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Reactive Chemical Incidents, What Does Existing Data Tell Us?

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ABSTRACT

On April 18, 1998, a runaway reaction initiated a sequence of events that led to an explosion and fire at the Morton International Plant in Patterson, New Jersey. The U.S. Chemical Safety and Hazard Investigation Board's (CSB) investigation of the Morton incident, one in a series of recent reactive chemical incidents, increased concerns regarding reactive chemical hazards. To better understand the nature and causes of such incidents, many stakeholders requested that the Board pursue a more generic and systemic analysis of the safety problems presented by reactive chemicals. As a result, CSB decided to conduct a hazard investigation that will review and evaluate historical trends involving reactive chemical incidents and examine industry preventative practices.

To accomplish the first of these two objectives, CSB is currently developing a database of reactive chemical incidents. This paper presents the lessons learned during development of the database, as well as the findings from analysis of incident data. The paper discusses the following areas:

- Current practices for incident reporting and tracking as related to reactive chemical incidents and near misses.
- Data accuracy.
- Data source access limitations.
- Impact of reactive chemical incidents.
- Observable trends within the past 10 to 20 years with regard to reactive chemical incidents.
- Common chemicals involved or classes of chemicals (e.g., polymerizing, decomposing, organic peroxides).
- Common industries or processes (e.g., phenol formaldehyde resins, ABS resins, polyolefins, urethanes, acrylic resins, hazardous chemical recycling, nitration, sulfonations).
- Common equipment (e.g., batch reaction systems, fixed storage vessels, drums, transfer piping, ventilation systems, heat exchangers).
- Common causes (both immediate and underlying, where known).
- Regulatory coverage.
- NFPA reactivity ratings for chemicals.
- Overall comparison/contrast of the reactive chemical problem as evidenced by domestic and international incidents.
- Future needs for reactive chemical process safety.

Reactive Chemical Process Safety – What Do Existing Data Tell Us?

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Abstract

The U.S. Chemical Safety and Hazard Investigation Board (CSB) began operation as a new independent Federal agency in 1998. Its primary mission is to aid in the prevention of chemical-related incidents (e.g., fires, explosions, or toxic releases) in fixed commercial or industrial facilities.

This paper discusses some of the preliminary findings from the incident data analysis segment of CSB's reactive chemical hazard investigation, which originated from the investigation of a serious process incident at Morton International, a plant in Paterson, New Jersey. The objectives of the reactive chemical hazard investigation are to: (1) determine the impact of reactive chemical incidents; (2) examine how industry, the U.S. Department of Labor's Occupational Safety and Health Administration (OSHA), and the U.S. Environmental Protection Agency (EPA) address reactive chemical hazards; (3) determine the differences, if any, between large/medium/small companies with regard to reactive chemical policies, practices, in-house reactivity research, testing, and process engineering; and (4) analyze the appropriateness of and consider alternatives to industry and OSHA use of the National Fire Protection Association (NFPA) instability rating[1] system for process safety management.

The analysis of incident data addresses various elements within each objective of the hazard investigation. This paper presents some of the lessons learned during CSB development of the database, as well as some of the preliminary findings from analysis of incident data.

Introduction

The U.S. Chemical Safety and Hazard Investigation Board (CSB) is an independent Federal agency whose mission is to investigate and promote the prevention of major chemical incidents at industrial facilities. CSB is a scientific investigatory organization; it is not an enforcement or regulatory body. In addition to conducting investigations and reporting on findings, the Board is directed by Congress to conduct special hazard investigations to analyze policy, guidelines, regulations, and laws governing chemical safety.

Created by the Clean Air Act Amendments,[2] the Board began operations in January 1998. Modeled after the National Transportation Safety Board (NTSB), CSB's authorizing statute provides for five Board members with academic backgrounds and experience in chemical safety. Each member is nominated by the President and confirmed by the U.S. Senate.

The Board's principal roles are to investigate accidents at fixed facilities, determine the conditions and circumstances that led to the event, identify the causes, issue safety recommendations, study chemical safety issues, and evaluate the effectiveness of related policies and actions. The Clean Air Act prohibits the use of any conclusions, findings, or recommendations of the Board relating to any chemical incident from being admitted as evidence or used in any lawsuit arising out of any matter mentioned in an investigation report.

