

**EXPLOSION AND FIRE
AT THE PHILLIPS COMPANY
HOUSTON CHEMICAL COMPLEX, PASADENA, TX**

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In the discussion that follows, it is important to realize that the development of OSHA standards is a lengthy process and that two standards ostensibly of particular interest to the Phillips 66/Pasadena event were not yet in place. The development of the first of these, 29 CFR 1910.147: Control of Hazardous Energy Source (Lockout/Tagout), began in January 1977, when OSHA issued a "Request for Technical Issues and Notice of Public Meetings". After receipt and evaluation of many comments from interested parties, OSHA issued an Advanced Notice of Proposed Rulemaking on June 17, 1980. The preliminary draft of the standard was issued for comment in July, 1983; was published in the Federal Register as a proposed standard on April 29, 1988; and became effective on October 31, 1989.

The development of the second of these pertinent standards, 29 CFR 1910.119: Process Safety Management of Highly Hazardous Chemicals, was based on lessons learned from a series of tragic events, among them Flixborough (1974), Seveso (1976), and Bhopal (1984) and the fear that unless significant improvements in chemical process safety occurred, an "American Bhopal" would probably happen. The Center for Chemical Process Safety of AIChE was formed in 1985 partly in response to that probability. In 1985, the U.S.E.P.A. initiated a program in response to the potential for catastrophic releases, followed in 1986 by Title III of SARA.

A series of serious releases of highly hazardous chemicals from a plant at Institute, WV, in August, 1985, indicated to OSHA that a program was needed to examine the industrial practicality for the prevention of disastrous releases and the mitigation of the effects of non-preventable releases. The primary result of this program was the determination by OSHA that a comprehensive inspection approach was needed which would evaluate both physical conditions and management systems. This result was the genesis of OSHA's process safety management standard. It was based in part on input from public testimony and publications by CCPS and many other organizations. Notable among them was Recommended Practice 750: Management of Process Hazards published by the American Petroleum Institute in 1990. The OSHA process safety management standard was formally proposed on July 17, 1990, and became effective on May 26, 1992.

On October 23, 1989, a massive explosion demolished the Phillips 66 Company polyethylene plant in Pasadena, TX, (a Houston suburb) when more than 85,000 lb_m of flammable material was instantaneously released to the atmosphere. This massive gas cloud was ignited within less than two min. The initial explosion threw debris as far away as six miles and registered between 3 and 4 on the Richter scale on Rice University seismographs. There were many secondary explosions. In all, 23 lives were lost and 314 people were injured. Capital losses were initially estimated at over \$715 million. Business disruption losses were nearly as great, \$700 million.

Background

High-density polyethylene is manufactured in Plants IV and V (Figures 1 and 2) of the Houston Chemical Complex (HCC) at high temperature and pressure. The reaction is one of condensation polymerization of about 95% ethylene dissolved in isobutane. Other chemical species (hydrogen, hexane, etc.) are present in the highly flammable reaction mixture in order to meet product requirements. The resulting polyethylene particles (fluff) are removed from the settling legs (Figure 3 and 4) of each reactor through a product take-off valve at the bottom of each leg. In the event that the settling leg or the product take-off valve becomes clogged with product, the settling legs can and must be isolated from the reactor by closing a large (8-in.) ball valve (Figures 5-7, Demco® brand) installed where the settling leg joins the reactor. If the Demco® valve were open during any cleaning-out operation, the reactor contents would be vented directly to the atmosphere. These ball valves are operated by compressed air. In the case of reactor 6 of Plant V, the compressed-air hoses are physically disconnected as a safety measure when the valve is closed for maintenance. Unfortunately, the air connections for opening and closing this valve were identical. There appears to have been no way for a Phillips 66 employee or contract employee to tell whether the valve was rotated open or closed.

"A major function of this [8-inch Demco ball] valve is to isolate the settling leg and other equipment downstream from the reactor for maintenance. The procedure for maintenance work that was being performed on this settling leg at the time of the accident required that this valve be closed, locked out, and the air supply that operated the valve removed. Statements from both hourly and supervisory personnel who work in this plant confirm that the details of this procedure and the consequences of not following it were well known and clearly understood.

