

The Texas City Disaster.

A Staff Report.*

Four hundred and sixty-eight persons are known to have lost their lives, over a hundred are still missing (July 1, 1947), and 3000 were injured as the result of fires and ammonium nitrate explosions aboard two ships docked at Texas City, Texas, April 16-17, 1947. Property damage and contingent losses are estimated at \$67,000,000.

The account of the disaster in this staff report is presented as follows:

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I. Introduction.

The terrible disaster resulted from the explosive decomposition of ammonium nitrate fertilizer under fire conditions.

The tremendous violence of the blasts resulted from the formation of large volumes of decomposition gases within the confined areas of the holds of the ships involved.

The large loss of life occurred because of the immediate proximity of persons engaged in the industrial activity of the port and its exposed properties. This concentration of population was augmented by firemen and a considerable number of curious persons who had been attracted to the scene by the pre-explosion fire.

The huge property destruction occurred

because of the direct exposure to blast damage of high valued industrial plants and facilities. Much of this property was particularly vulnerable to blast damage and self-propagated resultant fires because of the flammable nature of materials employed in the processing activities or stored preparatory to shipment or use.

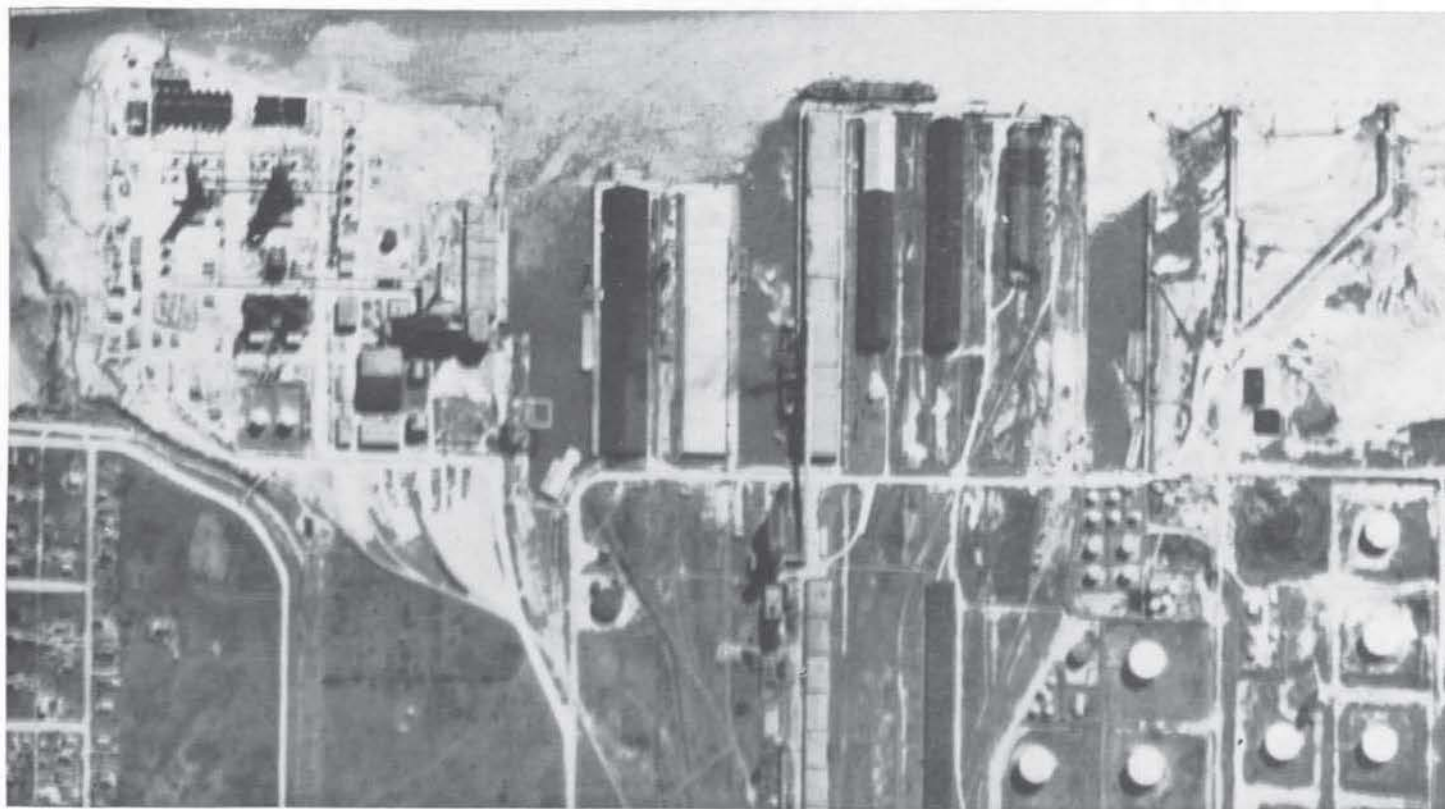
II. Chronological Sequence.

Prior to 8:00 A.M. April 16, the 7000-ton Liberty vessel S.S. *Grandcamp* had been loaded with approximately 2300 tons of ammonium nitrate fertilizer. It was berthed in the North Slip, adjacent to "Pier O," of the Texas City Terminal Railroad Company's docking facilities. The vessel was owned by the Republic of France and operated by Compagnie Generale Atlantique, commonly known as the French Line. It had arrived at Texas City on the morning of April 11. Loading operations had commenced that afternoon. The ammonium nitrate fertilizer had been shipped to Texas City via rail on government bills of lading from three Midwest ordnance plants. The fertilizer was shipped, handled and was being stowed in the *Grandcamp* in 100-pound, 6-ply, moistureproof paper bags marked: "Fertilizer, Ammonium Nitrate, Nitrogen 32.5%." The material had been stored in the warehouse on "Pier O" and stevedores were loading the vessel from this source.

Approximately 1400 tons had been stowed in No. 2 hold and 880 tons in lower No. 4 hold when loading operations ceased at 5:00 P.M. April 15. Other cargo in separate holds included cotton, binder twine, peanuts, boxed machinery, oil well equipment and 16 boxes of small arms ammunition.

Loading operations were resumed about 8:00 A.M. on the 16th in lower hold No.

*See Section VI for sources of information.



U. S. Army Air Forces.

Vertical photograph of Terminal before the explosion. Monsanto plant at left, with South Slip (where *Grandcamp* was berthed) adjacent. The *High Flyer* was in the Main (center) slip adjacent to the longest fire-resistive warehouse. Note relation to oil tank farms at lower right.

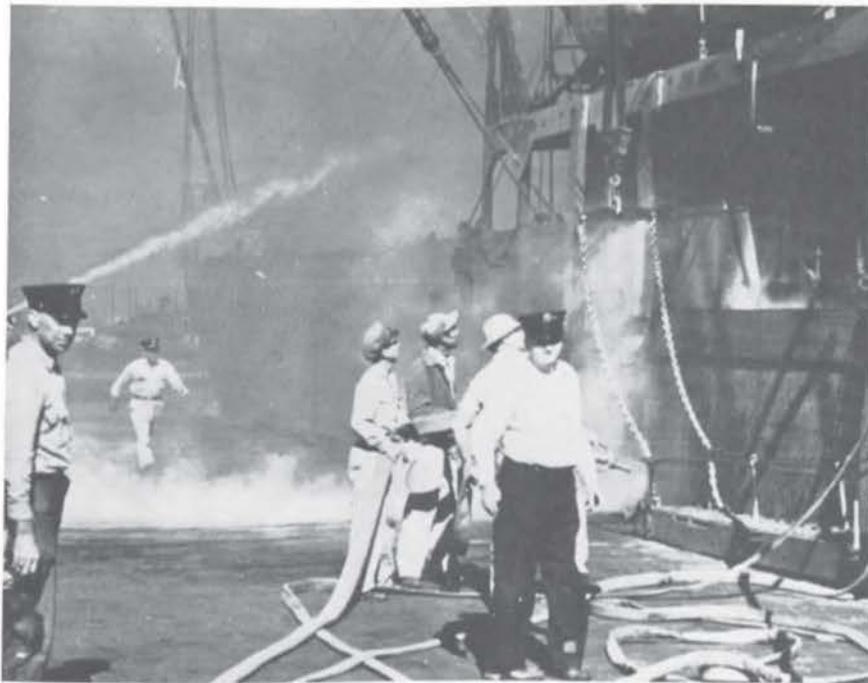
4. No fire or smoke was visible at this time according to survivors. One crew of four workmen commenced to stow bags of the fertilizer already in the hold on the port side of the vessel. A second crew of four sat down on the starboard side to await further supplies from topside. It is believed one or more of this idle crew smoked a cigarette during the interval. There was known to be smoking on the main deck.

The First Fire.

About 8:15, smoke was observed in lower No. 4 hold on the starboard side issuing from an open space about 8 inches wide between the hull and cargo battens. Attempts were made to extinguish the fire with drinking water and hand fire extinguishers, but flames were observed to increase along the starboard side. The ship's whistle was sounded to give the alarm and all persons were ordered out of

the hold. A ship's fire hose was lowered into the hatch, but the first mate (known as second captain on French ships) ordered that no water be used as it would damage the cargo. (Water was available and the ship's fire pump operating at full working pressure.) The hatch was then covered, a tarpaulin put in place and wet down, vent cowls were sealed, and steam introduced into No. 4 hold through the installed steam smothering system.

It was 8:30 by this time and the smoke continued to increase despite efforts to smother the fire. A telephone alarm of fire was received about 8:30 by the Texas City Fire Department. Two fire trucks responded immediately, followed by the two remaining pieces of apparatus. A total of 27 volunteer firemen responded out of the total 50 members of the department. Crew members of the *Grandcamp* left their ship and assembled on the adjoining



Press Association.

