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Mining Sessions HIGH PRESSURE HYDRAULIC HAZARDS

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High pressure hydraulic systems serving as prime movers and control media are becoming more widely used in the iron and steel industry. As hydraulic equipment becomes more complex, the design trend is toward compactness and ever-increasing pressures in the hydraulic systems involved. Increased pressures have been accompanied by an increase in the frequency of accidents resulting from hydraulic systems failures.

It is frequently assumed that personnel who work on or with hydraulic equipment are aware of the principal hazards associated with it. This is not always true. Investigations of recent serious lost time accidents, caused by pinhole leaks in high pressure systems, have shown that many persons responsible for operating or maintaining this type of equipment are unaware of the dangers involved when a fine, high velocity jet of oil is allowed to strike some part of the body. Under these conditions oil enters the body as in a hypodermic injection, and once inside can cause severe irritation, with swelling and eventual destruction of tissue and bone in the area.

An analysis of a number of accidents associated with high pressure hydraulic equipment revealed a large number to be similar and could happen on any type of equipment. The following discussion illustrates how such accidents have happened throughout industry.

1. While welding a bracket near a 1/4 inch hydraulic oil line, a welder accidentally struck the tubing with his welding rod and punctured it. A pipefitter, seeing the slight oil leak, tried to stop it by wrapping the tube with friction tape. While doing so, the high pressure oil stream of 2,500 psi pressure struck his finger. At the time, he said, "It just felt like a bee sting." After months of treat-

ment, a section of the finger had to be removed.

2. In the process of cutting a one-inch round steel bar with a portable hydraulic shear, the hose leading to the shear cylinder developed a pinhole rupture adjacent to the hose coupling. Hydraulic oil at 5,000 psi was injected into the injured person's neck. This necessitated a tracheotomy operation to save his life.

3. While greasing a wheel assembly king pin bearing on a truck, grease under pressure was forced out through the bottom of the bearing. It entered the workman's arm at the wrist and about three ounces of it traveled to the elbow just under the skin. It is assumed that air, trapped in the grease hose assembly, acted as an accumulator and sustained a pressure until grease was forced through the tight bearing. Most service stations have 40 to 1 ratio grease pumps operating on 150 psi air pressure which could account for approximately 6,000 psi grease pressure. This same condition could exist in any of our industrial greasing systems.

4. In the process of testing diesel engine fuel injectors, a paper is sometimes placed under the nozzle and the test unit is pressurized in excess of 3,500 psi. The pattern of the oil holes through the paper is indicative of the condition of the nozzles. An operator, holding the paper in his hand, inserted it too far and was hit by two of the five possible streams of high velocity oil. After a lengthy series of treatments and two major operations, the injured person's arm was amputated near the shoulder.

5. The crawler tracks on certain bulldozers have spring actuated take-ups adjusted hydraulically. The springs become compressed by the high shock loading on the track and remain bound. A repairman attempting to

remove a clogged spring cylinder charging fitting on the highly pressurized cylinder was killed when he was struck by the fitting as it became dislodged.

6. Many accidents have occurred during minor adjustments on highly pressurized systems. In one such instance an oiler, in the process of tightening a valve gland, broke a pipe bushing. The valve was blown free and struck him in the chest, resulting in a broken rib and a serious abdominal injury.

7. Mobile equipment in the category of highlifts, bulldozers, etc., have exposed piping and hoses in the vicinity of the operator. Many operators have been sprayed with hot oil when piping or hoses have been ruptured. Oils sprayed onto hot objects from these failures have also been the cause of fires. The causes of these accidents can be grouped under several hazards such as: high pressure, high velocity fluid jets entering the body; parts of systems striking the body with great force; and fire hazards. Many people are not aware of the serious potential of these hazards. Discussion with manufacturers' representatives, safety engineers, and administrators have high-lighted the necessity for further study of such hazards in order to devise adequate protective measures necessary to eliminate them. There was general agreement among all contacted that four things are necessary to combat these hazards. The following is a list of remedies and precautionary measures which have been found to be effective in reducing accidents caused by failures of hydraulic equipment.

Additional Protective Shielding

Service hoses on all hydraulic jacks, coupling pullers, pipe and conduit benders, etc., have been covered with a flexible metallic conduit or additional hose.

On all mobile equipment, the hoses and couplings in the vicinity of the operator have been covered with an additional oil resistant hose. Hoses within the operators' cabs which can be replaced with tubing have been replaced. Many manufacturers apply hose for convenience where piping or tubing should be used.

Piping or hoses in cabs have also been shielded with thin metal plates where addi-

tional hose protection was not practical. High pressure tubing near walkways and catwalks have been guarded by hose, pipe, or plate protection. Hose assemblies on all hydraulic tools are being inspected on a periodic basis for faulty couplings, threads, hose abrasions, and external shielding.

All systems in excess of 600 psi have been posted with a sign which reads "Danger—Hi-Pressure System."

Safe Working Procedures

Much can be learned from a study of accidents, but these studies will be of little value until they are publicized and the lessons learned are put into daily practice. One way this is accomplished is through the development of safe working procedures. Such procedures are usually made jointly through the cooperative effort of men skilled in the repair of hydraulic systems, safety engineers, and management. These procedures should include a list of the elements of a job and the precautionary measures to be taken against known hazards inherent in each element. Following is an outline of a recommended safe job procedure on repair and maintenance of hydraulic systems and component parts.