"It has been established by statement[s from] employees who worked in the polyethylene Plant V on shifts preceding the October 23 day shift that, according to procedures, the Demco valve on the No. 4 leg of Plant V, reactor 6, was closed, the lockout device was properly installed, airline block valves were closed, the air lines to the cylinder that operated the Demco were disconnected, and the settling leg and transfer lines to the flash chamber were ready for maintenance. The lockout and air line disconnection had been performed on the preceding Saturday, but, because of work priorities, maintenance did not begin on this leg until Monday, October 23 (Silas and Cox, 1990)."

At about 1:00 – 1:05 pm. on October 23, 1989, an explosion occurred as a result of a massive gas release from reactor 6: more than 85,000 lb_m, or 99% of the reactor contents were released almost instantaneously. Within 90-120 sec., this gas mixture "found" a still-unidentified ignition source and exploded with the force of 2.4 tons of TNT. Potential ignition sources were a forklift, a gas-fired catalyst activator with an open flame, nearby welding and cutting-torch operations, vehicles near the polyethylene plant office building, and electrical gear in the finishing building and control rooms. This initial explosion threw debris for about six miles and, according to seismographic data from Rice University, registered between 3 and 4 on the Richter scale. A pair of secondary explosions occurred about 10-15 min. after the first one when two 20,000 gal. isobutane storage tanks exploded. About 25-45 min. after the first explosion, another polyethylene reactor failed catastrophically. There may have been as many as six more explosions in all.

As a result of the initial explosion, two of the six-man contract maintenance crew and 21 employees of Phillips 66 were killed. Of the fatalities, 22 died at the incident site, and a 23rd victim died in a local hospital. All those killed were within 250 ft of the point where the gas was initially released. That release occurred, as determined by post-incident tests by the FBI, through the open Demco® valve at the top of settling leg number 4 on reactor 6. Those tests also showed that the hoses which supplied the compressed air to rotate the valve to the "open" or "closed" positions had been improperly reversed when last re-connected prior to the product blockage-clearing procedure in progress. As a result, the valve would have been in the "open" position when the actuator switch in the control room was in the "valve closed" position.

Cause of the Explosion

According to the Report to the President (Occupational Safety and Health Administration, 1990), "Established Phillips corporate safety procedures and standard industry practice require backup protection in the form of a double valve or blind flange insert whenever a process or chemical line in hydrocarbon service is opened. Phillips, however, at the local plant level, had implemented a special procedure for this maintenance operation which did not incorporate the required backup. Consequently, none was used on October 23.

"Additionally, the following unsafe conditions existed: (1) the DEMCO® valve actuator mechanism did not have its "lockout" device in place, (2) the hoses that supplied air to the valve actuator mechanism could be connected at any time even though Phillips's operating procedure stipulated that the hoses should never be connected during maintenance, (3) the air supply valves for the actuator mechanism air hoses were in the open position so that air would flow and cause the actuator to rotate the DEMCO® valve when the hoses were connected.

"Field tests have since confirmed that the DEMCO® valve involved in the accidental release was capable of being physically locked in the open as well as in

the closed position. The valve lockout system for this maintenance operation was inadequate to prevent someone from inadvertently or deliberately opening the DEMCO® valve during a maintenance procedure."

According to the results (Silas and Cox, 1990) of the investigation of this incident by the Phillips 66 Company, "Examination of the evidence after the accident indicates that the lockout device had been removed and the air hoses had been reconnected to the valve operator on the Demco® valve of the No. 4 leg. The valve was open, and the settling leg was open to the atmosphere at the bottom of the leg where a swedge spool leading to the product take off valve should have been connected. Block valves to the air lines for the Demco and the piping leading to them had been damaged as a result of the explosion and moved, making their position meaningless. The evidence indicates the release occurred through this No. 4 open Demco valve and settling leg.

"The only surviving individuals believed to have been in the immediate area of the accident were employees of Fish [Engineering and Construction, Inc.]. In interviews with two of these employees shortly after the accident, one of the Fish employees placed a P66Co operator at the accident site. Statements made by a P66Co employee and the location of the body of the operator assigned appear to contradict this. Neither the HCC team nor the Committee were able to interview the Fish employees about the accident, making it impossible to determine the exact sequence of events leading to the release. However, the evidence suggest that either:

- 1) the lockout device was removed from the Demco, the air lines were reconnected, and the air line block valve was opened with the leg open to the atmosphere; or**
- 2) the lockout device was removed from the Demco, the air lines were reconnected, the air line block valve was opened with the leg closed to the atmosphere, and the leg subsequently was opened to the atmosphere without first relocking the Demco, closing the air line block valves, and removing the air lines.**