Role of Hazard Investigations in CSB Mission
Major chemical incidents are rare events, whose causation, frequency, severity, and complexity vary widely among industrial processes and sectors. Causation and recommendations from individual field investigations often reflect very specific aspects of manufacturing operations, which typically use specialized procedures, equipment, and technologies. However, occasionally in the course of conducting incident investigations, the Board is alerted to significant safety issues that are beyond the scope of any one particular investigation. In this case, a hazard investigation or safety study is conducted to better understand the nature and causes of more generic and systemic safety problems. Findings from a hazard investigation could lead to a variety of recommendations, which may or may not include proposals for regulatory action.

Morton Investigation and Reactive Chemicals Hazard Investigation
On April 8, 1998, an explosion and fire occurred during the batch production of Automate Yellow 96 Dye at the Morton International plant in Paterson, New Jersey. The incident resulted from a runaway reaction that overpressured a 2,000-gallon chemical reactor and released flammable material that ignited. There were nine injuries, two of which were serious. Potentially hazardous materials were released to the community, and the physical plant was extensively damaged.

The Board completed an incident investigation,[3] finding that:

- The preliminary hazard assessment and a formal process hazard assessment failed to address reactive hazards.
- Process safety information did not warn of the potential for a dangerous runaway chemical reaction.
- Hazards of previous operational deviations were not evaluated.
- Management of change (MOC) procedures were not followed to review significant changes made in reaction vessel and batch size.

During the Morton investigation, many stakeholders also raised concerns that reactive chemical problems merited a more systemic analysis by the Board. Several recent incidents were highlighted, including Napp Technologies (Lodi, New Jersey, April 21, 1995)[4] and Georgia Pacific Resins (Columbus, Ohio, September, 10, 1997).[5] Therefore, the Board decided to conduct a hazard investigation of reactive chemicals. The objectives of the hazard investigation are to:

- Determine the impact of reactive chemical incidents.
- Examine how industry, OSHA, and EPA currently address reactive chemical hazards.
- Determine the differences, if any, between large/medium/small companies with regard to reactive chemical policies, practices, in-house reactivity research, testing, and process engineering.
- Analyze the appropriateness of and consider alternatives to industry and OSHA use of the NFPA instability rating[1] system for process safety management.

- Develop recommendations for reducing the number and severity of reactive chemical incidents.

Reactive chemical hazard investigation process

The following primary tasks will be undertaken in completing the hazard investigation, including:

- Solicit concerns and suggestions of key stakeholders on the management of reactive chemicals.
- Review, collect, and analyze reactive chemical incidents from various data sources.
- Survey reactive chemical hazard management practices in industry.
- Visit facilities to observe implementation of reactive chemical hazard management practices.
- Analyze regulatory coverage of reactive chemicals.
- Hold a public hearing to present preliminary results and obtain feedback from key stakeholders.
- Publish a report with findings, conclusions, and recommendations for improving reactive chemical process safety.

This paper presents some of the lessons learned during the review and collection of reactive chemical incident data, as well as some of the preliminary findings from the data analysis. The purpose of the paper is to provide some preliminary insight into the nature of reactive chemical incidents through limited, anecdotal information. A comprehensive examination of all available data is now nearing completion. The full data analysis will be published in the Board's final report scheduled for issue early in 2002.

Reactive Chemical Incident Data

CSB investigators searched public-domain data sources for incidents that meet specific chemical reactivity criteria. The purpose of the data search and analysis was to better understand the magnitude of the reactive chemical problem by estimating the scope, severity, and causes of such incidents. CSB's data collection and analysis efforts are believed to be the first systematic evaluation of domestic incidents involving chemical reactivity, though respected experts such as Etchells,[6,7] Barton,[8,9] Drogaris,[10] and Rassmussen,[11] among others, have studied this issue internationally.

The search criteria for the CSB data collection focused on incidents where the primary cause was related to chemical reactivity, as defined below:

> *A reactive chemical incident is a sudden event involving an uncontrolled chemical reaction with significant increases in temperature, pressure, and/or gas evolution that has the potential to or has caused serious harm to people, property or the environment.*

The scope of the incident search was limited to events that took place at chemical manufacturing or bulk usage locations, including raw material storage through chemical processing to product storage. Incidents involving transportation, pipelines, laboratories, minerals extraction, mining, explosives manufacturing, pyrotechnic manufacturing, or military uses were excluded. For purposes of the incident search, the definition of a reactive chemical incident was limited to incidents that had caused serious harm. Events involving simple combustion (i.e., rapid reaction of fuel (liquid, vapor, or dust) with oxygen in air) were excluded from the incident search.