1. Notify authority in charge of operation prior to starting to work. Where practical, rope off area and place signs to indicate work is being done. Be certain everyone is clear of moving parts before operating any equipment. Observe system in operation. Visually check all component parts for leaks or other malfunction. Do not run hands over lines to feel for leaks or place ear over parts to detect leaks by hearing. Obtain authorization from supervisor in charge for permission to shut down equipment for repairs.

2. Preparation for Repair or Correction. De-energize and lock out source of electrical power. Pull and lock out electric switches. Secure manually operated pumps by locking power supply handle in closed position. Make sure loads have not been left suspended in any part of the system. Remove load if practical; if not, make secure by blocking or clamping. Relieve any trapped pressure in the system. Lock open bleeder or drain valve. If a line has to be loosened to relieve pressure,

position one's self to avoid exposure to high pressure spray and loosen connection gradually to bleed system.

3. Replacement or Correction of Defects. Remove defective part or make necessary correction to the system. If the system is equipped with an electrical immersion heater in the reservoir, the power to the heater must be locked out before draining fluid to avoid a possible explosion of oil vapors. Some hydraulic fluids contacting the skin or eyes can result in serious injury. If fluid is induced into the eyes, flush with water for 15 minutes and then go to the plant hospital. When it is necessary to use additives to improve fluid characteristics, learn supplier's instructions for handling them and the instructions for treatment should you be splashed with the additive. Do not burn, weld, or use open fires until work area is completely ventilated. Repairs by burning, welding or brazing should be made by removing part and taking it to a well ventilated area free of oil. Weld or braze with both ends of pipe, tube, or equipment unplugged and open to atmosphere.

4. Checking out System. Unhook and energize source of power after making sure everyone is in the clear. Make trial operation. Make any necessary adjustments. Bleed trapped air, adjust pressure settings, and visually check for leaks.

5. Inspect Equipment for Compliance with Safety Regulations. "Danger—Hi-Pressure System" warning signs must be replaced. Replace maximum working pressure sign. Make sure all guards are replaced. Clean work area. Wipe dry all spillage. Inform authority of completion of job.

After a safe job procedure has been developed, compliance with the procedure must be made compulsory.

Better Equipment Design

Facts relating to equipment failures which have caused accidents must be made known to manufacturers and designers as promptly as possible. Designers rarely have information relayed to them on the hazards found to exist in their equipment after it has been placed in service.

One major item overlooked by designers is ample valving to relieve trapped pressures.

Equipment employing liquid power should be designed to include a means to shut off and lock out the power supply, whether it involves electrically driven pumps or hydraulic accumulators, and to drain these sections of lines between the shutoff valves and the equipment being serviced.

Mobile machinery such as tractors, bulldozers, etc., should have the fluid reservoirs located where the operator cannot come in contact with contents. The reservoirs should also be provided with a heat shield in event unit is employed in high heat areas. All such equipment should be designed for use with fire resisting fluids. The conversion to these fluids after purchase is expensive, inconvenient, and often not practical.

Basic Training Program

Basic training programs must be so prepared and executed that men who either operate or maintain high pressure hydraulic equipment are thoroughly trained for their task. This applies to both the technical aspects and the safety aspects related to such systems. Training programs for the most part should be tailored to the job to be done.

One effective training aid used to demonstrate the destructive power of high pressure streams of oil is a device designed by the author. The unit consists of a hand pump capable of generating 10,000 psi oil pressure, an accumulator with a volume of at least 12 cubic inches, a pressure gauge, and a blow-out metallic disc assembly with a .015 inch orifice through which the high pressure oil escapes after the disc ruptures.

The unit is pressurized by the operation of the hand pump. The pressure at which the rupture disc will blow-out is predetermined by the thickness of the disc in the blow-out assembly. Material to be tested or demonstrated is fastened by clamps in front of the blow-out assembly orifice.

For demonstration purposes, a piece of 1/8 inch hard gasket rubber is used. A pressure of 3,000 psi forcing oil through the .015 inch orifice is sufficient to penetrate the test piece. However, for a more dramatic effect, the unit is set to blow-out at 6,000 psi pressure for more destructive penetration. After a few seconds, the flow of the jet stream is stopped by

venting the accumulator to the reservoir in the pump assembly.

It is believed that this unit, used as a training aid, has successfully conveyed to all who have observed it the hazardous potential ever present in high pressure hydraulic systems.

Demonstration training programs may be presented to all persons concerned. The compact blow-out unit can be taken to the work areas, where practical. It is in these areas that

men are more apt to enter into the program. Through such instructive sessions hazardous conditions and unsafe practices may be exposed which may otherwise go un-noticed.

Our responsibility as plant managers or operators extends not only to providing the best modern devices for plant operation but also to making these devices as safe as possible for men who operate and repair them.

SAFER BLASTING—HOW FAR HAVE WE COME?

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The overall objective of this paper is to thoroughly and specifically answer the question, "How far have we come in safer blasting?" Consider the implications of the question for a moment. First, it implies that safety progress is being made. Second, it also implies that there is still progress to be made. Therefore, another objective of this paper is to present an analysis of the status of the progress in safety that is situated between terribly dangerous blasting and completely safe blasting. Furthermore, the last phrase also suggests another implication of the title question; this is the additional question, "Will we ever completely achieve safer blasting?"

