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00 Relevance of Selected Non-nuclear Experience to Possible Future Employment of Nuclear Weapons (1980)

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.

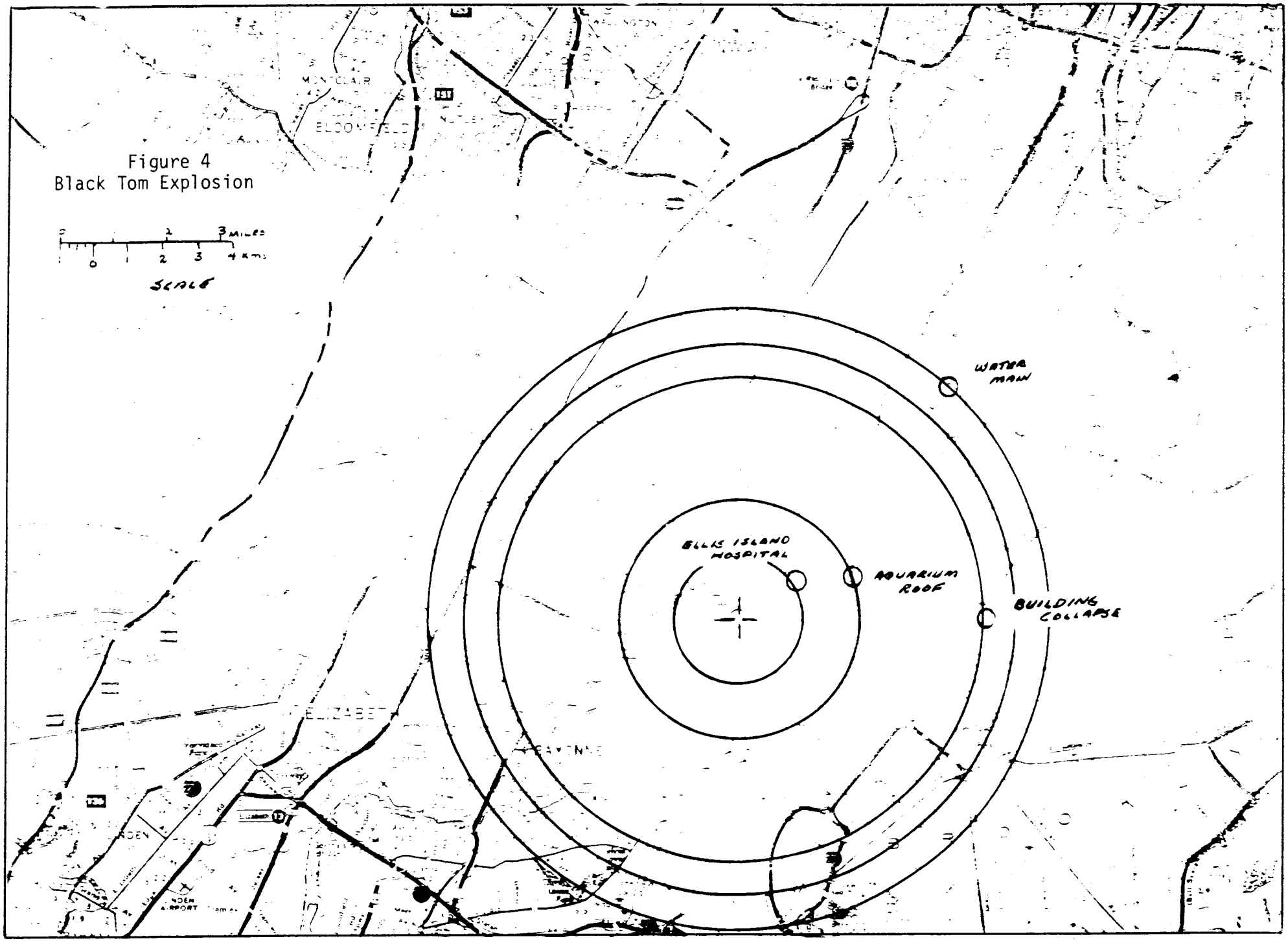
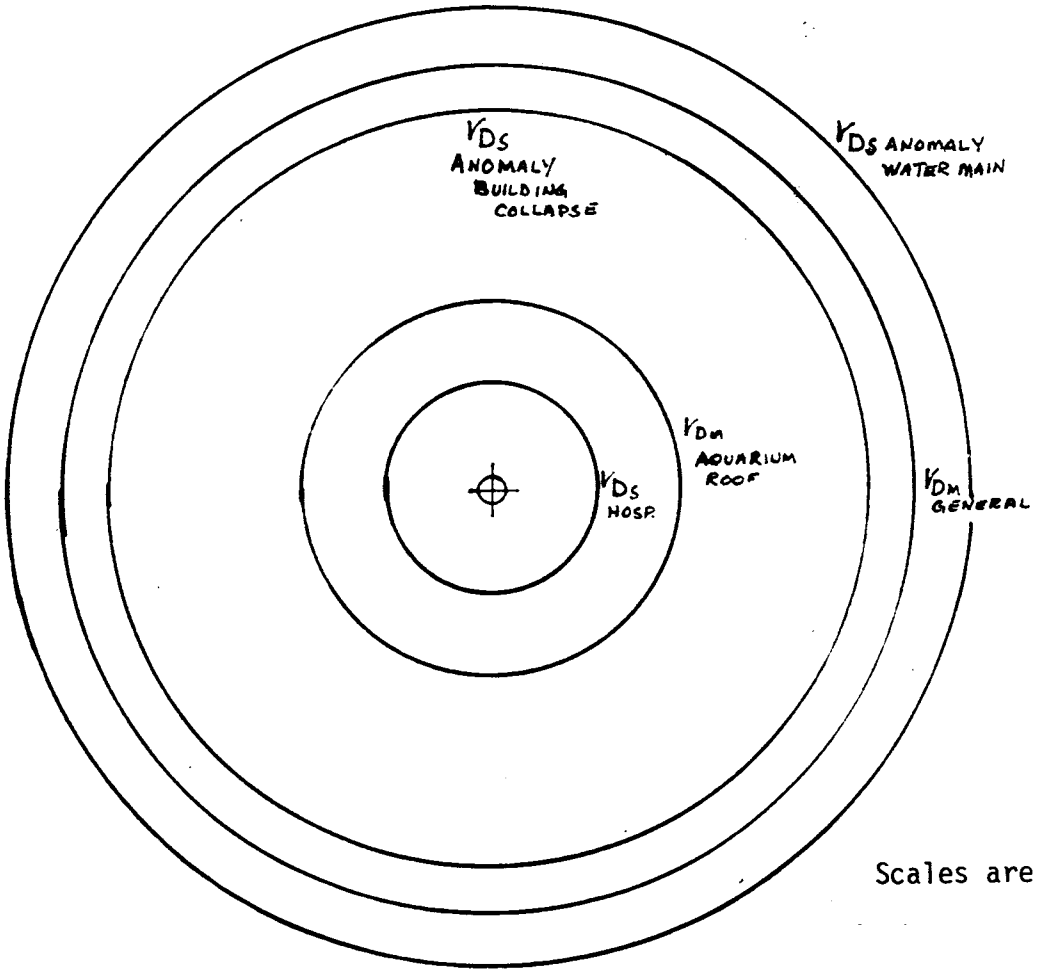


