

Ammonium nitrate explosion hazards

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FOR MORE THAN FIFTY years ammonium nitrate (AN) has been an important industrial chemical in explosives and agricultural fertilizers. Markets for ammonium nitrate have continued to expand and currently there is widespread acceptance of AN mixed with various fuels as a low-cost replacement for dynamite and blasting agents.

As an explosive ingredient or as an explosive material, AN is exceedingly stable. It is classified as an oxidizing agent for transport and storage and in the pure form can be stored at ambient conditions in large amounts without fear of self-ignition or spontaneous explosion. In many ways it is an ideal chemical material.

Ammonium nitrate decomposes with the liberation of heat and gases and has excess oxidizing capability over that of the oxidation of ammonia; it can therefore oxidize as much as 6% by weight of hydrocarbon or other fuel. As a result, fires in AN cannot be smothered. In the past, many fires involving moderate quantities of AN have been fought without hazard. In other circumstances, AN has been involved in incidents with extensive and devastating damages and many of

these incidents were not expected on the basis of prior experience. It is believed that the extensive use of oil and AN presents a hazard which may lead to the development of explosion from fire in frequent and unexpected ways. Certain features of the accelerated decomposition of masses of fueled, liquid ammonium nitrate may cause detonation in circumstances which, until recently, would not have been expected.

History of ammonium nitrate

The safety of ammonium nitrate, in spite of its potential for rapid oxidation and explosion, has been the basis of many of its uses. Early applications of AN to military purposes were based upon the fact that AN could not be exploded with rifle fire. In many ways, the expansion of the uses of AN have been based on its relative safety in comparison to other compounds of equal effect; in fact, hazard from explosion had been so remote that a major use is as a chemical fertilizer which for the most part, is handled without concern for hazard.

The history of accidents involving AN (1) can be looked at as a series of surprising and devastating events



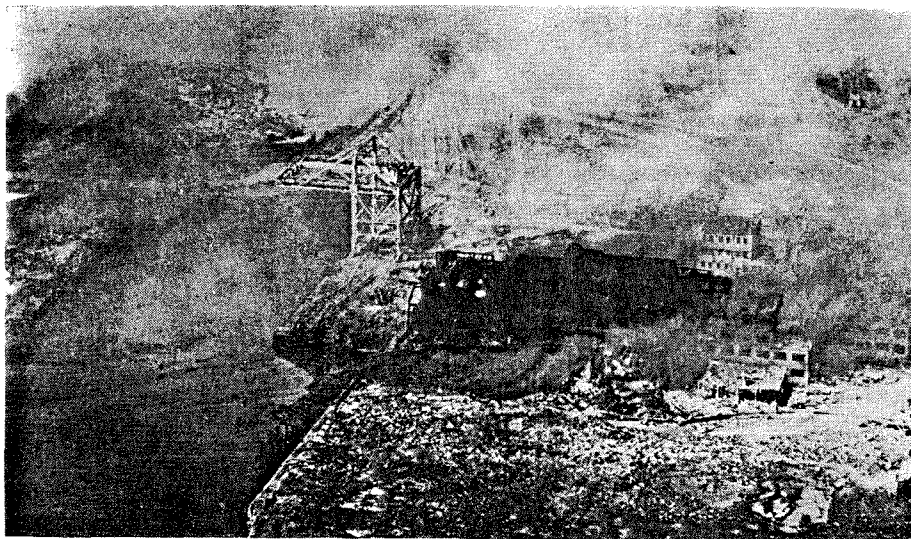
The S. S. Grandcamp just a few minutes prior to the explosion on board.

in what is otherwise an exceedingly useful and steadily expanding market. The development of uses for AN and in part the expansion of its production rate has led to periods of increased and unexpected hazard. The careful study of the conditions and causes for an unexpected consequence has led to its removal as a consequence only to be followed later by a new and as yet unexpected consequence.

