

Physical and chemical analysis of Beirut Ammonium Nitrate Blast: A concern of status of particulate matter in atmosphere

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SUPPLEMENTARY MATERIALS

Table S1 List of ammonium nitrate accidents in past 100 years in the world

	Location	Date	Amount of AN	Casualties	Causes
1	Kriewald (Germany)	July 26, 1921	30,000 kg	30 people	An explosion occurred when the mining explosives were used to dislodge the solid mass of AN into the wagons (https://www.shippingandfreightresource.com/the-hazards-of-ammonium-nitrate-and-100-years-of-related-disasters/)
2	Oppau (Germany)	September 21, 1921	4,500,000 kg	561 deaths, 1952 injuries, 7500 left homes & loss of materials about \$1700, 000.	An explosion occurred in the tower silo when the industrial materials were used to disaggregate the cake fertilizer (50:50) mixture of AN and ammonium sulphate. Investigation of the incident highlighted that there were pitfalls on the drying by new spray process, and the wrong composition of AN: AS (AN higher than 50) might have triggered the detonation (Hörcher, 2016).
3	Nixon, New Jersey (U S A)	March 1, 1924	2,000 kg	18 deaths, 2 missing, 15 hospitalized, 100 injured, 40 buildings damaged and demolished the “tiny industrial town of Nixon”	The explosion was theorized to be triggered by Trinitrotoluene (TNT) used in the plant. The official inquiry sued Nixon Nitration Works for the blast that was thought to be caused due to the ill condition of the plant (Scott & Grant, 1948b).
4	Muscle Shoals, Alabama (USA)	May 3, 1925	Two carloads of 220 barrels of AN in each	No	The explosion was thought due to the fire by the friction of AN with niter-impregnated Manila paper during transportation (Munroe, 1925).
5	Emporium PA (USA)	May 7, 1925	~ 250 kg	1 killed, 1 injured and the operation shed was demolished	On evaporation of AN at around 136 °C, the boiler was contaminated with organic matter and an explosion occurred (Munroe, 1925).
6	Miramas (France)	August 5, 1940	240 tons	No	When AN was hit by a shell, it exploded from a nearby fire .i.e., a road accident (https://www.chemeurope.com/en/encyclopedia/Ammonium_nitrate_disasters.html#Miramas.2C_France.2C_1940)
7	Tessengerlo (Belgium)	April-29, 1942	150,000 kg	190 death, 900 injuries, and many homeless	The rise in temperature of AN, and build-up gas caused the explosion on the storage site (https://www.100yearstessengerlo.com/en/home/1942/april-29-1942-explosion).
8	Milan (USA)	February-1, 1944	4800 pounds(lbs)	4 deaths, 17 injuries	On evaporation of AN at around 175 °C, the boiler was contaminated with organic matter and an explosion occurred (Gillis & Ranganathan, 2017; Oxley et al., 2002).
9	Texas (USA)	April-16, 1947	2,000 tons	Nearly 600 death, ~3500 injured, \$50- \$75 million property loss as of 1947	Ignorance, lack of care and skill of handling of the explosive chemicals, and human error contributed to the fire and explosion of a cargo ship that caused an explosion to another cargo ship (Stephens, 1993).

