LIGHTNING WARNING FOR EXPLOSIVES HANDLERS

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ABSTRACT

This paper gives an overview of the methods that can provide warning of impending lightning to explosives handlers. The methods discussed range from the simplest, most inexpensive to the state-of-the-art. Warning that lightning will enter a sensitive area can be accomplished by visual or public techniques and instrumented techniques. Visual or public techniques include weather patterns, weather forecasts, and weather observations. Instrumented techniques include AM radio methods or spheric detectors, electric field measurements, interferometry, and network systems.

INTRODUCTION

If lightning strikes an explosive or explosive device, detonation is very probable, regardless of the precautions taken. Even a near miss could cause a detonation. Many studies have shown that a lightning strike can initiate standard electric blasting caps (2 amp all-fire) many kilometers away. Only a direct strike will initiate nonelectric initiation systems.

A number of industrial activities are sensitive to an unexpected lightning discharge. Mining operations and any other endeavors that involve explosive materials are particularly vulnerable. Because of the volatility of the materials, devastating financial or personnel losses could occur in the event of a lightning strike. A system that provides warning of the approach of a thunderstorm is essential to the safety and efficiency of such operations.

Lightning is a threat to any surface or underground operation using volatile materials. Although surface operations are more vulnerable, electric systems and spark-sensitive materials underground at any depth are susceptible to lightning. If lightning strikes conductors leading underground, like the headframe, the energy imparted into the grounding system is too much to handle. The current travels (possibly kilometers) underground, bleeding itself off and arcing along the way. Even if lightning strikes the ground above, dangerous currents can travel nearly 900 m deep in mountainous terrain and over 150 m deep in flat terrain (Berger 1977).

The unexpected detonation of explosives is just the beginning of the problem. Only part of the loaded shot detonates in 90% of all prematures caused by lightning. This creates not only safety problems but prolonged downtime and extensive wear and tear on the machinery that digs the poorly broken material. A typical surface coal mine would lose nearly $200,000 if lightning prematurely detonated a shot (Santis 1988).

There are two ways to reduce the vulnerability of an operation. The first is the implementation of a lightning warning system (LWS), and the second is the use of an initiation system that is less sensitive to lightning. The discussion in this paper is limited to lightning warning methods and procedures.

Thunderstorms develop in two ways. The first is the frontal type storm caused by a cold air mass overtaking a warm air mass. The second is the convective type storm caused by the solar heating of the Earth's surface or the right combination of wind direction and topographical features as shown in Figure 1 (Banta 1987).

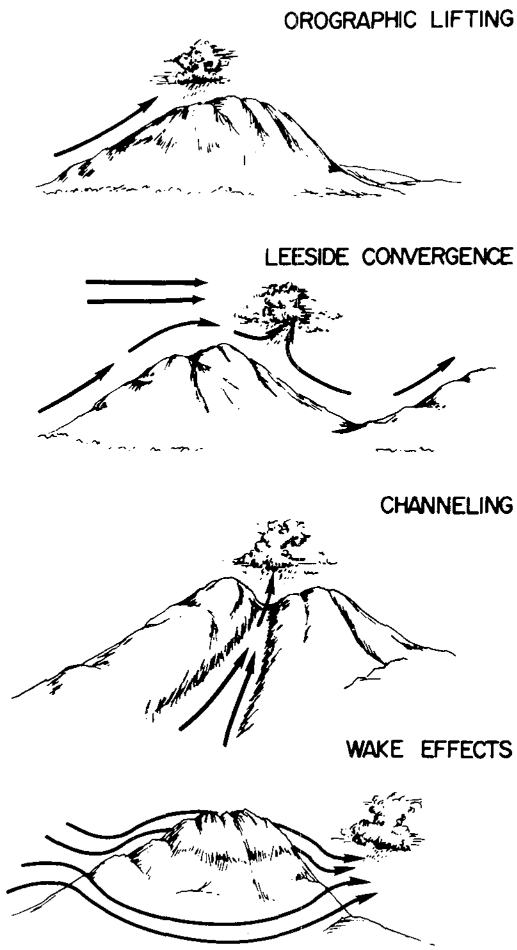

Figure 1.

In both cases, the cloud becomes electrified by the movement of water particles carried by the rising air.