In moving toward the examination of these prime objectives, vital safety matters will be discussed. Areas to be examined include: (1) properties of products that affect the degree of safety with which the products can be used; (2) transportation, storage, and usage procedures for explosive materials that affect safety; and (3) personnel concepts involving training, awareness, and safety philosophy at all organizational levels.

As a result of this examination process, it is hoped that the final objective, that of instilling a desire to continue the significant progress made in recent years toward the elimination of all blasting accidents, will be achieved. Achieving this objective, however, requires commitment. Money, time, and work at all levels of organization are required. In several real senses, blasting safety is on a "downhill pull." The message is: Do not pull up short of the goal. Do not be overly impressed by the lower number of blasting tragedies by letting up on safety efforts or by failing to take advantage of the safest products and methods. Do not abbreviate or eliminate blasting safety meetings and training

for employees and supervisory personnel. Do not stop requiring safe blasting methods as a condition of employment. And do not become comfortable with the gamble that blasting accidents are statistically unlikely.

It is the nature of many businesses to require certain gambles, such as the future costs and prices, the amount of rock in unclassified excavation, and who is likely to bid on a desirable job. A different attitude, however, is needed for blasting safety.

The Du Pont Company safety philosophy is, for example: Do not gamble on blasting safety. All blasting accidents have causes which can usually be identified after the accident, but these accidents can be prevented because they are caused by unsafe acts.

No one budgets for a blasting accident. Although infrequent in occurrence, they are intolerably expensive and enormously tragic. Practically speaking, it must be assumed that these accidents will not occur. This assumption must then be ensured to the fullest by utilization of products, procedures, and programs consistent with the safest blasting.

Through proper documentation, it will be shown just how far we have come in safer blasting. First to be considered are the physical properties of the basic products for blasting which affect safety.

Many times an assessment of safety progress ends with these physical properties. Technology, safety awareness, improved procedures, regulatory pressure, and what is called the maturing of the broad concept of industrial safety are factors that should also be considered part of the safety progress assessment.

But the improvements in product safety are indeed impressive. When Nobel introduced it, dynamite became the first improvement because it replaced black powder. Dy-

namite is much less sensitive to friction and much less likely to ignite and detonate from a little spark. For 80 years, it was the main blasting product used in construction, mining, quarrying, and other less known consumers of explosives. Today, the safety properties of the more-recently developed ammonium nitrate fuel oil (ANFO) blasting agents and the water gel slurries now greatly exceed those of dynamite.

With the total consumption approaching 3 billion pounds, about 75 per cent of the blasting material now used in this country is ANFO. Of the remaining 25 per cent, half is water gel slurries and half is dynamite, although the latter's rate of use is declining as the less-sensitive blasting products are used. There are three reasons why dynamite has been used extensively in the past: (1) its water resistance, a quality not found in ANFO; (2) its sensitivity and performance, which give it reliability in adverse conditions, another quality not found in ANFO; and (3) its ability to shoot well in small diameters down to 7/8-inch cartridges, a quality found only recently in some water gel slurries.

Today, water gels can probably perform a job just as well as dynamite and can do it with much greater safety. One exception is propagation-shooting for ditch blasting in mud, a very small consumer of explosives. In this application, dynamite's greater sensitivity to sympathetic detonation still would be necessary.

Essentially, what this means is that modern water gels of today and tomorrow will do the job: where a week or more of water resistance is needed; where a product is needed to shoot well in a 7/8-inch diameter; where the velocity of high velocity gelatin dynamite is required; where a product with less toxic and smelly fumes and smoke is needed; and where underground operators require a product that will shoot reliably with no special primer (just a cap or detonating cord).

Even more impressive are the things that water gels will not do. For instance, they will not go off if a shovel digs into water gel, or if a cat runs over and grinds up a stick or case, or even if a bullet is fired into a cartridge of slurry. Water gels will not catch fire from a stray cigarette, a hot piece of machine

ery, or direct application of a flame, while dynamite is very flammable and may shoot any time it is on fire.

There are 300,000,000 pounds of dynamite used per year at present. Dynamite still is used for priming ANFO—some for very wet small-diameter blasting, like pre-splitting—or jackhammer holes, and for small "plug" shots where a half-stick is needed to shoot with a cap. Because their first experience with water gels may not have been good, some blasters continue to do primary wet hard blasting with dynamite. By now, it has been established that the improved small-diameter water gel slurries of today are performing all these tasks well.

Men doing the actual blasting work have conceptions about dynamite that are dangerously wrong. There is a widespread belief, for instance, that when on fire, dynamite will only burn and not shoot. This is incorrect. It may shoot at any time, especially in any kind of confinement—a drill hole, a stack of cases, a magazine, or truckload. And yet, men continue to burn it regularly for a variety of reasons, without taking proper precautions. Firemen are being killed regularly, proving there is still progress to be made in training before the "safety" can be put into safer blasting. In sum, dynamite on fire may shoot at any time, and all dynamite fires must be treated accordingly. This is the basic fact that all blasting crews should be aware of—no dynamite fire is ever fought by members of the explosives industry; evacuation is the safety procedure.

What, then, about ANFO and slurry fire and heat hazards? As mentioned earlier, slurries are difficult to ignite, and many of them, because of their water content, will not burn unless fueled by an outside flame source. The only exceptions are the heavily aluminized slurries, some of which will support combustion. Although these too are relatively hard to ignite, they may dry up and shoot in a large fire.