Boosting to detonation by another explosive is one major recurring cause for hazard from AN which, once learned, in newer circumstances has had to be relearned. Incidents of this type include Morgan (1918), Kriewald (1921), Oppau (1921), Tessenderloo (1942), and Roseburg (1959). Of these Oppau deserves special mention since before the accident many thousands of explosive charges had been used to break up the heavy cake of the double salt 2 nitrate-1 sulfate without incident. Also at Roseburg, the ammonium nitrate was mixed with a stoichiometric amount of fuel oil, a fact that undoubtedly increased the scale of the damage.

Heating with confinement

A number of experiments have indicated that confined AN (as in a closed pipe) when heated to the point where a decomposition reaction begins will detonate in a short time. Fuel, such as oil or vapor, in contact with the confined AN reduces the time interval for heating to explosion by providing additional highly exothermic reactions that can be initiated from relatively low temperatures. The sensitivity of AN to initiation is, in general, considerably increased at ele-



Texas city shortly after the explosion of the S. S. High Flyer. The S. S. Grandcamp was moored beyond the left edge of the picture.

vated temperatures so that a small accidental explosion in the presence of a larger heated sample may produce initiation that otherwise is unexpected. Incidents where fire was not observed prior to explosion include Kensington (1896), Gibbstown (1916), Nixon (1924), Merano (1936), Milan (1944), and Benson (1944).

It was learned that an air lance in a high pan could become contaminated with oil or could become plugged and act as a bomb. This discovery has led to corrective measures which can eliminate this hazard.

Precautions for designing drain-off tubes for high pans and for other processing equipment can be taken that reduce the amount of AN present and that do not allow the development of pressure. Further precautions with regard to potential zones of confinement in storage can also be taken to reduce the hazard of decomposition under confinement. Experimentation both at the Bureau of Mines and Picatinny Arsenal have elaborated specific conditions and, along with other work on the importance of pressure, have increased considerably our understanding of this form of hazard.

Fires

The most perplexing aspect of ammonium nitrate is its behavior in a fire. Large amounts of AN have been involved in a number of fires which have burned or been extinguished without incident. These fires are common enough so that some have not even been reported in the literature. Accidents involving fire in AN have been divided into incidents of two kinds: first, where the origin of fire was unknown and spontaneous heat-

ing could be involved; second, where the origin of fire was from some external source. In either event, the addition of organic matter, as in the case of FGAN (fertilizer grade ammonium nitrate coated with 0.5% to 1.0% wax, etc.), seems to have contributed to the energy release in the decomposition reaction and, therefore, to the hazard.

The practice at government ordnance works, prior to 1947, of bagging and shipping FGAN at approximately 90°C was apparently responsible for a number of fires caused by spontaneous heating. Between 1946 and 1949, thirteen freight cars loaded with FGAN burned without explosion. During the same period, in other cars charred materials were found even though fire did not develop. The fires in both the S.S. Grandcamp (1947) and the S.S. Ocean Liberty (1947) have been attributed to spontaneous heating. In the absence of free acid, it has been demonstrated that AN in paper bags is not subject to spontaneous heating if the material is assembled at ambient temperature. Incidents involving proven spontaneous heating have not been reported for more than a decade.

Explosions

There were a number of cases in processing plants where fires in AN have transformed to explosion. These include Oakdale (1916), Emporium (1925), Gibbstown (1932), and Hercules (1953). In each of these fires, organic material was present in some form.

There have been four ship explosions from fire. Three ships carried FGAN: S.S. Grandcamp, S.S. High

Flyer (1947), and S.S. Ocean Liberty (1947), while the S.S. Tirrenia (1953) carried nitrate of unspecified composition. A fire in a ship carrying pure AN (CPAN) in casks was extinguished without incident: S. S. Hallfried (1920).

There were several attempts to reproduce the conditions that led to explosion in ships carrying FGAN, using scaled down models. In no case was a detonation obtained.

As a general summary, fires in pure AN have been less intense and more manageable while fires in AN with intermixed organic matter have been more intense, extensive and have sometimes involved conversion to explosion. In several cases whistling noises increasing in pitch were heard, indicating localized pressure conditions with the presence of accelerating chemical reactions.

