

## Using the PEAC tool for Industrial Vapor Cloud Explosion and Fire Accidents

### BP Texas City Refinery Accident



AP aerial photo from CBS 60 Minutes website

On March 23, 2005, the worst U.S. workplace accident in 16 years occurred at the BP Texas City refinery when flammable vapors from a blow down vent ignited; the resulting explosion and fire killed 15 workers and injured 180. The accident occurred during startup of the refinery's octane-boosting isomerization unit (boosts octane content of gasoline), when a distillation tower and attached blowdown drum were overfilled with highly flammable liquid hydrocarbons (the major part of gasoline). Because the blowdown drum was vented to the atmosphere,

there was a geyser-like release of flammable liquid and vapor onto the grounds nearby causing a series of explosions and fires that killed workers in and around nearby trailers. The blast was felt up to 5 miles away. The accident was covered in the news media, including CBS 60 Minutes. It was also investigated by the U.S. Chemical Safety Board (CSB) and discussed in various journals, popular magazines, including the Nov 6 and 13, 2006, issues of Chemical and Engineering News published by the American Chemical Society.

### U.S. Chemical Safety and Hazard Investigation Board Investigation



The U.S. Chemical Safety and Hazard Investigation Board is an independent federal agency charged with investigating industrial chemical accidents at fixed facilities. The Board members are appointed by the President and confirmed by the Senate. The agency does not issue fines or citations but does make recommendations to the industry involved and to regulatory agencies and labor groups. It is designed to conduct scientific investigations as to the root cause of chemical accidents and is not an enforcement or regulatory body. Most of the Board members and staff have degrees in chemical or mechanical or

other engineering disciplines, have Professional Engineer licenses, have chemical process industry experience, or are health or safety professionals. Congress in establishing CSB specifically stated (see 42 U.S.C. section 7412(r)(6)(G)): "No part of the conclusions, findings, or recommendations of CSB relating to any chemical incident may be admitted as evidence or used in any action or suit for damages arising out of any matter mentioned in an investigation report".

The Board's final report on the BP Texas City refinery accident is expected in March 2007, but because the investigation has been ongoing, various interim reports are available to the general

public at the CSB website, <http://www.csb.gov/>. AristaTek visited the website to obtain information about the flammable vapor release for the purpose of modeling in the PEAC tool.

The CSB has already made three major recommendations as a result of investigating the BP Texas City refinery incident:

- The first recommendation, made immediately after the accident, was for BP (all of the BP refineries) to remove trailers from locations near process equipment.
- Later, CSB recommended that the American Petroleum Institute (API), the leading oil industry trade association that develops widely used safety practices, should revise its “Recommended Practice 521, Guide for Pressure Relieving and Depressuring Systems” to warn against using blowdown drums such as at the Texas City refinery, and to use the inherently safer flare systems instead. Companies must plan effectively for large-scale flammable liquid releases from process equipment.
- The U.S. Occupational Safety and Health Administration (OSHA) should establish a national program promoting the elimination of unsafe blowdown systems in favor of safer alternatives such as flare systems. OSHA should also emphasize the need for companies to conduct accurate relief valve studies and use appropriate equipment for containing liquid releases.

The CSB upon accident investigation also documented eight previous releases from the same blowdown drum during the period 1994 to 2004. In six of the releases, dangerous flammable vapor clouds formed at ground level but did not ignite. In the other two cases, the blowdown stack caught fire. The lead investigator for the CSB investigation noted a number of safety problems, and remarked: “This drum simply wasn’t large enough to hold all of the liquid released from the distillation tower if it flooded. Not only could the blowdown drum not hold enough liquid, but it could not assure safe dispersion of flammable vapors through the vent stack”.

Since the accident, BP has pledged to eliminate all of the blowdown drums from its five U.S. refineries (a total of 17 blowdown drums) and use a safer flare system (an adequately sized vessel for containing liquids and a stack with a flame for safely burning flammable vapors).