ANFO, however, is in the medium hazard range. When on fire or exposed to extreme heat, it has detonated in a number of cases. The most impressive example of this is the 500 plus deaths in the 1947 Texas City disaster. Mix plants have blown up after catching

fire, and ANFO or ammonium nitrate packed pipes and augers have shot with fatal results when being welded or burned with cutting torches. Thus, ANFO is easier to ignite than water gel, but not as easy as dynamite. Once started, it burns vigorously and may shoot; whether oiled or not, ANFO is given the same safety treatment as dynamite—evacuation. The belief that there is no explosion hazard from burning ANFO or ammonium nitrate is incorrect.

But how does this fire and heat hazard relate to job exposures and precautionary measures? The locations where fire and heat may exist are first identified and then they are altered to preclude fire possibilities. For example, many times a motorist's flipped cigarette has wound up in the back of a passing open powder truck. To avoid this hazard, closed body trucks or trucks covered by fire-retardant tarpaulins should be used.

Care should also be taken to deter transportation fires and detonations that start from tire fires, hot brakes, fuel leaks, or electrical fires on trucks carrying explosives. Moreover, operators show good sense when they institute truck-condition check-procedures for each delivery or loaded trip.

Fire sources should also be guarded against at the magazine. Trash, papers, brush, and other flammables should not be allowed, so that spontaneous combustion, approaching grass, and forest fires do not burn and shoot the magazines. At the blast site, other fire and heat sources may be found and should be guarded against: smoking by personnel, hot holes from springing, water bombing, or for some operators, burning ground can cause accidents.

Whether with dynamite, ANFO, or slurry, these fire and heat sources are dangerous. However, there will be fewer accidents from burning slurries, and this type of accident will disappear if the existing recommended precautions are followed. This "if" is part of the potential problem. As products become less sensitive and less susceptible to many types of hazards, operators are presented with a choice. One possibility is to relax precaution and attention to safety measures. The other alternative is to keep the safety emphasis and procedure in effect, taking the

benefits in the form of greatly reduced chances for an accident. Though the latter seems to be an easy choice, unless it is considered in the light of full information, the first choice might be made—the choice of complacency of letting down the bars to dangers in the belief that it is no longer necessary to be so careful with today's products.

Still another property which is critical to safe use of explosives is the sensitivity to impact. When dynamite is detonated as planned, a blasting cap or detonating cord explodes in contact with it and delivers a terrific impact accompanied by extreme heat. This heat and impact initiates a detonation shock wave in the dynamite. Accidental means of delivering enough impact-heat energy to detonate dynamite are numerous, and detonations regularly happen. Dynamite goes off when drilled into, when struck directly by a shovel bucket, when hit just right in a crusher, when hit by bullets, when ground under vehicle track, or under a train wheel in a mine.

What is happening in these kinds of events is not related especially to the fact that steel causes sparks, but rather to the hardness of metal in general. Since the time of black powder days, emphasis has been placed on avoiding sparks around explosives. It is still a good idea to avoid sparks around all blasting materials; but where a spark would immediately shoot black powder, it becomes a minor possibility for setting dynamite on fire, and not an immediate detonation hazard. Because it is in order to avoid sparks with all explosive materials, nonsparking tools for opening boxes, punching and slitting dynamite, are recommended. Many times, however, the real point of this discussion is missed: steel is *too hard* to be allowed impact with it on dynamite. Also true for iron, brass, bronze, aluminum, and stainless steel; this is why the Blasters' Handbook has said for many years that no metal should be used in a blast hole once explosives have been loaded.

Here again, many workmen and supervisors believe that if a spark is not possible, as in a wet hole, or with nonsparking metal, dynamite will be safe from metal tools. They vigorously chew into the dynamite with a

blow-pipe of nonsparking metal, or with an iron blow-pipe if the hole is wet, not recognizing the impact hazard. This abusive use of steel blow-pipes usually comes about in an effort to unload a misfired hole or remove a stuck cartridge.

It is also sometimes argued that if no cap is in the drill hole, the powder can be drilled out with safety. This misinformation is lethal—dynamite detonates a high percentage of the time when drilled into.

Dynamite is drilled into in one of two main ways. Underground workmen sometimes like to start new drill holes in the remainder of old ones, a process called "drilling in the bootlegs." If the old hole contains dynamite, the dynamite will often detonate, even if it is wet or there is no cap in it. Another way dynamite is drilled into, both underground and on construction and pit work, is by drilling into unexploded holes in previously blasted areas; for instance drilling the second lift and hitting some unexploded dynamite from the first lift. This also occurs by drilling into dynamite in high bottom, such as when a ditch blast does not break full depth. If an area does not break, caution is required. An effort should be made to determine if misfires are the reason; if they are, this information should be reported to the proper personnel so that drilling into a misfire can be avoided, possibly preventing an accident.

Drilling into dynamite and hitting it with metal blow-pipes, crawler tracks, crushers, shovel buckets, and bullets have all been mentioned. From available information, none of these has ever shot ANFO or water gel slurry; even the cap-sensitive underground water gels are not set off by bullets. This is enormous safety progress.