After the use of FGAN was discontinued, incidents involving AN were rare in spite of the fact that increasing amounts of AN were being produced. However, burning to detonation has taken place in two incidents, Traskwood (1960) and Norton (1961) (2), each of which had certain conditions which require further study. Both could have involved a mixture of AN and organic material (accidentally in Traskwood) and in each case a fire burned for some thirty minutes before explosion took place.

Mechanisms of burning

There are two mechanisms of burning for AN and its organic mixtures which involve quite different processes (3), although both processes can occur in the same incident. One mechanism is that of propellant burning where, if the AN composition is initiated from an external source, burning can take place on the surface of the mass only with the consequent free and unconfined venting of the gases. Where this process dominates, apparently large amounts of AN can be consumed without an explosion; e.g., Barksdale (1920), Cleveland (1922), Muscle Shoals (1925), Gibbstown (1940), St. Stephens (1947), Presque Isle (1947), and Independence (1949). The evidence indicates that in these cases where fire alone occurred, the process of decomposition and oxidation of fuel is restricted to a limited zone on the surface of relatively cold material.

The second method of AN decomposition involves the heating, melting, and collecting of sizeable quantities of liquid which finally will fume-off. This process will be accelerated in

the presence of catalysts or organic material.

Decomposition reactions

AN is capable of a number of decomposition reactions which can be generally classified as involving the oxidation of ammonia to nitrogen and water and which provide oxidizing agents such as N_2O , other oxides of nitrogen, or free oxygen as by-products. These processes of decomposition are exothermal and for the most part can be described satisfactorily by first order rate constants. The feature of importance is that an arbitrary quantity of liquid AN, because of its liquid phase exothermal decomposition reactions which are themselves an increasing function of rising temperature, can have an accelerating decomposition in which the heating is equally distributed throughout the entire volume of the liquid phase instead of being in thin zones over the surface as in the case of propellant burning. Without interruption, this self-accelerating, run-away reaction would inevitably lead to explosion if a critical mass or critical venting cross section were attained. All of the behavior of AN in partially vented enclosures verifies this view.

Temperature limiting mechanism

A unique feature of AN is its dissociative volatilization to ammonia and nitric acid—a process that absorbs large amounts of energy, transfers ammonium nitrate away from the reaction zone, and, if adequate venting is present, limits the rise of temperature to a function of the applied pressure. This volatilization interrupts and limits the self-accelerating and run-away reaction (4). The temperature limit at 1 atm. is approximately $292^\circ C$ for pure AN decomposing to N_2O and water. Other forms of decomposition which involve oxidation of organic matter or catalysis to other oxidative products with greater release of exothermic energy can effectively raise the energy dissipated within the reactive mass, but will not raise the temperature of AN higher than a value determined by its own dissociative vapor pressure.

The dissociative vapor pressure has been measured by Reik (5), by Feick (6), and by Brandner (7). These data are summarized in Figure 1.

For a given pressure, the dissociative vapor pressure curve gives the highest attainable temperature in the condensed phase. This temperature applies even though high temperature flames or oxidative reactions proceed adjacent to the liquid surface. Al-

though these added sources of heat will increase the rate of gas formation, the endothermy of evaporation limits the temperature of the liquid, just as for water, the maximum temperature at 1 atm. pressure is $100^\circ C$. This temperature-limiting mechanism is the major means for controlling the decomposition of AN and its mixture with reducing agents. A mechanism which overcomes this temperature limiting feature can cause extreme hazard.

Rate of decomposition

The rate of decomposition (3) has been measured by a number of investigators on pure AN and in combination with other materials. In general, acids, chlorides (allowed to go acid), chromates, and a few other materials markedly affect the rate of decomposition at low temperatures. For example, dichromate is an active catalyst that raises the rate of decomposition in pure AN, presumably by changing the decomposition products and increasing the exothermy over that obtained in uncatalyzed reactions.

It is clear that the rate of decomposition is a function of the temperature. The unusual feature of AN is that, at the temperature-limiting level for 1 atm. pressure, pure AN or any of its catalyzed products do not produce rates of decomposition that convert to shock-wave detonation processes in "laboratory-size" samples. This full statement with its limitations of pressure rise and sample size is necessary since any mechanism which could develop rapidly accelerating rates of reaction and shock processes could convert a controlled deflagration of AN to an uncontrolled detonation.