In 1992, the same Texas City refinery, then owned by Amoco Corporation, was cited by OSHA for operating an unsafe blowdown drum. But Amoco succeeded in having the citation and fine withdrawn, citing that it had complied with the API Recommended Practice 521. The Amoco refinery was acquired by BP in 1998.

Another accident, on July 28, 2005 at the same refinery, prompted CSB to investigate safety practices in general at the refinery. In this case a pipe elbow failed at a residual hydrotreater unit releasing hydrogen gas at high temperature and pressure. The hydrogen immediately ignited; the resulting fireball burned for two hours causing an estimated \$30 million in damages. According to the CSB lead investigator, the root cause was inadvertent substitution of a carbon steel elbow (instead of a specialized alloy which can hold up under the conditions of use) when the system was disassembled and reassembled during an earlier maintenance. Verification of the piping material should have been done using an x-ray fluorescence test device. Overall, CBS found that BP’s global management were aware of problems with maintenance and responded to safety

concerns, but the emphasis was on improving procedural compliance and reducing occupational injury rates. Catastrophic safety risks remained. Unsafe and antiquated equipment designs were left in place, and unacceptable deficiencies in preventive maintenance were tolerated, according to CSB chairman Carolyn W. Merritt.

The magazine, Chemical and Engineering News, Nov 13, 2006, carried an article on lectures made by CSB chairman Carolyn W. Merritt to the chemical processing industry throughout the United States criticizing “corporate culture behavior”, which in order to improve the immediate bottom line for shareholders results in a history of corporate cost cutting. The cost cutting results in maintenance, safety, and plant infrastructure deterioration. The problems at BP are not unique to one refinery or one corporation. At BP, there was a culture where people at the refinery accepted higher levels of risk than they should have, and there was no feedback loop from past incidents. Merritt has given her speech to company corporations “hundreds of times”, and she says after giving her speech, someone comes up invariably and says to her, “You’ve got to come to our company and give this presentation”.

BP has set aside \$1.6 billion to settle more than 1000 claims against the company.

### **Analysis of BP Vapor Cloud Explosion at BP**

A video description of the BP accident (produced November 2005 by the CSB) is available at [http://www.csb.gov/index.cfm?folder=current\\_investigations&page=info&INV\\_ID=52](http://www.csb.gov/index.cfm?folder=current_investigations&page=info&INV_ID=52). This video has been viewed about 350,000 times since CSB first released it.

The startup of the isomerization unit began overnight, when light hydrocarbon liquid (a major component of gasoline) was added to the distillation tower. The video makes mention of a faulty level indicator on the tower which showed a liquid level of only 10 feet when in reality there was much more liquid in the tower, causing operators to overfill the tower. When a heat exchange system was started the next morning for heating the hydrocarbon, a valve on a pipeline leading from the tower should have been open as per normal procedure but was closed resulting in further overfilling the tower to a depth of 138 feet. The heating of the hydrocarbon liquid increased the pressure inside the tower resulting in excess liquid to be diverted to a nearby blowdown drum fitted with a 100 foot tall vent stack. The heating also expanded the liquid volume in the tower. An observation was made just before the vapor cloud explosion; there was a geyser-like fountain of liquid and vapor coming from the top of the vent stack for at least a minute before the explosion. The hot, liquid droplets fell to the ground and evaporated forming a vapor cloud near the ground; some liquid entered a nearby storm sewer. Plant records for earlier years showed overfilling and at least a start of vapor cloud formation eight times before. For two of the times, a fire occurred in the vent stack, and the other six times the vapor cloud dispersed and did not ignite. But this time considerable vapor formed and was ignited (1:20 PM) apparently by a diesel pickup truck parked 25 feet away from the blowdown drum. The blast killed 16 people located in nearby trailers. The blast also set off secondary fires and explosions at processing equipment injuring more people and damaging over 50 chemical storage tanks. Some of the injuries occurred when workers cut their hands on the barbed wire fence surrounding the refinery when they tried to escape the fires (the fence was not scalable).

