# Experience and Capabilities in the Investigation and Analysis of Fires and Explosions

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APTECH®

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# Section 1
# OVERVIEW

The "typical" fire and explosion accident in an industrial process plant is generally "typical" in only one respect: it comes as a surprise. When the ensuing investigation is carried out and the root cause of the accident is determined, one or more of the following features is found to be responsible: improper equipment or process design, improper materials of construction, or improper operation and/or maintenance.

With improper equipment or process design, the process fluid (or solid) is brought to conditions that are incompatible with the equipment. With improper materials of construction, perhaps in conjunction with improper operation or maintenance, process fluid (or solid) conditions are, again, incompatible with the equipment. Then, what almost always happens is a loss of mechanical integrity of components in the plant, including piping, valves, vessels, tanks, pumps, compressors, boilers, heat exchangers, furnaces, etc.

Mechanical integrity is lost through degradation mechanisms. In general, these degradation mechanisms are related to temperatures, pressures, chemical conditions, mechanical loads, and flow velocities that are outside the capability of the component.

Some degradation mechanisms, such as high-temperature creep and corrosion, can be very slow and require years to run their course. In contrast, a degradation mechanism, such as brittle fracture, can be extremely rapid, requiring only a few milliseconds to do its damage. Whatever the rate, the typical fire and explosion accident is a result of transient events in the process and in the component's mechanical integrity. These transient events are almost never considered in the original plant design, and they greatly contribute to the "surprise" nature of the event.

The investigation of a plant fire and explosion event, and the eventual determination of root cause, requires a wide range of technical expertise. This includes field inspection expertise requiring hands-on familiarity with the equipment, and with evidence discovery and preservation. Expertise must also include the engineering capability to analyze an accident from the perspective of mechanical, chemical, civil, metallurgical, and electrical engineering. This engineering analysis must culminate in a "reconstruction" of the accident over the relevant time frame, with a quantification of the important parameters (pressures, temperatures, concentrations, etc.) and events (mechanical loadings, fracture, etc.) at each step in time. Finally, expertise must be available to clearly explain the findings of the

investigation and the accident root cause, both in technical terms and in lay terms, as appropriate.

Aptech Engineering Services, Inc., has investigated over 2300 accidents and equipment and material failures over the past 21 years. We are an independent, privately-held consulting company with no vested interests in equipment design, manufacture, or sales, or in process plant design, operation, or sales. Thus, our services are provided without technical or financial bias.

APTECH has a staff of over 50 mechanical, metallurgical, chemical, civil, and electrical engineers stationed at locations throughout the U.S. We have assisted in the investigation of many of the major fire and explosion accidents that have occurred in the U.S. in the past decade. These accidents caused substantial loss of life, property, and business. We have successfully determined the accident root cause by assembling and coordinating a team with many kinds of technical expertise.

Our investigations have often been performed directly for the plant owner/operator. In other cases, we have been retained directly by insurance companies who insure the property, or by attorneys who represent the property owner or insurance companies. We have frequently served as both consultants and expert witnesses to law firms. In cases where we have testified before juries or arbitration panels, we have used state-of-the-art videodisc animation and other demonstrative techniques.

In the remainder of this booklet, a number of investigations conducted by APTECH are summarized. The cases summarized focus on accidents involving fires and/or explosions.

## ADDITIONAL INFORMATION

If you would like additional information regarding APTECH's capabilities and experience, please contact us.

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# Section 2
# SUMMARY RESUMES OF KEY PERSONNEL

The following members of our technical staff are the key personnel in the area of fire and explosion investigation and analysis.

### Kimble J. Clark
### B.S., M.S., Ph.D. — Vice President

**Expertise:** Mechanical engineering; heat transfer; fluid mechanics and thermalhydraulics; combustion and chemistry; fluid transport and thermophysical properties; fires and explosions; accident investigation and reconstruction; failure root cause determination; chemical process analysis and optimization; run/repair/replace decision making; engineering analysis, laboratory testing, and full-scale field testing in the above areas.

**Projects:** Chemical (ammonium perchlorate) plant explosion; refinery hydrogen explosion; glass furnace explosion; heat-treating salt bath explosion; chemical warehouse fire; elevator fire; vehicle fires; water heater fires; boiler waterwall tube corrosion failure; boiler superheater tube creep failure; diesel engine failure; steam turbine failure; heat exchanger failure; boiler performance testing; industrial refrigerator performance testing; patent infringement on semiconductor fluid pump design.

### Geoffrey R. Egan
### B.E., D.I.C., Ph.D. — President

**Expertise:** Applied mechanics; fatigue, fracture, and stress analysis of welded structures involving piping and pressure vessels, offshore platforms, bridges, and steel framed buildings.

**Projects:** Crane failure analyses; oil and gas pipeline fractures; cracking in bridge structural elements; railroad tank car derailment and toxic spill; provided expert testimony for disputes involving airport, hospital, and refinery construction; pumped storage project penstock failure; nuclear power plant piping replacement; failure analysis of coal-fired power plant equipment; nuclear power plant pressurized component failure analysis; nuclear power plant “safe end” analysis; refinery component failure analysis; chemical plant fire and explosion.

**Richard J. Schreiber**
**B.S., M.S., P.E., C.F.E.I.**
**Expertise:** Mechanical engineering; analysis of failures of mechanical devices that lead to accidents, losses, fires, and explosions; combustion; energy systems engineering; fuel switching; applied heat transfer; fire and explosion accident investigation; thermal systems instrumentation and testing.

**Projects:** Utility boiler explosion; gas turbine combustor flashback; propane gas migration and explosion; mechanical seal failure and vessel explosion; chemical (ammonium perchlorate) factory explosion; chemical warehouse fire; home furnace, range/oven, and pool heater fires; elevator fire; truck tire/rim injury; package boiler explosion; paper mill injury; machine tool injuries; electrical shock injury; industrial refrigerator performance evaluation; vehicle fires; power plant cycling performance and damage evaluation; patent infringement of semiconductor fluid pump design; oil well fire and explosion; railroad tank car derailment and toxic spill; deep fryer fire; gas main piping explosion; gas pressure regulator failure; tank float valve failure.

