Chapter

7

Ship Explosions: USS *Maine, SS Fort Stikine,* SS *Mont Blanc*

Combustion. Combustion is a chemical change, especially oxidization, accompanied by the production of heat and light. All forms of fire and explosion are subtypes of the larger term, combustion.

Fire. Fire is a rapid and persistent combustion that releases heat and light, especially the heat-releasing (exothermic) combination of a combustible substance with oxygen. Depending on the nature of the combustible substance and the availability of oxygen to the chemical reaction a fire can burn quickly or slowly.

Deflagration. A deflagration is a fire in which a highly combustible substance burns very rapidly and produces exceptionally great heat and light, but without generating a high pressure wave.

Explosion. An explosion is type of combustion characterized by a sudden, rapid and violent release of mechanical, chemical, or nuclear energy from a confined region; especially, such a release that generates a radially propagating high pressure shock or blast wave accompanied by a loud, sharp report, flying debris, heat, light, and fire.

High explosives. High explosives (HE) are used in military ordinance, blasting and mining. High explosives have a very high rate of reaction, high pressure development, and a detonation wave that moves faster than the speed of sound (1,400 to 9,000 meters per second). High explosives include "primary explosives" (e.g., nitroglycerin) that can detonate with little or no stimulus or shock and "secondary explosives" (e.g., dynamite, TNT), that require a strong stimulus or shock provided by a detonator such as a blasting cap. High explosives detonate "high order."

Low explosives. Low explosives change into gases by burning or combustion. These are characterized by deflagration and do not generating a high pressure wave. Low explosives are characterized by a lower reaction rate than high explosives. Low explosives (gun powder is the only common example) produce a range of reactions from deflagration to a "low order" detonation, in which the detonation wave generally moves slower than 2,000 meters per second.

Fireships. Ships-of-war, commercial ships, pleasure ships and pleasure craft have been liable and subject to damage and destruction by fire since the beginning. One of the first boatmen paddling a primitive bundle of floating reeds who set out to cross water while carrying live coals from his breakfast fire was certainly the first man to have his boat burn out from under him. In warfare, long before the invention and development of chemical high explosives and gunnery projectiles, fire had been employed as an instrument of naval combat. The fireship has been used from the very beginning of directed naval combat. A boat specific or adapted to the purpose would be laden with combustible materials including barrels of tar and oil, oil-soaked sail canvas and masses of rope, and ignited. Towed by a sailing ship or a crew of oarsmen in a longboat, or propelled unmanned by current or wind, the burning fireship would get alongside an enemy combatant with the intent to set it ablaze.

One exemplary use of a fireship in naval combat was observed and reported by an eyewitness to a naval battle between the Greeks and Turks at the beginning of the Greek War of Independence, 1821-32. The Greek rebellion within the Ottoman Empire was a struggle which resulted in the establishment of an independent kingdom of Greece, but the Greeks were actually waging a holy war because it was not simply Greek against Turk but Christian (Greeks) against Muslim (Turks). The Greek cause was saved by the intervention of the European powers, with U.S. encouragement, who favored the formation of an autonomous Greek state. On 20 October 1827, Great Britain, France and Russia sent their naval fleets to Navarino (now Pylos), where they destroyed the Egyptian fleet which was allied with the Ottoman Turks. Although this loss severely crippled the Ottoman forces, the war continued, complicated by the Russo-Turkish War, 1828-29. A Greco-Turkish settlement was finally determined by the London protocol of 3 February 1830 which declared Greece an independent monarchical state under European and Russian protection.

Ioannis D. Frangoudis, a Cypriot clerk on the Greek ship-of-war *Heracles* commanded by Captain Arargyros Hadji-Anargyros, provides a description of the destruction wrought by a fireship:

"About 4 o'clock in the morning of 27 May 1821 Captains Ghikas D. Tsoupas and Konstantinos Babas arrived. At this moment the wind being favorable, a north-west wind, Papanikolis' fireship put up the sign of battle. Then we attacked, together with a few ships from Spetsae [a small island in the Argosaronic Gulf of Greece], firing at the enemy fiercely and crying 'hurrah,' our cries echoing in the nearby mountains and valleys.

"To encourage the men in the fireship we went so deep into the enemy's fire that the shells of its cannons went through the shrouds of our own ship to hit the boats behind us. We finally saw our purpose succeeding, that is to say the fireship was secured to the enemy ship and the fire started spreading from the prow to the whole vessel. We all went mad with joy and ran about the deck crying loudly 'Great is the Lord,' shelling the burning boat incessantly. Meanwhile the enemy sent back a rain of bullets, propelled by the fire and intensified by the despair of the Turks, who were doing their best to chase us away so as to be able to jump into the sea and escape from the flames. Our men, exalted and full of courage, wanted to board the burning frigate, but our Captain wisely prevented them."

Spontaneous combustion.

