# RELEVANCE OF SELECTED NONNUCLEAR EXPERIENCES TO POSSIBLE FUTURE EMPLOYMENT OF NUCLEAR WEAPONS

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## INTRODUCTION

The prospect of the use of tactical nuclear weapons in future combat raises questions about their effects that cannot be fully answered without direct observation on the battlefield. Extensive testing programs have contributed substantially to understanding how such weapons work and what their physical effects would be, particularly in the realm of devastation and personal injury, through blast, heat or radiation. The experiences of Hiroshima and Nagasaki are very valuable as the only experiences of use of nuclear weapons, with the concomitant devastation and casualties. But the data from these sources is still insufficient to provide adequate understanding of what effects the introduction of nuclear weapons to a battlefield will have. In the absence of experience, then, it is believed useful to seek in nonnuclear catastrophic events that have occurred in the past information that might be relevant to a study of and preparation for a future nuclear combat situation.

This paper is the first step in an attempt to establish the potential relevance of such experience. From this beginning it is hoped that some means of extrapolating profitably from nonnuclear experience may be developed.

Catastrophic or disruptive events may be divided into two broad general categories, natural and man-related or man-influenced. Natural disruptive events include earthquakes, volcanic eruptions, cyclonic winds, droughts, floods, avalanches and landslides, and tidal waves. Man-related or man-influenced events include military combat, accidental and intentional explosions, air crashes, riots, and ship sinkings. Some types of events may be either, such as a fire, which may be caused by lightning, wind, or earthquake, or may result from some human act. Others are both, like the bursting of a man-made dam as the result of an earthquake.

In Figure 1,19 naturally-caused events are briefly described. A first reaction to this summary data is a profound impression of the

Figure 1

Selected Naturally-Caused Disruptive Events

| Date | Type | Location | Description |
|---|---|---|---|
| 5 October 1864 | C | India | 40-foot wave; 200 ships destroyed; 50,000 killed; 50,000 died of disease. |
| 31 October 1876 | C | India | Wind pushed 40-foot wave ashore; 100,000 killed immediately; 100,000 died of disease. |
| 1877-78 | M | China | Famine; 9.5-13 million died. |
| 27 August 1883 | V | Krakatoa | Greatest natural disaster in recorded history; 120-foot Tsunami; 36,000 killed; 5 cubic miles of rock thrown up; 3,000 foot mountain disappeared leaving hole 800 feet deep with 5 mile radius; ash thrown 17 miles into atmosphere; shock wave circled earth 7 times. |
| 16 October 1883 | E | Asia Minor | 21,000 killed; thousands homeless; many more died of starvation and exposure. |
| 31 May 1889 | F | Johnstown, Pa. | Flash flood over 5 square kilometers; dam burst; 2,200 dead, 967 missing; heavy industrial loss. |
| September 1911 | F | China | Flood; 90 of 130 Hopei Province Districts under 10 feet of water for months; 200,000 dead in 90 days; 25 million destitute. |
| 1-3 September 1923 | E | Japan | Great Kwanto Earthquake; 8.2 Richter; 143,000 killed; 600,000 homes destroyed; 200,000 hurt, 500,000 homeless. |
| 18 March 1925 | T | Missouri | Mile wide funnel stayed 219 miles on ground; $16.5 million property damage; 689 killed. |
| 19 July 1926 | X | New Jersey | Lake Denmark explosion caused by lightning; 30 killed; 400 hurt; $85 million damage. |
| 24 January 1939 | E | Chile | 3-minute tremor; 50,000 killed, 25,000 in one village; 60,000 hurt; 700,000 homeless. |
| 21 December 1946 | E | Japan | Quake 5 times larger than 1923 event; 2,000 ships wrecked; 50 cities destroyed; 40,000 homes destroyed; 2,000 killed; 500,000 homeless; 60,000 square miles inundated. |
| 15 August 1950 | E | India | 1,000 killed, $25 million damage; off Richter scale; earth shook for 5 days; thousands homeless. |
| 29 February 1960 | E | Morocco | 12-second tremor; 6.25 Richter; 70% destruction; 12,000 killed. |
| 21 March 1960 | E | Chile | 5 quakes; 8.9 Richter; tidal wave; 6 volcanos erupted; 100,000 homes destroyed; 20% of Chilean industry destroyed. |
| 20 March 1963 | V | Bali | Volcanic eruption; all life eradicated in 10-mile radius, 1,200 killed; 200,000 refugees. |
| 27 March 1964 | E | Alaska | Epicenter 100 miles southeast of Anchorage; 30-60 miles deep; 8.6 Richter; 12-foot Tsunami hit Crescent City, California; $500 million damage. Scientists judge energy release equivalent of 10 million Hiroshima bombs. |
| 23 December 1972 | E | Nicaragua | Earthquake 2½ hours; 6.25 Richter; 7,000 killed; 10-15,000 injured; 200,000 homeless; 60-75% of Managua razed; large fires. |
| 28 July 1976 | E | China | Earthquake at Tangshan; 7.8 Richter; 52 square kilometers of Tangshan destroyed; felt in Beijing, 100 kilometers away; estimated 750,000 of 1,000,000 casualties; total disruption of major industrial area. |