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10	Brest (France)	July 28, 1947	3,000,000 kg	30 deaths and thousands of injuries	A small fire on the cargo ship was unable to extinguish carried out the explosion (Gillis & Ranganathan, 2017).
11	Presque Isle (USA)	August 26, 1947	200 tons	No death, A.W. Higgins Company plant was destroyed	The spontaneous fire was caused by the curing pile of mixed fertilizer. Some of the ammonium nitrate was destroyed by fire extinguishing water and the rest burnt without explosion . An estimated property loss was around \$100,000 (Scott & Grant, 1948).
12	St. Stephen, New Brunswick (Canada)	September-1, 1947	400 tons	No death, Summers Fertilizer Company was destroyed	Spontaneous fire in the stockpile was caused and engulfed all of the AN without explosion (Scott & Grant, 1948).
13	Red Sea (Israel)	January 23, 1953	4-8 thousand tons	No death, the ship exploded	Spontaneous fire in the Finnish cargo ship <i>Tirrenia</i> was unable to extinguish and the ship was allowed to explode in an abandoned place (Prugh, 2020).
14	Roseburg, Oregon (USA)	August c7, 1959	2-ton dynamite and 4.5 tons of AN	14 death, 120 injuries, many buildings were demolished, and an estimated loss of \$10- 12 millions.	A loaded truck caught fire and exploded like a bomb blast at the parking place at midnight (Lalande, 2018).
15	Traskwood, Arkansas (USA)	December 7, 1960	140-180 tons	No personal injuries (Unknown)	During the rail transportation 23 loaded cars were derailed; They contained AN, HNO ₃ , polyethylene, petroleum paper, etc. AN might have mixed with organic compounds produced fire and exploded (Nygaard, 2006; Pitmann et al., 2014; Van Dolah et al., 1966).
16	Traskwood, Arkansas (USA)	February 1963	Unknown	No personal injuries are known	A derailed car loaded with AN burned without explosion by the spilled fuel. The reason for the derailment is unknown (Pitmann et al., 2014).
17	Oulu (Finland)	January 9, 1963	10 tons	10 deaths	The explosion was caused due to the ignition of AN in a fertilizer industry (Al-Hajj et al., 2021).
18	USA	1966	-	No	Storage of AN fertilizer with pesticides and combustible materials caught fire and explosion (Wood & Duffield, 2002).
19	USA	1967	50 tons	-	Rail transport of AN in paper-bags in the wagon of wooden interior. AN burn without explosion (Wood & Duffield, 2002).
20	Taroom, Queensland (Australia)	August 30, 1972	12 tons	3 deaths, more than 800 hectors of bushland were destroyed	Low density AN prills in the bags caught fire by an electrical fault during road transportation . The driver stopped the burning truck at the side, it exploded (Marlair & Kordek, 2005).
21	Cherokees (USA)	January 1973	14000 tons	No deaths	Sudden fire in the storehouse of the wooden structure destroyed about 10 tons of AN by an explosion (Marlair & Kordek, 2005).
22	USA	1978	500 tons	No death	The Storage of AN in the warehouse burnt completely without explosion (Wood & Duffield, 2002).
23	UK	1982	-	-	The wooden structure and AN in the warehouse burnt down completely without explosion (Wood & Duffield, 2002).

24	Kansas City, Missouri (USA)	November 29, 1988	23 tons	6 death	The explosion was an act of arson in the dispute between laborers and a construction company at the construction site (USFA, 1988).
25	Progeria Mines (Papua New Guinea)	August 2, 1994	80 tons	11 deaths	The emulsion of ammonium nitrate, fuel, and water was exploded by the fire at the storage site (Goulob, 2007).
26	Port Neal, Iowa (USA)	December 13, 1994	5700 tons	4 deaths, 18 injured	A large quantity of nitric acid and liquid ammonium nitrate were spilled in the site by the explosion . The accident was caused due to lack of proper storage , safe handling of chemicals, and operation disorder of the plant running without the analysis of hazard (Thomas et al., 1994).
27	Brazil	1997	Unknown	No death, severe injuries	A truck loaded with AN caught fire and stopped aside, a petrol tanker passing from its side caught fire and exploded . The delayed explosion possibly due to a propane bottle on the trailer (Marlair & Kordek, 2005).
28	Xing ping Shaanxi (China)	January 6, 1998	27.6 tons of liquor AN	22 deaths, 56 wounded	Xinghua Fertilizer company got an accident causing a series of explosions in the plant (http://www.chinabaik.com/z/aq/hg/266152.html).
29	Kentucky (USA)	1998	4000 tons	No death, 2500 were evacuated	All of the stock in the warehouse was burnt with explosions believed in the propane cylinders (Wood & Duffield, 2002).
30	Florida (USA)	2000	-	1 killed by the impact	The truck carrying AN collided with a gasoline tanker and all of the AN burnt out without explosion (Wood & Duffield, 2002).
31	Toulouse (France)	September 21, 2001	~400 tons	30 deaths, ~10,000 injuries and 140000 got therapeutics for post-acute-traumatic stress.	Experts report highlighted the explosion in the storehouse of Azote de France (AZF) fertilizer factory was caused by the accidental combination of sodium dichloro-isocyanurate and downgraded AN (Gyenes & Dechy, 2016).
32	St. Romaine n Jarez (France)	October 3, 2003	3-5 tons of AN with plastic bottles, boxes, piles, wooden crates, quick lime etc.	26 injuries (18- firefighters), 82 houses damaged	A sudden fire in the barn (Storehouse) of a farmer caused an explosion (Milanka et al., 2015).
33	Neyshabur (Iran)	February 18, 2004	399 tons of AN, Sulphur, cotton oil etc.	300 deaths, more than 450 injuries	A railcar was loaded with 51 wagons, collided with a locomotive stopping station and a fire was produced which caused the explosion (Jahangiri et al., 2018).
34	Castellon (Spain)	March 9, 2004	25 tons of AN	2 deaths, 5 injuries	The truck collided with a car and the fire was started by the spilled fuel that triggered the explosion (Milanka et al., 2015).
35	Mihailesti Romania)	May-24, 2004	23 tons of AN in bags	20 deaths, several houses damaged	The loaded truck skid off the road and turned off. The fire started and led to the explosion . Neither the truck nor the driver was qualified for the transportation (Milanka et al., 2015).