Either of these actions would have been a serious violation of well established and well understood procedures and would have created the conditions that permitted the release and subsequent explosion. "

In addition to the 23 deaths and 314 injuries (185 Phillips 66 and 129 contract employees), estimates (Mahoney, 1993) of the property damage at the HCC and the lost income due to disruption of business are \$715.5 million and \$700 million, respectively. Phillips 66 Company also agreed (USDoL, 1991) to pay a \$4 million fine and to institute process safety management procedures at four of its facilities. Another key component of the settlement involves training of on-site contractor employees as well as Phillips employees about potential hazards. The details of the settlement agreement between OSHA and Phillips 66 Company are reported in USDL/OSHA news release 91-416 of August 22, 1991. The settlement agreement between OSHA and Fish Engineering is described in USDL/OSHA news release 92-497 of August 4, 1992, and required payment of a \$100,000 fine and implementation of a corporate-wide safety and health program as detailed in the news release.

Response to the Explosion

Early Response

The initial response was provided by the Phillips 66 Company fire brigade which was soon joined by members of the Channel Industries Mutual Aid association (CIMA). This organization had 106 members in the Houston area at the time of the HCC fire and explosion. The mission of CIMA is to provide emergency assistance to members with regard to firefighting, search and rescue, first aid, and equipment. Site command and coordination was vested in the incident commander who was the Phillips 66 Company fire chief. Technical assistance was provided by a team from the US EPA. Cooperating governmental agencies were the Texas Air Control Board, the Harris County Pollution Control Board, the FAA, the U.S. Coast Guard, and OSHA.

Fire Fighting

The fire-fighting water system at the HCC was part of the process water system. When the first explosion occurred, some fire hydrants were sheared off at ground level by the blast. The result was inadequate water pressure for fire fighting. The shut-off valves which could have been used to prevent the loss of water from ruptured lines in the plant were out of reach in the burning wreckage. No remotely-operated fail-safe isolation valves existed in the combined plant/fire-fighting water system. In addition, the regular-service fire-water pumps were disabled by the fire which destroyed their electrical power cables. Of the three backup diesel-operated fire pumps, one had been taken out of service, and one ran out of fuel in about an hour. Fire-fighting water was brought in by hoses laid to remote sources: settling ponds, a cooling tower, a water main at a neighboring plant, and even the Ship Channel. The fire was brought under control within about 10 hr. as a result of the combined efforts of fire brigades from other nearby companies, local fire departments, and the Phillips 66 foam trucks and fire brigade.

Search and Rescue

All search and rescue operations were coordinated by the Harris County Medical Examiner and County Coroner. Search and rescue efforts were delayed until the fire and heat subsided and all danger of further explosions had passed. These operations were difficult because of the extensive devastation in the HCC and the danger of structural collapse on the search and rescue team. The Phillips 66 Company requested, and the FAA approved and implemented, a 1-mile no-fly zone around the plant to prevent engine vibration and/or helicopter rotor downwash from dislodging any of the wreckage. The U.S. Coast Guard and City of Houston fire boats evacuated over 100 trapped people across the Ship Channel to safety. OSHA preserved evidence for evaluation regarding the cause of the catastrophe.

Findings of OSHA's Investigation

The findings of OSHA's investigation of the Phillips 66 disaster involve deficiencies in what we now refer to as process safety management, emergency planning and response, building or facility egress and escape routes, and employee training. The most serious of these findings follow.

- 1) No process hazard analysis had been utilized in the polyethylene plant. As a result, many serious safety deficiencies were ignored or overlooked.
- 2) Phillips' own existing safe operating procedures (Silas and Cox, 1990) for opening lines in hydrocarbon service were not required for maintenance of the polyethylene plant V settling legs. Rather than rely on a single block valve (the Demco® valve), a double-block-and-bleed valving arrangement or a blind flange after the single block valve should have been used.
- 3) The single block (Demco®) valve on the settling leg was not designed to fail to a safe (closed) position in the event that the air pressure operating the valve were to be interrupted or to fail.
- 4) No provision was made for the development, implementation, and enforcement of an effective permit system for line opening, hot work, or vehicle entry into an area which could contain hazardous vapors, i.e., a Class I, Division 1 area.
- 5) Phillips did not follow adequate procedures such as ANSI Z244.1-1982 for lockout/tagout of equipment in a known hazardous area. Such procedures are now covered by 29 CFR 1910.147 which was not in effect at the time of this disaster.
- 6) No permanent combustible gas detection and alarm system was located in or near the polyethylene reactors to provide an early warning of leaks or releases.
- 7) Ignition sources (open flame on a gas-fired catalyst activator) were located near or downwind (The prevailing winds at the HCC were from SE to NW) from large hydrocarbon inventories. In addition, ignition sources (forklift truck, welding and cutting-torch operations and vehicles) were introduced into such high-hazard areas without testing for the presence of flammable gases.
- 8) Ventilation system intakes for buildings were located in close proximity to or downwind from hydrocarbon processes or inventories. The ventilation system for the Plant IV and V finishing building could draw in air containing flammable gases in the event of a leak or release in the Plant V reactor area. That situation could have resulted in a confined vapor cloud explosion.
- 9) The fire protection system, particularly the fire-fighting water supply and its associated pumps, both regular and standby, was not maintained in an adequate state of readiness to provide adequate fire-fighting capability as already discussed.

