AN ANALYSIS OF A VAPOR CLOUD EXPLOSION

November 2006 Explosion at CAI/Arnel in Danvers, Massachusetts

On November 22, 2006, at approximately 2:45 AM, in Danvers, Massachusetts, an explosion completely destroyed a local ink and paint manufacturing facility. The blast from the explosion injured ten community members, damaged or destroyed more than 100 homes and businesses, and broke widows up to one mile away. About 300 residents (77 families) were initially evacuated. As of May 2007, 50 families were still unable to return home, and 16 homes and two businesses were razed. No workers were injured, as the facility was vacant at the time of the explosion. The accident was investigated by the U.S. Chemical Safety Board (CSB), which presented their preliminary findings in a Public Meeting in Danvers on May 9, 2007. A copy of their power point presentation is available at http://www.csb.gov/completed_investigations/docs/Danvers%20public%20mtg.pps

CSB Chairman Carolyn Merritt commented on the accident: "The Danversport explosion caused the most serious community damage of any U.S. chemical accident since the CSB was established in 1998. But for the fortuitous time of the explosion, nearby residents could have easily been killed by flying debris or collapse of heavy building structures. We all have a strong stake in preventing such devastating accidents that disrupt communities."

The manufacturing facility itself was completely destroyed by the explosion. Fire was confined to the facility and did not spread to the community. The blast from the explosion did do considerable community damage.

CSB Investigation

The U.S. Chemical Safety and Hazard Investigation Board, Washington, D.C., (also called Chemical Safety Board, or CSB) is an independent federal agency that investigates chemical accidents with the objective of protecting workers, the public, and the environment. The CSB does not issue citations or fines but does make safety recommendations to plants, industry organizations, labor groups, and regulatory agencies such as OSHA and EPA. While Congress has written into law that CSB findings cannot be admitted in court for litigation purposes, a visit to their website, www.csb.gov, shows that the organization is very blunt and specific when pointing the finger at the root causes of specific chemical accidents and making their findings available to the public.

Organizations involved in emergency response included:

- Danvers fire and police departments
- Salem, Peabody, Beverly, and other fire and police departments
- Massachusetts Environmental Police
- U.S. EPA
- U.S. Coast Guard
- U.S. Bureau of Alcohol, Tobacco, Firearms, and Explosives
- Massachusetts State Police
- Massachusetts State Fire Marshal
- Massachusetts Department of Environmental Protection

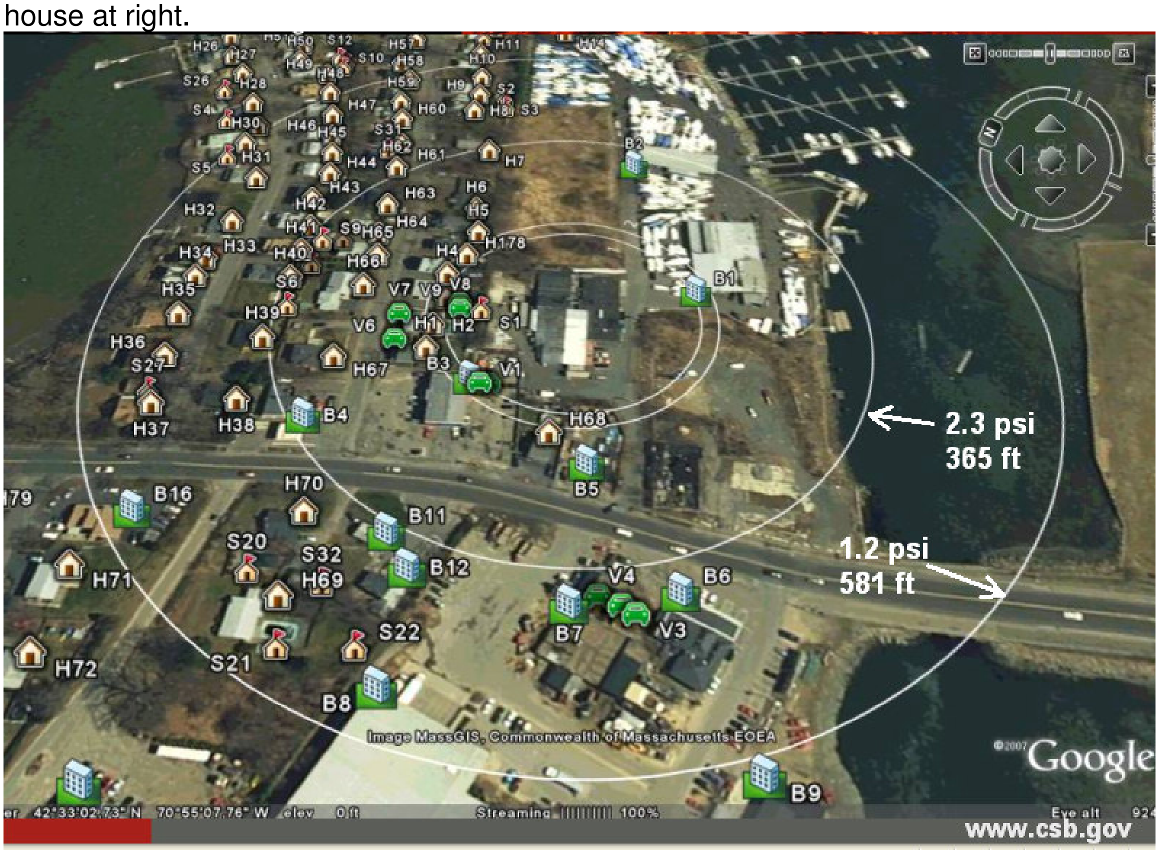
Remember, the blast occurred just before 3 AM. The facility was closed. There was no one around who witnessed the blast. When the CSB began their investigation, there was the visible evidence of blast damage, the accounts of emergency response personnel, off-site floor plans of the facility and some information on facility operations, and facility workers to interview. Some photos used in the CSB public presentation are illustrated below.

