Gasoline Fires and Explosions

A PEAC-tool user called AristaTek offices recently and said that when he modeled for "gasoline", large damage distances (about ¾ mile) were displayed on the PEAC tool for blast 0.5 psi overpressure distance and heat radiation to 2nd degree burns, and it was his experience that gasoline spills even with trailers do not result in this kind of damage distance.

There are several menu selections in the PEAC tool for different "what if" or "worst case" situations. The modeler had selected a situation where the contents of a very large trailer had spilled its contents (71,000 lbs) and the gasoline had completely vaporized in a somewhat confined area; also the vapors did not disperse before finding an ignition source. Another possible menu selection for the same quantity of gasoline spilled is the situation where the gasoline did not vaporize to any significant degree before ignition; the result is a pool fire. This is explained in the "acknowledgment statements" when the user makes the selection, but the PEAC tool is designed for the responder to run through a lot of "what if" situations quickly with a minimum of reading. The PEAC tool displays "what can happen".

Nevertheless, large explosions and fires with gasoline do occur. We will look at some examples.

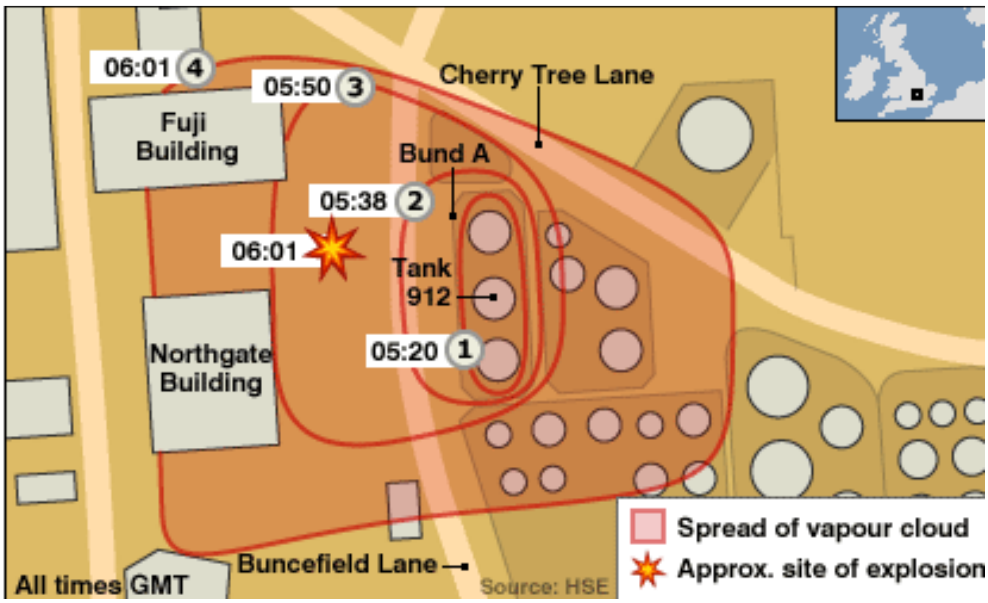
Buncefield (England) Explosion and Fire, 11 December 2005

The Wikipedia website, http://en.wikipedia.org/wiki/Buncefield_fire, gives a good description of this incident with links to government investigation reports.

At 6:01 AM on Sunday, 11 December 2005, a large explosion and fireball occurred at the Hertfordshire Oil and Storage Terminal west of London in the United Kingdom. This terminal supplies 30% of the fuel for Heathrow Airport. The blast measured 2.4 on the Richter scale according to the British Geological Survey; the noise was heard as far away as Belgium, France, and the Netherlands. Nearby offices were damaged so badly that almost every window was broken. The blast knocked down a warehouse wall 0.5 miles away and blew out windows as far as 5 miles away. Some industrial buildings were destroyed or rendered unstable. Smaller secondary explosions were set off within the storage terminal at 6:27 and 6:28 AM, and eventually fires engulfed 23 large storage tanks. Cars on nearby streets also caught fire. Off-site damage estimates (from insurance claims) totaled one billion English pounds. There were 43 reported injuries. Fortunately the accident occurred Sunday morning when the work areas were almost vacated so there were no fatalities.