Texas City firemen fighting the fire aboard the *Grandcamp* prior to the explosion. Note one hose line in service, others being prepared. All 27 firemen who responded were killed by the blast.

pier to assist firemen who stretched hose lines from dock-side hydrants. Photographs taken between 8:30 and 8:50 show one hose stream in use from the dock with another line being assembled, but it has not been possible to determine precisely what fire fighting was accomplished before the explosion.

Pressures were being built up within the ship's hold as the hatch covers blew off and an orange-brown smoke (characteristic of oxides of nitrogen) was observed. The hull in the way of the fire was sufficiently heated to vaporize water running off the deck before it reached the surface of the slip.

The First Explosion.

The explosion occurred at 9:12 A.M.

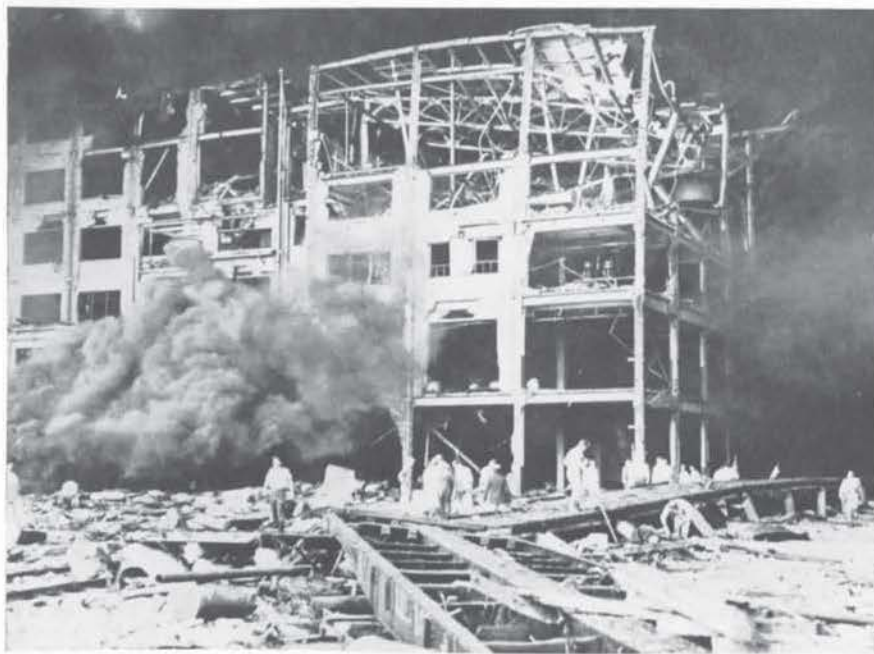
Those on the pier fighting the fire and over 400 others in the vicinity were killed, the great majority instantaneously. Others, felled by the blast, were cremated by ensuing fires.

The *Grandcamp* completely disintegrated and fragments were thrown in all directions.

Missiles, varying in size from large sections of ship's plate weighing tons to compact fragments weighing less than a pound, were thrown through the air for thousands of feet, leveled some structures, damaged others, pierced oil tank roofs, crushed automobiles, severed railroad tracks and buried themselves in the ground. Heated missiles ignited flammable vapors at their source while others split tanks and released vapors which were subsequently ignited from friction sparks or open flames in the vicinity.

Explanation of Shock Waves.

Concussion damages were most severe. They took three distinct forms. First, the initial shock waves leveled such buildings as Warehouse O, the Monsanto warehouse building directly across the slip,



Acme.

Damage to the five-story polystyrene building of the Monsanto Company while fires were still burning in the area. This building received direct explosion blast from the *Grandcamp* across a distance of only 350 ft.



Los Angeles Fire Dept.—Capt. Conlin.

View of Monsanto property, showing wall failures in warehouse at right and damage to office building at left.

and caused severe direct concussion damages to other structures within range. Two private airplanes were knocked out of the sky, and their occupants killed.

It seems substantiated that the only major explosion was the nitrate cargo at this hour, although there were minor tank explosions immediately thereafter. Residents of the area who speak of other major blasts shortly after the initial explosion are believed to have confused the time differential between the shock and sound waves or to have been mystified by the pattern of the shock waves themselves.

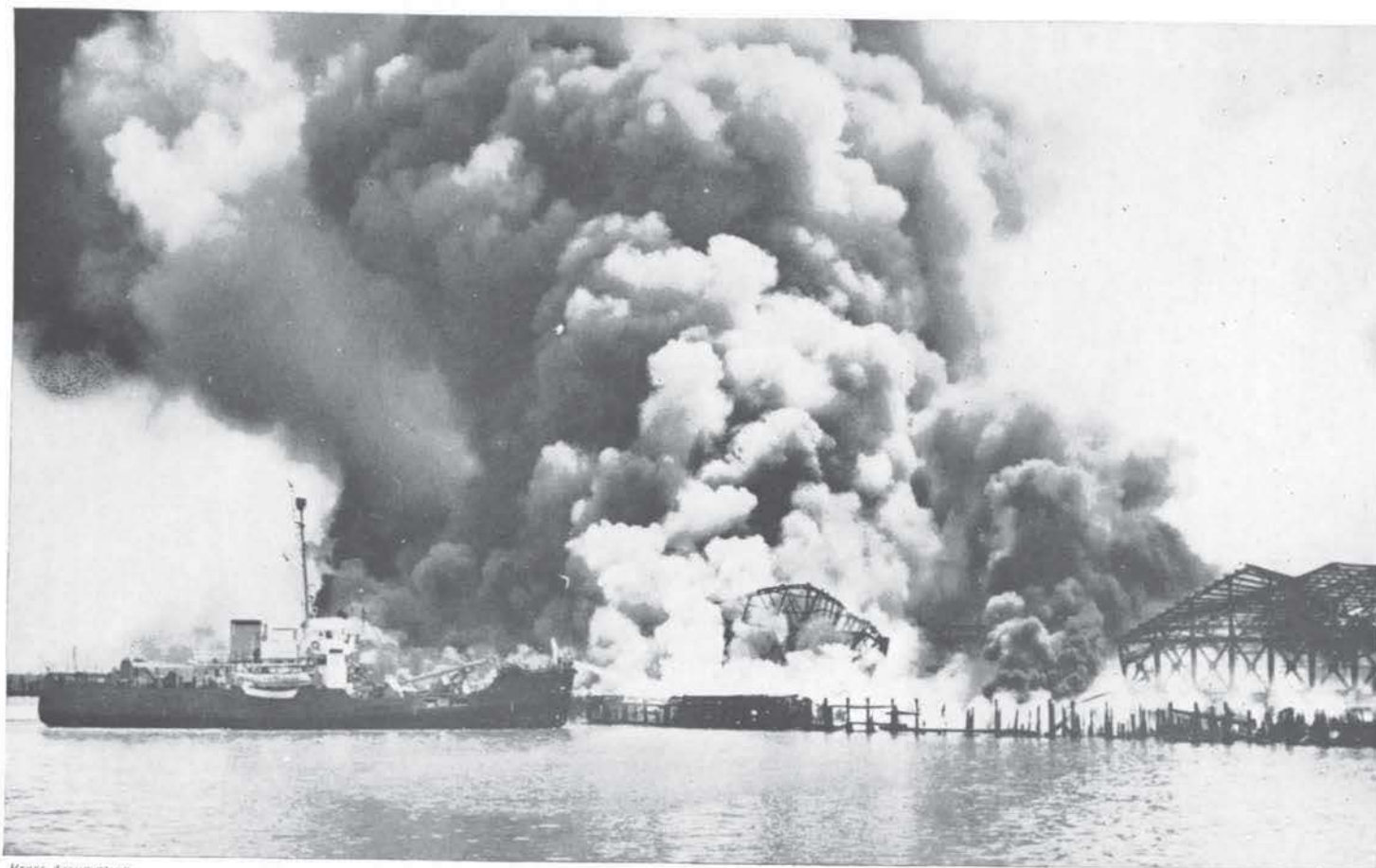
Some of the blast effect was deflected by the impact with substantial nearby structures, and since the explosion occurred in lower No. 4 hold of the *Grandcamp*, the horizontal forces, as initially applied against the water in the slip, were deflected at a high angle. These deflected shock waves formed a second high pressure effect. A very definite pattern, in terms of distance from the scene of the explosion, is evidenced by damages caused by the deflected waves. Buildings affected by such concussion waves show the effect of downward forces of high magnitude as contrasted to buildings where concussion

was obviously horizontal. Many of these buildings were clearly shielded from the direct concussion forces.

Despite this deflection, sufficient force was applied on the water in the North Slip (depth 30 ft.) to drive it shoreward. The volume of water displaced was adequate to lift a steel barge (11 ft. draft, 150 ft. long, 28 ft. wide) and deposit it 100 ft. inshore.

Beyond this, there was evidence to support the thesis that a third type of blast damage occurred. This was occasioned by the negative pressure front or vacuum created by the displaced air at the core. Properties affected were those on the outer rim of the explosion-rocked area. The vacuum effect was manifested by upward thrusts on roofs of buildings, automobile engine hoods, and outward fragmentation of glass windows.

Another result of the first blast was that the S. S. *High Flyer* (a C-2 cargo vessel of American registry) was blown across the main slip where it was berthed at Pier A to lie against the Liberty ship, S. S. *Wilson B. Keene*. This was significant when the *High Flyer* caught fire later on in the day.



Press Association.

Fires in Warehouses C, D, and E from the Bay side. Docking in front of Warehouses was wood plank on wood piles and supported oil pipe lines used for bulk shipments from this Terminal.

Fires Following the First Blast.

The fires occasioned by this initial blast are best portrayed photographically. The Monsanto plant was literally engulfed in flames. In the main, these fires were caused by the ignition of combustible hydrocarbons, especially in the polystyrene building, the ethylene purification units, the process equipment and control facilities of the alkylation unit, the distillation towers and the fourteen main storage tanks of benzol, fuel oil, and other low vapor pressure hydrocarbons. Ground fires spread fire damage to piping and were fed by flammable liquids which escaped from broken or melted lines. The fact that the highest pressure on equipment in the plant was around 15 pounds was a factor which must be credited, at least partially, with the fact that there were no separate explosions in the Monsanto plant area.