Type of Event

E - Earthquake
V - Volcanic Eruption
X - Explosion
T - Tornado
C - Cyclonic Winds
M - Miscellaneous
F - Flood

enormity of the power, that is, the energy released. Figure 2 shows the dimensions of expected damage areas resulting from detonation of tactical nuclear weapons of from 0.2 to 100 kiloton yield. Derived from unclassified standard effects data published by the US Army in FM 101-31-3, this table is included only to provide a means of rough comparison between the theoretical damage characteristics of nuclear weapons and the actual results of the nonnuclear events described in this paper.*

Most of the events described in Figure 1 had results of a magnitude far beyond the results of detonating any of these tactical weapons. The volcanic eruption on the island of Bali in 1963, for instance, killed all life within a ten-mile radius. There is no tactical nuclear weapons standard against which to measure such an event. The area of total destruction is theoretically equal to that to be expected from a nuclear device with more than a 100-megaton yield. The Alaskan earthquake on 27 March 1963 produced an energy release of ten million times the yield of the atomic bomb dropped on Hiroshima. Considering that the latter was approximately 12 kilotons, the release would be the equivalent of 120,000,000 kilotons, or 120,000 megatons, of TNT. Clearly events of such magnitude do not lend themselves to direct quantitative comparison with tactical nuclear warfare with weapons yielding only the equivalent of from 0.2 to 100 kilotons. This is not to say that they cannot offer

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* In using FM 101-31-3, one is immediately struck by the mass of data related to nuclear blasts that is available, and the lack of data on disruption, that is, quantified effects of the detonation of a nuclear device. Consequently, the desirability of seeking historical data related to nonnuclear events of catastrophic dimensions that may be used to approximate the results of a tactical nuclear detonation is apparent.

## THEORETICAL DAMAGE AREAS OF NUCLEAR WEAPONS*

Figure 2

| Weapon Yield (kt) | Personnel in Open Immed Perm r(m) | Pers in Brick Structures Immed Perm r(m) | Personnel in Wood Frame Structures Immed Perm r(m) | 2d Degree Burns to Personnel Summer r(m) | Severe Damage to Brick Structures r(m) | Severe Damage to Wood Frame Structures r(m) | Severe Damage to Factories r(m) | 1 PSI Over-pressure r(m) | Wildland Fires Mixed Forest/ Cover <r(m) | Ignition Point Wood Shingles <r(m) | Extraneous (5%) Personnel Casualties in Open r(m) | Extraneous Moderate Damage (5%) to Wood Frame Structures r(m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.2 | 230 | 220 | 220 | 140 | 180 | 220 | 50 | 600 | 410 | 250 | 630 | 500 |
| 1.0 | 410 | 390 | 480 | 330 | 390 | 480 | 150 | 1,170 | 1,040 | 580 | 1,000 | 1,060 |
| 2.0 | 560 | 580 | 720 | 530 | 580 | 720 | 220 | 1,780 | 1,800 | 980 | 1,780 | 1,580 |
| 3.0 | 630 | 710 | 890 | 680 | 710 | 890 | 290 | 2,160 | 2,320 | 1,270 | 2,320 | 1,890 |
| 5.0 | 710 | 870 | 1,100 | 890 | 870 | 1,100 | 360 | 2,670 | 3,060 | 1,680 | 3,110 | 2,290 |
| 8.0 | 810 | 1,070 | 1,360 | 1,170 | 1,070 | 1,360 | 490 | 3,270 | 3,880 | 2,170 | 3,980 | 2,760 |
| 10.0 | 810 | 1,120 | 1,430 | 1,250 | 1,120 | 1,430 | 520 | 3,440 | 4,130 | 2,820 | 4,260 | 2,880 |
| 20.0 | 840 | 1,340 | 1,740 | 1,630 | 1,340 | 1,740 | 670 | 4,130 | 5,110 | 2,920 | 5,390 | 3,470 |
| 50.0 | 980 | 1,900 | 2,460 | 2,500 | 1,900 | 2,460 | 1,070 | 5,720 | 7,720 | 4,100 | 8,470 | 4,830 |
| 100.0 | 1,270 | 2,530 | 3,250 | 3,440 | 2,530 | 3,250 | 1,530 | 7,490 | 11,180 | 5,350 | 12,540 | 6,340 |

* This table is based on unclassified data found in Field Manual 101-31-1, June 1977. All heights of burst (HOB) are $\leq 1$ meter.

This table is included only to provide a means of rough comparison between the theoretical damage characteristics of nuclear weapons and the actual results of the nonnuclear events described in this paper.

useful information, but that they are useful primarily for general understanding of the effects of a nuclear event as a major disaster.