Therefore, with ANFO and water gel slurries, many hazards from impact are reduced. In a typical operation, the impact-sensitive material is now just the dynamite primer, or the cast primer and cap, or the water gel primer with the cap on it. This means that the main ANFO or slurry charge will not be detonated by machinery. But the use of these necessary detonator products does indicate that there will always be the potential for accidental blast caused by machinery encountering certain explosives. Vigilance in

eight at a time, were hauled in and around the motorman's cockpit.

The salesman had stepped against the wall of the tunnel to be out of the train's way, and the dynamite sack fell from and was run over by the locomotive right beside him. It did not shoot that day. Later, in a similar incident, the dynamite did shoot in that same mine and resulted in loss of life.

Example Three. In 1971, two locations accounted for four incidents involving unshot dynamite in machinery-impact situations. Only one injury occurred.

In one case, secondary breaking of boulders in a quarry was being done by using a drop ball. The drop ball struck a boulder which had a drill hole in it that had not fired. The explosive detonated. Though no one was hit by the flying rock, the possibilities of fatal and serious injuries are obvious.

In another incident, a front-end loader bucket loading shot rock dug into dynamite and shot a small amount in the muck pile. No injury resulted.

Still another time, when a shovel bucket was emptied into a truck, a detonation occurred. Again no injury was sustained.

The last incident involved some explosive detonating in a primary crusher. This time, a rock was blown through the side of the crusher and injured a nearby workman.

Example Four. The next case history is concerned with ANFO and ammonium nitrate. In an ANFO mix plant in the South, maintenance welding was being done on a bucket elevator used to raise ammonium nitrate and dump it into the mixer. The bottom of the elevator was below floor level where it picked up the prills. The welding was done in that area (below floor level) without flushing out all of the ammonium nitrate and without emptying the building of prill bags and mixed ANFO. As a result, over 100,000 pounds of ANFO exploded.

The welding caused a fire in the sub-floor pick-up pit which resulted in detonation of the entire contents of the building. Fortunately, evacuation prevented injuries.

A similar but smaller accident occurred in the Midwest when welding was done on an auger without first cleaning it out with water. The confinement of the auger tunnel was

enough to cause the ANFO to detonate, and the welder lost a limb.

Example Five. A company blowing ANFO into drill holes had used a loading platform surrounded by a railing made from pipe. One vertical railing support had broken loose at the upper end and had gradually filled with ANFO spilling into it.

Later, that loading platform railing was being repaired with a burning torch and the ANFO-filled pipe exploded from the heat of the torch, killing the repairman.

This same accident has occurred several times with minor variations in circumstances.

The kind of accident described in examples four and five can be eliminated, but not through ANFO or water gel use. To avoid this type of accident, machinery, buildings, and pipes must be thoroughly flushed clean and emptied before maintenance can be safely done.

Equally important, all quantities of explosives must be removed from trucks before they are placed in a repair shop. Fires, too frequent around shops, may originate from gas and oil, from welding and cutting, and from electrical causes. Many times, a building fire has involved explosives that were not supposed to have been stored there. One of the classic disasters illustrating this point was the Roseburg, Oregon, blast that occurred in the late 1950's.

Example Six. The tragic Roseburg, Oregon, disaster killed 13 people. A powder truck loaded with dynamite and ANFO was parked overnight in town, and the driver was asleep in a hotel. During the night, the truck was involved in a fire at the lumberyard where it was parked. Firemen on the job believed that the explosives would only burn and not detonate. But they did detonate, injuring 129 in addition to those killed.

Small, one-company versions of this accident have also happened.

Progress in safer blasting has also been made in the area of detonators, which can cause accidents but which also have seen improvements in safety characteristics. Manufacturers in this country no longer use fulminate of mercury, a fact that has been true for many years. As a result of this change, caps

are less sensitive to impacts than they were many years ago.

More recently, there have been advances in the safety of electric blasting. Problems of static electricity, radio hazard, and lightning premarures are now better defined, understood, and protected against. Better instruments are available to assess possibilities of stray current hazards. The Blasters' Multimeter reads the presence of stray voltage and then can indicate if any dangerous amperage is present along with the voltage. In addition, positive systems are available to detect approaching lightning before it becomes dangerous. Radio frequency hazards are well defined, and safety measures are written out in an explosives industry booklet which ANSI has adopted as a guide.

Another step toward safer blasting has been the dissemination of better information to blasters in an effort to help them work more safely. For instance, those familiar with induction know that a lightning strike near a blasting job can cause currents to flow in cap circuits. Most blasters have knowledge of this, but many are not convinced about the seriousness involved. In the same manner, induced current experts can appreciate that an induced current is more likely in a wired-up and shunted series of caps than in single caps or an unshunted series. These facts are being taught to blasters who have been comfortable with their cap circuits shunted. Shunts are fine for the common sources of stray current such as leaking powder in nearby conductors, and they do give some protection from static electricity (though no immunity). But a shunted loop circuit only increases the possibility that induced current detonations will occur from lightning.

As a possible remedy, nonelectric delay caps in millisecond timing and the slower half-second delays for underground uses have come onto the market. These detonators, at moderate extra cost, can be used where the presence of electrical hazards makes electric blasting dangerous. For many years, many operations have fired their blasts with detonating cord, eliminating both the electrical-sensitive aspect and the cap itself from the hole. These systems mean that operators also have many options available to them from a

detonator standpoint.

Differences of opinion exist on the topics of electric versus nonelectric blasting, and caps versus cord. These options are examined in greater detail below.