Because the intent of the investigation is to analyze data and learn about industry's current performance in managing reactive chemical hazards, the data search was limited to incidents that occurred within the past 20 years.

No single data source provided a comprehensive collection of reactive chemical incidents. Sources of incident data include a variety of public-domain databases, technical literature, and news accounts. The following list shows the types of data sources used in the investigation:

- Notification databases
  - National Response Center (NRC)[12]
- Regulatory
  - OSHA Integrated Management Information System (IMIS)[13]
  - EPA Accidental Release Information Program (ARIP)[14]
  - EPA Risk Management Program - RMP*Info[15]
- Other Government Databases and Incident Reports
  - CSB – Chemical Incident Reports Center (CIRC)[16]
  - U.S. Department of Energy – Chemical Safety Reports
  - NTSB – Hazardous Materials Incident Report
- Industry associations
  - The Chlorine Institute[17]
- Professional societies
  - NFPA – Fire Incident Data Organization[18]
- Insurance industry
  - J&H Marsh & McLennan[19]
- Fire department response data
  - U.S. Fire Administration – National Fire Incident Reporting System[20]
- News/current events publications
- International databases (all contain information on some domestic incidents)
  - United Kingdom Health and Safety Executive – Major Hazard Incident Data Service (MHIDAS)[21]
  - Institute of Chemical Engineers – The Accident Database
  - European Communities – Major Accident Reporting System (MARS)
  - TNO Process Safety and Dangerous Goods – FACTS
- Topical journals and texts
  - Brethericks – Reactive Chemical Hazards[22]
  - Loss Prevention[23]
  - Proceedings of the Loss Prevention Symposia

Several other data sources were reviewed for reactive chemical incidents, but they provided no incident data. Some privately funded sources of incident data were requested for review, but they were unavailable.

The results of the incident data search are only a sampling of recent reactive chemical incidents. Although CSB has dedicated significant resources to searching these data sources, it is recognized that there are major limitations that may affect our overall analysis. Data collected by CSB include a large percentage of reactive incidents that were reported in publicly available databases, but very limited information on near-miss events, which typically go unreported. There are very few requirements (which may vary from state to state) to track or report reactive chemical incidents unless they involve specific consequences.

Nonetheless, the analysis of incident data is important in focusing the Board's findings and recommendations on the areas of greatest need in terms of improving reactive chemical safety.

Impact of Reactive Incidents

The reactive chemicals incident database contains 167 known domestic incidents over nearly 22 years (1980 – June 2001). No clear statistically significant trends exist within the data; however, we can discuss preliminary findings regarding the severity, consequences, and public impact of reactive incidents.

Severity

Of the 167 known reactive incidents since 1980, 48 account for a total of 108 fatalities. Most were single fatality incidents, but 16 involved multiple fatalities. From 1991, there have been on average 3 fatal reactive incidents per year, resulting in an average of 6 fatalities per year. The 119 incidents with no fatalities did result in injuries or produced significant property or environmental damage. Table 1 provides examples of severe reactive chemical incidents. .

CSB also analyzed the data in terms of reactive incidents that caused significant harm to people (i.e., fatalities and/or injuries). The database contains 138 incidents that have caused significant harm, 86 of which occurred from 1991 – 2000.

In summary, over the past decade, the United States has averaged 10 reactive incidents per year. Three of the 10 caused fatalities, and nine of the 10 caused significant harm to people.

Consequences

Reactive incidents produce a range of consequences — from minor process shutdowns to fires, explosions, hazardous liquid spills, toxic gas releases, or any combination of such. At least a dozen incidents in the CSB database resulted in property damage alone exceeding $10 million, with 3 cases in which this loss exceeded $100 million. Injuries and fatalities to plant personnel and the general public, and damage to the local environment have occurred as a result of these incidents. Fires and explosions were the most frequently reported consequence, followed by toxic gas releases. In several cases, a combination of fire, explosion, and toxic release occurred in the same incident.