Effect of pressure

The higher the applied pressure, the higher the self-limiting temperature, and therefore the greater the reaction rate. It is clear that at some value of the applied pressure, the process of liquid fume-off in large volume can produce shock processes which detonate the remainder of the liquid. Pressure can be generated from several sources: 1. externally applied pressure, 2. pressure produced by gaseous reaction products vented through a limited aperture, 3. pressure produced from the momentum change of gases evolved at the surface of the liquid, and 4. pressure produced by inertia of liquid surrounding an expanding bubble within the liquid.

Measurements with partially vented bombs and with indirect evidence

from other kinetic rates of reaction near explosion suggest that fueled AN will detonate in relatively small samples with applied pressures of the order of 300 lb./sq. in. (20 atm.).

Lacking experimental evidence in the transition to detonation region, it is difficult to state whether one or a combination of these mechanisms is most significant. Certainly, the apparent pressures required to reach the point for deflagration to detonation based on vented bomb tests (300 lb./sq. in. for FGAN) preclude the possibility of detonation based on confinement by the static head of material present.

To develop an understanding of the transition process, simple mathematical analyses of some of the gas flow processes that would occur in the mechanisms, previously described, have been attempted. Based on these analyses it seems that resistance to flow through a small vent appropriate to the sample size would produce such pressures that the initial pressures would be within the static head range and a final rapid pressure rise would be possible with confinement provided by the inertia of the material confining the liquid.

Another effect would be the pressure generated by the momentum required to accelerate the reacting gases away from the liquid. Such a process would be an important factor in the final pressure rise.

Surface shock processes

Pressure can raise the rate of burning for propellant type surface burning as well as for the fume-off of liquid. In the propellant case the gas-phase flame is driven closer to the surface with an increase in heat transfer but with only moderate increases in burning rate. Eventually, surface shock processes may be developed which could initiate thin heated layers of more sensitive material at the surface.

For liquid fume-off, the pressure mechanism is more direct. In Figure 1, the limiting temperature for any zone in the liquid phase is given; if the pressure rise is a step function, the increase in temperature of the liquid is directly related to its rate of reaction and this rate in itself is an exponential function of temperature.

For pure AN at the self-limiting point the rate of temperature rise for a step increase in pressure is of the order of $1^\circ C/sec.$, while at the AN boiling point for one atmosphere (that is with high energy influx) the rate of rise may be as much as 5° to $10^\circ C/sec.$ Because heat flow into the

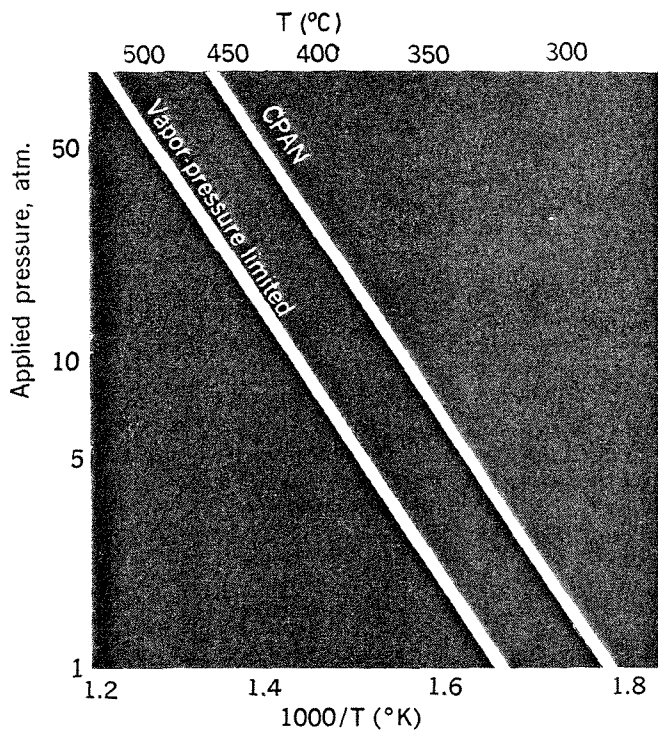


Figure 1. Fume-off of ammonium nitrate at limiting temperature as a function of pressure.

