CHAPTER XI

INDUSTRY ACCIDENT HISTORY

Accidents like the one at the Phillips 66 complex are, in OSHA's experience, rare events. When they occur, however, the consequences can be catastrophic. The purpose of this chapter is to evaluate the frequency and severity of accidents in the petrochemical industry, as well as their causes, to determine the relevance of OSHA's findings in the Phillips investigation to the petrochemical industry in general. A select number of data bases and studies containing information on chemical accidents were examined.

Two Department of Labor data sources have been reviewed: the annual estimates of occupational injury and illness data published by the Bureau of Labor Statistics (BLS), and OSHA's own case files of accident investigations. Two insurance industry surveys of accidents that caused large property damage have also been reviewed: the American Insurance Association's *report on a Hazard Survey of the Chemical and Allied Industries* [21], and the Marsh & McLennan Report on *Large Property Damage Losses in the Hydrocarbon Chemical and Allied Industries* [22]. Also described in this chapter is a study done by Charles River Associates [23], done in connection with OSHA's preliminary work on a proposed Standard for Process Safety Management of Highly Hazardous Chemicals.

A number of data bases that provide information on releases and on emergency response were not reviewed. These include two EPA data bases: the Accidental Release Information Program data base, which has information on causes of significant releases and ways to prevent them, and the Emergency Response Notification System, which clarifies and enhances initial notifications made to the National Response Center. A third EPA data base, the draft Acute Hazard Events Data Base was reviewed, but was not included because of the uncertainty of some of its information, which comes from varied sources, including Department of Transportation data and newspapers services, most of which were not independently verified.

BLS ANNUAL SURVEY OF OCCUPATIONAL ILLNESSES AND INJURIES IN THE UNITED STATES, BY INDUSTRY

BLS publishes annual estimates of occupational injuries and illnesses and--to a lesser extent--fatalities in U.S. industry, according to U.S. Standard Industrial Classifications (SICs). The injury incidence rates reported by BLS for the chemical and petroleum industries (SICs 28 and 29), and for the selected petrochemical

industries described in Chapter X, show that the frequency of injuries (overall recordable injury cases) and of serious injuries (injuries that result in time lost from work) is lower than the average for all manufacturing sectors (SICs 20-39). The national average lost workday injury rate for the manufacturing sector is the criterion used by OSHA to target most of its programmed safety inspections in the manufacturing sector. (The overall injury rates include fatalities; the lost work day injury rates do not.)

The BLS estimates are based on an annual survey of a representative sample of 280,000 employers nationwide. BLS also collects information about work-related fatalities in its survey. From this sample, BLS reports estimates of the incidence rate of workplace injuries and illnesses for the various sectors. The size of the sample is not sufficiently large to yield fatality estimates or fatality rates for the petrochemical industry. The incidence rates reported by BLS are average rates for each industrial classification surveyed. The Bureau does not generate injury rates for specific companies. Therefore, it is not possible, from BLS data, to compare Phillips' annual injury rate with other companies or to rank Phillips within the petrochemical industry.

Tables 2 and 3 show the trends in overall injury incidence rates from 1973 to 1988, and from 1985 to 1988, for the manufacturing sector as a whole, for the chemical and petroleum industries as a whole, and for selected petrochemical industrial categories. Tables 4 and 5 show comparable trends in lost workday injury incidence rates over the same periods.

Since 1973, the overall recordable injury incidence rates in the chemical industry have declined by 26 percent--from 8.8 injuries per 100 full-time workers in 1973, to 6.5 in 1988 (the most recent year for which these estimates have been published). Over the same period, the injury rates in the petroleum industry have declined by 28 percent--from 9.2 in 1973, to 6.6 in 1988. For the same years, the overall injury rate for the manufacturing sector dropped by only 18 percent--from 14.7 in 1973, to 12.1 in 1988 (see Table 2).

Also apparent is a significant rise in overall injury rates since 1984 (see Table 3). From 1985 to 1988, the overall injury rate for Chemical and Allied Products (SIC 28) increased by 35 percent--from 4.8 in 1985, to 6.5 in 1988; and, for Petroleum and Coal Products (SIC 29), by 63 percent--from 5.1 to 6.6 injuries per 100 workers. The increase in rate of injury in Industrial Inorganic Chemicals (SIC 2869) is also notable. The incidence rate for that sector doubled over the past 4 years. While the overall manufacturing rate has also risen during this period, the increase in the rate of injury in manufacturing has not been as great as in the petrochemical industry. The same trends are apparent in the incidence rates for lost workday injuries (see Table 5).

Table 2
Recordable Injury Incidence Rates
1973 - 1988

SIC	Industry	1973	1988	Percent Change
	Private Sector	10.6	8.3	-21.70
	All Manufacturing	14.7	12.1	-17.69
2800	Chemical and Allied Products	8.8	6.5	-26.14
2821	Plastic Materials and Resins	9.9	6.4	-35.35
2822	Synthetic Rubber	8.7	7.1	-18.39
2869	Industrial Organic Chemicals, Not Elsewhere Classified (NEC)	*	5.4	*
2900	Petroleum and Coal Products	9.2	6.6	-28.26
2911	Petroleum Refining	6.6	5.4	-18.18

Source: *Occupational Injury and Illness Survey*, BLS, 1973-1988.

* There is no BLS-estimated injury incidence rate for SIC 2869 for 1973. The first year for which this rate is available is 1977, when the rate was 4.8. The percent change from 1977-1988 was +12.5 percent.

Table 3
Recordable Injury Incidence Rates
1985 - 1988

SIC	Industry	1985	1988	Percent Change
	Private Sector	7.7	8.3	+7.79
20-39	All Manufacturing	10.0	12.1	+21.00
2800	Chemical and Allied Products	4.8	6.5	+35.42
2821	Plastic Materials and Resins	4.1	6.4	+56.10
2822	Synthetic Rubber	3.9	7.1	+82.05
2869	Industrial Organic Chemicals, NEC	2.7	5.4	+100.00
2900	Petroleum and Coal Products	5.1	6.6	+29.41
2911	Petroleum Refining	3.3	5.4	+63.64

Source: *Occupational Injury and Illness Survey*, BLS, 1985-1988.

Table 4
Lost Workday Injury Incidence Rates
1973 - 1988

SIC	Industry	1973	1988	Percent Change
	Private Sector	3.3	3.8	+15.15
20-39	All Manufacturing	4.3	5.3	+23.26
2800	Chemical and Allied Products	2.7	3.1	+14.81
2821	Plastic Materials and Resins	2.6	3.2	+23.08
2822	Synthetic Rubber	3.6	2.8	-22.22
2869	Industrial Organic Chemicals, NEC	*	2.1	*
2900	Petroleum and Coal Products	2.6	3.2	+23.08
2911	Petroleum Refining	1.8	2.6	+44.44

Source: *Occupational Injury and Illness Survey*, BLS, 1973-1988.

* There is no BLS-estimated injury incidence rate for SIC 2869 for 1973. The first year for which this rate is available is 1977, when the rate was 1.9. The percent change from 1977-1988 was +10.53 percent.

Table 5
Lost Workday Injury Incidence Rates
1985 - 1988

SIC	Industry	1985	1988	Percent Change
	Private Sector	3.6	3.8	+5.56
20-39	All Manufacturing	4.4	5.3	+20.45
2800	Chemical and Allied Products	2.2	3.1	+40.91
2821	Plastic Materials and Resins	1.8	3.2	+77.78
2822	Synthetic Rubber	2.0	2.8	+40.00
2869	Industrial Organic Chemicals, NEC	1.2	2.1	+75.00
2900	Petroleum and Coal Products	2.4	3.2	+33.33
2911	Petroleum Refining	1.6	2.6	+62.50

Source: *Occupational Injury and Illness Survey*, BLS, 1985-1988.

Some but not all, of the increased rate of injury in the petrochemical industry over the past 5 years can be attributed to the increased emphasis OSHA has placed on enforcement of employer recordkeeping requirements since 1985 (when the largest penalties yet proposed in the agency's history at that time were proposed for egregious violations of recordkeeping practices by the Union Carbide chemical processing facility in West Virginia. That OSHA enforcement action placed the industry on notice that inaccurate and underreported accident records would not be tolerated.)

While the BLS injury estimates for the petrochemical industry indicate some problems in accident prevention since 1985, they continue to show an industry with low injury rates relative to the manufacturing sector as a whole. It must be remembered, however, that the injury rates of contractors are not included in these rates. Also to be considered is that accidents in this industry may be infrequent, but when they occur, they can be of a catastrophic nature involving extensive property damage and loss of life, which the BLS data do not capture.

