teheran metropolitan area was 7.52 million in 1985 and 9.38 million in 1990. (John W. Wright, ed., *The Universal Almanac 1990* (Kansas City: Andrews and McMeel, 1990), p. 533.) Assuming a constant rate of growth during this time, the population in 1988 would have been 8.6 million.

²⁷ *The World Almanac and Book of Facts 1992* (New York: Pharos Books, 1992), p. 821. According to the accompanying text, "to the extent practical, non-residential areas such as parks, airports, industrial complexes and water were excluded from the area," so the population density estimated here may be somewhat too high.

²⁸ Bierman, "A Battered City," p. 34.

²⁹ Carus and Bermudez, "Iraq's Al-Husayn Missile Programme," p. 244.

³⁰ Assuming a total mass of 1500 kilograms and a velocity of 1600 meters per second at impact.

³¹ Bierman, "A Battered City," p. 28.

³² At least some of the problems with the Iraqi-modified Scud missiles were known to the Iranians. In March 1988, Iranian Majlis speaker Rafsanjani publicly discussed the modifications the Iraqis had made to the basic Scud missile in order to increase its range. He stated the welding done by the Iraqis was of poor quality and that the

equivalent of 250 kilograms of TNT. (Recall that the total energy released on impact by the V-2 was equivalent to about 900 kilograms of TNT). Since the area subjected to a given peak overpressure scales as the yield to the two-thirds power, assuming an energy release equivalent to 250 kilograms of TNT, the lethal area created by the impact of the modified Scud (and therefore the expected number of casualties and houses destroyed) would be about 0.43 times that of the V-2.

Thus, scaling for differences in population density and warhead yield, one would have expected the casualty rate in Tehran to have been roughly three times greater than that in London, with 14 deaths and 35 serious injuries expected per Scud impact. This estimate is in general agreement with the available information, albeit scarce and of unknown reliability, about casualties in Tehran. However, it is difficult to draw any conclusions because there are relevant circumstances in Tehran that may have differed significantly from those in London, and about which we have inadequate information (for example, construction practices and civil defense -- see our subsequent discussion of construction practices in Israel).

The Scud Attacks in Afghanistan

Beginning in October 1988, the Soviet-backed government of the Democratic Republic of Afghanistan (DRA) launched over 2,000 Scud missiles at positions held by Mujahideen guerrillas.³³ Unlike the missile attacks on London and Tehran, many of these attacks were directed at military targets: Mujahideen formations, staging areas, ammunition dumps, and supply lines. Because these relatively small targets are difficult to destroy with inaccurate missiles (the Scud-B is estimated to have a circular error probable (CEP) of about 1 km)³⁴ armed with

modifications had led to stability problems that could cause the missiles to "do somersaults" while outside the atmosphere. He also claimed that the missiles had a number of additional problems which he did not wish to reveal to the Iraqis. "2d Sermon on Missile Attacks," *Daily Report - Near East and South Asia*, Foreign Broadcast Information Service (hereafter referred to as *FBIS*), March 14, 1988, pp. 59-62.

³³ For information on missile attacks in Afghanistan see Joseph S. Bermudez, "Ballistic Missiles in the Third World - Afghanistan 1979-1992," *Jane's Intelligence Review*, February 1991, p. 51-58. See also Anthony H. Cordesman and Abraham R. Wagner, *The Lessons of Modern War, Volume III: the Afghan and Falkland Conflicts* (Boulder, Colo.: Westview Press, 1990), pp. 163-164.

³⁴ Steven Zaloga, "Ballistic Missiles in the Third World: Scud and Beyond," *International Defense Review*, November 1988, pp. 1423-1427. The CEP is the radius of an imaginary circle, centered at the missile's aimpoint,

conventional warheads, the attacks were militarily ineffective. The attacks did, however, serve to terrorize villages that were captured by the Mujahideen or that were suspected of supporting the guerrillas. For example, when the village of Khost was captured by the Mujahideen, four Scuds were fired by the DRA, killing 14 and wounding 30. The most frequently cited attack is one in which two Scuds hit a crowded bazaar in Asadabad, reportedly killing 300 and wounding 500.³⁵

The missiles used in these attacks were apparently unmodified Scud-Bs, with full-size (1000 kg) warheads. While their poor accuracy has been noted above, they almost certainly were considerably more accurate than the modified Scuds used by Iraq against Iran, Israel, and Saudi Arabia. It is also possible that larger, more accurate Scud-Cs (with a CEP estimated at 300 m)³⁶ were used in Afghanistan.

Unfortunately, very little detailed information is available about the number of attacks on civilian targets and the resulting casualties and damage in Afghanistan, and we are not able to determine if the casualties are consistent with what would be expected based on the London V-2 experience.

THE SCUD ATTACKS ON ISRAEL

The 39 modified Scud missiles that reached Israel directly killed two people and injured about 230 more.³⁷ Almost all of the injuries were light, with only ten classified as moderate and one as severe. The number of Israeli deaths and serious injuries produced by the modified Scud missiles at first glance seems remarkably low compared with previous ballistic missile attacks. In fact, the *total* number of direct deaths and serious injuries in Israel was less than that caused by just *one* average missile impact in London or Tehran.³⁸

inside of which half the impacts would occur. The actual impact patterns of ballistic missiles are typically elliptical rather than circular, however, with the range error generally being larger than the cross-range (or track) error.

³⁵ Bermudez, p. 52.

³⁶ Cordesman and Wagner, p. 164.

³⁷ Casualty statistics are given in Eric Karsenty, Joshua Shemer, Itzhik Alshech, Bruno Cojocar, Marian Moscovitz, Yair Shapiro, Yehuda L. Danon, "Medical Aspects of the Iraqi Missile Attacks on Israel," *Israel Journal of Medical Sciences*, Vol. 27 (November-December, 1991), pp. 603-607; and Avi Bleich, Anat Dycian, Meni Koslowsky, Zahava Solomon, and Michael Wiener, "Psychiatric Implications of Missile Attacks on a

Most of the casualties and damage in Israel occurred in the Tel Aviv area. As discussed above, it is necessary to account for differences in population density and warhead yield when estimating the expected casualty rate. The Tel Aviv metropolitan area had a population density of about 7,000 per km² in 1991.³⁹ As was the case in London and Tehran, many people left Tel Aviv during the missile attacks. One study of Israeli casualties cites this as a factor in reducing casualties, noting that "quite a number of the badly damaged homes were in fact empty at the

Civilian Population: Israeli Lessons from the Persian Gulf War," *Journal of the American Medical Association*, Vol. 268, No. 5 (5 August 1992), p. 613-615. These two studies differ only marginally in the total number of direct casualties cited (234 and 231 respectively).

Many reports cite only one, rather than two, direct deaths. This discrepancy arises from the third attack on Israel, when a single Scud hit the Tel Aviv suburb of Ramat Gan on the evening of 22 January and three people died. Initial reports attributed all three deaths to heart attacks (and this is what was widely reported afterwards), but one of these deaths was a direct result of the Scud attack: "It should be noted that heart attack was not the cause of death in all three cases, as reported earlier. The dead woman who was taken to Ichilov Hospital died of crushing wounds as a result of the explosion. The two other dead women suffered heart attacks as a result of the missile impact." *Jerusalem Voice of Israel and IDF Radio Network*, 4:20 am [Israel Time], 23 January 1991, in FBIS, *Daily Report: Near East and South Asia*, 23 January 1991, p. 28.

The other death was a man killed (also in Ramat Gan) in the fifth attack, on the evening of Friday, 25 January, apparently from a head wound. "Brig. Gen. Yehuda Danon, chief medical officer of the Israeli Defense Forces, said one death resulted from a direct hit on a house Friday night and the other was a woman who was crushed by debris and cut by shattered glass." The latter is the death described in the preceding paragraph. William Claiborne and Jackson Diehl, "Patriots Launched to Meet New Scud Attack Over Israel," *Washington Post*, 27 January 1991, p. A22.

In addition to the direct casualties, there were also a large number of indirect casualties in Israel. Seven people suffocated due to improper use of gas masks and five fatal heart attacks were attributed to the missile attacks. Another 815 indirect casualties were treated at hospitals and can be attributed to the Scud attacks. These were primarily cases of people with acute anxiety or who had injected themselves with the atropine provided in their civil defense kits. More than half of the indirect injuries were not due to actual missile attacks but to the five false alarms that occurred during the first few days of the attacks. Karsenty, et. al., "Medical Aspects."

³⁸ It is the direct casualty figures that are generally mentioned in discussions of casualties in Israel, and we assume the casualty figures cited for London and Teheran are also for direct casualties. It is worth noting that the number of indirect casualties per Scud attack on Israel declined rapidly as the war progressed. Sixty four percent of the anxiety reactions and atropine injection cases requiring hospitalization in Israel occurred in the first day of the attacks and another 15% were due to the second attack (Bleich, et. al., "Psychiatric Implications," p. 614). On the other hand, London had been subjected to bombing for several years prior to the V-1 and V-2 attacks.

³⁹ The population density of the metropolitan Tel Aviv area was 5,910 per km² in 1983 (*Atlas of Israel: Cartography, Physical and Human Geometry* (New York: MacMillan, 1985), map 23.). Between 1985 and 1990, the Israeli population increased at a rate of 1.66 percent per year; between 1960 and 1990, the percentage of the Israeli population living in the Tel Aviv area increased from 34.9 to 40.9 percent (World Resources Institute, *World Resources 1992-93* (New York: Oxford University Press, 1992), p. 247, 265.). Assuming constant growth rates during these periods, the population density of the Tel Aviv area would have been 7,030 per km² in 1991.

time of explosion."⁴⁰ Although this evacuation was widely noted in the press, its extent is difficult to estimate, especially since many of the evacuees left only at night, returning to their jobs in the morning.⁴¹ In the absence of better information, we assume the same fraction of evacuees as in London (about 20%), which would give a population density of about 5,700 per km² for the Tel Aviv metropolitan area during the missile attacks--about 1.6 times that of London.

The Iraqi-modified Scud missile (the al-Hussein) used against Israel was apparently the same as that used against Iran, and it appears that essentially all of the missiles launched by Iraq during the 1991 Gulf War broke up on reentry. Thus as with the Iraqi attacks on Tehran, we assume that the total energy released on impact was equivalent to 250 kilograms of TNT.⁴² Recall that the total energy released by a V-2 impact was equivalent to 900 lbs of TNT. Thus, taking into account the differences in population density and warhead yield by applying the appropriate scaling factors to the casualty rates from V-2 attacks on London, the expected casualty rates are about 3.3 deaths, 8.1 serious injuries, and 18 slight injuries per Scud impact in Tel Aviv. This would lead to 129 expected deaths, 316 serious injuries, and 702 slight injuries from the 39 missiles that struck Israel, assuming that all the missiles fell into a metropolitan area similar to Tel Aviv. Thus, the actual number of direct deaths (two) that resulted from the Scud attacks was more than sixty times less than what one might have expected based on this very simple extrapolation from the V-2 experience in London. Similarly, the number of serious injuries (11) was roughly 30 times smaller, and the number of light injuries (220) more than 3 times smaller than would have been expected based on the V-2 data. However, as we discuss below, there are a number of factors that can account for most or all of these apparent discrepancies.