A form of nonelectric blasting, cap and fuse, was the first detonation system employed. When used properly, it did and still does a good job of initiating blasts under certain conditions. Some mining companies, some trench contractors, and some detonating cord blasters still use this system when it meets their particular needs. It is also utilized by many once-in-a-lifetime users of explosives for shooting one or two rocks or stumps.

The cap and fuse system operates in the following manner: a sufficiently long piece of fuse, at least two minutes by law, is crimped onto a blasting cap. When the fuse is lit its black powder train burns at its characteristic speed of 40 seconds per foot, plus or minus 10 per cent, until the flame reaches and shoots the cap.

A clean cut of the fuse, protection against moisture, selection of a safe fuse length, proper crimping tool, proper order of lighting for desired rotation, safe lighting methods so that the holes will not begin shooting while others are still being lighted, are all critical items to be considered when using cap and fuse.

When these items are properly carried out, however, blasting can be done satisfactorily and safely. Moreover, the chief advantage of cap and fuse is its lower initial cost, the usual reason for its use by some miners.

A very small percentage of the roughly 15 million fuse caps used per year are utilized by operators who believe that electrical hazards which will not permit safe electric blasting are present. Other operators fire detonating cord blasts with cap and fuse, so that they do not have to be concerned about lightning. The fact is that any known detonator or blasting material can be detonated by direct hits of lightning. This is not because of electric current flow, but because the enormous heat and impact of a lightning strike has ample energy to detonate caps, dynamite, ANFO, slurry, or detonating cord if a direct hit to the product occurs. Thus, the safety message is: All blasting and explosives handling operations should stop during light-

ning.

Although very satisfactory blasting can be done with cap and fuse, this system has had some serious shortcomings. They are:

1. Once the fuse is lit, there is no safe way to abort the blast.
2. In very wet conditions, lighting the fuse can be difficult and unsure. Better fuse lighting devices of recent years have improved the situation, but the fuse lighting problem still exists. When a fuse is hard to light, or may not be dependably lit, two of the most frequent accident causes with cap and fuse blasting may occur: the man who stays too long trying to light may be injured; a hole may misfire.

3. Another serious shortcoming of cap and fuse is the inability to do millisecond delay blasting. Cap and fuse is only appropriate to the firing of one hole at a time, with a few seconds or more between several holes. When holes must fire rather precisely together, or with delays of a few milliseconds, cap and fuse can not be used, ruling it out for many possible applications.

4. For many years, a fuse could not withstand even moderate water without the occurrence of either a relatively high number of misfires from the cap, or the fuse getting wet. Although this has been improved, cap and fuse does not equal the waterproofness of electric blasting.

5. Until the last 20 years and before Ignit-e-cord, the lighting of cap and fuse was always done from a point of exposure to the blast. This should no longer occur, although there have been many reports from operators complaining that their miners still stay and watch the cord light every hole. This practice should be stopped immediately. If personnel must watch the sequential lighting of holes, perhaps there is a need for a more reliable detonation system.

Just before 1900, electric caps were invented, and as they were perfected, even the early ones represented a real advance: Firing could be done from a safe distance or sheltered location; water resistance became excellent; instantaneous firing of holes became possible. Later, controlled delay blasting became possible for slow intervals and, finally, for millisecond intervals. This greatly im-

proved fragmentation, face conditions, bottom shear, vibration control, and other aspects of today's sophisticated blasting. Circuit checking made it possible to tell if a wire had been broken and if all caps were connected and would be initiated. The electric current signal was safer than a burning powder signal, which would sometimes fire a black powder hole very early when a flame spurted out the side of a damaged or defective fuse.

The use of over 75 million electric caps per year is representative of the large percentage of the total cap use achieved by electric caps. Methods and product reliability have improved to the point where some companies that are large volume users of electric caps have not been aware of any misfires for years in their electric blasting. But the advent of electric blasting caps has not been entirely free of problems. They were, and are, susceptible to some electrical hazards, mainly leaking stray currents from defective electrical machinery and lightning. There are also a small number of accidents from static electricity and radio transmission. Studies have been made to identify and scope these last two problems, and as a result, excellent detection gear for determining the presence of stray current and the approach of lightning have been developed.

One symbol of the success of these protective measures is the fact that New York City, one of the most heavily regulated jurisdictions known, requires that every bit of blasting in Manhattan be electric, and blasting in that locale is presently at a 10-20,000 pounds per day rate. There are two main reasons for this electric blasting requirement: (1) safety measures and safety problems are better controlled with electric blasting; and (2) control of blasting security details is better with electric blasting.

The details of New York City's decision to require electric blasting may relate to many people's needs. Compared to detonating cord, electric blasting is quieter and causes less concussion. The exact moment of firing is precisely controlled, and millisecond delay caps mean that delay blasting under blasting mats is possible. The slowness of cap and fuse or underground electric delays means that

the early caps can throw the mats off, and later holes fire unmatted. Other reasons are also related to the security and control needs of New York City. It is interesting to note that in the country's largest concentration of population, electrical gear, and radio transmission, the city code requires electric caps and the surprisingly high amount of blasting in Manhattan is all done in this manner.