In the past, lightning warning techniques offered only moderate improvements in safety and efficiency. Recently the ability to warn if lightning will enter a particular area has improved. It is relatively easy to predict where an active thunderstorm will travel during its lifetime. The problem of lightning warning, however, is a very difficult one because of the random behavior of lightning and site-dependent variables such as weather patterns, degree of vulnerability, warning time requirements, and schedule flexibility. It is particularly difficult to predict when and where the first strike will occur. The first strike is the very first cloud-to-ground discharge from a thundercloud.

Lightning behaves in such a haphazard manner that no single device or even array of devices will provide valid warning 100% of the time. Thus, the problem cannot be attacked simply by picking a system. Rather, it involves a program centered around lightning awareness.

Any effective lightning warning system will be a combination of three things. The first of these, visual or public techniques, involve making casual observations and using public information such as National Weather Service broadcasts and statistical data on local weather patterns. Secondly, spheric detectors, interferometers, and networks track active thunderstorms and allow for short-to-medium range localized forecasting. Finally, atmospheric electrostatic field (E-field) monitoring provides the only verified way to warn of a thundercloud building overhead.

VISUAL OR PUBLIC TECHNIQUES

Weather Patterns

On a global scale, lightning behaves haphazardly, but on a local scale, it tends to move into an area in a habitual fashion. It is very important to understand the tendencies of lightning in your location. Without this knowledge, solving your lightning problem would be like buying a set of rock drills without knowing what kind of rock or what size hole you needed to drill.

Determination of your local weather patterns may be obtained by analyzing the following--

1. Number of discharges per square kilometer per year. Operations in areas of high flash densities should incorporate the best LWS, whereas operations in areas of low flash densities may opt for a less expensive LWS. MacGorman, 1984 provides a good reference for the United States (U.S.).

2. Prevailing storm direction.

3. Type of storm, frontal or convective, that predominates.

4. Seasonal variations in lightning activity. Although lightning can occur at any time of year, summer months are the worst. Changery, 1981 provides a good reference for the U.S.

5. Time of day variations in lightning activity. Usually the hours of noon to 5:00 p.m. are the worst.

6. Any local topographical features that may be thunderstorm genesis zones.

If possible, schedule blasting activities at times of low lightning probability. U.S. Mine Safety and Health Administration (MSHA) records show that only 7% of lightning-caused premature initiations of explosives in mining operations occurred during the morning hours.

To supplement this information and gain a more individualized perspective, routinely record observations on days that lightning occurs, and look for patterns. Record such information as the date and time, the kind of storm, the direction it came from, how long it lasted, the weather conditions, how the warning (if any) was received, and if any strikes occurred nearby. This approach may also identify local thunderstorm genesis zones by examining the wind direction when convective storms develop.

Weather Forecasts

Weather forecasts have improved greatly recently. In fact, a 3-day forecast now is as reliable as a 1-day forecast 20 years ago. Still, weather forecasts alone are not reliable as a lightning warning technique. Like the variables mentioned above, they only indicate when trouble can be expected. A person charged with blasting activities should actually become an amateur meteorologist. Learn how to read a weather map and look for a cold front pushing a warm front (frontal-type storms). Convective type storms are much more difficult to predict but occur almost every day in some areas (Florida and mountainous areas) during certain times of the year.

If possible, subscribe to the Weather Channel or a local radar station through either cable, satellite, or closed circuit broadcasts to obtain up-to-the-minute visual information on storm activity. Level 3 or above on a radar plan position indicator usually means electrical activity is in progress or imminent. If neither of these broadcasts can be received, call the local National Weather Service (NWS) weather information service to receive updated information before sensitive activities begin. Also, the local NWS broadcasts 24-hour weather reports in the U.S. on a frequency between 162.40 and 162.55 MHz. Some radios can pick up this frequency but it can also be picked up with a special radio sold in department stores for about $15.

Observations

By making routine observations, you will have a better idea of what to expect, and will learn to recognize when blasting activities should stop. Prediction of thunderstorms for an area does not always mean that they will arrive. Even if thunderstorms do arrive, it is possible that the vulnerable area is situated such that the storm activity will skirt around it. Conversely, thunderstorms may occur when they were not predicted.