Fire and explosion in a merchant ship's fuel or cargo, or among the munitions of a warship, does not require an active source of ignition. Spontaneous combustion is defined as the ignition and burning of a mass independently of contact with any burning body. One uniquely contemporary example of spontaneous combustion was detailed in a Federal Food and Drug Administration Public Health Advisory issued June 27, 1996: "Potential Risk of Spontaneous Combustion in Large Quantities of Patient Examination Gloves."

In the spring and summer of 1995, the spontaneous combustion of powder-free latex medical patient examination gloves caused fires in four areas of the U.S. The fires all occurred in warehouses and involved large quantities of non-sterile, powder-free, chlorinated latex gloves stored on pallets. Investigators ruled out arson and concluded that high warehouse temperatures accelerated an exothermic chemical reaction on the chlorinated gloves to the point where the latex ignited. The same gloves in substantial quantity carried as cargo in the poorly ventilated confinement of a ship's cargo holds and subject to the intense summer heat of the Tropics would offer a serious threat of spontaneous combustion and consequent fire hazard to the ship and crew.

Innumerable ships and sailors have been and will be lost consequent to the spontaneous combustion of ships' cargoes. Spontaneous combustion in the sweltering cargo holds of the sailing ships that transported the prodigious tonnages of coal that fueled the Industrial Revolution was a frequent cause of disaster among those colliers. When the world's sail-driven commercial and naval fleets were superceded by coal-fired steam engine propelled ships, spontaneous combustion in those ships' coal fuel bunkers was similarly hazardous.

USS Maine, 15 February 1898.

USS *Maine* was a 6,682 ton second-class battleship built at the New York Navy Yard and commissioned in September 1895. The precipitating cause of the Spanish-American War (21 April-13 August 1898) was the explosion and sinking of the *Maine* in the harbor of Havana, Cuba, at 9:40 the evening of 15 February 1898. More than five tons of powder charges for the battleship's six- and ten-inch guns exploded, virtually obliterating the forward third of the ship; 260 American servicemen were killed in the explosion. Debate has continued for 100 years whether the *Maine* explosion was caused by spontaneous combustion and undetected fire in the battleship's coal bunker, the heat of which detonated the ship's adjacent forward powder magazine, or if the detonation of a naval mine placed against the ship's hull by unknown saboteurs had caused the magazine to explode.

USS *Maine*, circa 1895-1898

Sensational and inflammatory newspaper reports of the incident, in which the Hearst and Pulitzer newspapers took the active lead, provoked public opinion in hostility toward the government of Spain, which then controlled Cuba and other of the Caribbean islands, as well as the Philippine Islands in the Pacific. In the Caribbean, U.S. opinion and policy generally favored the objectives of a homegrown Cuban insurrection which at that time sought to expel the Spanish governor and Spanish military from Cuba to permit establishment of local sovereignty. An exceptionally grotesque and repressive Spanish administration had by that time resulted in the starvation and death of 100,000 Cubans. Many U.S. citizens were morally outraged; but establishment of local sovereignty in the Caribbean was also anticipated to be favorable to U.S. political influence and economic interests in Cuba, which the Spanish had resisted.

A four-week Board of Inquiry investigation by the U.S. Navy Department concluded that a mine had been detonated under the ship, but the board did not attempt to determine how or by whom that mine had been placed. The newspapers' warmongering diatribes insinuated that agents of the Spanish government had placed the mine that, when detonated in an act of sabotage, triggered the catastrophic explosion of the ship's gunpowder stores. On 21 April, President William McKinley ordered the Navy to begin a blockade of Cuba; Spain followed with a declaration of war on 23 April 1898. Congress responded with a formal declaration of war on 25 April, retroactive to the start of the blockade. But Spain, in 1898, was politically, economically and militarily unable to mount a significant war effort.

On 1 May, Assistant Secretary of the Navy Theodore Roosevelt directed Commodore George Dewey to take his Pacific Squadron of six ships to the Spanish-controlled Philippine Islands area to engage the Spanish Pacific fleet, which Dewey surprised at anchor in Manila Harbor. During a 7-hour attack, remembered as the Battle of Manila Bay, Dewey's squadron sank all ten ships of the Spanish fleet. None of the ships of Dewey's squadron was disabled and only eight U.S. sailors were wounded, while 381 of the Spanish navy and marines were killed. The Spanish were defeated in the Spanish-American War, and the U.S. moved to the status of a world power in the Pacific and Caribbean areas—probably because of an explosion aboard the USS *Maine* caused by spontaneous combustion in a coalbunker.

In 1911 a second Navy Board of Inquiry confirmed the 1898 board finding that a mine had been the precipitating cause of the explosion, but technical experts at the time of the investigations disagreed with both boards' findings and advocated that spontaneous combustion of coal in the bunker adjacent to the forward reserve powder magazine was the most likely cause of the explosion of the *Maine*. In 1976 U.S. Navy Admiral Hyman G. Rickover published his book *How The Battleship Maine Was Destroyed.* The admiral engaged two experts on explosions and their effects on ship hulls who concluded that the damage caused to the ship was not consistent with the external explosion of a mine. The most likely cause, they speculated, was spontaneous combustion of coal in the bunker next to the forward reserve powder magazine, that the intense heat of an undetected coal fire, transferred through the separating bulkhead, had detonated the powder magazine.