The blast site, obliterated facility at right; note proximity of houses.

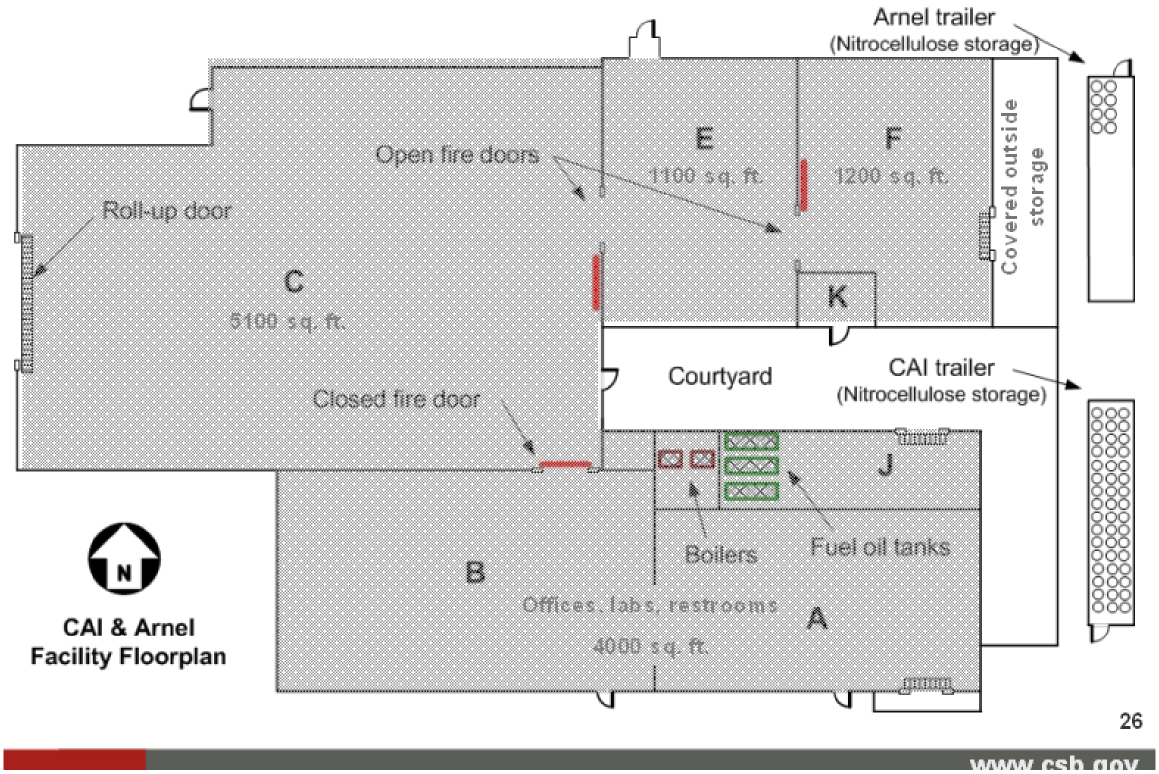
Severe structural damage to nearby houses occurred because of the blast