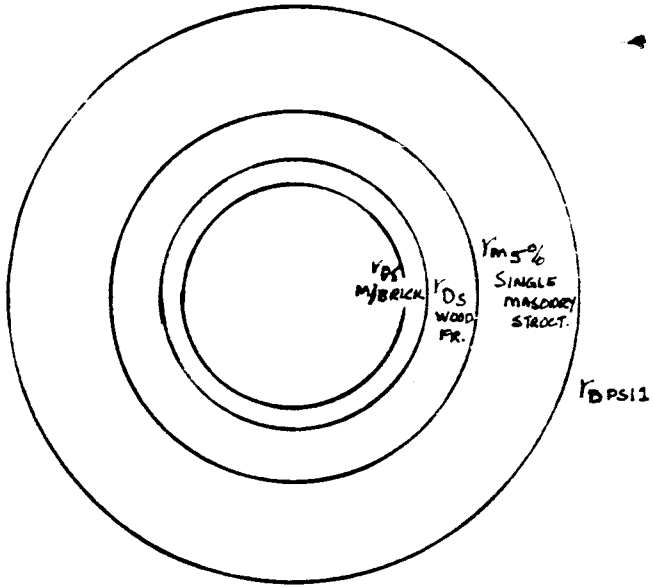
Figure 4
Black Tom Explosion
0 1 2 3 4 KMS
0 1 2 3 MILES
SCALE
WATER MAIN
ELLIS ISLAND HOSPITAL
AQUARIUM ROOF
BUILDING COLLAPSE
BLOOMFIELD
ELIZABETH
BAYONNE
NEWARK AIRPORT

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:

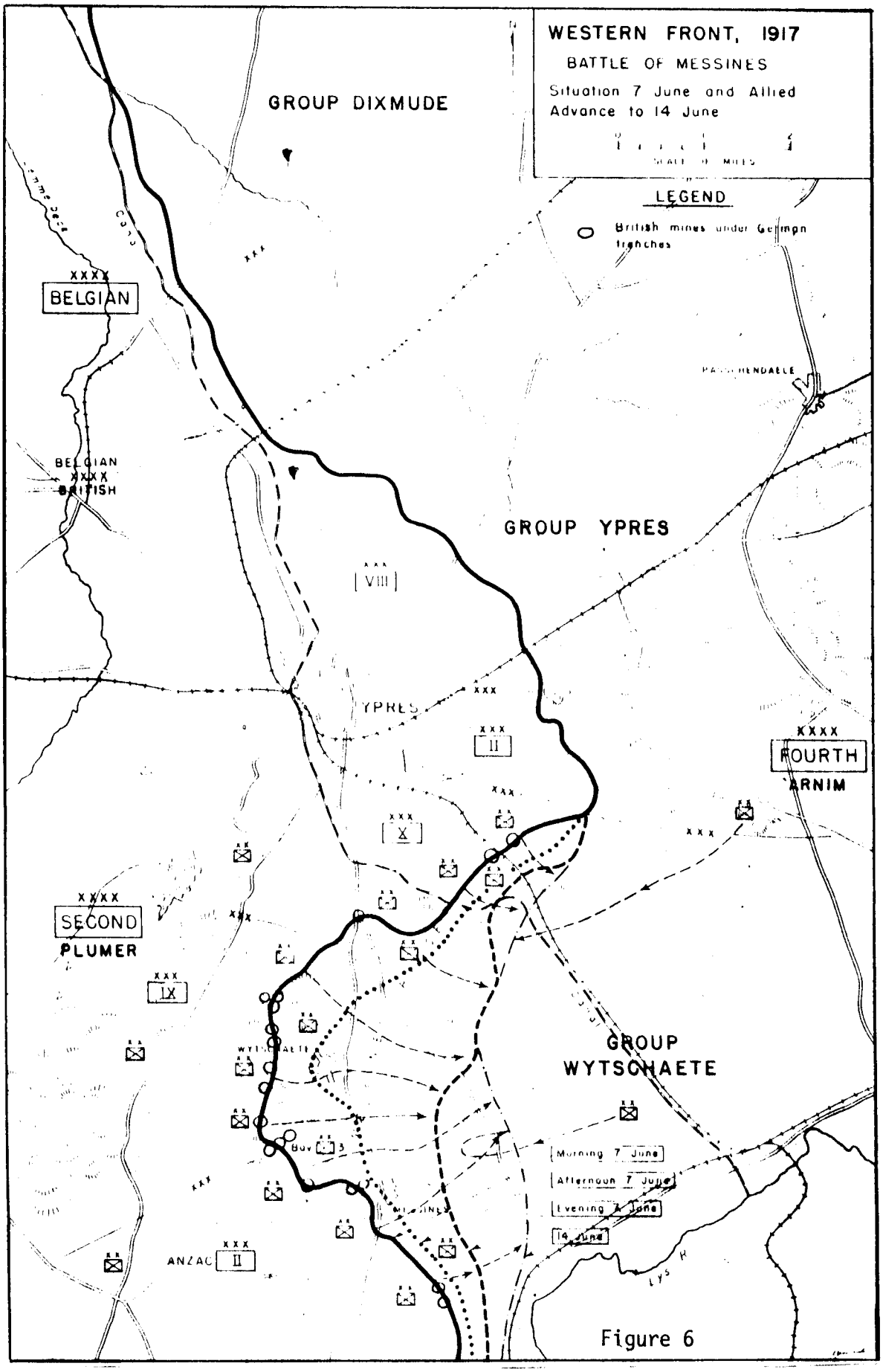

WESTERN FRONT, 1917
BATTLE OF MESSINES
Situation 7 June and Allied Advance to 14 June
LEGEND
British mines under German trenches
GROUP DIXMUDE
GROUP YPRES
GROUP WYTSCHAETE
XXXX BELGIAN
BELGIAN XXXX BRITISH
XXXX SECOND PLUMER
XXXX FOURTH ARNIM
ANZAC
YPRES
Morning 7 June
Afternoon 7 June
Evening 7 June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

