Explosion and fire at a pesticide manufacturing plant

28 August 2008

Institute, West Virginia

United-States

Runaway reaction
Methyl isocyanate (MIC)
Procedures / operational guidelines
Management of changes
Operation restart
Operations in a degraded mode
Ageing
Intervention difficulties / communication

THE FACILITIES INVOLVED

The site:

The agro- pharmaceutical plant mainly products pesticides and is located on a multi-tenant facility (7 tenants / 16 production units and 5 utility units). This large chemical complex covers 2 km² on the kanawha river, 15 km west from Charleston. It is located in a populated area near the west Virginia state university.

About 520 employees work for the operator on the site, divided in several manufacturing units, each using highly toxic or flammable chemicals, including MethylIsoCyanate (MIC), the highly toxic chemical involved in the Bhopal accident and used to produce carbamate pesticides.

The MIC production is stored underground in a 90.6 t vessel. MIC is daily pumped to production units through jacketed pipes provided with safety devices (leak detection in jacket space, isolation valves, nitrogen purge after use…).

A MIC “day Tank” is situated at about 20 m from the Methomyl unit. It is made of stainless steel, 2.4 m diameter and 5.8 m tall with a max pressure of 5.2 b for a max fill of 16.8 t. This insulated and refrigerated reservoir is equipped with safety measures (redundant pressure, temperature and level instrumentation, emergency dump tank…) and protected from domino effects (projections) with a steel shelter (“blast blanket debris shield”). At the time of the accident, the reservoir was filled with 6.2 t of MIC.

MIC day tank shield blanket structure

(Picture CSB – R.R.)

The involved unit:

The Methomyl / Larvin unit, where the accident took place, is in service since 1983. The Control system of the Larvin unit has been upgraded during the summer 2007.

During summer 2008, the Methomyl unit is shut down for several month for the upgrading of the control system together with the installation of a new “residue treater” [1].

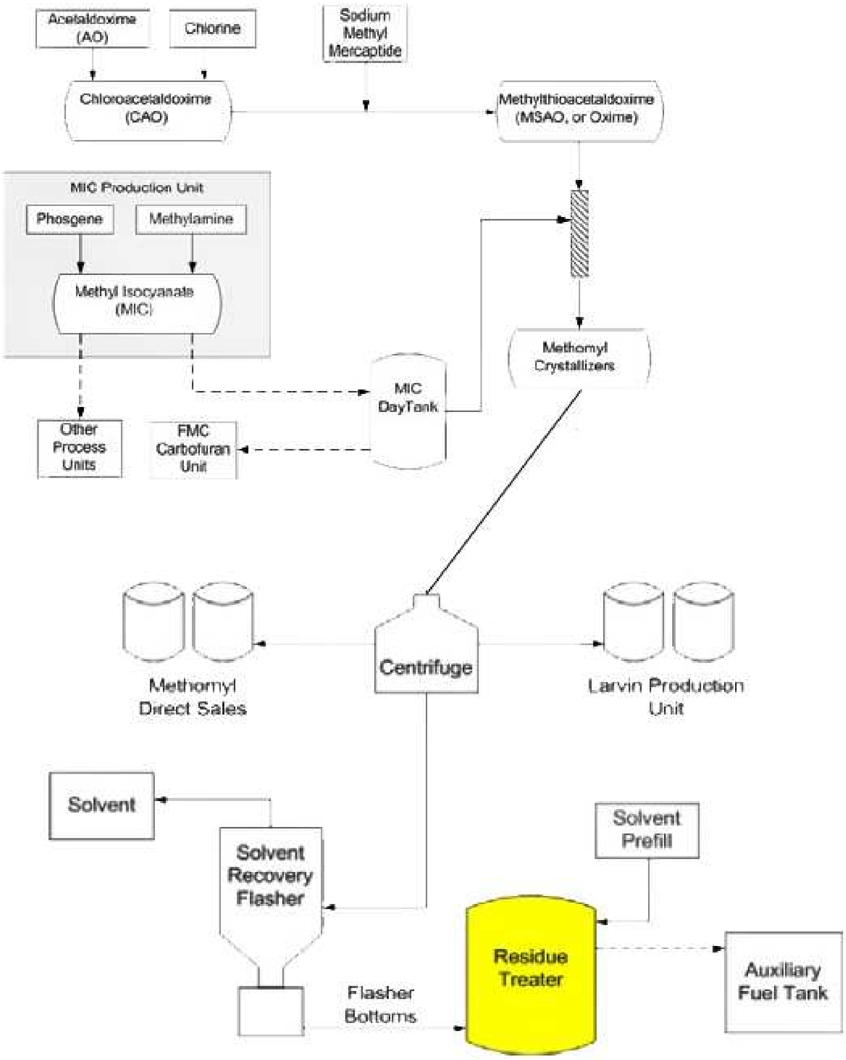
This 17 m^3 pressure vessel (max press. 3.5 b) is used to decompose residual Methomyl at a high temperature and using a methyl isobytyl ketone solvent (MIBK) so that the waste solvent (containing not more than 0,5% by weight of Methomyl) could be used as a fuel elsewhere in the plant.