Government investigation [directed by the Health and Safety commission, available at http://www.buncefieldinvestigation.gov.uk/reports/initialreport.pdf], present a time line for

events just prior to the explosion. The following sketch is from the Health Safety Executive as released to the public by BBC news:



Much of the information as to the cause of the accident was obtained from facility site closed circuit TV footage linked to the control room.

- At 19:00 hours on 10 December, Tank 912 began receiving unleaded gasoline (petrol) at the rate of 550 m^3 per hour.
- At 05:20 hours on 11 December, calculations indicated that tank 912 should have been full at the fill rate, and that the protection system should have automatically shut off the supply of petrol to the tank to prevent overfilling, but the tank continued filling.
- At 05:38 hours, TV footage show escaping fuel from the overflowing tank. The overfilling fuel tended to splash as it overfilled at the top, fragment and vaporize as it hit a deflector plate on the side of the tank with some liquid dropping to the ground within the bund area surrounding the tank.
- At 05:46 hours, TV footage showed a shimmering vapor cloud about 2 meters thick flowing from the bund area in all directions.
- At 05:50 hours, the vapor cloud continued to grow as shown by area 3 in the sketch. A delivery person seeing the advancing cloud a few minutes later abandoned his vehicle and ran away from the cloud.
- At 06:01 hours, just seconds before the explosion, the vapor cloud reached the area defined by 4 in the sketch.
- At 06:01 hours, an explosion and fireball occurs. The ignition source was not definitely determined, but a bright flash was recorded by closed circuit TV in the direction of the Fuji building an instant before the explosion (which also destroyed the camera), at a pump house location. The fleeing delivery person was knocked down from the force of the blast but survived.

- At 06:08 hours, an emergency services major incident was declared. Incident command and control was set up near the site.
- Further explosions occur at 06:27 and 06:28 hours, and 23 fuel storage tanks were engulfed in fire.
- Peak of fire at 12:00 hours. 180 firefighters, 20 support vehicles, 25 water pumps. Used 785,000 liters of foam concentrate and 68 million liters of water. Fires extinguished on 14 December.

Blast and heat damage to off-site property, Maylands estate businesses, photo from http://www.buncefieldinvestigation.gov.uk/reports/recommendations.pdf

The amount of gasoline vaporized and exploded in the Buncefield incident is uncertain, but one estimate was 30 tonnes, or 66,000 lbs (10% of the gasoline that overflowed from tank 912). This was roughly the same amount (about 71,000 lbs) that the PEAC tool modeler used in his hypothetical trailer accident, and reported damage estimates of ¾ mile for heat and blast. The key to modeling damage is, "How much gasoline vaporizes and is available for explosion".

The group of oil companies that owned the Buncefield fuel storage depot believed that cold gasoline could not explode in open air (reference: Travor Kletz, professor at Loughborough University (UK), page 15, Chemical Processing, December 2009), but it did. This kind of event has not happened before, the owners thought.

Other Depot Storage and Refinery Explosions and Fires

A 2004 Swedish study, H. Persson and A. Lönnermark, Swedish National Testing and Research Institute Report 2004:14, available from http://www.sp.se/sv/units/fire/Documents/Skydd/SP_report2004_14.pdf reviewed 480 worldwide tank fire incidents at fuel storage depots and refineries during the period 1951-2003. The emphasis of the report is on firefighting of large tank and pool fires. Several of the gasoline explosions and fires were initiated due to tank overfilling; the resulting gasoline vapors contacted an ignition source and exploded resulting in a fireball, which set off tank fires. Some fires were started by lightning. The degree of explosion and initial fireball depended upon how much gasoline vapor was available at concentrations between the upper and lower explosive limit; the fireball flash quickly ignited liquid fuel and fuel vapor above the upper explosive limit concentration blurring the distinction between a pool fire and fireball. In the interest of safety, the authors strongly recommended that information on incidents be shared openly to minimize future accidents.