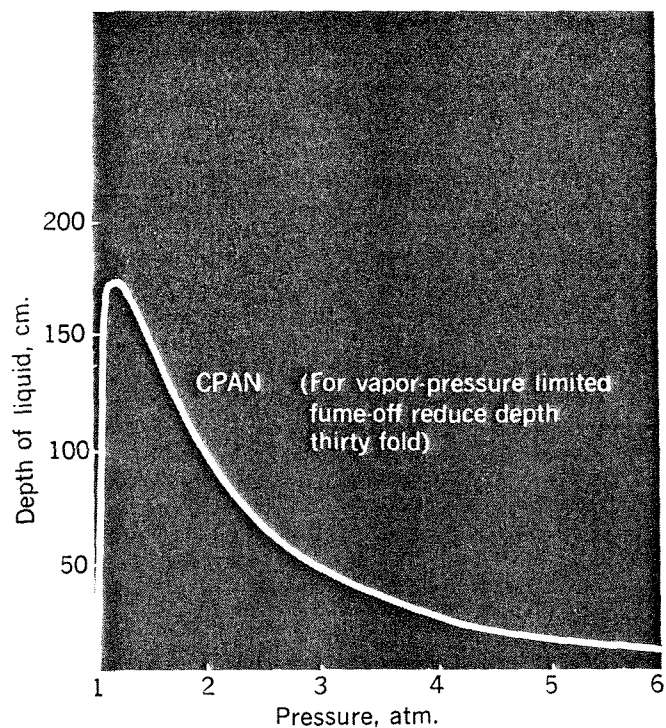


Figure 2. Depth of fuming-off liquid required to satisfy conditions of continuity and acceleration.

molten liquid is not necessary in the self-heating process that generates a temperature rise, a step function increase in pressure can lead to a very rapid temperature rise of the fuming liquid and a very rapid increase in the rate of decomposition for the liquid that remains. Thus, the pressure dependence of the rate of gas evolution is far greater in the case of liquid fume-off than in surface burning.

Critical depths of liquid

An order of magnitude estimate of the depth of liquid required to give a rate of gas evolution adequate to develop a high pressure can be made by assuming the following: 1. the flame results solely from the burning of gaseous fume-off products; 2. the flow is one dimensional near the flame.

The following criteria are imposed: 1. the continuity in the gas flow is maintained; 2. the overpressure on the liquid (resulting from the reaction in the gases) is equated to the rate at which momentum is added to the gas stream in the vicinity of the flame. (This implies that the pressure becomes atmospheric reasonably close to the flame area.)

The velocity of sound in the burning gas is approximately 1.8×10^5 cm./sec. and the density of the burning gas is $2.2 \times 10^{-4} P$ g./cu. cm. where P is the pressure in atmospheres. (These correspond to a gas of $\gamma = 1.4$, molecular weight 27, and

temperature 1500°K .) The gaseous evolution from self-heating of pure ammonium nitrate is approximately given by

$$Q(P) = 2.5 \times 10^{-2} P^{3.2} \text{ g./sec.-cu. cm.}$$

If M denotes the ratio of the velocity of gas flow to sonic velocity, then the depth of liquid D required to maintain continuity of the gas flow is

$$D = 1.6 \times 10^3 M P^{-2.2}$$

Equating the overpressure to the rate of momentum increase (recalling that 1 atm. is approximately 10^6 dynes/sq. cm.), one obtains

$$D = 2.5 \times 10^2 (P - 1)/M P^{3.2}$$

Equating these two expressions for D , one finds

$$M = 0.4 (P - 1)/P$$

which leads to

$$D = 640 P^{-2.7} (P - 1)^{0.5} \text{ cm.}$$

This expression is plotted in Figure 2.