Vapour generated in the Methomyl decomposition reaction exited through the vent condenser to the process vent system where toxic and flammable vapour were removed.

[1] The “vessel mechanical integrity program” inspection results found that the 25-year-old vessel had sustained significant wall thinning due to generalized corrosion. Using its management of change (MOC) program, the operator planned to replace the vessel with a new stainless steel pressure vessel to improve corrosion resistance. The existing recirculation piping, controls, and instruments were not modified.

The process is highly energetic (exothermic reaction) and is carefully controlled (cooled down) to prevent runaway reactions.

Methomyl process :



Old residue Treater / Picture CSB (R.R.)

The plant management has been modified between 2004 and 2007. It shifted from an organisation with rotating shifts consisting of first-line supervisors who directed the work of a team of operators, to a different structure, with the first line supervisors in each unit being “replaced” by 2 day-shift workers (a technical advisor and a run plant engineer) and one shift leader responsible for all facility operations.

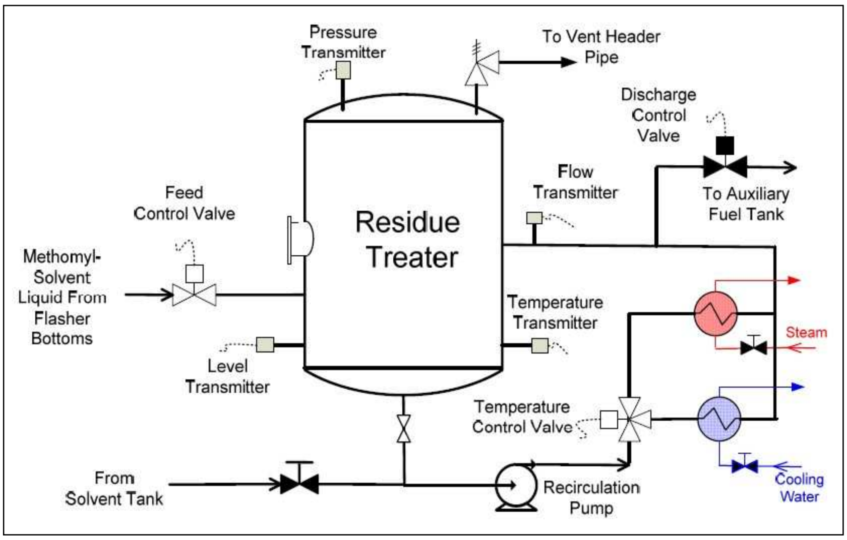
Those changes resulted in the loss of a work-checking function done by the first line supervisor but inexistent in the new system, as the technicians did not report directly to the technical advisor.

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

Due to a growing demand of his pesticide, the operator was eager to restart the unit as soon as possible. The Methomyl unit thus restarted on august 21, with the Methomyl production starting on Wednesday, august 27.

The restart was premature : the new control system is used for the first time and the workers, despite numerous working hours (overtime), faced several difficulties (technical problems, incomplete calibration of the new computing system…).



The operating procedure specifies that the waste tank vessel has to be prefilled to a level of 30% with "clean" solvent and heated before introducing residues coming from the solvent recovery flasher bottom ; this would dilute and heat the incoming residues, allowing an immediate start of the decomposition process rather than a dangerous accumulation of Methomyl. The procedure also specifies, in certain cases (when the temperatures drops below 130℃ or during start-up…) to control the Methomyl concentration in the tank, as the risk of runaway reaction had been identified if the concentration toped 1,3%.