Figure 6

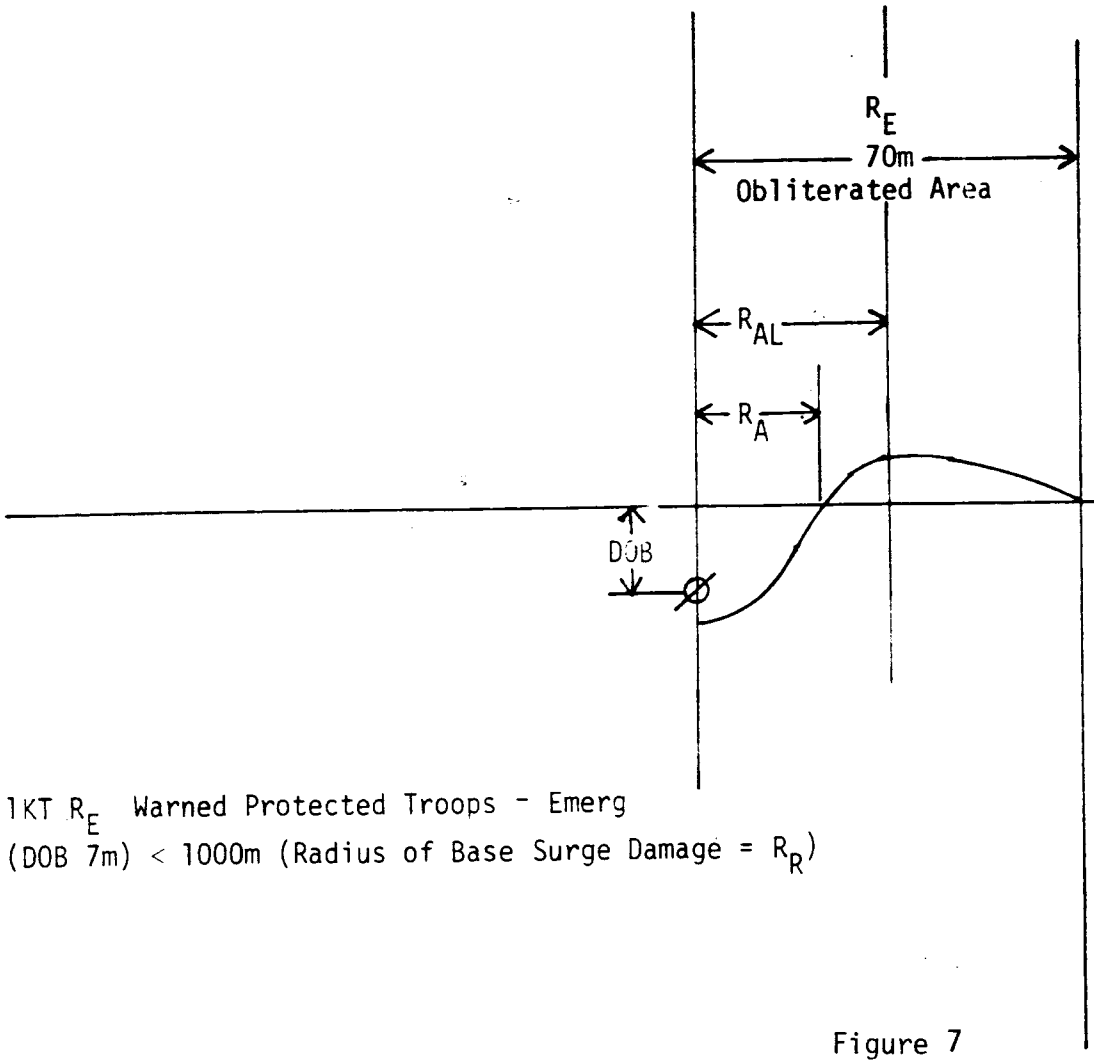
If there were 20 mines and 600 tons of explosives which were equally distributed among them, then each shaft would have had 30 tons or 27,000 kilograms. This is a much smaller amount of explosive than is found in a 0.2 kiloton weapon, 30 tons equalling 0.03 kilotons. What is of interest here is the opportunity to test the reinforcing effects of multiple subsurface detonations. (Figure 7)

Besides the obviously small yield, a problem in equating Messines Ridge to tactical nuclear weapons is that an ADM -- that is, a subsurface detonation -- would usually be employed against targets such as terrain features, material, and structures and not against personnel. The exercise at Messines seems to have been aimed at personnel disruption even more than at breaking up the strong trench system. Another problem is that a subsurface burst of a nuclear weapon would have created unacceptable radiation levels for periods of time in excess of that permitted for the exploitation of the breach by the British.

There are still other lessons to be learned from Messines. At the site of the Spanbrockmolen shaft, everything was obliterated for a radius of 64 meters around the blast site. It is not understood whether this means in extension of the crater or from the center of the crater. It seems to mean outside the crater, however, and because of this the plot shown in the accompanying diagram is of some interest. The data appears to equate this portion of the Messines operation with a 1 kiloton ADM detonation effect set.

3. The Explosion in Halifax Harbor, 7 December 1917

At 9:00 am on 7 December 1917, the French Line munitions ship Mont Blanc blew up in the channel between Halifax Harbor and Bedford Basin. (Figure 8) Approximately half of the city of Halifax was razed by the explosion. What was not blown down was consumed in a major fire that began as many small ones, ignited instantanously by the explosion itself and various other causes throughout the damaged area. Many of the 4,000-8,000 killed -- the number will never be known exactly -- died as a result of the fire which they could not escape. Entire city blocks were thus completely obliterated in a two and one half square mile area of the northern half of Halifax proper, called Richmond. Across the channel in Dartmouth, the damage was equally



If a 1KT ADM would cause severe damage to trenches with a DOB of 8 meters (27') to a radius of 100 meters, then a yield of .03KT should produce a considerably smaller r_{Ds}. Thus, the RA (Radius of apparent crater would be < 70m and the 70m would be the RE (Radius of ejecta).

R_{AL} - Radius of Lip Crust = $1.5 \times R_A$ (Radius of apparent crater)

R_E therefore is > R_R (Radius of Rupture zone

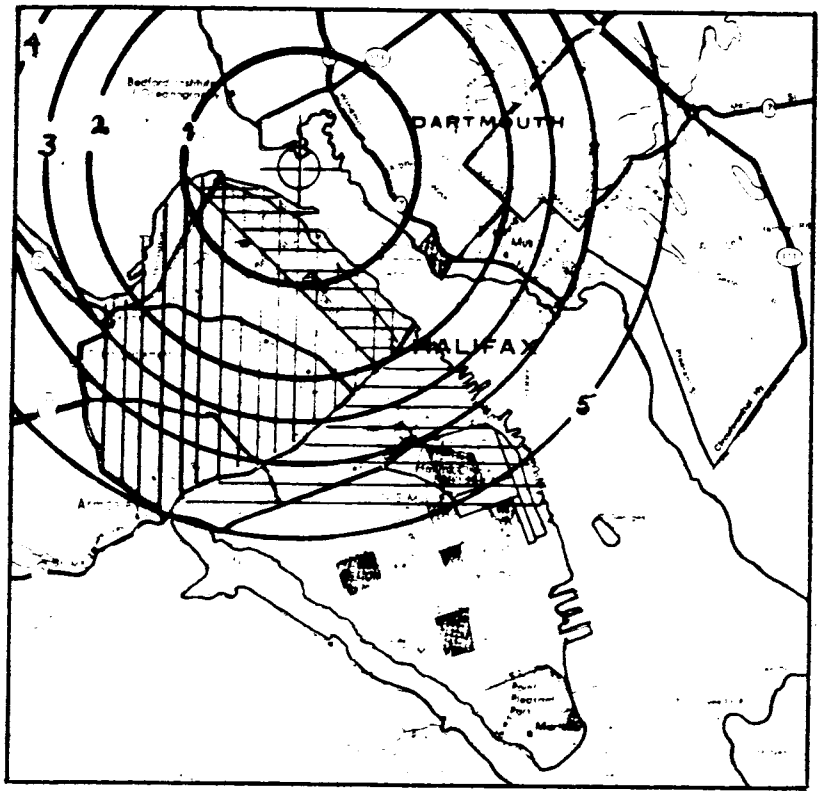
1KT R_E Warned Protected Troops - Emerg
(DOB 7m) < 1000m (Radius of Base Surge Damage = R_R)

Ejecta - equals the material blown from the crater that does not fall back into the crater. This material is generally propelled at high velocity causing a missile effect.