Public Impact

Reactive incidents primarily cause onsite impacts such as worker fatalities and injuries, and severe business impacts including lost production and property damage. However, a significant number of incidents have led to public impacts. Incidents causing harm (injury or fatality) to the public, evacuation, or shelter-in-place are considered public impact incidents. From 28 to 32 percent of the 167 incidents are known to have had public impacts.

Profile of Affected Industries

Reactive chemicals are used in many different industries and serve various functions, such as manufacturing other chemicals or products, cleaning, or neutralizing. A reactive incident can occur virtually anywhere chemicals are manufactured or used.

Type of industry

Data show that reactive incidents are not unique to the chemical manufacturing industry. Anyone who stores, handles, transports, or manufactures chemicals needs to address hazardous chemical reactivity. The CSB database contains incidents that occurred in chemical manufacturing, waste processing, petroleum refining, and bulk storage, handling, and distribution. Although a majority of the incidents were in the chemical manufacturing industry, nearly 40 percent of the 167 known incidents occurred in other industries. Bulk storage, handling, and distribution facilities account for 75 to 80 percent of the incidents at nonmanufacturing industries.

Size of business

CSB analyzed the incidents in the database according to company and facility sizes — more than 1,000 employees, large; 100 to 1,000 employees, medium; and fewer than 100 employees, small. Governments and municipalities were considered as a separate entity. A large percentage of the data regarding company and facility information was undetermined/unknown because of lack of information and mergers.

Of the incidents where data on company size could be obtained, 75 to 80 percent of the known incidents from 1980 to 2001 occurred at large companies. The remaining incidents were split between small and medium companies, and governments/municipalities. Of the incidents where facility size could be obtained, 45 to 50 percent occurred at medium-size facilities. The remaining incidents were split between large and small facilities, and governments/municipalities.

Although limited, these data contradict a common perception that reactive incidents primarily occur at small- and medium-sized companies/facilities.

Profile of Reactive Incidents

Most chemicals are reactive under the right conditions. Reactivity is a highly desirable characteristic because it allows a variety of chemical products to be made under relatively moderate process conditions (temperature and pressure), saving time and money. However, chemicals reacting in an unintended or unanticipated manner may lead to unsafe conditions or hazards. Potential hazards can be a result of deviations in reactive chemistry (e.g., interactions between different chemicals and site-specific factors, such as temperature, pressure, quantity, concentration, and impurities) or inherent chemical instability. If the hazard is not addressed through diligent process safety management — including reactive hazard identification, process hazard evaluation, good engineering design, effective operating procedures, and other controls, — it could result in an incident.

Type of chemical classes

Data show that the reactive chemical issue is not limited to any one or a few classes of chemicals.

A wide range of chemicals and chemical classes were involved in the 167 incidents. A list of chemical classes commonly involved in incidents includes acids, monomers, oxidizers, organic peroxides, bases, inorganics/metals, and hypochlorites. None of these classes represent a majority of the known incidents.

Type of reactions

The problem is not limited to any one or a few types of chemical reactions. A wide range of chemical reactions can cause reactive incidents. Approximately 90 percent of the 167 incidents involved chemistry known to industry, though not necessarily to the personnel involved. The diversity of chemistry involved is exhibited by the following types of reactions within the CSB database:

- Decomposition
- Acid/base
- Water reactive
- Polymerization
- Oxidation
- Decomposition initiated by another reaction
- Redox
- Chlorination
- Catalytic cracking
- Halogenation
- Hydrolysis
- Nitration

Type of equipment

Not all reactive incidents involve chemical reactors.

A reactive incident can occur in most equipment used to store, handle, manufacture, and transport chemicals. The incidents within the database occurred in a variety of equipment — including reactors, storage tanks, separation equipment, process vessels, transfer equipment, and bulk storage drums. Twenty-five to 30 percent of the incidents involved reactor vessels; 20 to 25 percent occurred in storage equipment (tanks, rail cars) and designated storage areas; approximately 20 percent involved process equipment, such as holding tanks, mixers, and dryers; another 10 to 15 percent occurred in waste, separation, and transfer equipment; and nearly 10 percent involved bulk storage drums (primarily 55-gallon drums). A small percentage of data could not be attributed to particular equipment.