To prevent the accumulation of Methomyl during start-up, a safety interlock would prevent the Methomyl to enter the reservoir if the temperature was too low, the pressure too high or if the fluid recirculating loop was not established.

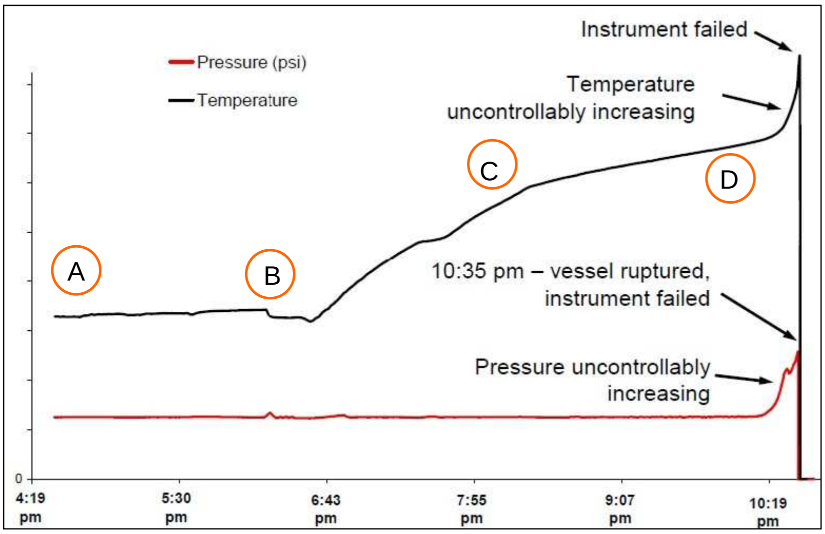
Numerous equipment problems diverted the operators from supervising closely the waste tank. On the day of the accident, they forgot to prefill the tank with clean solvent. Adding to that, it was common practice to by-pass the safety interlock of the residue treater; the operators, with the support of thesupervisor, did so, using a password on the new computer system.

A – At 4 am, the residues entered the tank, whose temperature was too low and without recirculating loop.

The first analyses of the content of the tank were not carried out, as the Methomyl concentration was supposed to be low during the start-up phase.

The status of the tank was not discussed during the shift change at 6 am, other problems having precedence.

B – Among other examples, the outside operator of the day shift did not know that the filling of the tank had already started when he activated at 6.14 am the recirculation pump upon demand of his colleague in the control room.



The level of liquid in the waste tank was approaching 30 % (5 m^3) and the temperature (65 ℃) was well below the necessary temperature to decompose Methomyl (135 ℃).

Adding to that, problems with the crystalliser led to significantly higher concentrations of Methomyl in the residues. The operators, facing difficulties with the centrifuge and crystallisers, did not review the lab results indicating a Methomyl concentration of 4 % in the liquid exiting the centrifuge and going to the solvent recovery flasher (8 times the specified operating limit). As a consequence, the Methomyl concentration in the residues from the recovery flasher bottoms entering in the empty tank reached 40 % for a “normal” value of 22 %[2].

C - The over-concentrated residues started to decompose in the waste task, producing heat.

D - The exothermic reaction then self-accelerated. By 10 pm, the temperature in the reservoir was approaching the safety operating limits (140℃) and climbing.

By 10:17 pm, the pressure rose in the reservoir, but went unnoticed by the technicians, who were dealing with other equipment problems.

At 10:25 pm the residue treater high pressure alarm activated. The board technician mistakenly believed the pressure went high because the vent pipe had become blocked, as it already happened before. Consequently, he sent 2 technicians to check the vent pipe and set the cooling system to full.

But the runaway reaction could not be controlled. Around 10:33, the tank relief valves opened, followed by the violent rupture of the residue treater, destroying part of the production unit (piping, electrical conduit and a structural steel support column).

More than 8 m³ of flammable and toxic materials sprayed onto the road and into the unit and immediately erupted in flames as severed electrical cables or sparks from steel debris striking the concrete ignited the solvent vapour. The whole unit sat on fire.

Consequences of the accident:

The two employees who went to investigate why the pressure was unexpectedly increasing in the residue treater where fatally injured. One died immediately from trauma and burns ; the other, transported to a Burn Center, died 41 days later.