OSHA ACCIDENT INVESTIGATION RECORDS

OSHA's case file records of accident investigations in the petrochemical industry over the past 5 years have been reviewed. The investigations of accidents that occurred in 1989 were examined in detail. The agency's computerized Integrated Management Information System (IMIS) selected, from the 50,000 to 60,000 inspections conducted annually by Federal OSHA, those inspections in the petrochemical industry that involved an accident investigation associated with a chemical process and that resulted in issuance of citations of violations.

For the 5-year period, 1985-1989, Federal OSHA conducted 1,404 inspections in the petrochemical industries (SICs 1321, 2821, 2822, 2869, and 2911). (This compares to 94,935 inspections conducted in all manufacturing industries.) The highest numbers of inspections in the selected petrochemical industries were conducted in 1985 and 1986, the years immediately following the Bhopal disaster (see Chart 1).

Of the 1,404 inspections, 75 were investigations of chemically related accidents. Thirty of these investigations were conducted by OSHA in 1989. Of these 30 inspections (which were coded in the IMIS as accident investigations), 27 actually involved deaths or injuries.

The violations cited on Federal OSHA inspections in the petrochemical industry show the following trends. Charts 1 and 2 refer, respectively, to the number of Federal OSHA inspections and the resulting citation activity in the petrochemical industry from FY 1985 through FY 1989. In 1985, 263 inspections were conducted and 396 violations cited, of which 103, or 39 percent, were serious, willful or repeat,

Chart 1
Federal OSHA Inspections of the Petrochemical Industry

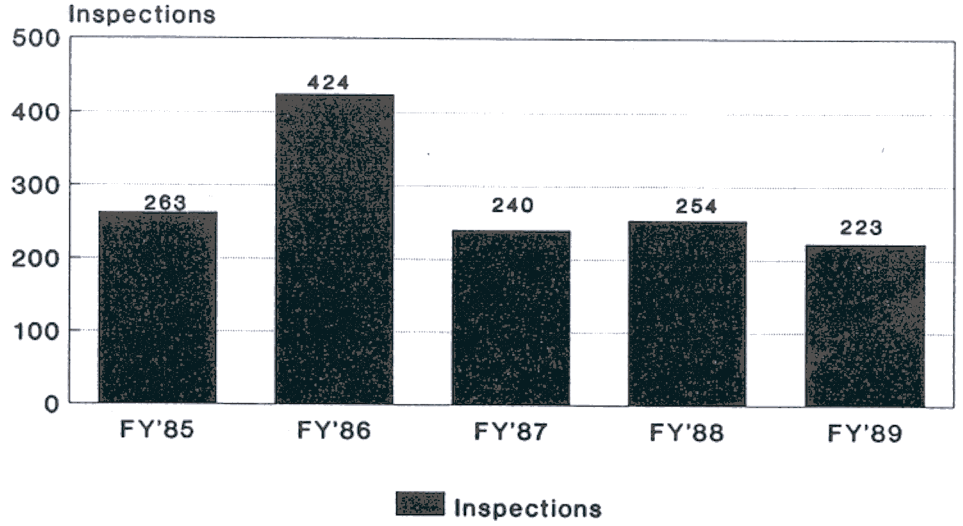
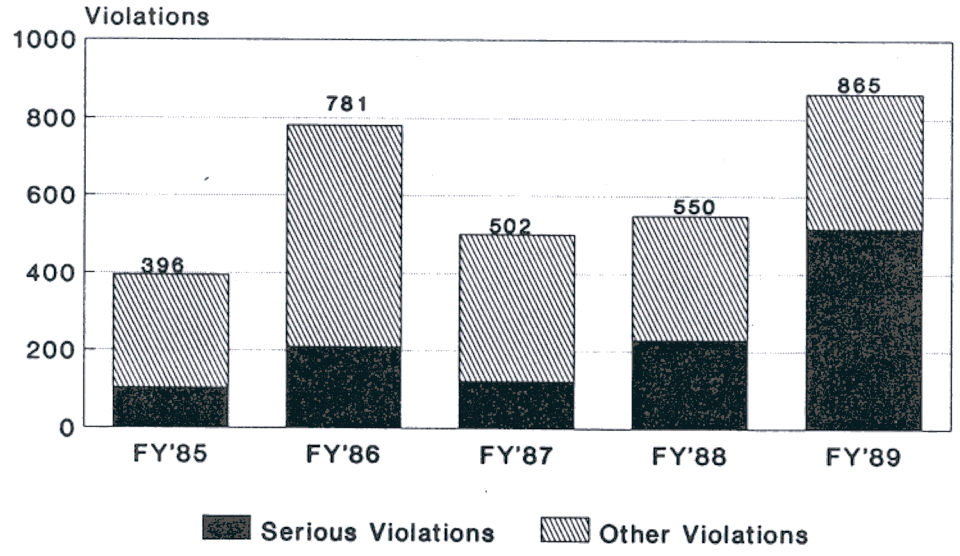


Chart 2
Serious Violations versus Total Violations in the Petrochemical Industry



and 293 were other-than-serious. In 1989, by comparison, there were 223 inspections conducted in these industries, with 865 violations cited, of which 518, or 60 percent, were serious, willful or repeat, and 347 were other-than-serious. In general, the inspection data from the past 5 years demonstrate a steady increase in the number and percentage of serious, willful, and repeat violations cited in the petrochemical industries. While inspection activity declined by 15 percent, the number of serious, willful, and repeat violations increased by 503 percent, and the total number of violations cited increased by 218 percent. (Again, it must be pointed out that citations of contractor violations are not included in these data.)

The trends in the manufacturing sector as a whole are similar, but the increases in violations cited are not as dramatic as in the petrochemical industries. In 1985, 23,783 inspections were conducted in all manufacturing industries, and 58,660 citations were issued, of which 16,609 (or 28 percent) were for serious, willful, or repeat violations. In 1989, 15,530 inspections were conducted, and 85,066 citations issued, of which 44,016 (or 52 percent) were serious, willful, or repeat. Thus, from 1985 to 1989, there was an increase of 265 percent in citations of serious, willful, or repeat violations in the manufacturing sector, and an increase of 145 percent in citations of all violations, while the number of inspections conducted declined by 34 percent.

Charts 3 and 4 illustrate Federal OSHA's history of accident investigations in the petrochemical industry. An accident investigation can result from a fatality or a catastrophe, which employers are required to report to OSHA, or from any other accident which comes to the agency's attention. Chart 3 shows a marked increase in the number of accident investigations conducted. In 1985, 16 accidents were investigated; in 1989, 27 were investigated. Indeed, four more accidents were investigated in the last 2 years than in the previous 3 years together.

Charts 5 and 6 illustrate OSHA's experience with Phillips. In FY 1986, the first year of the agency's Chemical Special Emphasis Program, 15 inspections were conducted at Phillips sites; 21 violations were cited on those inspections; of those, three were serious, willful, or repeat. In contrast, in 1989, four inspections were completed, with six violations cited, of which four were serious, willful, or repeat. While these data are not sufficient for any conclusions to be drawn, the high proportion of serious violations cited in 1989 reflects the trend previously identified in the petrochemical industry in general.