Other factors contributed to the extent and severity of this disaster. Four are especially notable:

- 1) proximity of high-occupancy structures (control rooms) to hazardous operations,
- 2) inadequate separation between buildings,
- 3) crowded process equipment, and
- 4) insufficient separation between the reactors and the control room for emergency shutdown procedures.

Recommended layout criteria and separation distances have been available (Lees, 1980; Mecklenburgh, 1973; Wells, 1980) for many years.

OSHA Citations

The major findings of OSHA's investigation of the incident provided the basis for the Phillips 66 Company citations (U.S. Department of Labor, 1990a) based on alleged willful and serious violations of OSHA standards. These deficiencies included three categories of willful violations as quoted from OSHA news release 90-193 of 4/19/90 and are summarized in the table.

- 1) "Failure to prevent the uncontrolled release of flammable vapors.
- 2) Failure to minimize or mitigate the consequences of a release of flammable materials.
- 3) Failure to provide adequate fire protection

and nine serious violations:

- 1) "Obstacles to safe egress from the facility.
- 2) No second means of egress.
- 3) Inappropriate evacuation routes for employees with no alternate routes established.
- 4) Inadequate emergency planning for water to fight fire.
- 5) Failure to provide medical exams to determine employees' ability to wear respirators.
- 6) Inaudible emergency alarm siren in the finishing building.
- 7) Failure to inform and train maintenance employees to work safely with hazardous chemicals.
- 8) Procedures were not established for emergency escape respirators.
- 9) Employees were not familiar with emergency evacuation procedures and hot work permits were not issued for vehicle entry

As a result of the settlement (OSHA news release 91-416 of 8/22/91) between OSHA and Phillips 66 Company, OSHA agreed to delete the willful characterization of the citations and the Company agreed to pay a \$4 million fine and to institute process safety management procedures at Pasadena, Sweeny, and Borger, TX and also at its facilities in Woods Cross, UT. The process safety management procedures include

- 1) "analysis of each process having the potential for an uncontrolled release of highly hazardous chemicals;
- 2) "evaluation of:
 - a) safety and hot-work procedures;
 - b) lockout/tagout procedures;

- c) proper electrical classification of hazardous locations and control over ignition sources introduced into those areas;
 - d) contingency planning for upset conditions and emergency response;
 - e) upset and emergency condition detection systems and systems to mitigate the scale of hazardous chemical releases;
 - f) siting, separation, and design and configuration of physical facilities and equipment to ensure safety;
 - g) training of operators, technicians and maintenance personnel;
 - h) safety of existing standard operating procedures and maintenance procedures; and
 - i) assignment of authority to plant personnel to identify and correct hazardous conditions;
- 3) “Phillips will
- a. prepare written responses to each process hazard analysis, detailing action to be taken or justification for not taking action if management disagrees;
 - b. promptly implement and document actions taken pursuant to process hazard analyses;
 - c. communicate actions to affected employees, including contractors; and
 - d. assure that all corrective action is completed.”

In addition, the Company will “develop and maintain a compilation of written safety information for employees and contractors. . . and communicate this information to all affected employees focusing on hazards of chemicals and information on the equipment and technology involved in the process. Phillips will also prepare written operating procedures to provide clear instructions for safely conducting process and maintenance operations.” As another part of the agreed worker education and training, Phillips “ will provide an overview to each employee involved in a covered process or maintenance operation of the process . . . pertinent operating procedures emphasizing safety. Phillips will conduct annual and refresher safety training or as needed when processes change. Employees will receive training before assignment to a process or maintenance operation.