**Eric V. Sullivan**
**B.S., P.E.**
**Expertise:** Metallurgical engineering; welding engineering; failure analysis; nondestructive examination; field testing and instrumentation; nuclear power plant materials engineering; mechanical testing; OSHA 1910.120 hazardous materials management and emergency response training.

**Projects:** Power plant component cracking; hydroelectric plant vessel failure and explosion; mining equipment failures; diesel and natural gas engine operation and metallurgy; chemical factory explosion; light aircraft crash; train derailment; gas turbine blade failures; natural gas filter vessel failure and fire; underground gas main piping explosion; vehicle fire.

**Thomas D. Burnett**
**B.S.**
**Expertise:** Fossil utility boiler, steam turbine operation and maintenance; marine engineering.

**Projects:** Equipment and component failures; critique of plant operating and maintenance procedures; coal ball mill failure; pulverized coal piping fire; power plant structural collapse; lime kiln drive chain failure.

**Marvin J. Cohn**
**B.S., M.S., P.E.**
**Expertise:** Civil and metallurgical engineering; stress analysis; seismic qualification of equipment; member of ASME code committees; QA auditor (ANSI N45.2.23).

**Projects:** Earthquake buckling of storage tank; heat exchanger brazing failure; high energy piping and headers stress analysis; stress analysis of buried piping systems; catastrophic pipe failure accident reconstruction.

**Michael T. Cronin**
**B.S., B.S., P.E., C.W.I.**
**Expertise:** Mechanical engineering; analysis of steady-state and transient stress, strain, and temperature fields using finite element and finite difference methods; fatigue and fracture analysis; risk analysis procedures for making run/repair/retire decisions; nondestructive examination using ultrasonic, magnetic particle, and radiographic methods; non-linear stress and heat transfer analysis. AWS CWI Certificate 97120771.

**Projects:** Fitness-for-service analysis of steel framing; stationary diesel engine failure; vessel explosion by autorefrigeration; steam turbine and generator failure; bridge collapse; grain silo collapse; aircraft engine fan disk failure; hotel walkover collapse; fabric dryer explosion; natural gas pipeline rupture; drilling rig collapse; chemical process vessel fracture control plans; railroad collision; space station and satellite battery fracture control plans; helicopter rotor shaft failure.

**Rodney L. Dail**
**B.S.**
**Expertise:** Metallurgical engineering; welding engineering; failure analysis; mechanical testing; nondestructive examination; corrosion engineering; technical training.

**Projects:** Failure analysis of 50,000 ton forging press; nuclear plant piping replacement prudence; nylon processing vessel explosion; pickling solution heater explosion; process plant equipment failures and explosions; power plant piping; equipment and boiler component failures.

**Charles A. Greene**
**Ph.D.**
**Expertise:** Petrochemical refinery processes

**Projects:** Coal beneficiation failure, sulfuric acid tank explosion, pollution releases from refineries.

**Jeffrey L. Grover**
**B.S., P.E., C.W.I.**
**Expertise:** Civil and mechanical engineering. AWS CWI Certificate 97120831.

**Projects:** Airport and refinery construction dispute resolution; flaw evaluations for bridges, penstocks, ships, steel framing, cryogenic valves, power plant components, and wind tunnel piping; offshore structures corrosion fatigue evaluation; piping failures; codes and acceptance criteria.

**Robert J. Impey**
**B.S.**
**Expertise:** Mechanical engineering; power plant operation.

**Projects:** Coal pulverizer failure; package boiler explosion; frost damage in paper mill; chemical plant explosion; food processing plant fire; diesel engine explosion; industrial and utility boiler explosions; stationary and marine boiler troubleshooting.

**Stephen M. Kohan**
**B.S., M.S., Ph.D.**
**Expertise:** Chemical engineering; risk analyses; chemical process modeling.

**Projects:** Catalytic cracker accident; petroleum refinery testing; refinery methods improvement program; gas drying to satisfy DOT regulations; geothermal, wind, biomass, and solar power plants; catalytic conversion of natural gas to liquid; cogeneration case studies; economic model critique and development.

**Todd A. Kuntz**
**B.S., M.S., P.E., C.W.I.**
**Expertise:** Metallurgical/materials engineering. AWS CWI Certificate 97120891.

**Projects:** Airport and refinery construction dispute resolution; power plant instrumentation for damage monitoring; bicycle suspension failure; piping failures; structural welding certification; trailer hitch failure.

**Steven A. Lefton**
**B.S. — Vice President**
**Expertise:** Chemical and mechanical engineering; management and operational expertise in fossil and nuclear utility power plants, including the construction, start-up, and on-line operational procedure writing and check-out of power plant equipment; fuel handling and fuel burning equipment; calibration and design of utility boiler-turbine control systems. Expertise in water treatment and boiler water control measures used to prevent deposition and corrosion damage to power plant equipment.

**Projects:** Evaluation of boiler manufacturer design processes; boiler water chemistry practices; Public Utilities Commission testimony on utility boiler ratings; impact of cycling and deration on plant life and reliability; fossil utility boiler explosion investigation; failure

analyses of turbines, diesel engines, ball mill bull gear, and tubes; analysis of air preheater failure and proposed redesign.

**Philip B. Lindsay**
**B.S., M.S., P.E.**
**Expertise:** Metallurgical and corrosion engineering; materials selection; development of corrosion test laboratory technology; corrosion failure analyses; field corrosion testing; applied research in ferrous alloy development; corrosion engineering group supervision; powder metallurgy fabrication; transmission and scanning electron microscopy analyses; computer analysis of engineering data and metallurgical instruction.

**Projects:** Residential water pipe contamination ("blue water"); soil corrosion; home foundation failure; corrosion of reinforced concrete; heat exchanger failures — feedwater heaters, condensers, service water heaters; ammonium nitrate plant explosion.

**Richard S. Moser**
**B.S.**
**Expertise:** Metallurgical engineering; nondestructive testing; remaining life assessment; development of mechanical field testing techniques.

**Projects:** Pressure vessel corrosion and failure; power plant tubing failure analysis; railroad tank car rupture; welded structure failures; oil well fire and explosion; natural gas engine valve wear and cracking.