Base Surge is "earthquake effect"

Figure 7

Messines Ridge



RADII

1. Severe blast damage - Frame structures 5KT yield generally coincides with area of severe damage sustained
2. Theoretical of severe damage measured to intersection of Gettinger & North Sts. Would equate to 50KT yield
3. Theoretical limit of 1 PSI over pressure from 5KT yield
4. Theoretical limit of thermal ignition of Class 1 Forest - would probably be slightly more than thermal ignition of wood shingled sided houses
5. Area of reported appreciable damage

Figure 8

HALIFAX - 7 December 1917

severe. Communications with the outside world were almost entirely cut. Rescue operations were hampered by this fact and by a blizzard that began that night and covered the area with over three feet of snow that soon turned to ice.

Without question the explosion at Halifax is the largest scale man-made accident to date. This is especially interesting since the size of the explosive charge detonated was only the equivalent of about five kilotons of yield. Although German sabotage was at first suspected, it soon became evident that the principal fault lay in poor navigation, through the "Narrows," by the munitions ship and by the Norwegian ship Imo, which was on its way to Belgium with relief supplies. Poor harbormaster control over dangerous shipping was later determined to be a contributing factor.

Property damage was initially estimated at well over $25 million, which is probably a conservative figure. The suffering endured by the population, which was totally caught by surprise, undoubtedly approximates the type of damage that would be caused by the collateral effects of a nuclear detonation.

Technical Analysis

The munitions ship carried 2,800 tons of gunpowder and guncotton, 30 tons of TNT, and 35 tons of benzol, a commercial derivative of benzene, a total explosive power approximately the equivalent of a 5 kiloton weapon.

The ship was located at a point where the channel is about one half mile wide. The shoreline of both sides of the channel was lined with light and heavy industrial structures and piers. The land slopes upward rather sharply from both shorelines, creating a bowl shape that added to the blast wave reinforcement of the detonation. In the Halifax (west) side of the channel and above North Street was the Richmond area, where the low-income families of the city lived. The structures in this area were predominantly of wood frame construction. To the south of North Street lay the commercial business district of the city with a preponderance of masonry structures, many several stories high.

The ship blew up in a single explosion, the shock of which broke windows 98 kilometers away. About two and one half square kilometers of Richmond, especially the area between the waterfront and Gettingen Street, was totally destroyed by the blast. (There is little data immediately

accessible about the damage in Dartmouth, across the channel.) Further south along the west side of the channel major munitions loading warehouses and piers escaped the main force of the explosions but were severely damaged. There were no secondary explosions of any consequence from this or any other comparable source, although there were numerous secondary explosions from ruptured gas lines generally ignited by the fire that swept the damaged area.

Inland from the area of total destruction, almost all the structures in Richmond suffered severe to moderate damage, but the exact extent of the blast damage radii will never be known, as the entire area was immediately engulfed in flames, started by overturned stoves and heaters, in addition to what was caused by the blast itself. The blast damage radii were accentuated by the bowl shape of the surrounding terrain, which caused a reinforcement of the initial blast wave as it travelled outward. This phenomenon probably also helps account for the damage 98 kilometers away.

A total casualty picture will never be known, but the estimates of dead range from 4,000 to 8,000, although some accounts are considerably higher. The number of injured was not accurately counted because of the chaos existing after the explosion, fire, and the blizzard that followed. The death toll was greatly increased by the collateral effects of the fire and the subzero weather that ensued.

While the severe damage radius may be adduced with some certainty from the reports, defining the radii of actual moderate and negligible damage to the various types of structures involved is more difficult because of the damage by fire. Similarly, the radius of ignition from the blast itself, as opposed to the various collateral fire damage radii, is extremely difficult to determine. The actual damage radii and the theoretical blast damage radii for a 5-kiloton weapon that have application to this event are shown on the accompanying map (page 34). The double-hachured area is the area of total destruction.

Based on the simulated, theoretical data, found in FM-101-31-3, for a 5 kiloton weapon, the r_{Ds} for the types of structures found in the waterfront area in Richmond is 1,100 meters for wood frame, 870 meters for multi-story brick and 360 meters for factories (based on HOB of 0). The

moderate damage radii are, of course, of a larger magnitude in each case, but not on a geometric scale. Under most conditions moderate damage over a sufficiently wide area will contribute as much disruption as a smaller area of severe damage.

As no accurate contemporary population figures are readily available, an accurate evaluation of comparable personnel casualty figures is not possible. Considering the use of a 5 kiloton weapon with the same ground zero and the same height of burst, no one within 6,600 meters would have been totally safe if he were exposed and taken by surprise by the detonation. Within Radius 1 on the map, a minimum of about 35% of all personnel would have received immediate permanent injuries in a nuclear explosion, while about 62% would eventually have become fatalities.

4. The I.G. Farben Explosion, Ludwigshafen, Germany, 28 June 1948

A major explosion occurred at the chemical factory of the I.G. Farben company in Ludwigshafen, in the French Occupation Zone of Germany, on 28 July 1948. The city, still in its first phase of reconstruction and rehabilitation after World War II, was rocked by the blast, which shattered windows as much as 8 kilometers from its center. The plant had been 80% destroyed by wartime bombing but had been almost completely reconstructed at the time of this latest blast. This same plant had suffered another major explosion in 1921, when over 600 were killed.

At least 22,000 people were at work in the plant on 28 July 1948, when the first explosion took place in the lacquer factory. About 4,000 cubic meters of a chloroethyl solution exploded, creating havoc and igniting a major fire that spread to the area where methyl violet was produced. Three more secondary explosions added to the confusion and damage. Twenty-four hours after the blast, several hundred people were still trapped in the debris of the shattered factory buildings. The initial blast was of such strength that it was clearly felt in Heidelberg, 20 kilometers away across the Rhine River.

Initial estimates placed the death toll considerably higher than the final official count of 250 dead and 2,000 seriously injured. Both US and French troops assisted local German authorities in the rescue operations, substantially reducing the potential toll.

Although the cause of the blast was never clearly determined, sabotage was not ruled out, as there had been some labor disputes between the German workers and the French administration. The Soviets claimed the blast was due to the unauthorized manufacture of V2 rocket fuel -- a claim apparently substantiated by some of the German workers, although never admitted by the authorities.