Businesses were damaged because of the blast

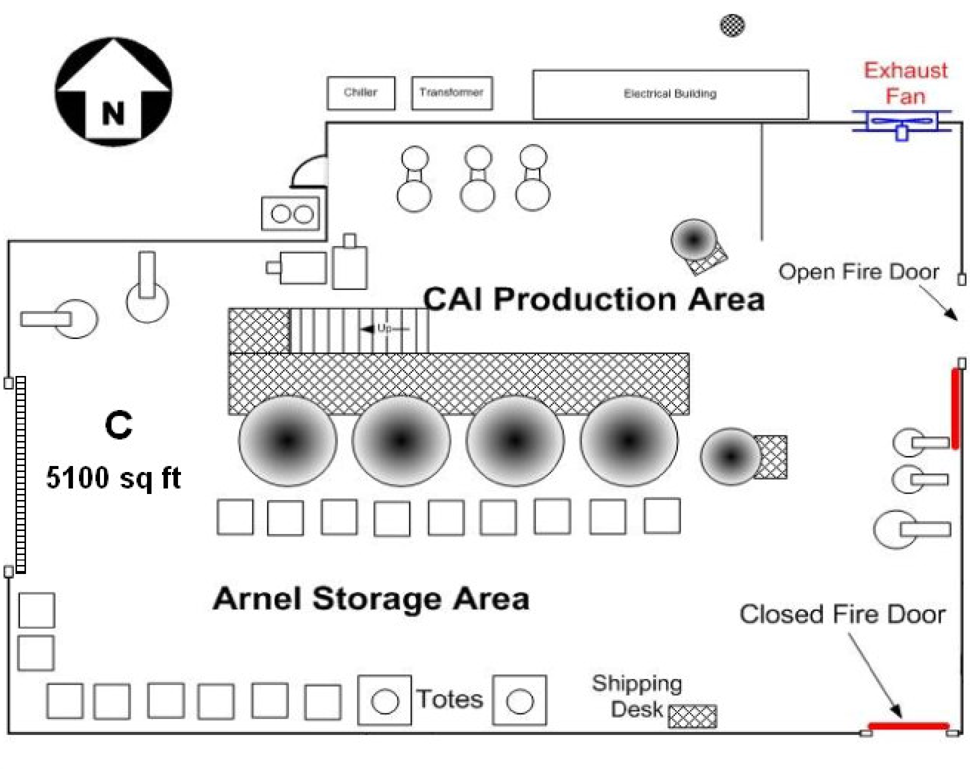
The CSB examined what was left of equipment at the facility. Note proximity of nearby house at right.



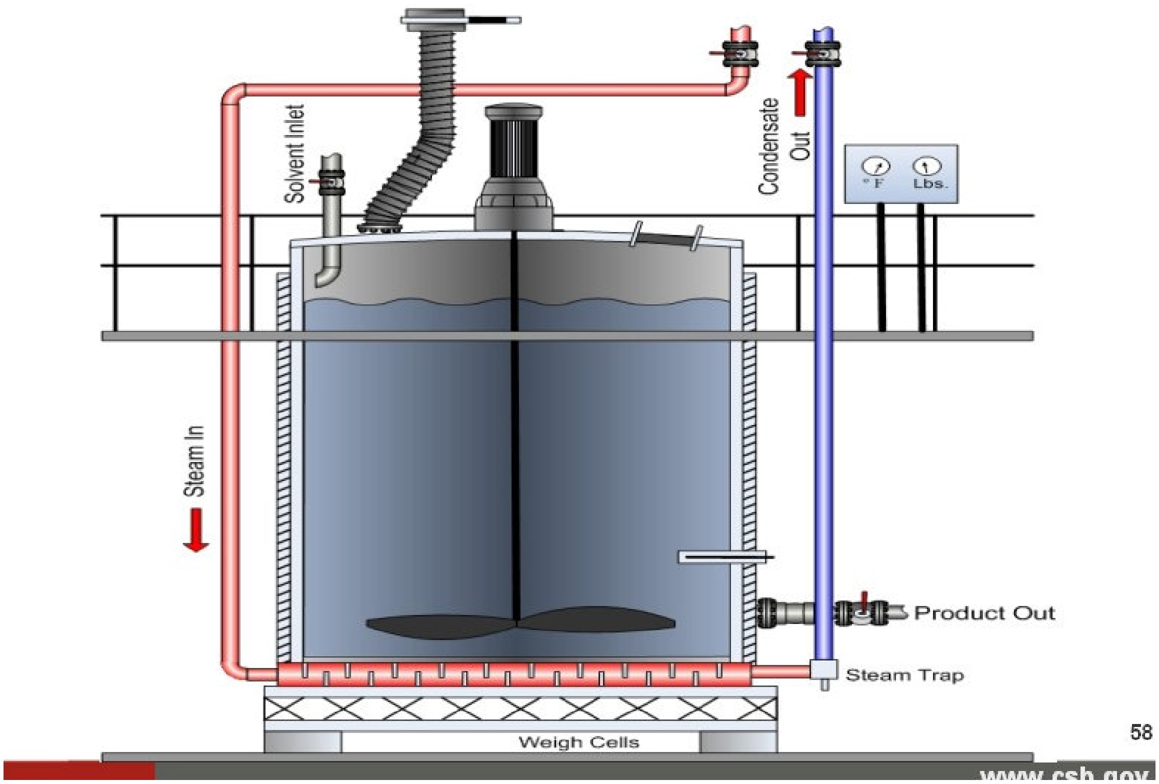
A key part of the CSB investigation was to map damage assessment as a function of distance from “ground zero” and relate to peak blast overpressure. The above image is a projection of the findings on anaerial photo supplied by Google taken before the accident.