“Phillips will inform contractors of any known potential fire, explosion or toxic release hazards of processes on which or near which the contractor[’s employees] will be working. The Company will ensure that contract employees are trained in necessary work practices and emergency procedures to do the job safely.”

OSHA also alleged (U.S. Department of Labor, 1990b) that Fish Engineering and Construction, Inc. was contributory to the 10/23/89 disaster and that willful and serious violations of OSHA standards had occurred. The deficiencies listed in the willful citations follow:

- 1) “Failure to require employees to use hot work permit [and]
- 2) Failure to obtain hot work permits when cranes were brought into the polyethylene unit.”

Among the serious violations were

- 1) “Failure to determine combustible gas levels and
- 2) Inadequate hazard communication and emergency procedures training.”

As a result of the settlement (OSHA news release 92-497 of 8/04/92), OSHA reduced the originally proposed fine from \$729,000 to \$100,000 which Fish agreed to pay. Fish also agreed to “implement a corporate-wide safety and health program to include

- 1) all items cited by OSHA and [the] conditions covered by [OSHA’s] general industry and construction standards,
- 2) other hazards subject to Section 5(a)(1) of the Occupational Safety and Health Act,
- 3) management systems already implemented . . . to address safety and health,
- 4) an audit program and an action plan, and
- 5) to correct any potential hazards noted in the audit program.”

Learning from the Disaster

As a member of the Channel Industries Mutual Aid association (CIMA) and as a result of its involvement with the Local Emergency Planning Committee (LEPC), Phillips met CIMA guidelines for equipment and training and had coordinated its emergency plans with other responders. After the explosion, representatives of CIMA, LEPC, the media, and local government began a year-long cooperative effort to review their emergency plans and to learn from the Phillips explosion (Richardson, 1991). The results of these efforts are divided into three parts: findings/critique, accomplishment, and recommendations.

Findings and Critiques

One of the principle findings was that worst-case scenario, such as the massive series of explosions, had not been considered in developing the emergency plan. Crisis management planning had been initiated at the corporate level, but was not complete when the explosion occurred. The incident reinforced the necessity and value of continuous employee training in emergency-response procedures. Phillips management found that participation in a cooperative emergency training and response network such as CIMA and LEPC was essential in providing the necessary manpower and equipment to the site in response to the emergency. Responders from the community and other industries were effective, not only because of their own training, but also because of mutual training in potential problems at each other’s sites.

The review revealed that efficient communication was severely hindered or at times impossible because of insufficient coordination among responders and with the media. It became obvious that a regional communication plan was needed, perhaps similar to that developed by the Harris County EMS base station.

The Phillips explosion provided the strongest of incentives for CIMA members, other industries, and local governments to review and update their emergency plans. As a result, working committees were established to develop recommended solutions to problems identified in the review. Four specific findings were developed. The first was that federal and state officials at the scene did not coordinate their activities, and in some cases, contradicted each other and plant officials when talking to the news media.

The second finding concerned critical sites. No backup emergency operation/command center had been pre-planned. Apparently, no plans had been made for the location of a triage station. The station was initially set up where some casualties were located, but had to be moved twice. The first move was caused by the second explosion in the Houston Chemical Complex. The triage station was re-located to avoid being caught in a 'kill' zone should an even larger explosion occur. The second move was necessitated by a change in wind direction that sent smoke from the burning plant over the new triage site. The third critical location was a series of pre-planned landing zones for helicopters with easy access for ambulances.

The third finding addressed the number of telephone calls jamming the lines for hours after the incident. Although the public and family members of Phillips employees were justifiably concerned and needed information, the number of calls delayed dissemination of that very information. The number of calls also delayed broadcasts on the Emergency Broadcast System by the staff of the Pasadena Emergency Operations Center. In addition, many Phillips and emergency personnel were tied up responding to the public and the media and were thus unavailable for other essential work (Richardson, 1991). Since the Phillips disaster, procedures for the development and evaluation of crisis communication plans have been summarized by Traverso (1993).

The fourth finding was that the warnings from the emergency operations center omitted information that the smoke and fumes were not toxic (Richardson, 1991).

Accomplishments

Among the accomplishments of the committees, three seem most important to chemical engineering faculty and their students. The first was the development of a control contact point for information about victims for use by the community emergency operations center and the facility involved in the incident. Another was the development of a checklist for reporting and responding to all types of emergency off-site incidents. The third was agreement on standard signals for outdoor warning systems.