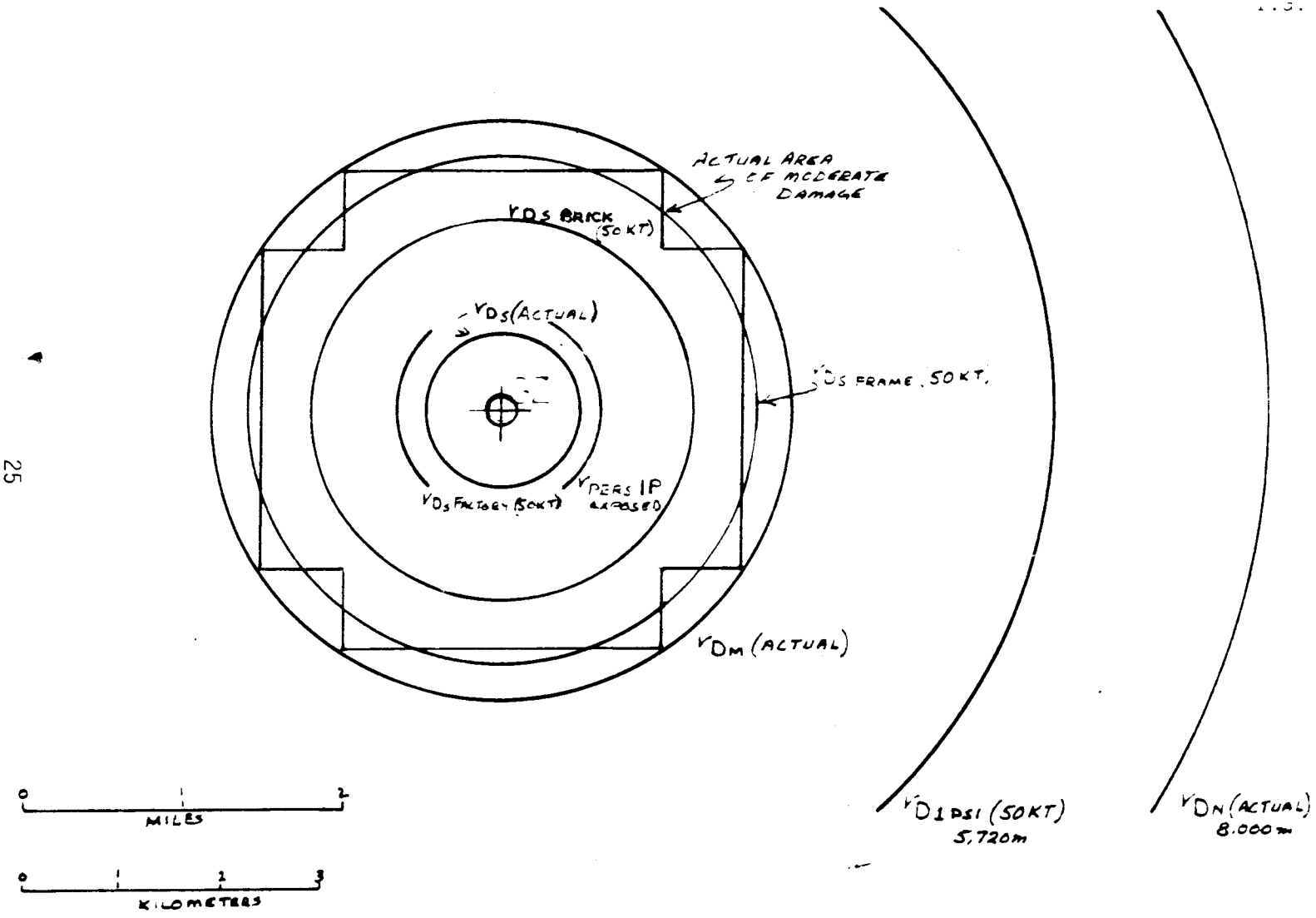
Despite the extent of the blast, about 60% of the plant was back in operation two days later. Although the immediate disruption had been quite widespread, the after effects of the explosion were minimal. Except for the buildings actually destroyed, the remainder of the plant was back to normal within 72 hours.

Technical Analysis (Figure 9)

Contemporary press accounts defined the area of moderate damage associated with this explosion as 20,718,722 square meters, or approximately 11 square kilometers. Thus, the moderate damage radius (r_{Ds}) is calculated at 2,568 meters. Reports place the radius of light (negligible) damage (r_{Dn}) at 8,000 meters. If, as reported, 60% of the plant was back in operation in two days, the severely damaged area could have constituted 40%. Assuming that the factory covered two square kilometers of the moderately damaged area, the severe damage radius would be 812 meters. (However, for reasons evident in the subsequent discussion, less than 40% of the plant was severely damaged.)

To create this damage level in a factory complex, a 50 kiloton nuclear weapon would be required. (Based on the theoretical, unclassified nuclear weapons data, a 20 kiloton weapon would cause severe damage to a radius of 670 meters while a 50 kiloton weapons would cause severe damage to factory buildings to a radius of 1,070 meters.) On this basis, the 50 kiloton weapon was chosen to insure the expected damage. Hereafter, then, the 50 kiloton weapon effects tables were used to determine other effects. For reasons indicated below, however, it appears plausible that comparison should be made with a lower yield weapon. More data than is currently available is required for more definitive comparison.

Figure 9
I.G. FARBEN EXPLOSION



$V_{DS\ BRICK(50KT)} = V_{PER\ IP\ BRICK\ (50KT)}$

$V_{DS\ FRAME(50KT)} = V_{PER\ IP\ FRAME\ (50KT)}$

If a 50 kiloton weapon had been employed, casualty rates could have been expected to be considerably higher than those encountered in the I.G. Farben incident. If the factory complex was two square kilometers in area, and there were, as reported, 22,000 people at work at the time of the blast, at least 90% would have been immediate permanent casualties. The remainder would have succumbed either to the immediate transient effects or to the latent lethal effects of the weapon. Another important point is that the factory area would have been unusable for a considerable period because of the residual radiation effects and because of the fallout from a height of burst (HOB-0) detonation. Thus, while collateral damage may be measured with some accuracy and, within certain limitations, be directly equated to the actual experience, additional factoring would be required to achieve a viable estimate of the possible effects of radiation, both residual and from fallout.

5. The Explosion in Cali, Colombia, 7 August 1956

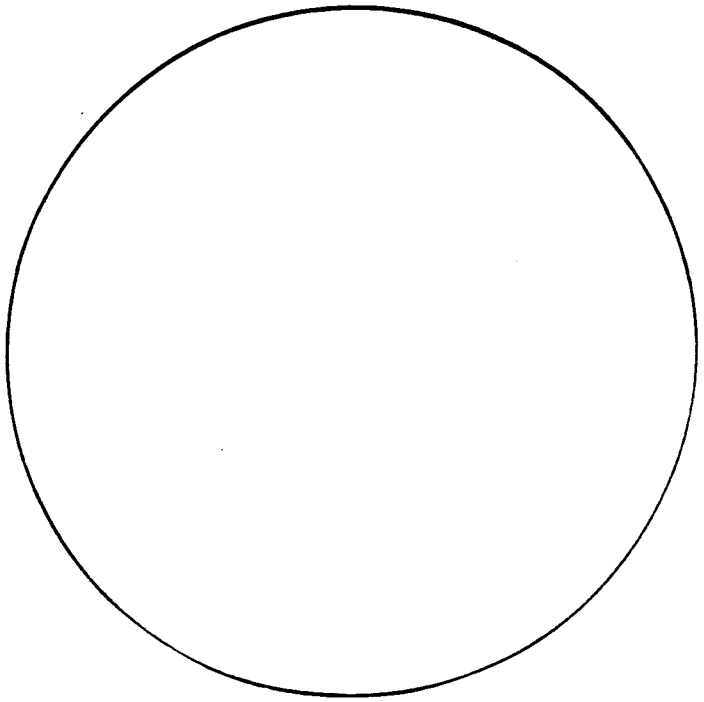
A seven truck convoy loaded with high explosives, part of a larger shipment of 20 truckloads of munitions, blew up in Cali, 185 miles from Bogota, at 12:04 am on 7 August 1956. The government immediately claimed sabotage, although the proximate cause is not known. Cali is the seat of the Cuaca Valley Department of the Colombia government.