Monitor the sky in the direction where storms usually develop or where they were predicted and look for cumulonimbus cloud formations, particularly anvil-type clouds, and darkening of the sky. Lightning begins to form when the cloud tops of summer convective storms reach about 8.5 km (Moore 1981). Winter thunderstorm tops develop at much lower altitudes and are harder to predict.

Keep alert for indicators that can give warning that a lightning discharge may occur nearby, like--

1. Illumination of distant clouds caused by lightning discharges.

2. Thunder. Thunder can be heard up to 13 km from the source (Pierce 1977). The distance to the strike in kilometers is equal to the time in seconds between visual observation and thunder arrival divided by three.

3. Rain or hail. A cloud giving as little as 3 mm/hour precip-itation can produce lightning (Moore 1977).

4. Relative humidity and temperature. Moist air aids in the development of thunderstorms, and it is unlikely that lightning would form below certain limits (Pierce 1977) (see figure 2).

5. A sudden drop in barometric pressure or temperature, or a change in wind direction, especially a 180° change. These changes often indicate the approach of a cold front.

6. Luminescence around high or pointed objects (St. Elmo's fire).

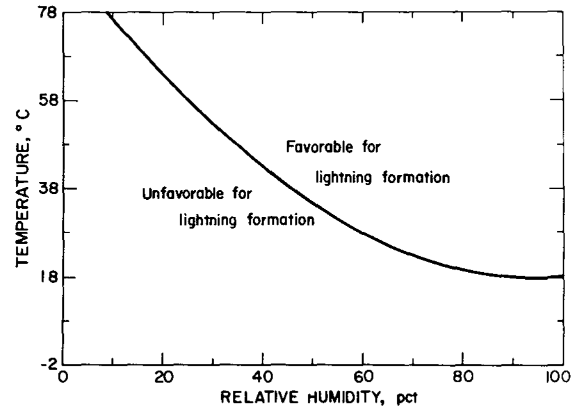

Figure 2.

Using the above-mentioned tactics with AM radio methods will provide a very inexpensive way to warn of potential lightning hazards. However, this approach has substantial drawbacks, such as:

1. The warning criteria are subjective.

2. Possible insufficient warning time to evacuate sensitive area.

3. A nearby lightning discharge may occur without any of the previously mentioned indicators being noticed.

INSTRUMENTED TECHNIQUES

AM Radio

The use of an ordinary AM radio is one of the simplest methods of detecting lightning. Most people are familiar with lightning's distinctive static crackling noises that disturb reception during thunderstorms. Every lightning discharge creates strong atmospherics (radio waves) throughout the AM radio band. By tuning the receiver to an unused or clear frequency in the lower end of the band, and listening for these static bursts, you can determine if lightning is occurring within 30 to 160 km, depending on the sensitivity of the receiver.

Lightning comes from an electrically active cell within a thundercloud. As a cell builds in intensity, lightning occurs more regularly. As the cell decays, so do the spheric bursts. Through the life of a cell, usually 1/2 to 1 hour, lightning flashes 2 to 3 times per minute. This rate varies greatly but usually peaks at about 10 discharges per minute. By listening to the radio and counting the number of bursts in 1 minute, every 5 to 10 minutes, one can get a feel for whether a storm is building or decaying. This approach is subject to large errors because two or more cells may be active at one time within listening range and there is no way to distinguish among them.

The loudness of the bursts give some idea of how close the activity is. If the static on an AM radio gets increasingly louder, the storm is probably moving closer. Again, this is subject to large errors owing to the overlap of other cells and the variability of lightning itself. The strength of the spheric bursts is a function of the distance to and the strength of the discharge. The current in a cloud-to-ground lightning bolt could peak anywhere between 1 and 200 kiloamperes; thus, a very intense strike far away would sound the same as a very weak close strike.

The advantages of using the AM radio method of lightning warning are that it is inexpensive, no training is required, and no special equipment is needed (most operations have an AM radio on site already).

There are significant disadvantages since the method--

1. Gives no indication of storm direction.

2. Gives poor indication of storm distance.

3. Has very subjective warning criteria.

4. Cannot filter out static that may sound like lightning but actually could be caused by electrical equipment, powerlines, dust storms, corona discharge, a faulty radio, or other sources.