Because of the historical importance of the sinking of the USS *Maine* as the precipitating event of the Spanish-American War, the cause of the explosion will likely be debated another hundred years. Most recently, in 1996-97, the National Geographic Society underwrote another comprehensive study that employed computer-modeling to attempt to resolve the cause of the explosion. That study was reported in the February 1998 issue of *National Geographic Magazine* and abstracted by the historian Thomas B. Allen in the January 1999 issue of the United States Naval Institute periodical, *Naval History*.

SS Fort Stikine, 14 April 1944.

The most detailed and engaging account of the Friday 14 April 1944 explosion of the merchant munitions ship SS *Fort Stikine* in Bombay harbor was written by John Ennis: *The Great Bombay Explosion*, published 1959 in England (Cassell) and New York (Duell, Sloan and Pearce). The book has been out of print for 40 years but is one of the core masterpieces of the particular variety of historical narrative literature that engagingly and factually recount enormously destructive ship explosions, books that are based in comprehensive documentary research, that draw extensively from contemporary newspaper accounts and many personal interviews conducted by the authors with individuals who were participant in the event and survived, eyewitnesses of all sorts, and others affected in different ways by the event.

SS *Fort Stikine,* North Sands Class freighter.

SS *Fort Stikine* was a coal burner of 7,130 tons, 441 feet of length and carrying 1,395 tons of wartime munitions. Cause of the explosion was spontaneous combustion among 9,000 bales of cotton, loaded at Karachi, that were a part of her cargo. Of fringe interest, *Fort Stikine* carried among her cargo 124 gold bars each weighing 28 pounds, valued in total at two million Pounds Sterling ($1,821,000). The gold had been shipped from London to stabilize the Indian currency, the Rupee, then sagging in value because of wartime economic disruptions and fear of an invasion of India from Japan. The ship explosion blasted those gold bars throughout the immediate area onshore and into the harbor waters. Most of the gold bars are reported to have been quickly recovered from different parts of the city, but during the 1970s two of the gold bars were recovered during normal harbor dredging operations and returned to the British government.

In 1944 India was still a fairly content British colony, and India provided courageous, well trained and well disciplined troops to the Allied cause and many valuable military bases, war materiel, and supply services. Bombay, India's principal seaport, was the clearing-house, distribution center and storehouse of war materiel that supported the China-Burma-India (CBI) Theater of Operations. The closing of the Burma Road left only one route open to supply Chinese and American troops fighting the Japanese on the Chinese mainland: the exceptionally hazardous air route maintained by the U.S. Army Air Corps flying from India's Assam Valley over "The Hump" of the Himalaya Mountains into China.

Fort Stikine was one of 90 Canadian-built wartime cargo vessels of the North Sands Class that were very similar to the U.S.-built Liberty ships; *Fort Stikine* was built and launched July 1942 at Prince Rupert Drydock & Shipyard, Prince Rupert, British Columbia, Dominion of Canada, purchased by the U.S. War Shipping Administration and transferred to British operation and ownership. The ship's principal cargo was wartime munitions, but before coming into the Victoria Docks at Bombay she had made a number of port calls along the Indian Ocean coast to take on whatever additional cargo the crew could manage to squeeze into her holds and onto her deck. At Karachi she took on the cotton bales that would ultimately destroy 18 ships and a large part of Bombay.

Prior to shipment loose ginned cotton is compacted into bales under high pressure to reduce the volume of the shipment. Extreme tropical heat and humidity in the poorly ventilated cargo hold that contained the cotton bales raised the temperature at one or more places in the cotton cargo to the point of spontaneous combustion, which process was encouraged by the pressure within the compacted cotton bales; that compaction augmented the absorption and retention of heat. The ship had come to dock before the first wisps of smoke from the smoldering cotton were noticed rising from the ventilators. A red flag signifying an explosive cargo had not been raised on the ship's mast so the potential for disaster presented by fire aboard the *Fort Stikine* was not recognized. For awhile before the municipal fire brigade was summoned, the crew with limited equipment tried unsuccessfully to extinguish the fire.

Flames were beginning to appear from the No. 2 cargo hold when the first municipal fire brigade and equipment arrived. More firefighters and equipment were called until even the most antiquated pumpers had been hauled to the docks and every available firefighter was at the scene. An hour and a quarter after the first fire brigade arrived, the forward section of the ship's hull, which contained the fire and 611 tons of explosives, displayed a bright cherry-red glow. At 4:06 P.M. the forward section of the ship exploded killing hundreds of spectators, all the 66 gallant officers and men of the Bombay Fire Brigade, and destroying most of Bombay's firefighting equipment.