These data contradict a common perception that a majority of reactive incidents involve reactor vessels. Nearly 60 to 70 percent of the potential equipment affected by reactive incidents falls into other categories.

Common Technical, Initiating, and Underlying Causes

Reactive chemical incidents occur when a set of permitting conditions (or scenario) is fulfilled in a process that stores, handles, transports, or manufactures chemicals. The scenario is often complex, requiring multiple, simultaneous initiating events or conditions (Figure 1).

Figure 2 presents a simplified fault tree analysis of the Morton incident. It indicates how various underlying causes — such as inadequate guidance on design, operating procedures, training, transfer of research information, and hazard assessments — along with a combination of other factors, led to a runaway reaction hazard (technical cause). The "other factors" included:

- Starting the reaction at a temperature higher than normal.
- Leaving steam on too long to initiate the reaction.
- Delaying the use of cooling water to control the reaction rate.

Technical causes, such as the runaway reaction at Morton, are often the direct result of either intrinsically unsafe processes or process deviations (initiating cause), and indirectly related to some underlying causes.

Common technical and initiating causes

Reactive incidents result from more than thermal runaways. In fact, analysis of data from the 167 known incidents suggests that mixing incompatible materials should be of equal or greater concern.
Data analysis identified three common technical causes — material incompatibility, runaway reaction, and decomposition from thermal/mechanical shock. Of the 167 incidents, 58 to 62 occurred as a result of incompatible materials, 55 to 60 due to thermal runaway, and 13 to 18 from thermal or mechanical shock. The hazard was unknown for 30 to 35 incidents. No one of these technical causes represents a majority.

Data analysis identified several initiating causes — mischarging of reactants or catalysts, inadequate temperature control, human factors, contamination, and incorrect operating conditions. Forty-five to 50 percent of the incidents that occurred as a result of material incompatibility were initiated due to inadvertent mixing. At Napp Technologies, for example, water was inadvertently introduced into water-reactive materials (aluminum powder and sodium hydrosulfite) during a mixing operation (according to EPA/OSHA report). The Whitehall Leather incident[24] is another case where two incompatible materials were inadvertently mixed.

Common underlying causes
Only 36 of the 167 incidents had underlying cause information.

Analysis of this limited set of data revealed a variety of underlying causes, including:

- Inadequate understanding of the reaction chemistry, leading to failures to identify chemical reaction hazards.
- Lack of understanding of the reaction chemistry, leading to inadequate process hazard evaluations.
- Inadequate procedures for safe storage, handling, or manufacturing of reactive chemicals.
- Inadequate training for storage/handling of reactive chemicals.
- Inadequate change management system to identify/evaluate reactivity hazards.
- Inadequate process design for reactive chemicals.
- Inadequate design to prevent human error.
- Inadequate company-wide communication of hazards.
- Inadequate emergency relief system design.
- Inadequate safe operating limits.
- Inadequate near miss/incident investigation.
- Inadequate inspection/maintenance/monitoring of safety critical devices in reactive chemical service.
- Reactive chemical hazards previously unknown to industry.

It should be recognized that most major reactive incidents often have several underlying causes.

Although data are limited, nearly 60 percent of the incidents occurred because of an inadequate understanding of reaction chemistry, which subsequently led to failures to identify chemical reaction hazards or to conduct adequate process hazard evaluations. Forty-five to 50 percent of the 36 incidents also point to inadequate procedures for safe storage, handling, or manufacturing of reactive chemicals.

Regulatory Aspects

OSHA and EPA have been consulted on CSB's hazard investigation. CSB is particularly interested in understanding both the regulatory requirements and the other resources or guidance provided by these agencies. The primary regulations that apply in this case are OSHA's PSM[25] (Process Safety Management) and EPA's RMP[26] (Risk Management Program). The incident data were analyzed in respect to the strengths and weaknesses of PSM and RMP.