Perhaps most interesting is an analysis of the blast structural damage of the approximately 44 trailers located within 1000 feet of ground zero (the blowdown drum location) at BP refinery as investigated by CSB. Not all of the trailers housed people; many were used for storage and were unoccupied. A detailed analysis of trailer damage is presented at [http://www.csb.gov/completed\\_investigations/docs/CSB\\_BPTrailerData6-30.06.pdf](http://www.csb.gov/completed_investigations/docs/CSB_BPTrailerData6-30.06.pdf). All of the 15 deaths occurred in occupied trailers located closest to ground zero. At distances less than 200 feet, trailers were essentially demolished. Major structural damage occurred between 200 and 500 feet. All windows were broken at 500 feet. The roof of one trailer at 597 feet collapsed, and its walls were heavily damaged. The threshold distance for window breakage appeared to be around 700 feet. Most trailers located beyond 700 feet were relatively undamaged by the initial blast.

**Table 1. Summary of Injuries and Fatalities in Trailers Near Ground Zero**

Trailer	Distance from Ground Zero, ft	# People in Trailer	Outcome
T1, T2	121	22	12 fatalities, 10 injuries, trailer essentially demolished by blast
T3	135	3	3 fatalities, trailer demolished by blast
T101	349	2	2 injuries from flying debris in trailer, trailer heavily damaged
T303	413	2	1 injured from flying glass, 1 uninjured, wall damage
T113	422	2	2 injured, major blast damage to trailer
T104	439	2	1 injury from flying glass, 1 uninjured

The reason that the company had located trailers at the site was to accommodate staff and contractors who were doing maintenance and renovations on nearby process units, and that the trailers were said to be temporary. After the accident, BP developed a new corporate trailer siting policy that provided exclusion zones for areas where explosions are possible.

### **PEAC Tool Use by Industrial Facilities**

The PEAC tool is primarily developed for use by first responders in the event of a toxic chemical release, fire, or explosion. It also contains an extensive database on the physical properties, reactivity, and health hazards of many thousands of chemicals. There are over 100,000 chemical names in the database. There is also information on cleanup in case of a spill. Evacuation zones are presented in case of a toxic chemical release, explosion, or fire. The tool is designed to give results quickly with the user supplying only a minimal bit of information.

A safety inspector taking a walk through the facility might input information on flammable chemicals and establish exclusion zones for vehicle traffic or location of trailers, or for clearing the area of nonessential personnel during critical operations. The user might input information on the size of the vessels and assume a worst case where the vessels are nearly full and all of the flammable chemical is released, vaporized, and ignites in a vapor cloud explosion.

In the case of a non-flammable, toxic chemical release the action taken will be different. The chemical facility should have in place a plan for evacuation and/or shelter in place to minimize exposure from an airborne chemical cloud. The PEAC tool can provide information on exposure to the chemical as it travels downwind from the release site. The tool is designed for responders to go through a variety of different release or weather scenarios quickly.

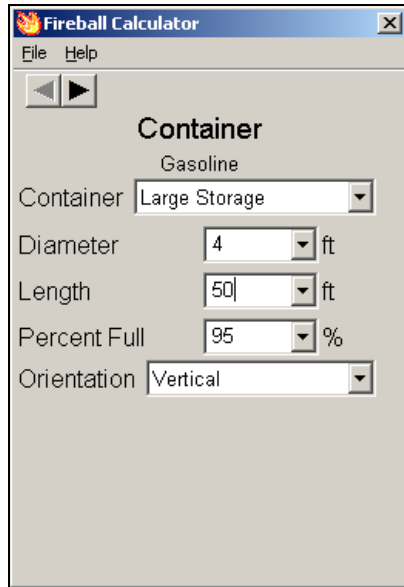
The Environmental Protection Agency requires industry to have in place a facility off-site consequence analysis in the case of release of flammable or toxic chemicals. The analysis should include a worst-case scenario, where all of the chemical stored or used is released at once and explodes or becomes airborne as a toxic cloud. The worst-case weather condition for a toxic cloud for this type of analysis is the clear nighttime, low wind speed condition (the so-called “F stability”). About 200 chemicals are covered by the regulations. This is in addition “Community Right-to-Know” regulations where companies are to provide information to fire departments, local emergency planning committees, etc., on what hazardous chemicals are stored or used on site. There are also Occupational Safety and Health Administration (OSHA) regulations of worker safety including limiting exposure to toxic chemicals.