The explosives industry has defined the electrical danger level for electric caps very clearly. All commercial caps made in this country are designed and manufactured to require at least 0.25 amps to detonate. Reliable firing current is much higher, of course. A safety factor of five is used to select tolerable levels of stray current, so that the safety level becomes 0.05 amp. At least one excellent blasting multimeter that detects these levels and makes precise cap circuit resistance readings is tied directly into this 0.05 amp safety level on its meter scales. An operator with this meter can readily see if there is any stray voltage (including small values) and if significant amperage is associated with the voltage. Because this meter indicates 0.05 amp as 1/3-scale reading and not just a twitch of the needle, there is confidence in the reading.

Fine lightning detection instruments have been produced in recent years which warn operators of approaching electrical storms, and even of the developing conditions for immediate lightning activity. In electrical language, these instruments show the *spherics* and the *potential gradient*. They indicate the distance and rate of the approaching activity, and also show when threatening skies have no associated electrical activity. The latter, an important development, requires a fairly expensive device, (around \$3,000 or more) but this is cheap compared to the cost of an accident or unnecessary downtime. Availability of this instrument is not widespread; it is manufactured by a few companies, such as Litton Systems of National City, Calif.; B. K. Sweeney Manufacturing Company of Denver, Colo.; and Nitro-Nobel of Sweden. The Army Corps of Engineers requires "positive lightning detection system" on their major construction blasting work.

Caps versus Cord

The explosives user's choice between caps and detonating cord has been made on several behavioral differences between the two. Detonating cord is not affected by electrical sources. Also, it is not used with a cap down the hole for each cord, except for the one application where it is used as an upward detonating line from a capped bottom primer, the purpose being to detonate the redundant primers in the upper parts of the hole. In addition, detonating cord is the detonator product least sensitive to impacts; and the chances are remote that a shovel, bucket, or a drill steel will shoot it when encountered in a misfire situation.

This combination of impact resistance and no response to electrical sources has attracted a large number of users to the detonating cord system, when the blasting needs are fulfilled by this system. It is also true that detonating cord does not perform all blasting jobs as well as caps-in-the-hole.

Cord detonates the first sensitive material it contacts; in a dynamite hole, this would be the top stick. In an ANFO hole or slurry hole, the top primer is detonated first. This feature is a disadvantage for blasting operations (and there are many) that are affected by top priming.

Because the detonating cord explodes at 21,000 feet per second, a blast with cord only is essentially an instantaneous blast. This restricted detonating cord's use for years to instantaneous blasts and blasts where delay caps should be tied onto the downlines to sequentially shoot the holes. And spacings had to be wide—of the magnitude of large-diameter quarry and pit holes—to use this latter method. In close jackhammer holes or underground drill patterns, these tied-on caps were occasionally sheared off by rock movement before they could detonate the later holes.

In 1952, the millisecond delays for detonating cord blasting were introduced. These have been instrumental in wider use of detonating cord blasting, but they must be placed on the surface and can not be used down the hole. This means that some conditions still produce rock movement cutoffs,

and cut cord lines from missiles. There is also the hazard of having these cap-like devices lying on the surface where an impact like a falling rock, or machinery impact can fire the whole blast. In general, the big pits and quarries using six-inch or larger diameter holes usually use detonating cord. Operations between three- and six-inch holes are divided, and the holes below three inches are more often detonated with caps.

Now, what progress in safer blasting has been made for the cord users? Considerable progress has been achieved, but more still has to be made. With caps, accidental detonations do not occur from normal handling; they do not shoot from transportation and loading procedures unless they are damaged, deformed, bent, mashed or, in other words, subjected to excessive abuse. Excessive abuse should never be permitted with detonating cord, either. It has been known to shoot from direct hit lightning, under train wheels, and in cases of extreme impact, but only a very few times. Detonating cord's degree of resistance to impact is very strongly in its favor when compared to other detonation systems.

In approaching lightning conditions, it should be remembered that all blasting materials can be shot by direct hit lightning. Therefore, explosive operations must stop in the event of a lightning storm. Although experiences with lightning have been bad over the years, advances in lightning safety can come about in several ways: first, by improved detection; and second, by full awareness of its danger by all. All personnel must know and believe that there is nothing to be complacent about in lightning safety. For some operators, nonelectric blasting adds a measure of safety, if the remaining precautions are remembered.

Another candidate that may improve lightning safety and that has become available in recent years is the nonelectric delay cap. This device works by using a small exploding detonating cord line to carry the detonating signal down the hole, a function usually performed by a fuse or electric wire, and into the cap. This tiny cord is detonated by a larger standard detonating cord system, and provides nonelectric bottom hole priming, with millisecond or slow-delay timing.

Although this product eliminates electrical hazards, the impact hazards common to caps down the hole still remain.

This nonelectric delay cap product is very attractive to some operators; many electrical blasting operators have taken effective measures and up-dated their training efforts to be sure that electrical blasting safety problems are not allowed to exist for them either.

The nonelectric delay cap products now on the market have some drawbacks. They are:

1. Most electrical blasting operators depend on the galvanometer to check to see if there is a circuit present and to determine if the reading shows that all caps have been wired in. This checking is not possible with the nonelectric delay.

2. For many operators, the necessary air blast noise of the nonelectric delay surface detonating cord system is intolerable.

3. Many operators have not been willing to pay the additional cost of the nonelectric delay.

4. Nonelectric delays have other characteristics which are for some a disadvantage; they are three to four times as bulky to store.

5. They cannot be used with ordinary dynamite, but require primers and products that are not detonated by the small detonating cord which fires the delay cap.