**T. Steven I. Torbov**
**B.S., M.S.**
**Expertise:** Mechanical engineering; power plant design, operation, and materials selection.

**Projects:** Diesel engine failure; evaluation of industrial burner systems; boiler explosions; low NOx burner malfunctions; boiler performance testing; boiler water circulation model; boiler tube and header failure analysis; steel mill coke oven gas explosion; boiler fire.

**Phillip L. Wheeler**
**B.S., M.S., P.E.**
**Expertise:** Electrical engineering; electrical power systems. (Consulting Associate.)

**Projects:** Failure analyses of power electrical equipment in substations, transmission lines, interconnections, switchgear, cables and power plants; residential appliances and commercial equipment failures and fires.

# Section 3
# SUMMARIES OF SELECTED CASES AND LOSSES

This section contains brief summaries of selected cases and losses that involved fires and explosions. The summaries are arranged by the type of machinery, process, or structure in which the accident occurred.

## Boilers and Power Machinery

### Gas-Fired Utility Boiler Explosion

During shutdown, explosions occurred in the furnace and backpass of a 170 MW gas-fired utility boiler. The utility company's insurance carrier retained APTECH to do a third-party investigation of the origin and cause of the incident. The boiler was a 1950s-vintage, Combustion Engineering unit with front-wall mounted burners. The burners did not have flame scanners, so the boiler was operated under the NFPA's manual operation guidelines. APTECH experts examined the operational data and found that alarms for carbon monoxide and combustibles had occurred prior to the explosions. We walked down the entire boiler and documented the damage pattern. The furnace buckstays and the walls of the backpass were bowed outward. The outward deflection of the walls caused the economizer to fall into the hopper below. The superheater screen tubes were severed at the roof. Most of the severed screen tubes were found deflected into the superheater, but one of them fell to the furnace floor. The evidence indicated that there were at least two separate, but temporally closely spaced, explosions – one originating in the furnace above the burners and the other in between the superheater and reheater. Metallurgical examinations of the screen tubes showed that they had preexisting hydrogen damage. The examination also showed that the tubes had been severed when the furnace explosion lifted the roof. The reaction forces from the steam jets accounted for their final positions. APTECH determined that the fuel that exploded was raw natural gas from unignited burners. The bottom row of burners had been extinguished when they became too fuel-rich as the fuel, but not the air, was shut off to the upper burners. The unignited burners were not detected due to the absence of flame scanners. APTECH provided an origin and cause report to the client.

### Explosion at Solar Energy Plant

APTECH was asked to determine the root cause of an explosion at a solar trough steam-electric power plant. Tanks holding the circulating heat transfer fluid had unexpectedly exploded. APTECH conducted an onsite investigation including interviews with witnesses; and a metallurgical and engineering investigation and analysis using samples and data acquired at the plant. APTECH prepared a report of its findings.

## Coal-Fired Utility Boiler Explosion

A 760-megawatt utility boiler (cyclone-fired) in the midwest suffered a severe explosion in the upper furnace. APTECH was retained by in-house counsel of the utility to investigate the cause and origin of the explosion and to quantify the extent of damage to the boiler. The explosion occurred while test-firing western coal; the boiler was designed for midwestern or eastern coal. APTECH made recommendations for the improvement of the boiler control system and identified deficiencies in the boiler furnace enclosure design. The operator evaluated our recommendations and made the necessary upgrades and improvements.

## Pulverized Coal Pipe Fire

A fire broke out in a coal pulverizer in a 110 MW coal-fired power plant. An APTECH power plant engineer was hired by the insurance adjuster to evaluate the cause and origin of the fire. The equipment was thoroughly inspected and photographed. The plant's operation and maintenance personnel were interviewed, and work orders, drawings and other documentation were reviewed on site. We found that a modification to the coal/air piping had been done improperly, which caused the failure of an expansion joint. The resulting jet of pulverized coal caught fire, and this flame ignited common combustibles. Damage to the plant was considerable, and subrogation potential was assessed.

## Gas Turbine Fire

A gas turbine was exposed to a fire that was fed by a leak in the lubricating oil supply line. APTECH was retained to evaluate the condition of the turbine rotor with respect to the possible loss of strength and material embrittlement. Our evaluation of the material indicated that the time/temperature fire exposure history would not result in degradation of the rotor's material properties. We concluded that the rotor was not adversely affected by the fire, and recommended that dimensional checks of the rotor be performed.

## Steam Turbine Failure and Explosion

A steam turbine in an oil refinery was undergoing a routine trip test following maintenance work. During this test, the turbine broke apart into several pieces causing personnel injury and death. APTECH was retained by the refinery to determine the root cause of the accident. To reconstruct the accident, we examined the layout and components, interviewed plant personnel, inspected operating records and logs, and reviewed safety procedures. APTECH performed metallurgical failure analysis, turbine reconstruction, roto-dynamic and energy calculations to determine the root cause.

## Package Firetube Boiler Explosion

An explosion occurred in a package boiler in a downtown office building. There were no injuries and damage was confined to the boiler and plant from the explosion. APTECH was hired to find the cause and origin and to make sure that it did not recur. First, we interviewed witnesses and examined and documented the condition of the as-found boiler.

Next, we prepared a "punch list" of recommended repairs and modifications. Finally, we gathered test data when the boiler was brought back on-line. Based on our findings, we presented four possible failure scenarios to the client, including gas supply over-pressure, a fault in the flame detector system, a build-up of unburned fuel, and an overly-rich fuel/air mixture. Modifications to the boiler and its operating procedures were made to prevent a recurrence of this explosion.

### Catastrophic Failure of High Energy Power Plant Piping (Mohave Plant)

A 30-inch diameter hot reheat steam pipe, operating at 1000°F and 600 psig, ruptured without warning in a fossil power plant. This accident caused numerous fatalities and major property loss. APTECH was hired by one of the defendants to investigate the failure of the pipe. APTECH performed a detailed stress analysis of the as-built line configuration and evaluated the material properties and the likelihood of creep damage under stresses sustained during normal operation. APTECH also investigated maintenance practices over an extended period at the plant prior to the failure. We concluded that the failure was caused by creep damage in local regions adjacent to the heat affected zone of the long seam weld.

