

Beirut Ammonium Nitrate Explosion

Taking Stock of the Shock Wave

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Exponent Principal Ali Reza was recently featured in the “Spotlight on Safety” column in the September issue of CEP Magazine, published by the American Institute of Chemical Engineers. Following the massive ammonium nitrate explosion in Beirut on August 4th, Ali explored the significant fire and explosion risks created when large quantities of this widely used fertilizer are stored in populated areas. The article also discussed U.S. and international regulations around the storage of ammonium nitrate. Ali offers additional insights regarding this explosion below:

While investigations into the cause of the explosion remain ongoing, a number of key technical points can be gleaned from widely available video footage. The most striking feature of the footage is the very prominent, hemispherical shock wave, which provides conclusive proof that a detonation occurred. What this means is that the speed of the reaction front within the ammonium nitrate exceeded the speed of sound, and the reaction products created a shock wave consisting of highly compressed gases. This shock wave can propagate large distances and caused much of the structural damage in Beirut.

Although the total quantity of stored ammonium nitrate in the warehouse at the Port of Beirut was reported as approximately 2,750 tons, not all the fertilizer detonated. Some burned or decomposed in the initial fire, some melted because of heat from the fire, and depending on the initial storage configuration, some was likely scattered by the shock wave before the bulk detonation. Nonetheless, the detonation was extraordinarily powerful, which has prompted many to ask whether the observed damage is consistent with the amount of stored ammonium nitrate.

The energy of an explosion can be quantified by comparing it to the energy release from a trinitrotoluene (TNT) detonation. The shock wave associated with a TNT

explosion is well understood because it is widely used in the construction and blasting industries and by the U.S. Department of Defense, so expressing an explosion in terms of equivalent tons of TNT can offer a useful comparison. The destructive force of the shock wave from a detonation occurs at the leading (front) edge of the expanding wave from the explosion. Assuming perfectly horizontal ground, the shock wave would expand as a hemisphere, with the destructive force concentrated shock front. This is why the video footage shows damage to structures as soon as the shock wave hits them.

A careful examination of damage radiating out from the seat of the explosion can provide estimates for the effective force expressed as a TNT equivalent. This approach involves measuring the extent of damage or deformation and calculating the force necessary to cause the damage. The force can then be converted into a pressure, which in turn can be related back to the strength of the shock wave created by the detonation. This allows the strength of the explosion to be expressed in terms of an amount of detonating TNT that would cause similar damage. For example, if the conditions of the ground immediately below the detonation are known, the size of the crater can provide useful information about the total yield.

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Estimating the yield from an ammonium nitrate explosion can be non-trivial. This fertilizer is a powerful oxidizer, with the additional complexity that it can release heat when it decomposes (i.e., exothermic decomposition) and becomes an explosive when it mixes with an organic fuel. In the case of the Beirut explosion, the initial fire likely heated up and melted the stored ammonium nitrate, and a portion of it likely detonated because it had been sufficiently contaminated with carbon-based fuel. The initial detonation then likely triggered the remaining material. The 2013 ammonium nitrate detonation in West, Texas, likely occurred because molten ammonium nitrate mixed with seed, hay, and other organic materials, which provided the fuel source.

Exponent has significant experience investigating fires and explosions, including those that involve ammonium nitrate and organic fuel. We conducted experiments with 80-lb (36.3-kg) batches of ammonium nitrate and fuel oil (ANFO) mixtures after the [1995 bombing of the Murrah Federal Building in Oklahoma City](#) and determined that the maximum yield of an ANFO explosive was approximately 0.6 that of TNT (i.e., 1 lb of ANFO was equivalent to 0.6 lb of TNT). We presented our peer-reviewed results at the annual conference sponsored by the International Society of Explosives Engineers in 1999. The overall yield of stored ammonium nitrate in previous accidental explosions has ranged between 0.1 and 0.4 of TNT equivalence. Preliminary estimates for the yield from the Beirut explosion range from several hundred tons to approximately 1,000 tons of TNT equivalent. However, there are open questions about what other chemicals (including fireworks) contributed to the event.

The shock wave from the Beirut explosion also appears to encapsulate a white cloud within the hemisphere. This is a result of condensation of water vapor. As the shock wave propagates into the surrounding air, it compresses and accelerates the air. Spherical symmetry requires

zero velocity at the center of the explosion, so an expansion wave follows the shock wave. This expansion reduces the air pressure to below the initial atmospheric pressure, and adiabatic cooling from this expansion can cause the condensation of water into liquid form. When the air temperature increases, the water droplets re-evaporate, causing dissipation of the cloud.

[High-speed video of the ANFO testing conducted by Exponent](#) also clearly demonstrates the expanding blast wave generated by detonation, but in our case, a condensation cloud was not created behind the shock. This is because our tests were conducted under very hot and dry conditions in the Sonoran Desert in the American southwest.

My colleagues and I have significant expertise and experience investigating accidental explosions. Exponent's Thermal Sciences practice investigates how and why detonations occur, and our Structural Engineering practice determines the damage caused by detonations and measures structural deformation and crater depths. These measurements allow us to determine the energy released in the detonation.

How Exponent Can Help

Exponent's thermal science experts have significant experience and expertise in investigating accidental explosions, including those involving ammonium nitrate in the United States and abroad. Given the stakes involved with ammonium nitrate, it is important to understand its hazards, as well as existing global storage and use regulations. Our experts also serve as members of the National Explosives Code (NFPA 495), which identifies expected levels of safety for the manufacture, transportation, storage, sale, and use of explosive materials.



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