As a first step toward trying to find relatable effects in man-made or man-influenced events, ten events, some military, some not, were examined:

1. Battle of the Crater, 30 July 1864
2. Gas attack at Ypres, 22 April 1915
3. First day of the Battle of the Somme, 1 July 1916
4. Black Tom explosion in New York harbor, 30 July 1916
5. Cratering of Messines Ridge in Belgium, 7 June 1917
6. Explosion in Halifax harbor, 7 December 1917
7. Four Hamburg fire raids, July-August 1943
8. Fire raid on Tokyo, 9-10 March 1945
9. I.G. Farben explosion in Germany, 28 July 1948
10. Explosion in Cali, Colombia, 7 August 1956

As a first step, five of these events (Nos. 1, 2, 3, 7, and 8), along with three of the natural disasters (the Johnstown flood, and the earthquakes at Managua and Tangshan), a total of eight events, were examined in terms of characteristics that might be useful in describing and analyzing the effects of a nuclear event.

In a second step, the other five events listed above (Nos. 4, 5, 6, 9, and 10), for which more detailed data was available, were studied in a preliminary effort to compare the physical dimensions of the events and their results to the dimensions of the tactical nuclear weapons effects and their results shown in Figure 2.

## ANALYSIS IN TERMS OF GENERAL CHARACTERISTICS

The characteristics surveyed to seek similarities and areas of comparability in the eight examples are:

- Time span or duration
- Affected area
- Casualties
- Immediate results
- Material damage

Fire

Disruption

Panic, morale

Political/economic impact

Long-term results.

The results of this analysis are summarized in Figure 3. Brief narratives of each of the events may be found in Appendix A. A few general comments are in order.

Time Span

A nuclear explosion and its first cluster of events take place over a very short period of time, almost instantaneously. Of these eight nonnuclear events only the first, the Crater explosion, was instantaneous and caused immediate death and destruction. Although the other events occurred rapidly, their brief time span was measurable.

Affected Area

The size of the areas significantly involved in these nonnuclear events varied greatly. The Crater explosion affected a comparatively small area, less than the radius of damage of the smallest yield weapon shown in Figure 1. The first day of the Battle of the Somme devastated an area of about 65 square kilometers. Although the initial bomb target area in Tokyo was much smaller, by the time the rapidly spreading fires were extinguished, 41 square kilometers of the city were destroyed.

At Hiroshima the detonation of the nuclear weapon resulted in total damage to a 15 square kilometer area of the city, still well below the size of stricken areas in some nonnuclear cases. It does not compare, for example, with the earthquake destruction at Tangshan, said to be close to 52 square kilometers.

Casualties

The number of killed, wounded, and injured in these nonnuclear events varied from a few thousand to tens of thousands, and, if reports can be trusted, as many as 750,000 casualties occurred at Tangshan. Many of the losses were as large as, or larger than, those to be expected from a nuclear strike under battle conditions.

The problem of rendering necessary medical aid to casualties in many of these cases was similar in its magnitude to the problem that would be associated with a nuclear event. Tangshan and Managua are particularly

Figure 3

Nuclear-relatable Characteristics of Selected Nonnuclear Events

| Event | Time span | Affected Area | Casualties | Immediate results | Material damage | Disaster by fire | Disruption | Panic, morale | Polit/econ impact | Long-term results |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Battle of the Crater, 30 July 1864 | Instantaneous explosion | $150m^2$ | Confed: 278 | Cratering, followed tardily by Union attack | Negligible | No | Local, temporary | Temporary distress | None | Minor |
| 2. Johnstown Flood, 31 May 1889 | 45 minutes | $5km^2$ | 3,167 | Devastation of city | Major | Some | Complete | Panic not general | Economic impact major | Slow, eventually complete rebuilding |
| 3. Gas at Ypres, 22 April 1915 | 15 minutes | 8km front | 15,000 | Shock, 7km gap in front, no follow-up | Slight | None | Total, but transient | Significant panic | None | General use of gas warfare |
| 4. Somme first day, 1 July 1916 | 0730-2400 hours | $65km^2$ | British - 57,470 Germans - 8,200 | Failure | Some | None | Supply confused | No major panic | Contributed to enormous British losses | Contributed to changes in leadership and tactics |
| 5. Four Hamburg fire raids July-August 1943 | 4x30 minutes attacks | $78km^2$ | 2d raid 41,000 | Fire storms | Most structures destroyed or damaged. Ships destroyed | Widespread | Up to 48 hrs | Some fleeing, no mass hysteria | Considerable | Slow recovery |
| 6. Fire raid on Tokyo 9/10 March 1945 | 0015-0300 hours | $41km^2$ | 124,793 1 million homeless | Uncontrolled fires and fire storms | 267,171 bldgs destroyed, 25% of city | Widespread | Complete, temporary | Panic, no mass hysteria | Considerable | Slow recovery |
| 7. Earthquake at Managua 23 Dec 1972 | 2½ hours | City of Managua | c.20,000 200,000 homeless | Devastation | 60-75% of city destroyed | Numerous | Localized | Mass fleeing | Considerable | Slow recovery |
| 8. Earthquake at Tangshan 28 July 1976 | Brief | $52km^2$ | c750,000 | Devastation | Major | Some | Complete | Unknown | As much as 20% of PRC economy destroyed | Massive rebuilding |

