

Explosions and Blast Injuries



AlfredHealth



Definition

- The almost instantaneous conversion of a solid or liquid into a gas at 10-15,000 times the original volume producing
 - Blast wave
 - Fragmentation
 - Incendiary effects
- Low explosive
 - < 300 m/sec
 - deflagration
- High explosive
 - > 300 m/sec
 - detonation



Table 1. High-Order Explosives.

- Nitroglycerine
 - Dynamite
 - C-4 (Composition C-4 is a plastic explosive mixture of RDX explosive, plastic binders, and plasticizers)
 - Picric acid
 - Semtex is a general-purpose plastic explosive (first made by the Semtin Glassworks in the former Czechoslovakia, hence the name). It is similar to the US composition C-4 in characteristics and use.
 - Dynamite (A mixture of diatomaceous earth and nitroglycerin patented by Alfred Nobel in 1867)
 - Ammonium nitrate-fuel oil (ANFO) mixture
 - TNT (trinitrotoluene)
 - PETN
 - TATP (triacetone triperoxide, a nonnitrate high explosive)
-

Blast Injuries: Physics

- Gases expand rapidly and compress the surrounding air
- Pressure wave and blast wind are generated and spread in all directions
- Pressure wave is affected by the medium through which it travels, (air vs. water)

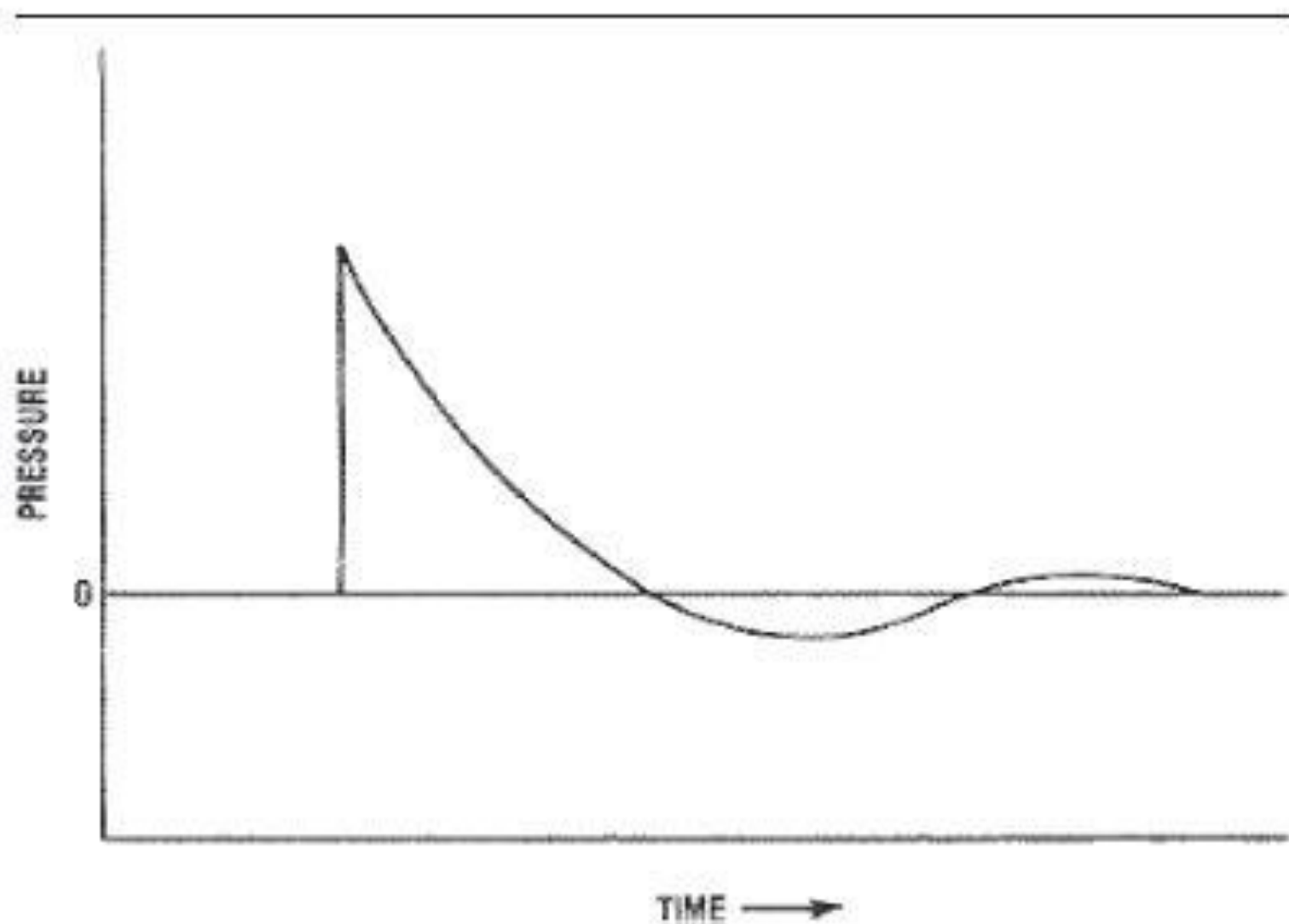
Blast Consequences

- The rapid expansion of gases creates an overpressure or blast wave
- Wave can reflect and be focussed. Magnified in enclosed spaces
- Immediately followed by negative pressure change (sucking effect)
- Only seen with high explosives



(NavSource Naval History)

Idealized representation of pressure-time history of an explosion in air.



Courtesy Virtual Naval Hospital, Emergency War Surgery
NATO Handbook. Available at: <http://www.vnh.org>.



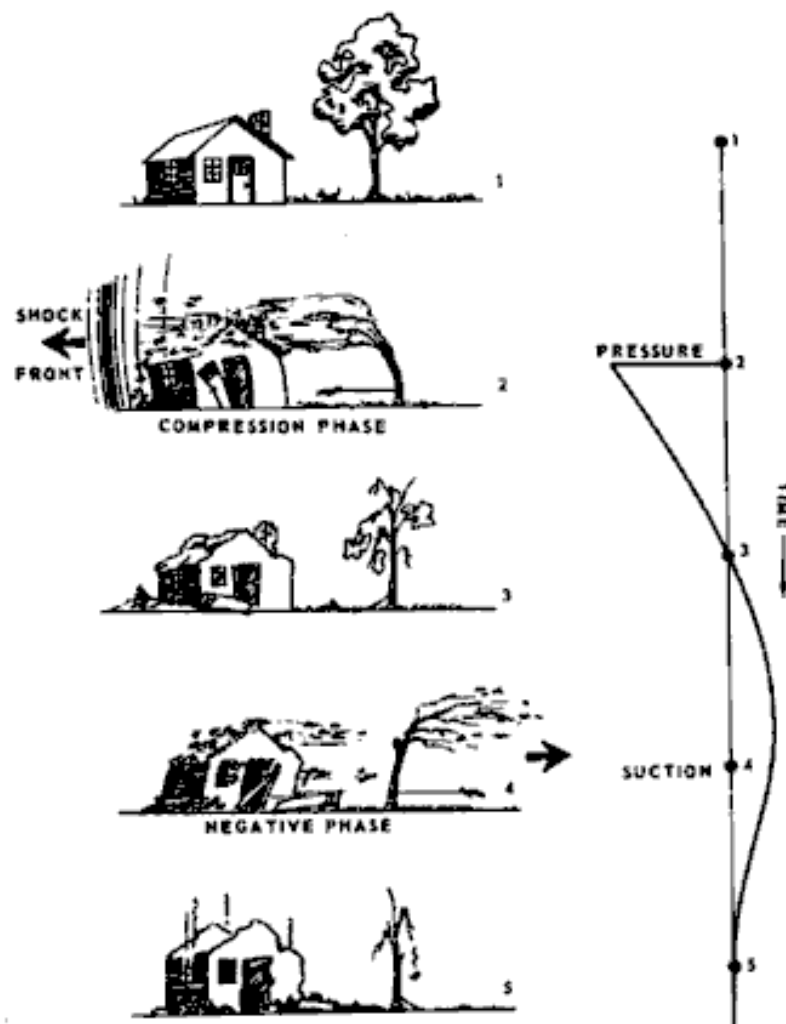


Figure 3-III. Variations of Blast Effects Associated with Positive and Negative Phase Pressures with Time









Peak Overpressure psi	Typical Damage
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0.5-to-1	Glass windows break
1-to-2	Common siding types fail: <ul style="list-style-type: none"> - corrugated asbestos shatters - corrugated steel panel joints fail - wood siding blows in
2-to-3	Unreinforced concrete, cinder block walls fail
3-to-4	Self-framed steel panel buildings collapse
5	Oil storage tanks rupture
7	Utility poles snap
7	Loaded rail cars overturn
7-8	Unreinforced brick walls fail

Blast Injury Pressure Versus Injury.