### Downcomer Pipe Exposed to an Oil-Fed Fire

A downcomer pipe in a large electric generating plant was exposed to an oil-fed fire. APTECH evaluated the pipe using wet fluorescent magnetic particle, ultrasonic shear wave, field metallographic, and hardness testing techniques. These tests indicated that the downcomer pipe and connecting welds were satisfactory for continued service.

### Transformer Fire in a Utility Power Plant

A fire occurred at the Haynes Station of the Los Angeles Department of Water and Power. The fire started in an output transformer for Unit 1 (230 MW). APTECH was retained to evaluate the effects of the fire on structural components, including a gantry crane that was situated immediately above the fire. Mechanical property characterization tests (hardness, tensile, and Charpy V-notch tests) and temperature estimates (from response of paint and tempering of high strength fasteners) indicated that these components were not adversely affected by the fire. However, our examinations revealed unexpected degradation of the gantry crane from corrosion of its internal structure.

## Process Plants

### Explosion in a Chemical Blending Vessel Due To Unrecognized Explosion Hazard of Blended Materials

APTECH was retained to investigate the cause of an explosion in a blending vessel in a chemical processing facility. The explosion destroyed the plant and caused fatalities and injuries among the plant workers and first responders. At the time, the vessel was mixing together powdered sodium

hydrosulfite, aluminum powder, and potassium carbonate. Several hours before the explosion, the mixture began bubbling and producing heat and hydrogen sulfite fumes. Sodium hydrosulfite is known to react exothermically with water at room temperature. APTECH analyzed the unique explosion chemistry of the mixture of water, sodium hydrosulfite, aluminum, and potassium carbonate. We determined that the aluminum powder acted as a high energy fuel which magnified the explosion energy release by several hundred percent. APTECH provided expert testimony during depositions.

### Explosion in a Blending Vessel due to Mechanical Seal Failure

APTECH was retained to investigate the cause of an explosion in a chemical blending vessel in a processing facility in New Jersey. The explosion, which was completely unexpected, destroyed the plant and caused fatalities and injuries among the plant workers. The toxic plume from the ensuing fire injured several firefighters. APTECH's investigation focused on identifying how water might have been introduced into the blender. We determined that the water would have to have been injected into the interior of the powder bulk, and that the built-in agitator bar would have been the water conduit. The agitator's drive shaft had an outboard mechanical seal, which was water-cooled. The carbon-graphite sealing face was examined and found to be worn out. This wear would have allowed the cooling water to leak between the faces. Such a leak would have flowed along the agitator, through the felt packing, and into the middle of the bulk solids. The carbon sealing face had been damaged by particles in the water. APTECH determined that the vessel manufacturer, who advertised that their product could blend a wide variety of chemicals, had incorrectly used a water-cooled seal instead of a dry-running seal. The elimination of the risk of a water leak would have prevented the explosion. APTECH provided expert testimony during depositions.

### Explosion in Ammonium Nitrate Fertilizer Manufacturing Plant

In 1994, a massive explosion occurred in a fertilizer manufacturing plant in Iowa. APTECH was retained by outside counsel for the plant's insurance carriers to determine the origin and cause of an explosion event. We were called in early to inspect and analyze the thousands of metal fragments collected at the site that originally came from explosion-damaged vessels, piping, pumps, and valves. We determined that the explosion was a detonation and that it originated in a large vessel called the nitric acid–ammonium nitrate neutralizer. We worked extensively with consultants from several other organizations to reconstruct the conditions leading up to the explosion. We performed simulation tests of various process flow streams during the neutralizer shutdown and stand by conditions. Through laboratory and field tests, we quantified the thermal decomposition and explosion characteristics of the combination of ammonium nitrate, nitric acid, and reactive metals (i.e., titanium and aluminum). From this work, we determined that the explosion resulted from a thermal cook-off process that occurred in the neutralizer vessel while it was off-line. We performed a detailed evaluation of the neutralizer design and concluded that design defects, both in mechanical configuration and in materials of construction, were the root causes of the accident. APTECH provided expert reports and deposition testimony.

### Fire and Explosions at an Ammonium Perchlorate Plant (PEPCON)

A fire of unknown origin broke out at a large ammonium perchlorate manufacturing plant. The fire quickly got out of control, and eventually led to the detonation of thousands of pounds of the chemical stored at the site. The detonation demolished the plant and its shock wave caused significant property damage. APTECH was hired to investigate the

accident. Our work included examining and documenting the accident site, testing subscale chemical containers, reconstructing and locating the explosion sequence, and analyzing the metallurgical condition of an underground natural gas pipeline.

### Heat Exchanger Failure in an Olefin Plant

During start-up of a olefin plant, a large heat exchanger shell ruptured catastrophically causing extensive fire damage to the plant and injury to plant personnel. APTECH performed a detailed root cause analysis of the shell failure scenario, including modeling of the two-phase working fluid thermodynamic transients, convection, and conduction heat transfer in the shell, and stress and fracture mechanics analyses of the shell/tubesheet weld where the brittle fracture originated. An insurance coverage dispute developed, and our root cause analysis was vigorously challenged by an opposing team of experts. This dispute was resolved in arbitration proceedings, during which our engineers testified for 40 days. The arbitration panel voted unanimously in favor of APTECH's determination of the root cause of the accident.

### Hydrogen Explosion in Steel Plant Coker Area

Four workers were performing routine maintenance and cleaning inside an off-line ammonia scrubber vessel. Suddenly, an explosion occurred and all four workers were killed instantly. APTECH was brought in to perform a detailed review of all process variables preceding the explosion, in order to determine the root cause of the explosion. It had been determined that a coke oven gas valve was leaking, but blanking of valves and purging of the vessel had been performed so the explosive gas accumulation was a mystery. APTECH performed detailed analyses to determine the patterns and magnitudes of the gas and air flows in the vessel and the eventual stratification of explosive gas at the vessel top. APTECH also performed detailed stress analysis of several deformed valve blanks to determine the blast over-pressure resulting from the explosion.

### Explosion in an Aluminum Annealing Molten Salt Tank

A molten salt tank exploded while being brought on-line from cold conditions. Three people were killed and extensive structural damage to the facility resulted. APTECH was asked to assess alternate theories for the root cause of the explosion, including both local and global overheating of the salt bath. Our investigation included an analysis of the radiation and convection heat transfer in the furnace and salt bath and an analysis of various chemical reactions in the salt bath proposed as the root cause of the final detonation.