The Terminal Warehouses O and A, and the frame compress between these buildings, were immediately involved. Sulphur stored in Warehouse A was ignited, giving off noxious fumes. What other Terminal buildings were immediately involved in fire cannot be definitely established because of the extent of concussion damage, the subsequent explosion of the *High Flyer*, which destroyed evidence, and the heavy smoke which drifted with the 20 mph wind over the entire area. There were fires, however, on the water edge of piers as far as the south slip, presumably from oil pipelines that had parted by concussion or had been pierced by missiles. It is also positively established that six tanks in the Stone Oil Co. farm and one in the Richardson-Republic farm ignited. All other oil tank farm fires were caused by the *High Flyer* explosion.

During the period between 9:12 and 1:10 A.M. the following morning, the scene was one of unparalleled tragedy, mitigated only by many exhibitions of personal sacrifice, individual heroism, and distraught initiative.

Rescue Activities.

Rescue efforts were the first order of business. Fire fighting in the Monsanto and Terminal area was impossible. Even the Coast Guard cutter *Iris* could not approach the docks for effective fire suppression following its 10:40 A.M. arrival from Galveston. It picked up survivors in the water and returned to its station. The 27 Texas City firemen on duty at the *Grandcamp* were killed outright. Their total of four pieces of fire apparatus was wrecked. Other volunteer members of the department responded to the emergency following the explosion, but the water supply systems in both the Terminal and Monsanto areas were inoperative due to explosion damage. Drafting water from the slips or bay was barred by fires and wreckage. Houston fire equipment and manpower drove 50 miles to the scene following commercial radio broadcasts of the disaster. Army fire-fighting crews from Fort Crocker were dispatched by the Commanding Officer, who observed the smoke and felt the explosion. There was no direct call for assistance to these or other neighboring fire departments on the 16th, although other communities also responded with pumpers and manpower on their own initiative. All fire-fighting personnel, including local plant brigades, concentrated on rescue work except at the Stone and Richardson-Republic tank farms which were segregated from the main explosion-damaged area. Fire equipment, in the main, was parked in the school yard in the town during the first day.

The uninjured crews on the *High Flyer* and *Wilson B. Keene* found their position untenable due to the smoke and sulphur fumes, and abandoned their ships at 10:30 A.M. The *High Flyer* could not be moved under its own power as its main turbine casing had been removed for inspection. An anchor was lowered to hold the vessel in place. The *Keene* was also "dead" because of blast damages. Two

tugs which were despatched from Galveston at 8:50 arrived at the Texas City turning basin at 9:50 A.M., but could not enter the harbor due to dense smoke, fumes, and debris. The tugs picked up survivors and returned to Galveston. The *Iris* returned to Texas City at 3:00 P.M., but again could not enter any of the three slips for fire fighting and left at 7:40 P.M.

Fourth Army, Red Cross, and Salvation Army rescue and medical workers rushed to the area. The small Galveston Red Cross Chapter was sending help to the scene within thirty minutes. The readily available services of the Fourth Army from headquarters at Fort Sam Houston, Fort Crockett, Ellington Field, San Jacinto Ordnance Depot, and the Galveston District Engineer were invaluable until the Red Cross could muster sufficient personnel to handle the emergency. (The tornado in Texas and Oklahoma on April 9th had drained normally available Red Cross workers in the Southwest.) An indication of the efficiency of rescue work may be gleaned from the statistics of the University of Texas Medical Branch. Within the first five hours this one hospital in Galveston handled 360 casualties. A deactivated hospital at Fort Crockett was placed in service by 6:00 P.M. and was handling patients (total admissions, 121 persons). The Fourth Army sent 9000 lbs. of blood plasma from Austin, medical personnel (69 officers, 50 nurses and 232 enlisted men), plus surgical equipment, food, gas masks, heavy road and construction equipment, and similar emergency relief supplies. Army aircraft brought needed medicines from St. Louis supply centers. Army specialists in gas gangrene were flown to the scene. General Wainwright, commanding the Fourth Army, had joined Governor Jester of Texas at the scene by 4:20 P.M. to speed all possible relief to the area. There was no lack of succor for the victims of the disaster on the part of relief organizations and the Army despite the lack of an integrated

community disaster plan. However, the existence of a Disaster Plan would have speeded the organization of the several agencies involved.

Further Trouble Brewing.

While rescue work was proceeding, further trouble was brewing for the already heavily damaged port. The *Grandcamp* blast carried away the hatches of the *High Flyer*, jumbled the cargo, sprang the steam lines, distorted and deflected the superstructure and decks, besides injuring the captain and crew members. There was no fire observed on this ship, however, until approximately 6:00 P.M. of the 16th. It is not difficult to imagine that flames from the burning piers and warehouses spread to the *High Flyer*, reaching the cargo through the open hatchways. Sulphur in holds No. 2 and No. 4 (total 2000 tons) was observed burning about



Los Angeles Fire Dept.—Capt. Conlin.

The remains of the *Keene* in the Main Slip. The *High Flyer* exploded as it lay against the *Keene*, having been blown across the slip from Pier "A" by the *Grandcamp* blast.

six o'clock. It was known that the ship had also been loaded with 860 tons of ammonium nitrate in hold No. 3. A call was made to Galveston at 8:00 P.M. for four tugs with oxy-acetylene cutting equipment and gas masks because authorities were apprehensive concerning the explosion potential in this second situation. The tugs arrived at Texas City between 11:00 and 11:20 P.M. Personnel boarded the



Los Angeles Fire Dept.—Capt. Conlin.

General view of wreckage on Pier A, showing remains of the fire-resistive warehouse. In center, wreckage is former Pier "O," and note that outer end is under water. Seatrain crane marks edge of Monsanto property. The *Grandcamp* was docked in slip next to Pier "O."

High Flyer and made several attempts to cut the anchor chain (finally succeeding) and to move the vessel. The latter effort could not be accomplished because tow lines failed, the two vessels were jammed and fouled, and the smoke, fire, and sulphur fumes had become so heavy that the area had to be evacuated. White smoke was observed about this time issuing from the No. 3 hatch. Efforts were abandoned to tow the vessel from the slip at 12:55 A.M. on the morning of the 17th.

The Second Explosion.

The *High Flyer* exploded at 1:10 A.M.

As far as can be accurately determined, only one additional life was lost due to this second explosion.

The *High Flyer* like the *Grandcamp*, completely disintegrated. That portion of the *Wilson B. Keene* abaft No. 2 hatch was also destroyed. The wrecked and remaining forward portion of the *Keene*, which had a cargo consisting only of 445 tons of flour, may be seen in the photographs.

Missiles were again hurled through the air for thousands of feet. Testimony by eye-witnesses verifies that exceedingly high temperatures had been reached, as some of the pieces of metal observed in the air were

"red hot," resembling a fireworks display. Large sections observed on the ground similarly showed the effects of tremendous heat and were warped and twisted into grotesque shapes. It was the missiles from the *High Flyer* which caused the severe damage and fires in the oil tank farms in the Humble and Richardson areas south of the main Terminal facilities.

Concussion forces were again severe. Reinforced concrete Warehouses A and B were reduced to rubble, except a small portion of Warehouse B on the shore end, which remained standing. Warehouses C, D, and E (unprotected steel) were collapsed further, original damage having been from fires started by the *Grandcamp* explosion and from exposure to the oil fires burning along the water front. A structural steel grain conveyor which connected the reinforced concrete grain elevator with Warehouse B (over the roof) was collapsed. Other buildings in the Terminal area, damaged by the first explosion, were demolished by the second.

Fires After Second Explosion.

Fires gained impetus in the Terminal area following the *High Flyer* explosion, but the most sensational new fires occurred in the oil tank farm areas. In the Humble

Pipe Line Co. property four tanks were ignited immediately and four additional tanks fired from these exposure fires; in the Stone farm two more tanks were ignited; in the Republic Refinery one tank was ignited; while in the Carbide and Carbon Terminal property an aluminum tank containing isopropyl acetate and one steel tank burned.

All day during the 17th, rescue operations proceeded without measurable efforts at fire control. The ravished area was beyond salvage. Fires still burning in the Monsanto and Terminal Buildings slowed rescue workers and spread gradually among the rubble of twisted steel and flammable contents. The tanks were flaming torches and the crude oil fires burned with a black smoke which could be observed for miles around. A spectacular "boil over" occurred on the 19th, which is shown in the illustrations. Lack of water supplies in the Humble Company

area prevented any attempt at fire control until the morning of the 20th, when a tank of bunker oil which burned slowly was extinguished with foam. Water was drafted from the South Slip for this purpose and foam powder brought from other refineries was used, as Humble's foam supplies had been ruined by heat.

Additional Rescue Work.

Cleaning up the debris-strewn area had to precede much of the rescue operations. Mayor Trahan of Texas City on the morning of April 17 appointed a special committee representing each of the industries affected to supervise relief and rescue operations under the direction of the chief engineer for the Pan American Refining Corporation. Governor Beauford Jester declared a "state of emergency" and designated the State Department of Public Safety to coordinate all police and rescue activities. There was some confusion of



Los Angeles Fire Dept.—Capt. Conlin.

Wreckage in foreground was spheroid, similar to undamaged one at right. Smoke in background from fire on Humble Farm.