Overpressure (psi)	Effect
1-2	Frame house destroyed
3-5	Typical commercial construction destroyed
5	Tympanic membrane rupture (threshold)
15	Tympanic membrane rupture in 50% of patients
30-40	Possible lung injury (threshold)
40	Reinforced concrete construction destroyed
75	Lung injury in 50% of patients
100	Possible fatal injuries
200	Death most likely

Bomb Threat Stand-Off Distances

Threat Description	Explosives Capacity ¹ (TNT Equivalent)	Building Evacuation Distance ²	Outdoor Evacuation Distance ³
 Pipe Bomb	5 LBS/ 2.3 KG	70 FT/ 21 M	850 FT/ 259 M
 Briefcase/ Suitcase Bomb	50 LBS/ 23 KG	150 FT/ 46 M	1,850 FT/ 564 M
 Compact Sedan	500 LBS/ 227 KG	320 FT/ 98 M	1,500 FT/ 457 M
 Sedan	1,000 LBS/ 454 KG	400 FT/ 122 M	1,750 FT/ 533 M
 Passenger/ Cargo Van	4,000 LBS/ 1,814 KG	600 FT/ 183 M	2,750 FT/ 838 M
 Small Moving Van/ Delivery Truck	10,000 LBS/ 4,536 KG	860 FT/ 262 M	3,750 FT/ 1,143 M
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 Semi-Trailer	60,000 LBS/ 27,216 KG	1,500 FT/ 457 M	7,000 FT/ 2,134 M

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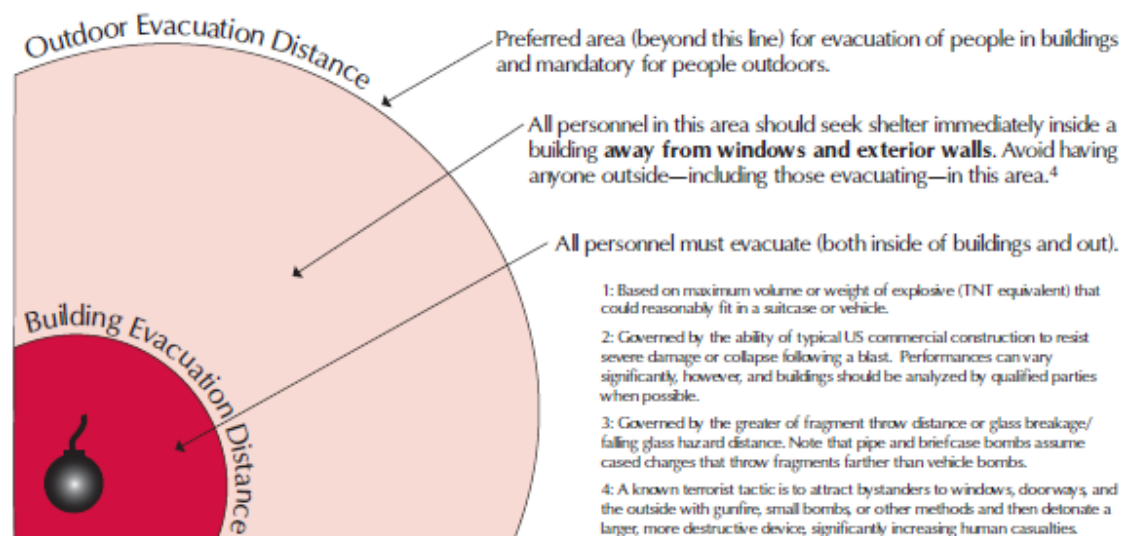
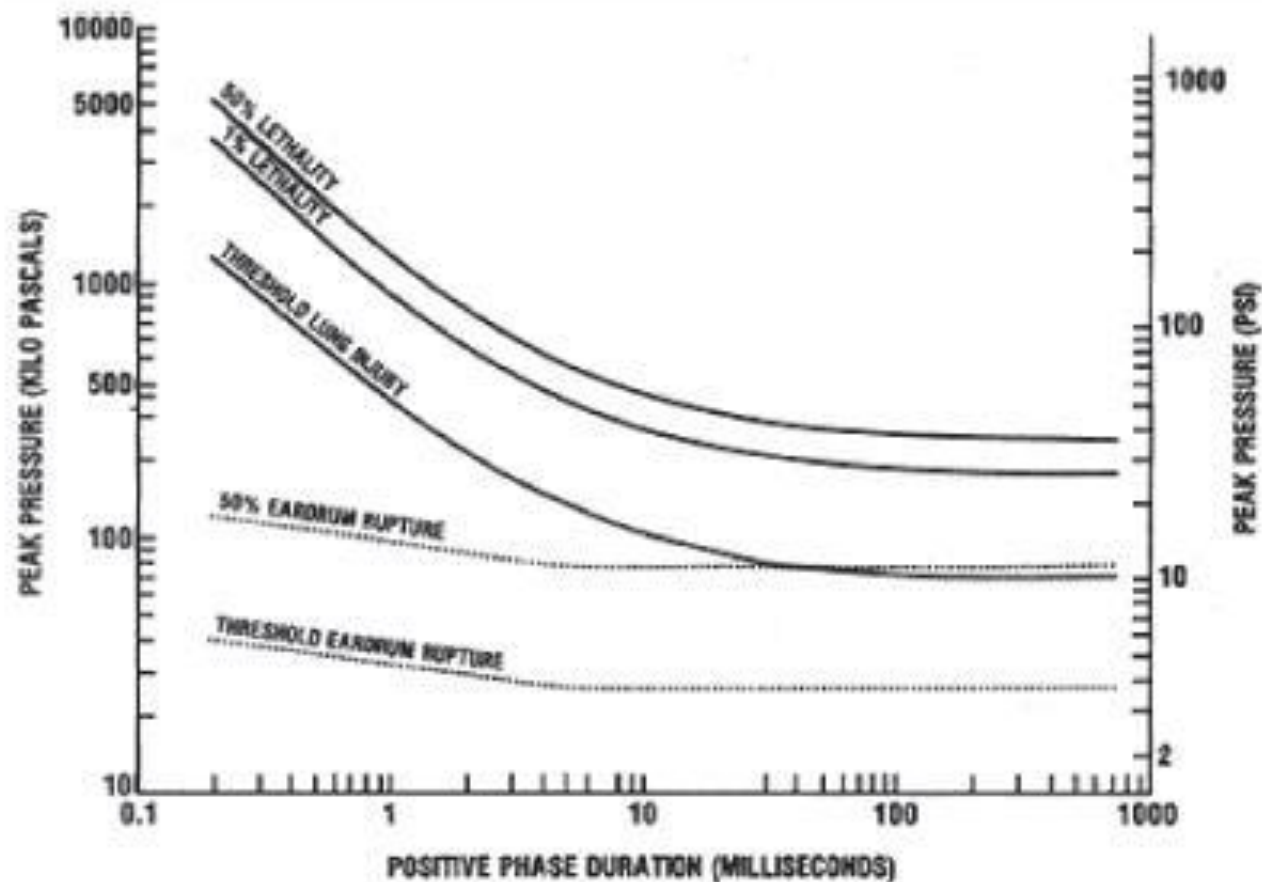


Figure 5. Estimated blast energy needed to cause damage in humans.



Courtesy Virtual Naval Hospital, Emergency War Surgery
NATO Handbook. Available at: <http://www.vnh.org>.

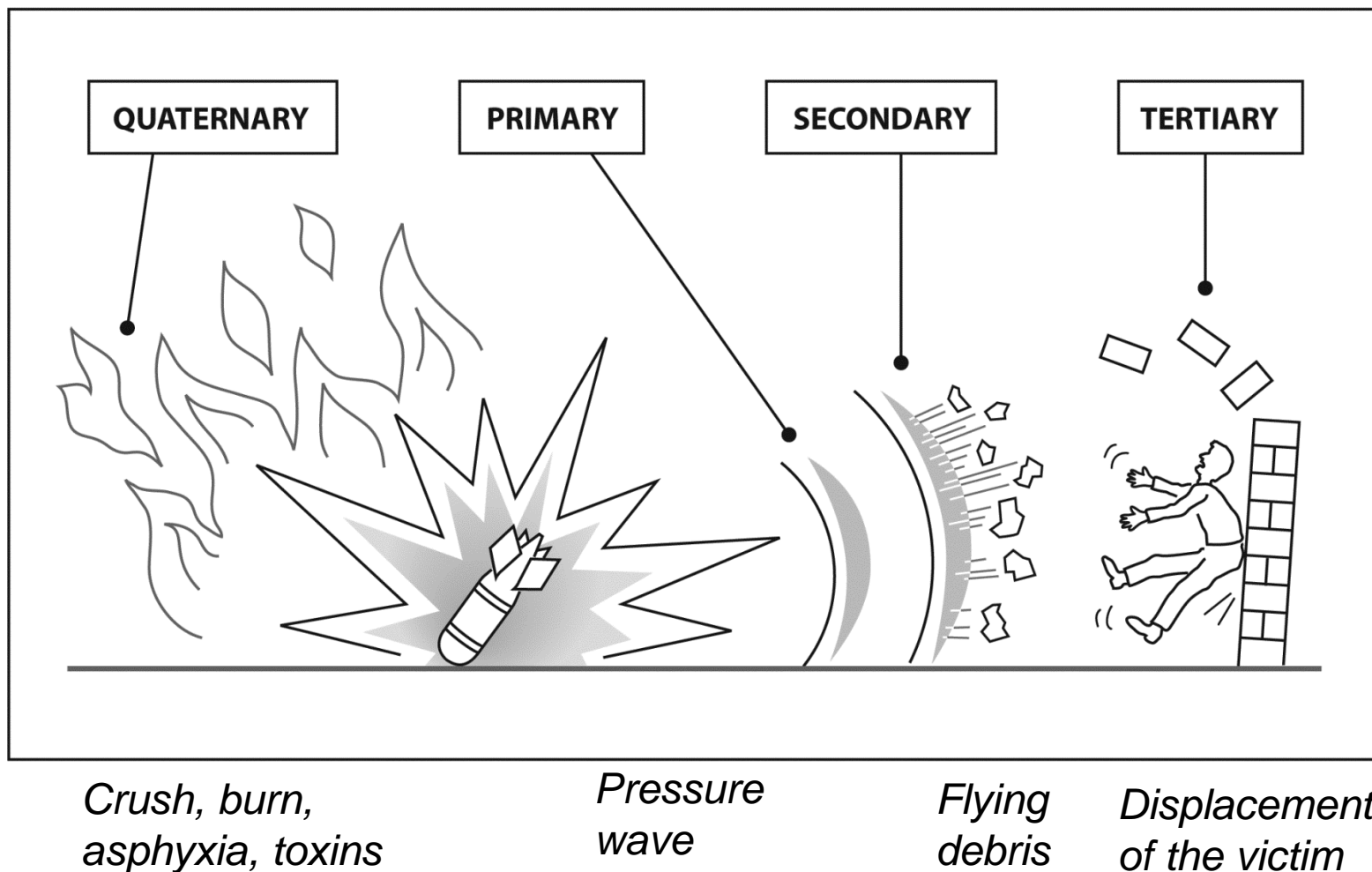
Blast Consequences

- Fragmentation
 - Device components
- Shrapnel
 - Materials (bolts, nails, etc) added to the device to increase the rate of injury
 - Travel by line-of-sight
- Incendiary
 - LE burns longer. HE burns hotter
- Secondary hazards
 - Gas, powerlines, structural collapse, smoke

Blast Injury: Severity

- Nature of device – agent, amount
- Method of delivery – incendiary, explosive
- Nature of environment – open, closed
- Distance from device
- Intervening protective barrier
- Other environmental hazards

Blast injury classification



Blast Injuries: Primary

- Blunt trauma from over pressure wave
 - Unique to high-order explosives
 - Results from the impact of the over-pressurisation wave with body surfaces
 - Blunt force injuries
 - Produces barotrauma









April 30, 2003, a 22 year-old British citizen ,Asif Mohammed Hanif, blew himself up outside Mike's Place, on the Tel Aviv seaside promenade. He killed three civilians and wounded 50.