### Sodium Hydrosulfite Container Fire

A steel drum containing sodium hydrosulfite ignited and generated a sulfur dioxide plume which extended over many blocks of an industrial/residential area of Berkeley (California). Sodium hydrosulfite is a solid granular material used in the dry cleaning industry and is highly reactive with water and air. APTECH was hired to evaluate this event from a

technical point of view, to determine whether a "fire" had occurred in the usual sense of the word. This was relevant to the question of insurance coverage. We performed a detailed investigation of the chemistry of sodium hydrosulfite decomposition and ignition, including combustion, heat transfer, and plume analyses.

### Urea Autoclave Vessel Explosion

A high-pressure urea reactor vessel in a fertilizer plant exploded with tremendous energy release, causing extensive damage to the plant and hurling pieces of the vessel up to a quarter-mile away. APTECH was part of a team of investigators retained to determine the root cause of this accident. The vessel was 30 years old and had a laminated wall design with a stainless steel liner. We reviewed and analyzed this vessel's lengthy and complicated maintenance and alteration history. The origin of the vessel fragmentation was found to be a local area where extensive corrosion had occurred through several of the wall lamina, thus substantially wakening the vessel in this area.

### Natural Gas Compressor Station Fire

A fire broke out in a gas turbine-driven natural gas compressor, causing damage to the unit and to adjacent equipment. APTECH was hired to determine the root cause of the fire and to itemize the extent of damage produced by this fire. Our evaluation involved site inspections, interviews with site personnel, field metallurgical testing (e.g., metallurgical replication, hardness measurements, etc.), reviewing the lubrication system designs and fire suppression, and a nondestructive laboratory failure investigation of a fractured lube oil line. We determined that an unnoticed oil line vibration caused fatigue at a fitting and the oil line ruptured. The oil impinging on the hot section of the gas turbine ignited and caused the fire. APTECH provided expert opinions regarding the cause of the fire, the extent of subsequent damage, and the repair cost estimates.

### Natural Gas Filter-Separator Vessel Failure and Explosion

The closure of a 40-inch diameter filter separator (a pressure vessel used for filtering natural gas) failed and resulted in an estimated $25 million in damages. The 5000 pound steel head of the vessel was shot approximately 1/4 mile and the vessel was launched 30 feet in the opposite direction. Much of the surrounding equipment in the plant was destroyed by a fireball that was created when the escaping gas was ignited. No one was present when the failure occurred. If it had occurred on the previous night, up to 20 people may have been killed.

APTECH was contracted by the manufacturer's representative to determine the cause of the failure. Our on site activities included visual surveying and analysis, photo documentation, video documentation, and dimensional analysis of the wreckage. During the site investigation, it was determined that the operator of the vessel had used oversized o-rings during an overhaul of the vessel just hours prior to the accident. Analysis in our laboratory included metallurgical evaluations, finite element stress analysis, scanning electron

microscopy of components involved in the accident, and load testing of exemplar components of the closure. The exemplars were fitted with strain gages. Data was collected by means of a computerized data acquisition system.

Subsequently, pressure testing was performed on a near-full-scale mockup of the entire vessel. The mock-up also was fitted with strain gages at strategic locations. After performing the tests with both standard-sized and oversized o-rings, it was determined that the stress at critical locations was up to five times higher with the oversized o-rings.

### Gas Explosion and Fire in an Industrial Building

An investigation and analysis of an explosion which occurred in the attic space of a newly constructed industrial building was performed. The physical evidence indicated that the accident resulted from ignition of an accumulation of natural gas. The gas was being purged through a new gas line being attached to a gas heating furnace. Visual examination, interviews with plant personnel, review of accident reports, leak testing of the gas piping, and evaluation of ventilation requirements were included in APTECH's evaluation of this accident.

## Petrochemical Refineries

### Refinery Delayed Coker Accident

A refinery contracted with skilled concrete workers for the repair of concrete structures supporting delayed coking vessels. The refinery staff believed that repairs could be safely made while the unit was operating. If the coker had to be shut down to make these repairs, the refinery would have to reduce production to accommodate the unavailability of the unit. While the crews were working on the unit, a freak accident caused superheated steam to be released, severely scalding several workers. APTECH was retained by a law firm representing these workers. We were asked to investigate the prudency of assigning repair crews to work on an operating unit of this type, to survey the experience of other refineries regarding safe work practices, to develop accident statistics, and to determine if any mechanical failures were involved.

### Refinery Asphalt Pump Failure and Fire

A small refinery that produced asphalt and ink oil experienced a serious fire under the atmospheric and vacuum bottoms tower. No injuries were suffered, but the fire caused extensive damage to the plant and resulted in one year of business interruption. An investigation by the refinery pointed toward the accidental ignition of light oil that was spraying out from a leaking pump shaft sealing device. A series of unexplained pump seizures was also included in the accident scenario. Working for the refinery, APTECH analyzed the design and materials of the pump shaft sealing system (metal bellows, dynamic

type), and evaluated the fitness-for-purpose of the type of asphalt pump that was supplied by the manufacturer.

### Refinery Coker Unit Fire Caused by Ruptured Piping

A fire broke out under a coker unit in a large oil shale processing plant. Liquid hydrocarbons feeding the fire eventually caused the formation of a pool fire that spread over 20,000 ft2 of the premises. The plant's pressure vessels and piping were extensively damaged due to overheating. APTECH was hired to find the cause and origin of the fire. The field inspection revealed that a slurry recycle pipe had been the first to rupture and spill its combustible contents. Metallurgical testing of the ruptured pipe showed that the wall thickness of the pipe had been greatly reduced by corrosive attack from the slurry. The rupture occurred at the thinnest part of the pipe wall.