That disaster was bad enough, but that first explosion launched flaming cotton bales through the air to distances up to one mile from the explosion. In the areas surrounding the docks those flaming bales of cotton fell into and ignited the packing-case shacks and shanties of the Bombay slums, which had mostly been reduced to kindling wood by the first blast wave. Soon 300 acres (120 hectares) of docks, warehouses and most of the Bombay slums were in flames. No system of firefighting water hydrants had been laid in the slums and, anyway, all the city's firefighting equipment had been destroyed. The fires burned two days and two nights, until there was nothing left to burn. Thirty-four minutes after the forward section of the ship exploded, 784 tons of munitions in the burning aft section of the ship exploded.

Eighteen merchant ships in Bombay harbor were either sunk or severely damaged. The number of persons killed and injured by the two explosions is impossible to determine because the class of slum dwellers, the Untouchables in Indian society, who were most severely affected by the disaster, were uncounted. Estimates of the number believed to have been killed range between 336 and 1,376, but some writers assert the number killed was more likely 6,000. Five hundred persons are reported to have been hospitalized, but most of the impoverished residents of the Bombay slums who were injured in the explosion would not have sought medical treatment at public facilities; they were cared for by family and friends and most were not counted among the reported casualties.

A good eyewitness account of the *Fort Stikine* explosion by John Garside, 19 years old at the time, is available at the WWW link below. John, a British Royal Navy D.E.M.S. gunner aboard the SS *Fort Crevier*, another of the North Sands Class, watched the fire from 400 yards through binoculars and was knocked unconscious by the blast. Equivalent to the complement of U.S. Navy Armed Guard gunners aboard armed U.S. merchant ships during the war, British-flagged Defensively-Equipped Merchant Ships (D.E.M.S.) carried a complement of Royal Navy gunners. John remembers, “The blast picked me up and dropped me into an open coal bunker. When I came to and scrambled out on deck we had been on fire for some time.”

http://members.tripod.com/~merchantships/fortcrevier1.html

It is interesting to notice in John Ennis’ book *The Great Bombay Explosion* that the U.S. Army Corps of Engineers is credited for the many photographs reproduced there of the fires and devastation that resulted from the explosion. Army Corps of Engineers Major General Leslie R. Groves from 1942 was the military commandant of the Manhattan Project, and he would probably have learned those photos had been taken at Bombay by Corps photographers and obtained copies for the Manhattan Project. The 14 April 1944 Bombay explosion occurred 3 months before the Port Chicago explosion, but among the presently identified and declassified Port Chicago explosion documentary materials held by Los Alamos National Laboratory Archives no mention of the Bombay explosion is made. The photos of the firestorm that swept the Bombay docks and slums following the explosion of the *Fort Stikine* would have been a valuable preview of the firestorm that was anticipated to ravage any Japanese city that would be targeted for combat use of the atomic bombs. Manhattan Project scientists at Los Alamos had, however, thoroughly studied the available literature descriptive of effects of the World War I explosion of the ammunition ship *Mont Blanc* in the harbor of Halifax, Nova

Scotia, British Dominion of Canada. Most of North End Halifax was burned to the ground.

SS Mount Blanc, 6 December 1917.

The harbor at Halifax, Nova Scotia, on the Canadian Atlantic coast at approximately the latitude of Bangor, Maine, is an ice-free natural harbor, long and deep, lying on an axis roughly running to the northwest from the Atlantic harbor mouth. Entry is from the southeast through a strait, cleverly named The Narrows. When an inbound ship has cleared The Narrows, the town and maritime docks of Halifax are seen off the port bow on the south shore of Halifax Harbor. Off the starboard bow, opposite Halifax, lies the city of Dartmouth on the north shore of Halifax Harbor. Ships that will not immediately go to dock along the Halifax waterfront proceed several miles northwest through Halifax Harbor to anchorage in the much larger inner harbor, Bedford Basin.

In December 1917, during World War I, Halifax was the principal East Coast deepwater maritime Canadian port. Ships that had been loaded at the Halifax docks with supplies for the war in Europe, food, materiel, munitions and troops, gathered at anchorage in Bedford Basin to assemble the slow, wallowing convoys of 15 or more merchant ships that would somewhat be protected from German surface and submarine attack during the trans-Atlantic voyage by an escort of naval warships. Ships waiting to be loaded at Halifax also made anchor in Bedford Basin. Ships loaded with war materiel at the ports of New York City and Boston steamed north to Halifax to join the trans-Atlantic convoys forming there. Halifax harbor was a very busy port on 6 December 1917, and the civilian population of Halifax was very much increased because of the port's wartime employment; several thousand Canadian troops were stationed at Halifax in garrison or in barracks waiting transportation to the European war.