5. Cannot operate automatically.

The main problem with the use of an AM radio as a lightning warning device is that it is very subjective. As with any subjective method, the operator must decide if conditions warrant a stoppage of operations. Underestimation leads to safety concessions; overestimation leads to unnecessary downtime. However, it is better than nothing, and when used with visual or public methods, it offers a cautious operator greatly improved safety.

Spheric Detectors

Spheric detectors also monitor radio waves to detect a discharge. These devices are merely AM radios with added circuitry to eliminate the human factor and unwanted signals. Some of the newer detectors are reasonably reliable as they use statistical analysis methods to monitor the growth and decay of a thunderstorm. Most devices have range settings and predetermined criteria for alarm. They work well in areas where only frontal-type storms develop (Johnson 1979).

Interferometry

This method involves the differentiation of the radio wave spectrum emitted from a thunderstorm. Various activities in a thunderstorm produce different frequencies. By monitoring, differentiating, and relating these signals, the devices determine the approximate distance to and the direction of the thunderstorm. One system incorporates radar precipitation images to determine if a cloud formation is electrically active. The French developed a system, SAFIR, that actually maps discharges in two or three dimensions using three remote stations. These devices are very useful but are also very expensive.

Networks

The development of lightning detection networks (see figure 3) has made the biggest breakthrough in the area of lightning warning. Networks provide the best real-time, real-location detection of individual lightning strokes (Johnson 1979). Presently two methods are used: magnetic direction finding (MDF), and time of arrival (TOA) location finding.

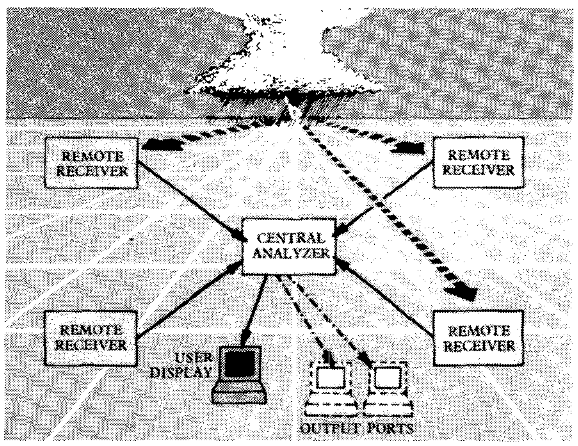

Figure 3.

The MDF network employs an array of two crossed loop antennas to determine an azimuth to the discharge. A central computer then triangulates between two or more remote stations to determine the location of the discharge. The network records and stores almost every (70%-90%) flash within the network's range. A lightning display system (LDS) can receive real-time or stored information on lightning activity. The network covers the contiguous United States, although detection efficiency is poor in the northern Midwest. The network can determine the location (within a few km), polarity, multiplicity, and peak current of a particular strike. It can compute flash rates and flash densities for a particular area. Flashes can be color coded chronologically. This allows easy determination of the direction the storm is moving and its velocity. Figure 4 is a typical display from the network. Dots are negative discharges, and plus signs are positive discharges. Although not very noticeable in black and white, six color codes in 1-hour increments provide a chronological record of each event.

The other network, TOA, uses an array of simple whip antennas to record the real-time (within microseconds) that the very low frequency (VLF) wave peak from a discharge arrives. Knowing how fast the spherics travel, the central computer uses hyperbolic intersection between two or more remote stations to find the location of the flash. Output from the TOA network is similar to that of the MDF network.

The TOA network offers a service called the Weather Sentinel Service (WSS). For a moderate monthly fee, the network computer will monitor a user-defined area within the network's range for lightning flashes. As soon as it senses a discharge in the defined area, the WSS computer notifies the subscriber via numeric or digital display, microprinter, or pager. Audible alarms notify the user of new messages. Perhaps the best definition of the warning area is a bullseye-like set of range circles at 25, 50, and 100 km radius. This would tell if a storm is moving closer to or away from the sensitive area.

The WSS also provides general weather information every morning that could be useful, such as predicted high and low temperatures, relative humidities and dew points, maximum possible rainfall, % chance of precipitation, % chance of severe weather, % of possible sunshine, and atmospheric inversion.