The screenshot shows the PEAC-WMD software interface. At the top, there is a menu bar with 'File', 'Edit', 'Tools', and 'Help'. Below the menu bar is a toolbar with various icons for search, zoom, and other functions. The main window is divided into several sections:

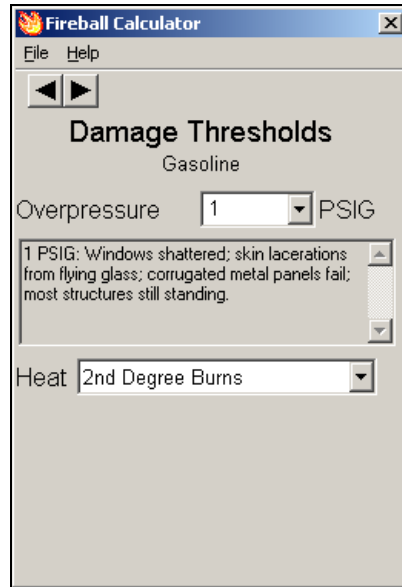
- Lookup By:** A dropdown menu set to 'Name'.
- Lookup:** A text input field containing 'gasoline'.
- Chemical Information:** A dropdown menu set to 'Chemical Information'.
- Search Results:** A list of search results for 'gasoline', including various language versions and related terms like 'GAS VENENOSO', 'GASOLINA', and 'GASOLINE BLENDING STOCKS: ALKYLATES'. 'Gasoline' is highlighted in blue.
- Chemical Information Panel:**
  - Gasoline** (CAS 8006-81-9, UN 1203)
  - [GUIDE 128 - Flammable liquids \(non-polar / water-immiscible\)](#)
  - Colorless-amber volatile liquid; petroleum odor
  - Known Carcinogen
  - NFPA Information:**
    - Health (Blue): 1 Slightly Hazardous
    - Fire (Red): 3 Flash Point < 100°F
    - Instability (Yellow): 0 Stable
- Bottom Panel:** A text input field containing 'Gasoline'.

Let’s see how this might work. A safety inspector going through a refinery notes a piece of process equipment which contains heated light end hydrocarbons which is a major component of gasoline. Assume a worst-case situation where level controls fail, the vessel is overfilled, and

the vessel contents spill and vaporize. Assuming the vessel is four feet in diameter and is 50 feet tall, what is the maximum blast distance if the entire vessel contents vaporize and ignite. The PEAC user types in the word “gasoline” under “lookup” and then clicks on the red and yellow blast/fireball icon [🔥] pictured at left to initiate the calculation for blast effects and the fireball. There is also a scroll down bar where the user can also get information on the physical properties and health effects on exposure to gasoline, but we are not interested in this now.