On the basis of these simplifying assumptions it can be concluded that for CPAN a depth of liquid accumulation of approximately 175 cm. would be adequate to support an unlimited pressure rise; further, at the vapor pressure limit the critical depth would be reduced from about 175 cm. to about 6 cm. The presence of fuel oil probably has a significant effect on the rate of fume-off and introduces correspondingly greater hazard in fires.

Notice that M is a monotonic increasing function of P . In one incident of a fire burning to detonation it was

reported that whistling noises of increasing pitch were heard before the detonation; this would appear consistent with an increasing velocity of gas flow.

The attainment of these critical depths of liquid clearly requires an initial depth in excess of those for a given pure liquid ammonium nitrate and for a given catalyzed liquid ammonium nitrate since some of the liquid would be consumed in attaining the temperature and associated reaction rate in equilibrium with the rising pressure. The initial depth must be such that all points on the critical depth versus pressure curve are attainable from self-heating of the liquid originally present.

Effect of foaming

A further effect in the fume-off of accumulated, self-heating liquid is the violent splashing and foaming that occurs. In a fire, one can conceive that a cavity in a mass of unheated material might be partially filled with liquid AN below the self-limiting temperature, this liquid being collected from the liquid film adjacent to the burning and decomposing surface. The average temperature of this film would be well below the surface temperature which in turn can be no higher than the limited temperature. Self-heating in this liquid becomes rapid once some critical volume is reached.

In the final stages of liquid fume-off the very rapid gas evolution ex-

poses thin films or sprays of liquid AN to surface flames with the attendant accelerated volatilization, increasing gas volume and energy release. These accelerating processes can produce surging in the burning process and contribute to the dynamic effects of pressure. An increase in pressure will, in turn, raise the limiting temperature, accelerate further the rate of decomposition of the liquid, increase the volume of gas to be vented and enhance the probability of converting burning to detonation.

Confinement mechanisms

The detailed descriptions of the fume-off mechanisms for liquid ammonium nitrate provide a means for understanding the most puzzling aspect of the burning-to-detonation transfer in AN fires, *i.e.*, how a process that apparently requires pressures greatly in excess of the hydrostatic head of solid or liquid material present can be operative in the absence of a mechanism for maintaining such pressures under static conditions. At least two separate mechanisms can cause a rapid increase in reaction rate with confinement. The combination of these mechanisms can give a basis for developing a pressure-accelerated reaction in a sufficient amount of liquid AN which has sufficient rapidity so that inertial confinement alone may be adequate for transition to detonation once a critical condition is passed. It is evident that additional confinement makes these processes more likely to occur.

New experiments required

The possibility in a fire of a runaway reaction within large quantities of decomposing liquid AN in the presence of fuels may well be an important consideration in the widespread use of oil and AN. An adequate understanding of this phenomenon is required to protect property and human life, and new experimentation of a type that has heretofore not been attempted is needed.

This experimentation is complicated and demanding, since the specification of the composition of the amount of material burned and of its arrangement alone are not sufficient conditions for the accumulation of sizable quantities of liquid which come to fume-off in pressure-generated surges. The unique conditions which need to be controlled are the accumulation of liquid nitrate, the presence of fuel or catalysts, fire within the pile and the capacity of the venting. No known experiments have been made with

significant quantities of liquid nitrate within a fire. In the past, the possibility of liquid decomposition in the confinement of air-lances, floor drains or other piping, has been pointed out as a source of hazard, but the possibilities of these mechanisms leading to detonation in a pile alone has not been investigated directly. The storage configuration of bulk or bagged AN is important, but it cannot be stated at this time how to provide storage that would eliminate the hazard of an extensive fire and the thermal decomposition of accumulated liquid.

As is shown by Traskwood (1960), the possibility of an incident that is initiated by the accidental association of fuel and ammonium nitrate cannot be dismissed even with AN that may be produced for agricultural purposes. The further understanding of the role of the liquid in the burning-to-detonation transfer is essential to provide the key for preventing further disasters in ammonium nitrate, a very common and useful material. #

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Sykes Johnston Hainer

Wendell G. Sykes received his B. S. in Chemical Engineering Practice at M. I. T. He has been associated with Arthur D. Little, Inc., since 1950. His interests have been in the general field of instrumentation with applications in the field of explosives, electronics, industrial hazards, meteorology and physics.