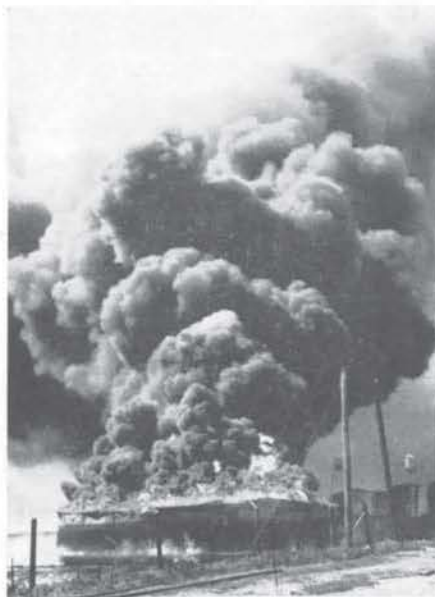
authority, but the emergency situation was so urgent that individual participants normally did the necessary without undue concern as to authorization. Army and civilian bulldozers, cranes, dump trucks and similar heavy duty equipment worked efficiently and speedily to remove wreckage so that buried bodies might be retrieved and the single access road cleared for use. Assistant Chief Dowdy was placed in charge of the remaining local volunteer firemen, who speedily received replacement apparatus from the War Assets Administration. Effective fire fighting in the Terminal area was not started, however, until the afternoon of the 18th, when Houston and Pasadena sent apparatus and manpower to the scene. Water was drafted from the slips, as the underground system still could not be used. The Coast Guard cutter *Iris* was used to pour water from the bay on the smoldering piers during the 18th. Isolated fires were still burning in the Monsanto property during the 18th also, a burning benzol tank providing the greatest volume of smoke. No fire fighting was attempted in this area and the flames only subsided as their fuel was consumed.

By the morning of the 19th, clean-up work had progressed admirably and fire fighting was systematic in the Terminal area. Most of the bodies that were to be located had been removed to mortuaries. The buildings in the city had been inspected and those unsafe were placarded.

III. Conclusions.

In a disaster of this nature and magnitude, evaluation of the principal contributing factors presents difficulties, but the following recommendations are offered for those who, in studying Texas City, desire to prevent similar disasters in their own communities:

(1) The "impossible" happened again at Texas City. Large fires and explosions continually emphasize the need for preparedness and throw the stigma of folly into the faces of



Los Angeles Fire Dept.—Capt. Conlin.

One of the Humble Oil tanks burning two days after the explosion of the *High Flyer*. Ignition attributed to hot missiles.

those who repeatedly say: "It can't happen here."

(2) Prompt detection and reporting of fires remain the chief keys to control. (Delay in transmitting the alarm of fire on the *Grandcamp*, attempts to fight the fire without calling the fire department, and poor judgment in prohibiting the use of hose streams set the stage for the tragedy.)

(3) Chemical products must be continually analyzed to determine their fire and explosion hazards. Fire departments must search out chemical hazards within their protection zones. (The explosive violence of ammonium nitrate explosions was a matter of record, but even the experts erred somewhat in evaluating its hazards under fire conditions.)

(4) Special protection facilities required by the inherent nature of certain industrial enterprises must be provided to safeguard life and property which might be exposed. (The lack of readily available marine towing equipment, the lack of a port warden to govern handling of hazardous materials were serious deficiencies at Texas City.)

(5) More strict industrial zoning is obviously required; especially where an explosion



Los Angeles Fire Dept.—Capt. Conlin.

General view of damage in Monsanto plant. One of the 190 ft. distillation towers at right foreground, alkylolation towers at rear, propane tanks in left center, and wreckage of low-pressure hydrocarbon tanks in center foreground.

potential exists. (The 5000 employees of the concentrated industrial area surrounding the port facilities at Texas City were innocent victims in the disaster.)

(6) Dependence on established fire protection facilities in explosion hazardous areas is dangerous. (With the Terminal and Monsanto fire protection systems knocked out by the first blast, effective fire fighting was delayed (even after rescue operations had been essentially completed) because there was no organized plan to draft water from the bay and to utilize pumper equipment available.)

(7) Open areas between structures will mitigate explosion damage and are the only logical method other than subterranean construction. (The lessons at Texas City were similar to those of World War II in this respect. Reinforced concrete buildings within 200 feet of the explosions failed, while those 700 feet away were only damaged and did not collapse. Concussion forces were less severe on rounded surfaces and unencumbered structural steel.)

(8) Operational practices in industrial occupations established for convenience or utility but counterpoised to safety must be re-examined. (Disabling the *High Flyer* during loading of hazardous chemical was a serious act leading to the second fatal fire and explosion.)

(9) Proper storage of petroleum products

remains of utmost importance. (At Texas City the installations were reasonably well planned and only about 22 per cent of the petroleum stored within a 1½-mile radius was lost by fire.)

(10) Port operational procedures and docking facilities require renewed fire safety analysis. Better supervision, increased protection facilities, and improved fire protection on ship-board are needed. (Texas City's disaster followed two ship fires and the Los Angeles explosion of June 22, 1947, is an indication that the end is not yet.)

(11) Most important, preplanning against disaster confusion incorporating regional fire defense organization is obligatory. (The lack of such planning was a severe handicap at Texas City, overcome only by individual initiative and personal heroism of those on the scene.)

IV. Losses.

On June 22, 1947, 67 days following the disaster, Texas City committed its 63 unknown dead to "God's gracious mercy and protection." These charred and broken bodies brought to 468 the known victims of the blasts. Over 100 others are still missing. The Red Cross reported 3000 injured, of whom more than 800

were hospitalized and 380 were still confined on June 1, 1947. Two thousand people were given shelter following the damages to homes in the city and 15,000 people were fed during the emergency

period of several days.

Dollar losses are still indefinite and insurance claims not fully adjusted. Based on information available to the N.F.P.A. the following estimates are given below:

Property Damage

Monsanto Chemical Company	\$14,750,000
Texas City Terminal Railway Co.	11,450,000
Dwellings and contents, Texas City ..	2,500,000
Mercantile, city, and school property, Texas City ..	2,000,000
Marine hulls	1,500,000
Humble Pipe Line Company	1,200,000
Republic Refining Company	1,000,000
Ludlow Manufacturing and Sales Co.	900,000
Automobile (1100 cars) and aircraft (2) ..	750,000
Slips and turning basin	600,000
Railroad rolling stock	500,000
Southport-Republic Terminal Co.	300,000
Sid Richardson Refining Co.	300,000
Pan-American Refining Co. (Oil Docks) ..	300,000
Grain in elevator	300,000
Carbide and Carbon Chemical Co. (Terminal tanks) ..	250,000
Seatrains Lines (Loading crane)	200,000
Sub-total	\$38,800,000

<i>Business Interruption, Debris Removal and Incidental Expenditures</i>	\$20,000,000
Sub-total	\$20,000,000

Life, Accident, Workmen's Compensation Insurance Loss Estimates

Monsanto Company employees (Life and Workmen's Compensation Insurance estimate)	5,000,000
Other life insurance estimated	2,000,000
Other Workmen's Compensation Insurance estimated	1,000,000
Texas City Volunteer Fire Department accident insurance estimate ..	75,000
Other accident insurance estimate	125,000
Sub-total	8,200,000

Total	\$67,000,000
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Los Angeles Fire Dept.—Capt. Conlin.

The steel barge which was carried 100 feet inshore by the displaced water in the slip where the *Grandcamp* exploded.



U. S. Army Air Forces.

View of Texas City Railroad Terminal property from an altitude of 5000 ft., taken two weeks after the disaster. (See other similar photos of oil tank farm areas and the Monsanto Plant.)

V. Details.

A. Texas City Terminal Railway Co.

The Texas City Terminal Railway Company is jointly owned by the Santa Fe, Missouri-Kansas-Texas, and the Missouri Pacific Lines, and the Terminal is served by these railroads. The property was operated as a rail terminal and possessed warehouse and dock facilities. Pier and terminal warehouses data, given below, show that total floor area was 1,067,424 sq. ft. (about 24½ acres) under cover.

Other buildings included: (1) the idle

compress building, built in 1915, which was a one-story, sprinklered frame structure, 22,610 sq. ft. in area and containing a small boiler plant; (2) the reinforced concrete grain elevator, 171 ft. high and the twelve adjoining reinforced concrete tanks 98 ft. high and 24 ft. in diameter, erected in 1910; (3) the one-story shop, generator and pump house of mixed construction erected during 1904-10; (4) the steel grain conveyor, 18 ft. wide and 790 ft. long, extending from the grain elevator to the roof (and 460 ft. along the roof) of Warehouse B, supported by steel frame-

Texas City Terminal Railway Warehouses.

Warehouse	Construction Features	Date Erected	Dimensions	Total Floor Area
0	Steel frame, sheet iron walls and roof. Two fire division walls. One story. Not sprinklered.	1914	155 ft. by 880 ft.	136,400 sq. ft.
A	Reinforced concrete. Two fire division walls. One story. Automatic sprinklers.	1912	155 ft. by 880 ft.	136,400 sq. ft.
B	Reinforced concrete. Three fire division walls. Two stories. Automatic sprinklers.	1929	120 ft. by 1160 ft.	278,400 sq. ft.
C	Steel frame, brick and metal walls, concrete tile on steel truss roof. Two fire walls. One story. Automatic sprinklers.	1910	100 ft. by 750 ft.	75,000 sq. ft.
D	Same as Whse. C except not sprinklered.	1911	100 ft. by 750 ft.	75,000 sq. ft.
E	Same as Whse. C except not sprinklered.	Uncertain	120 ft. by 520 ft.	62,400 sq. ft.
Note — The above warehouses, located on the waterfront, stood on filled earth. Wharf aprons were 36 ft. to 72 ft. wide, uncovered, wood flooring on wood piling over water, except for partially covered apron along north side of Whse. B, which had concrete floor on wood girders and pilings.				
No. 1	Frame sidewalls with brick end walls, wood joist roof, 7 fire walls of 16 in. brick. One story. Automatic sprinklers.	1904	76 ft. by 1024 ft.	77,824 sq. ft.
No. 2	Steel frame and metal walls with tile on steel frame roof. One story. Not sprinklered.	1904	100 ft. by 250 ft.	25,000 sq. ft.
No. 3	Same as No. 2.	1904	100 ft. by 250 ft.	25,000 sq. ft.
No. 4	Same as No. 2.	1904	100 ft. by 250 ft.	25,000 sq. ft.
No. 5	Same as No. 2.	1904	100 ft. by 250 ft.	25,000 sq. ft.
No. 6	Wood frame (except one stone veneered end wall) with metal walls and roof. One story. One substandard division wall. Automatic sprinklers.	1904	90 ft. by 1400 ft.	126,000 sq. ft.
Total				1,067,424 sq. ft.