Six fire-fighters who assisted the operator’s fire brigade at the unit reported possible chemical exposure symptoms. Two external employees working at the facility the night of the incident also reported chemical exposure symptoms, but none reported acute or long-term effects.

The residue treater severely damaged the unit (Picture CSB - R.R.)

Inside the factory, the blast overpressure moderately damaged the unit control building and other nearby structures. Debris was thrown some 50 m in all directions. Flying debris struck the protective steel shield blanket surrounding the MIC “day tank”, but fortunately did not damage it, avoiding a toxic domino effect. The steel blanket also protected the MIC day tank from the radiant heat generated by the nearby fires that burned for more than 4 hours.

Outside of the site, residences, businesses, and vehicles sustained overpressure damage that included minor structural and minor exterior damage and broken windows, 2.5 km from the explosion centre (main directions along river banks), with on case being reported at 10 km.

The energy of the explosion was estimated to an equivalent of about 7.7 kg of TNT. Acrid, dense smoke drifted over Interstate 64 and nearby roads to the north of the facility, forcing many road closures, disrupting highway traffic and forcing about 40,000 residents to remain confined at home for about 3 hours.

The operator received claims for external property damage whose amount reached 37,000 $ (25 000 €). The internal costs due to property damage were not disclosed.

MIC air monitoring devices in the unit were not functioning at the time of the incident, preventing the accurate measurement of any MIC release from piping or equipment that might have resulted from the explosion and fires. Therefore, the toxicity of the plume was not deeply investigated. Detectors inside de MIC production unit did not detect any abnormal concentration. There were no report of river water contamination from fire suppression water runoff.

[2] Despite the hazard identification in the process hazard analysis, the standard operating procedure did not require sample collection and analysis and no sample collection point was available on the system.

The European scale of industrial accidents

By applying the rating rules applicable to the 18 parameters of the scale officially adopted in February 1994 by the Member States' Competent Authority Committee for implementing the '*SEVESO II*' directive on handling hazardous substances, and in light of the information available, this accident can be characterised by the four following indices:

The parameters composing these indices and their corresponding rating protocol are available from the following Website: http://www.aria.developpement-durable.gouv.fr

Two parameters are involved in determining the rating level of the "hazardous materials released" index: Q1 and Q2:

- The released quantity being about 2.6 t of highly toxic (and flammable) material, it builds up to 13% of the Seveso threshold for highly toxic substances (20 t), which produces a level of 6 for the Q1 parameter.
- The TNT equivalent of the explosion was estimated at 7.7 kg, and the distance at which windows have been broken reached 2.5 km. Hence, parameter Q2 is rated at a 1 level.

Consequently, the "dangerous materials released" index reaches 6.

Seven parameters are involved in determining the level of the "Human and social consequences", among which 4 are known in this rating: H3, H4, H5 and H7.

- Parameter H3 reached level 3, since 2 employees died.
- Parameter H4 reached level 2: 1 fire-fighters spent more than 24 h in hospital for intoxication.
- Parameter H5 reached level 2: 2 external employees and 5 fire-fighters being intoxicated.
- Parameter H7 reached level 5 due to the number of people who were confined for more than 2 hours (40,000 people during 3 h).

As a result, the overall "Human and social consequences" index rating is 5.

No real environmental investigations have been carried out (toxicity of the smoke ?), but no river water contamination from fire suppression water runoff has been reported either. The index thus appears at 0 as a default value.

The amount of external property damage was evaluated at 37,000 $. The costs of the internal property damage were not disclosed. However, the parameter "economic consequences" can be approximated to 4. Indeed, according to press reports, the costs of rebuilding the unit would amount to $ 25 million (20 million € - which can be assimilated to parameter € 15 for the amount of damage).

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

The exothermic decomposition reaction to the arrival of the process flow is a "normal " phase of the process, however because of equipment problems upstream, leading to poor crystallization of Methomyl in the previous step, as well as forgetting the pre-fill of the tank with clean solvent and preheating, the concentration of Methomyl in the residue treater was increased tenfold, which led to a runaway reaction and an increase in pressure that exceeded the resistance of the discharge system then the residue treater.

Several causes or circumstances, mainly organisational and human deficiencies, can be raised in this accident. They are presented below in order of appearance of items in the Seveso Directive (Annex III on the safety management system - SGS).