The French ship SS *Mont Blanc* had sailed from New York City to Halifax to join an assembling convoy but arrived 5 December after the antisubmarine nets closing Halifax Harbor at night had been raised, and she necessarily waited at anchorage to enter the harbor until 7:30 the morning of 6 December. *Mont Blanc* was a munitions carrier. Her cargo holds were lined with wood affixed to framing with copper nails, which could not spark if struck by steel, but an hour later when the *Mont Blanc* collided bows-on in the harbor with the Norwegian cargo ship in ballast, the SS *Imo,* although her bow was only moderately gashed, barrels of highly inflammable liquid benzene stored on her forward deck were ruptured, and the flow of benzene from those ruptured barrels was ignited by the spectacular cascading barrages of sparks generated as the ships' steel bows ground together. A raging fire that could not possibly be extinguished immediately engulfed the bow of the *Mont Blanc.*

Smoke cloud formed above the explosion of the SS *Mont Blanc.*

The captain, pilot and crew of the *Mont Blanc* knew the ship carried an explosive cargo of 200 tons of TNT, 10 tons of gun cotton, 25 tons of benzene, and 2,300 tons of picric acid. They expected the ship would explode immediately. They launched the ship's lifeboats, abandoned her, and rowed with all haste to the Dartmouth shore where they warned everyone they passed to take cover as they ran to refuge behind a low hill; all the crew of the *Mont Blanc* were saved except one of the crew who was fatally injured by one of the 3,000 tons of steel fragments of the ship blasted miles through the air when the ship exploded at 9:05 A.M., 20 minutes after she was abandoned. The massive smoke cloud formed above the explosion of the *Mont Blanc* is said to have risen one mile (5,280 feet).

Gun cotton (fulmicotton) dates from 1845 and is cotton fiber treated by immersion in a mixture of nitric and sulphuric acids, transformed into a paste and compressed. Gun cotton was primarily used during World War I as an artillery projectile propellant, but because it is corrosive and brisant the deterioration of gun barrels was rapid. Picric acid (trinitrophenol) is highly explosive and extremely heat, flame, shock, and friction sensitive. The high explosives lyddite and melinite are composed mostly of compressed or fused picric acid. Picric acid is often used as a booster to detonate a less sensitive explosive, such as TNT. Picric acid is toxic by all routes of entry, inhalation, ingestion and dermal, and reacts with metals to form metal picrates which are also highly explosive and toxic.

The captain, pilot and five members of the *Imo'*s crew were among the 1,900 persons immediately killed in the explosion, which also injured 9,000; hundreds later died of their injuries. The captain of the *Mont Blanc* had not ordered the red flag hoisted on the ship's mast, which would have signaled that the burning ship carried explosive cargo. The abandoned, flaming ship drifted to the Halifax piers, brushed one and set it afire before she came against Pier 6 and grounded. Members of the Halifax Fire Department responded and were positioning their pumper to the nearest hydrant when the *Mount Blanc* disintegrated.

Large crowds of sightseers had run from the downtown area to the docks to watch the spectacle; most were killed. On the slope of the hills that rise behind the waterfront, families gathered at their windows to watch the ship burn in the harbor below. The blast wave blew-in every window in North End Halifax. Thousands of the injured were lacerated by flying glass; 1,000 persons received severe eye injury; surgeons removed 250 eyes that could not be saved.

The blast wave flattened almost all buildings within an area of two square kilometers, converting the mostly wooden homes and structures to kindling wood; 1,630 homes were destroyed. Then the tidal wave from the explosion rushed ashore and many of the injured and uninjured in downtown Halifax were drowned. The water wave raced across the harbor to the Dartmouth shore, swamping and sinking ships and boats as it moved. On the Dartmouth shore the wave gained intensity as it funneled into Tufts Cove where it washed away the entire settlement of Micmac Indians encamped there. In Halifax, following the rain of steel fragments, many coal- and wood-burning stoves that were overturned and thrown around by the blast wave ignited the rubble of buildings collapsed by the blast wave and 325 acres of the city burned. That night a blizzard burdened the city's

View of the Halifax disaster, looking south, 6 December 1917

agony with 16 inches of snow; 6,000 persons were without shelter from the storm.

On the morning of the explosion when news of the disaster reached Boston, Massachusetts, the city immediately mobilized an extra-ordinary relief effort and rushed medical teams and medical supplies to Halifax, followed by ship- and trainloads of tents, food, clothing and bedding, and hundreds of volunteer construction workers with the materials and supplies necessary to begin reconstruction of the city. In continuing thanks, the citizens of Halifax every year send the towering Christmas tree that is mounted in Boston's Prudential Plaza.

Los Alamos documentary records: Comparison of the Halifax and Port Chicago explosions.

Captain William S. Parsons, USN: Memorandum of 24 July 1944.

Among the declassified Port Chicago explosion literature available in the Archives of Los Alamos National Laboratory, the first comparison of the Halifax and Port Chicago explosions was made by Navy Captain William S. Parsons in his memorandum of 24 July 1944, "Port Chicago Disaster: Preliminary Data." The memorandum was addressed and transmitted to Rear Admiral William R. Purnell, Navy member of the Government's 3-man Atomic Bomb Military Policy Committee:

"Comparing loss of life to the Halifax disaster, it appears that all but some five of the victims at Port Chicago were right on top of the explosion, in a position corresponding to some 25 crew members and fire fighters at Halifax. Thus, in comparison for remote victims is Halifax about 1,475, Port Chicago less than 5. If the two explosions are considered to be of the same order of magnitude, the difference in loss of life can be attributed to the fact that Port Chicago was designed for large explosions."