Reed H. Johnston received his B. Sc. in Physics and Mathematics from McGill University and his Ph. D. in Physical Chemistry from Stanford University. He is a physicist on the staff of Arthur D. Little, Inc., where he is engaged in the various applications of physics to industrial problems including industrial hazard evaluation.

Raymond M. Hainer received his B. A. from the College of Wooster and his Ph. D. in physical chemistry from Brown University. At Arthur D. Little since 1945, he has worked in areas of molecular spectroscopy, industrial problem solving, and new product development.

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Questions and answers

Transcript of the comments which followed the presentation of this article at the A.I.Ch.E. Denver meeting, August, 1962.

S. B. Johnson, Monsanto Chemical Co.

—I would like to make three comments regarding incidents mentioned in your paper. First, at Roseburg, Oregon, as pointed out in the ICC hearing, the explosion involved dynamite and nitro-carbo-nitrate, not ammonium nitrate.

Second, I investigated the Traskwood accident within a few hours after the explosion. I would like to describe what happened as we know it. The wreck included a box car of bagged ammonium nitrate, a hopper car of bulk ammonium nitrate, a tank car of 99% nitric acid, 3 tank cars of ammonium nitrate in urea solution, about 3 or 4 tank cars of petroleum products (refined crude oil and fuel oil), 3 cars of gasoline, 3 cars of drummed lubricating oil, and 2 cars of roll paper. The reasons for the detonation have been extensively investigated since it occurred, and tests by Spencer, Phillips, Monsanto, and others have determined that burning petroleum products such as refined crude, when mixed with concentrated nitric acid, will immediately detonate. It has also been determined that a stoichiometric mixture of urea and ammonium nitrate is very shock sensitive and could have contributed to the initial detonation.

There have been a number of investigations and considerable study into what happened at Traskwood. I think that even though a year and a half has passed since Traskwood, it is still premature to say that ammonium nitrate exploded from the fire, or that it exploded because it was mixed with oil in the fire. I mentioned that the Bureau of Mines has undertaken a study of ammonium nitrate properties for the Manufacturing Chemists Association. One of the major reasons for the Bureau of Mines' study is to determine the cause of the Traskwood explosion.

We are sincerely interested in finding out what happened at Traskwood, so that it will not happen again. When this study is completed, I think we can tell you more about it. In some tests that have been run by Spencer, Monsanto, and others—it has been determined conclusively that burning petroleum products such as the partially refined crude oil, when mixed with

concentrated nitric acid will immediately detonate. There is no question about this. This has been repeated time and time again. It has also been determined that certain urea and ammonium nitrate mixtures, are very sensitive—that they are very shock sensitive, and that this could have caused the initial detonation at Traskwood. Now we are not trying to say that ammonium nitrate did not detonate at Traskwood. We only want to find out what did happen so that it can't happen again.

Let's assume that there was an external source of energy, either from the concentrated nitric acid and petroleum products or from the urea-nitrate, and that this in turn propagated to the ammonium nitrate. We do believe that the boxcar of ammonium nitrate was detonated. We were unable to find any parts of that car. We were also unable to find any parts of one of the fuel oil cars, and we were unable to find any parts of one of the ammonium nitrate-urea cars.

All of the cars involved were a total loss, but of these three cars, there were no identifiable parts in the area. I think that until we find out from the Bureau of Mines study, and there may even then be some question, it is premature to say that ammonium nitrate was the initial cause of this explosion, or that the fuel and ammonium nitrate that might have combined in the fire was the cause of it.

We do know that the ammonium nitrate in the hopper car did not explode. We found two major pieces of this hopper car—it looked as if it had been hit by the force of the explosion. One part—was on one side of the tracks, 200-300 ft. away; the other part was on the other side of the tracks, 200-300 ft. away. Prilled ammonium nitrate was scattered over the entire area. The crater was probably 20-ft. deep and 60-80-ft. across. We found prilled ammonium nitrate in the crater. Prills were every place, indicating that they fell back into the area after the explosion. There was fuel oil and there was concentrated nitric acid scattered over the area. The nitric acid car ruptured from internal pressure as did many of the other cars.