Blast Injuries: Primary

- Most common injuries:
 - Blast lung—pulmonary barotraumas
 - Traumatic brain injury (TBI), concussion
 - Tympanic membrane (eardrum) rupture
 - Middle ear damage
 - Abdominal hemorrhage
 - Abdominal organ perforation

Blast Injuries: Blast Lung



Used with permission of CHEST, December 1999; 116(6): 1683-1688

Primary Blast Injury

- Blast lung injury
 - Apnoea, bradycardia, hypotension are the classic triad
 - Pulmonary petechiae & haemorrhage
 - Dyspnoea, cough, haemoptysis, chest pain. May not appear for 48 hrs
 - “Butterfly” appearance on CXR



Blast Injuries: Blast Lung

The most common fatal injury caused by the primary blast among the initial survivors of the explosion.

May not be apparent externally or immediately, but may lead to death if not diagnosed and treated promptly.

An overpressure of about 40 psi will cause lung injuries.

Pulmonary blast effects in survivors have been described as rare in the British literature, but are observed more often in the Israeli experience, with enclosed explosions that occur on a bus

HADAMARD CENTER
ELSCINT CT TWIN HEAD
25 FEB 80 05 14 34
120KV 325ma
27 40W
SW 11.0cm
ST 15.0
2 1.0



CT Scan of Twin Head

Blast Injuries: Blast Lung

- Clinical manifestations
 - Tachypnea
 - Hypoxia
 - Cyanosis
 - Apnea
 - Wheezing
 - Decreased breath sounds
 - Hemoptysis
 - Cough
 - Chest pain
 - Dyspnea
 - Hemodynamic instability

Blast Injuries: Head

- Primary blast waves can cause concussions or mild traumatic brain injury (MTBI) without a direct blow to the head

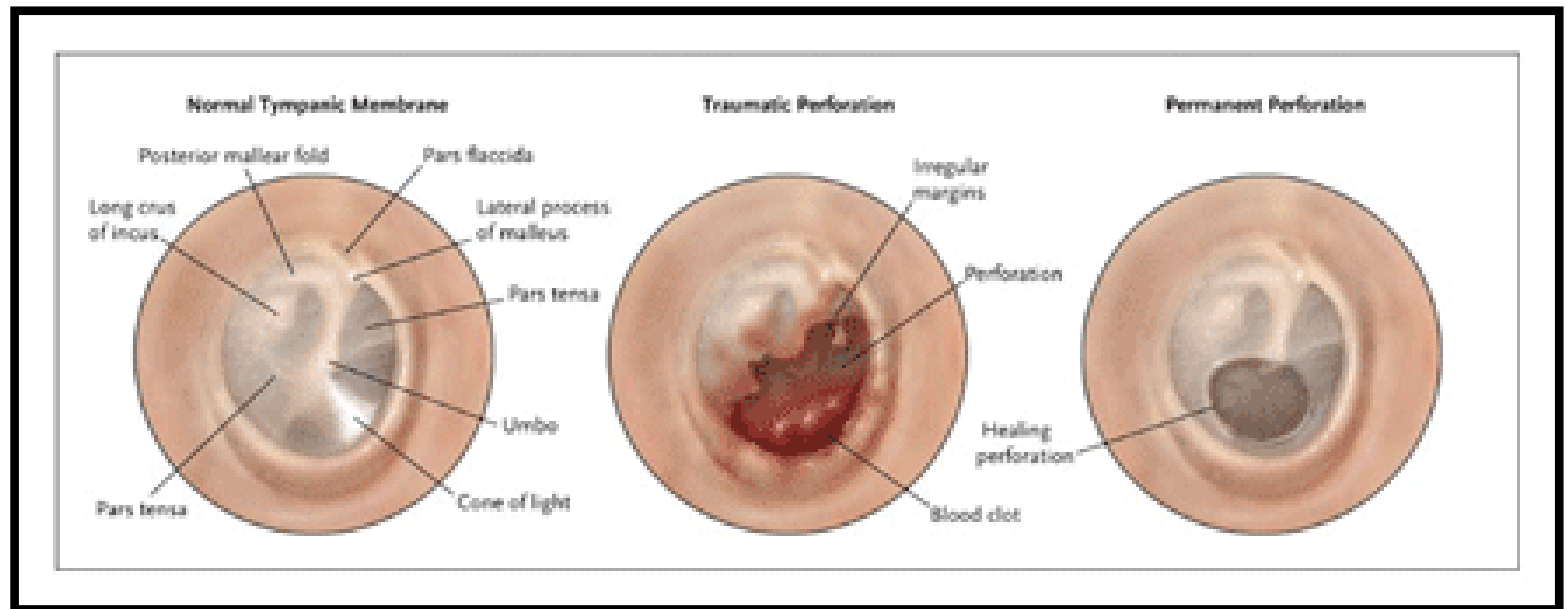
Blast Injuries: Head

- Loss of consciousness
- Headache
- Fatigue
- Poor concentration, lethargy, amnesia, or other constitutional symptoms
- Symptoms of concussion and post traumatic stress disorder (PTSD) can be similar

Blast Injuries: TM Rupture

- Tympanic membrane rupture indicates exposure to an over pressurization wave. It may be found in victims with severe pulmonary, intestinal, or other injuries, or it may be found in isolation. Its presence does not indicate that more sinister blast injuries exist.

Blast Injuries: TM Rupture



In the Oklahoma City bombing, the incidence of auditory injury was 35%

Blast Injuries: Ear

- Ear injuries may include not only tympanic membrane rupture, but also ossicular disruption, cochlear damage, and foreign bodies.