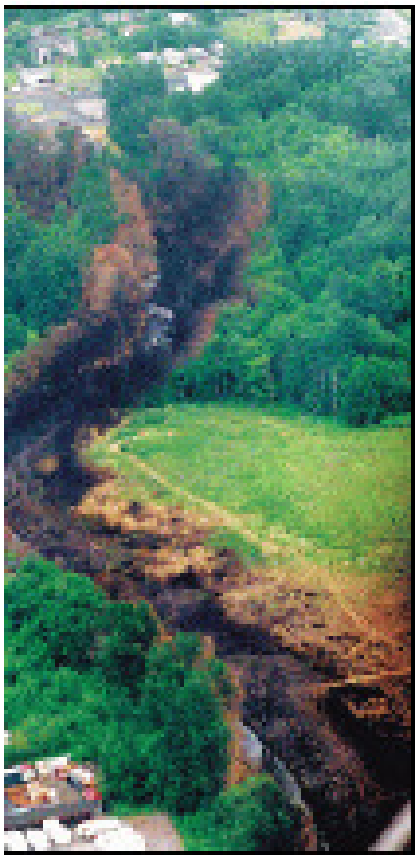
Small Gasoline Spill, Homeowner Working on Car, 13 March 2010

A homeowner was working on his car near his garage in Yakima, Washington and spilled some gasoline. The gasoline vapors contacted an ignition source in his garage (apparently from a space heater, but one account said a lighted cigarette) which ignited and exploded. The resulting fire and explosion destroyed his garage, with flames spreading to the back of his house. Firemen arrived quickly. Damage totaled $150,000.

Gasoline Pipeline Rupture, Washington, 10 June 1999, 3 killed, Environmental Damage

Source: http://www.cob.org/services/environment/restoration/olympic-pipeline-incident.aspx. and http://www.iosc.org/papers/00888.pdf.

On 10 June 1999, a 16-inch gasoline pipeline owned by the Olympic Pipe Line Company and supplying fuel to the Seattle-Tacoma airport and other customers ruptured spilling an estimated 231,000 gallons of gasoline into Hanna and Whatcom Creeks in Bellingham, WA. The spill occurred in wildlife/park areas killing over 100,000 salmon, trout, and other fish. The vapors from the gasoline contacted an ignition source resulting in an explosion and fireball which raced 1.5 miles down the creek bed killing two boys and a young fisherman. Nine people were also injured, and 26 acres of forest were burned. The explosion resulted in $45 million in property damage, including blast damage to a water treatment plant and water intake vault. The families of the victims also settled in court for $100 million in damages. The pipeline company also paid for environmental cleanup as required by the Oil Pollution Act of 1990. Environmental cleanup included the list at http://www.ecy.wa.gov/programs/spills/Special_Focus/Bellingham_Pipeline/Bellingham_Pipeline_p2.html.



At left is a view along the path of the fire along Whatcom Creek (14 June), from an EPA report, located at http://www.iosc.org/papers/00888.pdf.

Just prior to ignition, Bellingham firefighters were investigating a report of gasoline odor in the area. The firefighters found a shimmering vapor cloud about 10 feet above the creek. The explosion occurred at 5:02 PM, 38 minutes after the first 911 calls reporting gasoline odor. The ignition source was unknown, but a fireplace lighter found near the confluence of Whatcom and Hanna Creeks and possibly used by the two boys who were killed has been suggested. The fire lasted for less than an hour, including both the initial "fireball" and a "pool fire" on top of the water, but secondary fires lasted five days. Fires extended for two miles along the creek.

Responders established a Unified Command which include the U.S. Environmental Protection Agency, state agencies, the local Bellingham Fire Department, the principal responsible party (pipeline company), and Lummi tribal representation. Other agencies participated later.