### Coking and Fire in a Refinery Hydroprocessing Vessel

A pipe rupture in an operating hydroprocessing unit in a refinery caused a fire and extensive coking within several vessels (reactors, columns, etc.). The refinery carried separate fire and boiler/machinery coverages. As part of the ensuing arbitration, the insurers were interested in the extent of coking (and time to clean out the coke from the vessels) if there had been no fire. This information would permit proper allocation of a portion of the business interruption claim. APTECH was retained by one group of insurers to independently estimate the downtime due to coking assuming no fire had ensued. We delivered several time-lines of event sequences, contacted operating and industrial maintenance companies for relevant experience, and developed independent estimates of worker productivity when mining coke inside of confined spaces.

### Refinery Maintenance Accident and Hydrogen Fire

A refinery piping assembly that was being dismantled by a contractor suddenly released flammable gases. The gases subsequently ignited and the contractor suffered burn injuries. APTECH was retained by the refinery's law firm to determine the cause and origin of the fire. To reconstruct the accident, we examined the site of the fire, interviewed plant personnel, inspected the plant's operating logs and safety procedures, and reviewed witnesses' statements and deposition transcripts. Key components of the piping system were examined, photographed, and pressure-tested (hydrostatistically) to document their current condition.

### Refinery Piping Erosion Failure and Fire

In this project, APTECH evaluated the root cause of a pipe failure and ensuing fire at a refinery in Southern California. The oil/catalyst slurry at high temperature that is used for heat recovery boilers is an erosive mixture for normal carbon steel piping in refinery plants. In-plant systems are developed to monitor erosion as it occurs using various nondestructive testing techniques. In this particular incident, the FCC main column Bottoms slurry piping eroded to such an extent that the flange connecting the piping to the vessel bottom failed

catastrophically. The ensuing fire caused significant plant damage and personnel injuries. APTECH investigated the inspection procedures, the materials involved, and the process parameters that led to the accident.

### Refinery Process Heater Fire

A rupture of a fired heater piping connection containing a thermally stabilized silicone polymer fluid led to a fire and extensive secondary damage to other furnace components. APTECH performed a detailed root cause evaluation of the ruptured tube and a suitability-for-service evaluation of the remaining furnace components. This evaluation involved interviews with plant personnel, field evaluation of the critical components in the furnace, review of operation and maintenance manuals and records, detailed metallurgical evaluations of select components, and engineering life assessments. A technical report and expert opinions were presented to all concerned parties.

## Oil Production

### Oil Well Drill Rig Fire

An oil well drilling operation was conducting a routine fracture stimulation process when a truck-mounted oil pump/storage tank caught fire. The fire spread and injured a worker, destroyed valuable drilling equipment, and eventually ignited the oil well itself. APTECH was retained by one of the defendants to determine the original ignition source. Our investigation and analysis revealed many alternative sources of ignition, including a spark from an electrical short-circuit, a frictional spark, a static electrical discharge, and flames from a Diesel engine exhaust pipe.

### Oil Well Abandonment Accident and Fire

While a field crew was "killing" an old oil well, a massive volume of natural gas was suddenly and unexpectedly released from the well head piping. Shortly thereafter, the subsequent gas/air mixture was ignited, resulting in a brief, but extremely intense, fireball. One person was killed, several more were severely burned and the nearby equipment was totaled. The oil company hired APTECH to assist its staff engineers with a cause and origin evaluation. We photographed and diagrammed the accident site and piping, provided immediate advice on site preservation (to avoid future claims of evidence spoilation) and performed a detailed examination of the pipe fittings and potential gas release points. Our reconstruction of the events leading up to this accident was aided by an engineering mechanics analysis of the forces applied to the piping by the crew and their hand tools.

## Commercial and Residential

### Underground Migration and Explosion of Propane Gas

On a November morning in 1996, a massive explosion occurred in a commercial building in a busy shopping district in San Juan, Puerto Rico. The explosion caused 33 fatalities and numerous injuries. The building was destroyed and adjacent structures and vehicles were also damaged. APTECH was retained by the Plaintiffs' Steering Committee to conduct an independent engineering investigation of origin and cause of the explosion. Explosion and structural analyses by APTECH established that the origin of the explosion was in the basement of the building. This is consistent with the fuel that exploded being heavier-than-air propane, which would have settled into the basement. Soil testing revealed the presence of residual propane gas in the soil and groundwater in and around the explosion site over 1 year after the explosion. Also, the soil at the site was found to be sufficiently porous to allow gas to migrate through it. Finally, during a field test at the site, we established that Argon gas introduced into the soil near the leak site readily migrated through the soil toward the building. We concluded that the origin of the explosion was in the building basement, the fuel for the explosion was propane, the source of the propane was leaking underground pipes, and that the propane migrated through the soil from the leaks to the basement.

### Agricultural Chemical Warehouse Fire

A fire in an agricultural chemicals warehouse destroyed the building and its contents. APTECH was retained by the building owner's law firm to find the cause and origin of the fire. Previous investigators, including the fire department, had narrowed down the source of the fire to a pickup truck that was parked inside the warehouse. We reviewed the witnesses' deposition transcripts, inspected the exemplars of the pickup truck (because the original truck had been destroyed), and examined the truck manufacturer's drawings and specifications. Our investigation indicated that an electrical wiring harness had short-circuited and ignited a nearby plastic fuel line.

### Abandoned Gas Main Piping Explosion

A large explosion occurred under a busy city street, creating a 25-foot crater. The explosion originated in a large-diameter, natural gas main pipe buried under the street. Fortunately, there were no injuries or significant property damage. The gas utility company hired APTECH to find the cause of the explosion and to suggest ways of preventing future incidents. We discovered that, some months earlier, the pipe had been plugged and abandoned by the utility. Our investigation focused on identifying the explosive gas mixture, the gas source, and the ignition source. On-site engineering activities included site photo documentation, crew interviews, residual gas sampling, and soil and metallurgical sampling. Subsequent analysis led to an explanation of the explosion event. We also recommended that changes be made in piping configuration management, abandonment procedures and crew safety guidelines.

## Ammonia Cylinder Failure

A pressurized cylinder containing anhydrous ammonia ruptured and exploded inside a blueprint plant. The cylinder broke free from its wall anchors and launched itself into an occupied room. Injuries and property damage were caused by the ricocheting cylinder and by the release of ammonia gas. APTECH was hired by one of the defendants to determine the root cause of the failure of the cylinder. Metallurgical examinations led to the conclusion that the rupture initiated at a small fatigue crack on the inside surface. The fatigue crack had formed slowly over the years due to pressure cycling. The cylinder was judged to have been in service beyond its safe operating lifetime.