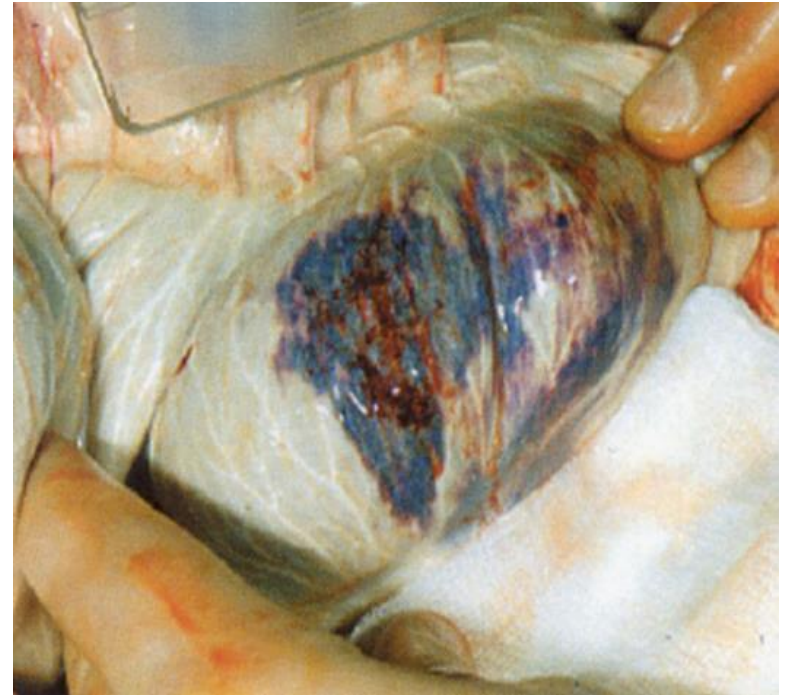


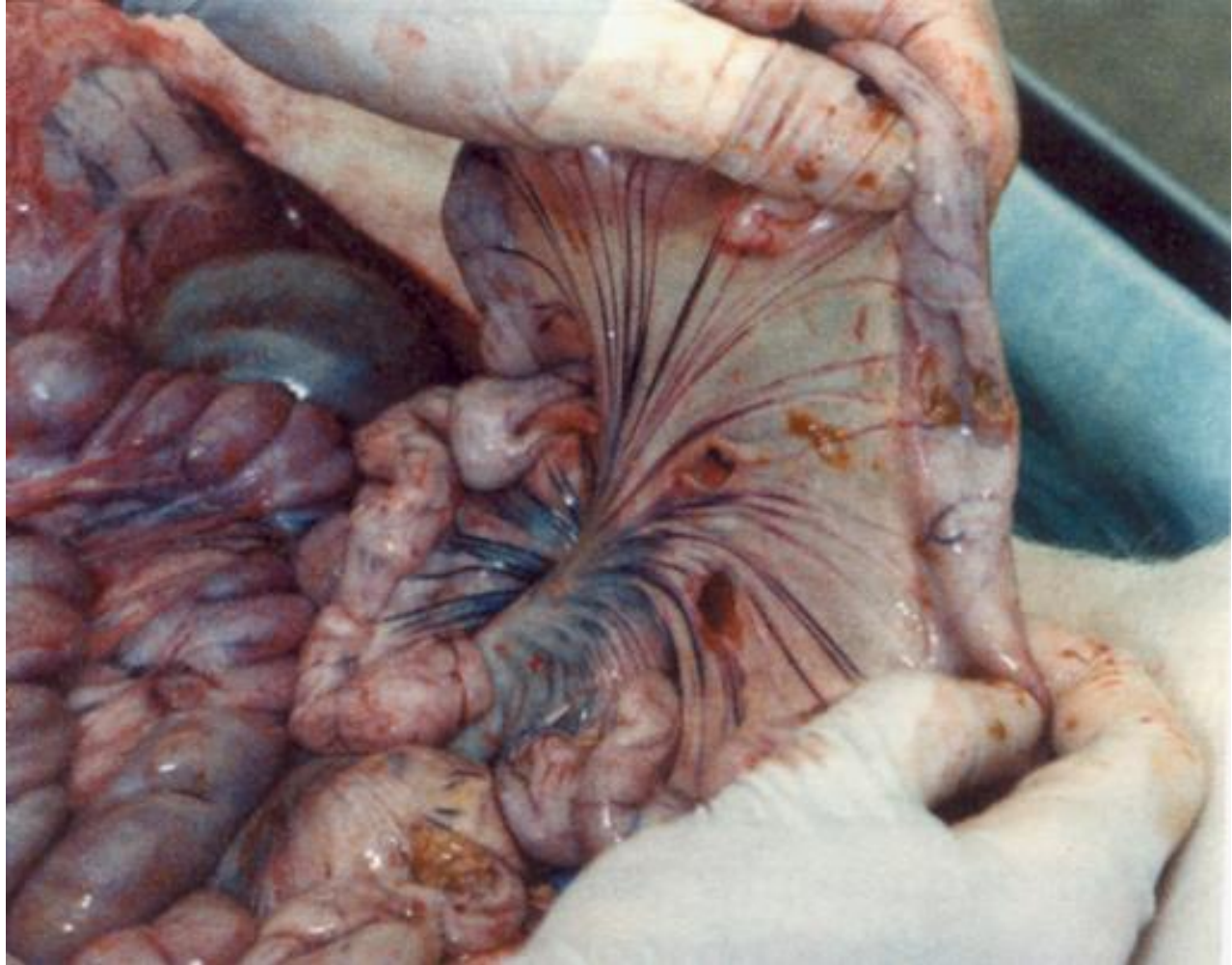
Blast Injuries: Abdomen

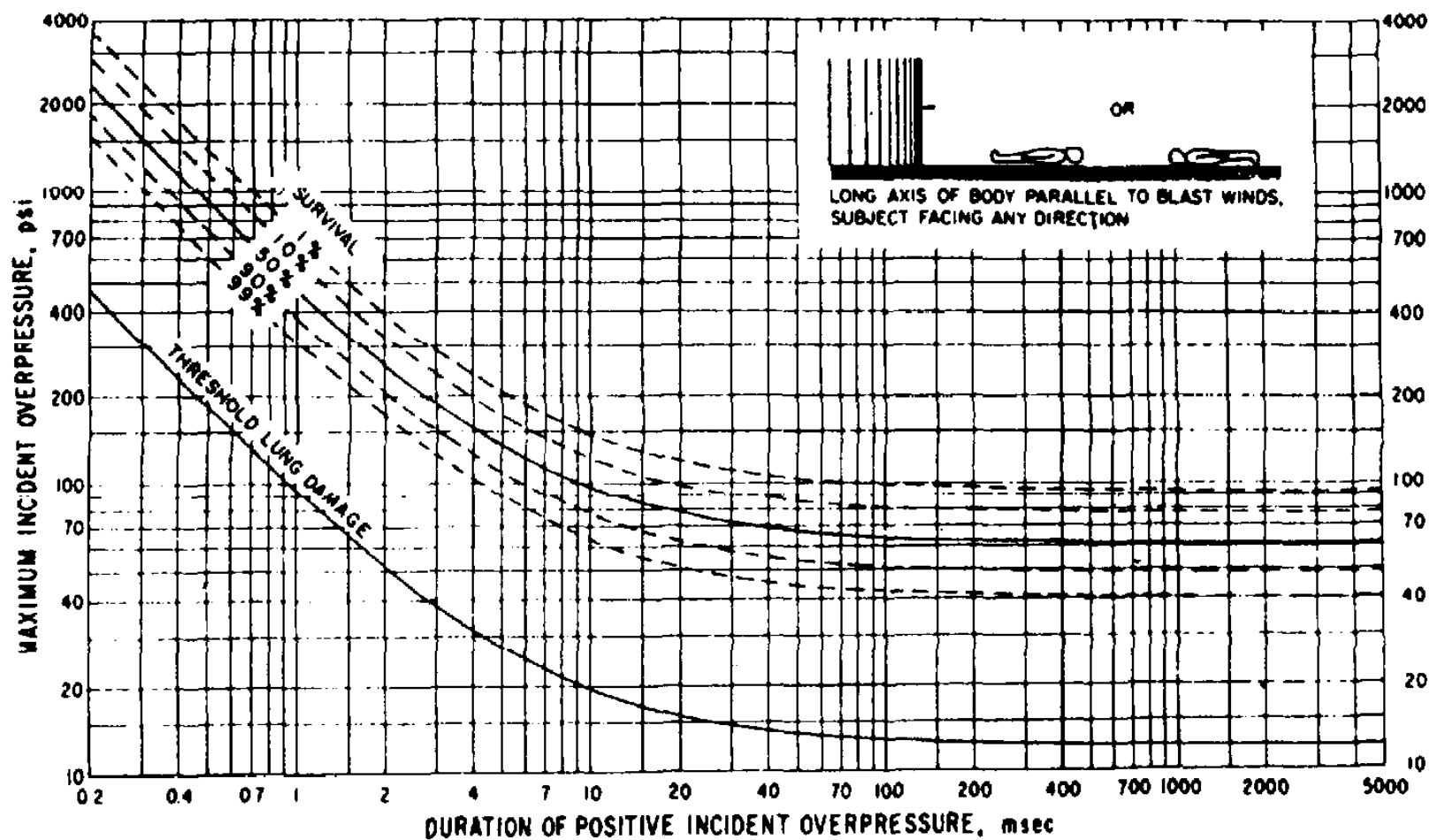
- Abdominal injuries (also called blast abdomen) include abdominal hemorrhage and abdominal organ perforation