U. S. Army Air Forces.

Vertical photograph of the Monsanto plant and adjoining Terminal property two weeks after the explosion. This picture and other U. S. Army Air Forces photographs were taken to study the concussion damage effects and to compare them with bomb damage inflicted in Europe and Japan during World War II.

work (erected 1929); and (5) a locomotive shed of steel frame, metal-clad construction.

The oil piers were wood and extended 1032 ft. into the bay on wood piling. Smaller structures included a reinforced concrete grain dryer house (16 ft. by 26 ft.), a frame stucco dock superintendent's office (25 ft. by 80 ft.), another small office of frame construction near the elevator, two frame, metal-clad auto sheds, and miscellaneous small buildings.

Water supplies for fire protection consisted of one 100,000-gal. elevated (100 ft.) gravity tank which supplied the automatic sprinkler systems and the private hydrants (except that 8 hydrants near warehouses Nos. 2, 3, 4, 5 were fed from a second 100,000-gal. tank used principally for domestic purposes). The main fire service tank was supplied by a 600-gpm electric motor-driven service pump taking suction from a 300,000-gal. concrete reservoir, which was filled from two private wells having 230 and 240 gpm



NEPA.

Shows part of fire resistive Warehouse B, which remained upright.

sprinkler heads were installed in the protected buildings and pressure from primary supply was 42 lbs. on top line.

B. Monsanto Chemical Co.

This plant was built by the Defense Plant Corporation in 1942 to augment the supply of styrene in the wartime synthetic rubber program, at a cost of approximately \$18,000,000. It was purchased by the Monsanto Chemical Co. in 1946 and was in operation at the time of the disaster, producing styrene and polystyrene plastic products.

Well laid out on a rectangular waterfront tract approximately 1300 ft. by 1450 ft. (43½ acres), the property was formerly occupied by a sugar refinery and some of the older utility and office structures were originally part of this enterprise. The construction was chiefly structural steel and masonry for major buildings and open steel framework for processing units. Spacing of structures was adequate for safety, and fire protection measures had been thoughtfully planned and executed. The severe damage done to the installation cannot be ascribed to any fail-



Los Angeles Fire Dept.—Capt. Conlin.

View of reinforced concrete column failure in Warehouse "B."

capacity electric pumps. Secondary supplies were from two 1000-gpm electric fire pumps also taking suction from the reservoir. A good system of 6 and 8-in. mains supplied sprinkler systems and private hydrants. There was no connection to public water sources or mains. A total of 8850

ure to provide adequate resistance or protection from explosion or fire, and, as a matter of judgment, it was obvious that even greater damages might have resulted

had not construction and layout been superior. The fire protection provided was, nevertheless, rendered ineffective by the initial explosion.

Main Unit Groupings of Monsanto Structures.

Name	Damage*	Description
1. Polystyrene Building	Total C-F	A five-story masonry and steel structure (formerly the sugar house of the old sugar refinery) used in plastic production and for storage.
Adjoining Warehouses	Total C-F	Warehouses adjoining were one and two-story masonry and steel structures, the one story section extending along the waterfront. The latter building was only 300 ft. from the <i>Grandcamp</i> .
2. Steam Plant and Power House	Total C-F	One story masonry and steel building adjoining Polystyrene Building on the east, concrete stack. Building 500 feet from <i>Grandcamp</i> .
3. Office Building	Major C	Three-story masonry and steel with concrete roof and floors.
Service Building	Major C	Two-story masonry and steel with third story in process of construction.
Laboratory	Total C-F	One story, brick, wood joist.
4. Warehouse	Total C-F	One story masonry and steel directly behind Polystyrene Building.
Instrument Shop	Total C-F	One story, brick, wood joist also behind Polystyrene Building.
5. Ethylene Purification Units	Major to Light C-M-F	Two 60 ft. fractionating towers supported by steel framework, two heater buildings with steel framework and refractory heaters, six compressor units in a steel frame, asphalt protected, metal building, and a masonry and steel control house.
6. Alkylation Unit	Major except to tanks C-M-F	40 ft. unit supported by heavy structural steel framework with converter equipment reactors, and control house. Four 500-barrel storage tanks, one 250-barrel storage tank.
7. Distillation Units 1, 2	Towers: Unit 1, Major; Unit 2, Considerable; Unit 3, Slight. Towers withstood C, damaged by M and F. Control houses heavily damaged by C.	Two separate tower groups 190 ft. in height, each having two vacuum fractionating columns 165 ft. high, 10 ft. in diameter with six smaller towers, all embraced in steel framework. Each group has its own auxiliary equipment, control room, and horizontal tanks adjacent to the base of the tower. Piping considerable. Auxiliary equipment includes exchangers, pumps, and condensers.
8. Cracking Unit	C and M Moderate	Twenty low pressure, high temperature cracking units in structural steel framework, with control room of masonry construction.
9. Dehydrogenation Unit	C and M Light	A series of catalytic cracking furnaces and chambers and steam superheaters in steel framework with masonry enclosed control and instrument room.
10. Pump House	C—Heavy to building, light to contents	Brick-steel joist building housing nine sea water pumps for domestic use. Fire pump (1000 GPM steam unit) located in separate subterranean structure on harbor bank.

11. Tankage† Benzol	Total C-F	Three 10,000-barrel tanks of benzol on east and north sides of area destroyed.
Other Large Atmospheric Pressure Tanks	Total C-F	A total of 14 situated throughout the plant destroyed. Contained low pressure hydrocarbons.
Propane Pressure Tanks	Light C	Eight tanks (510 barrels capacity each) on concrete pillars, containing propane, withstood blasts and exposure fires.
Small Atmospheric Pressure Tanks	Varied Heavy to Light C-M-F	Approximately 25 tanks, horizontal and vertical types, located adjacent to processing units. Heaviest damage to 4 vertical tanks near Distillation Units.
12. Fire Department and Foam House	Total C	Totally destroyed; buildings of light construction.

*C—Concussion Damages; F—Fire Damages; M—Missile Damages.

†See also Part C, this section, on major tankage.

C. Oil Tank Farms and Refineries.

The nearest refinery processing and service equipment within a mile and a half radius from the Texas City Terminal area was fortunately two-thirds of a mile distant. By virtue of this fact alone, the damage to the actual processing units of the Republic, Stone, and Richardson's Refining Companies was limited. Concussion damages in the Republic process area was the most severe of the three, but was not sufficient to halt operations. A missile from the *High Flyer*, weighing over a ton, virtually sliced the 2-story, brick, wood-joist-

ed office building in half. Fortunately, vital and hazardous areas were not struck. The refinery area proper of the Stone Oil Company suffered serious damage only at one of the shell stills which was struck by a missile from the *Grandcamp* explosion, causing ignition of released vapors. This fire was extinguished before serious complications ensued. The Richardson refinery facilities sustained only superficial damage from the shock waves and missiles.

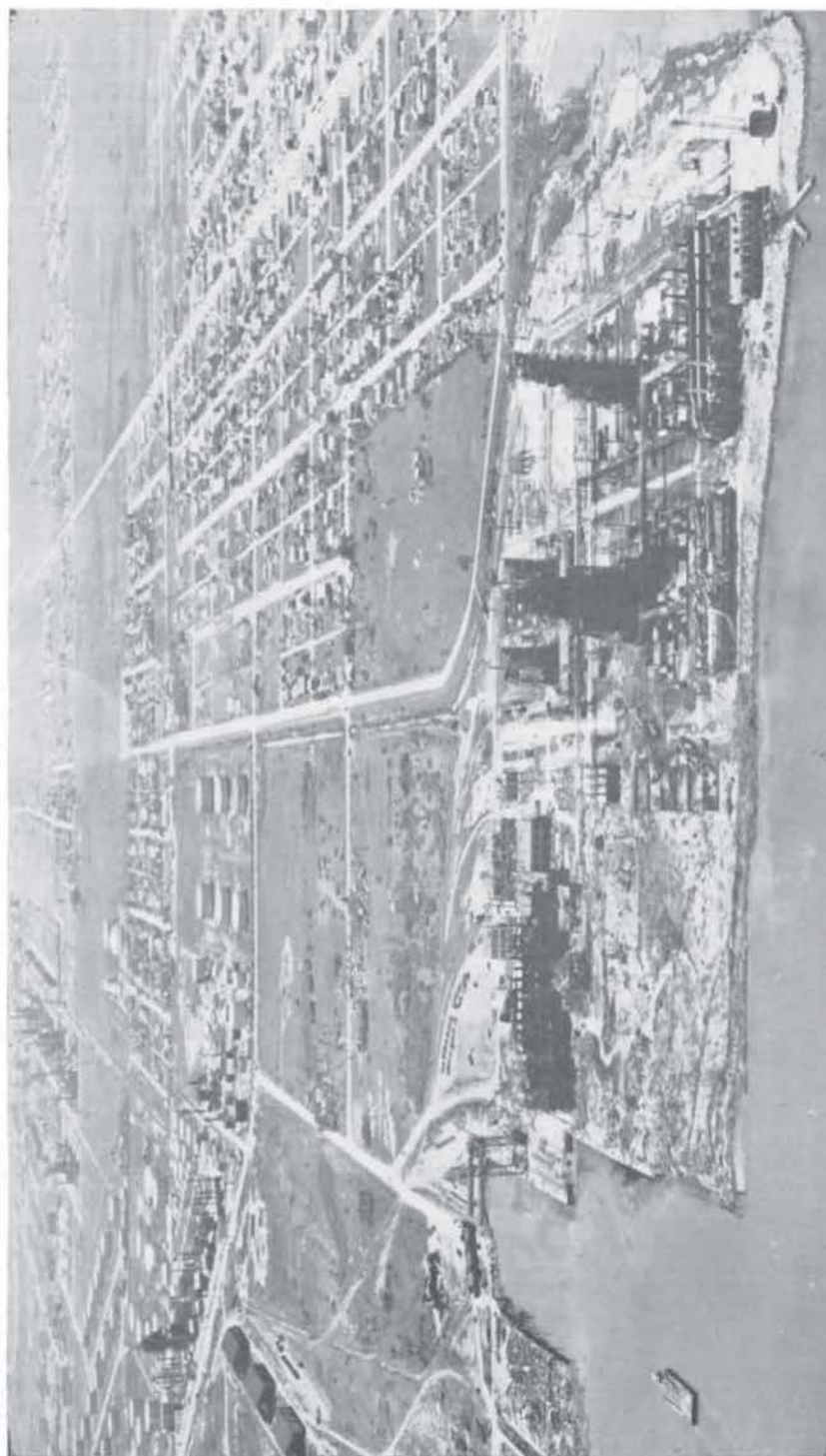
A summary of the petroleum tankage in the area and the damage sustained by fire is given below.