Issue of NFPA Instability Ratings

Reactive chemistry (or chemicals) presents unique challenges to regulators. Unlike other hazardous chemical characteristics, such as toxicity (e.g., inhalation LC_{50}, dermal LD_{50}, oral LD_{50})[27] and flammability (e.g., flash point below 73 °F, boiling point below 100 °F), reactivity is less clearly defined. One approach to defining reactivity has been developed by NFPA. The NFPA standard 704 committee rates reactivity/instability of chemicals (along with other hazards) due to short-term, acute exposures under emergency conditions such as fires and spills. Those chemicals rated by the NFPA 704 committee are published in NFPA standard 49 or 325.[28,29] The NFPA 704 reactivity/instability hazard categories address the susceptibility of chemicals (due to inherent instability) to release energy; they do not address reactivity in terms of chemical interactions (with the exception of water). The instability rating system ranges from 0 to 4, with 4 assigned to chemicals that pose the greatest hazard. CSB analyzed the incident data in terms of chemicals published within NFPA 49 or 325. The data show that 85 to 90 percent of the 167 known incidents involved chemicals that were rated NFPA 0, 1, or 2, or not rated at all.

The OSHA PSM standard contains a list of 137 highly hazardous chemicals — some of which are considered highly reactive based on NFPA 3 or 4 instability ratings. Public and labor union concerns as the result of a number of reactive incidents have caused OSHA to consider revisions to PSM. One alternative OSHA is considering to address the reactives problem is to add the remaining NFPA 3 and 4 chemicals and all NFPA 1 and 2 chemicals to the PSM list. However, CSB's data analysis suggests that such an approach would capture less than half of the chemicals involved in the 167 incidents analyzed.

Regulatory Coverage

CSB analyzed the incident data in terms of chemicals covered by OSHA's PSM and EPA's RMP. CSB determined if the chemical was PSM or RMP covered by identifying whether the chemical involved in the incident was listed in PSM or RMP or considered flammable by OSHA's definition. The analysis is limited by insufficient knowledge of chemical concentrations, quantities, or other covered chemicals in the same process.

Nearly one-third of the 167 incidents do involve chemicals covered by process safety regulations; however, about half involved chemicals not considered highly hazardous (i.e., not listed by PSM and RMP). "Highly hazardous" means either a specifically listed chemical or one that exhibits flammability characteristics. Regulatory coverage could not be determined for a small amount of incidents.

Hazard Investigation Completion

The preliminary results of the hazard investigation (data analysis, site survey and visits, and regulatory analysis) will be presented in a public hearing in late 2001 or early 2002. The purpose of the hearing is to communicate CSB findings, and to gather input from all interested parties prior to the Board issuing a final report and recommendations. There will be an opportunity for public comment. The date and location of the hearing will be announced within the next few months.

[1] **NFPA 704**, "Standard System for the Identification of Hazards of Materials for Emergency Response", 1996. In the 1996 standard, the terminology was changed from "reactivity" to "instability".
[2] "United States Clean Air Act", 42 USC §7412
[3] A copy of the report is accessible at: http://www.csb.gov/reports/2000/morton/index.htm
[4] A copy of the report is accessible at: http://www.epa.gov/ceppo/pubs/lodiintr.htm
[5] A copy of the report is accessible at: http://www.epa.gov/ceppo/pubs/gpcasstd.pdf
[6] **Etchells, J**, "Why Reactions Runaway", **IChemE Symposium Series**, (No. 141), 1997
[7] **Etchells, J**, "Prevention & Control of Exothermic Runaway: An HSE Update", (unpublished)
[8] **Barton, JA, Nolan, PF**, "Incidents in the Chemical Industry Due to Thermal Runaway Reaction", **IChemE Symposium Series**, (No. 115), 1989
[9] **Barton, J, and Rogers, R**, "Chemical Reaction Hazards, A Guide to Safety", 2nd Ed, 1997, IchemE
[10] **Drogaris, G.**, "Review of Accidents Involving Unexpected / Run-away Reactions", Community Documentation Centre on Industrial Risk, (1992)
[11] **Rasmussen, B.**, "Unwanted Chemical Reactions in the Chemical Process Industry", Riso National Laboratory, Report M-2631, (1987)
[12] http://www.nrc.uscg.mil/index.html
[13] http://www.osha.gov/oshstats/
[14] http://www.epa.gov/ceppo/arip
[15] http://oaspub.epa.gov/ceppo/overview$.startup
[16] http://www.csb.gov
[17] http://www.cl2.com/
[18] http://www.nfpa.org/
[19] **J&H Marsh and McLennan Consulting Service,** "Large Property Damage Losses in the Hydrocarbon-Chemical Industries – A Thirty-year Review", 18th Ed., J&H Marsh& McLennan Risk Control Strategies
[20] http://www.usfa.fema.gov/nfdc/nfirs.htm
[21] http://www.silverplatter.com/catalog/oshr.htm
[22] Bretherick, L., "Bretherick's Handbook of Reactive Chemical Hazards", 6th Ed, Butterworth-Heinemann, London (1999)
[23] **F.P. Lees**, "Loss Prevention in the Process Industries", 2nd edition, Butterworth-Heinemann, London (1996)
[24] A copy of the report is accessible at: http://www.NTSB.gov
[25] 29 CFR 1910.119, PSM contains a list of 137 chemicals, which OSHA considers highly hazardous.
[26] 40 CFR 68, RMP contains a list of 77 toxics and 63 flammables, which EPA considers highly hazardous.
[27] LC stands for "Lethal Concentration." LC 50 is the concentration of the chemical in air (inhalation experiments) that kills 50% of a group of test animals in a given time (usually four hours). LD stands for " Lethal Dose." LD 50 is the amount of a material, given all at once, which causes the death of 50% of a group of test animals.
[28] NFPA 49, "Hazardous Chemicals Data", 1994
[29] NFPA 325, "Hazardous Chemicals Data", 1994