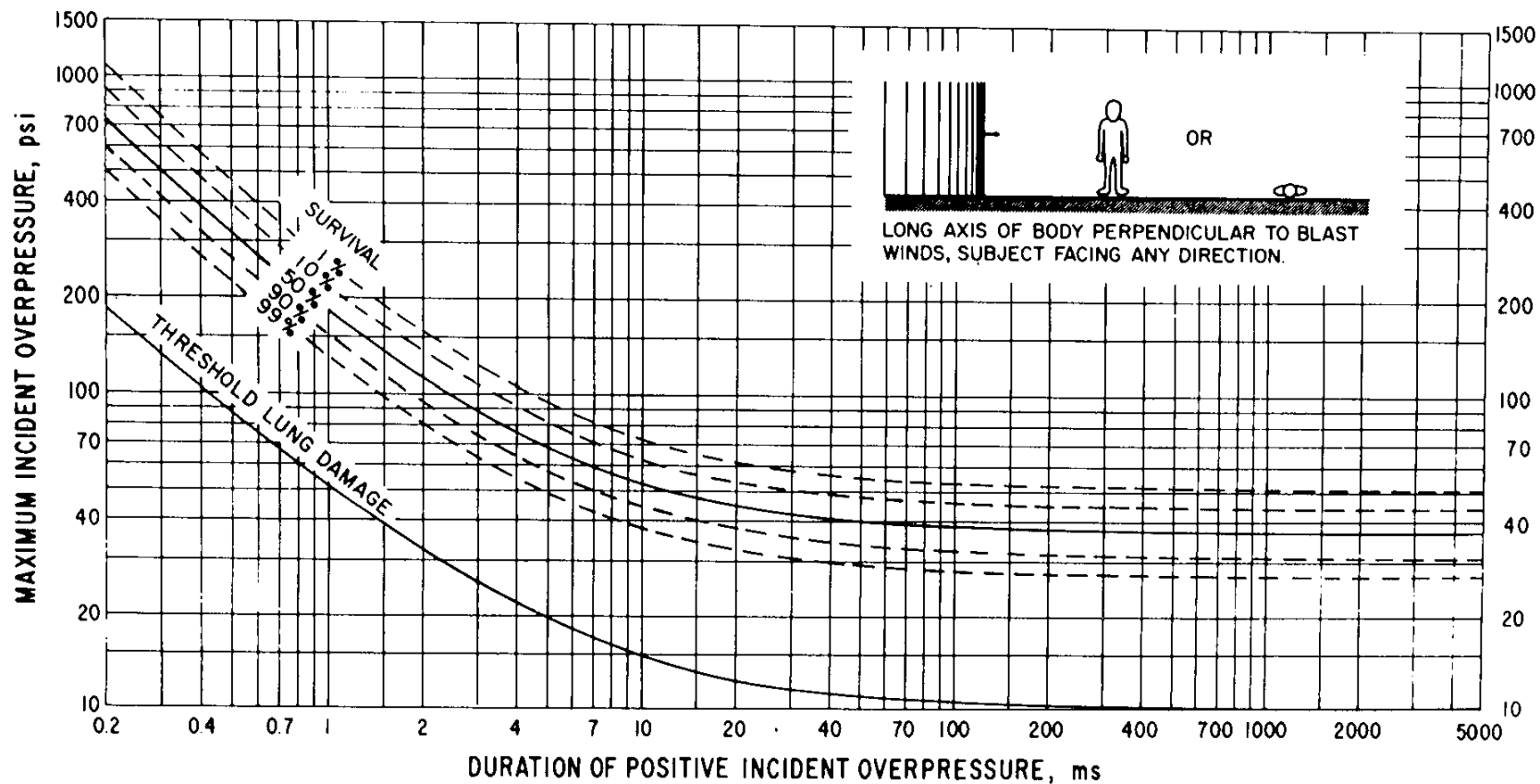
Primary Blast Injury

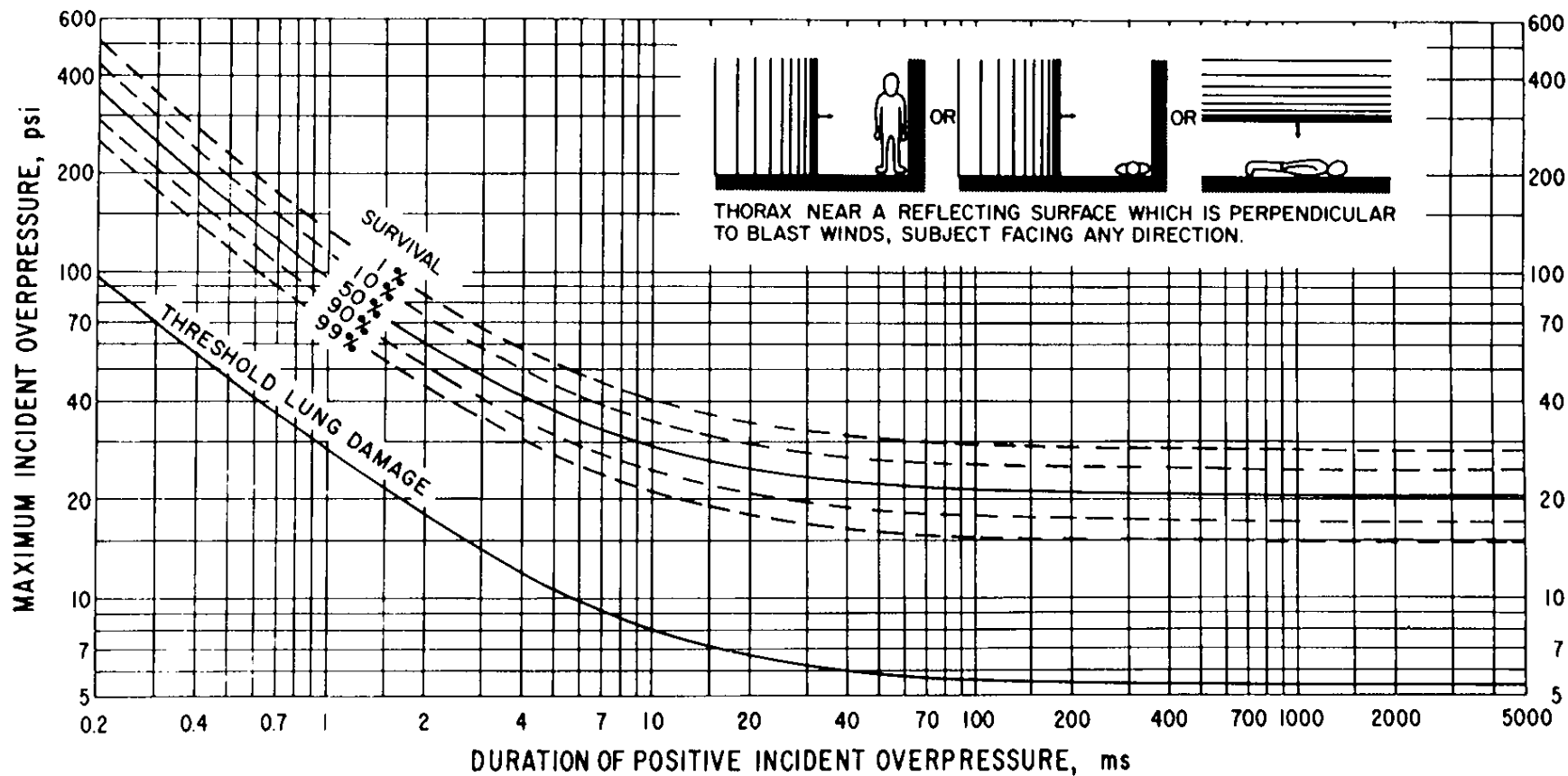
- Abdominal injury
 - Mesenteric shearing & perforated viscus, solid organ lacerations, testicular rupture
 - Abdo pain, nausea, vomiting, haematemesis, tenesmus, testicular pain, unexplained hypovolemia, signs of an acute abdo











Suicide bombings

Israel Experience

Nov 2000 to May 2003

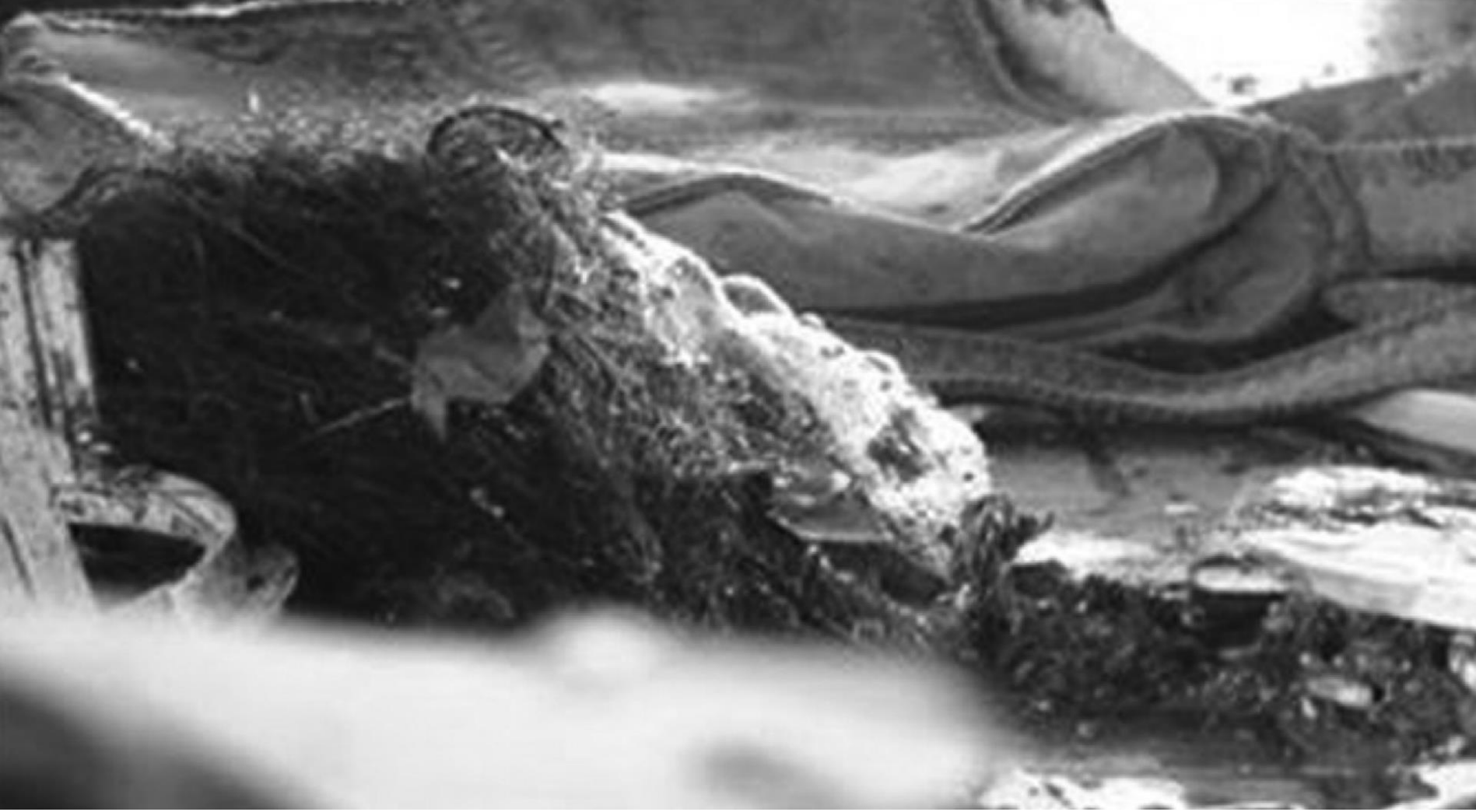
Open Space - 15 % mortality

Semi-confined space (*restaurants, cafes*)

Confined space (*buses*) - 40 % mortality

Place of Explosion

	Open Space %	Enclosed Space %
Mortality	2.8	15.8
ISS>15	6.8	11.0
Multiple Injury	4.7	11.1
Surgery Required	13.5	17.6
ICU Required	5.3	13.0



October 4, 2003, Hanadi Jaradat, a 29 year old attorney, walked into Maxim's, a Haifa restaurant with 80 diners and blew herself up, killing 21 Israelis and wounding 60 others. Among the victims were two entire families, including four children, one a two-month-old baby. The front portion of her head had been separated from her torso. The upper portion of her body was shattered and her legs were cut off below the pelvis.



Female suicide bomber, Zaynab Abu Salem, after she blew herself up at the French Hill intersection in Jerusalem on September 22, 2004. Two people are killed and fifteen injured in the attack. The blast is targeted at the large number of civilians at the station at the time of attack.