1 - Organisation (description of roles and responsibilities of employees, staff management)

Because of changes in internal organisation, technical assistance staff was insufficient, particularly in view of the importance of this start-up phase. The days preceding the accident, the only adviser assigned had worked 15 to 17 hours per day and 10 hours straight the day before the accident. Throughout the evening before the accident, operators have attempted to stabilise the operating conditions in the Methomyl unit, while the Technical Advisor had already left for the day.

During this critical first startup using a new control system, management should have ensured that a highly experienced Technical Advisor was assigned to the control room staff during both shifts. The plant engineer, supposed to be a second technical assistance was mainly involved working on improvement and repair projects, and turnarounds. He had little involvement on day-to-day operational support. Finally, the production leader worked the day shift and was responsible primarily for administrative activities and therefore had little interaction with the operators related to unit startup and operation.

The organisational changes directly contributed to the incident causes. With the self-directed team organization in place, management did not directly advise or control the unit restart schedule. Furthermore, management was so far removed from the process operation that they were unaware that the operators seldom used the standard operating procedures and some bypassed the critical safety interlocks, which directly led to the residue treater explosion.

2 - Formation

Operation personnel were inadequately trained to operate the Methomyl unit with the new, and yet not sufficiently calibrated, distributed control system (DCS).

3 – Risk identification and evaluation

The standard Pre-startup Safety Review (PSSR) was not applied to the Methomyl control system redesign project.

4 – Process control

Some procedures were incomplete or unrevised after the summer changes.

The level of the residue treater was very high : the residue treater liquid level control was designed to operate in an automatic, continuous flow mode. However, in this operating mode, the flow rate was very low. Thus, the transfer pipe frequently became plugged with viscous material. Therefore, the board technicians kept the level controller in the manual operating mode and allowed the residue treater level to increase to the upper fill limit, and periodically transferred the liquid at a much higher flow rate to prevent the line from becoming plugged. The standard operating procedure had not been revised to incorporate this change, which risk was never assessed.

The out-of-specification Methomyl-solvent mixture was fed to the residue treater before the residue treater was pre-filled with solvent and heated to the minimum safe operating temperature. The risk of runaway reaction was identified in the process risk analysis if the Methomyl concentration exceeded 1.3%; however, the operation procedure did not mention any control of the Methomyl concentration of the solvent recovery flasher bottoms. Thus, the operators were not aware that it was too high.

Insufficient shift change communication : technicians maintained an electronic notepad on the computer system to summarize daily progress and identify ongoing activities for the incoming shift. They also held a verbal turnover meeting in the control room when shifts were changing. However, a number of key items were inadequately addressed in the shift change during the morning and evening shift changes the day of the incident (maybe due to the many difficulties encountered).

5 – Management of change

Neither the equipments nor the DCS were tested and calibrated before the unit was restarted. The procedures have not been revised to incorporate “operator’s practices” or changes introduced at the residue treater level.

6 - Emergency Management (procedures, emergency plans and exercises)

The communication of information towards the different stakeholders including local authorities was faulty, leading to the confinement of 40 000 people for 3 h.

In addition to the organisational deficiencies, equipment malfunctions (broken valves, missing or misaligned, dysfunction of the crystallizer ...) and poor validation of the control system prevented the technicians from achieving correct operating conditions in the crystallisers and solvent recovery equipment.

Destruction of the unit and former place of the residue treater vessel (picture CSB / R.R)

ACTIONS TAKEN

Emergency response

The in-house fire brigade responded quickly to the accident. In application of a mutual aid emergency response protocol, external Fire Departments arrived in less than 10 minutes in support. However, poor communications[3] with the Metro 9-1-1 call centre delayed the community shelter-in-place notification and interfered with effective off-site response activities.

The St. Albans fire chief, unable to obtain specific information about the chemicals involved or the extent of the incident, assumed that the smoke drifting across the river might contain toxic chemicals. After many unsuccessful attempts to communicate directly with the operator's incident commander (IC) during the first hour of the incident, the Kanawha/Putnam County Emergency Management director declared a shelter-in-place, which affected approximately 40,000 residents during 3 hours.