The tensile strength of the fire cord is relatively low, considering the inability to test it with meters. There are fewer delay periods available than with electric caps.

If these shortcomings do not preclude their use, or introduce other hazards, these nonelectric delay caps are clearly safer than electric caps when stray current is present or possible.

Personnel Aspects of Safety

Much progress has been made in personnel aspects of safe blasting. Safety professionals are being used by a growing list of operations to keep an eye on blasting, to conduct training on safe methods, and to hold safety meetings. And, for the first time, professional training on the subject of safe blasting is being given on a regular basis. Many supervisors, safety department personnel, and government and insurance engineers have

availed themselves of this training, along with a few blasters and powder crew personnel. It should be emphasized that the personnel aspects of safety have everything to do with the success or the failure of safety efforts. In this context, supervision and then blasters will be discussed.

Supervisors are the key to an operation's success. They must keep things and men operating. They not only must produce the product, whether in tons of crusher throughput or cubic yards excavated, but they must also forecast, report, requisition, plan, authorize, hire, and direct. They must follow computer directives and find out why things happened that should not have.

An additional item that should be placed on the supervisor's list, and that increasingly is on his list of responsibilities, is strong participation in the company's ongoing safety efforts. The supervisor is the direct link with workmen; getting to work on time, doing the work while on the job, taking care of the tools and machines, and working with the skill called for by the job and experience are all directed by the supervisor. In other words, there are distinct items each man must perform as part of his job. One of these items must be to conduct his work in a safe manner. When safety becomes a condition of employment for each man (which has to come from his immediate supervisor) then safety improvements can move forward. The supervisor needs to be in full partnership with the designated safety department, because he is the implementing arm. This reflects the methods used by Du Pont to achieve enviable safety performance. Safety is a function of line organization, and the system works.

The economic and humanitarian reasons for avoiding accidents need not be examined here in detail. That has been ably and impressively done by others. The Du Pont Company calculates its cost for a lost-time accident at \$10,000, not including replacement of facilities and other associated costs. The amount of product that has to be produced by any business to offset a \$100 accident is amazing. The temptation is to cite dollar figures to prove that safety pays, but a number can not be put on those visits to tell the family bad news.

In sum, then, supervision has a vital role in operational safety. This role—knowing the safety methods demands of the job—should filter from every supervisor to each man working for him. The responsibility for safety can not be delegated or neglected without causing the entire safety program to suffer.

In order to successfully complete his safety role, the supervisor must be knowledgeable on the subject of safety. Just as he can tell if a pit truck is traveling recklessly fast and is too close to the bank, or if a drill is set up on cracked ground close to the face, or a shovel is operating too close to an overhang, the supervisor must also be able to knowledgeably determine if a powderman is working safely or not. Too often, the supervisor's knowledge is not sufficient, and he lacks the basis for evaluating a powderman's performance on blasting safety.

As far as the blasters are concerned, all of them need to be fully informed and kept up to date on blasting safety matters. They have not been professionally trained, since there have not been any schools or courses on blasting safety. Anything they have learned they know by word-of-mouth transmission or by reading available literature. And unfortunately, not all of the literature is thorough or accurate; some of it is dead wrong. This is also true for much of the hand-me-down safety advice—inaccurate, incomplete, sometimes incorrect—received from whoever taught the men now to blast.

In blasting safety, the idea that experience is the best teacher and can replace formal training is completely unrealistic. Blasters can not learn blasting safety by experience; not many blasters have had their own blasting accident to teach them that a certain practice or procedure is unsafe. Therefore, when dealing with the subject of blasting a recognized authority, one who specializes in the subject, knows all the details and all the experiences that contribute to a safe career of blasting, must be relied upon.

Most blasters have never been exposed to such a learning experience. And even now that blasting safety training is available by professional, authoritative people, most blasters are not being sent for training. Superintendents, safety directors, loss-control

engineers, and federal inspectors are filling the training courses, but where are the blasters? They need the training the most, and yet they are the ones industry has the greatest problems sending to take a training course because of the questions: Who does their work while they are taking a training course? Can they be spared for a three-day seminar on blasting safety?

These are the questions that stand in the way of blasters becoming as knowledgeable as they should be. Only industry can answer these questions but until answers are found, blaster safety training will continue to receive only lip-service treatment.

Conclusion

It is true that some blasting products have become harder to accidentally detonate, but the possibility of detonation still can happen. Accidents are caused by unsafe acts that have occurred many times before and that still continue. This is an accident potential that will respond to training; the training, though becoming available, is still badly needed by most explosives users.

For the future, tragic and expensive blast-

ing accidents are still possible, although these possibilities have been considerably lessened by safer products. Safer products and better technology have clearly been provided by the explosives industry. Blasting safety training was sought, was demanded, and is now taught, an achievement in line with other earlier advances.

But blasting safety has come a long way; perhaps still safer products will be implemented in the future. At the present, however, blasting safety training represents the best available additional measure to ensure against accidents. Here is the opportunity for blasters and supervisors to achieve real understanding, perspective, and knowledge of blasting. This opportunity to dispel mistaken ideas and replace them with facts, recent accident experience, and the latest products and methods should be encouraged and supported by all personnel connected with the explosives industry. And when safer products and procedures are fully utilized, and when all receive safety training, then the blasting safety program will be complete.

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