good examples for more detailed study of this problem, since the complication of casualties buried under debris at the same time large numbers require immediate help may offer insight into treatment of delayed reactions to a nuclear blast. It is unlikely that adequate preparations can ever be made for the very heavy casualties expected to result almost instantaneously from nuclear events, but the experience of handling great numbers, including many very seriously injured, when facilities were not equipped to do so is worth intensive study.

Immediate Results

In addition to injuries or death, the immediate effect of each of these nonnuclear events on the people concerned was shock. The flood and earthquakes created unusually extensive destruction of property in a very short span of time. The attack at the Somme, which lasted longest of these examples, resulted in failure. The fire raids in which a series of incendiary and high-explosive bomb attacks were the destructive cause, were closest in nature to a nuclear event. They resulted in widespread fires and fire storms, which in their rapid and deadly progress through the city resemble the effects of an atomic explosion.

In neither of the tactical surprise attacks, the Crater explosion or the gas attack at Ypres, was the sought-for tactical effect fully achieved, for in neither case was the attacking force prepared to exploit the advantage it gained. In the long term, however, the use of a new weapon at Ypres, gas, introduced a significant change in the nature of combat.

It appears from examination of the immediate results of these military disasters that some tactical gains are likely, provided that appropriate plans and provisions for exploitation are in hand. For an attacker to count on fear and panic alone to achieve success can instead produce failure, since target troops have in the past sometimes behaved in most resolute and steadfast fashion in the face of otherwise overwhelming adversity.

Structural and Material Damage

The causes of the extensive damage to urban areas suffered in the nonnuclear events is of several kinds: fire and fire storms resulting from bombing, earthquakes, or other causes; the shifting of ground and overpressures resulting from earthquake; floods or extremely heavy rainfall; and conventional bomb damage from direct hits or related blast effects. A nuclear explosion, as witnessed in Hiroshima and Nagasaki, would cause similarly widespread damage, differing primarily in that the time involved would be more compressed, as well as in the problem of radiation damage. As in the great fires in Tokyo and Hamburg and the earthquakes in Managua and Tangshan, residual problems would include clearing debris to release people trapped under it and the long-term prospect of cleanup and rebuilding.

Fire

The ultimate helplessness of people to deal with a truly great fire is apparent in most accounts of such disasters. Self-help is almost completely limited to survival. Great urban fires overwhelm firefighting resources and destroy equipment. The basic inadequacy of a water system is multiplied by the destruction of piping and pumping facilities. Water stored in ponds or towers seldom suffices. The flood of displaced people and people injured by direct burns, suffocation, or hits from flying materials saturates aid facilities. All of these results are to be expected in a nuclear event in an urban area.

But a nuclear explosion uniquely produces radiant heat at extreme temperatures that can cause serious burns almost instantly to people at considerable distances from the explosion. It ignites flammable material of all types. Somewhat similar results come from the "sowing" of incendiaries to produce multiple ignition points and create large burning areas very quickly. Thus accounts of fires deliberately set as a military action and the effects they created can offer useful insights into the nature of fires started by nuclear means and problems associated with their aftermath. The damage caused by the first flash of radiant heat is unique to the nuclear event and would probably require special provisions for burn treatment, but in all other respects the burning city of World War II offers valuable opportunities for planning direct action and recovery procedures in tactical nuclear fire.

Disruption

A major disaster, of whatever sort, disrupts most of the routine activity in its area. Analysis of civil and military experience suggests that such disruption will be characterized by the fact that:

- Normal activities of whatever nature will be seriously slowed or stopped as attention turns to the immediate situation.
- Transport will suffer severely. Vehicles and roadways will be heavily damaged and movement will be difficult. The movement of people trying to escape will further degrade general mobility.
- The physical means by which government or command is enforced -- headquarters installations and communications systems -- may be seriously damaged or destroyed.
- Sources and supply systems for food, water, and shelter will be destroyed or damaged, and their replacement or repair will become a major task.
- Medical resources and services, including hospitals, ambulances, and medications, will suffer serious damage or loss at the time of greatest need for them. Doctors, nurses, and other medical personnel will be in insufficient supply.
- Security forces and traffic control may be disrupted at a time when special forms of public security and movement control are necessary.