⁴⁰ Karsenty, et. al., "Medical Aspects," p. 606.

⁴¹ The daily exodus from Tel Aviv resulted in massive traffic jams. (Judy Siegal, "Gridlock, Tel Aviv Style," *Jerusalem Post*, January 28, 1991, p. 2; and Michal Yudelman, "Coping with the Indignities of Life," *Jerusalem Post*, January 25, 1991, p. 2). This daily evacuation occurred because the Israeli population understood that Coalition air power was forcing Iraq to launch after dark. The only daytime attack on Israel was the second one, which occurred at 7:15 am on 19 January.

⁴² Since Tel Aviv and Haifa are 50 to 100 kilometers closer to Iraqi launch sites than Teheran, Iraq could have armed the missiles launched at Israel with slightly heavier warheads. It is quite likely, however, that the same warhead was used in both cases.

THE ROLE OF PATRIOT

The Scud attacks on Israel began early in the morning of 18 January, 1991, but the first Patriot battery did not become operational in Israel until after 12 Scuds had already fallen. Of the 39 Scuds that reached Israel, 27 were fired after Patriot was operational; of these, 17 were engaged by Patriot missiles.⁴³ Most or all of the other ten Iraqi missiles apparently fell in areas not covered by the Patriot batteries, which were deployed in the Tel Aviv and Haifa areas,⁴⁴ and produced few casualties and no significant damage.⁴⁵

According to the U.S. Army's most recently revised estimates of Patriot effectiveness, of the 17 engagements in Israel, only 40 percent were successful.⁴⁶ Furthermore, the Army stated that it had "highest" confidence in only 40 percent of the claimed successful engagements in Israel and Saudi Arabia.⁴⁷ Thus, of the 17 Scuds engaged in Israel, the U.S. Army credits Patriot with at most seven successful intercepts, with only about three of these being in the "highest" confidence category (assuming equal confidence levels in Israel and Saudi Arabia). Moreover, as we shall discuss subsequently, six Scuds fell in areas defended by Patriot before it was operational. Thus even using the Army's data, Patriot would have been expected to reduce the casualty rate by no more than 13 to 30 percent.⁴⁸ Moreover, there are reasons to believe that the Army's

⁴³ Eric Schmidt, "Israel Plays Down Effectiveness of Patriot Missile," *New York Times* (International edition), 31 October 1991, p. A8; and Ethan Bronner and John Aloysius Farrell, "US, Israeli Experts Dispute Patriot Claims," *Boston Globe*, 19 March 1992, p. 1.

⁴⁴ There were two Patriot batteries in Haifa and four at Tel Aviv. In addition, a Dutch battery arrived towards near the end of the war and was deployed near Jerusalem, however, it did not engage any Scuds.

⁴⁵ Bleich, et. al., "Psychiatric Implications," p. 614, indicate that two people were injured on 25 February. The two Scuds fired at Israel that day fell in the Negev desert, well out of the range of Patriot batteries in Tel Aviv.

⁴⁶ U.S. General Accounting Office, *Operation Desert Storm: Data Does Not Exist to Conclusively Say How Well Patriot Performed*, GAO/NSIAD-92-340, September 1992, p. 3.

⁴⁷ The assignment of an engagement as a high confidence successful intercept does not mean that the Army is claiming that it is certain that the engagement was successful. "According to the Deputy Project Manager, the assignment of a high confidence level to an engagement's outcome did not mean that the Army was absolutely confident that the assessed outcome was correct. Rather, given the limited data available for assessment purposes, the Army scorers had higher confidence in the assessed outcome of these engagements than in others." U.S. General Accounting Office, *Operation Desert Storm: Data Does Not Exist*, p. 3.

⁴⁸ These percentages are calculated assuming 3 to 7 out of 23 Scud warheads were destroyed. The total number

claimed Patriot success rate is too high.⁴⁹ In addition, any damage prevented by successful intercepts must be weighed against the damage caused by the at least four Patriot missiles that struck the ground and exploded in Israel.⁵⁰ Finally, debris from Patriots that detonated above cities or from intercepted Scuds may have caused some damage.⁵¹ Due to the lack of accurate track data on the Scud and Patriot missiles, the effect of Patriot in mitigating casualties and damage in Israel will never be known with any certainty. Since large statistical fluctuations would be expected in the damage caused by small numbers of inaccurate ballistic missiles armed with conventional warheads, any effect that Patriot may have had on casualties and damage in this case is lost in the noise.

Casualty and damage statistics support this conclusion. Of the 231 direct casualties, 52 occurred before Patriot was operational (4.3 per Scud) and 179 after (6.6 per Scud).⁵² All but

of Scuds reaching Israel (39) should not be used in this calculation because Scuds that fell outside of defended areas were much less likely to cause casualties.

⁴⁹ See Conyers, "The Patriot Myth". A recent report by the U.S. General Accounting Office concluded that only about 9 percent of the Patriot engagements are supported by "highest" confidence data indicating a successful intercept. U.S. General Accounting Office, *Operation Desert Storm: Data Does Not Exist*.

In addition, there is a substantial body of evidence in the form of news media videos of Patriot engagements that suggest that its success rate was much lower than the current U.S. Army claims. See George N. Lewis and Theodore A. Postol, *An Evaluation of the Army Report "Analysis of Video Tapes to Assess Patriot Effectiveness," Dated 31 March 1992: A Study Performed in Response to a Request by Congressman John Conyers, Jr., Chairman of the House Government Operations Committee* (Cambridge, Mass.: M.I.T. Defense and Arms Control Studies Program, September 1992).

⁵⁰ The U.S. Army and Raytheon acknowledge that some Patriots dove into the ground, although the exact number remains classified. Publicly available news media videos show at least three Patriots diving into the ground in Israel on the night of January 25; two of these were in Tel Aviv and one was in Haifa (Lewis and Postol, "An Evaluation of the Army Report," p. 61). At least three Patriots reportedly dove into the ground in Tel Aviv on this night, with two of them striking residential neighborhoods (Fred Kaplan, "Specialists Debate the Value of Patriot," *Boston Globe*, 5 May 1991, p. 1). Charles Zraket (Zraket, "Patriot Gave Stellar Gulf Performance") states that four Patriots hit the ground in Israel (however, Zraket also incorrectly says that no Patriots dove into the ground in Saudi Arabia). More recently, in interviews conducted by Reuven Pedatzur and Theodore Postol, three Israeli experts gave figures of 8, 9, and 11 for the number of Patriots that dove into the ground in Israel.

⁵¹ The Patriot intercept attempts together with the Scud breakups must have generated a considerable amount of falling debris. Such debris would have been greatly slowed up by the atmosphere, greatly reducing its damage-producing potential. Most Israelis were indoors during the attacks, and thereby had a considerable degree of protection from such debris. Nevertheless debris undoubtedly caused some damage to buildings, most of it probably light, and appears to have caused at least a few injuries.

⁵² Casualty figures for each day of the Scud attacks are given in Bleich, et. al., "Psychiatric Implications," p. 614.

two of the 179 casualties that occurred after Patriot was operational were caused by Scuds that were apparently engaged by Patriot. Moreover, both direct deaths occurred during the period of Patriot defense, and press reports suggest that most or all of the injuries that occurred before the Patriot deployment were light.

The situation with respect to property damage is more complicated. The Tel Aviv newspaper *Ma'ariv* compiled a list of damage to buildings that indicated 2,797 apartments suffered damage before (233 per Scud) and 9,029 after Patriot was operational (334 per Scud).⁵³ However, much of the damage to apartments was very light (e.g., broken windows). If only apartments that were seriously damaged or destroyed are counted, the figures are 37 per Scud before, and 34 per Scud after the deployment of Patriot.⁵⁴ Unfortunately, no definitive studies of damage comparable to those on casualties appear to be available.

Thus while serious damage to apartments per Scud appears to have decreased slightly

To calculate casualties on a per missile basis, we assume 12 Scuds before Patriot and 27 afterwards. In these calculations, we have included all the Scuds that struck in or near Israel. An argument could be made that the ten Scuds that were not engaged after Patriot was operational should be excluded, because most or all of them presumably fell outside the Patriot's defended perimeter and thus almost certainly fell in areas of much lower population density. However, this has not been done because we are unable to make the corresponding determination of how many of the Scuds launched before Patriot would have been outside of the defended perimeter. A better argument can be made that the three Scuds apparently fired at Dimona should be excluded; however, to be conservative, we have included these as well (excluding them would slightly increase the per missile damage and casualties after Patriot).

⁵³ Translated and reproduced in Postol, "Lessons of the Gulf War Experience," pp. 141-144.

⁵⁴ The interpretation of the *Ma'ariv* statistics has been a subject of dispute. Light damage is generally conceded to be greater after Patriot activation, but the situation for heavy damage has been disputed. Postol excludes from his count those Scuds which *Ma'ariv* lists as not falling in the Tel Aviv or Haifa Metropolitan area and which caused no damage, and finds that heavy damage per Scud was greater after Patriot. (Postol, "Lessons of the Gulf War.") This is not entirely satisfactory because the number of Scuds falling in metropolitan areas is not broken down for the four multiple missile attacks, which account for almost 60% of the Scuds reaching Israel, including all of those before Patriot was operational. Thus it is possible that some of the Scuds launched before the deployment of Patriot also did not fall in a metropolitan area, and should also be excluded, thereby giving a higher damage rate before Patriot was operational.

Stein, in his rebuttal to Postol, argues that very few Scuds fell on Tel Aviv before Patriot, and that the heavy damage per Scud was greater before Patriot. (Stein, "Patriot Experience in the Gulf War," p. 222). This conclusion follows from his statement, presumably based on classified data, that more than twice as many Scuds fell on Tel Aviv after Patriot than hit before Patriot. However, Stein's acknowledgement that the light damage in Tel Aviv was greater after Patriot indicates that fewer than three times as many Scuds fell after Patriot deployment than before Patriot. This indicates that even with Stein's figures on the numbers of Scuds before and after Patriot, that the casualties per Scud were still greater after Patriot if one uses the casualty figures cited in this paper (which are far more definitive and authoritative than ones in the *Ma'ariv* article used by Postol and Stein).

after Patriot became operational, light damage, deaths, and injuries all increased. Given the small number of Scud impacts in inhabited areas, however, the differences before and after Patriot are not statistically significant. The only conclusion suggested by the available data is that Patriot had relatively little effect on casualties or damage.

FACTORS THAT CONTRIBUTED TO LIMITING CASUALTIES IN ISRAEL

The role that the small size of the modified Scud warheads and the breakup of the Scud missiles played in reducing the explosive yield and kinetic energy of the Scuds has already been described in the section "Scud Attacks on Tehran." There are a number of additional factors that could have played a significant role in limiting the casualties from the Scud attacks on Israel.