The convoy was parked overnight directly in front of the railway terminal when the blast took place. The terminal building was leveled, and there was severe damage to other structures, including hotels, a military police headquarters, and an army barracks, where 500 troops were asleep. A total of eight blocks were leveled as a result of the blast.

The initial death toll was 850, with an additional 2,000 injured. The city's population was about 250,000. Several American-owned companies had their offices in the blast area. Only the timing of the explosion prevented much greater numbers of casualties. Windows were shattered as far as three kilometers from the blast site.

Technical Analysis (Figure 10)

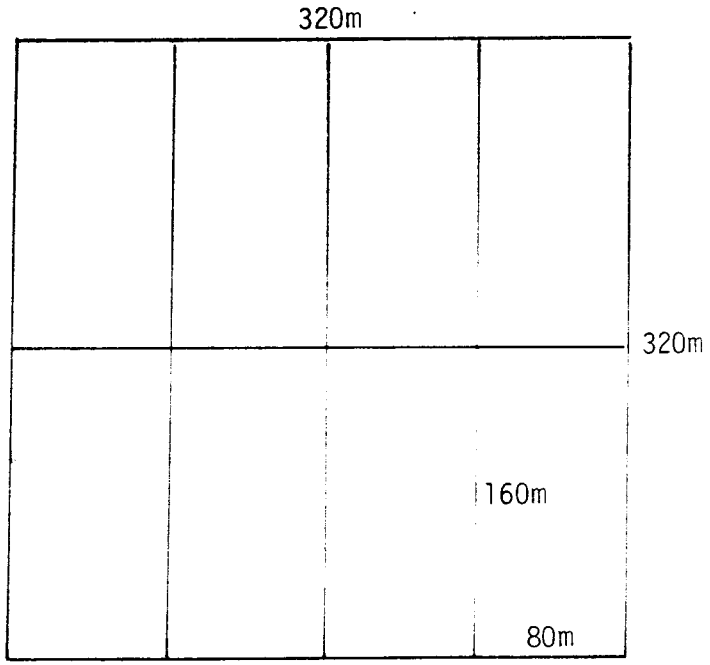
An extensive search of material available in this area yielded no more specific data than has been mentioned above. Without access to contemporary



Area of Moderate damage to brick structures
r_{Ds} (m/BR) .2KT = 180m

The area of a circle with a 180 meter radius equals 101,790 square meters
Converted to a square:

$$\sqrt{A} = a = 320m$$



Dividing this square into 8 blocks as in Cali r_{Ds} would give a block 160m x 80m or 525'± x 275'±
Under current standards a city block is approximately 600' x 300'±
Thus, the effect of the Cali blast in giving r_{Ds} approximates a .2KT nuclear yield in this one element. Hence .07KT Real = .2KT theoretical (predicated on street size and lay-out in Cali, c. 1956.)

Figure 10
CALI, COLOMBIA - 7 August 1956

Colombian newpapers or other Colombian sources the possibility of meaningful analysis is limited.

The amount of ammunition carried on the trucks -- even the size of the trucks -- was not discovered. However, it may be assumed that the trucks were somewhere in the range of 2-1/2 to 10 ton capacity. With a 10% overload the weight of the ammunition would have been between 17.7 and 77 tons. Since 1,000 tons of TNT is equivalent in explosive power to a one kiloton nuclear yield, the explosion of 77 tons of conventional ammunition would be about the equivalent of the detonation of a .07 kiloton nuclear device. The severe damage radius for a multi-story brick building produced by a 0.2 kiloton nuclear weapon is 180 meters, with an area of damage of 101,790 square meters. This area is the equivalent of a square with sides of approximately 320 meters, which is a reasonable size for the eight block area reported leveled.

Comments

1. There is a relationship between the five examples of historical disruptive events and the expected effects of tactical nuclear weapons employment. For this initial effort, unclassified nuclear effects data was used to obviate the need for dealing with classified data. It is anticipated that somewhat different results would be obtained using actual nuclear effects data, either increasing or decreasing the viability of this type of correlative effort.

2. In the case of the Halifax incident the correlation is extremely interesting and is nearly perfect. But further study is required before it can be certain that this is not coincidence. By the same token, the Cali incident is also interesting in that it appears to suggest substantially higher radii for less yield than the most nearly equivalent simulated nuclear weapon. More detailed analysis should clarify whether or not this indication is correct, and if so, why.

3. To meet any type of criteria for effects determination, the selection of appropriate historical noncombat disruptive events requires the use of those where the incident took place in a built-up area, and measurable effects were observed. Does this mean, therefore, that this type of analysis is limited to fighting in built-up areas? Probably not, but a determination will require a greater data accumulation and analysis effort than has been possible in this study.

4. Although there is a considerable amount of data accumulated on the preceding pages, it is not yet possible to compare ambient factors affecting these examples systematically, either with those in conventional battle experience, or on a possible future nuclear battlefield. The Halifax example appears to offer promise as a first step in such a comparison. More data is believed to exist for this and the other four examples and compiling and analyzing this additional data should permit clarification.

SOME GENERAL CONCLUSIONS

It is clear even from this limited survey that natural and man-made nonnuclear events can create levels of damage and subsequent conditions whose sheer magnitude make them comparable to the damage that would result from the use of at least the lower range of existing tactical nuclear weapons. The level of physical damage produced by a nuclear explosion should not of itself, therefore, be seen as a novelty. In this respect, levels of casualties and damage and to some extent psychological effects caused by conventional means of destruction can be used as a basis for analysis of potential results of nuclear combat.

How closely such nonnuclear events can be correlated with hypothetical combat use of theater/tactical nuclear weapons cannot be determined without more detailed data. More work is needed on determining how to compare highly destructive but chronologically expanded nonnuclear events, particularly combat events, to the almost instanteous results of tactical nuclear weapon detonations. If such a comparison can be made -- and this can be determined only with further, more detailed analysis -- then it should be possible to develop a substantial data base of destructive events which can with reasonable reliability be considered as tactical nuclear weapons surrogates. Comparison of the surrogate outcomes with the outcomes of conventional combat engagements will permit assessment of the changes in the factors that influence combat outcomes that can be expected in tactical nuclear weapons.