Recommendations

The committees recommended that application be made for an emergency broadcast system transmitter to facilitate information transfer by plant personnel or the incident/emergency response commander. The committees also recommended that each site include a backup emergency operations center in its emergency plan.

Implications for Chemical Engineering Curricula

If we as faculty have learned anything from the Phillips 66 Company disaster, it is that we must teach our students how to behave as professionals. Such a student, upon graduation and reporting to work, will be able to

- **understand and use the important safety features and procedures within a plant environment,**
- **take ownership of all assignments and projects,**
- **promote effective teamwork,**
- **avoid or resolve conflicts within a team,**
- **listen discerningly to instructions,**
- **understand assignments and project objectives,**
- **critically review and assess assignment descriptions for omissions and redundancies,**
- **ensure that all team members understand their individual as well as the team's responsibilities,**
- **listen objectively to the concerns of team members,**
- **develop and refine plans for action, and**
- **develop and adhere to a reasonable time schedule for completion of all assigned or assumed tasks.**

Such a young professional seeks opportunities for developing his/her leadership skills and is fully aware that he/she is accountable for all of his/her actions. To reach this level, the young engineer will have developed effective communications and interpersonal skills and will have become a facilitator.

The students/engineers described will be able to function effectively and contribute their knowledge and skills to any team, whether in a design or unit operations laboratory course or as a company representative to or participant in a LEPC or a mutual aid organization such as CIMA. Such people will have had their skills honed by HAZOPs and other process hazard analysis techniques and will be willing to consider occurrence of even the most extreme event, e.g., total reactor or process venting followed by a series of explosions that leapfrog through the plant. These young engineers will be able to accept criticism, even if not always constructive, of their designs and analyses and be able to evaluate dispassionately the failures of their designs or procedures in order to learn from them as was done in the cooperative review after the Phillips disaster.

The young professional described above will not have at graduation all the chemical process safety, communications, etc. skills which he/she needs. The concepts of

inherently safer designs (intensification, substitution, attenuation, limitation of effects, and simplification as described by Kletz (1993)) can be woven into fundamental chemical engineering courses starting with process principles, unit operations, and thermodynamics, and reinforced in the process design course. Students can be exposed to the necessity of and procedures for selecting and sizing relief valves and safety valves in their basic sophomore fluids and thermodynamics I courses. Two-phase flow through safety relief valves is too complex for inclusion in such undergraduate courses.

Many common industrial training requirements can be previewed (Bethea, 1991) in process control and unit operations laboratory courses. This training can include lockout/tagout procedures, start-up inspection and start-up of equipment or (unit) processes, equipment/experiment shutdown, and emergency shutdown and evacuation procedures. Those laboratory courses can also be used to show the students how to prepare limited emergency plans and how to conduct at least one type of hazard analysis. The preparation of multi-part operating directions can be covered in engineering communications courses. Discussions of well-known accidents and incidents can be held as part of undergraduate seminars or even AIChE Student Chapter meetings. Auditing of departmental teaching and research laboratories, shops, and storage facilities to ensure that adequate procedures are in place to prevent the occurrence of incidents can be handled by a departmental safety committee composed of seniors and graduate students, with a faculty member as team leader. Hopefully, training of undergraduate students in the techniques of accident and incident investigation and reporting procedures will not be required as part of their laboratory work.

The Senior process and plant design course(s) can logically include electrical classifications of areas and the corresponding effects on site layout, distance requirements between types of facilities or processes, and control room location and design requirements. Wells (1980) and Lees (1980) are excellent sources of such supplementary material as is the Dow Fire and Explosion Index (1994). Control system design including selection of components, fail-safe designs, and hazard analyses of the resulting PIDs can be, and usually is, included in process control courses. Such topics as diking and drainage, fire-water distribution and water and foam deluge systems, while necessary components of the student's loss prevention education, are so specialized that they cannot be incorporated into the undergraduate chemical engineering curriculum. As part of the design courses(s), the students must be made to realize the importance of seeking expert assistance and guidance as necessary as a part of their responsibilities in the design and operation of safe facilities and plants. Indeed, one of the greatest challenges to the instructor of such courses is helping the student to recognize when such assistance is needed.