Ensign George T. Reynolds, USNR: Analyses of structural damage from the Halifax and Port Chicago explosions; discussion of seismic effects of the Halifax explosion.

A more comprehensive comparison of the 6 December 1917 Halifax explosion with the 17 July 1944 Port Chicago Naval Magazine explosion was prepared by Los Alamos scientist Ensign George T. Reynolds, USNR, and transmitted by Capt. Parsons from Los Alamos 31 August 1944 to Adm. Purnell of the Atomic Bomb Military Policy Committee; Adm. Purnell was Capt. Parsons' commanding officer. Captain Parsons was Ens. Reynolds' commanding officer.

Ensign Reynolds' two-page comparison of the explosions reproduced here is Section IV of the body of his report, "Port Chicago: Analysis of damage due to air blast and earth shock," which is Enclosure D of Capt. Parsons' 31 August 1944 memorandum to Admiral Purnell, "Port Chicago Disaster: Third Preliminary Report."

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IV. Comparison with Halifax. The cargo of the Mont Blanc involved in the Halifax disaster was as follows:

1) 2,114,000 kg. picric acid, wet and dry.
2) 204,000 kg. TNT
3) 56,000 kg. guncotton

The heat of explosion for these various components are approximately:

Picric acid	870 calories per gram
TNT	750 " " "
Gun Cotton	1000 " " "

The equivalent TNT involved was then approximately:

$$\frac{(2.11 \times 8.7 + .204 \times 7.5 + .56)\ 10^{11}}{454 \times 2000 \times 750} = \frac{20.5 \times 10^3}{4.54 \times 2 \times .75}$$

$$\doteq 3000 \text{ tons.}$$

The actual load of combined explosives was 2620 tons. Since it is believed that some of the picrid acid burned before the explosion, and some of the explosive sank without detonating, the figure 2800 tons will be considered as the load of the ship. The most reliable eyewitness report of the Halifax disaster available at present is due to H.L. Bronson in his report to The Royal Society of Canada in 1918. In addition there is also available a map of the city showing zones of destruction. This was made available through the Dept. of Munitions and Supply, Montreal, Canada, and was prepared by Fire Marshall of Nova Scotia and the Nova Scotia Board of Fire Underwriters. The map includes the boundaries of "an inner area of devastation, and an area of total destruction or very severe structural damage." In the area of very severe structural damage may be pictured blocks or buildings destroyed (collapsed or destroyed by fire) but surrounded by others which escaped comparatively lightly". Outside of the latter area there is a zone of buildings "damaged more or less by breakage of glass, plaster, and interior finish". In the light of this, and in the absence of more detailed description the best procedure is to accept the inner area of devastation as the area of A damage, and the area of total destruction or severe structural damage as the area of 90% B damage. These areas are roughly in the form of rectangles with sides parallel to the northwest and northeast directions. The following are the approximate distances to which the zones of damage extended into the city in various directions :

A damage:	Northwest	2500 ft.
	West	2700 ft.
	Southwest	2000 ft.
	Southeast	2000 ft.
	South	2300 ft.
B damage:	Northwest	2800 ft.
	West	4400 ft.
	Southwest	4800 ft.
	Southeast	3800 ft.
	South	5400 ft.

In the B damage, the long radius to the south was apparently due to the presence of the Nova Scotia Car Works with large wooden sheds from a distance of 5400 ft. The southwest direction included car shops and exhibition grounds for a distance of 3900 ft. on. The average value for the B damage radius from these data is taken as approximately 4000 ft.

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In general it can be said that Bronsons report and the available maps are very consistent. In his report, the statement is made that: " In a general way, it can be said that buildings within a radius of half a mile of the explosion were totally destroyed and that up to one mile they were very largely rendered uninhabitable and dangerous".

In comparison to the Port Chicago explosion, the Halifax disaster was no more effective in destruction that was to be expected when due consideration is given to the larger charge, more densely populated region exposed, this region not being designed to serve as a magazine, and the topography. It is estimated that the slope of the shore at Halifax is about 5 degrees at the scene of the explosion. This had two effects tending to increase the amount of damage caused.