Inaccuracy of the Modified Scuds

A crucial factor in limiting the damage to Israel was that the modified Scud missiles were so inaccurate that many of them did not strike populated areas.⁵⁵ According to a study of Israeli casualties, only six Scud warhead explosions caused direct casualties.⁵⁶

As previously noted, the basic Scud-B, at its maximum range of 300 kilometers, is so inaccurate that half of the impacts would be more than one kilometer from the target. Moreover, the modifications made to the missile by Iraq decreased its accuracy even further, because the range of the missile was roughly doubled and the missile tumbled and broke up on reentry.⁵⁷ The

⁵⁵ Three of the Scuds, however, were apparently not fired at cities but at the Israeli nuclear facility at Dimona. All three apparently fell in the surrounding desert.

⁵⁶ Karsenty, et. al., "Medical Implications," pp. 604-605. This figure is not inconsistent more than 6 warheads detonating within cities, since some fell in nonresidential areas that would have been deserted at the time of the attack. In addition, it appears that two other attacks besides these six caused a few casualties, perhaps from falling debris. See the table in Bleich et. al., "Psychiatric Implications," p. 614.

⁵⁷ Since the CEP is roughly proportional to the range, the operational CEP of the al Hussein would be doubled simply due to the range extension. The breakup of the missile would also decrease its accuracy by altering its ballistic coefficient, thereby changing its reentry aerodynamics and its range in an unpredictable manner. Indeed, in 1988, an Iranian official said that the modifications to the Scud made it "not precise," and that the missile was three times less accurate than the Iranian Scud-Bs ("Rafiquist, Kharrazi Discuss War of Cities," *FBIS*, 11 March 1988, p. 65).

Scud-hunting campaign carried out by Coalition aircraft also may have significantly reduced the accuracy of the Scuds by causing the Iraqi launch crews to rush their setup and alignment procedures and to launch Scuds from locations that had not been surveyed in advance.

It is difficult to determine the exact number of Scud impacts in Israeli metropolitan areas.⁵⁸ To avoid giving useful targeting information to Iraq, Israeli censorship regulations did not allow the release of the precise locations of Scud impacts, and did not allow the reporting of impacts in the Mediterranean Sea. After the first two weeks of the missile attacks, Israel also stopped reporting whether or not Patriots were fired at particular Scuds. In addition, the breakup of the Scuds, Patriot intercept attempts, and Patriot ground impacts caused debris to be scattered over a wide area.⁵⁹ Thus, even an attack by a single Scud could result in widespread damage, making it more difficult to determine from news reports the location of the warhead impact or even if there was a warhead impact.⁶⁰

Nevertheless it is possible to sort out much of what must have happened in the attacks in Israel. A chronology of the Scud attacks on Israel and Saudi Arabia is given in the Appendix.

In attacks involving a single Scud missile to a given area, there is little difficulty in

⁵⁸ The metropolitan area we consider here is the area shown as having a 1983 population density of 5,910/km² in *Atlas of Israel*, map 23. This area of about 200 km² is approximately a 10-by-20-km rectangle, with its long side parallel to the Mediterranean coast. Thus we take any Scud falling near Tel Aviv and within 10 km of the coast as having fallen in the metropolitan area. (One Scud landed approximately 10 km from the coast on February 12; it caused casualties and damage, so we count it as falling in the metropolitan area). For Haifa, the geographic situation is more complicated. However, it appears that only one warhead exploded in the Haifa metropolitan area.

⁵⁹ See Postol, "Lessons of the Gulf War," pp. 148-149, for figures illustrating the possible extent of debris scattering. The breakups of Scuds often led to the double-counting of Scud impacts in Teheran (FBIS, 11 March 1988, p. 67).

⁶⁰ There is, however, a enormous difference between the effects of falling debris and a high-explosive warhead. Relatively small, dense pieces of debris could potentially penetrate several floors of a building. At least one person in Israel was injured by being directly struck by missile debris, when a missile motor crashed through his ceiling (Karsenty, et. al., "Medical Aspects," p. 606.), and some injuries also may have resulted from flying glass, etc. produced by falling debris. Less dense pieces of debris, which were much more common, would fall more slowly and would only be dangerous to people caught outside. Thus, the timing of the attacks and the few minutes of warning may have been important in reducing casualties from debris. Unlike debris, a high-explosive warhead produces intense destruction in a relatively localized area. The blast wave generated by the explosion can knock down walls and destroy nearby buildings, and can shatter windows over a much greater distance. Any small building directly hit by such a warhead would be completely destroyed. If the warhead explodes on or near the surface, a crater will be produced. Thus, there should be little difficulty in distinguishing between the explosion of a warhead and damage caused by debris for anyone who had access to the area after an attack.

identifying the cases in which a warhead detonated in a populated area. In the fifteen single-Scud attacks, only three warheads appear to have exploded in populated areas in or near Tel Aviv or Haifa.⁶¹ The other twelve warheads fell in uninhabited areas, were duds, or possibly were destroyed by Patriot missiles.⁶²

It is more difficult to sort out what occurred in the four multiple-Scud attacks in which eight, four, seven, and five missiles, respectively, were fired at Tel Aviv and Haifa.⁶³ The first two attacks occurred before Patriot was operational. Eight missiles were fired at Tel Aviv and Haifa at about 2 am on 18 January, and four missiles were fired at Tel Aviv at about 7 am on the following day. Stein states that the majority of these missiles "were not on target, and only very few fell on Tel Aviv."⁶⁴ Taken literally, this means that no more than five Scuds were on target; and as we shall see, at least one of these did not explode. A Pentagon briefing on 25 January 1991 also implied that no more than five or six of these missiles landed in populated areas and caused damage.⁶⁵ As discussed in the Appendix, we have been able to identify six Scud warhead

⁶¹ These attacks occurred on 22 January, 9 February, and 12 February 1991. See the Appendix for details.

⁶² It is possible that some of these Scuds landed in areas, that although uninhabited, were still in a metropolitan area. The Scud fired at Haifa on the evening of 23 January was the only one of these twelve not reported by the Israeli government or press to have landed in an uninhabited area. This was also the only one of these twelve Scuds reported as causing damage, but the damage (primarily broken windows) was attributed to debris falling over a wide area, which might well have been caused by debris from the breakup of the Scud or from the Patriots that were fired at the Scud. There were no injuries and no reports that suggested a warhead impact. Joel Brinkley, "No Immediate Retaliation, Israelis Say," *New York Times (International Edition)*, January 24, p. A15; and Jackson Diehl and William Claiborne, "Patriot Battery in Israel Intercepts Iraqi Missile," *Washington Post*, January 24, p. 1.

⁶³ Even the number of missiles fired in each of these attacks is somewhat uncertain, as the various data sources for these numbers are not always in agreement. The numbers used here represent our best estimate based on currently available information.

⁶⁴ Stein, "Patriot Experience in the Gulf War," p. 222.

⁶⁵ According to Gen. Thomas Kelly, "Up until today [January 25]...34 Scuds had been launched against Saudi Arabia and Israel -- 21 against Saudi Arabia, 13 against Israel. Eighteen of them were destroyed by Patriots, nine landed in uninhabited areas or in the sea. Of the remaining seven, to one degree or another they impacted the earth and caused some damage." Pete Williams, Lt. Gen. Thomas Kelly, and Capt. David Herrington, Pentagon Briefing, 3:30 pm, Jan. 25, 1991 in Steven A. Hildreth, *Evaluation of U.S. Army Assessment of Patriot Antitactical Missile Effectiveness in the War Against Iraq*, report prepared for the House Government Operations Subcommittee on Legislation and National Security, 7 April 1992, p. 31.

At this point, only two of the thirteen Scuds that had reached Israel were fired after Patriot was operational. The one on the 22nd caused significant damage and the one on the 23rd was credited as a successful

impacts (one warhead did not explode) in populated areas in these first two attacks.

The other two multi-Scud attacks occurred during the period of Patriot defense: seven Scuds were launched at Tel Aviv and Haifa on 25 January and five the next day. In neither attack were there reports of explosions in populated areas near Haifa. In the first of these two attacks, we have so far been able to clearly identify only two explosion sites in populated areas in or near Tel Aviv. In addition, at least three Patriots dove into the ground and exploded in or near Tel Aviv on this night.⁶⁶ There were also reports of damage from falling debris. In the second attack, a Scud is known to have exploded on a deserted beach north of downtown Tel Aviv.

From press reports, it is possible to identify about ten or eleven Scud warheads that exploded in populated areas in Israel. Interviews conducted by Reuven Pedatzur in Israel have established a number of additional Scud warhead impact sites and have allowed us to construct the map shown in figure 1. This shows the impact location of 17 Scuds that fell in the general vicinity of Tel Aviv.⁶⁷ Three of the Scud warheads (numbers 3, 7, and 13 on the map) did not explode. Two others (numbers 15 and 17) are outside our defined Tel Aviv metropolitan area (that is, they are more than 10 km from the coast). Thus about 13 warheads exploded on the ground in the Tel Aviv metropolitan area. Since one additional warhead is known to have exploded in the Haifa metropolitan area, it appears that a total of 14 Scuds exploded in Israeli metropolitan areas.

intercept. Even assuming that none of the Scuds in Saudi Arabia caused any damage (although one of the earlier attacks did cause damage and injuries in Riyadh), this means that no more than six Scuds impacted the ground in inhabited areas in the January 18 and 19 attacks on Israel.

⁶⁶ Although no reports specifically attributed damage to Patriots diving into the ground, it is clear that most or all of the incidents of Patriots diving into the ground in Israel occurred on the night of 25 January.

⁶⁷ This map is based on the best information available to us at the time of publication. Some of the impact points, in particular those for which no date is given, are somewhat uncertain. It is likely that most of the impact with no date occurred on January 25 or 26.

What happened to the other Scuds? Of the 39 Scuds, three were fired at Dimona and landed harmlessly in the desert. Roughly six others were fired at Haifa; most of these probably landed in the Mediterranean. Roughly 30 Scuds were fired towards Tel Aviv; 17 are shown on figure 1 and another four apparently landed in the West Bank. It seems likely that many of the remaining Scuds landed in the Mediterranean. An anonymous senior Pentagon scientist reportedly stated that Scuds not engaged by Patriot "either fell in the sea or out of range of the Patriot batteries, near towns in the West Bank or in the Negev desert."⁶⁸ One the Israeli casualty studies noted that of the missiles launched against Israel, "a number fell in the sea or exploded in the air."⁶⁹ It is also possible that a few Scuds were destroyed by Patriots.

Finally, it is interesting to see if the available data can tell us anything about the CEP of the modified Scuds. First, however, it is important to note that the concept of CEP may not be truly applicable to the entire set of Scud attacks on Israel. This is because the accuracy of the Scuds may have changed as the war progressed. The general pattern of the Scud attacks on Israel suggest that the accuracy of the Scuds may have decreased dramatically towards the end of the war.