	Total Victims	Average Age	Age Ranges	Admitted to Hospitals (%)	Mortality (%)
OA	204	20 years	3–82 years	73 (36)	15 (7.8)
CS	93	31 years	16–69 years	40 (43) ^a	46 (49.5)
^a $p < 0.0001$.					

Blast Injuries: Bus Versus Open-Air Bombings--A Comparative Study of Injuries in Survivors of Open-Air Versus Confined-Space Explosions.

Leibovici, Dan; Gofrit, Ofer; Stein, Michael; Shapira, Shmuel; Noga, Yossi; Heruti, Rafael; Shemer, Joshua

Journal of Trauma-Injury Infection & Critical Care. 41(6):1030-1035, December 1996.

Most of the victims of civilian bombings in Israel were slightly injured.

87% of bombing victims were slightly injured,
Only 10% severely injured?

28% of patients were admitted to the hospital and stayed an average of 16days.

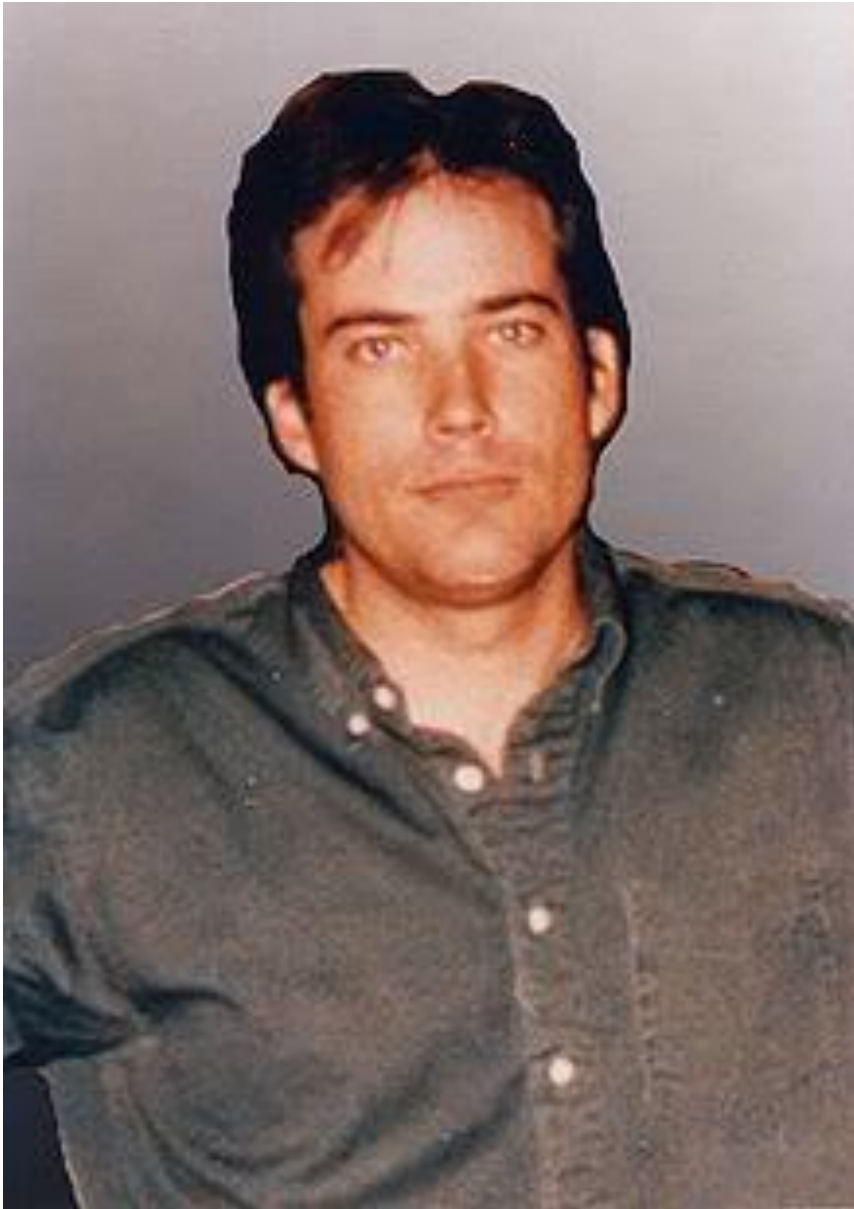
The in-hospital mortality rate was 2.3%.

Blast Injuries: Secondary

- The most common cause of death in a blast event is secondary blast injuries. These injuries are caused by flying debris generated by the explosion. Terrorists often add screws, nails, and other sharp objects to bombs to increase injuries.

"There is a bomb in Centennial Park. You have 30 minutes."





Rudolph planted a green U.S. military pack, containing three pipe bombs surrounded by nails, underneath a bench near the base of a concert sound tower.

The pack had a steel plate as a directional device, and could have done more damage, but it was slightly moved at some point

It was the largest pipe bomb in US history, weighing in excess of 40 lbs



Two dead and the 111 injured,
panicked revelers scattered in a spray of nails
and screws.

EXPLOS

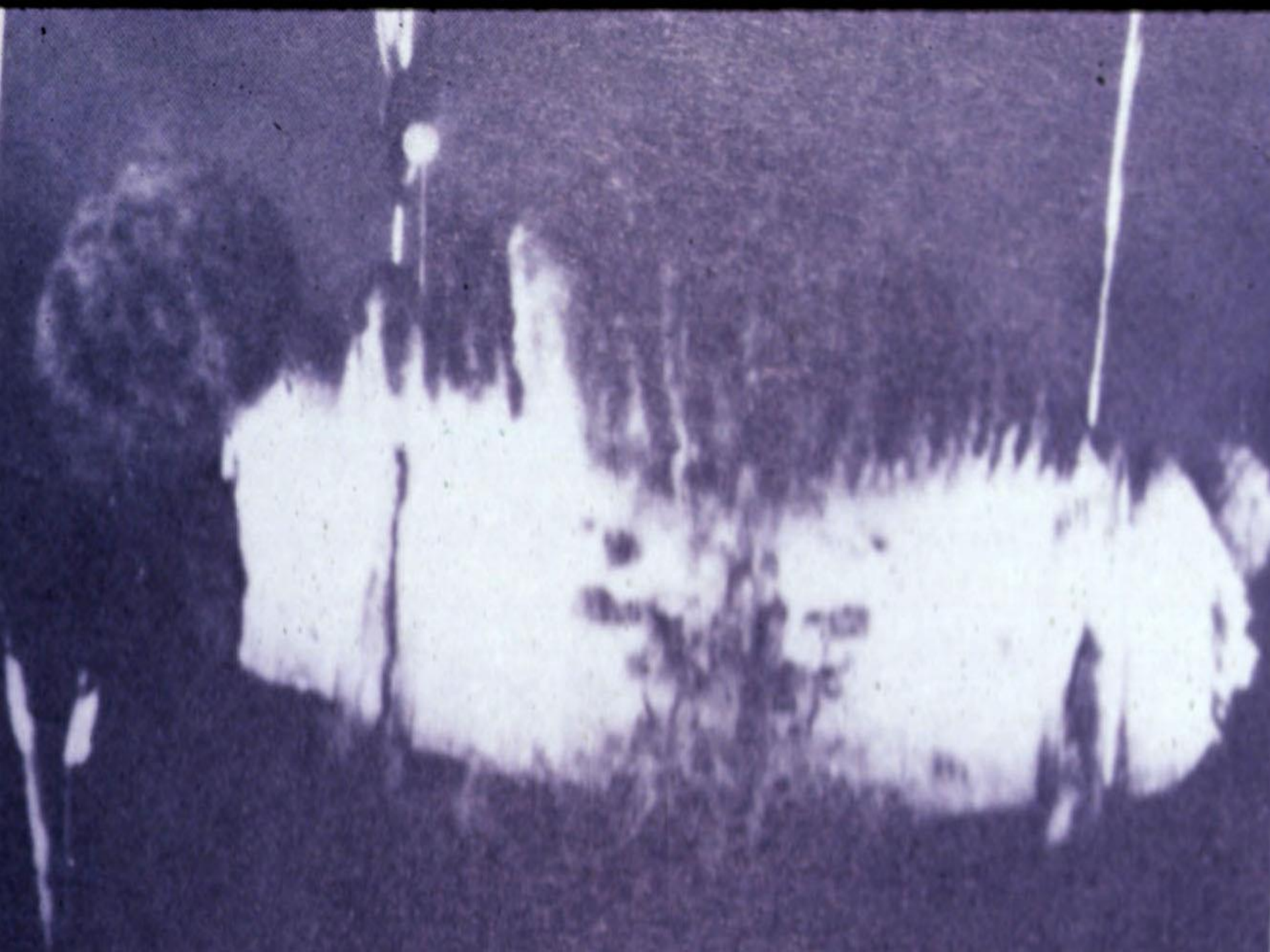
395-F

EXPLOSION

SCOT 4 101 POWER

395-F

39-
3357











Alice Hawthorne was killed by a nail that struck her in the head

Feds Eye Link In Atlanta Bombings

BY DEAN CHANG

Sunday, February 23, 1997

Another nail-studded bomb strikingly similar to ones that tore through Centennial Olympic Park last summer and an abortion clinic last month exploded inside one of Atlanta's best-known lesbian bars.

Five people were hurt in the Friday night blast, which authorities feared could be the work of a serial bomber.

A second bomb was found in a backpack outside the club, and may have been meant for emergency workers rushing to the scene.

"This is eerily reminiscent of last summer and last month," Atlanta Mayor Bill Campbell said at a press conference. "We truly believe we are dealing with a deranged killer, but one who is very clever as well."



Submit



Download

"Several customers thought a lady had been shot," bartender Rhonda Armstrong told the Associated Press. "She rolled her sleeve up and had a spike nail through her arm."