Figure 1: Reactive Incident Scenario Pathway

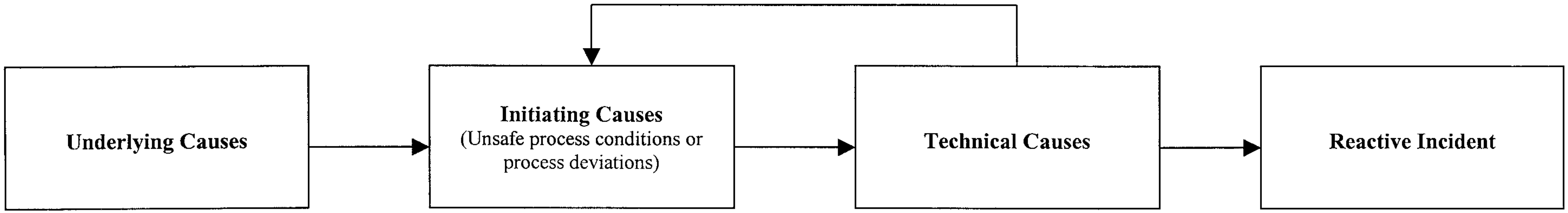
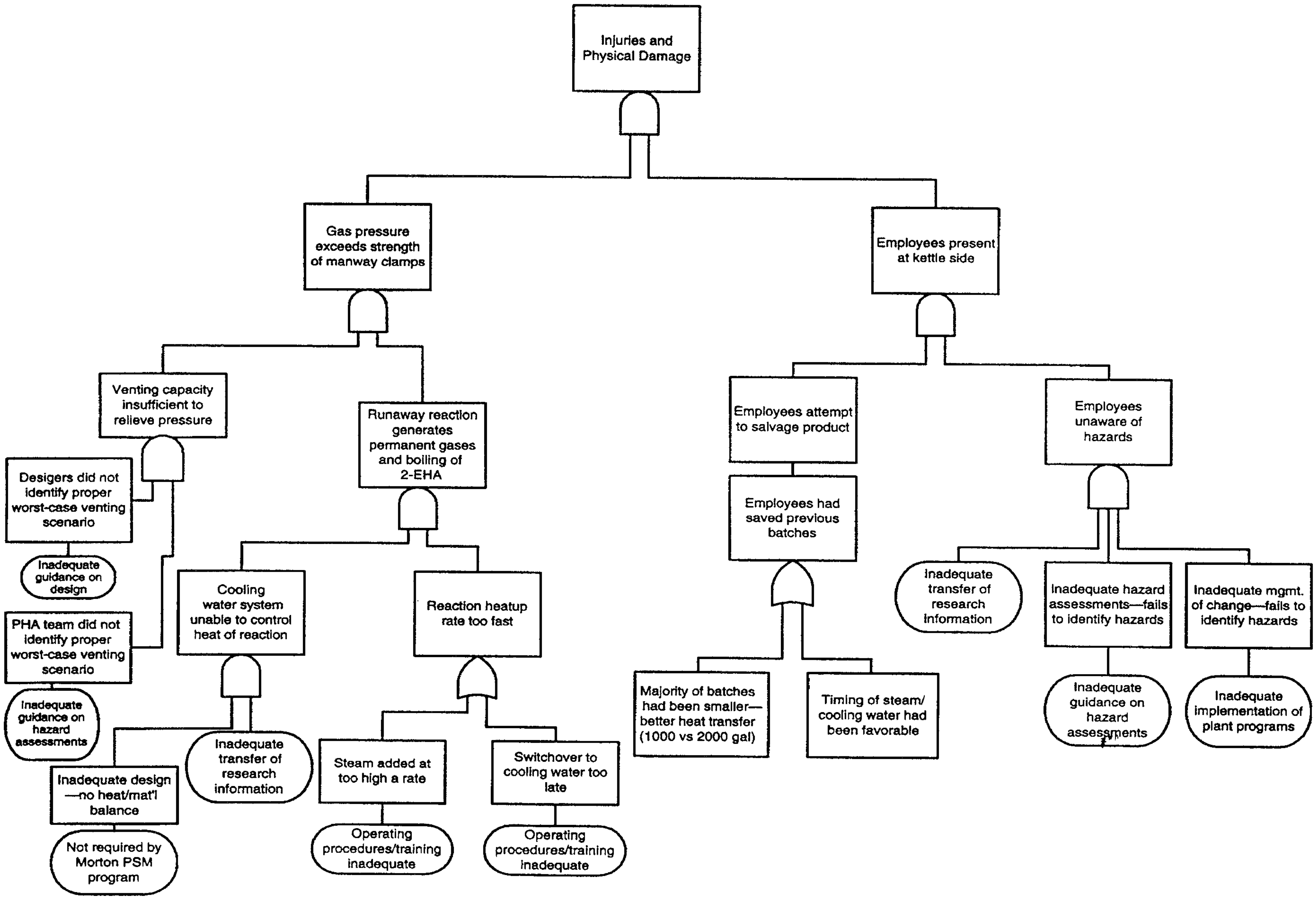