1) The houses up the hill were not effectively shielded by those near the water front.
2) The angle of slope tended to increase the pressure by reflection. Work on small charges investigating the effect of angle of reflection on reflected pressures will be described in a forthcoming NDRC report. This work indicates that on a 5° slope, the reflected pressure is 1.9 psi when the incident pressure is 1.5 psi, and is 3.2 psi when the incident pressure is 2.5 psi. If then, on the basis of the Port Chicago discussion above, 2.5 psi is taken as the B damage criterion, it appears that this will occur at distances up the hill at which the hydrostatic pressure would normally be 2 psi. Taking 4000 ft. as the 90% B radius, the charge weight is given as 3400 tons. It is felt that, considering the larger charge, the sloping hill with its increasing effect on pressure and decreasing effect on shielding, and the weak construction of the homes in the region hardest hit, the Halifax and Port Chicago effects are not inconsistent. The sense of disaster was undoubtedly enhanced in the Halifax case by the fact there were so many structures very near, so many people exposed to serious injury and so much disaster brought on by the fire and severe weather which followed. Bronson reports that a barograph record at a distance of 9900 ft. from the explosion showed a pressure of at least .62 psi and might have gone off scale. At this distance .62 psi is to be expected from a charge of 2100 tons.

There are several isolated facts which serve to tie the two incidents together. The greatest distances at which fragments were found at Halifax were reported as 3 - 4 miles. In the Port Chicago case, these distances were 2 - 3 miles. Across the water from Halifax at a distance of 1/2 mile, trees were reported to have blown over. At Port Chicago, telegraph poles a distance of 1/4 mile over land (instead of water) with less area offered to blast (no branches) were tilted away from the explosion at angles of the order of 45°. The formula $d = .18\sqrt[3]{T}$ quoted above when applied to Halifax assuming $T = 2800$ tons gives 9.5 - 10 miles, which is reasonable according to Bronson. At Halifax, "considerable" glass breakage was reported at distances up to 10 miles. The figure for Port Chicago is about 6 - 7 miles.

Concerning earth shock at Halifax, Bronson states the following, which is consistent with the other discussions available: "All evidence points to the fact that the air was the principal factor in the transfer of this energy (from the explosive). Within a radius of 4 or 5 miles the earth wave was distinctly felt and was followed by the concussion of the air which caused all the damage. The experience of the writer (Bronson) confirms this point and indicates in a rough way the relative magnitudes of the earth and air shock. At the time of the explosion I was standing in my laboratory on the second floor -- about 3500 meters from the explosion. I first felt a shaking of the building no greater than that caused by heavy blasting in the railroad cut, but it seemed directly under the building. ... (About 6 - 10 seconds later) the (air) crash came which completely destroyed the windows and sashes on 3 sides of the building, broke heavy doors and locks, and even shifted partitions. The comparatively slight earth shock can be explained by the fact that the explosion was practically on the water, even though the ship was touching ground."

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Ens. Reynolds' comparison of the Halifax and Port Chicago explosions categorizes structural damage with the terms A, B, and C damage. In Section I of his complete report of the Port Chicago damage due to air blast and earth shock, of which Section IV is his comparison of the

Halifax and Port Chicago explosions, Ens. Reynolds defines the parameters of A, B, and C damage.

A damage, means a building completely demolished.

B damage, means a building damaged beyond repair.

C damage, means a building temporarily uninhabitable, but repairable.

In discussion of the A, B, and C damage caused by the explosions at Halifax and Port Chicago, radius means the distance from the source of the explosion to points where 90 percent of typical buildings have experienced A, B, or C damage. Typical buildings are taken "as structures estimated to have the same resistance to damage as well constructed frame dwellings of American types." Considering damage at the Port Chicago Naval Magazine, but not damage in Port Chicago town, Ens. Reynolds notes that "some extrapolations and interpolations are necessary because of the nature of construction at the ammunition depot."

Ensign Reynolds calculates the energy of the Halifax explosion to have been equivalent to 2,800 tons of TNT. Captain Parsons in his 31 August memorandum to Adm. Purnell reports that blast damage from the Port Chicago explosion "was consistent with a high order detonation of 1,500 to 1,600 tons of TNT." The 2,800 tons charge weight of the Halifax explosion was 1,250 tons (80 percent) greater than the 1,500-1,600 tons TNT equivalent charge weight of the Port Chicago explosion. But as Capt. Parsons wrote to Adm. Purnell, the explosions should be considered to be "of the same order of magnitude." In scientific quantification an increase of one order of magnitude is the same as multiplying a quantity by 10.

If the Halifax explosion had been one order of magnitude greater than the Port Chicago explosion, rather than of the same order of magnitude, the charge weight of the Halifax explosion would have been 15,000-16,000 tons TNT equivalent, or 10 times the 1,500 to 1,600 tons TNT equivalent charge weight of the Port Chicago explosion. There is, however, a reality quirk about large explosions that will be discussed later: The physical effects of explosions involving a charge weight greater than 1,000 tons of TNT, or the nuclear equivalent, augment only by the cube root of the charge weight of explosive. To determine the physical effects of a 10,000-ton TNT equivalent atomic bomb the effects of a 1,000-ton bomb are multiplied, not by 10, but by 4.