Chart 7 indicates the relative importance of the major factors that contributed to accidents in the petrochemical industry. The data were obtained directly from OSHA's official case files. Of the 30 accident investigations recorded in the IMIS for FY 1989, 27 involved deaths or injuries--25 fatalities and 36 nonfatal injuries in all. Seventy-seven percent of those accidents involved the performance of regular

Chart 3
Federal OSHA Accident Investigations of the Petrochemical Industry

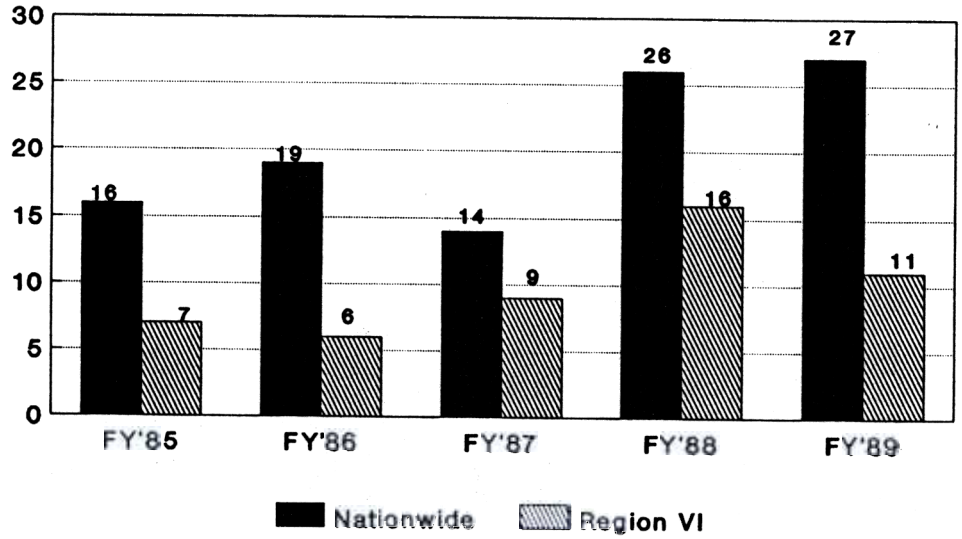


Chart 4
Federal OSHA Fatality Investigations of the Petrochemical Industry

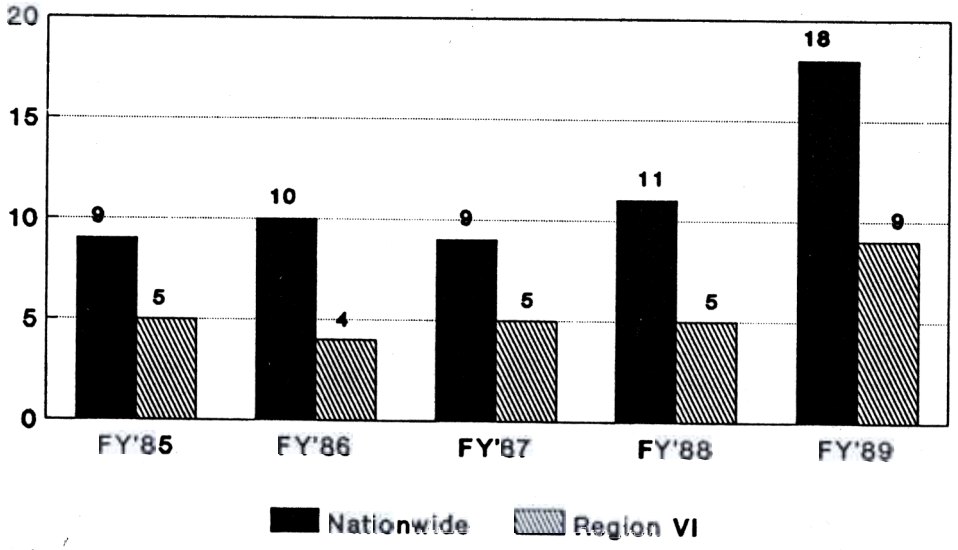


Chart 5
Federal OSHA Inspections of Phillips 66

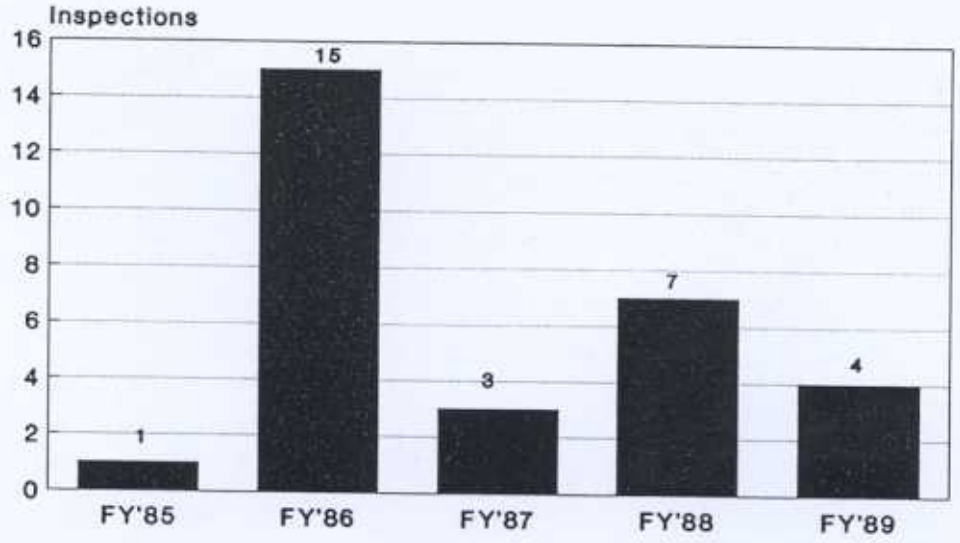


Chart 6
Phillips 66 - Serious Violations versus Total Violations

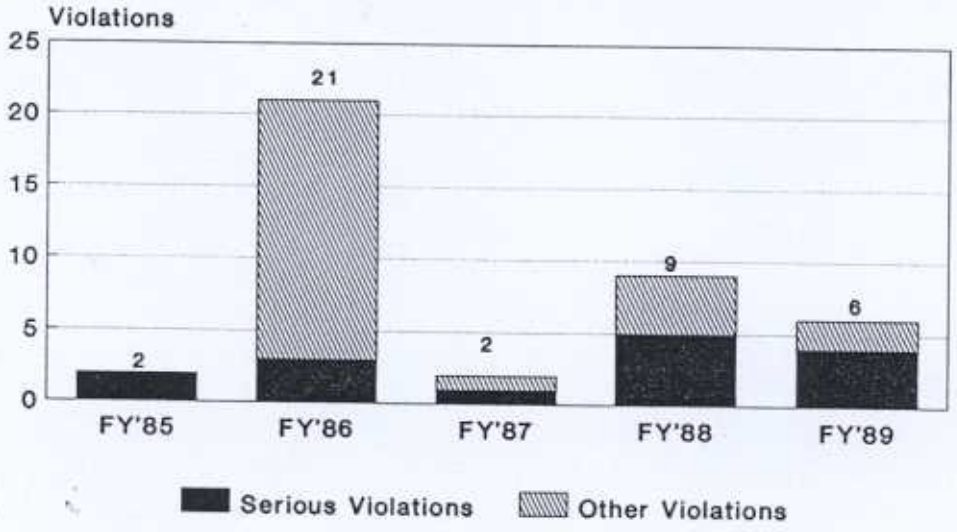
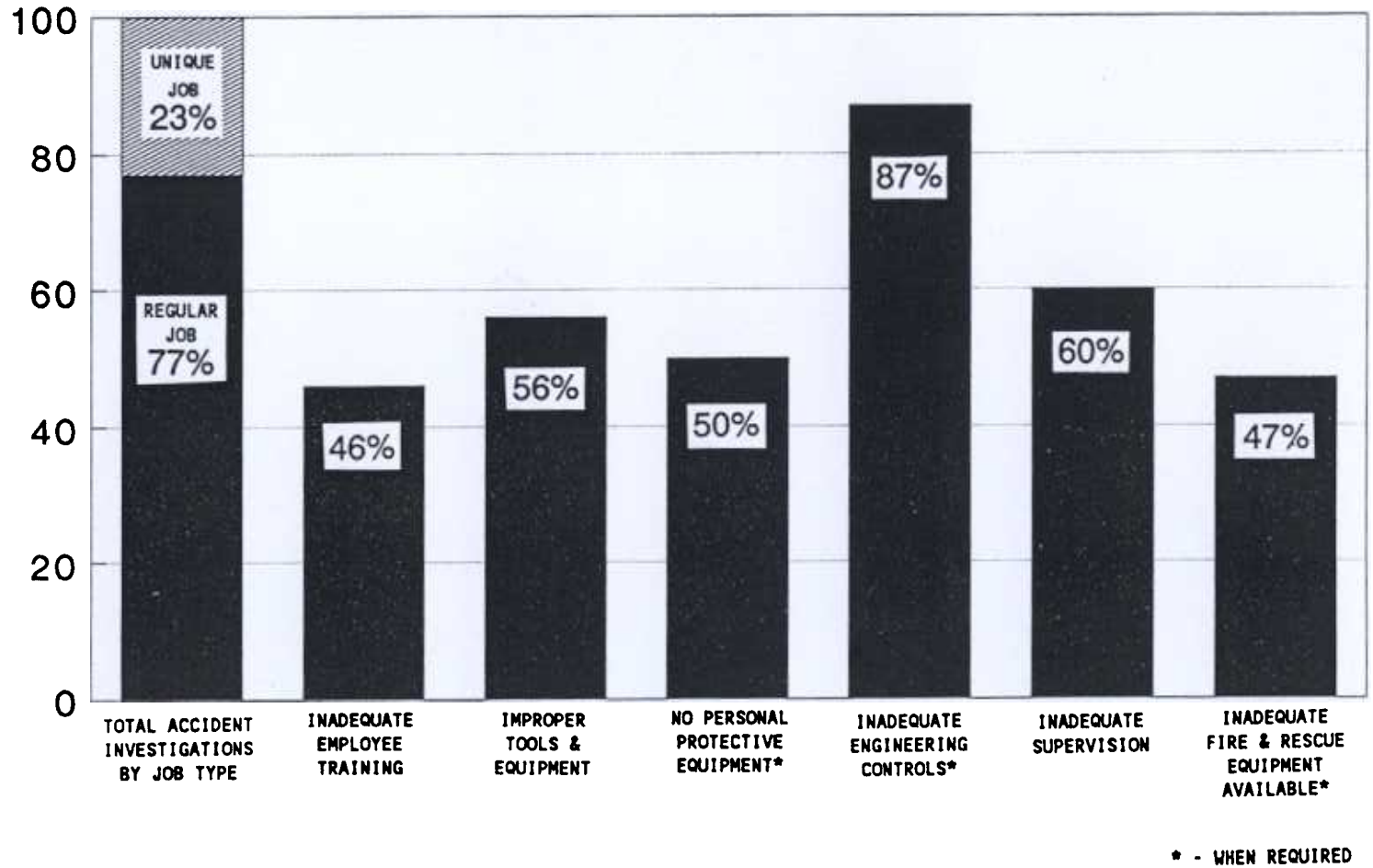