In the first two attacks, before Patriot was operational, 12 Scuds were fired at Tel Aviv and Haifa. One landed in Haifa and five near Tel Aviv. Four of the five Tel Aviv impacts (one of which did not explode) were within the Tel Aviv-Jaffa city limits. It seems quite probable that most or all of the other Scuds landed in the Mediterranean.

The next 14 Scuds fired at Tel Aviv and Haifa came in four attacks over five days after Patriot was operational. It appears that about 11 or 12 of these were engaged by Patriot.⁷⁰ However, this tells us relatively little about the CEP because the area defended by Patriot was quite large.

The accuracy of the last ten Scuds fired at Tel Aviv and Haifa (we exclude the three apparently fired at Dimona) appears to be significantly poorer than that of the earlier Scuds.

⁶⁸ Schmidt, "Israel Plays Down Effectiveness," p. A8.

⁶⁹ Karsenty, et. al., "Medical Aspects," p. 604.

⁷⁰ This assumes that the figure of 17 total engagements in Israel is correct. There were at least 5, and possibly 6, engagements after this period.

Only five or possibly six of these last ten Scuds were engaged. Four Scuds landed far short of Tel Aviv in the West Bank. Even two of the Scuds that were engaged landed well east of downtown Tel Aviv (these are the Scuds that hit on February 12 and February 19 -- numbers 10 and 3 on figure 1). This strong eastward shift of the impact points strongly suggests a change in the nature of the Scud or a change in the way it was being launched.

Thus the available information strongly suggests that, at least towards the end of the war, the accuracy of the Scuds declined greatly. This is not surprising given the vigorous Coalition air campaign against the Scud launchers.

The other major problem in attempting to assess the Scud's CEP is that many of the impact points are not yet known and none of the Scud aimpoints are known (we do not know if all the Scuds fired at a given metropolitan area had the same target). It appears that there were about 30 Scuds fired at Tel Aviv. We know the exact or approximate impact point of 17 of these and we know four others landed somewhere in the West Bank. So this leaves us with about 9 "missing" Scuds -- about half before Patriot deployment and half afterwards.

These missing Scuds would not necessarily be a problem in estimating the CEP if it could be assumed that their geographic distribution was similar to that of the Scuds whose impact point is known. However, such an assumption would clearly be incorrect in this case. The absence of news media reports on these missing Scuds suggests that many of them may have fallen in remote areas. Most importantly, Tel Aviv and Haifa are coastal cities, so some Scuds would be expected to fall into the Mediterranean -- and wartime Israeli censorship rules forbade reporting of Scuds that fell into the Mediterranean. Thus it appears likely that many of the "missing" Scuds fell into the Mediterranean.

Without knowing how many Scuds fell into the Mediterranean, no meaningful conclusions about the CEP of the Scuds can be drawn. If we assume that most or all of the missing Scuds landed in the Mediterranean and were relatively close to shore, and we exclude the last 13 Scuds fired at Israel, then the data might support a CEP of about 4 kilometers. If many of the missing Scuds landed outside the metropolitan area and we include all the Scuds fired late in the war, the data suggest a larger CEP -- but no greater than about 7 kilometers. At present, the available data is simply inadequate to allow a reliable CEP estimate to be made. However, in any case, the CEP was much greater than that of the unmodified Scud-B.

Warning Time

A major difference between the V-2 attacks on London and the Scud attacks on Tel Aviv was that the Israeli population generally had a few minutes warning time in which to take cover, because the United States shared satellite information on missile launches with Israel.⁷¹ We can account for this very approximately by comparing the casualty rate for the V-1 attacks, for which there was some warning, with that for the V-2 attacks, for which there was no warning. After correcting for its slightly smaller yield, the death rate from V-1 attacks was 0.50 times that from the V-2 attacks.⁷² The corresponding ratios for serious injuries and light injuries were 0.58 and 0.35, respectively. Thus, taking into account warning time in addition to population density and warhead yield, the expected casualty rates in Tel Aviv are reduced to about 1.6 deaths, 4.7 serious injuries, and 6.2 slight injuries per missile impact.

Another factor that may have played a role in reducing casualties is that virtually all of the missile attacks occurred at night, whereas the attacks on London and Tehran occurred throughout the day.⁷³ Thus, most people were at home during the attacks, and on hearing the warnings simply had to go into interior rooms to obtain a degree of shelter, as they were instructed to do by the Israeli government.⁷⁴

Blast-resistant dwellings

⁷¹ However, in the first two attacks on Israel, the population had at most only a few seconds of warning time.

⁷² The Strategic Bombing Survey also attributed the lower death rate from V-1s to the more intense disintegration of debris produced by V-2 explosions, but, as discussed earlier, this was not a decisive factor. In any case, apparently due to the much lower yield of the al Hussein and the reinforced-concrete construction of Israeli apartment buildings, such intense disintegration did not appear to occur from the impact of the modified Scud missiles in Israel. Video of damage scenes show relatively coarse debris at Scud detonation sites, and there were several instances of people being dug out relatively unharmed from beneath destroyed buildings. Moreover, both deaths in Israel were reportedly instantaneous (Karsenty, et. al., "Medical Aspects," p. 604).

⁷³ A 1944 British study, based on a number of the first V-1 attacks, estimated that nighttime attacks would cause only half as many casualties as daytime attacks. Dunn, *The Emergency Medical Services*, p. 171.

⁷⁴ While these rooms might not have been as effective as underground blast shelters, victims of V-1 attacks had little time to get into such shelters if they waited (as many did), for the sound of the V-1 engine sound to stop 8 to 12 seconds before impact.

One Israeli study of the Scud casualties concluded that the most important factor in reducing casualties was the construction practices used in modern Israeli apartment buildings.⁷⁵ The multi-story apartment buildings erected in Tel Aviv over the last 30 years are constructed with reinforced concrete columns, beams, and floors.⁷⁶ The reinforced concrete elements apparently prevented buildings close to Scud detonations from collapsing and burying their inhabitants.⁷⁷ Even when the external unreinforced masonry block walls were destroyed, as long as the buildings did not collapse, the occupants were generally not seriously injured.⁷⁸ On the other hand, in the few cases in which missiles struck near single-family houses or older, unreinforced masonry buildings, the buildings were often completely demolished, with the roof and walls collapsing.

In contrast, the typical London dwelling was the brick row house, which, because its walls were load-bearing, readily collapsed when explosions occurred nearby. The limited data available on the effects of V-2 missiles on reinforced concrete buildings indicates that the area of structural damage was roughly eight times smaller than for brick row houses.⁷⁹ Since deaths and serious injuries were due primarily to structural collapses, significantly decreased rate of deaths and

⁷⁵ Karsenty, et. al., "Medical Aspects," p. 606.

⁷⁶ David Rudge, "Keeping Those Buildings Up," *Jerusalem Post*, 22 February 1991, p. 8; Karsenty, et. al., "Medical Aspects," p. 606.

⁷⁷ According to Ya'acov Gluck, a Professor of Structural Engineering at Israel's Technion University: "Our buildings, as a whole, have stood up well against the blast effects. We have seen very few total collapses except in the case of direct hits or incidents relating to old buildings or those not constructed in accordance with modern standards." He went on to say that they had been ". . . pleasantly surprised by the ability of buildings to withstand the shockwaves from explosions. It is very fortunate, otherwise we would have had a catastrophe with far more casualties." Rudge, "Keeping those Buildings Up."

⁷⁸ According to Professor Gluck, when this occurred, "there would normally be limited effects in inhabitants. People in the vicinity of the walls and windows would be injured, but not seriously." According to Gluck, the majority of injuries were from this type of incident. Rudge, "Keeping those Buildings Up."

Israeli doctors noted the same effect: "When the buildings involved were of the multi-level type - i.e., apartment blocks constructed of concrete with a steel girder shell and deep foundations - the injuries were mainly superficial, resulting from glass splinters or building fragments." Karsenty, et. al, "Medical Aspects, p. 605.

⁷⁹ Strategic Bombing Survey, *V-Weapons in London*, p. 22, gives a total floor demolition area of 94 m² for reinforced concrete buildings, compared with 740 m² for similar-sized buildings with load-bearing walls (740/94 = 8). Moreover, the mean distance from the warhead explosion at which walls were demolished was 11 m for reinforced concrete walls and 31 m for the 9-inch-thick unreinforced walls of brick row houses; note that $(31/11)^2 = 8$.

serious injuries would be expected for reinforced concrete buildings compared with brick load-bearing buildings.

It is important to note that the buildings in Tehran during the War of the Cities were generally similar to those in Tel Aviv. While the traditional architecture in Tehran features buildings made of mud bricks, most of the buildings in modern day Tehran are constructed with steel skeletons and walls that are not load-bearing. Tehran is in an earthquake zone and for the last few decades, has had strict building codes based on those for San Francisco.⁸⁰ Moreover, most of the buildings in Tehran are relatively new: the population of Tehran roughly doubled in the decade 1978-88. As a consequence, by the 1986 census roughly 12% of the residential units in Tehran were steel or reinforced-concrete structures, and an additional 80% were constructed of brick and steel or stone and steel, where the underlying load-bearing structure is steel and the outer walls are covered by a cladding of brick or stone.⁸¹ Presumably a similar fraction of commercial and other buildings were constructed with load-bearing steel substructures.

Recall that after adjusting for warhead yield and population density, the expected casualty rate in Tehran roughly agreed with that in London. However, since the construction found in Tehran in 1988 was quite similar to that in present-day Tel Aviv and quite different from that in World War II London, we might expect the deaths and injuries (adjusted for warhead yield and population density) in Tehran to have been reduced relative to those in London. On the other hand, the civil defense benefits of such construction are realized only if people are inside. Thus, advance warning of an attack and the time of attack are also critical factors. In contrast to the situation in Israel, no warning was available in Tehran and the attacks took place during both day and night. It therefore seems likely that the benefits of the steel reinforced building construction in Tehran were not fully realized because there was no warning and the attacks took place when people were not necessarily inside. Nevertheless, we caution the reader that the data available on damage and casualties in Tehran is sparse, and that we do not have a thorough

⁸⁰ Private communication with Professor Fred Moavenzadeh, Director, Center for Construction, Massachusetts Institute of Technology, 15 October 1992.

⁸¹ Data taken from 1986 National Census of Population and Housing, compiled by the Statistical Center of Iran. This information was provided by Ata Safai, Tehran.

understanding of the various factors that played a role in modifying the consequences of the attacks on Tehran.

Dud Warheads

Some Scud warheads landing in Israel simply failed to detonate; there were also reports of dud warheads in the Scud attacks on Tehran.⁸² By contrast, very few if any of the 518 V-2 warheads landing in London failed to detonate.⁸³ At least four Scud warheads striking Israel failed to detonate. In the second attack on Israel (on 19 January, before Patriot was operational), one Scud warhead penetrated several floors of a building in downtown Tel Aviv before coming to rest in a ground-floor jewelry store, where it was recovered intact.⁸⁴ In addition, one of the missiles fired at Israel did not carry an explosive warhead, but only concrete.⁸⁵ Two other Scuds, one that fell on February 19 (number 3 on figure 1) and one that fell on a presently unknown date (number 13 on figure 1), were also duds.⁸⁶ Based on this very limited data, the dud rate in

⁸² According to one source, "several" of the first 60 Scuds fired at Teheran in the 1988 War of the Cities failed to detonate. *Middle East Economic Digest*, 19 March 1988, p. 10.