I do think that we must take these other factors into consideration and should not prematurely judge Traskwood. This is true in many cases when there is an explosion. We've got to get all of the facts before we can judge it.

Third, we had a man at Norton shortly after the explosion. It was reported to our man at the site that there was a case of dynamite in the

building. It was not reported, in the Bureau of Mines report on the Norton incident, that dynamite existed. This is very hard to substantiate, and we were unable to get a documented statement that dynamite was present.

I think that all of these facts must be recognized before we can say that ammonium nitrate by itself, from fire alone, fueled or unfueled will explode.

W. G. Sykes, A. D. Little, Inc.—I will answer your comments in order. First you are quite right that in the Roseburg incident the ammonium nitrate was mixed with fuel oil (presumably 6% fuel oil). Based on my own experience, I am sure that pure ammonium nitrate would also have been detonated by the dynamite under the conditions at Roseburg, although the total yield of the explosion would have been less for unfueled nitrate.

Second, I would like to comment that it has been difficult for those who were not directly involved to obtain information about Traskwood. We have had word-of-mouth information, but it seems unfortunate that there has been no report issued about this potentially disturbing accident.

Perhaps Traskwood does not indicate the existence of a new effect, but until the questions raised by this accident have been answered—and certainly they have not yet been answered—those who are shipping ammonium nitrate should consider the possibility of similar accidents.

Third, in regard to your comment about dynamite at Norton. This is not the only case where such a question has been raised. Certainly it would be in the interest of the owner to claim that dynamite was not present. So whom do you believe—the evidence is gone.

Ralph Miller, Spencer Chemical Co.—While investigating the cause of Traskwood, we discovered the reaction between nitric acid and burning petroleum. Pouring nitric acid into burning petroleum gives an instantaneous detonation with velocities nearly equivalent to nitroglycerine in the 20,000 ft./sec. range. It is a very substantial booster.

W. H. Doyle, Factory Insurance Assoc.—Has any consideration been given to the solubility of the decomposition products of ammonium nitrate in molten nitrate as a possible means of reducing the heat carried away by the endothermic reaction?

Sykes—We wrote our paper because we do not feel that enough attention has been given in the past to phenom-

ena that may occur in the liquid. I do not know the answer to your question.

P. Dyer, Phillips Petroleum—One further comment on the Norton, Virginia, incident: I believe that in your discussion of it you mentioned that this was an incident where there was probably no confinement. On the contrary, if you look at the type of mixing equipment which probably was there—although this may be information that is not completely reported—you will find there is a very distinct possibility that there might have been severe confinement of a fine oiled material somewhere in the mixing equipment. Therefore, it is premature to conclude, from the incident, that even oiled ammonium nitrate will detonate in a fire without confinement.

We can overlook the possibility of hollow shafting for instance, in the mixing equipment, which could have led to the incident—again all this points up that it is certainly premature to say that we have conclusive evidence—that even the oiled material will go to detonation in fire alone. These questions have been raised and, as indicated, the Bureau of Mines is searching for answers to them. Whether it's going to find a conclusive answer, certainly, we can't say at this time, but the project is thorough and is being handled on a completely objective basis.

It is very significant to record that 12 ammonium nitrate producing companies are underwriting this independent objective research project to try to find clear-cut answers.

John Lawrence, Armour Agricultural Chemical Co.—I would like to ask your opinion about the relative safety of a properly vented tank containing a hot 96% to 97% solution of ammonium nitrate and water. Would such a tank be almost foolproof if there were no fuel present and no pressure build-up?

Sykes—There are several factors to consider in areas where data are lacking. First would be the critical volume-temperature relationship to permit self-heating for these solutions. Presumably the hazard would be less than for pure ammonium nitrate, but I doubt that reaction rate vs. temperature data is known. Second, the liquid depths for a runaway reaction given in our paper are only approximations at best, and it would be impossible to state without further experimentation what depths of liquid would be dangerous if a self-heating process started and went to a fume-off in a large tank. #