Chart 7
Accident Investigations Major Contributing Factors in the Petrochemical Industry FY 1989



job functions, whereas only 23 percent of the accidents involved unique or infrequently performed tasks.

It is of particular note that 46 percent of the accidents involved employees who had not received any safety training, and 56 percent involved the use of improper tools, materials, and equipment. In 50 percent of the cases where the use of personal protective equipment was required, the employees did not have or were not using the required equipment at the time of the accident.

Of major significance is the finding that in those cases where engineering controls were required, 87 percent of the employers involved were cited for inadequate engineering controls. Finally, in 60 percent of the cases, there was inadequate, improper, or no supervision of employees; and in 47 percent of the accidents involving fires or explosions, the fire and rescue equipment was inadequate.

AMERICAN INSURANCE ASSOCIATION REPORT ON A HAZARD SURVEY OF THE CHEMICAL AND ALLIED INDUSTRIES

Both this report, and the Marsh and McLennan report described below, are insurance industry analyses of the causes of accidents, which are based on data relating to property loss and not directly to injuries and fatalities.

The American Insurance Association Report, published in 1979, was based on 465 major fires and explosions that occurred between 1960 and 1977 and that resulted in 279 fatalities and 1,727 nonfatal injuries. An analysis of the 465 incidents was performed to determine the causes of the accidents.

The data presented in the report show that inadequate material evaluation, chemical process problems, material movement problems, operational failures and equipment failures accounted for over 80 percent of the total accidents within the period covered by the report. From 1967 through 1977, the following were found to be the principal causes or factors contributing to the accidents studied: (1) Approximately 26.6 percent of the incidents resulted from operational failures, which generally involved one or more of the following: (a) absence of detailed descriptions and recommended procedures in operating the various sections of the plant, (b) inadequate startup and shutdown procedures, (c) lack of emergency control plans and drills, and (d) poor training programs. (2) Approximately 20.1 percent of the incidents resulted from inadequate materials evaluation and chemical process problems. These inadequacies and problems included (a) insufficient evaluation of fire, health, and stability characteristics of all material involved; (b) lack of required information on process temperature or pressure variations; and (c) failure to observe requirements for extreme process conditions. (3) Approximately 26.3 percent of the incidents resulted from equipment failures due to such

factors as (a) processes that exceeded design limitations, (b) poor maintenance programs, (c) inadequate repair and replacement programs, and (d) lack of "fail-safe" instrumentation.

MARSH AND MCLENNAN REPORT ON LARGE PROPERTY DAMAGE LOSSES IN THE HYDROCARBON-CHEMICAL INDUSTRIES

The Marsh and McLennan report reviews the 150 industry accidents that had the largest dollar losses from 1959 through 1988. Those accidents represented more than $5 billion in property damage based on the January 1989 inflation index. The dollar losses increased steadily over the period studied. The number of accidents also increased from 1959 through 1983, but declined for the final 5-year period studied, from 1984 through 1988.

The increase in losses in the industry are attributed to major changes over the 30-year period studied. Those changes included (1) a switch from batch processes to large single-train operations; (2) increased size of process units; e.g., ethylene production rose from 20 million pounds per year to 1.5 billion pounds per year; and (3) reduced spacing of process equipment within plants to minimize energy requirements, piping, and instrumentation. The causes of the losses and their size (the median loss was $20 million) indicate the magnitude of the potential risk and possible areas of concern.

Information about the types of complexes, the causes of the losses, the equipment involved, and the types of losses included in the report is presented in Tables 6 through 9.

The data presented in Table 6 show that the largest dollar losses occurred in the petroleum refinery industry. The Marsh and McLennan report also indicates that refineries were represented more frequently than any other complex in the accidents studied.

Table 7 lists the various causes of loss for these incidents. Mechanical failure is blamed for 41 percent of the accidents, and operational error accounts for an additional 19 percent of the incidents. Process upsets account for only 10 percent, whereas other causes account for 17 percent. The table indicates that approximately 60 percent of the incidents in the industry were due to mechanical failure and operational error.

Table 8 shows that piping systems were the most frequent origin of loss. Storage tanks were the next most frequent origin of loss. The move toward larger storage tanks is responsible for an average tank loss of over $40 million. Process towers were the originating point of only four incidents but were responsible for the

Table 6
Distribution of Losses by Type of Complex

Type of Complexes	Percent of Losses
Refineries	40
Petrochemical Plants	17
Terminals/Bulk Plants	13
Plastic/Rubber Plants	9
Chemical Plants	8
Natural Gas Processing	7
Miscellaneous	4
Pipelines	2

Table 7
Cause of Loss

Reason for Loss	Percent of Losses	Average Trended Loss (Millions of Dollars)
Mechanical Failure	41	36.0
Operational Error	19	38.6
Unknown/Other	17	25.9
Process Upset	10	40.7
Natural Hazard	5	43.2
Design Error	4	60.5
Sabotage/Arson	4	19.0

Table 8
Equipment Involved

Type of Equipment	Percent of Loss	Average Trended Loss Millions of Dollars
Piping Systems	31	41.9
Tanks	17	40.5
Reactors	13	28.9
Miscellaneous	9	34.7
Process Drums	7	25.5
Marine Vessel	6	32.0
Unknown	5	25.0
Pumps-Compressors	5	19.2
Heat Exchangers	3	24.0
Process Towers	3	53.8
Heaters-Boilers	1	28.6

Table 9
Type of Loss by Complex
(Percent)

	Explosion	Fire	Vapor Cloud	Other
Refineries	13	52	32	3
Petrochemical Plants	42	12	46	0
Terminals/Bulk Plants	21	42	32	5
Plastic/Rubber Plants	29	29	42	0
Chemical Plants	75	8	17	0
Natural Gas Processing	0	40	60	0
Other	0	67	33	0

highest average damage. Pumps and compressors, which are often thought to be responsible for more process industry fires than any other equipment, were involved in only eight incidents in this study. It is the opinion of the Marsh and McLennan consultants that most of the losses which involve compressors and pumps result in smaller dollar losses. Consequently, they were not included in this study, which addressed only the largest 150 incidents.

Table 9 shows that virtually all of the 150 losses resulted from fires, vapor cloud explosions, or other kinds of explosions. The sources of ignition of more than one-half the 150 incidents are still unknown. Open flames from heaters, furnaces and boilers were the leading known source of ignition. Cutting and welding were responsible for only one of the 150 losses despite the large amount of hot work done in the industry. The rigid hot work permit system used in the industry is the reason given to explain the low incidence of accidents from this source. Other sources of ignition included chemical reaction, electrical equipment, internal combustion engine, auto ignition, lightning, hot surface, and static electricity.

Among the other findings of this study are that free-flow sensing valves, redundant instrumentation, or other fail-safe systems in major piping systems that would shut down in the event of failure might reduce the amount of flammable material released.