⁸³ In the first 1,150 V-2 impacts in Britain and continental Europe, only two dud warheads were recovered. In all, only four or five were found. Strategic Bombing Survey, "V-Weapons in London," p. 9.

⁸⁴ Joel Brinkley, "Israel Says It Must Strike at Iraqis but Indicates Willingness to Wait," *New York Times*, 20 January 1991, p. 1. There is also a report of an intact Scud warhead being recovered by a French ordnance team at the base of a mosque on 24 February in Riyadh. Jeffrey M. Lenorovitz, "Poor Workmanship Discovered in Scud Missile Fragments," *Aviation Week and Space Technology*, 11 March 1991, p. 61.

⁸⁵ We have been able to confirm only one concrete warhead impact in Israel, although it is known that more than one Scud armed only with a concrete warhead was fired during the war (it is possible that the other(s) may have been fired at Saudi Arabia). This Scud landed in the Negev desert in southern Israel. ("Iraq Fired Scud with Concrete Warhead," *Flight International*, 13-19 March 1991, p. 13; David Ellis, "...and Stone-Age Scuds," *Time*, 8 April 1991, p. 21.). Another report cites eyewitness accounts of warheads containing nothing but concrete. Hildreth, *Evaluation of U.S. Army Assessment*, p. 11.

⁸⁶ These last two duds were presumably both engaged by Patriot and are presumably both claimed as warhead kills by the U.S. Army. However, despite recovering the warheads, the Army could not produce for Congressional investigators any chemical or metallurgical evidence that Patriot was responsible for causing the warhead to fail to explode. In no case was a Patriot warhead fragment recovered from a dud Scud warhead.

According to the Chairman of the House Government Operations Committee, "In the Army assessment, a dud Scud scored as a warhead kill if a Patriot had attempted an intercept. However, many of the Scuds were duds to begin with. Scuds were found with concrete warheads, or little explosive, or broken wires in the fuzing section. Several of these were scored as kills, even without corroborating evidence such as radar data. The duds were often burned and broken from impact, but this was hardly "clear physical evidence of Patriot intercept damage,"

Israel was apparently somewhat greater than 10%.

A possibly related factor is that there were apparently no injuries in Israel from shrapnel produced by the warhead explosions.⁸⁷ The Scud explosions apparently produced only small numbers of large fragments. It is unclear whether this was by design, or whether it was due to some flaw in the warheads.

Civil Defense

Most of the beneficial effect of civil defenses has already been accounted for in the discussion of warning time. While most Israelis apparently followed their government's instructions and remained in sealed interior rooms rather than going to bomb shelters, this still provided much better protection than was available in Tehran or London, where there was no warning. This is especially true given the reinforced concrete construction prevalent in Israeli apartment buildings. In addition, Israel devoted substantial effort to rapid rescue efforts (e.g., sending helicopters aloft on warning of attack to rapidly pinpoint impact locations and using trained dogs to find people trapped in demolished buildings), and several people were rescued from under collapsed buildings with only minor injuries. However, it is unlikely that Israeli efforts were much better than those of the British rescue services, which had experienced several years of German air attacks. Thus, excluding warning time, civil defense probably played a minor role in reducing the casualty rate relative to that in London.

Coincidence

For ballistic missile attacks involving only small numbers of missiles, large statistical fluctuations in casualty rates would be expected. Since, as we discuss above, only about thirteen warheads appear to have exploded in Israeli metropolitan areas, the statistics of small numbers

although in one case an Army officer thought a Patriot fragment caused a hole. This opinion was not supported by any chemical or metallurgical analysis or recovery of a fragment. Duds not engaged by Patriot showed similar damage." John Conyers, Jr., "The Patriot Debate: Part 2," *Arms Control Today*, January/February, 1993, pp. 27, 29.

⁸⁷ Karsenty, et. al., "Medical Aspects," p. 606.

come into play and coincidence inevitably will be an significant factor in the casualty rate. There is considerable anecdotal evidence that good fortune may have played a role in reducing casualties in Israel. The following descriptions of the identifiable Scud impacts in the six attacks that inflicted the bulk of the damage give an indication of the role luck may have played.

In the first attack on Israel, at 2 am on 18 January, one Scud hit a densely populated neighborhood, but "at the edge of the only empty lot for blocks."⁸⁸ The external walls of a number of buildings collapsed (but the buildings themselves did apparently did not collapse), but only light injuries from flying glass resulted. Two other Scuds exploded at a shopping mall that was under construction in Haifa and at a leather factory near Tel Aviv, both of which would have been deserted at the time of the attack.

At about 7 am on 19 January, one of four incoming Scud warheads struck a building but failed to explode.⁸⁹ Of the two warheads that did explode in or near Tel Aviv, one struck next to a municipal center, blowing open a basement that was used as a bomb shelter (but which was empty at the time), and the other fell in a park near the Tel Aviv exhibition center.

On 22 January, a missile landed in an alleyway between several apartment buildings, killing one person and injuring 84.⁹⁰ One family was buried for several hours under the wreckage of their home, but they were not seriously injured.

At 6 pm on 25 January, two Scuds exploded a few hundred meters apart in a residential area. One warhead destroyed a two-story house and severely damaged several others. Another missile landed next to an empty school in a residential neighborhood, seriously damaging it.⁹¹ However, only one man was killed in this attack and 67 were injured. According to one report, two people in one house survived only because they disobeyed government instructions and went to their basement bomb shelter.

⁸⁸ Sabra Chartrand, "A Day of False Alarms and Fear, Flanked by Real Explosions," *New York Times*, 19 January 1991, p. 7.

⁸⁹ Joel Brinkley, "Israel Says It Must Strike at Iraqis but Indicates Willingness to Wait," *New York Times*, January 20, 1991, p. A1.

⁹⁰ William Claiborne and Jackson Diehl, "Dazed Israeli Survivors Assess Wreckage in Streets of Tel Aviv," *Washington Post*, January 23, 1991, p. A1.

⁹¹ Joel Brinkley, "7 Iraqi Missiles Are Fired at Cities in Israel," *New York Times*, January 26, 1991, p A1.

On 9 February, a Scud struck in the middle of a road in a residential area of Ramat Gan.⁹² Although the front walls were pulled from buildings on both sides of the road, there were no deaths and no serious injuries.

On 12 February, a Scud struck between two private houses, demolishing both of them and seriously damaging a number of other houses.⁹³ One of the two houses was empty; in the other an elderly man was buried and, with the assistance of dogs trained for rescuing earthquake victims, was rescued with only minor injuries. Seven or eight people suffered minor injuries.

Two clear trends emerge from these reports. First, many Scuds hit unoccupied sites that would have been occupied during the daytime. Second, in instances where Scuds struck residential areas, the deaths and serious injuries appear to be lower than might be expected given the location of the impacts - although much of this effect may be attributable to Israeli building practices.

ASSESSMENT OF EXPECTED CASUALTIES IN ISRAEL

As we discuss above, based on the V-2 experience, and taking into account the explosive yield of the modified Scud missiles and the population density of the Tel Aviv area, one would have expected 3.3 deaths, 8.1 serious injuries, and 17.6 slight injuries per missile exploding in a metropolitan area in Israel.⁹⁴ By taking the availability of warning into account, these figures are reduced by roughly a factor of two, to 1.6 deaths, 4.7 serious injuries, and 6.2 slight injuries per missile. Thus from the roughly 13 warheads we estimate exploded in Israeli metropolitan areas, we would expect a total of about 21 deaths, 61 serious injuries, and 81 slight injuries.

However, it is likely that a somewhat higher number of casualties would be expected, for several reasons. Most importantly, the four or more Patriots that dove into the ground in Israel are not included in the above estimates. Although the Patriot's explosive warhead is smaller than

⁹² "Tel Aviv Missile Attack Renews Feeling of Fear," *Jerusalem Post*, February 10, 1991, p. 2.

⁹³ Seven Hurt, Homes Wrecked in Scud Attack No. 33," *Jerusalem Post*, February 13, 1991, p. 2.

⁹⁴ Note that we do not treat Haifa (which is a smaller target but has a higher population density) separately. However, since only one missile Scud warhead explosion appears to have caused damage in Haifa, apparently without producing any serious injuries, this is not a serious shortcoming.

the one in the Scud, it is likely that each of these missiles also contained a substantial amount of unburned rocket fuel at impact. However, at present, little information is available about these Patriot impacts and their consequences. In addition, some casualties could have resulted from Scuds that fell outside of metropolitan areas.⁹⁵ It is also possible that there are a few missile impacts in Israeli metropolitan areas that we have not been able to identify. Finally, as discussed previously, some casualties resulted from falling debris. Thus it is likely that the total number of expected casualties should be somewhat higher than the above figures.

As we discussed earlier, the actual casualty totals were 2 deaths, 11 serious injuries, and about 220 slight injuries. It appears that much of the apparent discrepancy between expected and actual casualties may be attributable to Israeli construction practices, which apparently played a crucial role by preventing the collapse of heavily damaged buildings. As previously noted, the limited data from London indicates that the area of destruction for reinforced concrete buildings was eight times smaller than that for brick row houses. If we apply this factor of eight to the expected total casualties in Israel, they are reduced to 2.6 deaths and 7.6 serious injuries. This factor of eight is probably too high, since not all of the residential buildings destroyed or damaged were of reinforced construction. Nevertheless it is clear that construction practices played a crucial role in holding down deaths and serious injuries.

The influence of Israeli building practices on the number of slight injuries is less clear. By preventing the collapse of damaged buildings, these construction practices may have in effect transformed deaths and serious injuries into slight injuries. This may in part explain why the number of slight injuries in Israel (220) was actually higher than the 87 slight injuries (before taking building practices into account) that would be expected based on the V-2 experience. However, it is also possible that the standards for determining which injuries are significant enough to be reported were significantly different in London during World War II and in Israel in 1991.

⁹⁵ The almost 600 V-2s that fell outside the greater London area on average caused 0.38 deaths per missile; however, some of these were aimed at cities other than London (Dunn, *Emergency Medical Services*, p. 179). In the Israeli case, it appears that Scuds falling outside metropolitan areas caused little damage and at most only a few injuries. In Saudi Arabia, however, there was at least one Scud that fell outside Patriot's defended perimeter at King Khalid Military City, destroying several buildings and causing several minor injuries (see February 14 in the Appendix).