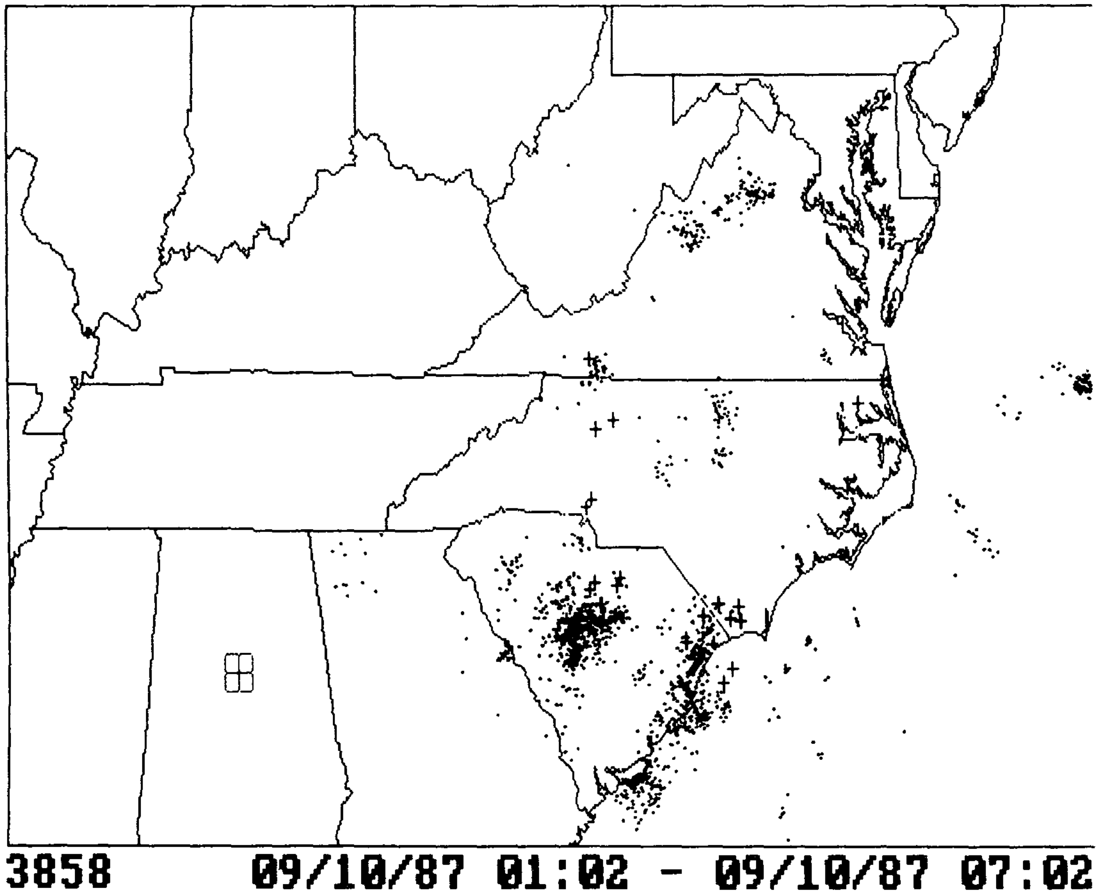

Figure 4.

Figure 5 shows the network's coverage area.

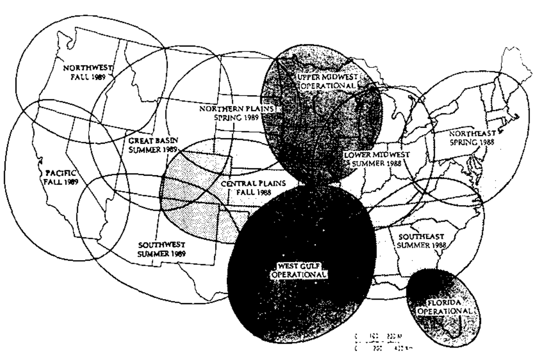

Figure 5.

A third network has been proposed. NASA is investigating the possibility of using satellites to detect the illumination of cloud tops caused by lightning. This project is still in the development stages. It does not appear to offer any significant advantages over the existing networks other than detecting intercloud discharges. These discharges occur up to six minutes before the first cloud-to-ground strike. This could give very short warning of the first strike.