The study further indicates that 24 percent of the incidents occurred during other than normal operations--i.e., startup, shutdown, on-line maintenance, or turnaround --or while the plant was idle. Other than normal operations may place more stress on equipment and personnel because of rapidly changing physical conditions such as temperature, flow, and pressure, which may approach or exceed the design limits of the equipment. The study suggests that establishing specific equipment requirements to cover substantial excursions above steady-state operating parameters might alleviate this problem.

INDUSTRY PROFILE FOR A PROPOSED OSHA STANDARD FOR PROCESS SAFETY MANAGEMENT OF HIGHLY HAZARDOUS CHEMICALS

This report was prepared by Charles Rivers Associates for OSHA's preliminary work on a proposed standard for Process Safety Management of Highly Hazardous Chemicals. The report provides unrefined estimates of fatality and injury rates in the chemical and petroleum industries (SIC codes 28 and 29) from 1982 to mid-1988.

The sources consulted for these estimates were OSHA's fatality and catastrophe inspection files, OSHA area office first reports of accidents, a survey of five major regional newspapers, the National Response Center Database, National Fire

Protection Association Fire Statistics and the Bureau of Labor Statistics Supplementary Data System. The methodology used for data collection and analysis was not reviewed beforehand by OSHA and is still to be subjected to review by the public during the notice-and-comment period of the rulemaking process. Therefore, at present, the results of this study cannot be considered an official OSHA report.

The most serious incidents that occurred in the petrochemical industry from 1982 to 1988 are discussed in the report. A serious incident is defined as one that involves multiple fatalities, more than 10 injuries, more than 1,000 evacuees, or more than $1 million in damage. By this definition (which is markedly different from the OSHA definition of a catastrophe), serious incidents in the industry accounted for 25 percent of the total incidents reported in this study, 60 percent of the fatalities, and 80 percent of the injuries.

Fatality rates, injury rates, and causes of incidents are also estimated in the study by three- and four-digit SIC codes within SICs 28 and 29. These rates are based on the total number of fatalities and injuries accumulated from the above data bases and normalized by the number of workers within each SIC code within the industry. The injury rates reported in this study should not be confused with the BLS injury incidence rates because the rates in the Rivers study were determined only from major incidents.

In this study, the overall fatality rate for the chemical industry (SIC 28) and for the petroleum refining industry (SIC 29) is estimated to be 4.0 deaths per 100,000 full-time workers. Rivers was unable to provide accurate estimates of the injury rates in this industry from its methodology.

The Rivers study indicates that petroleum refining is a high hazard industry compared to other industrial sectors in the petrochemical industry. The largest number of incidents and injuries and the second largest number of deaths within the industry were reported for petroleum refining. The petroleum refining industry is estimated to have a fatality rate of 8.6 deaths per 100,000 workers.

The study classifies the causes of the incidents in four broad categories: human error, equipment failure, other, and unknown. While the percentage of incidents due to each cause varies within the petrochemical SICs, the report estimates that human error and equipment failure each accounts for 25 percent of the accidents within the industry as a whole. Approximately 33 percent of the incidents are of unknown origin, with the remainder attributable to other causes. This analysis of cause does not go beyond the obvious; the underlying factors that contribute to accidents in the petrochemical industry have not been examined.

Based on the data collected, the report estimates that the petrochemical industry can expect approximately 100 incidents per year resulting in an estimated 53 fatalities, 985 injuries, and the evacuation of 18,000 people. The study concludes that the majority of incidents analyzed did not involve multiple fatalities and injuries, major evacuations, or major property loss.

CONCLUSION

This brief survey of five sources of information on chemical accidents indicates a need for a comprehensive data base, consistent in definition and content, which could produce statistically valid accident, injury, and fatality data for the petrochemical industry.

The five sources reviewed in this chapter call attention to problems in the petrochemical industry that need to be addressed. The BLS estimates show an increase in injury rates since 1985; while some of that increase could be the result of improved reporting by the industry, the upward trend is a cause for concern. The other data sources provide useful information about factors that precipitate accidents and exacerbate their impact, including the following:

1. A significant number of accidents occur during other-than-normal operations; that is, during startup, shutdown, on-line maintenance, or turnaround, or while the plant is idle. This finding suggests more attention needs to be paid to other-than-normal operations. Such operations are of brief duration relative to total plant operating time, but demand close attention in order to reduce overall risk.

2. Increases in the size of industrial processing units, changes from multiple-batch operations to continuous-train operations, and reduced spacing of processing equipment have resulted in an increased risk of explosion and of injury or death to workers.

3. Within the petrochemical industry, petroleum refining has been identified as the most hazardous sector. All of the data sources, including OSHA's own inspection data, indicate that a fire or explosion is more likely in petroleum refining than in other petrochemical sectors.

4. Although the number of OSHA inspections in petrochemical facilities has declined somewhat in recent years, the number of serious violations found by OSHA compliance officers in those facilities has increased significantly. Along with the trend in injury rates noted above, the rise in serious violations may be indicative of increasing safety and health problems in the industry.

5. The American Insurance Association (AIA) study and the data in OSHA's case files underscore the critical importance of good management of chemical process safety systems. The AIA study recognizes the necessity for management programs and proper process design in safe plant operation. OSHA's analysis of its accident investigations in the petrochemical industry in FY 1989 revealed that inadequacies in engineering controls, supervision, employee training programs, improper tools and equipment, and fire and rescue equipment--all the result of inadequate management systems--contributed to the accidents themselves and to the severity of their impact.

OSHA's findings in the investigation of the Phillips Complex disaster support the conclusion that poor risk assessment and management, lack of redundant systems and fail-safe engineering, inadequate maintenance of equipment, poorly conceived operational or maintenance procedures, and incomplete employee training are the underlying factors that contribute to or heighten the consequences of an accident. Because of the trend toward larger, continuous operations, the hazards within this industry are being magnified. Best industry practice in chemical process safety must become the standard. That is OSHA's goal in developing a proposed rule for Process Safety Management of Highly Hazardous Chemicals.

CHAPTER XII

A STUDY OF SAFETY AND HEALTH PRACTICES RELATING TO THE USE OF CONTRACTORS IN SELECTED PETROCHEMICAL SECTORS

BACKGROUND

OSHA has been concerned for some time about the diffusion of responsibility for worker safety and health when employers contract out work. This practice is inherent in the construction sector, where OSHA has established procedures for assigning responsibility; however, there are instances where divided responsibilities at a construction site may act to the detriment of workers.

Following the L'Ambiance Plaza apartment complex collapse in Bridgeport, Connecticut, in April 1987, in which 28 workers were killed, OSHA held the primary contractor responsible for meeting the safety and health requirements at the site. It was the agency's position that the primary contractor, in its role of supervisor of the entire project, could have prevented those violations regardless of whether part of the work was subcontracted.

When the Phillips accident occurred, OSHA was concerned that an engineering contractor, who was regularly employed by Phillips to perform key maintenance operations, had been working on the reactor leg in Plant V when the explosion occurred. That same contractor had also been involved in a fatal accident at the same facility 3 months earlier. OSHA's experience in the petrochemical industry was that many firms use contractors to perform regular maintenance procedures, repairs, construction, and renovation, but the agency believed more information was needed about the extent to which contract work might affect plant safety.

OSHA looked first at available data on contractors employed at manufacturing sites and found that while some information was retrievable from the agency's IMIS data, much was not. One of OSHA's contractors, who was conducting research to develop a safety process management proposal for highly hazardous chemicals, shared the results of a study it had done in August 1987, in its capacity as a management consultant firm: "The Seven Best of the Best in Maintenance in North America [24]." For that study, The A.T. Kearney Company had conducted a survey on use of contractors for maintenance operations in 300 firms. The results of the survey showed the use of long-term contract maintenance was slowly declining, but that short-term contracting for environmental services was increasing. According to the Kearney study, contracting accounted for approximately 16 percent of total

maintenance costs in the chemical and other process manufacturing industries (such as paper manufacturing), and for approximately 14 percent of maintenance costs in the discrete manufacturing sector (as opposed to the process manufacturing sector).

OSHA decided to have an outside research institute do an indepth study of the safety and health implications of using contractors in the petrochemical industry. Questions had been raised at a hearing on November 6, 1989, before the House Government Operations Subcommittee on Employment and Housing [23] as to whether contractor employees were adequately trained to recognize the potential dangers of their work. The congressional hearing also raised questions about how responsibility for safety and health at petrochemical plants is managed when contractors conduct hazardous operations such as maintenance and renovation.