Given the significant statistical fluctuations in expected casualties that would be anticipated for such a small number of warhead explosions, the factors discussed in this paper appear to be able to account for the relatively small number of deaths and serious injuries in Israel. However, it is also true that with such a small number of detonations, luck will inevitably play a role, and in terms of deaths and serious injuries, Israel's fortunes appear to have been relatively good. Even a single direct hit on a densely occupied residential building could have drastically altered the casualties in Israel.

PROPERTY DAMAGE IN ISRAEL

The available data on damage to buildings in Israel is incomplete and often inconsistent, but suggests the following overall picture: a total of 4,100 buildings were damaged in some way, and at least 28 of these buildings were destroyed. Nine to twelve thousand apartments suffered some form of damage, with roughly 200 to 400 apartments destroyed, and roughly 1,600 to 2,500 apartments suffering moderate to heavy damage.⁹⁶

Based on the London experience, after scaling for the reduced yield of the modified Scud

⁹⁶ The *Jerusalem Post* reports that a total of 4,095 buildings were damaged and that 1,644 families were evacuated in Israel. The latter number probably corresponds to the number of apartments damaged seriously enough to render them at least temporarily uninhabitable. ("Scud Toll: Summing Up the 39 Missile Attacks," *Jerusalem Post*, 1 March 1991, p. 2.)

A table in the Tel Aviv newspaper *Ma'ariv* gave totals for both the City of Tel Aviv and for the most heavily damaged Tel Aviv suburb, which was Ramat Gan. In these two cities 7,559 apartments were damaged, with 2,493 of these heavily damaged (the article does not indicate how many apartments were actually destroyed). At least 28 buildings (containing about 118 apartments) were destroyed in Ramat Gan. The descriptions of some of the individual attacks on Tel Aviv refer to 152 apartments being destroyed, but it appears that some of these may have been outside the city limits of Tel Aviv. Another 1,700 apartments were damaged in Haifa, (although it appears that most of these were not heavily damaged). Few if any apartments were destroyed in Haifa or anywhere else in Israel outside the Tel Aviv area. (*Ma'ariv*, 29 March 1991. An English translation of the table appears in Postol, "Lessons of the Gulf War," pp. 141-144.) (continued . . .)

(. . . continued) The data in the *Ma'ariv* article suggest that the number of apartments destroyed could be over 400. *Ma'ariv* does not give a total for apartments destroyed within the city of Tel Aviv, but it does report that in Ramat Gan, 700 apartments needed major repairs and at least 118 apartments were destroyed. *Ma'ariv* reports 1,793 heavily damaged apartments in the city of Tel Aviv. If the ratio between heavily damaged and destroyed apartments was the same as in Ramat Gan, then about 300 apartments would have been destroyed in Tel Aviv, for a total of over 400 apartments destroyed in Tel Aviv and Ramat Gan.

Another report cites a total of 12,118 apartments damaged in Israel, of which 195 were destroyed and 1609 suffered moderate damage, with the remainder being only lightly damaged (*BIAF--Israel Aviation and Space Magazine*, No. 72 (Spring 1991), p. 31.). According to the Israeli housing ministry, over 200 buildings were totally destroyed and hundreds more seriously damaged.

warhead and the greater population density of Tel Aviv, we would have expected about 90 houses to have been destroyed and about 520 to have been seriously damaged by the roughly thirteen Scud warhead detonations in Israeli metropolitan areas.

Comparisons between London and Israel are not straightforward, however, because in London damage was reported in terms of the number of houses destroyed, whereas in Tel Aviv it was reported as numbers of apartments destroyed. If a typical London row house is roughly comparable to three to five Tel Aviv apartments,⁹⁷ then the number of apartments destroyed and seriously damaged in Tel Aviv would be in general agreement with the London experience. While this comparison is very rough, it suggests that property damage in Israel per warhead exploding on the ground was not anomalously low.

THE SCUD ATTACKS ON SAUDI ARABIA

Although our primary emphasis is on the attacks against Israel, it is useful to consider briefly the attacks on Saudi Arabia. About 42 modified Scud missiles landed in or near Saudi Arabia, 17 of which were fired at Riyadh and seven at King Khalid Military City (KKMC). The remainder were apparently launched at the large airbase at Dhahran; at least five of these fell into the Persian Gulf. It appears that as many as 29 or 30 of the Scuds fired at Saudi Arabia were engaged by Patriots. The U.S. Army currently claims that 70 percent of the engagements in Saudi Arabia were successful, but, as noted previously, the Army says it has high confidence in only 40 percent of its claimed successful engagements, and there are reasons to believe that the actual percentage of warheads destroyed was much lower than the Army claims.

It is difficult to establish a clear picture of the effects of the attacks on Saudi Arabia because the Saudi government, which routinely downplayed the extent of the damage caused by the Scuds, has not released comprehensive damage or casualty data. The 17 Scuds fired at Riyadh killed one person and injured more than 70, although most of the injuries were reportedly

⁹⁷ Maps in Strategic Bombing Survey, *V-Weapons in London*, indicate a density of roughly one row house per 300 m². Stein states that a typical Israeli apartment building contains 12-24 apartments and has a plan area of 750 to 1,500 m², or roughly 60 m² per apartment. (Stein, "Patriot Experience in the Gulf War," p. 221.) Thus one row house in London corresponds to about five Tel Aviv apartments. Allowing for open space around the Israeli apartment buildings would reduce this scaling factor to some extent.

minor. Four explosions appear to have accounted for all of the casualties and almost all of the publicly reported damage in Riyadh (one of these explosions may have been due to an errant Patriot). Since the population density of Riyadh is similar to that of wartime London, casualties at first glance again appear to be much lower than might have been expected from the number of missiles launched. However, many of the same factors that resulted in lower casualties in Israel also appear to apply to Riyadh.⁹⁸

There is relatively little data on damage or casualties due to the attacks on Dhahran and KKMC. Other than the Scud that hit the U.S. military barracks, killing 28 and injuring 98, and a Scud that destroyed a house and an automobile repair workshop near KKMC (there were four minor injuries in this attack),⁹⁹ there were no reports of casualties or significant damage. Given the low population density of these areas, the 28 deaths at the barracks are almost certainly more than would have been anticipated from the number of impacts in these areas. This simply illustrates the statistical nature of casualties from conventionally-armed ballistic missiles.¹⁰⁰

⁹⁸ Based on press and Saudi government accounts, only four explosions accounted for most of the damage and casualties in Riyadh. Three of the four explosions were in areas that were unoccupied or nearly unoccupied, but which would have contained many people during the day. The other Scud did hit a residential area at about 1 am on 3 February; 29 people were injured, but all were released from the hospital the same day.

⁹⁹ It appears that this may be the only Scud that fell outside of areas covered by Patriot to cause significant damage.

¹⁰⁰ A similar effect was also seen in London, where 537 deaths (more than 19% of the total) were due to only five V-2s. (Strategic Bombing Survey, *V-Weapons in London*, p. 27).

What if Chemical Warheads Had Been Used?

Although all of the missiles used by Iraq in its attacks on Iran, Israel, and Saudi Arabia were armed with conventional high-explosive warheads, Iraq had used aircraft-delivered chemical agents extensively against civilian and military targets during the Iran-Iraq War. It was precisely for this reason that Israeli civil defense efforts concentrated on preparing the population for chemical attack. Indeed, United Nations' inspections of Iraq after the Gulf War revealed the existence of several indigenously-produced chemical warheads for the Scud, as well as extensive programs to develop nuclear and biological weapons.

If the modified Scuds launched against Israel had been armed with chemical warheads, casualties could have been far greater. Assuming that each chemical warhead could have efficiently dispersed 70 kilograms of the nerve agent sarin over Tel Aviv,¹⁰¹ each attack would have created, under average weather conditions, an area of about 0.01 to 0.03 km² in which unprotected people would die; if the attack occurred during unfavorable weather conditions, the lethal area would increase to 0.2 to 0.3 km².¹⁰² Since the population density of Tel Aviv during the attacks was about 6,000 per km², a single chemical warhead would have had the potential to kill hundreds, and perhaps even thousands, of unprotected people.

The widespread availability of gas masks and sealed rooms would have substantially reduced, but would not have eliminated, casualties from chemical attacks. It is commonly assumed that sealed rooms greatly reduce the dose received, but in fact a chemical agent will still leak in. Even tightly sealed rooms will not afford much protection unless they are thoroughly ventilated as soon as the cloud passes, for otherwise the occupants will receive about the same dose as individuals remaining outdoors, but at a slower rate.¹⁰³ Gas masks provide excellent

¹⁰¹ Only about 30 percent of the mass of a chemical warhead is agent, and the most efficient warheads could distribute no more than half of the agent as a fine, respirable aerosol. Because of its high volatility and lethality, sarin--a nerve agent known to have been manufactured by Iraq--would be ideally suited for attacks on civilian populations.

¹⁰² Steve Fetter, "Ballistic Missiles and Weapons of Mass Destruction." It should be noted that unfavorable weather conditions--calm, clear nights--occur frequently in desert climates.

¹⁰³ If people remain inside buildings for several hours, the dose inside will be nearly equal to the dose outside. To see this, consider a house of volume V in which the residence time of air is T ; air will flow into the house at a rate of V/T . If the concentration of agent in the outside air is c for the time of the cloud passage t , then the amount of agent flowing into the house is $c(V/T)t$, and the concentration of agent inside the house, C , is equal to ct/T .

protection against nerve agent, but they must be applied immediately and they must fit properly. Even among soldiers carrying masks and trained for chemical combat, the U.S. Army estimates that 4 to 8 percent of troops who would have died without masks will die nevertheless because of delayed masking, mask leakage, defective or missing masks, or early unmasking.¹⁰⁴ The percentage of masking errors among civilians would undoubtedly be much higher; it seems unlikely that even the best civil defense program could reduce fatalities to much less than 10 percent of the number that would die without protection. Atropine, which was included in Israeli civil defense kits, can be an effective antidote for people who know that they have been exposed to high doses of agent, but the undeniable benefits of atropine and gas masks are counterbalanced to some extent by the consequences of their misuse by an untrained populace. Even in the absence of chemical attack, seven Israelis suffocated from improper use of gas masks, five died from heart attacks, and 815 were admitted to hospitals suffering from acute anxiety, unwarranted atropine injections, and from injuries sustained while rushing to shelters.¹⁰⁵ If Iraq *had* used chemicals, the ensuing panic, which creates symptoms that can be mistaken for nerve-agent poisoning, undoubtedly would have led to far more casualties from heart attacks, atropine injections, and anxiety.

Thus, the impact of 14 chemical warheads in Israeli metropolitan areas might have caused on the order of 100 deaths if all of the attacks occurred under average weather conditions. On the other hand, just one attack under unfavorable weather conditions could have killed as many people, even if the entire population was equipped with gas masks. In addition, hundreds or thousands of additional casualties may have been caused by the indirect effects of chemical attacks.