The Facility floor plan was examined. Attention was focused on room "C". Rooms E and F are also used in production, but on the night of November 21-22, there was no overnight solvent processing and the rooms were empty of chemicals except for small batch quantities



Overnight (unattended) solvent processing occurred in room C during the night of November 21-22. Workers reported that it was customary to turn off the exhaust fan during unattended overnight processing to save building heat.
The CSB investigation eliminated (1) natural gas, (2) fuel oil, and/or (3) nitrocellulose as the possible source of the explosion. None of these sources were capable of producing the blast damage seen. The nitrocellulose at the facility did not explode but burned rapidly inside the storage trailers. The CAI/Arnel facility did not have natural gas service. The closest natural gas pipeline to the CAI/Arnel building was 215 feet south, and there was no post-explosion natural gas fire or leak. The fuel oil tanks were intact after the explosion.



The CSB investigation centered around a 3000 gallon mix tank which was charged with 2000 gallons of printer ink ingredients and flammable solvents n-heptane and n-propanol, and mixed overnight unattended. This mix tank was one of four mix tanks in room C, but only one was in operation that night. Also in room C were several 500-gallon capacity tote or storage tanks containing flammable solvents. While the possibility exists that one of the 500-gallon storage tanks failed, resulting in solvent leaking onto the production floor which evaporated, the more likely cause was that mix tank overheated and the solvent evaporated. The mix tank had no automated temperature controls nor high-temperature steam shutoff. The tank was not sealed. The room exhaust fan was turned off. The vapors accumulated in the building reaching the lower explosive limit. An unknown ignition source explosively ignited the vapor cloud.

The lower explosive for n-heptane is 1.05%. The lower explosive limit for n-propanol is 2.1 %. The CSB estimated a facility air volume of approximately 110,000 cubic feet. If the facility were uniformly filled with 1.05% vapor volume of n-heptane, the minimum mass of n-heptane vapor can be calculated:

$$0.0105*110000*100.2/386.78 = 300 \text{ lbs}$$

Here, 100.2 is the molecular weight of heptane and 386.78 is the number of cubic feet in a lb-mole at 70^{o}F. Similarly, for n-propanol, a minimum mass of 358 lbs is calculated.

The actual amount of chemical in the vapor cloud would need to be greater than the lower explosive limit. The upper explosive limit for n-heptane is 6.7%. The upper explosive limit for n-propanol is 13.7%. Some of the flammable chemical vapors may have leaked outside and participated in the explosion. We don't know exactly what happened.

The maximum amount of vapor in the facility is limited by the amount of solvent in the mixing tank. The total amount of chemicals in the mixing tank was 2000 gallons. For example, if 1000 gallons of n-heptane evaporated, the amount of n-heptane in the vapor cloud would be 5250 lbs.

Perhaps the best way of estimating the amount of chemical is to back calculate from the map CSB used for overpressure damage estimates. Using the PEAC tool, we calculate a minimum of 1630 lbs of n-heptane (or 2400 lbs of n-propanol) for the blast pressures. More likely, there would be some mix of the two chemicals, and the amount could be as closer to 5000 lbs of n-heptane (or a mix the two chemicals). Both numbers are within range of the amount of chemicals charged in the mix tank and would produce vapor concentrations between the upper and lower explosive limits within the building.

A big unknown when doing vapor cloud explosions is the fraction of vapor that participates in the explosion. This is the yield factor, which is generally around 0.02 to 0.05 (on a mass basis) for hydrocarbons and closer to 0.2 for more energetic chemicals with oxygen or nitrate in their structure. The PEAC tool when doing vapor cloud explosion analysis informs the user what yield factor was used in the calculation. Another issue is the shape of the vapor cloud that explodes. In the example discussed here, the shape of the vapor cloud is defined by the volume of the facility. Outdoors, the shape is defined by air movement, and because of unknowns, the PEAC tool applies a safety factor of two on the distance displayed. The PEAC user is informed of this.