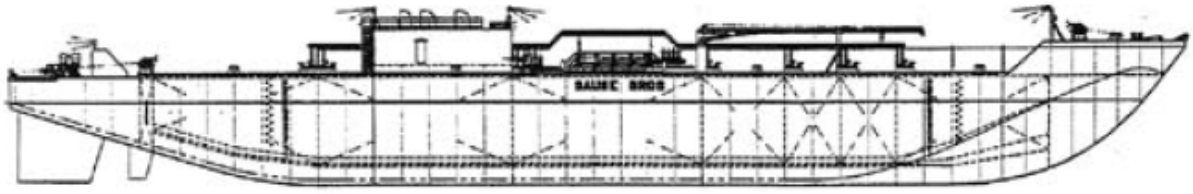
Our review based on available information obtained from Internet websites is that the "explosion" was probably limited to near the pipeline break and the water intake vault near the water treatment plant, and most of the creek underwent a deflagration (a rapid advancing flame front). The two boys, who were found still alive, died of burn injuries. The fisherman's death was due to drowning.

Gasoline Barge Explosion and Fire, 21 February 2003, at Port Terminal on Staten Island

(see http://www.professionalmariner.com/ME2/dirmod.asp?sid=420C4D38DC9C4E3A903315CDDC65AD72&nm=Archives&type=Publishing&mod=Publications%3A%3AArticle&mid=8F3A7027421841978F18BE895F87F791&tier=4&id=5677DAB0D61F4EB2B5B1CD6757E1C09E.)

At 10:10 AM on 21 February 2003, a gasoline barge delivering gasoline at the ExxonMobil dock on Staten Island's western shore exploded killing two people on the barge and badly burning a dockside depot worker. Witnesses told of metal chunks flying in the air and of searing heat and blast forces that knocked people down, and shattered windows miles away from the explosion, according to accounts in the New York Times. Harbor surveillance video taken by the Coast Guard captured the 5-second blast footage which was shown on local television. After the blast, the gasoline which remained in the barge or spilled into the Arthur Kill waterway continued to burn as a pool fire. The barge quickly sunk.

Initially, city officials and also firefighters who rushed to the scene thought "terrorism", but by early afternoon Mayor Bloomberg told reporters that there was no reason to think that this is nothing more than a tragic accident. The 118,000 barrel capacity, 340-foot long barge was carrying 100,000 barrels and was halfway unloaded (50,000 barrels still left in the barge) when the blast occurred. The burned dockside worker who was hospitalized in critical condition said that he heard a "grinding noise" apparently coming from the barge diesel engine powering the gasoline transfer pump which had been "repaired" the day before unloading began. Investigators focused on the pump as an ignition source for the explosion. A single cargo transfer hose was being used to transfer gasoline from the barge to a single on-shore tank. As gasoline was pumped from the barge, air was pulled into the barge compartment space.



A typical large fuel barge, from http://www.marcon.com/library/market_reports/2002/tank_barge/tb06-02.pdf

Normally, the vapor space in any barge or other gasoline carrier including an automobile fuel tank would be too rich to result in a vapor cloud explosion. But if the vapor concentration in the barge was between the lower explosive limit and upper explosion limit mixed with air in the barge vapor space, a vapor cloud explosion will occur upon ignition. Assuming that the total vapor space contains gasoline vapor at an upper explosive limit of 7.6%, we calculated roughly 5000 lbs of gasoline vapor contributing to the explosion. If the PEAC tool model is run for gasoline, 5000 lbs of exploding gasoline vapor (in a confined space) results in a 1613 foot damage distance for 0.5 psi overpressure, or 15223 feet for 0.1 psi overpressure. Glass under stress can shatter at 0.1 psi overpressure, which is consistent with the observation that window breakage was reported several miles away.

NOAA aerial photo of area taken about 3:30 PM, from http://www.noaanews.noaa.gov/stories/s1101.htm.