Of particular interest to OSHA was how the injury incidence rates of contractors employed at petrochemical facilities compare to the injury rates of the host employer. Because contractor employee injury records are kept separate from petrochemical company records, it is possible that the low injury incidence rate of the industry (as reported by petrochemical plants to the BLS survey), may not be indicative of the actual accident experiences in the industry.

To obtain more information about the contracting process in the petrochemical industry, OSHA asked the John Gray Institute, a component of The Lamar University System headquartered in Beaumont, Texas, to conduct a study of safety and health issues as they relate to contract work in the petrochemical industry. The Institute, which is located in the geographical heart of the petrochemical industry, has been supported by both management and labor in that industry. Several factors led to OSHA's selection of the Institute, including its reputation for working closely with representatives of labor and management; its commitment to providing practical, educational, and applied research services that contribute to individual and organizational excellence in the workplace and the community; and its achievements of service and assistance as an objective party.

Study Protocol

The John Gray Institute began work on this project in December 1989. The study addresses the extent of industry reliance upon contract employees; the nature of work performed by contractors; the role of safety records in contractor selection; the training provided to employees and the supervision accorded to safety and health compliance for contract operations as compared with that for company operations; and injury/illness recordkeeping. The study is being conducted in three phases: first, a national survey of 400 petrochemical plant managers; second, (to be performed simultaneously with the survey) indepth case studies at nine

petrochemical facilities; and third, surveys of employees in the petrochemical industry and contractor firms.

The general direction of the study is being guided by a prestigious National Steering Committee, which includes balanced representation from the petrochemical industry, contracting firms, labor, the academic community, and the safety and occupational medicine professions.

The scope of the study is limited to the five petrochemical industries described in Chapter X. These industries were selected because their normal production processes have the greatest potential for fire, explosion, or catastrophic release of highly hazardous material.

Status of the Study

A partial analysis of a national survey of 400 petrochemical plant managers and nine case studies of industrial facilities have been completed. Yet to be conducted are additional national surveys of employees of firms and of contractors in the petrochemical industries selected for the study. No conclusions or policy recommendations can be made until all the planned research has been finalized and thoroughly analyzed.

Presented here is a summary of the preliminary observations of the John Gray Institute, based on the national survey of petrochemical employers and nine case studies of industrial facilities. Though considerable diversity was observed in responses to the national survey and in the case study findings, the following dominant patterns emerged:

1. Contract workers perform a wide variety of work in the petrochemical industry, including maintenance work and, to a limited extent, operations on a long-term basis; intermittent renovation, turnaround, and shutdown work; and short-term services that range from lawn care, painting, janitorial services, and general labor to more hazardous, highly specialized activities such as tank cleaning, hydroblasting, solid waste removal, asbestos removal, acid cleaning, and underwater diving.

2. Reliance upon contractors in the petrochemical industry has increased, particularly in the areas of routine and non-routine maintenance--major renovation, turnarounds (major unit maintenance), and shutdowns. Among national survey respondents, 43 percent reported an increased reliance upon contractors for major renovation. Survey findings indicate that 33 percent of contract labor forces work in major renovation, 25 percent in maintenance/repair, 20 percent in turnarounds, and 12.5 percent in specialty work. Increases in contract workers in plant operations were found to be insignificant.

3. National survey respondents cited flexibility, cost, specialty in asbestos removal, and capital expansion as the predominant reasons for their increased reliance upon contractors. Case study research confirms these findings, with plant management most frequently citing cost and flexibility.

4. Plant and contract management at the case study sites reported a significantly higher turnover rate for contract employees than for permanent employees. Annual turnover rates for contract employees ranged from 10 percent (in a plant with model practices) to 50 percent, while rates for full-time permanent employees were reported as consistently below 5 percent.

5. The national survey and the case studies suggest that contract workers experience higher injury/illness rates than permanent employees. More detailed analysis is necessary, however, to determine whether these higher rates are a function of more hazardous work performed by contractors or are the product of weaknesses in the training, management systems, or skills of contract employees.

6. Plant management in the case study group reported using a variety of safety selection criteria with varying weights in screening contractors, including consideration of OSHA injury/illness rates, experience modification rates (which are used in adjusting worker compensation premiums), established respiratory and drug testing policies, accident investigation logs, insurance coverage and bonding, number of fatalities and, in one plant, employee benefit provisions.

7. Compared to permanent employees, contract employees receive significantly less safety and health training and are less knowledgeable about workplace hazards, hazardous materials, and emergency response in petrochemical facilities.

8. Contract employees work under less comprehensive safety management systems than permanent employees. The most widely used method of oversight cited by plant management in the national survey was the requirement that accidents be reported.

9. In the case study group, responsibility for safety training of contract employees was observed to be largely the responsibility of the contractor.

10. As observed in the case study group, contract employees are often treated as a segregated, compartmentalized work force in petrochemical facilities.

11. Contract employees are less likely to have direct employee involvement in safety issues.

12. The national survey and the case study findings suggest that petrochemical facilities do not routinely track the injury/ illness rates of contract employees on site nor do they incorporate site-specific contractor performance into overall plant goals.

The preliminary findings of the case studies also reveal differences among unskilled short-term contract employees (those who do not provide highly specialized services) compared to long-term contract employees and, to a greater extent, permanent employees. Unskilled short-term contract employees often experience higher injury and illness rates and higher turnover rates. Additionally, unskilled short-term contract employees may receive less safety training.

With notable exceptions, joint safety and health committee activity among even permanent employees was found to be minimal and often regarded as having insufficient authority to affect safety and health practices in the plants included in the case study group. Such activity was virtually non-existent among contract employees.

An exception to these observable patterns was found in the model facility that was studied. At this facility, plant management has assumed responsibility for the direction of all employees on site, including contract employees. In doing so, the facility has deviated from its parent corporation's policy of avoiding co-employment responsibilities for exposures. This plant has effectively eliminated differences in practices, as illustrated by dominant patterns observed in the case studies, and has achieved the best combined safety performance among those sites studied.

The dominant patterns observed in the employer survey and the case studies are that reliance upon contractors is increasing in the petrochemical industry and that contract employees receive less safety training, sustain more injuries, have higher turnover rates, work under less comprehensive safety and health protections or policies, and are routinely segregated from the management, labor, and employee involvement systems governing permanent employees. In the model plant where this segregation does not exist, however, investment in uniform job skill requirements, training, testing, oversight, reward systems, and participatory processes has resulted in a higher level of safety performance for all employees on site.

Final conclusions must await the completion of the full study, which will include national surveys of contractors and of permanent and contract employees in the petrochemical industry. The final report of the John Gray Institute is expected to be delivered to the Department of Labor by August 1990.

CHAPTER XIII

CONCLUSION

Four major chemical disasters that occurred outside the United States over the past 16 years--Flixborough, England (1974), Seveso, Italy (1976), Bhopal, India (1984), and Mexico City (1985)--caused worldwide concern. From 1982 to 1985, the UK and the European Economic Community responded with legal instruments requiring industries to identify sites where highly hazardous chemicals are used or stored in sufficient quantities to create a potential for disaster, and to notify local planning authorities. International organizations such as the World Bank and the ILO, produced documents to assist their constituencies in addressing the issue of chemical accidents. Private industry and professional groups, in the U.S. and abroad, followed suit with voluntary programs designed to prevent the occurrence and mitigate the consequences of catastrophic chemical releases.

The U.S. reacted to the December 1984 catastrophic release of methyl isocyanate from a Union Carbide plant in Bhopal, India. The subsequent release in 1985 of aldicarb oxime from a West Virginia plant of this same corporation heightened awareness in this country of the possibility of a catastrophic accident. A number of States in the U.S. responded to the risk of a major chemical incident with laws and regulations similar to those of the UK and the EEC.

The U.S. Government responded initially with programs under existing laws and regulations. EPA launched a voluntary Chemical Emergency Preparedness Program (CEPP) in 1985, and at the same time, OSHA undertook an investigation of all U.S. producers and users of methyl isocyanate, the substance released at Bhopal. In November 1985, OSHA followed with a Chemical Special Emphasis Program (ChemSEP) of inspections in the chemical processing industry. OSHA also began preliminary work to revise its standard for storing and handling hazardous materials to include requirements for process safety management.

EPA's CEPP program was made mandatory in the 1986 Emergency Planning and Community-Right-to-Know Act, and in 1988, EPA undertook a voluntary Chemical Accident Prevention Program involving, among other things, onsite chemical audits of major plants. OSHA in 1987 and 1988 issued directives to its compliance officers on conducting inspections of process safety management systems [12,13]. Such inspections proved to be resource-intensive. Early in 1989, OSHA began work on a proposed standard for Process Safety Management of Highly Hazardous Chemicals.