Approximations of Stocks in Tanks (10,000-barrel or Larger Capacity) and Their Fire Damages in the Farm and Refinery Areas Within 1½-mile Radius of Terminal.*

(Quantities expressed in 42-gal. barrels)

Type Hydrocarbon	Stock of Oil in Tanks on April 16th	No. of Tanks	Ignited Direct from Explosion Missiles		Ignited from Exposure Tank Fires	
			Stock Qty.	No. Tanks	Stock Qty.	No. Tanks
Natural Gasoline (14 lb. and lighter)	12,500	4	None	None	None	None
Gasoline and Naphthas.....	293,000	24	3,400	2	None	None
Crude Oil.....	995,000	25	232,900	6	139,900	4
Kerosene and Gas Oil.....	431,250	26	None	None	5,600	1
Topped Crude and Miscellaneous Other.....	68,950	14	None	None	None	None
Residual Fuel Oil.....	23,000	4	None	None	None	None
Benzol, Other Aromatics.....	29,600	5	29,600	5	?	?
Total.....	1,853,300	102	265,900	13	145,500	5

*Figures secured from report by George Armistead, Jr. Smaller tanks (less than 10,000 barrels) not included.



U. S. Army Air Forces.

Aerial view of the Monsanto plant two weeks after the disaster. The *Grandcamp* exploded in the slip at the left. (See other similar photos of the Terminal and oil tank farm areas.)



U. S. Army Air Forces.

Aerial view of the oil tank farms. Note tanks burned out and those damaged by missiles and concussion. Refinery areas in background. (See other similar photos of Terminal and Monsanto plant.)

Several observations are in order concerning the statistics given above.

1. The total capacity of the 120 major tanks was 6,324,500 barrels, but 102 of these were only 29 per cent full (1,853,300 barrels) on the day of the explosion.

2. On the basis of stock susceptible to fire loss in these tanks (1,853,300 barrels), only 22 per cent burned (411,400 barrels).

3. On the basis of total major tanks subject (120), only 15 per cent (18) were ignited by either direct blast damage or exposure.

4. Of the 18 major tanks which ignited, 8 were directly ignited following the *Grandcamp* explosion, 6 following the *High Flyer* blast, and 4 additional due to exposure conditions after the second blast.

5. The high loss of crude oil was principally caused by the burning of the 8 tanks in the Humble area where tannage was over 50 per cent full, and 80 per cent of this fuel was burned.

6. The losses of low-flash point fuels were low (except for benzol), principally because of distance factors. Benzol losses were high because of their close proximity



NFPA.

Fire-resistive grain elevator on the Terminal property (damaged more than photo illustrates) and collapsed conveyor.

to the blasts and it is reasonable that any other flammable liquid in those tanks would have been ignited. There is little relation, therefore, between relative flammability and losses; it is obvious instead, that location and the missile trajectories influenced losses.

Other interesting factors concerning the oil tank fires can be briefly mentioned:

1. The damage of the oil facilities was of three types:

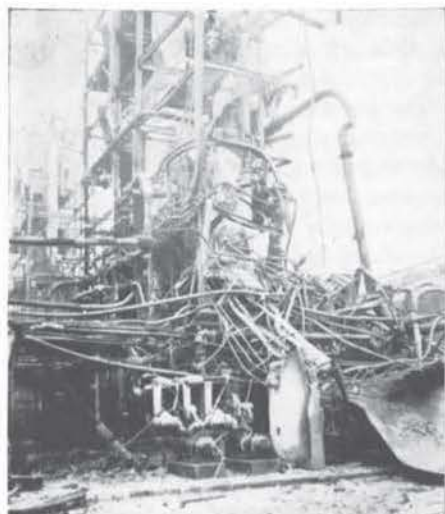
(a) Concussion: tank roofs of wood or sheet steel were pushed down (rafters and other supports failing through overload) and shells of empty tanks were dented, but forces applied horizontally were not sufficient to cause collapse.

(b) Missiles: hot and cold missiles, weighing from a few ounces to nearly 100 tons, fell in farm areas. In nearby areas, trajectories were flat, increasing toward the vertical as range increased. At $2\frac{1}{2}$ miles the missiles fell almost vertically. Tank roofs, thin-walled pipes, upper shell courses of large tanks were perforated. Few missiles striking tanks on a horizontal plane had sufficient force to pierce tank



NFPA.

This photo was taken within seconds of a boilover in a crude oil tank in the Humble Tank Farm. This ignited a tank of bunker oil previously not involved.



NFPA.

Wreckage of piping at base of ethylene purification fractionation towers in Monsanto plant.

shells. Where explosive mixtures existed, explosions resulted, followed by fire.

(c) Fires: most of the fires are believed to have been caused by heated missiles (above ignition temperature of flammable liquid vapors) especially in nearby Terminal farm areas (and in the Monsanto plant). This is supported by the fact that only hot missiles could have ignited wooden wharf planking, wood roofing of tanks, and pile clusters in the surrounding regions. Evidence also supports the theory that hot missiles were in greater abundance following the *High Flyer* blast and more fires in nearby farm areas resulted from this explosion than from the *Grandcamp*. (It will be remembered that the fire is known to have burned for seven hours before the *High Flyer* blast and only one hour prior to the *Grandcamp* explosion. This would result in high temperatures developing in the former case. Also the fire is known to have involved several holds on the *Flyer* rather than No. 4 only on the *Grandcamp*.)

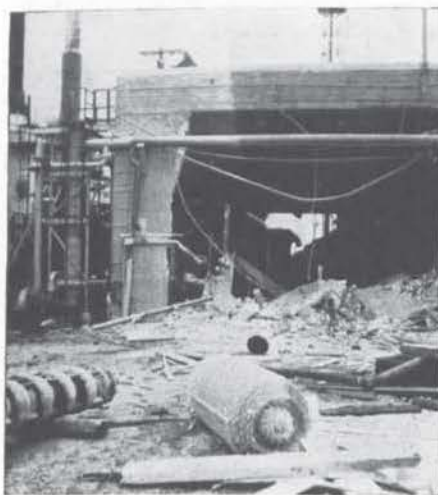
2. Whether tank roofs were blown off or collapsed inside following a considerable period of burning was influenced

by the force of gas explosions which, in turn, was influenced by the volume of liquid in the tank at time of ignition. The higher percentage of volume of liquid, the less the violence of the gas expansion.

3. Boilover occurred in one observed case in the Humble Farm, resulting in the spread of fire from a tank of crude oil to a large tank containing bunker oil which otherwise would not have been partially lost. (The bunker tank was subsequently extinguished.)

4. Several "empty" tanks were exploded by hot missiles or friction sparks. Fragmentation from these detonations was not serious, few portions being carried beyond dikes.

5. Where inadequate vents were provided, tanks subject to heat from fires were distorted from internal pressures. In the Carbide and Carbon Chemical Co. tank area this was particularly noticeable. An aluminum tank containing isopropyl acetate (flash point 40° F.) burned and melted to the ground, presumably due to the lack of a flash arrester. Adjacent tanks, including three identical aluminum tanks, were distorted as well as lifted from their foundations.



NFPA.

Failure of brick wall in Monsanto Pump House.

D. City of Texas City.

The closest dwelling properties were approximately a half mile from the core of the explosion. Such segregation was indeed fortunate for, while the damages sustained were serious, the distance factor must be looked upon as a mitigating element. Other cities are not so fortunately zoned.

Frame bungalow type, single and double family structures were severely battered, many totally collapsing, in an area roughly $\frac{1}{2}$ mile from the Terminal docks. This heaviest damage included approximately 12 blocks, which contained perhaps 150 homes. Beyond this area and within a radius of a mile, damage to dwellings was chiefly to roofs, windows, and porches, although many were so struck by the concussion waves that they were rendered unsafe for occupancy. Walls shifting off their foundations and thrown out of alignment were chiefly responsible. Beyond the mile radius and up to approximately $1\frac{1}{2}$ miles, window glass damage was extensive and some missiles pierced roofs.

Concussion damage in the closer building was too complete to determine how the forces were applied, but in those some distance away evidence showed downward pressure zones formed a decided pattern,

while even farther from the source of the blast, the negative pressure effect (uplifting of roofs) was readily discernible.

The school building was located about a mile from the Terminal. Damage to this 2-story structure was of interest, as every partition inside was destroyed, while the brick exterior walls were not damaged. The school was in session and while many children were injured, none were killed, and teachers evacuated the children from the building and the area promptly.