Although in the combat examples the attacking units did not exploit their opportunities, they did in fact gain a significant tactical advantage. The experience of the defending side was comparable to that of a victim of nuclear attack and indicates that in a nuclear attack:

- $C^3$ will be affected.
- Substantial losses of men and weapons will weaken combat effectiveness.
- Morale and esprit may be adversely affected, but this has not always been the case in nonnuclear events.
- Local disruption will, to some degree, affect senior echelons in the command chain and impose new considerations and possibly significant changes in future plans and goals.

## Panic, Flight, and Morale

Only one of the events discussed -- the earthquake in Managua -- resulted in an uncontrolled situation, as far as can be ascertained from the records. Flight, inevitable if there is a chance to save one's life, occurred in those events for which information is available. Depression and periods of disorientation occurred in some instances -- Ypres in particular -- but in many instances of sudden disaster, of which Pearl Harbor is a notable example, morale has been galvanized by a catastrophic event, and a determination to resist or recover has developed. It appears likely that panic might develop in a unit under military nuclear attack, and the attacker should be prepared to exploit it.

## Political and Economic Impact

None of these events altered the local political situation, but loss of productivity and destruction of life and property in the non-military cases had an immediate impact on the local economic situation. The extent of the impact varied according to the dimensions of the incident and the economic resources of the area. The first use of tactical nuclear weapons seems equally unlikely to affect the local political situation, but its international impact could be considerable. The economic impact would not be expected to extend beyond the areas physically affected.

## Long-term results

All of the disasters in urban areas were followed by slow recovery and rebuilding, which of course would be expected to be the case in a nuclear event. None of the war-related events discussed in this paper by itself caused a cessation of warfare or a radical alteration of operations plans. The introduction of gas at Ypres did lead to the use of gas throughout the remainder of the war by both sides, and if one side in a future war should use tactical nuclear weapons reciprocation might be swift.

# ANALYSIS IN TERMS OF PHYSICAL DIMENSIONS

As noted above, five man-influenced incidents involving large scale explosions were selected for more detailed analysis, both because of their nature and because of the apparent availability of sufficient data to attempt to relate them quantitatively more closely to nuclear events.

The five events thus analyzed are:

1) The Black Tom explosion in New York harbor on 30 July 1916;
2) The cratering of Messines Ridge in Belgium on 7 June 1917;
3) The explosion in Halifax harbor on 7 December 1917;
4) The I.G. Farben explosion in Germany on 28 July 1948;
5) The explosion in Cali, Colombia, on 7 August 1956.

## 1. The Black Tom Explosion, New York Harbor, 30 July 1916

At 2:08 am, 30 July 1916, an explosion took place in New York Harbor that was of such magnitude that it was felt in Baltimore, Maryland, almost 150 miles away. The cause of the explosion was a fire on a barge loaded with explosives tied to a pier at Black Tom Island -- actually a small peninsula, jutting out from the New Jersey side into New York harbor. The fire had burned for over 45 minutes before being reported. In all, 14 barges of dunnite, the most powerful explosive then manufactured in the United States, apparently went off in the first explosion. Numerous smaller secondary explosions followed, as twelve railroad box cars loaded with numerous types of explosives, including primed shrapnel artillery shells, went off one by one.

Apparently no explosives were stored in the 24 huge warehouses in the shore installation, although 40 tons of sugar caught fire and burned with such intensity that: 1) the adjacent box cars detonated, and 2) fireboats could not get in close enough to shore to be of any benefit. All communications between New York and New Jersey were cut by the first blast. The bridges in and around New York City were all shaken to their foundations and had to be checked for safety before they could be used.

Central Brooklyn, a densely populated section of New York City, and directly across the harbor from the point of the blast, took the brunt of the explosion, although downtown Manhattan did not escape. There was severe damage as far uptown as 5th Avenue and 42d Street, and the entire business area of New York City was damaged to such an extent that looting became an immediate problem. For twelve hours after the initial blast, secondary explosions, which threw the shrapnel rounds all over the harbor area, continued. The Statue of Liberty was holed by one of the explosions, and the bow of one of the blown barges fell onto the parade ground at the base of the statue. Oddly, the ground shock was strong enough to rupture a major water main at 5th Avenue and 42d Street, but it failed to trigger the seismograph at the Museum of Natural History on the west side of Central Park. From the Battery to 34th Street in Manhattan, almost every window was broken. Carelessness and not sabotage was finally adjudged the cause of the explosion.

Technical Analysis

Available data related to this event contains many inconsistencies, which make analysis difficult. For example, damage to the hospital on Ellis Island is reported as severe. (See Figure 4) Severe damage at that distance from the center of a nuclear detonation would require a device of 50-100 kiloton yield. (See Figure 5) If, however, the building knocked down in Brooklyn or the burst water main in New York City is taken as the distance, the damage would be equivalent to a yield greater than 10 megatons.

The roof of the aquarium in Battery Park at the foot of Manhattan, a radial distance of 3,500 meters from the site of the explosion, was blown off. This would probably indicate a moderate damage radius ($r_{Dm}$) consistent with a 50 kiloton yield. The building collapse in Brooklyn and water main damage in Manhattan may have been due to wave reinforcement across the expanse of water or some subterreanean structural phenomena.