Table 1: List of severe reactive chemical incidents

Location	Date	Injuries, Fatalities or Evacuations
Channelview TX	7/5/90	17 fatalities
Charleston SC	6/17/91	9 fatalities
Sterlington LA	5/1/91	8 fatalities
Lodi NJ	4/21/95	5 fatalities
Allentown PA	2/19/99	5 fatalities
Port Neal IA	12/13/94	4 fatalities
Auburn IN	6/28/88	4 fatalities
Gulfport MS	6/2/82	3 fatalities
Barceloneta Puerto Rico	6/12/86	3 fatalities
Belpre OH	5/27/94	3 fatalities
West Helena AR	5/8/97	3 fatalities
Pasadena TX	6/23/99	2 fatalities
Pasadena TX	3/27/00	1 fatality
Bucks AL	9/4/99	1 fatality
Alamogordo NM	8/6/99	1 fatality
Whitehall MI	6/4/99	1 fatality
Columbus OH	9/10/97	1 fatality
Patterson NJ	4/8/98	9 injured
Baltimore MD	10/13/98	5 injured
Deer Park TX	3/29/00	> 1000 evacuated



Injuries and Physical Damage
Gas pressure exceeds strength of manway clamps
Employees present at kettle side
Venting capacity insufficient to relieve pressure
Runaway reaction generates permanent gases and boiling of 2-EHA
Employees attempt to salvage product
Employees unaware of hazards
Desigers did not identify proper worst-case venting scenario
Inadequate guidance on design
PHA team did not identify proper worst-case venting scenario
Inadequate guidance on hazard assessments
Cooling water system unable to control heat of reaction
Reaction heatup rate too fast
Employees had saved previous batches
Inadequate transfer of research information
Inadequate hazard assessments—fails to identify hazards
Inadequate mgmt. of change—fails to identify hazards
Inadequate design —no heat/mat'l balance
Inadequate transfer of research information
Steam added at too high a rate
Switchover to cooling water too late
Majority of batches had been smaller—better heat transfer (1000 vs 2000 gal)
Timing of steam/ cooling water had been favorable
Inadequate guidance on hazard assessments
Inadequate implementation of plant programs
Not required by Morton PSM program
Operating procedures/training inadequate
Operating procedures/training inadequate