36	Ryongchon (North Korea)	April 22, 2004	-		161 deaths, ~3000 injuries, destruction of a train station, and 8000 houses	Human error during rail transport , an oil tanker was reported to have hit by a railcar loaded with AN (mining explosives?) and produced a fire that triggered an explosion (Milanka et al., 2015).
37	Estaca de Bares, (Spain)	February 2007	400 tons		No death	The cargo of 6012 tons of NPK (nitrogen, phosphorus, and potassium) fertilizer aboard the Ostedijk underwent a self-sustaining decomposition (SSD). Compounds like nitrous oxides, moisture, ammonium, chloride, etc. produced by the decomposition of NPK fertilizers may have increased the temperature above 175 °C. Once the fire was supposed to be extinguished, high temperature developed by the exothermic decomposition caused an explosion of the ship (Hadden & Rein, 2011).
38	Coahuila (Mexico)	September 4, 2007	22-25 tons	ANFO	28 deaths, 130 injuries	A truck carrying ANFO collided with a pick-up truck in the road and resulted in a fire . The fire was not controlled but resulted in an explosion (Pitmann et al., 2014).
39	Bryan, (USA)	Texas July 30 2009	-		No death, but 10 individuals admitted to hospital for the respiratory problem by the inhalation of smoke	A sudden fire occurred in the warehouse of fertilizer grade ammonium nitrate (FGAN), Nearly 70000 residents were evacuated due to the danger of explosion and poisonous smoke inhalation but no explosion was observed (Xu et al., 2020).
40	West (USA)	Texas April 17, 2013	~200 tons		15 deaths, 200 injuries, and many houses destroyed	The fire in the warehouse may have caused an exothermic decomposition of AN in the presence of carbon and other organic matter. The high-temperature decomposition led to an explosion (Willey, 2017).
41	Wyandra (Australia)	September 5, 2014	56 tons of AN	in bags	The driver and six firemen were injured	The loaded truck skidded off from the road and the fire started. Explosions were caused due to the combustion of AN and other contaminants (https://www.queenslandcountrylife.com.au/story/5844428/qld-government-launches-lawsuit-over-2014-truck-explosion/).
42	Tianjin port (China)	August 12, 2015	800 tons with nitrocellulose, naphthalene, sodium sulphide, furfuryl alcohol etc.		165 deaths, 8 missings, 798 injuries, 304 buildings, 12428 vehicles, 7533 containers, Gross economic loss= 6.86 Yuan	The spontaneous fire in the storage yard of nitrocellulose spread to the various combustible materials. High temperature and pressure ignited the stack of AN, the subsequent decomposition of AN caused an explosion. So, the accident is a result of unsafe storage and handling of hazardous materials (Fu et al., 2016).
43	Beirut (Lebanon)	August 4, 2020	2750 tons of AN		220 deaths, more than 100 missing, 7000 injured, 30000 homeless, & 10-15 billion USD of property loss	The cause of the incident might be a deliberate attack or accidental explosion of a large amount of AN stored in an unsafe and abandoned manner for about 6 years. The initial fire brought series of small and massive explosions (El Sayed, 2020; Shakoor et al., 2020).

Table S2 List of terrorist attacks using ammonium nitrate

Date	Place/country	Deaths	Injuries	Explosive used
April 19, 1995	Oklahoma/USA	168	591	A truck carrying explosives was detonated by a homemade bomb in a rented truck on Alfred P. Murrah Federal building in a terrorist attack (Teague, 2004).
June 15, 1996	Manchester/UK	-	212	A vehicle borne IED was detonated by about 1.5 tons of AN as the main charge (William, 2016).
October 12, 2002	Bali/Indonesia	202	-	Series of explosions at nightclubs by bombs containing AN as main charge (https://www.bbc.com/news/world-asia-19881138).

April 28, 2011	Marrakech/Morocco	17	23	The blast was made by an IED bag containing AN and triacetone triperoxide (TATP) (Marrakesh blast was remote-controlled bomb: France Reuters)
July 22, 2011	Oslo/Norway	8	dozens	A car bomb exploded with a strong IED with AN and fuel oil. The assassin disguised police shot many people before he was arrested (Ray, 2020).
February 23, 2013	Hyderabad/India	16	100+	Two serial explosions were done by using AN, and trinitrotoluene (TNT) in a bicycle (Hyderabad blasts: six detained for questioning (ndtv.com)).
October 2017	Mogadishu/Somalia	500	300	A truck loaded with an explosive of AN exploded and ignited a fuel tanker (Grantham, 2020).

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