Firefighters concentrated their efforts on protecting a nearby fuel barge and on the depot tank farm, letting fire from the burning barge and gasoline spilled in the water burn itself out. A New York City Firefighters account on protecting a nearby fuel barge is published at http://marine1fdny.com/port_mobile.php. Quick response by firefighters prevented a chain reaction from igniting any of the on-shore petroleum storage tanks or a possible explosion from the nearby barge being unloaded which still contained 344,000 gallons of gasoline.

According to the Coast Guard investigating the accident, divers surveying the wreckage of the sunken barge the next day reported that the blast created a tunneling effect in the barge with the upper deck folded over. All 12 compartment tanks of the barge were destroyed by the explosion.

Cargo Trailer Accidents

Gasoline cargo trailers delivering fuel to filling stations typically have a capacity for carrying 7000 to 9000 gallons of gasoline and are divided into several compartments.

National Transportation Safety Board (NTSB) reports (see http://www.ntsb.gov/Publictn/publictn.htm) were reviewed for gasoline spills involving tractor cargo trailers. The National Transportation Board issues a report for only a few accidents; in many situations the spilled gasoline is cleaned up without any fire or explosion. Sometimes there is a small explosion and fire involving spilled gasoline, but the cargo trailer remains intact. Sometimes the cargo trailer ruptures and is engulfed in fire. We did not find any NSTB report where the cargo trailer released all or most of its contents as vapor which exploded, or any report where an intact cargo trailer was engulfed in flames resulting in a BLEVE-type explosion. There was a vapor cloud release under essentially zero wind conditions from a gasoline cargo trailer accident near Houston, TX, in the 1960's, which resulted in a fireball and explosion, but we were unable to find details (no report located on the Internet, nothing on the amount of gasoline in the vapor cloud).

A typical report was NTSB Number HAR-98.02, accessed from the NTSB website, which involved a collision of a truck tractor pulling a cargo tank containing gasoline with a sedan under an overpass on the New York State thruway, at 12:10 AM on 9 October 1997. The ensuing fire destroyed both vehicles and the overpass, closing the throughway for six months. The driver of the sedan was killed. Property damage was estimated at $7 million.

Train Car BLEVE explosion: http://www.youtube.com/watch?v=Xf3WKTwHpIU.
BLEVE is an acronym for "Boiling Liquid Expanding Vapor Explosion".

What Does This Mean To the PEAC Tool User?

Real-world gasoline spills or other flammable liquid spills can take place under many different circumstances. Under an emergency situation, a responder cannot be burdened with a complex interface menu. He/she needs answers quickly. The PEAC tool allows either two choices, either a spilled liquid pool which catches fire or the flammable liquid vaporizes resulting in a vapor cloud explosion and fireball. Both circumstances require an ignition source

(an electric motor, a vehicle, cell phone, static electricity, etc.). The truth is that ignition of a typical gasoline spill results in both a vapor cloud explosion, a short-duration flash fire ("fire ball"), and a longer duration pool fire. The responder would need to know how much gasoline had vaporized and was between the upper and lower explosive limit to do a fireball and blast damage calculation. The PEAC tool chose to represent both situations. The responder can run the PEAC tool using say a 5% vapor cloud release to obtain a possible explosion or fireball damage estimate and also run the pool fire model to see what can potentially happen, or run the model with all of the gasoline vaporized.

An experienced firefighter will be alert to potential hazardous circumstances that can result in a vapor cloud explosions. Especially hazardous circumstances include (1) vapor filling a confined or partially confined space such as a building interior, corridor, or drainage ditch;(2) even an unconfined outdoor situation where gasoline vapors accumulate, e.g. odor, a "shimmering" vapor cloud; or (3) a gasoline tank or other flammable liquid storage tank engulfed in fire. The explosion and heat damage distances can be great. And as the Bellingham Washington gasoline pipeline rupture example showed, the damage distance is not necessarily circular. Experience and training is important in developing a sense of what can potentially happen.

Additional Reading:

- An Analysis of a Vapor Cloud Explosion, 22 November 2006, Danvers Massachusetts, May 2007 PEAC Newsletter.
- Vapor Cloud Explosions and Fires, June 2006, PEAC Newsletter.