APPENDIX A

Narratives

1. THE BATTLE OF THE CRATER, 30 JULY 1864

This incident was part of a larger confrontation between Confederate and Union forces in the neighborhood of Petersburg, Virginia, during the Civil War. In a static situation with forces entrenched on both sides at the beginning of June 1864, the Union command assigned troops to the task of digging under the Confederate position. This activity soon became evident to the Confederate soldiers. Countermining was ordered, but although the Southern troops could hear the Federals digging they were never able to break into their galleries. The Union diggers mined to a distance of just over 150 meters from their starting point, and emplaced 8,000 pounds of powder. The Confederate troops prepared above-ground positions in the rear of the occupied main line, but they continued to occupy the original main position. At dawn on 30 July the mine was fired.

The actual area of physical damage from the single explosion was not much larger than the length of the main tunnel -- 150+ meters. Some 278 men were killed by the explosion or buried under tons of earth. The close combat that followed as a direct consequence of the event actually produced a victory for the target force, mainly because of Union command blunders. A Confederate counterattack recaptured the ground, killed or wounded some 3,500 Union men, and took about 1,500 prisoners. The Confederates suffered a total of 1,500 casualties. The speed and skill with which the Confederates rallied and reacted to the disastrous event were more impressive than the performance of the other side.

This event produced little change in the tactical situation, although its consequences must have weighed on the minds of the Northern participants. The area involved in this action was a piece of contested ground, and no important structures or other material things were present. Damage was

largely confined to military equipment in the immediate vicinity. Whatever effect the Crater affair may have had, it was not large enough to alter the course of the war significantly.

2. THE JOHNSTOWN FLOOD, 31 MAY 1889

The city of Johnstown, Pennsylvania, is located in a narrow valley on the Conemaugh River. About 13 kilometers upriver from the city there was in 1889 a recreation area that included a lake, impounded behind an earth dam, and containing 20 million tons of water. Johnstown's population was 28,000, concentrated mainly in an area of 5 square kilometers. There were a number of small industrial sites in the city.

Heavy rains in the area began on the afternoon of 30 May. There was some warning that danger was increasing as the rain continued, and some people were evacuated, but in the main there was a tendency to see the warnings as "crying wolf," and people remained in place. At 3:10 on the afternoon of the 31st the dam gave way. A wall of water 15 meters high rushed down the river and, at 4:10 pm, washed over the city, literally drowning it in ten minutes. The rush of water lasted for three quarters of an hour. By early morning of 1 June the water level was dropping substantially.

The immediate effect of this disaster was the wiping out of a sizable city and the elimination of many of its economic and social functions. Other towns in the vicinity suffered some damage, but the catastrophic experience was confined to the 5 square kilometers of Johnstown proper. The flood and associated events produced 2,200 dead and 967 missing. Six of 35 physicians practicing in the area were lost. The police department was put entirely out of action. The industrial section, situated on low ground, received heavy damage. A partial inventory of losses includes:

- Severe damage was done to the mills of the iron company and to woodworking shops, the woolen mill, and the flour mill.
- A viaduct and several bridges were destroyed.
- Furnaces, boilers, heavy machinery, and tons of heavy steel cable were washed away.
- Heavy damage was done to railway installations. The roundhouse and several other buildings were destroyed; 33 locomotives, weighing from 50 to 85 tons, were washed away; 18 rail passenger cars and 315 freight cars were washed away, along with 80 kilometers of track.

- The waters carried off hundreds of tons of pig iron and moved large amounts of brick, mortar, and stone from hundreds of smashed houses.
- As the flood descended it bore with it people, animals, and machinery from farms in its path upstream.
- Despite the rain and rising water there were a number of destructive fires.

The resort area never recovered, but the people returned to the city, and eventually it was restored.

3. THE USE OF CHLORINE GAS AT YPRES, 22 APRIL 1915

The First Battle of Ypres in October-November 1914 had produced about half a million casualties among the British, French, and German participants, with very little effect on the strategic situation. To break the stalemate in that area the German command decided early in 1915 to use chlorine gas as a surprise attack weapon. This was actually the second use of gas in World War I, since on 31 January 1915 18,000 rounds of gas shells had been fired at Russian troops at Bolimow, but the effort did not produce tactical success. Apparently the extreme cold made the gas ineffective. That event seems to have been known to Allied intelligence agencies, but its importance was not recognized. Thus the first use of gas at Ypres on the Western Front found the troops ignorant and unprepared.

The gas was first released on 22 April 1915, across a front of eight kilometers against a line held by French Territorial and Canadian troops. The emission of gas from emplaced canisters went on for about fifteen minutes. Associated subsequent actions lasted for several hours, and gas was used again the following day. The actual area affected by the gas was shallow.

Altogether some 15,000 men were killed or sickened by the gas attack; some died a slow death or endured long-term invalidism.

The initial Allied reaction included significant shock and panic. The few French-African troops who escaped the attack ran in terror. French Territorial positions were broken up, and the men wandered aimlessly. Some Canadian troops in the area stood their ground. The attack produced a seven kilometer gap in the Allied front and exposed the British flank, but the Germans were unable to exploit because their troops were afraid of getting into the cloud, and they had not provided enough troops for effective exploitation.

Overall, the use of nonpersistent gas created a situation of some local impact, but over time it cannot be seen as having major significance in terms of ground taken and held or tactical advantage gained. The position of troops on the ground was changed very little.

There was little nonmilitary property to suffer damage in the barren battle area. Anything made temporarily useless by chlorine would recover as a matter of course, since this was not a persistent agent like the mustard or lewisite introduced later.

This use of gas did produce significant long-term changes in the conduct of the war. Eventually chemical weapons were used by both sides. More deadly and more persistent agents came into use. Training and equipping the soldier for chemical warfare became necessary, and the logistics of this new system added to the load of supply and evacuation services. A distinguished retired general who was gassed at Belleau Wood and at Soissons commented that the troops never ceased "to feel fear of gas and apprehension about its use that were markedly greater than their apprehension about combat in general."*

4. FIRST DAY ON THE SOMME, 1 JULY 1916

The British part of this operation involved some 143 infantry battalions, attacking along a 26 kilometer front. In addition to organic divisional light artillery units, the British force included some 467 heavy guns. The attack, over ground that was generally open and rolling, was begun after what was initially believed to be an adequate artillery preparation. Incorrect assumptions and lack of command flexibility produced a bloody failure when troops tried to cross open ground into well-prepared defensive positions held by a determined enemy.

The general battle area as conceived in planning covered about 390 square kilometers, but the part in which heavy fighting actually took place was about 65 square kilometers. Except for a penetration of 1.6 kilometers at the extreme southern end of the British attack, no significant gains were made, and the German second line remained intact.

Between 7:30 am, 1 July 1915, the start of the attack, and midnight of that day, British casualties were

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* Conversation reported by Col. Angus Fraser, USMC.

Killed in action or died of wounds	19,240
Wounded in action	35,493
Missing	2,152
Prisoner of war	582
TOTAL FOR THE DAY	57,470

Almost half the men in 143 attacking infantry battalions were casualties. The British had two casualties per meter of front over a length of 26 kilometers, most of them in front-line infantry units. German losses for the day have been calculated at 6,000 killed and wounded and 2,200 prisoners.

The most trying immediate problem in this engagement was handling the unexpectedly large number of casualties. There were serious breakdowns in the evacuation and treatment system which produced suffering, delay, and unnecessary loss.