Therefore, the time-integrated dose inside the house (CT) is equal to the dose outside (ct). The effects of most chemical agents are insensitive to the time over which the dose is delivered. If the building is tightly sealed, T will be large (e.g., 10 hours) and C initially will be much smaller than c , and occupants can greatly decrease their total dosage by ventilating the house after the cloud passes. To do this, however, the occupants must be told when it is safe to go outside. A series of chemical attacks, or fears of additional attacks, could keep people in their houses for many hours (which is comparable to the residence times of air in western dwellings).

¹⁰⁴ FM 3-10, *Employment of Chemical Agents* (Washington, DC: Department of the Army, March 1966), p. 36.

¹⁰⁵ Karsenty, et al., "Medical Aspects."

CONCLUSIONS

Given the number of missiles fired, casualties in Israel at first glance appear to be very low compared to what might be expected based on previous ballistic-missile attacks.

Several characteristics of the modified Scud missile helped to limit damage and casualties. The inaccuracy of the missile (together with what appears to be a roughly 10% dud rate) was a major factor in limiting damage. Only about one-third of the Scud warheads detonated in Israeli metropolitan areas. In addition, the reduced size of the warhead and the breakup of the modified missile diminished the lethal area of the Scud by more than a factor of two relative to the V-2s fired at London.

The warning time provided by U.S. launch-detection satellites was an important factor. The difference in the V-1 and V-2 casualty rates suggests that warning reduces casualties by an additional factor of two. The Coalition air attacks that forced Iraq to launch their Scuds after dark, when most Israelis were at home, ready to move quickly into their sealed rooms, may also have made an important contribution.¹⁰⁶ Israeli construction practices probably contributed greatly to casualty limitation by preventing the collapse of many heavily damaged buildings.

Given the significant statistical fluctuations that would be expected in a casualty rate based on such a small number of explosions, the factors discussed in this paper can account for the observed casualty rate in Israel. Further, the damage to buildings appears to be generally comparable with the damage caused by V-2 impacts in London. In addition, the anecdotal evidence discussed above suggests that, as far as casualties are concerned, Israel's luck was probably relatively good. As illustrated by the Scud that hit the barracks in Dhahran and killed 28 soldiers, shifting the impact point of a single missile by tens of meters could have changed the casualty statistics dramatically.

While the number of casualties in Israel was low, the available evidence does not support claims that this was due to the Patriot missile defense system. Although the U.S. Army claims that Patriot destroyed from three to seven warheads that would otherwise have caused casualties, the available data contains no evidence for a reduction in casualties or damage due to Patriot.

Several important lessons can be drawn from the Gulf War experience. First, the widely held

¹⁰⁶ These air attacks may have also made an important contribution by reducing the accuracy of the Scuds.

belief that ballistic missiles are themselves weapons of mass destruction is simply incorrect, as demonstrated by this as well as past episodes. It is the nature of the warhead, not the mode of delivery, that counts.

Second, however, attacks with conventional warheads can vary greatly in lethality. The Scuds fired by Iraq during the war were very inaccurate, had relatively small warheads, and had a significant dud rate. Had the Iraqi missiles instead had a CEP of roughly 1 km or less (in which case almost all of them would have landed in Israeli metropolitan areas), and had a reliable explosive energy release comparable to the V-2 missile, their expected lethality would have been roughly seven times greater.

The Israeli experience also illustrates that in addition to the characteristics of the missile and warhead, other factors can have an important effect on the casualty rate. These factors include the characteristics of the target (such as construction practices), the amount of warning available, and the timing of the attacks. The type of building construction and its vulnerability to nearby explosions will in part determine the relative benefits of different civil defense measures. Depending on the size of the warhead, an underground shelter may only be marginally better at providing protection against a conventional explosive than an interior room in a building with steel-reinforced construction and non-load-bearing walls. The Israeli government faced an apparent dilemma of whether to advise its population to go to underground shelters where they might be more vulnerable to chemical attack, or to stay in above-ground buildings, where they would presumably be more vulnerable to high-explosive warheads. Had the civil defense benefits of reinforced steel construction been understood before the war began, this dilemma would have been eased.

The experience in Israel and Saudi Arabia also reemphasizes the World War II lesson derived from the different casualty rates from the V-1 and V-2 attacks: even a small amount of warning time of missile attack can significantly reduce casualties. However, at present, only the United States and Russia have early-warning satellites (or large early-warning radars) capable of detecting missile launches, so a country under missile attack would be dependent on receiving warning from the U.S. or Russia.¹⁰⁷

¹⁰⁷ Israel reportedly is being given a downlink from U.S. warning satellites. (Barbara Starr, "Israel Will Get

The distribution of the population during an attack will be affected by the time of attack; for example, several empty buildings that were hit by Scuds would have been occupied during the day. Since the Coalition attacks on the launchers forced the Iraqis to launch primarily at night (and probably also reduced both the number of missiles fired and their accuracy), they played an important role in reducing casualties despite the fact that they apparently destroyed relatively few of the Iraqi mobile missile launchers. For this reason, there may be benefits from attempting to attacking missile launchers even if these attacks are not highly successful.

Finally, the casualties in Israel, and particularly in Saudi Arabia, highlight the statistical nature of casualties caused by small numbers of conventionally-armed ballistic missiles. Although there are steps that both the attacker and defender can take to change significantly the expected lethality of a ballistic missile attack, if the number of missiles fired is comparable to or smaller than that fired at Israel or Saudi Arabia, luck will inevitably play a key role in determining the final outcome.

Early Warning Downlink," *Jane's Defence Weekly*, February 13, 1993, p. 5.) Under certain circumstances, it may be possible for radars associated with air or missile defense systems, such as Patriot, to detect a missile in either the boost or re-entry phases of its flight. However, if detected during re-entry, there may not be sufficient time available to transmit a warning to the population.

Appendix

Chronology of the Scud Attacks in Israel and Saudi Arabia

Many details about the attacks on both Israel and Saudi Arabia remain classified or otherwise unavailable. This chronology represents our best current assessment of events, and is constructed from a variety of often-contradictory public sources including U.S. and Israeli government announcements, newspaper and television news reports, and published articles as well as private communications from Israelis.¹⁰⁸ All times given are local time in either Israel or Saudi Arabia.¹⁰⁹

It appears that about 81 Scuds fell in or near Israel and Saudi Arabia and that somewhat less than 47 of these were engaged by Patriot.¹¹⁰ It has also been reported that an additional small number of Scuds (roughly 5 to 8) failed shortly after launch and thus did not reach either Israel or Saudi Arabia.¹¹¹

¹⁰⁸ The most important sources used in constructing this chronology were: U.S. military press conferences (a very useful compilation of these is contained in Hildreth, "Evaluation of U.S. Army Assessment"; Official Israeli and Saudi Arabian statements (contained in FBIS); the compilation of attack damage in *Ma'ariv* (March 29, 1991) and the *Jerusalem Post* (March 1, 1991, p. 2); Joseph S. Bermudez, "Iraqi Missile Operations During Desert Storm -Update," *Jane's Soviet Intelligence Review*, May 1991, p. 225; Bleich et. al., "Psychiatric Implications"; daily reporting in the *New York Times*, *Washington Post*, *London Times*, and *Jerusalem Post*; and television reports from the ABC, BBC, CBS, CNN, and NBC networks. Much of the information on the Scud attacks in Israel (in particular, on impact locations) is based on interviews conducted by Reuven Pedatzur in Israel.

A generally similar chronology (based in large part on reporting by the *Los Angeles Times*) appears in Gregory S. Jones, *The Iraqi Ballistic Missile Program: The Gulf War and the Future of the Missile Threat* (Marina del Rey, Calif.: American Institute for Strategic Cooperation, 1992).

¹⁰⁹ During the war, the time in Israel and Saudi Arabia was respectively 7 and 8 hours ahead of the time in the eastern United States.

¹¹⁰ The figure of 47 engagements was released by the U.S. Army after the war, but the Army's current figures are somewhat lower. Conyers, "The Patriot Myth," note 3.

¹¹¹ The U.S. Army reported that 88 Scuds were launched. Another source says 86 Scuds were launched, but that five of them broke up immediately after launch (Bermudez, "Iraqi Missile Operations - Update"). The Iraqis claim that they launched 93 Scuds during the Gulf War (5 of which were a longer-range Scud variant called the al-Hijara). "Iraqi Scud Missile Declarations," *Arms Control Today*, November, 1992, p. 28.

ISRAEL

It appears that about 39 Scuds fell into Israel or the adjoining Mediterranean Sea. Twelve Scuds fell before Patriot was operational, and 27 afterwards, of which 17 were engaged. The Scud attacks directly killed two people, seriously injured 11, and slightly injured another 220.

~~January 18, about 2 am~~ - 8 Scuds towards Tel Aviv and Haifa (probably five or six to Tel Aviv). Patriot was not yet operational. One Scud hit in a poor and crowded neighborhood in the Ezra district of Tel Aviv, but hit "at the edge of the only empty lot for blocks." A second Scud exploded at or near a leather factory in the Tel Aviv suburb of Azor. Another Scud exploded at a shopping center under construction in Haifa. Twenty-two injuries were reported (apparently all due to the Scud in the Ezra district), but most or all were light injuries.

~~January 19, about 7:15 am~~ - 4 Scuds towards Tel Aviv. Patriot was not yet operational. Three Scuds fell in Tel Aviv. One directly struck a multi-story building in downtown Tel Aviv but did not explode, and its warhead was recovered intact from a ground-floor jewelry store. One Scud hit directly next to a municipal center in Tel Aviv's Hatkiva district, blowing open a basement bomb shelter (it was unoccupied). The impact point was only about three hundred meters from the one in the Ezra district the previous day, and most of the injuries on January 19 occurred here. The third Scud fell in Yarkon Park, near the Tel Aviv exhibition center. The fourth Scud reportedly fell along the coast somewhere south of Tel Aviv. Thirty people were injured, apparently all lightly.

~~January 22, about 8:40 pm~~ - 1 Scud towards Tel Aviv. This was the first Scud to be engaged by Patriot in Israel. The Scud warhead detonated in an alleyway between two apartment buildings on Abba Hillel street in the northwestern part of the Tel Aviv suburb of Ramat Gan. One building apparently collapsed, and many other buildings were damaged. A woman was killed and 84 other people were injured.

~~January 23, about 10:20 pm~~ - 1 Scud towards Haifa. It was engaged by Patriot. No casualties occurred, but falling debris caused some damage. News media videos suggest that the Scud exploded in the Mediterranean.

~~January 25, about 6 pm~~ - 7 Scuds (some sources say only six) towards Tel Aviv and Haifa. Most of these were towards Tel Aviv, and most or all were engaged by Patriot.¹¹² No casualties or damage were reported in Haifa. At least two Scuds exploded in residential areas in the Tel Aviv area. In addition, at least three Patriots struck the ground in Tel Aviv on this night (as well as at least one in Haifa). One Scud impact site was in Ramat Hatayasim in southeastern Tel Aviv; the Scud other fell only several hundred meters away across the border in neighboring Ramat Gan. It is known that a missile struck a two-story house destroying it and damaging many nearby buildings, and another fell next to a school (for crippled children, according to one report) in a residential neighborhood, seriously damaging it; however we have not yet been able to correlate these explosions with specific impact points. One Patriot struck in or near Hamaccabia Stadium, just north of downtown Tel Aviv.¹¹³ The impact points of the other Patriots are not known to us at present. Falling debris also caused damage. One man was killed (in Ramat Gan), and 67 were injured.