In the mercantile district many buildings of brick wood-joist, brick veneer, and stucco construction were heavily damaged, the higher buildings and those of largest area suffering the greatest loss. Two theatres suffered roof collapse, while several 2-story mercantiles had similar damage. Plate glass loss was extremely heavy throughout the business district.

In a survey of all dwelling and business buildings, 539 were condemned as unsafe out of a total of 1500 inspected.

E. Miscellaneous Properties Involved.

1. The Vessels.

The *S. S. Grandcamp* (French Line) totally disintegrated from the explosion. The ship was built in 1942 and was formerly the *S. S. Benjamin R. Curtis*. A Liberty type, the vessel was 422 ft. long,



Los Angeles Fire Dept.—Capt. Conlin.

Damage to dwellings in the residential area of Texas City over a mile from the explosions.

had a gross tonnage of 7176, and had 5 cargo hatches. Cargo on board the vessel included 2339.69 tons of ammonium nitrate, 380 bales of cotton, 16 cases of ammunition and unknown quantities of binder twine, tobacco, shelled peanuts, machinery and drill stem.

The S. S. *High Flyer* (Lykes Bros. Steamship Co., Inc.) also totally disintegrated from the explosion aboard that vessel. The ship was built in 1944 and was a C-2 type, with a length of 438 ft. and a gross tonnage of 6214. There were five cargo hatches and, at the time of the explosion, contained 961 tons of ammonium nitrate, 871 tons of knocked down box cars and 2000 tons of sulphur.

The S. S. *Wilson B. Keene* (Lykes Bros. Steamship Co., Inc.), is considered a total loss, although the bow portion remained visible. This vessel was a Liberty ship of the same type as the S. S. *Grandcamp* and had a cargo of 445 tons of flour when the explosion occurred.

2. The Turning Basin and Slips.

Major obstructions in the turning basin were removed by the Corps of Engineers at an estimated cost of \$15,000. The largest item removed was a 35-ton portion of a ship's hull, undoubtedly from the *High Flyer*. Other pieces of bent, twisted and ragged steel plate weighing from 13 tons to $\frac{1}{2}$ ton were lifted from the basin at points up to 600 feet off the bay end of "Pier" B, where the average depth is 35 ft.

Soundings taken in the main slip beneath the *High Flyer* anchorage reveal a crater 63 ft. deep. The pre-explosion depth was 34 feet, with the last previous dredging completed in December, 1946. No unexploded ammonium nitrate could be found in this slip following several days of exploration by a diver. Soundings taken in the North Slip when the *Grandcamp* exploded did not reveal any substantial crater; rather soundings showed a depth of only 20-25 ft. in a position near the stern and 30-33 ft. at the bow end.

(Hold No. 4 where explosion occurred was aft of midship house.) The difference is accountable due to the lifting of the water in this slip and its resettling plus the destruction of the earth foundation of "Pier O."

3. Oil Shipping Facilities.

Almost all of the waterfront area was arranged for bulk shipment and receipt of petroleum except on "Pier O," where the *Grandcamp* was docked. Extensive pipe lines to tanker loading and unloading berths fronted at "Piers" C and D. Wood piling supported the piping at this location. Fire caused extensive damage in this area, but it could not be determined what precise sequence of events preceded their outbreaks. It is known that missile damage on some pipes released oil, which was subsequently ignited and undoubtedly contributed to the extensive damage to these facilities. The oil dock equipment at the South Slip was almost totally ruined.

The well-segregated oil shipping units of the Pan American Refining Corporation below the South Slip and facing on the channel were comparatively undamaged. A few small fires in this area destroyed approaches and are believed to have originated from burning oil on the water's surface from spills in the South Slip's facilities.

4. Seatrail Loading Crane.

Damage to this installation was caused by flying missiles which struck the steel supporting legs with such force as to bend main members, throwing the structure out of alignment.

5. Molasses Terminal.

Three tanks, located in a group directly opposite "Pier O" were collapsed by the concussion. One of these had a capacity about 10,000 barrels, while the other two were 2000 barrel size. Small wooden buildings were also collapsed. There was no fire observed in this area.

6. Roadways.

Only a single access road serviced the Terminal area. This road passed directly in front of "Piers" and the North and Main slips. The explosion of the *Grandcamp* caused the barge *Leghorn II* to be cast across this roadway and littered the area with heavy debris which made it unusable for traffic. The collapse of the grain conveyor from the *High Flyer* blast similarly cut the road to traffic and again cast heavy steel objects across the single artery. The effects of this damage handicapped rescue activity measurably. Bay St. and South St. in the town were also badly pock-marked and caved by heavy missiles.

7. Railroad Rolling Stock.

A survey showed that 360 freight cars (mostly of the box car type) were destroyed or heavily damaged. Many contained flour and were ignited by hot missiles which penetrated roofs or caught fire from adjacent burning structures.

8. Automobiles and Aircraft.

No accurate count of the number of automobiles destroyed is available, but estimates run to 1100. Most of these be-

longed to employees working in the immediate vicinity and to those curious people who came to the dock area to witness the pre-explosion fire on the *Grandcamp*. In addition, the Texas City fire department trucks, cars belonging to volunteer members and a host of other vehicles in the area at the time of the *High Flyer* blast were wrecked. Two aircraft were destroyed by the concussion waves as they flew over the terminal when the first ship exploded.

F. The Ammonium Nitrate Fertilizer.

1. Production.

The ammonium nitrate fertilizer involved at Texas City was produced at the Iowa Ordnance Plant, Burlington, Iowa; the Cornhuskers Ordnance Plant, Copland, Nebraska; and the Nebraska Ordnance Plant, Wahoo, Nebraska. These facilities are operated on a contracting basis by the Emergency Export Corporation for the Ordnance Department, United States Army.

Basically the production techniques followed at these facilities, which are actually graining plants, are to process ammonium



Bureau of Mines.

Showing method of loading ammonium nitrate fertilizer aboard ship. Note 100 lb. paper bags and concentrated piling. Broken bags are visible in original print in left foreground.

nitrate liquor received in tank cars by:

(1) lancing (to dissolve the crystallized ammonium nitrate); (2) evaporating -- maximum temperature allowable, 325° F. (to change the liquor to a molten form); (3) graining (to provide proper granulation); (4) waxing (to minimize moisture absorption by the granules); (5) adding clay (to assist in providing a free flowing product); (6) bagging. The finished product is required to meet the following government specifications:

Moisture content.....	0.25% maximum
Ether soluble material (wax) ..	0.75%±0.35%
Water insoluble material (clay)	3.50%±1.00%
Total nitrogen.....	32.50% minimum

Granulation specifications called for require 100 per cent minimum pass through a U. S. Standard No. 8 sieve, 55 per cent minimum through a No. 35, and 8 per cent maximum through a No. 100 sieve. The ammonium nitrate liquor used was also governed by strict government specifications as follows:

Ammonium nitrate, minimum.....	70.0%
Acidity	None
Alkalinity, maximum	0.05%
Phenol	None
Nitrites	None
Ether soluble material, maximum.....	0.10%
Water-insoluble material, maximum....	0.30%
Ferrocyanides, maximum	0.10%
Pyridine, maximum	0.005%
Thiocyanates, maximum.....	0.01%
Sulphates, maximum.....	0.50%
Chlorides, maximum.....	1.50%

The wax used was purchased from a single company and had the following manufacturers' specifications:

Hydrometer indication at 160° F. (API) ..	43-46
Flash point (ASTM D92-46).....	470°-490° F.
Fire point (ASTM D92-46).....	540°-560° F.
Viscosity, S.U. at 210° F. (ASTM D88-44)	47-50
Oil content (ASTM D721-44).....	11-14%
Melting point (ASTM D87-42) ..	139°-145° F.
Penetration, needle (ASTM D5-25).....	50-70
Color	Brown

All the plants used a kaolin-type clay

which contained less than 1 per cent moisture and was ground so that 97 per cent would pass a 200-mesh sieve.

It may be observed from this information that the material was of standard grade and tests of samples of all the box-car lots shipped to Texas City failed to reveal any decomposition or chemical changes in the material. These tests were conducted by the Emergency Export Corp. and the Bureau of Explosives, Association of American Railroads. The processes at each plant were examined by chemical engineers of the U. S. Bureau of Mines and it appeared unlikely that any materials other than normal constituents could have been incorporated in the product.

The only observations of possible significance to the fires and explosions at Texas City with regard to the manufacture processes employed are:

1. The paraffin wax was in direct contact with the ammonium nitrate, a strong oxidizing agent. Under conditions of high heat (as by fire), chemical reactions which would be self-sustaining would result between the two materials.

2. The paper bagging was a readily ignitable material and tests on small samples filled with the fertilizer showed that it would ignite when subject to a heat of 300° F. for five or six hours. A steam pipe would provide this much heat under certain conditions. The bagging when *not* filled with fertilizer did not ignite in similar tests.

3. The multi-walled paper bags were so constructed that the second sheets from the outside and inside were impregnated with an asphaltic material to provide moisture resistance. This material would increase the heat of combustion.

4. The labeling on the bags gave no indication that the material was hazardous and did not conform strictly to regulations in that the name "Fertilizer" preceded the designation "Ammonium Nitrate," instead of vice versa.



Bureau of Mines.

Stowage of ammonium nitrate fertilizer in ship's hold, showing cargo battens.

5. The material, being in a fine granular form, could easily escape from the bagging if the latter was damaged.

2. Handling.

The ammonium nitrate fertilizer was shipped to Texas City via rail on government bills of lading designated as "Fertilizer Compound (Manufactured fertilizer) NOIBN, Dry, in paper bags (Fertilizer grade Ammonium Nitrate)." (NOIBN stands for "not otherwise indexed by name.") The material was consigned to the "French Supply Council, Transit Division" and was stored in Warehouse O pending shipment abroad.