References

1. **Bethea, R.M.: Incorporation of Occupational Safety and Health into Unit Operations Laboratory Courses, NIOSH Instruction Module, U.S. Dept. of Health and Human Services, Cincinnati, OH (1991).**
2. **Cobb, J.T., Jr.: Essay/Viewgraph Package: Consequences of Operating Decisions, Center for Chemical Process Safety, Amer. Inst. Chem. Engrs., New York, NY (1995).**
3. **Dow's Fire & Explosion Index Hazard Classification Guide, 7th ed., Amer. Inst. Chem. Engrs., New York, NY (1994).**
4. **Kletz, T.: Plant Design for Safety: A User-Friendly Approach, Hemisphere/Taylor and Francis, New York, NY (1993).**
5. **Lees, F.P.: Loss Prevention in the Process Industries, Vol.1, Ch. 10 (Plant Siting and Layout), pp. 211-230, Butterworths, London (1980).**
6. **Mahoney, D.G. (Ed.): Large Property Damage Losses in the Hydrocarbon-Chemical Industries: A Thirty-year Review, 15th ed., M & M Protection Consultants, New York, NY (1993).**
7. **Mecklenburgh, J.C. (ed.): Plant Layout, George Godwin, Ltd., London (1973).**
8. **Merriman, M.: Emergency Medical Response Teams React Swiftly to Phillips Plant Tragedy, Occup. Safety & Health 59(3): 32, 33,35,36 (1990).**
9. **Mihm, J.C.: Principles of Performance, paper presented at the Southwest Regional Conference of Student Chapters of the American Institute of Chemical Engineers, Texas Tech Univ., Lubbock, TX (Feb., 1992).**
10. **Occupational Safety and Health Administration: Phillips 66 Company Houston Chemical Complex Explosion and Fire: A Report to the President, U.S. Dept. Of Labor, Washington, DC (1990).**
11. **Richardson, T.: Learn from the Phillips Explosion, Hydr. Proc. 70(3): 83-84 (1991).**

- 12. Silas, C.J. and G.A. Cox: Phillips 66 Company's Response to OSHA Citations, Phillips Petroleum Co., Bartlesville, OK (5/09/90).**
- 13. Traverso, D.K.: How to Develop a Crisis Communication Plan, Occup. Hazards 55(3): 58-61 (1993).**
- 14. U.S. Department of Labor: Citation and Notification of Penalty to Phillips 66 Company, Inspection no. 106612443, Occupational Safety and Health Administration, Houston, TX (04/19/1990a).**
- 15. U.S. Department of Labor: Citation and Notification of Penalty to Fish Engineering and Construction, Inc., Inspection no. 107365751, Occupational Safety and Health Administration, Houston, TX (04/19/1990b).**
- 16. Wells, G.L.: Safety in Process Plant Design, Ch. 8 (Damage Minimization and Control), pp. 145-178, John Wiley & Sons, New York, NY (1980).**

**Phillips 66 Disaster
Houston Chemical Complex
Oct. 23-27, 1989**

TIME min:sec:frame	TOPIC
00:00:00	START (Fully rewound)
00:08:12	fireball copyright warning
00:29:10	"Day One 10/23/89" header
00:33:13	home video: fireball
00:49:12	employee describes explosion and its effects on him
01:00:12	elderly couple describe explosion
01:12:04	smoke and initial explanation of probable cause of the disaster
01:35:26	telephoto view of burning plant from helicopter
01:48:27	vertical fire jet plume
01:52:29	Phillips employees describe explosion
02:15:19	emergency vehicles driving toward fire in Unit 5 where initial explosion occurred
02:27:11	Bill Stolz (Phillips 66 environmental director) gives first official statement about the disaster
02:37:09	Ben Wilson (Skyeye): description of burning unit, billowing smoke dispersion indicates scope of multiple fires
02:56:20	description of Rice University seismograph traces with comments by laboratory director
03:37:13	aerial view of Unit 5 area
03:40:29	ground-level view of explosion, note large debris rising on right side of screen
03:43:20	second major explosion

03:52:17 **aerial overview**

03:58:12 **Skyeye view, tower in close foreground; description of effect on workers and delayed alarm**

04:46:08 **emergency vehicles**

04:49:10 **ground view of fire through electrical substation; comments about loss of firefighting water because of the first explosion**

04:55:25 **employees and members of emergency response teams watching the disaster unfold**