Atlanta Secondary Device

Initial
Explosion site

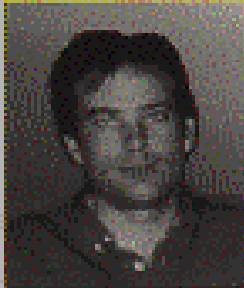
Command
Post

Location of
secondary
device



WANTED BY THE FBI

**MALICIOUSLY DAMAGED, BY MEANS OF AN
EXPLOSIVE DEVICE, A BUILDING AFFECTING
INTERSTATE COMMERCE IN WHICH A
DEATH RESULTED**



ERIC ROBERT RUDOLPH

Aliases: Bob Randolph, Robert Randolph, Bob Rudolph,
Eric Rudolph, Eric R. Rudolph

DESCRIPTION

Date of Birth: September 19, 1959; Place of Birth: Merritt Island, Florida;
Hair: Brown; Eyes: Blue; Height: 5' 11"; Complexion: Fair; Weight: 165-180
pounds; Sex: Male; Build: Medium; Race: White; Nationality: American; Scars
and Marks: Noticeable scar on chin.

CAUTION

ERIC ROBERT RUDOLPH IS CHARGED IN CONNECTION WITH THE
BOMBING OF AN ABORTION CLINIC IN BIRMINGHAM, ALABAMA, IN WHICH
A POLICE OFFICER WAS KILLED AND A NURSE CRITICALLY WOUNDED.
RUDOLPH IS KNOWN TO OWN AN AR-15 RIFLE.

CONSIDERED ARMED AND EXTREMELY DANGEROUS

REWARD

A REWARD OF UP TO \$1,000,000 IS BEING OFFERED FOR INFORMATION
LEADING DIRECTLY TO THE ARREST OF ERIC ROBERT RUDOLPH.

ADDITIONAL INFORMATION MAY BE FOUND ON THE FBI INTERNET PAGE:

<https://www.fbi.gov>

An abortion clinic in the
Atlanta suburb of Sandy
Springs on Jan. 16, 1997,

The Otherside Lounge in
Atlanta on Feb. 21, 1997,
injuring five,

An abortion clinic in
Birmingham, Alabama on
January 29, 1998, killing
part-time clinic security
guard Robert Sanderson,
and critically injuring nurse
Emily Lyons.

Blast Injuries: Secondary

- The most common types of secondary blast injuries are:
 - Trauma to the head, neck, chest, abdomen, and extremities in the form of penetrating and blunt trauma
 - Fractures
 - Traumatic amputations
 - Soft tissue injuries

Blast Injuries: Secondary

- Penetrating trauma (shrapnel wounds)
 - Foreign bodies follow unpredictable paths through body
 - May have only mild external signs
 - Have a low threshold for imaging studies (plain radiographs, computed tomograms)
 - Consider all wounds contaminated



These are some shells and bolts taken from bodies of victims at the Tel Aviv Discoteque terror attack which are deliberately put in bombs used to cause more casualties

- Pepper pot appearance of penetrating injury
 - Unable to predict depth or direction of fragments











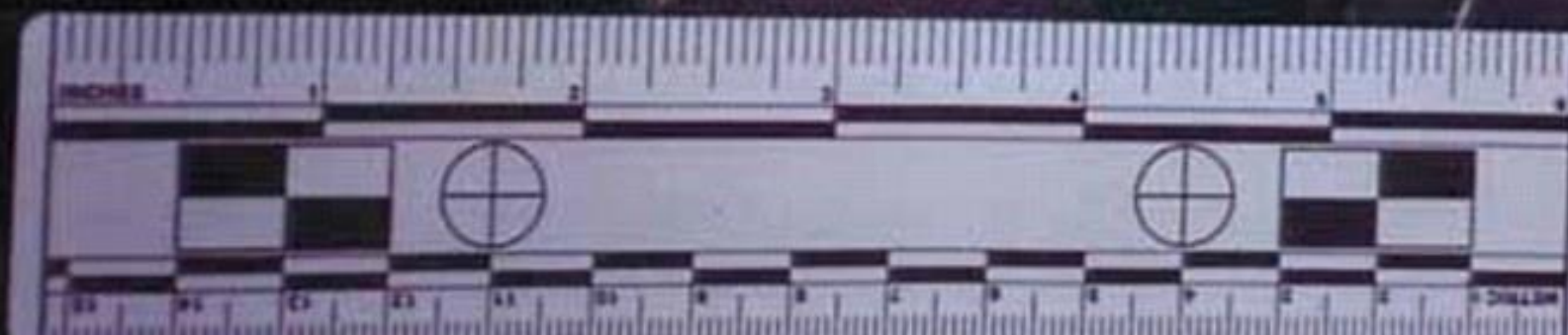
Blast Injuries: Secondary

- After the 1998 terrorist bombing of the US Embassy in Nairobi, flying glass wounded victims up to 2 kilometers away.
- For US Air Force personnel wounded in the Khobar Towers in 1996, 88% of patients were injured by flying glass.
- 8% of injured survivors of Oklahoma City sustained an eye injury, 29% of these were more than 100m from the blast.













FOX 5
DRUGS AND TRAFFIC



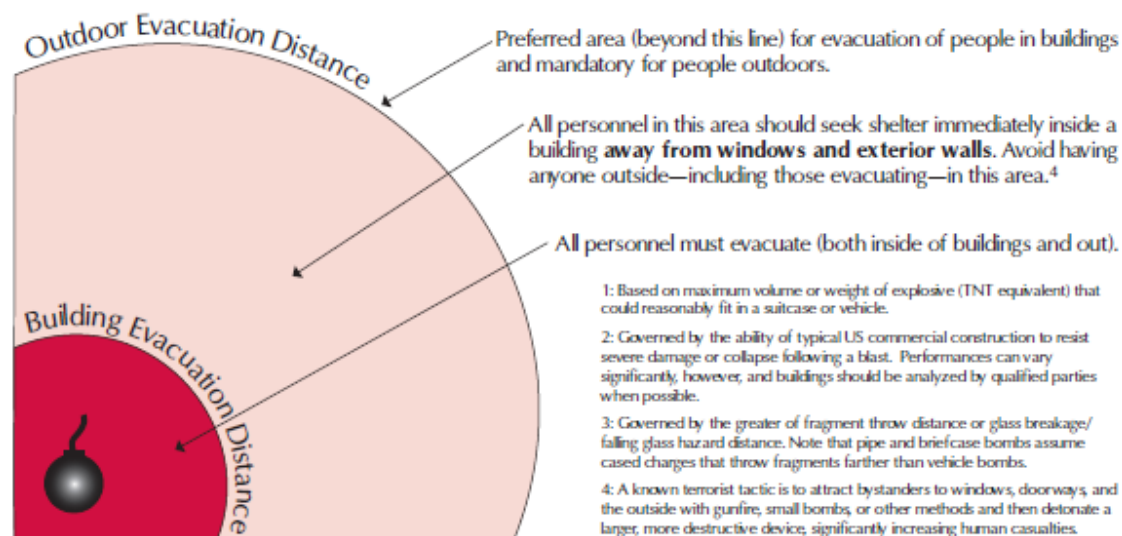




Bomb Threat Stand-Off Distances

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Blast Injuries: Tertiary

- Tertiary injuries result from individuals being thrown by the blast wind.
- The most common types of tertiary blast injuries are:
 - Head injuries
 - Skull fractures
 - Bone fractures
- Treatment for most tertiary blast injuries follows established protocols for that specific injury.

A person who is flung into a fortified immovable object with a velocity greater than 26 ft/sec will have a mortality rate of about 50%

Blast Injuries: Quaternary

- All explosion-related injuries, illnesses, or diseases not due to primary, secondary, or tertiary mechanisms are considered quaternary blast injuries. This includes exacerbation or complications of existing conditions.

Blast Injuries: Quaternary

- The most common quaternary blast injuries include:
 - Burns
 - Head injuries
 - Asthma
 - COPD
 - Other breathing problems
 - Angina
 - Hyperglycemia
 - Hypertension
 - Crush injuries







Blast Injuries: Quaternary

The unprotected human body can survive a blast with a peak overpressure of 30 psi, but buildings and other structures collapse with stress of only a few psi.

This means that people can survive the effects of a blast, only to be injured by collapsing buildings.

Ammonium Nitrate and Fuel Oil (ANFO)

- High Explosives favored homemade explosive
- Used in Oklahoma City, Bali (Sari Club), Oslo and Marriott Hotel (Jakarta)
- Common in car and truck bombs
- NH_4NO_3 has legitimate uses