For the Halifax explosion, Ens. Reynolds reported "the average value for the B damage radius . . . is taken as approximately 4,000 feet." For the Port Chicago explosion, Capt. Parsons reported in his 31 August memorandum to Adm. Purnell, "While no typical structures were near to the B-limit radius, estimates based on blast damage to freight cars at 1,400 to 1,500 feet, and to frame buildings at 3,500 to 5,500 feet, gave 90% B-damage to typical American dwellings at a radius of 2,500 feet." Class B damage is associated with a blast wave peak over-pressure of 2.5 psi.

Ensign Reynolds provides some discussion of the seismic effect, the earth shock, which resulted from the Halifax explosion, but the Halifax explosion literature does not mention that any seismographic station recorded the Halifax earth shock. Records of the Port Chicago explosion earth shock were made at twelve seismographic stations in California and one in Nevada. Those records will be reviewed and analyzed in a subsequent chapter.

Of particular interest in Ens. Reynolds' discussion of the Halifax earth shock is a quotation he provides from a report on the explosion written by the Halifax scientist H.L. Bronson and published, 1918, by the Royal Society of Canada: "Within a radius of 4 or 5 miles the earth wave was distinctly felt and was followed by the concussion of the air which caused all the damage."

At his position 3,500 meters from the Halifax explosion Bronson reports that the air blast arrived 6-10 seconds later than the earth shock. Recognition that at distances 4 or 5 miles from the Halifax explosion the earth shock arrived at least 6-10 seconds before the air blast wave arrival will be important in discussion of the number of explosions that occurred at Port Chicago. Many eyewitnesses to the Port Chicago explosion construed the violence of the earth shock to have been the manifestation of one explosion and the succeeding violence of the blast wave to have been the manifestation of a second explosion.

Dr. Maurice M. Shapiro: Comparison of the water disturbances caused by the Halifax and Port Chicago explosions.

Dr. Shapiro's sixteen-page report, "Effects of the tidal wave in the Port Chicago explosion of 17 July 1944," is Enclosure E of Capt. Parsons' 31 August 1944 memorandum to Adm. Purnell, "Port Chicago Disaster: Third Preliminary Report." Dr. Shapiro's sixteen-page report includes the three-page Appendix II, "Comparison of the water disturbances in the Port Chicago and Halifax explosions," from which the following extracts are taken.

"In the Halifax catastrophe a cargo of approximately 2,800 tons of TNT equivalent was involved, whereas in the Port Chicago disaster 1,550 tons exploded. The 3,000 ton ship Mont Blanc, which blew up in Halifax Harbor, was a smaller vessel than the Liberty ship SS EA Bryan, the former having a length of 330 feet and a beam of 40 feet, and the latter 440 feet and 55 feet, respectively. However, the two ships did not differ much in draft, the former drawing 20 feet of water, and the latter 22.5 feet just before they exploded. Each ship was close to shore, the SS EA Bryan being about 450 feet away, whereas the Mont Blanc was believed to have touched ground immediately before the explosion. The depth of water at the explosion site was less than 25 feet at Halifax, and approximately 35 feet at Port Chicago. However, in both ships the explosive cargo appears to have been situated at a level just below the water line, and both events must be considered as practically surface explosions. That is to say, for both cases the mechanism involved in the creation of the tidal wave was the delivery of an impulse to the water by a charge near the surface. In neither case was the charge sufficiently deep, relative to its size, to permit the formation of a dome by a pulsating underwater gas bubble and the spreading of a wave train following the collapse of the dome.

"[For the Port Chicago explosion] the wave height 1,300 feet away was of the order of 6 to 7 feet, and 3,200 feet away it was about 5 feet. [Scant quantitative information on the wave height for the Halifax explosion] permits us to set a rough upper limit of about 12 feet for the wave height at a distance of 800 feet from the explosion.

"It may be reasonably guessed that at Halifax the water flowed up a distance of 1,200 plus or minus 300 feet from the shore; at Port Chicago the farthest incursion of the water was about 1,800 feet from the banks, but this flow occurred in a shallow ravine or slough. From these facts it may be concluded that the tidal wave, like the other effects of the Halifax explosion, was a greater disturbance than that in the Port Chicago disaster."

Photographs and illustrations credits.

USS *Maine*. Source: U.S. Naval Historical Center, Photograph NH 60255-A. Photographed circa 1895-98.

SS *Fort Stikine,* North Sands Class freighter. Source: Robert G. Halford. *The Unknown Navy: Canada's World War II Merchant Navy*. Ontario: Vanwell Publishing, 1995.

Smoke cloud formed above the explosion of the SS *Mont Blanc*. Source: Nova Scotia Provincial Archives.

View of the Halifax disaster, looking south, 6 December 1917. Source: National Archives of Canada; panorama sections C-019944, C-019948, C-019953. Photographer: W.G. MacLaughlan.

Ensign George T. Reynolds, USNR. "Port Chicago: Analysis of damage due to air blast and earth shock": Enclosure D of Captain William S. Parsons' 31 August 1944 memorandum to Admiral Purnell, "Port Chicago Disaster: Third Preliminary Report." "Section IV. Comparison with Halifax," pages 9-10. Source: Los Alamos National Laboratory.