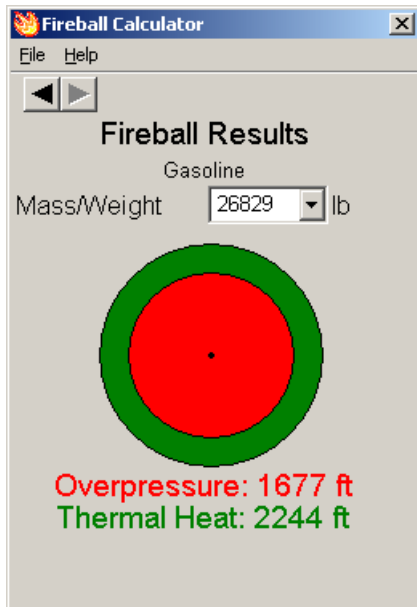


**Specifying the container size**



**Specifying damage thresholds**

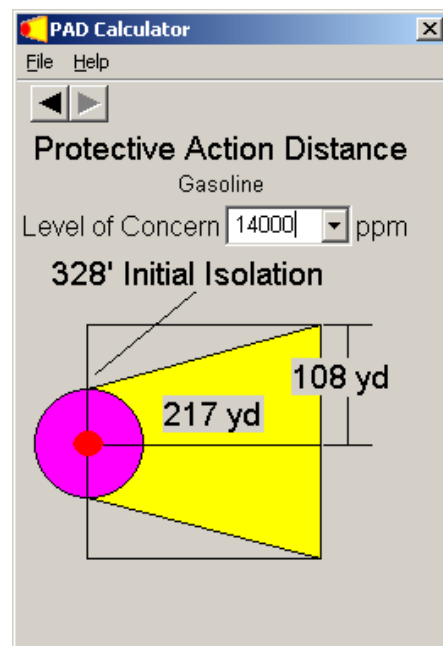
A screen pops up as shown above (left side). The user types in the vessel dimensions, and then clicks on the black arrow [▶] at the top left to proceed further. The PEAC tool then asks the user to input a blast overpressure and a heat damage choice (above, right side). For this example, we will chose 1 psi overpressure (windows shattered, most structures still standing but trailers may be severely damaged). We will ask the tool to also calculate the threshold distance for second degree burns (ignoring secondary fires and any pool fires).



**Calculated standoff distances**

the information, and print it later. A safety inspector can generate his lists as he/she walks through the facility, and use this information for developing exclusion zones for trailers and for possible ignition sources such as vehicles. The PEAC tool also automatically will display the standoff distances on a street map.

The Lower Explosive Limit for gasoline is 1.4%. This is equivalent to 14,000 parts per million by volume in air. By clicking on the PAD icon on the first screen, the user can estimate a distance downwind corresponding to 14000 parts per million. The worst-case scenario is for all of the gasoline to be released at once, and a clear nighttime sky at under a low wind condition. We will set the PEAC internal clock to a nighttime, specify clear skies, urban condition, a wind speed of 2 miles per hour, and a sudden mass release of 26829 lbs as calculated previously. The PEAC tool calculates that the concentration < 14000 ppm for vapor cloud explosion extends out to 217 yards (651 feet). Under daytime conditions or windy conditions, the distance will be less. This type of analysis may be useful in estimating ignition exclusion zones. The 328 foot initial isolation zone distance came from the 2004 Emergency Response Guidebook, published by the Department of Transportation, and does not apply here.



The Protective Action Distance can, of course, be based on toxicity and not on the Lower Explosive Distance.

The PEAC tool estimates the mass inside the container (ignoring end curvature) and the blast distance corresponding to a 1 psi overpressure. Assuming that a fireball immediately follows, the PEAC tool also calculates the distance to threshold of second degree burns for exposed flesh (ignoring any secondary fires or explosions). Because of uncertainties of the vapor cloud shape a safety factor of two is applied to all distances from ground zero. At 1 psi overpressure, windows break, and there is structural damage to trailers. The overpressure distance calculated is greater than experienced in the BP accident probably because less hydrocarbon (gasoline) was involved in the BP explosion, and the PEAC tool has a safety factor of 2 on distance. The PEAC tool is not limited to distance calculations linked to 1 psi overpressure or to the threshold for second degree burns. Other overpressures and damage estimates can be entered. The PEAC calculator can generate a list of damage estimates as a function of distance from ground zero, store

The important thing is that a tool is available for developing exclusion zones and dealing with safety issues.