The investigation of the Phillips catastrophe has caused OSHA to take stock and consider a strong course of action to prevent such disasters or mitigate their consequences when they occur. The primary causes of the accident were failures in the management of safety systems at the Houston Chemical Complex. Our survey of the accident history of the petrochemical industry and of the responses here and abroad to the four chemical disasters that occurred over the past two decades has provided useful precedents and a broad perspective on the issue of chemical risk management. The proposed actions and recommendations, which follow, address these issues and others.

CHAPTER XIV

ACTIONS

The major causes of accidents in any industry sector may be found in insufficient recognition of hazards, aging and poorly maintained equipment, unsafe conditions or procedures, poor planning, improper risk management, unsafe engineering practices, inadequately trained personnel, or disproportionate attention to production. Each of these factors reflects a failure in management responsibility to maintain a safe workplace. Collectively, they represent a breakdown of the management systems essential for controlling risk and preventing disaster. Accidents that have occurred in the petrochemical industry all reflect insufficient attention to these elements. Thus, it is important that companies in the petrochemical industry implement comprehensive chemical process safety management plans to manage these risks. Most companies have plans in effect that address some, if not all, of the key elements of process safety.

The key elements of chemical process safety management to prevent and mitigate these accidents have been identified by the Chemical Manufacturers Association in 1985 [18]; by OSHA in its 1987 report on its national special emphasis program in the chemical industry [11]; the Center for Chemical Process Safety in 1989 [25]; and the American Petroleum Institute in 1990 [16]. A *Chemical Engineering* survey of over 800 individuals in the chemical process industry [26] also indicated that more attention needs to be paid to the elements of process safety management.

The accident at the Phillips plant, resulting from the ignition of process gas escaping through an open valve, can be attributed to unsafe conditions and practices at that facility. OSHA's enforcement action, resulting from the agency's investigation of the accident, identified multiple deficiencies in the company's safety program and its implementation at the Pasadena plant. The actions proposed in this report are based primarily on OSHA's investigation of the Phillips accident and on a review of available information about previous catastrophes in the petrochemical industry.

In addition, a study of the industry practice of contracting out maintenance and other operations was begun in connection with this report. The study will be completed within the next 6 months, and the Department of Labor will share its conclusions and any further recommendations with labor, industry, and other interested parties at that time.

The actions proposed by the Department of Labor in this report are directed primarily toward the development and implementation of practices to prevent

chemical accidents. The actions proposed concern programs and policies dealing with the petrochemical industry and will be implemented in the coming months by OSHA. These actions address the means of reducing the potential for catastrophic chemical accidents. The investigation of the Phillips catastrophe confirms the importance of (1) determining not only the precipitating circumstances of an accident but also the underlying causes, (2) identifying the actions needed to prevent recurrence, and (3) widely disseminating the knowledge gained. Above all, the actions proposed in this report underscore the urgent need for increased attention to established principles of process safety management.

ACTION I **OSHA will expedite completion of its rulemaking requiring employers to implement comprehensive chemical process safety management plans for hazardous chemical processes.**

OSHA has a number of standards designed to assure a safe and healthful chemical workplace. (See Chapter VIII.) OSHA, however, does not have a standard specifically requiring employers to manage the risks of the chemical process. The agency has under development a draft proposal for rulemaking that requires employers to address the main elements of process safety management. These basic elements include (1) a management system to identify (in writing) and address the hazards involved in the use, storage, manufacturing, handling and movement of highly hazardous materials; (2) communication of that information to employees; (3) hazard analyses; (4) procedures to accommodate changes in plant equipment and technology; (5) safe operating procedures, including emergency and shutdown procedures; (6) training for employees in those procedures; (7) a preventive maintenance program that includes the testing and inspection of critical equipment; (8) a hot-work permit system; (9) a workplace facility emergency action plan; and (10) a program to make contractors aware of the hazards associated with their work at the site and of the safety rules and actions to be taken during an emergency. Most importantly, the proposed standard will examine the need for self-evaluation and followup through process safety audits. OSHA expects to publish a proposal no later than the summer of 1990 and to expedite the public rulemaking process so that a final rule can be issued as soon as possible.

ACTION II **OSHA will revise its current system for setting agency priorities to identify and include the risk of catastrophic events in the petrochemical industry.**

At present, OSHA allocates its resources according to a priority system based primarily on industry injury rates, which reflect accidents that have occurred. The current injury rates may not fully capture risk to workers in the petrochemical

industry. OSHA will be looking at other indices such as fatalities, the presence at worksites of significant quantities of highly hazardous chemicals, and the timing and conduct of critical maintenance operations.

OSHA will explore ways of determining where catastrophic releases, explosions, and fires may occur. Although such incidents are infrequent in the petrochemical industry, when they occur, the loss of life and injuries to workers is high, and the damage to property and the environment can be significant.

OSHA will revise its system of setting priorities to take into consideration factors that fully capture the real risk to workers. The agency will also review the recommendations developed from its earlier Chemical Emphasis Program and include them, to the extent possible, in the revised priority system.

ACTION III **OSHA will establish a catastrophe investigation protocol that will include plans, procedures, and an administrative framework to be activated in the event of a catastrophic accident.**

OSHA has learned from its recent investigations of such catastrophic events as the L'Ambiance Plaza building collapse and the Phillips explosion that there are common elements present in all such investigations that ensure their efficiency and effectiveness. OSHA, therefore, will develop an internal comprehensive catastrophic investigation policy to ensure that (1) information about chemical accidents, such as that available from the U.S. Coast Guard's National Response Center, is utilized; (2) the safety and health of employees of first responders is adequately addressed in the agency's investigations; (3) the activities of other investigating agencies on site are properly coordinated; (4) appropriate investigative techniques are promptly undertaken before the evidence becomes stale (such techniques include obtaining witness statements, videotaping cleanup operations, identifying and collecting essential company documents, surveying the site, and marking the evidence that will need to be examined or tested); (5) communications with the media are effectively handled; and (6) procedures are established to assure OSHA's control of the site so that evidence essential to the investigation is preserved.

ACTION IV **The Department of Labor will work with EPA to develop a joint investigation strategy for chemical accidents that affect both workers within the plant and the public and the environment outside the plant.**

Because OSHA and EPA each have separate authorities and responsibilities for regulating, inspecting, and investigating accidental chemical releases, a coordination strategy is needed. That strategy should include (1) a protocol for joint inspections and investigations on those occasions when both agencies have major investigative responsibilities; (2) procedures for disseminating information to labor, industry and the public regarding the findings of any joint investigations; and (3) a plan for effective information-sharing between the two agencies about the findings of chemical accident investigations that are conducted independently.

ACTION V **OSHA will employ all the means at its disposal to ensure that every establishment in the petrochemical industry implements technologies and safe work practices that are widely accepted and generally used by the industry and its contractors. The agency will encourage the petrochemical industry to incorporate new technologies into chemical processes to decrease the likelihood of a workplace accident.**

Significant improvements in process safety techniques related to the detection, mitigation, and prevention of chemical releases have been developed and adopted for use by most of the petrochemical industry. The Phillips investigation discovered an absence of management systems, resulting in a failure to implement basic safety procedures in common use in the industry. All petrochemical facilities must ensure that such elementary systems are in place and working.

The petrochemical industry itself has led the way in commissioning studies to develop new and improved technologies to reduce and mitigate catastrophic accidents associated with the release of toxic, flammable, and explosive chemical substances and at the same time improve production. An example is the research of the Design Institute for Emergency Relief Systems (DIERS) sponsored by the American Institute of Chemical Engineers [15]. The DIERS report of September 1988 recommended that the petrochemical industry remedy design deficiencies in its processing equipment to reduce the risk of a Bhopal-like catastrophic accident. Corporate management should ensure that the latest technological advances that promise improvements in the safety of chemical manufacturing are implemented to the extent feasible in all of its plants. OSHA is committed to using all of the tools available to it, including training, technical assistance, voluntary protection programs, consultation services, and enforcement, to encourage industry to adopt new and existing protective technologies.

Because OSHA and EPA each have separate authorities and responsibilities for regulating, inspecting, and investigating accidental chemical releases, a coordination strategy is needed. That strategy should include (1) a protocol for joint inspections and investigations on those occasions when both agencies have major investigative responsibilities; (2) procedures for disseminating information to labor, industry and the public regarding the findings of any joint investigations; and (3) a plan for effective information-sharing between the two agencies about the findings of chemical accident investigations that are conducted independently.