In general the British troops behaved calmly in a situation that might easily have produced panic and flight. There were isolated incidents of individual failure, but no mass reactions. The basic discipline within the British regimental system and the examples set by officers and NCOs seem to have kept control in a situation that must have had powerful immediate impact on the soldier as he watched his comrades fall.

There was some damage to villages and farms, but no major population centers or industrial installations were involved. Material losses were primarily confined to military equipment.

This battle produced significant changes in British ground tactics, involving a loosening of the rigid control over the way troops moved on the ground and an increase in the flexibility of artillery employment. The lack of any opportunity for action by the large cavalry force present helped speed the disappearance of that arm.

The army's territorial organization caused certain localities in Britain to suffer grievous losses. For example, Yorkshire units lost 9,000 men; Lancashire units lost 6,000; and London units lost 5,500. In the larger context the Somme made a substantial contribution to the destruction of the "cream of a generation" in the British society. To assess the Somme's part in the loss, it is noted that the total British casualty toll on the western front from 1914 to 1918 was 2,715,036; 2.12% of those casualties came on this single day of battle. Since this was only one of more than 2,000 battle days for the British Army on all fronts, the losses on this day were about 42 times greater than an average battle day's losses.

5. FIRE RAIDS ON HAMBURG, JULY AND AUGUST 1943

The fire raids on Hamburg in 1943 were carried out largely by the Royal Air Force, with minor participation by USAAF units. The attacks were designed to destroy the entire city, and, had the last of four actions been completely successful, this would have happened.

The strikes came at close intervals: the night of 24/25 July; the night of 27/28 July; the night of 29/30 July; and the night of 2/3 August. Although most of the raids lasted less than half an hour, damage was enormous. Within 30 minutes, each night larger areas of the city were aflame, and "spot" fires merged and spread. In some cases major fire storms quickly developed. It was impossible to enter some areas for 48 hours after an attack.

The first raid set fire to 44 square kilometers of the city, completely destroying about 12 square kilometers of it. It was the consensus of fire engineers that the second raid was the most devastating. On that occasion 720 bombers dropped 1,102.5 tons of high explosive and 968.5 tons of various incendiaries on the heavily built up and populated eastern part of the city. The number of dead as a result of that raid was reported as 41,000.

The four raids caused 78 square kilometers of the city to be burned out. Fifty-five percent of all buildings were rendered unfit for use. In the harbor two warships, seventeen other seagoing vessels, and various docks and smaller vessels were destroyed. There were 847 breaks in water mains, some of which were two meters under hardened streets.

Personnel losses were enormous. The population of Hamburg was reduced by about 1,000,000 from the 1943 count of 1,750,000. The four attacks made 720,000 people homeless.

The war-supporting function of Hamburg was greatly reduced by damage to plant, loss of workers, and destruction of 20% of the harbor facilities. Poeple filtered back after the raids and went to work. The real effects of the attacks on Germany's capacity to continue fighting would be hard to assess.

6. THE FIRE RAID ON TOKYO, 10 MARCH 1945

This raid and its results were not unique in the war with Japan. A number of similar attacks were made on other Japanese targets. Together they destroyed 2,000,000 buildings, over one-third of the total construction in some 259 square kilometers of built-up area in Japan. In all, 13,000,000 people were made homeless. The raids were carefully planned, with fire protection specialists among the planners.

The 10 March raid on Tokyo completely destroyed 41 square kilometers, part of the area considered to be the most densely populated in the world.

At 15 minutes after midnight on 10 March the first pathfinder aircraft dropped their marking bombs. A total of 333 aircraft took part in the attack, the last one departing from the area by 3:00 am. Within half an hour after the first bomb struck, the fire was completely out of control, according to the city's fire chief. He reported that all fires had burned themselves out by daylight, except for some in industrial buildings. A USAAF aerial photo taken at noon showed few fires still burning.

Twenty-five percent of the city of Tokyo was destroyed in this raid, including 267,171 dwellings. A few industrial structures suffered less than total destruction because of stronger construction and trained in-plant firefighting personnel. Damage to the marginally adequate firefighting system included the loss of 94 fire trucks. Water supplies were sharply reduced. Underground shelters, used for protection in conventional air raids, became death traps under fire conditions, largely through carbon monoxide poisoning.

One source puts the death toll at 83,793 and the injured at 41,000. While people fled the burning area as best they could, many were trapped by widespread ignition of fires in very rapid sequence and the blending of these fires into larger fire storms and conflagrations. Naturally there was widespread confusion and individual panic, but no mass hysteria was reported.

In addition to damage done to industry in the area (which, although significant, was not critical), there was some further effect on production because of people's need to find shelter against the severities of the Japanese winter.

This raid, and its fellows, no doubt helped to fix the conviction among the people that Japan could not win the war. The climate that finally induced surrender was the product of a number of conditions and events, however, and the contribution of this raid or any other single element to the outcome would be difficult to assess.

7. THE EARTHQUAKE AT MANAGUA, NICARAGUA, 23 DECEMBER 1972

The earthquake that struck Managua and its surroundings measured 6.2 on the Richter scale and with aftershocks continued over a period of two and one-half hours. While its effects were felt in the sparsely settled areas outside the city, damage was focussed in the capital city.

Of the 325,000 inhabitants of Managua, some 200,000 were made homeless. Estimated casualties were 7,000 killed and 10,000 to 15,000 injured. Survivors fled to outlying areas. Large areas of the city were burned out by fires touched off by the quake.

Civilian control broke down in Managua, and there was widespread looting, which hindered recovery. Some 60 to 75% of the city was razed, a major portion of it declared "contaminated" and ordered to be levelled, covered with lime, and made into a mass grave. The rehabilitation and recovery effort was prolonged, since extensive rebuilding was necessary.

This event was typical in that local resources for handling emergencies proved inadequate when a major disaster struck an essentially unprepared area.

8. THE TANGSHAN EARTHQUAKE, 28 JULY 1976

The earthquake, which may have been the most destructive event in history, registered 8.2 on the Richter scale and did some damage as far as 100 kilometers away in Beijing. The center of damage was in the industrial city of Tangshan, and it is to that location that the available information seems to refer.

Tangshan is a major coal producer and the site of considerable heavy industry, and the earthquake had serious impact in several kinds of activity. The data offered here must be read in light of the notorious secretiveness of the People's Republic of China. There are no complete accounts, and some reasonable questions cannot be answered.

Estimates of killed and injured run as high as 750,000 in a population of 1,000,000. Some particulars of casualties in specific places may suggest the intensity of the damage.

Iron and steel plant	1,892
Locomotive factory	10,486
Porcelain factory	1,280

An entire shift in the coal mines was trapped underground, but the number of people involved is not known.

Of 352 multi-story brick buildings in Tangshan, 117 collapsed entirely, 85 were partly destroyed, and 99 were seriously damaged; only four were completely unharmed. Electricity and water were cut off, and the water piping system suffered very heavy damage. Twenty bridges either collapsed or were severely damaged. Forty earth dams, including one that was 65 meters high and 94 meters long, had extensive damage. Many trains were derailed. Of 28 operating when the earthquake struck, seven were put out of action. Some 280 kilometers of track were affected. Molten iron in blast furnaces cooled and hardened when the power went off.