US Chemical safety and Hazard investigation board (CSB) investigation

The CSB investigated the accident and issued a report, a video as well as recommendations to operators, governmental and local authorities [1]. The investigation included an examination of the residue treater and its associated process equipment; the MIC day tank, blast blankets, and support structure; an overview of the control building damage; the mapping of the debris field; interviews of the employees working at the facility on the night of the incident; and interviews of outside emergency personnel who participated in the response. The CSB investigators also examined Methomyl unit operating procedures, control system data, process chemistry documents, worker training records, and maintenance records. Finally, the CSB commissioned computer modelling to evaluate the blast shield used to protect the MIC day tank.

It is to note that the operator attempted to use the US Maritime Transportation Safety Act (regulation concerning transport security) to restrict CSB investigative activities, block public disclosure of information, especially related to MIC, hoping it would avoid possible negative publicity. The delay in the public disclosure of the information and the related controversy it created resulted in a modification of the regulation to prevent its future misuse.

In 2010, the operator agreed to pay $143,000 (100 000 €) in fines for violations of federal workplace safety regulations (poorly planned operating procedures, flawed emergency systems and faulty employee training…). In return, 4 of the original 13 citations were dropped [2].

After the accident, the operator stopped the Methomyl production at the Institute facility. The operator also reduced the MIC storage by 80 %, eliminated all aboveground MIC storage and revised the MIC system Process Hazard Analysis.

[3] The different emergency response agency did not use a shared network to communicate. Thus, the responding agencies did not receive timely status updates.

LESSONS LEARNT

This accident underlines the importance of a detailed process hazard analysis and a full safety review before a new start-up including a verification of the completion of modifications, safety devices, computer system checks, technician training…

Unit start-ups should be done under the reinforced presence of qualified personnel in order to cope with the situations that can arise (equipments not operating properly, technical difficulties…). The communication between the teams in shifts is also essential not to lose information on possible ongoing difficulties. Finally, “field controls” should allow the verification of the adequacy between written and operating procedures to avoid “paper safety”.

Possible domino effect (MIC DAY Tank structure Design)

This accident also underlines the importance of the study of potential domino effects. The analysis of the structure of the MIC day tank concluded that the structure provided only marginal impact energy absorption protection from a large fragment strike at velocities predicted to result from an explosion such as the one that happened. Had the residue treater travelled in the direction of the MIC day tank, and struck the shield structure, the relief valve vent pipe might have been impacted, causing the release of highly toxic MIC vapour into the atmosphere (domino effect), which could have led to much catastrophic consequences in a urbanised area. That is why the operator reduced the risks created by the MIC storage at the source after the accident (see above / actions taken).

Emergency Planning, response and communication

This accident showed the importance of appropriate emergency planning and response between all actors. The responding municipal, county, and state agencies need to receive updated and reliable information regarding the status of the incident throughout the response, including the potential exposure to toxic substances (both to protect the responders and ease the shelter-in-place decision-making process).

To address the communication issues that occurred during the accident, local authorities developed new tools and processes for dealing with emergency situations in the Kanawha Valley. The following emergency response improvements were implemented:

- Creation of a list of questions to use when any fixed facility calls the centre and training of all telecommunications personnel,
- Establishment of one-mile zones around fixed facilities for rapid, automatic reverse ringdown phone calls in the event of a release.
- Development of a protocol for notification including processes for emailing residents (as well as sirens) in the affected zone when a release occurs,
- Increase of the call centre phone capacity by 50 percent to address increased telephone traffic during emergencies.

Health and environmental impact (see part on the consequences)
Especially in case of accidents involving toxic chemicals, the health and environmental impact should be investigated during and after emergency response, in order to adequately protect not only fire responders, but also the general public.

REFERENCES (INCLUDING PICTURES)

[1] The main information regarding this accident is the final report of the CSB investigation, including the recommendations and a video animation of the waste tank rupture. All the documents are available at : http://www.csb.gov/investigations/detail.aspx?SID=3&Type=2&pg=1&F_All=y

Media coverage :

- [2] http://www.allbusiness.com/government/government-bodies-offices/14210305-1.html
- Explosion ‘Dangerously Close’ to Second Bhopal http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aOnvwuLxlF.Y
- http://www.newsinferno.com/legal-news/bayer-plant-explosion-leaves-one-dead-in-west-virginia/
- http://www.youtube.com/watch?v=Fmx4ZSIq0QA 911 tapes (on emergency response difficulties)
- http://www.youtube.com/watch?v=yokbh8GpB3w Explosion coverage