Networks are in operation in other countries such as the United Kingdom, Japan, Brazil, Sweden, and the Netherlands using the MDF or TOA principle.

Atmospheric Electrostatic Field

This method monitors the electric (E) field between the cloud and the ground. The thundercloud environment is essentially a huge capacitor. The cloud acts as one plate, the earth acts as the oppositely charged other plate, and the lightning bolt acts as the discharge path.

By monitoring the electric field at the ground surface, a probability that a discharge will occur in the vicinity can be reached. Generally, fair weather fields are around +100 volts per meter, and lightning will form when the field reaches -2 to -5 kilovolts per meter.

This method provides the only verified way to warn of the first strike of a thundercloud building overhead. This quality is especially important in areas where convective type storms develop. However, operations should not rely upon electric field measurements as the sole method of warning because of the influence of space charges; also they may only allow minutes to take any action.

When an electrically active cloud moves in, oppositely charged ions flow from grounded objects into the air causing a masking or screening layer of space charge near the ground surface. This attenuates the magnitude of the E-field measured at ground level, which can lead to erroneous information on the location and magnitude of the charged area aloft. Even under fair weather conditions, there are many processes that introduce space charge into the atmosphere, including blowing snow or dust, splashing water, engine exhausts, industrial emissions, smoke, fog, and high-voltage powerlines. Wind can transport these space charges many kilometers.

Regardless, a particular site could arrive at criteria to stop sensitive operations and evacuate personnel when--

1. The E-field reverses polarity and/or steadily builds.

2. The E-field crosses the site-dependent threshold.
   a) Start with two kilovolts per meter.
   b) Through experience, determine if this value is suitable.
   c) Adjust threshold accordingly.

3. Jagged oscillations are noticed in the field. See figure 6. Notice how the E-field from the thunderstorm has almost straight up and down oscillations. These sudden collapses of the E-field are caused by lightning discharges.

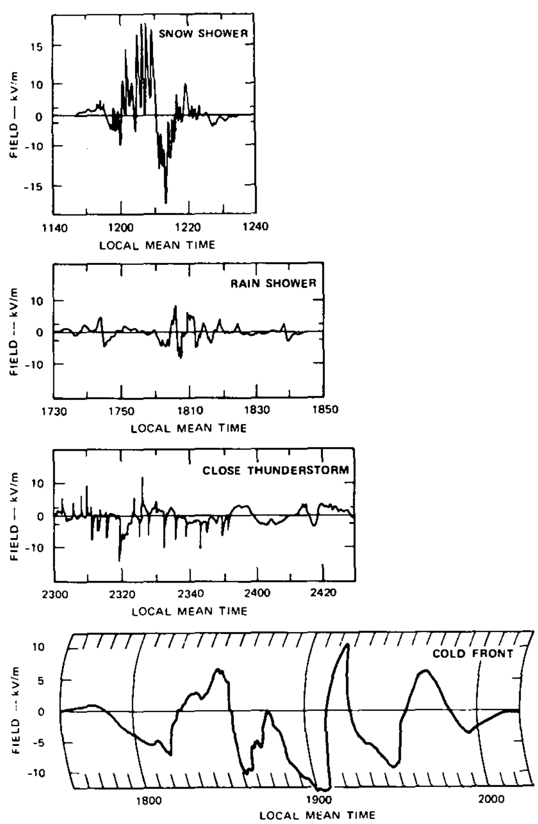

Figure 6.

EVACUATION PROCEDURES AND CRITERIA

Under certain conditions, lightning could set off electric blasting caps many kilometers away. From the existing literature on thunderstorm development (Cianos 1974), where D is equal to the range sensitivity of the operation to lightning in km, the following recommendations can be made for safe distances from known electrical activity at surface operations. When E-field measurements are available, the safe distance is D plus 8 km. When E-field measurements are not available, the safe distance is D plus 40 km. For operations where nonelectric initiation is used, D is 0 because a direct strike is necessary. For operations where standard electric blasting caps (2 amp all-fire) are used, D is 32 km in mountainous terrain and 8 km in flat terrain (Johnson 1979). Mountainous terrain is more hazardous because the strata typically have high resistivity values, allowing dangerous currents to travel farther.