2. Messines Ridge, Belgium, 7 June 1917

In June 1917 World War I had been raging for nearly three years. In April the French had suffered a severe and costly defeat, which had led to widespread mutinies in the French Army. The ability of France to continue the war was in doubt.

General Sir Douglas Haig, Commander of the British Expeditionary Force, determined to relieve pressure on the French, planned to initiate a series of offensives in order to break the German line in the Ypres salient. This operation could be successful, however, only if a critical terrain feature, the Messines-Wytschaete Ridge, could first be reduced. This mission was assigned to General Sir Herbert Plumer, Commander of the Second British Army, who began planning an attack.

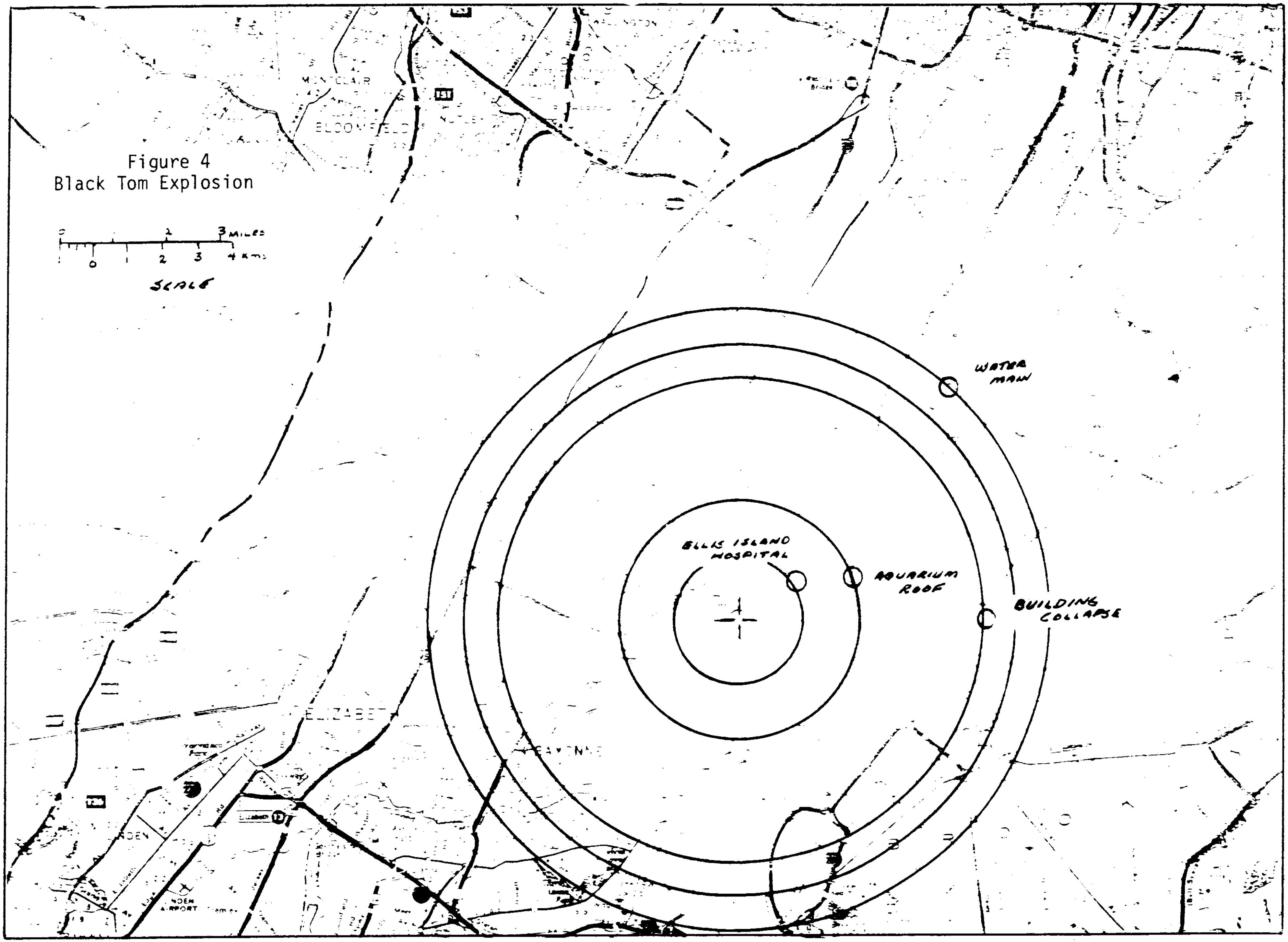
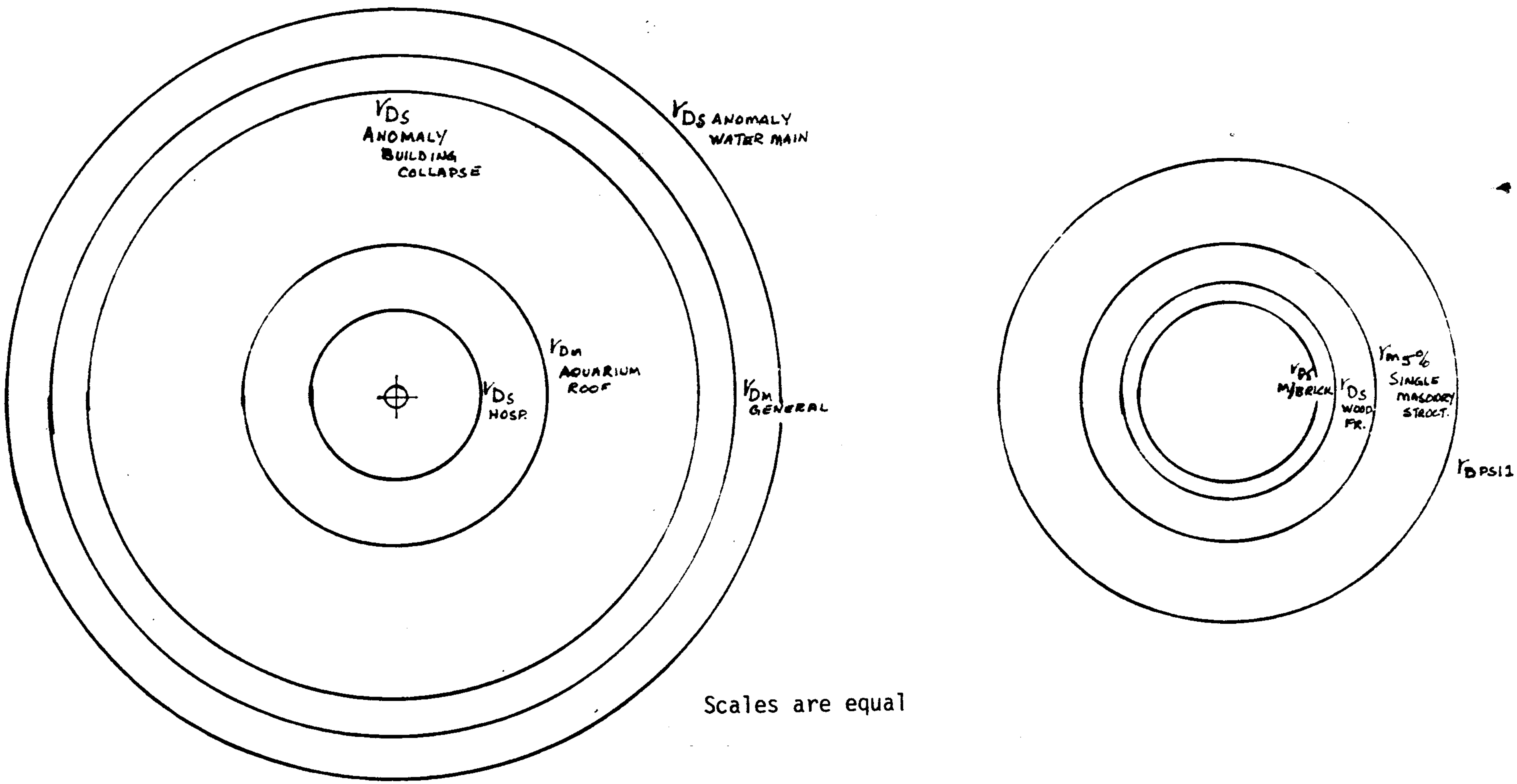