## Ammonia Tank Car Explosion

A transportable road tank car came uncoupled from its tractor, crashed onto a lower level freeway, and exploded. It caused significant personal injury and local damage. APTECH performed metallurgical and fracture analyses to establish the root cause of the tank car's structure failure that led to the crash and explosion.

## Bakery Explosion

An explosion and fire occurred in the basement of a bakery in Fresno (California), causing extensive damage to the contents in storage. Leaks were discovered at several locations in a four-inch gas main under the streets adjacent to the bakery. APTECH was hired to perform a gas migration and explosion analysis. Through our analysis, we were able to conclude which gas pipe leak was the cause for the amount of gas which accumulated in the basement and exploded causing the observed damage.

## Shopping Center Fire

A fire broke out in a small shopping center in a commercial district of a large city. The fire began in the ceiling of a fast-food restaurant and spread to the adjacent shops. Considerable damage was done, and faulty electrical wiring was blamed. APTECH was retained by the electrical subcontractor to investigate this possibility. To reconstruct this accident, we examined architectural drawings and electrical diagrams, reviewed a large quantity of documents and deposition transcripts, and evaluated the design of the electrical system. Also, other potential causes and original of the fire were investigated.

## Restaurant Grill and Ventilation System Fire

Early in the morning in a large restaurant, a fire started inside the kitchen's ventilation ducting system. The automatic fire extinguishers were overwhelmed, and severe damage was done to the roof before the fire was knocked down. APTECH was retained to evaluate the origin of the fire. The circumstances of the incident included a grease fire flare-up on the grill during adjustment of the gas burner, excessive room ventilation rates, and improperly cleaned ducting and grease traps.

## Gasoline Tank Farm Explosion and Fire

Gasoline was being delivered by a tanker truck to one of many above-ground storage vessels in a commercial tank farm. During the delivery, an explosion of a cloud of gasoline vapors occurred near the storage vessel. Besides destroying several buildings, the explosion breached the piping system. This led to an extensive release of gasoline, which caught fire and contaminated the soil. APTECH was hired by the plant's owner to determine how the explosion caused the failure of the piping system. Our metallurgical examination and fluid mechanics calculations indicated that the gasoline vapor explosion had severely distorted a swing check valve. This event blew off a threaded plug in the body of the valve. The absence of the plug allowed the free flow of gasoline. The gasoline continued to feed the fire and contaminate the soil until the pump was shut down.

## Restaurant Fire

An after-hours fire occurred in a fast-food restaurant. The fire department traced the fire's origin to a store room in the rear of the building. An independent fire investigator theorized that arcing from a faulty electric light switch ignited common combustibles. APTECH was hired by the electrical subcontractor to perform an engineering evaluation of the electric switch. Our examinations led to the conclusion that the switch could have been damaged as the result of the fire rather than having been the fire cause.

## Evaluation of Floor Furnace in Fire Damaged House

APTECH was retained to evaluate a gravity-type, gas-fired floor furnace in a fire-damaged house. We photographed the condition of the furnace and its piping and wiring as they were found in the crawlspace under the living room floor. The furnace then was removed and taken to our lab. Upon further examination, the furnace did not appear to have malfunctioned. Subsequently, the source of the fire was determined to have been a pile of newspapers and a couch that had been placed on the floor over the furnace's warm air register.

## Residential Explosion and Fire

In the middle of the night, a multi-story residence in South San Francisco exploded and burned to the ground. APTECH was hired by the local gas utility to come to the site and conduct a root-cause investigation. An immediate site inspection was required because the local fire department authorities required that the smoldering debris be removed immediately. In this way, the fire could be completely extinguished and any threat to adjacent structures eliminated. APTECH was on site immediately and, working with other investigators, quickly determined that the gas pipeline into the building had been hack-sawed completely through at a location upstream of the regulator. Deliberate arson was the obvious cause and was eventually traced to the building's owner.

## Apartment Gas Explosion

An apartment unit in downtown San Francisco exploded and burned, resulting in fatalities and significant property damage. Natural gas was suspected as having been involved. Working with the local gas utility's claims people, APTECH investigated the possible sources and migration paths of the gas. The evidence and our evaluations indicated that the room had filled with gas from an unignited range/oven burner that had been deliberately opened by one of the occupants. A combustible mixture of gas and air eventually developed. Subsequently, when the front door was opened by the other resident, the mixture flowed over to an ignition source and exploded.

## Swimming Pool Water Heater Fire

A fire originated in the equipment room of a 24-unit apartment building causing extensive fire and smoke damage to the structure and the tenants' possessions. APTECH traced the origin of the fire to a malfunctioning swimming pool water heater. The heater was disassembled in APTECH's laboratory, and a detailed inspection was performed on the burners, burner controls, and heat exchanger fire side and water side. The root cause of the heater malfunction was identified, and an article explaining how to avoid the situation was prepared for the equipment owner's group.

## Explosion in Three-Story Brick Building

A late-night explosion in a three-story brick building in San Francisco (California) totally destroyed the building and killed three nearby pedestrians. Within hours, APTECH was brought in by the local gas utility company to survey the scene and collect crucial evidence. The gas company wanted to determine if gas was involved and, if so, the location of the leak. The building was suspected of housing a drug-manufacturing laboratory, so the Federal Bureau of Alcohol, Tobacco, and Firearms was also involved, as well as the San Francisco Fire Department. We surveyed the effects of the blast wave on neighboring structures. We also examined gas piping, appliances and the gas meter inside the building, and the gas service piping outside the building. Finally, we performed a preliminary analysis of the ignition and explosion event.

## Natural Gas Migration and Explosion in an Apartment Building

In this project, APTECH was hired by the local natural gas utility company to evaluate the origin and cause of a gas explosion in a downtown apartment building. APTECH visited the accident scene shortly after it had occurred and performed analyses to investigate the following: (1) the likelihood of a gas leak from nearby regulators; (2) the likelihood of gas migration across the road to the location of the apartment building; and (3) the significance of mechanical tool marks on gas piping and gas fittings. APTECH's analysis eliminated all of the component failure events that could reasonably be responsible for the gas explosion. It was later concluded that the root cause of this explosion was due to human intervention.