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08:57:05 24

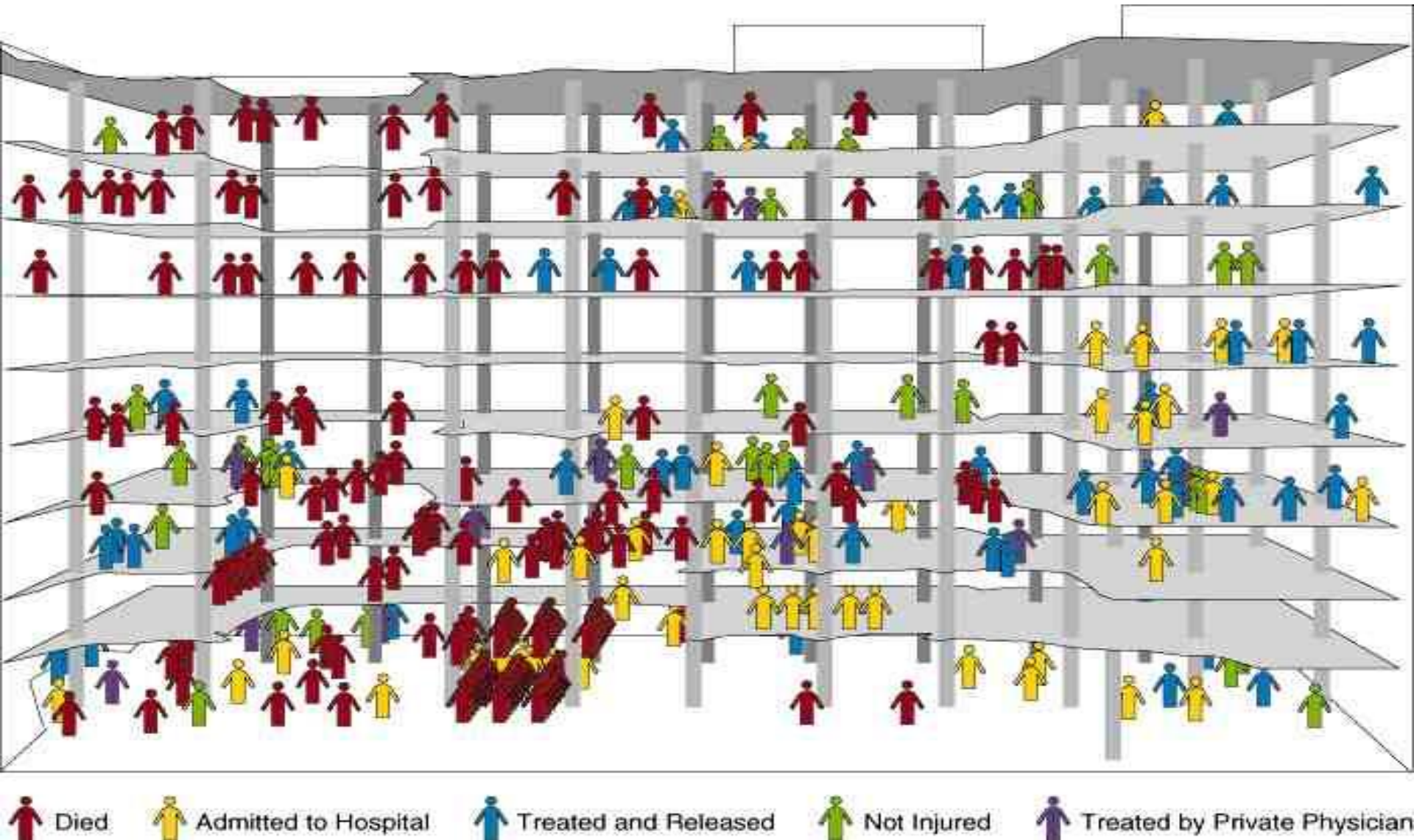
Oklahoma City Bombing







Murrah Federal Building, Oklahoma City (1993) – distribution of injuries





Bombings are broken down into 3 Categories:

- Immediate Structural Collapse
 - expect crush injuries, high fracture rates, and inhalation injuries.
- Confined Space Bombings
 - expect higher rate of pulmonary blast injuries, pneumothoraxes, blast lung, tympanic membrane ruptures, higher rate of burns, and higher rate of solid organ injuries.
- Open Air Bombings
 - increased rate of shrapnel or penetrating soft tissue injuries.
 - Most deaths will be immediate.
- ER deaths are statistically 1% or less.
- Usually the bottleneck in the ER will be the Chest Radiograph for screening of non critical victims.

Blast Injuries: Categories

- Primary injury
 - Caused by blast wave → over pressure
- Secondary injury
 - Caused by flying debris → shrapnel wounds
- Tertiary injury
 - Caused by blast wind → forceful impact
- Quaternary injury
 - Caused by other vectors → heat, radiation



Blast Injuries: Combined Injuries

- Combined injuries, especially blast and burn injury or blast and crush injury, are common during an explosive event.

Blast Injury: Combined Injuries

Typical confined space (e.g., a bus) injuries

- Primary—blast lung, intestinal rupture, TM rupture
- Secondary—penetrating injury to head, eye, chest, abdomen
- Tertiary—traumatic amputation, fractures to the face, pelvis, ribs, spine
- Quaternary— crush injuries, superficial and partial to full thickness burns

Blast Injuries: Combined Injuries

- Avoid tunnel vision during initial assessment
- Treatment protocols are often contradictory
 - Blast lung vs. burn injury, blast lung vs. crush injury
- Judicious fluid administration for adequate tissue perfusion without volume overload may be required in the multiple injured patient with blast lung
 - Presence of additional injuries complicates administration, rate, selection of fluids

- Whether a building collapses as the result of an explosion or as the result of an earthquake, its consequences and management are much the same.

Head Injury

- Head injury is the commonest cause of death
 - Madrid 52% of deceased victims had head injury
- Pathophysiology
 - Cerebral oedema, SAH & ICH, petechiae, air embolism, skull base penetration, metal & bone fragments in brain
 - Associated faciomaxillary injury, pharyngeal/laryngeal/oesophageal injury

Trauma

- Flying debris and violent impacts cause blunt and penetrating trauma
- Crush injuries and burns are similar to the same injuries caused by other mechanisms.
- Trauma not due to overpressure are very familiar to trauma care providers.

Extremities

- 60 – 70% of all injuries
- 1° may cause limb avulsion
- 2° penetrating injuries
 - Multiple, irregular in size & flight
 - Tumble, pitch & yaw cause tearing & ripping
 - Embedded debris
 - Associated crush & cavitation



Conditions associated with extremity wounds

- Maintain suspicion of compartment syndrome
- Injury to perineum/buttock/thigh may be intrabdominal also
- Haematoma or groin injury associated with vascular injury
- Small entry wounds can be associated with major injury
- Burns create an infection hazard



Figure 1 - Radiograph showing numerous penetrating injuries inflicted by spherical pellets on the patient's lower back, buttocks, and thighs.

Management of extremity wounds

- Prehospital
 - Catastrophic haemorrhage control – tourniquet, splint #, sterile dressings for open wounds
- Hospital
 - ATLS, careful inspection, document neurovascular injury, antibiotics & tetanus prophylaxis, expect imaging bottleneck
 - Some penetrating injuries can be safely left
 - Soft tissue only, no pleural/peritoneal injury, not infected/mine-related, no neurovascular injury
 - Clean & dress. DO NOT SUTURE
 - Surgery: debride, drain, skeletal stabilisation, delayed closure

Burns

- 10-15% of survivors of terrorist explosions have significant burns
- Associated major trauma greatly increases morbidity & mortality
- May present as “walking wounded”, and need re-triage preferably by burns specialist

Challenges

- Infection control

- Field care/ crowded treatment areas
- Unusual organisms
- Bone & tissue from other victims.

- Complications

- Blast lung & ARDS. Most survivors of BLI have good lung function after 1 yr
- Abdomen – delayed perforation, abdominal wall haematoma/ischaemia, abdominal compartment syndrome
- PTSD & acquired brain injury
- 1/3 of all TM ruptures have permanent hearing loss



Radiological Terrorism

The “Dirty Bomb”

CASE SCENARIO

A bomb explodes inside the lobby of the State Library at 9:00AM on a Tuesday.

Approximately 30 people are transported to area hospitals immediately with blast injuries.

At 9:45 AM the media reports that this was a “dirty bomb” and that individuals in the vicinity of the explosion should “seek medical attention.”

Dirty Bomb

- A radiation dispersion device, or RDD



- Conventional explosive device with radioactive material added
- Radioactive material spreads to surrounding area by physical dispersion and airborne diffusion

Dirty Bomb

- **Extent of contamination**
 - **Size and sophistication of the bomb**
 - **Type of radioactive material**
 - **Weather conditions**
- **Extent of human exposure**
 - **Speed of evacuation from contaminated area**

Dirty Bomb

- Threat of fear and disruption
- Panic over radiation exposure
 - Produce additional casualties
 - Disrupt rescue and evacuation efforts
- Disruption arises from area remaining off-limits and unusable during clean-up work



Dirty Bomb

- **Most likely to be used:**
 - cobalt-60,
 - strontium-90,
 - cesium-137, and
 - americium-241
- **Obtained from military, medical, industrial, academic or research sources**
 - **Examples:**
 - Cobalt-60 : food and mail irradiation
 - Americium-241 : smoke detectors



Dirty Bomb

- Major health risks include
 - Acute blast trauma
 - Cancer
 - Specific target organ damage
 - Heavy metal poisoning
- A non-linear, threshold model of exposure is favored by health physicists

Dirty Bomb

- **Primary contaminants: alpha and gamma emitters**
- **Shoe and clothing removal will reduce contamination by 90%**
- **Other external contaminants are particulates that can be washed off the skin and hair**
- **Internal contaminants pose no secondary threat to healthcare workers**



Fire, law enforcement, medical staff and local industries played roles in FEMA Region III's first CHER-CAP exercise in Bethlehem, Pennsylvania.

FEMA News Photo / Photo by Melissa Post

Things to Consider with a Dirty Bomb

What might be long-term consequences of this attack?

- Dirty bomb attacks are not likely to produce a large number of immediate casualties beyond those associated with blast injury
- They are intended to promote fear of radiation among the population

Blast Injury: Severity

- Primary injury
 - Barotrauma to air filled structures / crushing or rupture of other organs
 - Eardrum rupture, blast lung, bowel perforations, cerebral contusion, etc
- Secondary injury
 - Penetrating injury from fragmentation & shrapnel
- Tertiary injury
 - Blunt trauma as a result of being thrown
- Quaternary injury
 - Burns, smoke inhalation, crush injuries

Blast Injury: Severity

- Nature of device – agent, amount
- Method of delivery – incendiary, explosive
- Nature of environment – open, closed
- Distance from device
- Intervening protective barrier
- Other environmental hazards

Questions?



See Dick mix equal parts gasoline and frozen orange juice concentrate to make napalm. "We'll make them all pay" says Dick.