~~January 26, about 10 pm~~ - 5 Scuds (some sources say only three or four) towards Tel Aviv and Haifa. The Scuds were reportedly fired in two salvos separated by a short period of time. Most or all reportedly were engaged by Patriot. One Scud apparently fell on a deserted stretch of beach north of downtown Tel Aviv. No serious damage was caused, although two injuries occurred.

¹¹² Most of the engagements in Israel took place in the two attacks on January 25 and 26. It appears that there were at least seven engagements on other days in Israel. If the figure of 17 total engagements in Israel is correct, then it appears that about 10 of the 12 Scuds on January 25 and 26 were engaged.

¹¹³ The photograph on page 296 of the short version of this paper published in *Nature* (Fetter, Lewis, and Gronlund, "Why Were Scud Casualties So Low?"), captioned "Scud launched from Iraq hits Tel Aviv at Night in January 1991," actually shows a smoke cloud rising from the impact point of this Patriot.

~~January 28, about 9 pm~~ - 1 Scud towards Tel Aviv. The Scud fell short and landed near the village of Dir Balut in the West Bank (about 25 km east of Tel Aviv). No casualties or serious damage were reported.

~~January 31, about 7 pm~~ - 1 Scud towards Tel Aviv. Landed in the Samaria region, reportedly near an Arab village. The U.S. reported that it landed 15 miles southeast of Tel Aviv. No damage or casualties were reported.

~~February 2, about 8:30 pm~~ - 1 Scud towards Tel Aviv. It fell short and came down in an unsettled region of the West Bank. No damage or casualties.

~~February 3, about 1:40 am~~ - 1 Scud towards Tel Aviv. It fell short and landed in the West Bank. No casualties, but it may have caused some minor damage.

~~February 9, about 2:40 am~~ - 1 Scud towards Tel Aviv. It was engaged by Patriot. The warhead exploded in the middle of a street in the Tel Aviv suburb of Ramat Gan, pulling down walls on a number of buildings on both sides of the street. Thirteen people were injured.

~~February 11, about 7 pm~~ - 1 Scud towards Tel Aviv. It was engaged by Patriot. It was reported to have hit in an uninhabited area, and it probably fell in the Mediterranean north of Tel Aviv. No casualties or damage.

~~February 12, about 1:30 am~~ - 1 Scud towards Tel Aviv. It was engaged by Patriot. The warhead detonated between two houses in a neighborhood of mostly private homes in or near the town of Savyon, about 10 km east of Tel Aviv. Both houses were demolished and a number of other houses were seriously damaged. One of the demolished houses was empty, and a man was dug out from the debris of the other (he was not seriously injured). Nine people were injured.

~~February 16, about 8:10 pm~~ - 2 Scuds, 1 towards Haifa, 1 towards southern Israel (although an IDF spokesperson has said there were four, 2 to Haifa and 2 to the Negev Desert). The one

towards Haifa was probably engaged by Patriot and may have fallen into the Mediterranean. The one to southern Israel fell in an open area in the Negev desert and reportedly carried a concrete warhead. No casualties or serious damage were reported.¹¹⁴

~~February 19, about 7:50 pm~~ - 1 Scud towards Tel Aviv. It was engaged by Patriot. The Scud landed in an uninhabited area about 7 to 11 km east of the municipal airport. The Scud's warhead did not explode and no damage or casualties resulted.

~~February 23, about 6:50 pm~~ - 1 Scud towards Tel Aviv. It landed in an unpopulated area and there were no casualties or damage.

~~February 25, about 3:40 am and 5:40 am~~ - 2 Scuds towards southern Israel. Both fell in unpopulated areas of the Negev region. No significant damage was done, although two injuries were reported.

¹¹⁴ In all, Iraq fired three Scuds into the Negev desert in the southern part of Israel, probably aimed at the Israeli nuclear facility at Dimona. The Iraqis claimed that they fired four Scuds at Israel on February 16, with three of them aimed at Dimona. Bradley Burston, "Iraq: We Fired New Missile at Dimona," *Jerusalem Post*, February 18, 1991, p. 8.

SAUDI ARABIA

Approximately 42 Scuds fell in or near Saudi Arabia, and as many as 29 or 30 of these were engaged by Patriot. At least five of the Scuds appear to have landed in the Persian Gulf. The Scud attacks killed 29 people and injured at least 175, with 28 of the deaths and 98 of the injuries caused by the single Scud that struck the U.S. barracks in Dhahran on February 25.

~~January 18, about 4:30 am~~ - Patriots at Dhahran were fired. This was widely reported as first successful interception of an enemy ballistic missile, however, it is now known that this was a false alarm and that no Scud was present.¹¹⁵

~~January 20, about 9:30 pm~~ - 3 Scuds towards Dhahran. Most or all were engaged by Patriots. No reports of damage or casualties.

~~January 21, about 12:45 am~~ - 3 Scuds towards Dhahran, 4 towards Riyadh. Two of the Scuds to Dhahran were engaged; the other was not and fell into the Persian Gulf. No damage or casualties reported at Dhahran. All four Scuds to Riyadh were reportedly engaged. News media videotapes show at least two Scuds and one Patriot exploding on the ground in or near Riyadh. An explosion near an office building produced a 10 foot crater and blew out the back of the building; news reports suggest that this was possibly the result of a Patriot striking the ground. Twelve minor injuries were reported in Riyadh.

~~January 21, about 10 pm~~ - 1 Scud towards Dhahran. It was not engaged and fell into the Persian Gulf.

¹¹⁵ Conyers, "The Patriot Myth," pp 3-4. In all, it appears that about 24 Patriots were fired at "empty airspace." Most of these accidental launches occurred during the first week of the war, and were apparently due to electromagnetic energy radiated by other Coalition forces entering the Patriot radar through its back. Conyers, "The Patriot Myth," p. 7; and Joseph Lovece, "Electronic Noise from U.S. Gear Prompted Errant Patriots," *Defense Week*, September 28, 1992, p. 1.

~~January 22, about 3:45 am~~ - 2 Scuds towards Riyadh. At least one (and possibly both) was engaged by Patriot. A nearly intact Scud missile body -- minus its warhead and tail sections -- was found lying on a Riyadh street. No damage or injuries reported.

~~January 22, about 7:20 am~~ - 3 Scuds towards Dhahran. One was engaged, the other two were not and fell in the desert. No damage or injuries reported.

~~January 23, about 11 pm~~ - 5 Scuds: 2 towards Dhahran, 1 towards King Khalid Military City (also often referred to as the Hafr-al-Batin area), and 2 towards Riyadh. All 5 Scuds were reportedly engaged (although a Pentagon briefer said that one of the Scuds towards Riyadh was not engaged and fell in the desert). No injuries or damage were reported.

~~January 25, about 10:20 pm~~ - 2 Scuds towards Riyadh. Both were engaged by Patriot. One Scud hit a six story Saudi Department of Interior building in downtown Riyadh. The building was completely demolished; one man was killed and 30 people were injured, although most of the injuries were slight.

~~January 26, about 3:30 am~~ - 1 Scud towards Dhahran. It was engaged by Patriot. No reports of damage or casualties.

~~January 26, about 11 pm~~ - 1 Scud towards Riyadh. It was engaged by Patriot. The Scud warhead exploded in an area described as an "empty field" or "wasteland." No casualties or damage were reported.

~~January 28, about 9 pm~~ - 1 Scud towards Riyadh. It was reportedly engaged by Patriot. Debris was reported to have fallen on a farm in the Riyadh suburbs, but no casualties or damage were reported.

~~February 3, about 1 am~~ - 1 Scud towards Riyadh. It was engaged by Patriot. The Scud warhead exploded in a residential area of a Riyadh suburb, damaging a number of buildings. Twenty-nine

people were injured, although all of the injuries were apparently minor (all the injured were released from the hospital the same day).

~~February 8, about 2 am~~ - 1 Scud towards Riyadh. It was engaged by Patriot. It was reported that debris fell in a parking lot. No casualties or damage were reported.

~~February 11, about 10:20 pm~~ - 1 Scud towards Riyadh. It was engaged by Patriot. The warhead exploded next to a school or university building, causing extensive damage. Two security guards were slightly injured.

~~February 14, about 11:45 am~~ - 2 Scuds towards King Khalid Military City (or Hafir al-Batin). Neither Scud was engaged by Patriot apparently because they fell in an area not covered by the Patriot batteries at KKMC. One Scud destroyed a house and a car maintenance workshop. The other fell in a "civilian district" but apparently caused only minor damage (broken windows). A total of four minor injuries from the two Scuds was reported.

~~February 16, about 2 am~~ - 1 Scud towards Dhahran. It was not engaged and fell into the Persian Gulf.

~~February 21, about 5:15 pm~~ - 2 Scuds towards King Khalid Military City. One was engaged by Patriot, the other reportedly "exploded on its own in the air." No damage or casualties were reported.

~~February 21, about 9 pm~~ - 1 Scud towards King Khalid Military City. It was not engaged and no casualties or damage were reported. According to the US military, this Scud and the two previous ones were launched from inside the city limits of Baghdad.

~~February 22, about 2:30 am~~ - 1 Scud towards Dhahran (or possibly towards nearby Bahrain). It was engaged by Patriot. It was reported that the Scud fell into the Persian Gulf, and also that Scud debris fell in Bahrain.

~~February 23, about 5 am~~ - 1 Scud towards Dhahran. It was not engaged and fell in an uninhabited desert area.

~~February 24, about 4:40 am~~ - 1 Scud towards Riyadh. It was engaged by Patriot. No casualties or damage were reported.

~~February 24, about 12:30 pm~~ - 1 Scud towards King Khalid Military City. No information on whether it was engaged or on casualties or damage.

~~February 24, about 9:30 pm~~¹¹⁶ - 1 Scud towards Riyadh. It was engaged by Patriot. No reports of damage or casualties.

~~February 25, about 8:20 pm~~ - 1 Scud towards Dhahran. Due to a software problem, it was not engaged by Patriot. The Scud warhead hit a U.S. military barracks, killing 28 U.S. military personnel and injuring 98 more.

~~February 26, about 1:30 am~~ - 1 Scud towards Dhahran (or possibly Qatar). The Scud fell into the Persian Gulf.

¹¹⁶ There is considerable uncertainty about when this Scud fell. The only source we have seen that gives a time and place for it is Bermudez, "Iraqi Missile Operations," and the time given there is used here. However, the data from a Pentagon press briefing suggests that this Scud attack occurred late on the 23rd or earlier on the 24th. It seems likely that this attack did occur on the 24th, since ABC news videotapes show two Patriot engagements of Scuds in Riyadh on the 24th.

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