## Residential Gas Range Fire

The kitchen in an apartment unit suffered heavy damage from a fire that originated at the gas-fired range. The resident blamed a gas leak from one of the burner control valves. APTECH was retained by the insurance carrier's fire investigator to evaluate the condition and operability of the range. We examined and photographed the fire-damaged range in our lab, and reviewed the manufacturer's specifications. Pressure-testing of the gas valves and tubing revealed no leaks, and the valves operated normally. These conclusions pointed toward a simple grease fire as being the cause of the kitchen fire.

## Automobile Fires

APTECH has investigated several automobile accidents that have involved fires and explosions, including single- and multi-car collisions and component failures. Our activities have included accident site documentation, evidence preservation, witness interviews, component failure analysis, and accident reconstruction.

## Mobile Home Fire

A mobile home in an isolated location caught fire during the night and one occupant was fatally injured. APTECH was brought in by the insurance company for one of the potential defendants to determine the cause and origin of the fire. The investigation included a review of fire department accident reports and photographs, interviews of knowledgeable parties, and an examination of the accident site. Potential fire causes included non-code gas piping, a malfunctioning appliance, and an improperly discarded cigarette.

## Elevator Fire

A three-alarm fire broke out in a 14-story, senior citizen apartment building. The fire caused several fatalities and significant property damage. The source of the fire was traced to one of the passenger elevators. APTECH was hired by the attorney for one of the defendants, the elevator maintenance company, to find the cause and origin of the fire. The plaintiff's expert witness had developed a seemingly logical theory that involved the lubricant tubing (installed by the defendant) having acted like a fuse to spread the fire from the machine room, through the walls, and into the elevator shaft (hoistway). Experiments designed and conducted by APTECH cast doubt on this theory. We demonstrated that a flame attached to the tubing would have been extinguished by the wall's insulation batting before it passed through to the hoistway.

## Evaluation of Postulated Propane Explosion

An evaluation was performed to determine the effects of an explosion resulting from the postulated rupture of a propane line. Four types of analyses were performed:

- Thermal-hydraulic
- Diffusion
- Structural
- Probabilistic

The thermal-hydraulic analyses determined the rate and amount of propane gas that would evolve from a postulated line rupture. The analysis considered line design, operating conditions, controls, and operator actions. A transient blowdown analysis was performed to determine a mass release time history.

The diffusion analysis determined the size and combustible content of the vapor cloud as a function of distance from the break for various atmospheric conditions.

The structural analysis determined the conditions required to cause unacceptable structural damage to the facility of concern. The analysis determined the energy from various size vapor clouds and their effects on the structure based on detonations occurring at varying distances from the structure. The probabilistic analyses considered the following probabilities in determining whether an unacceptable explosion could occur:

- Pipe rupture occurrence
- Explosion of vapor cloud
- Wind direction
- Wind velocity - The vapor cloud would only be stable enough to remain as an explosive moisture far enough away from the break for limited wind velocities.
- Atmospheric stability
- Delay in ignition - The ignition had to be delayed until the vapor cloud was in close proximity to the target structure.

This analysis considered available ignition sources, as well as historic data on proximity of ignitions to gas releases.

## Risk Management and Prevention Program

For a major supplier of magnetic media, APTECH performed a formal Risk Management and Prevention Program (RMPP) for two inorganic acids as requested by the County government. The public disclosure report documented the site location; equipment and operations history; safety, audit, and inspection procedures; emergency response plans; and actions recommended as a result of a HAZOPS study. As a part of the RMPP, APTECH also prepared process flow diagrams, conducted a seismic walkdown, prepared a HAZOP study, and prepared an off-site consequence analysis for several worst-case chemical release scenarios.

## Life Assessment for Canadian Refinery

For a major Canadian refiner, APTECH conducted a life assessment study for major classes of equipment, such as columns, pressure vessels, heat exchangers, fired heaters, compressors, tanks, and piping. Over 200 pieces of equipment were evaluated. The majority of this equipment had been in continuous operation for about one design lifetime. Major degradation modes evaluated included creep rupture, stress rupture, corrosion, stress corrosion cracking, high temperature hydrogen attack, wet H2S cracking, and fires and explosions. APTECH identified those pieces of equipment with limited remaining life and for which the client's current maintenance program did not make adequate provisions.

Further, utilizing the results of prior risk assessments conducted for the facility, APTECH identified a list of unusually critical equipment which, upon failure, would result in a loss of production of six months or more.

# Section 4
# PRESS RELEASE

This section contains a Press Release distributed to the public in May 1993 regarding APTECH's involvement in the investigation of the Henderson, Nevada, PEPCON explosion.

**PRESS INFORMATION**

# APTECH HELPS LEGAL CONSORTIUM WIN LARGEST SETTLEMENT IN NEVADA HISTORY

Sunnyvale, California
May 19, 1993

Five years have passed since the devastating explosion at PEPCON's chemical plant in Henderson, Nevada (May 4, 1988). This destructive incident resulted in significant property damage and numerous insurance claims totaling nearly 90 million dollars.

APTECH Engineering Services, Inc., served as primary consultant in this recently-concluded litigation which produced the largest settlement in Nevada history.

Assisting a consortium of law firms representing a group of insurance carriers, APTECH led the engineering evaluation to determine the root cause of the accident and to support claims against various defendants. In that effort, an interdisciplinary team of engineering specialists was appointed to work closely with the consortium and other experts over a four-year period.

The result: Recovery of about 95% of the total claim — nearly 85 million dollars.

APTECH's contributions included:

- Complete site documentation and accident reconstruction
- Metallurgical testing and analysis of a failed 16-inch natural gas pipeline
- Engineering analysis of the detonation and combustion behavior of the chemical (ammonium perchlorate), including a pilot-scale experimental test program
- Accident reconstruction via videotape analysis and timeline recreation
- Information transfer via presentation seminars and computer graphics

This case demonstrates that APTECH has the proven capability to manage major engineering investigations.

**For more information, contact**
**APTECH Engineering Services, Inc.**
**800-477-2228**