05:01:29 **telephoto view of fire from 30 miles away**

05:19:18 **victim being ferried to hospital by helicopter**

05:47:02 **relatives trying to locate injured or missing employees**

06:43:03 **“Day Two 10/24/95” leader**

06:47:10 **Phil Archer describes body search**

07:20:15 **ground view of “fluff” section of polyethylene plant, description of initial survey of plant**

07:41:26 **Jere Smith (Phillips 66 spokesman) describes initial objective (put fire out) and efforts during the previous night**

08:04:03 **Bob Benz (Phillips plant manager) explains the possible sequence of events leading to the first explosion and what the Company knows so far**

08:16:20 **HCC layout (Figure 1) followed by close-up plan view (Figure 2) of initial explosion area (Unit 5)**

08:36:28 **scene at HCC followed by burnt-out area (Note: smoke shown in this area on Day One has been reduced to a light haze as a result of firefighting efforts, FAA has issued a 1000-ft advisory caution zone around the HCC)**

08:49:14 **aerial overview continues and focuses on haze rising from the area of the initial explosions**

09:19:26 **wide-angle view of devastated area**

09:34:15 Pasadena fire chief (Jay Goyer) gives update on extinguishment efforts

09:43:09 final knockdown efforts on several small fires

09:48:20 wide-angle aerial view

10:01:16 view straight down into devastated area

10:08:02 “Channel Explosion - Damage Survey” leader

10:13:16 overview from helicopter

10:26:26 close-up of fire zone

10:32:26 water still being played on two large columns

10:41:23 parking lot showing damage to parked cars (roofs smashed in, doors blown off) from the unconfined vapor cloud explosion

10:55:10 aerial view (gas holders and other tanks in foreground) from 1 mile away (FAA restriction during body search)

11:08:16 left center of Unit 5 area from 1 mile away

11:24:11 close-up of Unit 5 : smoke and rubble from the explosion

11:31:04 Bob Benz summarizes planned efforts for Day Two: damage and entry assessments, search for survivors

11:44:02 damage assessment team going in

11:48:27 close-up of Units 4 and 5

11:57:23 reporter explains two-stage plant warning signals and that employees have reported that the warning signals were effective and that those employees felt that their safety training was adequate

12:32:22 aerial view of damaged area (note: Ship Channel has been re-opened)

12:57:20 “Day Three 10/25/89” leader

13:01:04 “Channel Explosion Day Three” leader and maintenance shop area where third victim was found

13:10:14 reporter describes arrival of OSHA on site (aerial view of Unit 5 area)

13:21:29 Gil Saulter, OSHA Regional Administrator

13:37:13 Scott Carlberg (Phillips 66) discusses safety record at the HCC

13:58:15 heavy equipment removing debris (fourth body found)

14:15:05 “Channel Explosion - Inside look” leader followed by ground-level view of wrecked area

14:20:29 wreckage clearing, looking for asbestos and radioisotopes (e.g. cesium) used in measuring devices

14:41:10 Glenn Cox, Phillips 66 president, explains what the Company will do

15:25:23 “Day Four 10/26/95” leader

15:30:27 News of a leak in the area where the searchers are working

15:38:28 Reporter (Phillip Bruce) quotes a Phillips 66 spokesman (George Minter) who explains that there is “an apparent hydrocarbon leak near the reactor in plant number 5 where the searchers are.” The area is flooded with water and employees with hand-held [total hydrocarbon] monitors enter area to ensure that no small hazardous pockets of gas exist.

16:25:21 George Minter (Phillips 66 spokesman) explains what happened, what was done, why it was necessary to pull back from the Unit 5 area

16:41:05 ground shots of disaster area

16:44:29 “Day Five 10/27/89” leader

16:50:04 “Channel Explosion” leader, death toll now 7 as described by reporter in studio. She describes search and recovery operations planned for Day Five in the finishing area and the control room.

16:58:08 clearing away debris near the control room where the 15 missing workers may be buried

17:17:27 “Channel Explosion- The Response” leader

17:29:18 **Pasadena fire chief describes effectiveness of CIMA, Channel Industries Mutual Aid Association**

18:03:00 **explanation of need for CIMA and the cooperation with and support for it by local emergency responders**

18:14:17 **overview of industrial area along the Ship Channel where CIMA was developed**

18:28:03 **CIMA formed in 1947 after the huge Texas City fire**

18:33:15 **fighting HCC fire at night**

18:44:22 **END of tape**

18:49:09 **copyright warning**

19:13:28 **warning off, STOP tape**