ACTION V **OSHA will employ all the means at its disposal to ensure that every establishment in the petrochemical industry implements technologies and safe work practices that are widely accepted and generally used by the industry and its contractors. The agency will encourage the petrochemical industry to incorporate new technologies into chemical processes to decrease the likelihood of a workplace accident.**

Significant improvements in process safety techniques related to the detection, mitigation, and prevention of chemical releases have been developed and adopted for use by most of the petrochemical industry. The Phillips investigation discovered an absence of management systems, resulting in a failure to implement basic safety procedures in common use in the industry. All petrochemical facilities must ensure that such elementary systems are in place and working.

The petrochemical industry itself has led the way in commissioning studies to develop new and improved technologies to reduce and mitigate catastrophic accidents associated with the release of toxic, flammable, and explosive chemical substances and at the same time improve production. An example is the research of the Design Institute for Emergency Relief Systems (DIERS) sponsored by the American Institute of Chemical Engineers [15]. The DIERS report of September 1988 recommended that the petrochemical industry remedy design deficiencies in its processing equipment to reduce the risk of a Bhopal-like catastrophic accident. Corporate management should ensure that the latest technological advances that promise improvements in the safety of chemical manufacturing are implemented to the extent feasible in all of its plants. OSHA is committed to using all of the tools available to it, including training, technical assistance, voluntary protection programs, consultation services, and enforcement, to encourage industry to adopt new and existing protective technologies.

ACTION VI

OSHA will sponsor a conference of industry, labor and government leaders on the lessons learned from the Phillips disaster. The results of the study on the petrochemical industry's practice of contracting out maintenance work will be presented. Representatives from other Federal agencies and foreign countries will be invited to participate in a discussion of ways to improve worker safety and health in the petrochemical industry.

This tripartite conference will continue the dialogue among government, industry, and labor from the U.S. and other countries regarding catastrophic chemical accidents and releases, and advances in industry safety and health work practices and conditions affecting workers. OSHA will present information learned as a result of the Phillips accident investigation, the agency's study on the use of contractors in the petrochemical industry, and its proposed standard for Process Safety Management of Highly Hazardous Chemicals.

ACTION VII

OSHA will urge agencies involved in the collection of information on chemical accidents and incidents to establish an interagency working group to review available data systems with a view to including more information on the causes of chemical accidents.

The existing data collection and information systems do not include comprehensive information on the causes of chemical accidents. The Coast Guard's National Response Center data base reports only certain accidental chemical spills; OSHA's Integrated Management Information System only contains the results of the agency's investigations of chemical accidents. Other data bases that have information about chemical accidents, such as those maintained by EPA, CMA's Community Awareness and Emergency Response system, and others administered by the private sector are similarly limited.

The interagency group should determine (1) the value of sharing available data; (2) the various needs of the concerned agencies for additional information; (3) the benefits of a coordinated analysis of the data; and (4) the best way of sharing this information with industry and labor. Depending on the outcome of its review, the group will make recommendations for improvements in chemical accident data collection and dissemination.

ACTION VIII **OSHA will periodically publish *ChemAlert* bulletins.**

This effort is modeled on a system instituted by OSHA several years ago to alert interested parties to the circumstances surrounding fatal accidents in the construction industry. The agency will periodically publish a concise, one-page bulletin, entitled *ChemAlert,* to report equipment failures and specific deficiencies in work practices, procedures, and systems in the chemical industry and to make recommendations as to how such problems can be corrected in the interest of improved worker safety and health. These alerts will be widely distributed to trade associations, employer groups, unions, and individual companies for their internal use and for further dissemination.

REFERENCES

1. Marshall, Michael, and Salcedo, Andres. "Engineering Investigation Phillips Fire and Explosion." U. S. Department of Labor. Occupational Safety and Health Administration. Office of Construction and Engineering Support. Washington, D. C., April 1990.

2. U. S. Congress. House Committee on Government Operations. *Adequacy of OSHA Protections for Chemical Workers.* Hearings before the Subcommittee on Employment and Housing 101st Congress, November 6, 1989.

3. U. S. Environmental Protection Agency. "Chemical Safety Audit, Phillips 66 Corporation Houston Chemical Complex, Pasadena, Texas, November 6-7, 1989." Final Draft. Washington, D. C., March 12, 1990.

4. Kletz, Trevor A. *What Went Wrong? Case Histories of Process Plant Disasters.* Houston: Gulf Publishing Co., 1985. Pp. 38-39.

5. Howard, W. B. "Process Safety Technology and the Responsibility of Industry." *Chem Eng Prog* (84): 25-33, September 1988.

6. Ripple, Dennis F. "Hazardous Release Mitigation Developments in Europe. In: *Proceedings of the International Symposium on Preventing Major Chemical Accidents.* Edited by John L. Woodward. New York: American Institute of Chemical Engineers, 1987. P. 5.113.

7. Jones, David A. "How Can Regulations Help to Prevent Accidents?" In: *Proceedings of the International Symposium on Preventing Major Chemical Accidents.* Edited by John L. Woodward. New York: American Institute of Chemical Engineers, 1987. P. 2.9.

8. Kayes, P. J., ed. *Manual of Industrial Hazard Assessment Techniques.* The World Bank. London: Technical Ltd., 1985.

9. International Labour Office. "Working Paper on Control of Major Hazards in Industry and Prevention of Major Accidents." Geneva, 1985.

10. International Labour Office. *Major Hazard Control: A Practical Manual.* Geneva, 1988. 276 Pp.

REFERENCES (Continued)

11. U. S. Department of Labor. Occupational Safety and Health Administration. *Chemical Special Emphasis Program Final Report.* Washington, D. C., 1987. 28 Pp.

12. U. S. Department of Labor. Occupational Safety and Health Administration. "Systems Safety Evaluations of Operations with Catastrophic Potential." OSHA Notice, CPL 2-2. Washington, D. C., July 13, 1987.

13. U. S. Department of Labor. Occupational Safety and Health Administration. "Systems Safety Evaluation of Operations with Catastrophic Potential." OSHA Instruction, CPL 2-2.45. Washington, D. C., September 6, 1988.

14. Carmody, T.W. "Luncheon Panel--Post-Release Mitigation." In: *Proceedings of the International Symposium on Preventing Major Chemical Accidents.* Edited by John L. Woodward. New York: American Institute of Chemical Engineers, 1987. Pp. 5.121-5.43.

15. "AIChE's Design Institutes Help Reduce Industrial Risks." *Chem Eng Prog* 84:22-23, September 1988.

16. American Petroleum Institute. *Management of Process Hazards. API Recommended Practice 750.* Washington, D. C., January 1990.

17. Organization Resources Counselors, Inc. "Recommendations for Process Hazards Management Substances with Catastrophic Potential." OSHA Docket S-026 - Process Safety Management of Highly Hazardous Chemicals. Washington, D. C., 1988.

18. Chemical Manufacturers Association. *Process Safety Management (Control of Acute Hazards).* Washington, D. C., 1985. 47 Pp.

19. Schumacher, Randal. "The Chemical Industry Replies: Making America's Safety Industry Safer." *NY Times:*May 18, 1986.

20. Riegel, Quentin. *NAM's SAFESystem: The Pilot Project.* Washington, DC: National Association of Manufacturers, July 1985.

REFERENCES (Continued)

21. American Insurance Association. *Hazard Survey of the Chemical and Allied Industries*. New York, 1979. 112 Pp.

22. Garrison, W. G. *Large Property Damage Losses in the Hydrocarbon-Chemical Industries -- A Thirty-Year Review.* 12th ed. Chicago: Marsh & McLennan Protection Consultants, 1989. 11 Pp.

23. U. S. Department of Labor. Occupational Safety and Health Administration. Office of Regulatory Analysis. *Industry Profile and Cost Assessment for a Proposed OSHA Standard Covering Process Hazard Management in Chemical and Petroleum Industries.* Charles River Associates Report No. S-9-F-5-0059. Boston, February 1988. Pp. 223-300.

24. Kearney Company, A. T. "The Seven Best of the Best Maintenance in North America." Chicago, Illinois, 1988. Unpublished.

25. American Institute of Chemical Engineers. Center of Chemical Process Safety. *Guidelines for Technical Management of Chemical Process Safety.* New York, 1989. 169 Pp.

26. Mascone, C. F.; Gordon, H. S.; and Vagi, D. L. "CPI Safety: High Marks, But ...." *Chem Eng* 95 (14):74-86, October 10, 1988.