Underground operations or those using special initiators need to determine their own unique D. Since underground operations would generally require a strike directly above, an acceptable D is 8 km in mountainous terrain and 0 in flat terrain. Nonelectric initiation systems underground are considered to be immune to lightning. However, in theory, any spark sensitive material underground could be initiated by lightning under certain conditions.

As soon as a hazard is present, immediately remove personnel from the vulnerable area. Employ an alarm system to notify the workers as soon as possible. Do not try to pick up explosives already unloaded. Resume operations only if 30 min has passed and there was no indication of lightning activity.

CONCLUSIONS

Because of the unpredictable behavior of lightning, a lightning warning system that provides valid warning 100% of the time has not been and probably will not be developed. However, an operation can obtain substantial improvements in safety and efficiency by using some form of LWS. The following conclusions can be drawn:

1. Base the decision as to what type of lightning warning system to install on the following criteria.
   a) Degree of protection desired.
   b) Warning time necessary.
   c) Type of storms (frontal or convective) that predominate.
   d) Affordable cost. In general, the effectiveness of a lightning warning system is proportional to its cost.

2. Any effective LWS will be a combination of--
   a) Short-to-medium range forecasting to avoid times of high lightning probability.
   b) Immediate hazard detection and prompt evacuation of the sensitive area.

3. The most effective instrumentation seems to be a combination of devices based on spheric detection and electric field measurement.

4. Network systems provide the most reliable spheric detection method.

5. Cost reductions could be made by using other spheric methods instead of networks at the expense of effectiveness.

6. E-field measurements provide the only verified way to warn of the first strike. This quality is especially important in areas where convective storms develop.

7. E-field measurements alone are not recommended as a LWS. Accompany them with a spheric method.

8. Always use visual or public methods.

LIST OF MANUFACTURERS

Spheric Detectors

Atmospheric Research Systems, Inc.
2350 Commerce Park Drive, N.E.
Suite 3
Palm Bay, FL 32905
(303) 725-8001

Nuclear Instruments Corp.
2345 W. Mill Road
Milwaukee, WI 53209
(414) 228-8800

Safety Devices, Inc.
7910-A Hill Park Ct.
Lorton, VA 22079
(703) 550-9899 or
(703) 339-6650

Thomas Instruments, Inc.
Rte. 9, P.O. Box 50
Spofford, NH 03462
(603) 363-4500

Signal Design, Inc.
3 Autry
Irvine, CA 92718
(714) 581-2870

Interferometry

Aviation Safety Systems/3M
6530 Singletree Dr.
Columbus, OH 43229
(614) 885-3310

Lightning Location and Protection, Inc.
1001 South Euclid Ave.
Tucson, AZ 85719
(602) 624-9967

ONERA
29 Avenue D'La Division Le'Clerk
92320 Chatillion, France

Sperry Aerospace Group
P.O. Box 21111
Phoenix, AZ 85036-1111
(602) 867-2311

E-field

3M/Static and EMC
P.O. Box 2963
Bldg. 590
Austin, TX 78769-2963
(512) 834-1800

Airborne Research Associates, Inc.
46 Kendal Common Road
Weston, MA 02193
(617) 899-1834

Atmospheric Research Systems, Inc.
2350 Commerce Park Drive, N.E.
Suite 3
Palm Bay, FL 32905
(303) 725-8001

Electroforces, Inc.
P.O. Box 523772
Miami, FL 33152
(305) 594-0304

Electronique 2000
8, rue Rere Champhine
38600 Fontaine, France
(76) 26 53 27

Environmental Sensing Technology
1054 Hawthorne Ave., East
St. Paul, MN 55106
(612) 776-9668

Interstate Electrostatics Corp.
8627 Guthrie Rd.
Box 216
Calhan, CO 80808
(719) 683-2419

Langmuir Labs
New Mexico Institute of Technology
Socorro, NM 87801
(505) 835-5503

Lightning Eliminators Consultants, Inc.
13007 Lakeland Rd.
Santa Fe Springs, CA 90670
(213) 946-6886

Mission Instruments Co.
5937 East Pima St.
Tucson, AZ 85712-9242
(602) 721-9242

Monroe Electronics, Inc.
100 Housel Ave.
Lyndonville, NY 14098
(716) 765-2254

Qualimetrics, Inc.
P.O. Box 41039
Sacramento, CA 95841
(916) 923-0055

Thunderstorm Technology
1911 Main Avenue
Suite 236
Durango, CO 81301
(303) 259-1800