Loading on the *Grandcamp* was accomplished by stevedores who apparently had no specialized knowledge of the fire and explosion hazards of the material. Crew members of the *Grandcamp* who survived (seven out of the total complement of 41) similarly displayed ignorance of the hazards of ammonium nitrate fertilizer. All those who testified at the official U. S. Coast Guard inquiry also showed a lack of knowledge of the regulations governing handling of the material as published by the Bureau of Marine Inspection and Navigation, U. S. Department of Commerce and the U. S. Coast Guard. These rules are contained in "Regulations Governing Explosives and Other Dangerous Articles on Board Vessels" and are dated April 9, 1941. The essential provisions of these regulations as affect ammonium nitrate, follow, with indications of compli-

ance or non-compliance in the cases of the two Texas City explosions:

Regulations	Compliance— Texas City
1. The substance shall not be stowed in the same compartment or hold:	
(a) In which explosives are stowed.	No violations (small arms ammunition in separate hold on the <i>Grandcamp</i>)
(b) In which acids or other corrosive liquids are stowed, all chlorates and other nitrates.	No violation
(c) In which flammable liquids are stowed.	No violation
(d) In which cotton, sulphur in bulk, or charcoal are stowed.	No violation
2. The substance shall not be stowed in a hold over or under one in which sulphur in bulk is stowed.	No violation (sulphur in separate hold on the <i>High Flyer</i>)
3. The substance shall not be stowed in proximity to readily combustible materials such as textile products.	No violation
4. All containers shall be tight; no leaking or sifting containers or containers that give evidence of leaking or sifting shall be placed on board the vessel.	Violation
5. Shipper is required to give written notification in advance to the vessel regarding the characteristics of a dangerous cargo.	Violation
6. No smoking during loading operations.	Violation

The three specific violations are cited as contributing factors to the fires and explosions aboard the *Grandcamp* and *High Flyer*.

3. Characteristics Following Ignition.

Ammonium nitrate, like any nitrate, supplies oxygen when heated and thus possesses hazardous qualities when viewed from the fire propagation and explosion potential viewpoints. Decomposition of ammonium nitrate into ammonia and

nitric acid is rapid above 176° F. ($\text{NH}_4\text{NO}_3 \rightarrow \text{HNO}_3 + \text{NH}_3$). Nitric acid acting on organic material releases oxygen to form nitrous acid and then in succession nitrogen, water and nitrogen tetroxide, an even more vigorous oxidizing reagent. The reactions and reversible reactions of the decomposition products are too complex chemically for detailed explanation in this article. It is significant, however, that they are accompanied by exothermic heats which quickly bring about an explosion potential. Other factors (besides temperature), affecting explosion hazard and remarks concerning their part in the disaster are listed:

Factors Favoring Explosion Under Fire Conditions	Remarks
1. Strength of detonation impulse - the greater the impulse the greater the explosion hazard.	No pre-explosion detonation impulses at Texas City.
2. Density of stowage - the higher the density the more violent the explosion.	High densities present in holds of both ships.
3. Packaging - loose material which is subject to greater contamination increases explosion potential.	Paper bag breakage noted at Texas City.
4. Particle size - the smaller the particles the greater the explosion hazard.	Granulation according to Government specifications.
5. Moisture content - the lower the moisture content, the greater the explosion hazard.	Dry, unseasonably cool weather on April 16, 1947, with 20 MPH, NNW wind.
6. Impurities - acids, oxidizable materials, organic materials increase explosion hazard while alkali or alkaline earth tend to de-sensitize.	No known impurities. Paraffin wax coating and asphaltic bag coating only possibilities known.

Ammonium nitrate will propagate its own explosion wave. Under conditions as at Texas City where the high concentrations of small grain, treated fertilizer were stowed within the confined space in the holds of ships and subject to fires, the intense heat of decomposition could logically

be expected to cause a violent explosive reaction. It may be stated conclusively that fires caused the explosions and that they occurred without an impact force or detonator. What caused the fire in the *Grandcamp* will never be known with certainty. It reasonably could have originated from nothing more spectacular than a carelessly discarded cigarette or match or possibly ignition of bagging following prolonged exposure (five or six hours perhaps) to steam pipes reaching a heat of approximately 300° F. The fire on the *High Flyer* was caused by exposure conditions and most probably could have been prevented if the ship had been withdrawn from the danger area during the nine-hour period between the first explosion (9:12 A.M.) and the first indication of fire on the *High Flyer* (about 6:00 P.M.) or even later (prior to 1:10 A.M.) if fire-fighting facilities had been available and properly utilized.

4. Explosion Prevention Practices.

It would be good practice to adopt the following precautions to prevent another disaster involving ammonium nitrate fertilizers:

1. Exercise strict control over purity at point of manufacture to prevent contamination with acids, oxidizable, organic (carbonaceous) materials.
2. In mixed fertilizers (i.e., superphosphates, ammonium nitrate, and organic meals), neutralization will be required to avoid hazard of spontaneous ignition. (Treatment of the superphosphate with ammonia has been successful if applied properly.)
3. Storage of the material in warehouses or stowage on ships should follow present requirements - segregation from organic, acidic, oxidizable, highly combustible or explosive materials and storage in separate fire areas from large concentrations of ordinary combustible materials. In addition, ventilation, limitation of amounts stored in a single area and accessibility for fire fighting should be considered. Automatic sprinkler protection is recommended for all storage warehouses handling the material. Storage should maintain safe clearance from steam lines and electrical wiring.
4. Handling in transit requires the same pre-



Los Angeles Fire Dept.—Capt. Conline.
Wreckage in foreground is former one-story warehouse of the Monsanto Chemical Company, in left center, the former steam plant and power house, and in background, the polystyrene building.

cautions against contamination as in storage.

5. Packaging should be in metal drums or tight wooden casks to prevent accidental spillage. Any drums or casks split or broken in handling or storage should be removed and spillage disposed of immediately in a safe manner.
6. Labeling requirements should include markings in conformance with standards presently recommended for oxidizing materials, indicating the hazardous properties of the chemical.
7. Detonators should not be used to break up caked materials.
8. Strict no smoking rules should be enforced during storage and handling, and the use of any open flame devices prohibited.

5. Fire Fighting Operations.

In case of fire, immediate application of water in large quantities is probably the best procedure, even though a large water loss may result, as the ammonium nitrate is highly soluble in water. As ammonium nitrate is dissolved in water a cooling effect is produced (unlike many chemicals which produce heat when dissolving in water).

Carbon dioxide, foam and other extinguishment agents of the smothering type are ineffective, because ammonium nitrate provides its own oxygen for combustion. Steam is of no value whatsoever.

As in the case of any nitrate fire of major proportions, caution should be used in applying hose streams, as the sudden formation of steam may cause minor explosions which will scatter the burning material. Nevertheless, hose streams, applied from a considerable distance or from behind some barricade, apparently are the only practical method of fighting such a fire.

Automatic sprinkler protection for buildings where ammonium nitrate is stored is highly desirable, as it provides prompt application of water in case of fire without exposing fire fighters to personal danger. However, as in the case of any commodity, the nitrate should be placed in piles of moderate size and height to permit effective action by the sprinklers.

Gas masks should be worn by fire fighters, as the oxides of nitrogen are toxic.

6. Previous Major Fires and Explosions.

1906, Witten, Germany: Explosion involving ammonium nitrate, TNT, and potassium nitrate. Cause unknown.

January 14, 1916, Gibbstown, N. J.: Explosion of concentrate solution of ammonium nitrate during crystallization.

July 30, 1916, Wurgendorf, Germany: Explosion of compound 80% ammonium nitrate, 12% TNT and 4% nitroglycerin and grain mill. Sun on metal drums caused decomposition.

September 15, 1916, Oakdale, N. J.: Explosion during manufacture of ammonium nitrate in crystallizing pans.

October 4, 1918, Morgan, N. J.: Explosion of 9,000,000 pounds of pure ammonium nitrate and 12,000,000 pounds of amatol (a mixture of 80% ammonium nitrate and 20% TNT). Fire believed responsible for causing explosions.

April 12, 1920, Stolberg, Germany: Explosion of mixture of ammonium nitrate, powdered aluminum and TNT being converted from an explosive into fertilizer. Material had caked and explosion resulted from attempts to break up mass.

April 19, 1920, Brooklyn, N. Y.: Steamer *Hall-fried*—chlorate fire involved 8460 casks containing 4,230,000 pounds of ammonium nitrate. Approximately 3900 casks burned. Minor explosions but none severe enough to cause ship to disintegrate.

April 26, 1921, Kriewold, Germany: Explosion of ammonium nitrate in two railroad cars believed caused by attempts to blast caked mass. 19 persons killed.

September 21, 1921, Oppau, Germany: Explosion of 5000 short tons of ammonium nitrate and ammonium sulfate following dynamite blasting of caked materials. 586 killed, 1952 injured, and 2138 buildings destroyed.

April 4, May 3, 1925, Muscle Shoals, Alabama: Two separate fires involving railroad cars containing ammonium nitrate in wooden barrels. No report of explosion.

May 7, 1925, Emporium, Pennsylvania: Explosion in an evaporating pan during reprocessing. One killed.

VI. References.

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Braidech, M. M., National Board of Fire Underwriters.

- Butler, W. T., U. S. Coast Guard.
 Conlin, C. A., Jr., Capt., Los Angeles Fire Dept.
 Davis, H. H., Fire Prevention and Engineering Bureau of Texas.
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 Gross, Harry, Capt., Los Angeles Fire Dept.
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 Higbee, F. D., Warden, Port of Los Angeles.
 Keepers, Hugh V., Fire Prevention and Engineering Bureau of Texas.
 Richardson, G. W., Acting Chief, Houston Fire Dept.
 Whittlesey, Roy E., Chief, Houston Fire Dept.
- Special credits are given to the following sources of information (other than previous N.F.P.A. publications) which have been used in compiling this report:
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- In addition, letters from the following individuals are acknowledged:
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 Davis, H. H., Fire Prevention and Engineering Bureau of Texas.
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