Figure 4
Black Tom Explosion

Black Tom Island Explosion
Comparative Radii Analysis

Actual

Theoretical 50KT nuclear




Scales are equal

Figure 5

The Second Army had been in this sector for some time, and the concept of deep mining operations had been under study and experimentation since 1915. As manpower became available, active mining had been underway since January 1916. Over about an 18 month period, a large number of tunnels had been dug under the German lines despite major engineering problems and active German countermining operations.

By June of 1917, therefore, 24 mines (subterranean passages) had been constructed, of which 20 were inside the limits of the planned attack. (One other tunnel had been lost through German action.) The area beneath the ridge -- which was roughly half way between the towns of Ypres and Armentieres -- was honeycombed with tunnels, which totalled about 7,500 meters of galleries. Into these mines approximately 600 tons of ammonal were stuffed. The mines were detonated simultaneously at 3:10 am on 7 June 1917. The explosion was heard in England, 130 miles away. (Figure 6)

German accounts set their casualties at more than 35,000, of which about 20,000 were immediate dead. Some 7,000 dazed prisoners were taken, along with numbers of crew-served weapons.

As a result of the Messines operation the line at Ypres was straightened, facilitating Haig's planned offensive. The action did not end the war, but its initial effects were significant.

Technical Analysis

This event presents a unique opportunity to study a subsurface explosion in the context of relationship to an ADM. A thorough study of British military records will be required, however, to undertake the detailed analysis which this opportunity warrants. Available secondary sources contain insufficient data. Among items of information that are required -- but currently lacking -- are the following: Although the locations of the mines and the fact that each held varying amounts of explosive are known, we do not know how much was in each. The depth of the mines and (with one exception) the crater dimensions are also unknown.

In this preliminary analysis, however, it is possible to make some educated guesses:

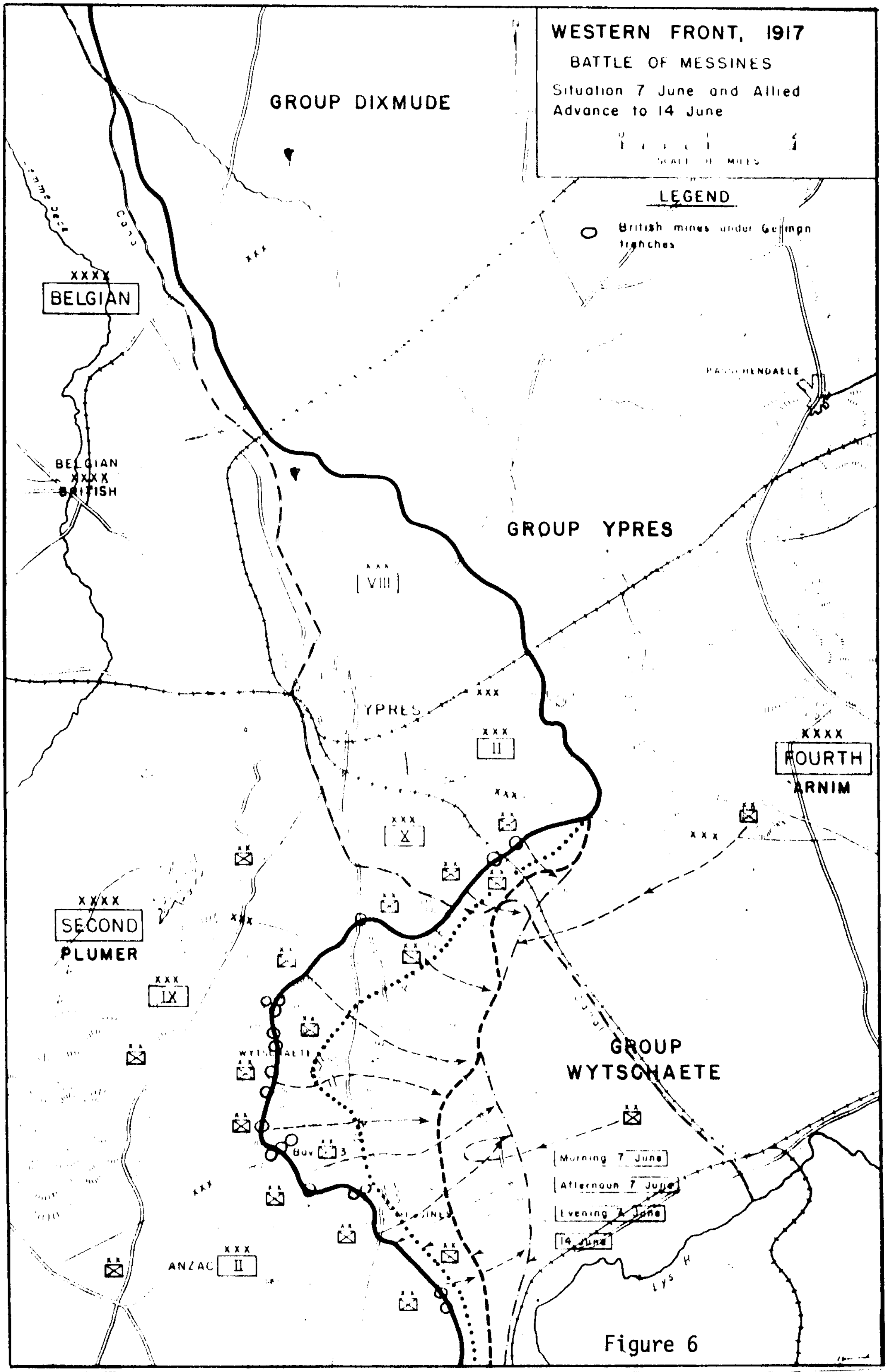

WESTERN FRONT, 1917
BATTLE OF MESSINES
Situation 7 June and Allied Advance to 14 June
LEGEND
British mines under German trenches
GROUP DIXMUDE
GROUP YPRES
GROUP WYTSCHAETE
BELGIAN
SECOND
PLUMER
FOURTH
ARNIM
VIII
II
X
IX
ANZAC II
YPRES
Morning 7 June
Afternoon 7 June
Evening 7 June
14 June

Figure 6