MDF Network

Bureau of Land Management
3905 Vista Ave.
Boise, ID 83705
(208) 334-9880

National Severe Storms Laboratory
1313 Halley Circle
Norman, OK 73069
(405) 366-0405

State University of New York at Albany
Dept. of Atmospheric Science, ES216
1400 Washington, Ave.
Albany, NY 12222
(518) 442-4555

TOA Network and WSS

Atmospheric Research Systems, Inc.
2350 Commerce Park Drive, N.E.
Suite 3
Palm Bay, FL 32905
(303) 725-8001

R*Scan Corp.
Minnesota Supercomputer Center
1220 Washington Ave., South
Minneapolis, MN 55415-1258
(612) 333-1424

The preceding list of manufacturers does not claim to be complete. Nor is it an endorsement of a particular company or product. In addition, Blasters Tool and Supply Co., of Frankfort, KY, (800) 634-6250, and Ideal Supply of Asheville, NC, (800) 533-0144, market LWSs.

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ALERTES A LA FOUDRE POUR LES MANIPULATEURS D'EXPLOSIFS

Lon D. Santis

Ce rapport présente une vue générale des méthodes d'alerte à la foudre destinées aux manipulateurs d'explosifs. Elles vont des plus simples et des moins coûteuses aux méthodes de pointe. L'alerte de la pénétration imminente d'une zone sensible par la foudre est donnée par des systèmes visuels, publics ou instrumentaux. Les systèmes visuels ou publics comprennent les courbes du temps, les prévisions et les observations météorologiques. Les systèmes instrumentaux comprennent les méthodes par radio AM ou par détecteurs sphériques, les mesures des champs électriques, la différenciation des ondes ou l'interférométrie, ainsi que les systèmes de réseaux. Mention est également faite des procédures et des critères d'évacuation.

BLITZWARNUNG BEI SPRENGARBEITEN.

Lon D. Santis

Dieser Vortrag gibt einen Überblick über die Methoden, die zur Warnung vor drohenden Blitzschlägen bei Sprengarbeiten dienen können. Die beschriebenen Methoden umfassen die einfachsten und billigsten Anlagen, sowie solche auf dem höchsten Stand der Technik. Die Warnung vor einem Blitzschlag in einem gefährdeten Gebiet kann durch visuelle oder allgemeine Techniken, oder durch Instrumenttechnik gegeben werden. Unter visuellen oder allgemeinen Techniken versteht man die Beobachtung des Wettergeschehens, Wettervorhersagen und Wetterzyklen. Die Instrumententechnik umfaßt die AM - Radio Methode oder sphärische Detektoren, die Messung des elektrischen Feldes, Wellenverschiebung oder Interferometrie und Nachrichtensysteme. Methoden und Kriterien zur Evakuation werden erwähnt.

ПРЕДУПРЕЖДЕНИЕ ВЗРЫВНИКОВ О ПРИБЛИЖАЮЩИХСЯ ГРОЗАХ

Лон Д. Сантис

Настоящий доклад предлагает обзор методов, которые предостерегают взрывников о приближающихся грозах. Обсуждаемые методы варьируют от простейших и дешевых до основанных на последнем слове техники. Предостережения о приближающихся грозах могут быть даны общедоступными видимыми сигналами или с помощью приборов. Первые включают наблюдения за погодой и прогнозы погоды. Инструментальные методы включают использование радио и сферических детекторов, измерения электрического поля, распознавание волн или интерферометрию, и другие системы связи. Описываются также критерии и порядок эвакуации.

爆破工作者对闪电应警惕的事项

郎 D. 山铁士

本文概括了爆破工作者能预知临近的闪电的方法。涉及的方法包括从最简单，最廉价到最先进的。对闪电将进入敏感区域的预报可用目测法，通俗的办法和仪器测量法。目测法和通俗的办法包括气象规率，气象预报，和气候观察。 仪器测量法包括调幅无线电法或球形集电器，电场测量法，波微分和波干涉测量法，以及网路系统法。文中提到了疏散步骤和规则。

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